Technical Report 2009-01

Management Measures for Protecting and Restoring the Puget Sound Nearshore

Prepared in support of the Puget Sound Nearshore Ecosystem Restoration Project

Margaret Clancy[1], Ilon Logan[1], Jeremy Lowe[2], Jim Johannessen[3], Andrea MacLennan[3], F. Brie Van Cleve[4], Jeff Dillon[5], Betsy Lyons[6], Randy Carman[4], Paul Cereghino[7], Bob Barnard[4], Curtis Tanner[8], Doug Myers[9], Robin Clark[9], Jaques White[6], Charles Simenstad[10], Miriam Gilmer[5], and Nancy Chin[5]

1. ESA Adolfson
2. Phillip Williams and Associates
3. Coastal Geologic Services
4. Washington Department of Fish and Wildlife
5. U.S. Army Corps of Engineers
6. The Nature Conservancy
7. National Oceanic and Atmospheric Administration
8. U.S. Fish and Wildlife Service
9. People for Puget Sound
10. University of Washington

EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE) and the Washington State Department of Fish and Wildlife (WDFW) co-lead an ecosystem study of the Puget Sound called the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). The study commenced in federal Fiscal Year (FY) 2001 and is scheduled to conclude in FY 2012. The purpose of the study is to evaluate significant ecosystem degradation in the Puget Sound Basin; to formulate, evaluate, and screen potential solutions to these problems; and to recommend a series of actions and projects to restore and preserve critical nearshore habitat. The second phase of work, which will entail implementing process-based restoration projects, will commence when the study is completed and federal and state restoration funds are dedicated for necessary projects. These projects will be carried out to improve the integrity and resilience of ecosystem processes and to promote environmental and human health and well being.

The geographical domain of the study area extends along 2,500 miles of shoreline from the Canadian border, through Puget Sound, and along the Strait of Juan de Fuca to Cape Flattery. PSNERP defines the nearshore as the area that extends from the top of shoreline bluffs or upstream in estuaries to the head of tidal influence waterward to the deepest extent of the photic zone.

The protection and restoration of nearshore habitats in Puget Sound requires the application of recovery actions or “management measures” that address nearshore ecosystem processes, functions, and structures. Management measures (MMs) are specific actions that can be implemented alone or in combination to restore the nearshore ecosystem. PSNERP has identified 21 management measures for implementing nearshore ecosystem restoration recognizing that (1) the measures can be capital projects, regulation, incentives, or education and outreach, and (2) the measures contribute to ecosystem recovery via protection, restoration, rehabilitation and substitution/creation. This technical report helps determine how to most effectively use the 21 management measures to accomplish process-based restoration in Puget Sound. The report also serves to:

1. Provide a common understanding of each measure’s strengths, weaknesses and constraints and describe the issues that should be addressed at feasibility, design, implementation, and evaluation phases of each management measure.

2. Provide a basis for describing proposed restoration actions for a programmatic Environmental Impact Statement to be prepared by PSNERP in 2010.

3. Provide a systematic organizational framework for describing management measures that can be used to develop and evaluate Puget Sound nearshore restoration alternatives by describing the benefits and constraints associated with implementing each measure.

The report is composed of an introductory chapter plus one chapter for each management measure. The introductory chapter describes the context in which management measures should be applied and provides background information on the relationships between management measures, nearshore processes, and Puget Sound shoreforms. Guiding principles for nearshore restoration developed by the Nearshore Science Team (NST) provide a foundation for this information. These principles favor process-based restoration and protection, which involves implementing projects that support or restore natural ecosystem processes, which in turn generate or maintain desirable nearshore ecosystem structure and functions, enabling the ecosystem to be naturally productive and resilient.

Process-based protection and restoration requires management measures that both preserve and reestablish the dynamics of nearshore hydrology, sedimentation and other habitat-forming processes

(Goetz et al. 2004). This report attempts to show that certain management measures have the potential to produce a sustainable effect on processes, while others mainly target restoring ecosystem structure. This report also shows that some measures have less direct effects on processes, but may contribute to restoration in other ways that are sometimes more difficult to gauge (e.g., through the modification of human behaviors).

This report discusses the varying degrees of applicability and utility of management measures in different geomorphic settings. In particular, measures that involve physical and direct alteration of the landscape are most effective when applied to the appropriate geomorphic system (rocky shores, beaches, embayments and deltas). Understanding the spatial and temporal characteristics of each management measure is also critical in the selection of appropriate measures in different geomorphic settings. Certain measures can produce an immediate functional lift while others may focus on a long-term reestablishment of natural processes. The combining of multiple measures in the appropriate landscape context can be very effective in achieving restoration goals (than relying on single measures) because both space- and time-benefits are addressed.

The individual management measure chapters contain five major sections:

Definition	A description of the measure and the range of actions encompassed or excluded
Justification of Need and Link to Nearshore Processes	A description and conceptual illustration of the relationship between the measure and nearshore processes, structures and functions
Complementary Measures	A discussion of the use of additional related measures that would maximize benefits of the action over time and space
Benefits and Opportunities	A discussion of potential benefits of employing the measure as well as opportunities for implementation
Constraints	A list of potential limitations associated with the measure
Best Professional Practice	A summary of best management practices that should be addressed during feasibility assessment, design, implementation and evaluation
Case Studies	Examples of past projects that employed the management measure including how and where it was implemented

The purpose of the individual chapters is not to provide an exhaustive review of the particular restoration measure, but rather to integrate each activity into a cohesive nearshore ecosystem restoration strategy. The chapters serve as science-based support for nearshore restoration and protection actions that integrate local, state, tribal, federal and non-governmental activities.

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ACKNOWLEDGEMENTS

The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) Implementation Team (IT) was responsible for identifying the 21 management measures (MMs), developing the outline and specifications for this report, and directing the compilation of the report. PSNERP Implementation Team (IT) co-chair Brie Van Cleve worked directly with the lead contractor, ESA Adolfson (ESA), during the development of the technical report. Members of the IT, Nearshore Science Team (NST), and Project Management Team (PMT) provided draft chapter material and reviewed the contractor's initial drafts of the report.

In addition to the report authors listed, the following PSNERP team members made contributions to this report: Ginger Phalen (U.S. Fish and Wildlife Service [USFWS]), Chemine Jackels (USACE), Patty Robinson (U.S. Army Corps of Engineers [USACE]), Jenna Norman (Washington Department of Fish and Wildlife [WDFW]), Mike Ramsey (Washington Recreation and Conservation Office [RCO]), Chris Behrens (USACE), Morgan Schneidler (Puget Sound Partnership [PSP]), Scott Campbell (USACE), Mary Ramirez (University of Washington [UW]), Tom Leschine (UW School of Marine Affairs), Randy Schumann (King County), Megan Dethier (UW/Friday Harbor Laboratories), Nancy Gleason (USACE), and Bernie Hargrave (USACE).

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Front cover: Nisqually Wildlife Refuge/Estuary with Luhr Beach in the background. Photo by Ilon Logan.

Back cover: Left: Beach Nourishment at Marine Park in Bellingham. Photo by Jim Johannessen. *Right:* Jones Creek Channel Rehabilitation, Qwuloolt Marsh, Snohomish Estuary. Photo by Steve Winter.

GLOSSARY

Accretion—The gradual addition of sediment to a beach or to marsh surface as a result of deposition by flowing water or air. Accretion leads to increases in the elevation of a marsh surface, the seaward building of the coastline, or an increase in the elevation of a beach profile (the opposite of erosion).

Adaptive management—The application of facts learned through project experience or from the results of scientific experiments to the making of future management decisions.

Backshore—The upper zone of a beach beyond the reach of normal waves and tides, landward of the beach face. The backshore is subject to periodic flooding by storms and extreme tides, and is often the site of dunes and back-barrier wetlands.

Beach—The gently-sloping zone of unconsolidated sediment along the shoreline that is moved by waves, wind and tidal currents.

Bluff—A steep bank or slope rising from the shoreline, generally formed by erosion of poorly consolidated material such as glacial or fluvial sediments.

Conceptual model—As used here, a model, either numerical or diagrammatic, that summarizes and describes a simplified version of the natural environment. See Simenstad et al. (2006) for a full explanation of the conceptual model framework (available at http://www.pugetsoundnearshore.org/technical_papers/conceptmodel_06.pdf).

Delta—A deposit of sediment formed at a stream or river mouth, or other location where the slowing of water flow results in sediment deposition.

Ecological integrity—Maintenance of the structure and functional attributes of a particular locale, including normal variability (NRC 1992).

Ecosystem—A community of organisms in their physical and chemical environment interacting as a mutually interdependent and competitive unit (NRC 1992).

Ecosystem function—Any performance attribute or rate function at some level of biological organization (e.g., green plants capturing light energy and converting it into chemically stored energy) (NRC 1992).

Ecosystem processes—Any interaction among physiochemical and biological elements of an ecosystem that involve changes in character or "state" (NRC 1992).

Ecosystem Services— Ecosystem services are the "outputs" and experiences of ecosystems that benefit humans, and are generated by the structure and function of natural systems, often in combination with human activities (MEA 2005, Ruckelshaus and McClure 2007).

Enhancement —Any improvement of a structural or functional attribute [of an ecosystem](NRC 1992).

Estuary— A semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage (Pritchard 1967). Sometimes defined more broadly to include other coastal inlets that connect coastal lagoons and swamps to the sea.

Geomorphic System—As used here, four broad categories of coastline (rocky coasts, beaches, embayments, and river deltas) that reflect the relative influences of wind, tidal, and fluvial processes in controlling the transport and distribution of sediments and the resulting evolution of landforms (Shipman 2008). See Shipman (2008) for a full explanation of typology.

Habitat—The physical, biological, and chemical characteristics of a specific unit of the environment occupied by a specific plant or animal. Habitat is unique to specific organisms and basically encompasses all the physiochemical and biological requirements of that organism within a specific location (Fresh et al. 2004).

Irreplaceability—A fundamental measure of the conservation value of a site in terms of its potential contribution to the achievement of a restoration goal (Pressey et al. 1994).

Landform—As used here, complex coastline features that reflect different long-term patterns of sediment accumulation and deposition. These are several types of landforms in each geomorphic system. See Shipman (2008) for definitions and descriptions of each type.

Landscape—A heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout (Forman and Godron 1986); a particular configuration of topography, vegetation cover, land use and settlement pattern which delimits some coherence of natural and cultural processes and activities (Green et al. 1996).

Management measure—An action that addresses the objective of restoring or improving nearshore ecosystem functions, structure, and/or processes. Actions include restoration or other physical alterations, as well as management and regulatory changes.

Mitigation—Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace the damaged ecosystems (NRC 1992).

Morphology—The shape or form of the land surface or of the seabed and the study of its change over time.

Nearshore—As defined by PSNERP, includes the area from the deepest part of the photic zone (approximately -20m below MLLW) landward to the top of shoreline bluffs, or in estuaries upstream to the head of tidal influence.

Process-based restoration—Intentional changes made to an ecosystem to allow natural processes such as erosion, accretion, accumulation of wood debris, etc,) to occur. Process-based restoration aims to return the landscape to its pre-disturbance, self-sustaining state (Wright 2009 personal communication). Also defined as, the restoration of processes that shape an ecosystem, such as sediment transport or erosion, rather than the restoration of ecosystem features, such as tidal marshes or species populations (Van Cleve et al. 2004).

Protection—Safeguarding ecosystems or ecosystem components from harm caused by human actions.

Puget Sound—Defined here to include all inland marine waters of Washington State inside of the entrance to the Strait of Juan de Fuca and including Georgia Strait south of the Canadian border.

Rehabilitation—Improvements to a natural resource of a visual nature; putting a resource back into good condition or working order (NRC 1992).

Resilience—The ability of a system to return to an earlier state after being changed (Forman and Godron 1986).

Restoration—Returning an ecosystem to a close approximation of its pre-disturbance state in terms of structure and function (NRC 1992). This includes measures needed to protect and preserve restored systems in perpetuity.

Substitution/Creation—The creation of an ecosystem or portion of an ecosystem where it was not historically present. Applied in situations where other recovery options are not considered possible and may even involve “installation” of a typical ecosystem such as a wetland in an upland area.

Valued Ecosystem Component (VEC)—Components that are considered the most important potential beneficiaries of restoration actions. VECs represent benefits that we hope to achieve through restoration. See http://www.pugetsoundnearshore.org/technical_reports.htm

ABBREVIATI0NS

°F	degrees Fahrenheit
ANS	aquatic nuisance species
BMPs	best management practices
CAO	Critical Areas Ordinance
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CGS	Coastal Geologic Services
CLC	Cascade Land Conservancy
CLI	Climate Leadership Initiative
CMZ	channel migration zone
CSO	combined sewer overflow
cy	cubic yards
DARRP	Damage Assessment Remediation and Restoration Program
DO	dissolved oxygen
DOH	Washington Department of Health
Ecology	Washington State Department of Ecology
EDC	endocrine disrupting chemical
EEAW	Environmental Education Association
EF&Gs	ecosystem functions, goods and services
EPA	U.S. Environmental Protection Agency
ERDC	Engineering Research and Development Center (USACE)
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
FEMA	Federal Emergency Management Agency
FY	Fiscal Year
GIS	geographic information systems
GMA	Growth Management Act
IPCC	Intergovernmental Panel on Climate Change
IT	Implementation Team (PSNERP)
km	kilometer
LID	low impact development
LWD	large woody debris
MEA	Millennium Ecosystem Assessment
mg/L	milligrams per liter
MHHW	mean higher high water
MHW	mean high water
MLLW	mean lower low water
MM	management measure
MRC	Marine Resources Committee
MTCA	Model Toxics Control Act
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NRDA	Natural Resources Damage Assessment
NST	Nearshore Science Team
NWAEE	North American Association for Environmental Education

NWSC	Northwest Straits Commission
OFM	Office of Financial Management
OHWM	ordinary high water mark
PAHs	polychlorinated aromatic hydrocarbons
PBDEs	polybrominated diphenyl ethers
PBTs	persistent bioaccumulative toxins
PCBs	polychlorinated biphenyls
PHS	Priority Habitats and Species
PMT	Project Management Team (PSNERP)
ppb	parts per billion
ppm	parts per million
PSAMP	Puget Sound Aquatic Monitoring Program
PSAT	Puget Sound Action Team
PSNERP	Puget Sound Nearshore Ecosystem Project
PSP	Puget Sound Partnership
PSRF	Puget Sound Restoration Fund
PVC	polyvinyl chloride
PWA	Phillip Williams and Associates
RCO	Washington Recreation and Conservation Office
RCW	Revised Code of Washington
Sea Grant	University of Washington Sea Grant Program
SEPA	State Environmental Policy Act
SLR	sea level rise
SMA	Shoreline Management Act
SMP	Shoreline Master Program
SRT	self-regulating tide gate
SSRFB	State Salmon Recovery Funding Board
TDR	transfer of development rights
TESC	temporary erosion and sediment control
TMDL	total maximum daily load
TNC	The Nature Conservancy
USACE	U.S. Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UW	University of Washington
VEC	valued ecosystem component
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WFWC	Washington Fish and Wildlife Commission
WRIA	water resource inventory areas
WSDOT	Washington Department of Transportation
WSU Extension	Washington State University Cooperative Extension
WWU	Western Washington University

INTRODUCTION

The U.S. Army Corps of Engineers (USACE) and the Washington State Department of Fish and Wildlife (WDFW) co-lead an ecosystem study of the Puget Sound called the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). The purposes of the study are to evaluate significant ecosystem degradation in the Puget Sound Basin; to formulate, evaluate, and screen potential solutions to identified problems; and to recommend actions and projects that will restore and preserve the nearshore ecosystem. The recommended actions and projects will include physical, policy, and educational measures (called management measures) carried out across the full range of nearshore geomorphic systems.

This report describes 21 management measures (MMs) that PSNERP will use to develop potential restoration solutions to address nearshore ecosystem degradation in the Puget Sound (Figure 1)[1]. These measures can be applied individually at specific sites or combined into larger, more comprehensive restoration and protection efforts at the basin or sub-basin scale.

Restoration practitioners can use this report to inform decisions about how to restore nearshore processes, structures, and functions. The selection of which measures to implement will vary depending on the geomorphic system being restored, the nature of the degradation, desired process improvements, and expected ecosystem function of the site, tempered against existing constraints. When combined and properly applied at the appropriate scale, management measures can improve the condition of the Puget Sound nearshore by restoring ecosystem processes and promoting environmental and human health and well being[2].

By providing this report, PSNERP seeks to:

- Provide a systematic organizational framework for describing management measures that can be used to develop and evaluate Puget Sound nearshore restoration alternatives composed of combinations of management measures applied at individual sites.
- Assist restoration practitioners in identifying the strengths, weaknesses, and constraints of management measures in the context of Puget Sound and PSNERP's guiding restoration principles (Goetz et al. 2004, available at http://www.pugetsoundnearshore.org/technical_papers/guiding_principles.pdf).
- Outline the principal issues that practitioners should address at the feasibility, design, implementation, and evaluation phases of each management measure.
- Assist restoration practitioners in identifying and assessing the effects of management measures on nearshore functions, structures, and processes.
- Provide a basis for describing the anticipated effects of restoration actions that will be documented in a future programmatic Environmental Impact Statement, which PSNERP is required to prepare.

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[1] Management measures are simplified from a list of National Estuary Restoration Inventory techniques and Pacific Coastal Salmon Recovery Fund reporting measures (Restore America's Estuaries and the Estuarine Research Federation 1999 and NOAA 2006).

[2] Restoration success is never guaranteed, as there will almost always be unforeseen challenges.

- Identify outputs or benefits of implementing management measures for use in PSNERP's cost-benefit evaluation as required by the USACE. PSNERP will use the analysis to determine the most effective and efficient measures and combinations of measures.

This document describes our current understanding of nearshore restoration and protection measures likely to be recommended for project implementation after the completion of the PSNERP ecosystem study. We anticipate that our technical understanding of these management measures will grow as we learn from implementing and evaluating the performance of these measures in the Puget Sound and in other ecosystems. To capture ongoing learning about restoration techniques, new ideas, strategies, and constraints, PSNERP will update this report periodically to reflect new information concerning best practices as the field of restoration ecology evolves.

Figure 1 - The Puget Sound[3] Nearshore

Report Scope and Limitations

The authors of this report followed a detailed outline prepared by the PSNERP Implementation Team and adhered to specific page limits for the background material (7-20 pages) and individual management measures chapters (7-10 pages each). As a result, the authors summarize background information on nearshore ecosystem restoration as it applies to Puget Sound and briefly describe the relationships between management measures, ecosystem processes, and geomorphic systems. Readers are referred to other PSNERP technical reports (available at http://www.pugetsoundnearshore.org/technical_reports.htm) and reference materials cited herein for additional, detailed background information.

[3] As used here, Puget Sound refers to the Strait of Juan de Fuca, Strait of Georgia and Puget Sound. These waters are also collectively known as the Salish Sea.

The report is not intended to be a design manual and does not provide a detailed prescription for addressing all of the impairments that exist in Puget Sound. Instead, the individual management measure chapters are designed to:

- Define and categorize each management measure.
- Describe situations in which the measure could be effectively used in Puget Sound ecosystem nearshore restoration efforts.
- Illustrate the relationship of the measure to nearshore processes, structure, and functions.
- Describe the potential benefits of employing the measure as well as constraints to be considered when implementing the measure.
- Summarize best professional practice considerations associated with engineering, ecological, and socioeconomic issues.
- Describe examples of past or current use of each management measure.

The authors attempted to present a uniform and consistent narrative for each management measure across all 21 chapters. However, some variability in the level of detail was inevitable because of differences in the complexity of the measures, the degree to which the pertinent information fit the standard chapter outline, and the availability of information concerning the measures.

The technical report is directed to an educated, lay audience where the level of technical understanding would be equivalent to PSNERP and regional nearshore restoration practitioners.

The Restoration Project Life Cycle

The goal of restoration is to return ecosystems to a close approximation of their natural, self-sustaining, and predisturbance condition (National Research Council [NRC] 1992). Restoration includes measures that protect and preserve the site for the long term so that the benefits are durable and sustainable in perpetuity. To achieve this restoration goal, restoration practitioners must overcome numerous technical and logistical challenges. A thoughtful and systematic approach to project planning and implementation is essential for success. This section explains how information in this report can be used to aid practitioners in all phases of the project life cycle.

Most restoration projects move from an initial planning phase to feasibility assessment, to design and implementation, and then into monitoring/evaluation (Figure 2)[4]. Each phase is marked by different tasks which vary depending on the complexity of the project and numerous other factors. The scope of each phase can vary and transitions between phases are often somewhat indistinct. Some tasks may overlap different phases or be reiterated as a project progresses.

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[4] This statement and the following statements about project planning and implementing apply to restoration efforts as defined herein as well as to rehabilitation and enhancement efforts. The term ‘restoration’ is used broadly in this section to refer to a wide variety of projects that would use one or more management measures.

The first step of any restoration project is to define specific restoration goals and objectives[5]. Goals should be consistent with the overall mission of the Puget Sound recovery program, appropriate for the geomorphic setting, and prioritized so that project sponsors and stakeholders clearly understand their relative importance and can objectively account for trade-offs (NRC 1992). Objectives describe the specific characteristics to be restored, rehabilitated, or enhanced; for example, objectives might target physical processes, habitat structure, valued ecosystem components (VECs), and/or biological functions. The management measures chapters illustrate some of the physical processes, structural changes, and functional responses that can be expected to occur as management measures are applied in different restoration scenarios. The conceptual model illustrations contained in each chapter should help restoration planners consider the outcomes of various restoration objectives and develop potential performance standards that could be used to measure project outcomes. Funding organizations such as the Estuary and Salmon Restoration Program and the Salmon Recovery Funding Board typically require restoration sponsors to present a conceptual model as part of the grant application process, so conceptualizing the restored processes and functional responses is an important part of project goal-setting.

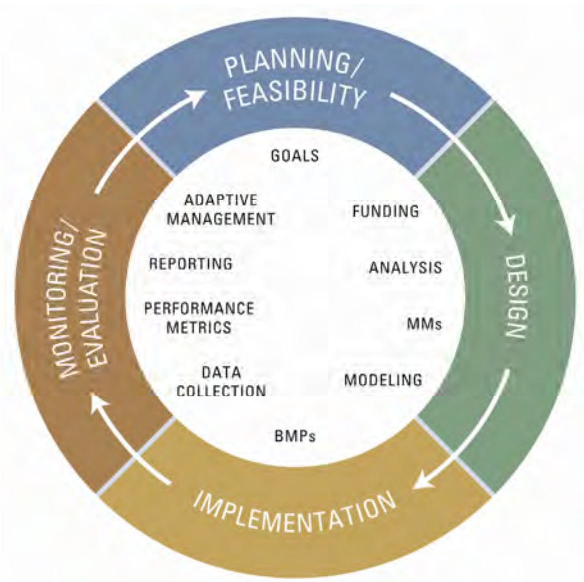

Figure 2 - The Project Life Cycle

Once goals and objectives are defined, restoration planners should assess project feasibility. The feasibility assessment phase typically involves substantial data collection and investigation to address pertinent ecological, social, economic, and political concerns. Common feasibility assessment tasks for nearshore restoration include flood analyses, testing for contaminants, species/habitat surveys, identifying available funding, and examination of historical maps, photographs and data. Feasibility assessment typically also involves an initial cost-benefit analysis and establishment of performance standards.

Scale is an important feasibility factor for several reasons (NRC 1992). First, the project area needs to be large enough to limit deleterious effects that boundary conditions may impose. Second, the restoration actions must be able to exert influence over an area in which major causes of ecological disturbance are occurring. Third, the area needs to be large enough so that effects of the restoration can be monitored. And finally, the project should be of an affordable size.

Knowing the target goals, objectives, and restoration scale enables restoration planners to select a suite of management measures appropriate for their sites. Selecting the appropriate measure(s) requires a thorough understanding of the causes and sources of ecosystem degradation, critical thinking about which measures provide the best opportunities for addressing those causes, and consideration of the geomorphic setting and other factors. The tables in this chapter relating management measures to processes and geomorphic systems are meant to help restoration planners in the selection process. Management measures that are shown to have a weak relationship to a target process or a geomorphic landform may be inappropriate and typically should be considered only as a secondary measure.

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[5] This assumes that the causes and sources of ecosystem degradation have been identified through a valid scientific process.

Each measure has one or more constraints that can undermine its effectiveness or lead to project failure; some of the constraints are specific to the management measure (e.g., downstream erosion potential) and some are common to multiple measures (e.g., cost). Rising sea levels and other climate changes will be a common constraint for most management measures that will need to be addressed during the feasibility assessment. Addressing climate change issues may require modeling or similar analyses that will inform project design, implementation, and monitoring. The individual management measure chapters describe some of key constraints associated with each management measure. Appendices A and B contain additional information on sea level rise (SLR) and the risks it poses to each management measure.

Biogeographical and legal information are critical for assessing project feasibility. Property ownership and land use issues for the site and surrounding areas must be considered to assess interactions of physical processes across geographic boundaries. In many cases restoration actions may require acquisition of property, conservation easements, or leases from the Washington Department of Natural Resources (for projects on state–owned aquatic lands).

Although restoration actions are generally perceived as having beneficial effects on the environment, they still require regulatory review by federal, state, and local agencies. Most restoration projects will require at least one (and usually several) permits or regulatory approvals (e.g., USACE permits for dredge/fill, state shoreline permit or letter of exemption, Hydraulic Project Approval, local city/county grading permit), each of which has specific application and procedural requirements. Fulfilling the permit requirements has implications on the project scope, schedule, and cost, which should be carefully evaluated during the feasibility assessment stage.

The design phase typically includes additional analysis, modeling, and investigation to evaluate different engineering approaches (such as whether to pursue full dike removal or partial dike breach), compare alternatives (such as whether to buy out properties that may be exposed to flooding or construct levees), refine the project scope (such as whether/how to accommodate public access), and describe the conditions that should result from construction. Other common design tasks include developing best management practices (BMPs) for site preparation, construction, and post-construction; preparing grading and planting plans; refining cost estimates; and planning for climate change effects. Often design studies are geared to satisfying permitting and regulatory requirements (for example, projects permitted under the Clean Water Act generally require delineation of wetlands and other waters of the United States). The level of effort required during the design phase will reflect the degree of uncertainty or risk inherent in the restoration project, the level of stakeholder interest/concern (i.e., controversial projects may require more design effort), and other factors.

Implementation occurs once all the feasibility issues have been addressed, the design is complete, funding is secured, and permits are obtained. Implementation activities must be sequenced and timed with respect to regulatory requirements (e.g., during authorized in-water ‘work windows’), ecological requirements (e.g., the life history stage of an invasive species targeted for removal), social concerns (e.g., effects on navigation, recreation, access/circulation, etc.), and other considerations. Restoration practitioners will want to ensure that the work is implemented in a way that minimizes the potential for and duration of adverse construction impacts.

The final phase involves monitoring and evaluation. The purpose of evaluating a restoration effort is to determine, in a reliable scientific manner, how effective the restoration has been, or in other words, how similar the restored ecosystem is to the target ecosystem (NRC 1992). A critical component of the monitoring and evaluation phase is to identify performance criteria. Performance criteria are specific biological, physical, and chemical indicators that can be measured to determine the extent to which goals and objectives have been met. Ideally in this phase, practitioners would verify the performance standards identified in the initial stages of goal setting and feasibility assessment. In any case, criteria should be identified for each objective and should assess process recovery, structural changes, and functional responses. The NRC (1992) offers examples of assessment criteria that restoration practitioners may want to consider when identifying appropriate indicators; however NRC's examples would have to be tailored to match individual projects. Practitioners may want to base performance criteria on observations of comparable, but intact reference sites (as available).

Restoration projects sometimes fail to achieve their goals and objectives due to poor planning and feasibility assessment, design flaws, unanticipated natural events (e.g., landslides or floods) or mistakes during implementation. Some projects suffer from a lack of evaluation and monitoring, which limits opportunities for adaptive management and corrective action. The information contained in this report should help illuminate many of the feasibility, design, implementation, and evaluation / monitoring challenges commonly encountered in nearshore restoration. By following this guidance and asking the following questions[6], restoration practitioners improve the likelihood that future efforts will succeed.

Pre-project implementation questions:

- Has the restoration been planned with adequate scope and expertise?
- Does the restoration design allow for midcourse corrections and adaptive management?
- Have sufficient baseline data been collected over a suitable period of time to facilitate before-and-after comparisons?
- Has the project been designed to make the restored ecosystem as self-sustaining as possible to minimize maintenance requirements?
- What impact will the restoration have on processes and will the beneficial effects be outweighed by offsite factors (e.g., on site erosion control measures may not be effective if there are major activities/sources off site that deliver large sediment loads)?
- How long will the project need to be monitored before the restoration effort can be declared effective?
- Have risk and uncertainty been adequately considered in project planning?
- Have adequate monitoring, surveillance, management, and maintenance programs been developed so that monitoring costs and operational details are anticipated and monitoring results will be available to improve restoration techniques as the project matures?

Post-project implementation questions:

- Based on the monitoring results, are the anticipated intermediate objectives being achieved? If not, are appropriate steps being taken to correct the problem(s)?
- Do the objectives or performance indicators need to be modified? If so, what changes may be required in the monitoring program?
- Is the monitoring program adequate?

[6] Adapted from *Restoration of Aquatic Ecosystems* (NRC 1992).

- How similar in structure and function is the restored ecosystem to the target ecosystem?
- To what extent is the restored ecosystem self-sustaining, and what are the maintenance needs?
- What lessons have been learned from this effort and have they been shared with other practitioners?
- What were the ecological, economic, and social benefits realized by the project?

BACKGROUND ON RESTORING NEARSHORE PROCESSES

The recovery of the Puget Sound nearshore ecosystem requires a variety of physical, policy, and educational measures aimed at protecting and restoring ecosystem processes[7]. Recovery involves taking actions that enable the nearshore system to generate and sustain the physiochemical and biological interactions that create nearshore structure and functions (Fresh et al. 2004).

Management measures address risks to and degradation of ecosystem process integrity at different scales across the full range of nearshore geomorphic systems (rocky coasts, beaches, embayments, and river deltas). Management measures can be applied as stand-alone actions or can be combined to serve as building blocks of multi-faceted nearshore restoration efforts.

The 21 management measures described here include restoration, rehabilitation, and enhancement actions as well as protection, management, and regulatory endeavors that address the objective of recovering or improving nearshore ecosystem processes, structure and/or functions (Table 1). In a large-scale restoration program, management measures are vital to describing the varied combination of actions that can be employed. Some of the management measures are narrowly defined around a specific activity or objective; for example, *Beach Nourishment* and *Large Wood Placement.* Others such as *Habitat Protection Policy or Regulation* are more general and potentially encompass a wide array of activities and objectives.

The list of measures reflects PSNERP's focus on physical restoration actions in the nearshore. Although non-physical measures are included (e.g., *Public Education and Involvement* and *Habitat Protection Policy and Regulation*), these are largely outside of the scope of anticipated USACE authority. They are included because they are recognized as critical tools for Puget Sound nearshore restoration and protection that are likely to be used by partner agencies and organizations. The composition of the management measures list should be interpreted only to reflect the focus of PSNERP and not as a definitive organizational scheme.

[7] The terms *protection* and *restoration* are used throughout the report according to the definitions in the glossary. Restoration (returning an ecosystem to a close approximation of its pre-disturbance state) includes measures that protect and preserve the site for the long term. Protection, while not succinctly defined in the restoration literature, is a component of restoration, but also refers to independent measures that save nearshore systems from harm.

Table 1 – Description of PSNERP Management Measures

No.[1]	Management Measure	Description[2]
1	Armor Removal or Modification	Removal, modification, or relocation of coastal erosion protection structures such as rock revetments, bulkheads, and concrete walls on bluff-backed beaches, barrier beaches, and other shorelines.
2	Beach Nourishment	The intentional placement of sand and/or gravel on the upper portion of a beach where historic supplies have been eliminated or reduced.
3	Berm or Dike Removal or Modification	Removal or modification of berms, dikes and other structures to restore tidal inundation to a site that was historically connected to tidal waters. Includes dike/berm breaching and complete dike/berm removal.
4	Channel Rehabilitation or Creation	Restoration or creation of channels in a restored tidal wetland to change water flow, provide habitat, and improve ecosystem function.
5	Contaminant Removal and Remediation	Removal or remediation of unnatural or natural substances (e.g., heavy metals, organic compounds) harmful to the integrity or resilience of the nearshore. Pollution control, which is a source control measure, is a different measure.
6	Debris Removal	The removal of solid waste (including wood waste), debris, and derelict or otherwise abandoned items from the nearshore.
7	Groin Removal or Modification	Removal or modification of groins and similar nearshore structures built on bluff-backed beaches or barrier beaches in Puget Sound.
8	Habitat Protection Policy or Regulations	The long-term protection of habitats (and associated species) and habitat-forming processes through zoning, development regulations, incentive programs and other means.
9	Hydraulic Modification	Modification of hydraulic conditions when existing conditions are not conducive to sustaining a more comprehensive restoration project. Hydraulic modification involves removing or modifying culverts and tide gates or creating other engineered openings in dikes, road fills, and causeways to influence salt marsh and lagoon habitat. This measure is used in managed tidal systems (as opposed to naturally maintained systems).
10	Invasive Species Control	Eradication and control of nonnative invasive plants or animals occupying a restoration site and control measures to prevent introduction or establishment of such species after construction is complete.
11	Large Wood Placement	Installment of large, unmilled wood (large tree trunks with root wads, sometimes referred to as large woody debris) within the backshore or otherwise in contact with water to increase aquatic productivity and habitat complexity.
12	Overwater Structure Removal or Modification	Removal or modification of overwater structures such as piers, floats and docks to reduce shading and restore wave regimes.
13	Physical Exclusion	Installation of exclusionary devices (fences, barriers, mooring buoys, or other devices) to direct or exclude human and/or animal use of a restoration site.
14	Pollution Control	Prevention, interception, collection, and/or treatment actions designed to prevent entry of pollutants into the nearshore ecosystem.
15	Property Acquisition and Conservation	Transfer of land ownership or development rights to a conservation interest to protect and conserve resources, enable restoration or increase restoration effectiveness.
16	Public Education and Involvement	Activities intended to increase public awareness of nearshore processes and threats, build support for and volunteer participation in restoration and protection efforts, and promote stewardship and responsible use of nearshore resources.
17	Revegetation	Site preparation, planting, and maintenance to manipulate soils and vascular plant populations to supplement the natural development of native vegetation.
18	Species Habitat Enhancement	Installation or creation of habitat features (sometimes specific structures) for the benefit of native species in the nearshore.
19	Reintroduction of Native Animals	Reestablishment of native animal species at a site where they existed or as replacement for lost habitat elsewhere.
20	Substrate Modification	The placement of materials to facilitate establishment of desired habitat features and improve ecosystem functions, structures, or processes.
21	Topography Restoration	Dredging, excavation and /or filling to remove or add layers of surface material so that beaches, banks, tidal wetlands, or mudflats can be created.

[1] The management measures are listed in alphabetical order. No hierarchy or priority order should be inferred.
[2] See individual management measure chapter for a complete definition.

All management measures have the potential to contribute directly or indirectly to restoration of ecosystem processes. However some management measures are by their nature more restorative of processes than other measures (as explained in the following section). Some measures tend to operate mainly by enhancing ecosystem structure, and some measures are prerequisites for other measures or are protective investments in preventing further ecosystem degradation (Table 2). Grouping management measures into categories based on their different roles and potential to restore processes can be a useful tool for creating an appropriate menu of actions for a given restoration site. The categories described below are one way to describe similarities and differences between various measures; presenting the measures in these groupings is not intended to render judgment on measures as "good" or "bad", but is rather meant to assist in the selection of appropriate actions.

- **Primary Restorative Measures** – These measures exert long-lasting effects on ecosystem processes and will often provide the best chance of achieving complete restoration of processes. This group includes measures that involve rehabilitation and enhancement actions using engineered approaches (including water control approaches to *Hydraulic Modification*, for example) which may not completely restore natural water flow processes.
- **Supplementary Enhancement Measures** – Includes mainly structural measures that provide immediate but often short-lived benefits in terms of habitat structure. These should frequently be applied in concert with primary restorative measures. In fact, some measures such as *Revegetation* will likely be a component of all restoration efforts to some degree.
- **Prerequisite Measures** – Includes measures that are often required prior to or in conjunction with other measures. For example, *Contaminant Removal and Remediation* may be a prerequisite for *Berm or Dike Removal or Modification*, *Hydraulic Modification*, and/or *Channel Rehabilitation or Creation*. *Property Acquisition and Conservation* may also be a prerequisite for many types of restoration actions.
- **Protective Measures** – Measures such as *Public Education and Involvement* and *Habitat Protection Policy and Regulation*, which focus on human behavioral changes, may have as much value as stand-alone actions as when they accompany other measures. These types of measures will often enhance the effect of other restoration actions but may not always be essential to achieving site-specific restoration goals. These measures tend to take effect over relatively long timeframes and may need continued and ongoing application in order to achieve lasting benefits.

Table 2 – Management Measures Grouped by their Potential Restorative Effect on Physical Nearshore Processes

<table>
<tr><th>Category</th><th>Restorative</th><th>Enhancement</th><th>Prerequisite</th><th>Protective</th></tr>
<tr><td>Role</td><td>Exert long-lasting effects on ecosystem processes</td><td>Create/promote structural elements (habitats) and/or mimic natural processes</td><td>Remove or prevent physical and chemical disturbances</td><td>Protect existing resources, limit future impairment, influence human behaviors</td></tr>
<tr><td rowspan="3">Management Measures</td><td>Armor Removal or Modification
Berm or Dike Removal or Modification
Groin Removal or Modification
Hydraulic Modification
Overwater Structure Removal or Modification
Topography Restoration</td><td>Beach Nourishment
Invasive Species Control
Large Wood Placement
Species Habitat Enhancement
Reintroduction of Native Animals
Substrate Modification</td><td>Contaminant Removal and Remediation
Debris Removal
Physical Exclusion
Pollution Control</td><td>Habitat Protection Policy or Regulations
Public Education and Involvement</td></tr>
<tr><td colspan="2"></td><td colspan="2">Property Acquisition and Conservation</td></tr>
<tr><td colspan="2">Revegetation
Channel Rehabilitation or Creation</td><td></td><td></td></tr>
</table>

To illustrate the differences reflected in the grouping shown above, consider a restoration project focused on a tidal channel that has become sediment-laden due to the lack of tidal exchange (restricted by a tide gate). A successful project will implement multiple measures in an integrated way: *Channel Rehabilitation or Creation* can help rehabilitate tidal-driven geomorphic processes of the channel and long-term reconnection to a broader channel network. *Hydraulic Modification* can produce an instantaneous source of tidal input through removal of the tide gate. *Large Wood Placement* can mimic detritus recruitment and retention at a local scale in the near-term, and *Revegetation* can enhance these processes—typically over a longer term and a broader area (although the durability and extent of the enhancement depend on the species planted, planting density, site preparation, maintenance, and other factors).

Management Measures and Process-Based Restoration

Ecosystem processes are the interactions among physiochemical and biological elements of an ecosystem that change in character or state over time (Fresh et al. 2004). Processes operate at naturally occurring rates, frequencies, durations, and magnitudes that are controlled by human and natural factors (Goetz et al. 2004). Human attempts to control dynamic systems such as beaches, bluffs, floodplains, and river deltas using structural approaches such as groins, bulkheads, dikes, and levees disrupt the natural processes and degrade nearshore systems. Restoration actions aimed at restoring damaged processes enable the ecosystem to be naturally productive, self sustaining, and diverse (Goetz et al. 2004).

This report emphasizes that successful recovery of the Puget Sound nearshore requires protecting and restoring the processes that create and sustain the structure of the nearshore rather than just restoring the structure itself (without addressing the underlying processes). The focus is on restoring key physical processes such as tidal hydrology and sediment supply, with less attention on the full suite of ecological processes such as primary productivity. The reason for emphasizing physical processes is because in dynamic environments like the nearshore, biotic processes are dependent on physical processes (P. Cereghino, personal communication)[8]. Readers are encouraged to review other PSNERP technical reports and other referenced documents for additional information on these topics.

The PSNERP Nearshore Science Team (NST) has identified guiding principles for nearshore restoration that favor process-based restoration over species-based restoration (see text box). The NST lists three main reasons for favoring process-based restoration (Simenstad et al. 2006):

1. Without restoring processes, the long-term maintenance of the structure and associated ecological functions is highly uncertain.
2. The processes are inherently involved in the functions we want to recover.
3. Incorporating or accepting natural ecosystem dynamics is less likely when considering only the services an ecosystem provides to a single species.

Process-Based Restoration

Process-based restoration includes intentional changes made to an ecosystem to allow natural processes (such as erosion, accretion, accumulation of wood debris, etc.) to occur. Process-based restoration aims to return the landscape to its pre-disturbance, self-sustaining state. Process-based restoration typically involves actions that support or restore the dynamic processes that generate and sustain desirable nearshore ecosystem structure (e.g., eelgrass beds) and important functions (e.g., salmon production, bivalve production, and clean water). Process-based restoration is often distinguished from species-based restoration which aims to improve the services an ecosystem provides to a single species or group of species as opposed to improving the entire ecosystem.

The concept of process-based restoration is linked to a broader doctrine of ecosystem-based management which examines "the complex linkages within the physical and biological components of an ecosystem, and how social and economic choices by humans can change these processes (Ruckelshaus and McClure 2007)." Proponents of ecosystem-based management stress the importance of understanding the consequences of human actions and values throughout the ecosystem when assessing the range of management tradeoffs to be made:

> *"Understanding interactions and linkages among species, habitats, and the processes that support them is critical to our ability to predict the ecosystem response to natural perturbations and management actions. An ecosystem-wide view of Puget Sound will improve our ability to choose cost-effective actions and predict long term results."* (Ruckelshaus and McClure 2007)

Alterations of natural processes damage nearshore ecosystem structures, which provide ecosystem services that people value (Millennium Ecosystem Assessment [MEA] 2005; Simenstad et al. 2006). Ruckelshaus and McClure (2007) define ecosystem services as the outputs and experiences of ecosystems that benefit humans, which are generated by the structure and function of natural systems, often in combination with human activities. PSNERP refers to these benefits collectively as ecosystem functions, goods, and services (EF&Gs) (Figure 3). Because people value EF&Gs, they provide useful benchmarks for evaluating restoration effectiveness from a socio-ecological perspective.

[8] Furthermore, page limit restrictions limit the authors' ability to cover ecological processes in more detail.

Provisioning	Food	Crops
		Livestock
		Captured fisheries
		Aquaculture
		Wild foods
	Fiber	Timber and wood
		Other fibers
		Biomass fuel
	Freshwater (quantity)	
	Genetic resources	
	Biochemicals, natural medicines	
Regulating	Air quality regulation	
	Global climate	
	Regional and local climate	
	Water (quality)	
	Erosion	
	Water purification and waste treatment	
	Disease	
	Pests	
	Pollination	
	Natural hazards	
Cultural	Ethical	
	Existence	
	Recreation and ecotourism	
	Educational	
Supporting	Nutrient cycling	
	Soil formation	
	Food web	
	Photosynthesis	

Source: Millennium Ecosystem Assessment (2005) as adapted in the PSNERP Change Analysis (in prep)

Figure 3 - Ecosystem Functions, Goods and Services

Management measures can affect ecosystem processes to varying degrees depending on how, where, and at what scales they are applied. The same management measure applied to different landforms will produce different effects on processes. For example, the effects of removing a bulkhead from a pocket beach will be different from those that occur when the same measure is applied to a coastal bluff, since the latter is generally more likely to supply sediment to foreshore, beach, and down-drift shores through littoral sediment transport, although both applications may improve forage fish spawning areas and other valued ecosystem functions.

The extent and degree to which processes are affected by management measures also may depend on whether the management measures are applied individually or in combination with other measures. Thus, pairing *Armor Removal or Modification* with *Groin Removal or Modification* down-drift of the restored feeder bluff may supplement the benefits of the bulkhead removal activity by taking away other impediments to littoral sediment transport (referred to as net shore-drift).

The potential for some measures to impact ecosystem processes may be limited or transient. For example, *Large Wood Placement* may create an immediate impact on beach structure by dissipating wave energy and allowing sediment accumulation, but the effects may be relatively short-lived as the wood material decays or is transported offshore. Still other management measures such as *Pollution Control* or *Public Education and Involvement* may by themselves have less direct effect on processes but may contribute to ecosystem restoration in other ways by modifying human behaviors, building public support for restoration efforts, and preventing or slowing causes of ecosystem degradation.

Table 3 shows the relative degree of influence that different management measures can have on the physical processes PSNERP has identified as being most pertinent to Puget Sound recovery efforts. The potential for an individual management measure to affect processes is categorized as:

- Strong – measure has the potential for durable and sustainable effects on process; typically full restoration.
- Weak – measure mainly targets structural ecosystem elements or has less durable/sustainable effects on process; resulting in partial restoration or enhancement.
- None – no relationship.

These ratings are based on best professional judgment, not on empirical data. They are intended to highlight broad distinctions between management measures, assuming that the measure is applied at the ideal scale for influencing processes. Actual effects will always be context-specific.

Table 3 – Potential of Management Measures to Influence Nearshore Processes

No.	Management Measure[1]	Relationship to PSNERP Nearshore Ecosystem Processes ● = strong effect; ◗ = weak effect; blank = no relationship									
		Sediment Supply and Transport	Beach Erosion and Accretion	Distributary Channel Migration	Tidal Channel Formation and Maintenance	Freshwater Input	Tidal Hydrology	Detritus Recruitment and Retention	Exchange of Aquatic Organisms	Solar Radiation (Sunshine)	Wind and Waves
1	Armor (a) Removal	●	●			◗		●			●
	(b) Modification		◗			◗					
2	Beach Nourishment	●	●								
3	Dike or Berm (a) Removal	●		●	●	●	●	●	●		◗
	(b) Modification	◗			◗	◗	◗	◗	◗		
4	Channel (a) Rehabilitation	●		◗	◗	●	●	●	●		
	(b) Creation	◗			◗	●	◗	◗	◗		
5	Contaminant (a) Removal								◗		
	(b) Remediation								◗		
6	Debris Removal	◗	◗		◗						
7	Groin (a) Removal	●	●	◗	◗	◗	◗	◗	●		●
	(b) Modification	◗	◗	◗	◗	◗	◗	◗	◗		◗
8	Habitat Protection Policy or Regulations[2]	◗	◗	◗	◗	◗		◗	◗		◗
9	Hydraulic Modification	◗				◗	◗	◗	◗		◗
9	Invasive Species Control	◗	◗		◗	◗	◗	◗	◗	◗	◗
11	Large Wood Placement	◗	◗	◗	◗			◗	◗		◗
12	Overwater Structure (a) Removal	◗	◗							●	◗
	(b) Modification									◗	◗
13	Physical Exclusion								◗		
14	Pollution Control								◗		
15	Property Acquisition and Conservation[3]	●	●	●	●	●	●	●	●	●	●
16	Public Education and Involvement[4]	◗	◗	◗	◗	◗	◗	◗	◗	◗	◗
17	Revegetation	◗	◗	◗		◗		◗		◗	◗
18	Species Habitat Enhancement								◗		
19	Reintroduction of Native Animals (Non-Plant)								●		
20	Substrate Modification	◗	◗		◗	◗			●		◗
21	Topography Restoration	●	●	●	●	●	●	●	●		●

[1]Some management measures are broken out into separate rows labeled (a) and (b) to distinguish variation in the degree of process restoration between full removal of a stressor and partial removal/modification of the stressor.
[T] This measure influences process via specific regulations such as the Shoreline Management Act and Growth Management Act, which limit shoreline armoring, overwater structures and removal of riparian vegetation; stormwater regulations, which require management of runoff, infiltration, etc.; and other regulations that protect processes.
[3] Measure has the potential to influence all processes to some degree and is essential for the long-term protection of ecosystem processes.
[4] Public Education and Involvement potentially influences most processes, albeit mainly indirectly and with varying durability.

Relationship of Management Measures to Geomorphic Systems

In order to execute strategic and process-based restoration of the nearshore, a framework for understanding and discussing the geomorphology of Puget Sound shorelines is essential. Geomorphic knowledge, coupled with an assessment of the most common changes observed in Puget Sound nearshore environments (described in more detail in subsequent sections), allows us to choose restoration actions that are appropriate for a particular area.

Puget Sound's nearshore environment contains more than 3,000 kilometers of diverse shoreline, including rocky coasts, sand and gravel beaches, coastal bluffs, small estuaries and lagoons, and river deltas. Each of these environments is characterized by different geomorphic and ecological processes and subject to a distinctive suite of environmental challenges and potential solutions (Shipman 2008).

Shipman (2008) provides a hierarchical classification of Puget Sound nearshore landforms. The classification reflects the primary role of geomorphic processes in shaping the landscape, which are the same processes that are relevant to nearshore restoration (e.g., supply and transport of sediment, tidal hydrology, etc.). The classification system recognizes four major geomorphic systems within Puget Sound: (1) rocky coasts, (2) beaches, (3) protected embayments, and (4) large river deltas.

Each geomorphic system contains many different and highly complex landforms reflecting different long-term patterns of sediment accretion or deposition. Several factors influence the distribution and character of Puget Sound landforms, including: large-scale topographic differences between watersheds that drain to Puget Sound, underlying geology, sea-level history, tidal range, climate, and wave exposure (Shipman 2008). Landforms are in turn composed of various substrate and elevation components (e.g., a berm and beach face on a barrier beach). Each landform is shaped by different ecosystem processes and therefore requires and responds to different management measures. Strong associations between geologic and hydrologic processes and nearshore landforms are shown in Table 4.

Table 4 – Relationship between Ecosystem Processes and Geomorphic Landforms

PSNERP Nearshore Ecosystem Processes[1]	Geomorphic Systems and Landforms[2] ●=strong relationship												
	Rocky Shores			Beaches		Embayments				Deltas			
	Plunging rocky shores	Rocky platforms	Pocket beaches	Bluffs	Barrier beaches	Open coastal inlets	Barrier estuaries	Barrier lagoons	Closed lagoons and marshes	River-dominated deltas	Wave-dominated deltas	Tide-dominated deltas	Fan deltas
Sediment Supply and Transport				●	●	●	●	●	●	●	●	●	●
Beach Erosion and Accretion			●	●	●								
Distributary Channel Migration										●	●	●	●
Tidal Channel Formation and Maintenance						●	●	●		●	●	●	●
Freshwater Input			●	●	●	●	●			●	●	●	●
Tidal Hydrology						●	●	●		●	●	●	●
Detritus Recruitment and Retention													
Exchange of Aquatic Organisms													
Solar Radiation													
Wind and Waves	●	●	●	●	●						●		●

[1]Key local process identified by PSNERP as being essential to recovery efforts.
[2]Based on Geomorphic Classification of Puget Sound Nearshore Landforms (Shipman 2008).

The relationship of processes to geomorphic systems and landforms suggests that management measures will also have varying degrees of applicability or utility in different geomorphic settings. *Beach Nourishment* tends to occur on beaches, or where beaches historically occurred. *Armor Modification or Removal* also tends to occur primarily on beaches or where bulkheads and other structures have been installed for stabilization purposes. Removal of armoring on low-energy shores (where the armoring serves an aesthetic/landscaping purpose but is not required for stabilization) may have less benefit in terms of restoring sediment delivery and transport processes, but may improve habitat structure (e.g., for migrating salmon) and function (e.g., forage fish spawning). *Berm and Dike Modification or Removal* tends to occur in river deltas and some embayments (estuaries or lagoons) but would not be an appropriate measure on coastal bluffs or rocky shorelines (Shipman 2009, personal communication). Other measures such as *Large Wood Placement*, *Revegetation*, and *Invasive Species Control* might happen in any geomorphic setting, although the methods may vary from one system or landform to another.

Table 5 shows strong relationships between landforms and management measures as a result of process linkages. The table focuses on management measures that involve physical and direct alteration of the landscape and which tend to have the most long-lasting and sustainable effects on the geomorphology of the nearshore zone. Management measures not listed in the table may also affect processes that contribute to landform creation and maintenance, but the effects are typically more ephemeral, indirect, or harder to evaluate than other measures.

Table 5 – Strong Relationships between Geomorphic Landforms and Management Measures

Management Measures	Geomorphic Systems and Landforms[1] ●= strong relationship												
	Rocky Shores			Beaches		Embayments				Deltas			
	Plunging rocky shores	Rocky platforms	Pocket beaches	Bluffs	Barrier beaches	Open coastal inlets	Barrier estuaries	Barrier lagoons	Closed lagoons and marshes	River-dominated deltas	Wave-dominated deltas	Tide-dominated deltas	Fan deltas
Armor Removal or Modification			●	●	●	●							
Berm or Dike Removal or Modification						●	●	●		●	●	●	●
Channel Rehabilitation or Creation[2]						●	●	●		●	●	●	●
Groin Removal or Modification				●	●								
Hydraulic Modification							●	●	●	●	●	●	●
Overwater Structure Removal / Modification													
Revegetation[2]				●	●	●	●		●				
Topography Restoration			●	●	●	●	●	●	●	●	●	●	●

[1]Based on Geomorphic Classification of Puget Sound Nearshore Landforms (Shipman 2008).
[2] These two measures can sometimes be process-based or restorative measures when applied in the proper contexts.

Benefits of Management Measures Based on Their Temporal and Spatial Persistence

Understanding the geomorphic framework and the temporal dynamics of processes and management measures can assist restoration practitioners in making decisions about which measures to apply in different settings. As an example, consider the differences between *Beach Nourishment* and *Armor Removal or Modification* in terms of restoring sediment-starved beaches within an impaired drift cell (Simenstad et al. 2006). *Beach Nourishment* imitates or jump-starts the natural processes of sediment supply and transport and can, in some cases, imitate restored sediment processes. There is an immediate effect at the site where the material is deposited (a change in beach profile and habitat enhancement, for example). Down-drift areas may change over time as the materials are transported by net shore-drift over a broader area. The lifespan of the deposited material will depend on local factors such as fetch and associated wave energy, and the benefits of the initial application will be relatively short-lived without continued intervention or repeated nourishment.

In contrast, reintroducing natural sediment to a drift cell through *Armor Removal or Modification* may not provide the same instantaneous sources of sediment or achieve habitat structure benefits as quickly, but the benefit of sediment delivery and transport will generally persist over a longer timeframe (and possibly over a broader geographic area). Relative to *Beach Nourishment*, restored sediment processes following *Armor Removal or Modification* are likely to be more resilient to disturbance events (sediment delivery may increase during storm events) and may be more sustainable over time (Simenstad et al. 2006; Johannessen and MacLennan 2007). Furthermore, *Armor Removal or Modification* tends to promote recovery of ecosystem processes, which allows dynamic reorientation of the beach profile with more favorable effects on the drift cell.

Management measures that are aimed at creating nearshore structure can sometimes, over longer timeframes, engage ecosystem processes. *Revegetation* can lead to the reestablishment of forested nearshore riparian zones, which in turn influence processes related to water delivery, erosion, and detrital inputs. Similarly, *Invasive Species Control* (e.g., removal of *Spartina*) can help to create and maintain tidal channels and natural food web relationships impaired by *Spartina* infestation (Buchanan 2006).

When evaluating the time-benefit relationships of different management measures, restoration practitioners should consider natural disturbance regimes (including disturbances related to global climate change) and their effects on ecosystem processes. Storms, floods, and large-scale erosional and depositional events often exert strong influences on the trajectory of both natural and restored ecosystems and should be considered during restoration planning and design stages. Successful restoration efforts take advantage of natural disturbance regimes to enhance benefits of restoring natural processes.

For management measures to effectively influence ecosystem processes, they also must be applied at the appropriate spatial scales. Although it is often true that management measures applied at large scales will produce greater benefits than measures applied at smaller scales, the relationship of restoration area to restoration benefit is complex. Therefore, it is important to understand the spatial scales at which targeted processes operate when deciding which management measures to apply and where. For example, *Armor Removal or Modification* on a single parcel of land might promote sediment transport that affects beach habitat for a short distance down-drift, but inadequate sediment supply at the scale of the whole drift cell (because of a bulkhead on a feeder bluff up-drift of the site, for example) may prevent full restoration of natural sediment processes. Similarly, removal of dikes on a large estuary may affect channel formation processes well outside of the project area (Hood 2004).

The graphs in Figure 4 show hypothetical measures of the benefits over time. The relationships are archetypal for different types of management measures. Graph A generally represents the primary restorative measures; graph B generally represents the enhancement measures; and graph C generally represents the protective measures. Prerequisite measures would generally be depicted by graphs B or C.

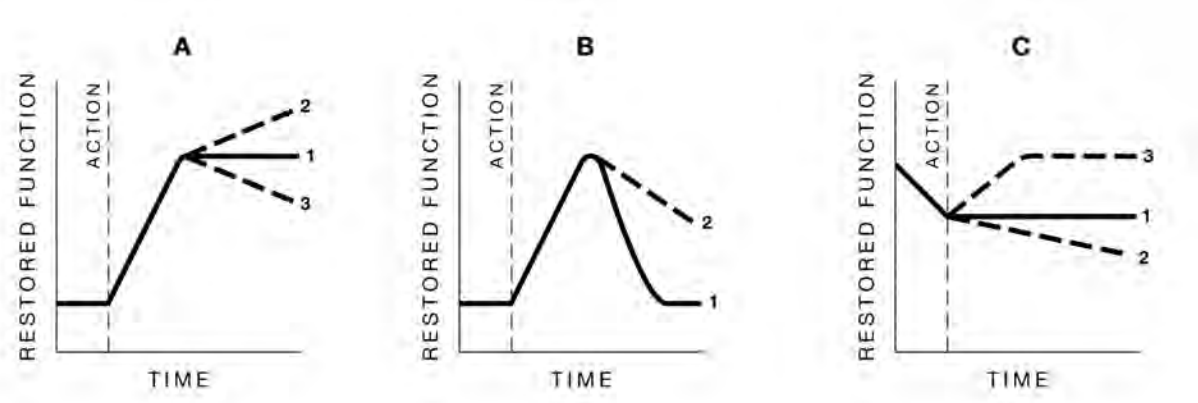

Figure 4 – Contrasting Restoration of Function Over Time for Different Groups of Actions. A) Restoration of nearshore processes leads to sustained restoration of habitat functions (A1), which may result in either a system response allowing for improvement in functions (A2) or decline due to external systemic stressors (A3). **B) Restoration of habitat structures in the absence of supporting nearshore processes** produces temporary recovery of functions (B1) or at best triggers a system response resulting in persisting benefits that decline over time due to lack of supporting processes (B2). **C) Protection of ecosystem processes** prevents or slows degradation (C1 and C2), or remediation of chronic stressors results in a natural return to a higher level of function (C3).

Trends and Current Use of Management Measures

Management measures have been used to varying degrees in the Puget Sound region during the past few decades, but data concerning their use has not been systematically recorded or tracked. The lack of a thorough accounting of their application trends and outcomes is due to the fact that restoration is an emerging practice, and efforts to restore Puget Sound are being implemented by different entities across a wide range of environmental, regulatory, and jurisdictional program boundaries (Gelfenbaum et al. 2006).

Photo 1 - Beach nourishment project at Seahurst Park (J. Johannessen)

Historically, some management measures were implemented for purposes other than restoration (NRC 1992). For example, *Debris Removal* was carried out to reduce risks to boating and navigation. *Revegetation* was sometimes practiced as part of the Conservation Reserve Program, which was designed to take agricultural land out of production. *Beach Nourishment* was frequently employed to enhance areas for recreation but is now commonly used as an alternative to bank armoring or as a complement to *Armor Removal or Modification* efforts (Shipman 2009, personal communication) (Photo 1).

Early restoration efforts primarily sought to place specific habitats, engineered structures, and/or animals in the landscape to address the symptoms of ecosystem degradation. Species- and habitat-specific restoration projects have had varying success (e.g., eelgrass restoration at the Anacortes ferry terminal, efforts to restore Salmon Creek in Discovery Bay by remeandering channelized stream segments). Enhancement actions (e.g., strategic placement of large woody debris in streams, riparian plantings, removal of fish passage barriers, livestock fencing, and creation of pocket beaches) have improved structural habitat components in many Puget Sound watersheds (Photo 2).

Hampering our early attempts to restore the Puget Sound nearshore is a general lack of understanding, information, and data on the linkages between ecosystem processes, structures, stressors, and management actions (Gelfenbaum et al. 2006). Institutional or cultural barriers may be interfering with our ability to perform thorough analyses of restoration project effectiveness. Currently, a shift toward strategic and synergistic nearshore restoration actions is occurring that recognizes the connectivity of the nearshore with other freshwater, terrestrial, shoreline, and marine ecosystems. As our knowledge of ecosystem recovery principles increases, actions that restore ecosystem processes are being implemented with greater frequency.

Photo 2 – Pocket beach creation at Olympic Sculpture Park in Seattle (H. Shipman)

Regional restoration efforts are undergoing a natural evolution; the scale of our assessments is increasing from site to population scales (as in regional salmon recovery efforts), and from single-species to multiple-species (in the case of ecosystem restorations). Currently, large-scale process-based restoration efforts (encompassing tens to hundreds of acres) are occurring throughout Puget Sound. These large-scale efforts have involved *Hydraulic Modification*, *Berm and Dike Modification or Removal*, and *Topography Restoration* for purposes of restoring estuarine wetlands associated with major river systems such as the Skagit, Stillaguamish, Snohomish, Skokomish, Duckabush, Dosewallips, Quilcene, Puyallup, Nisqually, and Duwamish. Some management measures such as *Debris Removal*, *Reintroduction of Native Animals*, and *Invasive Species Control* are being implemented on a quasi-programmatic basis in conjunction with specific state agency initiatives and/or public-private partnerships (e.g., Washington Department of Natural Resources' [WDNR] derelict vessel removal program, Washington Department of Agriculture's *Spartina* removal in Willapa Bay, and the Puget Sound Restoration Fund's Olympia oyster restoration project). Tribes, Marine Resource Committees (MRCs), local governments, conservation districts, salmon recovery Lead Entities, and other restoration practitioners are implementing site-scale projects involving *Revegetation*, *Large Wood Placement*, *Overwater Structure Removal or Modification, Beach Nourishment*, *Armor Removal or Modification,* and other measures both opportunistically, as properties and willing landowners become available, and as part of local/regional restoration programs. The Natural Resources Damage Assessment (NRDA) process under NOAA's Damage Assessment, Remediation, and Restoration Program (DARRP) has been a major impetus for the cleanup and restoration of waterways damaged by hazardous wastes and oil spills since the early 1980s. Ongoing restoration efforts in Commencement Bay, the Duwamish River, and the Snohomish estuary are being coordinated through the NRDA process (Photo 3).

Other regulatory mandates and court decisions (e.g., the 1974 Boldt Decision in the *United States et al., v State of Washington et al.*) are influencing the use and application of some management measures. Regulatory requirements drive some forms of *Channel Rehabilitation or Creation* involving culvert removal (to restore fish passage for example) as well as some *Pollution Control* and *Contaminant Removal and Remediation* actions associated with National Pollutant Discharge Elimination System compliance and "Superfund" site cleanup under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Salmon recovery efforts are another major force driving restoration in Puget Sound. Resource agencies, tribal governments, local jurisdictions, and watershed groups have responded to the Endangered Species

Act listings of Puget Sound Chinook salmon, steelhead, bull trout, and Hood Canal summer chum as well as declines in other salmon stocks (e.g., Puget Sound coho salmon) by sponsoring and implementing a wide range of restoration actions. These efforts have tended to focus on in-stream and riparian areas with less attention to nearshore systems other than river deltas and pocket estuaries. Lack of attention to nearshore areas reflects the relative dirth of information on salmonid use of nearshore environments compared with fluvial systems.

Photo 3 - The Qwuloolt Marsh, a NRDA restoration site in the Snohomish River estuary, will be re-opened to tidal action through levee removal/modification (ESA Adolfson).

Identifying Common Changes to the Nearshore

The PSNERP NST recently conducted a comprehensive analysis of Puget Sound nearshore conditions (Simenstad et al. in prep). The purpose of the analysis is to assess changes in nearshore ecosystem structure and associated ecosystem processes that have occurred over the last approximately 125 years. The *change analysis* uses spatially explicit data on specific attributes to compare historic and current nearshore ecosystem structure. The spatial data are arranged in multiple hierarchical landscape scales that incorporate the geomorphic classification of nearshore landforms (Shipman 2008), drainage basins, shoreline process units (i.e., drift cells), and delta process units (i.e., medium and large river deltas). The change analysis groups the different kinds of change into four categories:

> **Shoreform Transition** – changes in shoreform composition from historic (late 1800s) to current (2000-2006) shoreforms, including transition to artificial (e.g., nearshore fill).
>
> **Shoreline Alterations** – changes in historic attributes, such as wetlands, or anthropogenic modifications (or stressors) along the shoreline (e.g., loss/gain intertidal wetland classes, shoreline armoring, tidal barriers, breakwaters and jetties, overwater structures, marinas, roads, railroads)
>
> **Adjacent Upland Change** – Anthropogenic changes within a 200-meter-wide shoreline zone (e.g., land cover, impervious surface, roads, stream crossings, railroads, impounded drainage areas behind dams).

Watershed Area Change – Anthropogenic changes within the entire drainage area.

Change analysis results have been interpreted to assess the relative degree of impairment across different areas of Puget Sound and to help prioritize areas for restoration. These results have been reported at the scale of individual sub-basins[9] and across Puget Sound (Simenstad et al., in prep). The majority of the management measures have the potential to affect the types of change described by the Shoreline Alterations category and to some extent the Shoreform Transition and Adjacent Upland change categories.

Articulation of Strategic Needs Based on Nearshore Change

PSNERP will use the change analysis results to identify strategic needs for nearshore restoration and protection. Strategic needs are spatially explicit problem statements around which PSNERP will develop a set of solutions, generally nearshore restoration or protection actions. Management measures are the building blocks of solutions that will be deployed to address the identified needs. This technical report will support the selection of management measures to address identified needs in various locations, as well as the analysis of alternative combinations of measures for optimal benefit.

Effects of Climate Change on the Application of Management Measures

Implementers of nearshore restoration have always faced a number of engineering, design, logistical, political, and financial challenges. In the years ahead, the effects of global climate change will likely magnify these challenges and generate unforeseen obstacles to restoration success.

That human activities have altered global climate patterns is now well established in the science literature (Climate Leadership Initiative [CLI] 2009). According to the Intergovernmental Panel on Climate Change (IPCC), human activities such as fossil fuel burning and deforestation have increased the global average temperature by about 0.6°C and caused a global sea level rise of about 15 to 20 centimeters (IPCC 2007). Global precipitation has increased about 2 percent during this timeframe. Projected increases in global average temperature between now and 2100 will continue to increase sea level and overall rainfall, change rainfall patterns and timing, and decrease snow cover, land ice, and sea ice extent. These changes present new threats to nearshore process, functions, goods, and services to which restoration efforts must respond.

Sea level rise and changes in seasonal rainfall and weather patterns will be major issues for restoration practitioners during the next century. SLR is driven by the thermal expansion of the ocean, melting of land-based ice, changes in local wind patterns, and local land movement due primarily to tectonic forces (Mote et al. 2008). Estimates vary but the projected 2100 SLR for the Puget Sound region ranges from about 6 centimeters (conservative estimate) to 128 centimeters (high estimate) (Mote et al. 2008) (projections are much higher when snowmelt is factored in). Although many Puget Sound landforms and coastal wetlands have the potential to adapt to rising sea levels, sea level changes coupled with expected wetter winters and drier summers have the potential to confound restoration efforts (Mote et al. 2003). The stability of some projects may be affected by the higher frequency and intensity of storm events. Our inability to precisely predict these changes means that restoration planners will need to account for uncertainty. Appendix A provides additional information on current SLR projections.

[9] There are seven individual sub-basins: Hood Canal, Strait of Juan de Fuca, North Central, South Central, San Juan-Georgia Strait, South Puget Sound, and Whidbey.

Potential effects of climate change and rising sea levels on ecosystem processes based on the authors' professional judgment are identified in Table 6. The effects must be considered when evaluating how and where management measures are implemented. Additional information on how SLR affects the application of individual management measures is provided in the individual management measure chapters and in Appendix B.

Table 6 - Potential Impacts of Sea Level Rise and Climate Change on Nearshore Processes

Process	Anticipated Impacts
Sediment Supply and Transport	Increased sediment supply from bluff erosion and streams, increased littoral drift rates, likely loss of sediment sources due to new shore protection.
Beach Erosion and Accretion	Exacerbated erosion along erosional and generally stable shores, and likely shifted areas of accretion. Overall landward shift (transgression) of shore features and associated habitats.
Distributary Channel Migration	Channels may accrete with rising sea levels and have greater tendency for migration in response to altered freshwater input.
Tidal Channel Formation and Maintenance	Tidal channels may accrete and processes may become less predictable in response to altered freshwater input.
Freshwater Input	Freshwater input predicted to become more variable, with more flooding (winter-spring) and drought conditions (summer-fall).
Tidal Hydrology	Greater inundation and tidal flows into semi-enclosed systems, increased saltwater incursion.
Detritus Recruitment and Retention	Likely greater detritus recruitment due to overall greater wave energy reaching marine riparian zone. Likely increased storminess and storm surges (including more frequent and intense *El Nino* storms) and from rivers due to increased peak flows.
Exchange of Aquatic Organisms	Reduced productivity of threatened salmon stocks due to increased winter flooding, decreased summer and fall stream flows, and elevated warm season stream and estuary temperatures. Loss of biological diversity/localized extinctions of marine and freshwater species if habitat shifts outpace ability of species to migrate or adapt to changing conditions.
Solar Radiation	Altered solar patterns due to hotter summers and colder winters.
Wind and Waves	Overall greater wave erosion and potential accretion due to SLR and likely increased storminess and storm surges (including more frequent and intense *El Nino*).

Knowledge Gaps, Assumptions, and Uncertainties

Information on the use and effectiveness of management measures is rapidly becoming available, but too much of what we know about the use of management measures for protecting and restoring nearshore ecosystems is still based on inference and anecdotal evidence. Many different agencies have over the years collected and analyzed monitoring data and scientific information for different aspects of the Puget Sound ecosystem, including nearshore habitat. To date, however, the data have not been integrated to develop a comprehensive understanding of nearshore ecosystems and how they respond to different management measures.

The PSNERP NST has identified gaps in critical information that must be filled to anticipate ecosystem responses to different options for nearshore ecosystem restoration and preservation. These gaps are described in *Coastal Habitats in Puget Sound: A Research Plan in Support of the Puget Sound Nearshore Partnership* (Gelfenbaum et al. 2006). The plan relies heavily on the data and information gaps published by the Northwest Straits Commission (1999; 2000) and the King County Department of Natural Resources (2001). The NST plan identifies six overall goals:

1. Understand nearshore ecosystem processes and linkages to watershed and marine systems.
2. Understand the effects of human activities on nearshore ecosystem processes.
3. Understand and predict the incremental and cumulative effects of restoration and preservation actions on nearshore ecosystems.

4. Understand the effects of social, cultural, and economic values on restoration and protection of the nearshore.
5. Understand the relationships of nearshore processes to important ecosystem functions such as support of human health and at-risk species.
6. Understand the roles of information —its representation, conceptualization, organization, and interpretation—related to nearshore ecosystem processes on the preservation and restoration potential of Puget Sound.

The answers to questions identified in the research plan will explain observed ecosystem conditions by relating those conditions to natural and human factors, by defining the causes of spatial and temporal variations, and by predicting the effects of proposed nearshore restoration and preservation. Improved scientific information will assist decision makers in their efforts to balance the protection and restoration of the Puget Sound nearshore ecosystem with future sustainable development.

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MM 1 ARMOR REMOVAL OR MODIFICATION

Definition

This management measure pertains to the removal, relocation, or modification of existing coastal erosion protection structures built on bluff-backed beaches, barrier beaches, or other Puget Sound shorelines. Common examples of alongshore modifications (the main focus of this chapter) include rock revetments, treated-wood or wood pile bulkheads, and concrete retaining walls.

In general, complete removal of armoring provides more effective restoration than simply modifying structures to reduce selected impacts. Armor modification may include changing the design or dimensions of a structure, shifting to a more natural (less impacting) material or configuration, or relocating a structure to a more landward position. Modifying structures may be appropriate where the circumstances preclude complete removal, such as where the risks to upland development from natural erosion are unacceptable.

Justification of Need and Link to Nearshore Processes

Landowners typically armor the nearshore to attempt to stop wave erosion or to reclaim submerged lands for upland uses. However, in many instances armoring is installed where erosion is not substantial and the armoring functions more as a landscaping feature. Armor structures have varying degrees of impact generally related to simplification and disruption of shoreline processes; particularly when sited where interactions with wave and tidal forces are greatest. Alongshore structures such as bulkheads can directly impact shorelines through burial of habitat areas and altered sediment composition. Bulkheads can indirectly impact down-drift shores by decreasing sediment supply and increasing erosion.

The disruption of intertidal energy dynamics can affect shoreline processes and habitat through several pathways. The physical presence of the structure on bluff-backed beaches can eliminate recruitment of upland and bluff sediments that would have otherwise reached the beach through erosion. Disrupted sediment supply affects down-drift beach profiles and substrate characteristics. Vertical armoring on all Puget Sound shoretypes (excluding rocky shoretypes) can result in reflected wave energy, which can lead to coarsening of beach sediment (Kraus 1988, MacDonald et al. 1994). Armoring can also cause lowering or vertical erosion of the beach profile waterward of the structure (scour trough), end scour along shores adjacent to the structure, and reduced beach width. Armor can accelerate entrainment and transport of littoral sediment (Miles et al. 2001). Each of these impacts will likely be exacerbated by changing conditions resulting from sea level rise.

Many nearshore fish and wildlife require functioning high intertidal habitats to provide sources of food, migration corridors, cover, and spawning habitat. Armoring can lead to burial (placement loss) or incremental loss of important habitats such as forage fish spawning areas (Rice 2006). Additional adverse impacts depend on the level of impaired cross-shore connectivity resulting from the structure. These cross-shore impacts can include loss of overhanging riparian vegetation, reduced large woody debris (LWD) recruitment and storage, and altered groundwater regimes (Brennan 2007). Results include reduced insect input and loss of upper beach microhabitats. Each of these adverse impacts has direct and indirect effects on valued ecosystem components including marine riparian areas, forage fish spawning habitats, eelgrass beds, and shellfish areas.

Complete removal of bulkheads is the only known method to completely restore natural shoreline processes; however, upland infrastructure may still need to be protected. In these cases, armor modification may be appropriate to partially restore natural shoreline processes where other alternatives do not exist. For example, relocation of bulkheads and other armoring with replacement structures located inland and away from erosive forces can partially restore natural processes. Replacement of the armoring with alternative erosion control techniques that use natural materials is another option.

Conceptual Model

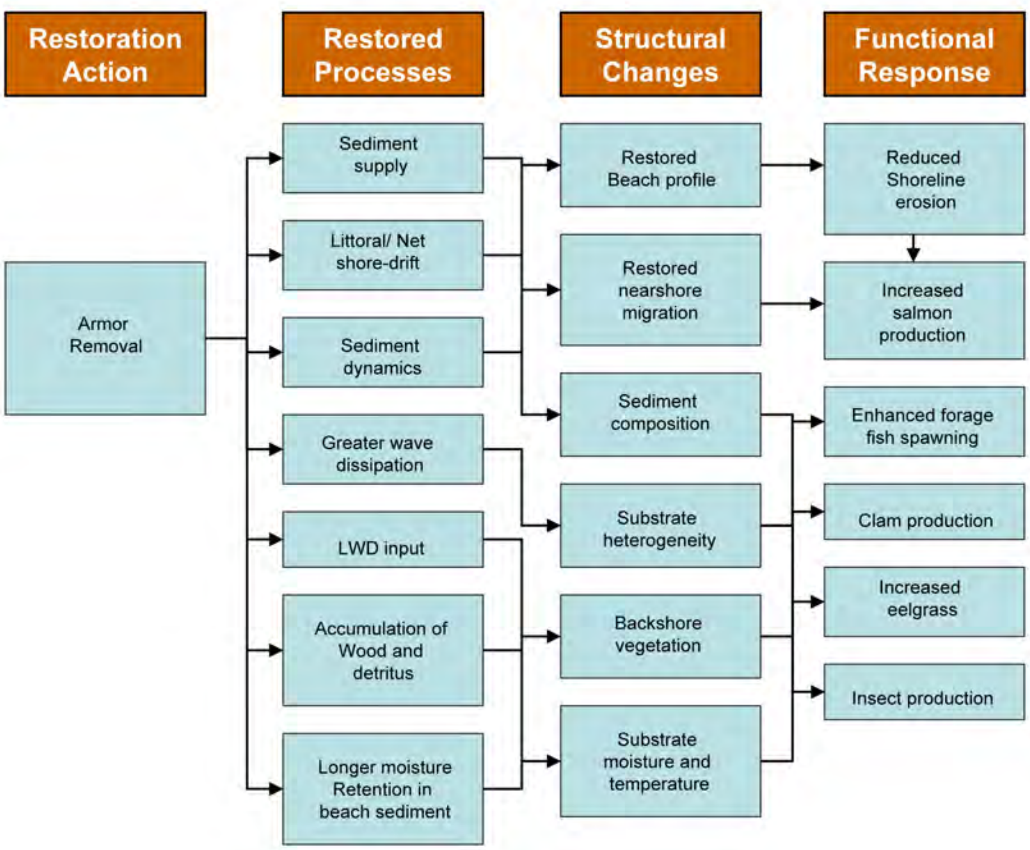
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 1-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Armoring at a bluff site eliminates or degrades (depending on tidal elevation and beach position) conditions required for sediment supply, spawning habitat of forage fishes, and recruitment of vegetation.

Change/Action: Removal of bulkhead and any related features restores sediment source, wave energy regime, and riparian vegetation.

Predicted Response: Beach-forming sediment erodes from the bluff, is transported by waves, and is deposited in the intertidal zone down-drift. Forage fishes have increased opportunity to successfully spawn at appropriate tidal elevations and sediment structure. Eggs have better survival rate due to riparian shading and other influences (e.g., seepage) affecting temperature.

Figure 1-1 Conceptual Model for Armor Removal or Modification



Complementary Management Measures

Management measures that typically complement *Armor Removal or Modification* projects include: *Beach Nourishment, Contaminant Removal/Remediation, Large Wood Placement,* and *Topography Restoration.* When armor is removed, fill may need to be removed to restore the beach profile *(Beach Nourishment)*. Techniques for achieving functional nearshore elevation, slopes, substrate, and vegetation are specified in separate management measures. The *Hydraulic Modification* management measure is also related, as removal of structures will also restore the hydraulic conditions.

Benefits and Opportunities

Benefits of the Restoration Action

By uncovering nearshore habitat buried under bulkheads and other types of armoring, this management measure recreates lost habitat. Other benefits accrued via this measure are:

Improved connectivity: The upland and longshore connectivity of sediment, hydraulics, and vegetative successional processes can be restored by removing or modifying shoreline armoring. This management measure can facilitate animal movement by helping to connect vital habitats including the marine riparian zone. It can also improve the connectivity of juvenile salmonid migratory habitats by removing/modifying armoring that substantially infringes on the intertidal zone.

Restored sediment transport processes improve shoreform diversity: Physical processes restored by armor modification or removal are generally eroding bluffs, net shore-drift pathways, and accretion at important landforms such as spits. In many Puget Sound locations, diverse landforms historically occurred close together. These landform assemblages are declining due to extensive shoreline development.

Climate change and sea level rise: When applied along bluff-backed beaches, armor removal and the restoration of nearshore sediment sources increases the resilience of down-drift shores, which require sediment to naturally adapt to the landward migration of the shoreline. Benefits can occur at down-drift habitats such as barrier beaches and estuaries.

Valued Ecosystem Components: This measure restores bluff-backed beaches, which are a VEC. By restoring and improving littoral systems this measure directly benefits salmon, forage fish, clams, and eelgrass, which are designated VECs. Other VECs such as Great blue heron and many species of nearshore birds also benefit indirectly when this measure is applied.

Social and political benefits: Removing shore armoring often increases the available beach area, which is especially evident at higher tides resulting in improved aesthetic and recreational values. Access is also typically improved, as visitors do not need to climb over or on slippery riprap or vertical structures.

Measurable Units

The area of beach and backshore uncovered by armor removal is the most direct measure of habitat improvement. Measuring restored functions (such as increases in eelgrass coverage in the vicinity of the project, use of the restored beach by forage fish species, etc.) in the footprint of the structure is straight forward, but quantifying the change in down-drift habitat areas or production is much more difficult. The rate of sediment input from bluffs where armor is removed can be quantified, and this gives an indication of the potential for off-site benefits.

Opportunities for Implementation

Armor removal or modification can occur anywhere that bulkheads are present, which tends to be beaches and bluffs. Projects involving this measure typically involve just a single property or small group or properties, so the scale of the projects tends to be relatively small. Entities that typically implement this measure include private property owners, local parks and public works departments (cities and counties), and state resource agencies such as WDNR and Washington State Parks.

Design life: Most engineered structures placed within the surf zone on marine shores tend to fail from natural forces over 15 to 40 years. Property owners may be more willing to consider relocation or removal alternatives when making replacement decisions, including evaluation of future costs. Over the long run, it is often more cost effective to relocate structures landward than to permit, build, mitigate, and maintain shore armoring.

Institutional recognition: Washington State responded to the Federal Coastal Zone Management Act of 1972 by enacting the Shoreline Management Act (RCW 90.58). This law states a preference for alternatives to armoring where technically feasible, and requires property owners to demonstrate that alternatives to armoring are infeasible prior to rebuilding or building new armor structures.

Public recognition: Increased public education on the role of nearshore habitats in recent years is starting to reach shoreline property owners and citizens who influence local shoreline planning decisions. Continued education and outreach activities are needed to increase the use of this management measure on private properties. There are several documented cases of bulkhead removal or relocation throughout the Puget Sound that were performed solely for their restoration values and were not linked to a need to replace a failing structure.

Constraints

Feasibility: Residential structures and other upland infrastructure along the marine shoreline are often located very close to the ordinary high water line. When armoring has effectively reduced coastal erosion, its removal may increase the risk of upland to erosion or slope instability. However, moving houses and infrastructure away from the shore is becoming more common.

Complex regulatory requirements: Puget Sound’s local jurisdictions often have different regulations and permit requirements for shoreline development. Local permitting requirements for armor removal can be complicated by the request to provide beach nourishment to offset bulkhead impacts and recreate beach profiles. Complicated permit processes may be a disincentive to armor removal.

Cost: Cost of demolition and/or modification is principally based on the costs of: engineering, permitting, construction equipment, labor, and materials. Distance to the nearest suitable landfill and site access greatly influence these costs. In the case of armoring relocation, the design also significantly influences cost.

Property value: Removal or modification of armoring structures can alter or be perceived as altering the “highest and best use” value of affected lands. Concerns about reductions in future development opportunity or lack of long-term protection may be a constraint to landowner acceptance. This may also place a logistical constraint on restoration practitioners looking to acquire lands.

Sea level rise: Removal or modification of armoring structures may make private property more vulnerable to anticipated implications of climate change and sea level rise (for example, accelerated erosion rates). This may make it more difficult to find property owners who are willing to have their bulkheads removed or modified.

Effects on navigation channels: Large-scale removal of bulkheads and other structures, as well as beach nourishment, may affect shoaling in navigation channels within Puget Sound.

Best Professional Practices

The feasibility assessment section below provides a general list of topics and studies to be considered during the scoping for design. Design considerations are specific engineering details to be addressed. Though the purpose of this management measure is to improve nearshore function, temporary impacts may occur during construction. Best management practices presented in the implementation section minimize construction impacts. Finally, a brief section detailing post-construction monitoring and performance measures is included.

Feasibility Assessment

The scope and detail of feasibility studies will depend on the project size, location, degree of certainty required and the documentation requirements of permitting agencies. Geomorphic and engineering studies for removing or relocating armored structures are outlined below.

Existing and historic conditions: For removal and modification projects, a review of the original structure design, purpose, and any engineering documentation of the design parameters should be evaluated at the onset of the project planning. Site maps and surveys should be examined for potential data gaps.

Coastal geomorphic assessment: Armor removal projects should consider coastal geomorphic conditions such as shoretype, littoral transport, sediment size, and off-site effects to ensure sustainability and adequacy of the restoration approach. The rates and patterns of erosion and deposition should be quantified by examining historic aerial photos and maps, conducting field studies to determine existing and historic conditions, and developing a conceptual sediment budget. A local sediment transport budget can be used to estimate the effects of the project on off-site areas.

Coastal and geotechnical engineering: For armor modification projects, potential feasibility studies may include wave hydraulics, siting, and the need for armoring. This involves characterizing the wave climate. Wave monitoring data are limited, and prediction techniques can vary widely—from sophisticated numerical modeling to visual estimations. Infrastructure, utilities, and access could be engineering constraints and may need relocation or protection.

Risk and uncertainty: Project designers should evaluate the risk and uncertainty for both armor removal and modification projects. The severity of risk can range from intermittent minor erosion, to damage to the armor modification structure, to loss of adjacent infrastructure. Project designs should state where uncertainty exists regarding engineering parameters. The scope and design factor of safety should be consistent with the anticipated outcome of the project (armor removal vs. modification), specific location, and type of armoring requirements.

Design

Complete armor removal is desired over armor modification for ecological benefit. Armor modification requires engineering design analysis that includes the demolition and disposal of the existing structure and the design of a more suitably designed and sited structure. Removal typically includes some amount of shore enhancement such as beach nourishment and revegetation. Beyond elements outlined in the Feasibility Assessment section above, Design needs are listed below.

Approach: The alternatives to be considered range from complete armor removal to soft armoring and *Beach Nourishment*, and/or construction of new armoring in a more landward position. Any armor modification project should attempt to maximize the restoration of natural processes while balancing the need for human safety. A removal or modification design that accommodates *Revegetation*, *Large Wood Placement,* and *Beach Nourishment* provides enhanced coastal processes and productivity, input and accumulation of detrital material, and increased potential nearshore habitat area. In general, full removal and enhancement should be the intent of armor modification, unless analyses determine that some form of less-impacting armor is required.

Site conditions: The physical characteristics of Puget Sound's shorelines are diverse and change notably over short lengths. Actions taken under this management measure may be unique to each site and not comparable across sites. The effects of the project on the natural system outside the project footprint should be understood in order to minimize any harmful effects due to the choice of an engineered design instead of beach nourishment or similar alternatives. Understanding the long-term response of the site under climate change and sea level rise may also be a priority.

Demolition: Demolition considerations may include: access, infrastructure, utilities, equipment availability, regulatory requirements, and disposal. Project designers should determine if relocation or protection is needed for existing utilities, infrastructure, or access routes. Access and demolition staging areas should be planned to avoid excessive impacts to upland vegetation, water features, or adjacent habitats.

Geotechnical engineering: For armor modification projects, designers need to consider static and dynamic forces on armoring structures, including soil and water pressures, wave action, and seepage to avoid excessive long-term maintenance. These include the maximum and minimum design water levels that lead to the required structure crest elevation and anticipated toe scour. The results of the coastal geomorphic and engineering evaluations should be used to site the relocated armoring structure. A secure foundation design is important to minimize settlement and allow for firm compaction of all fill and backfill material since failure at the toe can lead to failure of the entire structure. Armor removal projects generally remove all protective structures from the nearshore. As such, engineering assessments related to structural stability and design are usually not applicable.

Materials and stability: Materials for armor modification relocation projects are traditionally selected for structural properties but should also consider habitat value, aesthetics, maintenance, design life, availability, and cost. Freeze-thaw resistance, marine borers, ultraviolet light degradation, sand abrasion, vandalism, and chemical reactions should also be considered. Stability associated with the rigidity or flexibility of the structural material is a consideration. Rigid materials such as concrete have good initial strength, but without flexibility they may not withstand settling or toe scour. This can lead to premature structure failure or catastrophic failure. Seismic loading, ground deformation, and liquefaction may be stability considerations. Armor removal projects that require removal or reuse of onsite soils should include assessment for suitability as beach material, wetland substrate, or upland fill prior to placement.

Maintenance: The lifecycle maintenance of an erosion control structure should be considered in the planning phase. Design for future plantings, large woody debris placement, and beach nourishment material placement near infrastructure may be required for both armor removal and modification projects. In addition, armor modification projects may require periodic but routine evaluation of real property and inspection of structural components. Even after other engineering design considerations, some residual ongoing maintenance may be required.

Implementation

Logistics: Construction methods, material availability, contractor availability and experience, and access considerations for both armor removal and modification projects.

Fueling and hazardous wastes: This management measure often requires the use of heavy construction equipment. Fueling of equipment and handling of oils or hazardous materials should be conducted away from the beach. A preferable alternative is to have heavy equipment use non-petroleum fluids; however, contractors often resist this. A spill response plan should be developed for each project. Hazardous waste associated with the removal of creosote-treated wood armoring should be taken off-site and disposed of appropriately.

Erosion control: Ground disturbance associated with this measure can result in erosion and runoff if not addressed. Disturbance must be limited to the minimum area necessary to complete the project. Plastic sheeting, hay bales, and other temporary erosion control measures should be employed where fine-grain soils are handled to avoid long-term erosion or siltation of nearshore waters. Proper silt fencing, catchment basins, and other measures to control surface water runoff and turbidity may be needed. However, when work is conducted in areas with old beach or bluff deposits, erosion control is generally not needed as these are all natural elements of the shore environment. Avoiding the use of plastic sheeting and other material not only keeps costs down but reduces waste generated by the project.

Clean materials: Soils and other materials should be procured from established borrow sites and be clean of solid waste, invasive species seeds, and pollutants.

Disposal: Waste materials resulting from this management measure must be taken to an authorized disposal site or reused within the project footprint.

Native plants: Plants or woody debris may be installed as supplemental enhancements for this management measure. Native plant species should be used in all cases.

Timing: Work below ordinary high water must be completed when the fewest fish are likely to be present and only during approved in-water work time periods (“work windows”). Consult appropriate state and federal regulations for approved work times.

Inspections: Inspections should be performed within one year following project completion to ensure that activities implemented at individual project sites do not create unintended consequences to fish, wildlife, and plant species and their critical habitat.

Evaluation

Project proponents should create a monitoring plan to assess post-construction project performance and maintenance needs. The effectiveness of armor removal or modification can be measured by observing:

- topographic stability/ sediment erosion and accretion,
- sediment characteristics and available habitats,
- accumulation of wood,
- soil moisture/temperature, and
- backshore vegetation.

The uncertainty associated with the effectiveness of this management measure can be addressed with carefully thought-out monitoring of the restoration project. Data from nearshore early action projects or demonstration projects can also be useful. It may be desirable to identify drift cell armoring thresholds that trigger changes in processes through extensive monitoring of larger projects.

Only a few near-comprehensive data sets are available for armor removal. These are not of sufficient resolution or quality to address armoring impacts associated with location or the temporal and spatial variability of sediment transport processes. Monitoring of sediment and topography change is needed to further the understanding of site-specific changes and implications for long-term sediment supply in Puget Sound. Monitoring to support knowledge of the ecological aspects of the beach and the relationship between nearshore ecology and variation in beach sediment distribution is needed. Case studies conducted on armor removal projects (e.g., armor removal vs. monitoring of adjacent armored sites) may provide a way to collect data under controlled conditions.

Case Studies and Examples

Seahurst Park, Burien: Seahurst Park is one of largest shoreline parks on Puget Sound. The shore of the south portion of the park contained extensive, failing bulkheads, surf smelt spawning habitat, unstable forested bluffs, eelgrass beds, and a perennial stream delta. The park provided an excellent opportunity to restore natural beaches, habitat-forming processes ("feeder bluffs"), and to monitor the physical and biological response to these actions. The park is located in a highly impacted net shore-drift cell that extends all the way to West Seattle. The park contained extensive shore armoring in the form of rock-filled gabions that had failed and were covered with rock revetments. In addition, small landslides at the forested bluffs were trucked offsite prior to restoration planning, and sediment was lost from the nearshore system (Hummel et al. 2005). The combination of bulkhead-induced erosion from reflected wave energy and loss of sediment supply resulted in 3 to 4 feet of beach lowering between 1972 and 2002.

As a key component of park master planning, the City of Burien obtained Salmon Recovery Funding Board grant funding for a bulkhead alternatives analysis. This analysis resulted in a five-pronged strategy to restore and protect nearshore habitats and restore habitat forming processes (Hummel et al. 2005):

1. Preserve existing functioning nearshore habitats including unstable forested bluffs, eelgrass beds, and stream deltas.
2. Remove shoreline armoring consistent with park uses.
3. Model restored beach slope and substrate on-site and at adjacent reference beaches to provide habitat for forage fish spawning and public recreation.
4. Replenish gravel and sand lost to erosion since the park was developed.
5. Restore and protect the natural delivery paths of sediment and woody debris from the bluffs to the beach.

The first phase of park restoration was completed on the southern 1,200 linear feet of the park in February 2005 (Figure 1-2). The design was developed by Coastal Geologic Services and Anchor Environmental. The U.S. Army Corps of Engineers hired Marine Vacuum (Mar-Vac), who removed virtually all the armor and fill in the south portion of the park and imported gravel and sand by barge to restore the intertidal beach and backshore. The beach was nourished with a coarse gravel lower layer and a mix of finer gravel and sand in the upper layer, and coarse sand in the high backshore. The new beach surface was up to 3 feet above the 1973 surface and up to 5 feet below the old path/fill elevation. The City had the path moved landward, installed vegetation, and organized monitoring.

Physical beach monitoring included profiles, full topography, and sediment characterization. Overall the large majority of the sediment remained within the original nourishment area and had almost identical slopes as the reference beach. Between the initial beach nourishment in 2005 and 2008, 44% of the comparison area beach had less than 0.25 foot of vertical change (Johannessen and Waggoner 2008). The control beach had minor pockets of erosion and accretion. Most of the erosion in the nourishment area occurred high on the upper beach where imported sediment was originally placed in a distinct berm. The berm was 1 to 2 feet below the as-built elevation. North of the nourishment area, accretion of up to 1 foot vertical was seen, likely the result of northward sediment transport of nourishment sediment. The total amount of sediment lost from within the nourishment area was 562 cy of the total beach nourishment of approximately 9,000 cy placed in 2005 (217 cy/yr erosion).

A bluff landslide occurred at the southern bluff reach 2 years after the armor was removed. The sediment reached the upper beach and has gradually been entrained into the net shore-drift system. Beach sediment sorting occurred post-construction. Pebble has been worked to the surface of the beachface to form a thin pebble veneer over finer granule and coarse sand. Some coarse gravel has moved to the lower beachface, while sand and small pebbles have been pushed into berms high on the beachface. Total implementation cost for the beach work was approximately $1,200,000. Other than *Armor Modification or Removal* other management measures employed were: *Beach Nourishment, Large Wood Placement, Public Education and Involvement, Revegetation*, and *Topography Restoration*.

North Beach, Orcas Island: This site in northern San Juan County was comprised of four single-family houses/cabins. The properties had a large failing rock revetment at a no-bank gravel beach (Figure 1-3). The residents complained of the recurring need to restack the revetment rock, difficult beach access, the loss of dry beach area, and lack of places to store small boats. The 550-foot-long site is within a high-energy net shore-drift cell with some cyclical reversals in the littoral drift direction. One important element of the site is that the beach is generally swash-aligned (the shore is parallel to most incoming waves), which causes off-site sediment transport to be limited most of the time. This, along with the presence of a no-bank site, made nourishment feasible even though the site has a 90-mile fetch from the Strait of Georgia. The high fetch led the designer (Wolf Bauer, who pioneered gravel beach nourishment in Puget Sound) to include a rock drift sill at each end of the project. Forage fish spawning was not documented at this site due to coarse native sediment.

Removal of the large revetment and beach nourishment occurred in 1992. The revetment rock was used in upland landscaping or buried in the back of the backshore trench along with nourishment sediment. The beach profile was reestablished and an artificial storm berm was created with 2,400 cubic yards of gravel (up to approximately 2.5 inch in diameter) (Figure 1-3). Beach nourishment extended to the lower intertidal. Backshore revegetation was installed at several properties, consisting mostly of native dunegrass (*Elymus mollis*). The beach experienced initial onshore gravel transport, which is common with this type of nourishment, but has not experienced noticeable erosion. Beach area and backshore vegetation increased dramatically after removal of the revetment. The project was so successful that an adjacent landowner contributed funds after the project was proven. The site remains in excellent condition in 2009 and there is no discussion of armor by owners. Total project cost was approximately $60,000. Other management measures addressed included *Beach Nourishment, Revegetation, and Topography Restoration*.

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Figure 1-2 Southern Seahurst Park gabion wall and rip-rap removal and beach nourishment: Before (2004) and after (2009) at same location. Photos by Jim Johannessen

Figure 1-3 North Beach Orcas Island armor removal and beach nourishment: Before (1991) and after (2008) at same location. Before photo by Jan Kolton, after by Jim Johannessen.

MM 2 BEACH NOURISHMENT

Definition

Beach Nourishment is the artificial placement of sand and/or gravel on the upper portion of a beach where historic supplies have been eliminated or reduced by shoreline modifications. *Beach Nourishment* is also referred to as beach fill, beach feeding, beach replenishment, beach restoration, or beach enhancement. Nourishment does not include substrate enhancement (beach graveling for shellfish enhancement), the addition of fine-grained sediment to rock structures, capping of contaminated sites, or the creation of dry land through the placement of fill.

Justification of Need and Link to Nearshore Processes

Beach nourishment is used to restore beaches impaired by the loss of natural sediment supplies, the encroachment of upland modifications, or beach loss due to chronic shoreline erosion. Nourishment in Puget Sound may be used to supplement artificially reduced sediment supplies, to restore sand-sized material to unnaturally coarse beaches, and to reestablish upper intertidal beach profile elevations where they have been lost to erosion, fill, or other modifications (Shipman 2001, Johannessen 2002).

Although this management measure is commonly applied as a structural measure for placing beach sediment, it can also augment natural sediment recruitment processes where those processes have been impaired by up-drift shore modifications. The structural application of this management measure typically targets a small area with a more immediate response, while augmenting sediment commonly targets a longer shore reach with responses across a broader spatial scale. Beach nourishment is applied on barrier beaches, bluff-backed beaches or pocket beaches. In general, nourishment is not appropriate in protected embayments (which typically have marshy shores) or at river deltas except where they are already heavily modified.

Shore armoring, generally bulkheading, has greatly reduced sediment delivery from “feeder bluffs” to beaches in much of Puget Sound. As sediment is continuously transported along beaches by waves, shore armoring therefore “starves” beaches of sediment (Johannessen and MacLennan 2007) and leads to erosion and habitat loss (Thom et al. 1994). Beach nourishment can augment sediment supply in areas where sediment impoundment or impediments to littoral transport occur. Where applied to augment sediment supply, beach nourishment can be strategically placed in areas where sediment was naturally delivered or recruited to the nearshore, or down-drift of impediments to littoral transport such as a large groin, breakwater or jetty, thus allowing waves to distribute nourishment sediment to down-drift shores.

Conceptual Model

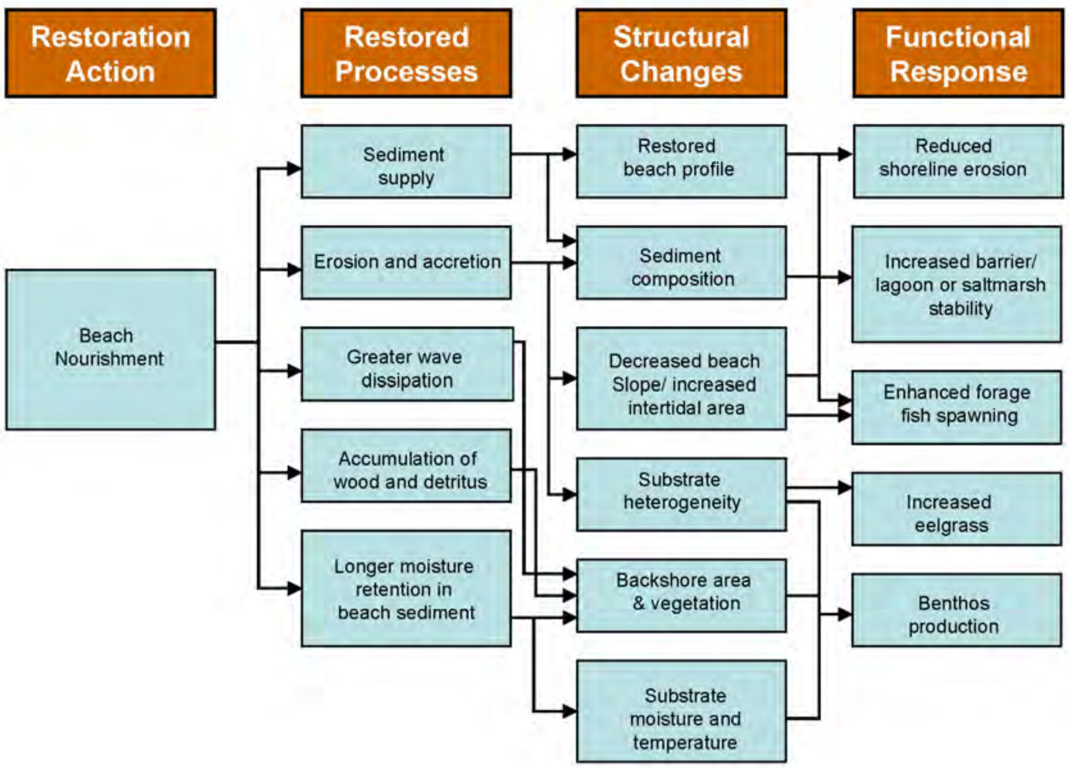
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions. The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Beach starved of natural sediment supply by extensive modifications (shore armoring) in drift cell. Armoring has reduced the natural sediment supply, virtually eliminated forage fish spawning habitat and upper beach/backshore, and reduced shallow water refuge for juvenile salmon.

Change/Action: Beach nourishment with mix of sand and gravel to the upper beach at several points in up-drift portions of a long drift cell.

Predicted Response: Nourishment increases the volume of sediment at down-drift beaches, raising the profile and shifting it waterward (Figure 2-1). The effect of nourishment on sediment composition depends on the size of sediment added, but sediment that contains coarse sand and fine gravel would recreate lost potential spawning area. The longevity and extent of increased beach area would depend on quantities and methods of delivery. Options include in-situ placement with or without grading, or delivery of nourishment sediment to up-drift locations to facilitate natural deposition along down-drift shores.

Figure 2-1 Conceptual Model for Beach Nourishment



Complementary Management Measures

Beach Nourishment is often used in conjunction with *Armor Removal or Modification* and *Topography Restoration* to rebuild natural beach profiles, restore appropriate sediment types and reestablish active sediment transport. Nourishment has been used with *Revegetation* of backshore and marine riparian areas by raising elevations to reestablish these zones. Nourishment can be a form of *Species Habitat Enhancement* to mitigate adverse impacts to forage fish spawning habitats. *Beach Nourishment* is often proposed as a “soft shore protection” alternative to conventional armoring as nourishment can be used to recreate or create a storm berm to absorb wave energy and protect private property or infrastructure from erosion (Johannessen 2000). Additionally, *Beach Nourishment* designs often include *Large Wood Placement* to aid in the reestablishment of a natural storm berm (for erosion control), to help retain nourishment sediment, and/or for habitat enhancement.

Benefits and Opportunities

Benefits of the Restoration Action

This management measure can be used to accomplish a variety of restoration goals. Specific benefits of beach nourishment include:

Habitat enhancement: Nourishment directly benefits the upper beach by restoring beach sediment to elevations appropriate for forage fish spawning and accumulation of large wood and detritus (for example, Lummi Shore Road, Bellingham Bay, Whatcom County). Nourishment may restore sand and gravel to areas deprived of natural sediment sources. Where nourishment is conducted waterward of a structure or in conjunction with bulkhead removal, juvenile salmonid migratory habitat can be enhanced as a result of increased connectivity of shallow water habitat alongshore. Nourishment has been used to restore or create barrier beaches that in turn shelter back-barrier wetlands (for example, Golden Gardens, Seattle; Dickman Mill, Tacoma). Nourishment can also be used to create sheltered marine environments where none existed before (such as on Jetty Island spit/salt marsh, Everett).

Off-site benefits: Nourishment puts sediment into the littoral system, often where sediment supplies have been historically diminished. Losses of sediment from a nourishment site may provide benefits to down-drift habitats (Lummi Shore Road, Bellingham Bay).

Increased erosion and storm protection: Nourishment generally raises beach elevations, which reduces the vulnerability of landward structures to flooding and wave damage as well as enhancing the beach (for example Driftwood Beach, Blakely Island). Nourishment in front of an erosion control structure can reduce exposure to large waves and protect the foot of the structure (to prevent undermining and reduce scour; for example Maple Beach seawall, Point Roberts). Beach nourishment may also facilitate a less expensive structure (for example, North Beach, Samish Island).

Sea level rise and climate change: The application of beach nourishment for erosion control can provide the beach with increased resilience under changing conditions, such as those associated with sea level rise and climate change. Beach nourishment preserves the dynamic nature of the beach and enables the shoreline to migrate landward, which is not possible with hard armoring. Beach habitats benefit when nourishment is selected over hard armoring because nourished beaches are able to migrate landward with sea level rise.

Social and political benefits: Nourishment often provides expanded upper intertidal and backshore areas favored for recreation and improved access to the water. Beaches usually provide safer, more direct use of the shoreline than seawalls and rock revetments (for example, Marine Park, Bellingham; Seahurst Park, Burien).

Measurable Units

The benefits of beach nourishment can be measured by qualifying changes in benthic production (biomass or species biodiversity), movement in beach profile (lack of change means stable conditions), and area/density of eelgrass colonization, among others.

Opportunities for Implementation

Beach nourishment is typically implemented on barrier beaches and pocket beaches but also has applications at bluff-backed beaches, and in some embayments (altered estuary shores and inlets). Typically, these projects are carried out at relatively small scales by private landowners (including community beach groups), by local governments (often at parks), and/or by resources agencies and tribes for habitat enhancement or restoration. In addition to habitat enhancement and other specific applications listed above, several other opportunities for project implementation are outlined here.

Beneficial use of dredged sediment: Nourishment may be an appropriate use of clean dredged sediments in situations where beach sediment has been trapped or diverted by an artificial channel and where a bypass operation allows sediment to be restored to down-drift beaches (Keystone Harbor, Whidbey Island, Point Roberts Marina, Whatcom County). The creation and restoration of larger beach environments may be appropriate use for clean sediment dredged from river channels (Jetty Island, Everett). Dredged sediment as a beneficial use is underutilized and can facilitate economical beach enhancement.

Colluvium side-casting: This measure can address the impact of the Burlington Northern Santa Fe Railway (between Seattle and Everett, for example) or other long shoreline modifications where landslides continually occur landward of the shore modifications. Beach nourishment in the form of side-casting landslide debris or strategic placement of landslide colluvium could be systematically conducted by the railway, working with state resource managers, to augment reduced sediment supply.

In place of bulkhead repair or reconstruction: Many existing shore modifications (bulkheads) in Puget Sound were constructed many years ago and are or will be in need of repair or reconstruction. In locations where feasible, bulkheads and other hard armoring could be replaced with Beach nourishment or soft shore protection, or a combination of both (Johannessen 2002).

Public education: The public accessibility of many nourishment projects, combined with the need for ongoing maintenance and monitoring, can offer opportunities for educating the public about beach processes and habitats through signage, volunteer monitoring and maintenance, and demonstration value.

Constraints

Footprint: Beach nourishment restores a more gradual slope between upland and lower tidal elevations. This can require expanded beach area, which typically means excavation of uplands and/or placement of sediment over existing intertidal benthic habitats.

Short-term environmental impacts: Nourishment typically requires placing sediment within intertidal areas potentially burying existing benthic habitat and releasing sediment into the water column. Projects are carried out with barges and heavy equipment. Large volumes of sediment may be stockpiled on or near shore. A benefit unique to beach nourishment, if carried out properly with prior assessment of potential adverse impacts, is that nourishment in general precludes lasting adverse impacts to adjacent shores, coastal processes, and biological communities (Finkl and Walker 2005).

Dynamic environments: Beaches are inherently dynamic environments and nourishment projects are subject to rapid changes. This creates difficulties for vegetation planning, assuring protection of upland improvements, and building public confidence in the technique. Desire for long-term stability or for minimal ongoing maintenance may lead to conservative designs that do not provide the dynamic elements of natural beaches.

Sediment loss: Nourishment is designed with the expectation that sand and gravel are mobile and therefore can be lost from the project area over time. This is not necessarily a problem, but it must be anticipated as it may affect the impacts of a project on adjacent habitats or the long-term stability and durability of the project. A terminal groin or drift sill can increase the lifetime of a *Beach Nourishment* project and expand the time between renourishment intervals (Charlier and Meyer 1995, Leonard et al. 1990).

Invasive species: Restored backshore areas may be subject to colonization by invasive plants. This is particularly true if the berm is built too high to be periodically inundated by tidal water. Invasive species may be an issue within intertidal benthic communities but this has not been investigated.

Sediment size and quality: Sediment size bears directly on behavior of a nourished beach and on its ecological characteristics. In general, attempts should be made to mimic the natural distribution of sediment sizes expected on a beach in the particular setting, rather than trying to optimize the distribution for a particular outcome, such as stability or forage fish spawning suitability. Overly coarse or overly fine sediment may be inappropriate for nourishment and may threaten the long-term sustainability or success of the beach nourishment project. Additional information regarding sediment size selection is included in the Best Professional Practices section below.

Storm, flood, and erosion protection: Nourishment inherently allows a greater dynamic response than static seawalls and revetments and may not provide the same level of certainty in the face of extreme events as a conventional structure.

Geomorphic setting: The efficacy and appropriateness of nourishment depends greatly on geomorphic setting. Geomorphic and engineering evaluations are necessary, along with site-specific design. Most nourishment projects on Puget Sound have been along no-bank shores, but most of the Sound's shoreline is high-bank, where the application of nourishment is more difficult and may be less appropriate. Additional considerations for feasibility include fetch, beach alignment (swash or drift aligned), sediment composition, drift cell context, and erosion/sediment transport rate at the site prior to construction.

Cost: The major cost of nourishment projects is the supply and delivery of sand and gravel. Most sediment used on Puget Sound nourishment projects comes from upland gravel pits. Costs per volume increase when the source is distant, when material must be rehandled (e.g., truck to barge), and when sediment size specifications require sorting or blending. Exploring in-water sediment sources such as the waterward face of large river deltas could dramatically reduce costs and eliminate impacts of gravel pits and trucking. In-water sources are commonly used in most other parts of the country. Design costs can be significant as nourishment often requires site-specific studies such as the collection of environmental data and modeling. The addition of secondary structures, such as groins or buried revetments, can add significant costs. Many nourishment projects require periodic renourishment, although on an interval much longer than in other parts of the country (for example, a 20-year interval instead of 5 years). Besides the future financial commitment for renourishment, projects may also require long-term monitoring and evaluation.

Regulatory concerns: Nourishment often extends waterward of Mean Higher High Water (MHHW), increasing biological concerns and triggering regulatory review. The Clean Water Act, State Hydraulic Code and the Shoreline Management Act restrict the placement of fill into tidal waters, influencing the design and location of nourishment projects and greatly complicating permitting. Nourishment on state-owned tidelands may require WDNR approval that is not required for conventional structures.

Climate change and sea level rise: Potential implications of climate change and sea level rise in Puget Sound include exacerbated coastal erosion rates, increased flooding and storm surges, as well as the landward shift of shorelines (Johannessen and MacLennan 2007). The response of natural and restored (nourished) Puget Sound beaches to these implications is difficult to predict with current uncertainty in global and regional sea level rise projections and the scarcity of long-term monitoring data on regional beach nourishment sites.

Effects on navigation channels: Large-scale beach nourishment efforts may affect shoaling in navigation channels within Puget Sound.

Best Professional Practices

A successful Beach nourishment project can be achieved by carefully following a four-phased approach that includes: 1) assessment, 2) design, 3) implementation, and 4) evaluation. The assessment section provides a general list of topics and studies to be considered during the scoping of engineering design. The design considerations are specific engineering details to be addressed related to the management measure. Proper implementation is critical to avoid adverse impacts and evaluation allows for adaptive management and advancement of the science.

Feasibility Assessment

Appropriate site selection includes evaluating the characteristics of the site and defining clear objectives for the nourishment project. Site characteristics compiled in the feasibility assessment will also be used in latter phases of the project, most notably in design. Depending on the objectives of the nourishment project, an alternatives analysis could be conducted to determine the comparative advantages of beach nourishment versus moving buildings/infrastructure farther landward (Johannessen 2002). This should be evaluated in terms of cost-benefit.

Coastal geomorphic and engineering assessment: Beach nourishment project design must take into account the local coastal geomorphic system (including net shore-drift, wave environment, tidal range, local bathymetry, etc.), geotechnical characteristics, and biological conditions. The level of investigation depends on the type, scale, and uncertainties of a project. Smaller and lower budget projects are typically designed based on general characterization of the wave environment and erosion transport rates. A reference site approach is often useful for informing design characteristics, using a minimally impacted site that is very similar in terms of wave climate and drift cell/landscape context. Larger and more complex sites (and those with considerably larger budgets) can benefit from coastal modeling of existing and potential future conditions. However, our basic understanding of mixed sand and gravel beaches of Puget Sound in terms of profile adjustment and sediment transport is quite limited, and models are at best a rough approximation of coastal processes and can be misleading. Also, local wind and wave data are very limited and useful modeling efforts are costly.

Of critical importance are the mechanisms and approximate rate of erosion (termed background erosion). This can be determined by developing a detailed site history that includes predevelopment coastal geomorphic setting, changes in both processes and trends at the site, and anticipated results of at least several management approaches. The project team should develop a quantitative map of shore changes and calculate erosion/ accretion rates through careful use of historic aerial photos and GIS maps. Identification of changes over the history of a site can illustrate the causes of erosion or shore change, both on the site and in the entire drift cell.

Setting/site geometry: Beach nourishment needs to be designed for the local wave environment. The wave environment (orientation and wave energy) affects longshore and cross-shore sediment transport and potential off-site losses. Orientation of the wave field greatly influences the configuration of the resulting beach, particularly in pocket beach environments. Orientation may dictate the need for secondary structures such as drift sills or groins. In terms of the alongshore extent of a project, size is important. Long beach nourishment projects experience greater longevity (Leonard et al. 1990). Shorter projects experience greater sediment loss.

The proximity to potentially threatened structures and infrastructure must be quantified and correlated with measured erosion rates. Sites near inlets must include analysis of increased nourishment volumes in anticipation of relatively high erosion rates (NRC 1995). Likewise, the proximity to important nearshore habitats must be determined by acquiring relevant mapping information, and in larger projects, completing a biological evaluation. Logistical considerations such as potential access, nourishment sediment source, and delivery methods need to be determined in the assessment phase.

Setting appropriate berm crest and backshore elevations can minimize initial profile adjustment and reduce initial erosion. Similarly slopes must not be overly steep to avoid waterward sediment transport.

Design

Important beach nourishment design parameters include placement approach and profile geometry issues including slope, berm crest elevation, backshore elevation, and transition from backshore to upland elevations along with sediment size and other parameters discussed above.

Nourishment placement approach: The approach for placing nourishment materials across the beach differs based on shore length, objectives for nourishment, and constraints such as avoiding important habitats and respecting property boundaries. Ideally, nourished beach profiles should be similar to those nearby created under natural conditions, with nourishment spread across the entire beach profile (Bruun 1988). However, project constraints often dictate a different approach. The general types of nourishment approach in terms of cross-shore placement are:

- Dune nourishment – placement of sediment in a dune landward of the typically active beach
- Subaerial nourishment – placement above MHW in the active upper beach and backshore
- Profile nourishment – sediment is spread over the entire active beach profile
- Bar or shoreface nourishment – sediment is placed on the lower beachface but within the active beach profile

Dune nourishment and subaerial nourishment (enhancement) are often employed at smaller length projects in Puget Sound as profile nourishment has much higher littoral transport at short reaches. Dune placement can be appropriate in high wave energy, no-bank sites where there is adequate room landward of the beach and the objective is to minimize storm erosion and damage of the uplands and structures. Subaerial nourishment is similarly used when the objective is to enhance the backshore and uplands at lower wave energy sites of limited length (Johannessen 2002). In some cases, the presence of intertidal habitats such as sand lance or surf smelt spawning areas can also serve as constraints and keep nourishment landward of the upper intertidal. Impacts to surf smelt and sand lance eggs can be minimized by avoidance of spawning season and when sand lance tend to burrow (usually winter).

Profile nourishment provides a more stable beach (Bruun 1988). This type of design is typically used where project lengths are adequate to allow for gradual offsite transport without undue sediment losses (Figure 2-2). Profile nourishment is often employed where there is limited backshore area, or where system-wide beach sediment and habitat enhancement are objectives. Bar or shoreface nourishment is employed when waves are expected to transport sediment onshore to benefit the profile in the down-drift area. This approach is seldom used in the semi-protected or estuarine conditions of the Puget Sound area.

Sediment size and quantity: Sediment size affects biological utilization, short-term and long-term stability, beach hydraulics, and offsite sediment movement. Coarse sediment results in a steeper and more stable beach profile and slope cannot be stipulated independently of sediment size (Dean 2002). On some projects, a single blend of sediment has been used, whereas on others different sediment types have been used in different elevations. As a general rule, nourishment sediment should resemble native sediment with a slightly coarser mix often employed (Terich et al. 1994). For increasing project longevity, a mean grain size diameter of at least 1.5 times that of the original sediment is sometimes recommended, although this must be weighed against habitat goals (Terich et al. 1994, Dean 2002). The use of sediment that is significantly coarser than natural sediment size typically results in gradual down slope sediment transport to the lower portion of the high tide beach.

Applying an ample volume of sediment per length of beach enhances the success of the nourishment project. Project designers should calculate the amount of over-fill needed to allow for volume depletion (primarily by loss of fines) and sediment transport beyond the project boundaries (Dean 2002).

Structures: In some cases, installing a small groin at the down-drift end of a nourished beach serves to hold the sediment fill in place. The term "drift sill" is used for a relatively short, typically rock structure that is constructed level with the up-drift nourished profile. Large wood placement (often anchored with buried anchors) can enhance function when reestablishing a storm berm for erosion control, particularly with shorter dune or subaerial placement projects. A setback revetment can limit erosion of valuable infrastructure in the case of rapid erosion. A submerged, shore-parallel structure is occasionally used to create a perched beach and limits waterward sediment transport.

Revegetation: Native plants are appropriate for planting the backshore, with regional and site-specific variation. Nourishment sediment is typically placed upslope of submerged aquatic vegetation, such as eelgrass or kelp, and replanting is not necessary.

Implementation

Logistics: Access for delivery of sediment and equipment must be worked out prior to implementation. Access by truck is typically more economical for most projects, but site disturbance must be minimized. Larger volume projects may be more economical with barge delivery. Barges need to avoid impacting eelgrass and macro algae.

Best management practices: Many standard construction site best management practices apply to beach nourishment to avoid and minimize construction impacts. This includes being prepared for oil leaks, etc. The use of silt fences is appropriate around wetlands and other critical areas above the beach. However, silt fences generally serve no purpose in intertidal areas as the sediment will be in contact with tidal waters within hours with or without silt fencing.

Timing: Beach nourishment is best carried out in summer-early fall when daytime low tides allow for work above tidal levels. However, work periods need to be coordinated around the approved in-water work windows set by state and federal regulatory agencies to protect resident and anadromous fish. Whenever possible, it is best to first nourish a coastal sector by starting at the up-drift end and emplacing sediment progressively in the down-drift direction.

Evaluation

Planned monitoring: Project monitoring should be designed to be consistently repeatable and of a level of detail that allows for determination of project outcomes. However, monitoring of smaller projects should not be so time-consuming that it does not get completed. Physical monitoring typically entails collecting beach topography and profiles that extend into the subtidal, along with sediment samples. Reliable survey control is key, especially vertical control in Mean Lower Low Water (MLLW) datum. Intertidal sediment characterization is important. Biological monitoring should include habitats/species of concern such as forage fish (egg density or available habitat), benthic invertebrates, and backshore vegetation. Annual monitoring should occur at a minimum for 3 to 10 years. Spring and fall monitoring is very informative for large or exemplary projects but project managers can schedule monitoring based on key species or biological monitoring needs. Otherwise, annual monitoring is best carried out in summer for access to subtidal areas.

Adaptive management: The dynamic nature of nourished beaches increases the need for regular monitoring of physical and biological responses. Monitoring allows project sponsors to make informed decisions, judge the success of the project, and evaluate the need for renourishment or other actions.

Renourishment: Renourishment is an ongoing operation associated with many nourishment projects and can be adjusted based on monitoring results. Renourishment should be anticipated where geomorphic analysis indicates the need (generally at moderate/high wave energy shores). A long-term monitoring and maintenance plan should be developed to assure that renourishment is budgeted for, carried out when needed, and that contingencies are also addressed. Volumes, sediment size, methods, location, timing and frequency are all easily adjusted in a renourishment program based on results of monitoring and adaptive management.

Vegetation maintenance: To establish vegetation in backshore and adjacent transition areas, least 5 years of weeding and removal of invasive species is usually required. Animal exclusion (for example, to prevent geese browsing) and replanting may be required.

Case Studies and Examples

Driftwood Beach, San Juan County: A 900-foot-long beach restoration project was carried out 1998 on a community-owned beach on northeast Blakely Island in the eastern San Juan Islands. The barrier beach was in a drift cell with low sediment transport volumes and a history of gravel mining from the beach, along with placement of soil and debris (Figure 2-3). Project objectives included restoring the beach by replacing fill and debris with a beach gravel similar to native sediment and establishing a native backshore plant community to protect the upland from further erosion and loss of community land. Permit agencies sought to avoid waterward migration of gravel and impacts to nearshore habitats (macro algae, eelgrass, and kelp).

Construction occurred in1998 using gravel and sand barged in from nearby Whatcom County. Drift logs were removed and replaced after grading. Sediment was conveyor offloaded at high tide which prevented grounding. Nourishment sediment consisted of 1-3 inch diameter washed, round gravel for the beachface and coarse, washed sand in backshore, along with a small volume of topsoil for certain planting areas (Figure 2-3). Results of 5-year monitoring revealed that Driftwood Beach has essentially remained stable following construction (which has continued through to 2009). Less than 0.25 feet of vertical change occurred over approximately 70 percent of the beach area. There was no indication of waterward migration of gravel below the lower project extent (elevation +3.0 ft MLLW) in any of the 5 years of monitoring. To the contrary, there was a net onshore movement of sediment from the lower beachface to the storm berm occurred. Total project cost was approximately $80,000. Other management measures addressed included *Debris Removal, Large Wood Placement, Public Education and Involvement, Revegetation, and Topography Restoration*.

Lummi Shore Road, Whatcom County: Beach nourishment was initiated along the Lummi Shore Road beach to mitigate forage fish spawning habitat loss that would occur as a result of road revetment construction at the Lummi Indian Reservation in northern Bellingham Bay, Whatcom County. The USACE constructed an almost 2 mile long rock revetment in 1998-99 to allow for rebuilding of the main road in the area that had been eroded down to one lane in many areas. Surf smelt (*Hypomesus pretiosus*), which are a primary forage species for Endangered Species Act-listed adult Pacific salmon, were known to spawn in the upper intertidal beach in the project area. Two years of pre-project monitoring data were collected, which consisted of beach profiles, sediment sampling, and surf smelt egg counts sampled several times per year. The monitoring and mitigation plan (Dillon and Johannessen 1998) called for keeping the new revetment higher on the beach and the buried toe deeper under the beach surface, as compared to the USACE plans. The plan also called for periodic beach nourishment to mitigate for the loss of sediment supply from the bluffs, placement loss (burial) due to the revetment, and any revetment-induced erosion that may occur.

The beach was depleted of fine grained sediment following road and revetment construction (Figure 2-4). Initially nourishment occurred immediately after revetment construction in early 1999 to rebuild the intertidal beach (Figure 2-4). Following monitoring recommendations the beach was renourished in years 2, 3 and 5. Gravelly pit run sediment was used twice, stockpiled beach and bluff sediment was used once, and sediment high in 1-8 mm sized material (the grain sizes utilized by surf smelt for spawning) was used once. Toppled rock was also removed from the beach. The Lummi Nation Natural Resources Department collected baseline forage fish spawn data and conducted post construction monitoring (with documented spawn density) with assistance from WDFW. Physical monitoring was conducted by Coastal Geologic Services for most of 10 years and consisted of total station surveys, sediment sampling and grain size analysis, and mapping of suitable spawning areas. Results of the monitoring effort reveal that dense surf smelt spawning areas have been recreated, with some spatial change. The trend of percent suitable surf smelt spawning substrate has generally increased gradually within the 3 beach sub-cells between 1997 and 2004. Surf smelt egg density surveys demonstrated that surf smelt egg density was higher following nourishment as compared to pre-project data. However, the long-term success of this effort along an erosional bluff-backed beach under moderately high wave energy was always in question. Total nourishment costs (4 events) were approximately $85,000. Other management measures addressed included *Debris Removal and Topography Restoration*.

Seahurst Park, Burien: Seahurst Park provided an excellent opportunity to restore a natural beach through nourishment to recreate habitats and sediment supply, as well as to improve recreation and public awareness of beach restoration and nourishment. Failure of the extensive rock-filled gabion shore protection at the park led to installation of rock rip-rap in the early 1980s, the removal of which is described in the *Armor Removal or Modification* chapter. The restored beach was designed to mimic pre-development conditions using old mapping from on-site and adjacent reference beaches. The USACE implemented the project in 2005. After all of the armor and fill were removed from the south portion of the park gravel and sand were imported by barge to nourish and restore the intertidal beach and backshore. A coarse gravel lower layer and a mix of finer gravel and sand in an upper layer were graded, and coarse sand was placed in the high backshore. In addition to *Beach Nourishment*, other management measures employed were: *Armor Removal or Modification*, *Large Wood Placement*, *Revegetation*, and *Topography Restoration*.

Other Examples: Other local examples of *Beach Nourishment* for residential applications exist from a community beaches on north Samish Island, and small sites such as Salisbury Point Park. These projects are summarized in Zelo et al. (2000) and Johannessen (2002). *Beach Nourishment* for mitigation and habitat creation was carried out at Jetty Island, Everett.

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Figure 2-2 Evolution of profile nourishment over time, from Dean 2002.

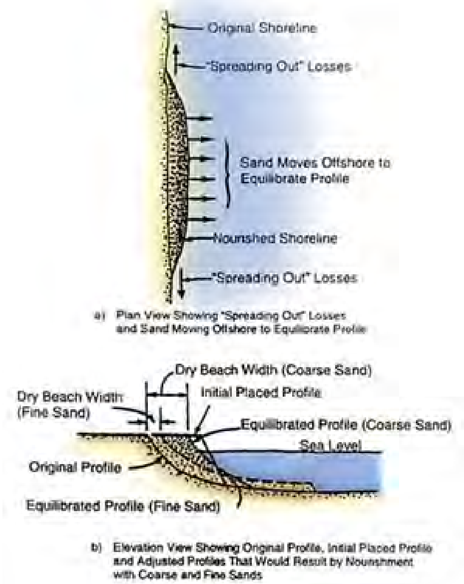


Figure 2-3 Driftwood Beach, Blakely Island beach nourishment: Before (1998) and after (2006) at same location. Both photos by Jim Johannessen.

Figure 2-4. Lummi Shore Road, Bellingham Bay beach nourishment: Before (1999) and after (2000) at same location. Both photos by Jim Johannessen.

MM 3 BERM OR DIKE REMOVAL OR MODIFICATION

Definition

This management measure includes the removal or modification of berms (or levees), dikes and other structures to restore tidal inundation to a site that was historically connected to tidal waters and supported tidal wetland ecosystems. These structures (collectively referred to here as dikes) were commonly constructed to eliminate or restrict the flow of tidal waters to areas deemed desirable for crop production and animal grazing practices. Complete removal of these structures is preferred over modification and should be performed unless site constraints preclude full removal. Dike modification typically consists of removing select portions of a structure (known as breaching). Dike modification requires careful consideration of the location and extent of the breaches.

Many dikes were constructed using materials from adjacent tidal marsh sediments (resulting in borrow ditches located parallel to the dike). In many cases, farmers added rock and gravel to maintain the structures. In some cases, the dikes are armored on the exterior margins to prevent erosion by river and tidal currents. Loss of tidal flow, or in some cases restriction by a tide gate, caused significant changes to the former tidal ecosystem enclosed by dikes/

Justification of Need and Link to Nearshore Processes

During the last century, the Puget Sound region has lost roughly 80 percent of its major estuarine wetlands due to dredging, filling, diking, and industrial development. Diking and development of smaller estuaries has occurred to a somewhat lesser degree but has reduced the historic extent of small estuaries by nearly half. Estuarine habitat loss has generally been greatest in the large and urbanized river deltas of Puget Sound (e.g., Snohomish, Duwamish, and Puyallup Rivers). However, loss of these ecosystems due to diking in less urbanized areas has also been significant (e.g., Skagit and Skokomish Rivers).

Diking associated with agriculture frequently involves installation of tide gates to facilitate drainage of water through ditches from enclosed areas while preventing inflow of tidal waters. Lack of tidal inundation to diked areas results in severe changes to the form and function of these areas. Diking of tidally influenced areas significantly changes vegetation composition, species use, and hydraulic processes (including sediment movement).

In the absence of tidal flooding, the surfaces of diked areas also typically subside (decline in surface elevation) due to the loss of sediment deposition, oxidation of organic matter, consolidation due to enhanced drainage and dewatering, and compression by animal and machine traffic. In some cases, subsidence can be so extreme that the initial restoration elevation is below that where vegetation can colonize. Such areas do not immediately return to their pre-diked state following restoration. The longer an area has been diked, the longer the period of recovery.

Dikes not only block tidal flows across the marsh but also act as barriers for a number of other processes. Dikes block the movement of water, sediment, organic plant material, and detritus that would otherwise move between the mudflat on the outside of the dike and the interior marsh on spring tides or during storm surges. Therefore, the persistence of a dike limits the ecological connectivity of the marsh with the estuary.

In addition, diking can indirectly affect sediment accretion and tidal channel formation outside of the diked area, often reducing the complexity of tidal channels and starving deltas of sediment. Dikes can also provide predators and people access to marsh habitats, which can lead to disturbance and unwanted intrusions, and colonization by invasive, non-native plants. Therefore, the total area influenced by dike construction is not simply on the landward side of the dike, but extends some distance outside the diked area.

Estuarine areas provide important feeding, rearing, smolting, and predator avoidance habitat for numerous species of fish and wildlife. In addition, they provide flood control benefits, water quality enhancement, and areas for recreation and scientific research. Diking precludes fish access to former estuarine wetlands and tidal channels landward of the dikes, including areas formerly used by juvenile salmonids for rearing and feeding. The changed hydrology and agricultural activities eliminate salt marsh vegetation. Fluvial processes that distribute sediment and nutrients are also interrupted as a result of diking in tidally influenced areas.

Dike removal can restore hydrologic processes (tidal inundation, sediment movement, and channel formation) and biological processes (e.g., juvenile salmon access, foraging, and growth) to areas landward of existing dikes. The extent to which processes are restored depends on whether the action is a partial dike breach or complete dike removal. Areas outside the dike can also benefit from removal actions through increased channel formation as a result of restored hydrology (increased tidal prism). Restoring tidal inundation facilitates delivery of tidal flooding and salinity regimes similar to those found in adjacent waters and provides conditions for recolonization by marsh vegetation.

Dike removal restores production of benthic invertebrates and insects that are preferred prey of juvenile salmon. These prey resources would have been generally unavailable to foraging fish because of blocked access to the diked area. When juvenile salmon can feed and have longer residence time in restored marsh areas, growth rates and nearshore survival increase.

Conceptual Model

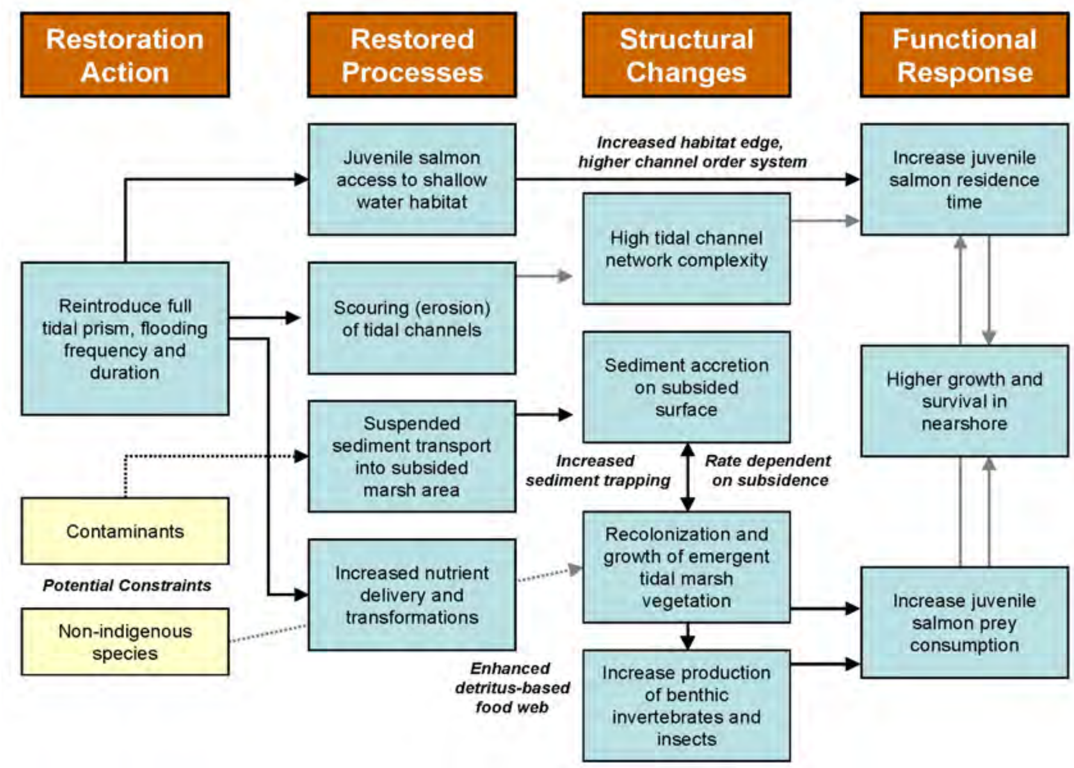
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 3-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: A diked wetland in an estuarine delta prevents or limits (depending on tide gate functionality) juvenile salmon rearing.

Change/Action: Removal (or breaching) of dikes initiates development of tidal wetland and allows immediate fish access, and removes predator access and human disturbances.

Predicted Response: Depending upon the species and life stage of salmon considered dike removal or modification increases the opportunity for salmon to occupy shallow water habitat and improves the capacity to support juvenile salmon foraging and refugia. This can then promote increased residence time, growth potential, and reduced predation. Removal of dikes may increase wave activity, leading to increased erosion and turbidity.

Figure 3-1 Conceptual Model for Berm or Dike Removal or Modification



Complementary Management Measures

Dike Removal or Modification cannot be viewed in isolation from other management measures nor other restoration sites in the same watershed. Removing dikes alters the tidal hydraulics of the wetlands, and so the related measures of *Hydraulic Modification, Topography Restoration*, and *Channel Rehabilitation or Creation* need to be considered. For instance, if the dike is removed then tidal inundation is increased, so tide gates along the inboard dike will have to be modified to allow drainage to continue; the elevation of the site will have to be assessed in relation to the new tidal regime, and channels will enlarge to accommodate the larger tidal prism. *Substrate Modification* in the form of disking can also be used in conjunction with *Berm or Dike Removal or Modification* to provide additional habitat enhancement benefits.

Benefits and Opportunities

Benefits of the Restoration Action

Dike removal or modification is one of the most effective and necessary measures for recovering the extensive salt marsh losses that occurred during the last century. Other benefits include:

Restoration of historical conditions: Restoring full tidal action to diked areas restores estuarine marsh habitat that has declined by nearly 80 percent since the late 1800s in the Puget Sound region. The restored marsh and associated processes will be largely self-sustaining over time. In particular, the complete removal of the dike allows the reestablishment of sheet flow across the marsh surface at higher tides which had previously been cut off by dikes.

Improved juvenile salmonid rearing: Dike removal or modification restores high-quality estuarine habitat for many salmonid species including Puget Sound Chinook salmon (primarily juveniles), steelhead and bull trout, which are listed as threatened under the federal Endangered Species Act. Providing more area where juvenile salmon can transition from fresh to salt water increases the opportunity to preserve life history diversity and alleviates density-dependent emigration from marsh and tidal channel areas which have high value for salmon foraging and growth. Dike removal or modification also increases primary production of organic matter contributing to overall estuarine detritus-based food webs.

Flood hazard reduction: In many instances, tidal wetland restoration projects can help reduce flood hazards. Many agricultural dikes are now in poor condition. Rebuilding a new dike inland provides an opportunity to improve the degree of flood protection for adjacent areas. Reestablishing a new vegetated marsh outboard of a relocated dike can significantly reduce the risk of erosion damage and the need for costly armoring. In addition, removal, lowering, or setting back dikes along tidal flood channels can also increase flood conveyance and reduce flood hazards upstream.

Reduced channel maintenance: Restoration sites may be located adjacent to where streams discharge to the estuary. Whereas these streams formerly discharged into natural channels that meandered through marshes before connecting to the estuary, their flows may now be confined within a diked tidal channel. Many of these tidal flood channels accumulate estuarine and alluvial sediments, requiring frequent expensive maintenance dredging to retain their design flood conveyance capacity. Restoring tidal action to restored marshes can significantly increase natural channel scouring and reduce the need for maintenance.

Access and recreation: Remnant or relic dikes may be maintained in place to provide for trails and public access. They can provide transitional marsh habitat and refugia for birds and wildlife.

Sea level rise: Sea level rise may lead to increased flooding and overtopping of dikes, causing land owners to either increase the height of the dike, or abandon the property. This could create opportunities to acquire land for restoration and compensate the landowner at a reasonable price.

Opportunities for Implementation

This management measure is typically implemented as part of large-scale restoration actions, often encompassing tens to hundreds of acres. Because of the scale of these types of projects, multiple resource agencies and organizations are usually involved (e.g., USACE, NOAA, WDFW, Natural Resources Conservation Service [NRCS], cities/counties, salmon recovery lead entities, The Nature Conservancy [TNC], and others). Such projects provide opportunities for inter-jurisdictional and inter-agency partnerships.

The removal of dikes can occur in any historic wetland area. Topographic restoration may be required where the historic wetlands have either subsided or been filled. Channels may need to be constructed if the historic channel pattern is not present.

Measureable Units

Benefits of this management measure include increases in salmon production and increases in production of benthic prey base. Sediment accretion on the site can be measured either as thickness or mass of sediment deposited or as change in elevation, usually expressed in mm per year. Recolonization of emergent wetland marsh vegetation can be measured in terms of area of desired species and also area of undesired species. The evolution of the channel network can be expressed in a number of ways, such as channel area, thalweg elevation, network characteristics and channel density.

Constraints

Flood management: Dike removal may increase flood risk to adjacent areas by (1) increasing exposure to inundation and or wave action and (2) removing a storage area for runoff from surrounding land. In these cases, special actions will likely be required. Breaching or removing a dike that were formerly the primary defense against coastal flooding typically necessitates construction of a new inboard dike. This new inboard dike should be constructed to provide equal or better protection than the original dike. Moving the primary flood defense dike inland can modify the drainage system on adjacent low-lying land. This drainage system may rely on passive discharge of runoff that is stored in ditches and retention areas through tide gates. If the storage volume is reduced by dike setbacks, improvements will need to be made to compensate for the potential increase impounded water level.

Erosion protection: In isolated cases it may be preferable to leave the dike in place and provide a tidal connection with a breach. Such actions are sometimes acceptable within the context of restoration if the dike is expected to ultimately erode and become obsolete after the restored area aggrades and revegetates. In this case, dikes may perform a valuable function of reducing incident wind and wave energy and allowing sedimentation to occur within the site until marsh vegetation can colonize. In addition, the dike may reduce wave energy that might otherwise erode the inboard (landward) dike. The need for the outboard (seaward) dike diminishes as the surface of the evolving marsh gains elevation. Once high marsh is established, shallow water depths, high canopy wave baffling, root binding, and high sediment shear strengths ensure greater resistance of the marsh to wave erosion. Once the site is fully colonized, the outboard dike becomes a redundant feature. Over time the relic dike will erode and subside into the marsh plain. In these cases, the dike is usually breached and lowered in one or more places to provide adequate hydraulic conveyance and inhibit undesirable access.

High tide refuge and transitional habitat: Dikes may provide refuge to certain species during high water levels and may provide an elevation transition and ecotone with habitat value. Typically, dikes will provide marginal benefit and will require reconfiguration to enhance these attributes.

Access corridors for invasive species: If remnant or relic dikes are left in place, they can serve as a colonization corridor for exotic plants. They may also provide corridors for access to the marsh interior.

Downstream erosion: Large increases in tidal prism can increase velocities and potential scouring in channels seaward of the restored wetlands, undermining existing dikes downstream. Hydrodynamic studies may be required to address the potential concerns for adverse impacts to downstream infrastructure. Tidal inundation may also threaten adjacent landowners through flooding. Land acquisition may minimize this in some instances; setback dikes may be required in other circumstances.

Change of existing land use: Many diked areas currently support agriculture or recreational opportunities that are to some degree dependent on the presence of a dike (e.g., hunting, bird watching, hiking). Citizens interested in these activities often resist changes at their favored locations, even though they may not directly use the areas inside the dikes. Agricultural interests, even if not directly affected, may express concerns related to drainage, water storage, and salt intrusion impacts that could result from tidal inundation of areas adjacent to their land.

Cost: Implementation of dike removal projects is relatively expensive, even without considering land values. Large equipment is necessary to excavate dike material, and the material may need to be trucked to offsite locations for disposal if redistribution in borrow ditches and on the diked area surface is not an option. Adjacent landowners may require construction of new setback dikes, or augmentation of existing dikes, to protect their land from flooding. Relocation or replacement of existing tide gates may also be necessary. The cost is reduced if the material can be sidecast into an adjacent ditch used to construct the dike (called a borrow ditch), other undesirable channels on site, or to build set-back dikes for flood management.

Climate change and sea level rise: Climate change and SLR can complicate implementation of this measure. Projects designed to restore tidal wetland habitat at a particular location in the estuary will need to consider the ability of the marsh to maintain its position vertically in the tidal frame. If the goal is to improve the functioning of the estuary, effects of SLR will depend on the ability of the tidal flat/marsh/upland transition to move landward. With accelerating SLR, the period of time required to reach colonization elevation generally will be increased. If SLR continues to accelerate, then at some point it will outstrip the rate of mineral and organic accretion and the marsh will start to “drown”.

Best Professional Practices

The scope and detail of engineering studies vary depending on the location and size of the project and the risks associated with project failure. The severity of risk can vary from intermittent minor erosion and flooding, to damage to the dikes, to flooding of adjacent infrastructure and potential loss of life. Professional judgment should be used to determine the appropriate risk and uncertainty of any project. The scope and design factor of safety should be consistent with the anticipated outcome of the project (dike removal vs. modification) and specific project, location, and restoration requirements.

Feasibility Assessment

Potential for flooding: The potential impact of tidal restoration on flood hazards and drainage of adjacent land needs to be analyzed and integrated in the design plan. Two types of flooding have to be considered: coastal and fluvial flooding due to dike erosion and overtopping from storm surges and high waves or high river waters, and flooding from the watershed due to precipitation.

Flooding analysis: An analysis of potential tidal and fluvial flooding should be undertaken to determine the likely extent and depth of inundation for a number of storm events (e.g., 10, 50, 100 year return periods). This may require additional analysis or wave run-up and overtopping if the dike is exposed to large wave fetches. A one- or two-dimensional numerical model may be required to allow analysis of alternatives. Project managers should discuss the precise conditions to be modeled and the models to be used with agencies such as the Federal Emergency Management Agency (FEMA) to ensure that the approach is acceptable.

Flood management: Project designers need to determine the assets that the existing dike is protecting. A new inboard dike may need to be constructed; this should provide equal or better protection than the original dike. Alignments for this new dike need to be considered. The drainage system on adjacent low-lying land should be mapped and documented. Storage areas for runoff should be identified. Runoff volumes should be estimated. An inventory of tide gates, culverts, and other structures with principal dimensions should be made to help identify the impact on the drainage system from changing the tide range.

Geomorphic assessment: Geomorphic conditions such as sediment supply and particle sizing must be considered to ensure that sedimentation rates in newly restored areas are sufficient to sustain the evolving marsh. A conceptual sediment budget for the area must be developed that considers not only the restoration site but also other existing sediment sinks and sources. A local sediment transport budget can be used to estimate the effects of the project on off-site areas.

Topographic assessment: Diking typically leads to subsidence of the wetlands enclosed within the dikes. Elevations of the interior portions of the diked area are therefore important to know when projecting future plant species likely to colonize the restored marsh surface. Species occurring at similar elevations in adjacent marshes (not within diked areas) are likely to be indicative of species colonization following dike removal.

Topographic survey: An accurate and up-to-date survey of the site topography is required together with cross-sections of the dikes and large channels. This survey should at least extend to cover the area that would be tidally inundated following the modification of the dike.

Existing dike construction: For both removal and modification projects, project designers should review the original dike design, its original purpose, and its present function and condition. Dikes were often constructed independent of adjacent structures on separate land parcels. The methods of construction, construction materials, and quality of construction can vary widely.

Design and Implementation

With any dike removal or modification project, the design should reduce erosion hazards to flood control dikes by establishing a vegetated marsh to reduce wave energy. Restoration of tidal action can also be designed to increase scouring of flood control channels, thereby increasing their flow capacity during flood events. To facilitate colonization and revegetation of restored marshes, disking of the soil is sometimes necessary to mix in the existing organic matter and to make the new marsh surface more susceptible to erosion of a new tidal channel network. Filling of “borrow ditches” that typically run parallel and adjacent to the dike is necessary to prevent them from capturing flows during incoming and outgoing tides and preventing water from flowing into more complex channel networks (both inside and outside the dikes). Filling ditches facilitates redevelopment of complex network of tidal channels.

Because of the difficulty associated with construction at intertidal elevations, dike removal often consists of some level of dike lowering. Dike lowering involves excavating down to an elevation that may or may not be at site grade. For tidal systems, dike lowering is typically desired to around MHHW or below to remove non-native vegetation and allow rapid establishment of vegetated marsh plain. Deeper excavations are required to provide full tidal action and hydraulic conveyance (see breaches). Excavated material can be placed in the site to fill low areas or “sidecast” below MHHW or other specified elevations. It is desirable to lower the dike on either side of the “breach” to allow contiguous wetland on either side of the channel. It is also important to consider flow at high water levels and the stage-discharge requirements of a subsided site. Lowering dikes along flood control channels can reduce flood elevations upstream by increasing channel conveyance and storage.

If incident wave energy propagating into the site is likely to be high enough to retard sedimentation, then some of the dike should be left in place but its crest elevation may be lowered. The dike has only to reduce wave energy and not act as a complete barrier. If portions of the dike are retained, they can be graded in a way that creates a transitional wetland-upland habitat.

Other design considerations vary depending on whether the project involves full removal or partial dike breaching. Breaching a dike will restore tidal flows across a marsh, but the remaining dike will still act as a barrier for a number of other processes. The dike will continue to block the movement of water, sediment, organic plant material, and detritus. If the dike is removed and the desire is to achieve a seamless vegetated marsh plain, it may be necessary to over-excavate the compacted dike material by up to 1 foot and allow natural sedimentation to restore suitable elevations and substrates. Other considerations for breaching include:

Sizing breaches and channel dimensions: Determining the size of the dike breach requires estimating both initial post-restoration and long-term equilibrium channel dimensions using empirical hydraulic geometry relationships (e.g. Coates et al. 1995, Williams et al. 2002, Hood 2007). There can be a significant error band in these predictions and, wherever possible, they should be calibrated with data on similar marshes in the vicinity of the restoration site. The cited hydraulic geometry guidance is primarily for the San Francisco Bay area of California and therefore requires adjustment for the larger tidal range found in the Puget Sound area, pending development of similar data for Puget Sound. The designer must consider the consequences of overestimating or underestimating equilibrium or transient channel dimensions. Post-restoration or short-term channel dimensions are calculated using the tidal prism of flooded site upon breaching. Long-term equilibrium channel dimensions can be inferred from estimations of the predicted marsh drainage area; assuming that a mature vegetated marsh will eventually evolve. Position in the estuary influences the size of a breach. Dikes or causeways that cross an estuary close to the edge of the historic marsh significantly interrupt expected estuarine processes. Breaches should be sized to restore surface (as opposed to channel) transport of water, sediment and organisms. Dikes that cross the estuary closer to the upland interface may consider mostly tidal channel geometry, in addition to any freshwater input. Small breaches, or "notches," are useful in inhibiting access by predators, humans and domestic animals.

Long-term breach evolution: Constructing breaches and connecting channels to the predicted larger sizes for the initial post breach tidal prism is generally not necessary if the channel and breach are free to erode. A breach should be excavated to at least the smaller long-term equilibrium dimensions to remove compacted material. This size breach will usually allow for a large enough tidal prism to quickly erode the breach to a larger size, but this should be checked by hydrodynamic analysis or modeling. The rate of breach erosion is site specific and determined by the volume of the body of water available to scour through the breach and dike composition.

Breach cross-sections: In general, it is also preferable to construct connecting channels to reflect long-term equilibrium dimensions to minimize excavation costs and to allow them to naturally evolve towards equilibrium dimensions, which are likely to be smaller than the estimated short-term dimensions. It is more important to excavate channels and breaches to their anticipated depth, and then allow for bank slumping to the angle of repose, than to replicate a specific cross section. In designing connector channels it should be anticipated that they may scour to the maximum size appropriate for the initial tidal prism and may widen beyond predicted equilibrium geometry due to bank slumping.

Other dike removal or breaching considerations:

- Minimize the length of connecting channels required across existing outboard marshes.
- Maximize opportunities for creating single, large, complex tidal drainage systems within the marsh rather than multiple smaller systems. Multiple breaches will ultimately create multiple separate tidal drainage systems within the site. Ideally, marsh watershed areas should be large enough to sustain high-order, subtidal channel habitat within the marsh.
- Maximize opportunities of deepening existing tidal channels for navigation and flood level reduction.
- Allow for rejuvenation of remnant tidal drainage features on the restored site. Where possible, the breach should be sited to take full advantage of any opportunities to reestablish a connection between an existing remnant channel network within the restoration site and the truncated higher order channel on the natural marsh. In this respect, the location of the breaches, the location of any internal watersheds, and the internal channel network should be seen as an integrated design.
- Establish early the design standards for any setback dike that may need to be constructed to protect remaining inland infrastructure. Conduct thorough geotechnical investigation (possibly including core sampling) to establish structural strength and permeability of the new dike's foundation material.
- Ensure compatibility with public infrastructure and maintenance access requirements/needs.

- Consider proximity to a suspended sediment source including adjacent mudflats where wind or waves resuspend fine sediments back into the water column, and areas close to estuary entrapment zones.
- Minimize risk of remobilizing contaminated sediments. For example, consider locating the breach away from outboard slough channels with contaminated or erodible sediments.

Evaluation

Compliance monitoring: Ensure through inspections that the removal, modification, and construction of dikes proceed according to the final plans.

Monitoring of site evolution: Using a combination of on-the-ground surveys and aerial photographs, document physical and biological changes to the landscape of the restored area. Dike removal changes would be expected in the tidal inundation regime, tidal channel evolution, marsh surface accretion, and plant species colonization. Previous experience shows that restored sites continue to evolve more than 10 years after the initial breaching or removal of the dike (Williams et al. 2002).

Adaptive management: Monitoring data can be used to inform adaptive management and corrective actions. For example, measurement of the tide within the site can indicate obstructions, such as resistant sills, that may need to be removed. Monitoring can also provide valuable information for guiding the design of future projects.

Case Studies and Examples

Deepwater Slough, Skagit River Delta: The Deepwater Slough restoration project located in the South Fork Skagit River delta is an example of complete dike removal (Klochak et al. 1999, Hood 2004). The 480-acre site is owned by WDFW, which has managed the area for waterfowl since the 1940s. WDFW allowed restoration on 205 acres, but maintained 275 acres in traditional waterfowl management by planting agricultural grains for waterfowl food and controlling seasonal flooding.

In the past, dikes were constructed around the project area to protect agricultural land from tidal flooding. The dikes disconnected the main Deepwater Slough channel from the river. Distributary and subsidiary tidal channel networks which formerly were connected to the main channel, as well as other non-mainstem open water, estuarine, palustrine, and riverine habitats, were reduced in extent, altered, or obliterated.

By isolating the project area from the influence of the river and tides, the dikes altered the natural fluvial and tidal hydrology. The dikes eliminated Deepwater Slough as an active river channel and isolated the remainder of the project area from riverine influence. The extensive blind tidal channel networks were no longer maintained due to the lack of regular tidal action. The salinity regime became fresher and no longer could support emergent salt-tolerant vegetation. Water quality suffered as the site was not subject to free exchange with the river and tides, resulting in seasonally increased water temperatures and reduced dissolved oxygen levels. Diking also interrupted the processes of sediment transport and storage, preventing sediment import or export from the site.

The site had also been altered by changes in offsite conditions. Hydroelectric dams and other modifications to the river’s hydrology changed the river flows in the Skagit River Basin. The amount and rate of sediment supplied by river flows was also altered by hydromodification, diking, and land use changes upstream of the project site.

The project was constructed in August and September 2000. To restore the connection between the project area, the Skagit River, and Skagit Bay tides, the outboard dikes were entirely removed (Figure 3-2). Access was relatively easy and excavators could be used to lower the dikes. A total of 2.77 miles of dike was removed which restored tidal action to about 200 acres of historic estuary. New inboard dikes were built, and existing inboard dikes were reinforced, to allow for the continuation of traditional waterfowl management activities in the remaining farmed area. Material that formed the outboard dikes was reused in the construction of the new dikes; although the material was of low quality it was suitable for dikes protecting the waterfowl management areas.

The project team did not excavate new channels because the imprint of the historic channel system was still evident. In places where large historic channels crossed the old outboard dike, the remnant channel was reconnected to the outside tidal channel by excavating through the foundation of the dike to match the cross-section of the outboard channel (Figure 3-3). A total of six channels were reconnected in this manner.

The early evolution of the restored site is described by Hood (2004). A comparison of orthophotos shows the development of the channel planform geometry. The reconnected pre-existing channels have increased in depth and width to accommodate the larger tidal prism. This process was probably accelerated by the decision to excavate through the old dike foundation. However, even where the foundation was not excavated, channels have formed across the old dike. Unlike a breached site which restricts the main flow to certain locations, removing the whole dike allows channels to develop anywhere in the site. In the first two years new tidal channels developed and cut across the old dike footprint in many locations. These channels are referred to as “proto-channels” by Hood (2004), reflecting their early stage in evolution. These channels are likely to continue to evolve as they capture and are captured by other “proto-channels.” Larger channels have also cut through the dike; these are outboard pre-existing channels that are growing through the process of headward retreat. In addition these channels are growing in size to accommodate greater tidal flushing.

Wiley Slough, Skagit River Delta: A new habitat restoration project is under development at Wiley Slough, a distributary channel of the South Fork of the Skagit River delta, very close to Deepwater Slough. This 175-acre project is another example of complete dike removal, benefiting from lessons learned from the Deepwater Slough project. The site was diked and tilled to allow traditional waterfowl management by planting agricultural grains for waterfowl food and controlling seasonal flooding. Dike construction resulted in the enclosure and isolation from tidal influence of 160 acres of tidal marsh and 16.3 acres of tidal channel. The dikes also prevented juvenile salmon from using the tidal channels. Inside the dikes, the smaller tidal channels were filled in entirely, plowed over, and assimilated into agricultural fields. The larger tidal channels, including Wiley Slough, accumulated sediments from farmland erosion and become narrower and shallower than they were historically. Tidal channels seaward of the dikes were also impacted by dike construction.

The intent of the project is to restore natural tidal and riverine flooding processes with the expected result of roughly 49 acres of tidal channel habitat in the restored area, as well as potential recolonization of native marsh and shrub vegetation. An additional 35 acres of tidal channel surface area will be restored through reconnection of the historic Wiley Slough channel to tidal flushing. Figure 3-4 shows the main elements of the project with roughly 1.2 miles of existing dikes to be removed, approximately 0.5 mile of new dikes to be constructed, and the retention and reinforcement of about 0.7 mile of existing dikes. In addition a new, larger tide gate structure will be constructed on Wiley Slough, and about 3,470 feet of borrow ditches within the site will be filled.

The dike removal is similar to that undertaken at Deepwater Slough. The dike will be lowered to the marsh elevation, and channel cross-sections will be excavated through the dike foundation where existing channels cross the dike. However, it is unlikely that old dike material will be useable in new construction because it does not meet the specification for dike and cutoff trench material. Instead, excess old dike material will be used on the site to fill existing borrow ditches that run parallel to the existing or historic drainage channels. These borrow ditches will be plugged at either end, drained, and then overfilled by 2 feet to allow for compaction.

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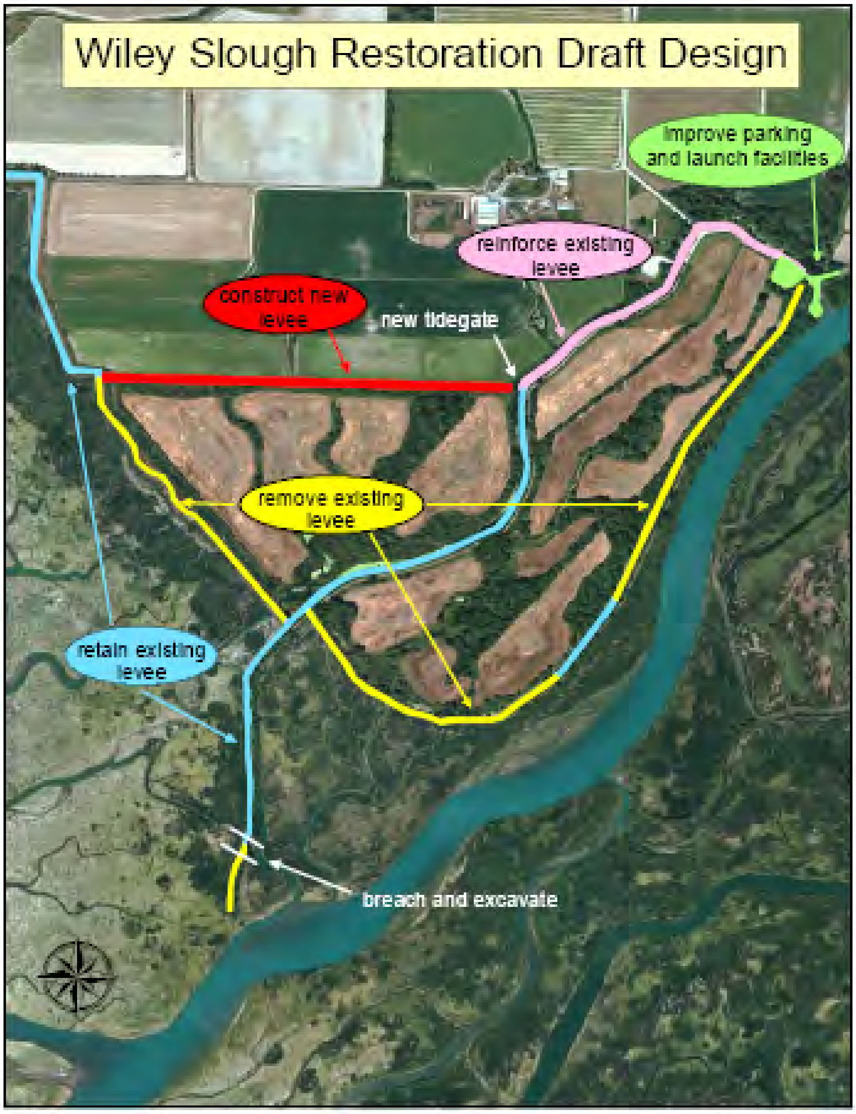
Figure 3-2 Removal of dike at Deepwater Slough, new dike construction at upper left (Hood 2004)

Figure 3-3 Reconnection of remnant channel with outboard channel by excavation through the dike foundation (Hood 2004)

Figure 3-4 Wiley Slough Restoration Design



MM 4 CHANNEL REHABILITATION OR CREATION

Definition

Channel Rehabilitation or Creation pertains to the restoration or creation of channels in a restored tidal wetland to change water flow, provide habitat and improve ecosystem functions. Common actions include reestablishing flows to historic channels, blocking flows to man-made ditches, and creating new channel networks. *Channel Rehabilitation or Creation* allows for better connectivity of the wetland with the tidal source and typically occurs in conjunction with other actions, such as *Berm or Dike Removal or Modification* and *Hydraulic Modification*. Small alluvial and distributary channels can also benefit from this management measure. *Channel Rehabilitation or Creation* assumes that the hydraulic system will be studied as a whole so that water crossings, breaches, channels, and channel networks are sized appropriately for the individual restoration site and for the watershed. Physical channel reconstruction is discussed under this management measure and is distinguished from *Topography Restoration* in that the former relates to channels and not the surrounding landscape. Engineering considerations and other constraints should be evaluated when selecting the appropriate degree of modification associated with this management measure.

Justification of Need and Link to Nearshore Processes

Tidal channels link the nearshore marine environment to tidal wetlands, and can also provide hydraulic connection and sediment supply from rivers and smaller drainages. They serve as conduits for water, sediment, nutrients, fish, and other aquatic organisms and detritus. They also provide important habitat for plants, fish, and animals. The tidal drainage system is intricately linked to the tidal hydraulics and sediment transport, as well as influencing the distribution of vegetation.

Tidal channels start to form concurrently with the physical evolution of the marsh. As mudflats accrete (rise) to intertidal elevations, mudflat tidal channels form and become fixed as vegetation establishes and the marsh plain develops (Beeftink and Rozema 1988). Depending on their contributing tidal watershed, channels may eventually incise into the evolving mudflat (French and Stoddart 1992; French 1993). As vegetation becomes established, these sinuous mudflat channels become imprinted in the marsh plain, eventually forming a dendritic or branching tidal channel system. Within this system, the tidal channel geometry at any given point is mainly dictated by the tidal prism of the area of marsh upstream (Williams et al. 2002, Hood 2007).

As the marsh evolves from primary colonized mudflat to low marsh and eventually to high marsh, the density of tidal drainage channels changes. In the young marsh, marsh plain elevations are low, tidal prism is large, and drainage density high. As sediments accrete above a certain level, tidal prism is reduced and drainage density decreases. The elevation of maximum channel density is usually estimated to be around the elevation of the neap high tide in semi-diurnal tidal regions (Steel and Pye 1997). Channel density therefore varies with elevation and hence age of the marsh: A low or young marsh tends to have more small channels in complex drainage patterns, while a higher or older marsh tends to have a less complex drainage pattern with fewer small channels.

Land development in estuarine and nearshore areas has altered many tidal drainage systems. The building of dikes, bulkheads, and roads disrupts the processes that create and maintain channels over time, so channels change, become isolated, or in some cases, disappear. Where there are culverts and tide gates, the tidal range is often muted and the tidal prism reduced, leading to sedimentation of the channel. Where culverts are lacking, the channels become completely isolated from marine water. Channels are also affected by upstream alterations; either by a reduction in the upstream tidal prism due to loss of floodplain, or diversion of tidal flows by borrow ditches or drains, which can result in further sedimentation and reduction in sinuosity. Diking, and subsequent restoration, therefore can have impacts on estuarine channels seaward of the dikes (Hood 2004).

Conceptual Model

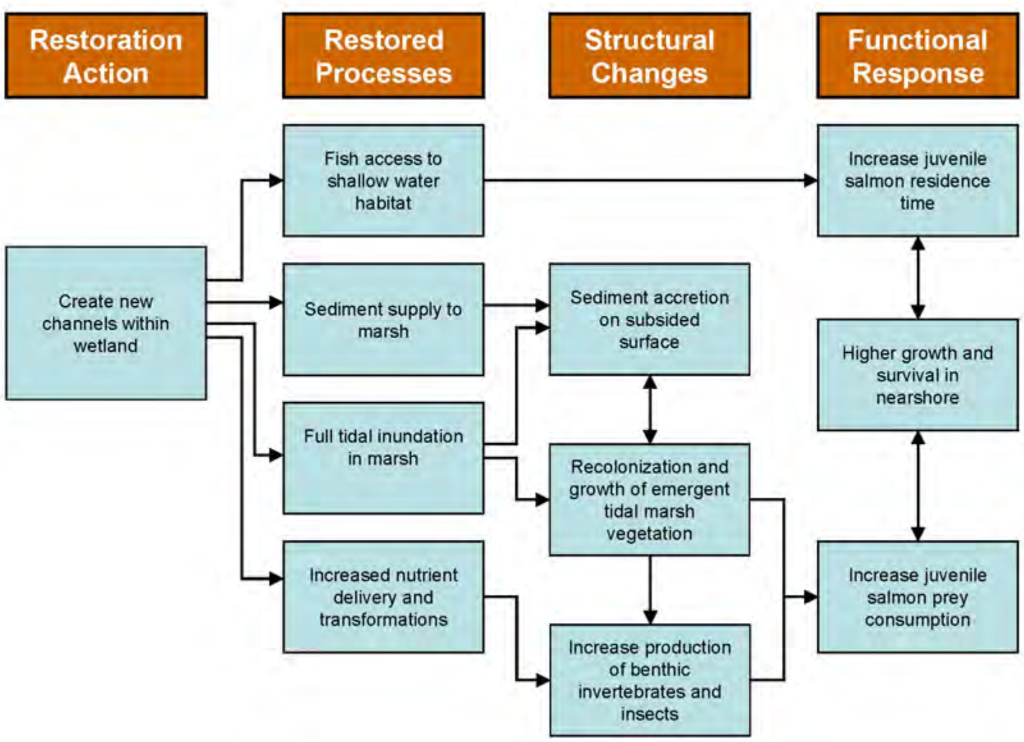
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 4-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Historic tidal channels within a wetland have become filled due to sedimentation after loss of tidal infiltration, or active modification of the site.

Change/Action: Tidal infiltration is restored; tidal channels are completely or partially recreated to allow more natural flow conditions to resume.

Predicted Response: Increased tidal prism will maintain a larger channel. Channel sinuosity may increase over time. The channel network will increase in complexity as new channels are established or reconnected to the network.

Figure 4-1 Conceptual Model for Channel Rehabilitation or Creation



Complementary Management Measures

Channel Rehabilitation or Creation is typically used in combination with other ecosystem-based or process-based measures. Any action that alters the tidal hydraulics of the channel will have an impact on the channel geometry. For instance, *Hydraulic Modification* involving the removal of a tide gate will likely increase the tidal prism, and the channel will respond by increasing its cross-sectional area. *Topography Restoration* can lower the general surface elevation and increase the tidal prism. *Berm or Dike Removal or Modification* may allow the channel to migrate rather than be held in position by a narrower breach, and facilitates conveyance during higher tides. Structural and protective measures such as *Revegetation, Physical Exclusion, Invasive Species Control* (of reed canarygrass [*Phalaris arundinacea*], for example) and *Public Education and Involvement* may also enhance the value or increase the benefits of restoration actions involving *Channel Rehabilitation or Creation. Contaminant Removal and Remediation* and/or *Property Acquisition and Conservation* may be prerequisites for this measure.

Benefits and Opportunities

Benefits of the Restoration Action

Improved connectivity: Creating a channel system that it sized appropriately for the marsh will improve the connectivity of the marsh with the marine environment. On intertidal river deltas, channel creation also facilitates re-establishment of distributary channel networks. This will allow the channels to serve as conduits for water, sediment, nutrients, detritus, and fish and other aquatic organisms. Marsh functioning will improve with greater connectivity. A complex drainage system well distributed across the site allows tidal access to all parts of the marsh.

Reconnected historic channels: On some subsided former salt marshes behind dikes, the original dendritic sinuous tidal channel system is still expressed in the topography, even if the channels have been mainly filled over time or interrupted by interior levees. Concentrating tidal flows into the old channels to scour out the loosely deposited sediments and rejuvenate the entire tidal drainage system can restore these channels. This can be done by suitable selection of breach locations, removal of obstructions, and blocking of borrow ditch channels.

Increased network complexity: With suitable grading prior to reintroduction of tidal action, a different channel system template can be created:

- Providing a larger tidal prism and removing channel blockages creates a more complex network. Channels will be easier to maintain.
- Removing constraints to channel movement allows channel migration.
- Creating a new channel network allows tidal processes to occur throughout the wetland.

If new channels are not excavated, existing channels that may have unnatural or otherwise undesirable planforms will likely capture the tidal flow. A high site, perhaps previously filled, may be too compact to allow channels to scour without excavation. Scientists agree that a dendritic, sinuous tidal channel system provides a more complex habitat and supports a wider range of wetland functions than linear channels. For example, a sinuous channel will sustain both steep overhanging vegetation and shallow areas that allow cordgrass colonization within the channel system.

Increased bank habitat*:* Many species of plants and animals rely on channel bank habitat. Increasing the sinuosity of channels provides more habitat with greater heterogeneity. A complex drainage system with a variety of channel orders provides a variety of channel sizes for different species.

Increased tidal prism: Upstream tidal restoration projects that increase the tidal prism can improve channels located downstream or seaward.

Improve sediment routing: A complex channel system allows water and sediment to move around the marsh, increasing the potential for sedimentation of the marsh surface. This assumes that there is a ready supply of sediment in the water column.

Drainage: Channels allow conveyance of full tidal action, which not only allows inundation, but also drainage. Both are important to pioneer establishment of native plants. In particular, adequate drainage prevents over-saturation of soil and limits wind wave action, both of which can impede plant establishment. Drainage can also be important from a flood management perspective; after high water events, channels facilitate drainage of upland areas thereby reducing the persistence of unnaturally persistent flood levels.

Generate fill for other features: Excavation of channels can also generate fill needed for other restoration or flood management features. Often, side casting the excavated material to form low mounds for intertidal or supratidal habitat can enhance site diversity, reduce wind-wave climate and provide a surface for rapid vegetation and habitat establishment.

Opportunities for Implementation

This management measure is typically implemented as part of large-scale restoration actions, typically encompassing tens to hundreds of acres. Because of the scale of these types of projects, several resource agencies and organizations are usually involved (similar to *Berm or Dike Removal or Modification*). Such projects provide opportunities for inter-jurisdictional and inter-agency partnerships.

The creation of channels can occur in any reclaimed historic wetland area that can be connected to existing tidal sources and fluvial channels outside the restoration area. Channels can only form where the ground surface elevation is above the predicted thalweg elevation of the channel. Sites that are high or have anthropogenic features that constrain channel development may need to be modified. In addition, *Substrate Modification* through disking may need to occur to break up consolidated surfaces.

Measurable Units

The area of recolonization of emergent wetland marsh vegetation is the most direct measure of habitat improvement following improvements in the channel network. This can be measured in terms of area of desired species and also area of undesired species. Changes in mixing and water quality due to improved channel connectivity can be measured both in terms of temperature and salinity measured at fixed locations on a seasonal basis. Other measures that show the evolution of the channel network include channel area, thalweg elevation, and network characteristics such as stream order and channel density. Improved salmonid production can also be measured to determine effectiveness (residence time, prey base, etc).

Constraints

Modified existing drainage: When tidal action is reintroduced to a subsided site, tidal flows tend to concentrate in existing ditches or depressions that then fix the location and shape of the tidal drainage system. Often the existing drainage system consists of straight field drains or ditches on the backside of levees. Tidal channels change very slowly. It is likely that once the existing drainage system captures the tidal flows, its pattern may persist for hundreds of years. Newly formed tidal channels might be poorly located or could erode adjacent infrastructure. As sedimentation occurs, mudflats build up and evolve into marshes in which the imprint of the drainage system can persist and dominate the nature of the tidal channel system in the new marsh.

Dependent on hydrology: Tidal channels can be reconnected or otherwise "restored," but at the same time this may not lead to restoration of the natural processes that led to their formation or continued existence. For instance, if the flow through the channel is controlled by a tide gate, the tidal range will remain muted and full tidal action will not be possible. If the channel flows through a breach or culvert that is undersized, flow velocities in the channel may be greater than that in the main stem of the channel, which could cause scour within the breach or a narrowing, reduction, or silting in of the main stem channel. Project designers must consider the complete hydraulic system when planning the restoration.

Local channel relationships: Many of the relationships used to scale channel and network properties are empirical. Project designers must be careful in applying them outside their observed range. Many of the relationships are influenced by local conditions and may not be applicable to other geographical locations. Proponents should conduct some level of risk evaluation associated with areas of uncertainty. Flooding, channel migration limits and erosion concerns associated with this measure would be of interest where applicable.

Erosion resistant earth and limited channels: Many sites that have been filled or farmed may have compacted earth that inhibits tidal formation. Some sites may not have sufficient existing channels to convey tidal and fluvial flows.

Constructability: Site access and disposal of excavated earth may increase the cost of channel excavation.

Climate change and sea level rise: Complications from increased precipitation, rising sea levels, and other climate changes could affect site suitability. The channel changes that might be expected with this measure are controlled by the tidal prism and are related to the elevation of the marsh. With gradual SLR, intertidal surfaces can keep pace with the increase in high water elevations and the tidal prism may stay relatively constant. Therefore, low rates of SLR may not produce large changes in channel form. With rapid SLR, the rate of vertical accretion may be insufficient to keep pace with high water elevations, and the mean depth and tidal prism of the marshes will increase. With increasing tidal prism the downstream channel cross-section will increase. There may also be changes in its planshape as discharges increase.

Best Professional Practices

As with other measures such as *Hydraulic Modification, Berm or Dike Removal or Modification, and Armor Removal or Modification,* the scope and level of effort needed for design and implementation will vary depending on the site location, up and downstream contexts, regulatory requirements, and risks associated with project failure. The scope and design factor of safety should be consistent with the anticipated outcome of the project and specific project, location, and restoration requirements.

Feasibility Assessment

Likely future evolution*:* Existing site topography should be analyzed to identify how the tidal channel system is likely to evolve without restoration. If the evolving channel system is likely to form in undesirable locations, the following measures can be taken to guide the location and layout of the tidal drainage system:

- Existing field ditches and drains can be filled and artificial obstructions to tidal flows removed.
- Pilot channels can be excavated in the desired location.
- The site can be graded or filled with dredged material to create low points where tidal flows will be concentrated.

- Berms can be used to define tidal watersheds and the location and size of evolving tidal channels.

Costs/benefits: The decision to excavate channels must consider the cost and benefits of excavating fill material low enough to allow appreciable natural scouring, versus the allowing the natural evolution of the tidal drainage system over time. Highly compacted sites may take hundreds of years for sea level rise and marsh accretion to create an appropriate tidal drainage system in the absence of channel excavation.

Channel migration: The channel restoration or creation design should allow for natural channel migration and consider any adverse effects of the ultimate channel meander zone.

Utilities and infrastructure: It is important to determine if access, utilities, or other infrastructure will need relocation away from the ultimate channel meander zone. Adjacent properties and infrastructure should be assessed for induced flood potential.

Contamination: Sediment contamination in the vicinity should be evaluated. Contaminant remediation can substantially increase costs of the project. Preliminary assessment of site history research and core samples can make the risk more predictable.

Design

Use historic channels: Where the remnant tidal channel remains intact, the site template can be graded to encourage tidal flows to reoccupy the original tidal system. This is done by choosing a suitable breach location, removing interior fill that might have divided the tidal system, and installing channel blocks in the interior borrow ditches. These interior borrow ditch blocks can be placed to completely isolate the borrow ditch, or placed between levee breaches at the anticipated location of the drainage divide between two slough systems.

Design of new channels: Use designs based on natural channels, e.g. Coats et al. (1995), Zeff (1999), Williams et al. (2002), Hood (2007). Excavated channel dimensions may be based on hydraulic geometry relationships derived from mature reference marshes (Williams et al. 2002). Note that these references provide guidance primarily for salt marshes in California. These methods must be adjusted for the greater tide range in the Puget Sound area, pending development of guidelines using local data. Numerical modeling of tidal inundation of wetland channels may be used to plan and design channel connectivity and calculate residence times for the desired ecological habitat. Channel density and sinuosity should be determined from nearby reference marshes. Changes in relative sea level and precipitation should be taken into account when designing new channel networks.

Channel excavation: Channel excavation on filled sites should be considered if typical fill elevations are higher than 1 foot below MHHW. Any erosion-resistant material, such as compacted sediments or concrete rubble, should be removed to 1 foot below the bottom of the channel. Channel excavation can add disproportionately to the costs for fill removal and disposal. Cost savings can be achieved by specifying depth and bottom width of channels and allowing channel banks to stabilize as they are cut by erosion, rather than requiring a design side slope. Slumping of the banks of cut channels is difficult to predict or control. It is particularly difficult to excavate small first- and second-order channels within a reasonable tolerance using standard construction equipment.

Marsh slope: The slope and topography may control future deposition and erosion patterns, sediment transport, and retention of water. Adjacent marshes should be gently sloped to the channel edge to encourage drainage and ensure channels do not evolve in undesired locations. Subtle berms or mounds along channel edges may be appropriate as these are observed in natural marshes and fluvial channels. The effects of topography and slope on processes and functions should be considered in developing a grading and revegetation plan.

Implementation

Grading: Wherever possible excavation should be done in dry conditions before reintroduction of tidal action. If the fill or underlying material is weak, the limited bearing capacity makes using heavy equipment difficult and may require placement of temporary load-bearing pads or mattresses for construction equipment to work from. New or modified channels or slopes may erode or fail if not constructed in accordance with soil engineering principles and best management practices that ensure stability under anticipated site conditions. In some cases, it may be acceptable to anticipate channel evolution, including channel bank erosion and even failure, as long as the site is on the desired evolutionary trajectory toward the targeted habitat. Sinuous or curved channels may seem difficult to survey and stake out for construction crews, but experience in San Francisco Bay has shown that sinuous channels are easily constructed if grade tolerances are practical.

Channel maintenance: Channel maintenance can be a concern if the natural sediment regime does not work with the new design. Bank maintenance can be an issue if there is any concern regarding channel migration and loss of property or infrastructure.

Evaluation

Compliance monitoring: The removal, modification or construction of channels should be checked by surveys during the construction period to ensure they conform to the final plans.

Monitoring of site evolution: Channels evolve over a period of time as they achieve equilibrium with the tidal prism. Repeated measurement of specified cross-sections within and downstream of the restoration site allows this evolution to be monitored. A long profile of the channel is also very useful to understanding the behavior of the channel.

Adaptive management: Measurement of the channel cross-sections can indicate obstructions, such as resistant sills, that may hinder downcutting and slow the evolution of then site. Monitoring can also provide valuable information for the design of future channel networks.

Case Studies and Examples

Deepwater Slough, Skagit River Delta: The Deepwater Slough restoration project, located in the South Fork Skagit River delta, is an example of a historic channel system being reconnected. The history and design of the project are described under *Berm or Dike Removal or Modification* along with the evolution of channels crossing the dike. Hood (2004) also describes the evolution of the channel planform geometry within the site. The opening of Deepwater Slough to both tidal and riverine flows resulted in significant widening of the channels as the tidal prism increased. New channels have also been observed forming within the restored marshes.

The restoration has also had significant impacts on channels outside the project area. By connecting the existing channel network, the external, downstream channels have generally deepened and widened to accommodate greatly increased tidal flows. Hood (2004) quotes an example of a downstream channel widening and deepening by 4 to 5 feet in two years. Channel width also increased very quickly in Deepwater Slough upstream of the restoration site. This channel widening begs the question of where the eroded material will be deposited. Hood (2004) suggests two possibilities: deposition in the mouth of the slough, contributing to marsh progradation in this area; or diversion of sediment into adjacent channels which are losing flow to the widening Deepwater Slough. Both possibilities reinforce the need to consider the long-term evolution of the estuary beyond the immediate project area.

Milltown Island, Skagit River Delta: The Milltown Island restoration project is a 310-acre habitat restoration located on the South Fork of the Skagit River (Skagit River System Cooperative 2006) (Figure 4-2). Construction of a series of dikes, beginning in the late 1800s disconnected Milltown Island from the Skagit River and Skagit Bay.

Previous restoration efforts on Milltown Island used several dike breaches; these are in addition to breaches caused by accidental dike failures during flood events. However, significant channels did not develop following these breaches, unlike the experience at Deepwater Slough described above.

The Milltown Island restoration project sought to restore natural hydrologic and biologic functions by removing hydrologic controls due to the dikes, encouraging channel restoration by extending the existing network of drainage ditches and promoting natural vegetative communities through plantings and *Invasive Species Control*. Unlike Deepwater Slough and Wiley Slough, Milltown Island had poor access for heavy equipment to the island. Rather than excavating the dikes and channels, the project team decided to use explosives. Work on the project site began in summer 2006. A total of 1,100 feet of dike were removed and 3,500 feet of channel created by winter 2007.

Tidal water is now able to reach the interior of Milltown Island. The created channels allow a greater volume of water to enter the interior of the island, increasing the tidal prism and energy potential for additional channel development. Erosion due to the increased tidal prism and river flow will aid in additional channel creation and improved quantity and quality of fish habitat.

In addition to creating new channels, existing channels were modified. Small breaches created previously had small blind channels that were only 30 to 40 feet long and received water only at high tides and high river flows. These existing channels were deepened and widened to improve flow through the existing dike breaches and initiate channel formation over a larger area.

While the method of creating the channels is novel, this project also illustrates that channel cross-sections do not have to be fully prepared (Figure 4-3). Channels tend to widen more quickly than deepen. Therefore, excavating or disrupting the sediment to a depth close to that of the equilibrium cross-section will often be sufficient.

Channel development was somewhat impeded by the presence of monolithic blocks of invasive reed canarygrass root mats. On other sites, agricultural practices have caused similar consolidation of soil blocks and also compressed and compacted soils. To facilitate *Revegetation* of restored marshes, disking of the soil is sometimes necessary to make the new marsh surface more susceptible to erosion of a new tidal channel network.

Swinomish Channel Fill Removal and Marsh Restoration, Swinomish Tribal Reservation: Another example of channel modification is the Swinomish Channel fill removal and marsh restoration project. This project aims to restore historic tide marsh habitats at six sites along the Swinomish Channel on Swinomish Indian Tribal Community property. A total of 10 acres of marsh habitat will be restored. As part of the project, one tidal channel will be excavated at each restoration site to create a total of 0.5 mile of channel. Channel design is based upon the channel geometry relationships developed with data from Skagit delta tidal marshes (Hood 2007).

The process used in the Swinomish restoration sites is to cut channels in the required plan form and to the equilibrium depth. The side slopes will then develop in time as the channel widens. This is a similar philosophy to that used at Milltown Island but using a different construction technique.

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Figure 4-2 Restoration features, Milltown Island.

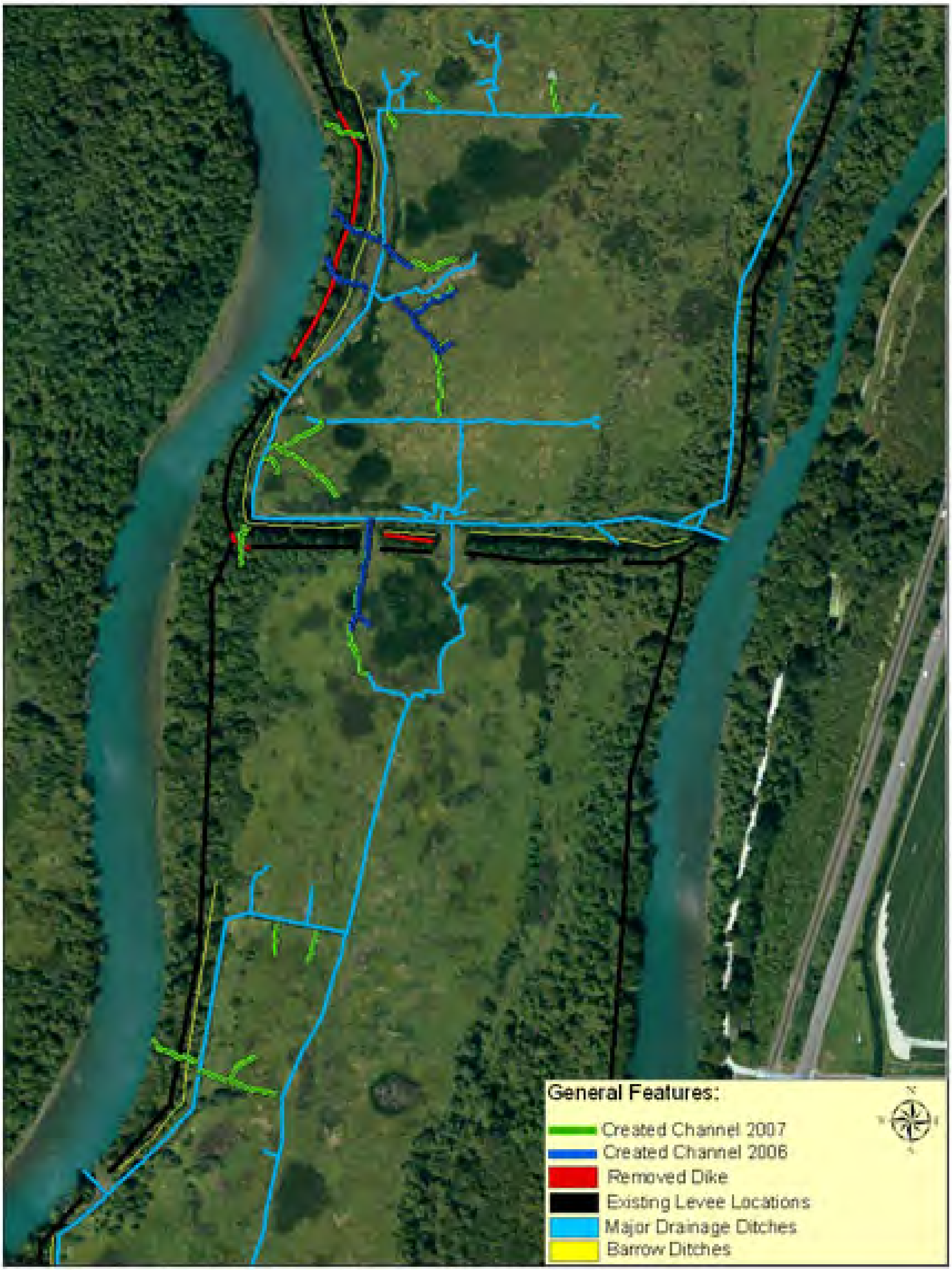


Figure 4-3 Milltown Island tidal channel created with explosives.

MM 5 CONTAMINANT REMOVAL AND REMEDIATION

Definition

C*ontaminant Removal and Remediation* is the removal and remediation of unnatural or natural substances (e.g., heavy metals, organic compounds, etc.) that are harmful to the resilience or integrity of the Puget Sound nearshore. This management measure is intended to cover remediation and/or physical removal of chemical contamination (e.g., through chemical remediation or biological treatment) occurring in substrates (sediments), surface and ground water, plants, and biota. The *Contaminant Removal and Remediation* measure is different from *Pollution Control* in that it addresses cleanup where contaminants have already entered the nearshore, as opposed to source control. As described in this chapter, *Contaminant Removal and Remediation* may occur through physical actions such as dredging, capping, or use of a remediation system, and is thus primarily focused on contaminated sediment. Natural attenuation of contaminants is also included in this measure. A biogeochemical process could also be used that converts a contaminant into a form that is not harmful or allows for easier removal. Although it does not directly alter physical nearshore processes, this measure may be needed to perform another management measure (e.g., *Berm or Dike Removal or Modification, Groin Removal or Modification*).

Justification of Need and Link to Nearshore Processes

Degradation of water and sediment quality from contaminant sources poses a significant risk to Puget Sound nearshore ecosystems (Ruckelshaus and McClure 2007). Contaminants enter nearshore environments from a variety of sources including commercial and industrial uses along waterfronts or in upstream areas, stormwater, and treated wastewater. Runoff from urban areas is known to contain numerous potentially harmful contaminants including endocrine disrupting chemicals (EDCs). These chemicals interfere with the endocrine system by mimicking, blocking, or altering hormones and their signaling systems. Other contaminants, such as arsenic, may be naturally occurring in soils and geologic formations, while others may be the result of land-based processes and chemical transformations (for example, the production of polycyclic aromatic hydrocarbons [PAHs] during forest fires). While some contaminants may be naturally occurring, their levels are often significantly concentrated when they are the product of a commercial or industrial process (PSAT 2003a). Many contaminants have an affinity for the organic or inorganic components of sediment; therefore, sediments often contain concentrated levels of contamination (PSAT 2003a).

Past research has typically studied the role of single contaminants and their impacts on aquatic ecosystems. The cumulative effects of multiple contaminants and the associated environmental stresses created from them are not well understood (Gelfenbaum et al. 2006). In general, contaminants are known to pose environmental health risks and act as ecosystem stressors, affecting biological processes in the nearshore environment. Contaminant removal and remediation reduces chemical stressors present in the ecosystem; however, it may also affect some physical processes.

Biological processes affected by contaminants include ecological and habitat interactions, organism and community metabolism, primary production, food web transformations, biodegradation, and geochemical transformation (via biochemical processes). Concentrated levels of contaminants have been shown to impair benthic invertebrate communities and increase the occurrence of disease in lower trophic organisms (PSAT 2003a). This impacts the food web by reducing the amount of organic matter produced and consumed and by reducing populations of lower trophic organisms. Furthermore, higher trophic organisms are exposed to contaminants through the process of bioaccumulation (PSAT 2003a). Plants and aquatic organisms absorb contaminants into their tissues and/or shells, later releasing them when the plant or organism dies (PSAT 2003a).

Healthy microbial communities found in sediments act to naturally break down and degrade certain contaminants (e.g., tributylin, polychlorinated biphenyls, PAHs). As nearshore ecosystems and food webs become more impaired and stressed, microbial breakdown is also affected (PSAT 2003a). Contaminant removal and remediation has the potential to restore healthy food webs and habitats for lower and higher trophic organisms.

Contaminants affect physical processes as well. Certain contaminants (such as cadmium) may flocculate or combine with particulates, organic matter, and metals present within the water column and sediments (PSAT 2003a). Contaminant removal and remediation can allow non-toxic particulates to undergo their normal geochemical transformations, forming naturally occurring particulates found in healthy environments.

Removal of contaminants can affect the physical processes of sediment supply and transport and freshwater inflow. Capping or removing sediments by dredging can remove sediment supplies needed by estuaries. Local groundwater movement may be slowed or intercepted by remediation systems used to remove contaminants.

Conceptual Model

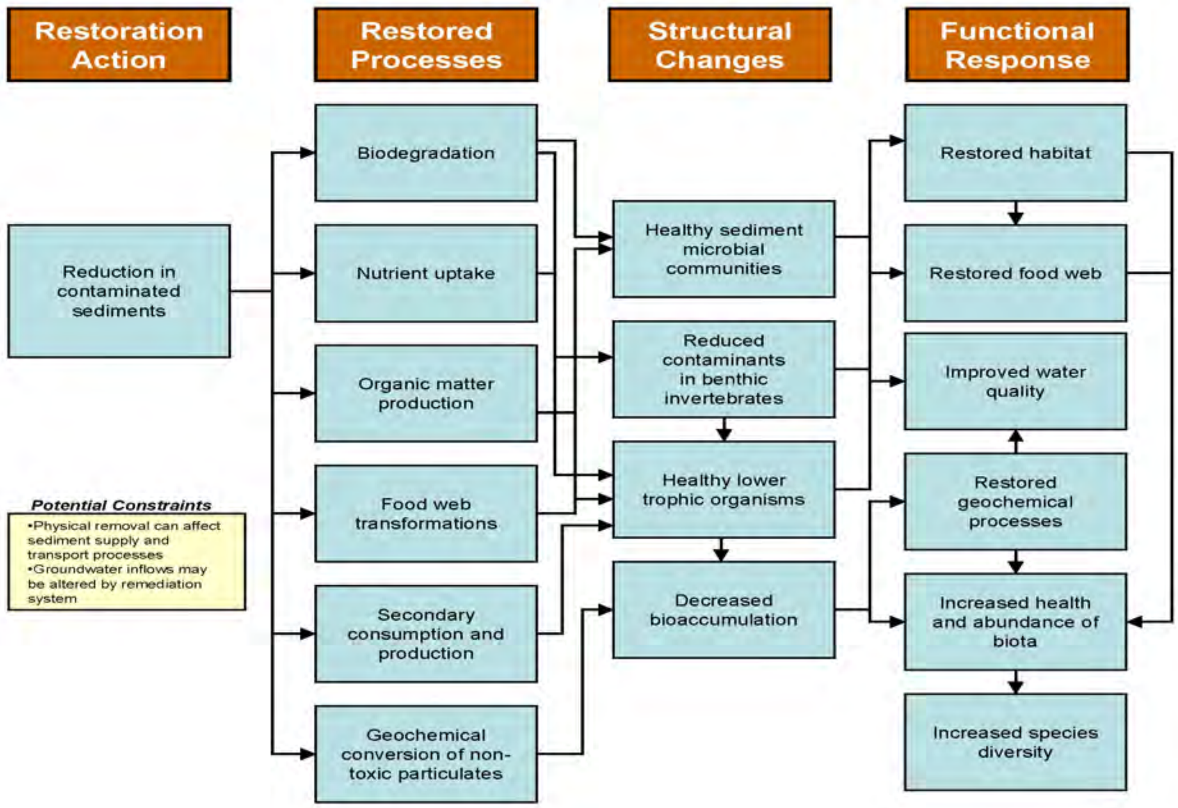
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 5-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Remediation feasibility investigation identifies an area of contaminated sediment in the nearshore environment that may affect nearby recreational beaches and shellfish beds.

Change/Action: Contaminated sediments are capped.

Predicted Response: Removal of toxic contaminants in the nearshore allows restoration of biota, habitat, and water quality. Results in enhanced forage fish spawning and survival rates of aquatic organisms and resumption of shellfish harvesting.

Figure 5-1 Conceptual Model for Contaminant Removal and Remediation



Complementary Management Measures

Contaminant Removal and Remediation is closely linked to the *Debris Removal* and *Pollution Control* management measures. Debris such as creosote pilings, old tires, and styrofoam containers is often a source of contamination; removal of such items can reduce and prevent further contamination. Controlling source inputs also prevents further contamination or recontamination of nearshore environments. *Contaminant Removal and Remediation* may occur prior to process-based management measures in preparation for restoring nearshore processes and functions.

Benefits and Opportunities

Benefits of the Restoration Action

Contaminant removal and remediation provides a variety of human health and ecological benefits, described below.

Restored habitats, food web, and valued ecosystem components: Contaminant removal promotes and restores primary production, organism transport and movement, healthy aquatic habitats and spawning grounds, and improved water quality.

Increased survival rates of nearshore biota: The removal of contaminated sediments reduces pollutants and toxic accumulation in forage fish spawning areas.

Pollution reduction: The marine shoreline in Puget Sound is contaminated with a variety of pollutants from many sources. Commercial and industrial operations, recreational uses (boats, recreational watercraft, and marinas), treated wastewater, and stormwater all contribute contaminants. While regulations currently exist to stem point and non-point sources though control measures, contaminant removal and remediation provides a direct means of reducing pollution in the nearshore environment.

Measureable Units

The following items are potentially measurable units for contaminant removal and remediation projects:

- Amount of contaminant removed (pounds or tons)
- Amount of sediment removed (tons)
- Levels of accumulated contaminants (parts per billion)
- Value of aquatic lands for economic resources such as geoduck (harvest per acre)

Opportunities for Implementation

This management measure is typically applied at the site or basin scale in embayments near commercial and/or industrial uses, which data suggest are the most contaminated (PSAT 2003a). A basin-wide sediment quality study conducted by Puget Sound Assessment and Monitoring Program (PSAMP) and NOAA, which randomly sampled 300 locations throughout Puget Sound from 1997 to 1999, revealed that the highest concentrations of heavy metals were usually found in Bellingham Bay, Everett Harbor, Sinclair Inlet, Elliott Bay, and Commencement Bay (PSAMP-NOAA, 2002 in PSAT 2003a). Site remediation is most often driven by regulatory requirements (as a result of known spills or releases of contaminants) or by land use changes (e.g., converting from commercial or industrial to recreational uses). A remediation feasibility investigation is often necessary to determine the opportunity for site remediation.

In instances where contaminant removal and remediation is driven by regulatory requirements, state and federal resource agencies likely to be involved are the U.S. Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology), and local jurisdictions (such as county health departments). Other entities involved may be commercial and industrial operators, non-profit environmental organizations, universities, and tribal governments.

Remediation engineers and scientist have, over the past 10 years, recognized that natural attenuation can be a very cost-effective approach for environmental cleanup. A critical aspect is that migration is limited and that current impacts of the contaminants are manageable. A case for natural attenuation is increased if active remediation has negative side effects, such as suspension of contaminants during dredging. Rigorous calculations or modeling are generally key components in demonstrating the feasibility of a natural attenuation strategy.

Constraints

Several factors may inhibit the use or effectiveness of contaminant removal and remediation as a management measure. Constraints will vary based on the type of site and the type and level of contamination.

Cost: The cost of remediation varies depending on the type of contaminant that is being removed, the desired level of contaminant reduction, and the type of remediation that is being performed. The technology needed for remediation is often very expensive. For example, remediation systems may require materials and resources to be built, energy sources for operation, workers to operate and maintain the system, monitoring to ensure that the system is achieving cleanup goals, and disposal of collected contaminants. Remediation may not be cost-effective for sites where a significant reduction in contamination cannot be achieved.

Habitat destruction: Remediation can potentially remove or cover sediments (through dredging or capping) that serve as habitat for invertebrates, salmonids, and other nearshore aquatic organisms.

Recontamination (long term effectiveness): Recontamination of nearshore environments can occur in a variety of ways. If contamination sources are not controlled, contaminants from nearby sources and land uses can be carried back to the nearshore. Sediment removal (either by dredging or by natural processes) can disturb contamination that was buried. Contaminated organisms that remain after removal or remediation have the potential to release contaminants (e.g., lead and cadmium) back into the environment once those organisms have died (PSAT 2003a). Contaminants that have been removed or displaced can also move back to sediment via groundwater movement. Long term weathering, biological processes, or chemical reactions could compromise isolation/stabilization treatments.

New sources of contamination: Current remediation systems do not address emerging contaminants (e.g., pharmaceuticals and personal care products) that may be present in sediments. Research is ongoing regarding the effects of EDCs and polybrominated diphenyl ethers in the marine environment.

Disposal issues: The end result of contaminant removal/remediation is either a concentrated collection of contaminants or a bulk quantity of contaminated sediments that must be disposed of according to applicable local, state, and federal laws. Special permitting, handling, and reporting may be required for the disposal of some contaminants.

Legal complications: Potentially responsible parties may be afraid to take action or report contamination and may resort to legal action to delay cleanup efforts.

Regulatory hurtles. Most regulatory agencies want cleanup. However, there can be obstacles to using innovative technologies that regulatory agencies are not familiar with. The regulatory process for cleanup can also be cumbersome and time consuming in many cases.

Adverse effects from remediation agents: Remediation agents such as nutrients are often added to stimulate the degradation of organic contaminants (such as PAHs). These nutrients could act as contaminants, creating algal blooms, for example.

Knowledge gaps associated with this management measure include:

Contaminant loading: Overall contaminant loads and background concentrations are not well quantified. The importance of local contamination sources compared to international contamination sources is poorly understood with respect to bioaccumulation in higher trophic organisms which may migrate over long distances.

Cumulative impacts: The cumulative impacts of multiple contaminants and their effect on ecosystem functions are poorly understood. Remediation efforts typically focus on physical processes to a greater extent than biological processes.

Best Professional Practices

Because this management measure involves the remediation and removal of substances that are often considered hazardous wastes, implementation of a remediation program involves following federal, state, and possibly tribal regulations. Sediment quality criteria began to be formulated and studied during the mid-1980s, with the inception of the EPA's Sediment Criteria Technical Advisory Committee. Since then, a variety of agencies (EPA, USACE, NOAA, Ecology, etc.) have published technical manuals and guidelines, which establish sediment cleanup standards in marine environments.

Ecology outlines its sediment management standards in WAC 173-204. This regulation establishes sediment quality standards (such as a maximum allowed level) for chemicals known to contaminate sediments and describes management measures required for sediment cleanup. Other federal regulations and programs may apply (e.g., CERCLA, Model Toxics Control Act [MTCA]), depending on site conditions, history, and regulatory setting.

Feasibility Assessment

A remediation feasibility/hazard assessment is generally required by federal and state regulations to identify the types, concentrations, and extent of contamination on a site. Areas exceeding sediment quality standards are defined through monitoring and sampling, characterized, and then ranked according to the hazards they present. Sensitive areas within or adjacent to the assessment area are identified and studied to determine contaminant impacts and evaluate appropriate remediation measures for the site. The assessment phase also involves coordinating with jurisdictions that have authority over the area being studied and assessing their cleanup standards.

Design and Implementation

Remediation system/cleanup program design and implementation are specific to each site and/or basin, as environmental conditions and regulatory requirements vary. Several design elements are required by WAC 173-204 (Sediment Management Standards); these may include but are not limited to:

- Cost for remediation and disposal of contaminants/contaminated sediments
- Contamination sources
- Sediment sources
- Size of the site
- Human health/ecological risk presented by contaminants and by remediation actions
- Cleanup standards required by jurisdictions with regulatory authority
- Surface and subsurface topography
- Surface and subsurface structures
- Utility lines and navigation lanes
- Geology and groundwater study (including structure, process, function analysis)
- Natural resources and sensitive areas study (including structure, process, function analysis)
- Adjacent land uses
- Monitoring program

To date, ecosystem-based sediment assessments have only been developed for freshwater ecosystems. The expected outcome for nearshore environments using an ecosystem-based approach would be restoration of ecosystem components (including processes, structures, and functions).

Best management practices to minimize short-term environmental impacts during contaminant removal and remediation include:

- Silt curtains and oil booms to prevent movement of contaminated sediments in the remediation area.

- Remediation technologies which require physical removal of sediments should avoid and limit resuspension of contaminated sediments in the water (e.g., clamshell dredges, hydraulic dredges, in situ treatment, biological treatment).
- In-situ treatments (biological and chemical) non-toxic to aquatic organisms.

Evaluation

Project managers can monitor sediment, water quality, and aquatic organisms to evaluate contaminant removal and remediation measures and reassess the need for further cleanup. Monitoring methods will vary depending on the contaminant(s) of concern, type of remediation pursued, and regulatory requirements. Biological treatments require frequent sampling of the sediment or soil to make sure that the process is working. With stabilization approaches monitoring of contact water is required to insure the treatment works. Technically, periodic sampling should be conducted indefinitely. If the contaminants are physically removed, monitoring is needed to make sure that the removal was complete and that other contaminants are not present. Once those parameters are verified, no further monitoring is needed. Several documents have been published regarding sampling techniques for environmental monitoring (see references at the end of this chapter).

Data gaps currently exist with respect to the cumulative effects of multiple contaminants in nearshore environments and the effects of emerging contaminants such as pharmaceuticals and personal care products. Additional studies of these topics could provide more insight into developing ecosystem-based remediation strategies.

Case Studies and Examples

Bellingham Bay Pilot Project, Bellingham. Created in 1996 through the partnership of federal, state, tribal, and local stakeholders, the Bellingham Bay Pilot Project is a multi-million-dollar cleanup effort of several sites along Bellingham Bay that have been identified as contaminated. Sites are typically associated with commercial or industrial uses. The Pilot Project is integrating several management measures, including contaminated sediment removal, debris removal, pollution control, and habitat enhancement. Ecology is the lead regulatory agency for the project.

Lower Duwamish Waterway, Seattle. The Lower Duwamish Waterway is a 5.5-mile-long segment of the Duwamish River near its confluence with Elliott Bay. In 2001, the Lower Duwamish was added to the EPA Superfund National Priorities List; in 2002, the waterway was added to the Washington Hazardous Sites List. Sediment removal and source control of contaminants have been identified as strategies for cleaning up the waterway. Seven sites have been designated as high-priority areas for sediment cleanup. Phase I of the cleanup, which includes completing remediation investigations and hazard assessments, is underway. Phase II, involving the removal of contaminated sediments, is currently being planned.

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MM 6 DEBRIS REMOVAL

Definition

Debris Removal is the removal of solid waste, debris, and derelict or otherwise abandoned items in the nearshore. Common examples include removal of derelict commercial and recreational fishing gear, creosote piles, wood waste, and sunken refuse (vessels, cars, tires). This measure includes physical debris removal but does not include removal of chemical contaminants, although contamination can be associated with the debris, such as creosote from treated pilings. *Contaminant Removal and Remediation* is a separate measure that may be needed to prevent the accumulation of unwanted materials in intertidal or subtidal areas. *Debris Removal* is considered a restoration measure in that it removes foreign items from natural environments. This chapter does not address polices and regulations aimed at reducing the amount of debris in the environment.

Justification of Need and Link to Nearshore Processes

The physical removal of debris from the nearshore reduces the amount of harmful structures and known contaminants in nearshore ecosystems and sensitive habitats. Ecological impacts caused by the presence of debris vary depending on the type of debris. Physical items can smother marine habitats and negatively affect marine species, while toxic pollutants can affect water and sediment quality in nearshore environments. Paradoxically, debris can also become part of the environment and is sometimes used as habitat providing refuge for some marine organisms. The removal of derelict fishing gear and sunken refuse is a relatively new practice compared to the cleanup and removal of contaminated sediments associated with industrial sites, which has a long history.

Derelict fishing gear, consisting of lost and abandoned fishing nets, lines and pots, is present in fishing grounds and can drift into adjacent nearshore areas. A variety of netting, ropes, polyvinyl chloride (PVC) pipes, polypropylene lines, buoys, and other materials used in marine aquaculture facilities can also become derelict gear as a result of storms, mechanical problems, or human error/neglect. Derelict nets can accumulate in most geomorphic landforms, including rocky coasts and embayments. Some of this gear has accumulated over decades.

The most common types of derelict fishing gear found in Puget Sound are gillnets and crab pots (Broadhurst 2007). Gillnets and abandoned crab pots capture and indiscriminately kill many marine species, including salmon, marine birds, mammals, and invertebrates. The introduction of synthetic nets has significantly increased the impact of derelict gear because the nets take decades to degrade. Carcasses that are trapped in the nets continue to attract predators and cause entanglement for many years.

Derelict fishing gear can negatively affect commercial harvest of marine species. An estimated 200,000 pounds of Dungeness crab are killed in derelict crab pots every year in Puget Sound, an amount worth approximately $335,000 (June 2007). This form of bycatch not only reduces the standing stock of fish and shellfish available to a fishery but also can reduce reproductive capacity and thereby compromise the long-term viability of the stocks.

Shoreline processes affected by derelict gear are sediment transport and the exchange of aquatic organisms as the abandoned nets can trap and accumulate sediment and in some cases impede migratory corridors. Removing derelict gear can restore local sediment dynamics, functioning intertidal and subtidal habitat, and result in increased survival rates of aquatic organisms.

Sunken refuse such as pilings from abandoned docks and piers, vessels, cars, and other debris can contaminate nearshore waters and sediments. Site contamination associated with historic timber processing sites once common in Puget Sound includes petroleum products, beach and intertidal debris, creosote pilings, and wood waste from past manufacturing practices. Creosote-treated wood leaches harmful chemicals, including numerous PAHs, which are known to be toxic and a pollutant of concern for Puget Sound water quality improvement efforts (PSAT 2007). Creosoted pilings and remnants work their way out of sediments and wash up on beaches as “rogue logs”. Rogue logs, whether freshly washed up or buried in the intertidal for decades, continually leach PAHs. Edible fish and seafood captured from creosote-contaminated areas or held in creosoted cages have been found to contain increased concentrations of PAHs and PAH metabolites (Melber et al. 2004). Creosote compounds can also bind to the sea surface microlayer where eggs and larvae float and juvenile salmon forage. Studies have shown that herring eggs exposed to creosote have a high mortality rate, and exposed English sole develop liver lesions (PSAT 2007). Removal of rogue logs in intertidal areas can restore habitat quality and biota important to the nearshore food web.

In 2002, the Northwest Straits Commission (NWSC) established a comprehensive survey and removal program for derelict fishing gear in Puget Sound. The WDFW now manages a database to track and record all known derelict gear and prioritize removal efforts. In 2002, with support from Governor Chris Gregoire and the Puget Sound Initiative, the WDNR developed a restoration program for creosote-treated wood debris removal. Thousands of tons of derelict creosote-treated logs and pilings are being removed from beaches and waters throughout the Sound. As a WDNR partner, the NWSC removed nearly 600 tons of creosote logs and pilings from aquatic lands between 2004 and 2006. MRCs throughout Puget Sound maintain programs for both derelict fishing gear and creosote-treated piling removal with support from the NWSC.

Conceptual Model

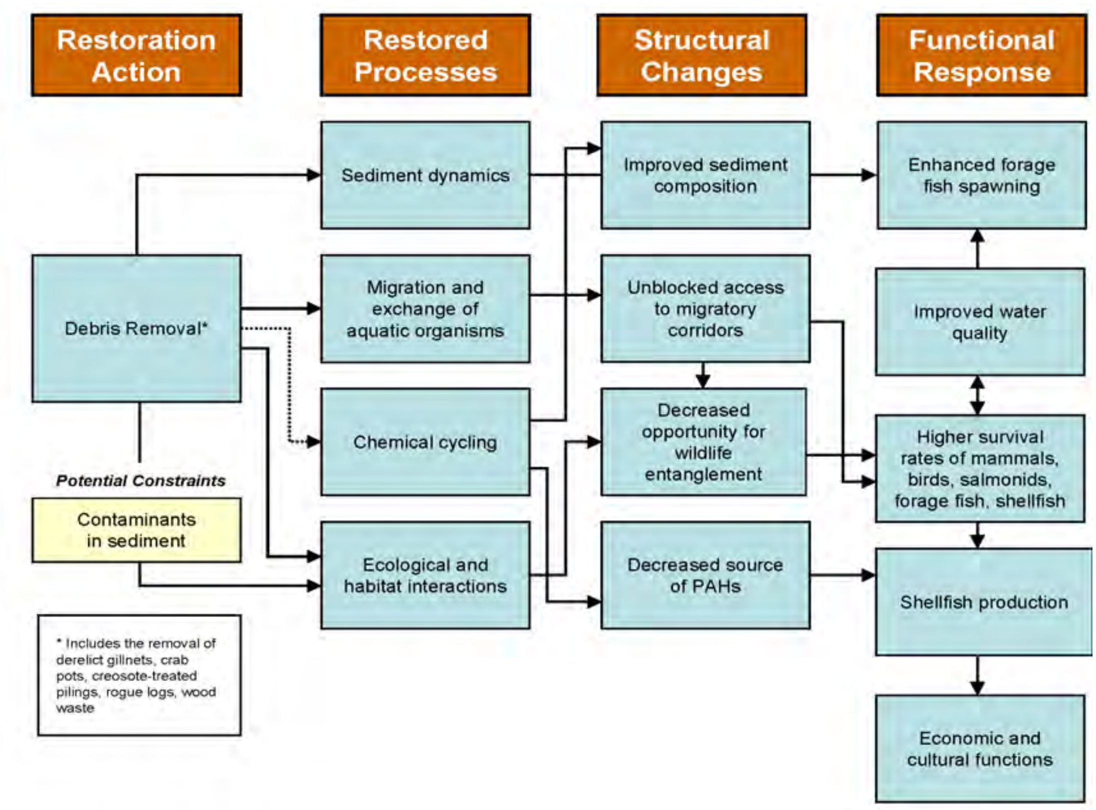
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 6-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario – Survey discovers concentrated area of lost and abandoned crab pots, gillnets, or sunken creosote-treated pilings or wood waste.

Change/Action – Removal of the sunken debris and rogue logs in intertidal and subtidal areas.

Predicted Response – Removal of foreign structures and potentially associated toxic contamination in nearshore allows restoration of nearshore biota, water quality, and sediment dynamics that provide habitat structure. Results in enhanced forage fish spawning and survival rates of aquatic organisms.

Figure 6-1 Conceptual Model for Debris Removal



Complementary Management Measures

The removal of contaminants harmful to the nearshore is accomplished through removal or source control, as described in *Contaminant Removal and Remediation* and *Pollution Control* measures, respectively. Physical removal, as described by this chapter, can be used as a stand alone measure, as in the ongoing derelict fishing gear and creosote-treated piling removal programs managed by WDFW and WDNR. It can also be used in conjunction with process-based measures such as *Armor Removal or Modification* and *Overwater Structure Removal or Modification*. Where armoring or overwater structures have been demolished, creosote logs often need to be removed.

Benefits and Opportunities

Benefits of the Restoration Action

The physical removal of discrete items from the nearshore has a variety of benefits to ecosystem services that highlight the simple, yet highly effective nature, of this management measure.

Restored habitats and food web: The removal of foreign items can restore local sediment dynamics, organism transport and movement, and water quality.

Increased survival rates of nearshore biota: The removal of derelict fishing gear and abandoned crab pots can reduce the risk of accidental entanglement. The decrease in PAHs and other pollutants (via the removal of creosote-treated materials) can reduce accumulation of toxics in forage fish spawning areas.

Inherent feasibility: Creosote-laden wood is easily identified and removal is clearly achievable. Similarly, wood waste deposits at historic and current mill sites are known and can be easily targeted for removal.

Immediate reduction in pollutants: The marine shoreline in Puget Sound is contaminated with PAHs from many sources. Boats, marinas, and stormwater all contribute PAHs, and regulations currently exist to stem those non-point sources through control measures. Creosote-treated wood is a significant source of PAHs that has not been addressed systematically, and its removal is generally straightforward and effective.

Low cost: Using the survey and identification programs already in place by WDFW and WDNR, projects involving the removal of creosote-treated wood or derelict fishing gear can be accomplished with some volunteer labor at low energy and capital costs.

Public education: The removal of recreational crab pots that have been abandoned highlights the linkage between humans and the marine environment.

Public engagement: The "low-tech" nature of many rogue log removal projects allows the use of untrained and/or volunteer labor, creating opportunities for local participation. This can lead to improved stewardship. Other established programs (e.g., Washington Coast Cleanup) involve large numbers of volunteers and result in broad education and awareness.

Economic benefits: Debris removal projects remove toxic pollutants from the nearshore, which can restore the value of aquatic lands for economic resources such as shellfish harvest.

Conversion potential: Hawaii's multi-partner marine debris group devised a unique program to recycle marine debris (fishing gear) into usable electricity through their "Nets to Energy" program.

Measurable Units

The following are potentially measurable units for debris removal projects:

- Amount of removed derelict fishing gear (tons)
- Amount of new derelict fishing gear or abandoned crab pots discovered by diver and sonar research through NWSC programs (tons)
- Value of aquatic lands for economic resources such as shellfish (harvest per acre)

Opportunities for Implementation

There is widespread support for the removal of derelict items in the marine environment. The *Puget Sound Acton Agenda* (PSP 2008) identified the removal of derelict fishing gear as a near-term action important to the restoration of ecosystem processes, structure, and functions. The exact amount of derelict gear in the Sound is not known, but the WDFW database currently contains over 4,000 targets that can be used to focus removal efforts. To provide the most effective use of money and resources for derelict gear removal efforts, implementers should target areas where marine species are at the most risk. For example, diving birds are particularly vulnerable to entanglement in derelict nets as they dive for food. In San Juan County, derelict gear removal efforts by the NWSC focused on rocky areas surrounding a national marine wildlife refuge complex set aside to protect colonies of nesting seabirds, including pigeon guillemots, double-crested cormorants, and pelagic cormorants (NWSC 2007).

The removal of creosote logs has also been identified as a high-priority cleanup measure and is currently being instigated Sound-wide in embayments, beaches, and rocky shores. The scale of creosote log removal projects ranges widely from less than 10 pilings associated with one abandoned pier or dock, up to several hundred pilings. Given the large number of beaches with creosote materials, removal efforts can be prioritized using two factors: (1) known forage fish spawning locations, and (2) areas with the highest accumulation of debris.

The NOAA Marine Debris Program was established in 2005. In 2006, the Marine Debris Research, Prevention, and Reduction Act was signed, which legally established the NOAA Program. This program has provided additional new funds for marine debris research projects on topics ranging from sources and composition of marine debris to impacts and approaches to mitigating those impacts through removal of debris or other approaches. Research, while focused on national concerns, is frequently conducted at a local level, such as in Puget Sound, Alaska, and Hawaii. The program supports two grant opportunities for marine debris activities. The first is in partnership with the National Fish and Wildlife Foundation and the second is in cooperation with the NOAA Restoration Center's Community-Based Restoration Program. The latter is a community-based marine debris prevention and removal project that will benefit coastal habitat, waterways, and NOAA trust resources including anadromous fish.

State government agencies (WDFW and WDNR) implement most debris removal projects. The NWSC is working with MRCs to develop strategies for removal. Many MRCs have established programs and incorporate volunteers. Some private entities may be required to conduct debris removal activities as mitigation for impacts or other contaminant removal regulations. Several historic mill sites are the location of wood waste and other derelict items that are being removed as part of regulated cleanup efforts. The Nature Conservancy has recently initiated creosote log removal projects on two of its preserves in Puget Sound. It is possible that other non-profit entities will become involved in other efforts to remove pollutants from beaches as part of ongoing stewardship activities.

Established volunteer-based beach cleanup efforts, such as the annual Washington Coast Cleanup, provide significant opportunities for debris removal. The Washington Clean Coast Alliance is comprised of nonprofits, community groups, and government agencies. It provides opportunities for one-day cleanup efforts along Washington’s beaches.

Debris that is removed from nearshore areas can sometimes be recycled. Large wood can sometimes be used in stabilization projects and small woody debris may be suitable for composting, erosion control, or used as a fuel source. Some metals are also recyclable. However, gear that has been in the marine environment for many years may have significant algal growth and be difficult to recycle.

Constraints

Several factors may influence the effectiveness of debris removal efforts, most of which relate to the disturbance caused during actual removal. Most constraints can be avoided through comprehensive survey and selection of target sites and the use of best management practices during construction.

Human risk: Removal operations for derelict fishing gear can involve risk to divers. Disease causing and infectious agents can pose a risk to removal crews. Many debris items are sharp and can cause cuts and puncture wounds if safety precautions are not observed.

Physical disturbance: Potential impact on other aquatic plants or species (e.g., eelgrass) during removal efforts for creosote logs or wood waste.

Chemical disturbance: Potential release of contaminated sediments during removal of creosote logs.

Loss of vertical habitat: Some pilings targeted for removal are used by perching and sometimes nesting birds.

Loss of recreational use: Some underwater vessels or creosote-treated structures targeted for removal are used as sites by recreational divers.
Disposal: Proper disposal of debris materials is very important and can be costly and logistically complicated.

Best Professional Practices

Feasibility Assessment

Implementers of this measure should consider the benefits and constraints noted above and evaluate the feasibility of safely removing and disposing of (or recycling) the debris. Project sponsors must assess whether the benefits of removing the debris outweigh the environmental impacts that will occur as a result of site disturbance. Part of this assessment includes identifying the species and habitats in the vicinity of the removal effort and determining the precautions that must be taken to prevent impacts. Work must be timed in accordance with state rules that are designed to minimize impacts to sensitive species and habitats. Habitats and species of special concern include: eelgrass and kelp beds; sand lance, surf smelt, rock sole, and herring spawning sites; lingcod and rockfish nurseries, and juvenile salmonid migration corridors. A second part of the assessment is assuring that removal crews are properly trained and equipped to employ the required methods and can conduct the work safely and in accordance with all environmental regulations. Derelict gear removal efforts should not be conducted in areas where commercial fishing is actively ongoing.

The feasibility of debris removal projects depends in part on our ability to accurately locate gear in intertidal and subtidal areas. Locating abandoned fishing gear typically requires the use of sidescan sonar surveys, remotely operated underwater cameras, and/or diver surveys. It is also important to have a mechanism that allows citizens to report lost gear or report encounters with derelict gear in the marine environment. Preliminary surveys allow the debris removal team to estimate the amount and type of debris in the area and to provide locations of derelict gear for recovery operations. Knowing the amount of gear that needs to be removed at any given site can be important when negotiating project-specific disposal costs.

The WDFW has published Derelict Fishing Gear Removal Guidelines (2002) for the environmentally acceptable removal and disposal of gear in Washington State. The guidelines contain best professional practices and should be consulted for all derelict gear removal projects. Under Washington Senate Bill 6313, derelict gear removal projects that are conducted according to these guidelines are not subject to permitting under RCW 77.55.100. WDFW recommends that sponsors of debris removal projects prepare a plan that addresses regulatory considerations, property owner notifications, site access, disposal and/or recovery of gear, restoration of the site following debris removal, and other matters. Projects on tribal lands may require tribal permission and may pose other feasibility challenges related to cultural resources and/or compliance with tribal regulations.

Design and Implementation

Design and implementation considerations will vary depending to the type of debris being removed and site conditions such as water depth, presence of contaminated sediments, and sensitivity of the adjacent habitats. Gear found on beaches can generally be removed by cutting the gear free from rocks or other anchor points or loosening buried items. These removal efforts often involve hand crews and do not require heavy equipment.

Derelict gear removal projects in deeper waters generally involve divers or require mechanical methods. Prior to removal operations, the project team should survey the area and report entangled animals, impacts of the gear on the habitat, and estimates of the size and nature of habitat impacts. Animals entangled or trapped by the gear should be removed if possible and left in place.

Net removal projects typically require the use of one or more vessels, three or more trained divers using surface-supplied air, bailout bottles, and a two-way voice communication system. Divers should cut buried nets loose rather than forcibly ripping the nets away, which causes more habitat damage. Once a net (or portion of a net) is freed and bundled, a strap and airlift bag can be attached and the net floated to the surface where it can be retrieved.

Removing derelict crab pots and traps typically requires only a single vessel. A diver assesses the condition of the pot and follows the state guidelines to decide whether to remove the pot or disable it in place. Pots that are more than half buried are typically disabled and left in place. If the pot is to be removed, it is floated it to the surface with a lift bag or removed using a hydraulic hauler.

Once the derelict gear is hauled to the surface, removal crews should identify and release any entrapped animals, inspect the gear inspected for personal identification tags, and record other information about the operation (condition of the gear, notes about gear left in place, etc.).

Gear retrieved during removal projects should be handled in accordance with the Washington State Abandoned Property Rights Law and applicable salvage laws. If tribal gear is recovered, appropriate provisions must be in place to ensure its return to tribal owners. Clean nets and other gear can sometimes be recycled at commercial fishing ports. Gear must not be dumped or disposed of in any facility that is not properly commissioned and licensed to handle it.

The WDNR has developed BMPs for removing creosote-treated pilings and rogue logs as part of the Puget Sound Initiative. The BMPs cover the removal methods, in-water work provisions, proper disposal, and protection of cultural resources. The WDNR has also developed a standardized permit process for creosote removal projects.

Creosote piles can be removed using several different methods. The preferred method for removing creosote piles is the vibratory hammer because it generates the least amount of turbidity; other methods are direct pull, clamshell bucket, and cutting. The choice of which method to use will depend on the structural integrity of the piles, the type of substrate, the presence of contaminated sediment, and other factors.

Pile removal equipment is typically deployed from a barge or pier. The work surface must have adequate containment to prevent piles and sediments from reentering the marine environment. Floating booms are also used to collect floating debris and prevent water quality degradation. Projects must also have a plan to deal with cultural resources in the event they are uncovered during removal efforts. Consult the WDNR BMPs for additional design and implementation considerations.

The removal of wood waste associated with old mill sites is a relatively new opportunity for restoration of the nearshore. The impacts and costs associated with wood waste removal and its subsequent benefits have not been extensively studied or reviewed. However, it is likely that this measure will increase as more wood waste deposits are discovered. The WDNR is reviewing its log storage leases on state-owned aquatic lands and developing protocols for cleaning up toxic materials on the leased sites (PSAT 2007).

Evaluation

Evaluation of debris removal projects typically involves monitoring the project area during and after construction to ensure that water quality standards are being met and disturbed habitats are fully repaired.

This can include evaluating species mortality in the vicinity of the debris removal and taking corrective actions if needed.

Case Studies and Examples

Bellingham Bay, Whatcom County: As part of the Bellingham Bay Pilot Project focused on cleaning up and restoring the bay in a comprehensive and cooperative way, the WDNR removed 819 pilings and a 16,329-square-foot overwater structure from the Squalicum Creek estuary. The pier was built for post-World War II shipbuilding and has a history of failure during recent winter storms. The Port of Bellingham subsequently removed barriers to fish passage within Squalicum Creek. Creosote pilings were also removed along the Fairhaven shoreline. The total cost of the piling and structure removal was $574,883.

Salmon Creek Estuary Restoration, Jefferson County: In 2008, the North Olympic Salmon Coalition and its partners removed gravel fill and wood waste to restore 11 acres of degraded estuary. Salmon Creek is located at the head of Discovery Bay near Port Townsend. The project began with a plan to remove lumber mill buildings and the fill material upon which they were built. The construction and operation of the mill included filling of mud flat and salt marshes in the estuary during the 1950s and 1960s. The primary intent of the project was to restore estuarine habitat for salmonids, especially out-migrating summer chum. During project planning, soil investigations led to a discovery that the 22,000 cubic yards of wood waste was leaching sulfur and ammonia. The toxic wood waste resulted in complications for project design and construction and the project took five years to get to implementation. Project construction removed a portion of a railroad grade to reconnect an area of partially isolated salt marsh. An additional five acres of salt marsh adjacent to the current lower Salmon Creek estuary were also created. Excavators were used to remove the fill down to marsh elevation, as well as for *Channel Rehabilitation or Creation* to create tidal channels after the gravel fill and wood waste were removed. During site construction, all the old material from five derelict lumber mill buildings, as well as trees removed from the site, were chipped and used to create the site access road. Wood waste was moved to a composting facility in Chimacum and fill materials were moved to an on-site spoils area as well as off site.

Kayak Point, Snohomish County: The WDNR removed 15.2 tons of creosote-treated materials from the beaches surrounding Kayak Point as part of a nearshore restoration project initiated by Snohomish County MRC. The total cost of the removal efforts was $4,910 ($327/ton).

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MM 7 GROIN REMOVAL AND MODIFICATION

Definition

This management measure pertains to the removal or modification of groins and similar nearshore structures built on bluff-backed beaches or barrier beaches in Puget Sound. This chapter primarily focuses on groins, which have some similarities to other nearshore structures such as jetties and breakwaters. Groins modify local wave conditions and littoral transport processes, changing the patterns of sediment accretion and erosion along the shoreline. These structures not only have a localized effect but can interfere with sediment movement within the entire littoral cell, capturing a portion of the transported sediment or moving it offshore, outside the influence of wave energy during the majority of the tidal cycle. Groin modification can involve notching or changing the orientation of the structure, altering length, or modifying attributes such as beach elevation. Groin removal allows for more complete restoration of littoral processes. Numerous engineering considerations and constraints must be evaluated when selecting the appropriate degree of modification or removal associated with this management measure.

Justification of Need and Link to Nearshore Processes

Groins are cross-shore structures that are designed to impact sediment processes by reducing alongshore littoral drift and dissipating wave energy. Groins are variable in size, composition, and construction, ranging from very small features on the beach to larger structures extending into the water. All such structures affect wave energy and current patterns and obstruct alongshore drift. These structures also impede the movement of many species both into estuaries and along the shore by changing current patterns, altering physiochemical conditions, and creating obstructions (Williams and Thom 2001). Many other nearshore structures, such as boat ramps and filled armored shores, can have groin-like effects that infringe on intertidal areas.

Groins directly impact conditions locally and can trap sediment on the updrift side of the structure. These structures can also indirectly limit sediment accretion in downdrift shores through loss of sediment supply. The scale of the impacts associated with these structures is generally a function of where the structure is placed along the beach profile (and whether sediment can bypass the tip of the structure) and the elevation of the structure (and whether sediment can pass over the structure). The impact of the groin is also dependent upon the sediment size; coarser material can be trapped by the groins while finer sediment may bypass the structure. This can lead to local coarsening of the substrate.

Impacts also depend upon location within different types of shoreforms. Close to river mouths, nearshore structures affect the mixing of saline and fresh water, causing widespread effects within the estuary on nutrient flux, suspended sediment concentrations, and physiochemical properties. On open shorelines, the impact on littoral transport is affected by location relative to sediment sources and drift cell length downdrift of the structures. Impacts can include changes to bottom habitats, beach stability, and sand dune volumes.

Many groins in Puget Sound are short and do not extend far into the littoral zone. They are often constructed of rock (often scavenged boulders from the beach); smaller groins may be made of wood or concrete. Many of the groins are old and were constructed before shoreline management regulations were put in place. Therefore, most of these structures were constructed without necessarily considering their impacts on the movement of sediment within the littoral cell and the maintenance of downdrift beaches. Shoreline regulations limit (but generally do not prohibit) construction of new groins, except where required for navigation channels or similar activities. The use of low groins and “sills” is often allowed in the context of beach nourishment projects.

Where existing small groins are filled or damaged and no longer trap sediment, longshore drift will pass around and over them. However, these groins continue to impact the rate of alongshore drift by modifying the local wave refraction pattern and directing some sediment offshore. This reduces the alongshore transport rate, and so downdrift erosion is an ongoing impact. Many of the larger groins and jetties are still filling. These larger structures also extend into deeper water, causing sediment to be lost offshore.

Because of their typically larger size, jetties and breakwaters can entirely block littoral transport, resulting in severe changes to net alongshore drift patterns. There are examples throughout the Puget Sound region where jetties and breakwaters, typically associated with marinas, have truncated or bifurcated littoral cells. In these cases the natural volume of sediment in the littoral cell could suffer considerable decline, resulting in erosion to downdrift shoreforms and changes or loss of nearshore habitats. In the case of marinas, these impacts are often exacerbated by the need to dredge, which can further alter sediment transport processes.

Williams and Thom (2001) identify a number of functions of estuarine and nearshore habitats that are affected by nearshore structures: fish migration routes may be altered; access to nurseries may be blocked; juvenile and adult food production may be altered; aquatic habitat may become fragmented; and the mixing, tidal prism, and physicochemical properties of estuaries may be altered.

In addition, the structures themselves, if constructed from rock, alter the substrate – replacing soft-bottom habitat with hard substrate in both shallow and deepwater areas. These structures attract a different assemblage of rocky shore organisms (including different prey assemblages); may attract and concentrate fish; and may also attract and concentrate predators and invasive species. Marine predators can effectively hide in the open spaces between riprap, and avian predators can perch on the unsubmerged portions of the structure.

Conceptual Model

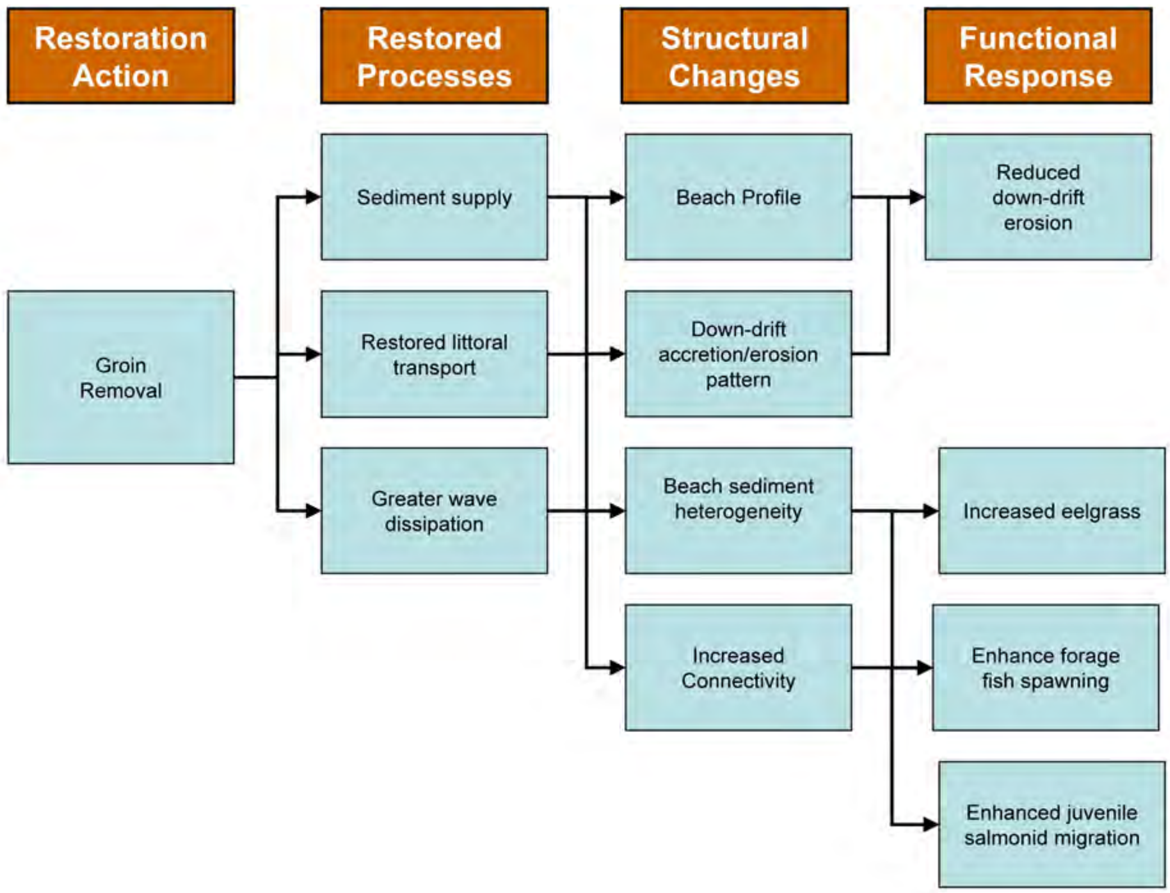
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 7-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Groins reduce downdrift beach condition required for beach profile maintenance; migration pathway of juvenile salmonids is pushed offshore, exposing juveniles to increased predation.

Change/Action: Removing groin restores alongshore sediment transport, wave energy regime, and bluff erosion, resulting in increased accretion.

Predicted Response: Natural beach materials are deposited in the intertidal zone. Increased opportunity for juvenile salmonid migration and forage fish spawning at appropriate tidal elevation and on requisite sediment structure. Increased connectivity of the littoral cell and reduction in downdrift impacts.

Figure 7-1 Conceptual Model for Groin Removal or Modification



Complementary Management Measures

Restoration projects that remove structures such as breakwaters, jetties, and groins may also employ measures such as *Beach Nourishment* and *Armor Removal or Modification*. Other management measures often associated with the removal or modification of nearshore structures include: *Contaminant Removal and Remediation, Debris Removal, Topography Restoration, Habitat Protection Policy and Regulation, Invasive Species Control, Large Wood Placement, Physical Exclusion, Pollution Control, Public Education, Revegetation, Substrate Modification,* and *Species Habitat Enhancement*. Once a groin is removed, most sites will require associated fill removal and restoration of the beach profile. Techniques for achieving functional nearshore elevation, slopes, substrate, and vegetation are specified in separate management measures.

Benefits and Opportunities

Benefits of the Restoration Action

Improved connectivity: Removing nearshore structures can improve alongshore and cross-shore connectivity. In the absence of large cross-shore structures, the shallow water migration corridor for juvenile salmonids is restored, allowing for a continuous nearshore migration pattern that facilitates growth and survival. Removal of structures also allows wave-induced erosion of bluffs which provide a source of sediment whilst reducing downdrift erosion.

Improved habitat for special-status species: The nearshore environment and functional beach and backshore habitat support many species of plants and animals such as salmon, forage fish, clams, and eelgrass that are afforded special protection status through local, state and/or federal law. The removal or modification of nearshore structures restores or improves the nearshore processes that support habitat function for these species and the food sources they rely upon.

Increased availability of habitat: Landforms restored by *Groin Removal or Modification* are generally beaches, including drift zones, spits, and cuspated landforms, which often occur close together in Puget Sound. These landform assemblages are regionally scarce and declining because of extensive development in the shoreline area. Removing a groin may restore upper beach habitat downdrift of the structure.

Ability to respond to sea level rise: Groins effectively hold the shoreline position. Beach habitats are likely to be reduced and degraded from both direct and indirect responses to sea level rise where the beach position is held. Encouraging groin removal/modification will enable beach habitats to migrate landward rather than be squeezed between a "held" shoreline and rising water levels. In addition, beaches downdrift of the groins will have less sediment supply with which to respond to sea level rise, accelerating the impact of sea level rise in these areas.

Opportunities for Implementation

Design life: The design life of groins and jetties may be 15 to 30 years. When structures fail or begin to deteriorate, there will be opportunities to remove or to modify them.

Public recognition: Increased public education about the role of nearshore habitats is starting to reach shoreline property owners and the general public. Effective use of the measure can help demonstrate to the public at large the benefits of repairing larger scale impacts on the littoral cell.

Interagency Partnerships: This management measure is typically implemented as part of large-scale plan, typically encompassing a littoral cell. Because of the scale of these types of projects, several resource agencies and organizations may be involved. Such projects provide opportunities for interjurisdictional and interagency partnerships.

Measurable Units

Metrics for measuring benefits may be based on the local scale and on the littoral cell scale. At the local scale, the length of beach that is no longer impounded by the groin and which allows back-beach processes to occur (e.g., erosion of bluffs) could be used as a direct measure of benefit. The area that was previously covered in rock by the groin also could be reported as newly recovered habitat. On a larger scale, the proportion of the littoral cell that is unimpeded by cross-shore structures could be reported, along with an estimate of the proportion of the alongshore drift that is restored compared to the potential alongshore drift.

Constraints

Prior development practices: The proliferation of existing shoreline residential and commercial uses is a common constraint for this management measure. The prevalence of houses and other upland infrastructure in close proximity to the shoreline makes application of this measure more complicated and potentially controversial.

Effects on adjacent property: One of the constraints to removing groins is that adjacent property may become more vulnerable to erosion.

Cost/benefit: The cost of removing groins and jetties may be substantial. The location and extent of the groin, and the section of beach it holds in place, may be so damaged that meaningful restoration may not be possible without unacceptable costs. Cost of demolition or modification is principally based on the costs of engineering, permitting, construction equipment, labor, and materials. Distance to the nearest suitable landfill and source material sites greatly influence these costs. Site access may also be a substantial factor. In the case of armoring relocation, the product types used in the rebuilt structure will also significantly influence cost.

Regional impacts: The effects of modifying or removing structures such as breakwaters, jetties, and groins could have a significant impact on the shoreline and estuary mouth. The impact of such projects needs to be considered on the scale of the estuary or littoral cell.

Best Professional Practice

For this management measure, the scope and detail of required engineering studies vary widely depending on the specific location and degree of certainty required. The degree of uncertainty tolerated is a function of the risk associated with project failure. The severity of risk can vary from intermittent minor erosion and flooding, to damage to the structure, to flooding of adjacent infrastructure and potential loss of life. Professional judgment should be used to determine the appropriate risk and uncertainty of any project.

This section describes potential studies that may be associated with groin removal or modification design. The scope and design factor of safety should be consistent with the anticipated outcome of the project (removal vs. modification of structures) and specific project, location, and restoration requirements.

Feasibility Assessment

Coastal geomorphic assessment of the littoral cell: Groin removal projects must consider coastal geomorphic conditions such as sediment transport, particle sizing, and downdrift effects to ensure sustainability and adequacy of the restoration approach. In particular, the scale of the assessment should include the entire littoral cell. During the feasibility phase it is important to:

- Identify the geologic setting of the site, littoral drift dynamics, and erosion/accretion trends for the project area.
- Identify the areas that are currently being influenced by the existing groin field.
- Quantify volume rates of erosion and deposition by examining historic aerial photos and maps, conducting field studies to determine existing and historic conditions, and evaluating sediment transport.
- Quantify the amount of fill material on the site.
- Develop a conceptual sediment budget for the appropriate area and time scale. A local sediment transport budget can be used to estimate the effects of the project on off-site areas.
- Identify whether the transport regime is supply- or transport- limited.
- Project the future shoreline evolution with and without the groin modifications.
- Consider the erosion potential associated with adjacent properties.

Erosion management: The assets that the existing groin is protecting need to be considered. New structures, not necessarily a groin, may need to be constructed to provide a similar level of protection to the infrastructure as the original groin. Bluffs may no longer be protected by a wide beach, and bluff erosion may be accelerated. Beach nourishment may be required to reestablish the continuity of the littoral system that was disrupted by the groins.

Sustainability: Long-term sustainability of littoral cell processes depends on restoration of processes that maintain the habitat and allow it to evolve into a mature, biologically and physically functioning ecosystem. If full restoration of the littoral cell processes is not feasible, or if groin modifications do not allow sufficient transport of sediment, long-term sustainability will be compromised, and project benefit to cost ratio made unfavorable.

Design and Implementation

Approach: Groin removal projects should include an assessment of how the shoreline is expected to change when the structure is removed. Project design needs to anticipate this future configuration – or include means of addressing undesirable changes (with use of nourishment, different groin configurations, seawalls, etc). The alternatives to be considered range from complete removal to modification to soft armoring and beach nourishment. Any groin modification project should attempt to maximize the restoration of natural processes while balancing the need for protection of property. The original intended goal of the structure should be expressed as clearly as possible to provide a context for alternative analysis. A removal or modification design that accommodates plantings, large woody debris placement, and beach nourishment enhances coastal processes and productivity. Such designs improve input and accumulation of detrital material and increase potential nearshore habitat area. In general, full groin removal is preferred over modification, unless an analysis of the littoral cell determines that some form of cross-shore beach control is required.

Site conditions: The physical characteristics of Puget Sound’s shorelines are diverse and change notably over short lengths. Littoral cell characteristics, shoreline exposure, tidal forces, and geological makeup may affect the natural function of each site. Project design should consider rates and volumes of sediment transport, shoreline orientation, historical change to the shoreline, and possible impact on adjacent property or coastal features (such as stream mouths or tidal inlets). Actions taken under this management measure may be unique to each site and will be dependent upon the groin’s position in the littoral cell (whether it is at the updrift or downdrift end of the cell).

Scale: Project sponsors and affected landowners need to understand the short- and long-term shoreline response of the littoral cell when considering this management measure. The effects of the project on the natural system outside the project footprint should be understood in order to minimize any harmful effects.

Removal versus modification: Removal versus modification decisions require consideration of access, infrastructure, utilities, equipment availability, regulatory requirements, and disposal. Project designers should determine if relocation or protection is needed for existing utilities, infrastructure, or access routes. Existing groin materials have historically included rock, timber, and concrete. Access and demolition staging areas should be planned to avoid excessive impacts to upland vegetation, water features, or adjacent habitats.

Evaluation

Monitoring of physical processes: A monitoring plan should be developed to assess post-construction project performance and maintenance needs. The effectiveness of groin modification or removal can be measured by observing conditions of interest and trends in: topographic stability/dynamics, sediment characteristics, accumulation of wood, soil moisture/temperature, and backshore vegetation. These measurements should be made on both the local and littoral cell scales. Given the length of some littoral cells, the impacts of removal or modification may take a considerable period of time.

Uncertainty and adaptation: The uncertainty associated with the effectiveness of this management measure can be addressed with careful monitoring of the restoration project and nearshore early action projects or demonstration projects. It may be desirable to identify littoral cell transport thresholds that trigger changes in process through carefully planned monitoring of early action or demonstration projects.

Case Studies and Examples

North Beach, Samish Island: This is a groin construction project done in conjunction with beach nourishment. The design included a modified groin to follow the natural beach profile and allow increased bypassing. Shoreline modifications including groins and bulkheads has substantially altered the erosion and sediment transport processes in the vicinity of the site. Extensive bulkheading had cut off the primary sediment source to the beach. Erosion of the bluffs was the primary source of sediment maintaining beaches along the north side of Samish Island. The project consisted of two parts (Figure 7-2) (Zelo et al. 2000). A drift sill (groin) was built at the east end of the beach (Figure 7-3). Essentially it is a groin constructed flush with the new beach grade (7H:1V) at the downdrift end of the site. The sill is designed to retain the nourishment that was added by the project while still allowing longshore drift to carry sediment normally down the beach above the new grade. Eighty tons of rock were used in its creation.

This was followed by the construction of a protective berm in front of 16 threatened properties. The berm is composed of two layers. Seven thousand cubic yards of berm gravel make up the majority of the fill. This was molded to create the bench and a 4.5H:1V grade beach. Then the beach slope was brought up to 7H:1V by adding 1,500 cubic yards of smaller gravel. This material is intended to provide habitat favorable for surf smelt spawning. The goal of adding this finer gravel was to mitigate the damage done by the project, not to restore the beach to its historical condition. In addition to the gravel, 260 cubic yards of sand were added to the berm.

The rapid erosion that triggered this project may have been largely related to the decay of a much older groin-like structure that had created an anomalously broad and stable high tide beach at the site (Shipman 1998).

Penrose Point State Park Shoreline Restoration: This project, currently at the feasibility stage (Anchor QEA 2009), is exploring design options including replacing a groin field along a barrier spit with a single terminal groin. The proposed project also includes removing a bulkhead, riprap armor, and fill along a bluff-backed beach. It is not known whether this project will succeed in achieving its goals, but since there are so very few examples of groin removal projects in Puget Sound, it is included as a case study to highlight potential future work.

Naturally low sloping beaches support juvenile migration corridors, as the shallows provide important refugia from larger, predatory species. Small chum fry especially utilize the shallow water fringing shoreline habitats and in water less than 2 meters in depth (Simenstad et al. 1982). Kelp, algae and eelgrass beds also provide important nursery habitat as the beds are highly productive feeding environments and support herring spawning activity, another important prey species for young salmon. The project reach, located within Penrose Point State Park, includes low sloping beaches that lead into a small eelgrass bed and an estuarine embayment. However, five cresote groins fragment the beach habitat and impair sediment transport across a barrier spit at the mouth of the embayment just southwest of the bulkhead.

One alternative is to remove the existing wooden groin field and replace the structures with a single terminal groin constructed of either wood or rock (Figure 7-3). This alternative will remove much of the creosote-treated piling from the intertidal area, create a continuous unarmored shoreline reach along the sand spit area, restore sediment transport processes, improve the beach profile for rearing and foraging salmonids, and enhance forage fish spawning habitat. The terminal groin would be designed and constructed to retain approximately the same volume of sediment that is currently being held with the existing groin field. As the shoreline adjusts to the groin removal and reaches a more natural equilibrium state, some areas of the shoreline will move slightly landward and others seaward.

A terminal groin tends to be longer than the groins in the field it replaces because it has to hold sand over a longer stretch of the shoreline. There may be permitting issues in relation to the length of the terminal groin and its position relative to ordinary high water or mean higher high water. In addition, terminal groins tend to retain as much sand as the groin field and so the impacts on the littoral cell may continue.

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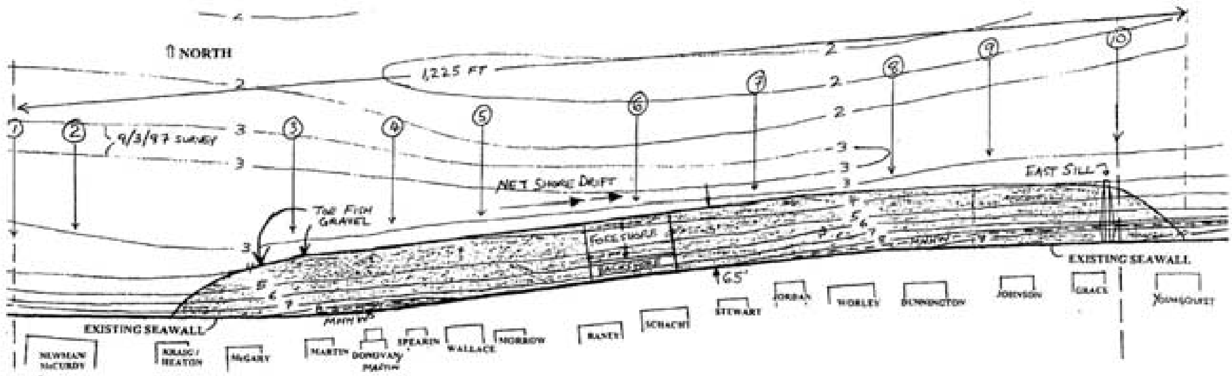
Figure 7-2 Drift sill and berm plan shape, Samish Island



Source: Zelo et al (2000)

Figure 7-3 Samish Island drift sill that forms the eastern end of nourishment

Source: Zelo et al (2000)

MM 8 HABITAT PROTECTION POLICY AND REGULATION

Definition

The *Habitat Protection Policy and Regulation* management measure can provide long-term protection of habitat (and associated species), and habitat-forming processes through zoning, development regulations, incentive programs, and other means. This management measure includes:

- Implementing and enforcing existing land use policies and regulations including the Growth Management Act (RCW 36.70A), Shoreline Management Act (RCW 90.58), State Hydraulic Code (RCW 77.55); zoning and building codes; state and local stormwater regulations; and other environmental controls on development activity.
- Revising existing policies and regulations to improve their effectiveness or remove impediments to restoration, and barriers to the use of voluntary conservation programs and incentive / disincentive programs that promote voluntary habitat protection.
- Adding new policies and regulations to fill gaps in the existing policy/regulatory framework.

Acquisition of property or development rights is a separate but related management measure (See MM 15).

Habitat Protection Policy and Regulation is a very broad management measure that encompasses a wide range of interrelated and sometimes overlapping regulatory and non-regulatory programs. This chapter focuses specifically on nearshore habitat protective policies and regulations. The chapter does not describe all of the individual policies and regulations that contribute to habitat protection in Puget Sound, but highlights important guiding policies and relevant regulations that affect nearshore ecosystem recovery and form the basis of the habitat protection regulatory framework.

Justification of Need and Link to Nearshore Processes

Nearshore habitat protection policies establish guiding principles and express overarching goals pertaining to the use and management of nearshore areas. Regulations are used to implement policies, Regulations protect nearshore habitat from degradation or physical destruction by controlling resource extraction and harvest, recreation, public access, and residential/ commercial/industrial use and development. Policies and regulations can either support or hamper restoration efforts.

Human population growth is one of the primary drivers of development activity including activity that converts forested habitats to urban landscapes. By 2030, the population in the Puget Sound region will reach approximately 5 million people (Office of Financial Management [OFM] 2007). Population growth is expected to cause continued habitat degradation as new homes, businesses, roads, and utilities are built to support the influx of new residents. Many of these new residents will want to reside near marine waters, which will put even greater pressure on nearshore resources. The use of nearshore areas for mineral extraction, aquaculture, recreation, commerce and other purposes will increase with increasing population pressure.

Development pressure coupled with the effects of sea level rise and global climate change pose significant land use and environmental challenges in Puget Sound. The region needs sound policies that prioritize protection and restoration of the nearshore system in balance with other policy goals (e.g., economic development, treating residential development on shorelines as an appropriate use). For example, the state's policy stating that instream flows are a beneficial use of water enables government agencies to make decisions about water use that balance salmon habitat needs (and other ecological considerations) with agricultural and municipal water needs.

The federal policy of no net loss of wetlands and the State's policy of no net loss of shoreline ecological functions are examples of existing policies that set important goals intended to shape our approach to managing wetland and shoreline resources. Despite the no net loss policies, impacts to wetlands and shorelines continued to occur which may not be fully offset through compensatory mitigation (NRC 2001). The region could benefit from developing new polices to better articulate habitat protection goals or by finding ways to better implement the no net loss policy (by changing the existing implementing regulations such as critical area ordinances and shoreline master programs). During development of the Puget Sound Partnership's Action Agenda, many scientists and public citizens expressed a need for policies that prioritize protection and restoration of nearshore ecosystems as opposed to just specific elements of the ecosystem such as wetlands or salmon.

Regulations flow from the policy framework. Regulations can reduce and sometimes prevent impairments to nearshore habitats and habitat-forming processes. By imposing standards for the location, density, size, design, and operation of roads, housing, businesses, and industries, regulations can protect valuable habitats from destruction and minimize effects of development on sediment supply and transport, erosion and accretion, surface and groundwater flows, primary production, food webs, habitat-species interactions, and other processes. For example, the State Shoreline Management Act (SMA) requires local governments to regulate (e.g., discourage, limit, and in some cases prohibit) construction of bulkheads and other shoreline modifications (e.g., docks, piers, jetties, etc). When such structures are allowed, the SMA influences their location, design, construction, and maintenance/repair with the intention of minimizing adverse effects on shoreline ecology.

Nearshore impacts occur despite our existing policy and regulatory framework. According to the 2007 State of the Sound report, development actions across the Puget Sound region have caused eelgrass, forage fish, salmon, rockfish, marine birds and orca populations to decline (PSAT 2007). Ten species are listed as threatened or endangered by the state or federal government and an additional 33 marine species are identified as species of concern, meaning their populations also are at risk. Declines in these species' populations are directly related to the destruction, degradation, and fragmentation of the habitats on which they rely. Much of this damage occurred prior to the development of our existing regulatory framework, but significant ecosystem impairments have also occurred since the advent of the major regulatory initiatives in the 1970s.

The habitat protection policy and regulation measure has the potential to protect all nearshore ecosystem processes and can play a role in restoring many processes. This measure works primarily through behavior modification mechanisms (see conceptual model below) designed to compel people to act in ways that have minimal adverse effects on the environment. The relationship between habitat protection policy and regulation and nearshore processes varies depending on the specific regulatory mechanism and the setting in which it is applied. Table 8-1 highlights some examples of how this management measure works to protect processes.

Table 8-1 Examples of How Some Regulations Protect Processes through Impact Avoidance and Behavior Modification

Regulation (Statute)	Key Impact Avoidance/Behavior Modification Components
Federal Clean Water Act and Rivers and Harbors Act (33 U.S.C. § 1251)	Require permits for dredging and filing in waters of the U.S. Establish mitigation standards to implement federal no net loss of wetland policy Prevent impacts to navigation
Federal Endangered Species Act (7 U.S.C. § 136, 16 U.S.C. § 1531)	Prevents harm to listed species and designated critical habitats
Critical Areas Ordinances (required by the Growth Management Act, RCW 36.70A)	Limits filling and grading in/near wetlands and streams Minimizes or prohibits fill in floodplains Requires designation and protection of channel migration zones Prevents impacts to eelgrass beds, forage fish spawning areas, and other sensitive habitats and species Limits development, clearing, and grading in landslide and erosion hazard areas Requires designation and protection of critical aquifer recharge areas Requires maintenance of vegetated buffers around wetlands and other sensitive habitats
Shoreline Management Act (RCW 90.58)	Discourages, in some cases prohibits, 'hard' shoreline armoring Controls the size, location, and density/intensity of shoreline development and use Requires establishment of buffers/setbacks between structures and rivers, lakes and marine shores Limits vegetation removal near shorelines Regulates placement and design of docks, marinas and other overwater structures Requires 'no net loss' of shoreline functions and values Regulates aquaculture uses and protects shellfish beds from effects of incompatible upland land uses Promotes public access to public waters
Hydraulic Code (RCW 77.55)	Controls timing of 'in-water' construction activity Ensures that culverts and bridges are designed to provide fish passage Regulates dock/pier construction and design of over-water structures (e.g., requires open grating) Restricts project type, design, location and timing for areas such as forage fish spawning areas, juvenile salmon migration corridors, and kelp and eelgrass habitats (i.e., Saltwater Habitats of Special Concern)
Instream Flow Rules (RCW 90.03, 90.54 and others)	Requires establishment of minimum flow standards through adoption of rules Requires base flows to be retained in streams except where there are "overriding considerations of the public interest" Requires that state waters be protected and used for the greatest benefit to the people and that allocation of water be based on the securing of "maximum net benefits" to the people of the state
Forest Practices Act (RCW 76.09)	Most deals with uplands, but regulates timber harvest on/near shorelines; limits frequency and intensity of harvest on shorelines of statewide significance
WDNR Aquatic Lands Program (RCW 79.105)	Authorizes conservation and development activities on state-owned aquatic lands Regulates aquaculture use on state-owner lands Establishes Aquatic Reserves
Floodplain regulations (various)	Limit development in the floodplain/floodway to maintains floodplain/floodway capacity
Stormwater regulations (various)	Require 'treatment' of pollutants prior to discharge to minimize water quality impacts Require detention of stormwater runoff to control peak flows

Regulations are designed to work primarily by preventing development impacts and harmful or destructive activities or uses. As a result even regulations that are not specifically aimed at nearshore environments can have an effect on habitats and habitat-forming processes. Regulations that fail to achieve their intended purpose (clean water, invasive species control, maintenance of stream flows, pollution source control, etc.) can influence whether nearshore processes will need restoration in the future.

Conceptual Model

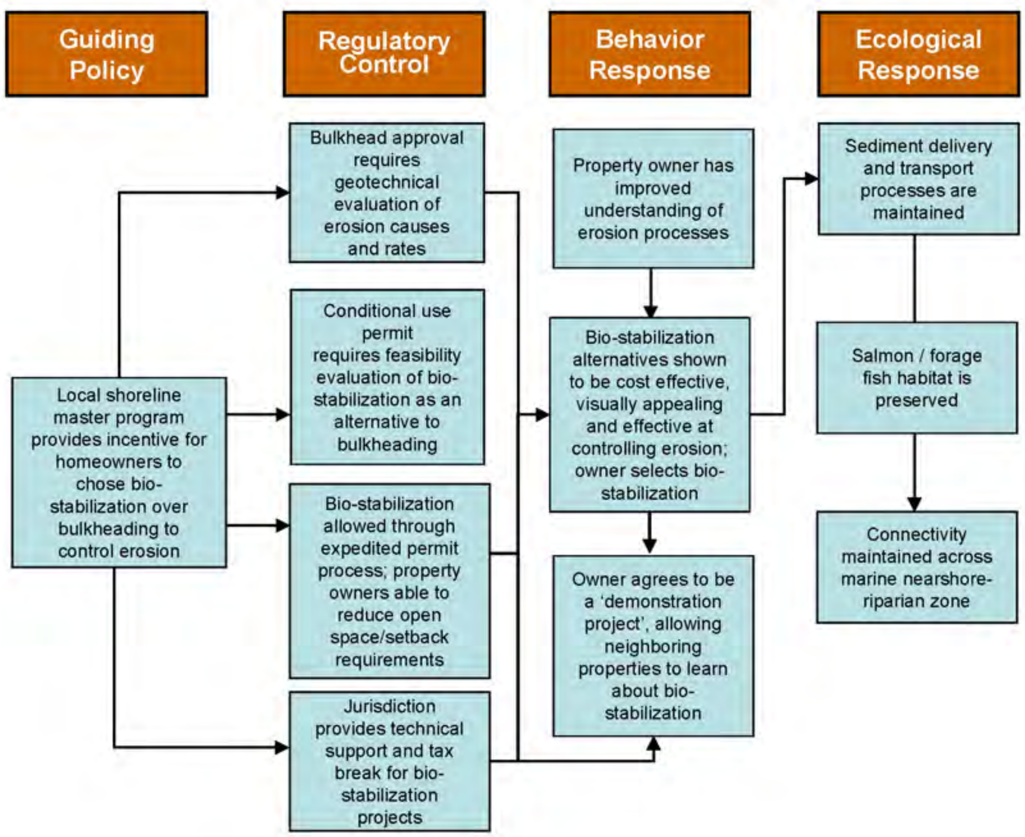
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 8-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario – Local city/county governments provides incentives to property owner to replace bulkheads with bioengineered stabilization.

Change/Action – Landowner applies for program and receives a tax refund and technical support for bulkhead removal. The project becomes demonstration sites in a neighborhood education campaign.

Predicted Response – Shore processes and habitat conditions improve.

Figure 8-1 Conceptual Model for Habitat Protection Policy and Regulation



Complementary Management Measures

This is primarily a protective management measure that facilitates or inhibits the use of other measures. Promoting habitat protection policies or regulations should complement other management measures as a means to ensure effective restoration and protection. *Habitat Protection Policy and Regulation* is also appropriate as a stand-alone measure that provides tangible benefits even in absence of other restoration actions. Often, this management measure is a prerequisite to other measures because virtually all other measures are either subject to policies and regulations or have policies and regulations that promote or encourage their implementation. As an example, removal of overwater structures is encouraged under the SMA and also requires approval from local, state and/or federal/tribal agencies prior to implementation. The *Pollution Control* and *Contaminant Removal and Remediation* measures in particular have a very strong regulatory nexus. The *Public Education and Involvement* measure can be used to improve the public's awareness and acceptance of policy and regulatory controls and to enhance compliance with existing policies and regulations. *Public Education and Involvement* is also essential to promoting the use of non-regulatory incentive-based approaches to habitat protection.

Benefits and Opportunities

Benefits of the Restoration Action

The habitat protection policy and regulation measure has potential to produce a number of important benefits including:

Cost savings: Protecting well-functioning habitats and habitat forming processes (avoiding impacts to them) is generally much less expensive than restoring degraded habitats and processes, so dollars spent on avoidance of harm are a prudent investment.

Reduced stress on restoration sites: Protection efforts make restoration actions more sustainable by reducing outside stressors that disrupt processes (e.g., regulatory limits on new bulkheads reduce the potential for down-drift restoration sites to be compromised by altered sediment processes). This helps protect public investments in restoration.

Shared responsibility: This measure affects a very large number of people—virtually anyone who owns or develops property, and in some cases resource users—so the responsibility for protecting habitats and habitat-forming processes is shared among a diverse population. As a result, application of this measure can result in widespread behavioral and ecological changes.

Healthier watersheds: Policies and regulations can prevent impacts and degradation anywhere on the landscape, so their protective benefits extend beyond nearshore zone. By helping to ensure the health of the entire watershed, this management measure strengthens nearshore systems.

Measureable Units

The benefits of this management measure can be quantified by assessing trends in ecosystem health/decline that occurred before and after specific regulations went into effect. Examples of useful comparisons include: changes in the rate of loss of tidal wetlands before and after the Clean Water Act; population estimates of sensitive species before and after the Endangered Species Act; rates of compliance monitoring; and, changes in the ecological health of streams before and after development on instream flow rules or water clean up plans.

Another measurable attribute is the number of property owners that take advantage of incentive programs or enroll in voluntary protection programs. If this information were available on a programmatic basis, it would provide a partial indication of the level of voluntary habitat protection being achieved across the Sound.

Opportunities for Implementation

Policies and regulations govern, to some degree, all nearshore habitats. In Puget Sound, regulations are used to protect and manage all types of habitats and habitat-forming processes any time there is a development action, because essentially every development action triggers regulatory review of some kind. Local, state, tribal, and federal agencies create, administer, and enforce habitat protection policies and regulations under the auspices of various statutes to achieve specific mandates such as the protection of wetlands, improvement of water quality, management of stormwater runoff, and prevention of flood damage; nearshore habitat protection is not always the central or sole focus of the policy or regulation.

Non-governmental organizations also play a role in implementing this management measure as compliance monitoring "watch dogs" or by providing technical support, training, and other resources to encourage sound stewardship of nearshore habitats. Education and outreach help promote policies and regulations that reflect public values; therefore education is important for secure implementation opportunities.

Regulations control actions, but policies can include providing incentives and disincentives for behavior change, paving the way for certain actions and making it difficult to choose other actions. There is usually a trade-off between policies and regulations wherein strict regulations often make it difficult to reward people for desirable actions/behaviors because the bar for "good behavior" is set high by the regulations.

Constraints

This management measure has a number of inherent limitations that that can undermine or limit its effectiveness as a protection and restoration tool. Factors such as funding, political will, enforcement, the level of public education/awareness, the efficacy of the mandated treatments (e.g., BMPs for stormwater), and the skill and experience of both regulatory staff and the person or persons complying with the regulations will determine how effective this measure is at achieving desired goals. These factors can change over time (based on economic cycles, elections, etc) and vary from jurisdiction to jurisdiction.

The existing policy and regulatory framework protecting nearshore habitat in Puget Sound evolved as series of individual responses to specific environmental concerns and threats and authority is vested in many different agencies. As a result there is no comprehensive policy or regulation that protects and/or restores the ecosystem as a whole. Most policies and regulations focus on controlling impacts from site-specific development actions; they are not designed to address habitat protection at a broad scale and are less effective at protecting processes which generally operate across broad geographic areas.

Most policies and regulations are not implemented except in response to development actions. This poses two problems: First, it means that even when agencies adopt new policies or laws, existing developments are not required to comply unless or until new development or redevelopment is proposed. Second, it promotes a reactionary system in which we rely on regulations to control damages instead of comprehensively anticipating habitat protection needs.

An additional constraint in Washington State is that local jurisdictions have broad authority for making land use decisions. For example, local governments have varying requirements for stormwater management, shoreline buffers/setbacks and mitigation procedures. This creates a patchwork of protections for species, habitats, and ecosystem processes as opposed to a uniform state wide overlay. Large-scale regional land use planning, which could increase regulatory consistency and coordination, has been limited to the work of a few regional planning agencies including the Puget Sound Regional Council and the Thurston Regional Planning Council. This results in uneven application of existing rules and regulations and different outcomes in terms of protection.

Implementation of policies and regulations often lags behind the discovery of the need for policy/regulatory actions because of public perceptions about property rights infringement. Scientists, elected officials, and the public often disagree on the existence of a threat and/or the level or regulation needed to address an apparent threat of habitat destruction or degradation. Compromises made during the legislative/political often weaken regulations. Even when strong regulations are passed and placed into law, they may be subject to litigation or poorly enforced, and therefore less likely to achieve their intended purpose.

Other limitations of the habitat protection policy and regulation measure include:

Inadequate resources: Resources for implementation, enforcement and monitoring are often inadequate – Not all local jurisdictions have the capability and/or expertise to evaluate development proposals to ensure that rules and standards are met. The fact that regulations are often subject to legal challenges increases the burden on agency/government staff and often snarls implementation efforts. Many regulatory agencies also lack resources for monitoring /enforcement efforts that can measure the degree to which habitat protections are achieving regulatory mandates and restoration goals.

Jurisdictional differences: Federal and state agencies regulate nearshore and offshore areas differently making it more challenging to protect marine ecosystems in a holistic manner. Local governments exercise little control over marine waters beyond the jurisdiction of the SMA.

Lack of enforcement: Currently, a disproportionately small share of our regulatory efforts goes toward enforcement. Even when enforcement actions are taken the penalties are so low as to not motivate compliance.

Mitigation failures: Compensatory mitigation measures are not always adequate or effective. Most policies and regulations rely on compensatory mitigation measures to replace or make up for habitat impacts. Several local, regional, and national studies show that mitigation projects frequently fail to fully achieve their intended goals and are not effectively replacing lost or damaged resources, habitats, and functions (Ecology 2008). One reason for the lack of success is that decisions on how and where to implement mitigation have typically tried to recreate site- and reach-scale conditions without taking into account the underlying ecosystem processes.

Public resistance: Citizens/property right advocates sometimes resist regulation. Recent efforts on the part of local governments to update critical area and shoreline regulations have met with resistance from some citizens concerned that regulations are unwarranted, result in a disproportionate burden on rural land owners, or infringe on private property rights and therefore require compensation for lost uses and rights. Legal challenges arguing for a reduction in regulatory burden or compensation for reduction in use rights are becoming common and some efforts to expand protection have been overturned by the courts and /or hearings boards.

Vesting rights limit protection: Implementation of new regulations sometimes lags behind the creation of the regulations because of state vesting laws. Under the current state law, developments are vested at the time of application. Vesting delays implementation of new protections such as buffers requirements and stormwater BMPs. In many cases, it may be many years or decades before newly adopted requirements are actually implemented in new projects.

Permit exemptions create gaps in the protection network: There are many land use actions that do not require a permit, but which individually and cumulatively can impact habitats and habitat-forming processes. Examples include small-scale grading actions which may not require a local grading permit and construction of single-family residences and bulkheads on shorelines, which are generally exempt from the requirement to obtain a shoreline substantial development permit under the SMA.

Coverage gaps: Some resources are not adequately protected via existing regulations. For example, there are several jurisdictions in Puget Sound that lack instream flow rules (WRIAs 2, 6, 16, 17, 18 and 19).

The instream flow rule has been effective in protecting rivers from future water withdrawals and for making informed decisions regarding future water allocation. However, the rules do not put water back into streams that are already being impacted by altered flow regimes.

Lack of scientific information: Although there are standards to address many threats to the health of Puget Sound, additional scientific information is needed to inform policy development and implementation of regulations. As an example, we do not have many studies that identify how wide nearshore buffers and setbacks should be. Local jurisdictions developing shoreline regulations typically rely on science from stream and wetland buffer studies, which may make the regulations subject to legal challenges. We know relatively little about effects of emerging contaminants such as pharmaceuticals and endocrine disrupting chemicals on nearshore biota, so we do not have numeric criteria to define regulatory thresholds and standards for those pollutants. There is also a lack of understanding about cumulative impacts of incremental habitat loss and degradation. We need better science and tools to help answer questions such as “how many docks can a given section of the shoreline support without irreversible impact?”

Overlap: Overlapping federal, state and local regulations create compliance complexities. The fact that there are multiple overlapping regulations pertaining to the same resources (federal, state and local wetland regulations, for example), increases the cost, time and uncertainty associated with the permit process and may create disincentives for compliance.

Conflicting policies confound ability to protect ecosystems: The Growth Management Act encourages growth and development in urban growth areas but also requires protection of critical areas. These diverse mandates are difficult to balance. The Growth Management Act also discourages the expansion of wastewater infrastructure outside of urban growth areas perpetuating reliance on septic systems in rural areas, potentially at the expense of water quality.

Difficulty in creating incentive programs: It is difficult to find examples of incentive programs that have successfully achieved protection of habitats and habitat-forming processes. Furthermore, voluntary protections can be removed if ownership changes.

Best Professional Practices

Best professional practices should be aimed at addressing the constants that currently limit the effectiveness of this management measure. This includes:

Feasibility Assessment

Assessing the feasibility of existing or new regulations to achieve habitat protection objectives requires critically evaluating existing policies regulations to assess whether they reflect the latest science on nearshore habitat protection. Identifying policy and regulatory impediments to restoration implementation is also crucial if we are to succeed in our restoration efforts. This could include adjusting permit requirements for restoration projects to reduce logistical burdens, costs, and timelines. Finally, implementers of this measure should engage the public in a dialogue about conservation values to help inform policy and regulatory changes.

Design and Implementation

Keys steps in designing and implementing new or modified policy/regulatory programs include:

- Integrating ecological protection and restoration priorities into land use plans;
- Effectively using watershed/ecosystem assessment principles as science basis for regulations;

- Conducting scientific investigations in areas where science basis for regulations is lacking (e.g., nearshore buffer widths needed to protect processes and functions);
- Making policy and regulatory protections more closely targeted to known threats including climate change;
- Increasing use of incentives programs that that reward compliance; and
- Effectively involving the public to build support and understanding for regulations.

Evaluation

Monitoring the performance of this measure could involve tracking development activity and compliance with permit requirements. Monitoring the extent of new shoreline armoring is one specific attribute that could be evaluated to assess the effectives of policies aimed at discouraging these structures. It would also be helpful to evaluate the number of people that participate in voluntary and incentive-based programs to determine if such programs are working.

Many scientists in the region are evaluating how best to assess whether the policy goals of no net loss of wetlands and no net loss of shoreline functions are being achieved. There is a widespread belief that they are not, but no comprehensive methods or programs are in place to provide an unbiased evaluation. Obtaining an accurate assessment of the no net loss goals requires a solid baseline against which future changes can be measured. Scientists and policy makers need to agree on how to define the baseline condition and then develop a more robust way to account for changes over time.

Case Studies and Examples

Mitigation that Works Initiative, Washington Department of Ecology. Ecology initiated the Mitigation that Works project in response to growing evidence that compensatory mitigation efforts for wetland and aquatic resource impacts were not very effective. Ecology convened a Stakeholder Forum that included representatives from local, state, federal, and tribal agencies, conservation interests, and building trades to develop policy recommendations for improving mitigation effectiveness. The Forum set out to provide a needed perspective on the challenges facing effective mitigation, and reach consensus on actions that could be taken to effect meaningful changes. They acknowledged that numerous regulatory agencies are involved in permitting mitigation and that there is a need for enhanced coordination, reduced overlap in the review process, and consistent review standards and permit conditions for proposed mitigation projects. In addition, the Forum noted that Washington State needs a range of mitigation options to adequately protect a variety of resources (wetlands, fish, uplands habitats and endangered species) that are impacted by development projects. As part of their deliberations, the Stakeholders developed a clear understanding of the meaning of "successful mitigation." The Forum's policy recommendations included the following (Ecology 2008):

- Reinforce the importance of avoiding and minimizing impacts to resources that are highly valuable and difficult to replace.
- Establish an ecosystem or watershed-based approach to mitigation.
- Develop and implement a wide variety of compensatory mitigation tools.
- Develop more coordinated, predictable approaches to reviewing development projects and associated mitigation plans.
- Support making mitigation work.

Details on the recommendations are available at http://www.ecy.wa.gov/biblio/0806018.html.

Ecology is actively working to implement the recommendations and reconvened the Forum early this year (2009) to report on the progress made in implementing the regulations.

Incentive Program for Stormwater Management and Removal of Impervious Surface, Lake Tahoe California. Congress created the Tahoe Regional Planning Agency (TRPA) and gave them authority to adopt environmental quality standards, called thresholds, and to enforce ordinances designed to achieve the thresholds. TRPA developed an impervious surface coverage program that is a tradable development rights approach to managing impervious surface. The coverage program was designed to address pollutant loadings to Lake Tahoe from increasing development in the watershed; stormwater runoff was the single largest source of pollutants to the lake. Property owners and developers in the basin are required to verify how much coverage they are allowed using a scoring system, and may 'bank' any coverage they do not use. Coverage that is banked may be sold to a third party to offset impacts to land that is equally or less sensitive according to the scoring system used.

This program is a prime example of one effort to provide incentives for avoiding and minimizing the creation of new impervious surface and for removing existing impervious surface. The program created financial value as a way to motivate private property owners to reduce impervious surface. To date, there have been over $10.4 million in transactions as a result of the program (http://www.trpa.org/).

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MM 9 HYDRAULIC MODIFICATION

Definition

This management measure involves modifying hydraulic conditions when existing conditions are not conducive to sustaining a more comprehensive restoration project. *Hydraulic Modification* commonly includes removing or modifying culverts and tide/flood gates or creating other engineered openings (e.g., constructed channels) in dikes, road fills, and causeways to influence salt marsh and lagoon habitat. This measure is used in managed systems (as opposed to naturally maintained systems) where the tidal inundation regime and sources and routing of fine sediments are controlled by the hydraulics of flow through the openings. Modification may include operational changes as well as structural changes.

Managed systems are less desirable than natural systems because in managed systems it is more difficult to accommodate natural variability with natural responses, thereby potentially affecting habitat and sustainability. In some cases, managed systems may even increase the risk to threatened species by attracting them to a “brittle” system that might fail catastrophically. Therefore, managed systems should be pursued only when constraints prevent unmanaged systems.

Justification of Need and Link to Nearshore Processes

Land development and cultivation in estuarine and nearshore areas has historically required the construction of dikes, bulkheads, and roads to restrict tidal action. Although landowners commonly installed culverts, tide gates, flood gates and other openings through dikes and road fills to allow drainage from upland streams, wetlands, and other sources, the size of these openings typically did not allow for the free exchange required for estuarine processes and unimpeded fish passage. As a result, Puget Sound has extensive areas of hydraulically modified shoreline, pierced with small openings for drainage. Restoring these former tidal wetlands requires removal of tide gates and culverts or the creation of open breaches. Such actions improve hydraulic and habitat connectivity, allowing tidal inundation, marsh evolution, improved fish passage, sediment transport, the movement of debris, and all the associated benefits of proper estuarine function.

Tide gates are typically attached to culverts that are placed through dikes where there is a tidal influence. Flood gates are placed where there is an influence from a freshwater source such as a river during flood stages. These structures are also used at dikes on tributaries and on floodplains not necessarily associated with specific drainage networks (Bates 2003). Tide gates alter hydrology, physical connections between habitats (e.g., the marsh and the estuarine system), sedimentation processes, water quality, and organic matter flow (Williams and Thom 2001). Tide gates modify the flow so that pulses of water are released at low tide. While the gate is closed, the water stagnates, oxygen is depleted, and anaerobic processes are enhanced. The water that is released by the gate has less dissolved oxygen, higher temperatures (in spring and summer), and higher concentrations of sulfides. The water is also generally less saline than the receiving water.

The presence of a tide gate restricts mixing between a tidal estuary and an adjacent diked or drained wetland area, changing the natural salinity gradient. Organic matter tends to only flow out of the diked wetland; little enters the wetland from the estuary. The movement of sediment is similarly impaired.

Tide gates create a barrier to fish migration when closed and even when open, unless they were specifically designed for fish passage (Bates 2003). Open tide gates may function as fish barriers because of the flow differential across the gate, small opening size, or by being perched above the downstream channel. Access depends on the flow rates through the gate, with high flow rates preventing small fish from accessing critical marsh and freshwater habitats (Bates 2003).

Culverts can also impede fish passage if not properly sized and designed (Bates 2003). The elevation of the culvert, as well as the timing and magnitude of water velocity, may make a culvert in a tidal channel a barrier for some organisms. Beamer and LaRock (1998) studied a culvert that did not significantly influence the distribution of fish (this culvert was carefully designed and located to minimize its impact on fish passage and tidal flow).

Conceptual Model

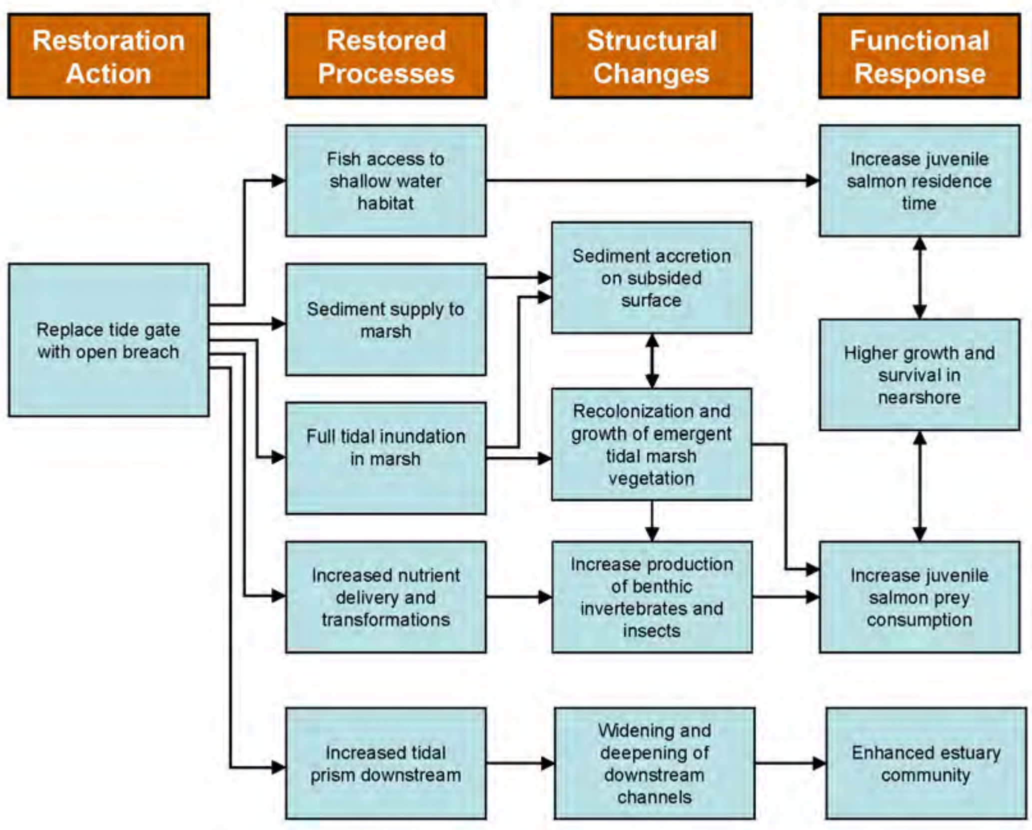
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 9-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Tide gates prevent or limit (depending on tide gate functionality) connectivity between the estuary and diked wetlands.

Change/Action: Removing (or modifying) the tide gate initiates development of tidal wetland and allows immediate fish access.

Predicted Response: Depending upon the species and life stage of salmon considered, modifying the tide gates provides increased opportunity for salmon to occupy shallow water habitat (refuge), and increased capacity to support juvenile salmon foraging. This can promote increased residence time, growth potential, and decreased mortality from predation.

Figure 9-1 Conceptual Model for Hydraulic Modification



Complementary Management Measures

Hydraulic Modification cannot be viewed in isolation from other management measures nor other restoration sites in the same watershed. Removing tide gates alters the tidal hydraulics of the wetlands and so the related measures of *Berm or Dike Removal or Modification, Topographic Restoration,* and *Channel Rehabilitation or Creation* need to be considered. For example, if a tide gate is removed then tidal inundation is increased, so the inboard dike will have to be raised to provide the same level of flood protection. The elevation of the site will have to be assessed in relation to the new tidal regime and channels will enlarge to accommodate the larger tidal prism. Projects that involve *Hydraulic Modification* will often also require *Property Acquisition and Conservation*.

Benefits and Opportunities

Benefits of the Restoration Action

Hydraulic modification has the potential to exert significant influence on nearshore processes, providing durable restoration benefits. The benefits depend on the type of manipulation. Restoring full tidal action to former tidal wetland areas requires the creation of open breaches and/or removal of tide gates and culverts. This improves hydraulic and habitat connectivity, allowing tidal inundation, marsh evolution, improved fish passage, sediment transport, the movement of debris, and all the associated benefits of proper estuarine function.

Modifying tide gates and/or installing larger culverts (in place of undersized structures) may not produce the same benefits as removing these hydraulic impediments, but such actions can remove barriers to fish passage and enhance connectivity between tidal systems. Increases in culvert size may beneficially affect channel and estuarine function, particularly in the degree and frequency of tidal or floodplain inundation, the reestablishment of normal circulation patterns and particle residence times, and the distribution of salinity and nutrients. Increased culvert size improves debris and sediment transport from upland sources to marine areas and tidal marshes (which receive suspended sediment from river water). These actions aid in recovery of special status species, notably juvenile chum and Chinook salmon.

Opportunities for Implementation

Managed wetlands can offset the loss of runoff storage for surrounding areas. Managed wetlands are sometimes required on a portion of a site with the remainder restored to full tidal and fluvial action. Managed wetlands can be used to phase-in overall restoration where the site is low in elevation and sediment supply is low. Once surrounding areas have aggraded and vegetated, or the managed wetland has aggraded and or vegetated, the hydraulic structures can be removed.

This management measure is typically implemented as part of large-scale restoration actions, typically encompassing tens to hundreds of acres. Because of the scale of these types of projects, multiple resource agencies and organizations are usually involved. Such projects provide opportunities for inter-jurisdictional and inter-agency partnerships.

Measurable Units

Measuring benefits of physical systems can be achieved by monitoring the evolution to some desired equilibrium form during a given time frame (e.g., the time required for a wetland to reach equilibrium with the tidal prism). The evolution of the downstream channels can be expressed as changes in the cross-sectional area. Sediment accretion on the site can be measured either as thickness of sediment deposited or as change in elevation, usually expressed in mm per year. Changes in mixing due to improved connectivity can be measured both in terms of temperature and salinity measured on a seasonal basis.

Improvements in fish passage can be determined by measuring/observing fish migration through the opening and by assessing fish use of the restored site.

Constraints

Downstream impacts: Large increases in tidal prism can increase velocities and cause potential scouring in channels seaward of the restored wetlands, undermining existing dikes downstream. Hydrodynamic studies may be required to address the potential concerns for adverse impacts to downstream infrastructure. Tidal inundation may also increase the risks of flooding on adjacent lands. Land purchases may be possible in some locations to minimize this; setback dikes may be required in other circumstances.

Land use impacts/landowner cooperation: Prior development practices can complicate application of this measure. Landowners may react negatively to actions that they perceive will adversely affect the ongoing use of their lands (for agriculture or other purposes) or impact property values/future uses. Landowner cooperation is important especially if property/development rights have to be acquired to enable application of this measure, which is often the case.

Cost/benefit: The effects of increasing tidal exchange on infrastructure may be significant. The location and extent of the dike or roadway may preclude meaningful restoration without unacceptable costs (long bridge or causeway). Homes or business located on fill may reduce the likelihood of success by eliminating marsh or floodplain.

Best Professional Practice

For this management measure, the scope and detail of required engineering studies vary widely depending on the specific location and specific restoration goals. Professional judgment should be used to assess the level of risk and mitigate uncertainty.

Feasibility Assessment

The sites chosen for hydraulic modification have been diked, ditched, graded, and drained in some combination. Their existing hydrology can vary from permanently impounded, to tidally influenced, to seasonally flooded, to almost permanently drained (e.g., agricultural areas and some rural areas drained for flood protection). For various reasons, these sites are not suitable for more comprehensive restoration actions that allow full tidal inundation so project designers must consider how sites will evolve under a managed tidal regime. Key feasibility considerations include:

Hydraulic performance criteria: A critical issue will be determining the level of tidal restoration that can be achieved. Hydraulic performance criteria (e.g., target water levels, inundation frequency, flow speeds, wave heights, etc.) are used to determine whether to create an open crossing through the existing dike, fill, or causeway or modify the existing structure to enhance connectivity. If full tidal inundation is not feasible or if hydraulic modifications do not allow sufficient transport of sediment and debris, long-term sustainability will be compromised, and project benefit to cost ratio made unfavorable.

Type of modification: Where the upland area surrounding the restoration site has been developed and restoring full tidal action is not possible due to concerns about potential flooding and salinity, a number of actions could still be taken to improve connectivity:

- Remove the crossing and replace it with an open breach (see also *Berm or Dike Removal or Modification*). The size of a natural equilibrium tidal channel is correlated to the tidal prism of the marsh. The crossing could be enlarged to at least the size of a natural channel, which would then allow full tidal action within the site and flows in the channel similar to that found in natural channels. Breaches sized wider than the channel will restore surface (as opposed to channel) transport of water, sediment and organisms.

- Increasing the capacity of the culvert to allow greater tidal action within the site and greater flows in the channel; at the same time velocities in the channel may be reduced. If tidal elevations would be too high with an unobstructed opening, it may be necessary to restrict flows.
- Modify the existing tide gate or install an automatic tide gate.

Flooding analysis: Potential tidal and fluvial flooding should be analyzed to determine the likely extent and depth of inundation for a number of storm events (e.g., 10-, 50-, 100-year return periods). A one- or two-dimensional numerical model may be required to allow analysis of alternatives. Project designers should discuss the precise conditions to be modeled and the models to be used with permitting agencies to ensure that the approach is acceptable.

Geomorphic assessment: Geomorphic conditions such as sediment supply and particle sizing must be considered to ensure that sedimentation rates in newly restored areas are sufficient to sustain the evolving marsh. A conceptual sediment budget for the area must be developed that considers not only the restoration site but also other existing sinks and sources of sediment. A local sediment transport budget can be used to estimate the effects of the project on off-site areas.

Design and Implementation

In managed tidal systems, design issues will be specific to the type of hydraulic modification as follows:

Culverts: Culvert design will be based on the flow hydrograph of the channel, either tidal or runoff. Typically some form of numerical modeling is undertaken to inform the design. Runoff and tidal hydrographs are specified. The flow rates for different water levels on either side of the culvert are modeled. The models may consider a variety of losses such as entrance and exit losses, friction, and form loses (such as bends). The size of the culvert will control its capacity and the flow velocity. Standard curves can be used to determine the required size of the culvert given a target flow velocity. The invert elevation of the culvert will establish the threshold and duration of flow and ponding. Shape is also an important factor as this will affect the flow rate at different elevations – an arched culvert will allow more flow at lower elevations and also allows a natural bed. Weir boxes may be used on the upstream side of the culvert to limit the low water level and gates or removable flashboards may be included to allow draining. Multiple barrels are often used where the capacity required is great and the height available low. They can be used to alter the tidal regime by creating asymmetric flow capacity. In this case some of the barrels have flap gates to allow outflow only while the other barrels allow inflow and outflow controlled by gates. This allows a muted tidal system to be established which also has capacity for flood storage. The storage provides a buffer between tidal and fluvial flooding and may become more important with rising sea levels.

Breaches: Crossing should be sized to equal at least the size of a natural channel, which would then allow full tidal action within the site and flows in the channel similar to that found in natural channels. Breaches sized wider than the channel will restore surface (as opposed to channel) transport of water, sediment and organisms.

Tide gates: If tidal elevations within the site are too high, it may be necessary to mute the tide. In this case a tide gate may be used to restrict maximum tidal elevations within the site. During the time when the gate is open, the crossing should act like a natural tidal channel, but when the gate closes passage of water, fish, and other organisms/materials is blocked. The objective would be to minimize the period and frequency of closure. The use of a control system to determine the closure of the gate would maximize the period when the gate can remain open and improve its performance in terms of fish passage. However, maintenance of a tide gate, even one designed for improved fish passage, does not fit the definition of sustainable restoration, nor does it accommodate restoration of key geomorphic processes such as sediment and debris transport, which maintain tidal marsh conditions.

Other questions to consider when designing tide gate restoration projects (Beamer, personal communication):

- Do juvenile salmon swim against the current or with the current?
- Where in the water column do the juvenile fish occur? Gate designs should take into account where fish are located relative to the opportunity to find passage.
- What water velocity can juvenile salmon swim against and for how long or far?
- When are fish present? Tide gates may need to be operated differently at times when juvenile salmon are present?
- Does swimming behavior and capability vary by the size of the juvenile and species?
- What water quality / habitat quality is necessary for juvenile salmon at sites with tide gates or candidate SRT sites?
- Can SRTs be designed to achieve both fish passage and habitat quality objectives while protecting adjacent land from flooding or salt intrusion?

Small conduits: Another approach to tidal muting is to provide smaller conduits, with some open all the time and some gated to allow only drainage. The small size of the open culverts can limit the tidal range, while the gated culverts provide increased drainage. This type of system may be better for fish passage since some culvert(s) are always open, and flood conveyance (drainage) is automatic.

Flood management: If the modification involves creating an open channel crossing, a new inboard dike may need to be constructed to provide adequate flood protection. Alignments for this new dike need to be considered. The drainage system on adjacent low-lying land should be mapped and documented. Storage areas for runoff should be identified. Runoff volumes should be estimated. An inventory of other tide gates, culverts, and other structures within the system should be made to help identify the impact of changing the tide range.

Evaluation

Restoration sponsors face considerable uncertainty when designing hydraulic connections to restore tidal marsh habitat; therefore projects must be carefully evaluated to determine if the desired responses are being achieved. Monitoring guides future restoration efforts and allows project sponsors to respond adaptively to undesired changes. Diurnal water level fluctuations within the site can monitored with a water level recorder or gauge or even piezometers as noted below. Development and evolution of new tidal channels can be documented along transects using boats with sounding equipment and sensitive GPS sensors or surveyed from shore with conventional surveying equipment if a solid vantage point exists. Aerial photography can be invaluable for documenting change over time. Depending on the size of the site, low elevation aerial photography can be achieved using balloon-mounted cameras. Installation of transects of simple piezometers can be used to monitor the location of the saltwater/freshwater transition, and track its movement over time. Permanent transects can be installed for monitoring vegetation succession, and mapping vegetative communities.

Case Studies and Examples

Fornsby Creek, Jefferson County: The Fornsby Creek salmon habitat and estuary restoration project is an example of the modification of existing tide gates to restore fish habitat in former blind slough channels. The goals of the project were to enable fish passage by restoring tidal influence to blind channels and restore channel habitat for juvenile salmon use. Agriculture dominates the land use. Any increase in tidal inundation had to be balanced with the need to protect agriculture and structures from flooding. There were also concerns that saltwater intrusion would affect agricultural production (Mitchell et al. 2005).

Dikes and flap-style tide gates had converted wetlands to agricultural land, preventing tidal inundation to about 900 acres of former estuarine wetlands. Approximately 5 miles of tidal channel had been isolated, including significant network remnants of Fornsby Creek. Much of the remnant network had been simplified as the land was drained for agriculture. Fresh water still entered the channels through stream and seeps, but saline water could not enter from the estuary due to the flap gates.

The constraints of flooding prevented the restoration of a full tidal regime. Instead two self-regulating tide gates (SRT) were installed to mute the tide below full range (Figure 9-2). These gates allow estuarine water to flood into the site and close when the head of water on the outboard side reaches a set elevation. They reopen as the tide falls and the outboard head is reduced (Figure 9-3). These gates also allow concerns of saltwater intrusion to be addressed as the tidal prism of the restoration can be controlled. As part of the project, monitoring wells were installed at 14 locations within the site to measure water, temperature, and chloride levels. These monitoring sites provide information to fine-tune the gate settings.

In addition, the project team replaced other culverts within the site with bridges to improve circulation. Many of the remnant channels were steep-sided and these were widened and given gentler side slopes. Sediment that was dredged from the channels as part of the regrading was then used to reinforce adjacent berms to protect agricultural areas from inundation.

Shine Estuary, Jefferson County: In the Fornsby Creek example above, internal culverts were replaced by bridges to improve tidal connectivity along channels. Another example of this modification is on the Shine Estuary which drains into the Hood Canal. The estuary and creek systems provide important habitat for several species of salmon smolts as well as steelhead and cutthroat trout. The estuary was divided by three culverts that prevented tidal action from reaching 77 acres of the upper parts of Shine Estuary. These culverts also served as barriers to fish and large woody debris, which were unable to pass through the openings. In 2005 the three culverts were removed and replaced with a 70-foot-long bridge over Shine Creek (Figure 9-4). Removing the culverts restored connectivity between the upper and lower Shine Creek estuary.

Browns Slough, Skagit County: Hydraulic modification need not be structural. Browns Slough on Fir Island is an example where the operation of a gated culvert is designed for partial inundation and fish passage. Following flooding in 1990, a levee with two tide gates was installed across the lower portion of Browns Slough in the Skagit River delta. This allowed drainage from the upstream reach but prevented both tidal action and fish passage. In 1994 another culvert was installed with a manually operated gate which remained open for nine months of the year and only closed when floods were forecast. Beamer and LaRock (1998) showed that fish passage was no longer impeded through the new gate while maintaining some drainage function and flood protection to adjacent land. Keeping the gates open for extended periods of time, rather than closing at each tide, was shown to improve connectivity, upstream water quality, and fish migration to some extent. However winter migrations may still be impacted because floods are most prevalent in winter and tide gates are closed. Ongoing monitoring results show annual variability in the abundance of fish upstream and downstream of tide gate. Potential causes for this variation are believed to include:(1) timing of river freshets that deliver juvenile salmon to the estuary and (2) changes in smolt population size (the wild Chinook smolt population size for 1996 was very low; larger populations might show more of a signal to constraints on local connectivity) (Beamer, personal communication).

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Figure 9-2 Installation of self-regulating tide gate at Fornsby Creek

Figure 9-3 Operation of self-regulating tide gate at Fornsby Creek

Figure 9-4 Culvert to bridge replacement, Shine Estuary.

MM 10 INVASIVE SPECIES CONTROL

Definition

This management measure is defined by two main types of activities: (1) eradication of nonnative, invasive plants and animals currently occupying a site; and (2) control measures to prevent introduction or establishment of invasive species after construction of a restoration project is complete. *Invasive Species Control* is used with increasing frequency in Puget Sound because many restoration sites are currently occupied by one or more invasive aquatic or terrestrial plant or animal species. Ridding a restoration site of invasive species is critical to the long-term establishment of native vegetation or animal communities. This chapter focuses generally on the concept of invasive species control and is not specific to all species that warrant control in the Puget Sound. Certain species are used as examples to illustrate the connection between nearshore processes and invasive species control, and to support considerations for design and implementation of this management measure.

Justification of Need and Link to Nearshore Processes

The control of invasive plant and animal species can shape the biological succession of restoration sites. It is important to recognize that there are some nonnative species that we chose not to control because they are benign or may even have positive impacts. The Manila clam (*Venerupus philippinarum*) and the Pacific oyster (*Crassostrea gigas*), both nonnative, are the basis of aquaculture industries in the Puget Sound. Some species (such as Japanese eelgrass [*Zostera japonica*]) we choose not to control due to their position in the nearshore and their occurrence among valued native species (common eelgrass *[Z. marina*]). However, certain nonnative species populations explode after introduction and have negative impacts. These invasive species — sometimes called “nuisance species,” “aliens,” “exotics,” or simply “nonnatives” — may harm or even cause the extinction of native species. Invasive species that pose the greatest threat are those that have the ability to become established and displace native species or change the ecological processes that shape an ecosystem (Apostol and Sinclair 2006).

Invasive plants can outcompete native species for resources (nutrients, light, water), changing the survival, reproductive success, and growth of native species. They can also alter sediment transport and tidal hydrology patterns. Cordgrasses (*Spartina patens, S. alterniflora, S. densiflora,* and *S. anglica*) and common reed (*Phragmites australis)* are the principal invasive plants of tidal wetlands. In the case of *Spartina* species, the bioengineering effect of clonal monocultures can cause excessive sediment accretion that displaces native flora and fauna. As mudflats become elevated and vegetated, tidal channels deepen, changing the speed and direction of water flow. The mononculture stands and associated constricted channels can also restrict freshwater inflow from terrestrial areas, causing increased flooding in uplands. The loss of mudflat also significantly reduces foraging area for shorebirds that feed on invertebrates found in open mudflats, as well as suitable oyster production grounds. Common reed has similar but less dramatic effects on tidal wetlands (Apostol and Sinclair 2006).

Invasive animal species can alter aquatic communities through predation, competition, habitat alteration, and food web disturbance. For example, invasive invertebrates (e.g., tunicates) can compete with native species for settling surfaces and can grow on the native organisms themselves. Other invertebrates prey on native species. The Asian oyster drill (*Ocinebrellus inornatus*) is an exotic marine gastropod that feeds directly on oysters, clams, and mussels. This species can severely affect reintroduction efforts of native species and also the cultivation of select nonnative species (for harvest). Some invertebrates such as the Atlantic slipper limpet (*Crepidula fornicata*) and Asian mudsnail (*Batillaria attramentaria*) also increase sedimentation and slow currents at the bottom, thus burying oysters, hindering their recruitment, and changing the structure of benthic communities. While some invasive shellfish (e.g., Mediterranean mussel [*Mytilus galloprovincialis*]) provide significant filtering of excess nutrients and are a source of prey for snails, starfish, birds, fish and mammals, they can also cause concentration of biological toxins, industrial pollutants, and heavy metals to move up the food chain as their meat is consumed as prey (Boersma et al. 2006).

Conceptual Model

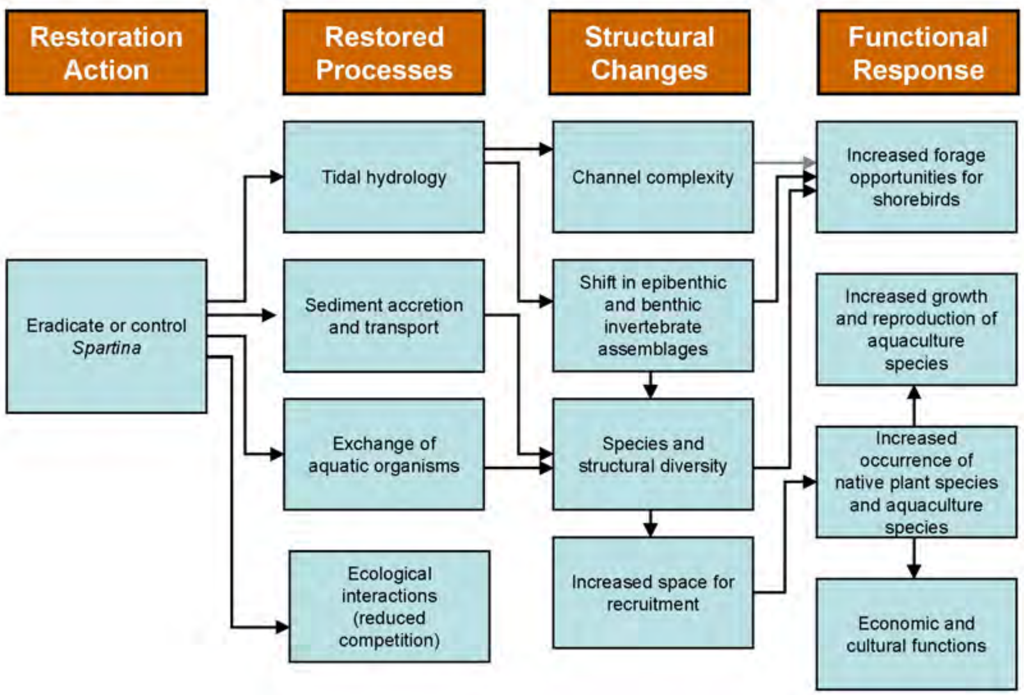
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 10-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: A vegetated mudflat is eradicated of non-indigenous *Spartina anglica.*

Change/Action: Removal of *Spartina* allows tidal channel complexity to return.

Predicted Response: Opportunity and capacity to support shorebird foraging and oyster production (for harvest).

Figure 10-1 Conceptual Model for Invasive Species Control



Complementary Management Measures

Containment or elimination of invasive species may be one component of a restoration project or the sum total of what is needed; an approach called restoration by subtraction (Apostol and Sinclair 2006). This measure is often most successful when implemented with *Revegetation*, which can serve to accelerate the natural recovery of habitat structure and functions and prevent reinfestation of invasives. In tidal areas, *Invasive Species Control* is often paired with *Hydrologic Modification* to increase tidal influence and *Topography Restoration* to restore intertidal elevations. This is particularly true in the case of *Spartina* and reed canarygrass (*Phalaris arundinacea*) infestations. *Contaminant Removal and Remediation* may be a complementary measure since contaminated sites are likely to be dominated by invasive plants species.

Benefits and Opportunities

Benefits of the Restoration Action

In addition to promoting the spread and growth of the native species, several other potential benefits accrue from the control or eradication of invasives.

Structural diversity: Removal of monocultures can restore structural diversity to a restoration site increasing species biodiversity.

Public engagement: Removal of the upland or backshore invasive plants (e.g., Scot's broom [*Cytisus scoparius*]) provides opportunities for participation of untrained or volunteer labor, creating opportunities for local education and participation leading to improved stewardship of the restoration site.

Management goals: Removal and control of invasive species addresses management goals (e.g., Washington Aquatic Nuisance Species Plan) at multiple levels and complies with relevant regulations.

Economic impact: In Pacific County, the removal of *Spartina* in Willapa Bay has direct economic benefit since two thirds of Washington's oysters are harvested there (23% of the nation's annual oyster harvest).

Measureable Units

The benefits of *Invasive Species Control* can be measured by monitoring the extent (acres) or population of the controlled species within a given time frame. Protected land or acres recolonized by native species could also be a measurement of benefits of the action.

Opportunities for Implementation

Likely implementers are state and federal agencies, city and county governments, private entities, Marine Resources Committees, non-governmental organizations (NGOs) such as People For Puget Sound (www.pugetsound.org/) and TNC http://www.nature.org/wherewework/northamerica/states/washington/). There are also opportunities for educators and volunteers at each removal/restoration site such as WSU shore stewards (www.shorestewards.wsu.edu/).

There are opportunities for implementation at multiple scales. At the landscape scale, this management measure could be used to address a single species in numerous, widespread locations where management policy is already in place (for that species). This measure can also be used at the site scale (as in the case of single species infestation). State-wide management plans are currently in place to control some invasive species.

In 2006, the Washington Invasive Species Council was formed by the Legislature as a cooperative, collaborative, and strategic effort to manage the threat of invasives in the state. The Washington Invasive Species Council's mission is to provide policy direction, planning, and coordination to empower those entities engaged in the prevention, detection, and eradication of invasive species. In 2008, the Council released *Invaders at the Gate: 2008 Strategic Plan*. A 16 member council is currently implementing the top priorities in the strategic plan.

In 2001, the WDFW released the Washington State Aquatic Nuisance Species Management Plan (WDFW 2001). The purpose of the plan is to coordinate all aquatic nuisance species management actions currently in progress within Washington, and to identify additional aquatic nuisance species management actions. As a landscape-scale approach to management, the Washington plan is focused on identifying feasible, cost effective management practices to be implemented in partnership with tribes, private, and public interests for the environmentally sound prevention and control of aquatic nuisance species. Legislative direction in the form of two bills (ESSB 6553 and ESSB 5699) in 2002 and 2005 provided funding mechanisms for an inspection program of recreational and commercial watercraft and programs that would prevent new introductions of aquatic nuisance species.

Constraints

Long-term site management: All invasive species control projects require significant monitoring and long-term management expenditures. Control of some invasive species requires continued or long-term human intervention, which may conflict with the goal of promoting a self-sustaining ecosystem via restoration actions.

Labor intensity: Some eradication methods can be very labor intensive. For example, one dropped seed or rhizome fragment of *Spartina* can grow into new plants, making complete eradication difficult.

Cost: Controlling *Spartina* is expensive. In Washington, $718,000 was allocated in 2000-2001, and since 2002 approximately $2.5 million per year has been spent.

Presence of sensitive species: Some techniques (e.g., herbicide application, dredging) may not be permissible in sites where federally or state listed fish and wildlife species are known to occur.

Off-site pressures: The presence of seed sources upstream or upwind of the restoration site may severely reduce the opportunity for success.

Infeasibility: Some invasive species are impractical to physically remove, (e.g., such as Asian mudsnail (*Batillaria attramentaria*) or Japanese mussel (*Musculista senhousia*).

Uncertainty of success: Methods for controlling invasive species are still being discovered and tested. Control efforts are typically a process of experimentation, evaluation and adaptive management.

Lack of funding: Government budget cuts have generally eliminated most formal management programs. The result is that many invasive species control efforts are in the hands of volunteer groups and NGOs, where resources are not abundant. For example, volunteers and shellfish growers are generally in control of European green crab (*Carcinus maenas*) management.

Lack of knowledge: Little is known about the distribution and abundance (in Puget Sound) of some invasive species (e.g., Chinese mitten crab [*Eirocheir Sinensis*], Asian mudsnail) that have been problematic in other regions.

Climate change: The predicted increases in temperature will likely affect natural events such as flowering, mating, and migration, resulting in profound effects on ecological systems and changes in species range. Species will be forced to respond to climate change, creating changes in habitat, food availability, movements of predators or competitors, and new diseases and parasites.

Sea level rise: Sea level rise can promote the spread of some invasive species through range expansion and habitat creation. Rising sea level can enable dispersal of some invasive species and can enhance the spread of other species across hydrologic gradients. Warmer water will allow warm-water fish species to expand their range and force cool- and cold-water fish species to contract theirs. Such events, potentially, would increase competition between non-native fish and native salmon.

Best Professional Practices

A number of methods are used to eliminate or reduce the presence of invasive species. Restoration practitioners should understand existing research regarding the invasive species in question, but should also seek emerging and innovative practices. The application and success of any practice will depend on many factors, including: the reproductive capabilities of the species, the overall condition of the site and ecology of the system being restored, available budget, and labor force. The discussion in this section provides a brief summary of considerations during design and implementation.

Feasibility Assessment

Distribution and abundance: Any control effort should start with baseline information about the presence and extent of the target invasive species. Surveys or existing data collection will determine the scale of the effort and anticipated constraints.

Species resilience: A firm understanding of the life history of the invasive species is the key for effective management. The methods for removal or control vary among invasive species as well as the length of time needed for effective management. Understanding the target species will dictate what level of control can be achieved at what spatial scale.

Off-site pressures: High-intensity land uses and adjacent seed banks can be detrimental to eradication of invasive plants. Understanding the land use and seed sources on and in the vicinity of the site is critical to determining whether or not control efforts are likely to be successful.

Vector control: For species where physical removal is impractical, prevention tactics are generally the only methods available for control. Prevention tactics in the vicinity of restoration sites are critical. For example, methods to promote public education and engagement about invasive species control are a prevention tactic. This could include such practices as careful cleaning and drying of clamming, crabbing, fishing and boating gear to prevent spread of invasive mollusks.

Risks: Herbicides used in control efforts may have negative and/or unwanted effects on other parts of the ecosystem. Projects that may propose the use of herbicides need to consider surrounding land uses and habitats. Applying herbicides can cause collateral damage and kill and injure other, non-target plants and animals.

Design and Implementation

Site preparation: Preparation will vary between sites depending on whether other complementary management measures are in use. If no earthwork is being conducted in the area containing invasive plant species, solarization and sheet mulching are two methods for site preparation. Sod stripping and removal may be necessary on sites with thick sod in order to remove the seed bank and prepare the soil for reseeding or replanting. Best management practices to reduce erosion impacts (e.g. silt fencing, hay placement) should be developed as appropriate.

Herbicides: Herbicides can be used to selectively kill invasive plant species or to completely kill vegetation over a given area to prepare a site for restoration. Herbicides are particularly useful for controlling deep-rooted and rhizomatous species. Careful selection of the chemical, application method, and timing of application can provide adequate control, usually at a small fraction of the cost of manual removal. Advice on the control of particular species using herbicides and related literature review are available from many sources, including TNC's Wildland Weeds Web site (http://tncinvasives.ucdavis.edu/). (Note: due to funding constraints, program management ended in

March 2009, but previous information is maintained at their website). Dead material from herbicide application may have to be manually removed and can be difficult to dispose of.

Shade intolerance: Many invasive plant species are shade intolerant. Management actions can be effective if they first cut back or temporarily control the invasive species and then establish or encourage later-successional species that will eventually overtop and shade out the offending invasive.

Repeated tilling and mowing: Invasive plant species that have extensive rhizome systems can be controlled or eliminated through repeated tilling and mowing. Mowing knocks plants back to ground level but does not disturb root systems. Repeated tilling and/or mowing can kill rhizomatous invasives by depleting energy reserves supplied in photosynthesis. In the case of *Spartina*, the large biomass and high storage capacity of the root systems mean that mowing *S. anglica* meadows will only kill the plants if repeated over many years and that even repeated mowings are minimally effective when herbicides are not used (Dethier and Hacker 2004).

Persistence: Several treatments may be necessary throughout the initial stages of recovery to provide a competitive advantage for native species. The plan for removal must be long enough to ensure success.

Life history stage: In the case of animals that are increasing in abundance (e.g., Asian oyster drill [*Ocinebrellus inornatus]*), removal of adults is less effective than removal of egg capsules. The effectiveness of removing the adult phase is directly related to survival, so if a species has a relatively low survival rate, removing adults does not measurably affect population growth in comparison to removing egg capsules (Ruesink unpublished.).

Revegetation: Removing the offending species is necessary, but most sites will also benefit from *Revegetation* to reestablish the native species (hopefully before the invasive species return) and other actions aimed at preventing reinfestation. Further, the environment may have to be modified to promote the growth of the natives (removal of contaminants, changing the hydrologic environment, etc).

Evaluation

Long-term maintenance: Recently restored ecosystems are vulnerable to invasive species because they lack the vegetation cover or the homeostasis of mature ecosystems. Monitoring and maintenance are necessary to evaluate whether an invasive species removal project is successful.

Adaptive management: Invasive species introduce a significant amount of uncertainty to restoration projects. Adaptive management approaches are effective for addressing ongoing invasive species management in the context of nearshore restoration projects. Management approaches can be altered after thorough monitoring (see below).

Monitoring: The three types of monitoring are: implementation, effectiveness, and validation monitoring (Apostol and Sinclair 2006).

- Implementation monitoring is conducted to ensure that the work is carried out as specified. (e.g., Scot’s broom removal in the backshore and upland area of a restoration site).
- Effectiveness monitoring is conducted to ensure that the work is undertaken in a systematic manner according to the plans that were developed before the work began.
- Validation monitoring tests the validity of the original hypothesis that removal of the particular invasive species will expedite the recovery of the degraded ecosystem.

Long-term eradication: A long-term plan for monitoring to ensure the reestablishment of native species and verify that invasive species are under control is essential for the long-term health. This should be developed early in the planning process so that adequate resources are allocated to this part of the restoration project.

Case Studies and Examples

***Spartina* Eradication Project in Willapa Bay.** *Spartina* most likely arrived in Willapa Bay in the 1890s as packing material in oyster shipments from the East Coast. Once established in the Bay, *Spartina* spread by seed and below-ground rhizomes. In 1984, the extent of *Spartina alterniflora* in Willapa Bay was estimated at 300 acres. By 2003, the estimate was 8500 acres of solid *Spartina* spread out over more than 35 percent (15,000 acres) of the Bay's intertidal region.

The removal and control of this aquatic invasive has been ongoing since the mid-1990s (Figure 10-2). In 1995, the Washington State Legislature took up *Spartina* control and enacted RCW 17.26 "Control of *Spartina* and Purple Loosestrife ". The law directed funding to three agencies, Washington Department of Natural Resources, Washington Department of Fish and Wildlife, and Washington State Department of Agriculture as the state lead, to begin a control program. Efforts to control *Spartina* began with using chemical and mechanical methods. Mowing was conducted to prevent seeds from being produced as well as rototilling to churn up roots and kill the plants. Herbicides have been applied by ground (backpack) and air (helicopter). In 2000, traditional control approaches were supplemented with a biological control program. The planthopper (*Prokelisia marginata*) was introduced after extensive testing and review and approval by a technical advisory group. The population is growing slowly and the full impact on the plant population will take several years to be fully realized.

The cost of the *Spartina* control program has been extremely high. As noted previously, $718,000 was allocated in 2000-2001. In 2002, when it was clear that the rate of spread still far exceeded the program, Washington state agencies and the U.S. Fish and Wildlife Service scaled up the control program to approximately $2.5 million per year. Since then, techniques for removal have dramatically improved the scale and efficacy of the program. Increases in success are due to the approval of a new chemical for use in aquatic environments (imazapyr), better machinery for operating in the mud, tidal exposure mapping, and the use of helicopter application of herbicide. For the past two years, an unprecedented amount of control work was conducted in Willapa Bay, which achieved success. In 2007, an estimated 2310 acres of *Spartina*, comprising 99 percent of the total infestation, were treated in Willapa Bay.

Port Susan Bay *Spartina* Removal and Control. The Nature Conservancy's Port Susan Bay preserve, located in the Stillaguamish River estuary, contains large-scale, intact emergent marshes, eelgrass beds, and soft sediment mudflats and tidelands. The reserve serves as a resting area for fish transitioning between fresh and saltwater habitats and is also critical for shorebirds, waterfowl, raptors, and estuarine invertebrate communities. *Spartina* was first observed at the preserve in 1979. In Puget Sound, the *Spartina* infestation grew from 15 acres in 1979 to more than 800 acres in 1997, with the largest infestations found at Triangle Cove in Port Susan Bay.

The Nature Conservancy has been working to control *Spartina* in Port Susan Bay by developing an inventory of areas of infestation. The areas are then treated using mechanical and chemical methods. The project is part of a multi-agency and NGO effort to implement the *North Puget Sound Spartina Management Plan*. From 2004 to 2005, TNC treated 220 acres of emergent salt marsh and 1,830 acres of mudflat using mechanical and chemical methods designed to control the further spread of *Spartina*. Several events also included volunteers who mapped *Spartina* clones and the areas surveyed with a GPS, flagged *Spartina* outbreaks, helped prepare equipment and supplies, and physically pulled and removed clones and seedlings. In total, *Spartina* was removed from 50 acres of salt marsh and 75 acres of mudflat.

TNC will also establish permanent plots and transects for ongoing monitoring of *Spartina* distribution and treatment effectiveness, which will be a guide for prioritizing future treatments and adaptive management.

The project is funded through a partnership between the National Oceanic and Atmospheric Administration Restoration Center and the Fish America Foundation. Additional partners include the U.S. Fish and Wildlife Service, Washington Department of Agriculture, WDFW, Snohomish and Skagit Counties, and the Swinomish Tribal Community.

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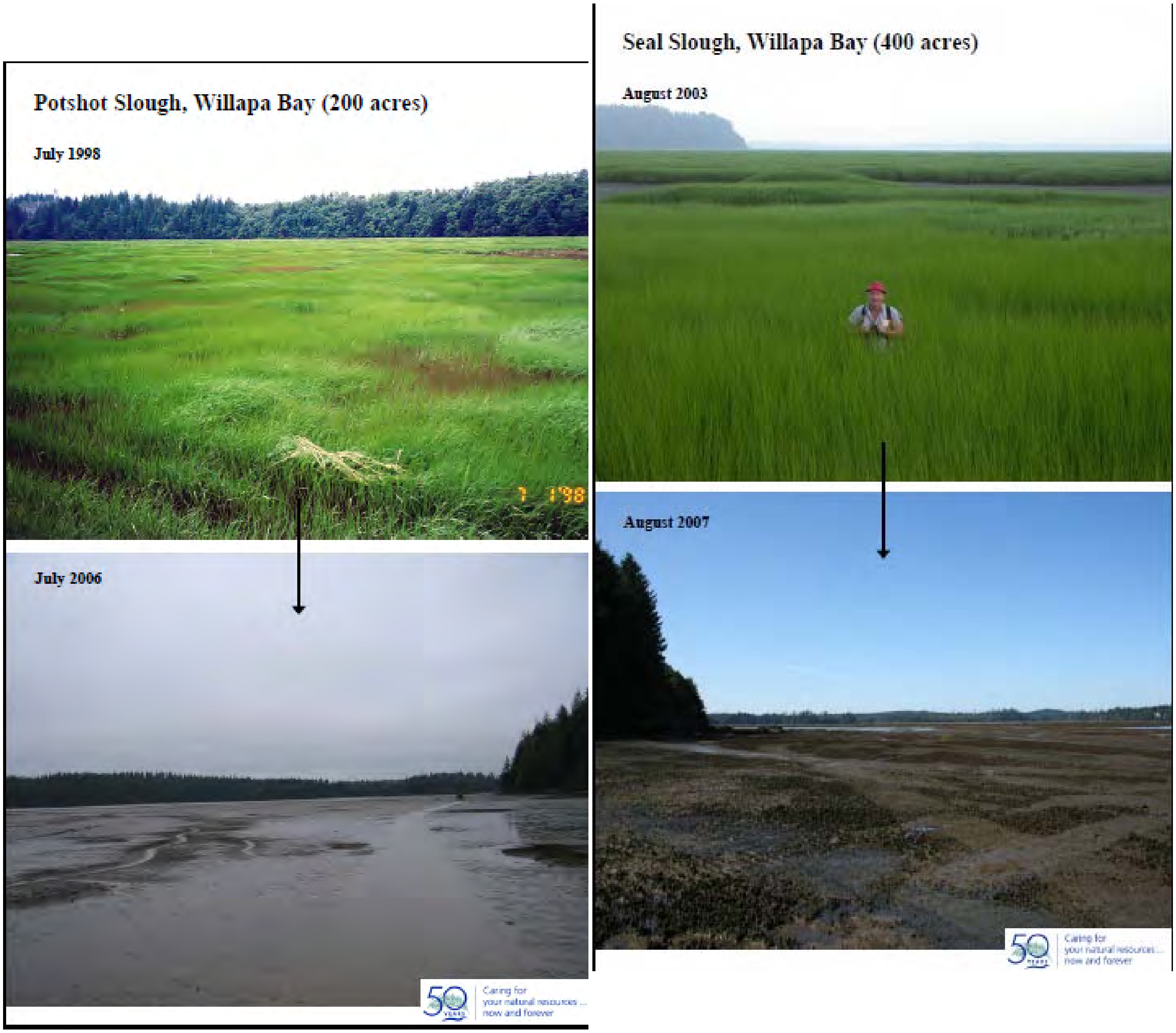


Figure 10-2 *Spartina* removal in Willapa Bay (source: WDNR)

MM 11 LARGE WOOD PLACEMENT

Definition

Large Wood Placement, also referred to as LWD placement, addresses the placement of (unmilled) wood in the nearshore, particularly large tree trunks with rootwads, within the backshore, or otherwise in contact with water. The objective of *Large Wood Placement* projects can vary considerably, but this management measure generally aims to replace or enhance upper beach structure that has declined as a result of reduced LWD in Puget Sound nearshore environments. This is a structural management measure that can enhance conditions, while LWD recruitment processes are restored. *Large Wood Placement* projects can be designed to achieve the following objectives: enhance shoreform structure, reduce shoreline erosion rates, and enhance marine riparian ecotone, aquatic productivity, and/or habitat complexity. Wood placement can provide erosion control functions by reestablishing the storm berm, thereby increasing wave energy absorption and structure of the upper beach. LWD can be placed singly or in groups, with or without rootwads, partially buried and/or anchored, or simply placed on top of the beach substrate, to produce the scale and function required for each application. LWD should be large enough that it remains functional while natural LWD recruitment develops. This measure is commonly used in beach nourishment and habitat enhancement projects. This measure does not include strapping or cabling LWD to existing shore armoring.

Justification of Need and Link to Nearshore Processes

The need to place LWD for increased habitat complexity and other structural functions is justified by the reduction of LWD in Puget Sound nearshore environments, both from direct removal and reduced LWD recruitment (Maser and Sedell 1994, MacLennan 2005). Riparian deforestation largely eliminated the formerly wooded shorelines of rivers and marine shores that historically contributed a steady supply of LWD. Physical removal of LWD from streams, rivers and marine waters was (historically) conducted throughout the Puget Sound region to improve navigation (1850-1920), facilitate log transport (1880-1915) and improve fish passage (1950-1970, Maser and Sedell 1994) and still occurs today to a lesser degree. The proliferation of shoreline armoring contributed to the shortage of nearshore LWD by blocking LWD recruitment (by slowing or halting bluff erosion) and inhibiting the natural deposition of LWD by increasing wave reflectivity and reducing upper beach area, within which LWD would normally deposit (Holsman and Willig 2007).

While this is a structural management measure, large wood placement can mimic the natural process of wood recruitment to the beach or salt marsh that might otherwise take many years to occur naturally in a restoring system (in the absence of a major event that alters the natural development trajectory of the system). The increased habitat complexity resulting from large wood placement often affects localized sediment transport processes as well as biological processes like the germination of certain plants, microclimate for beach in fauna, and attachment substrate for sessile invertebrates and boring organisms. Large wood placement can also be used to reduce shoreline erosion and replicate historic processes beneficial to many organisms, including salmonids.

Large wood placement can be applied on most Puget Sound geomorphic shoretypes, excluding rocky shores. Success has been more frequently observed along shores with low elevation backshores ("no-bank") such as barrier beaches, and within embayments. Fewer successful installations have been documented in deltaic environments and along bluff-backed beaches, although such projects could be successful if wood were present there naturally. The targeted response time of an LWD installation depends on the specific objectives of the installation; however most applications will provide an immediate response.

Since the goal of restoration is to return an area to its pre-disturbance condition, large wood placement should mimic the geomorphic structure and functional response of LWD that is deposited naturally or that occurred historically when LWD was more abundant in the nearshore. Large wood placement influences local geomorphic processes by providing additional physical structure (stability/structural foundation) to shoreforms such as spits and barrier beaches. It can also influence local sediment transport, promotes deposition, and tide channel formation and maintenance.

Where large wood placement is used to slow erosion, it can effectively function as part of a storm berm to absorb wave energy. This reduces erosion of the landward shore and deposition of fine sediment that would otherwise be transported down-drift. Winds deposit fine sediment in the lee of LWD in some exposed areas such as shores of the Strait of Juan de Fuca. The accretion of fine sediment enhances beach microtopography such as storm berms or depressions in salt marshes. Unique vegetation communities colonize these features and increase the species richness/diversity of the nearshore ecosystem. LWD can also function as substrate for dune and riparian vegetation (Hood 2007, MacLennan 2005).

LWD that is placed can affect several ecological functions and processes similarly to naturally occurring wood. For example, it can function as part of the detrital food web, such as food for wood degrading (boring) organisms, and provide microclimate effects such as benthic moisture retention and reduced temperature regimes. Microclimates can aid in the survival of forage fish spawn and invertebrate communities that serve as food for a number of nearshore species, including salmonids (Tonnes 2008). Geochemical processes can be directly affected by large wood placement as LWD is a major component of the carbon nutrient cycle, and can serve as substrate for nitrogen-fixing vegetation (Hood 2007). This management measure can also provide refuge from predation for migrating fish that forage upon prey items residing on or around LWD. An example is juvenile salmonids that feed on amphipods and insects in high intertidal habitats (Cornu et al. 2007, Toft et al. 2004, Sobocinski 2003, Williams and Thom 2001). Large wood placement can also benefit wildlife habitat as the wood provides habitat for nesting, foraging, and feeding for a number of bird species found in the Puget Sound region (Brennan 2007).

LWD pieces embedded in the beach can influence the location of tide channels by altering tide channel hydraulics (in a similar process to LWD in fluvial environments). LWD acts similarly in distributary channels, where it can aid in forming logjams that influence channel morphology and flow and channel geometry. An example of the geomorphic effects of LWD on distributary channel migration can be seen in the lower reaches of the Nooksack River in Whatcom County. Experiments in placement of LWD conducted in Oregon by the South Slough National Estuarine Research Reserve documented process and functional responses to LWD placed in the lower reaches of a fluvial system (Cornu et al. 2007).

Conceptual Model

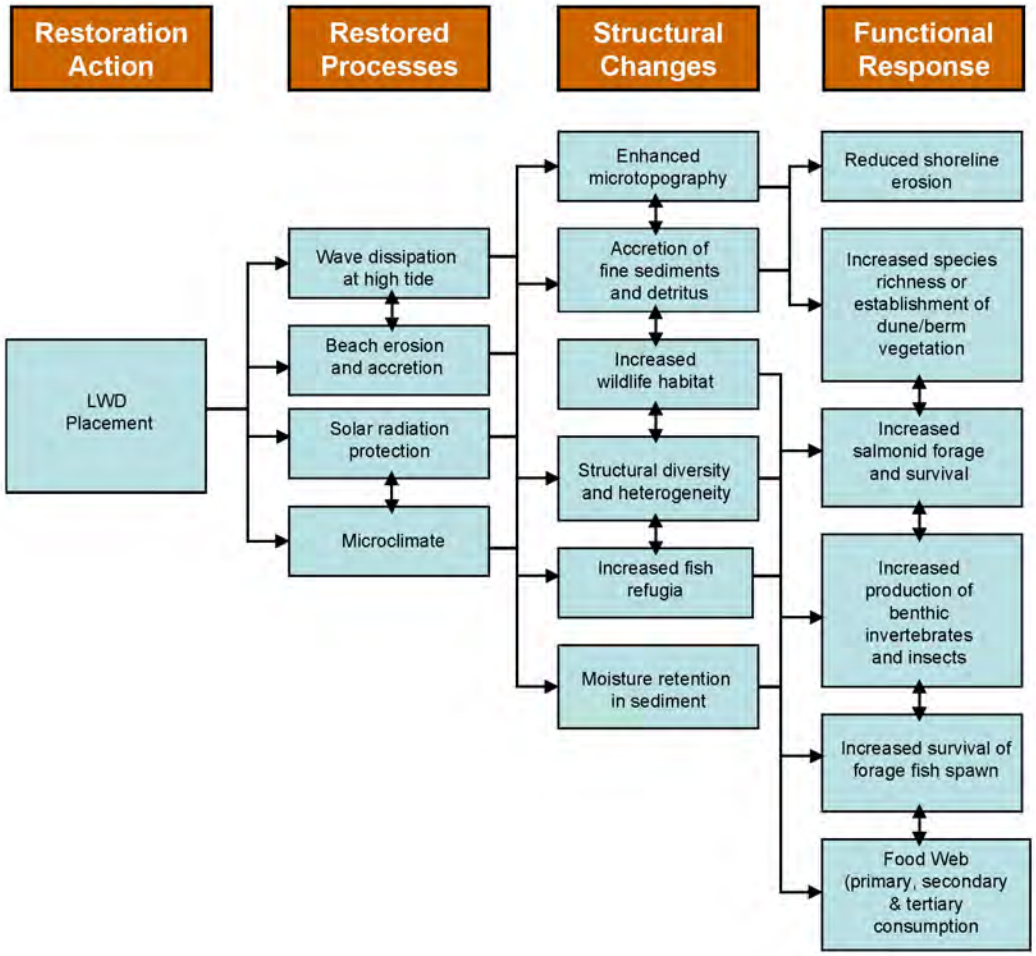
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 11-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Shoreline areas that have in the past been characterized by the presence of LWD, no longer have significant LWD remaining, resulting in increased erosion and less habitat diversity.

Change/Action: Large woody debris is placed at a supratidal portion of a beach to reestablish a storm berm to slow erosion and provide enhanced habitat functions.

Predicted Response: LWD partially buffers wave attack, slows erosion rate and traps and stores (fine) sediment and other organic material which leads to more complex microtopography, increased dune/berm vegetation richness and cover, substrate heterogeneity, nutrients, and moisture. Microclimate effects from added wood and cover aid in the survival of forage fish spawn and benthic invertebrate and insect production, thus resulting in increased forage opportunities, and functional refugia for migrating salmonids, and an increase in avian nesting and breeding opportunities.

Figure 11-1 Conceptual Model for Large Wood Placement



Complementary Management Measures

Large Wood Placement is commonly used as a design feature in *Beach Nourishment* projects and surge plain/tidal channel enhancement projects (e.g., *Hydraulic Modification*). This measure can also be used as part of *Armor Removal or Modification* measures that require erosion control around beach access or as part of soft shore protection. *Species Habitat Enhancement* projects can also incorporate *Large Wood Placement* when targeting enhancement for species known to use the supratidal and the marine riparian ecotone. *Large Wood Placement* can complement other management measures such as *Revegetation*, *Topography Restoration*, and *Substrate Modification*. Since some *Debris Removal* efforts can yield wood that is appropriate for use in LWD projects, *Debris Removal* is another complementary measure.

Benefits and Opportunities

Benefits of the Restoration Action

Placement of LWD creates a number or short and long-term benefits including the following:

Habitat enhancement: Large wood placement benefits upper beach habitats by increasing local deposition of fine sediments and organic material (including additional LWD), allowing greater substrate heterogeneity, moisture retention in sediment (Tonnes 2008), and providing substrate for dune and riparian vegetation, habitat for nesting, foraging, and feeding for a number of bird species. It also provides food and habitat for wood degrading (boring) organisms, and offers fish refuge from predation in aquatic environments (Cornu et al. 2007, Toft et al. 2004, Sobocinski 2003, Williams and Thom 2001, Brennan 2007).

Improved habitat for special status species and valued ecosystem components: Many species of plants and animals that are afforded special protection status under the state and federal regulations, such as salmon and forage fish, rely on the nearshore environment and functional backshore habitat. This measure can improve habitat function for these species, and for the food sources upon which they rely.

Increased beach (backshore) complexity: Large wood placement can enhance the complexity of the supratidal or backshore areas of the beach by increasing beach microtopography, species richness of dune and marsh vegetation assemblages, and substrate heterogeneity. When used to re-establish a storm berm as an alternative to shoreline armoring, this management measure supports the preservation of coastal processes which maintain the regions' beaches and bluffs, which PSNERP has been identified as VECs.

Marine riparian function and connectivity: This management measure can facilitate vegetative succession processes by contributing to the structural complexity of the marine riparian zone. LWD can function as a higher elevation substrate above MHHW for upland riparian species (MacLennan 2005, Hood 2007) and increase biodiversity of dune flora and fauna. By installing LWD, projects may enhance biological conditions faster than relying on natural LWD recruitment from restored/revegetated marine riparian areas. Marine riparian areas are also a VEC.

Increased resilience to erosion and storms: Large wood placement as a means of reestablishing a storm berm raises beach elevations (usually in conjunction with *Beach Nourishment*) and reduces the vulnerability of landward structures to wave damage and erosion. LWD that is anchored into the storm berm can dissipate wave energy that might otherwise erode the backshore.

Improved public access and recreation: Large wood placement can be used to protect beach access as an alternative to hard armoring, and can be placed in backshore areas favored for recreation. It can also be used to direct foot traffic (to reduce trampling or disturbance) around revegetated areas.

Improved aesthetic: Large wood placement (especially when used as a complimentary management measure to *Beach Nourishment*), can greatly improve the aesthetic of backshore areas, which is the portion of the beach most favored for recreation.

Measureable Units

The appropriate metrics to measure the benefits of large wood placement projects depend upon the objectives of the project and the specific benefit being sought. Habitat benefits could be measured by assessing changes in the abundance or richness of the species of interest. Standard methods exist for such measures for most species that use the nearshore, and should be used when available. Changes to physical processes should also be measured using standard methodologies such as: sediment grain size analysis (for sediment composition), high resolution beach topographic surveying/mapping (for sediment volume, topography, mapping sediment type, position of LWD relative to sediment, and other beach features of interest), and historic air photo analysis (for better understanding historic conditions and baseline erosion rates). Measuring social benefits such as improved access, recreation and aesthetic are considerably more subjective but might include analyzing the use of the site for recreation or conducting surveys of the individuals that recreate there to determine what brings them to the beach or if and how they value the enhancement of the site. Physical metrics that provide an indication of project success include number and distribution of LWD pieces and residence time of the wood.

Opportunities for Implementation

Large wood placement can be applied to many restoration (or enhancement) sites at all levels of intensity. It is appropriate for most Puget Sound shoretypes, excluding rocky platforms and plunging rocky shores, as LWD was historically present along most Puget Sound beaches. Innovative applications are still being developed and applied. The success of experimental large wood placement projects is limited due to the dynamic nature of the nearshore and the lack of best management practices on how to construct different large wood placement options. Likely implementers are private landowners, city and county governments, tribes, and community groups. Large wood placement may also be included with larger restoration (or enhancement) projects implemented by industryMRCs, and non-governmental organizations. Opportunities to implement this management measure could also exist as part of compensatory mitigation projects.

Many existing shore protection structures (e.g., bulkheads) on Puget Sound were constructed many years ago and are or will be reaching the end of their usefulness. Where feasible, bulkheads and other hard armoring could be replaced with soft shore protection that incorporates large wood placement. LWD processes can also be restored through shoreline stabilization techniques that utilize vegetation that could later be recruited to the beach. This is consistent with state Shoreline Management Act policies that favor alternatives to ‘hard’ armoring where technically feasible and encourage property owners to demonstrate the need for armoring when no other alternatives are practical. This creates opportunities for private landowners to consider large wood placement as a means to comply. Where applied along public shores, large wood placement can offer opportunities for educating the public about beach processes and habitats through signage, volunteer monitoring and maintenance, and demonstration value.

Constraints

Dynamic environment: Anchoring and/or placing LWD in dynamic environments (e.g., tide channels/distributaries) can prove problematic where dynamics are not well understood. This is especially true where conditions are expected to change as a result of climate change and sea level rise. Increased occurrence of storm surges and other flood events must be considered when deciding on the elevation of LWD placement.

Navigation hazards: Unanchored LWD can become a hazard to navigation in some instances. Using unanchored material in areas where this could be a problem should be avoided.

Available area for installation: Adequate supratidal area for installation is required to place LWD at the appropriate elevation within the beach profile.

Upland erosion: Structures/ infrastructure in close proximity can be a limiting factor in site selection because LWD placement can slow erosion rates but not halt erosion entirely. Also, LWD that is not well anchored can become mobile in storms and damage nearby infrastructure.

Availability and cost: It can be difficult to obtain large pieces of LWD of appropriate species, especially with intact rootwads. Transportation logistics can be challenging and expensive, especially along bluff-backed beaches and in deltaic environments. Helicopters have been used to deposit LWD in strategic locations, which can be very costly.

Climate change: Increased storm frequency, magnitude and occurrence of high water events (associated with *El Nino* conditions as well as storm surges) are all anticipated as a result of climate change. High water events could result in mobilization or loss of unanchored LWD and contrasting conditions from what the LWD placement project was designed to endure.

Sea level rise: Inland migration of the shoreline associated with sea level rise may result in anchored LWD being placed too low on the beach profile over future decades. It also would likely result in unanchored LWD being remobilized and carried offshore or deposited further landward and the shoreline naturally transgresses.

Best Professional Practices

Feasibility Assessment

Prior to initiating large wood placement specific goals and objectives should be outlined for the project. The subject site should be evaluated to determine if large wood placement is appropriate and if there are potential constraints that could limit the likelihood of project success. Determining the feasibility of a large wood placement project typically includes many aspects that are also critical to project design. Feasibility assessment of a large wood placement project should in all cases incorporate a thorough understanding of local coastal processes, the existing erosion rate (if being used to reduce erosion rates), existing habitat usage, wave energy and anticipated run-up, presence of additional stressors such as strong tidal currents or substantial vessel wake.

LWD can be placed singly or in groups to produce the scale and function required for each application. Objectives of the application shape design parameters. As in most projects, the available budget influences what can be purchased and delivered to sites, which are often quite remote for truck access. Refer to documents on approaches to alternative erosion control (Zelo et al. 2000) and evaluations of where large wood placement has been successful (Gerstel and Brown 2006).

Design and Implementation

Identifying the key objectives of the large wood placement (e.g., backshore/marine riparian structure, *Species Habitat Enhancement*, erosion control) is a necessary first step prior to design. *Species Habitat Enhancement* projects generally have flexibility in terms of placement location and appearance. When LWD is incorporated into a soft shore protection scheme, the desires of private residents may not allow for placement of very complex (high relief) designs or locations far enough landward. Design considerations should include:

- Wave energy and anticipated wave runup
- Additional stressors such as strong currents or substantial vessel wakes
- Approximate rate of background erosion for the site
- Determination of the appropriate elevation of wood placement for the shoretype and wave environment
- Assessment of adequate space to place the LWD at or above the appropriate elevation
- If LWD will be used as stand alone or in conjunction with other management measures

- Is partial burial appropriate and to what degree
- If anchoring LWD is necessary or required to fulfill objectives
- Availability and cost of various sizes and types of LWD
- Associated dune/riparian plantings

One of the most critical design criteria for project success is the elevation where the LWD is placed. If LWD is placed too low in the beach profile it can result in beach scour beneath the structure and project failure. Large wood can be placed at a wide variety of sites, but it will be more stable at lower energy shores. Similarly, if background erosion is high then a more conservative landward position should be used. If LWD is simply to be reintroduced to the local system for habitat, anchors are not needed. The use of anchors is only needed at sites where LWD is important for erosion control or specific habitat goals in certain areas. LWD should be of a size that it can remain functional in the application for a substantial period of time.

Large logs with intact rootwads are optimal because, if partially buried, the complexity of the rootwad helps to anchor the log in place. LWD with rootwads also function better as refuge for fish and traps for fine sediment and organic material (including additional wood) than LWD that is more cylindrical in shape. Conifers, particularly Douglas fir and western red cedar, should be used as the source of the LWD to protract longevity in wet environments. Deciduous woods can be used depending on the application. Treated wood should never be used.

The use of partially buried LWD can aid in retention, with large or “key pieces” partially buried and pinning other pieces in place. These larger pieces can be oriented to trap naturally recruited LWD, for example acting as traps oriented towards the dominant wave direction. LWD may be attached to buried concrete anchors for additional stability in high wave events, but the durability of some methods such as stainless steel cable may be less than expected. Small anchors such as Manta Ray or duckbill anchors have been used, but the long-term reliability of these is not clear. Buried deadman anchors such as large concrete well below an existing grade offer a reliable and economic approach. Disturbance when installing these larger anchors may be an issue, but it appears that this disturbance is extremely short in duration. Project designers should take steps to prevent risk of additional damage if anchors and cables partially release or create focused, repetitive impact in the event of partial scour and mobilization.

Nearby reference sites can serve as useful examples of appropriate elevations for large wood placement. Other than at very low energy sites, LWD should not be installed at or below MHHW. Most typical installations should be placed several vertical feet above MHHW.

Evaluation

Monitoring of large wood placement projects should address the specific objectives of the management measure and associated habitat and/or erosion control installation. This may be measured in terms of maintaining design characteristics (wood mobility, wood density/count, and sediment composition) and/or can be geared towards characterizing habitat features. Large wood placement projects that are more focused on improving nearshore habitats should monitor project performance using standard methods for target species/habitats such as changes in vegetation cover and species richness. Refer to *Species Habitat Enhancement* management measure for guidance.

Physical monitoring of large wood placement should include topographic mapping/ surveying conducted prior to and following wood installation as part of a baseline survey. Subsequent annual monitoring should be carried out in the same season and should aim to measure changes in beach/berm topography, sediment composition, position of ordinary high water mark, vegetation assemblages, etc.

Case Studies and Examples

Because most LWD installations in the nearshore have had the objective of providing some form of erosion control in an environmentally acceptable fashion, several projects are highlighted here that began as erosion control projects. Since monitoring for this type of project is virtually non-existent, (Gerstel and Brown 2006) there is clearly a need for a detailed analysis of LWD project success.

Blake Island State Park, Central Puget Sound: Blake Island is located in the Central Puget Sound, between southern Bainbridge Island and the north end of Vashon Island. The project site is just south of the boat basin on the northeast corner of the island. Construction of the boat basin on an accretion shoreform and construction of a breakwater that extends into deep water caused the disruption of net shore-drift sediment from the north (Zelo et al. 2000). This and the loss of fill prompted the project, which was initiated by Washington State Parks and incorporated large wood placement along with *Beach Nourishment, Revegetation, and Topography Restoration*. The site is approximately 600 feet long and was designed by Worthy and Associates. Construction of the project occurred in 2000. A berm was built up through *Beach Nourishment* and the “aesthetic treatment” was applied surrounding the cap of the new sheet pile wall. This consisted of logs cabled to ecology block anchors buried well below beach grade and berm and backshore vegetation plantings landward of the logs (Figure 11-2).

Private residence, Whidbey Island: A reach of no-bank shore of northwest Whidbey Island had experienced recent, rapid erosion. The owners applied for a bulkhead permit. Island County denied the permit on the grounds that that the house was not imminently threatened. The owner then pursued the use of alternative soft shore protection methods using LWD. Coastal Geologic Services developed an anchored log design that was oriented to trap natural LWD in the backshore, within the preexisting drift log zone. This shore has a moderately high amount of LWD of a wide variety of sizes, some of which were used along with imported logs. Logs were chained through concrete ecology blocks buried at least 3 feet below beach grade. The project was installed in 2008, and was not monitored in any detail (Figure 11-3). The site had attracted a small amount of additional wood in its first year. Total project cost was approximately $13,500.

Narrows Park, Key Peninsula: Narrows Park is located on an erosional shore subject to the unusually high tidal currents and deep water of the Tacoma Narrows. Anchored logs were installed on the upper beach using vertical steel posts in an erosional area down-drift of a concrete stream outfall. One element of the project that is uncommon was the completely rigid nature of the anchoring scheme, which unfortunately was located in an erosional area. The logs have been up in the air for several years (Figure 11-4). This project illustrates the need to have logs far enough into the backshore and to avoid the use of completely rigid anchoring systems.

Stillaguamish Tribe and The Nature Conservancy, Stillaguamish Delta: This experimental project was unfortunately unsuccessful due to the technique applied to place the LWD. LWD was “placed” via helicopter, where it was dropped from the air, based on the assumption that the LWD piece would penetrate through the delta sediments similarly to a lawn-dart. Unfortunately this assumption was flawed in that the LWD did not penetrate through the sediment and was carried off-site during the next tidal cycle.

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Figure 11-2. Blake Island State Park beach anchored log and beach enhancement design cross section (Zelo et al. 2000).

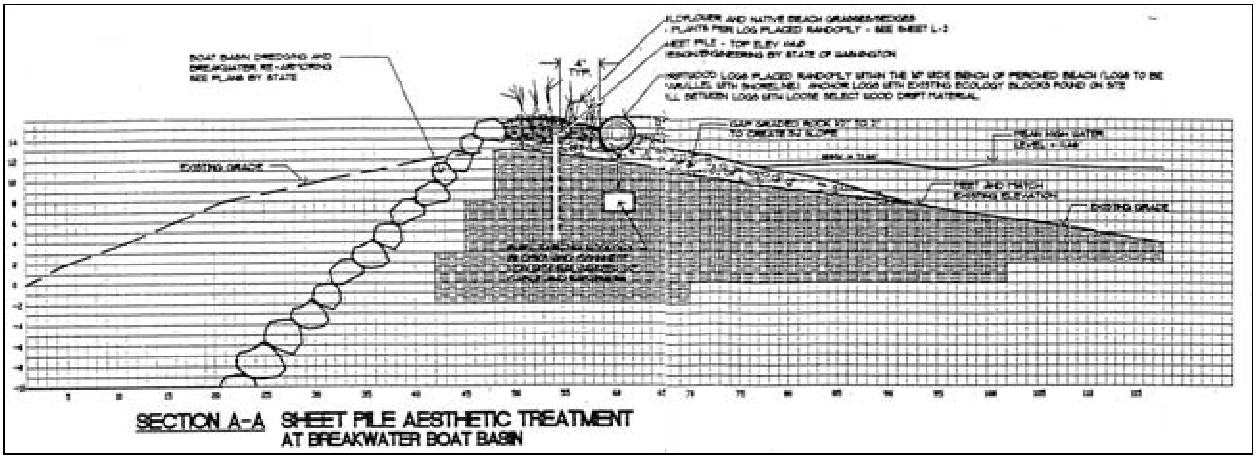


Figure 11-3 Anchored LWD project for erosion control immediately after installation in 2008 (Coastal Geologic Services).

Figure 11-4 Tacoma Narrows Park anchored LWD project in 2006 (Hugh Shipman).

MM 12 OVERWATER STRUCTURE REMOVAL OR MODIFICATION

Definition

This management measure pertains to the modification or removal of overwater structures such as piers, floats, and docks. Removal of such structures reduces shading, allows sunlight to reach the water surface, and can also help restore natural wave energy regimes. Common examples of modifications include changes to components of piers or floats, such as reducing overall the deck surface area, using grating to allow ambient light penetration through the structure, and moving/replacing treated wood piles with steel or concrete to reduce the leaching of toxics. Removal of an overwater structure typically involves the use of a floating barge with equipment to remove pier decking and supporting beams and piles.

Justification of Need and Link to Nearshore Processes

Overwater structures are common within Puget Sound, particularly in developed areas. These structures range from large industrial pier aprons (parallel to the shoreline) to fixed pier, ramp, and float configurations primarily constructed for single-family residences. These structures usually incorporate pilings for support or stability and provide moorage for commercial and recreational vessels of varying sizes, ranging from containerized cargo ships (at port facilities) to small private vessels.

Overwater structures are typically located in intertidal and shallow subtidal areas and can therefore impact a number of important physical and biological processes within this zone. Nightingale and Simenstad (2001) identify four habitat controlling factors—ambient light regime, wave energy regime, substrate, and water quality—that can be altered by overwater structures. These controlling factors in turn, can impact key ecological functions of spawning, rearing, and refugia. In particular, overwater structures have been documented to deflect or delay migration, limit prey production and availability, and alter predator-prey relationships associated with changes to nighttime lighting. The specific effects of the structure on ecological functions vary according to the location of the structure, its physical characteristics and use, and the condition of the surrounding landscape.

Docks, piers, and pilings can shade the water surface and limit the light available for plant photosynthesis. Distributions of invertebrates, fishes and plants beneath overwater structures have been found to be much reduced compared to adjacent unshaded areas. Structure height, width, materials, and orientation determine the shade footprint. Other impacts of shading include sharp underwater light contrast during daylight, which impacts fish migration behavior and increases mortality risks. Similarly, at night the use of artificial light also produces sharp underwater light contrasts, which affect migration but also the behavior of predators. This is in addition to the decrease in refugia for fish due to the lack of vegetation.

Overwater structures impact the local wave energy regime and sediment transport patterns. This can interfere with the natural evolution of beaches and spits and the substrate required for plant propagation, fish and shellfish settlement, and rearing and fish spawning. For example, Shteinman and Kamenir (1999) demonstrate how jetties and other in-water structures can partially or completely disrupt the longshore transport process, with smaller size sediments accumulating near the shore and coarser sediments moving towards the deeper areas—the reverse of the natural situation.

In addition, pilings that support the docks or piers can impact the substrate by changing the bottom bathymetry. Currents flowing past the piles induce scour which rearranges the sediment distribution. Heavy fastening chains or anchor lines that drag across the bottom during tide or wind events can cause scouring and disturbance of vegetation.

Grounding of floating docks, mooring buoys, and vessels often leads to the total loss of eelgrass beds and alteration of the benthic invertebrate community (Nightingale and Simenstad 2001). The risk of contact between floating structures and marine vegetation and substrate is greatest during low tides. Floats and piles can also act as substrate and settlement sites for invasive species.

Construction of overwater structures disturbs physical habitat. Pile driving directly affects benthic communities, and noise associated with piling driving operations may affect the distribution and behavior of salmon and other fish and wildlife species (Feist et al. 1996). Construction can also have indirect effects due to barge groundings and scour. Overwater structures provide moorage for vessels that can cause propeller wash (scouring of sediment), which disturbs submerged vegetation and benthic communities.

Cumulative effects are important (Nightingale and Simenstad 2001). To the degree that each dock structure alters the light, substrate, and wave energy regimes of nearshore habitats, it directly influences the potential that the system will suffer cumulative effects. Unfortunately, it is difficult to quantify the number of docks or piers a given area can support before impacts reach a threshold over which the nearshore habitat will no longer be able to support the biologic assemblages native to it.

Conceptual Model

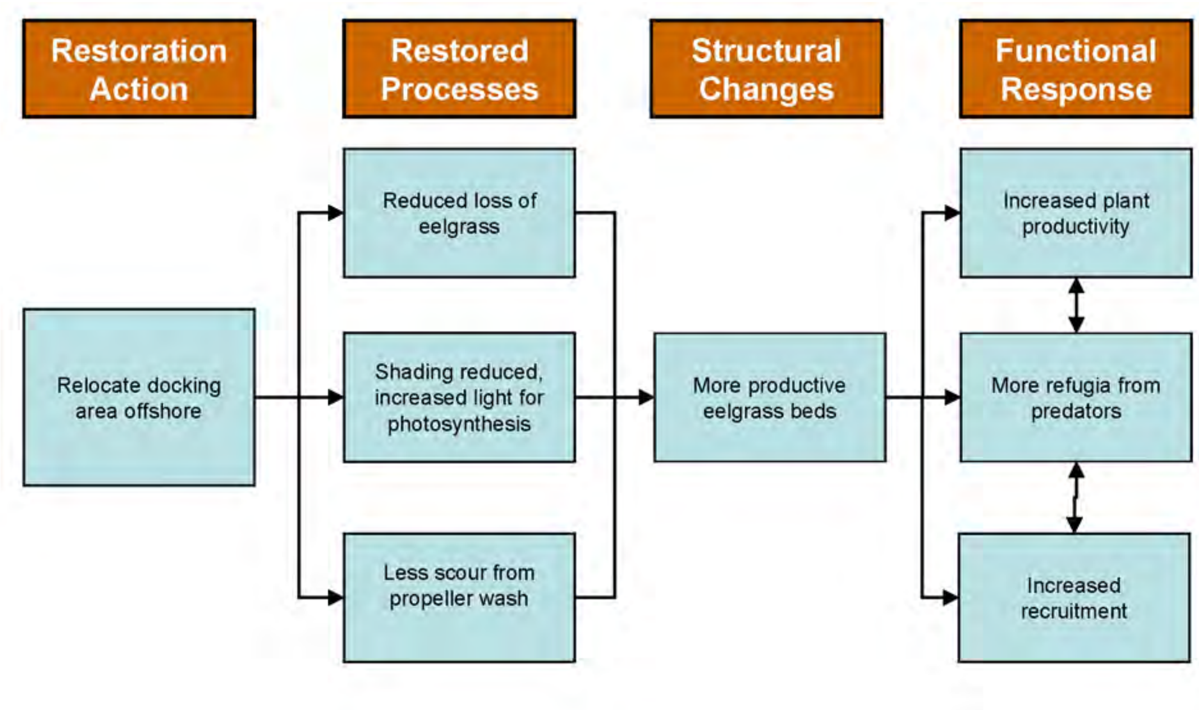
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions. The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Shading by docks limits invertebrate fish and plants; sharp underwater light contrast impacts fish migration behavior.

Change/Action: Relocate docking area offshore; reduce impact of docks by raising and narrowing structure; use open grating on decking to allow under-dock light transmission.

Predicted Response: Recovery of physical processes by providing more ambient light to the water surface and the water column (Figure 12-1). Increases light available for photosynthesis; increases plant productivity and provides more refugia from predators.

Figure 12-1 Conceptual Model for Overwater Structure Removal or Modification



Complementary Management Measures

Overwater Structure Removal or Modification uses similar construction techniques and equipment as *Debris Removal*, and quite often involves this additional measure due to past practices at industrial sites. It is also similar to *Contaminant Removal or Remediation* in cases where treated wood pilings are removed. Because the primary objective of *Overwater Structure Removal or Modification* is commonly to restore ambient light penetration to the water surface, it is dissimilar to *Debris Removal*, which is frequently targeted at materials located in or on the substrate. *Overwater Structure Removal or Modification* is sometimes used in combination with *Armor Removal or Modification*, *Large Wood Placement* and *Revegetation*. This measure has similarities to *Groin Removal or Modification* since some overwater structures produce groin-like effects. *Overwater Structure Removal or Modification* can also be used as a stand-alone measure.

Benefits and Opportunities

Benefits of Restoration Action

Removing or modifying overwater structures can lessen the impacts that these structures have on nearshore systems, which can result in several benefits. However, the level and specific nature of the benefits depends on many factors including the structure type and location and the condition of the surrounding area. Furthermore, structural removal/modification may be more beneficial in some geographic areas than in others and the types of benefits accrued may vary by geographic area. For example, removing large piers and docks from areas of active littoral transport may be very beneficial in terms of restoring sediment transport dynamics. The benefits of increased light transmission (as a result of structure removal or modification) are most likely to be realized in areas that support eelgrass. Other benefits of this measure include:

Reduction in cumulative effects: The removal of overwater structures, particularly in heavily developed areas, can reduce cumulative effects and assist in recovery of physical processes (primarily ambient light and wave energy regimes). Existing structures can be modified to reduce their effect on these physical processes. Grating can be incorporated into existing structures to allow greater ambient light.

Experimentation: There are opportunities to experiment with the removal or modification of overwater structures. These allow the evaluation of potential changes to nearby physical and biological processes.

Recreation: Removal of structures in areas with public access may permit enhances recreational use of the shoreline. Educational signage explaining nearshore habitat processes and functions can be incorporated for the public.

Opportunities for Implementation

Opportunities to modify existing overwater structures to incorporate open grating and other elements to reduce impacts are abundant in Puget Sound. Modifications such as relocating the structure in deeper water may not be justifiable on their own and may have to be undertaken in conjunction with a refurbishment project. Complete removal of the structure may also require a complementary project that provides the same service as the old structure but with fewer impacts. This measure is likely to be employed by private landowners who want or need to address aging docks, by Ports (at marinas and other sites), and by transportation agencies (such as at ferry terminals).

Measurable Units

Metrics for measuring benefits of modification or removal could be measured in terms of area of eelgrass before and after the project. The impact of the structure on migration patterns and the number and species of predators could also be monitored. Changes in the area of nearshore habitat shaded by overwater structures can also be evaluated over time.

Constraints

Cost: The cost of demolition or modification is principally based on tonnage and type of material removed, ease of site access, and distance to the nearest landfill site. In the case of modifications, the product types used in the rebuilt structure strongly influence cost as well (e.g., cost of grating or new steel piles).

Uncertainty: There is considerable uncertainty about the effects and benefits of this measure on some ecological process and functions. Although we have a reasonably thorough understanding of the effects of structures on light levels and the benefits of increasing light penetration (reducing shading), we know much less about the impact of docks on local wave energy and sediment transport patterns. Consequently, it is more challenging to determine which features of overwater structures need to be modified to amplify or moderate these effects (Fresh 2009).

Urban location: Overwater structures tend to be concentrated in urban areas where land values are typically high. In addition, many of the larger overwater structures in urban areas are used for navigational commerce which makes the structures themselves very valuable. As a result, potential opportunities for complete removals may be limited in urban areas.

Contamination: Substrates below overwater structures may contain toxic materials from past industrial practices, adjacent offsite sources, or as a result of contaminants leaching from treated wood pilings. Contaminant remediation can substantially increase costs. In addition, complete removal of pilings may be problematic in circumstances where toxic contaminants occur below the substrate and may be mobilized during removal. The use of vibratory removal techniques will minimize impacts from pile removal in potentially contaminated sediments.

Soil stability: Large-scale removal of pilings at industrial sites may reduce soil stability, particularly during seismic events, thereby limiting the number of piles that can be safely removed in certain locations.

Best Professional Practices

The scope and detail of engineering studies vary widely, depending on the specific location, degree of certainty required, and the documentation requirements of permitting agencies. Professional judgment should be used to determine the appropriate risk and uncertainty of any project.

Feasibility Assessment

Removal versus modification: Removal of overwater structures, including pilings, provides the best approach for resolving adverse impacts, whereas proper modifications may diminish ongoing impacts while still allowing functional use of the structure.

Ambient light: Structural designs to allow maximum light transmission are required to protect the ecosystems marine fishes rely upon. Multiple overwater structures in marine waters can significantly change the immediate and surrounding marine and estuarine ecosystems.

Wave energy: The risks due to overwater structures require the assessment of wave energy and substrate effects on the shoreline environment. These risks require assessment at the drift-cell level before considering the addition of new structures.

Contamination: Project designers must assess sediment characteristics and contamination in addition to contingency planning, particularly for former industrial sites.

Soil stability: Site stability may be affected by piling removal, particularly in areas constructed with fill material. Wave attenuation provided by pilings can be significantly modified by removal and may cause increased erosion or accretion.

Design and Implementation

Design of piers, docks, and other overwater structures must comply with state and federal regulations. The USACE and WDFW require permits for docks and piers as do most local governments. Mooring buoys are regulated by the WDNR. Design parameters (size, width, materials, placement, equipment use, etc) as well as construction timing will generally be dictated by the permitting agencies. Some of the main design considerations include:

Fixed docks: Design approaches to mitigate the impacts of fixed docks include:

- increasing dock height to allow light transmission under the dock;
- reducing dock width to reduce the shade footprint;
- aligning the dock in a north-south orientation to maximize sun exposure beneath;
- placing the dock in deep waters to avoid intertidal and shade impacts;
- inserting glass blocks or open grating to allow under-dock light transmission;

- using under-pier artificial lighting during daylight hours; and
- using reflective paint to reflect light to under-pier areas.

Pilings: Design approaches to mitigate the impact of pilings include:

- using materials (such as concrete or metal) that reflect light;
- using the fewest number of pilings necessary to allow light into under-pier areas;
- driving piles during environmental windows that include protection for salmon migration timing and forage fish; and
- sleeves can be placed over pilings to isolate the structure and prevent direct exposure to attached organisms or their eggs.

Floats: Design approaches to mitigate the impacts of floats include:

- minimizing width to reduce under-dock shadow area;
- placing floats in deep water to avoid light limitation and grounding impacts to the intertidal;
- aligning floats in a north-south orientation;
- removing floats during the season of low use;
- incorporation of grated decks to allow ambient light transmission; and
- use of float stops to prevent grounding of floats located in intertidal areas.

During construction and subsequent operation of the dock/pier special consideration must be given to impact avoidance. Key considerations are:

Debris management: Dock materials including pilings may require disposal at specific landfills designed to accommodate treated wood.

Adjacent habitats: Marine vegetation adjacent to structures proposed for removal should be protected from construction activities that may adversely affect their growth and function (e.g., excess turbidity or sedimentation, toxic contaminant release, etc.).

Spill control: Use of grates for ferry docks where automobiles and trucks could be stationary for long periods produces potential for spills in to the waters below. This needs to be address in dock/pier design or through appropriate operational measures.

Evaluation

Maintenance: The lifetime maintenance associated with rebuilding or modifying an overwater structure should be considered in the planning phase of this measure.

Adaptive management: Empirical data on the effectiveness of modifications to overwater structures are not abundant, although a small number of ongoing studies are being conducted. Ensuring that future removal and/or modifications are adequately studied will improve design effectiveness.

Case Studies and Examples

Northwest Maritime Center Dock, Port Townsend: Port Townsend Bay supports extensive eelgrass beds, an essential habitat for salmon species and nursery habitat for other key species such as Dungeness crab and lingcod. From the 1850s, the city of Port Townsend developed an extensive waterfront that expanded over the water to give maximum waterfront access. Natural shorelines gave way to sea walls and streets supported by pilings, a construction practice still visible today. Eelgrass has been impacted by these overwater structures and associated shading. An underwater video survey of the Port Townsend waterfront showed gaps in the eelgrass cover adjacent to existing docks (Norris 1999).

Planning for the redevelopment of the derelict 1930s Northwest Maritime Center dock identified goals for both the design and the environment (Diefenderfer et al. 2004). A new demonstration dock was designed that would provide the desired moorage and public use yet allow nearshore habitat functions to be restored by minimizing human impacts. The dock was reconstructed in 2004 (Figure 12-2).

Site surveys and shade modeling showed that, of the controlling factors in eelgrass development, light availability was most likely to have inhibited growth with the existing dock design. A number of options were considered to increase ambient light reaching the water surface. The use of technologies above the surface of the dock interfered with small boat trailer access; the use of gratings with large holes was inconsistent with Americans with Disabilities Act (ADA) guidelines; and the use of shallow grating to accommodate low-angle light penetration did not meet structural specifications. Instead, stainless steel reflective panels were placed beneath the dock, to reflect ambient light under the dock.

In addition to increasing ambient light beneath the docks, a number of other measures were undertaken to reduce the impact of the structure on nearshore processes. The dock trestle was extended 60 feet farther offshore and reoriented to move the greatest area of overwater structure beyond the depth where eelgrass is typically found and minimize shading. The piles were changed from creosote wood to steel. The number of piles was reduced from 84 to 38 to minimize shading, contaminants, and turbulence (Figure 12-3). Grating was placed in strategic locations to reduce sharp underwater light contrasts which are a barrier to fish passage.

Clinton Ferry Terminal, Whidbey Island: Clinton Ferry Terminal is another example of a structure crossing eelgrass habitat. Washington State Ferries needed to expand the terminal holding area to accommodate more vehicles with increased ferry traffic. The conventional approach to dock expansion would involve simply widening the dock to accommodate more traffic. However, the original design would have resulted in the loss of approximately 10,280 square feet of eelgrass. Ferries and ferry terminals impact eelgrass in a number of ways; during preliminary analysis of the project, impacts on subtidal vegetation from shading and ferry propeller wash were identified as major issues.

To provide the required deck area but reduce impacts on the eelgrass, the choice was made to lengthen rather than widen the pier (Figures 12-3 and 12-4). By lengthening the dock, it was narrowed considerably from the original design to minimize the shading effect on the adjacent eelgrass in the shallower water. The ferry slips were moved further offshore to minimize the impact from ferry propeller wash on the eelgrass beds. These design modifications avoided impact to approximately 2,130 square feet of eelgrass. An existing fishing pier and float were moved offshore to eliminate shading, avoiding an additional 2,000 square feet of eelgrass habitat.

Shading was further reduced by the installation of glass blocks and reflective undercoating in parts of the terminal deck. Glass blocks were installed in the pedestrian walkway to let light through to the eelgrass beds, reducing the impact to 2,640 square feet of eelgrass habitat. As an experiment, certain areas of the underside of the new dock were painted with highly reflective white paint. The paint reflects any light that reaches under the dock, increasing light to the eelgrass beds.

In addition to eelgrass habitat, brown macroalgae, used by rock fish as feeding and resting habitat, was also impacted by the dock expansion. A rock mound was constructed as an area for brown macroalgae to colonize, resulting in rock fish habitat to compensate for the loss of the existing seaweed.

In conjunction with design solutions, which reduced the impact from 10,280 to 3,444 square feet of eelgrass habitat, efforts were made to mitigate the impacts of construction (Thom et al. 2005). Eelgrass that would have been harmed by construction at the Clinton ferry terminal site was stockpiled in seawater tanks offsite. These transplants have since provided donor stock for mitigation plantings at the Clinton site. In addition, the construction contracts required any construction-related damage to be mitigated at the construction companies' expense which included the surveying of any damage to the eelgrass beds.

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Figure 12-2 Extended and reoriented pier, Northwest Maritime Center Dock.

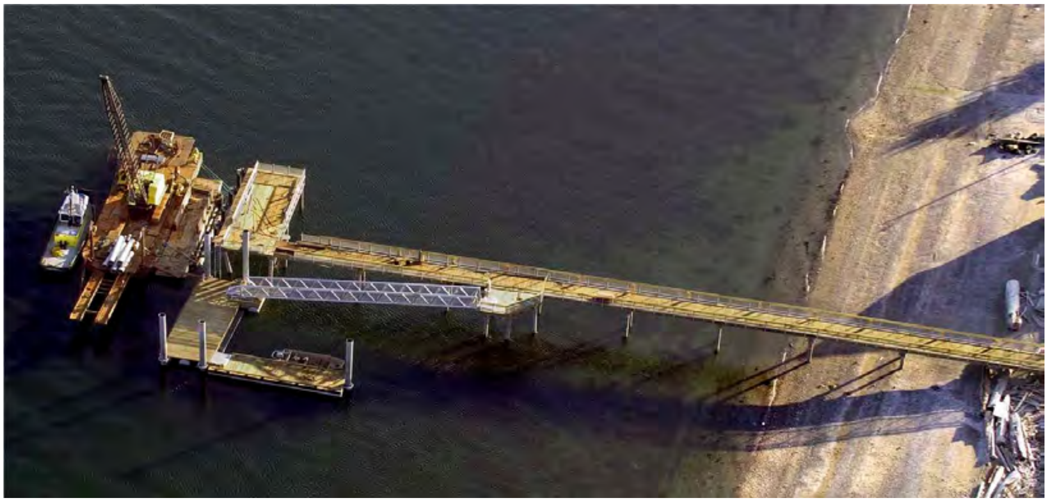


Figure 12-3 Removal of creosote wood piles, Northwest Maritime Center Dock.

Figure 12-4 Clinton Ferry Terminal during Phase I construction which widened the dock

Figure 12-5 Clinton Ferry Terminal after Phase I construction

MM 13 PHYSICAL EXCLUSION

Definition

This management measure pertains to the installation of exclusionary devices to direct or exclude human and/or animal use of a restoration area. The goal of the measure is to protect recently restored areas through installation of fences or barriers. *Physical Exclusion* is often required in conjunction with other management measures. Exclusion devices can be temporary or permanent features consisting of synthetic or natural materials. *Physical Exclusion* also includes placing features, such as boardwalks or mooring buoys, to exclude or prevent disturbance to sensitive environmental features (e.g., eelgrass or tidal marsh vegetation) or to focus human use toward more resilient or developed areas.

Justification of Need and Link to Nearshore Processes

Human and animal use of the nearshore, while important to maintaining a connection to ecosystem benefits, can be detrimental to fragile marshlands and intertidal habitats. Humans and animals can also disturb and disrupt the progress of recently restored sites. Once trails, openings, and cleared areas are established in or near restoration sites they often become focal points for further use and degradation. This often occurs on public lands and mooring areas that are open to the public, but private lands are also susceptible.

Excessive disturbance can alter or eliminate many natural shoreline processes, such as wood and other organic matter recruitment and retention, protection from solar radiation (shade), and intertidal plant and wildlife interactions. This is particularly concerning at restoration sites where *Revegetation* has been implemented since young plants need to be physically protected from humans and animals. Fences and other protective measures help ensure that long-term restoration goals are achieved. When applied proactively, these exclusion devices are very effective at precluding damage caused by trampling or consumption of plants by animals.

Conceptual Model

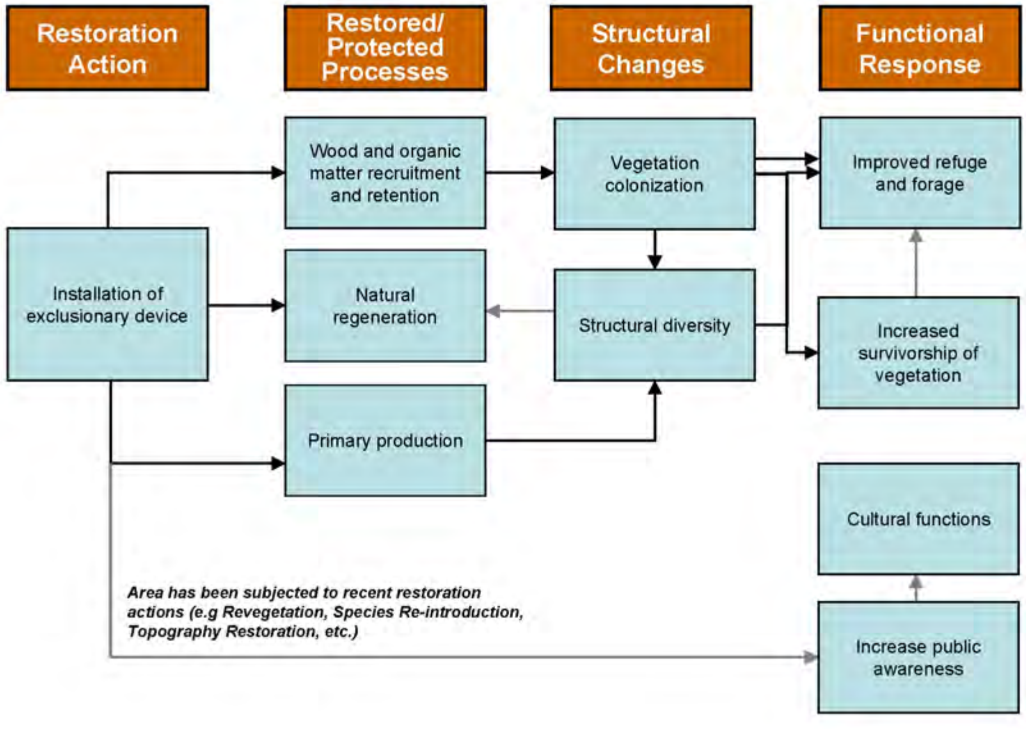
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 13-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Native animal species have been re-introduced and native plant species planted at a restored site. The plants and animals are susceptible to trampling and damage because the site is used for waterfront recreation.

Change/Action: Fencing and signage are installed at likely focal and access points to prevent disturbance by people and animals.

Predicted Response: Preserved or enhanced habitat for plants, fish, and animals.

Figure 13-1 Conceptual Model for Physical Exclusion



Complementary Management Measures

This management measure is directly related to *Revegetation* in that some species of plants can be used to minimize human disturbance or make foraging by wildlife less attractive, thereby providing *Physical Exclusion*. These same species, if used as part of the overall planting plan, do not constitute exclusion unless planted for that purpose.

This management measure also complements *Property Acquisition and Conservation* for areas that have been acquired for restoration or protection purposes. Restoration sites with goals for establishing and sustaining a fish or animal population (*Reintroduction of Native Animals*) would likely also use *Physical Exclusion* to protect the site from physical disturbance.

Benefits and Opportunities

Benefits of the Restoration Action

Physical exclusion can be designed and implemented to protect restoration sites, producing a variety of ecological, economic, and social benefits. In general, the benefits are directly related to the functioning of the restoration site and the specific actions implemented. However, the protection and preservation of natural areas contributes to additional ecosystem goods and services. Exclusion of animals or humans from a restoration site has cultural, spiritual, and aesthetic values associated with the recovery of the site. Proper placement of educational signs and exclusion devices can increase a sense of ownership and appreciation of the restoration site as described under the *Public Education and Involvement* management measure. It can reduce site maintenance and management costs (by minimizing the need for replanting or other corrective actions) and may protect public safety if the exclusion devices prevent access to potentially hazardous areas.

Measureable Units

The success or failure of physical exclusion activities can be measured qualitatively by assessing the level of disturbance and determining if it is acceptable based on the restoration goals. Implementers of this measure can monitor the degree of human-induced trampling of vegetation, herbivory, and other indicators of animal browse. Adaptive management strategies are often employed with this measure as physical disturbances are often site specific.

Opportunities for Implementation

Most opportunities for physical exclusion occur at publically owned restoration sites such as parks, refuges, and marinas. Excluded areas can also be used to provide education on habitat restoration and nearshore processes. Physical exclusion activities will likely be implemented by city and county governments, private entities, state and federal agencies, and non-governmental organizations. Implementation generally occurs at the site scale on any type of shoreform and is specific to the particular physical disturbance or threat.

Constraints

The use of physical exclusion is restricted by setting and place. Constraints associated with exclusionary devices should be carefully considered. Some constraints include:

Aesthetics: Physical presence of exclusion features may detract from natural views, which may be a priority for sponsors. Temporary exclusion features (netting/fencing) or use of natural materials and vegetation may reduce some aesthetic conflicts.

Conflicting uses: Restoration projects located on public lands may also have recreational opportunities (e.g. public parks and shoreline access points). Physical exclusion can be applied in a way that protects an area from human/animal disturbance and allows access to another area (focused access).

Cost: Cost of the exclusion device may be more than the damage potential. Maintenance of the feature, if permanent, will add costs.

Policy: The Shoreline Management Act encourages public access to public shorelines and waters, which may create a policy impediment to limiting public access to some restoration sites on public lands.

Best Professional Practices

The general phases of planning, designing and implementing exclusion activities are described below. Physical exclusion activities are highly site specific. The methods for deterring human and animal use should be determined on a case-by-case basis and take into account past failures and lessons from similar projects.

Feasibility Assessment

Determine threats: Assess the potential threats to the restoration site (beaver or waterfowl browse of newly planted vegetation; human trampling; etc.)

Land use: Plans for exclusion should consider the existing recreational or passive uses on the site or adjacent areas and the common traffic patterns.

Wildlife use: Exclusionary fences should consider the presence of wildlife and fish migration or movement corridors.

Design and Implementation

Scale: The amount and type of exclusion feature may vary within the site. Consideration should be given to aesthetic needs and extent of the feature given the topography and likely disturbance points.

Navigation: Installation of mooring buoys and other in-water exclusion devices must not impact navigation. Placement, markings, and materials must be consistent with state and federal regulations.

Fence/boardwalk siting: Exclusion features should be designed only to the extent required and sited in areas where they are consistent with the restoration purpose. Local conditions should be analyzed at the site to ensure proper materials are selected for the exclusion feature, particularly in tidally influenced areas.

Focused access: Consider providing focused access points that allow safe human access to water or other valued feature. In some cases, this will mean accepting that certain natural areas are going to be subject to human trampling.

Materials: Materials range widely from native plants to steel and concrete exclusion fences. Material choices will need to consider the types of disturbances to be limited, the aesthetic needs of the site, and access for maintenance. A typical example of split-rail wood fencing, commonly used at restoration sites, is presented at the end of this chapter. Vegetative fencing, such as densely planted trees or shrubs, can be more appropriate in some situations (Figure 13-2).

Waterfowl deterrents: Exclusion of waterfowl from tidal marshes (to allow growth/recruitment of natural or planted vegetation) is sometimes necessary (see attached examples). Typical fence details are based on the idea that ducks and geese are discouraged from landing in a given area if their landing approach and escape flight paths are obstructed (by appropriately placed wires and ropes). Deer netting attached to wood stakes is another approach (Figure 13-2).

Herbivory deterrents: The inclusion of protective devices at the base of newly planted trees and shrubs is common practice and highly recommended (Link 1999). One type of design detail is presented at the end of this chapter. Commercial-type “grow tubes” are also readily available (Figure 13-2).

Signs: Interpretive signs with exclusionary devices (for humans) can encourage a sense of public ownership by explaining why a restored area is valuable and should be protected.

Security: The purpose of physical exclusion in most cases is to provide security of a restoration or preservation site. Security levels for different types of exclusion features will depend on the type of disturbance to be limited and the potential for vandalism. Some fences such as split-rail wood fencing (Figure 13-2) are meant to designate or mark the boundary of a sensitive area, rather than protect from vandalism.

Maintenance: Where possible, select temporary features to minimize long-term maintenance costs and possible wildlife/aquatic connectivity impacts. Otherwise select natural features (vegetation) that will be low maintenance.

Evaluation

Monitoring: Develop a monitoring plan to assess project performance and maintenance of exclusion features.

Adaptive Management: Annual or bi-annual monitoring should assess damage or degradation of exclusion devices that informs maintenance needs. For example, waterfowl herbivory prevention systems (i.e., ropes and nets) will accumulate debris over time that needs to be removed. The level of maintenance and repair will be dependent on the success of the plantings and whether they can withstand exposure to waterfowl without deterrent devices (or require the exclusion to be continued for another season).

Case Studies and Examples

Skokomish Estuary, Mason County: In 2006, the Skokomish Indian Tribe removed approximately 3,600 linear feet of dike on the west side of Nalley Slough in the Skokomish River estuary. The project included removal of an elevated road network and restoration of 108 acres of emergent tidal marsh. An elevated boardwalk (approximately 3,000 linear feet) was also constructed to allow continued access but minimize disturbance to the estuary. The boardwalk is made out of concrete and allows tribal members access to harvesting and ceremonial areas as well as recreational access to Hood Canal beaches. The elevated walkway also allows tidal hydrology within the estuary. The property included the Nalley Farm and the Tribal Reservation near the mouth of the Skokomish River.

The 2006 project is the first part of a multi-phase effort to restore more than 300 acres of the Skokomish estuary to its historic conditions. Funding for the project came from the Estuary and Salmon Restoration Program. Additional support was provided by the Pacific Coast Salmon Recovery Fund, Washington Salmon Recovery Funding Board, City of Tacoma (land owner), Mason Conservation District, Mason County Public Utilities District No. 1 and Skokomish Tribal Nation. Other partners include the USACE, EPA, USFWS, NOAA, and WDFW.

Duwamish Restoration Sites, Seattle: Multiple restoration sites are part of People for Puget Sound's habitat restoration program, which began in 1995 to preserve and enhance habitat along the Duwamish River. Sites include Hamm Creek, Herring House, General Services Administration Site, Diagonal Marsh, and Turning Basin. High intertidal salt marsh vegetation and a protective buffer of upland riparian vegetation were planted at the sites. To protect the establishing salt marsh vegetation from herbivory by geese and other waterfowl, the use of exclusion fencing was essential. People for Puget Sound staff and volunteers constructed fencing systems that consisted of a series of T-posts and vertical netting. A "roof" of criss-crossed nylon ropes was connected to the T-posts. The fence systems required at least one maintenance visit every year to remove debris and ensure the fence is still intact. The fencing was necessary for at least 3 to 5 years at which point the vegetation was well enough established that it could sustain some herbivory each year, but still re-grow.

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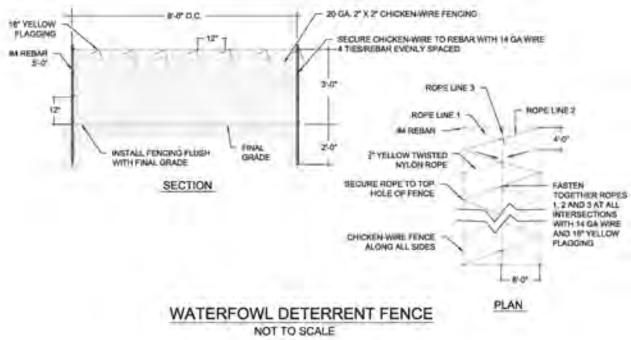
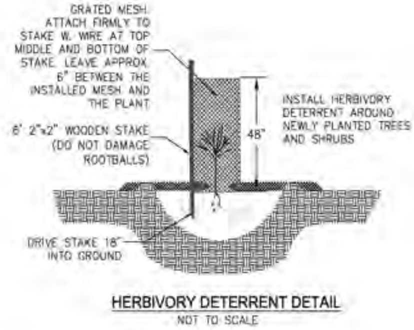
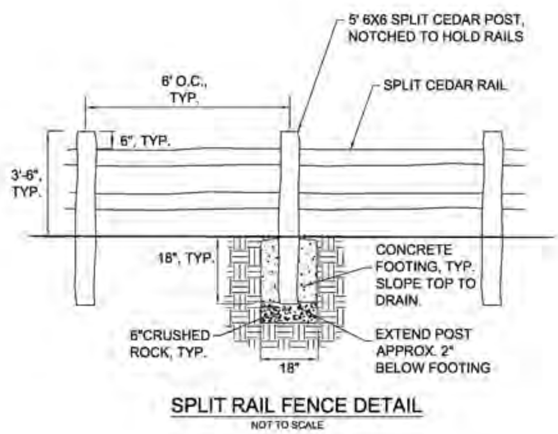
Figure 13-2 Examples of fencing and deterrent design details







MM 14 POLLUTION CONTROL

Definition

Pollution Control includes prevention, interception, collection, and/or treatment actions designed to prevent entry of pollutants (e.g., fine sediments, excess nutrients, chemicals, metals, bacteria) into the nearshore ecosystem. *Pollution Control* differs from *Contaminant Removal and Remediation*, which involve clean up of areas that are already contaminated.

Pollution Control can occur through source control, spill prevention and response, engineered treatment facilities for stormwater and wastewater, erosion control BMPs and other mechanisms. This measure also includes passive “control” of pollutants using wetlands and other features on the landscape that trap, store, and/or transform nutrients, pathogens, and toxins through denitrification, adsorption, decomposition and other processes.

Pollution Control is a broad topic that has many facets, only some of which are addressed here. This measure focuses generally on reducing and controlling nearshore water pollution and describes some specific aspects of stormwater runoff control during construction of restoration projects. It does not cover all of the regulatory requirements, complexities of water and sediment chemistry, pollutant pathways, or current trends in stormwater or wastewater engineering. Air pollution and water pollution associated with operation of marine vessels (e.g., oil tankers) are also not covered.

Justification of Need and Link to Nearshore Processes

Controlling or preventing entry of pollutants into nearshore areas is important because contaminants are not easily remedied once they reach nearshore waters. Degraded water quality from pollution sources poses a significant risk to the Puget Sound nearshore ecosystem (Ruckelshaus and McClure 2007). In general, contaminants are known to pose environmental health risks and act as ecosystem stressors, affecting biological and physical processes in the nearshore environment. Unfortunately, the relationship between multiple stressors and the impacts they have on the nearshore environment is only partially understood (Gelfenbaum et al. 2006).

By the nature of its location between upland and aquatic environments, the nearshore system is a pathway through which most pollutants travel. The movement of contaminants into the nearshore can lead to a variety of impacts, especially from the many toxic substances that persist or bioaccumulate in marine biota (such as forage fish, salmon and orcas). The low rate of flushing and freshwater exchange in Puget Sound puts Puget Sound at greater risk from pollutants than other estuaries in North America (PSAT 2007).

Contaminants affect biological processes including ecological and habitat interactions, organism and community metabolism, primary production, food web transformations, and geochemical transformations. Ecosystem stressors disrupt the food web causing imbalances in the number of aquatic organisms and their food sources. Ultimately, organism and community metabolism are impaired. Plants and aquatic organisms can also take up excess nutrients and contaminants, absorbing them into their tissues and/or shells, later releasing them when the plant or organism dies (PSAT 2003a). This can alter the natural nutrient cycling and geochemical processes that occur in the environment.

Fecal coliform bacteria and excess nutrients (primarily nitrogen and phosphorus) are two of the main water quality concerns contaminants in Puget Sound (PSP 2008). Concentrated levels of these contaminants have been shown to impair aquatic communities and increase the occurrence of disease or mortality. As of 2005, over 30,000 acres of commercial shellfish beds were closed to harvesting due to water pollution, including fecal coliform contamination (Newton et al. 2007). Oxygen depletion primarily occurs in embayments or areas that are subject to excess nutrient loading (Newton et al. 2007). Excess nutrient loading has been linked to anoxic conditions and fish kills in Hood Canal (Fagergen et al. 2004).

Pollutants reach nearshore areas via several pathways. Many municipal wastewater facilities discharge treated wastewater directly into Puget Sound. Combined sewer overflows sometimes discharge mixed stormwater and untreated wastewater to the Sound when conveyance or plant capacities are exceeded. Nearshore areas also receive pollutants from stormwater runoff. Stormwater impacts on stream hydrology and habitat have been well documented, and it is well established that stormwater is a significant transport mechanism for pollutants to receiving streams and marine waters (PSP 2008). These pollutants are both dissolved in water and attached to sediments and other particles (Gobel et al. 2007).

Pollution control measures/devices can impede the natural movement of pollutant sources to nearshore environments, removing toxic sediments and particulates that would naturally accumulate in estuaries. Furthermore, freshwater inflows may be slowed or intercepted by pollution control methods. Pollution control can therefore improve water quality and restore healthy food webs, habitats, and ecosystem processes for aquatic organisms (PSAT 2005b).

Conceptual Model

The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 14-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

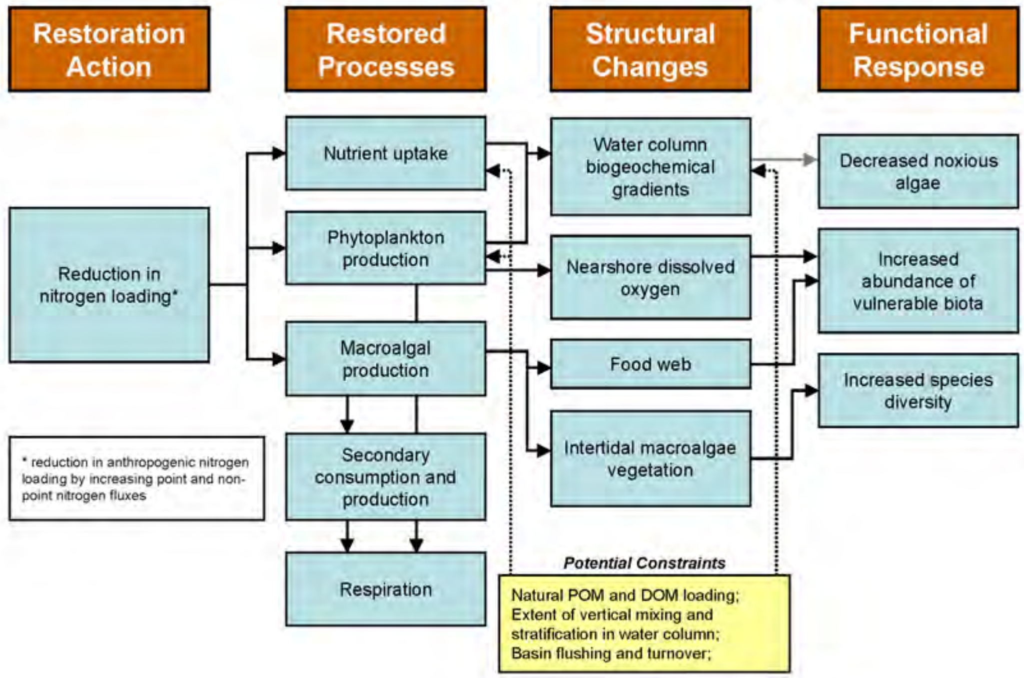
Pollution Control measures can address a variety of nutrients, pathogens and toxics in water, sediment and biota. The following model focuses on excessive nitrogen as one type of pollutant.

Scenario: Excessive loading of nitrogen allows for naturally nutrient-limited algal populations to overproduce. The resultant organic load/biomass leads to hypoxia (in water) and smothering (on sediments).

Change/Action: Local citizens develop a volunteer program to discontinue use of fertilizers in areas draining to an embayment. This reduces nitrogen loading and allows for natural cycles of productivity.

Predicted Response: The abundance, health, and diversity of nearshore organisms is not threatened from low oxygen or burial and returns to a more natural status.

Figure 14-1 Conceptual Model for Pollution Control



Complementary Management Measures

Pollution Control is complementary to and can be used in combination with all other management measures. It can also be used alone as it has considerable independent utility. This measure is commonly used together with *Contaminant Removal and Remediation, Public Education and Involvement*, and *Habitat Protection Policy and Regulations*.

Benefits and Opportunities

Benefits of the Restoration Action

Pollution control provides many human health and ecological benefits as described below.

- **Pollution reduction:** The presence of contaminants in the nearshore environment is reduced by preventing source inputs.
- **Increased survival rates of nearshore biota:** Pollution control can help restore primary production, organism transport and movement, healthy aquatic habitats and spawning grounds, and water quality.
- **Greater conservation value:** Preventing contamination is easier, less expensive, and more effective than cleanup (PSAT 2005b). Dollars spent on pollution prevention can be viewed as a cost savings and funds can potentially be re-directed to other conservation activities.
- **Technological ease: In many cases, it is technologically easier to prevent contamination of water than to clean up polluted waters once they have been contaminated (PSAT 2005b).**

Measureable Units

The following items can be measured to indicate the benefits of pollution control efforts:

- Number and type of impaired waters listed in the state Water Quality Assessment (303d listings)
- Levels of accumulated contaminants (parts per billion) in water, sediments, or biota
- Number of shellfish harvest closures

Opportunities for Implementation

This management measure has broad applicability. It can be applied at the site scale and/or basin scale. Site scale implementation may involve a variety of stormwater BMPs such as: grassy swales, detention/retention ponds, infiltration basins, constructed wetlands and buffers; adding, improving, and/or maintaining pumpout stations and shore-side facilities for marinas; installing engineered structures such as vaults and oil/water separators; and using low impact development techniques (Fagergen 2004). Basin scale implementation may involve onsite sewage system upgrades, upgrading wastewater treatment facilities with technologies such as membrane bioreactors, voluntary or mandated bans on chemical use, reducing impervious surfaces, stormwater retrofits and other measures (Mason County 2006).

Entities and agencies likely to use this measure include water and wastewater districts, county health and public works departments, road and transportation departments, restoration groups, and industrial and commercial businesses. Shoreline property owners and other private citizens can play a significant role in pollution control by refraining from using chemicals such as pesticides and herbicides, by maintaining native vegetation along the shoreline, by properly disposing of wastes (e.g., using pumpouts at marinas), and through other actions.

Constraints

Pollution control can be difficult to achieve because of the vast array of pollutants, pollutant pathways, and potential sources. Lack of understanding and/or data concerning interactions of pollutants and the environment are a major constraint. Preventive approaches to pollution can sometimes be perceived as interfering with property rights. These conflicts, when not resolved, can ultimately limit funding for preventive programs, regulatory enforcement and compliance monitoring to detect and correct problems in their early stages, and public education (PSAT 2005b). Some of the other primary constraints are listed below.

Variable effectiveness: The level of treatment provided by stormwater BMPs is highly variable and depends on many factors including design, maintenance, and influent conditions. Current design and application of stormwater BMPs are not demonstrated to consistently achieve water quality standards in receiving waters.

Lack of criteria: There are no set criteria or thresholds on which to base management practices for emerging contaminants (e.g., pharmaceuticals and personal care products).

Illicit connections: Illicit wastewater or industrial connections to stormwater systems can confound pollution control strategies and cause acute impacts to receiving waters.

Enforceability: Design and planning standards for control may not be enforceable or may be inconsistently enforced by regulatory agencies. Non-structural source controls are difficult to verify or enforce under current regulations.

Vesting: State vesting laws work against the application of effective stormwater management by allowing development to occur in areas that have been subsequently shown to be inappropriate for development, and by allowing vested development to be built under older and substandard stormwater codes.

Presumptive approaches: Total Maximum Daily Loads (TMDLs) requirements are typically presumptive rather than linked to numeric standards.

Integration with land use: Effective pollution control requires integration with land use and transportation planning.

Costs: Stormwater retrofits and treatment plant upgrades are expensive and face funding shortages in non-urban areas because most of the funding is through local sewer utility fees.

Regulatory impediments: The Growth Management Act prohibits municipal wastewater systems outside of Urban Growth Areas, so rural areas must rely on on-site septic systems. There are approximately 472,000 septic systems in the Puget Sound basin, according to previous estimates by the Puget Sound Action Team. Historically, the standards for septic system design do not address removal of nutrients and toxins. Septic system siting standards do not address specific receiving water conditions, including nutrient limitations.

In addition, gaps in our understanding of how different pollutants affect nearshore systems and how these effects can best be mitigated constrain our ability to effectively implement this measure. Some of the most critical knowledge gaps include:

- Effects of increased nutrient levels on the Puget Sound food web (phytoplankton and zooplankton constituents of the food web).
- How specific pollutants (e.g., specific forms of nitrogen and phosphorus) affect the biological community.
- Role of groundwater in nutrient and pathogen delivery to nearshore areas.
- Percent contribution of point versus nonpoint versus background contributions to Puget Sound from pathogen loads.
- Effects of climate change.
- Effects of multiple contaminant interactions in the nearshore environment and associated impacts.
- Location of problem areas due to a current lack of dense real time water quality monitoring stations.

Best Professional Practices

Feasibility Assessment

Pollution control strategies and programs can take many forms so deciding what types of approaches will produce the best results requires a detailed cost-benefit analysis. Factors that must be accounted for include the scale of the project area (e.g., size of the containment area, size of the basin and/or the size of the waterbody being protected); the type(s) of pollutant(s) targeted; the pollutant pathway (surface water, ground water, adsorbed to sediments, etc); the time available to achieve the pollution control benefits (acute water quality problems may require different strategies than emerging problems); available infrastructure; regulatory requirements; and the social context (urban versus rural land uses, for example). The cost-benefit analysis will help ensure that pollution control systems and programs are designed for the expected reduction in pollution that can feasibly be achieved. Feasibility analyses should consider tradeoffs between different approaches to pollution control such as:

- Constructing, operating, and maintaining infrastructure (for stormwater and wastewater treatment) as opposed to relying on passive or natural methods such as preserving natural wetlands or creating new wetlands to filter, trap, transform nutrients; or
- Getting people to change behaviors and practices (e.g., reduce fertilizer use) through public education and outreach as opposed to relying on increased regulation and enforcement.

Design

Pollution control strategies and programs can take many forms and design considerations will vary based on the pollutants being targeted, the technologies applied, the scale of the effort, regulatory requirements, and many other factors. Preventing or limiting the use of pollutants should be one of the central goals of any pollution control effort. At restoration sites, this can mean limiting the amount of site disturbance (acres of grading and clearing, for example), allowing on-site infiltration, dispersion, and/or retention to the greatest extent possible; protecting wetlands and sensitive areas (maintain hydrologic, vegetation, soil, and habitat characteristics); refraining from chemicals use (e.g., herbicides to treat invasive species); and designing BMPs for temporary erosion and sediment control (TESC) and spill prevention. Specific guidelines for designing and implementing construction, operational, and source control BMPs can be found in Ecology's Stormwater Management Manual for Western Washington (2005a-e). Design options will vary depending on factors such as:

- Soil composition and soil permeability
- Site topography
- Types of pollutants expected in the runoff
- Quality and condition of receiving waters, wetlands, drainages systems, etc.
- Local or regional water quality management plans, ordinances, or regulations
- Nearby land uses

Data are lacking on the cumulative effects of multiple contaminants and/or nutrients in nearshore environments, the effects of emerging contaminants such as pharmaceuticals and personal care products, and the performance and success of technologies to control pollution. Additional studies of these topics could provide more insight into better treatment designs and strategies.

Implementation

Implementing effective pollution control at restoration sites requires marking sensitive areas in advance of site disturbance, installing TESC measures, implementing a Stormwater Pollution Prevention Plan, implementing a Spill Prevention Plan, using environmentally safe construction equipment and materials, and training employees to use proper environmental procedures. Special attention must to be paid to vehicle/equipment operation and maintenance including the location of vehicle refueling and washing stations. *Revegetation* following construction can be an important component of pollution control because vegetation helps stabilize soils and can trap and slow pollutants in stormwater runoff. Monitoring during and following construction is critical for ensuring that BMPs are working and for correcting problems if they arise.

Evaluation

Monitoring to evaluate pollution control measures may include water quality testing, sediment and biota testing, and tracking the occurrence of shellfish and beach closures. Project managers can assess the performance of control measures by directly comparing monitoring results to applicable standards (e.g., TMDLs) and/or by tracking the number of 303d listings. Monitoring methods vary depending on the contaminants of concern, type of control measures, and regulatory requirements. Several documents have been published regarding sampling techniques for environmental monitoring (see references list at end of chapter).

Case Studies and Examples

Burley Watershed Restoration Project, Kitsap County: In 1999, the Washington Department of Health closed all shellfish growing areas in Burley Lagoon because of high fecal coliform levels in polluted runoff from failing septic systems and animal wastes. Kitsap and Pierce Counties worked together to create the Burley Lagoon Watershed Protection District, which worked with farmers and homeowners to decrease the levels of fecal coliform in the watershed. A grant program funded by the Department of Ecology identified and repaired failing septic systems in the area. Kitsap Conservation District also found funding to improve animal-keeping areas. The restoration project ended in 2002, when the Department of Health reopened 110 acres of shellfish beds (PSAT 2005a).

Low Impact Development Program, Chilliwack, British Columbia: Two new developments in Chilliwack were constructed using low impact development (LID) technologies. City planners worked closely with developers to incorporate several strategies, including directing road runoff to vegetated areas that infiltrate to galleries for detention. Infiltration into green areas allows pollutants to be removed from runoff and dissipates runoff volumes. The City of Chilliwack is planning to install monitoring stations at these galleries to monitor runoff volume and water quality parameters such as temperature, turbidity, dissolved oxygen, and pH (PSAT 2003b).

King County Combined Sewer Overflow (CSO) Program, Washington: King County has been upgrading its sewer system since the early 1980s. Since it performed baseline studies to determine the amount of overflow occurring in the combined sewer system, King County has achieved a 65.2 percent reduction in waters leaving the combined sewer system without treatment. King County adopted a pilot project in 2007 to identify and test potential CSO treatment technologies in the Lower Duwamish Waterway. Two technologies recommended for pilot testing were chemically enhanced primary clarification (CEPC) and CEPC with lamella plates; both of these technologies are commonly used for clarifying drinking water and industrial process water. The goal of the pilot test is to determine the level of performance, identify design requirements, and assess the feasibility of using these technologies for CSO treatment. Pilot testing will continue through 2009, until the facility plans are issued in 2010. Construction is planned for 2011 and should be completed by 2013 (King County 2008).

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MM 15 PROPERTY ACQUISITION AND CONSERVATION

Definition

Property Acquisition and Conservation includes the transfer of land ownership or development rights to a conservation interest to protect and conserve resources, enable restoration, or increase restoration effectiveness. This management measure can be used alone to protect and preserve ecosystem components (i.e., processes, habitats, and/or outputs/functions) or in conjunction with other management measures to ensure sustainability of basic nearshore processes and enhance the effects that other measures have on ecosystem processes. In many cases, acquisition of property or development rights is prerequisite to the implementation of other measures.

Property and development rights can be acquired through various mechanisms such as outright purchase of land (fee simple acquisition), conservation easements, conservation leasing, flowage or flood easements, deed restrictions, development rights transfers, open space tax programs, or any other mechanism that encumbers, limits, or transfers the development or use (including extraction of timber, minerals, water or other resources) of a property to a mutually agreed upon level. Public agencies can sometimes acquire property through involuntary condemnation; however, condemnation is not frequently used as a means of acquiring sites for restoration.

Justification of Need and Link to Nearshore Processes

Property rights are the rights that individual property owners have to use and develop their land. Usually when someone purchases a parcel of land they purchase the entire bundle of rights associated with the land. Some of the more common rights include the rights to develop, harvest timber and mine mineral deposits. The rights a property owner has to use or develop a parcel vary based on the parcel's location, size/acreage, land use designation, zoning, and other development regulations in effect for that jurisdiction.

Purchasing property rights often infers fee simple acquisition. Acquiring land in fee is distinctly different from acquiring an interest in land through a conservation easement, transfer of development rights (TDR) or other agreement. Each has specific effects on the property title and value of property, and each influences landowner/public perception of conservation activities differently.

Property acquisition and conservation is arguably one of the most important management tools for achieving ecosystem recovery in Puget Sound. Whether used alone or in conjunction with landscape-altering management measures (e.g., *Channel Rehabilitation or Creation*), property acquisition and conservation can allow for robust and long-lasting protection of nearshore processes, habitats, and functions.

Property acquisition and conservation can be used to protect lands that play a critical role in how processes operate. Examples include preventing development (e.g., through acquisition, a conservation easement, development rights transfer, or other means) within a floodplain or channel migration zone to protect/maintain channel formation and migration processes. PSNERP's NST lists protection of ecosystems with well-functioning processes as having the greatest certainty of all ecosystem recovery actions and recommends that protection actions supersede management measures that aim to recreate natural processes or damaged habitats (Fresh et al. 2004). Nearshore restoration practitioners throughout the region regard the concept of "protecting the best" as a top priority. The Puget Sound Partnership lists the protection of intact lands and resources as a strategic priority in the Action Agenda for Puget Sound (PSP 2008). The Puget Sound Salmon Recovery Plan (Shared Strategy 2007) highlights the importance of permanently protecting existing physical habitat as a key strategy for recovering Puget Sound Chinook salmon stocks. The Committee on Protection and Management of Pacific Northwest Anadromous Salmonids (1996) notes that "protection of intact and functional aquatic-riparian habitats should have a high priority; where protection is the desired management option to sustain fish and other aquatic organisms, human influences need to be prohibited or minimized." Property acquisition and conservation is therefore an essential management measure because it provides a very secure and durable way of "protecting the best."

This measure can be used to facilitate, and in some cases may be required for, implementation of process-based restoration actions in priority areas. Examples include acquiring properties that have been cut off from tidal action to enable *Berm or Dike Removal or Modification*, which allows channel formation and marsh development within the historic inundation area. Many such restoration projects, particularly large-scale efforts such as those that are currently occurring in the Snohomish estuary and Nisqually and Skagit Deltas, would not be possible without acquisition of private property (or development rights) by public agencies, tribes, or conservation entities.

Property acquisition and conservation will often be used to protect nearshore structural elements or specific habitats from unwanted effects of development activity (e.g., clearing, grading, bulkheading, etc.) or from disturbance caused by development activity on nearby properties. This can involve transferring development activity away from a sensitive resource (such as a great blue heron rookery) to a less sensitive area, or similar applications that place protective covenants over valued ecosystem components. In many cases, it will be appropriate to use this management measure to acquire lands to "buffer" areas adjacent to the target conservation or restoration site. Securing buffers through acquisition helps to protect the conservation / restoration site from adverse offsite impacts. In the absence of other ecosystem or process-based management measures such as *Hydraulic Modification*, these types of applications may have more pronounced effects on ecosystem structure than on nearshore processes because structural elements, habitats, and/or species are the main targets of the acquisition. Nearshore processes and ecological functions may benefit indirectly as a consequence of the acquisition because the structural elements of the ecosystem remain intact.

Property acquisition and conservation can be applied in any geomorphic setting and may involve lands of varying ecological condition (from pristine to highly impaired). In other words, use of this measure is not limited to any particular geophysical or ecological situation; in fact, it may involve acquiring property or development rights outside the limits of the nearshore zone when such actions are necessary to ensure restoration success or protect vital components of the nearshore ecosystem.

Conceptual Model

The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 15-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario 1: Protect functioning habitat/ecosystem processes from development threats – A high-quality forage fish spawning beach and adjacent forested uplands are available for sale. A developer is interested in purchasing the site, harvesting the trees, and building a waterfront resort and private marina.

Change/Action: Acquisition of the property would eliminate the threat of development and prevent direct habitat loss, loss of marine riparian vegetation, and overall degradation of habitat (from increased runoff, overwater shading, increased boat and foot traffic along the shoreline, etc.). Effects of human intrusion are abated.

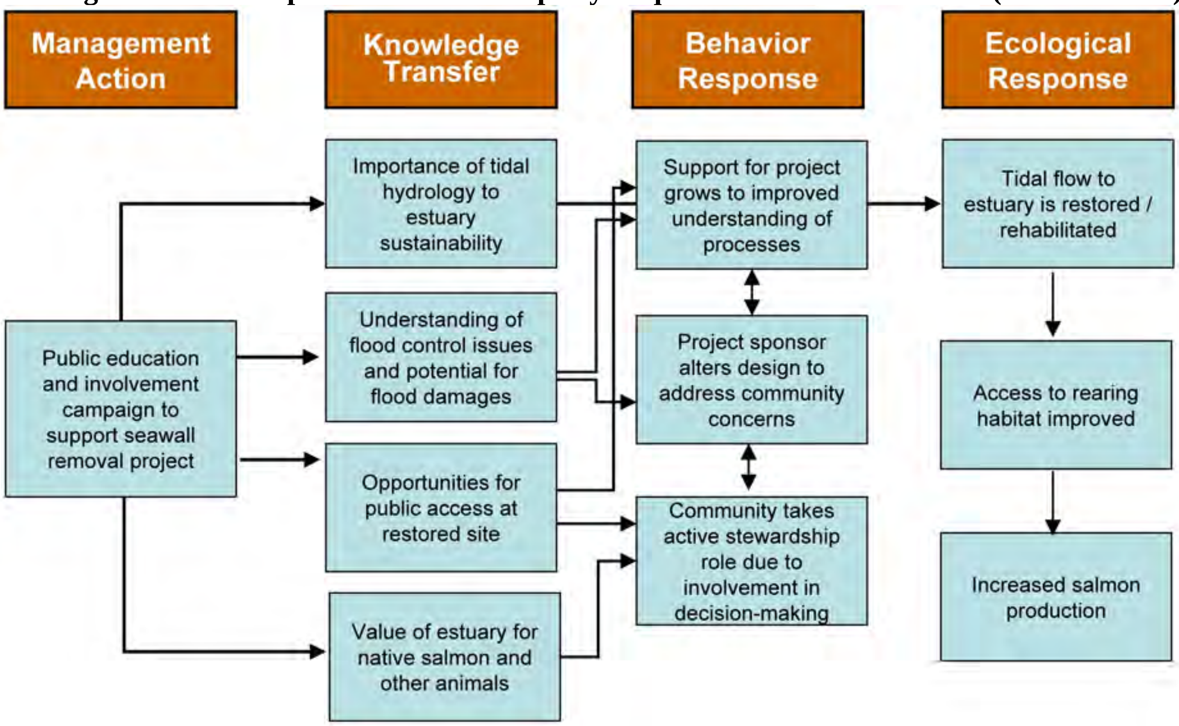
Predicted Response: Spawning habitat remains intact due to persistence of upland/nearshore cover (from vegetation), maintenance of runoff/infiltration patterns, and preservation of natural beach erosion and accretion patterns.

Scenario 2: Enable restoration of functioning habitat/ecosystem processes via property purchase – A dike within an estuary has altered the hydrology of the site, leading to changes in channel movement and formation, reduced fish access, and loss of habitat complexity for salmon and shorebirds. There are multiple property owners in the estuary with varying degrees of willingness to participate in full restoration through dike removal.

Change/Action: Acquisition of the property and procurement of flowage easements on adjoining properties allows removal of the dike, which is otherwise beyond the property owners' means.

Predicted Response: Acquisition enables restoration of tidal flow, formation of new channels, improved fish access, and shorebird habitat.

Figure 15-1 Conceptual Model for Property Acquisition and Conservation (for scenario 1)



Complementary Management Measures

Property Acquisition and Conservation is often a prerequisite to large-scale restoration actions involving multiple management measures such as *Berm or Dike Removal or Modification, Channel Rehabilitation or Creation, Hydraulic Modification* and *Topography Restoration.* Application of some management measures may be infeasible or inadvisable unless accompanied by *Property Acquisition and Conservation*. This is also a protective measure that can be used in combination with all other management measures to enhance recovery efforts. *Property Acquisition and Conservation* is sometimes linked to *Habitat Protection Policy and Regulation* because some acquisition mechanisms / programs (such as TDR programs and open space taxation programs, etc.) require enabling polices and regulations.

Benefits and Opportunities

Benefits of the Restoration Action

The benefits of property acquisition and conservation will almost always be long-lasting, but the degree and durability of protection vary depending on which complementary measures are employed, how the property or rights are acquired (fee simple versus a lease), and/or the intensity of the threats facing the property. This measure provides the following benefits:

Enables restoration: In some restoration situations, control of the property is a prerequisite to restoration-related construction activities. Public agencies may be unwilling or unable to invest in restoration efforts unless title to the property is secured, appropriate easements are granted, and/or applicable development rights are acquired. Property owners may be unwilling to participate in restoration, but may be willing to sell property/development rights to facilitate restoration.

Increase restoration effectiveness: Property and development rights can be acquired to expand the 'footprint' of the restoration action (e.g., purchasing a property or development rights so that overwater structures can be removed and acquiring an easement on adjacent tidelands in order to implement eelgrass transplantation).

Reduce offsite risk of restoration actions: This measure can protect lands adjoining or down-gradient of restoration sites from unwanted consequences of restoration actions. An example is the acquisition of a flowage easement on a property that may be exposed to increased flood risk due to removal of a tide gate, berm, or levee on a nearby site.

Reduce threats to restoration sites: Acquiring property or development rights to target restoration and conservation sites and their adjoining buffer areas increases restoration success by protecting restoration sites from offsite threats. This could involve purchasing an access right or easement so that public access to a restoration site can be controlled to prevent unwanted human intrusion.

Conserve high-quality/high-value areas: By setting aside (through purchase or conservation easements) areas that are largely intact, resource managers are better able to maintain ecosystem functioning even in the absence of other restoration actions. Protecting ecosystem components prevents their eventual loss or degradation so they are available for future generations. Protecting high-quality functioning habitat now is far less expensive than restoring degraded habitats in the future. Protection is also more certain than trying to restore or recreate sites/processes after they have been damaged or lost.

Protect habitats and species that are especially sensitive or rare: This includes acquiring lands that support keystone species and habitats since their loss can have disproportionately adverse effects on ecosystem sustainability. Protection generally is much less expensive than restoration, so dollars spent on protection can be viewed as cost savings.

Public services, health and safety: Acquisition of property/development rights by public agencies often provides valuable goods and services in the form of public shoreline access, recreation, flood storage, and scenic/aesthetic amenities. Restoration projects may provide benefits to adjacent landowners and the broader community. For instance, dike breaching may result in increased water flow and retention within the restoration site, which may minimize flooding upstream on adjacent properties.

Public education: When sites are brought into public ownership through this measure, there may be opportunities to create interpretive and/or educational experiences for the public, leading to improved stewardship and increased support for nearshore recovery efforts.

Public stewardship: Acquisition may promote voluntary participation in stewardship activities by individuals who would otherwise not be involved.

Human well-being: Decisions on where people live are often dictated by the amenities they receive versus the relative costs of living in that community. Ecologically healthy habitats increase human quality of life.

Partnerships: Use of this management measure provides opportunities for land trusts, salmon recovery groups, and government agencies to work together to achieve a common purpose. Such partnerships may increase funding opportunities and promote information sharing/collaboration for future restoration actions.

Multiple use: Acquisition can be used to join existing public lands to restoration sites and/or protected properties with use restrictions to provide multiple uses of shorelines with maximum ecological and social functions.

Measureable Units

The benefits of property acquisition and conservation can be measured in several ways including but not limited to, the number of acres of land preserved from future development/harm, the number of restoration projects enabled as a result of property acquisition, the number of properties made available to the public for stewardship, education, and public shoreline access/enjoyment.

Opportunities for Implementation

A wide range of agencies and organizations are likely to employ this measure. Common government agency implementers include the USACE, USFWS, NOAA, PSP, WDFW, WDNR, cities and counties, conservation districts, and various tribes. National (e.g., TNC, Ducks Unlimited) and local (e.g., Skagit Fisheries Enhancement Group, North Olympic Salmon Coalition) conservation organizations are among the many private entities likely to use this measure. Acquiring property and development rights is a central mission for land trusts such as the Trust for Public Lands, Cascade Land Conservancy, Jefferson Land Trust, and others. However, many funding agencies (e.g., U.S. Department of Agriculture and the RCO) will not fund acquisitions involving transfers of development rights. In some cases, these agencies are willing to purchase/receive underlying fee property from which development rights have been transferred.

Land trusts and some other private conservation organizations often work to facilitate public agencies' efforts to acquire lands at a fair market value. They can serve as intermediaries during negotiations and assume risks associated with buying and owning property, although their long-term goal may be to transfer ownership and management responsibility to a public agency.

This measure can be used in any setting as long as there are willing property owners. Although public agencies can sometimes acquire property through condemnation, condemnation is typically pursued only as a last resort when specific criteria have been met. The ability to acquire property and development rights through various mechanisms gives the purchaser the opportunity to tailor the application based on the property owners' needs and restoration objectives.

Ideally, property acquisition targets are prioritized based on a comprehensive assessment of restoration needs and opportunities. The PSNERP change analysis (see Introduction and Background) and Strategic Needs Assessment efforts are examples of comprehensive assessment tools that can be used to inform and guide the application of this management measure in Puget Sound. The Puget Sound Partnership is funding and supporting watershed characterization efforts throughout Puget Sound to identify high-priority restoration and protection sites; many of these sites will be appropriate for acquisition.

Some properties become targets for conservation using this measure because they cannot be protected or conserved adequately through other means. Such properties typically are characterized by the following:

- The sere (ecological community stage) is an imminent threat to the ecosystem processes the site provides
- The habitat value or risk is too great to rely solely on regulations for protection
- The current or anticipated future regulatory environment is questionable
- There are loopholes in existing regulations
- There is lack of regulatory enforcement

The management measure can also be used in support of in-lieu fee mitigation programs, where a government agency acquires a property or development right for conservation/restoration purposes and collects impact/mitigation fees from developers to fund the acquisition/restoration. Acquiring lands and development rights can be used to create migratory corridors and connections for fish, wildlife, and plants.

Table 15-1 provides an overview of the opportunities presented by different acquisition mechanisms.

Table 15-1 Benefits and Opportunities of Property Acquisition and Conservation

Mechanism	Description	Benefits and Opportunities
Fee Simple	Properties are acquired outright through a sale or through condemnation. The original property owner retains no interest in the land or resources. Secures the land in perpetuity.	Best when restoration objectives require full use of entire property or when the restoration action will interfere with the landowner's current use of the property. Also appropriate when restoration is so costly or complex as to preclude implementation by an individual landowner or when it might have impacts on the property that would decrease its value and therefore be a disincentive for private landowners to accept other forms of property rights acquisition.
Conservation Easements, Deed Restrictions, etc.	A conservation easement is a legal agreement between a landowner and a qualified conservation organization or government agency that permanently limits a property's use to preserve its conservation values. The land stays in private ownership but certain rights are conveyed to the acquiring agency/organization through the easement. The extent and nature of the restrictions are based on mutually agreed upon goals between the landowner and the conservation organization. Can be acquired through donation or outright purchase. Provides permanent protection binding future landowners. The organization or agency owning the conservation easement is responsible for enforcing the easement's restrictions.	Appropriate in a variety of restoration applications wherein full control of the property is not required. Examples include flowage easements on properties that may be subject to increased flooding due to *Hydraulic Manipulation* or other measures on nearby sites. Factors that promote the use of this measure are: Landowner receives monetary compensation. Landowner retains ownership of the property and may live on it, sell it or pass it on to heirs. Flexible and can be written to meet a landowner's needs while protecting the property. Benefits the property owner by lowering federal income and estate taxes and in some cases local property taxes. (requires a qualified appraisal)
TDRs	Transfer of Development Rights (TDRs) is a market-based mechanism designed to promote responsible growth, while conserving working forest, prime agricultural areas and environmentally sensitive lands. It is designed to steer growth -- not to limit or stop development. TDRs involve voluntary transactions whereby development rights are transferred from sending sites (sensitive lands, agricultural land, forest land) to areas that can accommodate additional growth (receiving sites). Landowners in sending areas receive compensation for giving up their right to develop, while developers in receiving areas pay for the right to a development bonus such as additional height or density than would otherwise be allowed. When development rights are removed from a parcel, a conservation easement is placed on the sending site (source: Cascade Land Conservancy. *www.cascadeland.org*)	Not typically used to enable restoration, but may be appropriate for protecting valuable or intact lands from development pressure. Several factors encourage use of TDRs: TDRs are voluntary and use private funding (as well as public funding). TDRs use the market to generate private funding for land conservation, helping to augment and leverage available public funds and programs. In contrast to zoning restrictions, TDRs compensate landowners who give up their right to develop. While zoning regulations can change over time, TDRs protect property permanently and allow resource uses to continue. By focusing development in areas that already have infrastructure capacity, TDRs can reduce a region's infrastructure costs and more efficiently accommodate growth. Property owners maintain some control over their lands, which may create incentives for them to join as partners in nearshore restoration efforts.
Open Space Taxation	The Open Space Taxation Act allows property owners to have their open space, farm and agricultural, and timberlands valued at their current use rather than their highest and best use. The Act states that it is in the best interest of the state to maintain, preserve, conserve, and otherwise continue in existence adequate open space lands for the production of food, fiber, and forest crops and to assure the use and enjoyment of natural resources and scenic beauty for the economic and social well-being of the state and its citizens. Any owner or contract purchaser may apply for current use assessment under the open space law.	Not typically used to enable restoration or improve restoration effectiveness, but may be appropriate for protecting valuable or intact lands from more intensive use. Provides a financial incentive to forego more intensive development of sensitive parcels/open space lands and protects forest land from conversion. Property owners receiving tax benefits may be more likely to invest in restoration activities.

Constraints

Several factors can complicate or impede the ability of a public agency or conservation organization to acquire private property rights for purposes of restoration.

Limited opportunity: Lack of willing sellers in priority locations.

Financial expectations: The appraised value may not meet the landowner's expectation of fair market value.

Land use conflicts: Potential conflicts with existing and planned land use (agricultural lands that will be inundated due to berm or dike removal or modification, for example).

Tax implications: Lack of public support due to perception of a potential loss of property tax income.

Loss of use: If acquisition causes the loss of a particular community use (e.g., hunting, fishing or recreational use) support for this measure may decrease.

Perceived / Actual high cost: Agencies may be reluctant to use this measure because of perceptions or knowledge of high costs. Waterfront properties are generally very expensive to purchase. However, in the long-term, land acquisition is actually one of the most cost-effective protection tools.

Legal complications: USACE and other public agency real estate requirements can be difficult to meet. Some public agencies (e.g., WDNR) may lack the authority to purchase private lands. Easement agreements must be carefully crafted to ensure provisions support restoration objectives and are enforceable.

Scale: This measure is typically used on a parcel-by-parcel basis, which makes acquiring process-based restoration sites over large landscapes more challenging. Furthermore, funding agencies sometimes only fund acquisition of "key" properties and not necessarily all of the lands needed to restore, protect, and/or preserve a target area.

Some of these same constraints can hinder the ability of public agencies to conduct restoration activities on public lands, including state-owned aquatic lands managed by WDNR. The state owns approximately 30% of the state's tidelands (tidally influenced shoreline) in Puget Sound, 100% of marine bedlands within Puget Sound and the outer coast (extending seaward three nautical miles), and extensive freshwater aquatic lands. WDNR grants use authorizations (leases for marinas, shellfish beds, rights-of-way across those aquatic lands, easements, and other activities) and encourages conservation projects on these lands to improve habitat, enhance connections with adjacent uplands, and restore or enhance ecosystem functions. WDNR can also sell state-owned lands to public agencies in some cases. However, WDNR cannot grant leases over state-owned lands in perpetuity. The time limits associated with aquatic lands leases can hamper public investment in some restoration efforts on state-owned tidelands without a change in legislation to be more flexible. Currently, qualifying lands can be designated as aquatic reserves for up to 90 years. Easements can be granted for up to 55 years on second-class tidelands (shores of navigable tidal waters belonging to the state, lying outside of and more than two miles from the corporate limits of any city, and between the line of ordinary high tide and the line of extreme low tide). WDNR can issue licenses for projects lasting less than one year, or that require only sporadic activity for up to 5 years; but these provide no future protection for the habitat improvement.

The time limits associated with aquatic lands leases can hamper public investment in some restoration efforts on state-owned tidelands. This is potentially an issue for larger scale projects, but smaller one-time restoration actions may be authorized via a license.

Public lands are also typically not eligible TDR "sending" sites. One exception to this rule is King County's TDR program, which allows for the purchase of development rights from WDNR surplus properties.

The constraints associated with using this management measure to protect or preserve high-value or intact lands and resources in public or private ownership include:

Species- or habitat-centric: Acquisition priorities are often based on single species/habitat, not ecosystem processes or biodiversity value.

Policy / regulatory conflicts: Setting aside land for ecological restoration or protection purposes can create challenges for local governments that need to meet urban density requirements unless development transfers can be arranged. Acquiring land for conservation purposes may also conflict with local policies for preserving productive agriculture or generally conflict with economic development goals.

Best Professional Practices

Feasibility Assessment

Before deciding whether to acquire a property or development right, it is important to assess the value or importance that site has in terms of overall restoration priorities. This requires a systematic scientific study to identify priority areas for acquisition and restoration ("protect the best first"). The PSNERP change analysis and Strategic Needs Assessment Report will be critical tools for identifying priority restoration sites. Other tools include:

- Puget Sound Shared Strategy Regional Nearshore Chapter (http://www.sharedsalmonstrategy.org/plan/)
- WDNR's Priority Marine Sites for Conservation in the Puget Sound (Palazzi and Bloch 2006)
- TNCs Puget Trough Ecoregional Planning Framework
- Local shoreline master program restoration plans
- Watershed characterizations similar to the approach used by Whatcom County in the pilot study for the Birch Bay watershed (http://www.whatcomcounty.us/pds/shorelines_critical_areas/workproducts.jsp)

The feasibility assessment also requires assessment of land use compatibility / site sustainability issues such as:

- Amount of land needed to protect the targeted process, function or structure; enable needed restoration; or be an integral component of a larger effort
- Lifespan of the project (typically a 50-year timeframe)
- Likely future uses of surrounding parcels
- Recreation opportunities or conflicts
- Future water quality issues impacting habitat function of the site
- Sea level rise and associated climate impacts
- Implementation of other related management measures
- Landscape context and habitat linkages - integrate protection, acquisition and restoration projects to benefit the largest combined areas

- Benefits of fee simple acquisition vs. easements (can the same benefits be realized, and is acquisition of an easement feasible?)
- Access and adjacent uses; educational/research opportunities

Choosing the appropriate mechanism for acquiring property rights will depend on the factors described above and summarized in Table 15-1. The landowner's needs must be taken into account along with the needs of the sponsoring agency.

Before proceeding with acquisition, it is important to confirm the landowner is willing to consider selling the parcel. This can be documented by securing proof of listing or through a Letter of Intent or Notice of Fair Market Value signed by the landowner. The next steps are to:

- Negotiate with landowner
- Obtain title report
- Obtain formal opinion of value
- Conduct due diligence (Environmental Site Assessment/Hazards Assessment)
- Conduct baseline surveys/inventories (physical or biological) as needed
- Survey property boundaries

The process may be slightly different when acquiring development rights on public lands. For example WDNR has a specific protocol for leasing aquatic lands.

Design and Implementation

For the property acquisition and conservation measure to fully protect or restore ecosystem processes, it must be applied at the appropriate scale. However, it will rarely be feasible to acquire all of the land needed to restore a given process (all properties within a single drift cell, for example). Nevertheless this measure can be used to target key process sites such as a feeder bluff (e.g., sediment source) or barrier beach (e.g., accretion area), which can achieve substantial benefits in terms of nearshore process, structure, and function.

Other issues to be considered when employing this measure are the size and scale of the area to be protected (patch size), the degree of connectivity or flow between other ecosystem components, and the representation and redundancy of similar areas in the landscape. The acquisition effort must be designed and implemented in light of the specific restoration or protection goals for the project as whole.

Evaluation

Evaluation efforts following acquisition of property and development rights should include:

- Acquisition monitoring to assess whether acquisition is actually protecting the site and/or target processes and functions.
- Compliance monitoring to evaluate the terms of the specific conservation easement or deed restriction. Its purpose is to see that the property continues to be protected as outlined in the agreement. Easement monitoring is focused on determining if changes have taken place that are inconsistent with the terms of the easement or deed restriction. However, it is not designed to assess impacts caused by actions not considered in the easement agreement or from external

sources the landowner cannot control (natural disasters, climate change, spread of invasive species, etc.).

Case Studies and Examples

Lily Point Acquisition, Point Roberts: Lily Point on the Point Roberts peninsula in Whatcom County contains high-value nearshore habitats that support juvenile salmon, orcas, and a globally significant migratory shorebird and waterfowl area. Feeder bluffs lining Boundary Bay are critical to local sediment delivery and transport processes. Lily Point is identified in multiple plans as a priority for acquisition to protect its ecological values and to meet shoreline access needs in Whatcom County. The site was targeted for acquisition because a proposed 74-unit development and golf course threatened to destroy its pristine qualities. The first phase of the acquisition was led by Whatcom Land Trust, with a $1.75 million grant from the Washington Department of Fish and Wildlife's Estuary and Salmon Restoration Program and funding from Whatcom County Conservation Futures, the state Department of Ecology, U.S. Fish and Wildlife Service, and numerous private contributions from the United States and Canada. A subsequent acquisition by The Nature Conservancy involved the 146-acre Lily Point-North parcel and reimbursement of a portion of the acquisition costs of the 130-acre Lily Point-South parcel acquired under Waiver of Retroactivity No. W08-011. TNC, Whatcom County and other partners including the Lummi Nation, USFWS, the Whatcom MRC, the Whatcom Land Trust and Friends of Lily Point, are planning restoration of the site. Ultimately, Whatcom County Parks will manage the site for recreation and conservation.

Christofferson Property Quwloolt Marsh Restoration, Marysville: Acquisition of the Christofferson property came about as a result of a unique collaboration of public agencies. The property lies on the north boundary of the proposed Qwuloolt estuary restoration project near Marysville. The Natural Resource Trustee Council which includes representatives from the Tulalip Tribes of Washington, National Oceanic and Atmospheric Administration (NOAA), USFWS, and Ecology and other partners (NRCS, City of Marysville, and the Stilly-Snohomish Fisheries Enhancement Task Force) are working to return the 380-acre area to its historic condition by reintroducing tidal action.

The Trustees have over several years acquired private properties and obtained easements over other properties to enable the restoration efforts, but some properties including the Christofferson site eluded acquisition until recently when Sound Transit stepped in to assist the Trustees in acquiring the land. Sound Transit needed to provide mitigation for impacts to nearshore habitats caused by the planned construction of its Sounder Commuter Rail. Sound Transit worked with Ecology to get approval to use the purchase of the Christofferson site as mitigation for its Sounder impacts if the site could be subsequently donated to the Trustees for incorporation into the Qwuloolt restoration project. To facilitate the deal, Sound Transit developed a Memorandum of Agreement outlining the terms of the acquisition with the property owner. A similar memorandum was developed to specify the terms of Sound Transit's donation of the land to the Trustees. Acquisition of the Christofferson site expands the footprint of the restored tidal marsh, reduces the need for interior levees, and enables more complete restoration of Jones Creek, which lies adjacent to the east property boundary. This collaboration produced a win-win situation for all involved.

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MM 16 PUBLIC EDUCATION AND INVOLVEMENT

Definition

This management measure includes actions that increase public awareness of nearshore processes and threats; build support for and volunteer participation in restoration and protection efforts; and promote stewardship and responsible use of nearshore resources. There are two basic components to this measure:

1. education and involvement of private property owners for the purpose of improving individual stewardship of private lands; and

2. education and involvement of the general public to garner support for restoration in general.

Public Education and Involvement can include holding public education events on public lands or accessible restoration sites, involving the public in on-the-ground restoration work (e.g., planting trees or monitoring), soliciting public opinion through surveys or other means, developing signs and interpretation materials for restoration sites, and creating general educational programs/materials for youth and adult audiences. Sponsors of restoration projects are often required to inform and involve the public in order to comply with the requirements of the National Environmental Policy Act, State Environmental Policy Act, Shoreline Management Act, or other laws, so public education and involvement are mandatory components of some restoration projects.

To be effective, education and involvement require two-way communication and interaction. The target audience includes shoreline property owners, policy makers, other restoration practitioners, citizens-at-large, restoration volunteers, and students. The educators are typically public agencies, institutions, and/or non-governmental organizations. Formal and informal educators are part of the target audience and practitioners in the two-way communication with scientists and policy makers.

Justification of Need and Link to Nearshore Processes

People knowingly and unknowingly impact nearshore processes through their actions and behaviors. People make choices about where to build their homes, which vegetation species to plant or remove, how to care for their lawns and gardens, and whether to install bulkheads based on a variety of factors including cost, aesthetics, functionality, convenience, regulatory requirements, and ecological considerations. One purpose of public education and involvement is to inform citizens, law and policy makers, and resource agency staff (among others) about the ecological consequences of actions and the need to preserve or restore nearshore processes. With an understanding of the cause and effect relationships of their actions, people may be more likely to choose ecologically sustainable options for developing and managing their property. People who become educated or involved in restoration efforts are more likely to volunteer time, donate money, and support legislation/regulations aimed at nearshore protection and restoration compared to people who are unaware of the benefits of restoration. As a result, this management measure is an essential tool for addressing all types of nearshore impairments and achieving support for restoration across the entire Puget Sound (all geomorphic systems). The ability to carry out beneficial restoration actions will be enhanced if restoration sponsors communicate with the public and stakeholders in a way that induces them to make changes and even sacrifices in support of restoration.

For decades, public and private property owners have constructed physical impediments to nearshore processes. Bulkheads were built because of fears (justified and unjustified) concerning shoreline erosion.

Levees, sea walls, and dikes were built to prevent flooding. Encouraging shoreline property owners to remove bulkheads and other process-impairing structures requires a concerted education and outreach campaign that fundamentally alters and improves understanding and acceptance of natural processes. This is an example of how education and involvement can help enhance or restore processes such as sediment supply, beach erosion and accretion, and ecological and habitat interactions. A well developed public education and involvement effort can lead to other process improvements as people are encouraged to plant vegetation, control invasive species, enhance habitat (e.g., constructing nest boxes), remove/replace dock decking with light-penetrating grating, reestablish species (e.g., Olympia oysters), and control runoff and pollution (avoid herbicides, use soil amendment to promote infiltration, conform with generous setbacks to distance buildings from the shore, etc.).

Public education and involvement can also be used to educate the public at-large and encourage buy-in from stakeholders through involvement in restoration planning, construction, and monitoring. Public education and involvement improves the public's understanding of the ecological sensitivity of restoration sites so that additional values can be gained from the restoration efforts (e.g., research opportunities, community stewardship, etc.). One of the most essential applications of this measure will be educating people about the effects of climate change so that adaptations can be made in advance of serious climate impacts.

Conceptual Model

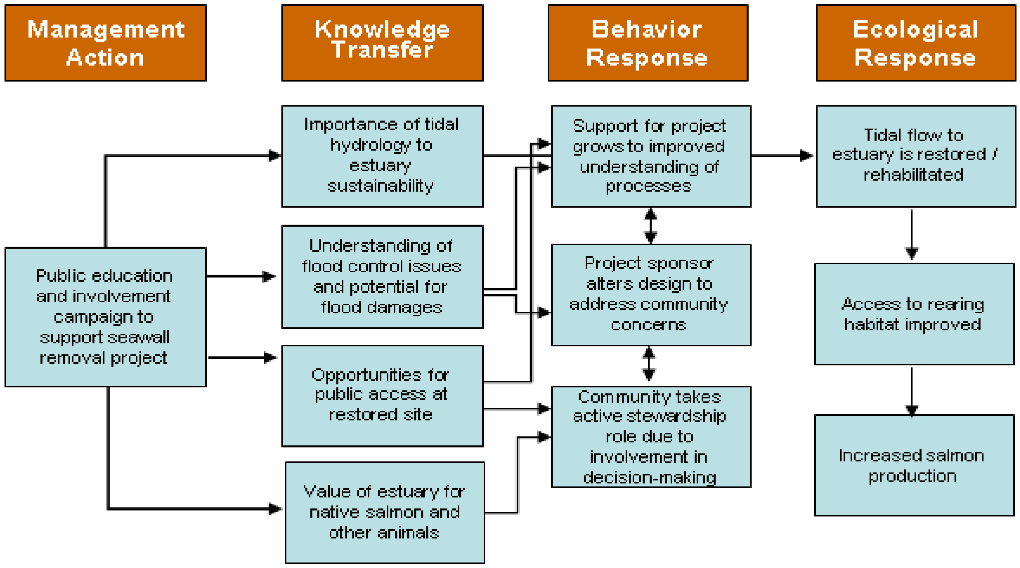
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 16-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: The USACE is considering removing a seawall, but many residents of the community oppose the project because of concerns about flooding.

Change/Action: USACE launches an education and involvement effort consisting of news media coverage, site walks, and workshops to build support for the project and identify workable design solutions that address community concerns.

Predicted Response: Citizens increase support for the project and withdraw opposition. Project moves forward due to improved understanding of nearshore processes and involvement of the public in planning and decision-making. Supportive citizens provide capacity for volunteer stewardship/monitoring.

Figure 16-1 Conceptual Model for Public Education and Involvement



Complementary Management Measures

Public Education and Involvement creates support for large-scale restoration actions involving multiple measures such as *Berm or Dike Removal or Modification, Channel Rehabilitation or Creation, Groin Removal or Modification, Hydraulic Modification*, and *Topography Restoration*. *Public Education and Involvement* can help facilitate other measures such as *Armor Removal or Modification, Overwater Structure Removal or Modification, Revegetation, Reintroduction of Native Animals, Species Habitat Enhancement,* and *Invasive Species Control* that are often applied on private properties or require public involvement as a regulatory compliance measure. *Habitat Protection Policy and Regulation* also typically requires substantial *Public Education and Involvement* to garner support for the adoption, implementation, and enforcement of policies and regulations. *Public Education and Involvement* should also be used independently of other management measures to enhance the public's understanding of and appreciation for nearshore systems.

Benefits and Opportunities

Benefits of the Restoration Action

Education and outreach programs play a critical role in connecting the missions and programs of restoration agencies to change the behavior of Washington's residents (EEAW 2008). The benefits of human behavior modification transcend physical manipulation of the landscape and create lasting value for nearshore protection and restoration. Specifically the benefits of this measure include:

Grassroots participation: This measure promotes grassroots participation in restoration, which improves stewardship of restoration sites and increases the chance for success.

Ownership: Public education and involvement promotes partnerships that instill a sense of ownership of the contributing problems as well as solutions.

Regulatory compliance: State and local governments have regulatory requirements for education and involvement under current environmental policies (NEPA, SEPA, etc.)

Reduce need for enforcement: Informed citizens are more likely to comply with policies and regulations designed to protect or restore nearshore systems. This reduces enforcement burdens on regulatory agencies.

Low cost: Compared to some management measures, education and outreach can be relatively inexpensive. Educational materials do not always need to be site- and/or location-specific. Once materials are created, they can be reused in different settings, communities, and scenarios.

Increased volunteerism: Educational workshops at restoration sites can be a source of volunteer labor (i.e., planting parties, weed removal crews, etc.). The time spent organizing the event and educating the attendees is offset by the work they do in support of the restoration project. According to a 2008 survey of education and outreach programs around Puget Sound conducted for the Puget Sound Partnership, the contribution of volunteer labor is substantial at nearly $3,000,000 annually (EEAW 2008; for more information see http://www.independentsector.org/programs/research/volunteer_time.html).

Measurable Units

The benefits of public education and involvement can be expressed in several ways, including: the number of volunteer hours devoted to restoration-related activities, the level of support/funding for restoration efforts, and the number of property owners willing to implement restoration actions. According to the Puget Sound Partnership-sponsored survey (EEAW 2008), program organizers commonly assessed the value of their outreach efforts based on:

- Increased change in personal practices at home or work
- Increased knowledge of conservation issues facing Puget Sound
- Increased involvement in conservation actions

Opportunities for Implementation

Public education and involvement concerning Puget Sound restoration occurs through a wide range of existing programs carried out by state resource agencies, MRCs, Washington Sea Grant Program and Washington State University Extension, and non-governmental organizations (EEAW 2008). Examples include, but are not limited to:

- Washington Sea Grant Program and Washington State University Extension – water quality field agents work with residents in five Puget Sound counties; marine specialists work with shoreline property owners.
- Washington Sea Grant Program and State Parks – educate boaters about clean boating practices and work with marinas and others to prevent small oil spills.
- Department of Ecology – involves hundreds of residents through water cleanup plans, watershed planning, and nonpoint pollution, stormwater, and shoreline programs.
- Department of Fish and Wildlife and the Recreation and Conservation Office – support numerous volunteer habitat restoration projects.
- Department of Health – educates the public on shellfish protection and onsite sewage system maintenance.
- Department of Natural Resources – involves the public in processes to designate and manage aquatic reserves throughout the Sound.
- Department of Agriculture – educates and assists property owners in managing pesticides and reducing invasive species to protect habitat and water quality.

- Conservation Districts – work with rural residents to improve land management and habitat.
- Department of Commerce – holds workshops and develops resource materials for local citizens, elected officials, and local planners.
- Puget Sound Partnership's Education, Communication & Outreach Network (ECO Net) – facilitates coordination between education and outreach providers in Puget Sound.
- People For Puget Sound – educates the public on Puget Sound science and values, conducts restoration activities with community involvement.

This management measure provides an opportunity to engage residents of the Puget Sound region in a discussion about social and ecological values. Leschine and Peterson (2007) support VECs as a communication tool for engaging the public in a dialogue about the importance of regional-scale restoration in Puget Sound. VECs can generally be defined as benefits that we hope to achieve through restoration. VECs are increasingly being applied in environmental management as a way to incorporate the human dimensions into management goals. PSNERP identified VECs that: (1) are likely to be enhanced by nearshore restoration; (2) each can be said to deliver "ecosystem services"; and (3) are already recognized by many people in the region as having associations with a "healthy" Puget Sound:

- Marine riparian vegetation communities
- Nearshore birds
- Native shellfish
- Great blue herons
- Juvenile Pacific salmon
- Beaches and bluffs
- Orcas
- Kelp and eelgrass
- Marine forage fishes

Emphasizing VECs is a way to articulate and communicate to the general public the links among restoration, ecosystem health, and the broader values that many people hold for Puget Sound. Leschine and Peterson (2007) assert that this is essential for a program of the scope envisioned by PSNERP to become a reality.

Marine Resources Committees, cooperative extension services, state/county government agencies (e.g., WDNR, WDFW, Ecology, PSP, King County), marine science centers (e.g., Port Townsend), and non-governmental organizations (such as People For Puget Sound, TNC, and Wild Fish Conservancy) are the most likely implementers of this measure. The 2008 Puget Sound Partnership-sponsored survey of educational programs showed that about 47% of the 104 respondents were government agencies, 32% were non-profit agencies, 9% were associated with a university, 8% were tribal governments, and 2% were other organizations (EEAW 2008). These programs involve the public in various ways. Some of the most common and effective education and outreach avenues include:

Electronic media: Websites and e-newsletters provide effective vehicles for disseminating information. Electronic databases can be used to track and monitor ongoing activities and to share information across programs. Electronic media are also very useful for opinion surveys, soliciting public comments, and showcasing restoration photographs or videos (e.g., King County's Life on the Edge videos produced for the County's Shoreline Master Program Update project available at http://www.kingcounty.gov/environment/waterandland/shorelines/current-program.aspx).

Print media: Educators typically use brochures, printed newsletters, Frequently Asked Questions, and similar materials to disseminate information to target audiences, including audiences that may not have ready access to internet resources.

Workgroups, caucuses, and forums: In some cases, it may be appropriate to convene specific groups for concentrated outreach and education. This may involve focused workshops or charrettes with stakeholder groups (e.g., residents who may be affected by a restoration project), meetings with business leaders whose support is needed for restoration efforts, or workshops wherein subject matter experts interact with citizens for information sharing. The topic forum workshops sponsored by the Puget Sound Partnership during development of the Action Agenda are a good example of this. In these workshops, participants discussed scientific understanding of problems facing Puget Sound, and identified policy and management strategies needed to achieve a healthy ecosystem. Over 550 people attended the workshops, including representatives of local jurisdictions, tribal governments, local organizations, businesses, federal and state agencies, non-profit organizations, and citizens (see http://www.psp.wa.gov/aa_topic_forums.php for more information).

Conferences: Scientific and/or policy conferences such as the Puget Sound Georgia Basin Conference, Nooksack Salmon Summit, South Sound Science Symposium, and others provide excellent opportunities to inform the public, local government staff, educators, consultants, and others about threats to Puget Sound, the latest advances in restoration science, and other important topics.

Restoration field trips: Field trips to restoration sites are essential for building public interest and support for restoration efforts and for keeping restoration practitioners accountable to the public. These trips can be used to showcase actions that individuals can take to restore or enhance their own property. An example would be soft shore protection demonstration projects that motivate private landowners to remove or soften bulkheads. Large projects on sites that hold substantial public interest (e.g., Nisqually Delta) also lend themselves to field trips. In these situations, a field trip following the initial restoration effort may help build support for subsequent restoration phases or actions. High school senior culminating projects and student field trips for all ages can also engage students in nearshore restoration activities in their communities.

Restoration work parties: Work parties allow people to take an active part in the physical work of restoring nearshore ecosystems. These events also enable restoration sponsors to take advantage of volunteer labor to accomplish activities such as planting, weeding, clean-up, and monitoring.

Informal outreach: Informal outreach often consists of handing out information at public events or areas where people congregate. The Jefferson County Department of Community Development recently staffed information booths at local establishments throughout the county to disseminate information concerning proposed changes to their shoreline master program.

Interpretive signage: Interpretative signage at restoration sites can inform visitors about the benefits of restoration efforts, explain linkages between human activity and ecosystem processes, alert people to sensitive areas, and reduce unwanted disturbances sometimes associated with public access. This may be especially effective at large-scale restoration sites involving multiple measures such as *Berm or Dike Removal or Modification*, *Channel Rehabilitation or Creation*, *Hydraulic Modification,* and *Topography Restoration,* but is not limited to such applications.

Classroom activities: Formal and informal educators have the ability to reach large audiences. Classroom projects are being developed around actual restoration projects involving students and community supporters. Free-choice learning institutions such as IslandWood provide opportunities to educate students about a variety of environmental topics.

Citizen science: There is growing interest in the use of citizen science as a restoration tool. Citizen science is the collection of scientific data by individuals who are not professional scientists (students, birders, amateur botanists, rockhounds, farmers, etc.). Whereas public education is typically thought of as professionals educating the public, citizen science allows the opportunity for the public to collect information that science professionals value.

Institutionalized, place-based education: Educators can develop restoration solutions for nearshore environments using classroom activities that can be taught year after year. Informal education institutions such as the Homewaters Project can provide opportunities for youth to participate in restoration and stewardship projects in their communities.

Constraints

Requires repeat treatments: One of the major constraints to this measure is that it requires frequent and ongoing effort. People often need repeated and long-term exposure to new ideas and information before it truly takes hold. Over time, the target audience changes as demographics of the region change and as property ownerships shift. Complicating this further, human values are likely to change through time and in ways very difficult to anticipate today (Leschine and Peterson 2007).

Soft funding: Another significant constraint is that public education and involvement is often a low priority for funding. A large percentage of education and outreach programs rely on soft money for funding. According to the 2008 Puget Sound Partnership-sponsored survey, nearly 46% of the programs surveyed were grant funded. Earned revenue (monies received after providing a product or service) was the second largest income source (EEAW 2008). Variable funding means that many restoration efforts must proceed with little or no outreach to citizens. Another slightly different aspect of funding is that even when fully educated and informed, some property owners will lack the means or expertise to implement restoration actions on their lands.

Reaching individuals with power to act: To be most effective, outreach and education must target individuals and groups with the power and resources to act. This can include shoreline property owners (who have the power to act to protect and restore resources on their land), policy makers (the legislature, local elected officials, and state resource agencies that develop, fund, and implement regulations and restoration projects), and managers of public lands (who carry out restoration at parks, tidelands and other areas), among others.

Lack of program integration: Puget Sound is fortunate in that there are a wide range of organizations providing public education and outreach. Additional coordination and integration across programs will improve efficiency, ensure that stakeholders are receiving consistent informational messages, and produce more lasting and desirable behavior changes.

Reluctance to use citizen science: Citizen science requires numerous dedicated individuals and a substantial investment of time and energy to ensure that the participants are knowledgeable, properly trained, use consistent and reliable methods, and collect accurate data. There may be reluctance on the part of some professional scientists to use information collected by citizen scientists because of concerns about data accuracy, dependability of the volunteer base, or lack of awareness of the concept itself. With the development of rigorous protocols suitable for a volunteer work force, reliable data collection methods, and sound volunteer management, citizen scientists can collect valuable and credible data.

Best Professional Practices

Feasibility Assessment

Public education and involvement will almost always be feasible at some level. As a result, feasibility assessment will typically focus on how the measure should be implemented (as opposed to whether it should be implemented). Key questions that will guide the assessment are:

- Who are the key stakeholders and affected parties (who needs to be educated/involved)?
- What is the best way to reach target audiences?
- What are the key messages/issues that will be the focus of the dialogue?
- What regulatory/procedural requirements need to be met?
- Who are the appropriate partners?
- What are the desired outcomes (support for project, volunteer participation, and financial donations)?

Design

When designing a project that involves public education and involvement, it is important to understand the cultural perspectives, needs, and interests of the target audience as well as the specific goals of the education effort. This can help build environmental literacy in the target audiences for sustainable changes in behavior over the long-term. The North American Association for Environmental Education (NAAEE 2004) identifies six basic characteristics that are essential to effective environmental education and outreach programs:

Fairness and accuracy: materials should be fair and accurate in describing environmental conditions, problems, and issues, and in reflecting the diversity of perspectives on them.

Depth: materials should foster an understanding and appreciation of environmental concepts, conditions, and issues, as appropriate for different developmental levels.

Emphasis on skills building: materials should build lifelong skills that enable learners to address environmental issues.

Action orientation: materials should promote civic responsibility, encouraging learners to use their knowledge, personal skills, and assessments of environmental issues.

Instructional orientation: materials should rely on instructional techniques that create an effective learning environment.

Usability: materials should be well designed and easy to use.

Organizations sponsoring public education and involvement measures should inventory existing programs to verify that the proposed new programs support, but do not duplicate, other efforts. Follow-up with recipients of information is critical to understanding the success of the education and outreach program.

The following recommendations were made to PSP based on the analysis of the Puget Sound Education and Outreach Purposive Survey (EEAW 2008):

- Education and outreach organizations should be given greater support in developing measurable goals and assessing the progress of those goals. A Program Assessment Team should be formed to provide this support and guidance. Through an evaluation and assessment process, the Team can also give feedback on the most effective techniques, tools, and methods to develop a Best Practices model useful for those working in education and outreach efforts.
- Key educational messages targeted at specific audiences should be aligned with the goals of the Partnership. Depending on the priorities of the Partnership, it may be necessary to identify groups that can provide support for education and outreach subjects that groups might not currently focus on.

- Support for informal education and outreach providers should be increased and strengthened. Much of the valuable education and outreach work is done by very small staffs and budgets. Providing greater resources will increase the capacity of these groups to change public perceptions and habits.
- Collaboration and synergy should be increased across professional areas and work cultures. The different work cultures between organizations and agencies need to be bridged to focus the informal education and outreach community on the work at hand.

Implementation

Educational and outreach materials and events must use methods and language that are appropriate for the age, experience, cultural background, and educational background of audience members. For on-site activities, logistical challenges such as parking, access/walkability, and restrooms must be considered to ensure the safety and comfort of the participants while also preventing adverse impacts to the site.

Evaluation

Participant/citizen surveys are an effective means for judging the outcomes of education and involvement actions. Focus groups and input at public meetings can also provide information about effectiveness. It is also possible to evaluate the utility of this measure by assessing changing trends in volunteerism, donations, support for regulations and conservation initiatives, etc. The results will not necessarily reflect a direct cause and effect relationship, but would provide an indirect measure of the extent to which education and involvement are working.

Case Studies and Examples

Washington Shore Stewards, various counties. Modeled after the National Wildlife Federation's successful Backyard Wildlife Habitat program, Shore Stewards was developed from the ground up with an emphasis on community-based marine shoreline protection. The Shore Stewards are waterfront and stream-side property owners who share ideas, information, and resources to enrich the beauty and abundance of shoreline properties. The members, which include residents, farmers and forest owners, parks, port districts, cities, businesses, and others, learn and voluntarily apply habitat-friendly approaches to managing their lands

Green Shorelines Guidebook, Seattle: The City of Seattle (Department of Planning and Development) collaborated with Seattle Public Utilities and the Lake Washington/Cedar/Sammamish Salmon Recovery Council to develop a guidebook for lakefront homeowners. The book, which was funded by a grant from the King Conservation District, provides photos, text, and illustrations to inform readers about alternatives to conventional shoreline armoring, stressing the aesthetic and ecological benefits of plants and beaches. The guidebook was developed in consultation with an advisory committee and contains current information on shoreline restoration techniques, restoration costs, and the permitting process. Although this guidebook is geared to lakeshores as opposed to marine shorelines, it provides an example of the types of educational materials that can be very effective in modifying human behavior and promoting better shore stewardship/restoration. Many of the concepts and approaches showcased in the Green Shorelines guidebook are applicable or at least adaptable to the marine shore. Information is available at http://www.seattle.gov/dpd/Planning/Green_Shorelines/Overview/

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MM 17 REVEGETATION

Definition

Revegetation uses site preparation, planting, and maintenance to manipulate soils and vascular plant populations to supplement the natural development of native vegetation. *Revegetation* is a diverse management measure potentially involving:

- Work of variable duration and intensity from reintroducing a single species to reassembling complex plant successions, involving single treatments or protracted management;
- Planting with seeds, cuttings, or rooted stock, including pre- and post-planting stock treatment to enhance survival or growth of native species ; and,
- Modifying the pre- and/or post-planting environment (sometimes including existing vegetation) to enhance plant stock survival and growth via the following methods: grading, grazing, mowing, burning, tillage, soil amendment, fertilization, mulching, irrigation, chemical or mechanical weed and pest control, and thinning.

Efficient *Revegetation* carefully considers landscape setting as well as local conditions to minimize costs and maximize certainty of success. While a diversity of habitat types provide for primary productivity in the nearshore, including sites vegetated by single-celled organisms and seaweeds, analysis of *Revegetation* in this chapter is focused on vascular plant habitats including:

1) nearshore forests and their associated freshwater wetlands
2) backshore and coastal spit vegetation
3) freshwater, brackish, and salt tidal marshes
4) eelgrass meadows

Justification of Need and Link to Nearshore Processes

Extensive deforestation following European settlement has altered the majority of uplands adjacent to Puget Sound shorelines. Disturbances such as filling, diking, armoring, overwater structures, upland structures, roads, ports, and other activities along shorelines have fragmented and reduced the diversity and abundance of marine riparian and freshwater wetland plant communities. The WDNR ShoreZone inventory (WDNR 1999) indicates that riparian vegetation overhanging the intertidal zone occurs at only 440 of the nearly 2,500 shoreline miles of Puget Sound (Redman et al. 2005).

Riparian forests were the first areas to be extensively logged because they were easily accessed, and logs could be rafted and floated to mills around the region. Because mature hemlock/Douglas fir forests take hundreds of years to develop, it is likely that there are few, if any, pristine nearshore riparian forests remaining, except possibly in areas where natural disturbance was frequent and persistent enough to maintain early seral communities (Brennan 2007).

Brackish and saltwater marshes have also been diked and drained for agriculture or dredged and filled to create buildable land with shoreline access. The development of two major river delta estuaries of Puget Sound's central basin, the Puyallup and the Duwamish, contributed to an estimated 98 percent loss of tidal wetland area in the Puget Sound Central Basin (WDNR 1998). More broadly, estimates based upon evaluation of 11 major deltas in Puget Sound indicate at least a 76 percent loss in tidal marshes and riparian habitat (Levings and Thom 1994). Except for Hood Canal and the Eastern Straits of Juan De

Fuca, no portion of Puget Sound has more than 50 percent of its historic tidal wetland area remaining (Collins and Sheik 2005).

The extent and condition of eelgrass meadows have declined sharply from historical conditions. Recent monitoring data show disturbing declines in Hood Canal and small embayments in the San Juan Islands (Dowty et al. 2005). Dredging or filling, nutrient loading, shading from overwater structures, propellers, and wake-driven waves have been shown to impact eelgrass meadows in Puget Sound and elsewhere (Mumford 2007). Important indirect stressors to eelgrass include hypoxia, eutrophication, and changes in trophic structure from harvest of competitors, herbivores, or predators of herbivores. Mumford (2007) provides a general model for reducing stressors to eelgrass for the purposes of restoration.

Revegetation in most environments focuses on the establishment of slow-growing, long-lived vascular plant communities using cultural practices from agriculture, horticulture, and forestry. In the nearshore environment, however, revegetation as a restoration measure must also be conducted with a firm understanding of the dynamic nature and character of the nearshore.

Nearshore ecosystems contain a mosaic of habitats, some of which support vascular plant communities and others that do not. Areas that are naturally unvegetated or sparsely covered are one component of the nearshore system. For example, sand or mudflats can support a very productive flora of microalgae, consisting of a thin veneer of algae over gravel or cobbles, with primary productivity as high as in an eelgrass meadow (Mumford 2007). Unvegetated areas also serve important ecological functions by providing high infaunal diversity and biomass (clams, worms, etc.) to upper trophic organisms, such as shorebirds. High banks eroding into the sea may be stripped of vegetation or dominated by weedy species, but these banks supply sediments critical for beach formation. Conversely, vascular plant communities in the nearshore perform different and important processes. For example, tidal salt marshes or backshores also provide detritus recruitment and retention processes, while intertidal vegetation, such as eelgrass, provides food web support and refuge for a wide variety of aquatic organisms.

Because of the dynamic nature of nearshore ecosystems, revegetation as a management measure must be applied to specific environments for specific purposes. The purpose of this chapter is to illustrate how nearshore processes affected by vegetation are context-specific and why they must be carefully considered. Some of the best management practices used in terrestrial systems may be inappropriate in the dynamic nearshore environment. Revegetation in the terrestrial environment often attempts to ensure permanent long-lived vegetation. However, engineering stability can result in projects that undermine nearshore processes that depend on disturbance (such as wind and wave action).

Revegetation, where successful, can alter the ongoing processes of native plant community assembly and succession. The above and below ground structures created by plants have the potential to affect a broad range of fundamental ecosystem processes over time:

Primary productivity: Vegetation provides the foundation for most terrestrial food webs and many aquatic food webs by storing solar energy in complex organic compounds.

Carbon cycling: Vegetation can provide a long-term sink for atmospheric carbon in wood and soil/sediment organic matter.

Nutrient cycling: Vegetation removes soluble nutrients from the substrate and increases development of substrate structure while increasing organic matter. Vegetation also “pulls” nutrients from the water column, which reduces nutrient loads. This results in increased belowground nutrient pools, cycling rates, and increased capacity to adsorb nutrients and buffer chemical processes.

Wave and tidal energy absorption: Eelgrass meadows and emergent marsh can absorb wave and tidal energy, stabilizing sediments, and affecting the energy reaching landward beaches and banks.

Hydrologic cycling: Upland vegetation intercepts rainfall, creates surface litter, absorbs and transpires soil moisture, and modifies soil permeability. These processes affect how water moves in the landscape.

Microclimatic processes: Vegetation can reduce local air temperature, increase humidity, reduce wind speed, and intercept solar radiation, creating microclimates supportive of life.

Revegetation with native species can also improve a wide range of ecological functions:

Refuge functions: Vegetation provides animals with refuge from weather and predation, potentially increasing the density and resilience of populations. Different populations show affinity with different kinds of vegetation, and so the character of the vegetation mosaic can affect the composition and density of animal communities.

Forage opportunities: Vegetation provides forage for grazers and foraging structures for predators.

Substrate stabilization: Plant roots, shoots, and litter increase the erosion resistance of substrates, typically reducing sediment suspension in moving water. By absorbing the energy of moving water, vegetation creates depositional zones when sediment is mobilized.

Alluvial functions of wood: Wood in river and creek channels creates more diverse instream structure and can affect the course of rivers, enhance rearing habitat, and increase floodplain habitat diversity.

Water quality functions: By slowing water movement, improving soil permeability, and increasing percolation rates, vegetation can help to trap nutrients that would otherwise become pollutants in aquatic systems.

Economic functions: Vegetation can be managed for the sustainable yield of a wide range of valued products either for economic or household purposes.

Cultural functions: Recognition and use of vegetation is among the most powerful catalysts for developing cultural relationship with landscapes. Native vegetation is valued by both native and contemporary populations.

Conceptual Model

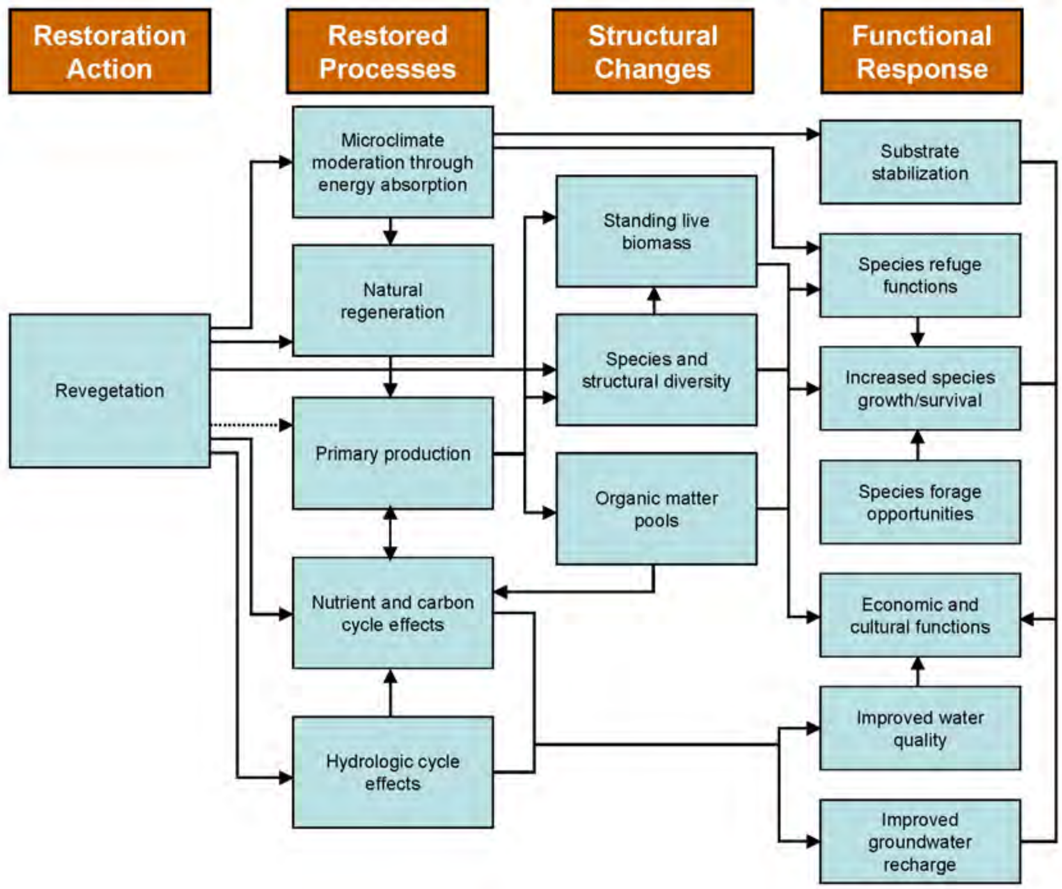
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 17-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows). The conceptual model depicts a generic approach to revegetation projects. The purpose is to assist restoration practitioners in developing more project-specific models that more explicitly address local domains and treatment schemes.

Scenario: Landscape-scale clearing of vegetation and/or modification of soils and sediments have greatly reduced above- and below-ground biomass as well as structural and biological diversity.

Change/action: A revegetation treatment is implemented specific to site and landscape conditions.

Predicted response: The trajectory of native vegetation development is altered in a positive direction.

Figure 17-1 Conceptual Model for Revegetation



Complementary Management Measures

Revegetation is one of the most commonly applied management measures, often used in conjunction with other management measures, particularly following disturbance of existing vegetation or bare soil. *Revegetation* can speed development of desired ecological conditions following *Hydraulic Modification*, *Topography Restoration*, or *Channel Rehabilitation or Creation*, particularly when there is no local plant population to colonize new environments. Reforestation is a long-term and potentially self-sustaining alternative/complement to *Large Wood Placement* and *Species Habitat Enhancement* in that habitat structures are grown on site. *Revegetation* in the form of biotechnical erosion control methods can also be used in conjunction with or in lieu of engineered structures as part of *Armor Removal or Modification*. *Revegetation* is also often a logical partner to *Invasive Species Control* efforts when a particular species is targeted for removal.

Revegetation is often required as a mitigation measure (to offset development impacts) and is therefore associated with *Habitat Protection Policy or Regulation*. *Physical Exclusion* can be applied to recently revegetated sites or to support regeneration where vegetation is limited by stressors like trampling or grazing. *Revegetation* can aid in *Pollution Control* because plants bind soil particles and can help slow or trap pollutants in runoff water. Such long-term habitat protection strategies are a useful complement given the long-term accrual rate of vegetation benefits.

Benefits and Opportunities

There are a number of other potential benefits from revegetation that can align with other elements of the physical or cultural landscape. These opportunities can be beneficially integrated into design and installation.

Natural recruitment: Revegetation established founder colonies for production of spreadable prologues. As a restoration measure, revegetation promotes plant dispersal and recruitment, which can pre-empt establishment of non-native species. Subsequent natural regeneration of native species can supplement or even supersede revegetation efforts. Successful revegetation initially accelerates the recovery of habitat structure and function and then supports natural regeneration in adjacent sites.

Improved habitat for special status species and valued ecosystem components: Many species of plants and animals that are afforded special protection status under the state and federal regulations such as salmon and forage fish rely on vegetation structure. Revegetation can improve habitat function for these species and their required habitat structure.

Potential low cost: With effective site selection and assessment, revegetation in more terrestrial environments can be accomplished with volunteer labor, simple tools, and inexpensive propagules, at relatively low energy and capital costs.

Economic benefits: Revegetation programs create a local industry for production and installation of native plant stock. Naturalized vegetation can provide opportunities for carefully managed harvest of products for human use. Successful revegetation projects can provide seeds and cuttings for successive projects. Economic benefits also include those ecosystem benefits from ecological goods and services.

Public engagement: The “low-tech” nature of many revegetation practices allows for participation of untrained or volunteer labor, creating substantial opportunities for public education and participation, leading to improved stewardship and stimulation of future projects.

Experimental observation: The short- and long-term survival and growth of plantings across environmental gradients is poorly documented. Revegetation sites provide significant but often overlooked opportunities to study plant community assembly to increase future revegetation success.

Diverse values: Land managers and users value diverse naturalized vegetation for providing passive recreation and a lower-cost alternative to more resource-intensive land management.

In addition to the restoration of habitat-forming processes, revegetation can also provide many ecosystem services (benefits that people obtain from ecosystems). The Millennium Ecosystem Assessment sorts ecosystem services into four categories: supporting; regulating; provisioning; and cultural (MEA 2005). As shown below, revegetation can provide important primary production and nutrient cycling, known as supporting services, as well as recreational and aesthetic functions, which support important cultural services.

Ecosystem services provided by *Revegetation*

Supporting	Regulating	Provisioning	Cultural
Primary production	Climate regulation	Food	Aesthetic
Nutrient cycling	Disturbance regulation	Fresh water	Recreational
Soil formation	Biological regulation	Raw materials	Spiritual
Hydrological cycle	Water regulation	Genetic materials	Historic
Habitat formation	Waste regulation	Medicinal resources	Scientific
Pollination	Nutrient regulation	Ornamental resources	Educational
Seed dispersal	Soil retention regulation		
	Flood regulation		
	Water purification		

Measureable Units

The success of revegetation efforts can be assessed in a multitude of ways including: the presence and abundance of target animal species and/or the degree of biodiversity of plant species. Plant community structure can be evaluated using standard vegetation survey techniques to assess whether long-term trajectory of the site will be as planned.

Opportunities for Implementation

Revegetation can be implemented at an infinite variety of site scales and intensities. Among the myriad landscape context considerations (e.g., bluffs, barrier lagoons, pocket beaches), it is important to determine how site selection fits in with the restoration agenda (i.e., local coastal management plan) in a given area, or how it can be combined with larger restoration efforts (e.g., coastal watersheds). Revegetation efforts may have a greater chance for success where they are adjacent to existing natural systems (seed sources) or are protected (from disturbance or future development) by policies and regulations.

Revegetation treatments are typically motivated by government regulation, compensatory mitigation, tax-funded site stewardship by private or public entities, or private investment in erosion control. Recent Critical Areas Ordinances and tax incentives like the Public Benefit Rating System aim to manage vegetation on private land. Conversely, land use practices that encourage clearing, grazing, and mowing can inhibit natural regeneration of soils and forest.

Constraints

Revegetation attempts to achieve complex self-sustaining vegetation in dynamic environments with fewer resources than other horticultural endeavors. The capacity of vegetation to naturally regenerate can be reduced by loss of local seed sources, changes in environmental conditions, and local animal populations. In many cases, natural regeneration may no longer restore historic vegetation structure, diversity, or function. While effective restoration is aligned with natural forces, there are many constraints that can undermine restoration efforts, most of which can be avoided through careful assessment and design:

Modified environmental conditions: Soils, hydrology, or water quality may be so modified that they prevent the development or reduce the resilience of historic vegetation.

Modified ecological conditions: The naturalization of exotic species or changes in local animal populations may result in competition, predation, or lack of facilitation that may reduce the viability of certain vegetation patterns.

Anthropogenic stressors: Trampling, harvest, over water structures, and air, water, and soil pollution may directly degrade new plantings or degrade them in the future.

Climate change: Change in seasonal patterns of precipitation or temperature, either anthropogenic or cyclic, may modify the development or resilience of target vegetation.

Sea level rise: Increased mean sea elevation can change the depth of inundation, affecting revegetation efforts especially those involving submerged aquatic and marsh communities. Higher sea levels will increase erosion and landslides.

Technical limitations: Techniques used in vegetation management for landscaping, agriculture, or forestry may be ineffective or inefficient when applied to establishment of complex, self-regulating native plant communities in degraded nearshore environments.

Costs: Cash resources available for revegetation are typically minimal and short term. Constraints can dramatically increase the costs of reaching performance targets. Revegetation of some environments can be expensive at a large scale.

Questions remain about how to increase and accurately measure short-term efficiency and long-term functional response. The data gaps create an additional constraint for revegetation efforts. In general, because of the effectiveness of horticultural and agricultural practices, we could assume that revegetation practices are equally effective. However, revegetation is qualitatively different then intensively managed systems in that it aims to produce complex, self-sustaining systems in perpetuity with little or no maintenance.

While many examples of eelgrass revegetation have been documented, quantitative monitoring rarely answers questions about best practices. Thom et al. (2008) concludes that eelgrass restoration science is hampered by knowledge gaps, reducing restoration success. For example, the mechanisms for recent eelgrass loss in the region are not obvious, which suggests that the scientific understanding of eelgrass biology and ecosystem conditions is inadequate to support environmental management actions in our region. The following is an incomplete list of data gaps related to revegetation in Puget Sound restoration efforts.

Species propagation efficiency: Limited information is available of the most cost effective approach for propagating each species across the range of conditions to which it is adapted to grow. Plant density has been correlated with several measures of revegetation success (Celedonia 2002), but costs increase exponentially with increased plant density. Use of seed and smaller stock can potentially increase short-term cover, but these methods are often avoided due to perceived risk of out-planting failure.

Planting into existing ecologies: Due to the lack of monitoring data, our understanding of how to efficiently change the development of existing forests stands is limited. This hampers our ability to successfully reintroduce conifers into hardwood dominated stands where conifers have been extirpated by forest practices.

Seeding: While seeding is common in restoration of Great Plains prairie systems, very limited data are available to describe the effective use of Puget Sound species from seed. Increased use of seed could increase cost effectiveness.

Soil restoration: While soil and sediment conditions are critical to all revegetation efforts, limited information is available about how treatments affect soils, and how soil condition in turn affects revegetation outcome. Agricultural and horticultural practices are regularly used in revegetation without consideration of how reference soils that develop under natural conditions may vary from those soils resulting from horticultural or agricultural practices in terms of nutrient pools, physical characteristics, or depth.

Presence and role of herbivores: Plant species and their susceptibility to herbivores specific to the Puget Sound area and sites within the area are likely poorly documented. Especially in cases of submerged and emergent plants, protection from grazers will probably be necessary during the establishment phases of revegetation.

Long-term trajectory: While short-term survival and growth are critical for project success, the long-term development of vegetation may veer from design targets. The effectiveness of revegetation ultimately lies in long-term performance, which is rarely measured.

Hydrologic tolerances: Very limited empirical evidence is available to clearly define the tolerances of species to inundation stress. Substantial experiential knowledge exists in the professional community that has not been summarized.

Functions: The specific functions of vegetation and how those functions vary with the structure, function, area, or continuity of vegetation have not been fully assessed. Understanding the nature of vegetation function will assist in prioritizing revegetation actions to maximize restoration of ecosystem functions that depend on vegetation.

Role of disease and pests: Sub-lethal stress on plant populations can cause susceptibility to disease or pests, particularly where plant monocultures create an easy vector for spread of disease or pest populations. We have limited information about the extent to which natural disease cycles are present or are exacerbated by human impacts or management. Introduced diseases and pests are an additional factor that may affect vegetation viability and ecosystem resilience now or in the future.

Best Professional Practices

Effective manipulation of vegetation is complex, and requires careful planning, sensitive design, and practical installation. The following sections provide general considerations for the planning and implementation of a revegetation project. At the end of this chapter is a summary of best management practices specific to different ecotypes (e.g., salt marsh, freshwater wetlands) (see Table 17-1). The table is meant to focus on ways in which best practices vary between systems. In all cases, appropriate species selection based on soil and water conditions and microsites is critical and assumed. Adaptive management, learning, effective recordkeeping, and communication are also critical. The need for and approach to managing invasive species vary dramatically depending on project goals and objectives, and so invasive management issues are not addressed in the table. Assessment and response to potential grazing/browsing pressure is assumed and should be considered for all situations (browse control is only mentioned in particularly important circumstances). Conservation and protection of soils is assumed for all ecotypes.

Restoration practitioners focusing on eelgrass restoration should also refer to *Eelgrass (Zostera marina L.) Restoration in the Pacific Northwest*: *Recommendations to Improve Project Success* (Thom et al. 2008) for the most current best professional practices.

Feasibility Assessment

There are many feasibility considerations when planting revegetation projects. Some of the main considerations include:

Soil/sediment conditions: Soil/sediment conditions strongly affect the survival and competitiveness of individual species. Artificially propagated stock or seedlings are more sensitive to environmental extremes than established vegetation. Soil texture, nutrient characteristics, and structure can be quantitatively or qualitatively assessed and compared to reference conditions. Existing vegetation can provide evidence of soil conditions. The salinity of soil pore water in tidal systems strongly controls marsh composition. Sediment texture can indicate energy environment. Plant species can be very sensitive to contamination in soils.

Water quality: Proper water quality conditions are critical for in-water revegetation particularly for eelgrass. Potential pollutants include nutrients, toxics, and sediments/turbidity (for proper light penetration).

Hydrologic regime: Frequency, depth, and duration of inundation interact to create low oxygen conditions in the soil that reduce survival and growth of many species. Species selection should be based on a clear understanding of the effect of the hydrologic regime on soil conditions. Falling water levels in freshwater marshes and other habitats can devastate recently completed revegetation efforts.

Solar exposure: Intensity of sunlight combined with solar aspect can affect species viability. Individual species are differently adapted to compete under different light levels. Eelgrass is particularly sensitive to shading or reduced sunlight caused by turbidity. Exposure can exacerbate drought conditions, or low light levels can reduce a species' ability to adapt to anoxic soils.

Seed banks and seed rain: Revegetation occurs in the context of natural regeneration. Revegetation treatments can be either enhanced or superseded by natural vegetation processes. Seed banks can be assessed through growing-out soil samples, observing seasonal recruitment on bare soil, or by making assumptions based on surrounding vegetation. Seed rain can be similarly assessed.

Competing vegetation: Regeneration and expansion of existing plant populations, including seed banks, can strongly affect vegetation development. For example, algae can be absent in winter, and then grow rapidly in spring, competing with eelgrass. Control of undesired vegetation can be integrated into site preparation, and planting design, as well as maintenance. Assess existing vegetation to clearly understand life history traits, response to treatment design, anticipated future recruitment and growth, and management options.

Disturbance regime: Local disturbances can include fire, herbivory, alluvial, tidal, or wave-driven erosion, turbidity, deposition, slope and substrate instability, pollution related impacts, and a wide range of direct human impacts. Revegetation can be severely undermined by poor assessment of the current disturbance regime. Pressure from beaver, deer, elk, goose, voles, rabbits or other browsers and other grazers (including aquatic grazers such as turtles, waterfowl, etc.) may be critical to planting survival, or may dictate the selection of plant species.

Regulatory concerns: Work in wetlands and other protected habitats (e.g., critical areas) is subject to local, state, and federal regulations that may constrain timing, extent, and specifications of work.

Design

Design considerations varying depending on the site conditions, but some of the key design issues are:

Adaptively manage and learn: Despite the sound designs, on-the-ground work is an opportunity to observe and learn. Careful assessment allows practitioners to anticipate, budget for, and adapt to potential constraints. Carefully documenting revegetation goals, objectives, effort, and outcome, combined with experimental designs that answer specific management questions, can improve the effectiveness of future projects. Installation and funding strategies must accommodate observation and course correction.

Examine reference conditions: The effectiveness of plantings can be increased by identifying similar conditions and mimicking patterns of composition and structure found at reference sites. Care must be taken to select appropriate reference sites that provide useful information about preparation and planting. For example, a mature forest may provide a limited view of species composition and vegetation structure during early stand establishment. Multiple reference sites may need to be examined and synthesized to match the unique environmental patterns of a site.

Anticipate succession: Vegetation changes soils, microclimates, and substrate conditions as it develops. Numerous theories predict how community composition and structure change over time. Successional design considers how planting species and density will evolve toward a future state that may not be readily apparent in the planting plan. Some efficiency may be gained by protracting the planting process to take advantage of evolving site conditions that support survival and growth of target species. Planned disturbance can be incorporated into revegetation design to manipulate vegetation structure and create niches to increase diversity. Protracted observation of natural systems can offer ideas for dynamic vegetation development.

Use natural regeneration: Where dispersal from surrounding native vegetation is robust, revegetation can occur by simply removing constraints to natural regeneration. Where adequate monitoring and contingency planning can be assured, restoration planners can test the effectiveness of unassisted regeneration during early phases of revegetation efforts. Revegetation effort can then be reduced or applied to supplement natural vectors of vegetation development.

Integrate cultural practices: Agriculture, forestry, horticulture, and agroforestry all have technologies and strategies that can be integrated into revegetation efforts. Species respond differently to cultural methods.

Consider timing: Survival and growth can be improved by aligning revegetation actions to avoid or take advantage of seasonal variation in precipitation, temperature, soil moisture, and disturbance. Advantageous timing can vary between sites, within sites, and among the species cultivated.

Evaluate environmental zonation: In wetlands, vegetation composition frequently varies in a pattern of concentric elevational bands corresponding with soil moisture and inundation regime. Planting growth and survival can be increased by accurately aligning planting patterns to match the environmental thresholds that control naturally observed zonation. The zonation of recruitment may not match the zonation of mature vegetation.

Anticipate hydrologic effects: Controlling hydrologic conditions to moderate extremes of inundation or drying over a period of plant establishment can increase the survival and growth of out-plantings.

Design around weed control: Opportunities for cost-effective control of undesired exotic weed populations decrease dramatically once a planting is installed. Effective weed control is designed into all phases of site work. Undesirable species can be imported with equipment, plant stock, or loose materials like soil, sand, or gravel.

Implementation

The following guidance will improve implementation effectiveness:

Design information flows: Sound design plans can go awry if the on-the-ground implementers are not aware of and motivated to implement design strategies. Document design intent and detail so that it is accessible and maintain regular and clear communication throughout bidding and construction.

Conserve and restore soils: Construction practices can rapidly degrade soil structure with irreversible impacts on revegetation efforts. Construction should be designed to preserve and enhance the structure and biology of existing and imported soils through stockpiling (as appropriate) and protective ground coverings for heavy machinery.

Start with pre-disturbance conditions: In eelgrass restoration sites, it can be important to restore site conditions as close as possible to pre-disturbance conditions. This may require manipulating site elevation through dredging or filling (e.g., Drayton Harbor), clearing debris (e.g., Clinton Ferry terminal), or removing structures (e.g., Maritime Center Dock) that inhibit eelgrass growth.

Protect existing vegetation: In riparian or upland sites, prevention measures may be necessary to protect existing vegetation. Construction fencing should be installed to delineate areas of clearing and protection. Root systems critical for tree health may extend far from tree trunks. Driplines of large trees should be designated and covered with protective covering.

Protect water quality: Chemicals and fuels, including those in machinery, must be managed carefully to prevent pollution. Anticipate and accommodate a range of weather scenarios when planning water quality protection measures.

Manage erosion and soil impacts: Bare ground should be protected from rainfall and construction disturbance using best practices (e.g. silt fencing, hay placement, etc.). Control and treatment of sediment laden water may be critical on some sites, but is secondary to prevention of erosion.

Stock quality control: Stock should be grown and staged under conditions that support rapid growth after out-planting, including adequate irrigation, appropriate fertility management, and protection from extreme heat or cold. Measures should be taken to ensure contaminants are not transported to restoration sites.

Carefully select installers: Ornamental landscape contractors may not be familiar with revegetation species, or best revegetation practices may vary from ornamental landscape practice. Careful selection or training of contractors may increase revegetation performance.

Complete as-built documentation: Accurate documentation of the extent and nature of the actual revegetation treatment as installed is critical to evaluating monitoring results, and any attempt at learning from past projects.

Adaptive installation: Actual site conditions can vary dramatically from design assumptions. Designers and installers should be able and prepared to adjust designs to meet observed field conditions while maintaining good quality documentation of the installation.

Evaluation

Qualitative monitoring of vegetation can provide detailed information for lower cost, and can allow for rapid response to site conditions. Quantitative monitoring requires a sound experimental design to draw meaningful conclusions. Robust experimental design is based on testing explicit questions. The long-term value of vegetation can be strongly affected by hard-to-measure phenomena like resilience to disturbance, invasive species, and plant succession. A range of vegetation parameters can be tracked based on project goals and objectives:

Planting area and density: Detailed records of planting extent and density are most easily maintained when integrated into construction practice. As-built planting records provide a critical measurement for evaluating the influence of revegetation treatments among multiple sites.

Survival and growth: Survival can be measured by comparing quadrat density before and after a specific time period. Initial sampling should closely follow planting. Inaccurate reproduction of plot boundaries can increase error in counts. Growth rates can offer more detailed information about the controls on variable planting performance than survival or cover. Highly variable growth observed immediately after out-planting may become undetectable over time if it is a relic of variable planting practices.

Estimated cover: Sampling method should be carefully assessed to minimize variance among independent cover estimates. The time interval between estimates should consider the rate of growth and the ability of the sampling strategy to detect change. A wide range of measurement techniques are available for measuring relative dominance between species, so hypotheses should be explicitly stated.

Structure: Simple vegetation structure can be captured by estimating species cover within discrete elevation ranges (strata). A range of more complex measurements and summary statistics can be used to quantify vertical or horizontal structure.

Annual productivity: Deciduous herbaceous systems like tidal marshes lend themselves to measurement of aboveground annual productivity. Comparison of above and below ground productivity may offer insight into vegetation condition. Non-destructive measures like shoot height and density may be a useful surrogate for productivity.

Seedling density: Patterns of natural seedling recruitment may be used to suggest that a desired state of self-sustaining process has been achieved.

Soil condition: Though plant growth can be used as a surrogate for soil conditions, some restoration objectives may involve targeted soil conditions that can be directly measured like bulk density, organic matter pools, or measures of biochemical condition, like sulfide concentration or reduction-oxidation state.

Wildlife utilization: Vegetation functions can be estimated by evaluating the presence, diversity, residence time, or diet of resident wildlife species. Certain species or phases of life history may provide indicators of vegetation functions.

Case Studies and Examples

Eelgrass restoration in Drayton Harbor and Blaine Harbor Marina Expansion, Blaine: As part of the Port of Bellingham's Blaine Harbor Marina Expansion, clean dredged material from the marina basin was deposited at a low spot in Drayton Harbor and resulted in the conversion of over 15 acres of subtidal area to an intertidal/shallow subtidal area. This was a voluntary action of the Port (not required as mitigation) and was also an alternative to the traditional open-water disposal of dredge materials. Five years of monitoring found that planted eelgrass survived and spread, and volunteer plants colonized much of the site. Monitoring for salmonid prey organisms indicated that the site provides rearing habitat for juvenile fish and Dungeness crab.

Riparian Surge Plain Restoration, Nisqually Tribe, Olympia: This project is included as a case study for the feasibility of a large-scale planting effort. As part of the Nisqually National Wildlife Refuge estuary restoration project, the Nisqually Tribe has implemented a large-scale restoration of approximately 54 acres of freshwater tidal riparian forest (also known as riparian surge plain) along the lower Nisqually River by intensively planting an area adjacent to existing surge plain forest. The project was phased over a two-year period. The first year, approximately 19,000 native shrubs and trees were installed over 24 acres in the fall and winter (2007-2008). The following year another 22,000 plants were installed over 30 acres. Adaptive management and innovative techniques were critical to get the project in the ground. The site was historically used for low-impact farming and consisted of a thick mat of pasture grasses.

The first year, the site was tilled and sprayed with glyphosate in the early fall before planting. With onset of the rainy season, the wet, tilled soils resulted in challenging conditions during fall and winter planting efforts. To avoid this constraint the second year, the site was not tilled, but was still sprayed with glyphosate to 'knock down' pasture grasses during live plant development. Plants appropriate for the site were selected and then generally placed in the field by their moisture tolerance at the time of planting. Due to the high number of plantings, the Tribe decided to install the plants in loose rows (as opposed to irregular clustering) to make future maintenance (mowing, weeding) activities feasible. The majority of plants were installed using paid labor (tribal crews) with approximately 10 acres planted during volunteer planting events in the fall. Volunteers installed containerized stock, which is easier to handle and more forgiving during installation. The majority of plants were live stakes and bare root. Plant storage between delivery and installation required some creativity (to maintain survivorship). Live stakes were stored in a penstock filled with water at the tribe's fish hatchery and bare root plants were stored during the first year at a cold storage facility owned by the Washington State Department of Transportation.

Tidal and estuarine marsh, Commencement Bay Natural Resource Damage Assessment and Restoration, Tacoma: Approximately 10-15 tidal marsh restoration sites have been installed surrounding the Port of Tacoma, motivated either by natural resource damage settlements or mitigation associated with industrial development. The National Oceanic Atmospheric Administration (NOAA) is the lead agency of the Commencement Bay Natural Resource Trustees and is responsible for managing restoration projects under the Commencement Bay Natural Resource Damage Assessment and Restoration Plan. A baywide restoration plan was adopted in 1997 that put forth a series of habitat restoration projects using funds, property, and inkind services obtained through damage claim settlements. The plan focused on replacing components of the historic ecosystem (e.g. estuary, mudflat, emergent marsh, eelgrass beds) that enhance populations of fish and wildlife. The majority of sites were implemented between 1999-2001. Information about each of the restoration sites, along with photographs, can be found on the web at http://www.darrp.noaa.gov/northwest/cbay/restore.html.

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Table 17-1 Summary of Best Management Practices by Ecotype for *Revegetation*

	Dry and Bluff Forests	Moist Forests	Freshwater Wetlands
Constraints	Reduced percolation from urbanization may reduce soil moisture. Poor access and difficult terrain may increase costs.	These are the most forgiving conditions to work under.	The current hydrologic regime of the site is most limiting factor. Modified hydrology may limit palette to most adaptable species. Beaver can strongly modify design hydrology.
Opportunities	Consider experimenting with techniques for improving survival of outplantings without irrigation including stock selection and seeding.	These conditions offer the greatest opportunity for volunteer involvement. Early succession hardwood species are easy to establish from seed. Keystone species are relatively well understood.	Wetlands are amenable to volunteer plantings – where drought is not a concern plantings can occur any time of year. Beaver can expand wetland function.
Assessment	Exposed bluffs can create high mortality from drought stress while irrigation on remote slopes may be difficult or expensive. Geologic strata can strongly affect groundwater movement and soil moisture regime. Aspect of slope can drive community composition. Slope failure and shifting soils can favor ruderal species.	Natural red alder (*Alnus rubra*) regeneration can strongly direct plant community development. Surface water drainage patterns can create mosaic of soil moisture regime.	Accurate assessment and prediction of depth, duration, and frequency of inundation (hydrologic regime or water budget) is critical to successful design. Seasonally changing water depths may require multiple plantings and/or timing of plantings to ensure that plants are within elevation ranges suitable to their growth. A need for nuisance plant species control may dictate integrated site prep, planting and maintenance strategies. Sediment transport from rivers and creeks can drive system function.
Design	Planting at the beginning of fall rains, use of small stock with high root to shoot ratio may increase survival in the absence of irrigation. Temporary drip irrigation may be cost effective for irrigation during establishment. Natural patterns of water flow may indicate microsites beneficial for plant establishment. Where constraints increase costs, patchy *Revegetation* followed by natural regeneration may be more cost effective.	Closing canopy to reduce competition from grasses may enhance growth of some species. Consider rapid canopy closure followed by thinning and introduction of shade tolerant species where shade intolerant exotic species are an issue. Irrigation may provide minimal benefits depending on soil conditions and interannual variation.	Plant community targets are carefully aligned with zonation related to hydrologic regime and reference wetlands. Reference wetlands may represent an unusual composition resulting from biogeographic dispersal patterns or past degradation. Planting can be delayed until after leaf emergence in spring to avoid long inundation stress on transplants (only where soil moisture is retained into summer). Large mono-specific stands of willow can be susceptible to beetle infestations. Several wetland species can be effectively propagated using un-rooted cuttings (dogwood, willow, etc.).
Construction	Crew traffic can increase erosion on slopes. Crew safety may require rope and harness. Adjust planting locations to match observed moisture patterns if previous observation of winter wetness was not feasible.	Mesic forest presents the least challenges to constructability.	Saturated soils are easily compacted. Excavation, storage and placement of soils need to be carefully managed. Seeds of invasive species can be easily imported in fill, so transport must be controlled.
Monitoring	Patterns of survival among species may guide future planting. In disturbance environments, establishment of natural dispersal and regeneration by target species may indicate system resilience.	Methods for monitoring (survival and growth, estimated cover, stem density) are widely used and proven successful for evaluating restoration goals and objectives.	Periodic monitoring of plant survival, growth, and spread combined with volunteer plant community development will provide decision-making information necessary for implementation of adaptive management practices (e.g., controlling nuisance species, planting additional native plants, etc.). Monitoring hydrology, water quality, grazing pressure, weather patterns, and human activity can provide critical information about patterns of planting mortality.

	Backshore/Spit Vegetation	Salt Marsh	Eelgrass
Constraints	Wind, shifting sand, soil salinity, and salt spray on leaves can create very stressful environments for plant establishment. Social trails can heavily impact fragile dune systems.	Salt marsh is created and sustained by sedimentologic processes that may be dramatically altered (in the past and future). Contamination may occur from industrial activity or contaminated fill.	Eelgrass transplanting requires specialized crews with diving equipment and expensive propagation facilities. Snuba could be viable (combination of snorkeling and scuba diving).
Opportunities	Consider experimenting with techniques for planting dune grass and other salt-tolerant plants.	Dredge spoils can be beneficially used to create areas of sediment for marsh establishment.	Many of the opportunities present in other ecotypes are absent with eelgrass. Given the high cost and experimental nature, maximize learning opportunities from each action.
Assessment	Salt spray combined with sandy soils and exposure to sun and wind can create severe drought stress. Ground water discharge can vary dramatically along a beach face or be non-existent or saline on a spit or foreland. The intensity of adjacent land use is a critical factor to selecting a site.	Hydrology, elevation, and salinity all critically control species composition. Presence of local seed source and position of the site to patterns of wrack accumulation may affect natural regeneration. Alluvial disturbance may be an issue. Resident Canada goose populations can also prevent marsh establishment.	Existing eelgrass populations best demonstrate tolerance of local disturbance regime. Viable habitat is typically bounded by exposure and wave disturbance at high elevations, and light levels at lower elevations. Presence of holdfasts can encourage algal dominance.
Design	Given the shortage of information on these communities, examination of reference conditions is critical. Diverse species are not frequently available, and may require contract growing or seed collection. Facilitation by pioneer species may be important for building soil organic matter and moderating the environment. Discontinuity and fragmentation of these systems may increase the need for *Revegetation*.	Soil redox regime can be strongly affected by pore drainage between tidal cycles. Porosity of constructed surfaces may be less than a natural formed marsh. In sandy sediments, facilitation by annuals or algae may improve organic content to support more robust growth of perennial marsh species.	Neighboring reference conditions are critical. Wave energy can vary over short distances. Staking to stabilize transplants is valuable. The connection between sediment chemistry and population viability is poorly understood.
Construction	Closure of the restoration site (*Physical Exclusion*) is critical to success.	Saturated soils are easily compacted. Excavation, storage and placement of soils needs to be carefully managed.	Orienting and accurately placing stock underwater with currents and waves can be difficult. Staking is useful to reduce mortality from erosion or predation.
Monitoring	Limited information is known about species autecology, interactions and succession in this environment. Patterns of survival among species may guide future plantings.	Elevation can strongly affect patterns of regeneration. Consider stratified sampling based on elevation.	Timing monitoring is critical to repeated samples. Shoot density is a common surrogate for biomass production, but can be variable from year to year due to factors other than *Revegetation* method. Establish control sites.

MM 18 SPECIES HABITAT ENHANCEMENT

Definition

This management measure includes the creation of habitat structure or installation of specific habitat features for the benefit of native species in the nearshore environment. The deliberate placement of artificial habitat features is a method for jump-starting recovery toward specific restoration goals. *Species habitat enhancement* includes a wide range of activities conducted for the purpose of enhancing survival or reproduction of one or more target species particular to the restoration site. Enhancement activities for the species discussed under *Reintroduction of Native Animals* and *Revegetation* are not repeated in this chapter.

Examples of habitat features could include tidal habitat benches, log and rock piles, snags, artificial reef structures, and plantings. Nest and roosting structures placed in the backshore or riparian zones of estuaries, such as boxes for cavity-nesting songbirds and ducks, gourds for martin and swallow, and platforms for osprey, are also examples of habitat features. Marine riparian vegetation and large woody debris are typical components of nearshore habitat enhancement and are critical to restoring habitat functions. Deliberate selection and placement of vegetation and wood in the nearshore can provide habitat structure for enhanced shelter, nesting substrates, and diverse forage for small mammals, amphibians, reptiles, fish, and birds. Some features may benefit multiple wildlife types (e.g., birds and amphibians or mammals and birds).

Justification of Need and Link to Nearshore Processes

This measure typically includes the placement of artificial structures that mimic natural features with the overall intent of benefiting habitat for targeted nearshore species. Structural measures do not typically ameliorate degraded nearshore processes, but they can replace lost habitat structure with an immediate response. Species habitat enhancement measures vary depending on the targeted species, the zone within the nearshore where the action will take place, and the level of degradation that the site has incurred. Structural measures can complement larger-scale processed-based restoration with delayed response times, and can function as a practical alternative where larger processed-based actions are infeasible.

Nearshore processes associated with this management measure are largely dependent on the specific action and the zone within the nearshore where the action occurs—upland, supratidal, intertidal, or subtidal. Measures taking place in the upland and supratidal would likely address nearshore processes such as: detritus recruitment and retention, transport and deposition of wood and sediment, and solar radiation exposure (lack of cover vegetation or wood). Actions taking place in the intertidal and subtidal zones of the nearshore would typically address sediment transport, beach erosion and accretion, exchange of aquatic organisms, and wind and wave processes. Finite processes addressed by species habitat enhancement may include primary production and ecological and habitat interactions. These processes can be restored by creating a short-term response of native fish and wildlife use (via specific habitat structures such as nest boxes and platforms) and long-term habitat structure through vegetative succession and decomposition (snags with nest cavities, diverse plant assemblages, wood debris and litter). Species habitat enhancement features (such as tidal habitat benches and large woody debris) can transform the food web to secondary and tertiary consumers, which benefits invertebrate communities that make up the food base for forage fish and juvenile salmonids.

Conceptual Model

The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 18-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

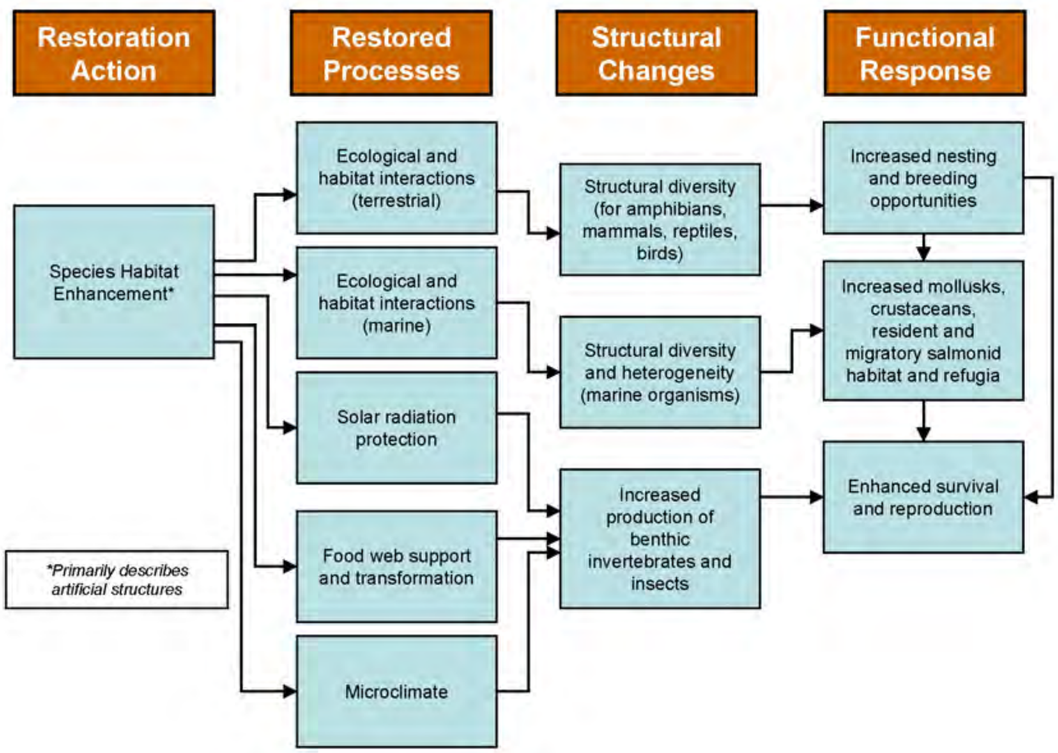
A conceptual model for species habitat enhancement activities recognizes a distinction between adding artificial structures to mimic natural habitat features versus enhancement of vegetation and woody debris. The placement of vegetation and wood into the nearshore environment has been discussed in *Revegetation* and *Large Wood Placement* chapters.

Scenario – Historical disturbance and degradation of the marine riparian has degraded and/or eliminated wildlife habitat and species diversity.

Change/Action – Installation of habitat features such as large woody debris and nest and roosting structures provide habitat structure that encourages foraging, nesting, and shelter by a variety of wildlife types.

Predicted Response – Opportunities for diverse wildlife use (multiple types) and long-term enhancement of primary production and ecological and habitat interactions.

Figure 18-1 Conceptual Model for Species Habitat Enhancement



Complementary Management Measures

Species Habitat Enhancement activities complement nearshore management measures involving the physical manipulation of land or hydrology, such as *Armor Removal or Modification, Channel Rehabilitation or Creation, Topography Restoration,* and *Substrate Modification.* In these situations, artificial habitat structures can be placed to jump-start native wildlife use of the site, which otherwise would develop more slowly as ecosystem processes are re-engaged. *Species habitat enhancement* also complements other structural measures such as *Invasive Species Control, Revegetation, Beach Nourishment,* and *Large Wood Placement* where specific-species elements are placed in conjunction with other habitat structures.

Benefits and Opportunities

Benefits of the Restoration Action

The benefits of this management measure vary widely in relation to the scale and landscape-context of the particular restoration site. The following are general benefits to consider:

Targeted habitat functions: Provides habitat function benefits to targeted species selected for the particular restoration project (e.g., juvenile salmonids, waterfowl, etc.). This measure also has the potential to indirectly provide salmonid habitat and food chain support.

Biodiversity in riparian systems: Enhanced riparian systems along marine shorelines support abundant and diverse assemblages of fish and wildlife. For example, within King County, Brennan and Culverwell (2004) identified 263 wildlife species (9 amphibians, 5 reptiles, 192 birds, 57 mammals) known or expected to be associated with marine riparian habitat. This accounts for 80 percent of all wildlife species found in King County.

Cultural benefits: Increased fish or wildlife use of the nearshore area increases recreation, scenic/aesthetic amenities, and cultural opportunities.

Measurable Units

Benefits of species habitat enhancement can be measured by projecting the targeted response of the particular species being addressed by the action and monitoring the species occurrence or behavior relative to that expected response. This could be done by monitoring the targeted species before and after that action has occurred and/or along an un-impacted reference site. Best available science should guide the specific monitoring measures for the targeted species. Previous monitoring metrics should mimic previous (successful) applications of similar enhancement actions.

There are numerous well-developed methods for sampling wildlife, most of which are designed to sample a particular aspect of a population. The sampling method chosen should be applicable to the restoration goal and should draw from best available science on the targeted species. To determine simple bird species richness at a given site, rigorous techniques such as line transects and point counts are necessary. Territory or spot mapping can be applied to small areas (under 20 hectares) to obtain the density and location of birds in the restoration area. Amphibians and reptiles are surveyed using a wide variety of techniques such as pitfall traps, audio strip transects, and visual encounter surveys. Long-term intensive sampling is necessary since it can take years to sample reptile or amphibian populations with numerous or secretive species (Morrison 2002).

Opportunities for Implementation

This management measure can be applied to nearshore areas of any Puget Sound geomorphic shoretype. Species habitat enhancement activities can be applied to nearly any restoration site at all levels of intensity. Innovative structures are still being developed as knowledge of nearshore restoration expands. Studies examining the addition of complexity to vertical seawalls (seawall test panel projects) are an example of promising new developments in nearshore restoration research in highly urbanized settings. The results of test projects conducted in 2007-2008 are being analyzed and eventual publications will help guide the future reconstruction of the Seattle seawall. The findings and techniques may also be applied to similar structures in aquatic settings, such as large bulkheads or marinas.

Areas of the nearshore that are restricted by high intensity land uses, and thus lack feasible restoration opportunities, can benefit from the installation of discrete habitat features. In particular, constrained sites that are adjacent estuaries, lagoons or other high value habitats should be targeted.

Likely implementers are city and county governments, tribes, private landowners, and community groups. Species enhancement activities may also be included with larger restoration projects implemented by industry, conservation districts, MRCs, Washington State University Shore Stewards, and non-governmental organizations. Opportunities to implement this management measure could also exist as part of compensatory mitigation projects, such as enhancement of a degraded habitat where structures or contamination were removed.

Constraints

Constraints of species enhancement activities are generally related to the spatial scale of the project and the temporary nature of the activities:

Scale: Some projects have a potential size restriction (i.e., very large sites may be infeasible due to funding and resource allocation).

Location: The landscape context of the restoration site will determine level of (ecological) benefit.

Temporal limitations: Most actions will provide only a temporary replacement or conversion of lost habitat.

Life cycle imbalances: Single species habitat structures typically are specific to only one life stage requirement (e.g., nesting via boxes) and do not address other life cycle needs (e.g., feeding).

Life expectancy: Most habitat enhancement actions are artificial structures that will degrade over time and may require staff time and funding for occasional maintenance.

Ecosystem dynamics: The installation of artificial structures may not integrate with whole system dynamics, but may unbalance the system (temporarily). Species habitat enhancement projects could create an artificial abundance of one species to the detriment to another (e.g., seawall test panels project could provide habitat for an unintended species).

Lack of historic habitat use data: Baseline data for species use is often not available (e.g., amphibians) or is not statistically usable for monitoring and referencing project performance.

Best Professional Practices

This section is intended to generally describe potential considerations and practices that may be associated with species habitat enhancement. The specific recommendations will likely depend on the other restoration actions occurring at the site, landscape context, and the habitat needs of the specific targeted species.

Feasibility Assessment

Target species: Restoration practitioners should consult background information about the restoration site and adjacent (and similar) habitats to determine what species will be targeted for habitat enhancement. Documentation of historic presence and/or habitat use is important for setting goals and objectives.

Species specific application: Relevant literature and habitat requirements for specific wildlife species (of importance in the nearshore) should be reviewed to determine the more appropriate nearshore zone within which to conduct enhancement for the targeted species, and the specific action that will best ameliorate the specific habitat degradation at the subject site. Literature is abundant, but new techniques and experiments should also be analyzed and considered.

Design and Implementation

Site conditions: Important considerations for engineering and design should include understanding of historic conditions of the site and species abundance prior to habitat degradation (where possible), the (historic) geomorphic shoretype, level of exposure and aspect. Existing habitat or species abundance (e.g., priority habitat species data from WDNR and WDFW) should be acquired for each site. Nearby seed sources for vegetation and vegetation zones should be characterized.

Permitting: Permit implications will vary depending on the action and the targeted species. The zone within the nearshore that the action will take place will largely determine the type(s) of permitting required, based on jurisdiction of the various permitting agencies, and the levels of engineering and design. If the target species is a federal or state listed species of species of concern, the restoration practitioner should coordinate with the responsible agency for permitting requirements and other information.

Design details: Engineering specifics and design considerations should include schematic drawings for most actions. Appropriate engineering specifications will also be dependent on the (spatial) scale of the project, and whether or not complementary management measures that may require more rigorous design specifications are associated with the project. For artificial structures, drawing details should be developed. Two general details are provided as examples at the end of this chapter: 1) wildlife snag, and 2) nest box (Figures 18-2 and 18-3).

Construction: Project implementation should adhere to best management practices, including timing restrictions and erosion and sediment control BMPs.

Evaluation

Multiple monitoring events: Baseline, post-construction and project performance monitoring should be conducted for all applications and should include standard and robust survey methods. The parameter(s) selected for monitoring in a restoration project will depend on the goal of the project. For example, if a project seeks to enhance foraging resources one should monitor the resource as well as the target species. Results of monitoring should be referenced against project performance measures and adaptive management should be applied to assure success where project performance has fallen short of the (anticipated) targeted response.

Case Studies and Examples

Nisqually Wildlife Refuge, Olympia: As part of the large-scale effort to restore tidal influence to the Nisqually Delta, the USFWS conducted some specific habitat enhancement activities for migratory waterfowl. Rather than returning the entire delta to estuarine wetland, the USFWS chose to retain 246 acres of freshwater wetland within the refuge to satisfy its mandate for providing habitat for multiple species of fish and wildlife. Prior to breaching dikes and levees within the refuge, a new interior dike was created. The dike will prevent tidal influence over 246 acres of existing freshwater wetland. Much of the wetland is dominated by reed canarygrass (*Phalaris arundinacea*) and is fed by seasonal rainfall. *Topography Restoration* was applied to enhance the existing wetland by removing some of the invasive plant and lower the elevation of portions of the site to allow for seasonal ponding (creating migratory waterfowl habitat). Nest boxes for swallow were placed at the edge of the newly graded ponded area (Figure 18-4).

Olympic Sculpture Park, Seattle: The construction of the Olympic Sculpture Park, located in downtown Seattle, Washington, transformed a former brownfield into an 8.5 acre urban greenspace which included aquatic marine habitat restoration along approximately 1,000 lineal feet of the shoreline. While the urban setting and historical industrial uses of the site limited the opportunity for process-based restoration, several innovative *species habitat enhancement* elements were incorporated into the design to improve the shallow nearshore migration corridor and rearing areas for juvenile salmon outmigrating from nearby rivers.

One element of the restoration was the construction of a low intertidal habitat bench along the seawall (Figure 18-5). The seawall stability needed to be enhanced through the placement of a riprap (large angular rock) buttress along its base. The buttress design included the creation of a 15 to 30 foot wide habitat bench of small substrate (2.5 inches in diameter and smaller) at approximately -1 foot Mean Lower Low Water. The habitat bench material is placed over riprap positioned to form a trough along the length of the seawall in the project area. The habitat bench provides low gradient habitat with substrate sizes that support the production of aquatic invertebrate prey items for juvenile salmon and other aquatic fauna.

The subtidal portions of the seawall included habitat restoration elements to support a kelp forest. This was accomplished by using smaller riprap material and quarry spalls on its surface along the subtidal portions. The surface materials are approximately 8 to 12 inches in diameter and were selected based on their suitability to support the holdfasts of bull kelp. This design provides habitat for the natural expansion of a kelp bed to the north of the site in Myrtle Edwards Park; kelp transplantation was not conducted.

The habitat enhancement elements at Olympic Sculpture Park replaced relatively unproductive armored seawall and subtidal habitats. Construction of the Olympic Sculpture Park habitat bench was completed in early 2007. Year-1 post-construction monitoring by the University of Washington has documented the rapid development of aquatic and terrestrial biota in the enhanced habitat areas (Toft et al. 2008). Snorkel surveys documented abundant juvenile salmon along the habitat bench and tidal embayment with high proportions displaying feeding behavior. The kelp forest has firmly established itself in subtidal areas as has a diverse macroalgae community along the habitat bench.

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Additional Resources

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Seattle Central Waterfront Seawall Habitat Test Panel Project: Integrating Intertidal Habitat into Seattle Waterfront Seawalls. 2007-2010. Charles Simenstad, Jeffrey Cordell and Jason Toft, School of Aquatic & Fishery Sciences, University of Washington. Funding provided by Washington Sea Grant.

Figure 18-2 Example design detail of wildlife snag

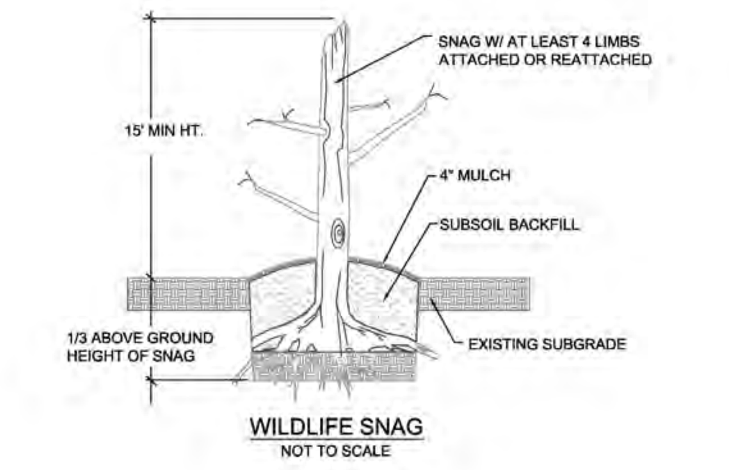
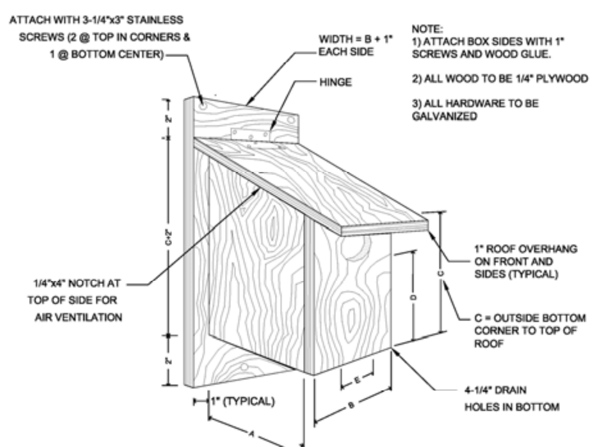


Figure 18-3 Example design detail of nest box



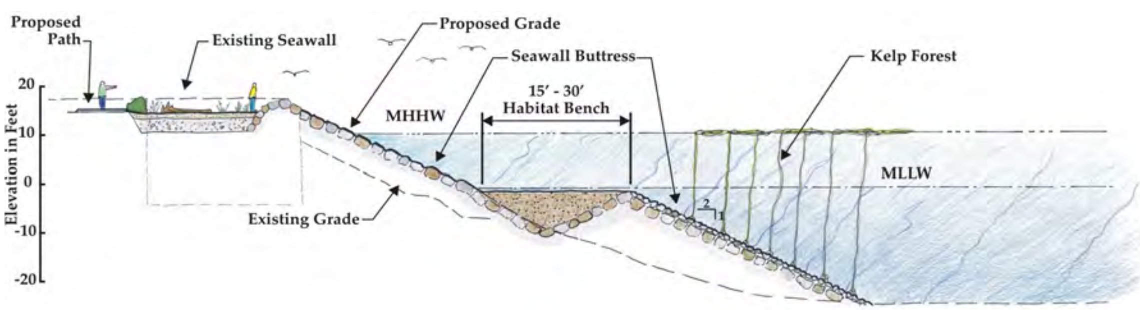
NEST BOX SPECIFICATIONS

TARGET SPECIES	FLOOR	DEPTH	ENTRANCE HEIGHT	ENTRANCE DIAMETER	ABOVE GROUND
	AxB	C	D	E	
CHICKADEE, NUTHATCH, DOWNY WOODPECKER	4" x 4"	8" - 10"	6"- 8"	1.125"	8'- 18'
HOUSE WREN	4" x 4"	6"- 8"	1"- 6"	1.125"	6'- 10'
TREE AND VIOLET-GREEN SWALLOW	5" x 5"	6"	1"- 5"	1.1.25"	10'- 15'

NEST BOX DETAIL
NOT TO SCALE

Figure 18-4 Habitat Enhancement, Nisqually Refuge

Figure 18-5 Habitat bench cross-section, Olympic Sculpture Park



*cross-section provided by Anchor Environmental LLC

MM 19 REINTRODUCTION OF NATIVE ANIMALS

Definition

This management measure pertains to the rehabilitation of native animal species at a site where they once existed or as replacement for lost habitat elsewhere. This measure pertains broadly to reintroductions of shellfish (e.g., native oysters and pinto abalone *[Haliotis kamtschatkana]*) or other non-motile animals, or the relocation of any locally extirpated species (e.g., native salmon in Chimacum Creek) or non-viable animal population. This measure is specific to direct placement of the animal itself and does not include efforts that only improve the habitat structure or supply a prey base for a specific animal. It also does not pertain to location or cultivation of animals for the purposes of commercial aquaculture. Native plant reintroductions are addressed under the *Revegetation* management measure.

Justification of Need and Link to Nearshore Processes

Native animal species provide important ecological, cultural, economic, and recreational values. Native salmon, birds, forage fish and shellfish are important to the ecology of Puget Sound because they comprise and support food webs and balance ecosystem dynamics. To illustrate the linkage between native animal reintroductions and nearshore processes, this chapter focuses on native shellfish in particular since there are multiple ongoing reintroduction efforts that can be used to exemplify this management measure. Other native animals may warrant consideration for reintroduction efforts, but are not described in detail in this chapter.

Of primary importance to nearshore processes, shellfish (defined loosely as oysters, clams, and crabs) filter nearshore waters and serve as prey for many aquatic organisms. As filter feeders, they can increase water column clarity and facilitate nutrient cycling. Shellfish also act as predators within the nearshore food web, contributing to the ecological balance. The ability of shellfish to contribute to certain ecosystem processes can be affected by the degradation of other nearshore processes. Virtually all shellfish are affected by human alterations of key ecosystem processes, such as sediment supply (Dethier 2006). Individual species have distinct types of sediment in which they recruit and/or grow best; thus, any process that alters sediment amount, grain sizes, organic content, etc., may negatively impact local shellfish populations. These alterations can come from changes in runoff from land, in sediment loads carried by rivers and streams (or held by dams), and in sediment supply from bluffs that have been hardened. Restoration of sediment supply and transport processes would likely benefit both natural and reintroduced native shellfish populations.

Shellfish in both adult and larval stages are also strongly affected by water column characteristics. Native shellfish species in Puget Sound spend as little as eleven days to as much as five months as larvae in the water column (Dethier 2006). Key physical conditions that larvae can be sensitive to include: temperature and salinity, turbidity, oxygen, pollutants, and food types and concentrations. All these can be affected by land use, shoreline modifications, stormwater and sewage discharge, industrial discharge, and other human activities.

Threats to shellfish and other native animals in Puget Sound also come from overharvest and direct loss of habitat. Populations of pinto abalone, a marine snail, along the west coast of the United States and Canada have experienced dramatic declines in the last few decades due to overharvest. Since 1992, abalone abundance at survey sites in Washington State has declined by 77 percent despite the prohibition of abalone fishing since 1994. As illustrated by Olympia oysters (*Ostreola conchaphila)*, commercial and recreational overharvesting contributed to the initial severe decline, but subsequent siltation and domestic and industrial pollutants from urbanization has continued to impair the recovery of this species. In terms of habitat, interidal and shallow subtidal habitats (in urban areas) that once supported shellfish populations have been completely lost (Dethier 2006). The construction and operation of port and commercial facilities (especially around Tacoma, Seattle, Everett, and Bellingham) often destroys habitat, especially soft-sediment and marsh areas. An estimated 4,800 acres have been lost because of such construction (Armstrong et al. 1993).

The reintroduction of native animal resources can speed recovery of ecosystem balance and begin to improve or provide habitat for other organisms. For example, pinto abalone naturally scrapes algae off rocks during foraging allowing other creatures to colonize, such as juvenile crustaceans and mollusks. Oysters grow together to form complex, hard substrates, both as reefs or flat beds, that provide a variety of settling surfaces for aquatic organisms. Subsequently, fish are attracted to the food resources associated with these hard substrate environments. The placement of seeded cultch (bits of oyster shell) can provide microhabitat diversity and initiate the formation of a diverse epibenthic community, including salmonid prey species.

Conceptual Model

The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 19-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

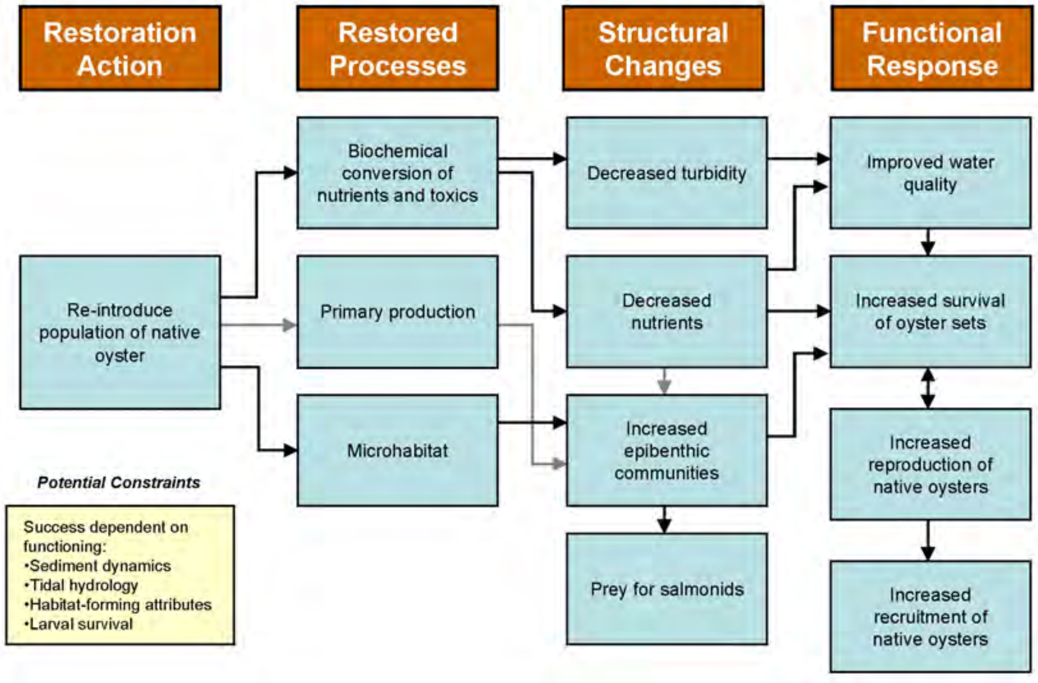
Species reintroduction efforts import species from another source and release or deposit the species in appropriate habitats within the nearshore. While some nearshore processes can be enhanced or restored following the reintroduction of native species, the success of the effort depends on the maintenance of a variety of other processes. In this example, an intertidal area that once supported native oysters is targeted for reintroduction. The conceptual model maps the connections between the reintroduction effort, the restored processes, the ecosystem structural elements that will change with altered processes, and ultimately the restored functions (e.g., natural recruitment of native oysters). The processes that support deposition of sand, mud and gravel; maintain appropriate temperature, salinity, and turbidity; and produce phytoplankton and edible detritus, are critical to reintroduction success and are therefore listed as constraints.

Scenario – Reintroduce population of native oyster.

Change/Action – Provide microhabitat diversity for other organisms, filtering of toxics and nutrients, and primary production.

Predicted Response – Create self-sustaining population to increase the density of spawning adults in Puget Sound.

Figure 19-1 Conceptual Model for the Reintroduction of Olympia Oyster



Complementary Management Measures

Reintroduction of Native Animals is similar to *Revegetation* in that it proposes the deliberate placement of a species to initiate recovery and begin a long-term natural recruitment. *Substrate Modification* activities could be applied in direct association with *Reintroduction of Native Animals* efforts. In this way, new habitat can be created in situations where no other management measure will provide recovery of nearshore functions. New habitats can be tailored to meet specific functional objectives, such as rehabilitating populations of native oysters, and can be interpreted as a form of *Species Habitat Enhancement*. The long-term natural recruitment often relies on protection of the site through the use of *Physical Exclusion* techniques and *Habitat Protection Policy or Regulations.* Reintroductions of native salmonid species often require or at least benefit from *Hydraulic Modification, Channel Rehabilitation or Creation* and *Berm or Dike Removal or Modification.*

Benefits and Opportunities

Benefits of the Restoration Action

Ecological support and balance: Native animals comprise a balanced food web and support ecosystem processes by serving as food sources (or predators), filtering nearshore waters, and providing habitat for other organisms.

Natural recruitment: In many settings, unassisted dispersal and recruitment of native species may not be possible. Immediate steps towards recruitment may speed ecosystem recovery. This is true of native oysters and some species of Pacific salmon in some watersheds.

Experimental observation: The survival and growth of reintroduced animals may provide opportunities to increase recolonization efficiency through systematic analysis of success.

Economic and recreational development: Recolonization of economically important species can create a local industry or recreational harvest opportunity.

Public engagement: The low-tech nature of many recolonization practices (i.e., of native oysters) allows for participation of untrained or volunteer labor, creating substantial opportunities for local education and participation. Recolonization highlights linkages between proper physical conditions and use by aquatic organisms.

Cultural connection: Native animals such as salmon and other species have been a critical part of subsistence and culture of native people in the Puget Sound region, serving both as food and trading items.

Measurable Units

The benefits of species reintroduction efforts could be measured in: acres of outplanted reef (in the case of pinto abalone) or beach; acres of beach opened for recreational shellfish harvest; revenue generated from commercial harvest (if allowed) and/or increased production (in the case of salmon).

Opportunities for Implementation

The success of Olympia oyster reintroduction efforts continues to grow with increased pilot studies and research projects occurring in the Puget Sound (as described in the following paragraphs). Partnerships between state agencies, research institutions and funding organizations are proving to be a working mechanism for reintroduction efforts (e.g., pinto abalone). Opportunities to reintroduce other species including native salmon are likely to increase as additional partnerships are formed.

The collection of oysters for seed production requires a permit from WDFW. A permit is also required to transport oysters from one site to another, in order to reduce the risk of spreading disease (e.g., *Vibrio* bacteria). Thus, reintroduction activities are ordinarily undertaken by non-profit organizations and commercial shellfish farming operations rather than individuals. However, the Puget Sound Restoration Fund (PSRF) encourages individuals and groups to become involved in Olympia oyster reestablishment projects. People who are considering planting oyster seed on their beaches are encouraged to contact PSRF to discuss the feasibility of their projects and to identify any adverse impacts, such as the introduction of shellfish disease or non-native pests that might result from such work.

Since 1999 the PSRF has partnered with over 100 individuals and agencies to enhance 25 acres of native oyster habitat and spread 10 million oyster seed at 80 sites. Examples include Liberty Bay and Dogfish Bay near Poulsbo, Woodard Bay, Frye Cove and Squaxin Island near Olympia, Fidalgo Bay at Anacortes and Raab's Lagoon on Vashon Island. Distributing a base layer of shell in these areas allows native oysters to re-occupy historic habitat while also preserving the genetic integrity of local populations. Washington's tribes, including the Skokomish, Suquamish, Squaxin and Jamestown S'Klallam, and the Lummi Nation are also working on reintroduction efforts. Others involved include the Northwest Indian Fisheries Commission, the PSRF, WDFW, WWDNR, and Taylor Shellfish Farms. Additional assistance is also offered by any of the seven MRCs supported by the Northwest Straits Commission. The MRCs in Clallam, Jefferson, San Juan and Skagit Counties have been very active to date in Olympia oyster reestablishment projects and are additional resources for those seeking to get involved.

Constraints

Modified environmental conditions: Modified soils, hydrology, or water quality may prevent the sustainability of introduced organisms through intraspecific competition or lack of specific food, cover, substrate, and hydraulic requirements.

Anthropogenic stressors: Sources of stress related to human activities range from trampling and illegal harvest, to over-water structures, to air, water, and soil pollution. These stressors may modify the sustainability and recruitment of native organisms. Non-point sources, such as failing onsite sewage systems, farm animal waste, and stormwater runoff, could compromise potential project success.

Introduced species: Competitors (other bivalves) and predators (e.g., oyster drills) have had a negative effect on clam and oyster populations. There is concern about the potential effects of European green crabs. Habitat-altering introduced species such as cordgrass (*Spartina* spp.) or Japanese eelgrass (*Zostera japonica*) can cause dramatic changes to mudflats, making them uninhabitable for some former occupants and potentially affecting reintroduction success.

Permitting requirements: Typically animals that are proposed for reintroduction are federal or state listed species or a species of concern. Regulatory compliance and agency coordination are a critical part of reintroduction efforts.

Cost: The above described sources of stress may dramatically increase the costs of establishing target species. The cost of collecting and transporting organisms may also limit attempts to recolonize.

Technical limitations: Techniques and tools for identifying conditions necessary for the sustainability of recolonized aquatic organisms may prove ineffective or inefficient in the long-term when applied to recolonization of self-regulating native organisms in degraded environments.

Uncertainty of success: Reintroduction or translocation of other locally extirpated or declining invertebrate or vertebrate animal species (such as freshwater mussels) as part of an estuary or freshwater restoration action may warrant consideration. However in most cases, such reintroductions would be considered experimental and is unadvisable because of the limited success of previous reintroduction attempts. Information about the genetics of the animals and the suitability of the site, such as habitat conditions, presence of competitors and predators, is often lacking. Furthermore, most reintroduction efforts are limited by the ability of captive bred animals to survive in nature.

Best Professional Practices

Feasibility Assessment

A comprehensive understanding of the biology, life history, and limitations of target species is critical to any reintroduction effort. Practitioners should consult best available science and critically review past and current efforts occurring in the region.

Morrison (2002) stresses the importance of a landscape perspective and suggests a thorough assessment of the local and regional distribution of the subject species. Since most wild populations are distributed in a metapopulation structure, the habitat required by a species is distributed in patches. Reintroduction of native animals or translocation efforts should be conducted with an understanding of how the restoration site or patch relates to other patches. Ultimately there is no reason to attempt a reintroduction if the restoration site is too distant from another subpopulation.

For shellfish reintroductions, the Pacific Shellfish Institute (PSI) is a private nonprofit organization created in 1995 to develop and disseminate scientific and technical information to the general public, shellfish farmers, and public officials in connection with shellfish-related environmental and animal/human health and safety issues. Researchers and practitioners interested in addressing priority shellfish research projects are encouraged to contact PSI, their state Sea Grant or aquaculture extension representative, local shellfish grower/harvester, tribal organization, and other appropriate groups such as the PSRF.

The preservation or restoration of relevant nearshore processes must also occur in order to attain long-term natural recruitment after the initial reintroduction. Key processes for oyster reestablishment include sediment dynamics and tidal hydrology. The restoration site must be free of armoring so that sediment supply and transport is allowed over the intertidal and subtidal. Hydrology must be unrestricted by culverts or dikes to improve sediment dynamics and to buffer and disperse upland runoff containing toxics and high levels of nutrients. Eelgrass beds are often critical to most aquatic organisms and native animals that use the nearshore. Thus, restoration of habitat attributes to encourage the growth of eelgrass should be considered.

Design and Implementation

Design considerations and implementation techniques for reintroduction efforts are species-specific. In general, the probability of success is based on the condition of the habitat at the new site and the level of short-term impact incurred during actual transport or placement. Techniques for minimizing stress and maximizing survival are again, species-specific.

The PSRF provides the most recent guidelines for reestablishing Olympia oyster populations (see Peter-Contesse and Peabody 2005). They provide considerations for site selection, recommendations for the placement of seeded cultch, and best management practices to increase growth and development. The first step to a site-specific reestablishment project is finding suitable oyster habitat. Typically intertidal areas with extant native oyster populations or those containing evidence that oysters have thrived in the past are strong candidates. Current reintroduction efforts target areas with limited settlement structure where there is still larval production from nearby remnant populations. Currently, due to lack of genetic research, it is unknown whether all of Puget Sound’s native oysters share most genetic material. Therefore, WDFW has established five management areas for oyster reintroduction efforts: Whidbey Basin, Main Basin, Hood Canal Basin, South Sound Basin, and the Entrance Sill Zone. WDFW suggests that brood oysters originate from the same Puget Sound management area in which their offspring will be spread. A map of the management areas is supplied in Peter-Contesse and Peabody (2005).

There are no established guidelines available for pinto abalone at this time, but information regarding the reintroduction efforts in Puget Sound is held on a website (www.pintoabalone.org) maintained by WDFW.

Evaluation

Project managers should collect baseline data through survey of existing conditions at the restoration site prior to reintroduction. Post-seeding or placement and subsequent monitoring should be conducted for all applications and should include standard and robust survey methods. The Northwest Indian Fisheries Commission has developed standardized monitoring forms for Olympia oyster reintroductions. Monitoring of seeded oyster beds should occur bi-annually, once in April/May and in September/October. Seeded sites should be visited within six months.

Monitoring the effectiveness of oyster reintroduction efforts can be measured using:

- Genetic identity of broodstock
- Survivorship of out-planted oysters
- Growth of out-planted oysters
- Reproduction and reproductive output
- Extent of larval settlement and recruitment onto shells

- Structural formation of shell clusters
- Processing of estuarine waters
- Ecological interactions /habitat use by invertebrates & fish
- Relative dominance of native/exotic species (if applicable)

Case Studies and Examples

Re-establishment of native oysters in Fidalgo Bay: Project organized by the Skagit County MRC in partnership with the Samish Tribe, PSRF, City of Anacortes, Skagit Beach Watchers, NOAA, WDNR, the Nature Conservancy, the Shell refinery and students from WWU. Native oyster seed on Pacific oyster cultch were planted in Fidalgo Bay during 2002, 2003, 2004 and 2006. Survival and growth of planted seed has been excellent at one site (Trestle Site), but poor in a second site. With the addition of seed on cultch during four years and augmentation of the Trestle Site with five cubic yards of Pacific oyster shell in 2006, a structured oyster bed is gradually emerging. Deployment of temperature sensors in 2006 showed that water temperatures easily reached the minimum temperature for gameteogenesis and spawning. Examples of larval spawning (veligers in the mantle cavity) and natural post-larval recruitment to the Trestle Site were documented in 2006. Several new sites within and around Fidalgo Bay are being evaluated for future restoration efforts.

Hatchery rearing and outplanting of pinto abalone in the San Juan Islands: Recent and on-going efforts to reestablish pinto abalone in the San Juan archipelago is being conducted by a consortium of parters including: University of Washington, WDFW, PSRF, NOAA, Northwest Straits Commission, Taylor Shellfish, Baywater, Inc., and the Jamestown S'Klallam Tribe. UW and WDFW scientists have conducted controlled experiments to assess changes in environmental conditions on pinto abalone and recruitment module experiments to determine the best recruitment surface for reintroduction efforts. In 2007, a pilot study outplanted juvenile abalone of different sizes into controlled and varied habitats in the Puget Sound to determine how large-scale outplants should be conducted in the future. After one year, survivors were retrieved and scientists were able to assess which sizes of abalone and in which habitats, survived best. In 2008, a hatchery was constructed in Port Gamble and abalone are currently being reared in the facility. Another pilot study in 2008 focused on larval survival through the outplanting of abalone larvae. The purpose of the study is to demonstrate whether outplants can be conducted with larval abalone or whether they need to first be reared in hatcheries for several years. In early 2009, scientists outplanted 3,000 juvenile abalone (reared at the Port Gamble hatchery) and will monitor and compare success to the larvae outplanting. The projects and research have been funded by a grant from the Russell Family Foundation and PSRF.

Re-establishment of native oysters in Netarts Bay, Oregon: Project funded by Oregon State University and The Nature Conservancy to evaluate feasibility of reestablishing native oysters without damaging eelgrass. In 2006, Olympia oysters from two cohorts, 2005 and 2006, were out-planted in an extensive, relatively uniform eelgrass (*Zostera marina*) bed. Native oysters were placed into experimental plots at low, medium, and high densities to determine the effect of shell substrate density on native oyster density and eelgrass abundance. Although preliminary results indicate shell density has a non-significant impact on eelgrass abundance, the long-term impact of the oyster reestablishment effort on eelgrass and subsequent essential fish habitat is under investigation.

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Diether, M.N. 2006. *Native Shellfish in Nearshore Ecosystems of Puget Sound.* Puget Sound Nearshore Partnership. Report No. 2006-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Morrison, M. L. 2002. *Wildlife Restoration: techniques for habitat analysis and animal monitoring.* Society for Ecological Restoration. Island Press. Washington D.C.

Peter-Contesse, T. and B. Peabody. 2005. *Reestablishing Native Olympia Oyster Populations in Puget Sound*. A Puget Sound Restoration Fund and Washington Sea Grant publication.

Additional Resources

USGS National Wetlands Research Center Digital Library. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates—Listed by Species Name. Available at: http://www.nwrc.usgs.gov/publications/specindex.htm

West Coast Shellfish Research and Education 2015 Goals and Priorities Pacific Shellfish Institute. Pacific Coast Shellfish Growers Association - National Shellfisheries Association/ Pacific Coast Section. Prepared by the Pacific Shellfish Institute Olympia, Washington. May 2006. Available at: http://www.pacshell.org/pdf/2015.pdf

NOAA Restoration Center. 2008. West Coast native oyster restoration: 2007 workshop proceedings. U.S. Department of Commerce, NOAA Restoration Center. 86 pp. Available at: http://www.nmfs.noaa.gov/habitat/restoration/publications/tech_glines.html

MM 20 SUBSTRATE MODIFICATION

Definition

Substrate Modification involves placing materials to facilitate the establishment of desired habitat features and improve ecosystem function, structure, or process. Specific activities included under this measure are the placement of fine or coarse materials on a beach (see also *Beach Nourishment*) or perhaps in a wetland (as a liner) to provide better soil conditions, allow for water retention, cover undesirable materials, or adjust the topography. At subtidal elevations, S*ubstrate Modification* could include placement of larger substrate, such as oyster shell, to form reef communities for invertebrates and marine fishes. Modification may also include changing other attributes such as elevation (see *Topography Restoration*).

Justification of Need and Link to Nearshore Processes

Substrate modification may be employed in areas dominated by littoral and estuarine processes. On littoral areas in Puget Sound, the sediments are typically cohesionless sands, gravels and cobbles. The sediment size and porosity affect nearshore morphology, which is also important for spawning of fish, and habitation by invertebrates and shell fish, and roosting, foraging and nesting of birds. Estuarine plants and animals are adapted to take advantage of and thrive in naturally deposited sediments with particular characteristics. Soil texture depends on the supply of sediment, and in turn is critical in determining rates of organic matter and nutrient accumulation. Unlike organic matter or nutrient concentrations, the texture of soil does not change over time unless changes occur in the supply of sediment.

Due to changes or degradation in the natural supply of sediment or placement of artificial fills, the texture of substrates can be altered such that plant and animal communities cannot achieve high productivity. This can occur due to activities in the upper the watershed that cause erosion and the release of excessive fines. When excessive fines are deposited in the lower reaches of estuaries, they change the sediment composition of intertidal areas. In contrast, bluff armoring, can reduce sediment supply, particularly if the armoring prevents erosion of feeder bluffs in the littoral cell. Depending whether the bluff was supplying coarse or fine material, this reduction in erosion can lead to a fining or coarsening of down-drift beaches.

Substrate modification can help restore shores where fill, armoring or reduced sediment supply have changed the soil composition and nearshore geometry. When fill is removed and replaced with sands, gravels and/or cobble littoral processes can be restored. Substrate modification can also help enhance or restore diked areas, which are no longer inundated by tides on a regular basis and have subsided due to the loss of sediment deposition, oxidation of organic matter, and compression from animal and machine traffic. Filled sites may have unsuitable substrates, perhaps due to high acidity, low nutrients, or excessive compaction.

Soil grain size and porosity strongly affect beach slopes and other geometric parameters, including response to changes in wave conditions (Lorang 2002; Zelo et al. 2000; Downing 1983; Bauer 1974). Where fill or armoring have been placed, the nearshore may scour due to wave reflection, reducing intertidal and shallow subtidal areas, and increasing currents. Removal of fill and armoring alone may not be sufficient to enhance or restore the shore. Placement of coarse sediment similar to native materials in terms of size, size gradation, density, hardness and angularity, is typically required to restore a natural morphology and facilitate ecologic restoration.

Soil acidity affects plant growth by altering the availability of soil nutrients or by increasing the solubility of metals to toxic levels. When dikes are breached in areas of former wetlands there is a period when soils adjust to the reintroduced tidal regime. In time, soils again become anaerobic with neutral pH values restored, and accumulated salts that inhibit seed germination are leached from the soil. With restricted tidal regimes, where mud surfaces do not remain under tidal waters, the combination of heavy organic matter and aeration facilitates the reduction of iron and sulfur oxides to form iron and hydrogen sulfides, potentially toxic to plants. Under these conditions, vegetation establishment is inhibited, plant growth is stunted, and the decomposition of dead roots and other buried plant material is slowed.

Conceptual Model

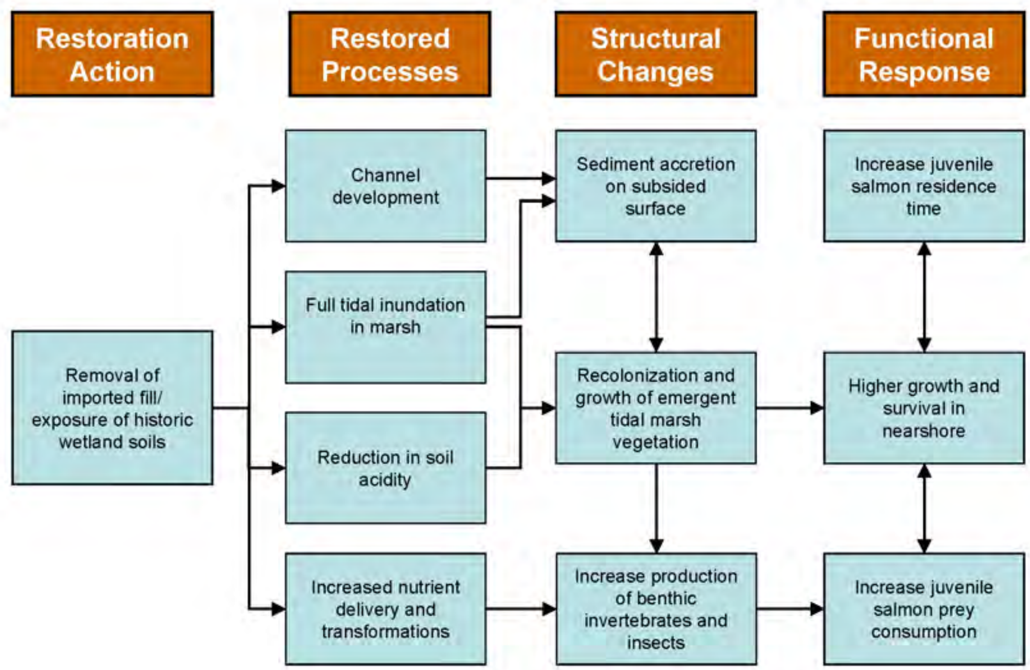
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 20-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: Diked wetland soils are buried under recently placed fill.

Change/Action: Removal of fill to wetland soil horizon. Discing of the soil to break up consolidated areas. Restoration of tidal action.

Predicted Response: Reestablishment of marsh vegetation, rapid accumulation of organic matter and nutrients, soil acidity reduced to neutral and channel development in marsh surface.

Figure 20-1 Conceptual Model for Substrate Modification



Complementary Management Measures

Substrate Modification is typically a supplementary measure that accompanies and enhances the benefits of other management measures. It requires similar construction techniques and equipment and can occur in combination with *Topographic Restoration* and *Channel Rehabilitation or Creation*. *Substrate Modification* can also occur in conjunction with *Armor Removal or Modification, Large Wood Placement* and *Revegetation* to facilitate the development of desired structural features and speed up restoration of processes. Protective measures such as *Property Acquisition and Conservation* and *Contaminant Removal and Remediation* may be required prior to *Substrate Modification*.

Benefits and Opportunities

Benefits of the Restoration Action

New habitat: New habitat, such as native oyster shell habitat, upper intertidal gravel habitat for surf smelt spawning and vegetated wetland can be created in situations where no other management measure will provide recovery of nearshore functions. New habitats can be tailored to meet specific functional objectives.

Historic soils: Suitable soils may already be in place but buried under fill. Coring to determine the elevation of historic surfaces should identify where horizons of native material are intact. Excavating down to these elevations will reduce the amount of additional soil that needs to be imported.

Soil treatments: Establishment of vegetation may be accelerated by soil treatment. In work in Galveston, Texas, Lindau and Hossner (1981) found that fertilizer applications were not effective. However, in a pickleweed *(Salicornia virginica)* marsh in Mugu Lagoon in Ventura County, Boyer et al. found that enriched with nitrogen and a lesser degree of phosphate, resulted in a greater biomass of pickleweed during the growing season, with pickleweed branching increasing by over 100 percent (Boyer et al. 2001). Soil treatments may also be as simple as the discing of the wetland surface prior to tidal restoration. This will break up soils consolidated by agricultural activities and allow marsh vegetation to establish.

Experimentation: There are substantial opportunities to observe the development of soil characteristics, and their influence on habitat functions in controlled environments.

Measureable Units

The benefits of substrate modification can be expressed in terms of increased colonization and use of the enhanced habitat by target plant and animal species, which in subtidal applications would include invertebrates and marine mammals. Availability of prey for juvenile salmon is another measure of effectives.

Opportunities for Implementation

This measure can be implemented in a variety of situations and settings. Because it is typically used in conjunction with / to supplement other management measures such as *Topographic Restoration*, *Channel Rehabilitation or Creation*, *Armor Removal or Modification*, *and Large Wood Placement*, the likely implementers are the same as those implementing the complementary measures.

Constraints

Cost: Cost of construction is primarily based on volume of material moved, ease of site access, and the distance to a potential fill site. Timing restrictions on when materials can be placed can increase costs. Timing restrictions are often required to protect ecologically sensitive species or habitats.

Sediment sources: Course sediments should be obtained where their extraction will not cause ecologic harm. Beaches and streams have historically been used as sediment mines due to the natural sorting and shaping that occurs, but mining in active aquatic systems can cause great ecologic harm. Deposits of coarse sediments far removed from active aquatic systems are preferred sources.

Compaction and composition: Sources of coarse materials may not match the desired native material sizes and size distribution. For example, large percentages of fines are not typically acceptable for beach nourishment. Substrate modification may require screening and mixing to achieve the desired gradation. Naturally developed marsh and mudflat surfaces are built up over time by deposition of mineral and organic material as mediated by biological processes. New surfaces constructed through grading may be compacted by overburden and equipment traffic or may have a composition or structure not typical for desired habitats.

Contamination: Soil material may contain toxic materials, either deposited during filling or accumulated during subsequent land use. The potential presence of contamination in fill is a deterrent to property acquisition, and remediation of contaminants can substantially increase costs.

Sediment supply: The sediment supply, its volume and mineralogy, needs to be considered. If the sediment supply is affected by external factors, then the desired mix of habitat may not be sustainable.

Soil acidity: The establishment of correct elevations, and hence tidal regime, is crucial for a longer-term solution to excess soil acidity. Experiments correcting acidity with treatments such as lime suggest that this is not a practical solution (Josselyn and Bucholz 1984).

Sea level rise: As the sea level rises over the next century, an adequate sediment supply will be needed to allow sites to be sustainable in the future. In addition, the tidal inundation regime of the restored site will vary, affecting soil characteristics.

Best Professional Practices

Feasibility Assessment

Sediment quality: The chemical and physical characteristics of sediments can strongly affect the biological colonization of new surfaces. Degraded sediments may limit functional recovery. Sediment reconstruction should be based on predicted recovery of sediment to reference conditions.

Historic soils: The soil characteristics of the existing and historic soils need to be studied. Project designers should compare these to the soil conditions associated with desired habitat (preferably using local analogs). The identification of any remaining historic soils on site should also include coring to locate soils covered by fill. This will allow a determination of how much additional material from off-site is required.

Contamination: The presence of contamination may substantially affect costs. Some preliminary assessment using core samples or site history research may make this process more predictable. In high-risk environments, some level of contingency planning is necessary regardless of pre-construction assessment.

Fill material options: Off-site sources of suitable material need to be identified along with the volumes that are available, the impact of moving them on the source location, and the cost and feasibility of moving them to the new site.

Geomorphic analysis: Geomorphic conditions such as sediment supply and particle sizing must be considered to ensure that sedimentation rates (estuarine systems) and sediment transport (littoral systems) in newly restored areas are sufficient to sustain the evolving marsh or beach. A conceptual sediment budget for the area must be developed that considers not only the restoration site but also other existing sinks and sources of sediment. A local sediment transport budget can be used to estimate the effects of the project on off-site areas.

Topographic survey: An accurate and up-to-date survey of the site topography is required together with cross-sections of the dikes and large channels. This survey should at least extend to cover the area that would be tidally inundated following the project.

Design and Implementation

Establishment of sediment sizes and characteristics: Littoral sediment processes are sensitive to grain size distribution, density, texture and hardness. Excessive fines can induce turbidity in adjacent waters and therefore need to be limited. The sediment characteristics must be specified and confirmed for each source, typically before delivery to the site.

Establishment of tidal conditions in restored marshes: Establish correct tidal elevations that assure full tidal inundation of the site and the development of channels throughout the marsh to buffer soil acidity. Following the restoration of tidal inundation, assume a period of time for soils to leach and become suitable for natural plant establishment.

Use of historic sediments in restored marshes: Historic wetland sites may have sufficient nutrients to support plant growth; therefore, there is little need for nutrient supplements. Future experimental work may provide new information that supports soil enhancement programs, particularly in the transition zone.

Soil treatments for estuarine sites: If the site substrate consists of coarse sandy material or imported upland fill, nutrients may be limited and soil studies should be undertaken to determine whether supplements should be added.

Placement and access: Placement of sediment is typically restricted to particular times and methods to limit adverse effects to the ecology of the site and surrounding areas (PWA 2007). Access may also be difficult due to site location, weak soils or lack of available roads or navigable depths.

Evaluation

Compliance monitoring: Ensure through inspections that the treatment of soils proceeds according to the final plans.

Monitoring: Using a combination of soil sampling, on-the-ground surveys and aerial photographs, document physical and biological changes to the landscape of the restored area (fish usage, plant species progression, etc.).

Adaptive management: Use monitoring data to inform the need for additional management actions.

Case Studies and Examples

Elliott Bay, Seattle: The Elliott Bay nearshore substrate enhancement project was undertaken at two sites on the western shore of Elliott Bay between Seacrest Park and Duwamish Head (Stark et al. 2000). The project goals were to enhance productivity of benthic infauna, increase the distribution and density of macroalgae and other primary producers, and improve support for resident and migratory marine and estuarine fish species. Mounds of cobble, quarry spall, pea gravel, and oyster shell were placed in the subtidal zone with the objectives of:

- increasing diversity of bottom substrates;
- providing intertidal substrates for bait fish spawning;
- providing suitable substrates at proper horizons for eelgrass;

- increasing the volume of physical and protective structures for juvenile and adult resident invertebrates and fishes; and,
- increasing hard structure surfaces for macroalgae.

Each grade of material was chosen with a specific purpose. Cobble and quarry spall, with rocks ranging in size from 2 to 12 inches, were chosen to increase the substrate and surface area for macroalgae attachment as well as provide cover for fish and invertebrates. Oyster shell was chosen to provide habitat for juvenile Dungeness crab specifically, and pea gravel was selected to provide habitat for juvenile salmonid prey.

The mounds were placed by barge and crane in March 1998; each mound contained about five cubic yards (Figure 20-2). At Duwamish Head two mounds of cobble and two mounds of quarry spall were placed along the -35ft MLLW contour, covering an area of about 10 square feet to a depth of about 18 inches. Similar mounds of cobble and quarry spall were placed at Seacrest Park on the -35 ft MLLW contour. In addition mounds of pea gravel and oyster shell were placed between -2 and -12 ft MLLW.

Video monitoring shows the coarse grade materials placed at both sites were effective for providing macroalgae and sessile invertebrate attachment sites. The macroalgae provided cover for several fish species, including sole and rockfish. The macroalgae, and the substrates themselves, also provided cover for invertebrates, such as crabs and shrimp. The effectiveness of the pea gravel application was more difficult to determine. Impacts of substrate modification are often complicated by different responses of the taxa at different times and sites (Simenstad et al. 1991). General observations suggested that there was an increase in the overall abundance of epibenthic invertebrates, including juvenile salmonid prey, in the year following the placement.

The oyster shell mound at Seacrest Park did not appear to be effective for providing habitat for juvenile Dungeness crab. However, limited larvae settlement at the mound and the control plot indicates overall low abundance of Dungeness larva in Elliot Bay in 1998. Although the oyster shell mound did not attract Dungeness crab, the mound did provide complex habitat for other crab species, invertebrates, and small fish.

Native Oyster Enhancement in Liberty Bay: The Liberty Bay project is being undertaken to restore self-sustaining populations of native Olympia oysters in Puget Sound by enhancing habitat to attract and support natural recruitment from remnant populations of oysters. The placement of oyster shell in nearshore areas with natural larval production accelerates re-colonization by native oysters and transforms the lower intertidal area into productive habitat.

The strategy is to restore physical substrate for oysters in area where existing oysters are present and spawning. The intent is to get natural recruitment onto the shell. In June 2007 nearly 1,700 cubic yards of oyster cultch was spread over 3 acres of habitat in close proximity to existing populations of native oysters. In the summer of 2008, another 4 acres were targeted for enhancement. Pending success at these sites, expansion of habitat enhancement will be initiated at a much broader scale. A further 2 acres of shell placement are planned for the summer of 2009. The shell is placed in a layer about 4 inches thick as it is assumed assuming that a proportion of the shell will sink into the soft underlying sediments.

Project monitoring is focusing on the health of the oysters themselves, but also on changes to the broader benthic community and on use of the newly created reefs by fish. Post-placement monitoring has shown the overall footprint of the shell layer has remained about the same, but the depth has decreased, as anticipated, to about 1-2 inches above the surface. Successful recruitment of new oysters onto these shells has been observed.

In 10 years, self-sustaining populations of Olympia oysters are expected, fulfilling their natural role in the ecosystem—filtering water to improve water quality, maintaining algae at natural levels, and providing habitat for other species such as salmon, starry flounder, Dungeness crab, shiner perch, surf perch, anchovies, herring, Pacific lamprey, juvenile rockfish.

Swinomish Channel and March Point: The Swinomish Channel fill removal and marsh restoration project aims to restore historic tide marsh habitats at six sites along the Swinomish Channel. A total of 10 acres of marsh habitat will be restored. As part of the project, one tidal channel will be excavated at each restoration site to create a total of 0.5 mile of channel. The grading and cutting of channels will generate about 200,000 cubic yards of clean fill material.

Disposal of fill material is a problem with restoration projects with the need to find economic and beneficial disposal options. For the Swinomish Channel project, material can be temporarily stockpiled on the site, but long-term disposal options need to be identified. Some material has been used in local construction and some may be retained for capping unsuitable soils.

Another option is the use of the sand fraction in the fill material for substrate modification at March Point. The presence of boat ramps and shoreline armoring has interrupted littoral drift around the March Point Peninsula of Fidalgo Island (CGS 2007). Beaches have become starved due to the lack of sediment supply. This has resulted in a coarsening of the beaches as the finer grades have been winnowed by wave action. When fines are removed from the upper intertidal beach, the beach is often converted to a gravel beach that does not provide the same quality of habitat as a fine grain beach. Beach coarsening can impact forage fish spawning habitat and hardshell clam habitat. To reverse the coarsening trend of the beaches, sandy fill material from the Swinomish Channel will be used to replace lost fines at March Point. Sand will be side dumped on the beach, roughly shaped, and then left for wave action to create a beach profile.

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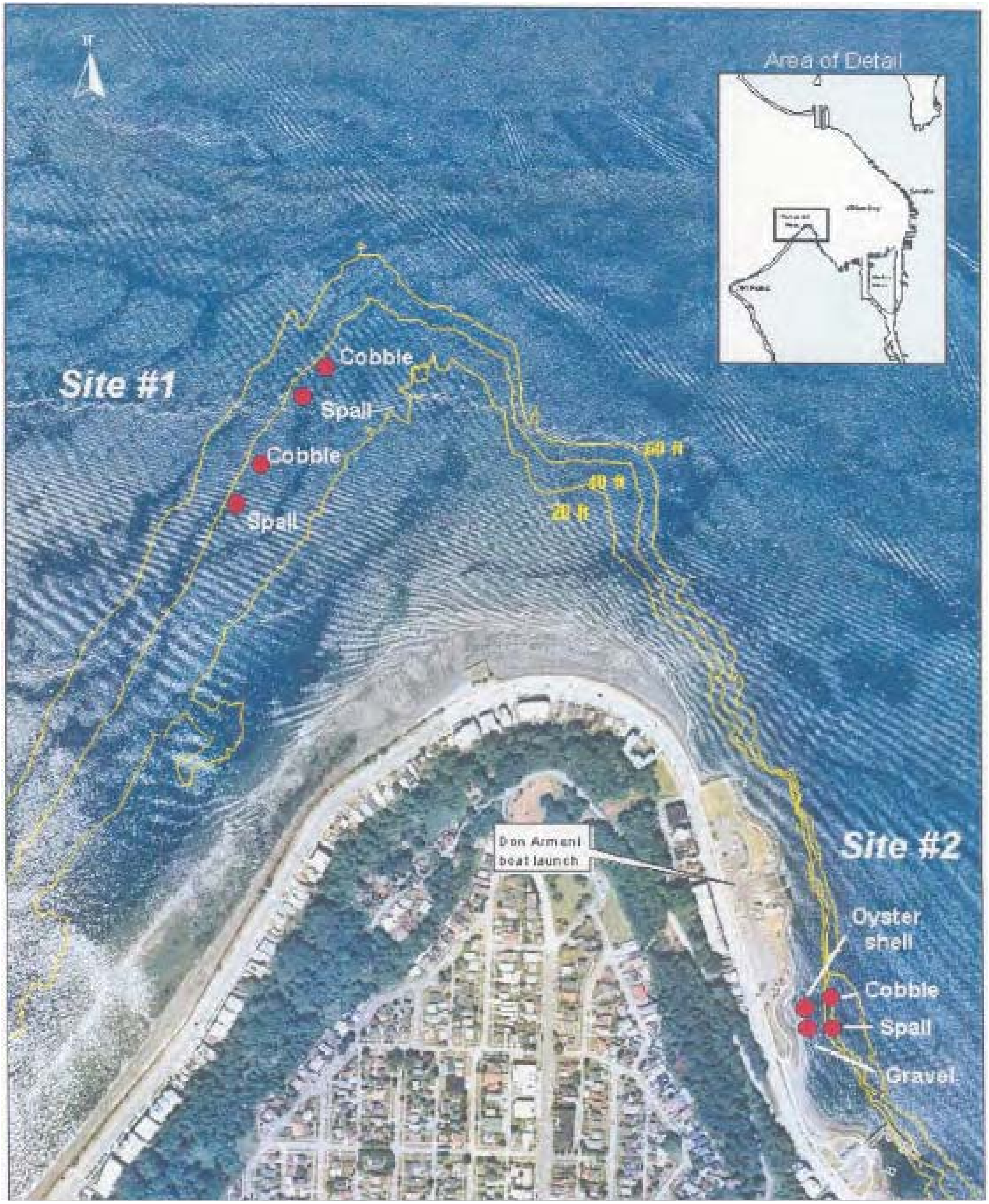
Figure 20-2 Experimental mound locations, Elliot Bay. Duwamish Head is labeled site #1 and Seacrest Park is site #2.



MM 21 TOPOGRAPHY RESTORATION

Definition

This management measure includes dredging, excavation, and/or filling to remove or add surface material so that beaches, banks, tidal wetlands, or mudflats can be recreated. Common examples of *Topography Restoration* are the removal of fill placed on historic wetlands and the placing of dredge fill to raise elevations of former wetlands that have subsided due to diking. *Topography Restoration* modifies the site elevation to bring it into the colonization range of the target vegetation. It also accelerates the rate of evolution for subsided sites. *Topography Restoration* can also occur on a smaller scale by increasing topographic irregularity to create diverse habitat micro-sites.

Justification of Need and Link to Nearshore Processes

Cornu and Sardo (2002) describe a positive feedback loop where vegetation, vertical accretion, and channel development within salt marshes are closely related and dependent on elevation with respect to tides. They found that marsh surfaces at mid-marsh elevations colonized rapidly while providing sufficient elevation below MHHW for channel development to occur. Where the marsh surface was lowered to low marsh elevation, there were more immediate and prolonged benefits to fish but vegetation colonization and channel development proceeded slowly. Where marsh elevations were too high, the feedback loop was eliminated.

Topography restoration can restore tidal hydrologic processes (tidal inundation, sediment movement, and channel formation) and biological processes (e.g., juvenile salmon access, foraging, growth) to areas that are presently too high or low within the tidal frame. Biomass produced by new marsh surfaces provides additional food for detritivores. Salt marsh and freshwater wetland biomass and sediments may serve as a sink for nutrients, helping to improve water quality. Salt marsh habitat provides quality foraging opportunities for diverse nearshore species. Areas outside the restored wetland can also benefit from restoration of marsh topography through increased channel formation as a result of restored hydrology (increased tidal prism). Restored tidal inundation facilitates delivery of tidal flooding and salinity regimes similar to those found in adjacent waters, creating better conditions for recolonization by marsh vegetation.

Topography restoration restores production of benthic invertebrates and insects that are preferred prey of juvenile salmon. If juvenile salmon can find feeding habitat, refuge from predators and increased residence time in restored marsh areas, this can increase growth rates and nearshore survival.

Conceptual Model

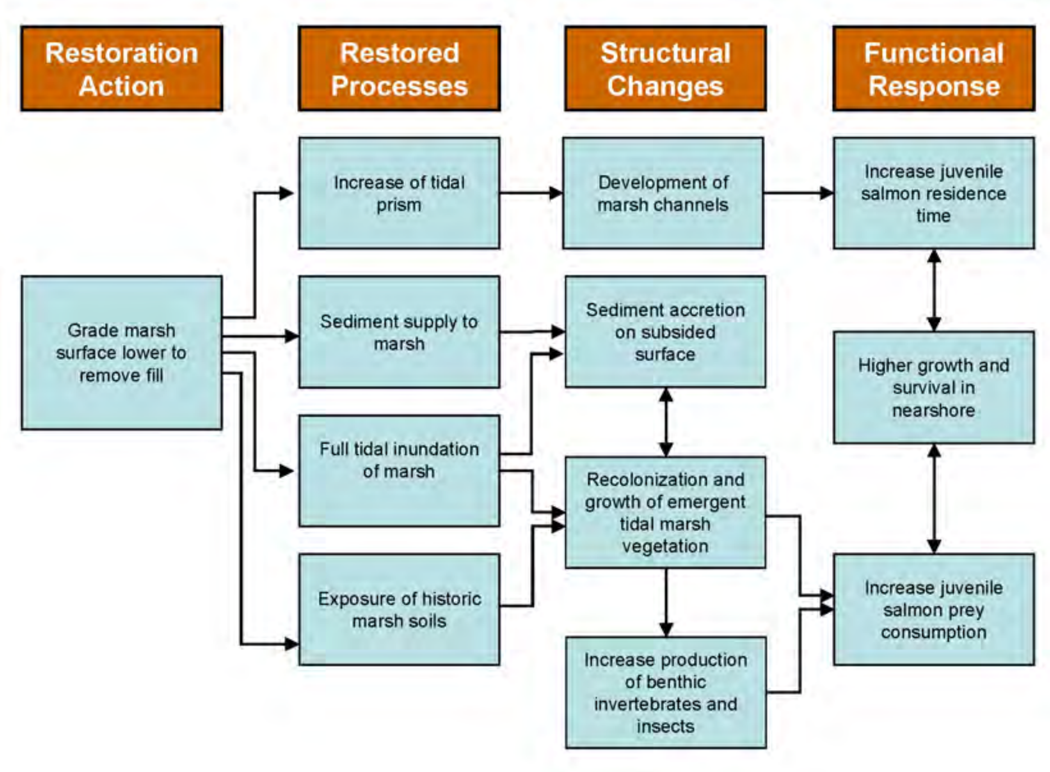
The figure below presents a conceptual illustration of the relationship of this measure to nearshore processes, structure, and functions (Figure 21-1). The arrows indicate the pathways through which responses are expected to occur. The strength of the relationship indicated by the type of arrow (black arrows show a stronger relationship than dashed or gray arrows).

Scenario: The elevation at a site is either too high, or too low, relative to the tidal range, to allow development of diverse aquatic and wetland habitat.

Change/Action: Re-grade surface higher or lower as required so that terrestrial wetland vegetation, tidal channels, or other wetland structures and functions can recover.

Predicted Response: Increased tidal exchange in terms of tide range and prism; increased velocities to scour channels. Increased tidal range, tidal prism and frequency of inundation, and deeper channels. Larger area and vertical extent of intertidal habitat, improved flushing, and deeper channels.

Figure 21-1 Conceptual Model for Topography Restoration



Complementary Management Measures

Like *Substrate Modification*, *Topography Restoration* is typically a supplementary measure that accompanies and enhances the benefits of other management measures. It will often have a role in large-scale restoration actions that also involve *Channel Rehabilitation or Creation Modification*, *Berm or Dike Removal or Modification*, and *Hydraulic Modification*. Excavation is also frequently used in combination with structural measures such as *Large Wood Placement* and *Revegetation*. Protective measures such as *Property Acquisition and Conservation*, *Species Habitat Enhancement* and *Contaminant Removal and Remediation* may be required prior to *Topography Restoration*.

Benefits and Opportunities

Benefits of the Restoration Action

This measure is typically applied at sites that were previously wetland or at other aquatic habitats adjacent to source water bodies. Topography restoration is typically applied to those areas that can be readily accessed by land or marine equipment to conduct earthwork and dredging. However, specialized equipment can be employed to reach less accessible sites typically characterized by shallow depths and weak soils for a cost premium. When applied in appropriate settings, Topography restoration can provide numerous benefits:

Create new habitat: Vegetated wetland and associated transitional habitat can be created in situations where no other management measure will provide recovery of nearshore functions. New habitats can be tailored to meet specific functional objectives.

Vegetation control: Elevation of new surfaces in tidal areas will control the tidal inundation regime that will in turn influence the character and composition of the plant community. The topographic configuration of the newly formed habitat may be controlled to affect the way in which surrounding geomorphic and biological processes affect the site.

Reduce erosion: If the site is filled or excavated to the colonization elevation, rapidly propagating marsh vegetation can dissipate energy from wave action.

Sediment sinks: Large deeply subsided sites have the potential to act as major sediment sinks and alter the local sediment budget. As the site fills in with sediment, source concentrations and the rate of sedimentation at the site may be reduced.

Opportunities for Implementation

This management measure is typically implemented as part of large-scale restoration actions, typically encompassing tens to hundreds of acres. Because of the scale of these types of projects, multiple resource agencies and organizations are usually involved (e.g., USACE, NMFS, WDFW, TNC, NRCS, and other entities). Such projects provide opportunities for inter-jurisdictional and inter-agency partnerships.

Topography restoration typically occurs in historic wetlands that have either subsided or have been filled. A suitable tidal or fluvial source must be present. In addition, channels may need to be constructed if the historic channel pattern is not present.

Measurable Units

Metrics for measuring benefits of this measure are typically tied to monitoring the evolution to some desired equilibrium form within a given time frame. For instance, how long the marsh surface takes to reach equilibrium with the tidal range. Sediment accretion on the site can be measured either as thickness of sediment deposited or as change in elevation, usually expressed in mm per year. Recolonization of emergent wetland marsh vegetation can be measured in terms of area of desired species and also area of undesired species. The evolution of the channel network can be expressed in a number of ways, such as channel area, thalweg elevation, network characteristics and channel density.

Constraints

Rate of evolution: The elevation of the restored site influences the rate of sedimentation. Flood tide deposition decreases with reduction in the period and depth of tidal inundation (Frenkel and Morlan 1990). Higher sites will therefore evolve less rapidly than lower sites.

Tidal prism: The higher the site, the smaller the volume of the diurnal tides flooding the site. This means that the higher the fill or excavation, the weaker the tidal scouring, and the longer it takes for tidal channels to form (Coats 1995). With a lower site, natural sedimentation will eventually build up the marsh plain and allow for the unimpeded development of first- and second-order tidal channels. Therefore, there is a compromise between filling the site high enough for vegetation establishment and keeping it low enough for a tidal channel system to form.

Loss of existing habitat: Grading causes the loss of the existing upland habitat, which may be unacceptable depending on the local context. Project managers must assess the mosaic of habitats that will be created relative to the existing habitats.

Compaction during construction: Naturally developed marsh and mudflat surfaces are built up over time by deposition of mineral and organic material, mediated by biological processes. New surfaces constructed through grading may be compacted by overburden and equipment traffic or may have a composition or structure not typical for desired habitats. At the same time, if fill is applied, it may need to be compacted to reduce erosion.

Disposal of fill: Removal and disposal of fill is costly. Reuse of excavated fill material to create upland "islands" for planting or to create trails for public access, for example, can reduce disposal costs.

Grade control: The temptation has been to grade the site down to a typical marsh plain elevation of MHHW and restore tidal action. However, it is difficult to precisely control grading. Grading tolerances are typically plus or minus 0.15 m (0.5 foot). This means that large parts of the site might be graded too high for typical marsh plain vegetation, and uneven grading can create depressions impeding drainage.

Characteristics of fill: Fill material is often compacted during placement, may contain construction debris, or be nutrient poor, and may not consist of cohesive estuarine sediments, the soils most suitable for salt marsh plant species. Under these conditions, while vegetation may colonize these sites, the substrate is likely to impede the vigor of vegetation growth.

Contamination of fill: Material that is excavated may contain toxic materials that were deposited during filling or accumulated during subsequent land use. The potential for contamination of fill is a deterrent to property acquisition and may impede use of this measure. Remediation of contaminants can substantially increase costs.

Consolidation of placed fill: Fill material will consolidate over time. The amount of subsidence depends upon the depth of fill and its water content, as well as the bearing capacity of the underlying material. The rate of subsidence declines with time as both the fill and supporting sediments adjust. Full consolidation may take several years. The amount of subsurface adjustment to loading will vary with location, increasing with the organic content of the soils as well as any changes in sediment texture (whether the deposit is sand grain or clay matrix-supported).

Construction access: Weak and or saturated soils and shallow submerged areas can impede or prevent use of traditional construction equipment. A lack of roadway can add significant cost to equipment mobilization and material transport, whether in terms of road construction or mobilization from the water side.

Construction impacts: Construction in intertidal and other wetland areas requires special actions to mitigate the impact on existing habitats such as the direct impact on biota and increased turbidity.

Best Professional Practices

Feasibility Assessment

Vegetation colonization elevation: The relationship between elevation and vegetation colonization needs to be established based on local tidal characteristics and adjacent reference marshes. This will be a primary determinant of how much cut and fill will be required. Studies by Cornu and Sadro (2002) on the impact of varying the marsh surface elevations on a variety of processes may be helpful.

Sediment budget: Project designers should estimate the expected rate of natural estuarine sedimentation on the site, accounting for proximity to sediment supply, consolidation of deposited material, compaction, and wind or wave resuspension of deposits. Sediment supply and particle sizing must be considered to ensure that sedimentation rates in newly restored areas are sufficient to sustain the evolving marsh. A conceptual sediment budget for the area must be developed that considers not only the restoration site but also other existing sinks and sources of sediment. A local sediment transport budget can be used to estimate the effects of the project on off-site areas.

Contamination of fill: The presence of contamination in the fill material may substantially affect costs. Some preliminary assessment using core samples or site history research may make this process more predictable. In high-risk environments, some level of contingency planning is necessary regardless of preconstruction assessment.

Disposal of fill: Disposal options for the fill material will need to be determined early on. It may be necessary to identify staging areas within or close to the site if disposal is not possible within the project timeframe.

Reuse of fill: Excavated materials including organic matter, large wood, and developed soils may be useful in restoring biological processes on newly constructed surfaces. The segregation and preservation of these materials will need to be integrated into project workflow.

Accessibility of required equipment: Transport of earth into or out of the site can require access that may not exist. Use of marine and amphibious equipment may entail construction impacts and special permitting considerations. Use of hydraulic slurry and pipeline for sediment delivery requires site work to control the return flow and restrict turbidity in the effluent. Use of specialized equipment will require special design, permitting, cost and schedule considerations. Availability of equipment and skilled operators may affect project success.

Design and Implementation

Colonization elevation: The elevation that is specified is critical for either excavation or filling (Cornu and Sadro 2002). If the site is filled or excavated to the colonization elevation, marsh vegetation can propagate rapidly and wave action is significantly reduced. Grading the site too high so that fill material forms part of the root zone for pioneer vegetation (approximately 1 foot below the surface) will result in a poor substrate for successful colonization. Sediments that are naturally deposited may provide a better substrate.

Channel evolution: Design grading to be about 1 foot below the marsh plain elevation at the time of breaching to give sufficient tidal prism for channel development. The higher the site is graded, the smaller the volume of the diurnal tides flooding the site. This means that the higher the site, the weaker the tidal scouring, and the longer it takes for tidal channels to form (Coats 1995). With a lower site, natural sedimentation will eventually build up the marsh plain and allow for the unimpeded development of first- and second-order tidal channels.

Wave activity: Wetlands created with fill material placed too low in the tidal frame, coupled with high wave activity, may run the risk of delayed evolution.

Importance of slopes: Design the grading so that there are significant areas above the colonization elevation that will vegetate quickly and reduce wave impacts. The slope and topography of a new surface may control the deposition patterns of sediments and propagules and retention of water. Cornu and Sadro (2002) found that slope was at least as important as elevation in affecting the size and sinuosity of incipient channels.

Grading of slopes: Newly excavated slopes may erode or fail if not constructed in accordance with soil engineering principles and best management practices that ensure stability under anticipated site conditions.

Fill placement: The surface that is created by filling will vary according to the method of placement. For dredged fill sites, allow for compaction between time of placement and breaching. For hydraulically placed fill, identify a disposal location so that fill slopes will drain toward the main drainage network. In placing fill, there is little control over how the material is deposited, except by relocating discharge locations. After placement, it is difficult and expensive to rework deposited sediments.

Soil treatments: Vegetation colonization of new surfaces can be strongly affected by the chemical and physical characteristics of sediments. Degraded sediments may limit the functional recovery. Sediment reconstruction should be based on the predicted recovery of sediment to reference conditions.

Grading tolerances: In specifying particular elevations, grading tolerances of +/-0.5 feet can be expected on most sites. The placing of dredged material is particularly problematic. The slope of the dredge spoil should be anticipated as well as hydraulic sorting of the sediment.

Slope stability: Topographic modification requires consideration of the maximum stable slope. Typically slopes are constructed flatter than the maximum stable slope based on geotechnical analysis. This may require subsurface exploration and analysis of soil samples. Slope stability is dependent on the height of the slope and its drainage. In some cases a rapid drawn of water may induce slope failure and require special consideration. Stable excavated slopes are often flatter than natural slopes as vegetation provides increased stability; as such some post construction steepening or sloughing may occur.

Vertical datum: Close attention should be taken to the correct specification and use of vertical datum.

Schedule: Work in critical resource areas is subject to local, state, and federal regulations that may constrain the timing, extent, strategies, and specifications of work.

Evaluation

Post restoration monitoring: The site should be periodically surveyed for elevation changes, channel formation, and plant colonization. These surveys should be compared to the same data at a comparable nearby reference site.

Case Studies and Examples

Gog-le-hi-te, Puyallup River Estuary: The Gog-le-hi-te site is located at the upstream limit of saltwater influence on the estuary of the Puyallup River (Figure 21-2). The Puyallup system at one time had 2,000 acres of mudflat and 3,800 acres of emergent marsh. With diking and filling, 90% of the mudflat and 99 percent of the marsh have been lost. The Gog-le-hi-te site is a former landfill protected by a dike. Two projects were undertaken in 1986 and 2008 to convert the landfill into a low-salinity, tidally influenced mudflat habitat.

In 1986, nine acres of the landfill were restored to create estuarine mudflats, wetlands, and grassland. The project team removed 72,000 cubic yards of mud and solid waste from behind the protecting dike. This dropped the surface by an average of 6 to 8 feet. The surface was graded to vegetation colonization elevation, based upon vegetation elevations observed locally, and a channel network was excavated. The outboard dike was breached and a new inboard levee constructed to maintain the level of flood protection. Project designers had to address a number of constraints. A gas line that crossed the landfill had to be rerouted before tidal action could be restored. During the construction, PCBs were discovered in the landfill. Their removal delayed breaching of the dike by a year.

The evolution of the site was the subject of a paper by Simenstad and Thom (1996). They noted that the site was over-excavated due to a datum error. A sedge (*Carex lyngbyei*) was planted in areas that were planned to be high marsh, but it rapidly retreated from areas of the site that were too deep. Cattails (*Typha latifolia*) emerged as the dominant vegetation due to low salinity of the site close to the tidal limit of the estuary. Sedimentation was relatively high, 1 to 3 feet in the first three years. This resulted in changed sediment grain size and surface elevation. Deposition occurred largely along the edges of the channels and immediately inside the breach. The excavated channel filled in and new channels began to form. Although the physical form of the restoration was not as intended, benthic organisms did slowly colonize, and fish and birds immediately occupied the site.

A similar project, Gog-le-hi-te II, was undertaken in the same landfill. The project included excavation and disposal of approximately 90,000 cubic yards of refuse and contaminated soil; construction of a setback dike to USACE standards; collection, treatment, and disposal of surface and subsurface water; grading of the habitat area; and breaching of the existing dike.

Herring's House, Duwamish River: Herring's House Park and intertidal habitat restoration project is located on the Duwamish Waterway at the site of the former Seaboard Lumber Mill, which operated from around 1929 until the early 1980s. The site is on the last remaining oxbow of the Duwamish River system. Historically, the upland site was a marsh of the Duwamish River. Developed as an industrial site, the area was filled with waste fill material consisting of silt, sand, and gravel mixtures with broken asphalt, rock, concrete, brick, wood, and metal debris. Investigations revealed soils with concentrations of lead, mercury, and PAHs.

The project objectives were to restore intertidal habitat from filled uplands for use by juvenile salmonids; create a protective low-energy environment with backwater pools to provide refuge and food sources; and establish areas of high intertidal salt marsh vegetation with a protective buffer of upland riparian vegetation.

A protective outer berm was constructed of quarry stone to completely contain low-level industrial contaminants. The marsh restoration consists of a 1.8-acre intertidal bay designed with a curvilinear edge to elevations between +6 and +12 feet MLLW. This was protected by two armored spits forming a mouth opening to the Duwamish River (Figure 21-3). The shoreline armoring protects the mouth from closing and is designed to provide a balance between creating low flooding and ebbing velocities, prevent low dissolved oxygen, and reduce the potential for fish stranding within the site.

Highly contaminated upland soil was removal from the site. Soil with low levels of TPH contamination was covered with a minimum of 2 feet of clean soil and erosion control features to ensure containment. An amended on-site soil mixture of silts and clays with a high organic content was distributed to a depth of 18 inches over the basin. This was then planted with emergent marsh plants at various elevations.

Swinnomish Channel Fill Removal and Marsh Restoration, Swinomish Tribal Reservation, WA. Another example of topography restoration is the Swinomish Channel fill removal and marsh restoration project. This project aims to restore historic tide marsh habitats at six sites along the Swinomish Channel on Swinomish Indian Tribal Community property. A total of 10 acres of marsh habitat will be restored. As part of the project, one tidal channel will be excavated at each restoration site to create a total of 0.5 mile of channel. A baseline study was made of the elevation distributions of native marsh vegetation along the Swinomish Channel. This was used to determine the grading for the new marsh surface and predict the habitat distribution of the restored marsh.

Most intertidal habitat excavation in Puget Sound has been conducted in the severely degraded Duwamish and Puyallup estuaries. The following is a list of other sites in Puget Sound where excavation was used to create new salt marsh habitat:

- Puyallup Estuary, Middle Waterway (Simpson/Trustees), 1995
- Duwamish Estuary, South Turning Basin, 1996
- Snohomish Estuary, Union Slough, 2001

- Puyallup Estuary, Middle Waterway (City of Tacoma), 2001
- Puyallup Estuary, Mowitch, 2001

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Frenkel, R. E. and J. C. Morlan. 1990. Restoration of the Salmon River salt marshes: Retrospect and Prospect. Final Report to the U. S. EPA (Region 10). 143 pp.

Simenstad, C.A and Thom, R.M. 1996. Functional equivalency trajectories of the restored Gog-le-hi-te estuarine wetland. *Ecological Applications* 6(1):38-56.

Additional Resources

Williams, P. B., J. P. Lowe, N. J. Garrity, and P. M. Faber. 2004. Design Guidelines for Tidal Wetland Restoration in San Francisco Bay. For the Bay Institute and California State Coastal Conservancy. Philip Williams & Associates, San Francisco. 83 pp

Figure 21-2 Gog-le-hi-te I restoration site

Figure 21-3 Herring's House Marsh restoration site

APPENDIX A

COMPARISON OF REGIONAL AND GLOBAL SEA LEVEL RISE PROJECTIONS

INTRODUCTION

Climate change simulations project a substantial rate of global sea level rise over the next century due to thermal expansion as the oceans warm and runoff from melting land-based snow and ice accelerates. This memorandum compares a range of future global sea level rises projections provided by the United Nations' Intergovernmental Panel on Climate Change (IPCC 2007) with those developed for the Puget Sound region (Mote et al. 2008), the state of California (Cayan et al. 2008) and with guidance provided by the U.S. Army Corps of Engineers (USACE 2009). This memorandum does not include an independent analysis of any source climate change data or scientific verification of any of the data or conclusions presented in the four studies. All four studies were developed over considerable time by qualified scientific experts and have undergone peer review.

Global Sea Level Rise Observations

Global sea level has risen approximately 120 m (400 ft) since the last glacial maximum some 18,000 years ago (Fairbanks 1989). Research suggests that the rate of sea level rise slowed from an average rate of about 50 mm (2 in) per century over the last 6,000 years, to 10 to 20 mm (0.4 to 0.8 in) per century over the last 3,000 years (Church et al. 2001).

Tide gauge data from the 20th century, indicates the present rate of global average sea level rise has been between 10 and 20 cm (4 and 8 in) per century. The few very long tide gauge records indicate that the rate of sea level rise was less in the 19th century. It is very likely that 20th century warming caused by anthropogenic impacts has contributed significantly to the observed sea level rise. Modeling studies indicate that both the thermal expansion of sea water and as well as widespread loss of land ice increased sea level from 1910 to 1990 by between 3 and 8 cm (1.2 and 3.1 in) per century (Church et al. 2001).

Components of Sea Level Rise

There are two main components of sea level rise – global sea level rise, which is controlled by global processes such as the warming of the oceans and the melting of ice; and local sea level rise, which is controlled by local or regional processes such as local winds and land movements. Local sea level rise is also referred to as relative sea level rise as it combines changes in the both the sea and land elevations.

Global, or eustatic, sea level rise is the combination of two factors:

1. <u>Thermal expansion of the ocean.</u> Thermal expansion is the result of higher water temperatures leading to an increase in ocean volume while the mass remains constant. Over the past 50 years the oceans have absorbed about 80% of the heating associated with greenhouse gases. Observations suggest an average sea level rise of about 10 cm (3.9 in) per century can be attributed to the thermal expansion component over recent decades (Cayan et al. 2008). The rate of thermal expansion will increase as global

temperature increases and will continue for about 1,000 years after atmospheric temperature stabilizes, due to the slow circulation of the deep ocean (Mote et al. 2008).

2. Melting of global ice. The melting of glaciers and land grounded ice caps, such as Antarctica and Greenland, will increase the mass of water in the oceans leading to sea level rise. Observations of glaciers and ice caps suggest an average contribution to sea level rise of 2 to 4 cm (0.8 to 1.6 in) per century over the last century (Church et al. 2001). However, several independent measurements of Greenland and Antarctic mass balance using lasers and gravity measurements indicate that both Greenland and Antarctica have recently (2002-2006) been substantial contributors to global sea level rise (Mote et al. 2008).

Local sea level rise is a combination of global sea level rise together with two local factors:

1. Local atmospheric circulation. Local atmospheric circulation effects relative sea level rise in the Puget Sound region on a seasonal and inter-annual time scale. The predominant southerly winds combined with the earth's rotation push water onshore and result in wind-driven enhancement of sea level (Mote et al. 2008). This can result in mean winter sea level being roughly 50 cm (20 in) higher than summer sea level on the Washington coast and within estuaries. Within the more protected Puget Sound basin this process would not be as pronounced. *El Niño* events also elevate sea level seasonally creating mean water level increases on the order of 30 cm (12 in) for several months (Ruggierio et al. 2005).

2. Vertical land movement. Relative sea level rise is the sum of global sea level rise and the change in vertical land movement. Thus, if sea level rises and the shoreline rises or subsides, the relative change in sea level could be lesser or greater than the global sea level rise. Vertical land movement can occur due to tectonics (earthquakes, regional subsidence or uplift), sediment compaction, isostatic readjustment and groundwater depletion (USACE 2009). As rates of global sea level continue to increase with climate change, at some point, the rate of vertical land movement will become less significant in determining the impact of sea level rise. However, areas that have subsided are particularly vulnerable to sea level rise.

Comparison of Global Sea Level Rise Projections

There have been a number of recent projections of sea level rise. Each of these projections has made different assumptions in relation to the various components of sea level described above. It is important to understand these assumptions and the context in which the predictions were made.

IPCC (2007)

The IPCC's fourth assessment report (AR4) provided projections of global sea level rise for six different emission scenarios. These included high emissions scenarios (such as A1F1 and A2) which represented a future in which economic growth is uneven and the income gap remains large between now-industrialized and developing parts of the world. In contrast, low emissions scenarios (such as B1) represented a future with a high level of environmental and social consciousness, combined with a globally coherent approach to more sustainable development.

Each of the emission scenarios was modeled using a number of global climate models to provide temperature and sea level rise projections. The results for each emissions scenario were then bundled together to provide an envelope of likely projections together with a mean projection. The use of multiple models reflects the uncertainty in the climate responses by greenhouse gases and other forcings and the variability amongst models in representing and calculating key processes.

The projections provided by AR4 are of global sea level rise and do not reflect local atmospheric circulation or tectonic movements. The projections range from 18 to 38 cm (7 to 15 in) for the lowest emissions scenarios to 26 to 59 cm (10 to 23 in) for the higher emissions scenarios (Table 1 and Figure 1).

Table 1. Low and high emission global sea level rise from Table 10.7 IPCC (2007).

Component	Low Emission B1	High Emission A1F1
	2100	2100
Thermal expansion	17 cm (6.7 in)	29 cm (11.4 in)
Ice sheet contributions	10.5 cm (4.1 in)	12.5 cm (4.9 in)
Greenland ice sheet	3 cm (1.2 in)	7 cm (2.8 in)
Antarctic ice sheet	-6 cm (-2.4 in)	-8.5 cm (-3.3 in)
Total global sea level rise	28 cm (11 in) ± 10 cm	42.5 cm (16.7 in) ± 16.5 cm

Note: the General Circulation Models used in AR4 indicated that the Antarctic ice sheet will receive increased snowfall without experiencing substantial surface melting, thus gaining mass and contributing negatively to sea level.

Subsequent research led to a reevaluation of the AR4 sea level rise projections which are now thought to be too low, and the approach used to derive the projections has been questioned. The projections were driven mostly by the thermal expansion component and excluded the significant contributions from the accelerated future melting of the Greenland and Antarctic ice sheets. The uncertainty in modeling how ice moves in large, land-based ice sheets led to the exclusion of this component and for the IPCC to state that it did “not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise” (IPCC 2007). The upper end of the AR4 projection is not an upper limit and it probably underestimates future sea level rise (Rahmstorf 2007; Jevrejeva et al. 2008). Other recent publications report different global sea level rise projections to those reported AR4. For instance, Rahmstorf (2007) used a linear empirical relationship which resulted in higher global mean surface temperature and rates of sea level rise to predict sea level rise increases of 50 to 140 cm (19 to 55 in) by 2100.

Mote et al. 2008

Scientists from the Washington Department of Ecology and University of Washington’s Climate Impacts Group (Mote et al. 2008) considered these higher estimates of global sea level rise in their study of sea level rise in the coastal waters of Washington State. They defined two projections which bracketed the range of likely global sea level rise, referring to these as “very low, and “very high”. For the “very low” projection they took the 5% value of the AR4 B1 emission scenario of 18 cm (7.1 in) by 2100. For the “very high” projection they used the 95% value of A1F1 of 59 cm (23.2 in)[1]. The ice sheet contribution calculated in AR4 (appendix 10.A.5) of 17 cm (6.7 in) was used to represent enhanced ice sheet loss. To this they applied a factor of two to give an upper limit to the ice sheet contribution of 34 cm (13.4 in) and a “very high” projection of global sea level rise of 93 cm (36.6 in) by 2100. A third, “medium”, projection was also defined as the average of the central values from the six scenarios used in AR4; a value of 34 cm (13.4 in) (Table 2).

Table 2. Projections of global sea level rise from Mote et al. (2008)

Component	“very low”	“medium”	“very high”
	2100	2100	2100
AR4 projection	18 cm (7.1 in)	34 cm (13.4 in)	59 cm (23.2 in)
Ice sheet contributions	0 cm (0 in)	0 cm (0 in)	34 cm (13.4 in)
Total global sea level rise	18 cm (7.1 in)	34 cm (13.4 in)	93 cm (36.6 in)

Cayan et al. 2008

A similar reassessment of the AR4 high end global sea level projections was undertaken by Cayan et al. (2008) for the state of California. This used the A2 (high emission) and B1 (low emission) scenarios and Rahmstorf’s methodology to project global sea level rise in 2050 and 2100 (Table 3). These projections were also adjusted to include the effects of dams on sea level rise which may have stored enough water worldwide to mask

[1] Refer to Table 1. “Very low” equals the mean for low (28 cm) minus 1 SD (10 cm) to yield 18 cm. “Very high” equals the mean of the high (42.5 cm) plus 1 SD (16.5 cm) which would yield 59 cm.

acceleration in the rate of sea level rise prior to 1993. Cayan et al. (2008) do not provide a breakdown of the relative contribution of ice sheet, dams, etc., which is why Table 3 shows only the total global sea level rise.

Table 3. Low and high emission global sea level rise from Cayan et al. (2008).

Component	Low Emission B1	High Emission A2
	2100	2100
Total global sea level rise	50 cm (19.7 in)	140 cm (55.1 in)

All three sets of global sea level rise projections (AR4, Mote et al.[2008], and Cayan et al. ([2008]) use a series of scenarios to bracket likely future greenhouse gas emissions. The latter studies bring added sophistication, incorporating additional components such as enhanced ice sheet loss and dam storage. However the general trend is for projections of sea level rise to increase as the processes become better understood (Figure 2). Perhaps even more noteworthy is that the estimated emissions growth for the period 2000 to 2007 was above even the most fossil fuel intensive scenario of AR4 (Science Daily 2008).

Local Sea Level Rise Projections

Local sea level rise is a combination of global sea level rise together with two local factors. Mote et al. (2008) provides estimates of both the local atmospheric circulation and local tectonic contributions.

1. <u>Local atmospheric circulation.</u> Local atmospheric circulation effects relative sea level rise in the Puget Sound region on a seasonal and inter-annual time scale. The predominant southerly winds combined with the earth's rotation push water onshore and result in wind-driven enhancement of sea level (Mote et al. 2008). This can result in mean winter sea level being roughly 50 cm (20 in) higher than summer sea level on the Washington coast and within estuaries. *El Niño* events also elevate sea levels producing mean water level increases on the order of 30 cm (12 in) for several months (Ruggierio et al. 2005). Within the more protected Puget Sound basin these processes would not be as pronounced.

2. <u>Vertical land movement.</u> Local land level changes can occur as a result of crustal deformations (associated with tectonic movement and isostatic rebound) or subsidence from sediment compaction (such as in deltas). The Puget Sound region is located along the western extent of the North American continental plate, beneath which the Juan de Fuca oceanic plate is subducting. The subduction processes produce uplift in the northwestern end of Washington State, subsidence in the central coast and smaller movement throughout the rest of the State (Verdonck 2006) (Figure 3). Exact measures of the rates of vertical land movement have been contrasting over recent years (Mote et al. 2008).

Mote et al. (2008) combine these local factors with their global sea level rise estimates to give estimates of sea level rise for the North West Olympic Peninsula, the central and southern Washington coast and Puget Sound. The Puget Sound estimates of local sea level rise are shown in Table 4.

Table 4. Projections of local sea level rise in Puget Sound from Mote et al. (2008)

Component	"very low"	"medium"	"very high"
	2100	2100	2100
Global sea level rise	18 cm (7.1 in)	34 cm (13.4 in)	93 cm (36.6 in)
Local atmospheric	-2 cm (0.8 in)	0 cm (0 in)	15 cm (5.9 in)
Vertical land movement	0 cm (0 in)	0 cm (0 in)	20 cm (7.9 in)
Total local sea level rise	16 cm (6.3 in)	34 cm (13.4 in)	128 cm (50.3 in)

Comparison with USACE Circular

In July 2009, the USACE issued circular EC 1165-2-211 which provides guidance on accounting for direct and indirect physical effects of projected future sea level rise in federal civil works projects (USACE 2009). The USACE requires that planning studies and engineering designs evaluate alternatives against a range of local sea level rise projections which are defined by "low", "intermediate" and "high" rates of local sea level rise.

The "low" local sea level rise projection is the historic sea level trend as observed at a long-term gauge. A minimum of 40 years of data is considered necessary to justify extrapolating into the future and use as a baseline for projecting future sea levels. This "low" projection is atypical and unlike AR4, Mote et al. (2008) and Cayan et al. (2008) as it does not consider future emission scenarios. Maintenance of the historic sea level rise rates into the future is unlikely given the overwhelming evidence of accelerated sea level rise in the future. The "low" projection serves more as a baseline against which to compare the more reasonable estimates of accelerated sea level rise given by the "intermediate" and "high" projections.

The USACE "intermediate" global sea level rise projection follows a similar rationale to the "medium" projection of Mote et al. (2008) in that it is based on the average of the central values from the six scenarios used in AR4. Rather than use the AR4 values, the USACE circular suggests using curves developed in the 1987 NRC study *Responding to Changes in Sea Level* (NRC 1987). NRC used a series of three sea level curves (NRC-I, II and III) that bracketed the then estimates of sea level rise by 2100. These same curves have been used in the USACE circular but modified to reflect the increase in the present rate of global sea level rise to 1.7 mm per year. Rather than reflect a particular emission scenario, the curves (modified NRC-I, II and III) are set equally across the range of then modeled predictions to reflect sea level rises of 50 cm (19.6 in), 100 cm (39.4 in) and 150 cm (59 in) (Figure 4). The AR4 projections for 2100 bracket the modified NRC-I curve and the guidance is to use NRC-I for the "intermediate" global sea level rise projections for 2100, a value of 50 cm (19.6 in).

In a similar vein to Mote et al. (2008) and Cayan et al. (2008), the USACE "high" global sea level rise projection takes account of increased ice sheet loss beyond the projections of AR4. Modified NRC-III curve is used to give a sea level rise of 150 cm (59 in) by 2100 (Figure 4). The rationale provided for the use of the curve is that:

> "This 'high' rate exceeds the upper bounds of IPCC estimates from both 2001 and 2007 to accommodate for the potential rapid loss of ice from Antarctica and Greenland." (USACE 2009)

Table 5 shows that NRC-III gives values close to that of Rahmstorf (2007) and Cayan et al. (2008). The terms "low", "intermediate" and "high" are used differently in each study, which in some cases reflects the emissions scenario; in other cases it brackets a possible range.

Table 5. Projections of global sea level rise from IPCC (2007), Mote et al. (2008), Cayan et al. (2008) and USACE (2009).

Component	"low"	"intermediate"	"high"
	2100	2100	2100
AR4 projection	18 cm (7.1 in)	34 cm (13.4 in)	59 cm (23.2 in)
Mote et al (2008)	18 cm (7.1 in)	34 cm (13.4 in)	93 cm (36.6 in)
Cayan et al (2008)	50 cm (19.7 in)		140 cm (55.1 in)
USACE (2009)	historic	34 cm (13.4 in)	150 cm (59 in)

USACE (2009) provides guidance on how to calculate local vertical land movement from historic sea level observations so that local sea level rise estimates may be incorporated into the "intermediate" and "high" projections.

Summary and Recommendations

Global sea level rise projections used by PSNERP should reflect a range of emission scenarios as used by AR4, Mote et al (2008) and Cayan et al (2008). As noted above, projections for future sea level rise are increasing with each new study. The AR4 projections are on the low side as they underrepresented not only the ice sheet component but also the emission scenarios.

The estimates in Mote et al (2008) and Cayan et al (2008) both include ice sheet loss. The "very high" value of 140 cm (55.1 in) from Cayan et al. (2008) is in line with other scientific publications since AR4. Cayan et al. (2008) is also in agreement with the modified NRC-III curve (USACE 2009). Cayan et al. (2008) has been endorsed by the State of California and is being reviewed by the National Academy of Science (NAS).

It is therefore recommended that Cayan et al. (2008) be used for global sea level rise projections in preference to AR4 and Mote et al. (2008). These should be combined with the projections of atmospheric dynamics and vertical land movement from Mote et al. (2008) (see Table 4) to give local sea level rise projections (Table 6).

Table 6. Comparison of "very high" local sea level rise estimates in Puget Sound for Mote et al. (2008) and Cayan et al. (2008)

Component	Mote et al. (2008) "very high"	Cayan et al. (2008) "very high"
	2100	**2100**
Global sea level rise	93 cm (36.6 in)	140 cm (55.1 in)
Local atmospheric	15 cm (5.9 in)	15 cm (5.9 in)
Vertical land movement	20 cm (7.9 in)	20 cm (7.9 in)
Total local sea level rise	128 cm (50.3 in)	175 cm (68.9 in)

No single piece of evidence should be used to recalculate the projections given the uncertainty surrounding the very complex and large-scale nature of climate change. Rather, a regular review cycle should be initiated that examines the recent scientific findings on both the global and local components of sea level rise and incorporates them into new state-wide projections. This review cycle could be every five years, perhaps synchronized with the IPCC cycle of assessment reports (AR5 is due in 2014).

In addition, there needs to be agreement at the state, county and city levels on which projections should be used. For example, in California, sea level rise projections are being developed by the state and are being confirmed by a NAS study. The final NAS Sea Level Rise Assessment Report will advise how California should plan for future sea level rise. The report will include relative sea level rise projections specific to California, taking into account issues such as coastal erosion rates, tidal impacts, *El Niño* and *La Niña* events, storm surge and land subsidence rates; and the range of uncertainty in selected sea level rise projections. A similar effort in Washington would improve PSNERP's ability to plan for and respond to sea level rise.

Furthermore, additional guidance is needed on quantifying probabilities. At present, the confidence limits that are quoted for projections such as AR4 describe the uncertainty in the models rather than the physical processes. The USACE circular alludes to the assessment of risk for different alternatives and projections however, the policies that provide such guidance have not yet been developed (USACE 2009).

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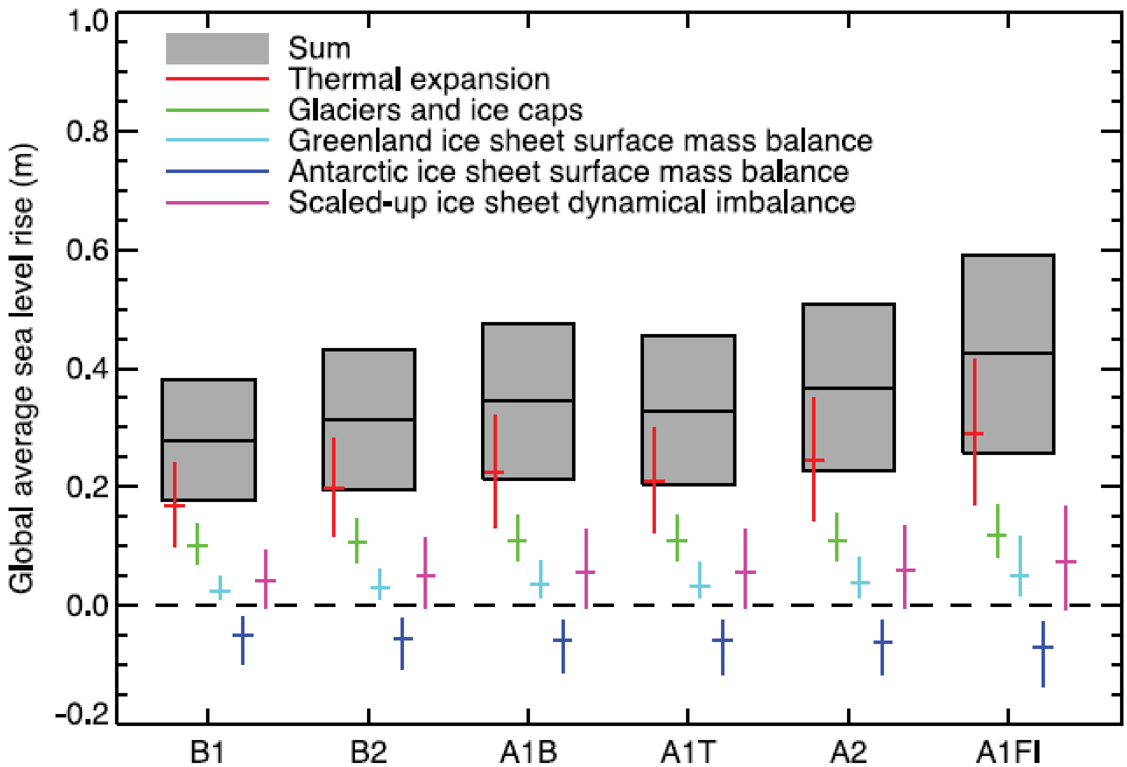

Figure 1. Projections and uncertainties (5% to 95% ranges) of global average sea level rise and its components in 2090 to 2099 (relative to 1980 to 1999) for the six emission scenarios (IPCC 2007).

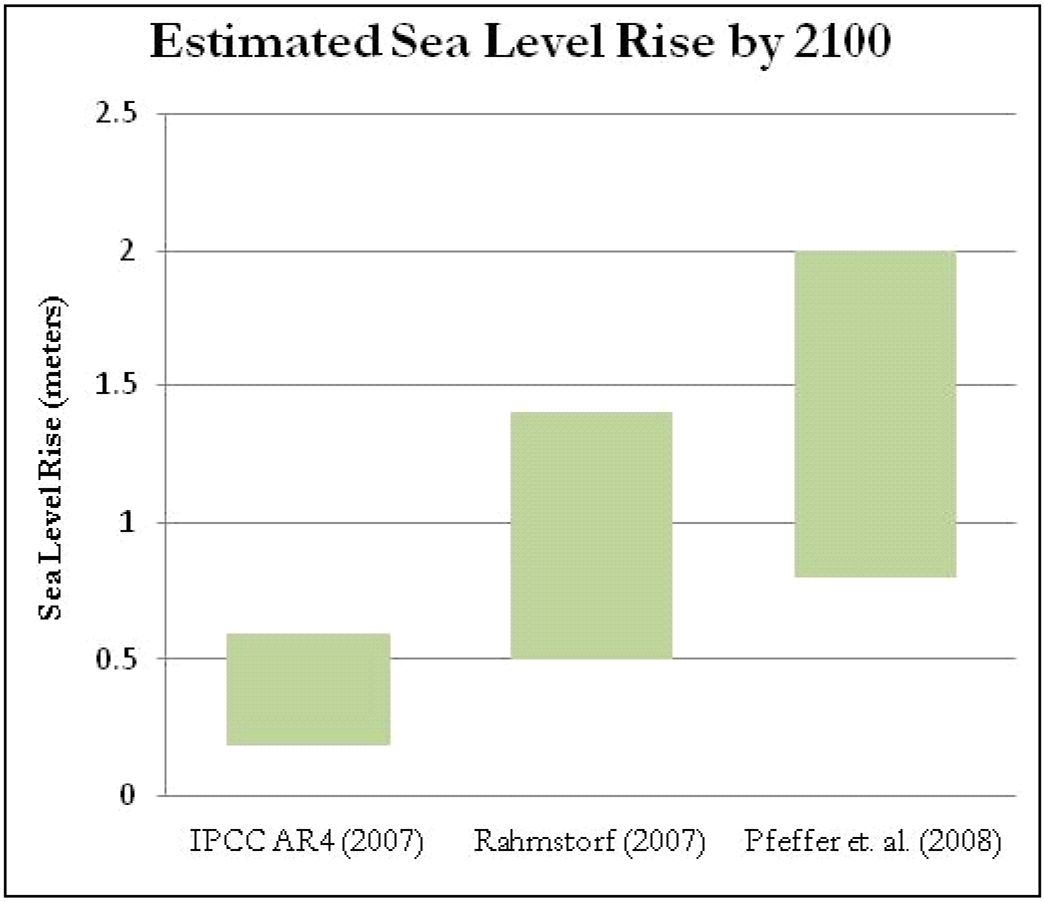

Figure 2. Comparison of recent estimates of sea level rise in 2100, relative to 1990 levels (Pew 2009)

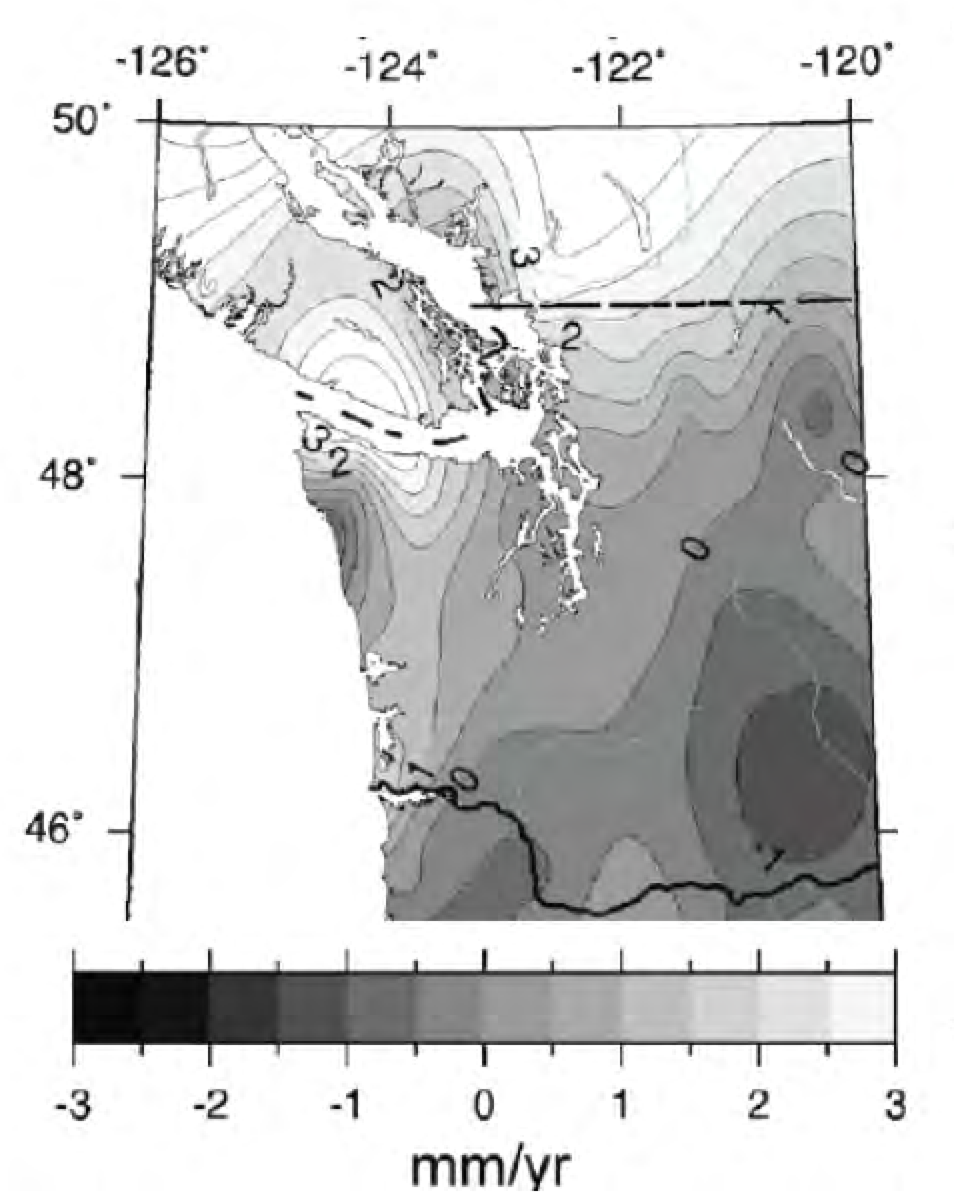

Figure 3. Vertical land movements (Verdonck 2006).

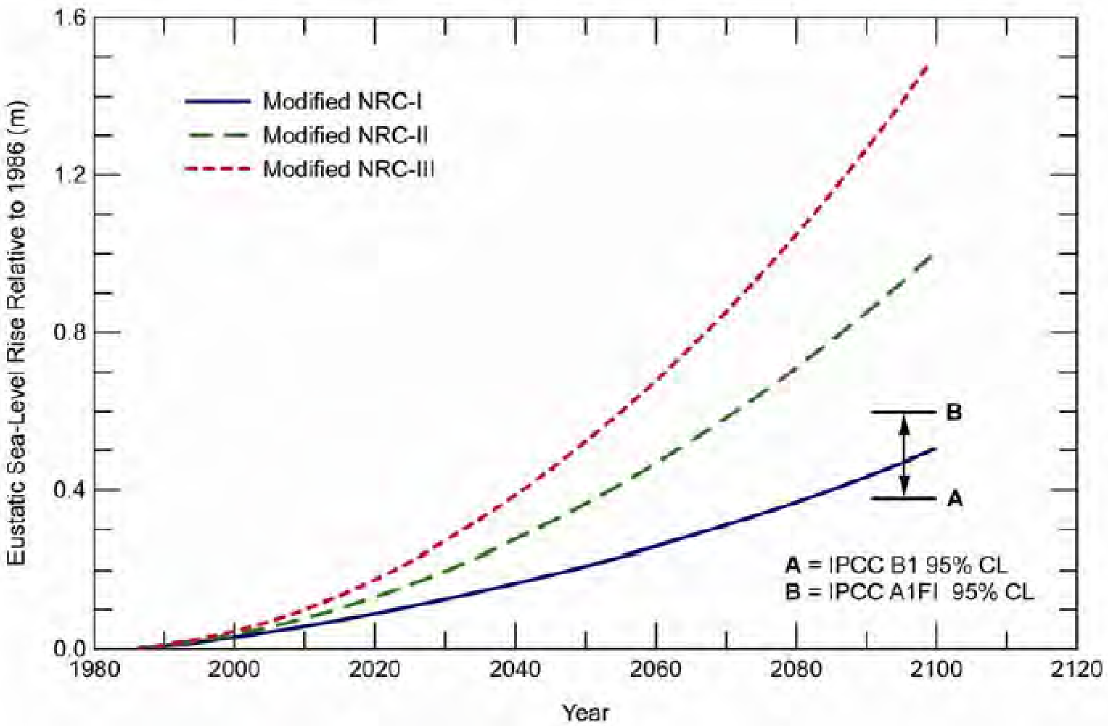

Figure 4. Modified NRC (1987) global sea level rise scenarios and the IPCC scenario estimates (USACE 2009)

APPENDIX B

SEA LEVEL RISE RISK ASSESSMENT

INTRODUCTION

Climate researchers from Washington State and around the world have gathered strong evidence that global sea level is rising at an accelerated rate compared to the previous two centuries (IPCC 2007, Mote et al. 2008). Projections of future sea level rise (SLR) are highly uncertain and vary depending on assumptions about the level of carbon emissions and numerous other factors. However, there is general consensus that sea level will continue to rise during the 21st century in response to a warming climate, thermal expansion of ocean waters, and melting of land-based ice sheets (IPCC 2007, Shipman 2009, CCSP 2009).

The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP), like all programs sponsored by the U.S. Army Corps of Engineers (USACE), is required to consider the effects that projected future sea level change could have on the management, planning, design, construction, operation, and maintenance of federal coastal projects (USACE Circular No. 1165-2-211; July 2009). To respond to the USACE requirement, PSNERP evaluated the relative sensitivity of the 21 nearshore management measures (MMs) (described in the main body of the Management Measures Technical Report) to the projected range of sea level rise for the Puget Sound region. The assessment relies on the referenced data and conclusions of qualified scientific experts, which have been developed over many years. PSNERP's assessment does not include an independent analysis of the climate change data or scientific verification of the data or conclusions presented in the referenced studies.

SLR Projections and Physical Effects on Nearshore Habitats

Climate scientists use tide gauge data, climate models, and satellite altimetry to estimate the level of future SLR. The estimating process is complex and relies on unverified assumptions about the various components of SLR (e.g., thermal expansion, melting ice sheets, vertical land movement, and atmospheric circulation). To mitigate the uncertainty inherent in the models, scientists have reported SLR projections as a range of values from low to high (IPCC 2007, Mote et al. 2008, and Cayan et al. 2008). The "low" projections range from 7.1 cm to 19.7 cm. The "high" projections range from 59 cm to 150 cm. See Appendix A for a more thorough description of the projected values and a comparison of regional and global SLR projections.

Anticipated effects of rising sea level include inundation of low-lying areas, increases in the frequency and severity of floods and storm-related flooding, increased coastal erosion, conversion of vegetated wetlands to tidal flats and open water, and increases in the salinity of estuaries and freshwater aquifers. These phenomena will affect natural ecosystems and human health and safety. The impacts will be cumulative, and in some cases, potentially irreversible (CCSP 2009).

Nearshore areas respond to rising sea levels differently depending on the type of landform and the dominant geomorphic processes at work in a given locality. Factors such as sediment type and supply, resistance to erosion, and the ability of the landform to move (translate) landward determine how an area responds to SLR (Shipman 2009, NRC 1987). The nearshore landforms in the Puget Sound region evolved under a regime of very gradually rising sea levels, but accelerated rates of SLR are anticipated to produce a number of potentially problematic changes to coastal landforms during the next century including:

- increased erosion and mass-wasting,
- accelerated bluff retreat,

- beach erosion and overwash,
- barrier migration,
- tidal inlet shifting,
- marsh erosion/accretion,
- changes in tidal prism, and
- altered inlet dynamics within river deltas and embayments.

These changes have the potential to alter nearshore ecology by causing loss of salt marsh habitat; loss of back barrier wetlands; shifts in ecological zonation on rocky shores, deltas, and other areas; and changes to in-stream habitat, among other things (Shipman 2009). These changes will also affect our ability to effectively plan, design, implement, and monitor nearshore restoration efforts.

Restoration planners will need to anticipate and plan for SLR effects if our efforts to improve and protect nearshore ecosystems are to be successful (Williams and Gutierrez 2009). This will entail planning for the relatively gradual increases in sea level caused by global warming, as well as planning for major storms and high water events since their frequency and severity will increase even with small increases in sea level (Shipman 2009).

Effects of SLR on Management Measures

This memorandum describes how each nearshore management measure is affected by SLR. The basic question being addressed here is whether projected rates of SLR pose a significant threat to our ability to successfully implement nearshore management measures. The intent is to provide a planning-level overview of each measure in terms of its overall vulnerability to SLR. Measures are considered to be highly *vulnerable* if SLR substantially increases the likelihood that they will fail. By contrast management measures that can be successfully implemented despite the added stresses imposed by SLR are considered to be relatively *resilient*. For purposes of this memo, successful implementation is defined as implementation that restores impaired nearshore processes consistent with PSNERP's general restoration goals for Puget Sound.

Describing a management measure as vulnerable or resilient without knowing specifically how and where it will be applied and which processes are being restored is a difficult task. As a result, the assessments of vulnerability and resilience presented here are qualitative and somewhat coarse; a more precise estimate of the risks posed by SLR requires detailed information about the site where the measure is being implemented and the specific restoration goals and design parameters of the project.

In most cases, uncertainty about SLR rates and expected water levels hampers our ability to accurately assess the degree of project vulnerability. This uncertainty affects each MM differently and makes it difficult to:

- determine the precise sizing or placement of fixed structures, which primarily affects MMs 1- 4, 7, 9, 12, 13, 20, and 21;
- anticipate human behavioral responses, which primarily affects MMs 8, 15, and 16;

- predict ecological responses, which primarily effects MMs 17, 18, and 19; and
- estimate the extent of impacts on uplands adjacent to the nearshore zone, which primarily effects MMs 1, 5, 6, and 14.

These descriptions build on information presented in the main body of the Management Measures Technical Report concerning common risks that SLR poses to the cost, feasibility, implementation, and outcomes of each measure. While this memo assesses a management measure's vulnerability/resilience to SLR, it does not assess the vulnerability/resilience of the nearshore ecosystem to SLR. Furthermore, the descriptions do not account for all aspects of climate change, but focus on the single component of SLR.

MM 1 – Armor Removal or Modification

Armor removal and modification projects are vulnerable to SLR and the combined effects of SLR and other climate changes such as increased storm frequency and magnitude. One of the most obvious effects may be increased resistance to the use of this measure in the face of rising sea level. Concerns about SLR may make landowners reluctant to pursue armor removal and modification projects and may even motivate property owners to install new structures to protect their lands from rising seas and high water events. In this regard, SLR may exacerbate the challenges property owners currently face when deciding how to protect vulnerable shorelines and may lead to increased reliance on engineered shore protection methods.

The response of armor removal projects to accelerated SLR will be influenced by site-specific variables, the nature of the project (removal or modification), the type of shoreform, and the local wind and wave conditions. The removal of armoring along eroding bluffs will improve natural sediment delivery and may provide benefits to areas beyond the removal site (the larger reach of the shoreline). In contrast, projects that simply move armoring landward will not improve sediment delivery and under rapid sea level rise may only provide benefits for a limited period of time.

The success of armor removal or modification projects is also affected by the assumptions and accuracy of the SLR projections used during project design. Estimates of SLR are reported as ranges that correspond to different climate scenarios (see Appendix A). This makes it challenging to determine the future extent of inundation when deciding where to relocate engineered structures. Planning for the upper range of projections may be the best way to achieve project success when relocating armor landward, as underestimating SLR may increase the chance of project failure.

Uncertainties in our understanding of how specific shores will respond to SLR can also complicate efforts to remove or modify shoreline armoring. For example, although we know that removing armor from the base of a bluff-backed beach will increase bluff recession rates, and we can expect erosion rates to accelerate as a result of SLR, there is considerable uncertainty about the rate of erosion that will occur. Several variables contribute to this uncertainty, including changing sediment supply in a drift cell due to SLR and changes in the amount of armoring, the frequency and magnitude of storm events, precipitation levels, and site-specific shoreline adjustments, among others. Projects that fail to fully account for bluff erosion induced by SLR and its effects on nearby infrastructure may cause a property owner to rearmor the shore after a bulkhead has been removed. Improved understanding of sediment budgets and erosion rates given different shoreline geology and wave conditions could reduce uncertainty and improve our ability to design projects that are resilient to SLR.

MM 2 – Beach Nourishment

Beach nourishment projects can be relatively resilient to accelerated SLR. In areas without adjacent constraints on the landward side of the presently active beach, nourished beaches generally can migrate or "translate" landward (meaning features and habitats are shifted inland). However, overwash, backshore erosion, and progressive loss of beach area and habitats can occur with SLR when there is inadequate area available for the beach to migrate or when up-drift sediment supplies are insufficient. Ample sediment supply is one of the most critical factors in determining resiliency since sediment is required for the translation process to occur. Where shoreline development or natural topography precludes landward migration of the beach, supratidal and intertidal habitats will be lost to rising sea levels. Where sediment supply is lacking (naturally or because of an up-drift impoundment such as a bulkheaded feeder bluff), additional nourishment may be required to maintain the beach profile over time.

Project design also affects the resilience of a beach nourishment project to accelerated SLR. A relatively low-energy beach could be exposed to more erosive forces as sea levels rise and storms become more frequent and severe. Such beaches may require a larger sediment size or more frequent nourishment than would otherwise be prescribed to minimize future erosion of the beach profile, in particular the upper beach and backshore. Ultimately, rising sea level may increase pressure to design more robust nourishment projects, which may require designs with different habitat values (larger volumes, coarser sediment, set back revetments, groins, etc.). This is particularly true if storm surges become more common as a result of climate change/SLR.

There is a moderate degree of uncertainty regarding how beach nourishment projects will perform under accelerated SLR and climate change. To overcome uncertainties and improve our ability to design successful nourishment projects, we need better understanding of sediments budgets, how mixed gravel and sand beaches respond to storms and high water levels, better monitoring and analysis of existing nourishment projects, and review of how nourishment projects in other geographic areas respond to rising sea level.

MM 3 – Berm or Dike Removal or Modification

The likelihood that a dike/berm removal project will succeed despite SLR depends on the specific restoration objectives. If the goal is to restore tidal wetland habitat at a particular location in the estuary, then success will depend on the ability of the marsh to maintain its position vertically in the tidal frame. If the goal is to improve the functioning of the estuary, then success will depend on the ability of the tidal flat/marsh/upland transition to move landward.

Historically, marshes and estuaries have responded to SLR by accreting vertically and migrating horizontally. When applied in areas that have a sufficient supply of mineral and organic sediment and adequate space for the marsh to migrate landward, dike removal or modification efforts are not more vulnerable to failure because of SLR. Furthermore, effective use of this management measure should make marshes and estuaries more resilient to SLR than they would be if dikes or berms had not been removed.

Vertical accretion rates will depend upon the ambient mineral sediment supply, rate of organic production, degree of subsidence prior to removal of the dike, the age of the project, and the rate of SLR. The time needed to reach an elevation that supports plant species colonization will depend upon the sediment accretion rate and the initial site elevation; the more subsided the site and the lower the sediment accretion rates, the longer the time needed to accrete to colonization elevation. With accelerating SLR, the period of time required to reach colonization elevation will increase. If SLR continues to accelerate, then at some point it will outpace the rate of mineral and organic accretion and the marsh will start to "drown."

There are a number of (qualitative) scenarios for drowning, each with unknown probabilities:

a. equilibration of existing marsh zones with no conversion of type;
b. gradual submergence with marsh type conversion ("downshifting" zones: high marsh to middle marsh, middle to low, low marsh to tidal flat) and marsh plain pan formation and expansion; or
c. a worst-case progression of (b) to overstepping marsh platforms, wholesale drowning of marshes, and pans "swallowing" fragmented marsh and expanding to tidal flats (like the extreme case of Gulf of Mexico marshes).

There will probably be a variable mix of (a) and (b) for the next 50 years, unless the SLR occurs at the highest projected rates. Equilibration of existing marsh zones with no conversion is optimistic because as marsh plain drainage decreases with submergence, so does plant productivity. Lower productivity will mean lower stem height and density for trapping and stabilizing suspended sediment, and there will be less production of organic matter in the soil profile.

If the vertical accretion of marshes cannot keep pace with SLR, then wetland habitats will tend to move landward. The horizontal rate of movement will depend upon the rate of SLR and the slope of the upland transition zone. If the marsh is bounded by an inboard levee or other structure or constrained by natural topography, then the zone available for landward migration will be much reduced and marsh habitat will be lost through "coastal squeeze."

Accelerated rates of SLR are likely to make projects more vulnerable to failure given that the supply of sediment is finite and the amount of space available for landward migration is constrained in most cases by levees and other structures. The major controlling variables are rate of SLR, sediment supply, and space for the marsh to migrate landward. Increasing the sediment supply by discharging dredged fine sediment onto or close to the wetlands may increase the local accretion rate. Increasing the upland buffer area and reducing the inboard levee slope will increase the space for migration.

A better understanding of marsh accretion processes and the amounts of sediment available for accretion should provide a better indication of the likely marsh response, whether it will accrete, migrate or drown in-situ.

MM 4 – Channel Rehabilitation or Creation

Channel rehabilitation and creation measures can be vulnerable to SLR because SLR can cause greater than expected changes in tidal prism. Channel characteristics are closely linked to the tidal prism of the watershed that the channel drains. With gradual SLR, intertidal surfaces can keep pace with the increase in high water elevations and the tidal prism may stay relatively constant. In contrast, with rapid SLR, high water elevations may outpace the rate of vertical marsh accretion and the mean depth and tidal prism of the marshes will increase. Therefore, rehabilitating the historic channel network or constructing new channels that are appropriately sized for the marsh may be more successful with low rates of SLR.

SLR will also increase in the size of the estuary as marshes migrate landward, which increases the subtidal and intertidal contributions to the tidal prism. With increasing tidal prism the downstream channel cross-section (its width and depth) will increase. There may also be changes in its plan form as discharges increase. These may alter the channel network from that anticipated in the project design.

It is observed in accreting marshes that channel density varies with elevation, and hence age of the marsh, as follows:

- Low or young marsh, where marsh plain elevations are low and tidal prism is large, tends to have higher drainage density, more small channels and complex drainage patterns.
- Higher or older marsh, where tidal prism is reduced and drainage density decreases, tends to have a less complex drainage pattern with fewer small channels.

The maximum channel density is usually estimated to occur around the elevation of the neap high tide in semi-diurnal tidal regions (Steel and Pye 1997). It is unlikely that this pattern works in reverse if higher marshes drown; rather it is possible that pan formation will capture channels, obliterating the existing dendritic pattern and expanding to tidal flats.

Because the channel changes that might be expected are controlled by the tidal prism (which is related to the elevation of the marsh), the success of this management measure in responding to SLR is also dependent on measures that promote marsh evolution (e.g., MM 3 and MM 9). Counteracting uncertainties will require hydraulic modeling, better understanding of regional/delta-specific channel morphology vs. tidal prism relationships, detailed typographic information for the project site (e.g., LiDAR or instrument survey), and other information.

MM 5 – Contaminant Removal and Remediation

Sea level rise is not expected to have a major effect on the success or failure of most contaminant removal and remediation measures, but rising seas, increased erosion, and more severe flooding may cause remediation sites near the shore to fail. Additionally, SLR may expose more nearshore areas to hazardous waste contamination and create a greater need to implement this measure over time.

Sea level rise can increase flood peaks and raise the tidal prism, causing remobilization of contaminants in coastal sloughs, wetlands, and other areas. Landfills located close to nearshore habitats may need to be moved landward or armored to prevent erosion or seawater intrusion (NRC 1987). In some cases these facilities may require cutoff walls to prevent groundwater contamination.

Shoreline retreat induced by SLR can mobilize hazardous materials and contaminated sediments that are located landward of existing floodplains, or otherwise not currently exposed to inundation or wave attack (Flynn et al. 2009). Flooding and wave attack could also weaken caps at existing waste sites, allowing contaminants to spread to nearby surface waters. Saltwater intrusion into existing disposal sites may increase leaching of hazardous wastes, exposing more nearshore areas to pollution.

Sea level rise can also impact existing drainage systems and cause more frequent sewage overflows, which could amplify pollution outfall to the nearshore. Erosion and scour caused by SLR-induced flood events may increase the probability that land-based pollutants and contaminated materials will be transported through the watershed. These risks increase with increasing SLR.

Factors that influence the resiliency of this management measure to SLR (beyond the rate of SLR) include elevation and distance from the shore of existing contaminated areas, fetch, land subsidence (such as on river deltas), and the type of remediation used. Information on groundwater levels/patterns, soil characteristics, and contaminant mobility will be useful in overcoming complications caused by SLR.

MM 6 – Debris Removal

Debris removal efforts are not expected to be materially affected by SLR. However, rapidly rising seas may result in increasing amounts of debris along the shoreline including failed bulkheads, groins, docks, and other materials, making this management measure more necessary over time. Otherwise, efforts to remove debris from nearshore areas should be relatively free from complications due to SLR. Decisions about where, when, and how to remove debris will be driven primarily by the type of debris (e.g., creosote pilings versus fishing gear) and the characteristics of the waterbody (e.g., shallow protected bay versus exposed shore or deep water area). SLR is not likely to be a major factor in designing or carrying out the removal activity. As a result, the effect of SLR on the success or failure of most debris removal projects will be relatively small.

MM 7 – Habitat Protection Policy and Regulation

The successful application of our existing habitat protection policies and regulations is very vulnerable as a result of SLR. Sea level rise poses a threat to virtually all of our existing habitat protection programs since most of them were developed before we began to understand the implications of SLR. As a result, existing policies and regulations governing shoreline setbacks, nearshore vegetation management, use of armoring, overwater structures, wetland protection, public access/enjoyment of the nearshore, and floodplain management/flood hazard mitigation may not adequately protect nearshore resources given SLR projections.

Society's response to SLR will likely require substantial changes to existing habitat protection policies and regulations—some of which are already underway. Governor Gregoire and the state legislature are already at work on a number of climate change initiatives including the Climate Action and Green Jobs bill. Policy makers, resource managers, and residents of the Puget Sound region are collectively grappling with decisions about how to protect existing developments near our shorelines, accommodate new development in coastal areas, and implement nearshore restoration efforts. Sea level rise is likely to make these policy and regulatory decisions much more complicated in the future.

Policy makers and regulatory agencies will need to reassess the effectiveness of existing policies and regulations in light of SLR data and make adjustments as needed. Policies and regulations pertaining to shoreline stabilization (use of armoring and other structures) are likely to be among the most complicated and complex issues. Existing rules and practices for permitting bulkheads may need to be re-examined in light of SLR. Hydraulic project rules pertaining to culvert and bridge design may need to be updated so that these structures function when subjected to SLR. Zoning regulations may need to be modified so that new developments avoid areas that are subject to increased inundation, erosion, or flooding because of SLR. New standards for shoreline setbacks may need to be developed to better account for SLR.

The fact that policy makers will not know for certain what level of SLR to assume when crafting new or modifying existing regulations is likely to complicate decision making. Policy/regulatory decisions aimed at accommodating "high" sea level projections may be perceived as too costly or too restrictive of private property rights. Conversely, basing policy and regulatory decisions on "low" sea level projections may mean that policies and regulations fail to achieve their desired protection goals. Creating incentives for property owners to proactively address expected SLR impacts could be an effective use of this management measure.

To effectively implement this measure in the face of rising sea level, we will need more precise SLR projections, better data on social values (through surveys, focus groups and other means), and more experience with successful incentive programs.

MM 8 – Groin Removal and Modification

The impact of SLR on the success of groin removal efforts is very uncertain. Successful projects will require a through understanding of erosion rates, transport pathways and accretion patterns – all of which are difficult to predict given varying rates of projected SLR.

Removing or modifying a groin or cross-shore structure will not only affect the local area but can alter sediment transport within the larger net shore-drift (littoral) cell. It is therefore necessary to consider not only the conditions in the vicinity of the groin but also throughout the littoral cell. As sea level rises, water depths increase, and wave refraction patterns change, the patterns of wave and current energy along the open coast will vary. Storminess and storm surges may also increase. These will combine to change patterns of erosion, accretion and littoral transport within the cell and may make the likelihood of achieving the desired restoration outcomes less certain. It is therefore important to consider SLR when forecasting future changes in the sediment budget, both with and without the groin in place. Future impacts on down-drift beaches may be greater due to SLR.

Projects that shorten or lower existing groins need to take into account the structure's effectiveness with future sea levels. It may be necessary to design the structure so that it can be modified in the future to maintain its effectiveness. For instance, the base of a rock structure may need to be wider so that its height can be increased in the future. Another consideration is the long-term evolution of the beach as sea level rises – in particular if the beach will migrate landward. It is possible for groins to be outflanked on the landward side.

Better knowledge of sediment budgets, transport pathways, and accretion patterns will help ensure that this measure can be applied successfully as sea levels rise.

MM 9 – Hydraulic Modification

This measure involves modification of hydraulic structures (tide gates and culverts) as part of a managed tidal system which includes muting the tide. Such systems are considered to be very vulnerable to SLR, therefore this measure is considered to be very vulnerable to failure because of SLR. Sizing of breaches and hydraulic structures requires an understanding of how the whole marsh/lagoon system is likely to respond to SLR. Structures such as tide gates and culverts may not function correctly when water elevations exceed certain thresholds due to SLR. For instance, elevations at which flap gates open and close need to be adjustable, otherwise they may be closed for longer periods of time for each tidal cycle. Similarly, invert elevations may restrict flows as sea levels rise.

Where this measure involves creating open channels through existing fill structures, breaches must be sized to accommodate the expected flows. Determining the appropriate size will be more complicated because of SLR. If marsh accretion cannot keep up with rising sea level, then the tidal prism will increase and breaches (or culverts) will have to be enlarged to accommodate the increased tidal discharge. The reestablishment of tidal conditions by removing gates and culverts, and/or enlarging breaches, will also require increased flood protection for adjacent lands because of SLR.

Given the uncertainty of future SLR projections, it would be wise to design structures that can be modified in the future to accommodate the larger flows. For instance, levee easements should be made wide enough to allow for future increases in levee elevation; culverts could be built larger in anticipation of larger tidal prisms. Despite the challenges, the removal of tide gates, the construction of breaches, and the modification of culverts should improve the ability of the nearshore system to adapt to rising sea level.

MM 10 – Invasive Species Control

Efforts to control and manage invasive species are very likely to be affected by SLR (and climate change generally). The specific consequences will vary depending on the species being controlled and the location of the infestation. Although there is widespread belief that SLR will have a major impact on biodiversity, few data are available to assess whether changing climate will facilitate invasions by favoring introduced over native species (Stachowicz et al. 2002) (IPCC 2007). As a result, it is difficult to determine whether accelerated SLR will increase or decrease the success of this management measure.

Sea level rise can make conditions more or less suitable for species invasion (EPA 2008). In general, ecosystem alterations (including climate change-induced alterations such as SLR) tend to favor the establishment of pioneer and disturbance-tolerant species. Since there is strong evidence that many invasive species are pioneers, SLR may promote their establishment and increase the need for control efforts in nearshore areas (EPA 2008).

Sea level rise can promote the spread of some invasive species through range expansion and habitat creation. For example, as coastal waters warm, species may shift their ranges northward and invade new areas (EPA 2008). Rising sea level (along with increased flooding and increased rainfall) can enable dispersal of some invasive species and can enhance the spread of other species across hydrologic gradients. This may make it more difficult to control invasive species in wetlands and other aquatic and transitional habitats, especially under moderate and high SLR scenarios.

Increasing ocean temperatures (a factor in SLR) may lead to new species invasions. For example, warm weather conditions in the 1980s are believed to have contributed to a rapid expansion of exotic cordgrass (*Spartina*) in Willapa Bay that threatened local species (Parson 2001 in EPA 2008). Other evidence suggests that some sessile invertebrate species (sea squirts) recruit earlier in years with warmer winter water temperatures (Stachowicz et al. 2002). Because community composition is often determined by which species settles first, introduced aquatic species may outcompete native species as ocean temperatures warm.

Sea level rise may subject estuaries and other tidal areas to new infestations of invasive species as salt water intrudes into freshwater areas. Consequently, species such as the Asian crab which tolerate a wide range of salinity and temperature conditions may become a greater threat. Altered conditions such as increased atmospheric carbon dioxide, warming ocean and coastal currents, increased ambient temperature, and altered nitrogen distribution also can increase invasive species' success in some situations, making efforts to control invasive species more difficult, costly, or prone to failure.

The effects of SLR on invasive species are not well understood, but climate trends suggest that increased dominance of marine habitats by non-indigenous species and new invasions are likely (Stachowicz et al. 2002). Efforts to control invasive species in the face of SLR will require better and more regionally specific data on species' life history requirements and their responses to climate conditions.

MM 11 – Large Wood Placement

Large wood placement projects are somewhat vulnerable to accelerated SLR, but since these projects can have a relatively short life-span, there will be opportunities to adjust and adapt to SLR. The exact implications depend on whether the large woody debris (LWD) is anchored and where the LWD is placed within the beach profile. The degree of SLR will also influence the resiliency of this management measure. Site constraints such as available backshore and upland area may restrict where LWD can be placed under "intermediate" and "high" SLR scenarios.

Sea level rise will increase the likelihood that unanchored LWD placed in the backshore will mobilize during storm events that coincide with high water. Unanchored LWD is likely to remobilize with SLR in all but low wave energy environments. This can be avoided by physically moving the LWD to a higher elevation on the backshore as the shoreline advances landward.

Anchored LWD pieces are less likely to mobilize due to accelerated SLR. As the shoreline migrates landward and the beach profile adjusts to SLR, anchored LWD will remain static and thus occupy lower and lower tidal elevations (or positions within the beach profile). The elevation where the wood is placed is one of the most critical design elements because LWD placed too low in the beach profile can cause beach scour beneath the structure, which can cause project failure. Therefore, project sponsors may want to relocate anchored LWD pieces landward or otherwise carry out adaptive management with moderate SLR.

Moderate design alterations may enhance the resiliency of LWD placement projects to accelerated SLR for restoration and enhancement projects (this is not always possible for soft shore protection projects as landowner constraints often limit options). For example, if multiple logs are placed at higher elevations on the beach profile rather than individual logs at lower elevations, the wood will likely provide similar benefits over time with less risk of long-term project failure due to accelerated SLR.

MM 12 – Overwater Structure Removal or Modification

Sea level rise is expected to improve the success of this measure primarily because it will create a greater incentive for overwater structure removal and modification. Existing structures are likely to suffer more damage and destruction due to SLR-induced wave action, since wave energy is strongly influenced by water depth (NRC 1987). As a result, dock/pier owners may be motivated to remove, relocate, and/or redesign overwater structures in ways that could benefit nearshore processes. For example, dock owners may begin to favor the use of floating docks over fixed or pile-supported structures, since the former may be more adaptable to rising sea levels.

Accelerated SLR can produce changes in tidal range and currents which can alter siltation patterns. This could increase or decrease the need for dredging at existing marinas, ports, and other facilities. To avoid the costs and regulatory hurdles associated with dredging, marina/port operators may be willing to remove, relocate or modify boating facilities and other overwater structures.

MM 13 – Physical Exclusion

Sea level rise may influence the placement and/or design of physical exclusion devices, especially in areas exposed to inundation, increased erosion, or more frequent/severe flooding. By altering the land-water interface, SLR could potentially create the need for an exclusion device where such need otherwise would not exist. In other cases, SLR may negate the need for exclusion devices by rendering an area or site less accessible to unwanted intrusion by people or animals.

The design, installation, and/or maintenance of some exclusion devices may become more expensive as a result of SLR—particularly if project sponsors design exclusion devices to withstand the highest projected rates of SLR. Otherwise this management measure is relatively unaffected by SLR.

MM 14 – Pollution Control

Sea level rise will impact the use and effectiveness of pollution control measures in much the same way it affects MM 5 (Contaminant Removal and Remediation) because these management measures are closely related. All of these risks increase with increasing SLR.

Sea level rise can increase the potential for polluted upland sites (e.g., abandoned industrial sites) to become exposed to inundation, increased erosion, and more severe flooding, which could spread contamination to nearshore areas and create a greater need to implement this measure over time. Sources of pollutants located close to nearshore habitats may need to be moved landward to prevent them from entering nearby receiving waters.

Sea level rise can also increase flood peaks and raise the tidal prism, causing remobilization of pollutants in coastal sloughs, wetlands, and other areas. In rural areas, SLR, increased precipitation, and flooding may render some on-site septic systems ineffective, leading to increased nutrient and bacteria loading in downstream waters.

Erosion and scour caused by SLR-induced flood events may increase the probability that land-based pollutants will be transported through the watershed. Pollutants such as phosphorus that adsorb to sediments will be more easily transported to receiving waters as a result of increased erosion.

Sea level rise can impact existing stormwater and wastewater infrastructure and cause more frequent sewage overflows, which could amplify pollution outfall to the nearshore. Existing infrastructure may need to be moved or retrofitted to withstand changing conditions. At the same time, new stormwater and wastewater facilities in coastal areas may need to be designed differently to withstand SLR and other climate impacts. Additional treatment and/or detention approaches may be required to mitigate stormwater and wastewater discharges in hydrologically altered environments.

Factors that influence the resiliency of this management measure to SLR (beyond the rate of SLR) include elevation and distance from the shore of existing pollutants or pollution control infrastructure; fetch; land subsidence (such as on river deltas); the type of pollutant, and the type of control measures used. Implementers of this measure are advised to evaluate these conditions to counteract uncertainties related to SRL.

MM 15 – Property Acquisition and Conservation

In general, property acquisition and conservation efforts are not made more vulnerable because of SLR. Accelerated rates of SLR could increase the effectiveness of this measure by removing some of the barriers or constraints associated with its use. For example, rather than face the implications of SLR, some property owners may become more willing to sell, give up development rights, or otherwise conserve their land. Concerns about SLR and the risks it presents to existing and future development along shorelines, in river deltas, and near floodplains may motivate landowners to seek alternative ways of deriving income from their properties that do not involve development (e.g., outright sale or a conservation easement). Whether or not public agencies are willing to acquire lands and development rights will depend on several factors, including whether or not acquisition is expected to be less expensive than trying to protect an area from inundation, flooding, and other hazards. Concerns about SLR-induced flooding could also make public agencies less wiling to acquire some properties.

Sea level rise also has the potential to expand the amount of land needed to carry out some nearshore restoration efforts, so the need to employ this management measure (as a prerequisite to other measures) is expected to increase. As an example, sponsors of berm and dike removal projects and other types of restoration efforts are often required to acquire property or easements for lands that will be flooded or open to tidal inundation. Where SLR would expand the area of inundation (or expand the FEMA-designated floodplain, for example) additional lands or easements may need to be acquired.

Overall acquisition and conservation appear to be particularly effective tools for addressing future SLR. This measure can create undeveloped area landward of existing shorelines to accommodate rising sea level without recourse to structural measures, storm protection, or major ecological tradeoffs.

MM 16 – Public Education and Involvement

The question of whether SLR will make efforts to employ this management measure more or less successful is difficult to answer. What is relatively certain is that the need for public education and involvement will increase dramatically as a result of SLR. In many respects, our effort to adapt to rising sea level and other climate impacts will be a direct result of our ability to successfully educate the public about the consequences of climate change and involve them in strategies to mitigate adverse impacts. According to the United Nations Environment Programme, Division of Environmental Law and Conventions, “the scale of the changes required [as a result of climate change] … and the vast number of people and interests that must be influenced, call for outreach activities of a much greater magnitude.”

Because of the complexity and uncertainty surrounding the causes, effects, and expected levels of SLR, efforts to educate and involve the public about the importance of nearshore protection and restoration in a climate-altered environment will require more effort and resources. This may be especially challenging considering that our understanding of SLR is rapidly evolving—projections are constantly being updated and new information is coming to light on a regular basis. This means that educators will need to update and revise content and educational messages frequently.

Faced with the threat of rising sea level, increased flooding, increased erosion, and other hazards, it is possible that the public will be more eager for and receptive to educational materials and opportunities for involvement. As the public begins to observe/experience “predicted” climate change impacts they may become more accepting of need to change behaviors that contribute to climate change. In that sense, the success of this measure may be enhanced as a result of SLR.

Future efforts to apply this measure will benefit from having a thorough understanding of public perceptions so that messages can be tailored to address real threats and people can be convinced of the need for action.

MM 17 – Revegetation

The effect of SLR on revegetation efforts will be similar to the effect of SLR on invasive species control (MM 10), species reintroduction (MM 19), and species habitat enhancement (MM 18). Sea level rise and other climate changes such as increased precipitation and high temperatures are anticipated to have a pronounced effect on the composition and structure of existing and newly established vegetation. The nature and severity of the effect will vary by species and plant community type.

The most obvious effect of SLR will be on revegetation of submerged habitats since these areas will be subject to greater depth of inundation, altered water temperature, and greater wind/wave energy than intertidal or terrestrial habitats. The potential for project failure may be most pronounced in areas where the ability of the shore to migrate landward is constrained by human development or major topographic gradients. Revegetation of floodplains, coastal bluffs, and backshore beach habitats will be highly vulnerable to failure because of increased wind/wave energy, erosion, flooding, and other SLR-induced phenomena. Risks increase with increasing SLR. Future revegetation efforts will require better and more regionally specific data on species' life history requirements and their responses to climate conditions.

MM 18 – Species Habitat Enhancement

Species habitat enhancement efforts are typically undertaken to replace lost habitat structure with the intent of increasing nearshore biodiversity. This measure can be implemented in subtidal, intertidal, supratidal, and/or upland habitats; enhancement actions in any of these areas could be vulnerable to SLR, but projects in higher elevations should be relatively resilient to SLR, especially if SLR is within the "low" projected range.

Species habitat enhancement measures tend to be implemented on a relatively small scale and may have a limited life expectancy in some cases. In this regard, such efforts may be somewhat less vulnerable to SLR-caused failure than measures that require large temporal and spatial scale in order to achieve results. With this measure the factors that influence success are largely the same in a climate-altered environment as they would be in the absence of SLR; namely, sound understanding of site conditions, target species, and habitat requirements.

Demand or need for this measure may increase due to SLR because of the need to counteract threats to biodiversity caused by SLR/climate change.

MM 19 – Reintroduction of Native Animals

The implications of accelerated SLR on this management measure are somewhat similar to the implications discussed above for MM 10 (Invasive Species Control). Efforts to reintroduce native animals into the nearshore are very likely to be affected by SLR, but the specific consequences will vary depending on the species being reintroduced and location of the reintroduction.

Efforts to reintroduce native animals such as Olympia oyster and pinto abalone in Puget Sound have been relatively limited in number and their success is largely still in question. Early projects focused on introducing live oysters, whereas more recent efforts have attempted to also restore physical habitat (via placement of Pacific oyster shell) in areas where natural recruitment is known to occur. Introducing live animals is likely to increase the pace of stock rebuilding efforts and may be more desirable, especially since SLR may slow or hamper habitat enhancement efforts, which tend to take longer even under “normal” climate scenarios.

Successful reintroduction efforts will depend on the availability of suitable habitats. Intertidal habitats are likely to become fully inundated due to SLR. Coincidentally, the availability of protected/sheltered areas is also likely to become more limited as sea level rises. These changes may pose substantial obstacles to future reintroduction of Olympia oysters and other native animal species.

Sea level rise presents yet another variable or set of variables to be accounted for when planning and executing species reintroduction projects. Given our relative lack of experience with animal reintroduction in the marine environment and the dearth of data on which to evaluate the success of past projects, it seems likely that SLR will make future reintroductions more complicated and potentially risky. To mitigate risks of failure related to climate change, sponsors of this measure will need to evaluate target species’ vulnerability to sea level rise based on its life history and ecological traits and ensure that the reintroduction will fall within the species’ current and future climate envelope.

MM 20– Substrate Modification

The impacts of SLR on substrate modification efforts are very uncertain because we lack adequate information about potential changes to erosion, transport pathways and accretion caused by SLR. Vulnerability of this measure to SLR depends on the landscape context of the site. If the site is connected to sediment sources and nearshore processes necessary for sustainability are relatively intact, then substrate modification projects are likely to be successful even if sea level rises. Conversely, if this measure is applied in highly degraded systems, vulnerability to SLR increases substantially.

Sea level rise may change the pattern of wave and current energy along the coast and in estuaries by increasing the depth of water. SLR also increases wave activity and storm surges. These changes alter patterns of erosion and accretion and change the composition of the substrate by a number of mechanisms. For example, shear stress may decrease in an area as waves start shoaling farther shoreward as water depth increases. Lower shear stress may be low enough to allow deposition of fine material carried in the water column. This may blanket existing coarser bed material. Similarly, shear stress may increase in an area as wave refraction patterns vary with water depth, and the focus of wave energy may change. Higher shear stress may result in selective sorting of bed material as finer sediment is winnowed out.

Increased water levels may lead to increased bluff erosion and an increase in sediment from feeder bluffs. Depending on the composition of the bluff, this could lead to a coarsening or fining of down-drift beaches. Increased tidal prism may lead to increased scour in tidal channels, revealing coarser lag deposits on channel beds.

Detailed information on SLR-induced changes to erosion, transport pathways, and accretion will aid our understanding of this measure and will help overcome uncertainties associated with future substrate modification projects.

MM 21– Topography Restoration

Topographic restoration includes excavating/dredging substrate or depositing fill to promote marsh development. This measure is vulnerable to failure in areas of low sediment accretion because these sites may not be able to maintain their elevations, leading to the “drowning” of existing marshes (as described in MM 3). If the goal of the topographic restoration is to accelerate colonization of marsh vegetation, success will often be compromised.

The elevation of the land surface in relation to the water surface is critical to the success of many restoration projects. The relative elevation of the land surface will control the frequency, depth and period of inundation, which in turn will control marsh vegetation. At mid-marsh elevations, colonization occurs rapidly while there is also sufficient tidal prism for channel development to occur. At low-marsh elevations, there are more immediate and prolonged benefits to fish, but vegetation colonization and channel development proceed slowly.

Ideally, topographic modification should include a variety of elevations, connected with low slopes to provide wide buffers of transitional habitat across which intertidal habitats can migrate. In designing the template for topographic modification, thought should be given to how the inundation pattern will change over time as the water level increases. Initially the site may have a larger proportion of upland habitat, but over time this is gradually converted to intertidal habitat. The amount of subtidal habitat is also likely to increase over time because of SLR.

Understanding how a site will evolve with increased inundation allows project designers to plan for changes to the future composition and structure of the marsh vegetation. This in turn will affect the rate of organic production, the ability to trap sediment, and anchoring of the substrate by root mass. These factors then feedback on the evolution of the marsh.

Summary

Climate change and SLR are expected to change the environment in myriad and in many cases unforeseen ways. Nearshore management measures vary in their vulnerability to failure as a result of SLR (Table 1). This creates special challenges for restoration planners and practitioners. Among the most obvious of challenges is the fact that SLR will increase the need for us to effectively employ all 21 of the PSNERP management measures. Not surprisingly, all measures that are vulnerable to SLR complications are more vulnerable at increasing levels of SLR. Uncertainties about specific SLR implications are numerous and reflect a need for more detailed information and data about nearshore processes and how they may be altered by SLR.

Table 1 – Estimated Risk of Failure due to SLR for each Management Measure

No.	Management Measure	Risk of Failure due to SLR Substantially increased = ↑ Substantially decreased = ↓ Highly variable = ↔ No effect / Unknown = (blank)
1	Armor Removal / Modification	↑
2	Beach Nourishment	↓
3	Berm / Dike Removal / Modification	↔
4	Channel Rehabilitation / Creation	↔
5	Contaminant Removal / Remediation	
6	Debris Removal	
7	Groin Removal / Modification	↑
8	Habitat Protection Policy or Regulations	↑
9	Hydraulic Modification	↑
10	Invasive Species Control	↔
11	Large Wood Placement	↑
12	Overwater Structure Removal / Modification	↓
13	Physical Exclusion	
14	Pollution Control	
15	Property Acquisition and Conservation	
16	Public Education and Involvement	
17	Revegetation	↔
18	Species Habitat Enhancement	↔
19	Reintroduction of Native Animals (Non-Plant)	↔
20	Substrate Modification	↔
21	Topography Restoration / Creation	↑

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NEARSHORE
ECOSYSTEM RESTORATION PROJECT

Puget Sound Nearshore Ecosystem Restoration Project

c/o Washington Department of Fish and Wildlife

Mailing Address: 600 Capitol Way North,
Olympia, Washington 98501-1091

Contact: *pugetsoundnearshore@dfw.wa.gov*
or vist our website at: *www.pugetsoundnearshore.org*