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FEASIBILITY OF USING SEDIMENT PROFILE IMAGING TECHNOLOGY TO EVALUATE SEDIMENT QUALITY AND IMPACTS TO BENTHIC COMMUNITIES FOUND AT TWO CONTAMINATED SEDIMENT CLEANUP SITES IN THE PUGET SOUND

Quality Assurance Project Plan

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TABLE OF CONTENTS

1.0 Project Description

This Quality Assurance Project Plan (QAPP) is prepared by Germano and Associates Inc, Bellevue, WA for the Washington State Department of Ecology (Ecology). This QAPP is a required deliverable as specified in Ecology Contract CO 600320.

This QAPP details the objectives, sampling design, data collection, analytical procedures, reporting, and organizational structure to be used by Germano and Associates for two sediment profile imaging (SPI) surveys in Puget Sound. The first survey will be conducted in the Lower Duwamish Waterway, Seattle WA and the second will be conducted at the former Pope and Talbot mill in Port Gamble, WA.

1.1 Project Objectives

There are several purposes for these SPI studies. A review of these goals was accomplished at an initial meeting of the project team held on June 1, 2006. The items discussed during this kickoff meeting are incorporated in this QAPP. A summary of the goals for both SPI surveys is provided below. The primary project objective for both the survey in the Lower Duwamish Water and the survey in Port Gamble is to collect SPI images and provide analytical data that can then be used by Ecology to evaluate SPI as a predictive tool for predicting the health or impairment of benthic communities.

1.1.1 Lower Duwamish Waterway SPI Survey Objectives

The Lower Duwamish Waterway (LDW) is an estuarine waterway subject to freshwater flow and tidal exchange. Furthermore, this waterway is channelized and highly industrialized with anthropogenic disturbances such as contamination, vessel traffic, and construction activities superimposed on natural, estuarine-fluvial disturbance patterns. Goals of the LDW survey include:

1. Characterize the spatial distribution of sediment types
2. Characterize the spatial distribution of benthic habitats
3. Characterize the spatial distribution of benthic communities
4. Characterize baseline conditions against which future monitoring studies can be compared.

1.1.2 Port Gamble SPI Survey Objectives

The Port Gamble site is a former timber mill and log storage facility. Although the Port Gamble site is subject to high tidal exchange, there is no fluvial input to the system and anthropogenic disturbances are mostly limited to historical deposition of wood and bark debris generated during the storage, handling and transfer of logs from the marine environment to the mill facility. Goals of the Port Gamble survey include:

1. Characterize the spatial distribution of sediment types
2. Characterize the spatial distribution of benthic habitats
3. Characterize the spatial distribution of benthic communities
4. Augment existing data on the distribution of wood residues.

1.2 Project Quality Objectives and Criteria

SPI is a benthic sampling technique in which a specialized camera is used to obtain vertical cross-section photographs (profiles) of the upper 15 to 20 cm of the seafloor (Rhoads and Germano 1982; 1986). This is a reconnaissance survey technique used for rapid collection, interpretation and mapping of data on physical and biological seafloor characteristics. This technique has been used in estuarine, coastal and deep-sea environments worldwide for over 20 years. Measurements obtained from sediment-profile images are used to characterize surface sediment types and small-scale (< 20 cm) depositional layering, map benthic habitat disturbance gradients, and follow ecosystem recovery after disturbance abatement.

Plan-view (i.e., horizontal plane) video records of the seafloor surface will be obtained in conjunction with the sediment-profile images at each station. The plan-view video records are acquired with a downward-looking camera and strobe light system attached to the sediment-profile camera frame. The video images are taken immediately prior to landing of the frame on the bottom and while the camera is sitting on the bottom. Plan-view video will be utilized in lieu of plan-view still photography due to anticipated water turbidity levels. Should turbidity levels at the site prove to be low, Germano and Associates may instead opt to collect plan-view photographs.

The quality objectives for this project are summarized in Table 1. Sediment-profile and plan-view imaging both represent semi-quantitative sampling techniques, and no specific reference materials or standards exist that can be used to evaluate directly the accuracy of the collected data. Comparability is assured by adherence to the standard operating procedures for field collection and subsequent computer-based analysis of images. Use of standard procedures for image acquisition, analysis and reporting ensures comparability among images obtained under different studies or among different times within the same study. Three replicate sediment-profile images and at least one plan-view video sequence will be obtained at each station.

For the three replicate SPI images obtained at each station full analytical results will be reported for each replicate and used for mapping and interpretative purposes. In addition, an average value will be calculated for each of the measured parameters (e.g., redox potential discontinuity [RPD] depth, camera penetration depth, small-scale surface roughness, Organism-Sediment Index). For parameters that are not expressed on a continuous number scale (e.g., successional stage designation; grain size major mode), all of the replicate values will be displayed in maps and used for interpretative purposes. It is not possible to specify acceptance criteria for precision or agreement among the values measured for the three replicate images; these values will reflect the small-scale (i.e., on the order of a few meters between individual drops of the camera onto the seafloor at each station) spatial heterogeneity or homogeneity which is naturally present at a given station.

The completeness objective for the sediment-profile and plan-view imaging work is 100%. The field procedures and associated QA/QC are designed to ensure that the 100% completeness goal is met. These procedures are described below. Briefly, back-up camera systems and a complete inventory of spare parts will be available to avoid loss of data due to mechanical or electronic equipment malfunction. The digital images will be downloaded to a lap-top computer and reviewed at regular intervals during the course of each field day. Any stations having missed images due, for example, to over- or under-penetration of the sediment-profile camera prism can be re-sampled. The camera penetration can be adjusted by adding weights, adjusting the stop-collars on the vertical rods that determine the prism penetration depth, or adding "mud doors" to increase the bearing surface of the instrument in soft muds; all of these techniques ensure successful image acquisition on a wide variety of sediment types.

Table 1.

Quality Objectives for Sediment-Profile and Plan-view Imaging

Monitoring Objective	**Data Requirements**	**Monitoring Approach**	**Field Decision Criteria/ Performance Specifications**
Based on features in the SPI images, determine the physical and biological characteristics of surface sediments in and around the Lower Duwamish Waterway and the former Pope and Talbot Port Gamble site	Full suite of analytical parameters listed below:	Collect sediment-profile images and sediment plan-view Video at each sampling station	Navigational accuracy should be ± 2m and sampling should occur within 10m of the proposed target location. Three replicate sediment-profile images and at a plan-view video sequence suitable for analysis will be collected at each station (100% completeness goal).

The full list of analytical parameters to be measured for this study are provided below. A more detailed description of each of these parameters is provided in Section 5.

1) Mean Prism Penetration Depth
2) Minimum Prism Penetration Depth
3) Maximum Prism Penetration Depth
4) Boundary Roughness
5) Mean RPD depth
6) Minimum RPD Depth
7) Maximum RPD Depth
8) Grain Size Major Mode
9) Minimum Grain Size
10) Maximum Grain Size
11) Presence or Absence of Sedimentary Methane
12) Presence or Absence of near-bottom low Dissolved Oxygen Conditions
13) Number of Feeding Voids
14) Minimum Depth of Feeding Voids
15) Maximum Depth of Feeding Voids
16) Presence or Absence of bacterial mats
17) Infaunal Successsional Stage
18) Number of Mudclasts at the Sediment-Water Interface
19) Oxidative State of Mudclasts at Sediment-Water Interface
20) Organism Sediment Index (OSI)
21) Benthic Habitat Quality Index (BHQ)
22) Presence/Absence of Bedforms
23) Sorting or Physical Disturbance Features
24) Amount of Wood Debris Present (Port Gamble)

2.0 Project Structure and Personnel

The Germano and Associates team is composed of Germano and Associates, Inc., Bellevue, WA, Browning Environmental Services, Olympia, WA; SeaRay Environmental, St. Mary's; GA, Exa Data and Mapping Services, Port Townsend, WA; and TerraStat Consulting Group, Snohomish, WA. A project organization chart is presented in Figure 2-1, along with the individual from each team member who will be contributing to the completion of the study. The personnel detailed in the project organization charts are committed to accomplish the specified tasks. No substitutions of personnel will be made throughout the course of this study.

2.1 Project Management

The project manager for this study is Dr. Joseph Germano, of Germano and Associates Inc., Bellevue, WA (Figure 2-1). Dr. Germano is responsible for ensuring the timeliness and quality of work products as well as the financial tracking of the project including invoicing. Dr. Germano is the primary point of contact for Ecology. Mr. David Browning of both Germano and Associates and Browning Environmental Services serves as assistant program manager and will be the point of contact after Dr. Germano.

2.2 Organizational Structure and Task Responsibilities

The Germano and Associates team is structured so that each team member has a specific and defined role. Figure 2-2 shows proposed project responsibilities for each team member and the responsible individual from each team member for each task outlined in the RFQQ. Our team is in the unique position of being able to provide redundancy for SPI expertise to ensure accuracy and timeliness of data products.

Dr. Joseph Germano will be responsible for the overall management and quality control of the project. Mr. David Browning will provide a large amount of technical input to the proposed program including QAPP preparation, SPI/plan-view video surveying, image analysis and reporting. Ms. Lorraine Read will provide input on sampling and experimental design for the QAPP and data analysis services for reporting. Ms. Peggy Myre will provide mapping and GIS services in support of report preparation and data deliverables to Ecology. Mr. Ray Valente will provide QA/QC for analyzed images on an as-needed basis.

Figure 2-1. The Germano and Associates Team and team organization

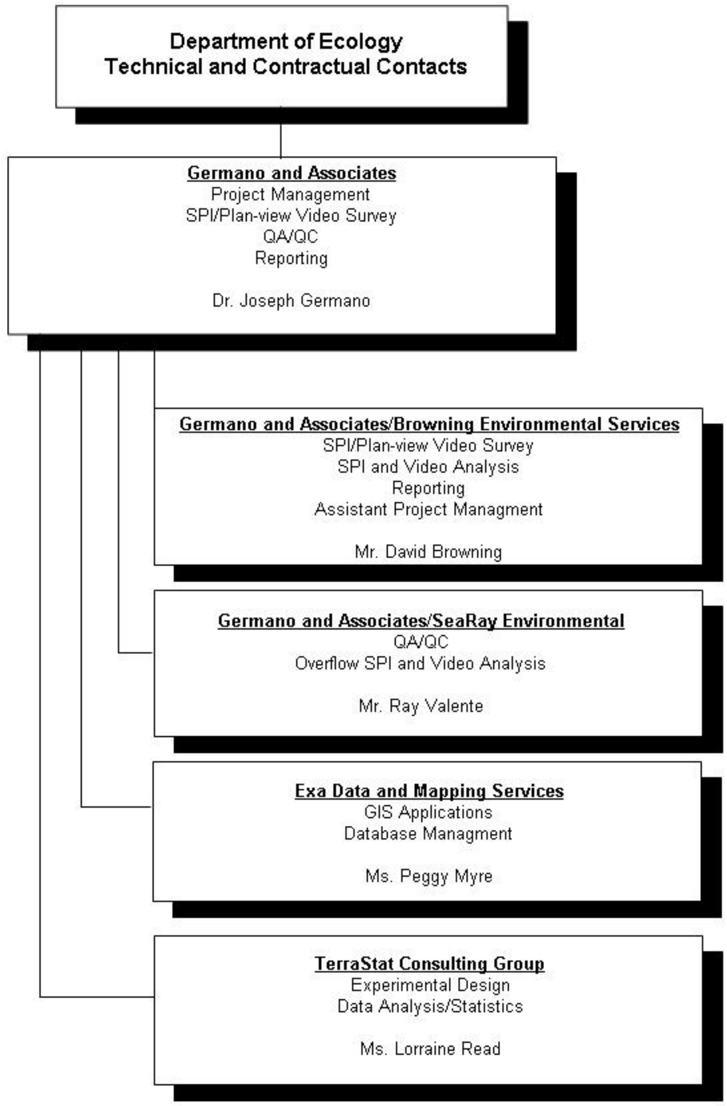
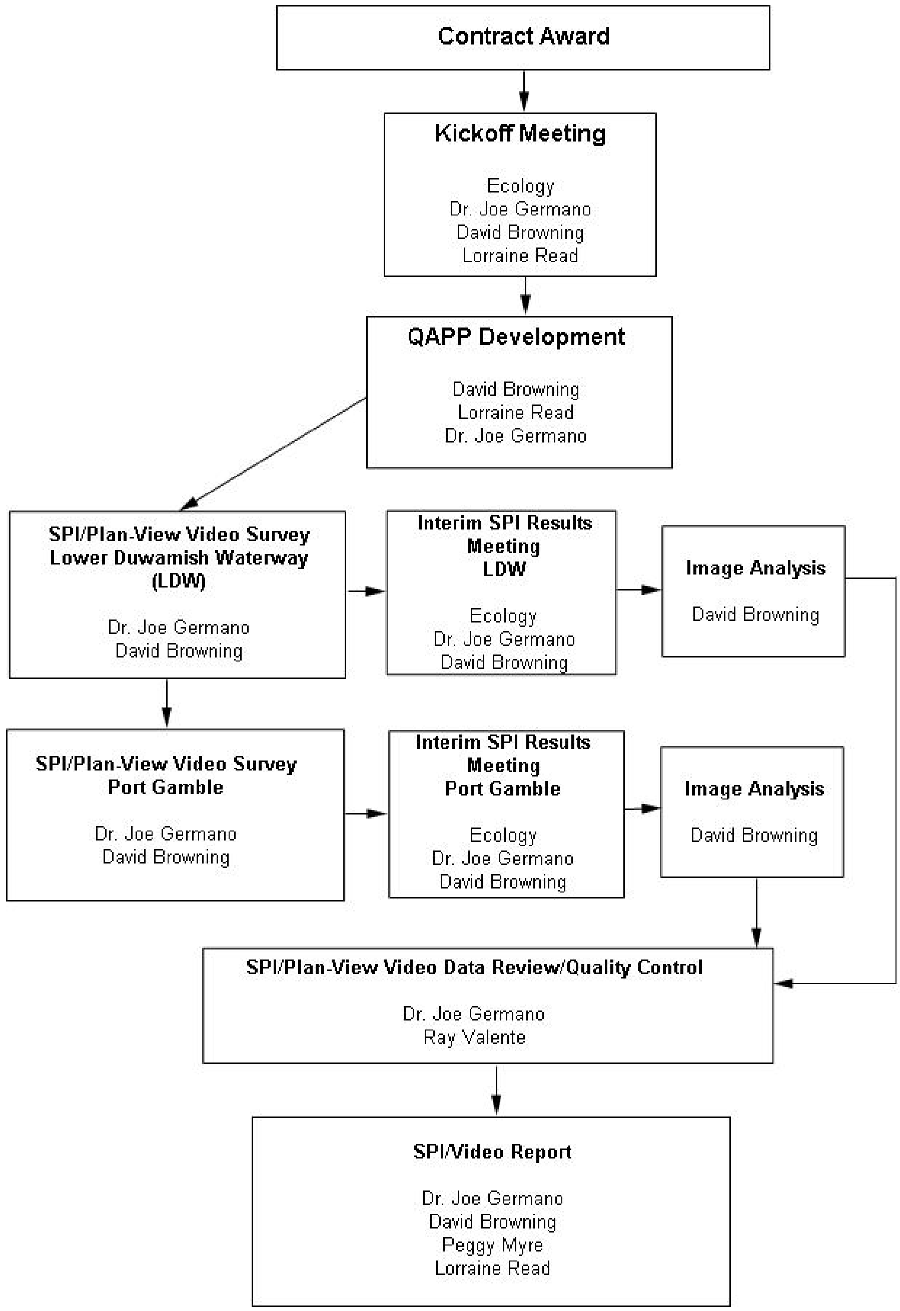


Figure 2-2. Flow Chart of Project Tasks and Responsible Personnel



The SPI surveys will be conducted by Dr. Germano and Mr. Browning aboard the Ecology-provided sampling platform the R/V KITTIWAKE. SPI and plan-view video results will be evaluated in the field and after the conclusion of sampling for consultation with Ecology.

After the conclusion of each sampling event, computerized image analysis of the SPI and video data will be conducted by David Browning. Mr. Browning will analyze each replicate image from each station and provide SPI and video data in a tabular format to Dr. Germano. The analytical results will be reviewed for completeness and accuracy by Dr. Joseph Germano and, if needed, Mr. Raymond Valente. Each replicate from each station will be reviewed for accuracy and completeness.

Reporting and synthesis of the SPI and video results will accomplished by Dr. Germano, Mr. Browning and Ms. Read with GIS support from Ms. Peggy Myre.

At each step of the proposed project, a team member is designated to serve as independent quality assurance/quality control, and other team members are available to serve in that role.

3.0 Sampling Design and Project Objectives

To meet the project of objective of correlating SPI results to sediment quality triad results, the selection of sampling stations for co-located SPI and Triad stations is of critical importance. Supplemental sampling stations for SPI will also be surveyed in addition to the co-located SPI/Triad stations.

Three types of SPI sampling locations are proposed:

1. Co-located SPI and Triad sampling stations
2. SPI-only sampling stations that are co-located with historical sampling locations
3. SPI-only stations that are not associated with triad or historical stations and will provide additional seafloor/habitat characterization information as well as serve as a baseline for future monitoring studies.

3.1 Study Design

Some knowledge about how the data will be analyzed is imperative for selecting an appropriate sampling design. The nature of this comparison is exploratory, and so several methods may be required to identify any patterns or correlations between the two sets of results. There are several possible approaches:

- A comparison of ordination results. This may be done using both visual comparisons of non-metric multi-dimensional scaling (N-MDS) plots, as well as a randomization test for comparing two ordinations (Mantel's Test). For the ordination of the complete TRIAD data set, care must be taken to initially select the best endpoints for each leg of the TRIAD (e.g., which benthic indices or summary metrics to use; and which method for expressing the collective chemical contamination, e.g., summation of SQL exceedance factors); as well as weighting the individual endpoints appropriately (e.g., so that each leg of the TRIAD has equal weight). An ordination of just the benthic results may also be used based on Bray-Curtis similarities. The ordination of the SPI data should use a distance metric that is appropriate for combining variables with different measurement scales (Kaufman and Rousseeuw 1990), because the SPI data are a combination of continuous, ordinal, and binomial variables.

- Investigation into ordination results. The N-MDS plots may show a gradient or a clustering pattern of stations to indicate different levels of benthic community structure and/or function. Correlations can be investigated between the N-MDS axes and independent variables in order to identify possible drivers for the particular ordination observed. For example, if the N-MDS is based on SPI results, the N-MDS axes would be correlated with the set of independent TRIAD endpoints.

- Chi-Square test on contingency table results. The contingency table may describe final categorization of stations according to SPI vs. TRIAD surveys. The types of categorizations may include overall status, or successional stage, etc.

- Linear Discriminant Analysis or Classification Tree Models. These methods attempt to describe class membership (e.g., SPI outcome/classification) as a function of independent variables (e.g., TRIAD endpoints). Alternatively, the set of variables could be switched so that the TRIAD outcome/classification is the dependent variable and the SPI endpoints are the set of independent variables.

All of these approaches require that there be a clear distinction across stations in the quality of the benthic community structure and/or function. The sampling design includes stations that are clearly impaired, and others that are clearly unimpaired. A smaller number of stations in the intermediate zone are also included to determine whether SPI results can be used to distinguish a gradient between the extreme conditions.

We have identified the primary factors expected to affect benthic community structure and/or function for each site. There are habitat factors (i.e., salinity, sediment grain size, depth) and anthropogenic factors (i.e., chemical contamination, wood waste, scour). In the sampling design, these factors will either be held constant, or will be used to stratify the sampling design. Those that are held constant will be factor levels within which conclusions will be limited (e.g., if all sampling occurs within a salinity range, then that salinity range is the universe for which inference will be made). The factors used to stratify the design should be present in all impairment categories to avoid confounding of habitat characteristics with anthropogenic factors that may be driving the impairment status.

Prior information regarding the above factors will be used to identify areas within each site that have high, moderate, or low potential for impairment. Areas with extremely high potential for impairment will be avoided, because these are expected to be clearly indicated as areas of impact based on both SPI and TRIAD results. A stratified design will be used to place the initial SPI stations within each potentially impaired category at a ratio of 40% of the total synoptic samples in the low potential category; 20% (moderate potential), and 40% (higher potential for impairment). The SPI results will be quickly reviewed, and stations for TRIAD analyses will be selected based on the following considerations:

- Stations that appear to contradict expectations (i.e., stations where initial SPI results look good but prior information indicated that these had a high potential for impairment; or vice versa).

- For the remaining stations (the total number minus those identified as contradictory, per the preceding bullet), the desired number of stations will be selected in each predefined impairment category by random allocation according to the original proportions (40/20/40 for low/moderate/high).

- Within each impairment category, the habitat factors that are expected to affect benthic condition will be used to define second level strata. For example, if the stations within one impairment category had both moderately fine-grained stations and very fine-grained stations, then equal numbers of stations should be placed in each group. If a minimum of 3 stations cannot be allocated to all strata, then some strata may be eliminated from the sampling design (and the universe for the comparisons will exclude those conditions).

The general design of the SPI portion of this study is based on an evaluation of existing information in order to identify areas expected to represent high, medium, and low benthic impairment. Consequently, the proposed station locations for these surveys are highly influenced by the spatial distribution of historical sampling locations and their observed outcomes in both the Lower Duwamish Waterway and the Port Gamble site. As such, the initial SPI station locations do not represent a strictly random sample of each survey site, but they are expected to be locations representative of the range of conditions at each site.

3.2 Lower Duwamish Waterway

For the Lower Duwamish Waterway (LDW), a total of 80 stations will be sampled using SPI. Table 2 shows the apportionment of the proposed sampling stations among the listed station and strata types.

In the LDW, stations proposed for SPI sampling by G&A and Triad sampling by Ecology will be linked to stations sampled and data reported during the LDW remedial investigation (Windward, 2003, 2005a-c). Because a purpose of the study is to determine whether SPI can be a predictive or correlative tool with Triad sampling, a range of expected conditions will be sampled.

The SPI survey of the synoptic areas, sampling will be limited to highly saline, subtidal areas of a minimum depth of 8 ft MLLW. Furthermore, the successional paradigm used in SPI biological evaluations is more suited for finer-grained sediments rather than very sandy sediments, so highly sandy areas will be avoided, and only areas expected to be more fine-grained ($\geq$ 60% fines) will be targeted. The same levels for the habitat factors should be present in all impairment categories so there is no confounding of these physical characteristics with the anthropogenic factors expected to drive the impairment status (i.e., wood waste, scour, chemical contamination). To normalize for habitat and physical influences, SPI and Triad station will be located in the northern portion of the LDW, from Slip 4 to the mouth.

Assuming a total of candidate 40 SPI/Triad stations (Table 2), the areas with high potential for impairment will get 40% of the total stations (n=16); moderate potential will get 20% (n=8); low potential will get 40% (n=16). Of these 40 stations, the 24 to 28 stations selected for TRIAD analyses (by Ecology) will include 9-11 stations in the high category, 5-7 stations in the moderate category, and 9-11 stations in the low category (barring any contradictory results). Again, these stations are linked to historical sampling stations where either or both chemical and toxicity testing has occurred.

For the SPI locations that are candidate TRIAD stations, the stations sampled in this survey which are linked to the historical stations will be offset from the historical station locations by 10 meters. This offset is applied in order to define a new and unique sampling location within the Lower Duwamish Waterway Superfund study framework. Each linked SPI/TRIAD station will be designated by the historical sampling location name followed by a "T" so that each SPI/TRIAD station will have a unique identifier relative to the historical stations (for example, the linked SPI/TRIAD station for historical station 06 will be designated 06T).

Table 2. Sampling Stations and Type for the SPI Survey in the Lower Duwamish

Station Type	Total Number	High Chemistry/ Toxicity	Medium Chemistry / Toxicity	Low Chemistry / Toxicity
SPI & candidate Triad Stations	40	16	8	16
SPI & Historical Stations	7	NA	NA	NA
SPI-only Baseline Stations	33-37	NA	NA	NA

A list of proposed sampling stations for the LDW is provided in Table 3. For the purposes of this study, 16 stations represent or are linked to historical stations that have chemical concentrations in excess of CSL, 8 have concentrations between CSL and SQS and 16 have chemical concentrations less than SQS. Contaminants that exceed regulatory levels at these stations are predominantly polychlorinated biphenyls (PCBs) and metals (ie. copper, mercury, cadmium). SPI sampling stations in the LDW are shown in Figures 1- 4. For stations that are linked and displaced from historical station by 10 m, the historical station name will be modified with a "T" designation to differentiate the historical station from the new SPI/TRIAD station. For stations that are not displaced from historical sampling locations, the station nomenclature will be consistent with the historical surveys. Locations for both the linked historical station and the new SPI/TRIAD station are provided in Table 3..

Seven historical stations that have been sampled for Triad analyses are also proposed as SPI stations (Figures 1-3). The Triad results from these stations are reported in Phase II Lower Duwamish Remedial Investigation (Windward 2005a-c). These stations may or may not supplant candidate Ecology Triad stations based on initial review of the SPI images collected during this survey. Minimally, SPI data obtained during this survey may be compared to historical results to evaluate any changes that have occurred. Although the Triad data are not synoptic with the SPI data, additional information regarding the importance of synopticity may be evaluated.

The Lower Duwamish Waterway is highly industrialized and is subject to near-constant human activities such as vessel traffic, construction, and commerce. Because of these factors, it may not be possible to safely pilot to each of the proposed locations, as obstructions or hazards may be present. In the event that it is not possible for the sampling vessel to reach a proposed sampling location, five candidate replacement stations are proposed and provided in Table 3.

Lastly, an additional group of 33 SPI stations is proposed to provide additional baseline information throughout the survey area. These stations are apportioned throughout the LDW to characterize the deeper (>20 ft) portion of the seafloor where there is most likely to be finer-grained sediments (>60% total fines) and a more stable, non-disturbed, benthic infaunal community. Furthermore, these stations are distributed throughout the LDW to allow gradients in benthic condition to be determined along with providing greater spatial coverage than the SPI/Triad and SPI/historical stations. These stations are named SP101-SP133 to distinguish them from historical sampling stations.

Table 3. Proposed SPI Station Locations for Lower Duwamish Waterway

Station Name	Exceedance	Chemicals	Latitude	Longitude
Expected High Impairment				
6	CSL	PCB, lead, BEHP	47 34.1358’ N	122 20.7656’ W
06T	Paired with 06		47 34.1400’ N	122 20.7600’ W
15	CSL	Mercury	47 33.9138’ N	122 20.8884’ W
015T	Paired with 015		47 33.9060’ N	122 20. 8800’W
73	CSL	Benzyl Alcohol	47 32.5776’ N	122 19.8168’ W
35	CSL	Multiple PAHs, Total LPAH, Dibenzofuran	47 33.3384’ N	122 20.5152’ W
035T	Paired with 035		47 33.3420’ N	122 20.5200’ W
37	CSL	PCBs, Mercury	47 33.3114’ N	122 20.5614’ W
037T	Paired with 037		47 33.3060’ N	122 20.5800’ W
49	CSL	Arsenic, Copper	47 33.0330’ N	122 20.4654’ W
049T	Paired with 049		47 33.0300’ N	122 20.4600’ W
48	CSL	Arsenic, Copper, Lead, Zinc, Mercury	47 33.0534’ N	122 20.4786’ W
048T	Paired with 048		47 33.0540’ N	122 20.4600’ W
56	CSL	PCBs, Arsenic	47 32.9646’ N	122 20.4798’ W

Station Name	Exceedance	Chemicals	Latitude	Longitude
056T	Paired with 056		47 32.9700' N	122 20.4600' W
95	CSL	Multiple PAHs	47 32.0766' N	122 19.4616' W
095T	Paired with 095		47 32.0820' N	122 19.4400' W
88	CSL	Mercury	47 32.1954' N	122 19.5264' W
088T	Paired with 088		47 32.2020' N	122 19.5600' W
EIT 066	CSL	PCBs	47 32.1072' N	122 19.1820' W
DR157	CSL	PCBs, Mercury	47 32.3622' N	122 19.9002' W
DR157T	Paired with DR157		47 32.3700'N	122 19.9200' W
DUD-8C	CSL	PCBs, BEHP, Mercury, Silver	47 33.7608' N	122 20.7684' W
DUD-8CT	Paired with DUD-8C		47 33.7620' N	122 20.8200' W
SG-04	CSL	PCB	47 32.1972' N	122 19.1496' W
S4-2T	Paired with SG-04		47 32.1480' N	122 19.2000' W
SG-03	CSL	PCB	47 32.2074' N	122 19.1322' W
S4-1T	Paired with SG-03		47 32.1660' N	122 19.1400' W
47	CSL	Copper, Arsenic	47 33.0720' N	122 20.5014' W
47T	Paired with 47		47 33.0780' N	122 20.5200' W
	n=16			
Expected Intermediate Impairment				
2	SQS	Fluoranthene, PCBs	47 34 1502' N	122 20.9292' W
02T	Paired with 02		47 34.1520' N	122 20.9400' W
85	SQS	Chlordane, PCBs	47 32.3286' N	122 19.8390' W
16	SQS	PCBs	47 33.9090' N	122 20.9304' W
17	SQS	Ind	47 33.9030' N	122 20.7876' W
26	SQS	BBP, PCBs	47 33.5550' N	122 20.6784' W
40	SQS	PCBs	47 33.2028' N	122 20.5044' W
40T	Paired with 40		47 33.1980' N	122 20.5200' W
50	SQS	PCBs	47 33.0282' N	122 20.3634' W
50T	Paired with 50		47 33.0360' N	122 20.4000' W
69b	SQS	PCBs	47 32.6400' N	122 20.1642' W
69T	Paired with 69b		47 32.6340' N	122 20.1600' W
	n=8			
Expected Low or No Impairment				
4	None		47 34.1406' N	122 20.7936' W
7	None		47 34.1118' N	122 20.7678' W
8	None		47 34.0740' N	122 20.8740' W
10	None		47 33.9834' N	122 20.9406' W
11	None		47 33.9720' N	122 20.8470' W
23	None		47 33.6828' N	122 20.8530' W

Station Name	Exceedance	Chemicals	Latitude	Longitude
34	None		47 33.3600’ N	122 20.7480’ W
36	None		47 33.3120’ N	122 20.7378’ W
27	None		47 33.4986’ N	122 20.6136’ W
45	None		47 33.0942’ N	122 20.4762’ W
51	None		47 33.0162’ N	122 20.4324’ W
52	None		47 33.0084’ N	122 20.3790’ W
63	None		47 32.8440’ N	122 20.1126’ W
66	None		47 32.7792’ N	122 20.3268’ W
79	None		47 32.5080’ N	122 20.0124’ W
96	None	n=16	47 32.0406’ N	122 19.3062’ W
Benthic/Historical Stations			*	*
B1b	SQS		47 34.0698’ N	122 20.9322’ W
B2b	SQS		47 33.4554’ N	122 20.3484’ W
B3b	CSL:		47 33.3780’ N	122 20.3886’ W
B4b	SQS		47 33.0564’ N	122 20.3760’ W
B5b	SQS		47 32.9760’ N	122 20.3274’ W
B6b	SQS		47 32.4540’ N	122 19.8816’ W
B7b	SQS	n=7	47 32.1294’ N	122 19.4700’ W
SPI Only Baseline Stations				
SP101	Ind		47 34.1700’ N	122 21.0600’ W
SP102	Ind		47 34.1340’ N	122 21.0600’ W
SP103	Ind		47 34.0980’ N	122 20.8800’ W
SP104	Ind		47 34.0680’ N	122 20.8200’ W
SP105	Ind		47 34.0080’ N	122 20.8800’ W
SP106	Ind		47 33.9300’ N	122 20.8200’ W
SP107	Ind		47 33.8400’ N	122 20.8800’ W
SP108	Ind		47 33.7560’ N	122 20.8200’ W
SP109	Ind		47 33.8100’ N	122 20.8200’ W
SP110	Ind		47 33.7020’ N	122 20.8800’ W
SP111	Ind		47 33.7080’ N	122 20.7600’ W
SP112	Ind		47 33.6180’ N	122 20.7600’ W
SP113	Ind		47 33.5760’ N	122 20.7600’ W
SP114	Ind		47 33.4080’ N	122 20.5200’ W
SP115	Ind		47 33.3840’ N	122 20.5200’ W
SP116	Ind		47 33.3840’ N	122 20.5800’ W
SP117	Ind		47 33.2760’ N	122 20.5800’ W
SP118	Ind		47 33.2220’ N	122 20.5800’ W
SP119	Ind		47 33.1680’ N	122 20.4600’ W
SP120	Ind		47 33.0780’ N	122 20.4000’ W
SP121	Ind		47 32.9460’ N	122 20.4000’ W
SP122	Ind		47 32.8980’ N	122 20.4000’ W
SP123	Ind		47 32.8380’ N	122 20.3400’ W
SP124	Ind		47 32.7300’ N	122 20.2800’ W

Station Name	Exceedance	Chemicals	Latitude	Longitude
SP125	Ind		47 32.6640’ N	122 20.2800’ W
SP126	Ind		47 34.0680’ N	122 20.1000’ W
SP127	Ind		47 32.5800’ N	122 20.0400’ W
SP128	Ind		47 32.5320’ N	122 19.9800’ W
SP129	Ind		47 32.4600’ N	122 19.7400’ W
SP130	Ind		47 32.3040’ N	122 19.6800’ W
SP131	Ind		47 32.2560’ N	122 19.4400’ W
SP132	Ind		47 32.0940’ N	122 19.3800’ W
SP133	Ind		47 32.0400’ N	122 19.2600’ W
SP134	Ind		47 32.0820’ N	122 19.1400’ W
SP135	Ind		47 31.9440’ N	122 18.8400’ W
SP136	Ind		47 31.7580’ N	122 20.9400’ W
SP137	Ind		47 34.0740’ N	122 20.7000’ W
SPI Candidate Replacement Stations				
022	SQS	BEHP	47 33.7343’ N	122 20.7122’ W
068	CSL	HCB	47 32.6876’ N	122 20.3064’ W
092	CSL	PCB	47 32.1163’ N	122 19.3862’ W
DR181	CSL	PCB	47 32.1282’ N	122 19.1826 W
DR111	CSL	DDTs	47 32.5440’ N	122 19.9932 W

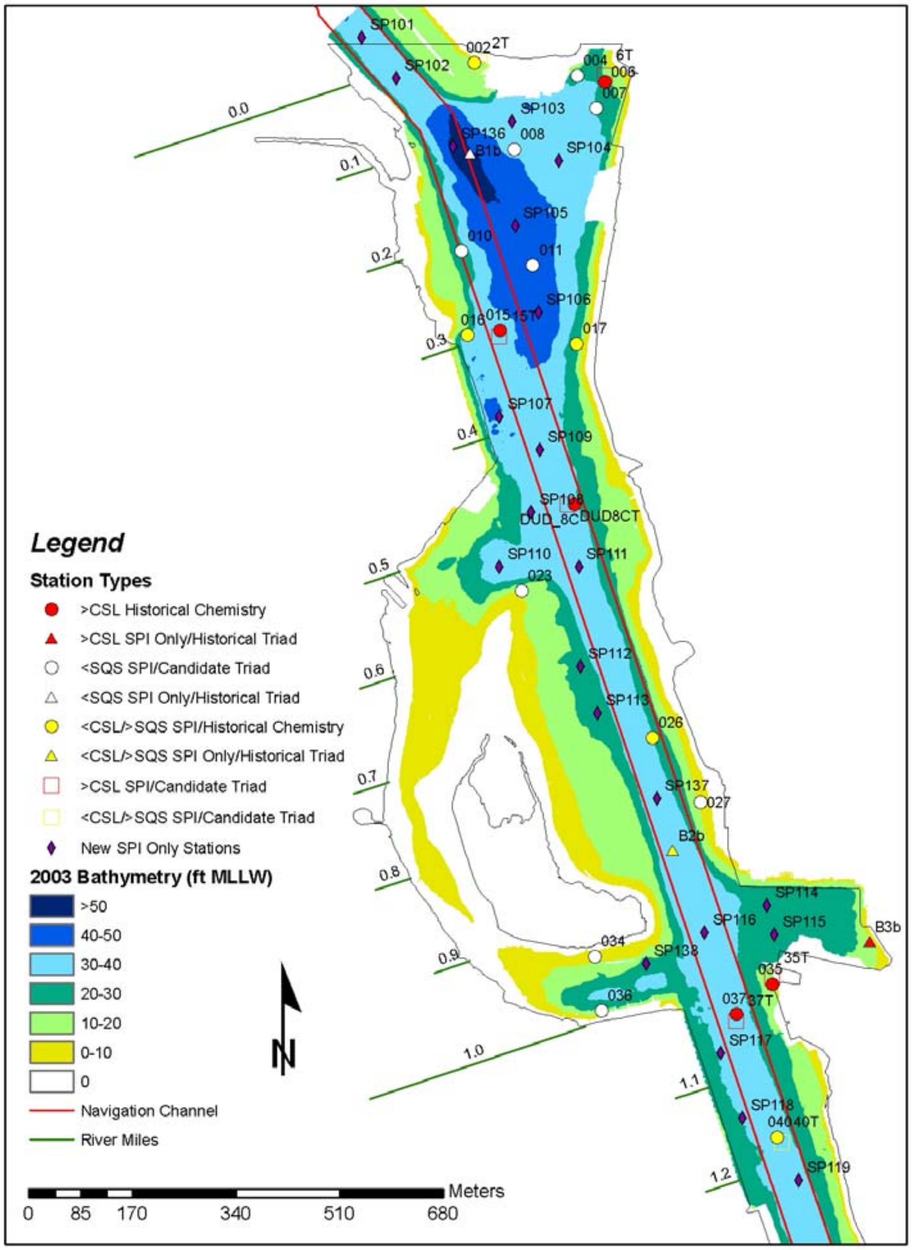


Figure 1. Location of Proposed SPI Stations, LDW River Mile 1

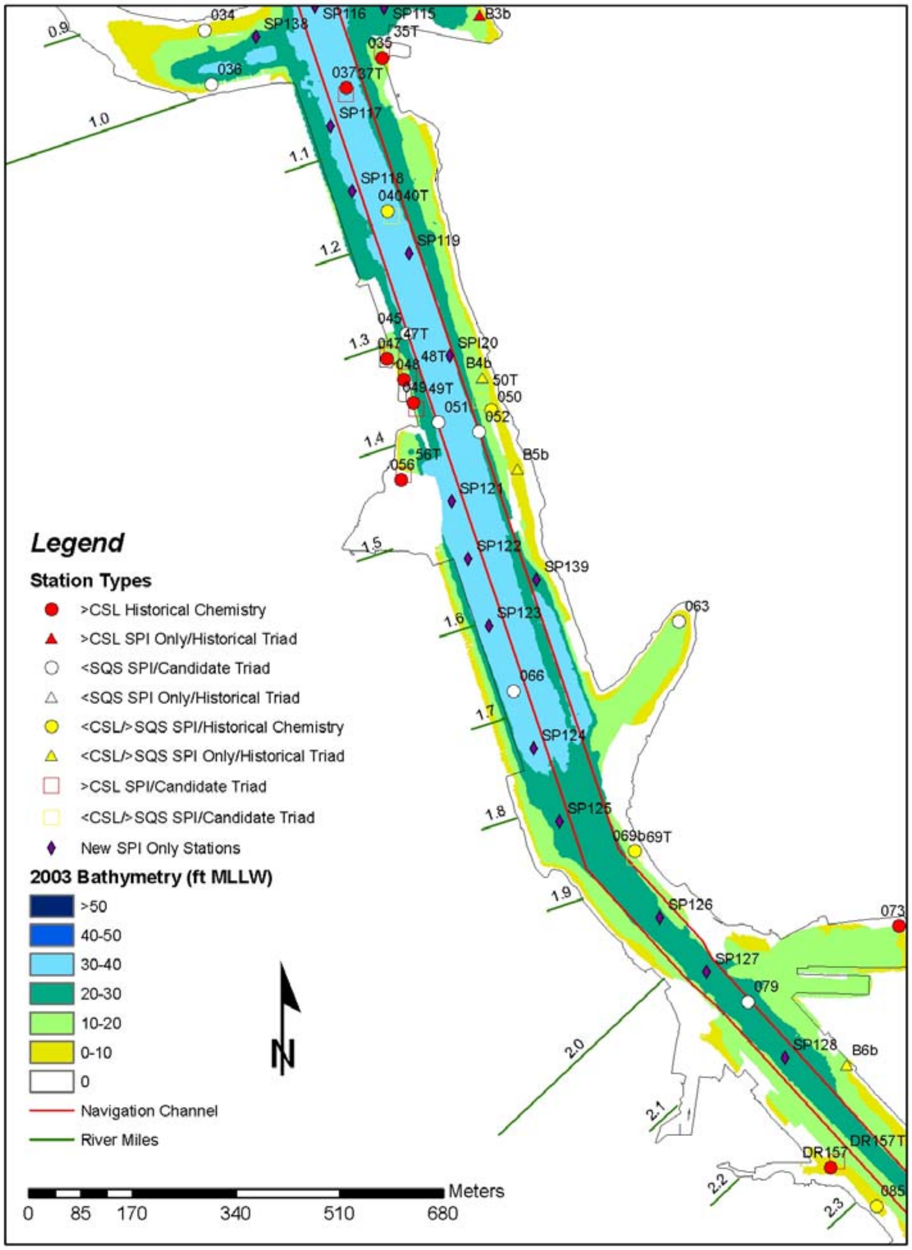


Figure 2. Location of Proposed SPI Stations, LDW River Mile 2

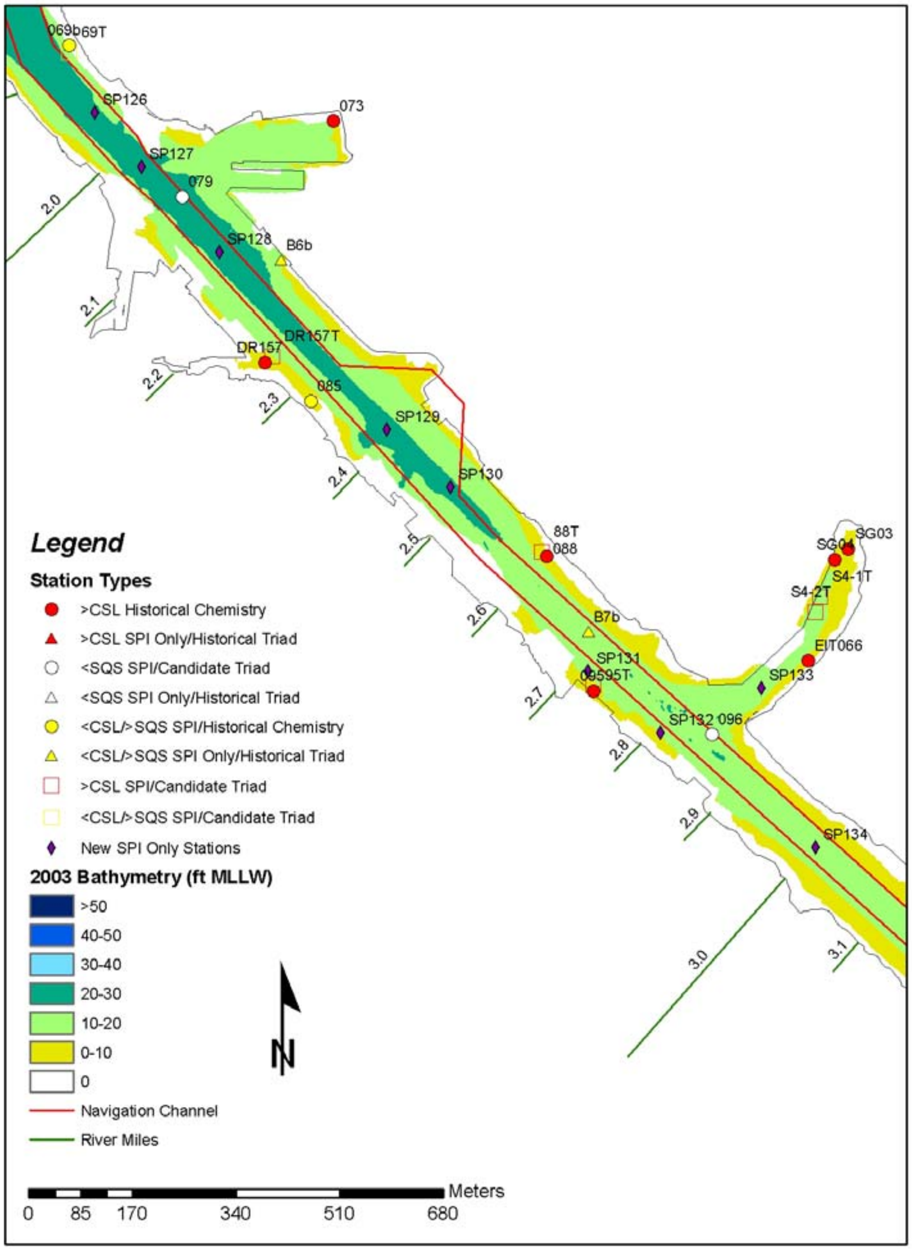


Figure 3. Location of Proposed SPI Stations, LDW River Mile 3

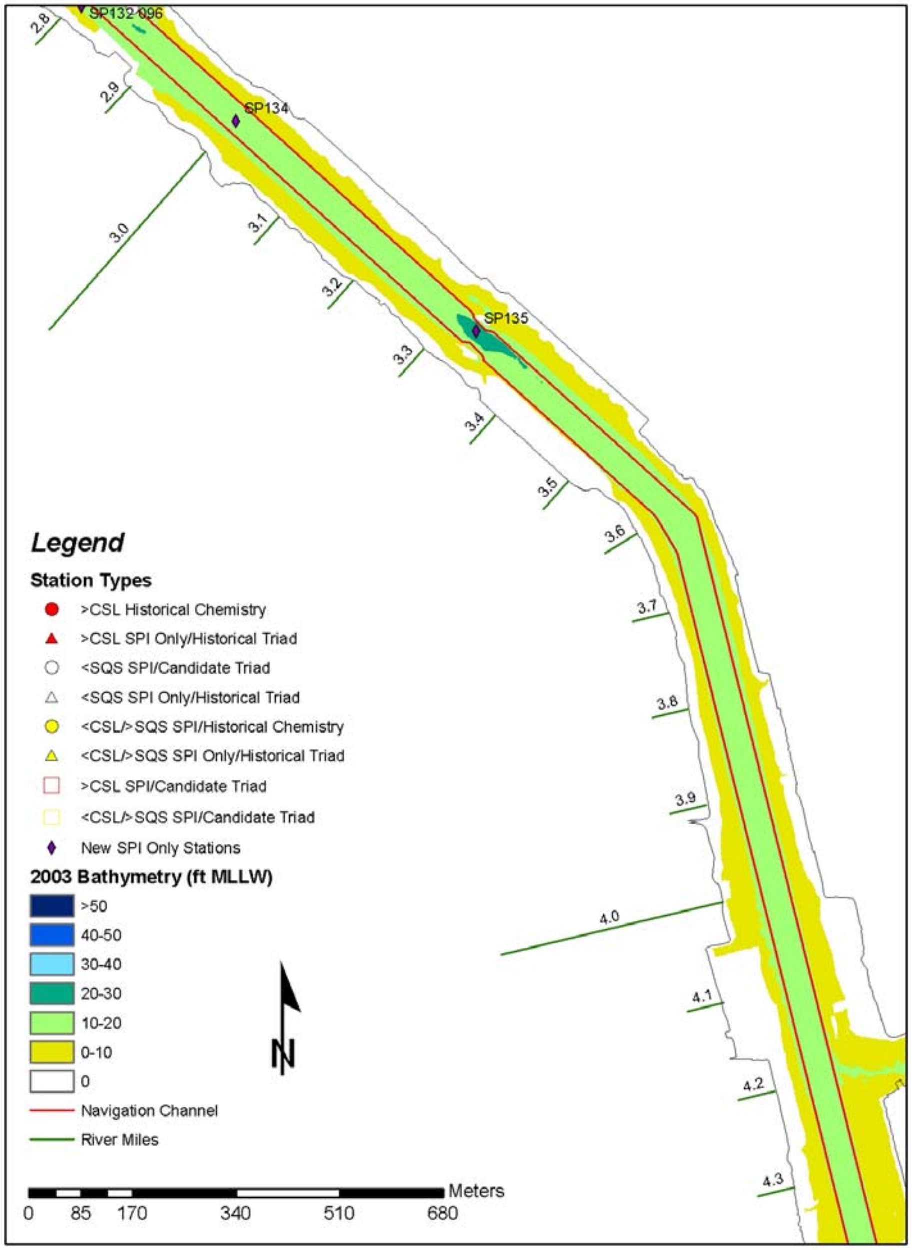


Figure 4. Location of Proposed SPI Stations, LDW River Mile 4

3.3 Port Gamble

At the Port Gamble site, a total of 25 stations will be sampled using SPI. Table 4 shows the apportionment of the proposed sampling stations among station types. The distribution of proposed sampling locations across the Port Gamble site is presented in Figure 5, and the proposed station name/coordinates are presented in Table 5.

Table 4. Sampling Stations and Type for the SPI Survey in the Port Gamble Study Area

Station Type	Total Number	High Chemistry/ Toxicity	Medium Chemistry / Toxicity	Low Chemistry / Toxicity
SPI & candidate Triad Stations	16	6	4	6
SPI-only Baseline Stations	14	NA	NA	NA

Similar to the LDW survey, a range of expected conditions is used in apportioning sampling stations across the Port Gamble site. Unlike the LDW where chemical contaminants and associated toxicity are the drivers for expected results, wood debris is the driver of expected results in Port Gamble. Stations are located with respect to the historical surveys conducted at the Port Gamble site (Parametrix 1999, 2004 a-b; Anchor 2006).

Proposed stations at the Port Gamble site are limited to the dredged area, the AOC area, the former log rafting area and sediments south of the former log rafting areas. In addition there are three stations located in the northeastern finger pier embayment and situated to be in areas of known soft sediment.

To limit the effects of sediment grain-size and water depth, stations are distributed in a north-south array. Stations are located in the deeper, depositional areas that are between the ridges of sandy substratum that tend north-south at the site. Past surveys indicated a sandy substrate to the east of the proposed sampling area and that the area classified as depositional largely trended north-south (Parametrix 2004 a-b). Furthermore, by orienting the proposed stations in this manner, an expected gradient of high wood debris coverage (expected impact) to low wood debris coverage (no expected impact) is captured. Stations proposed in the area of expected high wood debris coverage may be adjusted, under direction of Ecology, to further characterize areas that are being further studied by other parties (Anchor 2006).

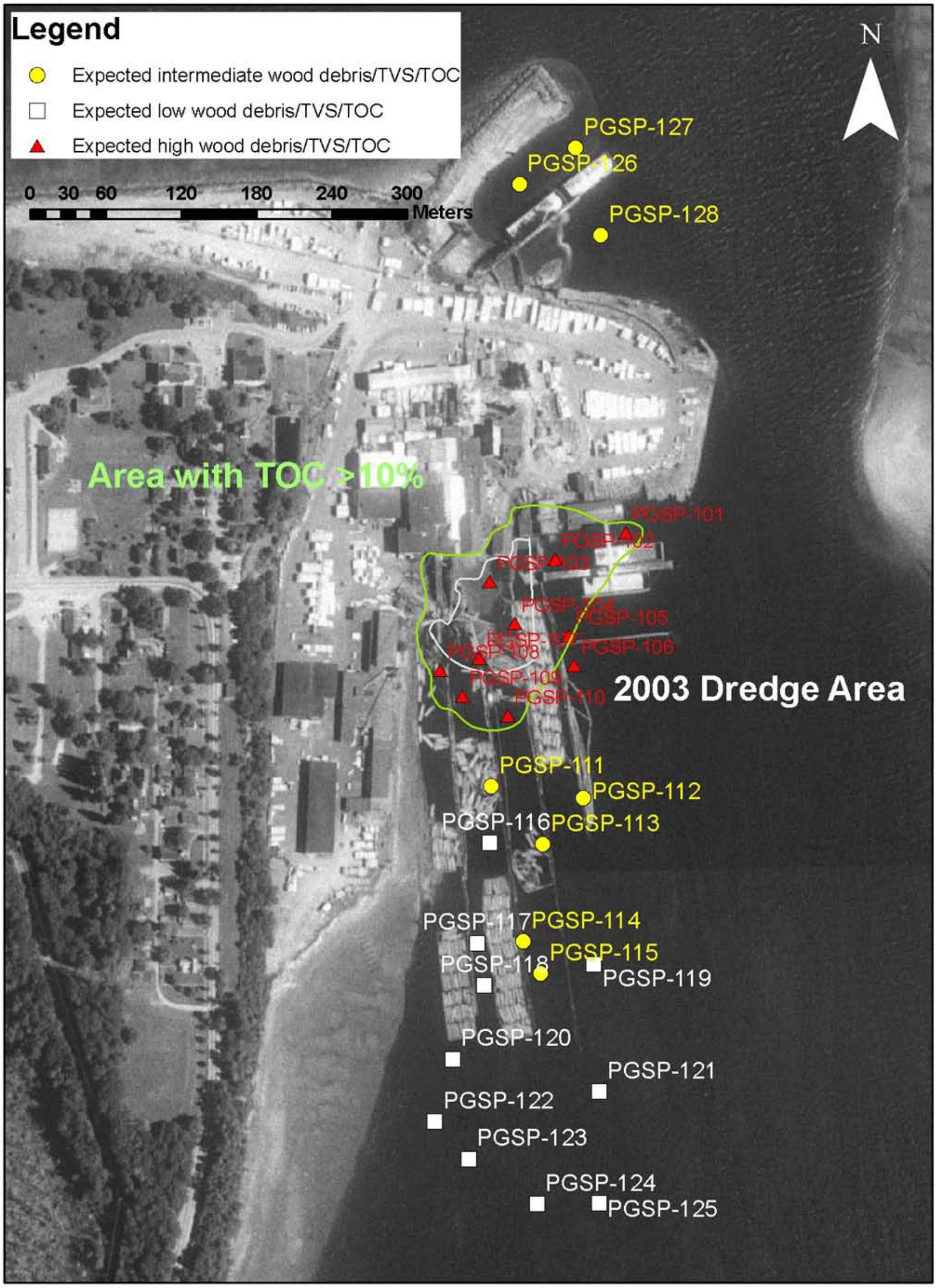


Figure 5. Proposed SPI Survey Locations in Port Gamble Study Area

Table 5. Proposed SPI Station Coordinates for the Port Gamble Study Area

Station	Wood Debris/TVS/TOC**	Latitude	Longitude
PGSP-101	High	47 51.2756' N	122 34.7775' W
PGSP-102	High	47 51.2644' N	122 34.8227' W
PGSP-103	High	47 51.2549' N	122 34.8643' W
PGSP-104	High	47 51.2369' N	122 34.8486' W
PGSP-105	High	47 51.2313' N	122 34.8141' W
PGSP-106	High	47 51.2188' N	122 34.8106' W
PGSP-107	High	47 51.2221' N	122 34.8712' W
PGSP-108	High	47 51.2170' N	122 34.8963' W
PGSP-109	High	47 51.2058' N	122 34.8824' W
PGSP-110	High	47 51.1974' N	122 34.8533' W
PGSP-111	Medium	47 51.1673' N	122 34.8643' W
PGSP-112	Medium	47 51.1618' N	122 34.8055' W
PGSP-113	Medium	47 51.1421' N	122 34.8316' W
PGSP-114	Medium	47 51.1005' N	122 34.8443' W
PGSP-115	Medium	47 51.0868' N	122 34.8331' W
PGSP-116	Low	47 51.1428' N	122 34.8654' W
PGSP-117	Low	47 51.0998' N	122 34.8736' W
PGSP-118	Low	47 51.0816' N	122 34.8693' W
PGSP-119	Low	47 51.0904' N	122 34.7993' W
PGSP-120	Low	47 51.0500' N	122 34.8896' W
PGSP-121	Low	47 51.0358' N	122 34.7963' W
PGSP-122	Low	47 51.0232' N	122 34.9013' W
PGSP-123	Low	47 51.0072' N	122 34.8800' W
PGSP-124	Low	47 50.9877' N	122 34.8362' W
PGSP-125	Low	47 50.9879' N	122 34.7967' W
PGSP-126		47 51.4255' N	122 34.8440' W
PGSP-127		47 51.4408' N	122 34.8081' W
PGSP-128		47 51.4032' N	122 34.7923' W
PGSP-129*	Low	47 50.7500' N	122 34.7970' W
PGSP-130*	Low	47 50.6500' N	122 34.7970' W

* These two stations are off the scale and not shown on map in Figure 5

** High wood debris/TOC/TVS defined by TOC >10% and TVS >25%
Medium is defined as TOC 5-10%
Low is defined as TOC <5%

4.0 Data Collection

The SPI images will be acquired using a model 3731-D sediment-profile camera system (Ocean Imaging Systems, North Falmouth, MA). The SPI camera consists of a wedge-shaped prism with a Plexiglas faceplate; light is provided by an internal strobe. The back of the prism has a mirror mounted at a 45-degree angle to reflect the profile of the sediment-water interface toward the camera, which is mounted horizontally on the top of the prism (Figure 6). The prism is filled with distilled water, through which the photographs are obtained. Because the object (sediment) to be photographed is directly against the clear window (faceplate) comprising the front of the prism, turbidity of the ambient seawater is not a limiting factor.

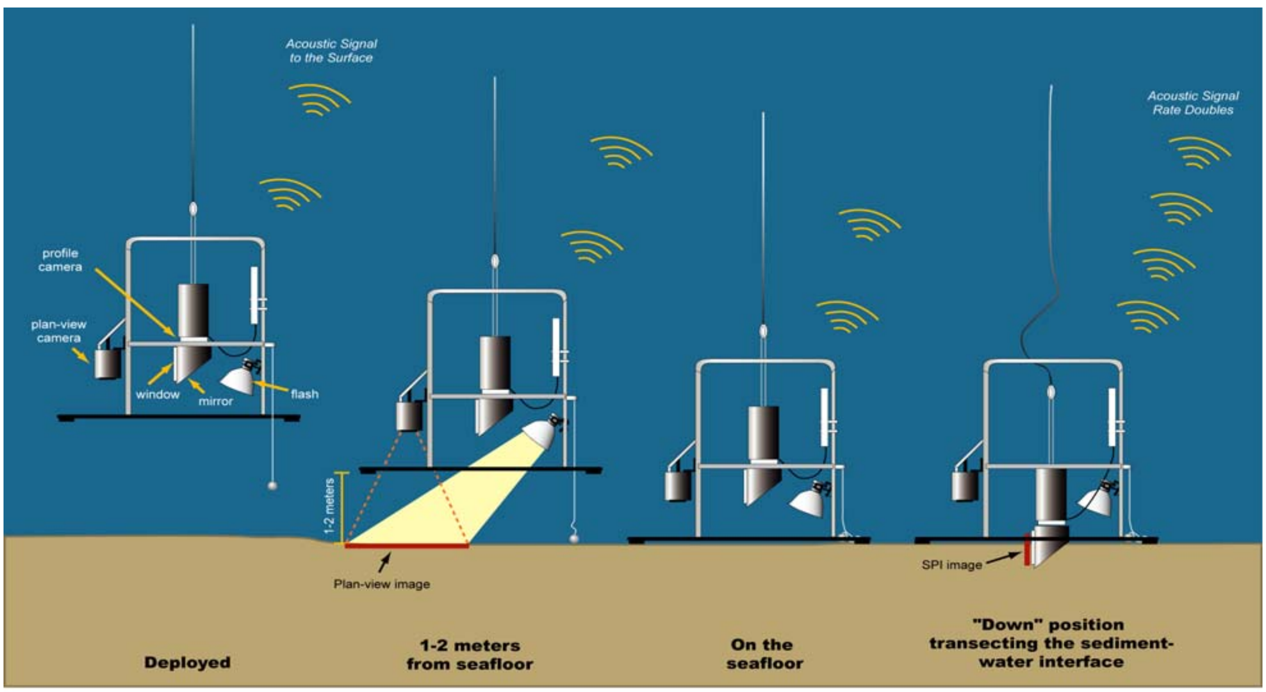


Figure 6. Schematic of SPI camera deployment with optional plan view camera attached

To collect SPI data, the research vessel will be piloted to each target sampling location. Once within a pre-determined distance of the target location, the SPI camera will be deployed. This distance, representing the radius of an imaginary "watch circle" around each target station", can vary depending on a number of factors. These include the distance among sampling stations relative to the size of the survey area and/or the seafloor feature of interest, the amount of wind- or current-induced drift experienced by the survey vessel during the survey, and the degree of small-scale spatial homogeneity or heterogeneity on the seafloor. Typically, a watch circle radius of 25 to 50 m around each target station is employed in SPI surveys. For this survey, SPI images will only be collected when the sampling vessel is within 3 m of the proposed sampling location. For deployment of the SPI camera system, it is first attached to the research vessel's winch wire. The camera prism is mounted on an assembly that can be moved up and down by producing tension or slack on the winch wire. As the camera is lowered through the water, tension on the wire keeps the prism in the "up" position (Figure 6). Once the camera frame contacts the bottom, slack on the wire allows the prism to vertically descend into the seafloor.

The rate at which the optical prism penetrates into the sediments is controlled by a passive hydraulic piston. This allows the optical prism to descend at approximately 6 cm per second and minimizes disturbance to the sediment column. As the SPI prism penetrates into the seafloor, a magnetic switch is triggered, and a photograph of the sediment column is taken 15 seconds from the time of switch contact. This time delay allows for optimal penetration of the prism into the sediment.

As the camera is raised off the bottom, a wiper blade automatically cleans any sediment off of the prism faceplate. The digital camera is automatically ready to take another photograph, the strobes are recharged, and the camera can be lowered for another replicate image.

When the camera is brought to the surface, the frame count is verified and the camera prism penetration is estimated from a penetration indicator that measures the distance the prism fell relative to the camera base. If penetration is minimal, weight packs can be loaded to give the assembly increased penetration. If penetration is too great, adjustable stops (which control the distance the prism descends) can be lowered, and "mud" doors can be attached to each side of the frame to increase the bearing surface.

The plan-view underwater video (PUV) will be recording during each descent of the SPI camera package. The SPI camera assembly will be left on the bottom for sufficient time for sampling-induced turbidity to dissipate and a representative plan-view video footage recorded. A Deep-Sea Power and Light RS-4000 underwater video camera with variable lighting is proposed for this survey, which employs a super-8 format at a resolution of 480 lines (480 x 640 total resolution).

In the event plan-view photography is conducted, the plan-view photographs will be acquired using a model DSC 6000 digital still camera and model 3831 self-powered strobe (Ocean Imaging Systems, Inc., North Falmouth, MA). The camera and strobe will be attached to the sediment-profile camera frame in a downward-looking position, and a bottom contact switch will be used to take photographs of the sediment surface immediately prior to landing of the frame on the bottom (Figure 6). This provides a record of the undisturbed sediment surface before penetration of the sediment-profile camera prism
.

4.1 Sample Handling and Custody

The samples to be obtained in this project consist of digital SPI and plan-view images. As indicated, these images will exist in the form of electronic files on computer hard-drives, with redundant back-up to permanent storage media on both a daily basis (i.e., "working" back-ups) and at the end of each survey. The G&A scientists (Joe Germano and David Browning) will be responsible for handling and storage of the digital files during both the field survey and subsequent analysis of the images at G&A headquarters and hindquarters (Bellevue, WA and Olympia, WA). Immediately following the survey, a complete back-up set of images will be sent on DVD to Dr. Germano for long-term archival storage at G&A headquarters in Bellevue, WA.

4.3 Field Quality Control

During the course of each field day, the digital images are downloaded and reviewed to ensure that a sufficient number of images of acceptable quality are obtained. Unacceptable images and the corrective actions taken during the re-sampling of unacceptable stations include:

- Underpenetration/No penetration. Check the number of weights and, if more can be added, revisit the site. If the site is too rocky, penetration may not be possible. Check the other replicate images obtained at the station and estimate whether penetration is possible.

- Overpenetration. Check and reduce the number of weights, possibly use the mud doors, and revisit the site. Some material may be too soft to support the weight of the camera.

- Pull out. The camera prism has started to pull away and is not flush with the sediment when the image is taken; revisit the site.

- Mud Smears. The wiper blade may not be near enough to the prism glass or material may be very sticky. Revisit the site after checking the wiper blade.

- Black image. No illumination of the sediment via the strobe light; check the strobe and revisit the site.

- Water shot. The camera may have triggered due to extreme vessel motion during the instrument descent. Revisit the site.

5.0 Data Analysis

Two analyses will be conducted in association with these surveys:

1. A quick-look analysis of limited parameters to be completed within five days of the SPI field survey
2. A full, complete, computerized image analysis of all parameters.

5.1 Field Quick-Look Analysis

After the conclusion of each field survey, all SPI images will be evaluated for sediment type, infaunal successional stage, physical disturbance and additional features that would indicate benthic stress (e.g. sedimentary methane, debris). Diagnostic criteria and methodologies are presented in section 5.2.

These data will be tabulated and presented to Ecology during the post-survey meeting between G&A and Ecology. The purpose of this analysis is to provide Ecology timely information regarding the selections of sampling stations for full Triad analyses. Specific attention will be given to benthic processes and features that indicate benthic impairment. The analysis and evaluation of SPI images for the "quick-look" analysis will also focus on the homogeneity or heterogeneity of substrate at a given station and whether that station is consistently representative of ongoing or native benthic processes (i.e. does not show random physical disturbance).

At the time of the "quick-look" results meeting, actual station location coordinates from the SPI survey will be provided to Ecology, or within five days of the completion of the survey. In addition, a subset of the stations sampled with SPI will recommended for triad sampling using the criteria of the degree of observed impairment, homogeneity of substrate, and representativeness of substrate.

5.2 Computerized Image Analysis

An analyst operates the computer-based image analysis system and generates a series of measurements for each sediment-profile image. Prior to the start of each session, the calibration of the image analysis software is verified by measuring a known distance on a ruler photographed by the SPI camera. The data for each image are stored in an Excel spreadsheet file, pending a review (QA check) by a senior scientist (Dr. Joseph Germano). Upon completion of the initial analysis, Dr. Germano reviews all of the measurements performed on each image. Any changes or corrections made are flagged within the Excel spreadsheet data file. The analyst responsible for the initial analysis must review and accept any changes made by the senior scientist. Upon accepting the changes, the data are exported to a final Microsoft Excel spreadsheet file for long-term storage. This Excel file is used to create summary tables and graphics that are presented in reports.

An archive CD is created to store all the image files, image analysis measurement files, and the spreadsheet of the exported bulk data.

Thorough measurements of all physical parameters and some biological parameters are subsequently measured directly from the digital files using a computer-image analysis system. The full color image analysis system can discriminate up to 16.7 million different shades of color, so subtle features can be accurately digitized and measured. Our software allows the measurement and storage of data on up to 20 different variables for each SPI image obtained. All data stored on disks are printed out on data sheets for editing by the principal investigator and as a hard-copy backup. Automatic disk storage of all parameters measured allows data from any variables of interest to be compiled, sorted, displayed graphically, contoured, or compared statistically. In addition, the integration of the SPI analysis software with our database and GIS software allows any SPI measurement to be plotted (and contoured if desired) on a base map of the survey area.

Specific SPI parameters to be measured for these surveys are presented below.

Sediment Type Determination: The sediment grain-size major mode and range are visually estimated from the photographs by overlaying a grain-size comparator which is at the same scale. This comparator was prepared by photographing a series of Udden-Wentworth size classes (equal to or less than coarse silt up to granule and larger sizes) through the SPI camera. Seven grain-size classes are on this comparator:. 4 phi, 4-3 phi, 3-2 phi, 2-1 phi, 1-0 phi, 0-(-)1 phi, < -1 phi. The lower limit of optical resolution of the photographic system is about 62 microns, allowing recognition of grain sizes equal to or greater than coarse silt. The accuracy of this method has been documented by comparing our SPI estimates with grain-size statistics determined from laboratory sieve analyses.

Prism Penetration Depth: The SPI prism penetration depth is determined by measuring both the largest and smallest linear distance between the sediment-water interface and the bottom of the film frame. Prism penetration is potentially a noteworthy parameter; if the number of weights used in the camera is held constant throughout a survey, the camera functions as a static-load penetrometer. Comparative penetration values from sites of similar grain-size give an indication of the relative sediment water content.

Surface Boundary Roughness: Surface boundary roughness is determined by measuring the vertical distance (parallel to the film border) between the highest and lowest points of the sediment-water interface. In addition, the origin of this small-scale topographic relief is indicated when it is evident (physical or biogenic).

Depositional Layer Thickness: Because of the camera's unique design, SPI has proven invaluable in detecting depositional layers ranging from 20 cm (the height of the SPI optical window) to 1 mm in thickness. During image analysis, the thickness of the newly-deposited layers is determined by measuring the linear distance between the pre- and post-disposal sediment water interface. .

Mud Clasts: During analysis, the number of clasts is counted, the diameter of a typical clast is measured, and their oxidation state is assessed. Overall, the abundance, distribution, oxidation state, and angularity of mud clasts are used to make inferences about the recent pattern of seafloor disturbance in an area.

Apparent Redox Potential Discontinuity (RPD) Depth: Aerobic near-surface marine sediments typically have higher reflectance values relative to underlying hypoxic or anoxic sediments. These differences in optical reflectance are readily apparent in SPI images; the oxidized surface sediment contains particles coated with ferric hydroxide (an olive color when associated with particles), while reduced and muddy sediments below this oxygenated layer are darker, generally gray to black. The boundary between the colored ferric hydroxide surface sediment and underlying gray to black sediment is called the apparent redox potential discontinuity (abbreviated as the RPD).

Sedimentary Methane: At extreme levels of organic-loading, pore-water sulphate is depleted, and methanogenesis occurs. The process of methanogenesis is detected by the appearance of methane bubbles in the sediment column. These gas-filled voids are readily discernable in SPI images because of their irregular, generally circular aspect and glassy texture (due to the reflection of the strobe off the gas). If present, the number and total area covered by all methane pockets is measured.

Percent Wood Waste: The percent wood waste volume of each cross sectional image will be visually estimated using a series of standard petrographic estimators (Folk, 1974); past studies have shown this to be a reliable estimate of wood waste volume as measured by TVS analyses (Browning, 2004).

Infaunal Successional Stage:
Determination of the infaunal successional stage applies only to soft-bottom habitats, where the SPI camera is able to penetrate into the sediment. In hard bottom environments (i.e., rocky substrates), camera penetration is prevented and the standard suite of SPI measurements cannot be made. In such instances, the infaunal successional stage is considered to be “indeterminate.” Hard bottom areas can support abundant and diverse epibenthic communities and therefore may represent habitat which is biologically productive or otherwise of value to various organisms as refuge or living space. However, the value of hard bottom habitats is not reflected in the SPI successional stage designation.

The mapping of infaunal successional stages is based on the theory that organism-sediment interactions in marine soft-bottom habitats follow a predictable sequence after a major seafloor perturbation (e.g., passage of a storm, disturbance by bottom trawlers, dredged material deposition, hypoxia). The theory states that primary succession results in "the predictable appearance of macrobenthic invertebrates belonging to specific functional types following a benthic disturbance. These invertebrates interact with sediment in specific ways. Because functional types are the biological units of interest, our definition does not demand a sequential appearance of particular invertebrate species or genera" (Rhoads and Boyer 1982). This theory is formally developed in Rhoads and Germano (1982) and Rhoads and Boyer (1982).

Benthic disturbance can result from natural processes, such as seafloor erosion, changes in seafloor chemistry, and predator foraging, as well as from human activities like dredged material or sewage sludge disposal, thermal effluent from power plants, bottom trawling, pollution from industrial discharge, and excessive organic loading. Evaluation of successional stages involves deducing dynamics from structure, a technique pioneered by R. G. Johnson (1972) for marine soft-bottom habitats. The application of this approach to benthic monitoring requires *in situ* measurements of salient structural features of organism-sediment relationships as imaged through SPI technology.

Pioneering assemblages (Stage I assemblages) usually consist of dense aggregations of near-surface living, tube-dwelling polychaetes (Figure 7); alternately, opportunistic bivalves may colonize in dense aggregations after a disturbance (Rhoads and Germano 1982, Santos and Simon 1980a). These functional types are usually associated with a shallow redox boundary; and bioturbation depths are shallow, particularly in the earliest stages of colonization (Figure 7). In the absence of further disturbance, these early successional assemblages are eventually replaced by infaunal deposit feeders; the start of this "infaunalization" process is designated arbitrarily as Stage II. Typical Stage II species are shallow dwelling bivalves or, as is common in New England waters, tubicolous amphipods. In studies of hypoxia-induced benthic defaunation events in Tampa Bay, Florida, Ampeliscid amphipods appeared as the second temporal dominant in two of the four recolonization cycles (Santos and Simon 1980a, 1980b).

Stage III taxa, in turn, represent high-order successional stages typically found in low-disturbance regimes. These invertebrates are infaunal, and many feed at depth in a head-down orientation. The localized feeding activity results in distinctive excavations called feeding voids (Figure 7). Diagnostic features of these feeding structures include a generally semicircular shape with a flat bottom and arched roof, and a distinct granulometric change in the sediment particles overlying the floor of the structure. This granulometric change is caused by the accumulation of coarse particles that are rejected by the animals feeding selectively on fine-grained material. Other subsurface structures, such as burrows or methane gas bubbles, do not exhibit these characteristics and therefore are quite distinguishable from these distinctive feeding structures. The bioturbational activities of these deposit-feeders are responsible for aerating the sediment and causing the redox horizon to be located several centimeters below the sediment-water interface. In the retrograde transition of Stage III to Stage I, it is sometimes possible to recognize the presence of relict (i.e., collapsed and inactive) feeding voids.

The end-member stages (Stages I and III) are easily recognized in SPI images by the presence of dense assemblages of near-surface polychaetes (Stage I) or the presence of subsurface feeding voids (Stage III; Figure 7). The presence of tubicolous amphipods at the sediment surface is indicative of Stage II. It is possible for Stage I polychaetes or

Stage II tubicolous amphipods to be present at the sediment surface, while at the same time, Stage III organisms are present at depth within the sediment. In such instances, where two types of assemblages are visible in a SPI image, the image is designated as having either a Stage I on Stage III (I-III) or Stage II on Stage III (II-III) successional stage. Additional information on SPI image interpretation can be found in Rhoads and Germano (1982, 1986).

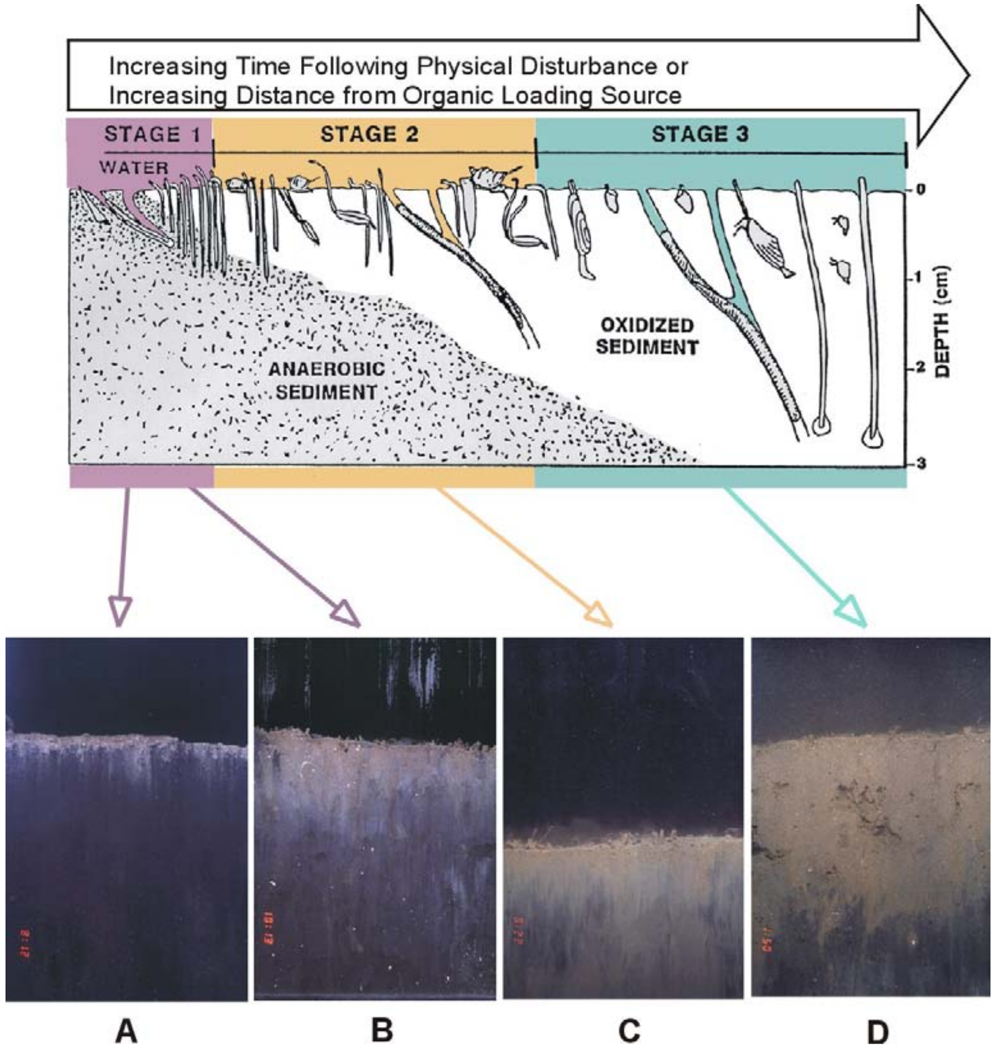


Figure 7. The drawing at the top illustrates the development of infaunal successional stages over time following a physical disturbance or with distance from an organic loading source (from Rhoads and Germano 1986). The SPI images below the drawing provide examples of the different successional stages. Image A shows highly reduced sediment with a very shallow redox layer (contrast between light colored surface sediments and dark underlying sediments) and little evidence of infauna. Numerous small polychaete tubes are visible at the sediment surface in image B (Stage I), and the redox depth is deeper than in image A. A mixture of polychaete and amphipod tubes occurs at the sediment surface in image C (Stage II). Image D shows numerous burrow openings and feeding pockets (voids) at depth within the sediment; these are evidence of deposit-feeding, Stage III infauna. Note the RPD is relatively deep in this image, as bioturbation by the Stage III organisms has resulted in increased sediment aeration.

Organism-sediment index:

While the multi-parameter Organism-Sediment Index (OSI) has been constructed to characterize disturbance gradients, we recommend that Ecology not use a derived index for subsequent data analysis once the SQT data are available, but instead use the raw component data that have historically been used to calculate the OSI. However, if Ecology still wants the OSI values calculated as part of the deliverables, we can readily accommodate that request.

Habitat disturbance in the OSI is defined relative to two end-member standards. The lowest value is given to those bottoms which have low or no dissolved oxygen in the overlying bottom water, no apparent macrofaunal life, and methane gas present in the sediment (see Rhoads and Germano 1982, 1986, for SPI criteria for these conditions). The OSI for such a condition is -10. At the other end of the scale, an aerobic bottom with a deeply depressed RPD, evidence of a mature macrofaunal assemblage, and no apparent methane gas bubbles at depth will have an OSI value of +11.

The OSI is a sum of the subset indices shown in Table 6. The OSI is calculated automatically by the image analysis software after completion of all measurements from each SPI image. The index has proven to be an excellent parameter for mapping disturbance gradients in an area and documenting ecosystem recovery after disturbance (Germano and Rhoads 1984, Revelas et al. 1987, Valente et al. 1992).

The OSI may be subject to seasonal changes because the mean apparent RPD depths vary as a result of temperature-controlled changes of bioturbation rates and sediment oxygen demand. Furthermore, the successional status of a station may change over the course of a season related to recruitment and mortality patterns or the disturbance history of the bottom. The sub-annual change in successional status is generally limited to Stage I (polychaete-dominated) and Stage II (amphipod-dominated) seres. Stage III seres tend to be maintained over periods of several years unless they are eliminated by increasing organic loading, extended periods of hypoxia, or burial by thick layers of dredged material. The recovery of Stage III seres following abatement of such events may take several years (Rhoads and Germano 1982). In our mapping experience with this parameter over the past 20 years, we have found that OSI values of 6 or less indicate that the benthic habitat has experienced physical disturbance, eutrophication, or excessive bioavailable contamination in the recent past.

Table 6. Calculation of the Organism-Sediment Index (OSI) Value

A. CHOOSE ONE VALUE:		
	Mean RPD Depth	Index Value
	0.00 cm	0
	> 0 - 0.75 cm	1
	0.75 - 1.50 cm	2
	1.51 - 2.25 cm	3
	2.26 - 3.00 cm	4
	3.01 - 3.75 cm	5
	> 3.75 cm	6
B. CHOOSE ONE VALUE:		
	Successional Stage	Index Value
	Azoic	-4
	Stage I	1
	Stage I ® II	2
	Stage II	3
	Stage II ® III	4
	Stage III	5
	Stage I on III	5
	Stage II on III	5
C. CHOOSE ONE OR BOTH IF APPROPRIATE:		
	Chemical Parameters	Index Value
	Methane Present	-2
	No/Low Dissolved Oxygen**	-4
ORGANISM-SEDIMENT INDEX =	Total of above subset indices (A+B+C)	
	RANGE: -10 - +11	

** Note: This is not based on a Winkler or polarigraphic electrode measurement. It is based on the imaged evidence of reduced, low reflectance (i.e., high oxygen demand) sediment at the sediment-water interface.

Benthic Habitat Quality Index:

The benthic habitat quality index (BHQI) from Nillson and Rosenberg (1997) will also be calculated from the component features below. Both the index and the component features will be provided in final SPI data provided to Ecology.

Sediment Level	**Features**	**Score**
Surface	Fecal pellets	1
	Small diameter tubes (≤ 2 mm)	1
	Large diameter tubes (> 2 mm)	2
	Feeding pit or mound	2
Subsurface	Infauna	1
	Few burrows (1 to 3)	1
	Many burrows (> 3)	2
	Shallow oxic voids (at ≤ 5 cm depth)	1
	Deep oxic voids (at > 5 cm depth)	2
	RPD depth 0.1 to 1.0 cm	1
	RPD depth 1.1 to 2.0 cm	2
	RPD depth 2.1 to 3.5 cm	3
	RPD depth 3.6 to 5.0 cm	4
	RPD depth > 5.0 cm	5

Sediment Level	Features	Score
Surface	Fecal pellets	1
	Small diameter tubes (≤ 2 mm)	1
	Large diameter tubes (> 2 mm)	2
	Feeding pit or mound	2
Subsurface	Infauna	1
	Few burrows (1 to 3)	1
	Many burrows (> 3)	2
	Shallow oxic voids (at ≤ 5 cm depth)	1
	Deep oxic voids (at > 5 cm depth)	2
	RPD depth 0.1 to 1.0 cm	1
	RPD depth 1.1 to 2.0 cm	2
	RPD depth 2.1 to 3.5 cm	3
	RPD depth 3.6 to 5.0 cm	4
	RPD depth > 5.0 cm	5

Physical Disturbance: Physical disturbance of the sediment column by anthropogenic, biological or hydrodynamic processes can be deduced from *in-situ* structures and syntactical relationships within the sediment column. For example, layered, normally graded, intercalated or stacked bands of sand indicates periodic bedload transport and deposition, which to a benthic community represents a staccato physical disturbance.

The identification of areas that may be currently, or have been in the past, physically disturbed will allow for a more appropriate comparison of benthic infaunal community metrics and SPI parameters by allowing the data to be stratified by disturbance regime.

Presence/Absence of Bacterial Mats: The presence of sulfur-reducing bacteria is indicative of low or hypoxic conditions typically associated with organic loading (Rosenberg and Diaz, 1993). These white, string-like bacteria colonies at the sediment surface are quite distinctive in sediment profile images and their presence at any station will be noted on the data sheet.

Depositional, Erosional or Transitional Status of Sediment Column: To the extent possible, based on *in-situ* stratigraphic features, such as layering, sorting, and bedding, a station or replicate will be designated as depositional, erosional, or transitional.

Depth of Bioturbation: The depth of bioturbation is measured as the maximum depth in the sediment column that infauna, infaunal feeding voids, or infaunal burrows are seen within the sediment column.

PUV Analysis: Plan-view video will be analyzed to determine surface spatial variability of the seafloor and the related biologic community, and at Port Gamble, for percent cover of wood debris on the surface, with particular attention noted to areas of continuous versus non-continuous cover. Plan view video will also be examined for evidence of biological activity (tube or burrow density) to assist in the interpretation of the benthic community assessment performed from the SPI analyses.

All measured SPI parameters will redundantly reviewed by a second SPI expert to ensure data completeness and accuracy.

6.0 Reporting and Schedule

6.1 Reporting

The primary objective of the technical report is to present a descriptive and analytical picture of conditions that exist in the water and on the seafloor in the LDW and Port Gamble. A synthesis of acquired photographic data and a draft project report will be prepared to address all project elements, including methods, results, anomalies and issues.

The report will describe methods used, actual conduct of the assessment work, conditions and difficulties encountered, apparent accuracy of sample point locations and assessment methods employed, and significant errors or discrepancies in measurements and findings. The report will address each item described above; fully characterize each aspect of the results; and present each aspect of the results in appropriate descriptive, tabular, or graphic format. While some example images will be reproduced in the report, an electronic copy of all images collected will be provided on CD or DVD to Ecology in Joint Photographic Experts Group (jpeg) format. All component data for each replicate SPI image will be provided to ecology in Microsoft Excel file form. Station name and location data will also be provided in the data deliverable.

Particular discussion will be provided concerning the nature and condition of bark and wood wastes in Port Gamble, and the successional stages and health of benthic biological communities in the LDW.

6.2 Project Schedule

Deliverable	**Estimated Schedule**
Meeting with Ecology staff	June 1, 2006
Draft Quality Assur. Project Plan	June 21
Final Quality Assur. Project Plan	July 14
Field survey, LDW site	July 23-25
Interim SPI data package, LDW site	Field survey + 4 work days
Field survey, Port Gamble site	August 15-16
Interim SPI data package, Port Gamble site	Field survey + 4 work days
Draft Data Report	Final field survey + *30 work days*
Final Data Report	Ecology Comments + 20 work days
Comments on Ecology’s draft report	January 2007

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