PUGET SOUND NEARSHORE ECOSYSTEM RESTORATION

APPENDIX E

MONITORING AND ADAPTIVE MANAGEMENT

Integrated Feasibility Report and Environmental Impact Statement

US Army Corps of Engineers®
Seattle District

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Puget Sound Nearshore Ecosystem Restoration Project

Monitoring and Adaptive Management Plan

June 2016

The following three site-specific monitoring plans describe the monitoring metrics, performance targets, and adaptive management measures to be applied at each of the sites of the recommended plan, which is detailed in the Final Feasibility Report and Environmental Impact Statement. The general Monitoring Framework that was developed during feasibility phase forms the basis for development of the monitoring metrics and follows the site-specific plans for reference. The three restoration sites of the recommended plan are as follows:

- North Fork Skagit River Delta
- Nooksack River Delta
- Duckabush River Estuary

North Fork Skagit River Delta

1 Project Monitoring Objectives: North Fork Skagit River Delta

As a restoration project, it is expected that this site will be dynamic and evolve. Thus, for some parameters, strict achievement of predetermined performance standards will not necessarily predict the success or reveal the failure of the restoration effort. The monitoring and evaluation will focus on determining whether the overall project objectives of the restoration are being met. Monitoring efforts will be performed by using monitoring metrics. All post-construction monitoring will be performed by qualified biologists and hydraulic engineers.

Evaluating the success of the restoration site will be based on the establishment of the targeted habitat within the restoration site and on the ecological functioning of those habitats. All post-construction monitoring will be cost shared between the Corps and the non-Federal sponsors for the first 10 years of monitoring. The non-Federal sponsors may choose to monitor beyond this 10-year period, although the cost would be 100% their responsibility. Data collection will be used to determine success of the project with the focus on the development of estuarine and freshwater tidal wetlands and vegetated riparian zone. Restored wetlands can take decades to reach their dynamic equilibrium conditions, therefore the initial monitoring period of approximately 10 years will be assessed as to whether the structural template has been established and if the site is on a trajectory toward ecological success (Haltiner et al. 1997). The Corps and the non-Federal sponsors will use the knowledge gained through this monitoring to adaptively manage the project sites.

The following site-specific objectives have been identified for restoration at the North Fork Skagit River Delta:

1. Reconnect and restore lost floodplain habitats including channel meander zone, shoreline complexity, and shaded refuge habitat.
2. Reconnect and restore lost tidally influenced area including estuarine and freshwater tidal wetlands and tidal channels in the North Fork Skagit River Delta.
3. Re-establish foraging habitat for Great Blue Herons, and improve resting and foraging tidal flat habitats for large flocks of waterfowl migratory shorebirds of the Pacific Flyway.
4. Improve aquatic habitat connectivity between lower river systems and upstream habitat networks.
5. Restore a more natural riparian corridor along the North Fork Skagit River Delta.

These objectives are expected to achieve three different habitat types across the restoration site: saltmarsh wetlands at the downstream end and lower elevations, a scrub-shrub wetland ecotone across most of the site given the existing and anticipated elevations, and a vegetated riparian buffer zone. The excavated tidal channels will intersect all three of these habitat zones. The site is expected to support a dynamic habitat mosaic as it reaches an equilibrium of restored interactive processes.

Section 3 lists monitoring metrics, performance targets, and potential adaptive management associated with the effectiveness monitoring, which aims to measure how well the habitat is developing according to performance criteria.

2 Reference Site

The reference site selected for the North Fork Skagit River project site is the reach of river that begins immediately adjacent to the downstream end of the project site (Figure 1). This reach is not considered to necessarily be in "historical condition" because upstream activities such as dams and farming over the past century have likely altered conditions that existed prior to these manipulations (Hood 2009). However, the reach has natural processes of sediment erosion and deposition, sustained tidal channels, as well as intact tidal inundation to sustain wetlands and is therefore a sufficient reference target for restoration of natural processes and ecosystem functions. The reference reach curves northward before turning west again to enter Puget Sound. The reach is approximately 2 miles long, and the left bank is mostly vegetated with no evidence of direct human interference. The right bank has a short modified reach but is otherwise natural. The channel width varies from 350 to 550 feet wide, which is roughly the same as the project site. The reference site is in the scrub-shrub zone and contains substantial native vegetation that can serve as a seed source as tidal inundation is restored to the project site, which will also be within the tidal elevations of the scrub-shrub zone once restored. The reference site contains all of the expected types of riverbank complexity features for this type of site including but not limited to shrubs, trees, accumulations of woody debris, varying substrate sizes, and erosional and depositional reaches. This reference site applies to all of the monitoring metrics listed in Section 3.

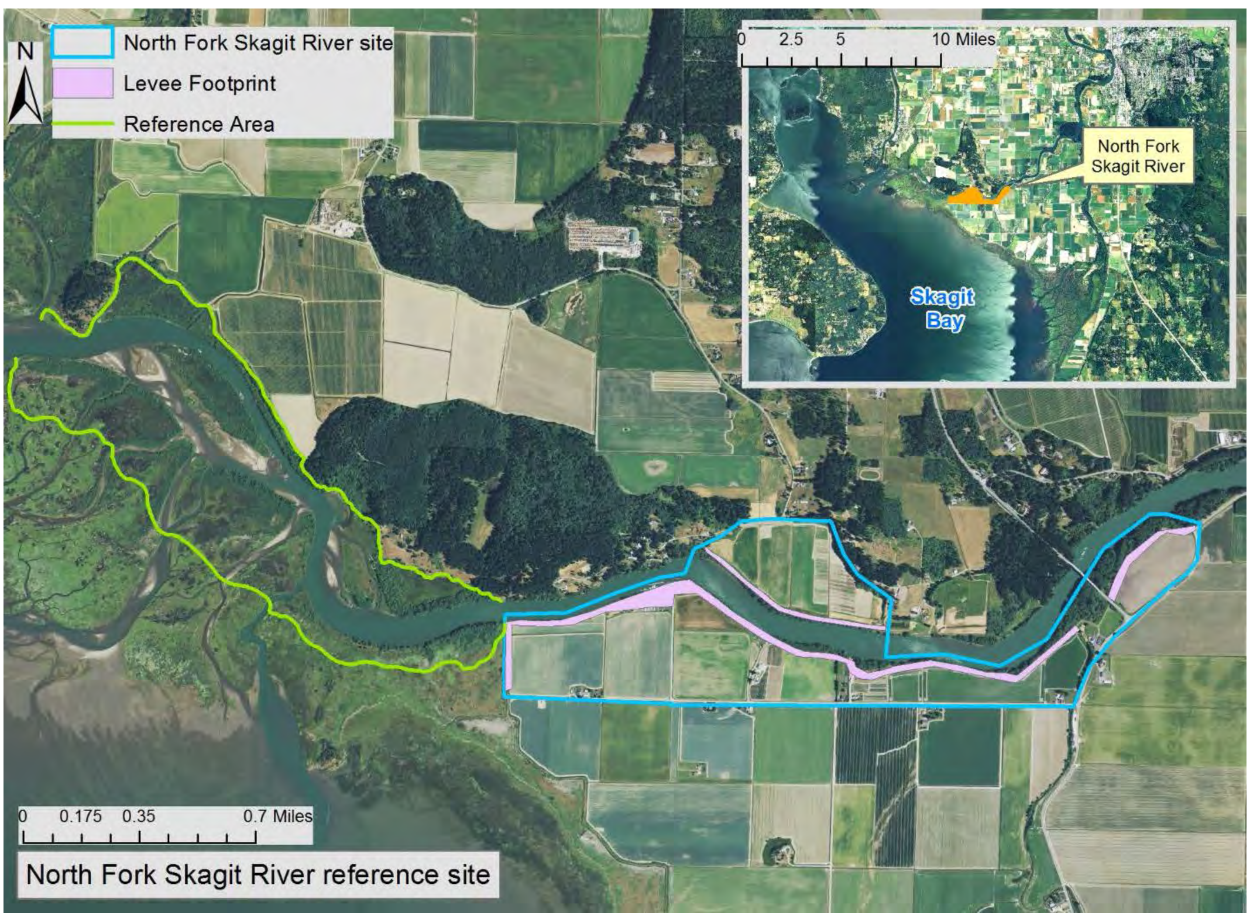

Figure 1. North Fork Skagit River project site and downstream reference site.

3 Monitoring Metrics, Targets, and Adaptive Management Measures

All of the following metrics, methods, targets, and adaptive management measures may be adjusted during pre-construction, engineering, and design (PED) phase as surveys, hydraulic modeling, and detailed designs are completed.

3.1 Monitoring Metric 1: Increased tidal prism of water reaching a reconnected floodplain (Objectives 1-4)

Methods and Timing: Existing conditions were determined through LiDAR and established NOAA tide stations; however, this method does not provide data with the local accuracy required for post-construction monitoring and adaptive management. To determine whether the site is reaching the performance target stated below, a water surface gauge or pressure sensing data logger will be installed on the left bank of North Fork Skagit River near the midpoint of the site. This sensor will be used to measure the tidal and riverine elevations and to quantify frequency, duration, and area of tidal inundation (Roegner et al. 2009). When combined with NOAA gauge No. 9448558 at La Conner ,WA and coastal hydraulic modeling, a single water surface sensor is sufficient to characterize the tidal elevations in the vicinity of the project as well as at the reference site. The sensor will be checked every 3-6 months. The data will be used to estimate intertidal prism parameters such as areas of highest and lowest tidal inundation and to calculate the volumetric difference between high tide and low tide. Morphological feature extents in the landscape profile (channels, hummocks) will be noted. The complete dataset will be analyzed once per year in years 1, 2, 6, and 10 after construction to verify project success of providing tidal influence to the site (Neckles et al. 2002). The greatest change will occur in the first two years. Subsequent measurements every 4 years will quantify additional change toward site conditions that may not be stabilized until 20 or more years post-construction. This duration of monitoring will allow sufficient time for higher high tides and significant floods to exert influence over the substrate materials and excavated channels. The predicted response, as shown in Table 4-1 of the Monitoring Framework, is that the period of inundation will increase as tidal hydrology is restored, then will decrease as the marsh elevation increases. By 10 years post-construction, data will show the trajectory of site development and decisions can be made regarding whether contingency measures are required. Site topography data would be collected via remote sensing and on-the-ground survey making opportunistic use of other LiDAR efforts in the Puget Sound area.

If a flood level greater than a 2% Annual Exceedance Probability occurs within the first 15 years after construction, then the site should undergo an additional monitoring assessment. Any monitoring after 10 years post-construction is at 100% cost of the non-federal sponsor.

Performance Target: The performance target is to achieve inundation of the newly constructed channels for at least 40% of the tidal cycle by 10 years after construction.

Adaptive Management: If the site has not reached its performance target by 10 years after construction, then additional removal of material where the levees stood may be needed, and/or more excavation at the breaches and/or along the channel excavations may be necessary. All site data should be integrated for a thorough analysis of conditions before additional construction actions are taken.

3.2 Monitoring Metric 2: Wetland development (Objectives 2 and 3)

Methods and timing: Three levees will be removed during construction. The acreage of the footprints of these levees is 29 acres for the main left bank area, 5 acres for the small left bank area upstream of Best Road Bridge, and 5 acres for the right bank area (see Figure 1). The footprint is considered to be all of the area excavated to remove each of the three levees, which would become bare soil on the site. This footprint of each levee removal area will be monitored to ensure the restored area is developing wetland characteristics. This is the critical area of disturbed soils that must be monitored. Planting the entire 256-acre site would not likely be cost-effective and passive colonization has been determined to be a successful strategy for estuarine marshes (Hood 2009). Wetland reconnaissance site visits will be conducted to document the presence/absence of hydric soils, hydrophytic vegetation, and wetland hydrology using the methods in the *USACE Wetlands Delineation Manual* (Environmental Laboratory 1987) and the *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys, and Coast Region* (USACE 2010). Monitoring site visits will occur in years 2, 3, 6, and 10.

Performance Target: The target is for at least 80% of each levee removal footprint (23 acres of main left bank, 4 acres of small left bank area, and 4 acres of right bank area) to function as wetland. If early monitoring results show that the site is not on a trajectory to achieve the target, implementation of adaptive management measures should be evaluated to determine whether the trade-off is worth the site disturbance as implementation would likely destroy some plantings.

Adaptive Management: If the target is not met, then additional removal of material where the levees stood and/or more excavation at the breaches may be necessary, but no more than 10% of initial construction quantities. The area would need to be analyzed for whether it can be manipulated to create hydrological conditions to support wetland soils and plants, and sampling could move outside of the footprint of the levee removal area for further investigation. The area should also be analyzed for whether it is providing equivalent functional value of a different habitat type to the performance target before undertaking any construction measures to meet the previously stated performance target.

3.3 Monitoring Metric 3: Increased area of soil salinity gradient (Objectives 1-4)

Methods and Timing: For each of the three discrete areas of the restored site, sample soil salinity during low tide at various ground elevations along transects across the site. Sampling timing will be focused on plant growing seasons and location will be focused on critical rooting depths.

Performance Target: The performance target for the restoration area that is at or below mean tide level is to have soil salinity levels within the range of at least 5-15 parts per thousand (ppt) to assist with saltmarsh development. This parameter will be monitored in years 2, 3, 6, and 10 after construction to verify project success of providing tidal influence to the site for the expansion of salt marsh habitat. This sampling will be combined with other metrics to follow the same transects. This duration of monitoring will allow sufficient time for higher high tides to exert influence over the substrate materials and excavated channels.

Adaptive Management: If the target of reaching the range of soil salinity levels is not achieved, then additional removal of material where the levees stood may be needed, and/or more excavation at the breaches may be necessary to meet the tidal exchange and salinity levels for saltmarsh establishment.

3.4 Monitoring Metric 4: Density of native woody species (Objectives 1, 2, and 5)

Methods and timing: Measure plant stem density along established transects of all planted areas during the late summer when seasonal vegetative growth is at its fullest. Post-construction monitoring is recommended to occur in year 3, since the contractor will be responsible for 100% survival of planted vegetation for the first year.

Performance Target: Native woody species (planted and volunteer) will achieve an average stem density of at least 80% of the installed plant density in all planted areas of the site by year 3. Installed plant density is projected to be 32 shrubs per 1,000 square feet (planted 6 feet on center) and 5 trees per 1,000 square feet (planted 15 feet on center). Thus, the 80% performance target density would be 26 shrubs and 4 trees per 1,000 square feet. This target density will be represented by native Puget Sound lowlands species. Trees and shrubs typically found in the Puget Sound lowlands may include, but are not limited to, the following species (Brennan 2007):

- Shrubs: Salmonberry (*Rubus spectabilis*), snowberry (*Symphoricarpos albus*), Pacific ninebark (*Physocarpus capitatus*), vine maple (*Acer circinatum*), Indian plum (*Oemleria cerasiformis*), oceanspray (*Holodiscus discolor*)
- Trees: Western red cedar (*Thuja plicata*), Western hemlock (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), bigleaf maple (*Acer macrophyllum*), black cottonwood (*Populus balsamifera*), red alder (*Alnus rubra*)

Adaptive Management: If the above target is not met, then additional plantings would be installed. If survival of certain species from the original planting plan is low, changes in species planted may be necessary. Additional irrigation of plants may need to be provided if they appear to have been water stressed during the first three years.

The local sponsor will monitor for invasive species; this must occur annually and treatment with monitoring must occur semiannually if invasive plants are detected. Invasive species shall not exceed 10% of the total plant coverage on the site. The duration of treatment and monitoring for invasive plants must continue until native plants are well established and would be the responsibility of the non-Federal sponsor.

3.5 Monitoring Metric 5: Aerial coverage of native woody vegetation (Objectives 1, 2, 4, and 5)

Methods and Timing: Measure percent aerial cover along established transects of all planted areas during late summer when seasonal vegetative growth is at its fullest. Aerial cover is the percentage of the ground surface covered by the aerial portions (leaves and stems) of a plant species when viewed from above. The surveyed area should include all ground disturbed by construction, and all planting areas at a minimum. Post-construction monitoring is recommended to occur in years 3, 6, and 15. Years 6 and 15 are included to provide a reasonable amount of time for shrubs to reach maturity and trees to reach the height that provides a strong chance of survival so the Corps can determine whether sufficient cover has been achieved or whether an adaptive management measure must be implemented. Any monitoring that occurs after year 10 will be 100% cost of the non-Federal sponsor.

Performance Target: It is expected that coverage will increase as planted and volunteer species grow. Planted and native volunteer trees and shrubs should be healthy and have a high percentage of aerial coverage. Trees and shrubs typically found in the Puget Sound lowlands may include, but are not limited to, the following species (Brennan 2007):

- Shrubs: Salmonberry (*Rubus spectabilis*), snowberry (*Symphoricarpos albus*), Pacific ninebark (*Physocarpus capitatus*), vine maple (*Acer circinatum*), Indian plum (*Oemleria cerasiformis*), oceanspray (*Holodiscus discolor*)
- Trees: Western red cedar (*Thuja plicata*), Western hemlock (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), bigleaf maple (*Acer macrophyllum*), black cottonwood (*Populus balsamifera*), red alder (*Alnus rubra*)

Performance targets include the following:

- Year 3: at least 30% aerial cover of native shrub and/or tree species
- Year 6: at least 60% aerial cover of native shrub and/or tree species
- Year 15: at least 80% aerial cover of native shrub and/or tree species

Adaptive Management: If the above targets are not met, then additional plantings would be installed and/or changes in species planted from original planting plan if survival of certain species is low. Additional irrigation of plants may needed if they appear to be water stressed during the first 3 years.

The local sponsor will monitor for invasive species; this for invasive species must occur annually and treatment with monitoring must occur semiannually if invasive plants are detected. The duration of treatment and monitoring for invasive plants must continue until native plants are well established and would be the responsibility of the non-Federal sponsor.

4 Contingency Planning and Implementation

Contingency measures (adaptive management) will be implemented if the monitoring program indicates performance targets are not being met and cannot be explained by extraneous variables. The Corps and the non-Federal sponsor would then assess monitoring metric parameters and initiate the implementation of corrective actions to address the identified issue. Monitoring and adaptive management activities in this plan will be refined in preconstruction, engineering, and design phase. Additional metrics, methods, performance targets, and adaptive management measures may be added if needs are identified.

The general timeline for meeting performance targets is 6-10 years after construction. This is estimated to be sufficient time to determine ecological success or at least a site's trajectory toward success through measurement of the physical and biological parameters outlined in this monitoring and adaptive management plan. Many metrics require sampling through at least year 6 post-construction. The Corps and non-Federal sponsor should analyze all data collected to this point and make an assessment as to whether ecological success has been achieved, or if the site is on a trajectory predicted to achieve success. An assessment can be made as to whether the monitoring should continue through year 10. If monitoring continues through year 10, it is at this point that the project partners should make an assessment as to whether any of the adaptive management measures should be implemented as a contingency for meeting ecological success.

5 Budget Estimate

Budget estimates have been developed for monitoring and adaptive management measures separately. Table 1 summarizes a total estimate for the monitoring efforts in this plan, and Table 2 is the summary of the cost estimate for the recommended adaptive management measures. The cost estimate and associated contingency for monitoring is similar to Pacific Northwest ecosystem restoration projects of this scope and scale. Monitoring metrics, methods, and targets may be adjusted during PED phase as surveys, hydraulic modeling, and detailed designs are completed. The 25% contingency includes roughly $76,000 of contingency to address the residual risk associated with metrics, methods, or targets being adjusted based on final design as well as potential changes in site-specific conditions between the feasibility phase and construction that may cause monitoring plans to be adjusted. Contingency for adaptive management costs is in alignment with contingency for the relevant components from the construction cost estimates.

Table 1. Estimated cost of monitoring effort for the North Fork Skagit River Delta

Activity	**Budget**
Physical Monitoring	$62,000
Biological Monitoring	$132,000
Vehicles, equipment, travel	$28,000
Coordination and Reporting	$81,000
Estimate	**$303,000**
Monitoring Total (Contingency of 25% added)	**$379,000**

Table 2. Potential adaptive management measures and their estimated costs.

Adaptive management measure	**Scale or extent of effort**	**Cost w/o Contingency**	**Cost + 36% Contingency**
Additional excavation on riverbank	Focus on breach locations; excavate approx. 60,000 cubic yards (cy)	$270,000	$367,200
Additional excavation in channels	Remove approximately 2,200 cy representing 6 inches to 1 foot	$15,000	$20,400
Additional large tree planting	Plant tree species across 10% of the planted area at 10 feet on center	$49,000	$66,640
Additional shrub planting	Plant shrub species across 10% of the planted area at 3 feet on center	$161,000	$218,960
Add anchored wood to banks of river or channels	Approximately 1 log per 40 feet of modified channel	$744,000	$1,011,840
Initiate work on site	1 mobilization and 1 de-mobilization of heavy equipment (Assume half the original mob/demob due to smaller scale of work for the adaptive management features)	$268,000	$364,480
Adaptive Management Total		$1,507,000	$2,049,520

6 Literature Cited

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Nooksack River Delta

1 Project Monitoring Objectives: Nooksack River Delta

As a restoration project, it is expected that this site will be dynamic and evolve. The monitoring and evaluation will focus on determining whether the overall project objectives of the restoration are being met. Monitoring efforts will be performed by using monitoring metrics. All post-construction monitoring will be performed by qualified biologists and hydraulic engineers.

Evaluating the success of the restoration site will be based on the establishment of the targeted habitat within the restoration site and on the ecological functioning of those habitats. All post-construction monitoring will be cost shared between the Corps and the non-Federal sponsors for the first 10 years of monitoring. The non-Federal sponsors may choose to monitor beyond this 10-year period, although the cost would be 100% their responsibility. Data collection will be used to determine success of the project with the focus on the development of estuarine and freshwater tidal wetlands and vegetated riparian zone. Restored wetlands can take decades to reach their dynamic equilibrium conditions, therefore the initial monitoring period of approximately 10 years will be assessed as to whether the structural template has been established and if the site is on a trajectory toward ecological success (Haltiner et al. 1997). The Corps and the non-Federal sponsors will use the knowledge gained through this monitoring to adaptively manage the project sites.

The following site-specific objectives have been identified for restoration at the Nooksack River Delta:

1. Reconnect and restore freshwater input to lost floodplain habitats including channel meander zone, shoreline complexity, and shaded refuge habitat in the Nooksack River Delta.
2. Restore tidal inundation to reconnect lost tidally influenced area including estuarine and freshwater tidal wetlands and tidal channels in the Nooksack River Delta.
3. Re-establish intertidal and shallow subtidal topography of the Nooksack River Delta to restore tidal prism and salinity gradient to increase nearshore habitat capacity and productivity for fish, birds, and other estuarine species.
4. Improve aquatic habitat connectivity and between lower river systems and upstream habitat networks of the Nooksack River.
5. Restore a more natural riparian corridor along the Nooksack River Delta.

These objectives are expected to achieve three different habitat types across the restoration site: tidal freshwater wetlands at the downstream end and lower elevations, scrub-shrub wetlands anticipated along the reconnected floodplain, and a vegetated riparian buffer zone. The site is expected to support a dynamic habitat mosaic as it reaches an equilibrium of restored interactive processes.

Section 3 lists monitoring metrics, performance targets, and potential adaptive management associated with the effectiveness monitoring, which aims to measure how well the habitat is developing according to performance criteria.

2 Reference Site

The reference site selected for the Nooksack and Lummi River Delta project site is the reach of the North Fork Skagit River that begins immediately adjacent to the downstream end of the North Fork Skagit project site (Figure 1). This reach is not considered to necessarily be in "historical condition" because upstream activities such as dams and farming over the past century have likely altered conditions that existed prior to these manipulations (Hood 2009). However, the reach has natural processes of sediment erosion and deposition, sustained tidal channels, as well as intact tidal inundation to sustain wetlands and is therefore a sufficient reference target for restoration of natural processes and ecosystem functions. The reference reach curves northward before turning west again to enter Puget Sound. The reach is approximately 2 miles long, and the left bank is mostly vegetated with no evidence of direct human interference. The right bank has a short modified reach but is otherwise natural. The channel width varies from 350 to 550 feet wide, which is roughly the same as the project site. The reference site is in the scrub-shrub zone and contains substantial native vegetation that can serve as a seed source as tidal inundation is restored to the project site, which will also be within the tidal elevations of the scrub-shrub zone once restored. The reference site contains all of the expected types of riverbank complexity features for this type of site including but not limited to shrubs, trees, accumulations of woody debris, varying substrate sizes, and erosional and depositional reaches. This reference site applies to all of the monitoring metrics listed in Section 3.

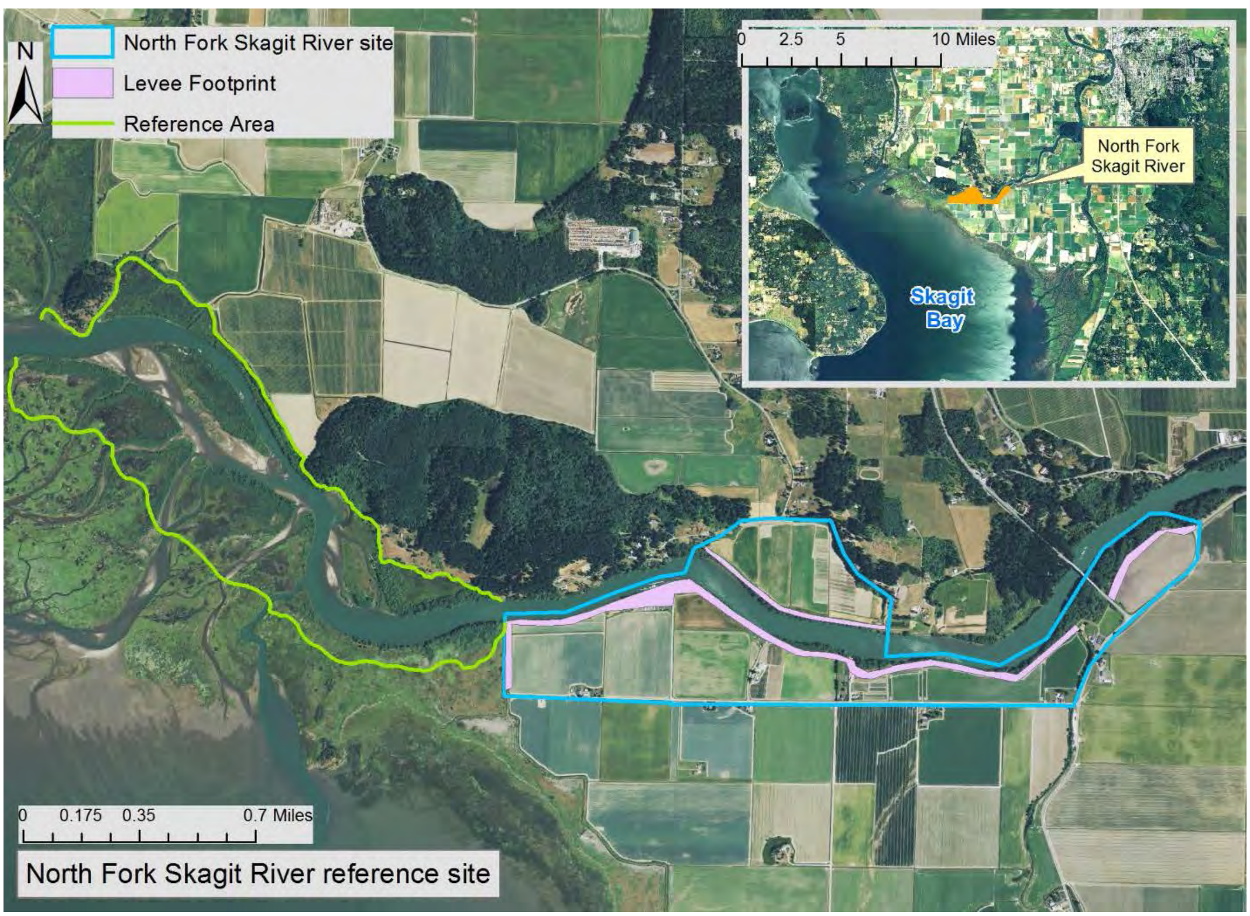

Figure 1. Reference site in unconstrained reach of North Fork Skagit River used for reference target conditions for the Nooksack River Delta project site.

3 Monitoring Metrics, Targets, and Adaptive Management Measures

All of the following metrics, methods, targets, and adaptive management measures may be adjusted during pre-construction, engineering, and design (PED) phase as surveys, hydraulic modeling, and detailed designs are completed.

3.1 Monitoring Metric 1: Increased tidal prism of water reaching a reconnected floodplain in Lummi River (Objectives 1-4)

Methods and Timing: Existing conditions were determined through LiDAR and established NOAA tide stations; however, this method does not provide data with the local accuracy required for post-construction monitoring and adaptive management. To determine whether the site is reaching the performance target stated below, a water surface gauge or pressure sensing data logger will be installed at the downstream end of the site near or at the Hillaire Road bridge. This sensor will be used to measure the tidal and riverine elevations and to quantify frequency, duration, and area of tidal inundation in the tidally influenced portion of the restored site on the Lummi River (Roegner et al. 2009). The sensor will be checked every 3-6 months. The data will be used to estimate intertidal prism parameters such as areas of highest and lowest tidal inundation and to calculate the volumetric difference between high tide and low tide. Morphological feature extents in the landscape profile (channels, hummocks) will be noted. The complete dataset will be analyzed once per year in years 1, 2, 6, and 10 after construction to verify project success of providing tidal influence to the site (Neckles et al. 2002). The greatest change will occur in the first two years. Subsequent measurements every 4 years will quantify additional change toward site conditions that may not be stabilized until 20 or more years post-construction. This duration of monitoring will allow sufficient time for higher high tides and significant floods to exert influence over the substrate materials. The predicted response, as shown in Table 4-1 of the Monitoring Framework, is that the period of inundation will increase as tidal hydrology is restored, then will decrease as the marsh elevation increases. By 10 years post-construction, data will show the trajectory of site development and decisions can be made regarding whether contingency measures are required. Site topography data would be collected via remote sensing and on-the-ground survey making opportunistic use of other LiDAR efforts in the Puget Sound area.

Performance Target: The performance target is to achieve an inundation depth of at least 6 inches over 40% of the ground surface in the area of the levee setbacks once per tidal cycle for a duration of 2 hours by 10 years after construction.

Adaptive Management: If the site has not reached its performance target by 10 years after construction, then additional removal of material where the levees stood and/or more excavation at the breaches may be necessary. All site data should be integrated for a thorough analysis of conditions before additional construction actions are taken.

3.2 Monitoring Metric 2: Wetland development (Objectives 2 and 3)

Methods and timing: Two levees and one roadway berm will be removed during construction. The acreage of the footprints of these levees is 24 acres and the berm is 12 acres. The footprint is considered to be all of the area excavated to remove the levees and berms, which would become bare soil on the site. The footprint of each levee and berm removal area will be monitored to ensure the restored area is developing wetland characteristics. This is the critical area of disturbed soils that must be monitored.

Planting the entire 1,807-acre site would not likely be cost-effective and passive colonization has been determined to be a successful strategy for estuarine marshes (Hood 2009). The footprint of the levee removal area will be monitored to ensure the restored area is developing wetland characteristics. Wetland reconnaissance site visits will be conducted to document the presence/absence of hydric soils, hydrophytic vegetation, and wetland hydrology using the methods in the *USACE Wetlands Delineation Manual* (Environmental Laboratory 1987) and the *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys, and Coast Region* (USACE 2010). Monitoring site visits will occur in years 2, 3, 6, and 10.

Performance Target: The target is for at least 80% of the levee removal footprint to be functioning wetland. If early monitoring results show that the site is not on a favorable trajectory to achieve the target, implementation of adaptive management measures should be evaluated to determine whether the trade-off is worth the site disturbance as implementation would likely destroy some plantings.

Adaptive Management: If the target is not met, then additional removal of material where the levees stood may be needed, and/or more excavation at the breaches may be necessary, to be determined at year 10, but no more than 10% of initial construction quantities. The area would need to be analyzed for whether it can be manipulated to create hydrological conditions to support wetland soils and plants, and sampling could move outside of the removed levee footprint for further investigation. The area should also be analyzed for whether it is providing equivalent functional value of a different habitat type to the performance target before undertaking any construction measures to meet the previously stated performance target.

3.3 Monitoring Metric 3: Increased area of soil salinity gradient (Objectives 2 and 3)

Methods and Timing: Monitoring effort will sample soil salinity during low tide at various ground elevations along transects across the Lummi River portion of the site. Sampling timing will be focused on plant growing seasons and location will be focused on critical rooting depths.

Performance Target: The performance target for the Lummi River area that is at or below mean tide level is to have soil salinity levels within the range of at least 5-15 parts per thousand (ppt) to assist with saltmarsh development. This parameter will be monitored in years 2, 3, 6, and 10 after construction to verify project success of providing tidal influence to the site for the expansion of salt marsh habitat. This sampling will be combined with other metrics to follow the same transects. This duration of monitoring will allow sufficient time for higher high tides to exert influence over the substrate materials and excavated channels.

Adaptive Management: If the target of reaching the range of soil salinity levels is not achieved, then additional removal of material where the levees stood may be needed, and/or more excavation to create breaches in the bank at the downstream end of the site may be necessary to meet the tidal exchange and salinity levels for saltmarsh establishment.

3.4 Monitoring Metric 4: Density of native woody species (Objectives 1, 2, and 5)

Methods and timing: Measure plant stem density along established transects of all planted areas during the late summer when seasonal vegetative growth is at its fullest. Installed plant density is projected to be 32 shrubs per 1,000 square feet (planted 6 feet on center) and 5 trees per 1,000 square feet (planted

15 feet on center). Thus, the 80% performance target density would be 26 shrubs and 4 trees per 1,000 square feet. Post-construction monitoring is recommended to occur in year 3, since the contractor will be responsible for 100% survival of planted vegetation for the first year.

Performance Target: Native woody species (planted and volunteer) will achieve an average stem density of at least 80% of the installed plant density in all planted areas of the site by year 3. This target density will be represented by native Puget Sound lowlands species. Trees and shrubs typically found in the Puget Sound lowlands may include, but are not limited to, the following species (Brennan 2007):

- Shrubs: Salmonberry (*Rubus spectabilis*), snowberry (*Symphoricarpos albus*), Pacific ninebark (*Physocarpus capitatus*), vine maple (*Acer circinatum*), Indian plum (*Oemleria cerasiformis*), oceanspray (*Holodiscus discolor*)
- Trees: Western red cedar (*Thuja plicata*), Western hemlock (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), bigleaf maple (*Acer macrophyllum*), black cottonwood (*Populus balsamifera*), red alder (*Alnus rubra*)

Adaptive Management: If the above target is not met, then additional plantings would be installed and/or changes in species planted from original planting plan if survival of certain species is low. Additional irrigation of plants may need to be provided if they appear to have been water stressed during the first three years.

The local sponsor will monitor for invasive species; this must occur annually and treatment with monitoring must occur semiannually if invasive plants are detected. Invasive species shall not exceed 10% of the total plant coverage on the site. The duration of treatment and monitoring for invasive plants must continue until native plants are well established and would be the responsibility of the non-Federal sponsor.

3.5 Monitoring Metric 5: Aerial coverage of native woody vegetation (Objectives 1-5)

Methods and Timing: Measure percent aerial cover along established transects of all planted areas during late summer when seasonal vegetative growth is at its fullest. Aerial cover is the percentage of the ground surface covered by the aerial portions (leaves and stems) of a plant species when viewed from above. The surveyed area should include all ground disturbed by construction, and all planting areas at a minimum. Post-construction monitoring is recommended to occur in years 3, 6, and 15. Years 6 and 15 are included to provide a reasonable amount of time for shrubs to reach maturity and trees to reach the height that provides a strong chance of survival so the Corps can determine whether sufficient cover has been achieved or whether an adaptive management measure must be implemented. Any monitoring that occurs after year 10 will be 100% cost of the non-Federal sponsor.

Performance Target: It is expected that coverage will increase as planted and volunteer species grow. Planted and native volunteer trees and shrubs should be healthy and have a high percentage of aerial coverage. Trees and shrubs typically found in the Puget Sound lowlands that may colonize the site may include, but are not limited to, the following species (Brennan 2007):

- Shrubs: Salmonberry (*Rubus spectabilis*), snowberry (*Symphoricarpos albus*), Pacific ninebark (*Physocarpus capitatus*), vine maple (*Acer circinatum*), Indian plum (*Oemleria cerasiformis*), oceanspray (*Holodiscus discolor*)

- Trees: Western red cedar (*Thuja plicata*), Western hemlock (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), bigleaf maple (*Acer macrophyllum*), black cottonwood (*Populus balsamifera*), red alder (*Alnus rubra*)

Performance targets include the following:

- Year 3: at least 30% aerial cover of native shrub and/or tree species
- Year 6: at least 60% aerial cover of native shrub and/or tree species
- Year 15: at least 80% aerial cover of native shrub and/or tree species

Adaptive Management: If the above targets are not met, then additional plantings would be implemented and/or changes in species planted from original planting plan if survival of certain species is low. Additional irrigation of plants may need to be provided if they appear to be water stressed during the first three years.

The local sponsor will monitor for invasive species; this must occur annually and treatment with monitoring must occur semiannually if invasive plants are detected. Invasive species shall not exceed 10% of the total plant coverage on the site. The duration of treatment and monitoring for invasive plants must continue until native plants are well established and would be the responsibility of the non-Federal sponsor.

3.6 Monitoring Metric 6: Appropriate river flows restored to Lummi River through Diversion Structure (Objective 1)

Methods and Timing: Measure stage, water flow (discharge), and temperature at the outlet of the diversion structure using a data logger. These parameters will be monitored continuously for at least the first 10 years after construction to verify project success of providing improved flow quantity and duration to the Lummi River. The data logger will be active for at least three months of each year. This duration of monitoring will allow sufficient time for higher river flows to occur to determine appropriate functioning range of the diversion structure. The purpose for monitoring temperature is to ensure no deleterious effects to water quality in either fork of the river.

Performance Target: The performance target for the restoration is to have up to 200 cubic feet per second (cfs) from the Nooksack River flow into the Lummi River during the months of February through April to assist the outmigration of juvenile fish. During periods of low flow (late summer/early fall) or poor water quality in the Nooksack River, the diversion structure may require lower flows.

Adaptive Management: If the target of achieving 200 cfs in February through April is not met, or if impacts to water temperature are detected in either fork of the river, then modification of the diversion structure would be required.

4 Contingency Planning and Implementation

Contingency measures (adaptive management) will be implemented if the monitoring program indicates performance targets are not being met and cannot be explained by extraneous variables. The Corps and the non-Federal sponsor would then assess monitoring metric parameters and initiate the implementation of corrective actions to address the identified issue. Monitoring and adaptive management activities in this plan will be refined in PED phase. Additional metrics, methods, performance targets, and adaptive management measures may be added if needs are identified.

The general timeline for meeting performance targets is 6-10 years after construction. This is estimated to be sufficient time to determine ecological success or at least a site's trajectory toward success through measurement of the physical and biological parameters outlined in this monitoring and adaptive management plan. Many metrics require sampling through at least year 6 post-construction. The Corps and non-Federal sponsor should analyze all data collected to this point and make an assessment as to whether ecological success has been achieved, or if the site is on a trajectory predicted to achieve success. An assessment can be made as to whether the monitoring should continue through year 10. If monitoring continues through year 10, it is at this point that the project partners should make an assessment as to whether any of the adaptive management measures should be implemented as a contingency for meeting ecological success.

5 Budget Estimate

Budget estimates have been developed for monitoring and adaptive management measures separately. Table 1 summarizes a total estimate for the monitoring efforts in this plan, and Table 2 is the summary of the cost estimate for the recommended adaptive management measures. The cost estimate and associated contingency for monitoring is similar to Pacific Northwest ecosystem restoration projects of this scope and scale. Monitoring metrics, methods, and targets may be adjusted during PED phase as surveys, hydraulic modeling, and detailed designs are completed. The 25% contingency includes roughly $101,000 of contingency to address the residual risk associated with metrics, methods, or targets being adjusted based on final design as well as potential changes in site-specific conditions between the feasibility phase and construction that may cause monitoring plans to be adjusted. Contingency for adaptive management costs is in alignment with contingency for the relevant components from the construction cost estimates.

Table 1. Estimated cost of monitoring effort for the Nooksack River Delta

Activity	**Budget**
Physical Monitoring	$123,000
Biological Monitoring	$154,000
Vehicles, equipment, travel	$47,000
Coordination and Reporting	$81,000
Estimate	**$405,000**
Monitoring Total (Contingency of 25% added)	**$506,000**

Table 2. Potential adaptive management measures and their estimated costs.

Adaptive management measure	**Scale or extent of effort**	**Cost w/o Contingency**	**Cost + 40% Contingency**
Additional excavation on riverbank where levees were removed	Excavate an additional 10,000 cy (10% of quantities removed during construction)	$53,000	$74,200
Additional large tree planting	Plant tree species across 10% of the planted area or along riverbank at 10 feet on center. 1665 total trees.	$28,000	$39,200
Additional shrub planting	Plant shrub species across 10% of the planted area at 3 feet on center. 18500 shrubs total.	$229,000	$320,600
Add anchored wood to banks of river or channels	Approximately 1 log per 40 feet of modified channel. 238 Logs total.	$394,000	$551,600
Initiate work on site	1 mobilization and 1 de-mobilization of heavy equipment (Assume half the original mob/demob due to smaller scale of work for the adaptive management features)	$85,000	$119,000
Adaptive Management Total		$789,000	$1,104,600

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Duckabush River Estuary

1 Project Monitoring Objectives: Duckabush River Estuary

As a restoration project, it is expected that this site will be dynamic and evolve. Thus, for some parameters, strict achievement of predetermined performance standards will not necessarily predict the success or reveal the failure of the restoration effort. The monitoring and evaluation will focus on determining whether the overall project objectives of the restoration are being met. Monitoring efforts will be performed by using monitoring metrics. All post-construction monitoring will be performed by qualified biologists and hydraulic engineers.

Evaluating the success of the restoration site will be based on the establishment of the targeted habitat within the restoration site and on the ecological functioning of those habitats. All post-construction monitoring will be cost shared between the Corps and the non-Federal sponsors for the first 10 years of monitoring. The non-Federal sponsors may choose to monitor beyond this 10-year period, although the cost would be 100% their responsibility. Data collection will be used to determine success of the project with the focus on the development of estuarine and freshwater tidal wetlands and vegetated riparian zone. Restored wetlands can take decades to reach their dynamic equilibrium conditions, therefore the initial monitoring period of approximately 10 years will be assessed as to whether the structural template has been established and if the site is on a trajectory toward ecological success (Haltiner et al. 1997). The Corps and the non-Federal sponsors will use the knowledge gained through this monitoring to adaptively manage the project sites.

The following site-specific objectives have been identified for restoration at the Duckabush River Estuary:

1. Reconnect and restore lost tidally influenced areas including estuarine and freshwater tidal wetlands in the Duckabush River Estuary.
2. Re-establish distributary channels in the Duckabush River Estuary to promote greater diversity of delta wetland habitats.
3. Restore mudflats and salt marsh in the Duckabush River Estuary.

These objectives are expected to achieve four different habitat types across the restoration site: mudflats and emergent saltmarsh wetlands at the downstream end and lower elevations, a scrub-shrub wetland ecotone across most of the site given the existing and anticipated intertidal elevations, and substantial lengths of saltwater tidal channels. The excavated tidal channels will intersect all of these habitat zones and restore the process of exchange of aquatic organisms. The site is expected to support a dynamic habitat mosaic as it reaches an equilibrium of restored interactive processes.

Section 3 lists monitoring metrics, performance targets, and potential adaptive management associated with the effectiveness monitoring, which aims to measure how well the habitat is developing according to performance criteria.

2 Reference Site

The reference site selected for the Duckabush Estuary project site is Dewatto River Estuary (Figure 1). This small river delta is less than 15 miles away across Hood Canal from Duckabush Estuary and is substantially similar to Duckabush River in its hydrologic regime, geomorphology, and suite of representative species including federally protected salmon species, marine bird concentrations, shellfish presence, and eelgrass meadows. This site is the nearest estuary relatively undisturbed estuary with similar characteristics to Duckabush and is among the least degraded estuaries in Puget Sound (Cereghino et al. 2012). Dewatto estuary has no substantial fill or constrictions and has natural processes of sediment erosion and deposition, sustained tidal channels, as well as intact tidal inundation to sustain wetlands and is therefore a sufficient reference target for restoration of natural processes and ecosystem functions. The delta is formed by the mouth of Dewatto River, which drains from the Kitsap Peninsula into the east shore of Hood Canal. The width of the estuary ranges from 650 to 1,200 feet wide. The site contains fringes of saltmarsh vegetation. This reference site applies to all of the monitoring metrics listed in Section 3.

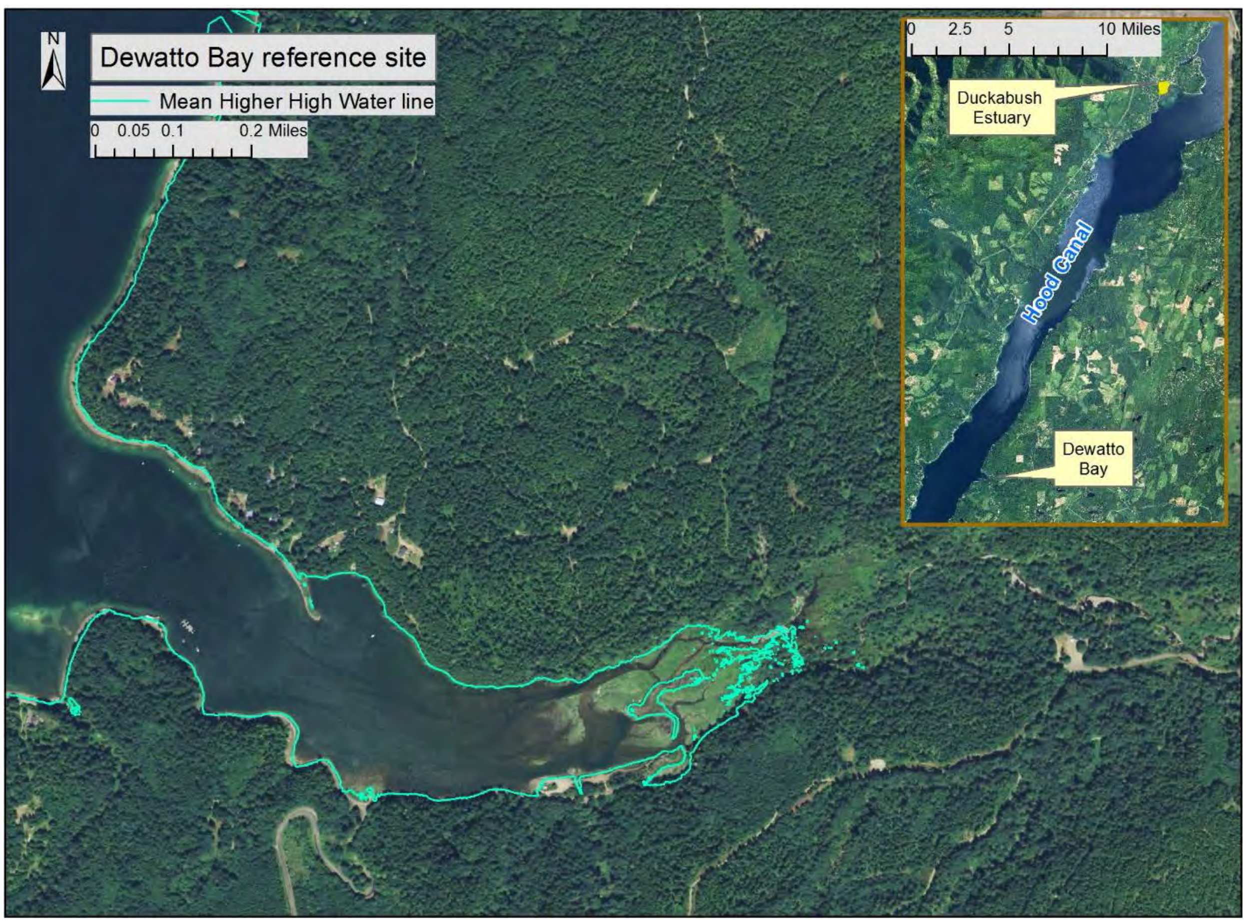

Figure 1. Dewatto River Estuary provides reference site conditions as target conditions for Duckabush River Estuary project site.

3 Monitoring Metrics, Targets, and Adaptive Management Measures

All of the following metrics, methods, targets, and adaptive management measures may be adjusted during pre-construction, engineering, and design (PED) phase as surveys, hydraulic modeling, and detailed designs are completed.

3.1 Monitoring Metric 1: Increased tidal prism of water reaching a reconnected floodplain (Objectives 1 and 3)

Methods and Timing: Existing conditions were determined through LiDAR and established NOAA tide stations; however, this method does not provide data with the local accuracy required for post-construction monitoring and adaptive management. To determine whether the site is reaching the performance target stated below, a water surface gauge or pressure sensing data logger will be installed near or at the existing southern Highway 101 bridge. An additional sensor may be required at the reference site. These sensors will be used to measure the tidal elevations and to quantify frequency, duration, and area of tidal inundation (Roegner et al. 2009). The sensors will be checked every 3-6 months. The data will be used to estimate intertidal prism parameters such as areas of highest and lowest tidal inundation and to calculate the volumetric difference between high tide and low tide. Morphological feature extents in the landscape profile (channels, hummocks) will be noted. The complete dataset will be analyzed once per year in years 1, 2, 6, and 10 after construction to verify project success of providing tidal influence to the site (Neckles et al. 2002). The greatest change will occur in the first two years. Subsequent measurements every 4 years will quantify additional change toward site conditions that may not be stabilized until 20 or more years post-construction. This duration of monitoring will allow sufficient time for higher high tides and significant floods to exert influence over the substrate materials and excavated channels. The predicted response, as shown in Table 4-1 of the Monitoring Framework, is that the period of inundation will increase as tidal hydrology is restored. By 10 years post-construction, data will show the trajectory of site development and decisions can be made regarding whether contingency measures are required. Site topography data will be collected via remote sensing and on-the-ground survey making opportunistic use of other LiDAR efforts in the Puget Sound area.

If a flood level greater than a 2% Annual Exceedance Probability occurs within the first 15 years after construction, then the site should undergo an additional monitoring assessment. Any monitoring after 10 years post-construction is at 100% cost of the non-federal sponsor.

Performance Target: The performance target is to achieve an inundation depth of at least 3 feet in the thalweg of the excavated large distributary channels for 40-60% of the tidal cycle for at least 70% of the lineal distance of the channel. The target in the small distributary channels is to achieve an inundation depth of at least 3 feet in the thalweg of the excavated small distributary channels at least once per tidal cycle for a duration of 3 hours for at least 70% of the lineal distance of the channel.

Adaptive Management: If the site has not reached its performance target by 10 years after construction, then additional removal of material where the highway crossed the delta may be needed, and/or more excavation along the channels may be necessary. All site data should be integrated for a thorough analysis of conditions before additional construction actions are taken.

3.2 Monitoring Metric 2: Wetland development (Objectives 1, 2, and 3)

Methods and timing: One section of bank armoring will be removed during construction. The acreage of the footprint of this bank armoring is 0.4 acres. The footprint is considered to be all of the area excavated to remove the bank armoring, which would become bare soil on the site. The footprint of the armoring removal area will be monitored to ensure the restored area is developing wetland characteristics. This is the critical area of disturbed soils that must be monitored. Planting the entire 38-acre site would not likely be cost-effective and passive colonization has been determined to be a successful strategy for estuarine marshes (Hood 2009). The footprint of the levee removal area will be monitored to ensure the restored area is developing wetland characteristics. Wetland reconnaissance site visits will be conducted to document the presence/absence of hydric soils, hydrophytic vegetation, and wetland hydrology using the methods in the *USACE Wetlands Delineation Manual* (Environmental Laboratory 1987) and the *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys, and Coast Region* (USACE 2010). Monitoring site visits will occur in years 2, 3, 6, and 10.

Performance Target: The target is for at least 80% of the levee removal footprint to be functioning wetland. If early monitoring results show that the site is not on a favorable trajectory to achieve the target, implementation of adaptive management measures should be evaluated to determine whether the trade-off is worth the site disturbance as implementation would likely destroy some plantings.

Adaptive Management: If the target is not met, then additional removal of material where the levees stood may be needed, and/or more excavation at the breaches may be necessary, but no more than 10% of initial construction quantities. The area would need to be analyzed for whether it can be manipulated to create hydrological conditions to support wetland soils and hydrophytic plants. The area should also be analyzed for whether it is providing equivalent functional value of a different habitat type (e.g. upland riparian habitat) to the performance target before undertaking any construction measures to meet the previously stated performance target.

3.3 Monitoring Metric 3: Increased area of soil salinity gradient (Objectives 1 and 3)

Methods and Timing: Sample soil salinity during low tide at various ground elevations along transects across the site. Sampling timing will be focused on plant growing seasons and location will be focused on critical rooting depths.

Performance Target: The performance target for the restoration area that is at or below mean tide level is to have soil salinity levels in the within the range of at least 5-15 parts per thousand (ppt) to assist with saltmarsh development. This parameter will be monitored in years 2, 3, 6, and 10 after construction to verify project success of providing tidal influence to the site for the expansion of salt marsh habitat. This sampling will be combined with other metrics to follow the same transects. This duration of monitoring will allow sufficient time for higher high tides to exert influence over the substrate materials and excavated channels.

Adaptive Management: If the target of reaching the range of soil salinity levels is not achieved, then additional removal of material where the bank armoring stood and the highway removal area may be needed to meet the tidal exchange and salinity levels for saltmarsh establishment.

3.4 Monitoring Metric 4: Density of native woody species (Objectives 1, 2, and 5)

Methods and timing: Measure plant stem density along established transects of all planted areas during the late summer when seasonal vegetative growth is at its fullest. Post-construction monitoring is recommended to occur in year 3, since the contractor will be responsible for 100% survival of planted vegetation for the first year.

Performance Target: Native woody species (planted and volunteer) will achieve an average stem density of at least 80% of the installed plant density in all planted areas of the site by year 3. Installed plant density is projected to be 32 shrubs per 1,000 square feet (planted 6 feet on center) and 5 trees per 1,000 square feet (planted 15 feet on center). Thus, the 80% performance target density would be 26 shrubs and 4 trees per 1,000 square feet. This target density will be represented by native Puget Sound lowlands species. Trees and shrubs typically found in the Puget Sound lowlands may include, but are not limited to, the following species (Brennan 2007):

- Shrubs: Salmonberry (*Rubus spectabilis*), snowberry (*Symphoricarpos albus*), Pacific ninebark (*Physocarpus capitatus*), vine maple (*Acer circinatum*), Indian plum (*Oemleria cerasiformis*), oceanspray (*Holodiscus discolor*)
- Trees: Western red cedar (*Thuja plicata*), Western hemlock (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), bigleaf maple (*Acer macrophyllum*), black cottonwood (*Populus balsamifera*), red alder (*Alnus rubra*)

Adaptive Management: If the above target is not met, then additional plantings would be installed. If survival of certain species from the original planting plan is low, changes in species planted may be necessary. Additional irrigation of plants may need to be provided if they appear to have been water stressed during the first three years.

The local sponsor will monitor for invasive species; this must occur annually and treatment with monitoring must occur semiannually if invasive plants are detected. Invasive species shall not exceed 10% of the total plant coverage on the site. The duration of treatment and monitoring for invasive plants must continue until native plants are well established and would be the responsibility of the non-Federal sponsor.

3.5 Monitoring Metric 5: Aerial coverage of native woody vegetation (Objectives 1 and 3)

Methods and Timing: Measure percent aerial cover along established transects of all planted areas during late summer when seasonal vegetative growth is at its fullest. Aerial cover is the percentage of the ground surface covered by the aerial portions (leaves and stems) of a plant species when viewed from above. The surveyed area should include all ground disturbed by construction, and all planting areas at a minimum. The timing assumes that very little vegetation would have established and exhibited any notable growth in the first 2 years. Post-construction monitoring is recommended to occur in years 3 and 6 (Neckles et al. 2002). Year 6 is included to provide a reasonable amount of time for shrubs to reach maturity so the Corps can determine whether sufficient cover has been achieved or whether an adaptive management measure must be implemented.

Performance Target: It is expected that coverage will increase as planted and volunteer species grow. Planted and desirable volunteer trees and shrubs should be healthy and have a high percentage of aerial coverage. Trees and shrubs typically found in the Puget Sound lowlands may include, but are not limited to, the following species (Brennan 2007):

- Shrubs: Salmonberry (*Rubus spectabilis*), snowberry (*Symphoricarpos albus*), Pacific ninebark (*Physocarpus capitatus*), vine maple (*Acer circinatum*), Indian plum (*Oemleria cerasiformis*), oceanspray (*Holodiscus discolor*)
- Trees: Western red cedar (*Thuja plicata*), Western hemlock (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), bigleaf maple (*Acer macrophyllum*), black cottonwood (*Populus balsamifera*), red alder (*Alnus rubra*)

Performance targets include the following:

- Year 3: at least 30% aerial cover of native shrub species
- Year 6: at least 60% aerial cover of native shrub species

Adaptive Management: If the above targets are not met, then a planting plan should be designed and implemented. This should include removal of any plant species that pose a risk to establishment of native and/or otherwise beneficial recruited species.

The local sponsor will monitor for invasive species; this must occur annually and treatment with monitoring must occur semiannually if invasive plants are detected. The duration of treatment and monitoring for invasive plants must continue until native plants are well established and would be the responsibility of the non-Federal sponsor.

4 Contingency Planning and Implementation

Contingency measures (adaptive management) will be implemented if the monitoring program indicates performance targets are not being met and cannot be explained by extraneous variables. The Corps and the non-Federal sponsor would then assess monitoring metric parameters and initiate the implementation of corrective actions to address the identified issue. Monitoring and adaptive management activities in this plan will be refined in PED phase. Additional metrics, methods, performance targets, and adaptive management measures may be added if needs are identified.

The general timeline for meeting performance targets is 6-10 years after construction. This is estimated to be sufficient time to determine ecological success or at least a site's trajectory toward success through measurement of the physical and biological parameters outlined in this monitoring and adaptive management plan. Many metrics require sampling through at least year 6 post-construction. The Corps and non-Federal sponsor should analyze all data collected to this point and make an assessment as to whether ecological success has been achieved, or if the site is on a trajectory predicted to achieve success. An assessment can be made as to whether the monitoring should continue through year 10. If monitoring continues through year 10, it is at this point that the project partners should make an assessment as to whether any of the adaptive management measures should be implemented as a contingency for meeting ecological success.

5 Cost

Budget estimates have been developed for monitoring and adaptive management measures separately. Table 1 summarizes a total estimate for the monitoring efforts in this plan, and Table 2 is the summary of the cost estimate for the recommended adaptive management measures. The cost estimate and associated contingency for monitoring is similar to Pacific Northwest ecosystem restoration projects of this scope and scale. Monitoring metrics, methods, and targets may be adjusted during PED phase as surveys, hydraulic modeling, and detailed designs are completed. The 25% contingency includes roughly $41,000 of contingency to address the residual risk associated with metrics, methods, or targets being adjusted based on final design as well as potential changes in site-specific conditions between the feasibility phase and construction that may cause monitoring plans to be adjusted. Contingency for adaptive management costs is in alignment with contingency for the relevant components from the construction cost estimates.

Table 1. Estimated cost of monitoring effort for the Duckabush River Estuary

Activity	Budget
Physical Monitoring	$53,000
Biological Monitoring	$42,000
Vehicles, equipment, travel	$15,000
Coordination and Reporting	$54,000
Estimate	**$164,000**
Monitoring Total (Contingency of 25% added)	**$205,000**

Table 2. Potential adaptive management measures and their estimated costs.

Adaptive management measure	**Scale or extent of effort**	**Cost w/o Contingency**	**Cost + 46% Contingency**
Additional excavation where highway crossed delta	Excavate approx. 1,600 cubic yards (cy), based on 30 feet wide 1,400 feet long	$450,000	$657,000
Additional excavation where bank armoring stood	Remove approx. 150 cy along river banks to lower bank elevation by 2 feet	$42,000	$61,320
Additional excavation in channels	Remove approximately 3,000-5,000 cy representing 6 inches to 1 foot	$628,000	$916,880
Additional shrub planting	Plant shrub species across 10% of the highway removal and armor removal areas at 3 feet on center. 1280 shrubs total.	$15,000	$21,900
Add anchored wood to banks of river or channels	Approximately 1 log per 40 feet of modified channel. 105 logs total.	$203,000	$296,380
Initiate work on site	1 mobilization and 1 de-mobilization of heavy equipment (Assume half the original mob/demob due to smaller scale of work for the adaptive management features)	$134,000	$195,640
Adaptive Management Total		$1,472,000	$2,149,120

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Puget Sound Nearshore Ecosystem Restoration Project Monitoring Framework

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Prepared by Tess Brandon, Nancy Gleason, Charles Simenstad, and Curtis Tanner

Puget Sound Nearshore Ecosystem Restoration Project

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List of Acronyms

BACI	Before-After-Control-Impact
EFG&S	Ecosystem Functions, Goods, and Services
GI	General Investigation
LWD	Large Woody Debris
PSNERP	Puget Sound Nearshore Ecosystem Restoration Project
VEC	Valued Ecosystem Component
WDFW	Washington Department of Fish and Wildlife
WRDA	Water Resources Development Act

1. Introduction

The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) is a large-scale, comprehensive initiative to protect and restore the natural processes, structures, and functions of Puget Sound's nearshore ecosystems. The initiative is being conducted under the U.S. Army Corps of Engineers (Corps) general investigation (GI) authority with the Washington State Department of Fish and Wildlife (WDFW) serving as the non-Federal sponsor. This GI is intended to support broader restoration efforts in the Puget Sound region, including those being coordinated by the Puget Sound Partnership. The culmination of this GI is the delivery of a Final Feasibility Report with a near-term plan of action, which includes recommendation for authorization of strategically selected restoration sites for implementation by the Corps.[1]

Successful ecosystem restoration requires two basic tools: the ability to alter ecosystems to recreate a desired condition, and the ability to determine whether those manipulations have produced, or are producing, the desired condition (Keddy 2000). This second tool is achieved through systematic monitoring of restoration outcomes. Accordingly, Corps regulations require as an element of the Feasibility Report a plan for "monitoring the success of the ecosystem restoration" (USACE 2009). The monitoring plan must focus on key indicators of project performance to address the question of whether restoration sites and associated management measures are achieving stated objectives.

In its Implementation Guidance for Section 2039 of the Water Resources Development Act of 2007 (WRDA), the Corps defines monitoring as "the systematic collection and analysis of data that provides information useful for assessing project performance, determining whether ecological success has been achieved, or whether adaptive management may be needed to attain project benefits" (USACE 2009). In this context, the Corps uses the term "adaptive management" to denote "contingency planning" – in other words, determining the need for, and implementing, mid-course corrections to restoration actions. Thus, the Corps recognizes that even the most strategically planned restoration actions can yield unexpected results. Comprehensive monitoring of a site documents and diagnoses these results especially in the early, formative stages, providing information useful for taking corrective action. In this way, it reduces the risk of failure and enables effective, responsive management of restoration actions.

The restoration sites selected by PSNERP employ a suite of management measures that attempt to address a complex set of objectives. These management measures are linked to their predicted ecological outcomes through a series of assumptions. While these assumptions are based on the best current scientific understanding, they involve scientific uncertainties inherent in ecosystem restoration. Monitoring and adaptive management

[1] As "restoration" is used here, it encompasses restoration activities as well as preservation and protection of undegraded sites. Preservation that is recommended as the result of a Corps feasibility study is the responsibility solely of the non-Federal sponsor.

provides a mechanism for testing assumptions and further reducing these uncertainties. As the scientific record develops, relationships, conceptual models, management measures, and ultimately restoration designs can be refined for use in future actions or to improve existing actions.

Comprehensive monitoring of any restoration program generally falls into three broad categories:

> **Implementation monitoring**, also known as compliance monitoring, evaluates whether or not planned restoration tasks have been carried out as intended. In other words, implementation monitoring is designed to answer the questions, "Did we do what we said we would do? Did we follow all applicable standards and guidelines when we did it?"
>
> **Effectiveness monitoring** evaluates whether or not restoration actions are achieving their stated objectives. Effectiveness monitoring is designed to answer the question, "Did the completed actions achieve the intended outcomes? To what degree did we meet our site-specific objectives?"
>
> **Validation monitoring** tests the assumptions linking objectives and program goals. It is designed to answer the question, "Are these objectives the right ones to achieve program goals, or are our underlying assumptions wrong?"

All three types of monitoring are critical to the success of a restoration program. The monitoring framework presented in this document focuses primarily on effectiveness monitoring, as it is the fundamental monitoring responsibility of the Corps and non-Federal sponsor. Validation monitoring is necessary for programmatic adaptation and learning, but is presented as secondary in this framework to reflect its prioritization level. The completion of implementation monitoring is assumed to be part of project construction best practices. Thus, guidance for implementation monitoring is outside of the scope of this document.

This document is intended to support comprehensive decision-making for the construction phase of the program, including engineering and design of restoration sites. It will be used to develop individual site-specific monitoring plans for the proposed restoration sites, providing a framework to assess the effectiveness of actions taken to restore nearshore ecosystem processes by measuring the response of specific indicators. Successful implementation of these plans will also enhance understanding of physical and biological nearshore processes and the ecosystem goods and services they support. This understanding will benefit the broader restoration community of Puget Sound.

2. Background

2.1 Process-based Restoration

PSNERP's approach to the GI study is unique in that it focuses on understanding, evaluating, and restoring degraded ecosystem processes (Table 2-1). Where other restoration initiatives focus on addressing symptoms of ecosystem degradation such as single-species population decline or habitat loss, PSNERP's approach addresses the physiographic problems that underlie ecosystem degradation. The scientific and technical basis for this approach is documented in PSNERP guidance documents and reflects the emerging scientific discussion about the need to integrate understanding of ecosystem process into restoration planning. Goetz et al. (2004) stresses the importance of the physiographic processes that are responsible for building and sustaining landscape structures that support functions of an ecosystem. These structures and functions in turn provide valued ecosystem goods and services.

While full recovery of ecosystem function can be attempted through recreation of ecosystem structure, the long-term performance and effectiveness of such an approach is highly uncertain without restoration of the fundamental processes that maintain that structure (Simenstad et al. 2006). Indeed, there is little evidence for successful, long-term restoration of habitat structure. Restoration of degraded physiographic processes enables an ecosystem to be naturally productive, self-sustaining, and resilient, maximizing the likelihood that it will continue to provide functions, goods, and services into the future (Goetz et al. 2004, Greiner 2010, Cereghino et al. 2012).

2.2 Program Context: Prior Work by PSNERP

PSNERP was initiated in 2001 to evaluate the degradation of nearshore ecosystems in Puget Sound and to guide the restoration and protection of these ecosystems. To achieve this purpose, PSNERP initially gathered Sound-wide data to perform an analysis of historical change. This analysis quantified changes to the structure of Puget Sound's nearshore ecosystems over the past as a proxy for understanding historical nearshore processes (Simenstad et al. 2011). Results of the analysis indicated dramatic changes in Puget Sound nearshore ecosystems, including loss of wetlands, coastal embayments, and other landforms, and widespread distribution of stressors that impact ecosystem processes. The impact of these changes on nearshore ecosystem functions, goods, and services was also evaluated (Fresh et al. 2011, Simenstad et al. 2011, Cereghino et al. 2012).

To understand better the observed changes and loss, PSNERP conducted a Strategic Needs Assessment to characterize the impact of anthropogenic shoreline alterations on nearshore ecosystem processes (Schlenger et al. 2011). The assessment identified the major stressors contributing to the observed degradation, and quantified this degradation for 11 critical landscape-forming processes (Table 2-1). The assessment also assessed the impact of major stressors on valued ecosystem functions, goods, and services. The result was a clear problem statement identifying the major changes in Puget Sound nearshore ecosystems that should be the focus of restoration and protection actions (Fresh et al. 2011).

Table 2-1: PSNERP Nearshore Ecosystem Processes. The broad physiographic processes identified by PSNERP as critical for creation, maintenance, and function of Puget Sound's nearshore ecosystems. From Simenstad et al. 2011.

Nearshore Ecosystem Process	Process Description
Sediment input	Delivery of sediment from bluff, stream, and marine sources to Puget Sound shorelines; depending on landscape setting, inputs can vary in scale from acute, low-frequency episodes (hillslope mass wasting from bluffs) to chronic, high-frequency events (some streams and rivers). Sediment input interacts with sediment transport to control the structure of beaches.
Sediment transport	Bedload and suspended transport of sediments and other matter by water and wind along (longshore) and across (cross-shore) the shoreline. The continuity of sediment transport strongly influences the longshore structure of beaches.
Erosion and accretion of sediments	Deposition (dune formation, delta building) of non-suspended (e.g., bedload) sediments and mineral particulate material by water, wind, and other forces. Settling (accretion) of suspended sediments and organic matter on marsh and other intertidal wetland surfaces. These processes are responsible for creation and maintenance of barrier beaches (e.g., spits) and tidal wetlands.
Tidal hydrology	Localized tidal effects on water elevation and currents, differing significantly from regional tidal regime mostly in tidal freshwater and estuarine ecosystems.
Distributary channel migration	Change of distributary channel form and location caused by combined freshwater and tidal flow. Distributary channel migration affects the distribution of alluvial material across a river delta.
Tidal channel formation and maintenance	Geomorphic processes, primarily tidally driven, that form and maintain tidal channel geometry. Natural levee formation.
Freshwater input	Freshwater inflow from surface (stream flow) or groundwater (seepage) in terms of seasonal and event hydrography. Freshwater input affects the pattern of salinity and sediment and soil moisture content near shore.
Detritus import and export	Import and deposition of particulate (dead) organic matter. Soil formation. Recruitment, disturbance, and export of large wood.
Exchange of aquatic organisms	Organism transport and movement driven predominantly by water (tidal, fluvial) movement.
Physical disturbance	Change of shoreline shape or character caused by exposure to local wind and wave energy input. Localized and chronic disturbance of biotic assemblages caused by large wood movement, scour, and overwash.
Solar incidence	Exposure, absorption, and reflectance of solar radiation (e.g., radiant light and heat) and resulting effects. Solar incidence controls photosynthesis rates and temperature patterns in nearshore ecosystems.

From this problem statement, PSNERP developed four program-scale objectives for achieving process-based nearshore restoration in Puget Sound:

1. Restore the size and quality of large river delta estuaries and nearshore processes the deltas support.
2. Restore the number and quality of coastal embayments.
3. Restore the size and quality of beaches and bluffs.
4. Increase understanding of natural process restoration in order to improve effectiveness of program actions.

These objectives provide a planning framework from which more specific ecosystem objectives and restoration actions can be developed.

2.3 Restoration Approach

In order to address program-scale objectives, PSNERP developed four restoration and protection strategies that focus on restoration of river deltas, beaches, barrier embayments, and coastal inlets (Cereghino et al. 2012). This classification scheme is consistent with Shipman's (2008) division of the Puget Sound shoreline by geomorphic system, and reflects the four distinct ways that nearshore processes structure the shoreline in each system. Accordingly, each system supports a distinct set of ecosystem functions, goods, and services. All four systems are required for restoration of historical ecosystem services provided by nearshore ecosystems (Cereghino et al. 2012).

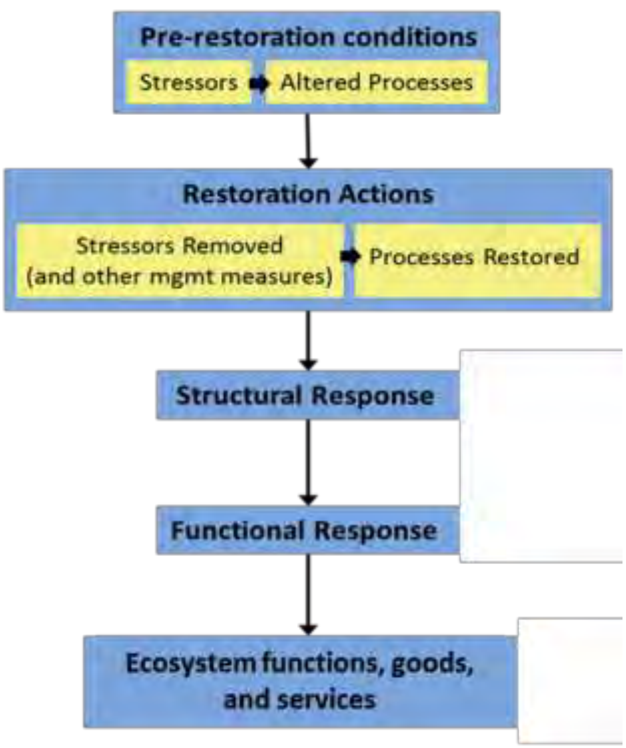

Figure 2-1: Basic conceptual model of process-based restoration.

Each strategy aims to restore critical landscape-forming processes by using management measures that remove the stressors currently impeding those processes (Clancy et al. 2009). Once restored, the processes are hypothesized to initiate structural and functional responses, ultimately leading to a productive, self-sustaining, and resilient system capable of producing the valued ecosystem goods and services historically associated with that strategy (Figure 2-1). The relationship between management measures, target processes, and ecosystem structures and functions for each strategy is based on a conceptual model derived from current scientific understanding of the system (Simenstad et al. 2006; Clancy et al. 2009). Specific conceptual models for each of the four landform strategies are described later in this document.

Management measures may be applied alone or in combination to remove stressors and restore target processes. Restoration sites consist of one or more management measures applied at one or more discrete locations, constructed concurrently or in succession. Eighteen restoration sites have been selected as part of the near-term plan for the GI, and are recommended for authorization and implementation by the Corps. These sites were selected from lists of restoration opportunities identified by various governmental and non-governmental organizations throughout Puget Sound (ESA 2011). As a group, they cover all four strategies, addressing the broad suite of process-based PSNERP objectives and contributing to the recovery of lost functions, goods, and services of nearshore ecosystems in Puget Sound. The sites, and the restoration strategies to which they belong, are listed in Table 2-2. Although the sites selected by PSNERP were used to develop this framework, it is intended to be applicable to any action designed to restore nearshore processes in river deltas, beaches, barrier embayments, or coastal inlets in Puget Sound.

Table 2-2: PSNERP Restoration Strategies and Associated Sites.

Strategy	Description	Target Processes	Primary Management Measures	Selected Sites
River Deltas	Restore freshwater input and tidal processes where major river floodplains meet marine waters	Tidal hydrology Freshwater input	Berm or dike removal	1. Nooksack River Delta 2. Everett Marshland 3. Telegraph Slough 4. Deepwater Slough 5. Milltown Island 6. Spencer Island 7. North Fork Skagit River Delta 8. Duckabush River Estuary
Beaches	Restore sediment input and transport processes to littoral drift cells where bluff erosion sustains beach structure	Sediment supply	Armor removal Groin removal	1. Beaconsfield Feeder Bluff 2. WDNR Budd Inlet Beach

Strategy	Description	Target Processes	Primary Management Measures	Selected Sites
Barrier Embayments	Restore sediment input and transport processes to littoral drift cells where bluff erosion sustains barrier beaches that form barrier embayments, and restore the tidal flow processes within these partially closed systems	Sediment supply Tidal hydrology	Berm or dike removal Fill removal Armor or groin removal	1. Point Whitney Lagoon 2. Livingston Bay 3. Dugualla Bay 4. Big Beef Creek Estuary
Coastal Inlets	Restore tidal flow processes in coastal inlets, and restore freshwater input and detritus transport processes within these open embayment systems	Freshwater input Tidal hydrology	Berm or dike removal Fill removal	1. Harper Estuary 2. Tahuya River Estuary 3. Snow Creek and Salmon Creek Estuary 4. Deer Harbor Estuary

3. Overview of Effectiveness Monitoring Framework

Effectiveness monitoring is the primary focus of this document, as it is the fundamental monitoring responsibility of the Corps and non-Federal sponsor. By evaluating performance criteria for each restoration action, effectiveness monitoring tests whether actions are achieving their stated ecological objectives. Measuring and tracking these criteria provides feedback to determine if any adjustments to the restoration action are necessary to improve its probability or degree of ecological success. If properly planned and maintained, this feedback leads to increased knowledge, reducing uncertainty in the outcomes of restoration, and allowing sequential improvement of management actions in meeting the objectives from site to project scales. This feedback is the basis of an adaptive management framework.

The extent to which different treatments are applied to address the same management objective, including no-action control treatments, determines whether the adaptive management program is considered “passive” or “active” (Murray and Marmorek, 2003). Currently, project managers perceive constraints within the Corps program, which likely preclude or limit actions that might be considered experimental in nature. Despite the recognized learning benefits associated with active adaptive management, these program constraints and associated funding limitations lead us to advance a narrower framework. This monitoring framework supports passive adaptive management at the site-specific scale, rather than more ambitious active programmatic adaptive management. If the authorizing environment for the program changes over the decades-long timeframe anticipated for implementation, this conservative approach may be reassessed and a more robust adaptive management approach developed.

3.1 Goals

The goals of effectiveness monitoring of PSNERP restoration actions are to:

1. Assess the effectiveness of restoration actions in achieving defined objectives;
2. Determine where corrective action is needed to improve the effectiveness of restoration actions, and inform decisions about how to take such corrective action; and
3. Reduce risks and uncertainties associated with future restoration actions by increasing understanding of the relationships between restoration actions and restored ecosystem processes, structures, and functions for Puget Sound nearshore ecosystems.

3.2 Approach

The four PSNERP restoration strategies identify management measures used to restore processes, which in turn generate a series of structural and functional responses specific to the ecosystem. These responses constitute a set of predicted ecological and other ecosystem goods and services outcomes that indicate the performance of the restoration site. Performance of the restoration site is documented through an evaluation of monitoring results as measured against these predicted outcomes. Thus, these outcomes effectively serve as strategy-specific objectives. In order to achieve the monitoring goals stated above, effectiveness monitoring of PSNERP restoration sites must answer the question, "Do management measures as implemented restore processes necessary to achieve objectives of improved ecosystem functions, goods and services?"

Processes are inherently difficult to measure and quantify directly, and need to be related to expected structural and functional responses in order to fully demonstrate restoration performance. As a result, structural and functional responses are typically monitored directly as indicators of restored processes. The causal relationships among restored processes and structural and functional responses are defined by strategy-specific conceptual models. This approach is consistent with the analytical process used to define and plan restoration needs: using the same conceptual models, structural changes documented in the historical change analysis were translated into implications of process degradation (Simenstad et al. 2011).

3.3 Indicators and Metrics

Ecosystem interactions addressed in the conceptual models occur primarily between process and structure, with both separately and in combination influencing ecosystem functions (Simenstad et al. 2006; Clancy et al. 2009). For each strategy, there are also two levels of ecosystem processes: target processes, without which ecosystem restoration would be considered incomplete; and secondary processes, which rely on restoration of the target processes to operate most fully. These overlapping hierarchies are captured in monitoring by three levels of indicators of increasing complexity and interrelatedness:

Primary indicators are structural responses that are directly related (i.e., through a single causal relationship in the conceptual model) to the target processes for that strategy. For example, tidal hydrology is a target process for the river deltas strategy. Enhanced tidal prism is a direct result of restored tidal hydrology, and is monitored as a primary indicator for restoration sites in the river delta strategy.

Secondary indicators are structural responses that are supported by any combination of restored processes for that strategy, including target and secondary processes. Compared to primary indicators, they are less directly related to restoration of the target processes for that strategy. For example, colonization by native vegetation is a structural response in the river delta strategy that relies on two restored processes: erosion and accretion of sediments, and exchange of aquatic organisms. These two processes operate most fully where tidal hydrology and freshwater input – the two target processes for the river delta strategy – are fully restored (Cereghino et al. 2012).

Tertiary indicators are structural or functional responses that require the restoration of all nearshore processes for that strategy, including both target and secondary processes, and often one or more structural responses as well. Compared to primary and secondary indicators, they are the most complex and least directly related to restoration of the target processes for that strategy. For example, increased shoreline length and complexity is a structural response in the river delta strategy that depends on at least partial restoration of all processes in the river delta strategy, as well as several structural responses, including marsh plain redevelopment and channel network redevelopment.

All three levels of indicators must be monitored to evaluate whether they follow a predicted response. This response is developed from the best scientific understanding of the system's evolution following implementation of the restoration site. Metrics for each indicator are selected to provide enough information to track an indicator through its predicted response, as well as to explain why an indicator is (or is not) developing as predicted. For example, in the river delta strategy, site-scale topography measurements will track marsh plain redevelopment over time. Should the marsh plain fail to redevelop, measurements of local sediment accretion and erosion may help provide an explanation.

In general, this monitoring framework anticipates the use of reference sites. A reference site provides a basis of comparison to the restoration site and to pre-restoration conditions, helps inform acceptable values for monitoring metrics (Goetz et al. 2004), and can serve as a covariate that takes into account natural variability (Roni et al. 2005). Use of reference sites is discussed further in Section 5.2.

Each indicator is presented in this document as an element in a monitoring table, together with its predicted response and the metrics required for assessment. Also listed are the primary processes that support it – in other words, the indicator can develop according to its predicted response only if those processes have been restored. Each indicator is also presented as an element in the conceptual model diagram (for example, Figure 4-2), either as a structural response or a primary functional response. This diagram provides a simplified graphical representation of the complex linkages between ecosystem processes, structures, and functions. One monitoring table and one conceptual model diagram are presented for each of the four PSNERP restoration strategies.

3.4 Uncertainties, Contingency Planning, and Programmatic Improvement

Several types of uncertainties exist in the practice of ecosystem restoration. These uncertainties are derived from:

The response of the system to restoration. These arise from assumptions made in the conceptual model and can introduce risk of failure or delay meeting objectives.

Cumulative effects. Multiple restoration actions, particularly within a shoreline “process unit”, can interact in unpredictable ways with synergistic or countervailing results.[2]

[2] A “process unit” is the basic spatial unit of the PSNERP change analysis (Simenstad et al. 2010), strategic needs assessment (Schlenger et al. 2011), and strategies analysis for nearshore protection and restoration (Cereghino et al. 2012), It is defined as a segment of Puget Sound shoreline comprising a drift cell, within which beach sedimentary processes are confined by drift cell indicators of sediment transport, convergence, and divergence; and the adjacent upland watershed area.

External factors and constraints. Factors outside the control of the restoration action can affect performance. These may include uncertain future change such as accelerated sea level rise, or practical constraints such as human modifications to watersheds or protection of private property.

In the PSNERP monitoring framework, uncertainties can be addressed at three scales: (1) the individual restoration site scale; (2) the scale over which individual projects may interact across common nearshore ecosystem processes, (e.g., the shoreline process unit scale); and, (3) and the collection of PSNERP restoration sites, or program scale. Effectiveness monitoring reduces risk associated with uncertainties at the site scale through contingency planning. At the program scale, information from effectiveness monitoring is used for programmatic improvement.

At the site scale, effectiveness monitoring reduces uncertainties associated with the response of the system to restoration by answering questions derived from the conceptual model. Each ecosystem interaction in the model, or linkage between a process, structure, or function, represents a separate monitoring question. Monitoring answers these questions by systematically tracking indicators over time and comparing results to a predicted response. If an indicator does not develop as predicted, a contingency plan presents options and instructions for corrective action. More specific adaptive management responses are presented for each indicator in the strategy-specific monitoring tables in the following section of this document.

Although effectiveness monitoring is performed at the site scale, the information it generates can be used to inform decisions and make improvements at the program scale. Monitoring of primary, secondary, and tertiary indicators tests assumptions and reduces uncertainties associated with the conceptual models, enabling refinement of those models over time. In addition to improving existing sites, refined models can be used to make the next generation of restoration sites more effective.

The large spatial scale and long timeframe that characterize the monitoring of PSNERP restoration sites are also critical to programmatic improvement. Information from effectiveness monitoring across all PSNERP restoration sites can be used to reduce uncertainties about cumulative effects, while also tracking progress toward PSNERP program-scale objectives. The same information, collected over a long period as part of the broader assessment of nearshore restoration in Puget Sound, can be used to track and understand the response of the system to external factors such as climate change and land use patterns. This information can be used to adjust the objectives, design, and implementation of the next generation of restoration sites, as well as to adapt program objectives to changing conditions.

Table 3-1 shows the types of monitoring questions and contingency plans that apply to the three levels of PSNERP indicators. Contingency plans are presented as management responses to unfavorable monitoring results. These responses consist of information that must be considered to explain the unfavorable results, and potential corrective actions to help reverse them and move the system toward success. More specific adaptive management responses are presented for each indicator in the strategy-specific monitoring tables in the following section of this document.

Although effectiveness monitoring is performed at the site scale, the information it generates can be used to inform decisions and make improvements at the program scale. Monitoring of primary, secondary, and tertiary indicators tests assumptions and reduces uncertainties associated with the conceptual models, enabling refinement of those models over time. In addition to improving existing sites, refined models can be used to make the next generation of restoration sites more effective.

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Table 3-1: PSNERP Monitoring Questions and Adaptive Management Responses.

Indicator Type	Monitoring Questions	Adaptive Management Response
Primary	• Do these management measures restore these target processes?	Considerations: ➢ Degree of stressor removal Potential actions: ➢ Further stressor removal
Secondary	• Do these management measures restore these target processes? • Do these restored processes generate the predicted structural responses?	Considerations: ➢ Degree of stressor removal; ➢ Other related metrics Potential actions: ➢ Further stressor removal; ➢ (Further) complementary management measures
Tertiary	• Do these restored processes generate the predicted structural responses? • Do these structural responses generate the predicted functional responses?	Considerations: ➢ All other metrics Potential actions: ➢ Further stressor removal; ➢ (Further) complementary management measures; ➢ Reassessment of conceptual model

4. Effectiveness Monitoring of Restoration Sites

Monitoring frameworks are presented in this section for each of the four PSNERP restoration strategies: river deltas, beaches, barrier embayments, and coastal inlets. Each strategy is described as a single system with a set of management measures and ecosystem processes to restore. This reflects the distinct way that nearshore processes structure the shoreline in each system, and is valid for the purpose of developing a monitoring framework. However, natural variation among restoration sites within each strategy will warrant slightly different approaches to monitoring.

It is assumed that as plans for the sites advance from current level of design (10%) to final design and construction, increasingly detailed monitoring plans will be developed for the sites. The indicators and metrics presented here for each strategy represent a comprehensive "shopping list" for monitoring restoration sites within that strategy. Monitoring plans developed for individual restoration sites are anticipated to vary from these according to site-scale conditions and requirements.

4.1 River Delta Strategy

4.1.1 Predicted Functional Outcomes

River deltas are formed where broad tidal surge plains meet marine waters. Most river deltas in Puget Sound have been extensively modified through urban and agricultural development and land use. Delta wetlands have been cut off from tidal flow by dikes, or eliminated through filling. Reduced tidal flushing and alluvial sediment input have prevented water and sediment from reaching marshes, causing subsidence, stalling of tidal channel formation and maintenance, and an overall decline in total delta shoreline length and complexity (Cereghino et al. 2012).

The restoration objective for river deltas is to remove dominant stressors to a degree that allows undegraded tidal flows and freshwater inputs necessary to support a full range of delta ecosystem processes, focusing on the reestablishment of complex wetlands (Figure 4-1). Restoration of tidal hydrology and freshwater input will lead to an enhanced tidal prism, as well as reconnection to natural flooding events. Increased flushing will change levels of organic carbon, oxygen, and nutrients in nearshore waters, and lead to the redevelopment of a salinity gradient appropriate to a diverse wetland system. Reconnection to freshwater input will lead to alluvial sediment and woody debris deposition and a gradual accretion of the marsh plain, which, together with the salinity gradient, will foster colonization by native marsh vegetation. Water flow and erosion will create tidal and distributary channel networks of varying complexity, which can deliver nutrients and detritus to nearshore ecosystems for use by invertebrates, fish, nearshore birds, and other species (Figure 4-2). Natural levees will develop alongside channels and can ultimately support riparian corridors (ESA 2011).

Following restoration of delta ecosystem processes, the system should develop redundant representation of delta ecosystem components, including tidal surge plain, tidal fresh and oligohaline transition swamp, salt marsh, tidal flat, subtidal flat, distributary channel, tidal channel, and riparian forest. The restoration site should consist of well-connected large patches, and total shoreline length should increase (Cereghino et al. 2012).

Primary management measures include berm or dike removal or modification in order to restore tidal hydrology and freshwater input. Where primary management measures may be insufficient to achieve predicted structural and functional responses, they may be complemented as necessary by channel modification, topographic restoration, or revegetation.

4.1.2 Uncertainties

Response of the system to restoration:

- The degree of channel excavation for several restoration sites is based on the assumption that increased flow and tidal energy will allow channels to redevelop and sustain themselves naturally. If this assumption is incorrect, further channel excavation may be necessary.
- Increased tidal flushing may increase wave action, increasing erosion and turbidity, as well as flood risk to adjacent areas.
- Unanticipated impacts to adjacent landowners.
- Ongoing maintenance costs that will limit project effectiveness in the long run (e.g., cost of removing invasive species, cost of maintaining dikes/berms)

Cumulative effects, external factors, and constraints:

- In general, there is uncertainty as to whether the alluvial sediment supply available for accretion within the site will be sufficient to sustain marsh development. Restoration sites within the same shoreline process unit could create new sediment sinks, reducing this sediment supply.
- The effects of climate change introduce uncertainty, particularly about flooding frequency, magnitude, and duration, as well as the salinity gradient and resulting vegetation distribution. Sea level rise due to climate change could outpace accretion rates, preventing marsh vegetation adaptation.
- Watershed conditions, such as urban development and land use, may strongly affect sediment deposition and maintenance of water quality.
- Drainage on neighboring or upstream agricultural fields.
- Existing public access and use of area.

4.1.3 Monitoring Indicators, Metrics, and Adaptive Management Responses

Based on our conceptual model for the river delta strategy, Table 4-1 outlines the relationships between indicators of structural and functional response and associated monitoring metrics. The predicted response and timeframe for metrics is described in general terms. Also listed are the primary processes that support proposed indicators – in other words, the indicator can develop according to its predicted response only if associated processes have been restored. This document is currently limited to an effectiveness monitoring framework for functional objectives. Site-specific constraints will also include actions necessary for protecting adjacent landowners, maintaining or replacing public uses of the site, and other factors to insure social acceptability. During future planning, engineering, and design phases, site-specific management constraints will be identified and addressed as part of the stakeholder involvement strategy, including the WDFW Restoration Pathway.

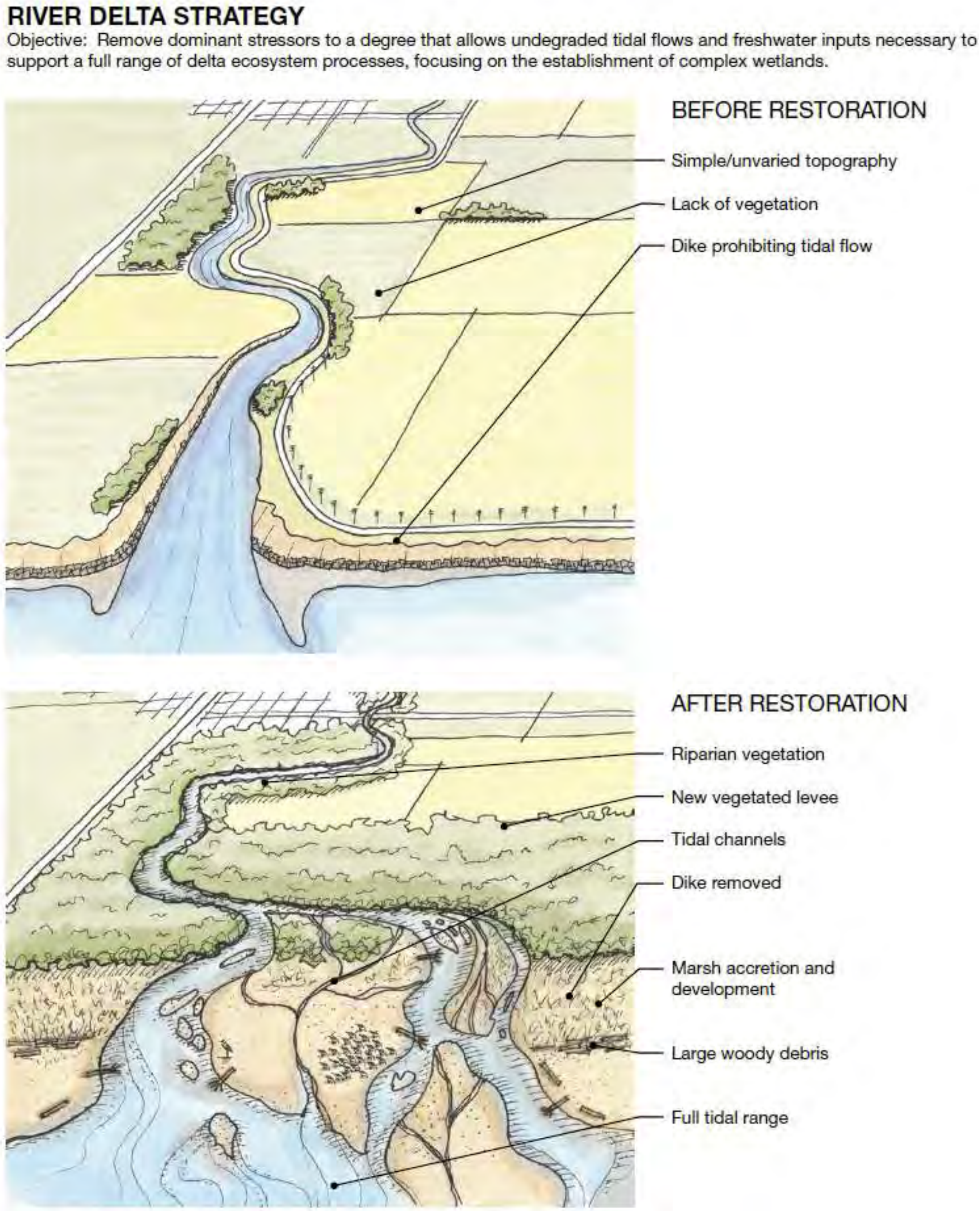

Figure 4-1: Example of a typical Puget Sound river delta depicting the degraded system prior to restoration, and the structural and functional responses of the system following restoration.

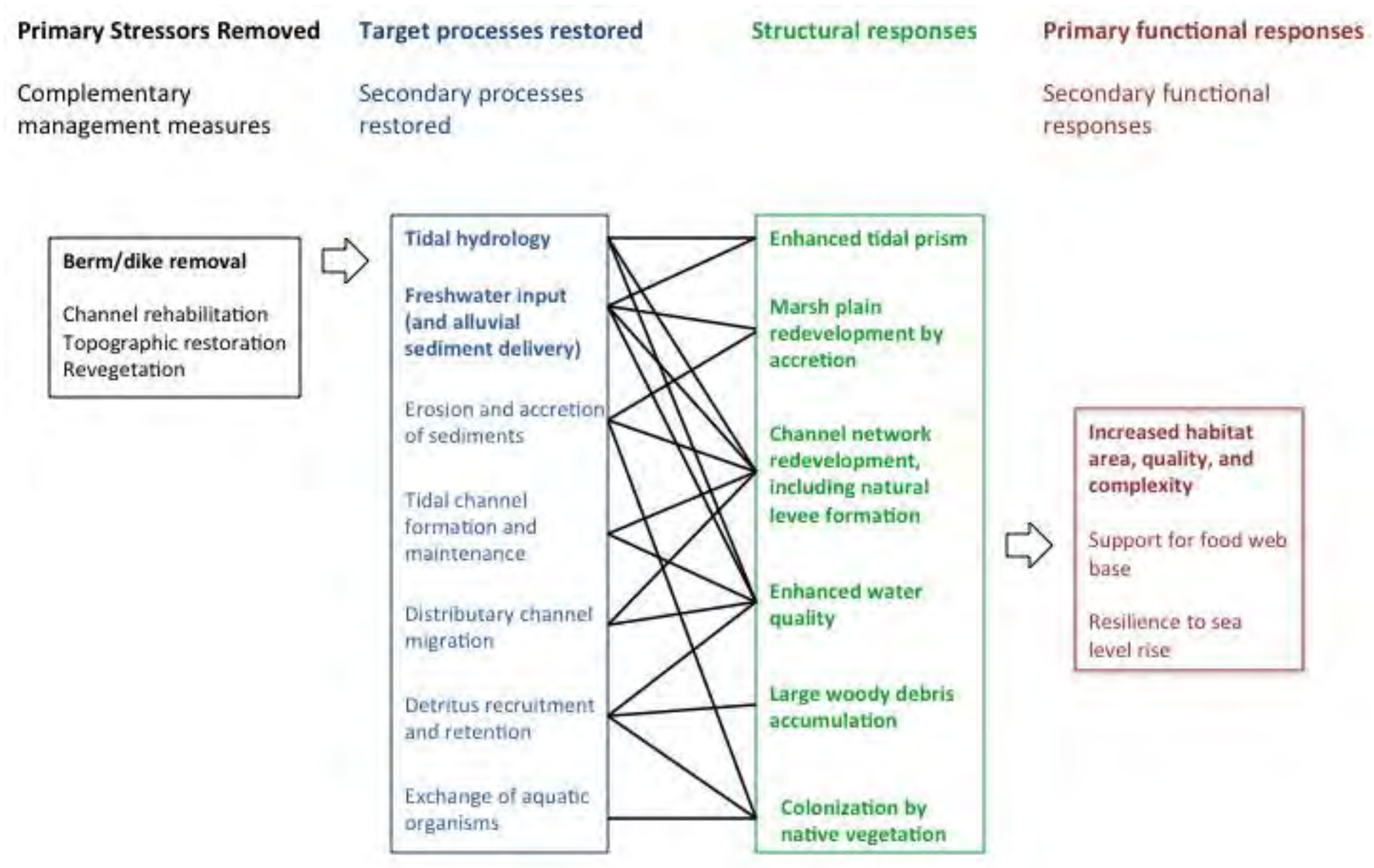

Figure 4-2: Conceptual model of management measures, restored processes, and structural and functional responses for the river delta strategy.

Table 4-1: River Delta Strategy Monitoring Table.

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
Primary Indicators					
Enhanced tidal prism	Tidal hydrology Freshwater input	- Water level (tidal elevations) - Water velocity - Inundation frequency, magnitude, duration, and area - Tidal prism (volumetric) - Salinity	Tidal prism will increase as tidal hydrology is restored to the delta. In most cases, tidal pattern should be the same inside and outside of the delta system. Natural flooding events will be restored, indicating restored connectivity to the river. Floodplain inundation will increase initially; then as marsh elevation increases, period of inundation will decline.	Immediately following restoration	Considerations: - Have stressors been removed to a degree sufficient to restore tidal hydrology and freshwater input? Potential actions: - Further stressor removal (berm/dike removal) as possible - Dredging of river channel

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
			Salinity patterns will change consistent with increased tidal prism, restoring a salinity gradient to the estuary.		

Secondary Indicators

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
Marsh plain redevelopment by accretion	Freshwater input Erosion and accretion of sediments	- Site-scale topography and bathymetry - Local sediment accretion/ erosion rates	Accretion of alluvial sediments will outpace natural subsidence and lead to elevation gain. Site will obtain a shallow elevation gradient (slope) appropriate to marsh development.	Rate and distribution of sediment accretion will vary with the size of restored tidal opening and degree of connectivity to river. Smaller openings and less connectivity will result in more gradual, episodic, and local redistribution of sediments.	Considerations: - Local rate of sea level rise - Alluvial sediment supply Potential actions: - Increase tidal opening/connectivity (further stressor removal) - Adjust restoration phasing and design to increase accretion, (e.g., by adding wave

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
					breaks or fill) - Remove/modify upstream dams or other hydraulic modifications.
Channel network redevelopment, including natural levee formation	Tidal hydrology Freshwater input Erosion and accretion of sediments Tidal channel formation and maintenance Distributary channel migration	- Dendritic tidal channel geometry measurements - Channel cross-section - Channel volume - Sediment structure (size and composition) - Site-scale topography and bathymetry - Local sediment accretion/	Restored tidal hydrology and freshwater input will increase flow of water and sediment through channels, leading to development of a channel network with density, complexity, and connectivity appropriate to phase of marsh development. Sedimentation patterns will change as a result of new distributary channel network, leading to a more	Rate of channel development depends on the degree to which tidal hydrology and freshwater input have been restored. Increased tidal hydrology will lead to faster development of larger channels. Actual channel migration could take decades, and is thus not an indicator of restoration success.	Considerations: - Have management actions interfered with existing drainage pattern? - Assumption: excavation of higher order channels will allow lower order channels to develop naturally Potential actions: - Filling of existing drainage channels - (Further) channel excavation

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
		erosion	diverse topography. Natural levees with coarser, better-drained soils will develop next to channels; these can eventually support riparian corridors. Channels should have the potential to migrate freely over time, though actual migration is not an indicator of restoration success.		- (Further) creation starter berms/levees
Enhanced water quality	Tidal hydrology Freshwater input Tidal channel formation and	- Dissolved organic carbon - Dissolved oxygen - pH	Increased flushing and connectivity will lead to enhanced water quality in terms of habitat conditions (i.e,. indicators directly relevant to biology),	Rapid change expected after restoration of tidal hydrology and freshwater input.	Considerations: - Water velocity and other indicators of flushing - Channel drainage network development

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
	maintenance Distributary channel migration Detritus recruitment and retention	- Temperature - Turbidity - Chlorophyll a - Sediment oxygen demand	including decreased temperature.		Potential actions: - Upstream watershed management - Applied studies to find causes of water quality problems
Large woody debris (LWD) accumulation	Detritus recruitment and retention	- Large wood composition, recruitment, and residence	Woody debris will be carried in naturally from restored tidal and freshwater flushing. Debris will contribute to the amount of organic carbon in the system, but should not interfere dramatically with flushing.	Potential for accumulation immediately following restoration of tidal hydrology; actual rate depends on flow and inundation rates.	Considerations: - Is tidal opening/connection to river large enough to allow passage of LWD? - Source of LWD Potential actions: - Increase size of tidal opening/connection to river - Removal and relocation of LWD from locations that cause blockage to

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
					flow, particularly following weather and/or inundation events
Colonization of native vegetation	Erosion and accretion of sediments Detritus recruitment and retention Exchange of aquatic organisms	- Distribution and abundance of native plants - Distribution and abundance of invasive plants	Vegetation assemblage will develop and change based on restored salinity and topography regime, (e.g., mudflat, tidal marsh, riparian, woody). In general, vegetation should transition from intertidal emergent vegetation to scrub-shrub and forested wetland. Facilitated by internally connected system of shifting distributaries and resulting	Dependent on rate of marsh surface elevation increase; anticipated to be detectable within 5 years of reaching appropriate elevations.	Considerations: - Size and configuration of tidal opening (e.g., one large hole vs. several small holes) - Potential barriers to organism exchange - Marsh plain elevation and topography - Water quality metrics - Invasive plant colonization Potential actions: - Increase tidal opening/connection

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
			unconstrained movement of organisms and nutrients.		to river - Adjust restoration phasing and design to increase accretion to colonization levels - Revegetation - Invasive plant removal

Tertiary Indicators

Increased habitat area, quality, and complexity	ALL	- Distribution and extent by habitat type - Habitat quality rating based on soil, water, diversity measurements collected as part of this monitoring plan - Shoreline length and	The system should develop redundant representation of the full range of delta ecosystem components, including river floodplain, tidal fresh and oligohaline transition swamp, salt marsh, tidal flat, subtidal flat, distributary	Extent and quality of habitats will respond gradually following establishment of all structural responses.	Considerations: - Analyze all available monitoring data to determine whether result is due to restoration or external factors Potential actions: - Assess relative to all other monitoring metrics – if processes

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
		complexity - Landscape connectivity and patchiness	channel, tidal channel, and riparian forest. Development of complex channel networks will result in enhanced shoreline length and complexity. The site should be formed of contiguous large patches that are well connected to each other and to the surrounding riverine, terrestrial, and marine landscape.		have been restored but habitat function has not, consider change to conceptual model

4.2 Beach Strategy

4.2.1 Predicted Functional Outcomes

Historically, 50% of the Puget Sound shoreline was composed of beach systems. Concurrent with coastal development, shoreline armoring has been built to protect private property on bluffs and banks from erosion. Armoring has led to the alteration of more than 500 km of bluff-backed shore, which has cut off the sediment supply that maintains down-drift beaches (Cereghino et al. 2012). Armoring also increases potential for loss of beach area and elevation over time (Johannessen and MacLennan 2007), which can decrease resilience to sea level rise (Pethick 2001). By removing or preventing colonization of vegetation and inhibiting wrack and woody debris accumulation, armoring can reduce beach productivity and diversity. Relative to river deltas, barrier embayments, and coastal inlets, degraded beach processes have a greater potential to impact nearshore ecosystems beyond the geographical limits of the altered beaches themselves.

The restoration objective for beaches is to remove or modify barriers to the movement of sediment from sources (bluffs) to sinks (beaches) to a degree that allows the full range of beach processes (Figure 4-3). Figure 4-4 outlines our conceptual model of the relationship between stressor removal, restored processes, and predicted structural and functional responses. Restoration of sediment supply and transport processes is expected to reinitiate bluff toe erosion and increase sediment delivery to down-drift beaches. Restored sediment input and erosion processes will redevelop the beach profile to its former configuration, and the beach will develop a well-sorted, natural sediment size profile. Both site and adjacent beach area should increase. Wrack, large woody debris, and native vegetation should accumulate and develop at the bluff-beach interface. In general, the landward portion of the nearshore zone should provide riparian functions, as well as a historical quantity and quality of ground surface freshwater inputs. This, together with increased overhanging vegetation, will contribute to enhanced sediment moisture content and cooler nearshore waters (ESA 2011; Cereghino et al. 2012).

The primary management measure for beach restoration is armor removal or modification in order to restore sediment supply from feeder bluffs. Groin removal is also a primary measure where cross-shore structures impound sediment and starve down-drift beaches. Where primary management measures are insufficient to achieve predicted structural and functional responses, they may be complemented as necessary by topographic restoration and revegetation.

4.2.2 Uncertainties

Response of the system to restoration:

- The timing of the system's response to armor removal is highly uncertain due to lack of empirical data on sediment delivery rates from natural beach systems or armoring removal management measures on Puget Sound shorelines. Benefits of armor removal may occur over a period of decades as opposed to years, relying on episodic storm events to trigger a release of sediment.
- The rate of sediment supply necessary to sustain a particular beach is unknown. Partial, rather than full restoration may be insufficient to achieve objectives of restoring sediment supply.
- Armor removal, unlike other management measures, is difficult to apply incrementally, and may be less reversible, making contingency planning more difficult.

Cumulative effects, external factors, and constraints:

- In general, beach dynamics are driven largely by external factors. Local geology, wave exposure, topography, tidal range, climate, weather events, mass-wasting events, and vegetation all contribute to shaping the beach. Thus, monitoring of structural and functional indicators is less valuable for understanding system dynamics than monitoring these driving factors.
- Loss of beach due to sea level rise is difficult to estimate due to lack of understanding of the differences between current and historical beach structure.
- Bluff erosion which poses a potential risk to infrastructure located adjacent to target restoration sites.

4.2.3 Monitoring Indicators, Metrics, and Adaptive Management Responses

Based on our conceptual model for the beach strategy, Table 4-2 outlines the relationships between indicators of structural and functional response and associated monitoring metrics. The predicted response and timeframe for metrics is described in general terms. Also listed are the primary processes that support proposed indicators – in other words, the indicator can develop according to its predicted response only if associated processes have been restored.

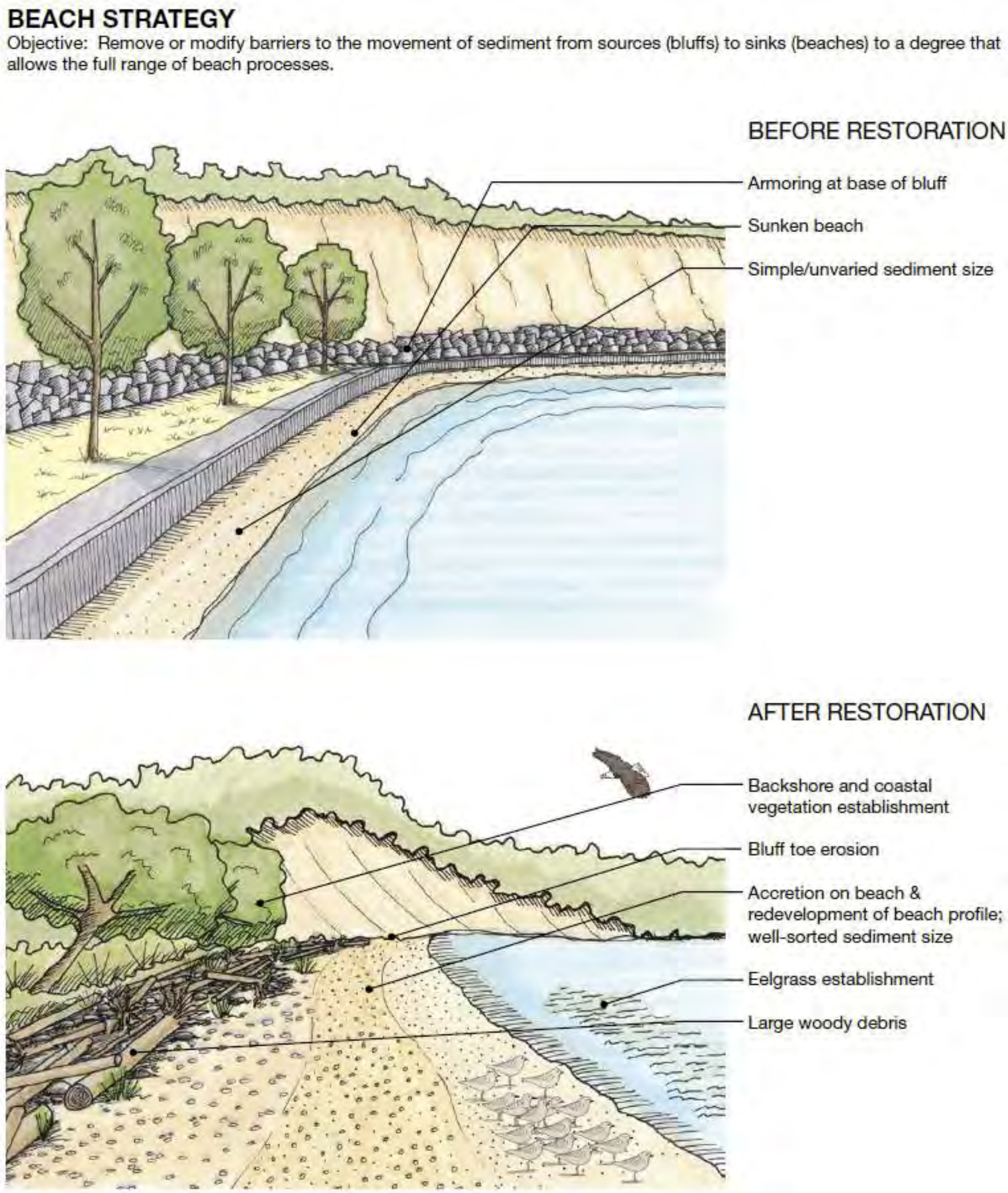

Figure 4-3: Example of a typical Puget Sound beach depicting the degraded system prior to restoration, and the structural and functional responses of the system following restoration.

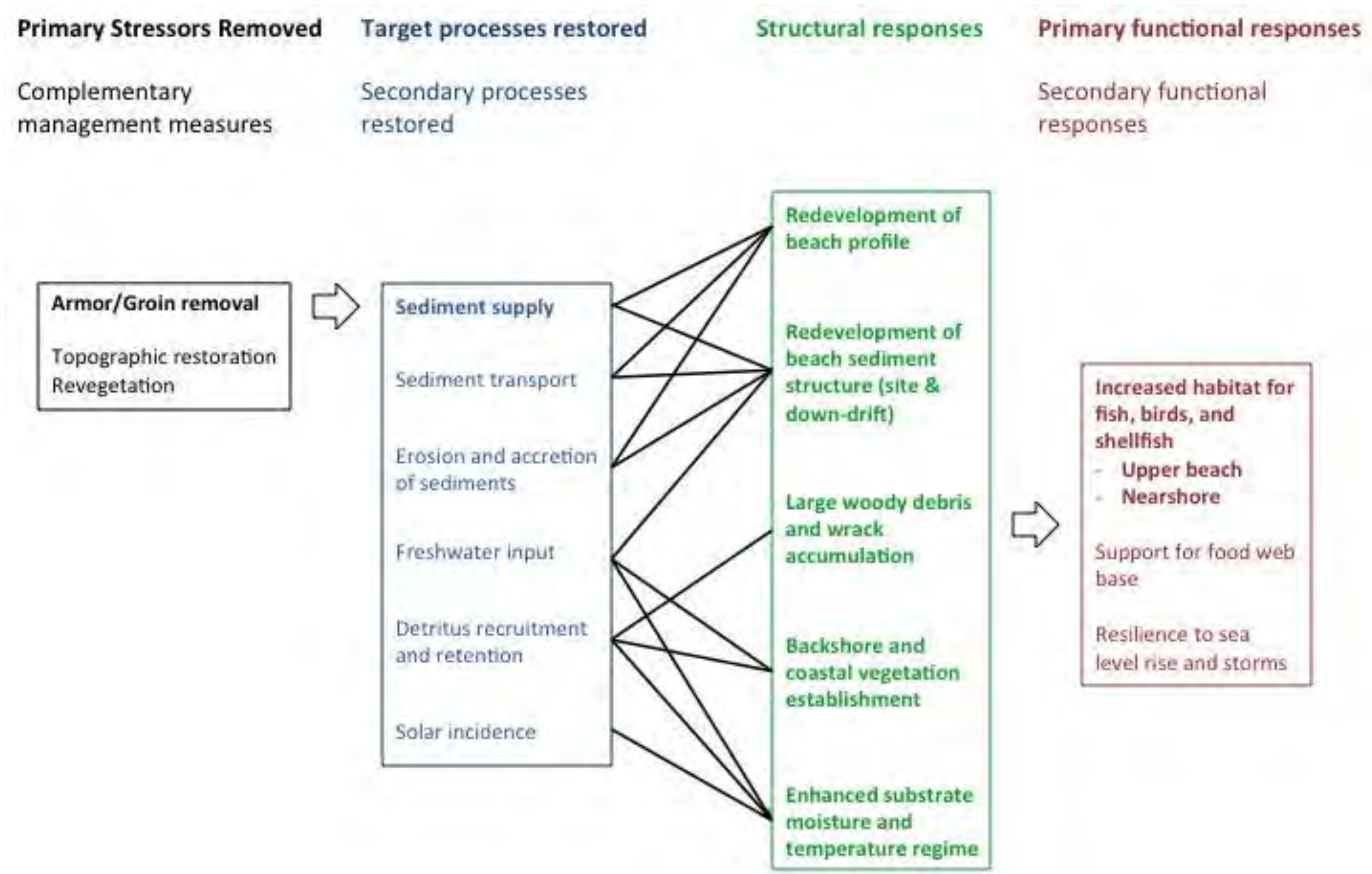

Figure 4-4: Conceptual model of management measures, restored processes, and structural and functional responses for the beach strategy.

Table 4-2: Beach Strategy Monitoring Table.

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
Primary Indicators					
Bluff recession	Sediment supply	- Topographic evidence of sediments accreted at base of bulkhead-removal bluff - Bluff toe erosion rate - Occurrence of landslide events - Bluff recession rate	Erosion of bluff toe will accelerate until new dynamic equilibrium is established. Over time, it will slow to the rate of reference/unarmored sites. Bluff recession may occur, but rate is dependent on external factors such as precipitation events.	Erosion of bluff toe will accelerate immediately following armor removal Slowing to equilibrium rate anticipated on the order of 15 to 30 years	Considerations: - Reassess geomorphic characterization of feeder bluff as sediment source - Reassess hypotheses regarding the rate of sediment delivery or of beach response Potential actions: - Further armor removal as possible - Beach nourishment
Secondary Indicators					
Redevelopment of beach profile (site & down-drift)	Sediment supply Sediment transport	- Beach topography profile - Accretion rates on	Upper beach should grade to its former configuration (determined by reference/unarmored beach) upon	Natural beach profile restored in approximately one year Timing of effects	Considerations: - Erosion and accretion rates - Timing and exposure to

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
	Erosion and accretion of sediments	down-drift beaches, within littoral drift cell	exposure to wave energy.	on down-drift beaches depends on rates of wind- and wave-driven sediment transport	wind and wave energy Potential actions: - Beach nourishment
Redevelopment of sediment structure (site & down-drift)	Sediment supply Sediment transport Erosion and accretion of sediments Freshwater input	- Sediment size and composition onsite - Sediment size and composition on down-drift beaches, within littoral drift cell	Beach should develop well-sorted, natural sediment size profile similar to reference beach, (e.g., pebble/sand beach face with sandy backshore.)	Response timing will depend on storms and mass-wasting events. Timing of effects on down-drift beaches depends on rates of wind- and wave-driven sediment transport	Considerations: - Erosion and accretion rates - Timing and exposure to wind and wave energy Potential actions: - Beach nourishment
Large woody debris (LWD) and wrack accumulation	Detritus recruitment and retention	- Wrack composition and amount - Large wood composition, recruitment, and residence	Large woody debris and wrack should accumulate at bluff-beach interface. This includes driftwood accumulations and active large woody debris recruitment from shallow	Within one year Exact timing depends on rates of wind- and wave-driven transport of LWD and wrack, as well as beach profile	Considerations: - Beach profile steepness - Source of LWD Potential actions:

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
			landslides.	response	- Driftwood placement
Backshore and coastal vegetation establishment	Freshwater input Detritus recruitment and retention	- Distribution and abundance of native plants - Distribution and abundance of invasive plants - Area covered by over-hanging marine riparian vegetation	Native vegetation should develop at the bluff-beach interface (backshore). Area receiving benefits of overhanging marine riparian vegetation (shade) should grow as vegetation is established.	Some vegetation should begin to establish itself within one year Exact timing depends on conditions of existing vegetation (pre-restoration)	Considerations: - LWD and wrack accumulation - Sediment structure - Invasive plant colonization Potential actions: - Revegetation - Invasive plant removal
Enhanced substrate moisture and temperature regime	Freshwater input Detritus recruitment and retention Solar incidence	- Temperature at high tidal elevation - Sediment moisture at high tidal elevation	Overhanging vegetation will decrease overall solar incidence, decreasing average water temperature (particularly below overhanging vegetation). Sediment moisture	Response rate will follow rate of establishment of over-hanging vegetation	Considerations: - Establishment of overhanging vegetation - Weather and climate conditions - Sediment size (drainage)

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
			content should increase as a result of slowed evaporation and restored freshwater input, where applicable.		Potential actions: - Revegetation - Invasive plant removal

Tertiary Indicators

Increased habitat area and quality	ALL	- Areal extent of backshore, intertidal, and nearshore habitat - Habitat quality rating based on sediment, water, vegetation measurements collected as part of this monitoring plan	Upper intertidal beach area should increase with armor removal. Adjacent and down-drift beaches and associated nearshore habitats within the drift cell should increase in area with the restoration of sediment supply. This includes habitat with substrate size appropriate for potential forage fish spawning.	Area lost due to placement loss will be gained back immediately following armor removal. Extent and quality of other areas will respond gradually following establishment of all structural responses. Difficult to predict when down-drift habitats may experience benefits.	Considerations: - Analyze all available monitoring data to determine whether result is due to restoration or external factors Potential actions: - Assess relative to all other monitoring metrics – if processes have been restored but habitat function has not, consider change to conceptual model

4.3 Barrier Embayment Strategy

4.3.1 Predicted Functional Outcomes

Structures and functions of barrier embayments are affected by the condition of the beach system that sustains the barrier, and are increasingly sediment-starved due to shoreline armoring. Transportation infrastructure built on top of barrier features can prevent natural migration and increase beach loss from erosion. Filling or diking for development has disconnected many embayments from tidal influence, and may cause the embayment opening to close completely.

The restoration objective for barrier embayments is to remove dominant stressors to restore sediment supply and transport processes to littoral drift cells where bluff erosion sustains barrier beaches that form barrier embayments, and to remove dominant stressors to restore the tidal processes found therein (Figure 4-5). Figure 4-4 outlines our conceptual model of the relationship between stressor removal, restored processes, and predicted structural and functional responses. Following removal of stressors to tidal hydrology, tidal prism will increase incrementally. This will result in enhanced tidal elevations and increased flushing, as well as the reestablishment of a salinity gradient throughout the embayment. Increased tidal flow through channels will lead to the development of a channel network and associated diverse topography. Increased flow will also improve levels of organic carbon, oxygen, and nutrients in embayment waters, especially in lagoons that are reconnected to tidal influence by the restoration action. Sediments delivered by tidal channels will lead to a gradual accretion of the marsh plain, which, together with the unconstrained flow of water and organic material through those channels, will foster colonization by native marsh vegetation. Restored sediment and transport processes will lead to sediment deposition within the embayment and along the shoreline, increasing the extent of barrier beach. Restored littoral processes will rework sediment in the embayment and barrier feature, depositing sediment within the embayment opening until equilibrium is achieved between tidal forces and wave action (ESA 2011).

Following restoration of barrier embayment ecosystem processes, the system should develop redundant representation of barrier embayment ecosystem components including, where historically present, stream delta or ponds, tidal flats, salt marsh, channels, tidal delta, beach berm, beach face, and low tide terrace. The restoration site should consist of one well-connected large patch, and total shoreline length should increase (Cereghino et al. 2012).

Primary management measures include berm or dike removal or modification to restore tidal hydrology where embayment topography is intact, or topographic restoration (fill removal) where an embayment has been filled. Armor or groin removal is another primary management measure to restore sediment supply to a barrier feature, as well as removal of infrastructure that hinders natural inlet channel form and movement. Where primary management measures are insufficient to achieve predicted structural and functional responses, they may be complemented as necessary by hydraulic modification or channel rehabilitation.

4.3.2 Uncertainties

Response of the system to restoration:

- The effect of restoration on flooding risk is uncertain. Removal of dams and other barriers to tidal hydrology may increase flood risk to non-acquired properties. At the same time, removal of such barriers could reduce the extent of fluvial flooding during high creek flows.
- Restoration could necessitate shore protection of non-acquired properties due to increased local erosion and channel migration.
- As with river deltas, the degree of channel excavation for several restoration sites is based on the assumption that increased flow and tidal energy will allow channels to redevelop and sustain themselves naturally. If this assumption is incorrect, further channel excavation may be necessary.
- Though marsh is a natural endpoint landform for this strategy, the rate at which the marsh surface topography will evolve over time is uncertain.
- Wave action could naturally build a sill which would prevent full drainage and tidal flushing, reducing the depth of the embayment opening or closing it entirely.

Cumulative effects, external factors, and constraints:

- Landward retreat of wetlands in response to sea level rise may be constrained by land use. This uncertainty is tied to the local rate of sea level rise.
- Changes to the watershed outside of the restoration site, such as urban development, could change the effect of restoration actions on embayment area and edge density.
- As with river deltas, there is uncertainty as to whether the sediment supply available for accretion within the site will be sufficient to sustain marsh development. Restoration sites within the same shoreline process unit could also create new sediment sinks, reducing this sediment supply.

4.3.3 Monitoring Indicators, Metrics, and Adaptive Management Responses

Based on our conceptual model for the Barrier Embayment strategy, Table 4-3 outlines the relationships between indicators of structural and functional response and associated monitoring metrics. The predicted response and timeframe for metrics is described in general terms. Also listed are the primary processes that support proposed indicators – in other words, the indicator can develop according to its predicted response only if associated processes have been restored.

BARRIER EMBAYMENT STRATEGY

Objective: Remove dominant stressors to restore sediment supply and transport processes to littoral drifts cells where bluff erosion sustains barrier beaches that form barrier embayments, and to removed dominant stressors to restore the tidal processes found therein.

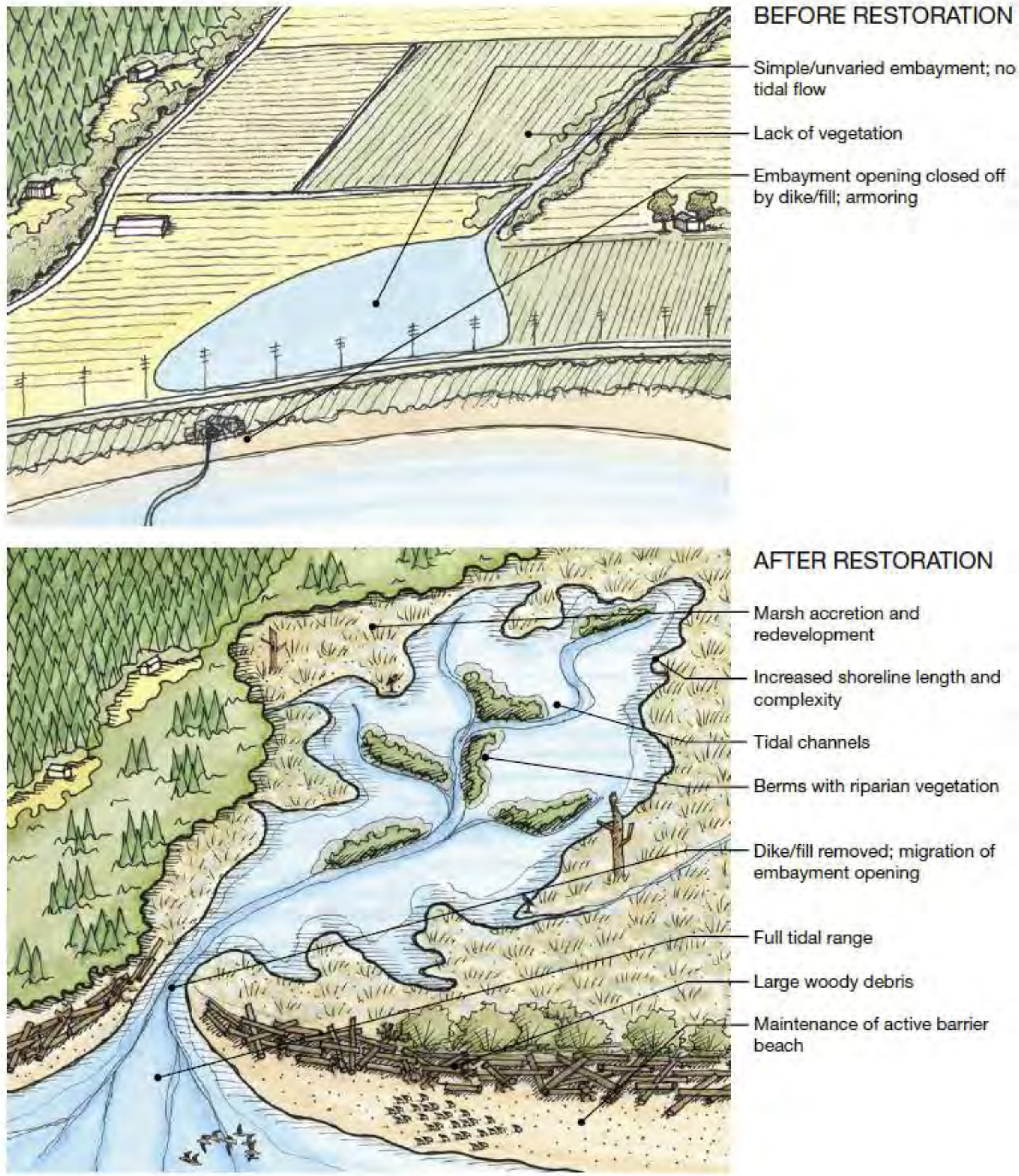

Figure 4-5: Example of a typical Puget Sound barrier embayment depicting the degraded system prior to restoration, and the structural and functional responses of the system following restoration.

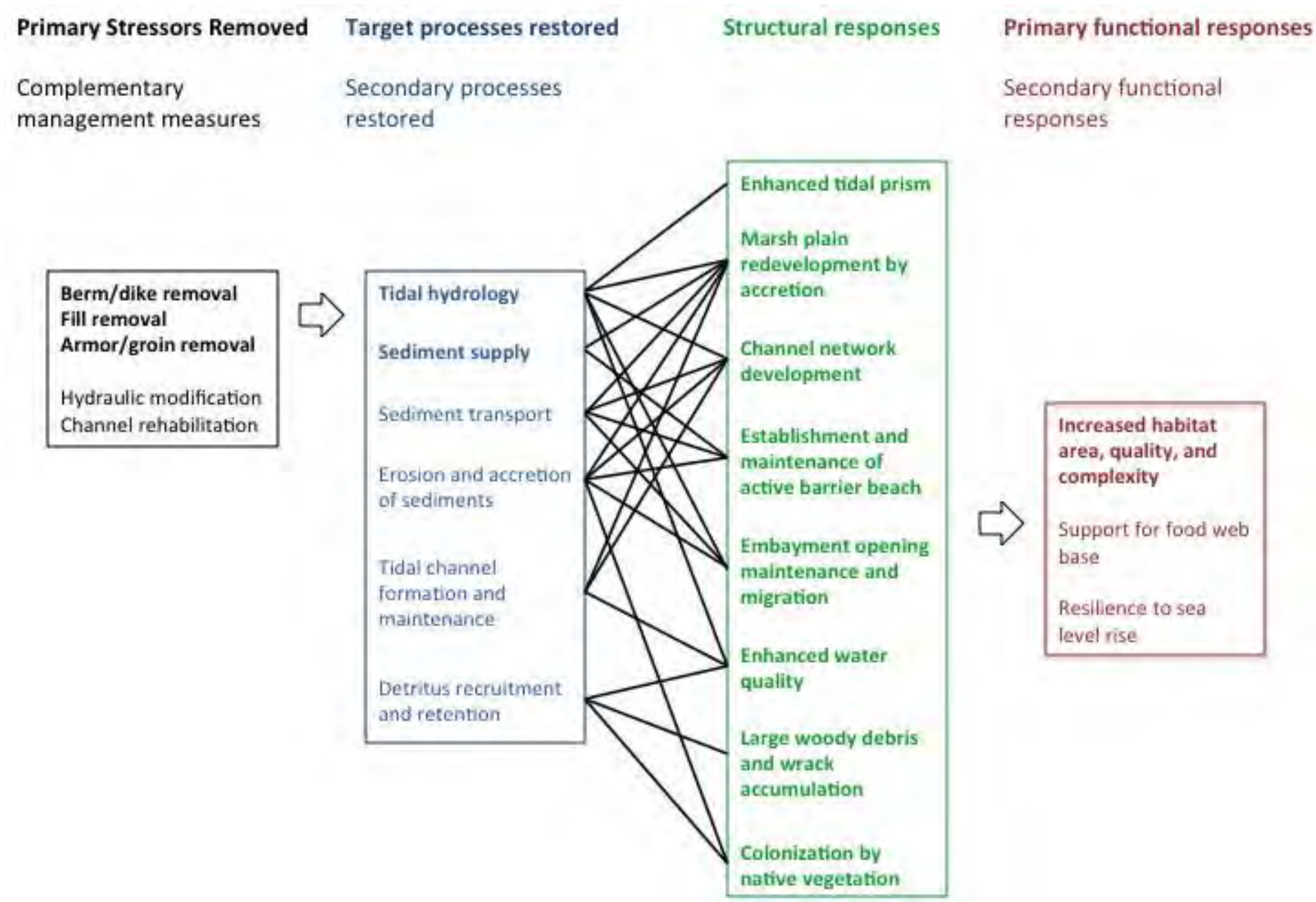

Figure 4-6: Conceptual model of management measures, restored processes, and structural and functional responses for the Barrier Embayment strategy.

Table 4-3: Barrier Embayment Strategy Monitoring Table.

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
Primary Indicators					
Enhanced tidal prism	Tidal hydrology	- Water level (tidal elevations) - Water velocity - Tidal prism (volumetric) - Salinity	Tidal prism will increase incrementally, resulting in enhanced tidal elevations, increased water velocity/flushing, and reestablishment of a salinity gradient throughout the embayment.	Immediately following restoration	Considerations: - Have stressors been removed to a degree sufficient to restore tidal hydrology and freshwater input? - Calculation of full, restored tidal prism and associated size of embayment opening Potential actions: - Further stressor removal (berm/dike removal) as possible
Bluff recession	Sediment supply	- Changes in topographic evidence of sediments accreted at base	Armor removal will restore sediment supply from feeder bluff to barrier feature by way of	Timing depends on rates of wind- and wave-driven	Considerations: -Reassess geomorphic characterization of

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
		of bulkhead-removal bluff - Bluff toe erosion rate - Occurrence of landslide events - Bluff recession rate	littoral transport. In sites without armor removal, sediment supply is largely external to the site.	sediment transport.	feeder bluff as sediment source Potential actions: -Further armor removal as possible -Beach nourishment to restore functioning intertidal beach and supply for barrier feature

Secondary Indicators

Embayment opening maintenance and migration	Tidal hydrology Sediment transport Erosion and accretion of sediments	- Cross-section and bathymetry of inlet/channel opening	Larger (restored) embayment opening will lead to larger tidal prism and improved flushing, which will in turn increase the likelihood that the embayment remains open. Erosion and migration of embayment opening are		Considerations: - Assumption: Embayment opening will naturally resize to accommodate tidal prism - Impounded sediments inside the

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
			also possible, but not indicators of restoration success. Over time, littoral processes will rework sediment in the embayment and barrier feature, depositing sediment within the excavated opening (as applicable) to develop equilibrium between tidal forces and wave action. Wave action could naturally build a sill which would prevent full drainage and tidal flushing, reducing the depth of the embayment opening		embayment - Sediment source outside the embayment - Water velocity/flushing sufficient to maintain opening - Manmade structures on barrier preventing natural migration Potential actions: - (Further) removal of fill/impounded sediments - (Further) removal of structures on barrier/across embayment opening

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
Establishment and maintenance of active barrier beach	Sediment supply Sediment transport Erosion and accretion of sediments	- Topography and profile of barrier - Accretion rates on barrier - Sediment size	Substantial sediment deposition within the restored embayment and along the shoreline due to increased tidal currents into and out of the embayment (littoral transport) will result in an increase of barrier beach extent and size. Over time, littoral processes will rework the sediment, rebuilding the beach berm. Beach profile should become wider and shallower, allowing more accretion and overwash of coarser sediments supplied by feeder bluffs.	Timing depends on rates of wind- and wave-driven sediment transport as well as littoral transport rates within the embayment.	Considerations: - Sediment supply - Erosion and accretion rates - Timing and exposure to wind and wave energy - Manmade structures on barrier preventing natural migration Potential actions: - Beach nourishment - Regrading of beach profile
Channel network redevelopment	Tidal hydrology Sediment	- Dendritic tidal channel geometry	Restored tidal hydrology will increase flow of water and sediment through channels,	Rate of evolution of tidal drainage network is	Considerations: - Have management actions interfered

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
	transport Erosion and accretion of sediments Tidal channel formation and maint-enance	measurements - Channel cross-sections - Panne and pond size distribution relative to channel network - Sediment structure (size and composition) - Site-scale topography and bathymetry - Local sediment accretion/erosi on	leading to development of a channel network with density, complexity, and connectivity appropriate to phase of marsh development. Increased channel complexity will lead to overall shoreline lengthening. Sedimentation patterns will change as a result of new channel network, leading to a more diverse topography. Natural levees with coarser, better-drained soils may develop next to channels. Initially ponding will occur, but over time sediments will fill in ponds and natural drainage will occur through channels. New drainage network should drain through	directly related to sedimentation rate. Ponding will retard site's evolution, but should only occur for 1-2 years before natural drainage takes over.	with existing drainage pattern? - Assumption: excavation of higher order channels will allow lower order channels to develop naturally - Empirical relationships between tidal prism and channel size - Effect of sidecast berms created to resemble natural levees Potential actions: - Filling of existing drainage channels - (Further) channel excavation

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
			barrier breach/embayment opening.		- (Further) fill removal, especially in the case of extended ponding - (Further) creation of starter berms/levees
Marsh plain redevelopment by accretion	Tidal hydrology Sediment supply Sediment transport Erosion and accretion of sediments Tidal channel formation and maint-enance	- Site-scale topography and bathymetry - Local sediment accretion/erosi on rates	Accretion of sediments delivered by tidal channels via littoral transport will outpace natural subsidence and lead to elevation gain. Erosion in tidal channels and deposition in backwater areas will result in a shallow elevation gradient (slope) appropriate to marsh development. Marsh is the natural endpoint landform; however, how marsh surface topography will evolve over time is	Rate and distribution of sediment accretion will vary with the size of restored tidal opening and. Smaller openings and less connectivity will result in more gradual, episodic, and local redistribution of sediments. Rate also depends on	Considerations: - Local rate of sea level rise - Sediment supply - Tidal channel network development Potential actions: - Increase tidal opening (further stressor removal) - Adjust restoration phasing and design

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
			uncertain. Increased tidal flow and wave energy will result in increased topographic complexity within tidelands.	sediment supply, which is often external to the site. Rate at which marsh surface elevation will increase is uncertain.	to increase accretion, (e.g., by adding wave breaks or fill)
Enhanced water quality	Tidal hydrology Tidal channel formation and maint-enance Detritus recruitment and retention	- Dissolved organic carbon - Dissolved oxygen - pH - Temperature - Turbidity - Chlorophyll a - Sediment oxygen demand	Increased flushing will lead to enhanced water quality in terms of habitat conditions (i.e., indicators directly relevant to biology), including decreased temperature. Particularly relevant in lagoons or other features that were fully or partially enclosed prior to restoration and have been reconnected to tidal influence.	Rapid improvement expected after restoration of tidal hydrology.	Considerations: - Water velocity and other indicators of flushing - Channel drainage network development Potential actions: - Active management such as baffles,

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
					aerators, etc. - Applied studies to find causes of water quality problems
Large woody debris (LWD) and wrack accumulation	Detritus recruitment and retention	- Wrack composition and amount - Large wood composition, recruitment, movement, and residence	Woody debris will be carried in naturally from restored tidal flushing. Debris will contribute to the amount of organic carbon in the system, but should not interfere dramatically with flushing. LWD should accumulate inside barrier berm from increased overwashing event.	Potential for accumulation immediately following restoration of tidal hydrology; actual rate depends on flow rates and weather events (overwashing).	Considerations: - Is embayment opening large enough to allow passage of LWD? - Source of LWD - Beach profile steepness Potential actions: - Increase size of embayment opening - Regrading of beach profile - Removal and relocation of LWD

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
					from locations that cause blockage to flow, particularly following weather events
Colonization by native vegetation	Erosion and accretion of sediments Detritus recruitment and retention	- Distribution and abundance of native plants by type - Species richness - Distribution and abundance of invasive plants	Vegetation assemblage will develop and change naturally based on restored salinity and topography regime. Colonization is tied to marsh plain redevelopment. However, some areas of the site may remain unvegetated naturally.	Dependent on rate of marsh surface elevation increase; anticipated to be detectable within 5 years of reaching appropriate elevations.	Considerations: - Disruption by management measures, (e.g., removal of fill) - Potential barriers to organism exchange - Marsh plain elevation and topography - Water quality metrics - Invasive plant colonization Potential actions:

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
					- Revegetation - Control of invasive plants, particularly in areas not affected by tidal inundation

Tertiary Indicators

Increased habitat area, quality, and complexity	ALL	- Distribution and extent by habitat type - Intertidal and shallow subtidal area - Shoreline length and complexity - Habitat quality rating based on sediment, water, vegetation measurements collected as part	Gentle topography and salinity gradient of site will allow full gradient of habitats to be established. A wider intertidal area and lower wave reflection, as well as coarser sediment size, will create conditions suitable for fish spawning and bird use, as well as salmonid rearing. The site should develop redundant representation of the full	Area lost due to placement loss, including from armoring as well as manmade structures on the barrier feature, will be gained back immediately following armor removal. Extent and quality of other areas will respond	Considerations: - Analyze all available monitoring data to determine whether result is due to restoration or external factors Potential actions: - Assess relative to all other monitoring metrics – if processes have been restored but habitat function has not, consider change to conceptual

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
		of this monitoring plan - Landscape connectivity and patchiness	range of barrier embayment ecosystem components including stream deltas or ponds, tidal flats, salt marsh, channels, tidal delta, beach berm, beach face, and low tide terrace where historically present. The site should be formed of a contiguous large patch that is well connected to adjacent terrestrial and marine landscapes.	gradually following establishment of all structural responses.	model

4.4 Coastal Inlet Strategy

4.4.1 Predicted Functional Outcomes

Like barrier embayments, coastal inlets are defined by an area protected from wave energy by landscape configuration, and provide sheltered conditions for aquatic species. Coastal inlets differ from barrier embayments in the more perennial input of freshwater in the inlets. In addition, though a barrier feature may be present, it is less important to restoration objectives, which are more focused on bringing tidal and freshwater flushing back into the inlet system. Thirty-eight percent of historically mapped coastal inlets in Puget Sound have been modified from natural shoreline (Cereghino et al. 2012). These features have been filled or diked for development, disconnecting them from natural freshwater and tidal inputs.

The restoration objective for coastal inlets is to remove dominant stressors to a degree that allows undegraded tidal flows and freshwater inputs necessary to support a full range of coastal inlet ecosystem processes (Figure 4-7). Figure 4-8 outlines our conceptual model of the relationship between stressor removal, restored processes, and predicted structural and functional responses. Following restoration of tidal hydrology, tidal flushing will increase, and the inlet will maintain an opening appropriate to the size of the restored tidal prism. Restored flow through tidal channels will mobilize sediments and import water, while creating a complex network of more distinct, larger tidal channels. Increased water velocity will also excavate a network of dendritic marsh channels, increasing marsh area and complexity. Increased flushing through these channels will improve levels of organic carbon, oxygen, and nutrients in nearshore waters, and lead to the redevelopment of a salinity gradient throughout the inlet. Woody debris will be imported naturally and contribute to the biomass and structure of organic material near shore, and vegetation assemblages should recolonize according to the restored salinity and topography regime. In particular, floral and faunal assemblages should change from freshwater to saltwater marsh upon reconnection to tidal flushing (ESA 2011).

Following restoration of coastal inlet ecosystem processes, the system should develop redundant representation of coastal inlet ecosystem components including, where historically present, creek delta with swamp, scrub-shrub, marsh, tide flat, and channels. The restoration site should consist of well-connected large patches, and total shoreline length should increase (Cereghino et al. 2012).

Primary management measures include berm or dike removal where inlet topography is largely intact or topographic restoration (fill removal) where an inlet has been filled. Where primary management measures are insufficient to achieve predicted structural and functional responses, they may be complemented as necessary by hydraulic modification or revegetation.

4.4.2 Uncertainties

Response of the system to restoration:

- The effect of restoration on flooding risk is uncertain. Removal of dams and other barriers to tidal hydrology may increase flood risk to non-acquired properties. At the same time, removal of such barriers could reduce the extent of fluvial flooding during high creek flows.
- Restoration could necessitate shoreline armoring of non-acquired properties due to increased local erosion and channel migration.
- As with river deltas, the degree of channel excavation for several restoration sites is based on the assumption that increased flow and tidal energy will allow channels to redevelop and sustain themselves naturally. If this assumption is incorrect, further channel excavation may be necessary.

Cumulative effects, external factors, and constraints:

- Landward retreat of wetlands in response to sea level rise may be constrained by land use. This uncertainty is tied to the local rate of sea level rise.
- Changes to the watershed outside of the site, such as urban development, could change the effect of restoration actions on inlet area and edge density.

4.4.3 Monitoring Indicators, Metrics, and Adaptive Management Responses

Based on our conceptual model for the Coastal Inlet strategy, Table 4-4 outlines the relationships between indicators of structural and functional response and associated monitoring metrics. The predicted response and timeframe for metrics is described in general terms. Also listed are the primary processes that support proposed indicators – in other words, the indicator can develop according to its predicted response only if associated processes have been restored.

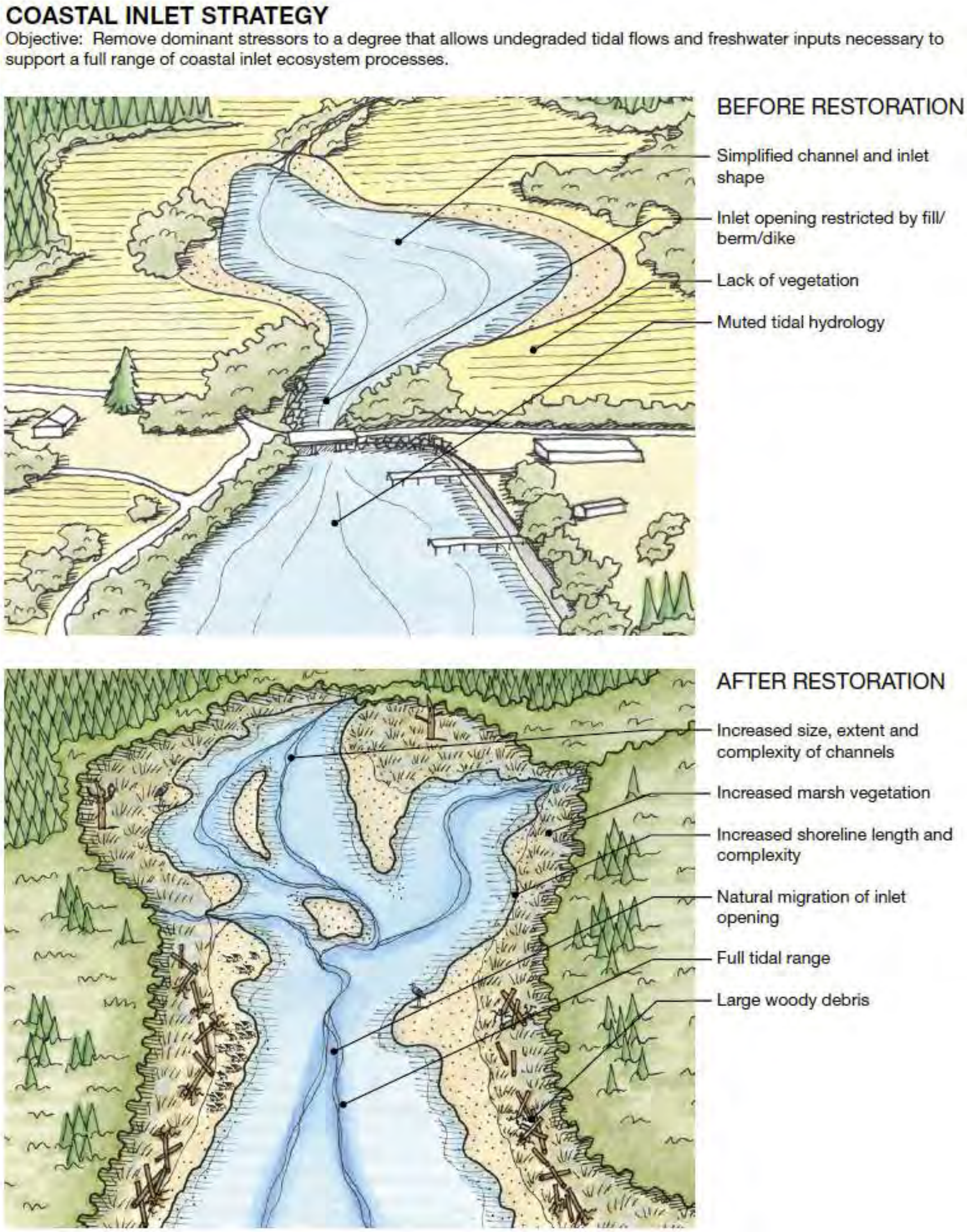

Figure 4-7: Example of a typical Puget Sound coastal inlet depicting the degraded system prior to restoration, and the structural and functional responses of the system following restoration.

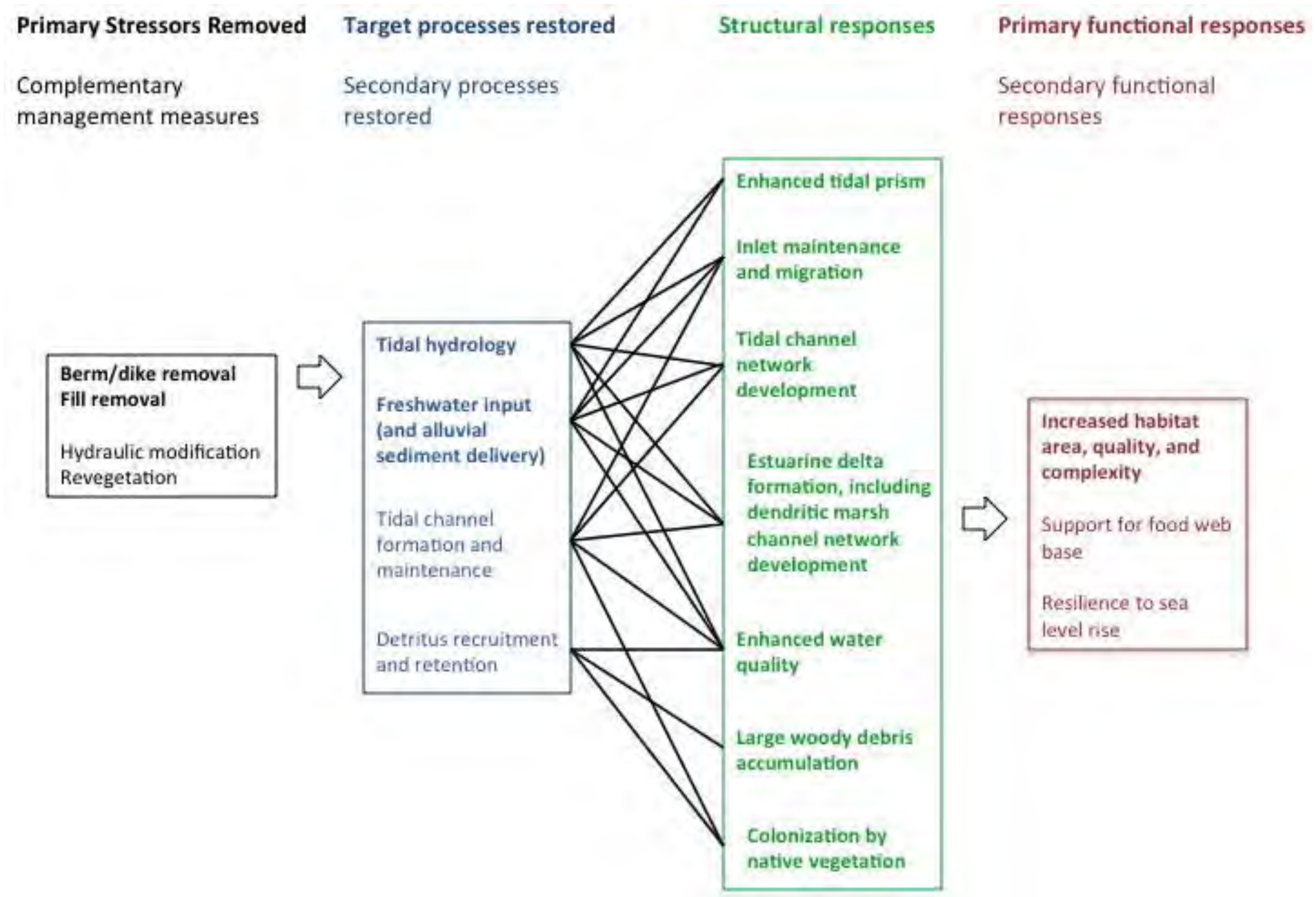

Figure 4-8: Conceptual model of management measures, restored processes, and structural and functional responses for the Coastal Inlet strategy.

Table 4-4: Coastal Inlet Strategy Monitoring Table.

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
Primary Indicators					
Enhanced tidal prism	Tidal hydrology Freshwater input	- Water level (tidal elevations) - Water velocity - Tidal prism (volumetric) - Salinity	Tidal prism will increase, resulting in enhanced tidal elevations, increased water velocity/flushing, and reestablishment of a salinity gradient throughout the inlet. Size of restored tidal prism is directly dependent on degree of stressor removal.	Immediately following restoration.	Considerations: - Calculation of full, restored tidal prism and associated size of inlet opening Potential actions: - Increase size of inlet opening - Topographic restoration
Secondary Indicators					
Inlet opening maintenance and migration	Tidal hydrology Freshwater input Tidal	- Cross-section and bathymetry of inlet opening	Inlet will maintain an opening sufficient for restored tidal prism. Restored flow through tidal channels will export impounded sediments and import	Immediately following restoration.	Considerations: - Assumption: Inlet will naturally resize to accommodate tidal prism

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
	channel formation and maintenance		water. Erosion and migration of inlet opening are also possible, but not indicators of restoration success.		- Impounded sediments inside the inlet - Sediment source outside the inlet - Water velocity/flushing sufficient to maintain opening Potential actions: - (Further) removal of fill/impounded sediments
Tidal channel network development	Tidal hydrology Freshwater input Tidal channel formation and	- Dendritic tidal channel geometry measurements - Channel density - Channel cross-sections - Panne and pond	More distinct, larger tidal channels will form. Where a single starter channel has been excavated, a more complex network will develop.	Rate of tidal channel network development depends on size of restored tidal prism.	Considerations: - Assumption: excavation of higher order channels will allow lower order channels to develop naturally

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
	maintenance	size distribution relative to channel network - Site-scale topography/bathymetry - Local erosion and accretion	Enhanced flow through channels will change sediment deposition patterns, resulting in erosion within the channels and deposition in backwater areas.		Potential actions: - (Further) channel excavation - Promote meanders with engineered log jams
Estuarine delta formation, including dendritic marsh channel network development	Tidal hydrology Freshwater input Tidal channel formation and maintenance	- Marsh area and edge density - Channel configuration - Sediment composition and structure	Network of dendritic intertidal marsh and marsh drainage channels will develop, increasing marsh area and complexity. Delta structure will change, including a reduction in delta "cones." Increased water velocity through the channels will result in coarser sediment overall.	Rate of tidal channel network development depends on size of restored tidal prism.	Considerations: - Have management actions interfered with existing drainage pattern? - Assumption: excavation of higher order channels will allow lower order channels to develop naturally Potential actions: - Filling of existing

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
					drainage channels - (Further) channel excavation - Promote meanders with engineered log jams
Enhanced water quality	Tidal hydrology Freshwater input Tidal channel formation and maintenance Detritus recruitment and retention	- Dissolved organic carbon - Dissolved oxygen - pH - Temperature - Turbidity - Chlorophyll a - Sediment oxygen demand	Increased flushing and connectivity will lead to enhanced water quality in terms of habitat conditions (i.e, indicators directly relevant to biology), including decreased temperature.	Rapid improve-ment expected after restoration of tidal hydrology and freshwater input.	Considerations: - Water velocity and other indicators of flushing - Channel drainage network development Potential actions: - Active management such as baffles, aerators, etc. - Applied studies to find causes of water

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
					quality problems
Large woody debris (LWD) accumulation	Detritus recruitment and retention	- Large wood composition, recruitment, and residence	Woody debris will be carried in naturally from restored tidal and freshwater flushing. Debris will contribute to the amount of organic carbon in the system, but should not interfere dramatically with flushing.	Potential for accumulatio n immediately following restoration of tidal hydrology; actual rate depends on flow rates.	Considerations: - Is inlet opening/freshwater connection large enough to allow passage of LWD? - Source of LWD Potential actions: - Increase size of inlet opening/freshwater connection - Removal and relocation of LWD from locations that cause blockage to flow, particularly following weather and/or inundation events

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
Colonization of native vegetation	Tidal channel formation and maintenance Detritus recruitment and retention	- Distribution and abundance of native plants by type - Species richness - Distribution and abundance of invasive plants	Vegetation assemblage will develop and change based on restored salinity and topography regime. In particular, assemblage should change from freshwater to saltwater marsh upon reconnection to tidal flushing.	Expected to occur rapidly upon restoration of tidal hydrology	Considerations: - Disruption by management measures, (e.g., removal of fill) - Potential barriers to organism exchange - Marsh plain elevation and topography - Water quality metrics - Invasive plant colonization Potential actions: - Revegetation, particularly following fill removal - Regrading of

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
					marsh surface - Invasive plant removal

Tertiary Indicators

Increased habitat area, quality, and complexity	ALL	- Distribution and extent by habitat type - Intertidal and shallow subtidal area - Shoreline length and complexity - Habitat quality rating based on sediment, water, vegetation measurements collected as part of this monitoring plan. - Landscape connectivity and	A greater diversity and functionality of habitats will develop. In particular, habitats with conditions (sediment size, water quality, vegetation) appropriate for shellfish, salmonid rearing spawning, and feeding will increase in area. Development of complex channel networks will result in enhanced shoreline length and complexity. The site should develop redundant representation of the full range of coastal inlet	Extent and quality of habitats will respond gradually following establishme nt of all structural responses.	Considerations: - Analyze all available monitoring data to determine whether result is due to restoration or external factors Potential actions: - Assess relative to all other monitoring metrics – if processes have been restored but habitat function has not, consider change to

Structural/Functional Response	Restored Process(es)	Monitoring Metrics	Predicted Response	Predicted Timeframe	Adaptive Management Response
		patchiness	components including creek delta with swamp, salt marsh, tide flat, and channels where historically present. The site should be formed of contiguous large patches that are well connected to each other and to the adjacent river, terrestrial, and marine landscapes.		conceptual model

5. Implementation of Effectiveness Monitoring

Effectiveness monitoring, using the framework outlined in Section 4, will be initiated upon completion of construction of the restoration site, although studies may have occurred at one or more reference sites prior to this time. According to Corps guidance, monitoring will be cost-shared between the Corps and the non-Federal sponsor for 10 years, after which time all costs will be the responsibility of the non-Federal sponsor. Once achievement of project objectives has been demonstrated by monitoring results and documented by the Corps and the non-Federal sponsor, no further monitoring will be required (USACE 2009). However, the non-Federal sponsors and other organizations pursuing more in-depth resolution of scientific uncertainties addressed by the site may continue certain elements of the effectiveness monitoring as part of more comprehensive validation monitoring efforts.

5.1 Development of Site-level Monitoring Plans

Earlier sections of this document provide a framework for monitoring PSNERP restoration strategies, and should be used to develop specific monitoring plans for individual sites. Site sponsors should draw from current scientific understanding, reference sites, historical conditions, stakeholder input, and traditional ecological knowledge to develop plans that satisfy the unique monitoring needs of each site. The Conceptual Design Report for each of the sites should be reviewed to determine if the identified site-specific risks and uncertainties have associated monitoring needs.

As required, additional scientific investigations and modeling should be used to develop site-specific predicted ecological outcomes and select appropriate metrics to measure and track these outcomes. Site-specific plans should also address monitoring of potential construction-related impacts such as sediment suspension or contamination from nearshore fill removal. To ensure integrity of the monitoring plan, site sponsors should work with PSNERP scientists, local scientists, and local resource managers to define monitoring targets for each metric, as well as an estimate of how long the site will need to be monitored before declaring functional performance.

5.2 Site Monitoring Design

5.2.1 Sampling Methodology

Design and implementation of site-specific monitoring of a restoration action should ideally originate with the development of restoration goals framed in part by the ecosystem processes, structure, and functions targeted for restoration. Effective monitoring of progress toward these goals can then be achieved through a scientific framework of repeated sampling, long-term data sets, and statistical analysis. Standard, proven, and repeatable monitoring methods should be used where possible to make results comparable across all PSNERP restoration sites. Monitoring methods should incorporate flexibility and event-triggered sampling to account for schedule interruptions due to natural variability, stochastic events, and regional trends. In general, sampling approaches and instrumentation selected for each restoration site should prioritize standardization and cost-effectiveness. For example, photogrammetric remote-sensing could be employed to provide information on a large number of monitoring metrics across all four restoration strategies.

Change can occur over multiple temporal and spatial scales, and this heterogeneity should be reflected in monitoring design. The landscape-forming processes that are the focus of PSNERP restoration strategy vary within a given region, and may encompass multiple ecosystem units. These processes typically range from meters to hundreds of meters (e.g., cross-beach, tidal slough) or hundreds of meters to kilometers (e.g., along-beach within a drift cell, or within a salinity regime). Site-scale monitoring is intended to examine development of these processes within the footprint of the site; this monitoring should include analysis of the restoration site as well as any reference sites. In general, monitoring should demonstrate trends through time, and sampling frequency should differ for each monitoring metric according to temporal scale, monitoring questions, resource availability, and instrumentation capacity. However, change that occurs early after restoration is often accelerated. As such, intensive monitoring that allows for contingency planning should occur in the first five to 10 years after restoration, followed by a period of less frequent sampling.

5.2.2 Reference Sites

Linking a desired ecosystem response to a specific management measure within a site will require careful selection of the most appropriate reference site(s), which should be explicitly identified as part of the site-specific monitoring plan. A reference site provides a basis of comparison to the restoration site and to pre-restoration conditions, helps inform acceptable values for monitoring metrics (Goetz et al. 2004), and can serve as a covariate that takes into account natural variability (Roni et al. 2005). It should have a minimal history of anthropogenic disturbance and exhibit a natural range of processes, and thus the target condition for the restoration (NRC 1992). The reference site should be comparable in process, structure, and function to the restoration site before it was degraded. Despite the challenges of identifying a relatively undisturbed reference site that is directly comparable to the restoration site, monitoring often involves pairing of treatment and reference (or "control") sites in a BACI (Before-After-Control-Impact) methodology to distinguish natural from treatment variability, and to reduce sample size and simplify data analyses (Roni at al. 2005). In general, the reference and restoration sites should be monitored with similar intensity to allow for more direct comparison of monitoring metrics, and baseline data should be collected from both reference and restoration sites before construction in order to detect change in critical processes over time.

The considerable natural variability in natural ecosystem processes (e.g., those influenced by landscape setting) often calls for monitoring a suite of reference sites (Short et al. 2000; Anisfeld 2012). The optimal timing for incorporation of reference sites, and particularly a complex of reference conditions, would be in the planning stage of the restoration, when goals are defined. However, inclusion of reference site structure and processes, much less ecosystem function, is inconsistent and relatively rare among the restoration sites considered by PSNERP. Comprehensive development of a suite of reference sites to monitor in concert with the PSNERP restoration sites would likely fall under broader, programmatic coordination with the non-Federal sponsors, especially when validation monitoring (see Section 6) is incorporated into such a comprehensive monitoring scheme. Such a coordinated approach would potentially serve other Federal and non-Federal restoration actions, as well as draw on established nearshore ecosystem monitoring, such as the Padilla Bay National Estuarine Research Reserve's long-term monitoring and research, to serve the needs of the broader Puget Sound restoration community.

5.3 Organizational Framework

Due to the complex nature of management of lands and natural resources, monitoring must be an inter-institutional effort. While it is possible that a centralized organizational framework may be established to oversee monitoring and analyze results, each of the 19 PSNERP restoration sites will not necessarily be monitored by the same organization. Instead, as part of the development of the site-specific monitoring plan, entities other than the Corps or the non-Federal sponsor will perform the monitoring at some or all restoration sites. Entities responsible for monitoring will provide monitoring results back to the Corps and the non-Federal sponsor. This direct line of communication is critical to allow for active contingency planning. All parties who are involved in or affected by the restoration site must have access to monitoring results, and results should be publicly available. The Corps will use these results in consultation with the non-Federal sponsor to guide decisions regarding any necessary mid-course corrections to the management measures applied at a restoration site (USACE 2009). They will also be used by PSNERP to continue to develop and improve new restoration actions that move the program toward its overall objectives.

Because ecosystem restoration affects people both within and outside of the program at every stage, stakeholder involvement and public outreach should be as transparent and inclusive a process as possible. Broad stakeholder involvement will benefit restoration planning by ensuring use of the best possible scientific information, including local and traditional ecological knowledge. Individual stakeholder groups may complement the program's assessment of monitoring results with analyses that cater to a specific ecosystem service, such as forage fish spawning or juvenile salmon rearing habitat.

In order to maximize the benefits of PSNERP restoration sites, monitoring efforts must be integrated with other outreach efforts of the broader Puget Sound restoration community. In general, stakeholder input at every level is necessary to address complex restoration issues, such as competing land uses or risks to adjacent properties, successfully. This can be accomplished through a combined strategy of sponsored community workshops, ongoing informal dialogues, and leveraging the outreach capabilities of involved, local non-governmental organizations. By fostering a relationship with the public, the Corps can facilitate the success of PSNERP restoration actions, and assist with broader nearshore ecosystem restoration in Puget Sound. Such information feedback will lead to better understanding of nearshore ecosystem restoration that will increase functional performance of PSNERP actions. Sharing of both emerging monitoring results as well as adaptive management actions will facilitate learning and programmatic improvement: restoration actions and scientific investigations conducted concurrently outside of PSNERP may provide insight into new science needs, restoration strategies, and monitoring approaches. Communication and collaboration should be fostered and maintained with Federal, state, and local agencies, as well as tribal governments, non-profit organizations, and community groups. This can be done as a continuation of the Stakeholder Involvement Plan developed during the feasibility phase of the GI. In addition to information sharing, this collaboration may include cooperative planning efforts, shared construction, shared operations and maintenance, or shared monitoring activities.

5.4 Analysis and Reporting

In order to support management of restoration sites, raw monitoring data and basic field reports should be supplied to the party conducting data analysis as soon as possible following data collection. Raw monitoring data must be processed and converted into actionable information. This involves quality control, statistical analysis, and summary and presentation in regular reports. These reports should emphasize full reporting and synthesis of results into coherent narrative and graphical presentations. They should be provided in a timely manner to the Corps and non-Federal sponsor, and published online through the PSNERP website for consumption by the broader restoration community and the public.

When appropriate, PSNERP should seek peer-review of the synthesized monitoring results. In general, peer review is a critical element of any science-based program. It helps to ensure use of best available science, can validate or provide alternative interpretations of monitoring results, and can make methods and conclusions defensible. PSNERP has incorporated product-specific peer review of technical documents as well as programmatic review of science usage into the selection process for restoration sites. Under this monitoring framework, peer-review will continue for reports, decision-support tools, and other products generated from monitoring results. Results should also be shared less formally through participation in regional conferences and major science symposia such as the Salish Sea Ecosystem Conference. These events can serve as two-way conduits for restoration knowledge between PSNERP and the broader restoration community. Ultimately, PSNERP should ensure that results from monitoring and adaptive actions are integrated with broader regional management initiatives, such as the Puget Sound Partnership's Puget Sound Science Update.

5.5 Data Management

In order to inform restoration science and decision-making into the future, monitoring data must be preserved and stewarded for long-term access and usability. Formal archiving is critical to ensure establishment of institutional memory within the program, and to develop the redundancy and long time series necessary for rigorous statistical analysis. A data management plan separate from this document should be developed in the pre-construction phase before monitoring data begin to flow. This plan should identify an agency or organization capable of providing long-term stewardship of the data while adaptively meeting the needs of the Project. Ideally, this agency will provide the full suite of archival services, including ingest, data management, archival storage, access, preservation planning, and administration (CCSDS 2003).

The data management plan should provide for data discovery and access by the public. This may be accomplished directly by the archival agency, or through a separate online portal. Data should be made available in standard, well-documented formats, so that they can be incorporated into a larger Puget Sound-wide data set. This will enable timely use of the data for site-scale improvement and adaptive management responses within the program. It will also allow scientists inside and outside of PSNERP to inform and refine ecosystem models, which in turn can be used to predict outcomes for future restoration actions or programs.

6. Validation Monitoring

Whenever feasible, effectiveness monitoring of PSNERP restoration sites should be integrated with regional initiatives that are testing the assumed linkages between functional objectives and overall goals of Puget Sound-wide conservation and restoration programs. Linking to these external monitoring and science efforts would increase understanding of the relationship between PSNERP's process-based restoration and the delivery of ecosystem functions, goods, and services (EFG&S). Validation monitoring is secondary to this document, and is not a responsibility of the Corps and non-Federal sponsor. Thus, the PSNERP strategy for validation monitoring involves enabling monitoring efforts of relevant EFG&S by other groups in Puget Sound. This strategy enhances PSNERP's connection to the broader Puget Sound restoration community, while simultaneously collecting valuable validation monitoring information that can be used to improve the next generation of restoration sites in Puget Sound.

6.1 Goals

Alterations of natural processes damage nearshore ecosystem structures and functions, all three of which provide EFG&S that people value. There is an emerging policy focus on framing restoration benefits in terms of EFG&S, which would allow more direct economic valuation. However, the response of EFG&S to specific restoration actions is difficult to predict due to a high degree of influence from external factors, natural variability, and uncertainty in response timing. For this reason, validation monitoring is not used to evaluate the effectiveness of restoration actions. Instead, the goal of validation monitoring is to increase understanding of the relationship between process-based restoration actions and EFG&S. This includes increasing predictability of social attitudes about nearshore ecosystems and the social and economic benefits derived from their restoration.

6.2 Approach

Validation monitoring of PSNERP restoration should be framed around the assumed linkages between process-based restoration and EFG&S. Where feasible, EFG&S can be monitored directly and results compared to predicted functional outcomes. These predictions are based on historical provision of EFG&S by a given system, as well as current scientific understanding of that system. Although EFG&S encompass a broad suite of provisioning, regulating, supporting and cultural benefits to humans (Simenstad et al. 2011), PSNERP has attached particular emphasis to Valued Ecosystem Components (VECs; Leschine and Peterson 2007). Although VECs form a very small subset of the EFG&S provided by Puget Sound nearshore ecosystems, they are intended to represent ecologically and socially relevant beneficiaries of PSNERP restoration actions, and are recognized by many people as emblematic of a "healthy" Puget Sound (Schlenger et al. 2011). Due to their regional importance, many efforts are underway across Puget Sound to monitor many of the VECs, providing PSNERP with opportunities to link their restoration actions to validation-monitoring goals.

The PSNERP restoration sites will provide opportunities to learn how various aspects of nearshore ecosystem restoration influence and are influenced by public perception and attitudes. Social data collection is especially important to those restoration sites constrained by private property. Willingness-to-pay or other valuation indicators can be used to assess how much the public values non-commodity EFG&S such as aesthetics. Social and economic monitoring are beyond the scope of the monitoring tasks performed by the Corps and non-Federal sponsor, but their analysis can be facilitated through efforts monitoring VECs. As more detailed plans for PSNERP implementation monitoring are developed, opportunities to leverage this investment and coordinate with Sound-wide monitoring efforts to address validation monitoring will be pursued.

6.3 Predicted Functional Outcomes

Although Puget Sound's nearshore ecosystems provide many EFG&S, one of the more important EFG&S is the provision habitat for a variety of fish, shellfish, birds, and other wildlife. Many species and life history types of juvenile Pacific salmon rely on tidal marshes and channel networks of deltas and small estuaries and shorelines of the barrier beaches of open coastal inlets for rearing and foraging. In addition, over 30 species of shorebirds, as well as migratory and predatory birds, use these habitats for migration, forage, feeding, roosting, and reproduction (Collins and Sheik 2005; Buchanan 2006; Dethier 2006; Fresh 2006; Eissinger 2007; Mumford 2007; Penttila 2007). In addition to these valued habitat functions, nearshore ecosystems provide EFG&S that are economically important, including production of benthic invertebrates and insects, nutrient cycling, water filtration, drainage and flood management, recreation, and shellfish production (Schlenger et al. 2011).

6.4 Uncertainties and Programmatic Improvement

Validation monitoring addresses uncertainties associated with the assumptions linking PSNERP process-based restoration with the delivery of EFG&S. These include questions regarding the impacts of stressors to nearshore processes on EFG&S, such as whether such impacts can be effectively reversed by site-specific restoration. Compared to structural and functional responses, predicted ecological outcomes are often less clearly or directly linked to restoration actions for EFG&S. As a result, causal relationships are difficult to define from monitoring results at the site scale. Analysis of validation monitoring results from a collection of restoration sites within a single strategy group, or across many regional restoration and protection initiatives, reduces these uncertainties.

As might be expected from the embryonic science and technology of ecosystem restoration, there are a plethora of uncertainties associated with assumptions about EFG&S that will reliably derive from the many management measures deployed, as well as across different types and scales of Puget Sound's nearshore landforms. An extensive list of questions was compiled for the comprehensive PSNERP research plan (Gelfenbaum et al. 2006), many of which are still unresolved and would be critical candidates for focused validation monitoring that could be deployed among the program's candidate restoration sites. A few examples of some of the more persistent uncertainties that still plague restoration planning and design across individual- to multiple-site scales, and which are prime candidates for validation monitoring, include:

Management measure-specific:

- Restoring Tidal Hydrology
    - Will dendritic tidal channel systems evolve more naturally complex plan-form structure (in erosive sediments) without intervention than with constructed tidal channels?
    - Is there a difference between dike breaching and dike removal in vegetation recruitment and fish utilization of a recovering wetland?
- Bulkhead Removal
    - What are the attributes of forage fish habitat that are restored or enhanced by a bulkhead removal?
    - At what scale does bulkhead removal become meaningful/beneficial? How effective are alternative techniques and do they restore the relationships among processes, structure, or functions?
- Beach Nourishment
    - Will forage fish spawn on nourished beaches?
    - Does sediment placed on the beach face move offshore to benefit nearshore biota outside the nourishment footprint?
    - Independent of a management measure or comprising multiple measures:
    - How does variability in site-scale habitat features (e.g., water depth and vegetation characteristics) and landscape-scale habitat features affect juvenile salmon and other VEC performance?
    - Is there a cumulative effect of restoring degraded nearshore ecosystems that are adjacent to protected/conserved shorelines?

For the same reason EFG&S responses are difficult to predict, they are also difficult to address through site-scale contingency planning. Results from validation monitoring of EFG&S are therefore used primarily for programmatic improvement, e.g., “adaptive learning” (McLain and Lee 1996). Analysis of these results can be used to increase scientific understanding of the links between restoration actions and EFG&S for a given strategy, which could lead to a shift in scope or approach for the next generation of restoration sites. Ultimately, the benefits of process-based restoration of nearshore ecosystems could be defined in terms of the EFG&S they provide, linking these directly to process, structure, and function and strengthening to our understanding of Puget Sound’s nearshore ecosystems.

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