Port Angeles Harbor
Supplemental Data Evaluation to the Sediment Investigation Report
Port Angeles, WA

Summary Report

Prepared for

Washington State Department of Ecology
Toxics Cleanup Program
300 Desmond Drive
Lacey, Washington 98504

Prepared by

NewFields
115 2nd Avenue N, Suite 100
Edmonds, WA 98020

December 2012

Table of Contents

Figures

Tables

List of Acronyms

ADCP	acoustic Doppler current profiler
BTV	background threshold value
COPC	contaminant of potential concern
CSM	conceptual site model
CSO	combined sewer overflow
DOI	U.S. Department of Interior
E & E	Ecology and Environment, Inc.
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
EPA	U.S. Environmental Protection Agency
FALCON	Fingerprint Analysis of Leachate Contaminants
GIS	geographic information system
HpCDD	heptachlorodibenzo-p-dioxin
HpCDF	heptafuran
HxCDF	hexachlorodibenzofuran
IDW	inverse distance weighted
LAET	lowest apparent effects threshold
LPAH	low molecular weight polycyclic aromatic hydrocarbons
MDL	method detection limit
MTCA	Model Toxics Control Act
OCDD	octachlorodibenzo-p-dioxin
OCDF	octachlorodibenzofuran
OSV	Ocean Survey Vessel
PAH	polycyclic aromatic hydrocarbon
PCA	principal component analysis
PCB	polychlorinated biphenyl
PQL	practical quantitation limit
RI/FS	remedial investigation/feasibility study
SAIC	Science Applications International Corporation
SIR	sediment investigation report
SMS	Sediment Management Standards
STA	sediment trend analysis
TEQ	toxic equivalency
TOC	total organic carbon
UCL	upper confidence limit
USACE	U.S. Army Corps of Engineers
WPCC	Washington Pollution Control Commission

1.0 Introduction

Port Angeles Harbor (Port Angeles, WA) is one of seven Puget Sound embayments that are being investigated by the Washington State Department of Ecology (Ecology) as part of the Puget Sound Initiative. Ecology is using special funding from this initiative to investigate sediment pollution and develop a strategy for cleaning up the harbor. In support of this strategy, Ecology conducted a sediment characterization study of the whole harbor with a focus on identifying potential sources to harbor contamination. In addition, Ecology has entered into an Agreed Order with Rayonier, Inc., operator of one of the largest and oldest pulp mill facilities on the harbor, which will result in the development of an Interim Action Report that will include the marine portion of the former Rayonier Mill Study Area.

Ecology tasked Ecology and Environment, Inc., (E & E) with conducting a sediment investigation to characterize the nature and distribution of chemical contamination and wood debris in Port Angeles Harbor. The sediment investigation included both harbor-wide sampling and sampling focused in the area adjacent to the former Rayonier Mill property. The resulting Port Angeles Harbor Sediment Investigation Report (SIR) (E & E 2012) provides supplemental data to that collected by Rayonier, Inc. as a part of the former Rayonier Mill Study Area marine investigation.

In order to supplement the Port Angeles Harbor SIR (E & E 2012), NewFields is providing technical support and expertise to Ecology for additional evaluation of data collected by E & E, Rayonier, Inc., and Nippon Paper Industries.

The supplemental data evaluations include:

- Spatial analysis of sediment data to identify areas of adverse impacts to sediment quality;
- Comparison of sediment chemical concentrations to natural background levels in order to identify areas of anthropogenic influence;
- Chemical fingerprint analysis to aid in dioxin/furan source identification;
- Determination of the primary sediment transport pathways to understand sediment sources and sinks;
- Assessment of chemical fate and transport in order to determine the likely sources of chemical contamination; and
- Identification of data gaps and data needs.

Ecology is also interested in developing preliminary sediment cleanup goals for Port Angeles Harbor based on the results of Port Angeles Harbor sediment investigations. The preliminary cleanup goals will be provided in a separate technical memorandum.

This report incorporates the data from the Port Angeles Harbor SIR (E&E 2012), Rayonier, Inc.'s Remedial Investigation for the Marine Environment Near the Former Rayonier Mill Site (Malcolm Pirnie 2007a) and Phase 2 Addendum Remedial Investigation for the Marine Environment Near the Former Rayonier Mill Site (Malcolm Pirnie 2007b), and Nippon Paper Industries' Sediment Grab Sampling and Log Density Survey (Anchor 2005) and Environmental Baseline Investigation (Exponent 2008). This report summarizes only the data from these studies. Please see the individual reports for details on objectives, sampling techniques, complete analytical results, and data analysis.

This page is intentionally blank.

2.0 Spatial Analysis Methods

Management and presentation of Port Angeles Harbor sediment data through geographic information system (GIS) applications allow for the identification of spatial patterns in sediment parameters. Analysis of these patterns can then be used to assess the sources and sinks of contaminants of potential concern (COPCs), as well as the dynamic processes responsible for the observed spatial patterns. The significance of COPC concentrations was determined by comparing the analytical results to Washington State Sediment Management Standards (SMS) and Puget Sound lowest apparent effects threshold (LAET) criteria. In this report, sediment chemistry results are only compared to LAET criteria when total organic carbon (TOC) concentrations are outside the range of 0.5 to 3.5 percent or when SMS criteria do not exist for a given analyte.

Five individual data sets were combined for use in the spatial analysis:

- Port Angeles Harbor Sediment Characterization Study (E & E 2012);
- Remedial Investigation for the Marine Environment Near the Former Rayonier Mill Site (Malcolm Pirnie 2007a);
- Phase 2 Addendum Remedial Investigation for the Marine Environment Near the Former Rayonier Mill Site (Malcolm Pirnie 2007b);
- Nippon Paper Industries USA Pulp and Paper Mill Sediment Grab Sampling and Log Density Survey (Anchor 2005); and
- Nippon Paper Industries USA Pulp and Paper Mill Environmental Baseline Investigation (Exponent 2008).

Tables 1 and 2 provide a list of the chemistry data sets for surface and subsurface sediments, respectively. Data sets were compiled in Microsoft Access and queried for COPCs before importing into ESRI ArcGIS for spatial analysis and mapping. Sampling locations and associated chemistry were organized into a geodatabase for analysis.

2.1 Geodatabase Development

GIS provides the tools necessary for the acquisition, storage, management, and analysis of geographic data. Data sets that contain both spatial and descriptive components are suitable for input into geospatial databases. These geodatabases provide a dynamic environment for the query, edit, analysis, and visualization of data that often are uneven in distribution, originate from multiple sources, and vary in resolution.

For this supplemental data evaluation, a Port Angeles Harbor sediment geodatabase was created from the data sources listed above. This geodatabase is based on data available in Ecology’s Environmental Information Management (EIM) database on May 20, 2011. Changes, corrections, or additions to EIM after this date may not be reflected in the following evaluation. The compiled data include physical and chemical analysis results for both surface and subsurface sediments and sediment toxicity testing results.

2.2 Data Interpolation

Interpolation is the process of approximating data by using measured values at a discrete set of points. Interpolated surfaces were produced for each parameter using an Inverse Distance Weighted (IDW) model in ArcGIS. This method estimates values at unknown locations by averaging the values of sample data points in the neighborhood. The closer a point is to the location being estimated, the more influence, or weight, it has in the averaging process. Because of the irregular point distribution, a variable search radius was applied for determining the sample locations used in the estimate. The resulting data products of the interpolations are surfaces of parameter values across the extent of Port Angeles Harbor. These data products are used in Section 6.0 of this report to identify areas of potentially adverse impacts to sediment quality and to assess the environmental fate of COPCs.

3.0 Background Sediment Concentrations

Comparison of study area chemical concentrations to natural background concentrations allows for the identification of localized anthropogenic influences on sediment quality. Natural background includes concentrations of chemicals that are naturally occurring, as well as concentrations of manmade chemicals that are globally distributed at low levels. This section evaluates available data sets that may be used to establish natural background threshold values (BTVs) for COPCs in Port Angeles Harbor. This evaluation provides information to assist with the development of sediment preliminary cleanup objectives within Port Angeles Harbor.

3.1 Compilation of Background Data Sets

BTVs for Port Angeles Harbor should be estimated based upon defensible background data. An appropriate background data set must be of a reasonable size, comparable character, and collected from a region proximal to the investigation area. A background data set should have at least 8 to 10 observations (more observations are preferable) to estimate BTVs or to perform background versus study area comparisons (EPA 2010). The background chemical data should be from an area that has the same basic sediment characteristics (such as mineral composition, grain size distribution, and organic carbon content) as Port Angeles Harbor; has not been influenced by industrial releases; and has not been influenced by other localized human activities.

The most extensive data set considered for determining Port Angeles Harbor background is that collected for the Ocean Survey Vessel (OSV) Bold Sediment Survey (DMMP 2009). This survey consisted of the collection and analysis of Puget Sound surface sediments from locations away from known sources of contamination and cleanup sites. Sediment collection included locations within four existing sediment reference areas (Dabob Bay, Carr Inlet, Holmes Harbor, and Samish Bay).

Because Port Angeles Harbor is located along the Strait of Juan de Fuca, a very different environmental setting than the majority of Puget Sound, Lower Elwha Klallam tribal stakeholders have expressed interest in using data sets collected in close proximity to Port Angeles Harbor to define local background. Accordingly, surface sediment chemistry data from both Freshwater Bay and Dungeness Bay were acquired from Ecology's EIM database for evaluation. The small number of sampling points from Dungeness Bay studies and the limited number of analytes investigated in Freshwater Bay (polychlorinated biphenyl [PCB] congeners and dioxin/furan congeners) make these data sets alone insufficient for calculating BTVs for most COPCs. However, the Freshwater Bay and Dungeness Bay data sets in conjunction with Bold data from within the Strait of Juan de Fuca and nearby San Juan Islands constitute a sufficient regional data set.

Three overlapping background data sets were compiled from the combined Bold, Dungeness Bay, and Freshwater Bay data sets for evaluation in order to determine the most appropriate for comparison to the Port Angeles Harbor data set. These background data sets are referred to as the following:

- **Puget Sound-wide** — consisting of all sampling locations from the 2008 OSV Bold Sediment Survey.
- **Puget Sound Reference Areas —** consisting of only reference area sampling locations from the 2008 OSV Bold Sediment Survey.
- **Port Angeles Proximal Area —** consisting of only Strait of Juan de Fuca and San Juan Islands sampling locations from the 2008 OSV Bold Sediment Survey and sampling locations in Freshwater Bay and Dungeness Bay.

3.2 Suitability of Background Data Sets

As part of Ecology's SMS, "reference sediments" are used during bioassay toxicity testing as a clean comparison to investigation-derived sediments. In order to account for matrix effects, the reference and investigation-derived sediments must have similar grain size to draw meaningful conclusions. Similarly, a background data set used to determine BTVs for a study area should have sediment grain size statistics comparable to the area. The amount of fine particles (silt + clay) is generally used to compare the grain size distributions of locations. Coarse sediment particles (sand and gravel) are generally associated with lower COPC concentrations. Therefore, using a background data set from sediments that are coarser-grained than the study area to define natural background may result in overly conservative BTVs. Conversely, less conservative BTVs are likely when using a background data set from sediments that are finer-grained than the study area.

Figure 1 displays box plots for percent fines data from the Port Angeles Sediment Investigation (E & E 2012) and the three potential background data sets discussed above. Box plots are used to compare multiple populations, with each box plot displaying the range of the data (whiskers), the 25^{th} and 75^{th} percentiles (extent of the box), and the median (horizontal line). Although the ranges for all of the background data sets are comparable to that determined in the Port Angeles Harbor SIR, median values suggest that the Puget Sound Reference Area and Port Angeles Proximal Area data sets are predominantly finer and coarser-grained than the study area, respectively. Use of either of these data sets for calculating Port Angeles Harbor BTVs will likely result in grain size effects that will overestimate (Puget Sound Reference Areas) or underestimate (Port Angeles Proximal Area data set) natural background concentrations. Underestimating natural background concentrations is the more conservative measure, and therefore use of the Port Angeles Proximal Area data set will likely result in the more conservative background concentrations than the other data sets evaluated.

3.3 Background Threshold Values

When the BTVs are not known or pre-established, appropriate upper statistical limits are used to estimate these parameters. Generally, upper percentiles based upon background data are used as estimates of BTVs, compliance limits, or not-to-exceed values. These upper limits are often used in study area (point-by-point) versus background comparison evaluations. Upper confidence limits (UCLs) are often used to determine background concentrations; however, only study area averages should be compared with UCLs, while individual observations should be compared with upper percentiles (EPA 2010). As evaluation of the Port Angeles Harbor data will require the comparison of individual observations, upper percentiles are used to define the BTVs rather than UCLs.

Model Toxics Control Act (MTCA) methods for defining BTVs (as described in WAC 173-340-709) have been applied to the three potential background data sets. For lognormal distributed data sets, MTCA defines background as the true upper 90th percentile or four times the true 50th percentile, whichever is lower. MTCA requires a minimal sample size of 10 to define BTVs for soil, but does not specify a minimum number of samples for defining sediment BTVs. Measurements below the method detection limit (MDL) were assigned a value of one-half the MDL. Measurements above the MDL but below the practical quantitation limit (PQL) were assigned a value equal to the MDL.

COPC data for all of the background data sets were lognormal distributed. Table 3 displays the calculated 90th percentile BTVs for each data set. The chemical constituents included in Table 3 are the SMS-listed chemicals that were analyzed in both the Port Angeles Sediment Investigation and the Bold data set. In the cases where the 90th percentile value was less than the value of the maximum reported MDL, the maximum MDL is reported. Table 3 also displays the percentage of Port Angeles Sediment Investigation surface sediment locations that exceed the BTV for the respective background data set.

For all investigated COPCs, with the exception of total low molecular weight polycyclic aromatic hydrocarbons (LPAH), the Port Angeles Proximal Area data set provides the most conservative BTVs. Generally, the Puget Sound-wide data set has greater BTVs than the Puget Sound Reference Area data set. Based on the Port Angeles Proximal Area data set, the BTV for most organic COPCs (including total PCB Aroclors) is below the MDL. Dioxin/furan toxic equivalency (TEQ), fluoranthene, pyrene, and phenanthrene in Port Angeles Harbor sediments have the greatest percentage of locations where concentrations exceed the BTVs.

3.4 Background Summary

Surface sediment data from the 2008 OSV Bold Sediment Survey, Dungeness Bay investigations, and Freshwater Bay investigations were used to compile three background data sets. These data sets were evaluated to determine whether they may be appropriate for establishing chemical BTVs to be used for sediments in Port Angeles Harbor. These background data sets were constructed to be representative of either Puget Sound as a whole, Puget Sound reference sediment areas, or the regions of Puget Sound in closest proximity to Port Angeles Harbor.

While any of the three evaluated background data sets are adequate for determining Port Angeles Harbor BTVs, specific caveats are associated with the use of each data set. The Puget Sound-wide background data set provides the least conservative BTVs among the evaluated data sets. Although this data set has a similar grain size population as the Port Angeles Sediment Investigation data, the locations of some Puget Sound-wide data (such as deep basins in Puget Sound) are not necessarily comparable to those in Port Angeles Harbor, have potential industrial source areas, or are located in strong current areas. Additionally, the types of non-point contaminant sources found throughout greater Puget Sound are far more abundant and diverse than those in close proximity to Port Angeles Harbor.

BTVs calculated using the Puget Sound Reference Area data set generally fall in the middle between the Puget Sound-wide and Port Angeles Proximal Area background data sets. Although the grain size population of the Puget Sound Reference Areas data set is generally finer than those of the Port Angeles Sediment Investigation, this grain size effect does not appear to cause increased background chemical concentrations. The sampling locations of the Puget Sound Reference Areas background data set are comparable to those of the Port Angeles Sediment Investigation as they are all collected from semi-enclosed bays under similar geomorphic conditions. As with the Puget Sound-wide background data set, the Puget Sound Reference Area data contains locations far from Port Angeles Harbor and may include contributions from non-point contaminant sources not typical of Port Angeles Harbor.

Due to the regionally specific nature of the Port Angeles Proximal Area background data set, it is most likely to encompass similar natural and anthropogenic sources as those found in Port Angeles Harbor. Using it to calculate BTVs results in the most conservative estimates of background concentrations. However, sediment samples that constitute this background data set are generally coarser-grained than those found in Port Angeles Harbor. Because coarse sediments are generally associated with lower COPC concentrations, the Port Angeles Proximal Area data set may underestimate the natural background concentrations associated with the finer material found in Port Angeles Harbor and, therefore, is more conservative than the other two data sets.

Based on the data available, use of the Port Angeles Proximal Area Background data set is recommended for determining natural background concentrations in Port Angeles Harbor. In order to compile a data set large enough to be statistically significant, samples collected from as far away as the San Juan Islands had to be included in this data set. A more ideal data set would consist of only samples from Dungeness Bay, as this location provides the most comparable natural sources and environmental conditions to Port Angeles Harbor.

Preliminary cleanup goals for Port Angeles Harbor are not being determined as part of this data evaluation. Determining preliminary cleanup goals for Port Angeles Harbor involves selecting between BTVs, PQLs, or risk-based concentrations for COPCs that have been identified as risk drivers. In the case that the BTV, based on the Port Angeles Proximal Area data set, is chosen as the cleanup goal, collection of a more robust, ideal natural background data set may be warranted. A more robust background data set would consist of 15 to 20 newly collected surface sediment samples collected from Dungeness Bay, as this location provides the most comparable natural sources and environmental conditions to Port Angeles Harbor. Targeted sampling locations within Dungeness Bay should encompass the range of grain size distributions collected as a part of the Port Angeles Sediment Investigation and collected samples should be analyzed for the full suite of SMS COPCs. This new background data set would provide adequate, defensible chemical data for determining BTVs specific to Port Angeles Harbor.

4.0 Chemical Fingerprinting

Chemical fingerprinting is a technique used to differentiate potential sources of COPCs. The process is carried out under the assumption that locations with similar profiles of COPCs have similar source types. The results of the fingerprinting can be compared against the spatial distributions of COPC concentrations to determine the relative contribution of various sources. In this section, fingerprinting analysis of the dioxin/furan congeners is analyzed in the surface and subsurface sediment samples.

4.1 Fingerprinting Methodology

Fingerprint analysis with dioxin/furan congeners involves determining the relative amount of each congener in each sample. The end result is referred to as a congener profile. To calculate the profiles, the concentration of each individual congener (not adjusted to TEQ) was divided by the sum of the total dioxin/furan concentration in a given sample. In the case of non-detects, concentrations were estimated at one-half the detection limit.

Data from E & E (2012) and Malcolm Pirnie (2007a, 2007b) were included for fingerprinting analysis. Congener profiles were calculated for all surface and subsurface samples with 10 or more detected congeners. Samples with less than 10 detected congeners were excluded from analysis in order to minimize the influence of non-detected congeners in defining profiles. A total of 211 of 266 samples were included for fingerprint analysis based on this data-screening criterion.

An initial round of analysis was conducted using EPA's Fingerprint Analysis of Leachate Contaminants (FALCON) (EPA 2004) method. This method consists of creating a correlation matrix relating each congener profile to all other samples. Locations with similar correlation coefficients are assumed to have similar dioxin/furan sources. While this method performs well with smaller sample sizes and or distinct sources, it proved cumbersome to interpret a correlation matrix of 211 samples. FALCON analysis was abandoned in favor of principal component analysis (PCA).

PCA is a statistical method that is used to condense the number of variables in complex data sets through the creation of new variables (components). In the case of dioxin/furan congeners, the objective of PCA is to derive components from the 17 possible variables (one per congener) that explain the largest amount of variability between samples. In an ideal case, the end result would be two or three components that explain the majority of the original data set's variability. Each component accounts for some portion of the congener profile of each sample. Groups of samples with similar congener profiles can be determined when the derived components are plotted against each other.

4.2 Results

The Factor Procedure (SAS/STAT 2008, SAS Institute Inc., Cary, NC) was used with options to perform the PCA. Initially, each variable (congener) was standardized to a mean of zero and a variance of one. The procedure then solves for the components that explain the variance, or the spread of the data set. The eigenvalue of each component is a measure of total variance.

Components with eigenvalues greater than one were retained in the analysis. These three components (Components 1, 2, and 3) accounted for 64.7 percent, 11.1 percent, and 6.2 percent of the variability in the Port Angeles data set, respectively.

The congener patterns explained by each of the three components are presented in Table 4. For each congener, the maximum loading has been highlighted. The maximum loading indicates the strongest correlation between a given congener and the component. As a result, a single component can describe the abundance of several congeners within the dioxin/furan profile. For example, Component 3 is best correlated to octachlorodibenzofuran (OCDF) (Table 4). Component 2 is best correlated to 1,2,3,4,7,8-hexachlorodibenzofurans (HxCDF), 1,2,3,4,6,7,8-heptafuran (HpCDF), and 1,2,3,4,7,8,9-HpCDF. The remaining 13 congeners are correlated to component 1. Octachlorodibenzo-p-dioxin (OCDD) has a strong negative loading on component 1, indicating that as the relative abundance of the other congeners increase, the amount of OCDD present in the congener profile decreases.

The congener profile of each sediment sample can be scored based on its relation to each of the components. For each component, the scores are normalized across all samples so that the mean of the scores equals zero and the standard deviation equals one. If component scores are exactly zero for all three components, that sample has a congener profile that represents the average congener profile of all samples. Component scores greater or less than zero explain how individual samples differ from the average congener profile.

Figures 2, 3, and 4 show the component/component plots in two dimensions. If multiple congener profiles were present, the component score plots would show separate and distinct groupings. Instead, most of the samples can be found in one central group surrounding the mean of zero. The samples in Figures 2 through 4 have been color coded depending on their distance from the mean. The 187 samples within two units of the mean are yellow, while the 24 samples greater than two are red. The use of two as a break point is arbitrary and is only meant to show the relative differences between congener profiles and aid in interpretation.

The congener profiles for both groups are presented in Figure 5. Each bar represents the average relative abundance of each congener. The whiskers represent the minimum and maximum relative abundance of each congener. Both congener profiles are similar and dominated by OCDD. 1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin (HpCDD), OCDF, and 1,2,3,4,6,7,8-HpCDF make up the remainder of each profile. The variability about the mean that is present in Figures 2 through 4 can be seen in the “red group” in Figure 5 in that the minimum to maximum range is greater in this subset of samples. However, the difference is not great enough or present in enough samples to suggest a separate source profile.

The sample groups from Figures 2 through 4 were also evaluated for any potential spatial distributions. Within the surface sediment locations, there were more red group samples near the former Rayonier Mill property but not enough to suggest a separate source (Figure 6). Samples from the red group were distributed throughout the bay for the subsurface samples. In both cases, the samples with high variability were intermingled with lower variability samples, leaving no clearly delineated source.

4.3 Conclusions

The PCA analysis indicates a similar congener profile is evident in sediments collected from Port Angeles Harbor. One component explained 64.7 percent of the variance in the data set, the component scores for individual samples did not reveal any sample subsets that might have a different profile, and the congener profiles were comparable for all samples. This analysis does not eliminate the possibility that different sources of dioxin/furan congeners were originally present and became mixed in the sediment over time, or that multiple sources within the harbor produced similar congener profiles.

Because the described chemical fingerprinting technique was unable to differentiate multiple sources of dioxin/furan congeners to sediments of Port Angeles Harbor, Ecology is pursuing a more intensive fingerprinting approach. Multivariate chemometric analyses (un-mixing analyses) of the Port Angeles sediment dioxin/furan congener data set is planned subsequent to this report. A similar chemometric analyses was performed for Port Angeles soil dioxin/furan congener data as a part of the *Rayonier Mill Off-Property Soil Dioxin Study* (E & E and Glass 2011). This chemometric evaluation was able to quantitatively differentiate three unique source patterns that account for the dioxin/furan profiles observed in soils.

This page is intentionally blank.

5.0 Sediment Transport

Successful cleanup of Port Angeles Harbor will be largely dependent upon an understanding of the natural physical processes operating in the environment and how these processes affect the fate and transport of contaminated sediments. This section provides a summary of findings for sediment transport studies performed in support of the Port Angeles SIR (E & E 2012). Due to the complexity of the physical processes affecting the harbor, results of these studies and others were integrated to construct multiple conceptual site models (CSMs) for sediment transport in the harbor and identify the key sediment transport pathways. Information presented in this section was used to construct Figure 7, which summarizes sediment transport pathways under different conditions. These hypothesized sediment transport pathways can be used in conjunction with the Port Angeles Harbor sediment chemistry results to determine the likely point sources of chemical contamination and the regions of the harbor influenced by these sources (Sections 6.0 and 7.0). Throughout this discussion the term "western harbor" is consistently used to refer to inner-most Port Angeles Harbor, a region that has been typically referred to as the "inner harbor" in E & E (2012).

5.1 Summary of Field Studies in Support of the Port Angeles Sediment Investigation

Three independent assessments of factors influencing sediment transport within Port Angeles Harbor were conducted as a part of the Port Angeles sediment investigation in order to determine the dynamic behavior of sediments from potential sources to sinks. A field study was performed to determine the intensity and direction of surface and subsurface tidal currents (Evans-Hamilton 2008). Sediment Trend Analysis (STA) was conducted to aid in the understanding of sediment transport and deposition within the harbor (GeoSea 2009). Finally, a marine geomorphic study investigated the physical environment of Port Angeles Harbor and integrated results from the current study and STA to determine principal sediment transport pathways (Herrera 2011).

5.1.1 Current Data Collection and Analysis

Sediments in all areas of the harbor may be subject to transportation by currents. Several previous studies, summarized by GeoSea (2009) and Herrera (2011), have characterized tidal currents in the Strait of Juan de Fuca and/or the Port Angeles Harbor area. None of these previous studies adequately characterizes the relative current or wave energy near the bed that initiates or maintains sediment transport within the harbor, particularly over periods of more than a few days.

In the current study (Evans-Hamilton 2008), three current monitoring stations were deployed to measure currents, waves, and suspended sediment (turbidity) over a one-month period (March 2008). While data collected during this time period do not reflect the seasonal variability of currents, they do encompass the timing of extreme tidal currents associated with spring tides. The monitoring units were placed near the Nippon Paper Industries (Station #1), between the City Pier and the former Rayonier Mill property (Station #2), and immediately south of the end of Ediz Hook (Station #3). Although the direct observations of sediment transport were limited to near the seafloor, the use of acoustic Doppler current profilers (ADCPs) provided information on currents at a variety of depths throughout the water column, including near the water surface and the bottom.

The main findings of the current study were:

- Currents and suspended sediment observed were attributed dominantly to tidal conditions, as no high energy wind events occurred during the deployment period.
- The strongest current events at each tripod occurred at different times, with no significant currents being observed at the other tripods during each of these events. This is interpreted to indicate that a single tidal eddy postulated in some previous studies likely does not represent the most important current events that initiate or maintain sediment transport. Instead, the most intense currents were consistent with highly localized tidal eddies.
- At the water surface in the outer harbor, tidal currents are energetic and driven strongly by tidal motions in the Strait of Juan de Fuca. These currents diminish with distance into the western harbor.
- At Station #3 south of the end of Ediz Hook, currents appear most often toward the east; however, they are not as strong as those toward the west. The strongest currents near the bed have a westward component.

5.1.2 Summary of Sediment Trend Analysis

The STA study was conducted to assess sediment transport regimes operating in the harbor (GeoSea 2009). The STA method developed by GeoSea Consulting Ltd. is a technique whereby patterns of net sediment transport are determined from relative changes in spatial grain-size distributions. In support of this study, 765 surface sediment samples were collected and analyzed for their grain-size distributions. STA enables the dynamic behavior of sediments in a region to be determined (i.e., net erosion, net deposition, dynamic equilibrium, etc.). Additionally, STA results are used to identify sediment “parting zones,” areas of sediment erosion from which sediment is transported away. While numerous uncertainties are associated with the STA methodology (USACE 2005; Poizot et al. 2008), STA remains the only Port Angeles Harbor study that derives sediment transport pathways through the quantitative analysis of sediment samples.

The main findings of the STA were as follows:

- Port Angeles Harbor acts as a slowly infilling sediment trap for material derived from the Strait of Juan de Fuca, longshore transport, and small tributary rivers.
- The area within 2,000 meters of the former Rayonier Mill property is either net erosional or in dynamic equilibrium.
- Sediment is supplied to parting zones during high energy events (periods of high rainfall and storm activity) and is subsequently redistributed by tidal currents.
- Net deposition is confined to the western harbor, where sediment transport is predominantly eastward (i.e., downslope).
- Most of the harbor sediment is trapped inside the Ediz Hook with little opportunity to escape. For this reason, large quantities of wood debris that have accumulated in the harbor are unlikely to be removed by natural processes.

5.1.3 Summary of Geomorphic Report

The geomorphic assessment of Port Angeles Harbor was prepared by Herrera Environmental Consultants with the purpose of describing the physical environment within the harbor and integrating results of the current study and STA (Herrera 2011). Their report includes a discussion of sediment inputs, sedimentation rates, nearshore sediment transport, and sediment transport by tides and currents.

The main findings of the geomorphic report were as follows:

- Small creeks and anthropogenic discharges are the major sources of sediment to the harbor.
- Most, if not all, of the sediment discharged to the harbor remains there.
- Wave- and current-induced sediment transport is expected to result from high energy wind events.
- Nearshore sediment transport is clockwise along the southern harbor.
- Clockwise transport in the nearshore is abruptly stopped in the western harbor near the neck of Ediz Hook.
- The repository of sediment in the western harbor experiences localized gravity flows downslope to the east.
- In deeper regions of the harbor, wind-induced eastward surface currents are balanced by westward counterflows near the sediment bed.

Additionally, analysis of cesium-137 and lead-210 in two sediment cores (MA06 and RL03) were included in this report in order to estimate sedimentation rates at these locations (Figure 7). Both locations were found to have low sedimentation accumulation rates, both with a range of 0.14 to 0.21 centimeter per year. The selection of core locations was made prior to other analyses that identified areas where sediment may preferentially deposit, such as the deep western harbor. Therefore, no cores were collected for radioisotopic dating to independently evaluate sediment accumulation suggested by other lines of evidence. Core RL03 is located within a parting zone identified by STA. While the lead-210 profile at this location suggests a low sediment accumulation rate over a long period, this radioisotopic analysis cannot be used to assess the short-term deposition and subsequent transport of sediment expected at a parting zone.

Radioisotopic analyses performed near the Nippon Paper Industries property (Figure 7) suggests significantly greater accumulation rates (in excess of 2.5 centimeters per year) in the eastern lagoon and western harbor (Exponent 2008). However, the extremely deep mixed layer depths measured in lagoon and western harbor cores imply that these locations may have been biased by human disturbance, such as dredging (Exponent 2008).

5.2 Conceptual Site Models of Sediment Transport

Results of the current study, STA, nearshore geomorphic analysis, radioisotopic measurements, and many previous hydrographic studies of Port Angeles Harbor together support CSMs of sediment transport in the harbor and the physical processes that drive transport. The current body of literature for Port Angeles Harbor implies complex conditions that result in multiple transport mechanisms, not all of which can be easily accounted for in a single CSM. In particular, significant differences are apparent in sediment transport pathways under low energy and high energy conditions. Therefore, a single CSM for sediment transport is insufficient to account for the natural variability in conditions responsible for the net movement of sediment within the harbor. CSMs for both low and high energy conditions are discussed below.

5.2.1 Low Energy CSM for Sediment Transport

The main concepts of the CSM for sediment transport under low energy conditions are that:

- Particles are subject to transport by localized currents;
- Predominantly weak tidal currents allow most particles to settle close to their sources;
- Deposition rates of suspended material are highest near the source and decrease with distance; and
- Because most contaminants are either released in association with particles or readily become associated with particles in the marine environment, their fate and transport within Port Angeles Harbor are governed by the transport of particles.

This CSM infers that particles and associated contaminants discharged to the harbor are transported while in suspension after discharge and are either deposited in the close vicinity of their source or transported by currents within the harbor. Therefore, contaminant patterns should dominantly resemble “hot spots” of sediment contamination near source outfalls, with concentrations decreasing with distance from the source. This CSM does not assign a direction to either net circulation or net sediment transport, as discussed below.

This proposed low energy CSM for Port Angeles Harbor is in many ways similar to one developed by Windward (2012) at the request of Rayonier. The Windward CSM is largely based on their interpretation of net hydrodynamic conditions and the subsequent transport of suspended materials. The Windward CSM also contends that:

- Net circulation in Port Angeles Harbor is counterclockwise,
- Net flow along the southern shoreline is east, and
- Suspended material will be transported by net circulation patterns.

The underlying conditions of the Windward CSM are based upon a select subset of surface current and hydrodynamic modeling studies conducted over the past four decades. Even under such low energy conditions, numerous studies indicate wide variability in the direction of surface currents and a high level of uncertainty in the direction of net circulation. Counterclockwise circulation is not constant in the harbor and may not even be the prevalent direction of circulation. A thorough survey of relevant literature shows that circulation within Port Angeles Harbor varies based on tides and winds, resulting in complicated flushing patterns and conflicting reports of surface circulation direction (Tollefson et al. 1971; EPA 1974; Ebbesmeyer et al. 1979; Shea et al. 1981; Foster Wheeler 1997). It has previously been concluded that the pattern of net circulation in the harbor cannot be determined based on available data (Ebbesmeyer et al. 1979). A conclusion of the current study (Evans-Hamilton 2008) was that localized tidal eddies were likely more important for initiating and maintaining sediment transport than a single harbor-wide tidal eddy. Together these studies suggest that net counterclockwise circulation throughout the harbor, as described in the Windward CSM, is not the only process driving sediment transport.

In 1972, Rayonier began discharging effluent to a submerged diffuser outfall located in the outer harbor. In the vicinity of this deepwater outfall, evidence exists for the potential westward transport of particles into the harbor under low energy conditions. In contrast to what was presented in the Windward CSM, Rayonier concluded during the process of designing their deepwater outfall that circulation in the vicinity of their property is dominated by a clockwise eddy (Tollefson et al. 1971). This clockwise eddy is supported by reported observations of westward migration of the Rayonier deepwater outfall plume (EPA 1974; Foster Wheeler 1997). Additionally, a significant portion of suspended solids in the deepwater effluent may never have reached the observable surface plume and were instead subjected to transport at depth. In the vicinity of the Rayonier deepwater outfall, bottom currents responsible for sediment transport oscillate in a bi-directional manner (east-west) but are of strongest magnitude in the westerly direction (Evans-Hamilton 2008).

Because variability in the direction of surface currents and uncertainty associated with net circulation patterns make it difficult to assess the direction of net sediment transport under low energy conditions, the low energy CSM does not assign a direction to either net circulation or net sediment transport. Apparent changes in current direction over tidal cycles likely allow effluent discharged from all harbor outfalls to experience localized, multi-directional transport. In the cases of the former Rayonier Mill property nearshore and deepwater outfalls, particle transported under low energy conditions likely included a westward component, rather than strictly eastward transport out of the harbor. Regardless of the direction of localized or net currents, under low energy conditions the predominantly weak tidal currents likely allow most particles to settle close to their sources, resulting in localized sediment contamination.

5.2.2 High Energy CSM for Sediment Transport

High energy events (periods of high rainfall and storm activity) appear to play an important role in sediment transport, allowing net sediment transport pathways to differ greatly from those inferred from surface currents and circulation patterns. Both the STA (GeoSea 2009) and geomorphic study (Herrera 2011) conclude, based upon direct observations of deposited sediment, that high energy events greatly influence sediment transport and are responsible for both the character of deposited sediment and the geomorphology of the shoreline. The high energy CSM accounts for many physical processes not relevant under low energy conditions, such as:

- Resuspension of deposited sediment;
- Enhancement of near-bottom currents, which are most likely to transport resuspended sediment; and
- Nearshore, wave-induced sediment transport.

The main concepts of the CSM for sediment transport under high energy conditions are that:

- Sediment is efficiently delivered to the harbor as runoff during storm events;
- The most extreme northeasterly wind condition can induce bottom currents at depths shallower than approximately 55 feet;
- The mouth of the harbor, including the area in the immediate vicinity of the former Rayonier Mill property, is net erosional or in dynamic equilibrium;

- Wave-induced nearshore sediment transport is clockwise along the southern harbor;
- Clockwise transport in the nearshore is abruptly stopped in the western harbor near the neck of Ediz Hook;
- Net deposition is confined to the western harbor, where sediment transport is predominantly eastward (i.e., downslope); and
- Sediment is supplied to parting zones during high energy events and is subsequently redistributed by tidal currents.

Sediment transport across the southern harbor is fundamentally different from that in deeper portions of the harbor because it is driven almost exclusively by wave action (Herrera 2011). While previous studies in Port Angeles Harbor have described large-scale currents, they did not account for wave-induced transport in the nearshore, even though many of the early contaminant releases occurred along the nearshore (Malcolm-Pirnie 2007a). Waves in Port Angeles Harbor result primarily from the predominantly westerly winds, but also from easterly and northeasterly winds. The largest waves in the harbor are associated with northeasterly winds due to the comparatively large fetch. Under the most extreme northeasterly wind condition, waves can induce bottom currents capable of sediment transport in water depths less than 55 feet (Herrera 2011). Therefore, it is important to consider wave-induced transport in the vicinity of the former Rayonier Mill property as the entirety of the harbor within 0.5 mile of the property is shallower than 55 feet. Sediment transport in deeper regions of the harbor is unlikely to be influenced by waves, even during the most extreme storms.

Herrera (2011) suggests that large wind-driven waves, as well as refraction of the swell entering the harbor from the Strait of Juan de Fuca, result in westward longshore sediment transport along the southern harbor. This clockwise sediment transport pathway was determined through observations of:

- Newly deposited sediment,
- Lateral coarsening and fining trends alongshore,
- Truncation of deltas in areas of wave erosion, and
- Changes in topography/bathymetry observed in historical documents since 1914.

Based on these observations, longshore transport occurs along the entire southern shore from Lees Creek, east of the former Rayonier Mill property, to the western harbor. This clockwise transport of sediment is abruptly stopped near the neck of Ediz Hook, where fine-grained sediment accumulates.

The STA (GeoSea 2009) provides one line of evidence that sediment transport pathways are influenced by high energy events. This analysis identified the outer harbor in the vicinity of the former Rayonier Mill property as being net erosional or in dynamic equilibrium, suggesting property-derived fine-grained particles settling in the nearshore during low energy intervals may only be temporarily deposited there. This fine-grained material appears to be scoured from this region during high energy events. Such a removal mechanism may explain why pulp waste mats observed in the former Rayonier Mill property nearshore (DOI 1967) were not apparent in subsequent wood waste surveys, while mats of similar thickness have persisted in the western harbor (SAIC 1999).

A sediment parting zone was identified offshore from the former Rayonier Mill property, which has the potential to be replenished with sediment during high energy events (Figure 7). While the STA does not predict the ultimate depositional location of material derived from the former Rayonier Mill property, it suggests the potential for dispersion throughout much of the harbor. STA identifies the western harbor as the predominant depositional region of Port Angeles Harbor, suggesting the western harbor as the terminus of some sediment transport pathways.

5.2.3 CSM Summary

A single sediment transport CSM does not encompass the complex conditions likely responsible for sediment transport in Port Angeles Harbor. In particular, counterclockwise net sediment transport presented by Windward (2012) cannot account for the lack of fine-grained material offshore from the former Rayonier Mill property and the sustained deposition of fine-grained material in the western harbor suggested through many lines of evidence. Instead, CSMs for a range of low and high energy conditions are required to account for discrepancies in sediment transport pathways inferred by surface currents, hydrodynamic modeling, particle size distributions of deposited sediment, and geomorphic evidence.

While the existence of multiple CSMs makes it difficult to assess the direction of *net* sediment transport, it is evident that material derived from the former Rayonier Mill property and other nearby sources has the potential to be transported both into and out of Port Angeles Harbor. Under low energy conditions, the highest concentrations of materials released from outfalls are expected to deposit in the close vicinity of their discharge point. However, tidal and wind-driven variability in the direction of surface currents likely cause a depositional footprint that is broader than that predicted by net currents. Additionally, high energy events appear to redistribute much of the sediment deposited during low energy conditions.

5.3 Overview of Sediment Transport Pathways

This section identifies the main sediment transport pathways inferred from the CSMs that may influence the spatial patterns in sediment chemistry observed in Port Angeles Harbor. Three very different, spatially segregated, transport pathways are largely responsible for the movement of sediment from sources to sinks within the southern, western, and central harbor (Figure 7).

5.3.1 Southern Harbor Sediment Transport

The majority of potential COPCs and sediment sources to Port Angeles Harbor (industrial outfalls, CSOs, creeks, etc.) are located along the southern harbor shoreline or contribute to runoff that enters the harbor along the southern shoreline (E & E 2008a). Of particular importance to historical sediment and COPC loading in this region was discharge from the Rayonier Mill nearshore and deepwater outfalls. Five nearshore outfalls discharged untreated mill effluent between 1937 and 1972. After this period, treated effluent was discharged to the outer harbor through a deepwater outfall until the mill's closure in 1997. During operation, the former Rayonier Mill discharged approximately 35 million gallons of effluent per day, with a solids load of approximately 20 tons per day (EPA 1974; Foster Wheeler 1997). In comparison, total annual CSO discharge to Port Angeles Harbor between 2003 and 2008 averaged 32 million gallons (City of Port Angeles 2009), making daily discharge from Rayonier approximately equivalent to yearly CSO discharge.

Under low energy conditions, particles delivered to the harbor as effluent or runoff deposit in close proximity to the discharge point, with fine-grained material subject to limited, multi-directional transport by weak tidal currents. Much of the fine-grained material entering the southern harbor in the vicinity of the former Rayonier property has the potential to be transported eastward out of the harbor (Battelle 2004). Sediment deposition likely continues under this regime until the onset of a high energy storm event.

Storm events that include precipitation efficiently deliver sediment to the harbor as runoff from both creeks and outfalls. This influx of sediment is subjected to wind- and wave-induced transport mechanisms that do not typically occur during low energy conditions. Waves produced by strong winds can induce bottom currents capable of resuspending surface sediments in the shallow southern harbor. These wind-induced waves can also act to enhance the bottom currents responsible for sediment transport in deeper areas of the harbor. Large wind-driven waves from the northeast, as well as refraction of the swell entering the harbor from the Strait of Juan de Fuca, result in westward longshore sediment transport along the southern harbor from Lees Creek to the western harbor. Sources of sediment carried by the longshore transport mechanism may include:

- Shallow resuspended sediment,
- Creeks that empty into the southern harbor,
- Anthropogenic releases along the southern shoreline,
- Private stormwater outfalls,
- Combined sewer overflows (CSO), and
- Eroding bank material.

Multiple structures along the southern harbor (docks, piers, jetties, etc.) protect the shoreline from the wave energy that causes longshore transport. One such structure that has historically provided protection is the rock jetty along the western side of the former Rayonier Mill property. The orientation of the jetty has protected the area adjacent to the former mill property from wave energy, likely minimizing westward longshore transport of sediment within the “log pond.” Additionally, logs stored within the log pond while the mill was operating served to protect the adjacent shoreline. The result of wave protection has been the trapping of sediment behind the jetty within the log pond. However, the jetty is currently showing signs of age and breaches are occurring in two locations. When log rafting ceased, the shoreline became exposed to intense wave erosion. As a result, the southern shore of the log pond has been re-armored to prevent erosion (Foster Wheeler 2000). The removal of approximately 2,000 sunken logs from the log pond may have had a destabilizing effect, increasing the susceptibility of sediment erosion from within the log pond.

5.3.2 Western Harbor Sediment Transport

Western Port Angeles Harbor serves as the long-term sink for depositional sediment within the harbor. The western harbor, extending from the western shoreline eastward approximately one mile, was one of only two regions of the harbor identified as being net depositional in the STA report (GeoSea 2009). Under low energy conditions, the dominant sources of sediment to this region are nearby outfalls. Similar to the southern harbor, sediment deposition is likely to occur in close proximity to outfalls of the western harbor during low energy conditions. During high energy events, additional sediment sources to the western harbor potentially include creek and southern harbor outfall discharge delivered by longshore transport.

Because there is little wave energy in the western harbor, sediment is subject to current-driven transport on a day-to-day basis and also intermittent, density-driven mudflows. Results of both the current study (Evans-Hamilton 2008) and the STA suggest that sediment transport is predominantly eastward toward the central harbor. Predominant westerly winds act to establish an eastward surface current in the western harbor that is counteracted by westward currents deeper in the harbor. Mudflows are expected to travel downslope to the east. Both of these eastward transport mechanisms are likely to disperse fine-grained sediment away from the shoreline and across the entirety of the western harbor. However, sediment transport likely does not continue unimpeded in the easterly direction, as STA identified a transport front approximately one mile from the harbor’s western shoreline (Figure 7).

An intertidal lagoon located at the western end of the harbor also serves as a likely sediment sink but also a possible source to the western harbor. The lagoon has historically been used for log rafting and the northeastern corner has previously been dredged (Exponent 2008). The lagoon connects to the harbor through a narrow, armored channel. Under low energy conditions, sediment delivered to the lagoon by either outfalls or flood tides is expected to deposit in the lagoon without the ability to be eroded during ebb tides. The narrowness of the channel and the steep bluff to the southwest of the lagoon likely prevent the lagoon from experiencing substantial wind- or wave-induced currents. Therefore, sediment introduced to the lagoon during high energy events is also likely to deposit there. This conceptualization of sediment deposition in the lagoon is supported by the STA, which identified the lagoon as being completely depositional (GeoSea 2009). Lagoon sediments may have the ability to be mobilized and transported to the western harbor if outfalls discharging to the lagoon scour the sediment bed. It is also possible that effluent discharging to the lagoon is transported directly to the western harbor during ebb tides without first depositing within the lagoon.

5.3.3 Central Harbor Sediment Transport

STA identified sediment parting zones in central Port Angeles Harbor approximately half a mile north of the former Rayonier Mill dock and also along the outer Ediz Hook (Figure 7). Because a parting zone clearly cannot be a continuous source of sediment without a replenishment mechanism, its presence implies both sediment loading and dispersion processes. Sediments throughout the central harbor were determined to be in a state of dynamic equilibrium (GeoSea 2009). Sediment loading to the parting zones likely occurs during extreme events, which can radically and rapidly replenish them with sediment. Sources of sediment to the parting zone closest to the former Rayonier property likely include sediment eroded by storm wave energy from the shallow southern harbor, as well as some new sediment delivered to the harbor by creeks during high runoff events.

After the parting zone has been recharged with sediment, typical day-to-day transport processes not associated with extreme events act to disperse sediment away from the parting zone. Based on currents measured during spring tides (Evans-Hamilton 2008), the strongest near-bed current at the locations of the parting zones is likely to the west. This bottom current is a combination of tidal current and the counterflow balance to the strong eastward surface current within the harbor caused by westerly winds. This same westward bottom current may also transport fine-grained sediment emanating from the Rayonier Deep Water Outfall and Port Angeles City Outfall, which discharge into the deep harbor east of the sediment parting zone. The winnowing of fine-grained sediment westward from the parting zone is a likely factor influencing the spatial patterns apparent in the surface sediment grain size distributions (see Section 6.1.1). As was the case with sediment moving eastward from the western harbor, sediment being transported westward from the central harbor is unlikely to move across the transport front and upslope into the western harbor (Figure 7).

6.0 Environmental Fate of Contaminants of Concern

The transport mechanisms discussed in Section 5.0 affect not only the movement and deposition of sediment within the harbor but also contribute to the observed spatial patterns in sediment conventional parameters and COPCs. This section discusses the spatial patterns in sediment characteristics and chemistry in the context of sediment transport pathways in order to identify areas of adverse impacts to sediment quality, the likely sources of deposited COPC, and the potential sources of apparent toxicity observed in sediments. Figures presented in this section include interpolated data models created by the spatial analysis methods discussed in Section 2.0.

6.1 Surface Sediment Conventional Parameters

6.1.1 Fines

The spatial distribution of sedimentary fines (clay + silt grain size fractions) observed throughout Port Angeles Harbor support inferences made in Section 5.0 regarding primary sediment transport pathways (Figure 7). In addition to the studies listed in Section 2.0, the 765 locations of sediment grain size analysis from GeoSea (2009) are incorporated into Figure 8. Outside of the immediate influence of buoyant plumes, the observed distribution of sedimentary fines in the harbor is a result of resuspension and transport by marine processes occurring near the seabed.

Grain size patterns are the result of a balance between fine-grained sediment supply and energy at the seabed. The relatively low amount of fine-grained material deposited in the outer harbor as compared to the western harbor illustrates the differences in sediment supply and energy between these two areas. The coarsest sediments of the harbor are found close to the shoreline east of Peabody Creek and extending out of the harbor. In this region there is a sharp alongshore gradient in fine-grained sediment composition, with fines decreasing from approximately 60 percent offshore of Peabody Creek to less than 30 percent approaching the former Rayonier Mill property. In addition, there is a prominent across-slope gradient in grain size related to bathymetry, which is consistent with waves approaching a shore face. These large-scale patterns reflect the change in energy regime as the seabed becomes less sheltered and less receptive to the long-term deposition of fine-grained sediments with increasing distance from the western harbor. These patterns are not likely attributable to a lack of fine-grained sediment sources to this region of the southern harbor, as creeks, CSOs, and Rayonier's former nearshore outfalls are all expected to have been sources of fine-grained material to the nearshore environment. Instead, wave energy in the outer harbor prevents this area from retaining fine-grained material, causing resuspension and dispersion across the observed gradients to the vicinity of the parting zone. This resuspension and dispersion may not occur to the same extent in the former Rayonier log pond, as the rock jetty located along its northern extent act to disperse or block wave energy.

Another large-scale pattern appears to emanate from the parting zone in the closest vicinity to the former Rayonier property. This parting zone is comprised of less than 50 percent fines. Finer sediments are found in broad zones which parallel both Ediz Hook and the Southern Harbor shoreline, with coarser sediments in the vicinity of the parting zone separating the two deposits. This gradient in fines radiating westward from the parting zone is a possible result of winnowing by westward bottom currents, transporting fine-grained sediment delivered to the parting zone during an extreme event toward the central harbor.

The presence of nearshore fine-grained sediment west of Peabody Creek is an indication that wave energy in this region is insufficient to resuspend the material. Ultimately, the grainsize pattern here is likely determined by protection from wave energy by Ediz Hook, with the seabed becoming more protected toward the western harbor. Along this shoreline there are also several places where greater than 50 percent fines were sampled in shallow water with no apparent seaward fining. This is likely another indication that the initial deposition of fine-grained material in this area is not heavily reworked by wave activity.

A pronounced feature of the grain size distribution is the apparent focusing of the finest-grained sediments (greater than 70 percent fines) to a well-defined zone within the western harbor, adjacent to Ediz Hook. Because this fine-grained depositional zone is distantly located from the creek and anthropogenic sources to the harbor, a clockwise or eastward movement of bottom currents is required to supply this region. It was hypothesized in Herrera (2011) that suspended fine-grained sediments transported westward from the southern harbor come to an abrupt end near the neck of Ediz Hook where they temporarily accumulate. This fine-grained material then has the potential to be dispersed eastward across the western harbor by both tidal currents and gravity flows, resulting in focused deposition of the fine-grained sediment in the deep western harbor (Figure 8).

6.1.2 TOC as a Proxy for Wood Debris

The greatest concentrations of TOC were found in two regions: the western harbor and in close proximity to the former Rayonier Mill property (Figure 9). Overall TOC concentrations are well correlated with qualitative observations of the quantity of wood debris present (E & E 2012) and sedimentary wood observations made for the STA study (GeoSea 2009). Because fine-grained sediments can only support approximately 5 percent TOC through sorption of organic matter to mineral surfaces under aerobic conditions (Nuwer 2008), sediment TOC concentrations above about 5 percent can be used as a proxy for the amount of organic debris (presumed to be wood debris) present in the sediment (Figure 10). All observations indicate that the central and outer harbor is relatively free of wood debris.

Sedimentary wood debris is concentrated in locations that are either active or historic log storage and transfer areas (Figure 10) (E & E 2012). These locations include the neck of Ediz Hook (active), the western harbor in the vicinity of the former Fibreboard property (historic), the vicinity of Terminal 1 (active), and the vicinity of the former Rayonier Mill property (historic). The locations where wood debris is found in surface sediments appear to have changed little since initial surveys were conducted (SAIC 1999). The presence of wood debris throughout much of the western harbor illustrates this region's ability to trap and store material.

Activities by Rayonier likely contributed to wood debris throughout much of the harbor despite the relatively small wood debris footprint currently found in the vicinity of the former Rayonier Mill property. Historically, the former Rayonier Mill was the principal source of both sulfite pulp and discharged solids among the Port Angeles mills (WPCC 1957; DOI 1967). Therefore, it is unlikely that the former Rayonier Mill was a smaller source of wood debris than western harbor facilities. The persistence of pulp mats in the western harbor suggests that degradation of this type of material is not sufficient to efficiently remove it from surface sediments. Instead, small pieces of wood debris initially deposited in the vicinity of the former mill property are likely to have been at least partially eroded and dispersed both into and out of the harbor. Logs that may have been a source of wood debris were specifically targeted for removal from the former Rayonier log pond after the closing of the mill. Additionally, Rayonier leased other marine areas of the harbor for log rafting.

6.1.3 Sulfides and Ammonia

Sedimentary sulfides and ammonia accumulate in the absence of dissolved oxygen in porewater. When molecular oxygen is not available, or when it has been used up, decay of organic matter occurs through anaerobic metabolism, producing sulfides and ammonia as byproducts. Throughout Port Angeles Harbor, high concentrations of sedimentary sulfides are associated with the presence of wood debris (Figure 11). The occurrence of wood debris in sediments may lead to the buildup of sulfides due to both the depletion of dissolved oxygen during degradation of the wood debris and the inability of organisms to effectively bioturbate wood-rich sediments. The greatest sulfides concentrations are located in the active/historic log storage and transfer areas identified as having the highest wood debris content.

Although sedimentary ammonia accumulates under the same anaerobic conditions as sulfides, the spatial distributions of ammonia and sulfides do not mirror each other (Figures 11 and 12). High ammonia concentrations are not observed exclusively in log storage and transfer areas, but also throughout the central harbor. Ammonia is released through the anaerobic decomposition of organic matter containing nitrogen. Because wood debris has a very low nitrogen content, high sedimentary ammonia concentrations in the central harbor may be associated with the anaerobic degradation of non-woody organic matter.

6.2 Surface Sediment COPCs

Surface sediments in Port Angeles Harbor exceed SMS or LAET criteria for numerous metals and organic COPCs in multiple locations (Tables 5 and 6). In cases where TOC concentrations at a location were less than 0.5 percent or greater than 3.5 percent, surface sediment concentrations were compared to LAET criteria (Table 6). The chemical data clearly identify two primary regions where sediment quality has been adversely affected by chemical concentrations greater than SMS/LAET criteria (Figures 13 and 14). As discussed in Section 3.0, the high concentrations of COPCs observed in Port Angeles Harbor surface sediment exceed typical sediment background concentrations and are therefore the likely result of anthropogenic sources. Metals that exceed SMS criteria generally occur in the western harbor near the neck of Ediz Hook; organic COPCs that exceed SMS/LAET criteria occur primarily in the vicinity of the former Rayonier Mill property. The spatial separation of metal and organic contamination suggests that they originate from different primary sources.

6.2.1 Metals

Arsenic, cadmium, mercury, and zinc concentrations that exceed SMS criteria were confined to the western harbor and lagoon, with the exception of a single SMS exceedance for mercury in the former Rayonier Mill log pond (Table 5; Figure 13). As discussed in Section 5.0, sediment deposition in the western harbor may integrate sediment from multiple proximal and distant sources (industrial releases, sediment carried by clockwise longshore transport, etc.). Spatial interpolation of surface sediment arsenic, cadmium, mercury, and zinc concentrations are shown in Figures 15 through 18. The maximum concentration of each of these metals is located along the western harbor shoreline with concentrations decreasing with distance into the deeper western harbor. In the central harbor and in the vicinity of the former Rayonier Mill property (outside of the log pond), concentrations of these metals are similar to calculated background values.

Although some of this metal contamination may be attributable to southern harbor sources transported to the western harbor by longshore transport, the spatial footprint does not suggest distant sources are responsible for the majority of these metals. Metals carried to the western harbor by longshore transport would be expected to move with the fine-grained sediment fraction and disperse eastward after reaching the neck of the Ediz Hook (Figure 7). The fact that the highest metals concentrations are found at the shoreline rather than deeper locations where fine-grained sediments ultimately accumulate suggests that there is a potential upland source of metals entering the western harbor at the shoreline in the vicinity of the lagoon. Such a source would be susceptible to eastward transport processes diffusing the contaminants throughout the western harbor. While metal concentrations in the former Rayonier log pond are elevated over background concentrations, they are generally an order of magnitude less than the maximum concentrations along the western harbor shoreline.

6.2.2 Dioxin/Furan Congeners

As with the metals mentioned above, dioxin/furan congener TEQs are greatest along the western harbor shoreline with concentrations decreasing with distance into the central and outer harbor (Figure 19). Unlike metals, dioxin/furan TEQs remain in excess of background levels throughout the central harbor. Dioxin/furan TEQs of the surface sediment samples collected within the lagoon are among the highest observed in this study. As with metals, sediment transport to the western harbor from distant sources is unlikely to be the dominant mechanism responsible for the observed dioxin spatial pattern. Also, the transport of airborne dioxin to the western harbor from source locations in the eastern part of the harbor is unlikely as winds are predominantly from the west. Instead, upland sources along the western harbor shoreline are the likely driver of the surface sediment dioxin pattern in the western harbor.

Dioxin/furan TEQs along the former Rayonier Mill dock and the log pond area are greater than those of the central and outer harbor, suggesting the former mill property as a potential dioxin source (Figure 19). The fact that a larger dioxin footprint is not apparent adjacent to this former industrial property infers that sediment transport processes may act to diffuse the dioxin signal away from the property. Dioxin derived from the former Rayonier Mill property initially deposited in close vicinity to their nearshore outfalls is likely to have been subjected to high-energy resuspension and subsequent transport by longshore and tidal currents, including multi-directional dispersion as it is winnowed away from the parting zone (Figure 7).

If the former Rayonier Mill property were the main source of dioxin to the western harbor, dioxin concentrations similar to those found in the western harbor would be expected along the clockwise longshore transport path in the areas that accumulate equally fine-grained sediment. These pockets of fine-grained sediments appear to exist near shoreline structures along the southern harbor (Figure 8). Although elevated dioxin/furan TEQ concentrations exist for fine-grained sediments in the vicinity of the City of Port Angeles' active CSOs and east of Terminal 1 (Figure 19), these concentrations are much less than those of the western harbor. These elevated concentrations may be due to localized CSO and Terminal 1 dioxin/furan sources rather than material transported from the vicinity of the former Rayonier Mill property. While the high-energy location of the former Rayonier Mill property likely causes it to be a contributor of dispersed dioxins/furans throughout much of the harbor, it is likely not the predominant source responsible for the observed spatial pattern of dioxin/furan contamination in the western harbor.

6.2.3 PCBs

The spatial pattern of surface sediment total PCB Aroclor concentrations varies greatly from the distributions of metals and dioxins (Figure 20). Because sediment transport processes are expected to disperse particle-associated contaminants in a similar manner, their dissimilar spatial distributions suggest that these contaminant classes either do not share the same sources or that their source intensities are different.

PCB Aroclors were frequently not detected in sediments of Port Angeles Harbor. When detected, the greatest total PCB concentrations were contained to a relatively small region near the former Rayonier Mill property. At this property, the greatest PCB concentrations are found both within the log pond and near the dock. Only a single location within all of Port Angeles Harbor exceeded SMS criteria for total PCB Aroclors (Table 6). Lower concentrations of PCBs were measured in samples along the southern harbor, western harbor, and lagoon. PCBs Aroclors were not detected in surface sediments of the central and outer harbor.

A much fewer number of sediment samples have been analyzed for PCB congeners in Port Angeles sediments. The spatial distribution and limited number of samples analyzed for PCB congeners preclude spatial interpolation of the data (Figure 21). Surface sediment samples collected in the western harbor and lagoon by Exponent (2008) did not undergo full PCB congener analysis and, therefore, total PCB congener results for these samples are likely to underestimate concentrations. Additionally, PCB source identification through chemical fingerprinting methods cannot be used on the full Port Angeles Harbor PCB congener data set, as not all sediment samples underwent full congener analysis. The highest total PCB congener concentration was measured in close proximity to Terminal 5, being an order of magnitude greater than any other samples. Total PCB congener concentrations were also in exceedance of SQS/LAET criteria in the vicinity of the Port Angeles Marina and the former Rayonier Mill log pond and dock.

There are potential discrepancies between the PCB Aroclor and congener data. While PCB Aroclor and congener data are in general agreement near the former Rayonier Mill property, relatively high levels of PCB congeners were measured near western harbor locations where PCB Aroclors were either at much lower concentrations or not detected (Figures 20 and 21). It is important to note that samples for Aroclor and congener analysis were generally collected for different studies. Only for the Exponent (2008) study were sediment samples analyzed for both PCB Aroclors and congeners.

PCB Aroclor data, in conjunction with PCB congener data, suggest the highest levels of sedimentary PCBs are localized close to their sources. Although sediment transport processes are likely to have dispersed PCBs into the harbor in a similar manner as other contaminants, they are found in such low levels as not to be detected in the majority of the samples collected from the harbor (Figure 20). The spatial distribution of PCBs suggests the former Rayonier Mill property as a primary source of PCBs to Port Angeles Harbor. The high PCB concentrations observed within the log pond suggest that this area effectively traps a portion of contaminant releases from the property, likely due to the wave energy protection provided by the rock jetty. While PCB Aroclors were frequently detected in the western harbor, spatial patterns and concentration gradients suggest these are likely derived from localized sources and not the former Rayonier property.

6.2.4 Other SMS Chemicals

Numerous organic COPCs (other than PCBs) were detected at concentrations that exceed SMS/LAET criteria in the vicinity of the former Rayonier Mill property, near the Port Angeles Marina, and in the western harbor lagoon (Figure 14). COPCs found to exceed SMS/LAET criteria include bis(2-ethylhexyl) phthalate, butyl benzyl phthalate, 2,4-dimethylphenol, 2-methylphenol, 4-methylphenol, phenol, and fluoranthene (Table 6). Because these compounds were not detected at most locations, spatial interpolation of their surface sediment concentrations was not practical. These COPCs are not widespread throughout Port Angeles Harbor, which suggests that the elevated concentrations that exceed SMS/LAET criteria may be due to nearby sources. Sediment transport mechanisms appear to disperse these COPCs in a manner that does not lead to diffuse, high concentrations throughout the harbor.

6.2.5 Resin Acids/Guaiacols

Resin acids and guaiacols are naturally occurring compounds in woody plants but are also commonly present in chlorinated form in pulp and paper mill waste effluents (Servos et al. 1996). Resin acids are a component of most softwood and are usually released from wood chips during the pulping process. Guaiacols were not detected in any of the Port Angeles Harbor surface sediments samples analyzed. The most commonly detected resin acid in harbor sediments was abietic acid. The spatial distribution of abietic acid indicates its widespread presence throughout the lagoon, western harbor, and the vicinity of the former Rayonier Mill property log pond (Figure 22). The greatest concentrations of abietic acid are present in active or historical log rafting and barging areas, which were also identified as having the greatest concentrations of wood debris (Figure 10). This finding confirms that the presence of elevated TOC levels in Port Angeles Harbor sediments is likely due to the presence wood debris, and therefore TOC is an appropriate wood debris proxy (Section 6.1.2).

The widespread presence of high levels of abietic acid throughout the western harbor suggests the entirety of the western harbor as a depositional region for woody debris. Transport pathways identified in Figure 7 imply that woody debris may be dispersed eastward throughout the western harbor under both high and low energy conditions, and also that woody debris may be introduced to the western harbor through the southern harbor longshore transport pathway. Relatively low concentrations of abietic acid in the central harbor (Figure 22) suggest that woody debris is not significantly transported in a west to east manner beyond the transport front identified by STA (Figure 7).

In the vicinity of the former Rayonier Mill property, abietic acid was present in high concentrations in the log pond and west of the mill dock (Figure 22). Abietic acid was not commonly detected in the sediment samples collected outside of the log pond or east of the mill dock, suggesting pulp waste mats once present in the nearshore surrounding the property (DOI 1967) have either been buried or eroded and dispersed.

6.3 Subsurface Sediments

COPCs were also detected at concentrations that exceed SMS/LAET criteria in subsurface sediments of Port Angeles Harbor (Table 7 and Figure 23). These exceedances were restricted to locations along the inner Ediz Hook, the western harbor, near the mouth of Peabody Creek, and near the former Rayonier Mill property. There was only a single location where both surface and subsurface sediments exceed SMS/LAET criteria for the same COPC. This suggests that surface sediment chemistry is not a good indicator for the potential of underlying subsurface contamination.

6.3.1 Metals

As in surface sediments, SMS exceedances of cadmium, mercury, and zinc in subsurface sediments were restricted to the western harbor and lagoon (Table 7). Station IH02 was the only sediment core location where both surface and subsurface sediments exceeded SMS criteria. At this location, the subsurface concentrations of both mercury and zinc exceeded that of the surface.

6.3.2 Dioxin/Furan Congeners

Dioxin/furan congener TEQ results from sediment cores collected in Port Angeles Harbor are displayed in Figure 24. Core locations on this figure are organized from west to east within the harbor. Comparable depth intervals were not analyzed in all cores, making interpretation of this data difficult. Additionally, several of the highest surface sediment dioxin/furan TEQs occurred at locations where cores were not collected. In general, dioxin concentrations in surface intervals are similar to subsurface intervals. This suggests that there has not been a radical long-term change in either the magnitude or location of dioxin sources to the system. Surface core intervals generally have lower dioxin/furan TEQs than subsurface intervals along the eastern side of the former Rayonier Mill property suggesting natural recovery in this localized region. The lagoon generally has substantially higher dioxin/furan TEQs in surface intervals as compared to subsurface intervals. This finding suggests that a relatively recent dioxin source may exist in the vicinity of the lagoon. Location NPI-L2 in the eastern lagoon has much higher dioxin in the subsurface interval. Radioisotopic analysis of this core indicates a mixed layer to at least 61 inches (Exponent 2008). Therefore, a high subsurface dioxin/furan TEQ may be due to anthropogenic disturbance rather than historic sources.

6.3.3 PCBs

Total PCB Aroclor concentration results from sediment cores collected in Port Angeles Harbor are displayed in Figure 25. PCB concentrations in surface intervals are generally similar to subsurface intervals, suggesting little long-term change in either the magnitude or location of PCB sources to the system. High concentrations of PCBs in subsurface sediments are confined to the log pond and dock area of the former Rayonier Mill property. Along the eastern side of the former Rayonier Mill property, surface core intervals generally have lower PCB concentrations than subsurface intervals suggesting natural recovery at this localized region. New sources of PCBs are not evident in the harbor, as no locations had substantially higher PCB concentrations in the surface interval compared to subsurface intervals.

6.3.4 Other SMS Chemicals

Numerous organic COPCs (other than PCBs) were detected in subsurface sediments at concentrations that exceed SMS/LAET criteria (Table 7). In the vicinity of the former Rayonier Mill property, exceedances of 4-methylphenol and multiple polycyclic aromatic hydrocarbons (PAHs) were restricted to near the mouth of Ennis Creek. Subsurface exceedances of butyl benzyl phthalate and bis(2-ethylhexyl) phthalate occurred at single locations in the western harbor region.

Although pesticides were rarely detected throughout Port Angeles Harbor, subsurface sediments at one location in the vicinity of the Ferry Terminal exceeded LAET criteria for two DDT breakdown products. This core was collected near the mouth of Peabody Creek where two active CSOs discharge to the harbor. The high subsurface pesticide concentrations at this location are likely due to historic stormwater runoff to the creek.

6.4 Bioassays

Results of Port Angeles Harbor sediment toxicity testing are summarized in Figure 26. The larval development bioassay was the most frequent of toxicity tests to fail SMS criteria. These failures occurred almost everywhere throughout the western and central harbor, as well as at numerous locations in the vicinity of the former Rayonier Mill property. Failures of the amphipod mortality bioassay occurred only in close proximity to the former Rayonier Mill property. Polychaete growth bioassays experienced failures primarily in the former Rayonier Mill log pond but also at a single location outside the Port Angeles Marina (Figure 23).

Apparent sediment toxicity in Port Angeles Harbor cannot be easily attributed to co-occurring SMS COPCs. Toxicity testing failures (Figure 26) were occasionally associated with chemicals that exceeded SMS criteria (Figures 13 and 14). The number of locations with bioassay failures was higher than locations with chemicals that exceeded SMS criteria. Some locations with chemicals that exceeded SMS criteria did not have associated bioassay failures (Tables 5 and 6). Additionally, many locations with chemicals that exceeded SMS criteria did not undergo toxicity testing. Overall, apparent bioassay failures in Port Angeles Harbor do not appear to be correlated with SMS chemical exceedances for COPCs.

Numerous SMS failures of the larval development bioassay may have been brought about by the presence of wood debris and excess organic matter in the western and central harbor. These regions have the greatest concentrations of sedimentary sulfides and ammonia in the harbor (Figures 11 and 12). However, it is unlikely that elevated concentrations of sulfides and ammonia were the source of the observed toxicity, as the larval bioassay method essentially removes all sulfides and ammonia through oxidation during dilution and mixing at the initiation of the test. Instead, the presence of wood debris or other forms of excess organic matter in sediment samples may have caused inaccurate counts of larvae at the bioassay endpoint. Fine-grained sediments rich in organic matter tend to aggregate, forming a flocculent sediment layer. Larvae that develop normally over the course of the bioassay test but become entrained in the flocculent layer may not be counted at the test endpoint. For this reason, a modified endpoint to the larval development bioassay has been developed that includes sediment resuspension to obtain a more accurate count of larvae. The modified endpoint method was not used for Port Angeles Harbor bioassay samples.

6.5 Summary of Chemical Transport and Fate

Multiple potential point sources of contamination and sediment transport mechanisms within Port Angeles Harbor create a complex system for evaluating chemical transport and fate. These dynamics can best be understood through the evaluation of spatial patterns in sediment conventional parameters, chemical concentrations, and bioassay results. These patterns tend to complement each other, providing multiple lines of evidence that allow for a cohesive interpretation of the transport and fate of COPCs from sources to sinks.

Interpolation of sediment conventional and chemical data support many of the predominant sediment transport pathways presented in Section 5.0. These pathways include eastward transport of sediment from the western harbor shoreline to the deeper region of the western harbor, and resuspension and multi-directional dispersion of southern harbor sediment in the vicinity of the former Rayonier Mill property. These transport mechanisms lead to distinct footprints of contamination in close proximity to sources as well as diffuse contamination throughout the harbor. Transport of COPCs by the clockwise longshore transport pathway is not as apparent, suggesting that this transport pathway may not be significant for the dispersion of contaminants associated with fine-grained sediments.

Wood debris in the harbor is found mainly in regions of active and historic log storage, with smaller amounts dispersed throughout the western harbor. The presence of wood debris appears to have resulted in anaerobic conditions allowing for the buildup of sedimentary sulfides and ammonia. While anaerobic sediment conditions appear to coincide with the multiple bioassay failures, it is possible that excess sedimentary organic matter interfered with the larval development bioassay resulting in inaccurate larvae counts and subsequent SMS failures. Regardless of whether or not wood debris causes sediment toxicity, its extensive presence on the seafloor may impair the quality of benthic habitat.

Patterns of surface sediment chemistry suggest two primary source locations of COPCs deposited throughout Port Angeles Harbor: the western harbor and the former Rayonier Mill property. Hydrodynamics of the western harbor cause it to act as a sediment trap for both local contaminant sources and those potentially transported by longshore currents from sources along the southern harbor. Despite the potential mixing of local and distant sources in the western harbor, the gradients and spatial patterns of chemical data suggest that western harbor sources overwhelm any potential distant sources. Overall, this implies that the westward longshore transport pathway is not significant for introducing contaminants associated with fine-grained sediments to the western harbor. Unidentified upland sources of metals and dioxin along the western harbor shoreline appear to be the primary supplier of these COPCs to western harbor sediments. These sources create chemical plumes emanating from the nearshore in the vicinity of the lagoon and spreading throughout the western harbor. Although the lagoon has similar COPC concentrations as the western harbor, lagoon sediments are not likely eroded and transported to the western harbor unless outfalls discharging to the lagoon cause localized scour. Instead, the lagoon likely acts as a sediment trap for the finest-grained western harbor sediment transported to the lagoon in suspension during flood tides. It is also possible that effluent discharging to the lagoon is transported directly to the western harbor during ebb tides without first depositing within the lagoon.

Hydrodynamic conditions in the vicinity of the former Rayonier Mill property are extremely different from those of the western harbor. The location of the former mill at the mouth of the harbor leads to localized contamination, as well as dispersion and dilution of much of the property-sourced contaminants. The former Rayonier Mill property is the likely source of dioxin and organic COPCs (PCBs, phenols, PAHs, etc.) that exceed SMS criteria close to the property, both within the log pond and near the mill dock. High energy events appear to scour the shallow area surrounding the property, dispersing fine-grained materials deposited during more typical conditions and resulting in little net deposition. While much of this fine-grained material is likely transported eastward out of the harbor, the bi-directional nature of tidal currents and enhancement of westward bottom currents by wind-induced eastward surface flow promote transport into the harbor. For these reasons the former mill property is a potential source of dioxin found above background levels in the central harbor, as are sources located in other regions of the harbor. Although other contaminants derived from Rayonier are expected to be transported in a similar manner as dioxins, organic COPCs dispersed from the property are generally diluted to the point that they are not present at detectable concentrations across the rest of the harbor. While high concentrations of PCB congeners were observed in the western harbor, spatial patterns and concentration gradients suggest these are likely derived from localized sources and not the former Rayonier property.

7.0 Source Identification

Sediment sampling locations for the Port Angeles Harbor Sediment Investigation were chosen in such a manner that potential source locations of COPCs to the harbor could be identified. This study design consisted of sampling within designated sub-areas of the harbor, each associated with a potential source or sources from E & E (2008a). These sub-areas were identified and delineated based on:

- Potential sources of COPCs due to current and historic shoreline use/operations and harbor-based activities, or
- Potential increased risk of human health exposure to sediment and/or biota based on prior investigations.

Sediment sampling for the harbor-wide investigation (E & E 2012) occurred in 14 harbor-wide sub-areas (Figure 27) and an additional seven areas close to the former Rayonier Mill property. Comparison of surface sediment analytical results between the study's sub-areas can be used to identify the potential sources responsible for COPCs found in the harbor. Potential sources include industrial activities associated with wood processing, marine shipping, petroleum storage, and commercial fishing, as well as municipal and residential releases. Table 8 presents a summary of COPCs associated with the different industrial and land use types found in the vicinity of Port Angeles Harbor (E & E 2008b).

This section presents a qualitative assessment of surface sediment results relative to the Areas of Concern identified and delineated by E & E (2008b) in order to identify likely COPC sources to the harbor based on the results of the sediment investigation report. This source identification assessment by sub-areas is supplemental to those using spatial analysis methods (Section 6.0).

7.1 Harbor-wide Sub-Areas

Sediment samples collected within the harbor-wide sub-areas generally consist of nearshore samples in close proximity to potential COPC sources and offshore samples that may be influenced by releases from these potential sources or other harbor-based activities (Figure 27). However, sub-areas such as the Barge Area and Outer Harbor contain no nearshore samples due to their delineation in open-water portions of the harbor. Table 9 contains information about each harbor-wide sub-area including potential sources and summarized results of surface sediment analyses. The summarized sediment results include COPCs that exceed SMS/LAET criteria, maximum dioxin/furan TEQs, maximum concentrations of wood debris, maximum concentrations of #2 diesel fuel (as a proxy for fuel releases), and failures of SMS biological criteria within the respective sub-area.

Based on the evaluation of harbor-wide sub-areas, those in the western harbor likely contain the predominant COPC sources (Table 9). Sediment samples with metal concentrations that exceed SMS criteria were located within the Inner Ediz Hook, Lagoon, and Inner Harbor areas. Organic COPCs that exceed SMS/LAET criteria were located in the Lagoon, Inner Harbor, and Port Angeles Marina areas. All sub-areas where metals or other COPCs exceed SMS/LAET criteria also had the highest dioxin/furan TEQ values and highest concentrations of both sedimentary wood debris and diesel fuel. Although SMS failures of the larval development bioassay were observed throughout the harbor (Section 6.4), the sub-areas with the greatest percentages of failures were found in areas likely influenced by northern, central, and western harbor sources (Table 9). Sub-areas likely to be influenced by northern, southern, and outer harbor sources contained no COPC concentrations that exceeded SMS criteria, and they also had the lowest concentrations of sedimentary wood debris and diesel fuel (Table 9).

The sub-areas located in the western harbor (Ediz Hook, Lagoon, Inner Harbor, and Port Angeles Marina) appear to be in proximity to the most likely sources responsible for adverse impacts to sediment quality in Port Angeles Harbor. These areas are associated with numerous historic and current industrial uses including wood processing, log booming, and/or ship-related activities. Sub-areas in the central and southern harbor, generally associated with marine shipping, do not appear to contain significant sources of COPCs. Sub-areas in the northern and outer harbor, including in the vicinity of the City of Port Angeles wastewater treatment effluent outfall, appear to contain the least likely sources of COPCs to the harbor.

7.2 Rayonier Mill Sub-Areas

Sediment samples collected within the former Rayonier Mill sub-areas are associated with specific structures at the property. Table 10 contains information about each Rayonier Mill sub-area including potential sources and summarized results of surface sediment analyses. A single sediment sample with a metal concentration that exceeded SMS criteria was located in the Log Pond area (Table 10). Organic COPCs that exceed SMS/LAET criteria were located in the Log Pond, Mill Dock, and East of Mill Dock areas. As with the harbor-wide sub-areas, the Rayonier Mill sub-areas with COPC concentrations that exceed SMS/LAET criteria also had the most frequent bioassay failures, highest dioxin/furan TEQ values, and the highest concentrations of both sedimentary wood debris and diesel fuel (Table 10). The samples collected closest to the shoreline and in the vicinity of the Rayonier Mill Effluent Outfall pipeline were associated with the lowest concentrations of sedimentary wood debris and diesel fuel, no COPC concentrations that exceed SMS criteria, and the fewest bioassay failures (Table 10).

7.3 Summary of Primary Source Areas

Dioxin/furans and the specific COPCs found in concentrations that exceed SMS/LAET criteria (metals, semivolatile organics compounds, and PCBs) have the possibility of originating from multiple industries or activities found in the vicinity of Port Angeles Harbor (Table 9). However, examination of the analytical results of surface sediments based upon the investigation sub-areas outlined in E & E (2012) suggest that the former Rayonier Mill property and industries located along the western harbor are the primary sources of COPCs, wood debris, and fuel to sediments of the harbor. Wood processing, log booming, and other industrial activities associated with current and historic uses of these areas appear to be causing adverse impacts to sediment quality in their localities. Facilities that are potential sources of high COPC concentrations to sediments of the western harbor and the vicinity of the former Rayonier Mill property are presented in Table 11.

Section 11.2 of the *Port Angeles Harbor Sediment Investigation Report* (E & E 2012) outlines recommendations for additional investigative actions in order to determine the extent of COPC contamination in Port Angeles Harbor sediments. Their specific recommendations for further sediment sampling and analysis are valid within the Inner Ediz Hook, Lagoon, Inner Harbor, and

Marina harbor-wide sub-areas, as well as the Mill Dock and East Dock sub-areas in the vicinity of the former Rayonier Mill property. In these sub-areas, E & E (2012) recommended the collection and analysis of additional surface and subsurface sediment samples in order to delineate the spatial extent and depth of contamination. Additionally, potential sources to these sub-areas (Table 11) may warrant further investigation to determine their potential contribution, if any, of COPCs to the harbor. Other sub-areas, including the Log Pond, do not require further action as contamination there is either well characterized or at low levels.

Chemical fingerprinting techniques can be used to differentiate possible contaminant sources when each source has a unique chemical fingerprint. Chemical fingerprint analysis (Section 4.0) was unable to discern unique dioxin fingerprints for different areas of Port Angeles Harbor. While this singular dioxin fingerprint found throughout the harbor may indicate a single primary dioxin source, it could also be indicative of multiple sources with similar dioxin fingerprints or a mixed source signature across the harbor. Investigation of dioxin/furan TEQ values by both spatial analysis (Section 6.2.2) and comparisons of Areas of Concern indicate that the former Rayonier Mill property and upland western harbor are the dominant sources of dioxin/furan TEQ to the harbor. Although the dioxin fingerprints found in the vicinity of these two areas were not discernible by the method used, a more intensive fingerprinting method may differentiate subtleties in the data that allow determination of the depositional footprint associated with each source.

Assessment of the sub-areas presented in this section support the main conclusion drawn from the GIS-based spatial analysis of sediment data (Section 6.0) that the former Rayonier Mill property and western harbor industries are likely the dominant sources of COPCs to Port Angeles Harbor. Despite this, identification of primary sources is best accomplished through the spatial analysis methods rather than comparing results within and among individual sub-areas as was done by E & E (2012). Without the investigation of sediment trends across the entire harbor, the influence of dynamic processes that act to transport materials between sub-areas is lost.

This page is intentionally blank.

8.0 Data Gaps and Data Needs

This section assesses the completeness of the existing, recently collected Port Angeles Harbor sediment data for evaluating adverse impacts to sediment quality by identifying potential data gaps. Fulfilling the data gaps outlined below may aid in defining the spatial extent to which sediment cleanup is warranted and identifying the specific sources responsible for sediment contamination.

8.1 Sediment Chemistry

The combined data set consisting of data collected in support of the Port Angeles Harbor Sediment Investigation (E & E 2012), data collected by Rayonier, Inc. (Malcolm Pirnie 2007a; Malcolm Pirnie 2007b), and data collected by Nippon Paper Industries (Anchor 2005; Exponent 2008) provides sufficient data for the broad assessment of the primary contaminant source locations to the harbor. However, the spatial extent of potential sediment contamination attributable to the former Rayonier Mill property is not well defined due to the lack of surface sediment samples collected beyond approximately 1,500 feet of the property. As a result, the actual extent of the former Rayonier Mill contamination footprint is uncertain using the spatial interpolation methods utilized in this assessment. Additional surface sediment samples between a radius of approximately 1,500 and 4,000 feet from the former Rayonier Mill property would aid in delineating the extent of the property's chemical footprint.

Other than the former Rayonier Mill property, results of this assessment appear to identify a western harbor upland source as a contributor to chemical contamination to the harbor. While surface sediment sampling in the western harbor is sufficient to identify the existence of this source, addition samples in the western harbor would help delineate its likely location. Additional western harbor surface sediment samples would also assist in defining the full spatial extent of the region that exceeds SMS criteria for arsenic, cadmium, mercury, and zinc.

Determining PCB sources to Port Angeles Harbor sediments could be aided by chemical fingerprinting analysis of PCB congeners. However, the existing PCB congener data for the harbor has limited utility because of both the spatial distribution of collected samples and limited number of samples that underwent full congener analysis. Sediment samples collected in the western harbor and lagoon by Exponent (2008) did not undergo full PCB congener analysis, preventing the use of fingerprinting methods on these samples. Collection of surface sediment samples for full PCB congener analysis in the western harbor and lagoon may be warranted as PCB Aroclors were detected in both of these areas (Figure 20).

8.2 Surface and Subsurface Wood Debris

Sediment cores collected during the Port Angeles Harbor SIR (E & E 2012) were sub-sampled in the field based upon visual and olfactory screening criteria that were not clearly defined. This sub-sampling methodology resulted in the analysis of sediment depth intervals that are not easily comparable between locations. The lack of comparable sediment core data makes it difficult to determine the extent of subsurface sediment contamination and whether or not sediment quality in the harbor is improving. Such an assessment is important as it could indicate where in the harbor natural recovery may potentially be an acceptable mechanism of sediment remediation.

One of the objectives of E & E (2012) was to characterize the distribution of wood debris in Port Angeles Harbor. Understanding of the distribution and depth of wood debris is particularly important, as the presence of wood debris is a possible cause of sediment toxicity and degraded benthic habitat throughout the harbor. A qualitative assessment of wood debris in sediments was conducted by estimating the percentage of wood debris observed in surface sediment samples and sediment core intervals (E & E 2012). However, sediment cores were not collected in many areas with the greatest amount of surface wood debris. The targeted cleanup of wood debris to improve sediment quality is difficult without a fundamental understanding of its depth distribution. Rather than the collection, sub-sampling, and visual inspection of sediment cores, a sediment profile imaging and video probe survey of the primary wood debris depositional areas would provide a rapid assessment of wood debris depth and distribution, as well as the quality of benthic habitat (SAIC 2009).

8.3 Sediment Radioisotopes

Sediment cores were analyzed by both Exponent (2008) (one lagoon and three western harbor cores) and Herrera (2011) (one western harbor and one central harbor core) to determine sedimentation rates. Together the radioisotope results from these cores do not convey a cohesive depiction of sedimentation in the harbor. This is likely because of both the locations chosen to collect sediment cores and anthropogenic disturbances to the sediments. In particular, deep mixed layers in both the northeastern lagoon and a nearshore western harbor location may be the result of dredging activities rather than high rates of sedimentation. Collection and radioisotopic analysis of sediment cores from within the western harbor metals and dioxin plumes (Figures 15 to 18) may constrain the timing of their deposition. However, other lines of evidence suggest this region as an active depositional zone and therefore the determination of sedimentation rates here may not be warranted.

8.4 Sediment Toxicity

As discussed in Section 6.4, apparent sediment toxicity in Port Angeles Harbor cannot be easily attributed solely to high levels of co-occurring SMS COPCs. While the presence of wood debris is a potential cause of toxicity at many locations in the harbor, its presence can also create a flocculent sediment layer that interferes with an accurate larvae count for the larval development bioassay. Because extensive areas of the harbor failed SMS criteria for the larval development bioassay without co-occurring COPC exceedances, it is recommended that further larval development bioassay tests include a modified endpoint whereby sediment resuspension is used to break up the flocculent layer. A small number of additional larval development tests may be warranted in areas of low COPC concentrations in order to verify whether flocculation was the previous cause of SMS failure.

Toxicity testing was not conducted at all locations containing chemical concentrations in excess of SMS criteria. The western harbor area is especially devoid of sediment toxicity data where SMS exceedances were measured (Figure 26). In particular, there are multiple locations where sediment samples exceeded SMS criteria for cadmium, zinc, mercury, PCBs, phenol, or butyl benzyl phthalate but were not tested for toxicity. Additional sampling for toxicity testing is warranted in the western harbor and lagoon where the highest concentrations of both metals and dioxin/furan TEQs were observed.

8.5 Chemical Fingerprinting

As discussed in Section 4.0, dioxin/furan congener fingerprinting was unable to discern multiple congener profiles for sediments of Port Angeles Harbor. A more intensive fingerprinting approach consisting of multivariate chemometric analyses (unmixing analyses) of the sediment dioxin/furan congener data is recommended to differentiate sources to harbor sediments. A similar approach of chemometric analysis was performed for Port Angeles soil dioxin/furan congener data as a part of the *Rayonier Mill Off-Property Soil Dioxin Study* (E & E and Glass, 2011). This chemometric evaluation was able to quantitatively differentiate three unique source patterns that account for the dioxin/furan profiles observed in soils.

8.6 Sediment Background Concentrations

As discussed in Section 3.4, insufficient data exist to create a natural background chemical data set for comparison to Port Angeles Harbor based on the data from Dungeness or Freshwater Bays alone. In order to compile an existing background data set large enough to be statistically significant, samples collected from the San Juan Islands and the Strait of Juan de Fuca were included. In the case that the BTV is chosen as the cleanup goal, collection of a more robust natural background data set may be warranted. This background data set should consist of 15 to 20 newly collected surface sediment samples collected from Dungeness Bay, as this location provides the most comparable natural sources and environmental conditions to Port Angeles Harbor.

8.7 Identification of Western Harbor Upland Sources

Spatial analysis of surface sediment chemical data suggests an unidentified upland source, or sources, of metals and dioxin/furan congeners along the western harbor shoreline. This source appears to be the most significant contributor of these COPCs to the western harbor. Identification and control of this apparent source is a necessary part of any remediation efforts of western harbor sediments. Stormwater, surface runoff, and industrial outfalls along the western harbor should be investigated to determine their potential to cause sediment contamination. Suspect outfalls should undergo sampling and chemical analysis of effluent water and solids to screen for COPCs and to determine chemical loadings to the harbor.

It remains unknown whether lagoon sediments are a source to the western harbor. Morphology and results of the STA suggest that the lagoon is completely depositional; however, it is not known if scouring and transport of lagoon sediments happens during high energy events. Additionally, direct discharges to the lagoon may escape immediate deposition and be transported to the western harbor while in suspension. Therefore, observation and characterization of lagoon outfall discharge should be a high priority for further investigation.

This page is intentionally blank.

9.0 Summary

9.1 Summary of Findings

Multiple point sources of COPCs and sediment transport mechanisms lead to both localized and diffuse chemical contamination in the sediments of Port Angeles Harbor. Development of CSMs for the harbor, spatial analysis of surface sediment chemical concentrations, and source investigation by harbor sub-areas allowed for the identification of two primary contaminant source areas to the harbor:

- The former Rayonier Mill property, and
- Western harbor shoreline sources.

Hydrodynamic conditions in the vicinity of the former Rayonier Mill property lead to localized contamination, as well as dispersion and dilution of much of the property-sourced contaminants. The former mill property is the likely source of dioxin and organic COPCs that exceed SMS criteria close to the property both within the log pond and around the mill dock. Additionally, high energy events appear to scour the shallow area surrounding the property, dispersing fine-grained sediment deposited under more typical conditions and resulting in little net deposition. While much of this fine-grained material is likely transported eastward out of the harbor, the bi-directional nature of tidal currents and enhancement of westward bottom currents by wind-induced eastward surface flow promote transport into the harbor. For these reasons the former mill property is a potential source of dioxin found above background levels in the central harbor, as are sources located in other regions of the harbor. Although other contaminants derived from Rayonier are expected to be transported in a similar manner as dioxins, organic COPCs dispersed from the property are generally diluted to the point that they are not present at detectable concentrations across the rest of the harbor.

Hydrodynamics of the western harbor cause it to act as a sediment trap for both local contaminant sources and those potentially transported by longshore currents from sources along the southern shoreline of the harbor. The spatial pattern of metals and dioxin/furan TEQ suggests that western harbor sources of these contaminants are more likely than any potential distant sources transported to the western harbor. Overall, this suggests that the westward longshore transport pathway is not significant for introducing contaminants associated with fine-grained sediments to the western harbor. Sediment contamination in the western harbor is likely derived from upland sources along the western harbor shoreline. Also, sources of western harbor contamination may initially be discharged to the lagoon before transport to the western harbor. These sources create sediment contamination emanating in gradients from the nearshore in the vicinity of the lagoon and spreading throughout the western harbor. While the lagoon acts as a continual trap for western harbor sediments, lagoon sediments have the potential to be transported to the western harbor during high energy events.

9.2 Recommendations

The Port Angeles Harbor Sediment Characterization Study and the Port Angeles Harbor Supplemental Data Evaluation to the Sediment Investigation Report are not a remedial investigation and feasibility study (RI/FS) as defined under the MTCA process. Ecology intends to work with identified potentially liable persons to complete full RI/FS reports before decisions about cleanup actions are made. These general recommendations provide an overview of concerns and potential remedies.

Remediation of Port Angeles Harbor sediments may require removal of deposits of wood debris, controlling ongoing upland releases of contaminants to the harbor, and cleanup of contaminated sediment hotspots.

9.2.1 Wood Debris

Remediation of accumulated wood debris will likely improve the quality of benthic habitat and diminish anaerobic sediment conditions throughout the harbor. Source control of wood debris or best management practices for reducing wood debris may also need to be implemented following wood debris remediation. Wood debris remedial activities should be focused in the vicinity of active and historic log storage and transfer areas. These areas of concentrated wood debris likely serve as source regions for wood debris dispersed throughout the western harbor. Direct removal of wood debris from the deep western harbor is of low priority. The deep western harbor likely experiences the greatest sediment accumulation rates and is therefore the most likely to benefit from natural recovery once wood debris source regions are controlled.

9.2.2 Upland Source Control

Control of upland sources of chemical contaminant releases to the harbor is necessary to prevent the ongoing contamination of harbor sediments or recontamination after cleanup. The upland RI/FS at the former Rayonier Mill property will address the potential for ongoing chemical releases from the property. Implementation of measures necessary to control or contain such releases will prevent the property from being a continuing source of contamination to the harbor once the sediments at the property have undergone cleanup.

Controlling contaminant sources to western harbor sediments will first require identification of upland sources potentially responsible for the observed concentrations of metals and dioxins. Both the measured chemical concentrations and the well-defined footprint of this western harbor source suggest that chemical releases may be ongoing rather than just historic. Identification of western harbor contaminant source(s) will likely require sampling and analysis of stormwater, surface runoff, and industrial outfalls discharging to the western harbor shoreline and lagoon. Once the primary western harbor sources of metals and dioxins have been identified, source control actions should be taken to prevent recontamination of sediment in the harbor.

9.2.3 Cleanup of Sediment Hotspots

Direct remediation of contaminated sediment hotspots may be warranted at two locations in the harbor where COPCs are the most concentrated.

Former Rayonier Mill Property

Assuming no new contaminant releases from the upland portion of the former Rayonier Mill property, sediment cleanup in a relatively small area may effectively eliminate this property as a potential continuing source of negative impacts to sediments of the harbor. All sediment contamination adjacent to the former Rayonier Mill property appears to be due to releases from the property rather than transport from other sources. Wood debris and chemical contamination co-occur in the vicinity of the former Rayonier Mill property. Therefore, targeted sediment remediation at the log pond and the area around the former Rayonier dock addresses both of these sediment quality issues with a single remedial action.

Western Harbor

Assuming no new contaminant releases from upland sources, remediation of sediment in the western-most harbor will likely eliminate sinks of metals and dioxin that may currently be dispersing across the western harbor by tidal currents. Cleanup should be targeted along the shoreline in the vicinity of the western harbor lagoon between properties operated by Nippon and M&R Lumber. Cleanup of deeper portions of the western harbor are of lower priority than the shoreline, as sediments here are less likely to be mobilized and have lower contaminant concentrations.

This page is intentionally blank.

10.0 References

Anchor. 2005. Sediment Grab and Log Density Survey Sampling and Analysis Report. Prepared for Nippon Paper Industries by Anchor Environmental, L.L.C. June 2005.

Battelle. 2004. Modeling of effluent dilution, transport, and solids deposition, former Rayonier Pulp Mill site, Port Angeles, WA. Prepared for Rayonier, Inc., Jacksonville, FL by Battlle Memorial Institute. December 2004.

City of Port Angeles. 2009. 2008 Annual CSO Report. Prepared for the Washington State Department of Ecology by City of Port Angeles Public Works and Utilities. May 2009.

DMMP (Dredged Material Management Program). 2009. OSV Bold Sediment 2008 Survey: Data Report. Prepared by The Dredged Material Management Program. June 25, 2009.

DOI (U.S. Department of Interior). 1967. *Pollutional Effects of Pulp and Paper Mill Wastes in Puget Sound*. Federal Water Pollution Control Administration, Northwest Regional Office. March 1967.

E & E (Ecology and Environment, Inc.). 2008a. Port Angeles Harbor Final Summary of Existing Information and Identification of Data Gaps Report, Port Angeles, WA. Prepared for the Washington State Department of Ecology Toxics Cleanup Program, Lacey, WA by Ecology and Environment, Inc. April 2008.

E & E. 2008b. Port Angeles Harbor Sediment Characterization Study, Port Angeles, WA: Sampling and Analysis Plan. Prepared for the Washington State Department of Ecology Toxics Cleanup Program, Lacey, WA by Ecology and Environment, Inc. June 2008.

E & E. 2012. Port Angeles Harbor Sediment Characterization Study, Port Angeles, WA: Sediment Investigation Report. Prepared for the Washington State Department of Ecology Toxics Cleanup Program, Lacey WA by Ecology and Environment, Inc. December 2012.

E & E and Glass, G.L. 2011. Rayonier Mill Off-Property Soil Dioxin Study, Port Angeles, WA: Public Review Draft. Prepared for the Washington State Department of Ecology Toxics Cleanup Program, Lacey WA by Ecology and Environment, Inc. and G.L. Glass. June 2011.

Ebbesmeyer, C. C., J. M. Cox, J. M. Helseth, L. R. Hinchey, and D. W. Thomson. 1979. *Dynamics of Port Angeles Harbor and Approaches, Washington*. Evans-Hamilton, Inc. Prepared for Office of Energy, Minerals, and Industry Office of Research and Development, U.S. Environmental Protection Agency. September 1979.

EPA (Environmental Protection Agency). 1974. *Evaluation of ITT Rayonier, Inc. Outfall – Port Angeles Harbor, Washington*. Office of Enforcement: National Field Investigation Center – Denver. EPA 330/3-74-001. December 1974.

EPA. 2004. Fingerprint Analysis of Contaminant Data: A Forensic Tool for Evaluating Environmental Contamination. Prepared by United Sates Environmental Protection Agency. August 2004.

EPA. 2010. ProUCL Version 4.00.05 Technical Guide: Draft. Prepared by United Sates Environmental Protection Agency. May 2010.

Evans-Hamilton. 2008. Port Angeles Harbor Current Data Collection and Analysis Report. Prepared by Evans-Hamilton, Inc. for Ecology and Environment, Inc. June 2008.

Exponent. 2008. Environmental Baseline Investigation DNR Lease 22-077766. Prepared for Nippon Paper Industries by Exponent. October 2008.

Foster Wheeler. 1997. Current Situation/Site Conceptual Model Report for Rayonier Port Angeles Mill Site, Mt. Pleasant Road Landfill, and 13th and M Street Landfill. Prepared for Rayonier Port Angeles, WA by Foster Wheeler Environmental Corporation. October 1997.

Foster Wheeler. 2000. Shoreline Stabilization Project Completion Report for Rayonier Port Angeles Mill Site. Prepared for Rayonier Port Angeles, WA by Foster Wheeler Environmental Corporation. June 2000.

GeoSea. 2009. A Sediment Trend Analysis (STA) of Port Angeles Harbor. Prepared by Patrick McLaren, GeoSea Consulting Ltd., for State of Washington Department of Ecology, February 2009.

Herrera. 2011. Geomorphic Report, Port Angeles Harbor. Prepared by Herrera Environmental Consultants for Ecology and Environment, Inc. November 2009.

Malcolm Pirnie. 2007a. Remedial Investigation for the Marine Environment Near the Former Rayonier Mill Site, Proposed Public Review Draft. Prepared for Rayonier, Jacksonville FL by Malcolm Pirnie, Seattle WA. September 2007.

Malcolm Pirnie. 2007b. Phase 2 Addendum Remedial Investigation for the Marine Environment Near the Former Rayonier Mill Site, Proposed Public Review Draft. Prepared for Rayonier, Jacksonville FL by Malcolm Pirnie, Seattle WA. September 2007.

Nuwer, J. 2008. Organic Matter Preservation along a Dynamic Continental Margin: Forms and Fates of Sedimentary Organic Matter. Ph.D. dissertation, University of Washington.

Poizot, E., Y. Méar, and L. Biscara. 2008. Sediment Trend Analysis through the variation of granulometric parameters: A review of theories and applications. Earth-Science Reviews 86, 15-41.

SAIC (Science Applications International Corporation). 1999. Port Angeles Harbor Wood Waste Study, Port Angeles, Washington. Final. Prepared for Washington State Department of Ecology, Olympia, WA, by Science Applications International Corporation, Bothell, WA.

SAIC. 2009. Sediment Characterization Study in Port Gardner and Lower Snohomish Estuary, Port Gardner, WA. Final. July 10, 2009. Prepared for the Washington State Dept of Ecology, Lacey, WA. Prepared by Science Applications International Corporation, Bothell, WA.

Servos, M. R., K. R. Munkittrick, J. H. Carey, and G. J. Van Der Kraak. 1996. Environmental Fate and Effects of Pulp and Paper Mill Effluents. St. Lucie Press, Delray Beach, Florida.

Shea, G. B., C. C., Ebbesmeyer, Q. J., Stober, K. Pazera, J. M. Cox, J. M., Helseth, and S. Hemingway. 1981. History, Dispersion and Effects of Pulpmill Effluents On Receiving Waters: Port Angeles, Washington. Northwest Environmental Consultants, Inc. January 1981.

Tollefson, R., J. G., Denison, and E. Tokar. 1971. *Outfall Location Studies – Port Angeles, Washington*. ITT Rayonier Inc. Olympic Research Division. H 10:1-3. August 1971.

USACE (U.S. Army Corps of Engineers). 2005. Use of Sediment Trend Analysis (STA) for Coastal Projects. Coastal and Hydraulics Engineering Technical Note. June 2005.

Windward. 2012. Port Angeles Harbor Conceptual Site Model, Delineation of In-Water Site Boundary: Draft Report. Prepared for Rayonier, Inc. by Windward Environmental L.L.C. May 2012.

WPCC (Washington Pollution Control Commission). 1957. An Investigation of Pollution in the Vicinity of Port Angeles. Summer, 1957.

This page is intentionally blank.

Figures

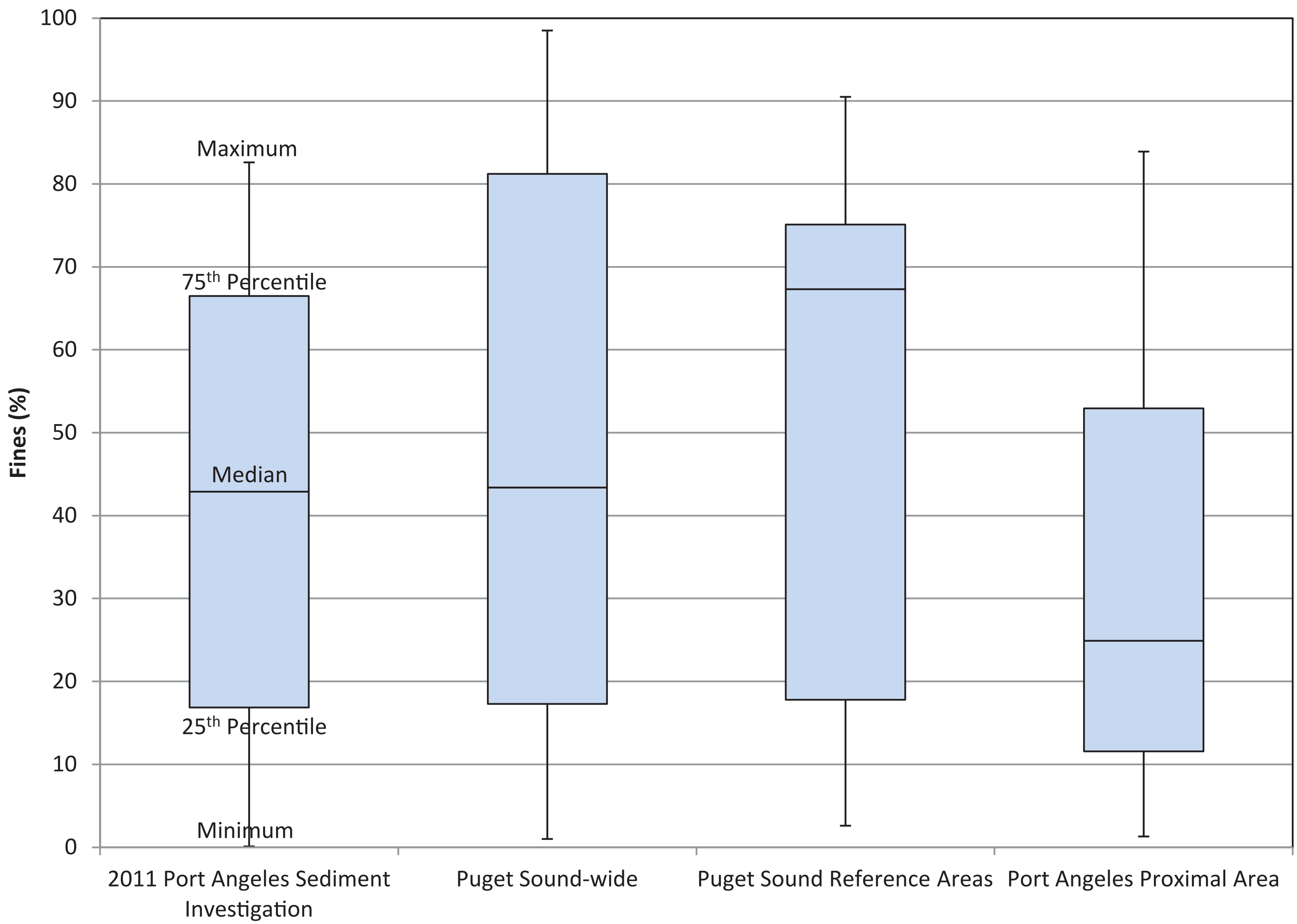


Figure 1. Box Plots of Percent Fines for Port Angeles Harbor and Background Data Sets

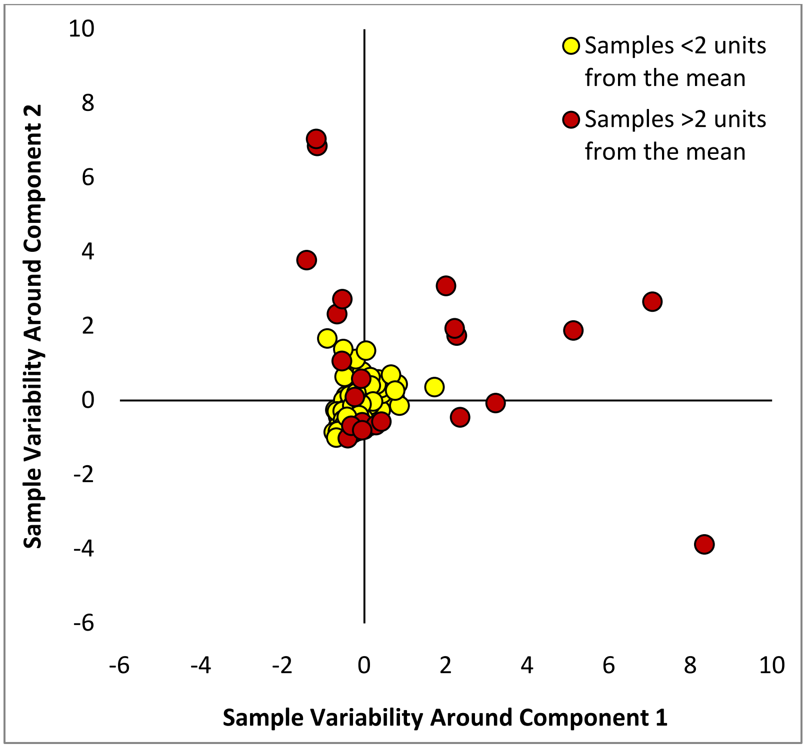


Figure 2. PCA Component 2 versus Component 1

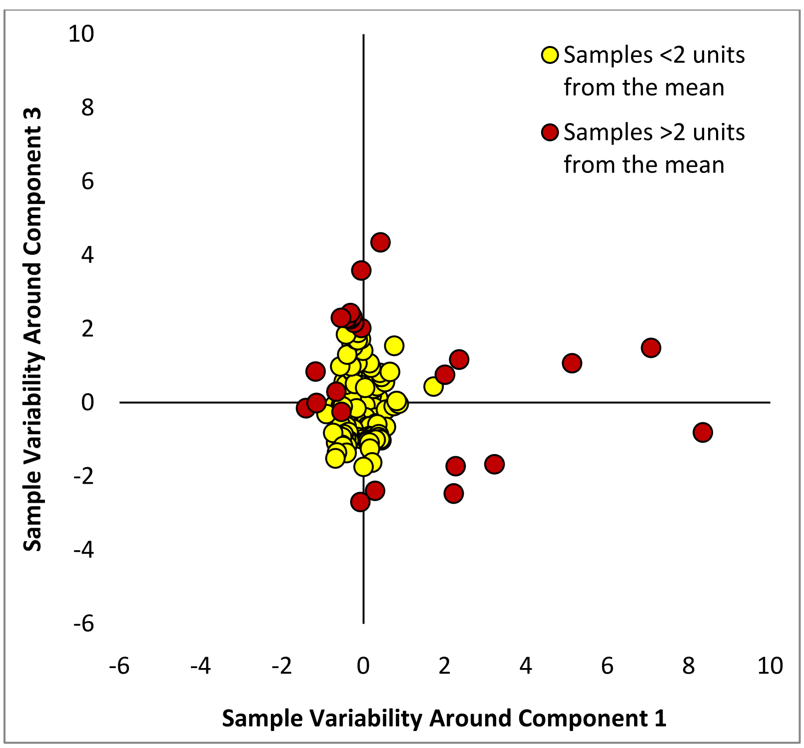


Figure 3. PCA Component 3 versus Component 1

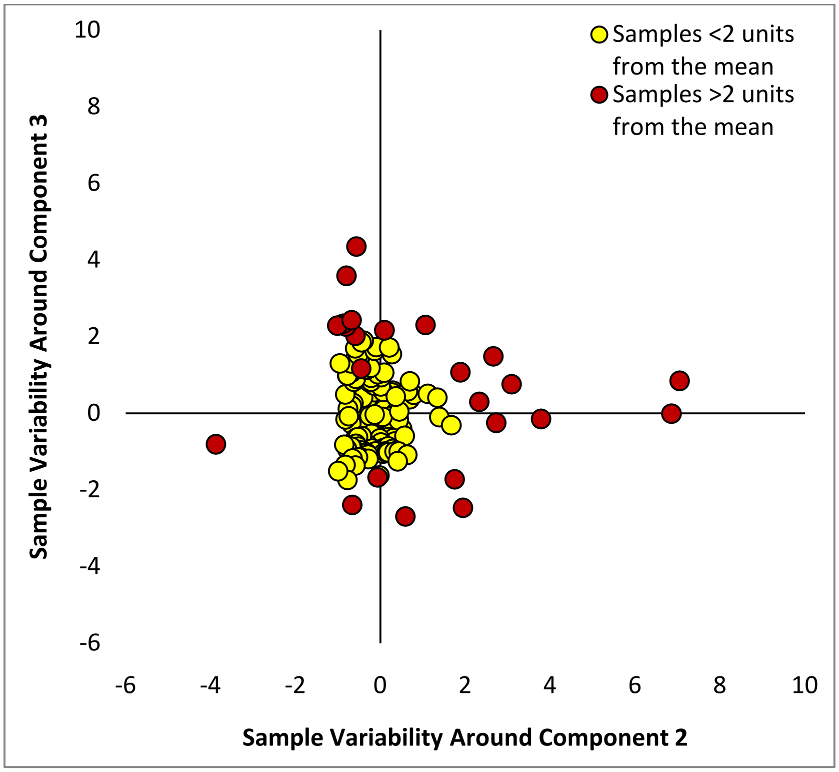


Figure 4. PCA Component 3 versus Component 2

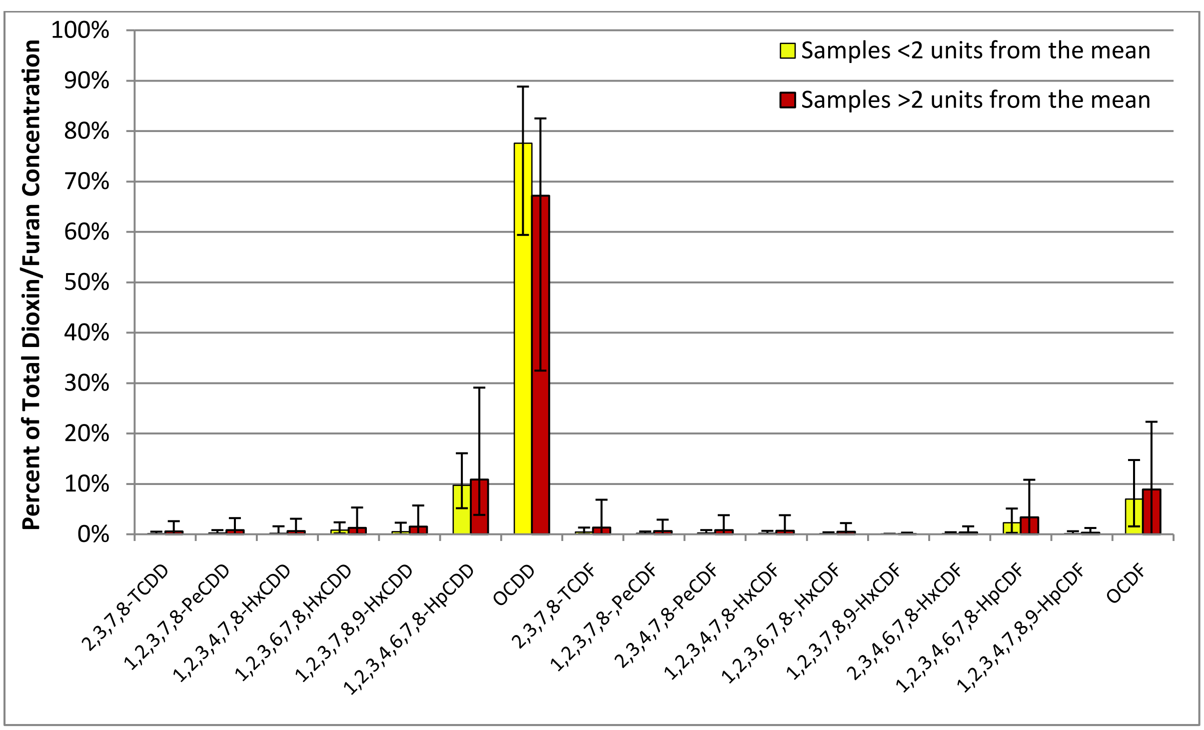


Figure 5. Congener Profiles for the Sample Subset Identified in Figures 2 through 4

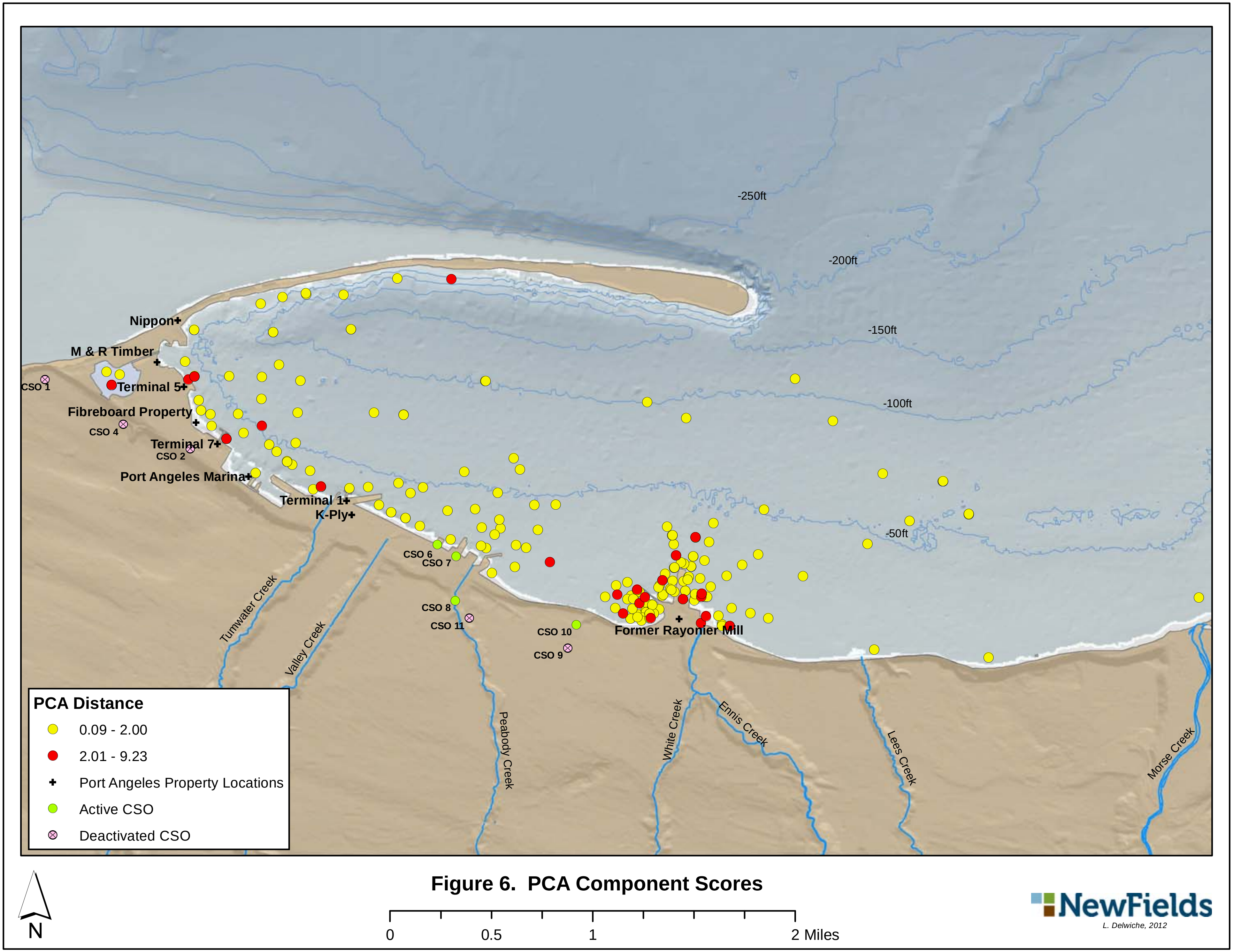
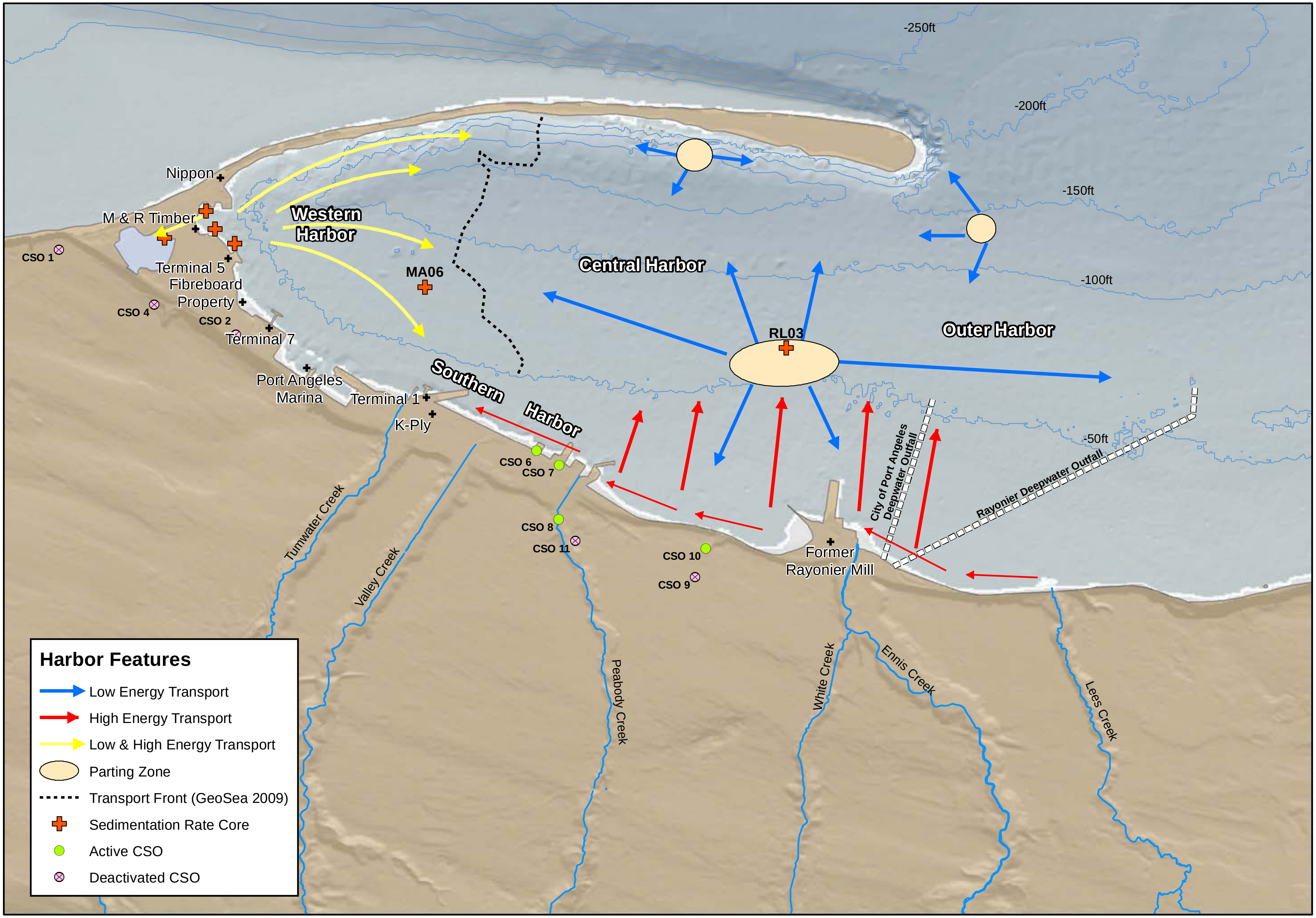


Figure 6. PCA Component Scores



N

Figure 7. Sediment Transport Pathways

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012

Y:\Ecology\PortAngeles\Projects\Finalized\Finalized for Report_Preston\PAReport_Transport_Nuwer.mxd

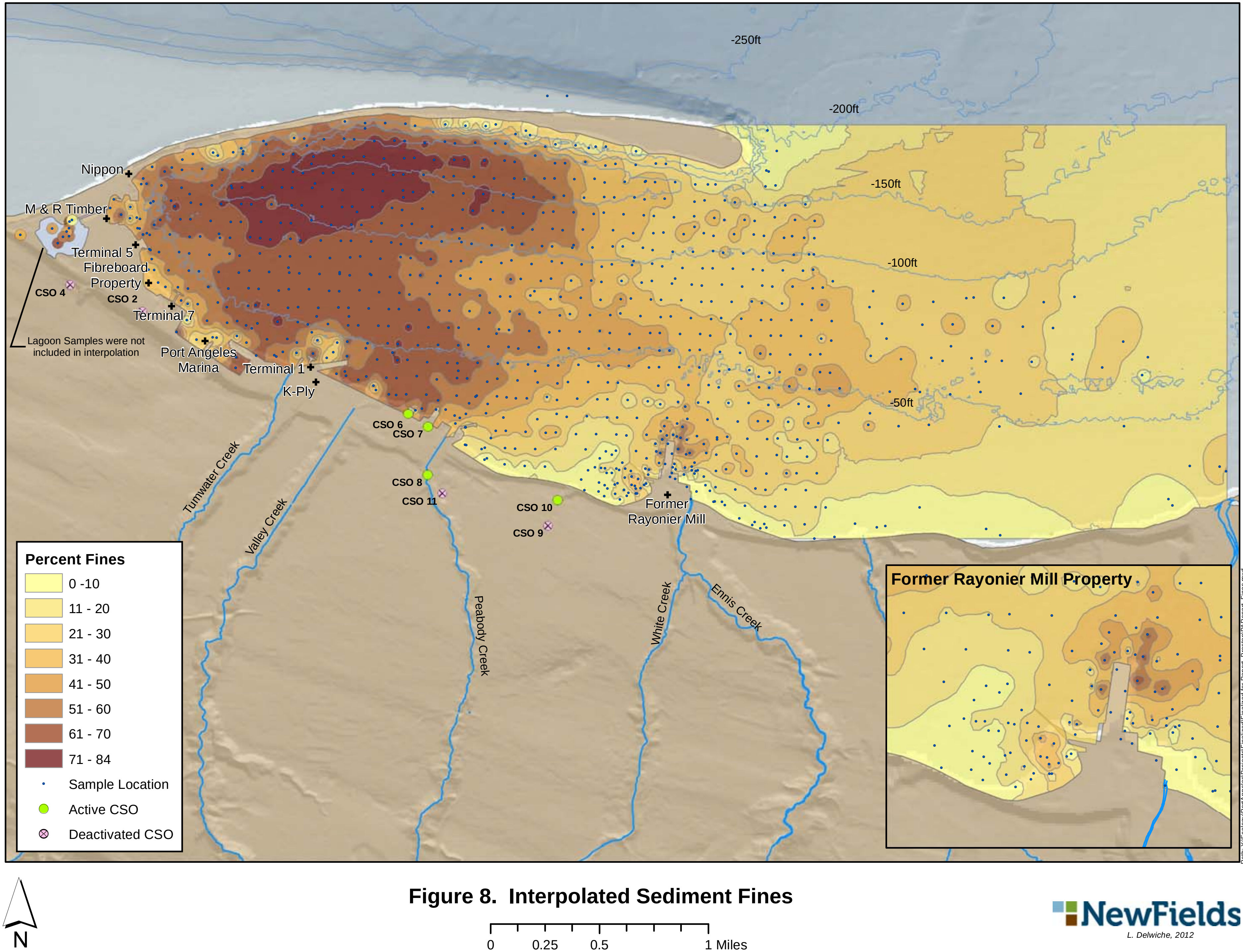


Figure 8. Interpolated Sediment Fines

NewFields

L. Delwiche, 2012

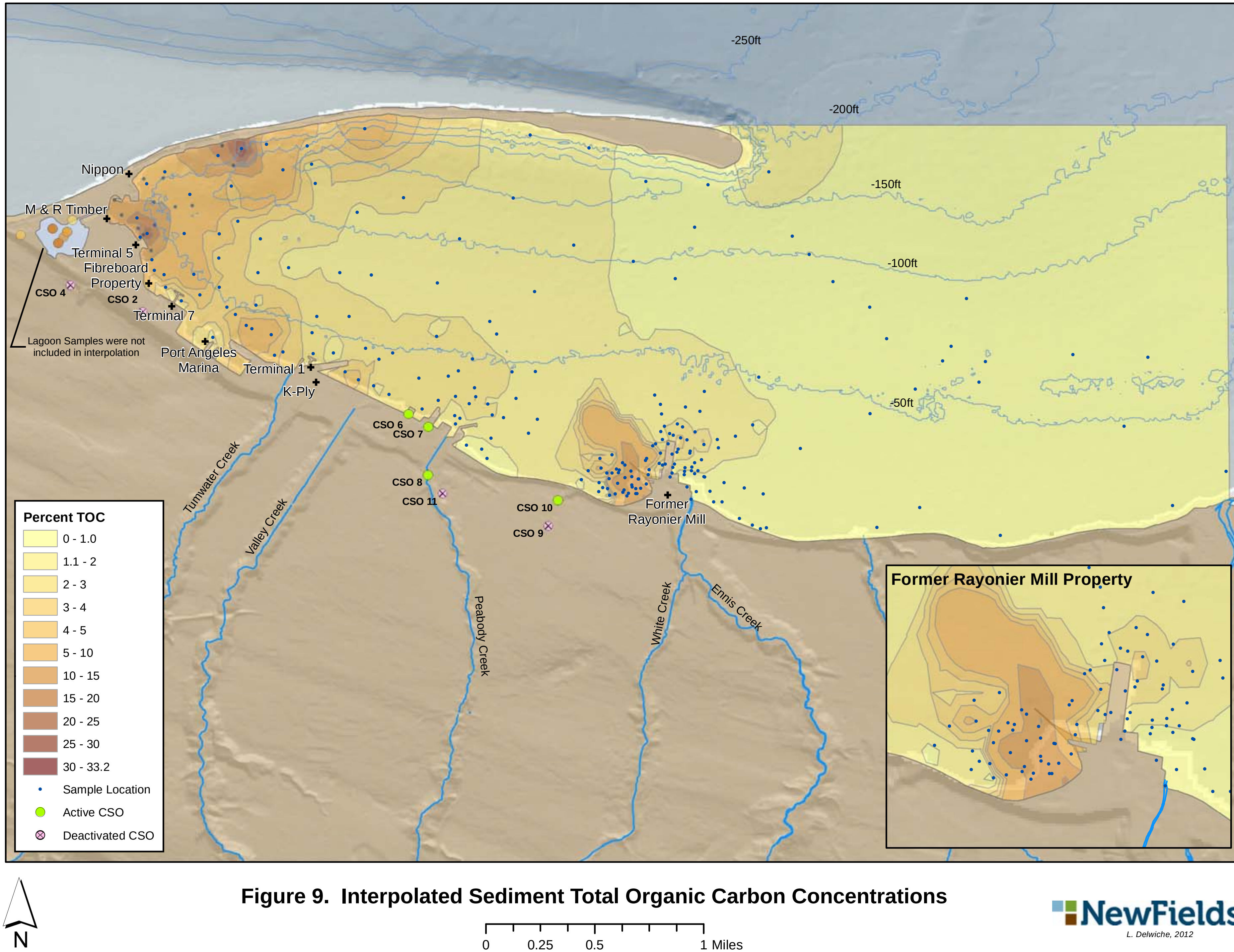
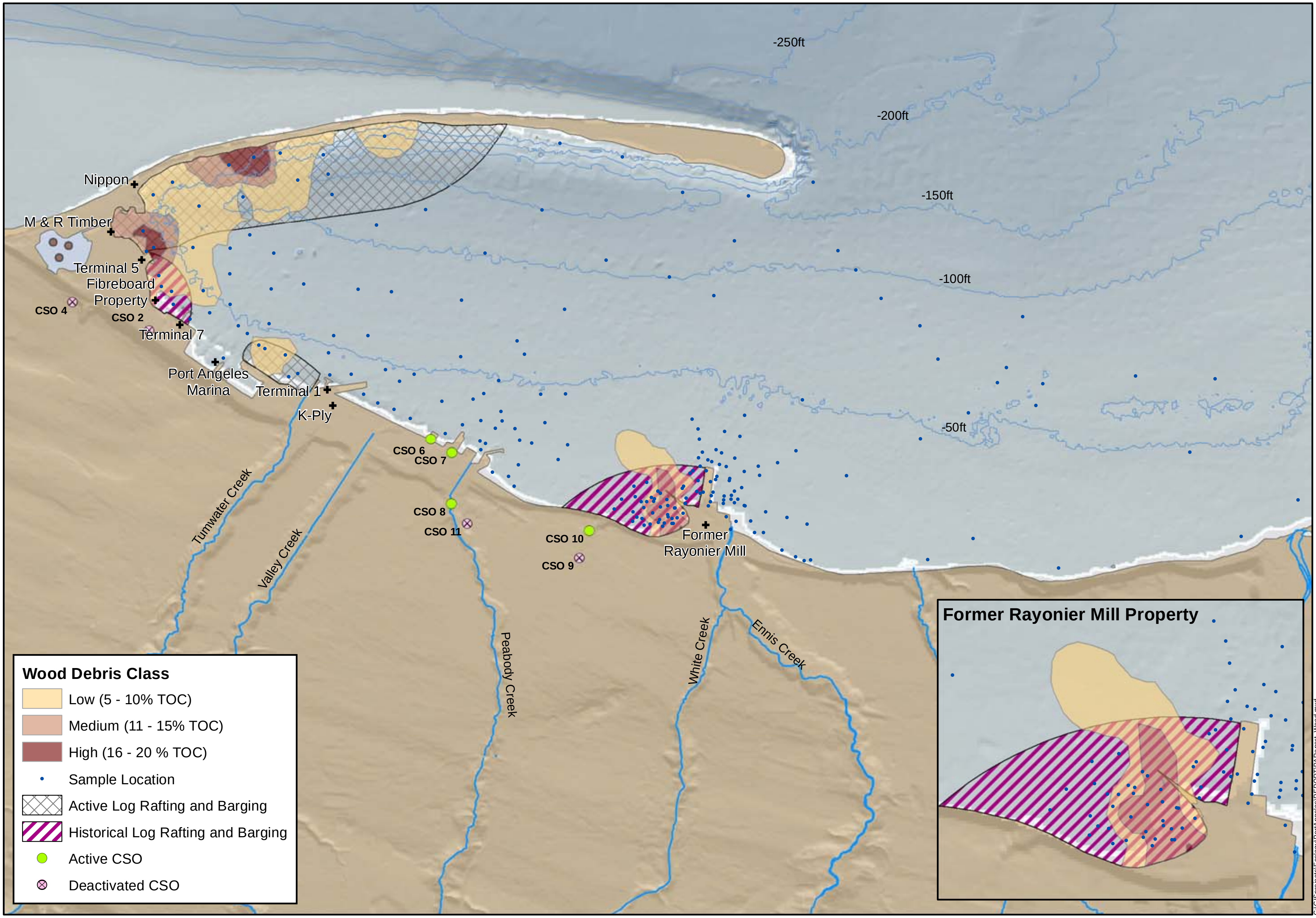


Figure 9. Interpolated Sediment Total Organic Carbon Concentrations

NewFields

L. Delwiche, 2012



N

Figure 10. Estimated Sediment Wood Debris

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012

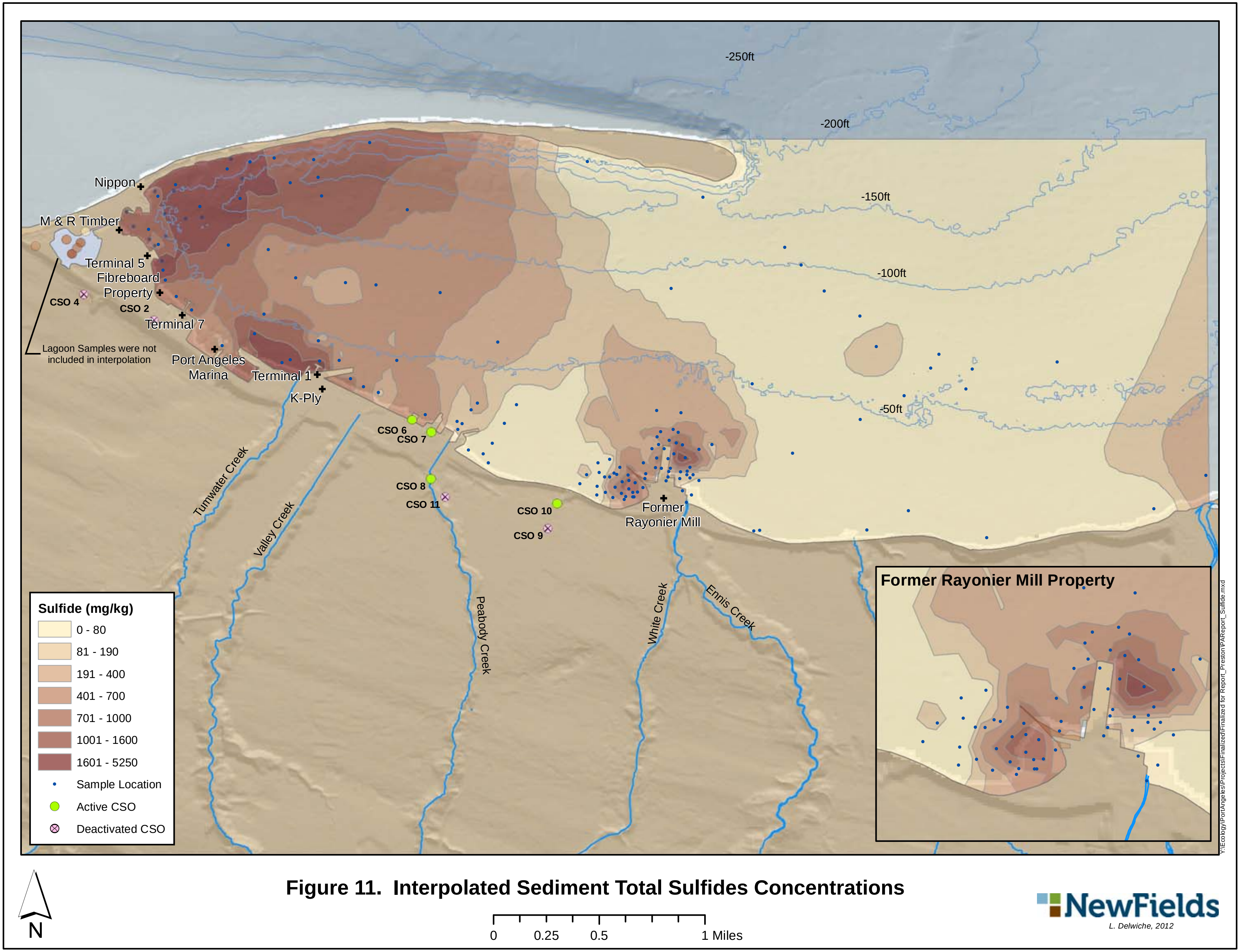
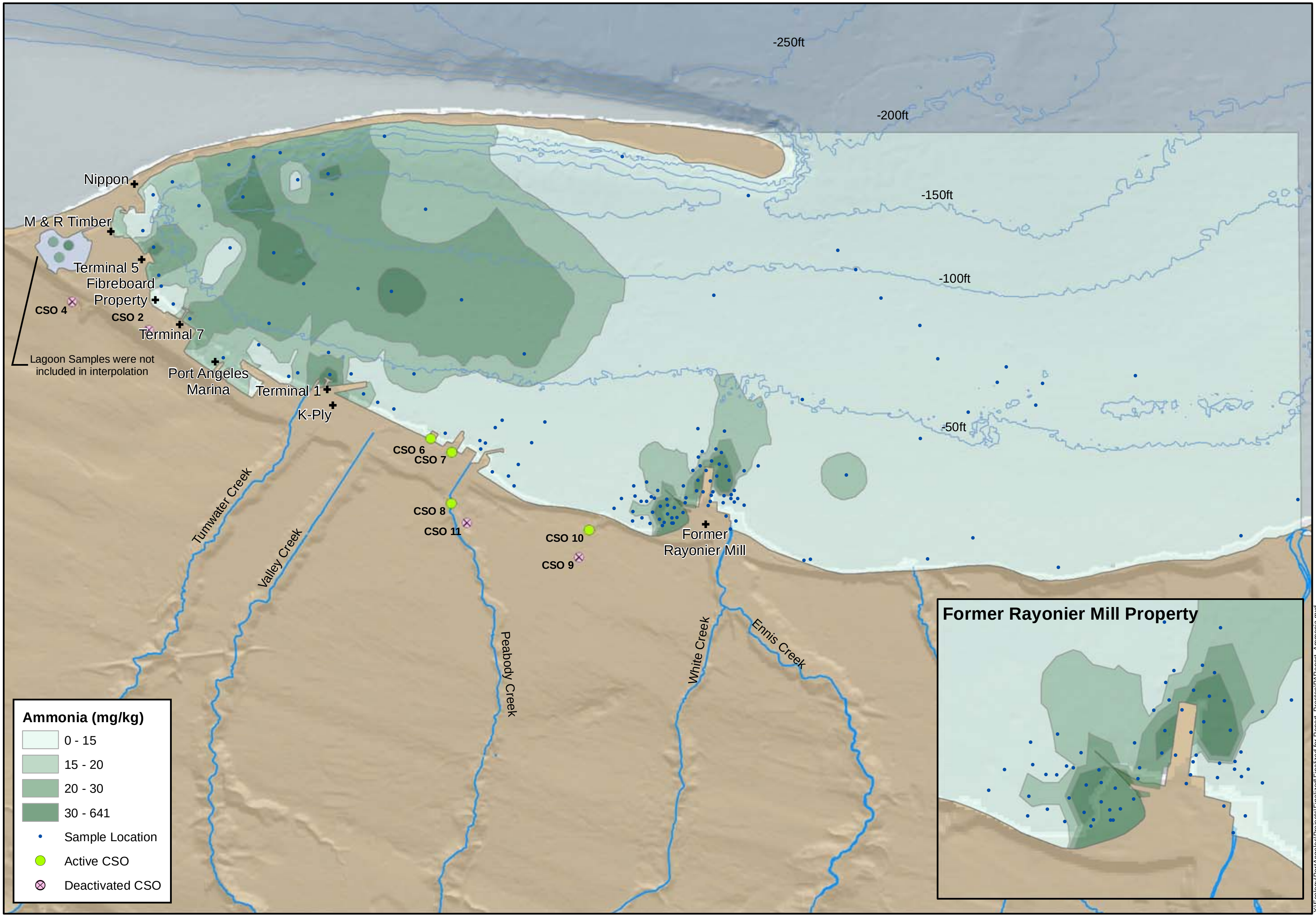


Figure 11. Interpolated Sediment Total Sulfides Concentrations



N

Figure 12. Interpolated Sediment Ammonia Concentrations

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012

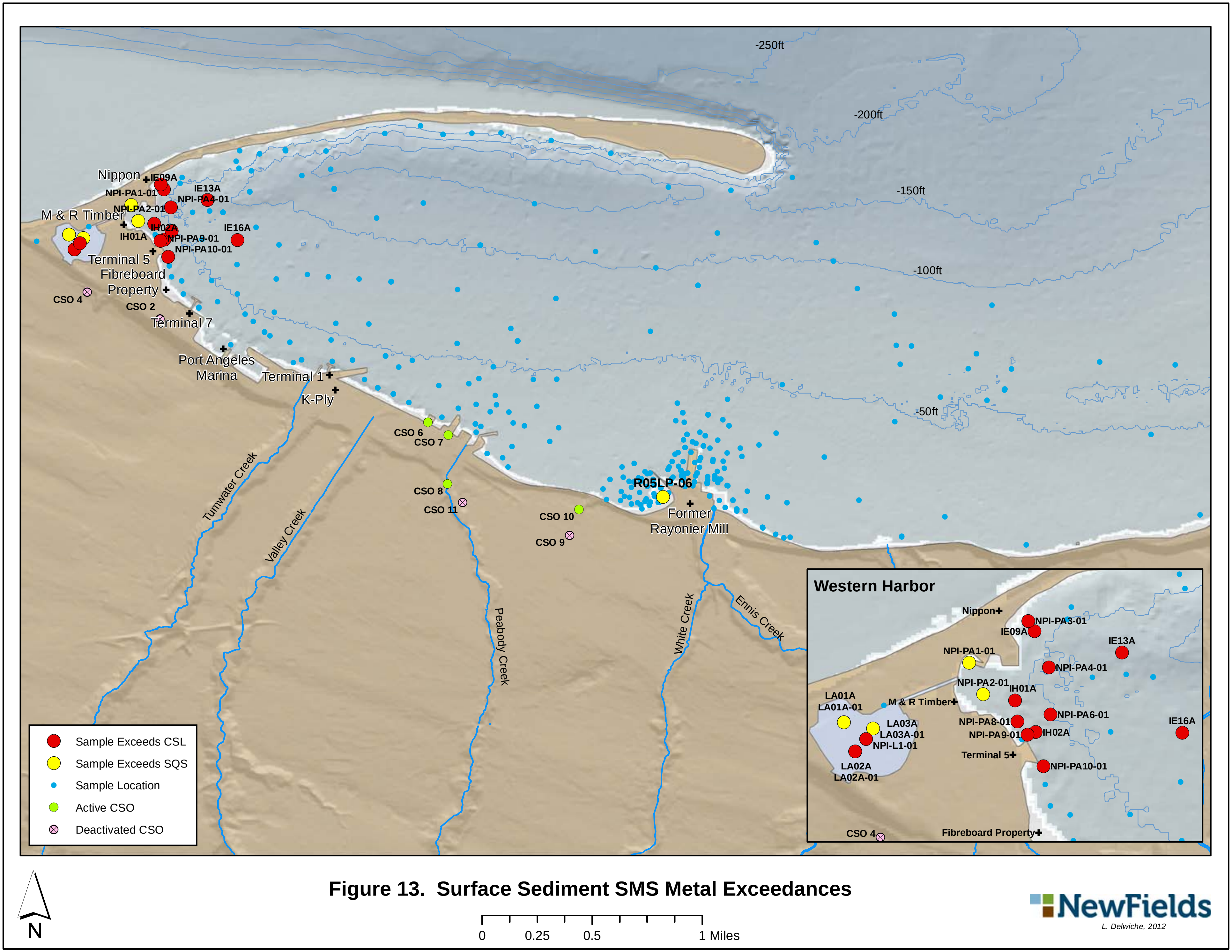
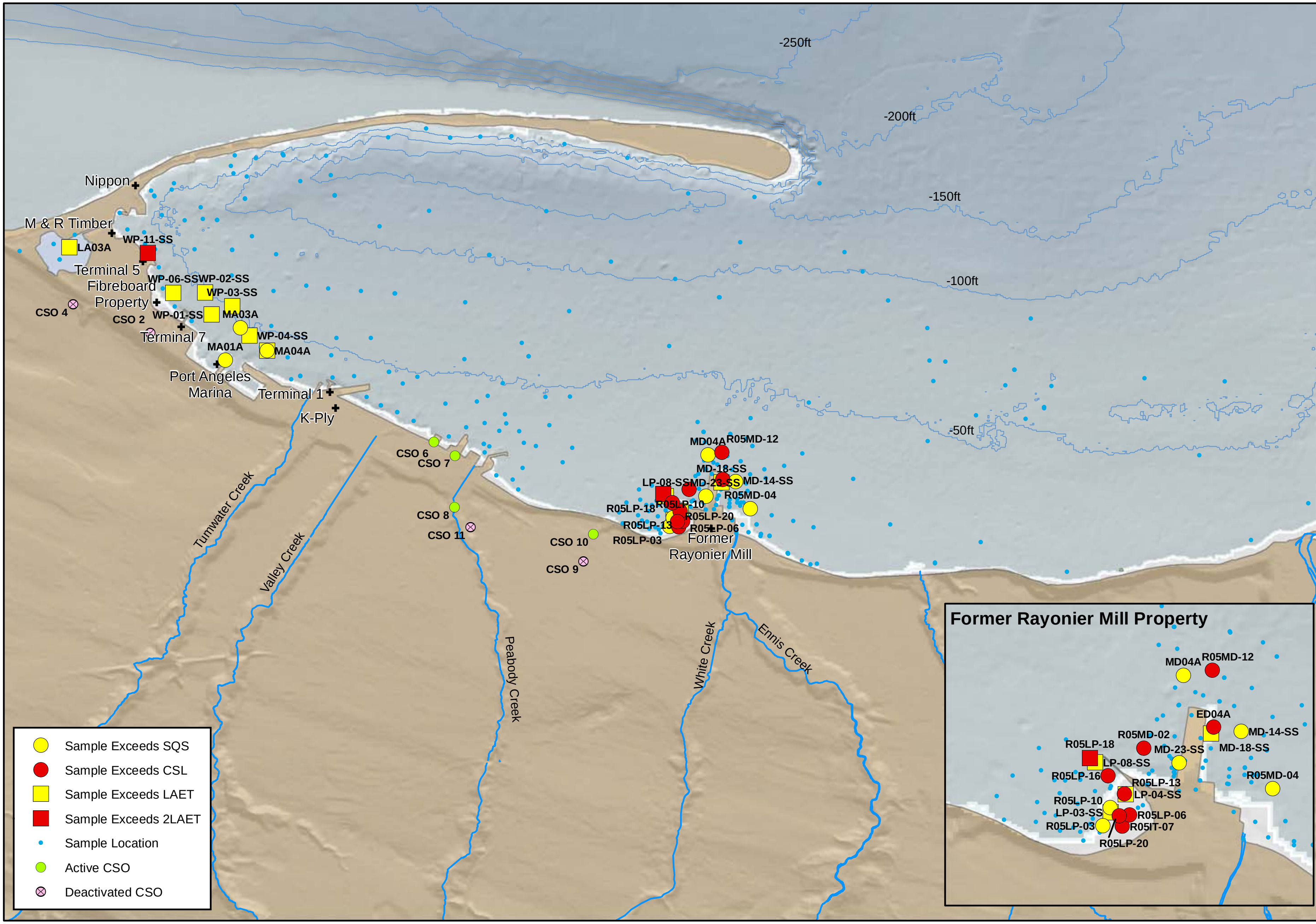


Figure 13. Surface Sediment SMS Metal Exceedances



N

Figure 14. Surface Sediment SMS/LAET Organic COPC Exceedances

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012

C:\GISprojects\Ecology\PortAngeles\REPORT\PAReport_Organic_Exceed.mxd

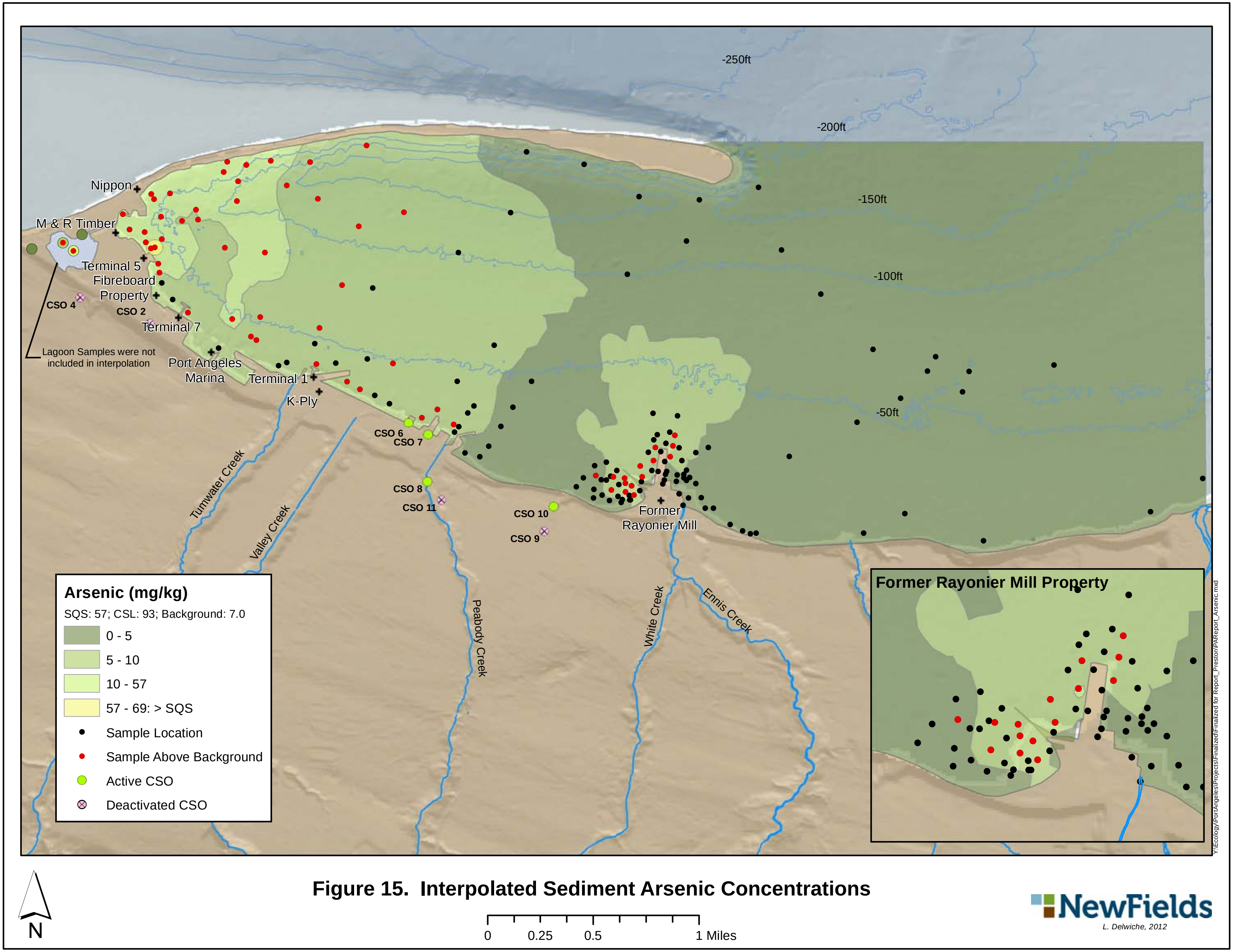


Figure 15. Interpolated Sediment Arsenic Concentrations

NewFields

L. Delwiche, 2012

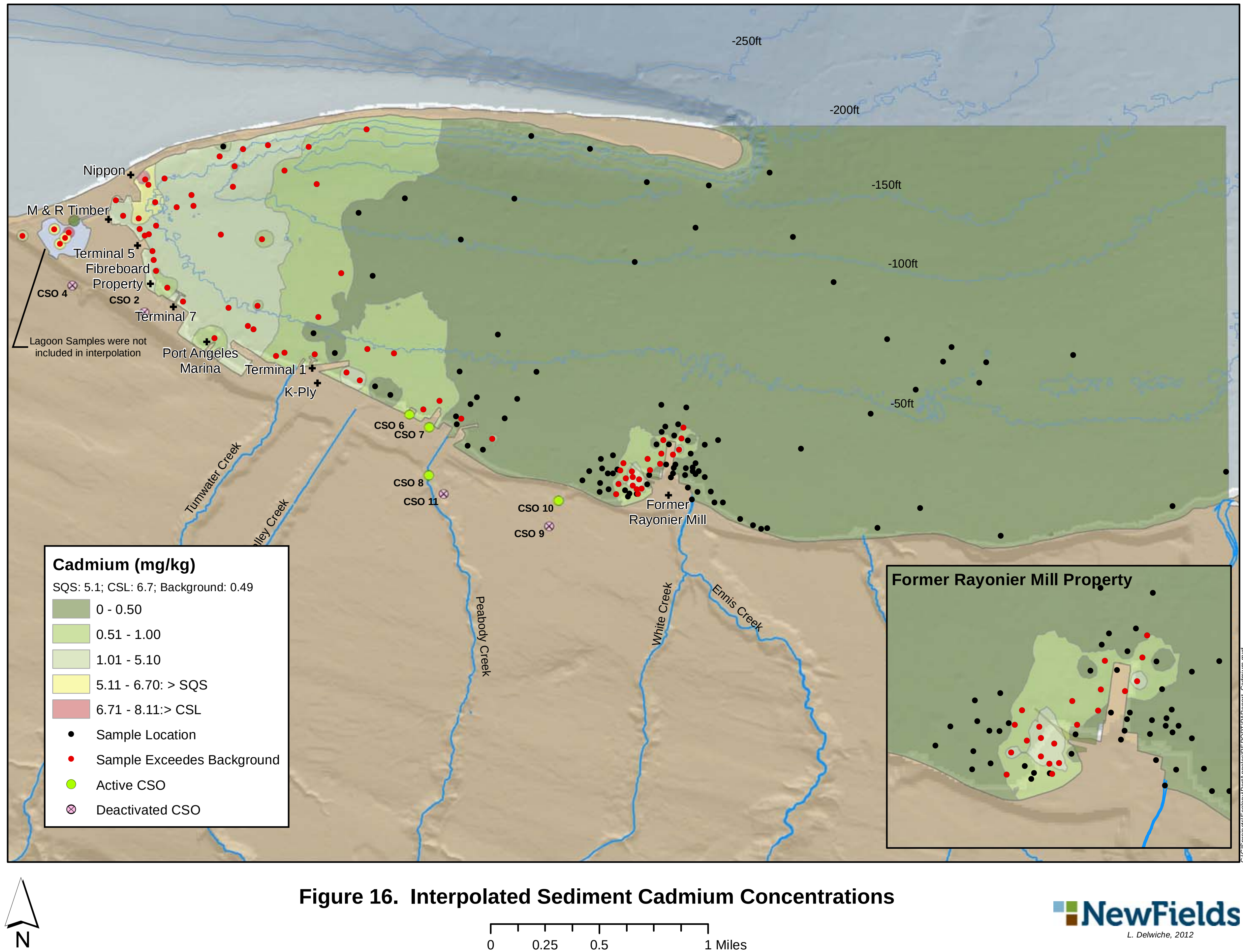


Figure 16. Interpolated Sediment Cadmium Concentrations

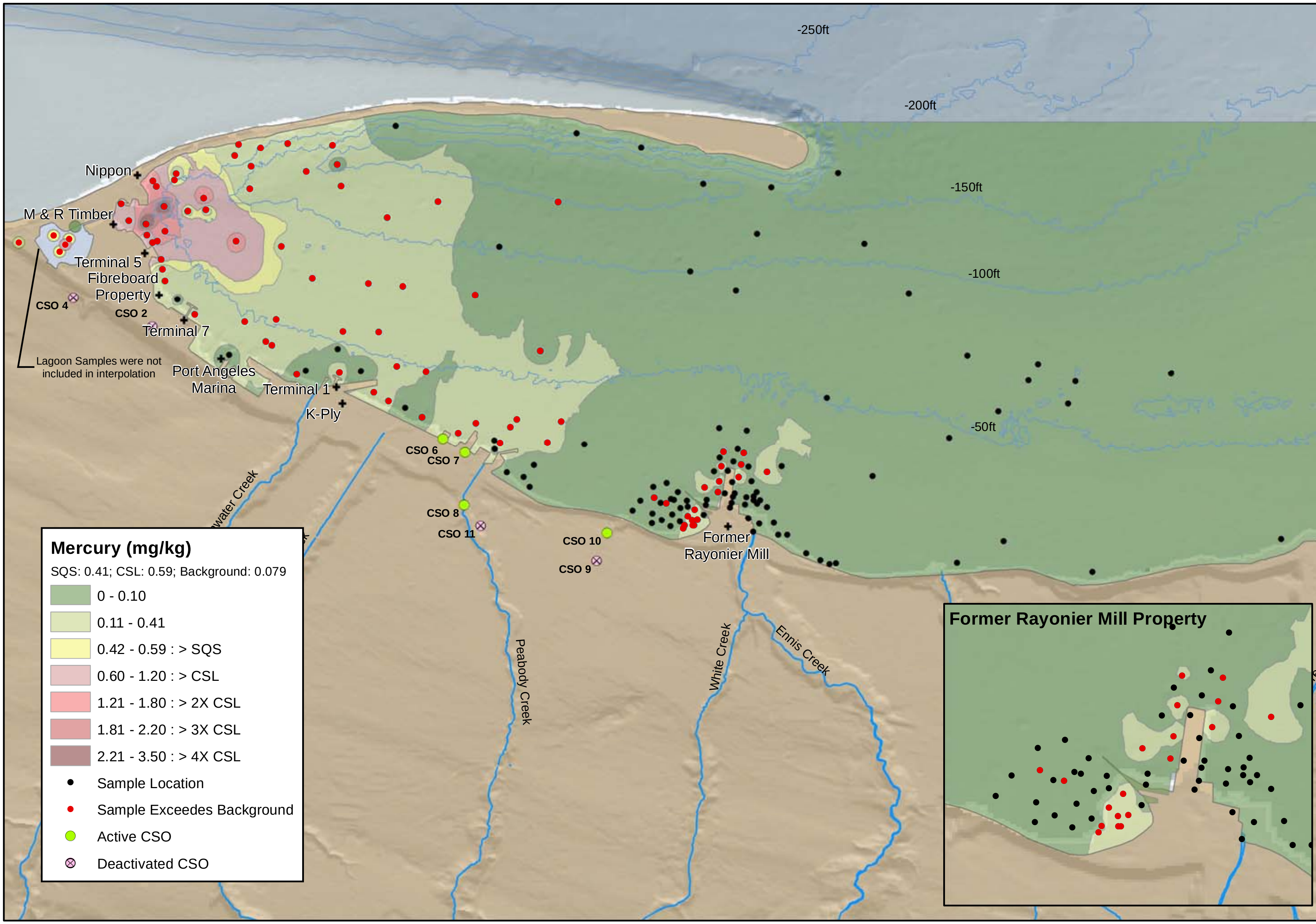


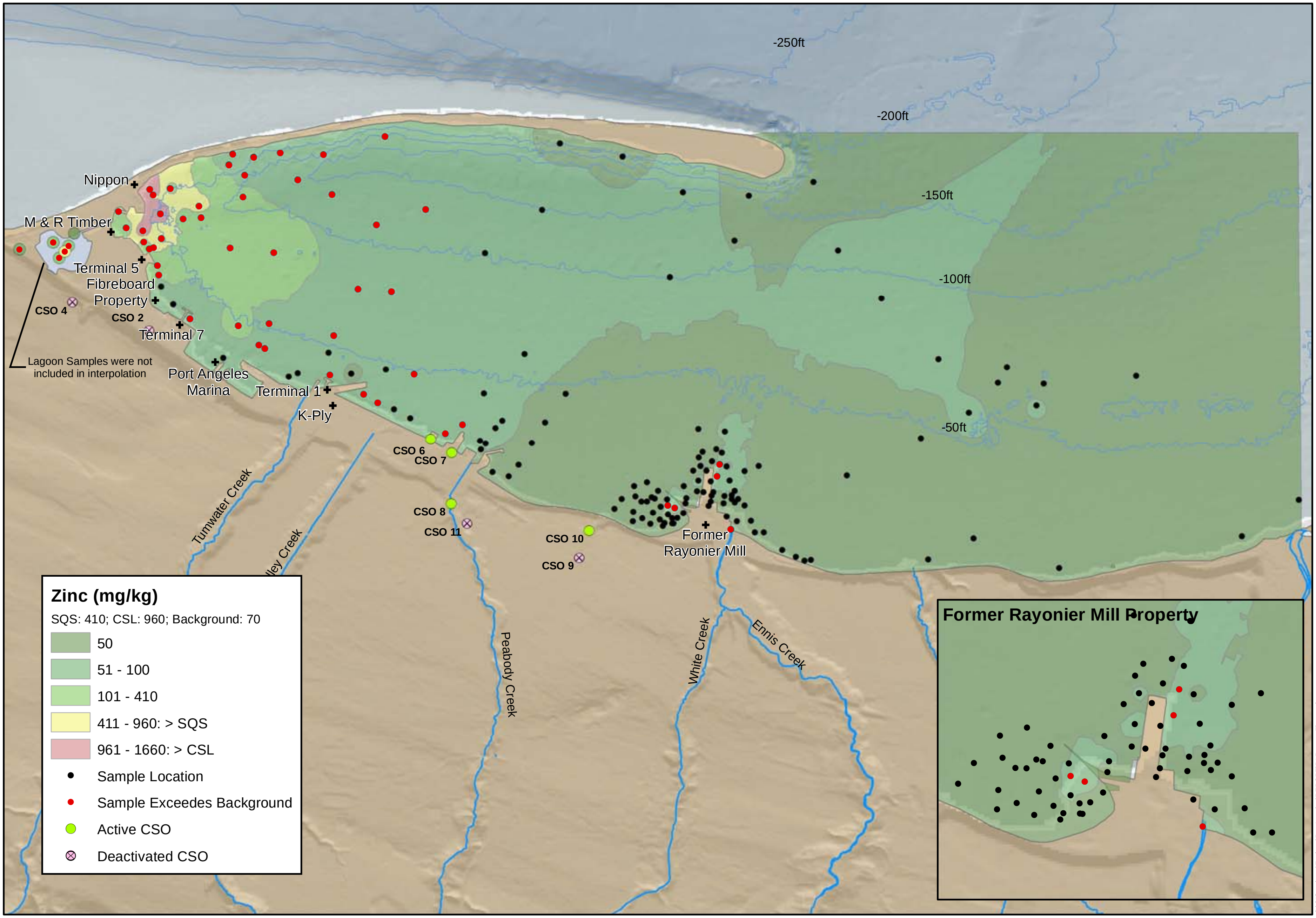
Figure 17. Interpolated Sediment Mercury Concentrations

N

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012



C:\GISprojects\Ecology\PortAngeles\REPORT\PAReport_Zinc.mxd

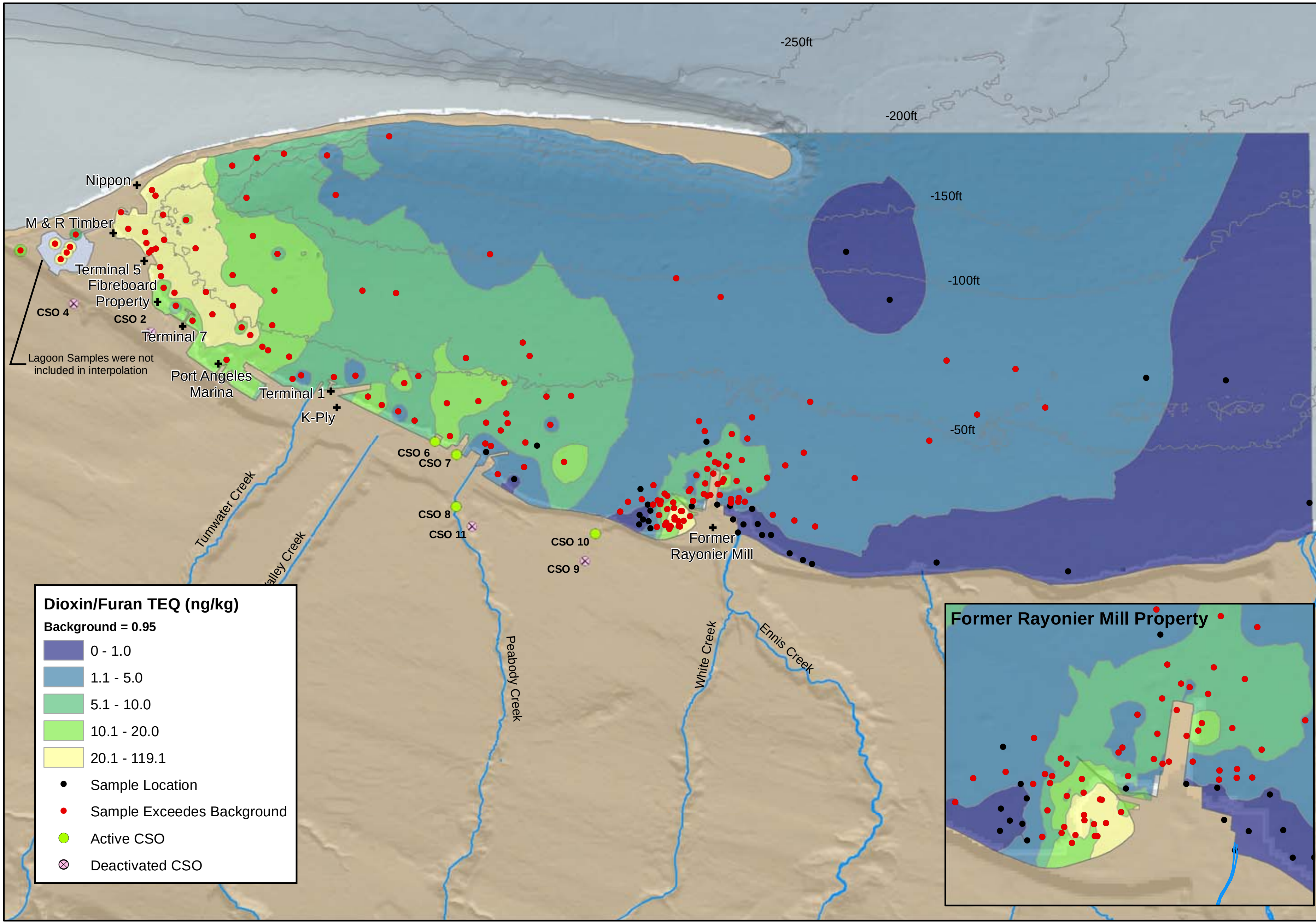
N

Figure 18. Interpolated Sediment Zinc Concentrations

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012



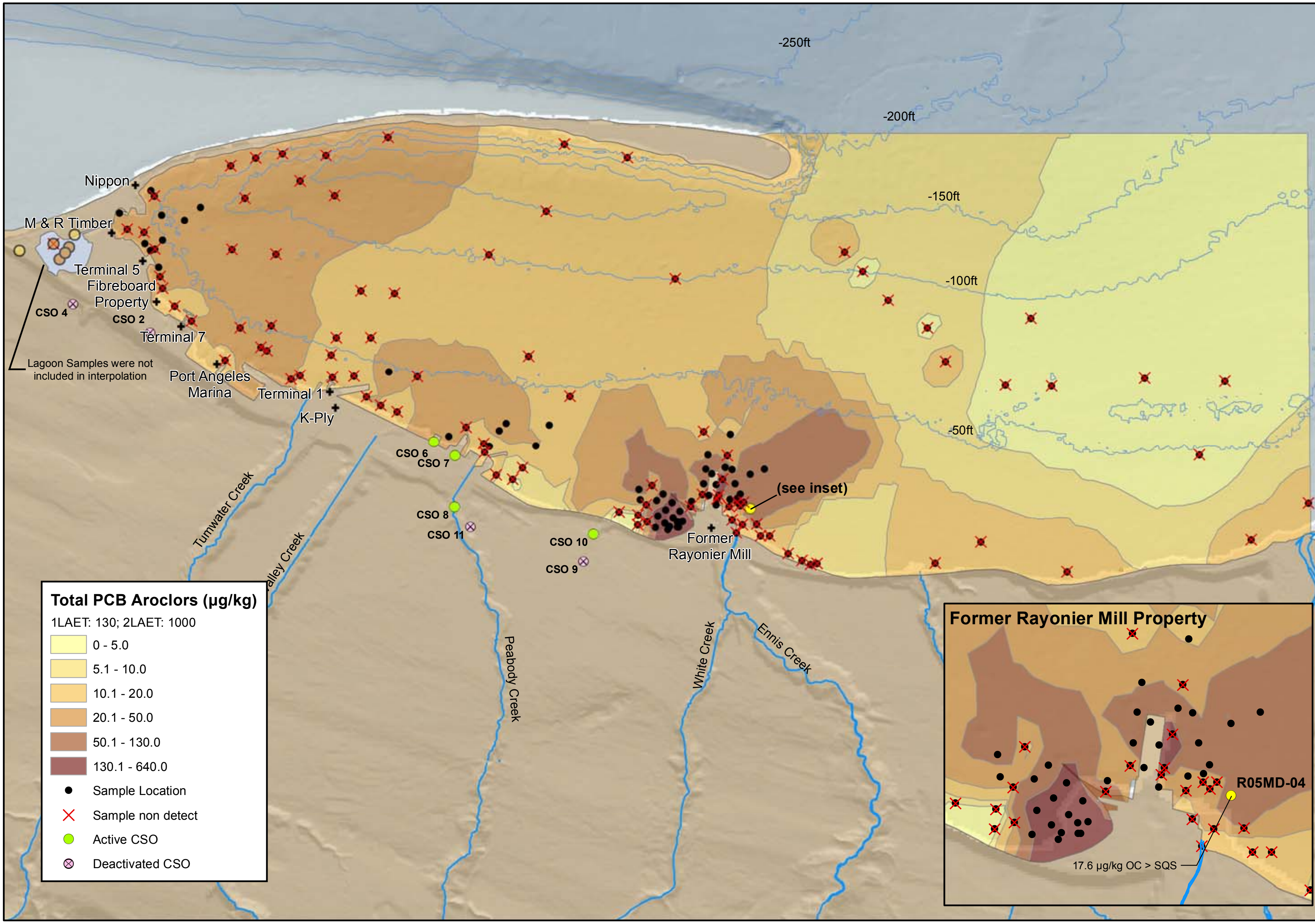
N

Figure 19. Interpolated Sediment Dioxin/Furan TEQs

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012



N

Figure 20. Interpolated Sediment Total PCB Aroclor Concentrations

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012

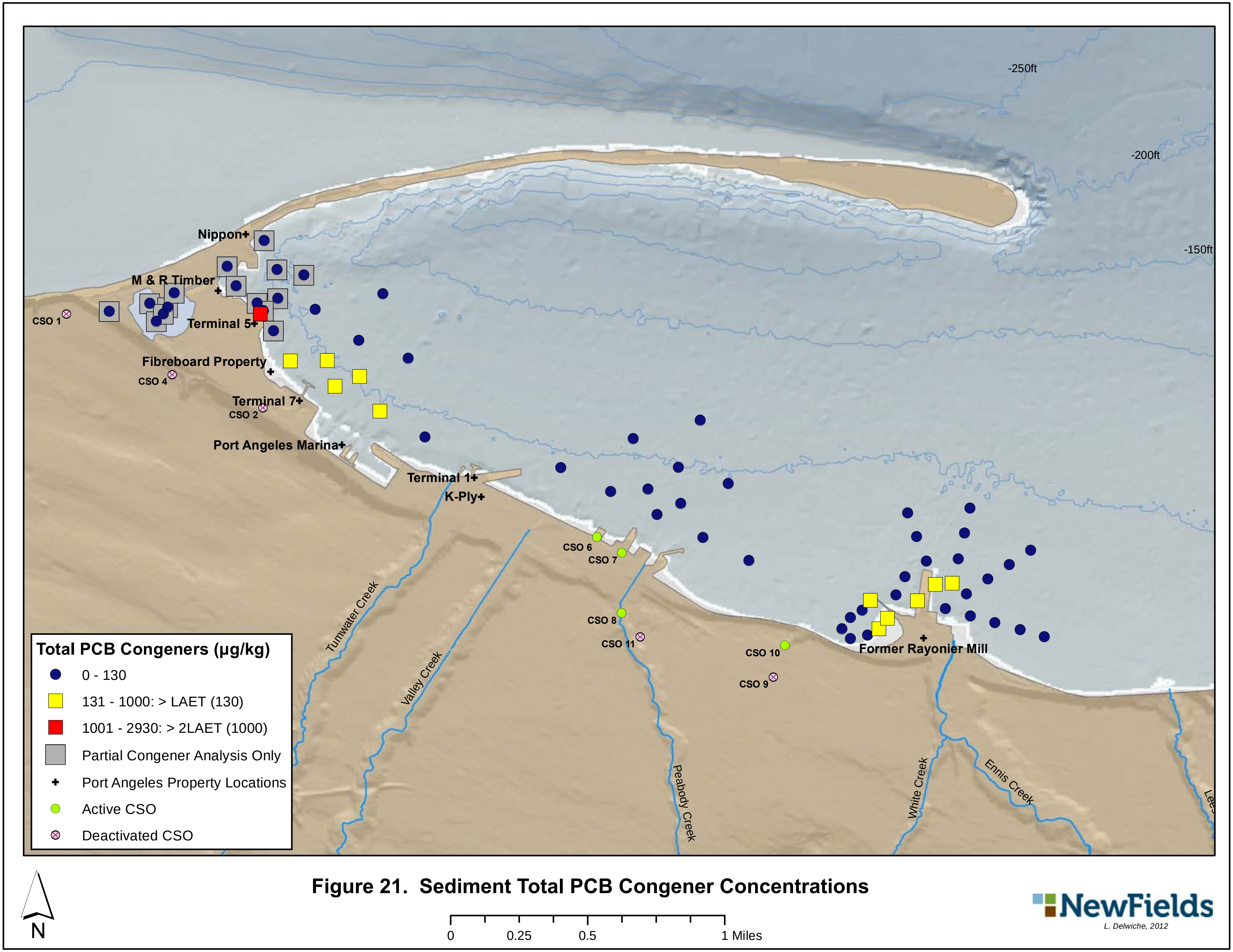
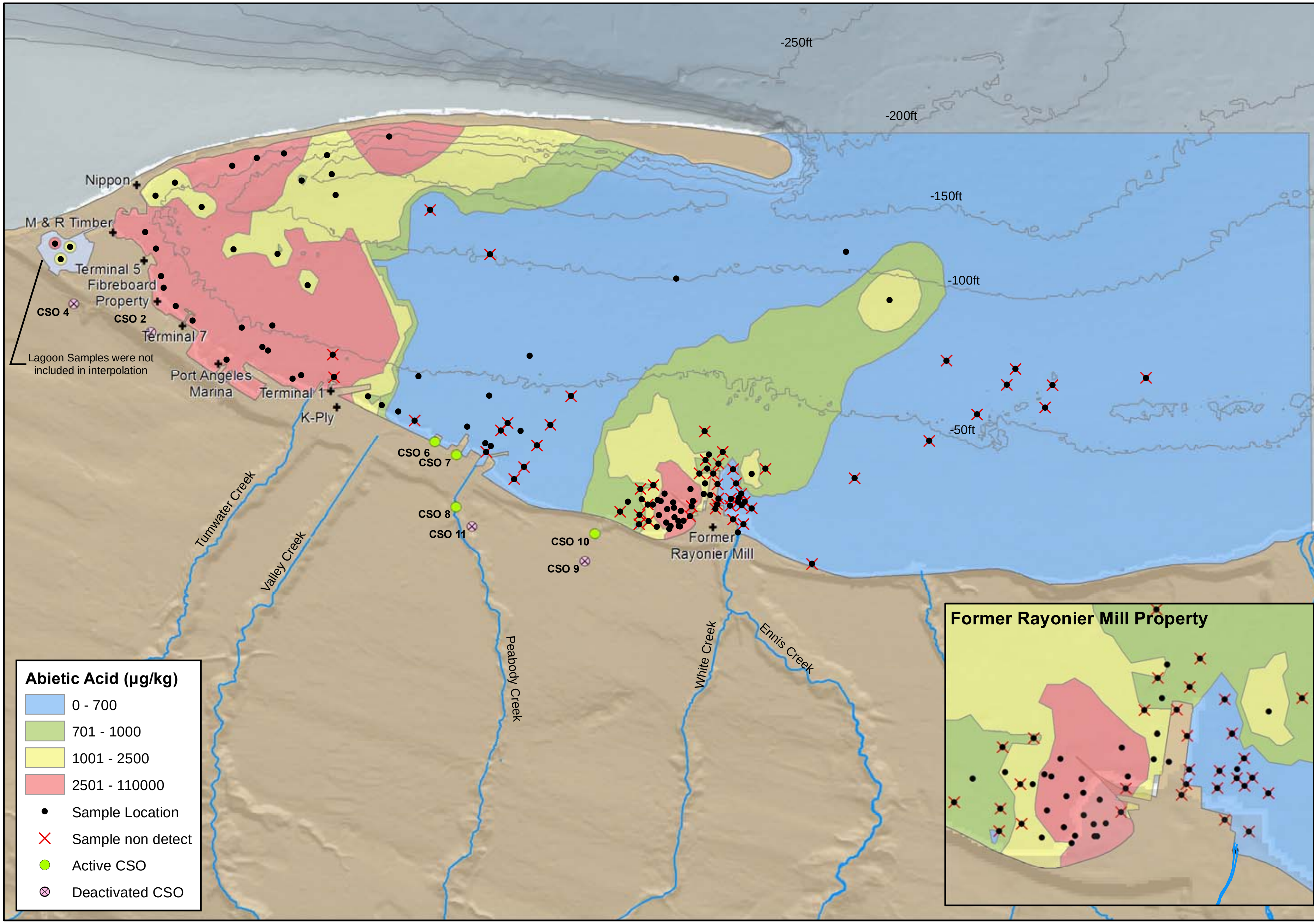


Figure 21. Sediment Total PCB Congener Concentrations



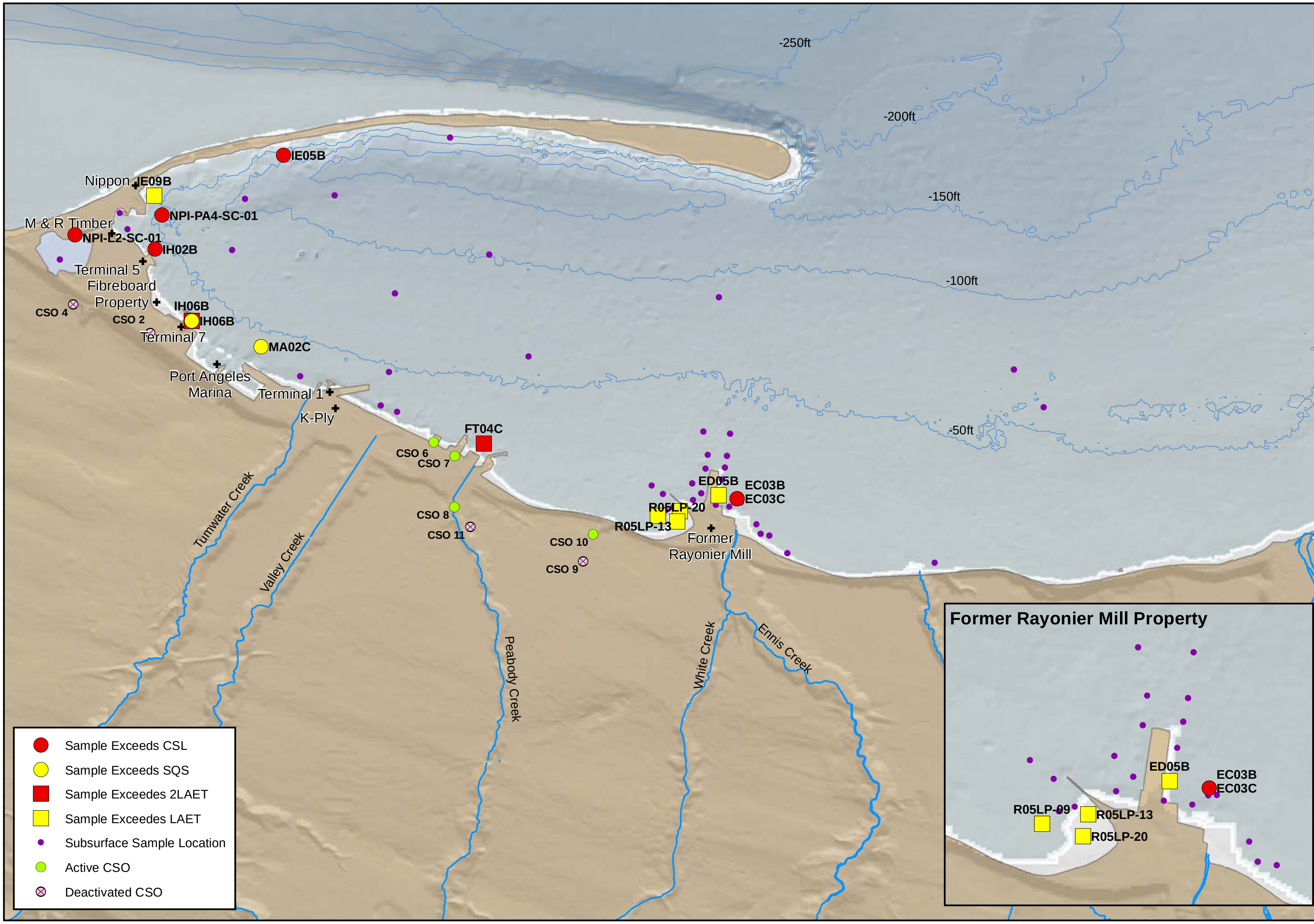
N

Figure 22. Interpolated Sediment Abietic Acid

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012



N

Figure 23. Subsurface Sediment SMS/LAET Exceedances

0 0.25 0.5 1 Miles

NewFields

L. Delwiche, 2012

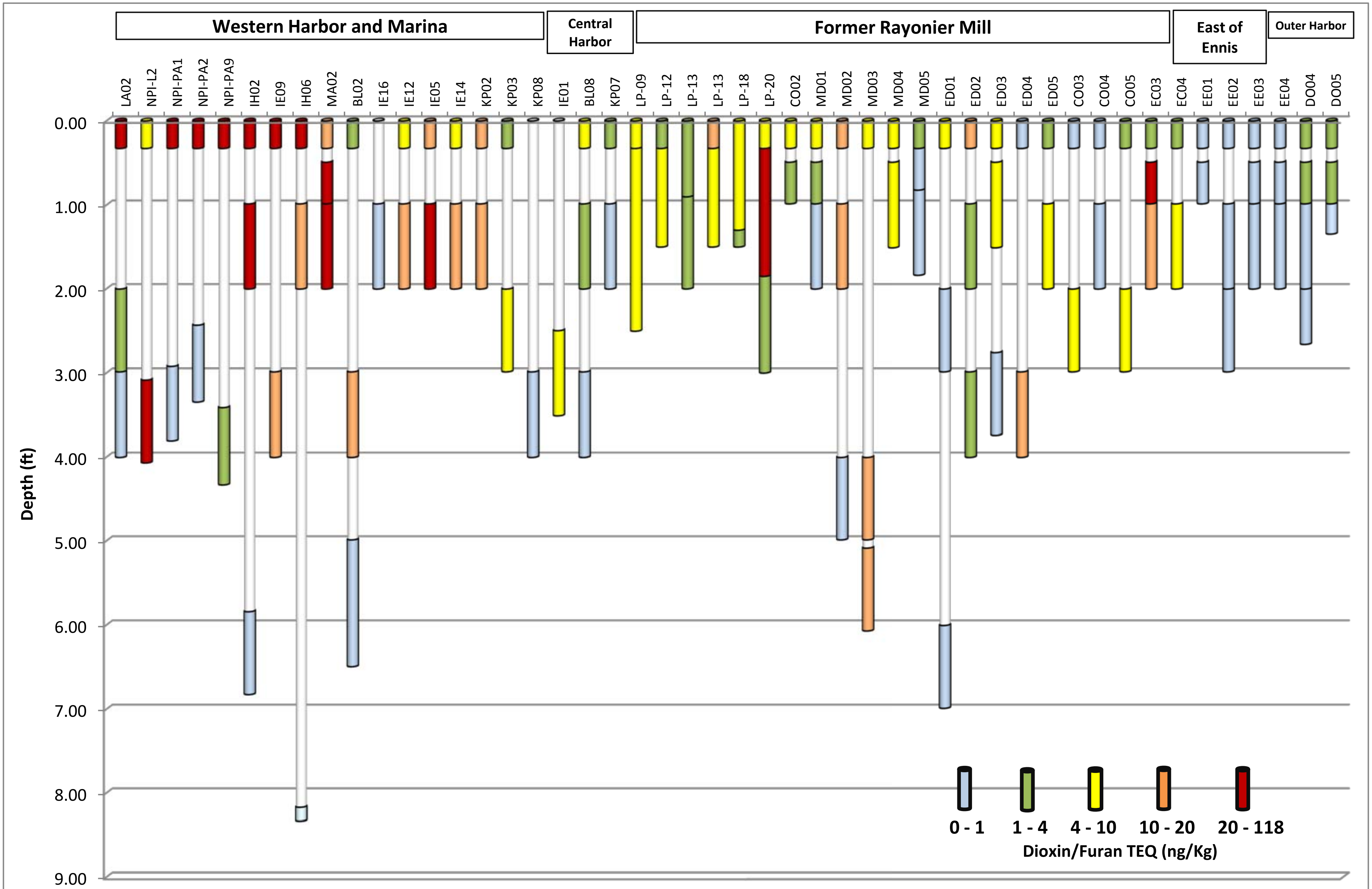


Figure 24. Sediment Core Dioxin/Furan TEQs

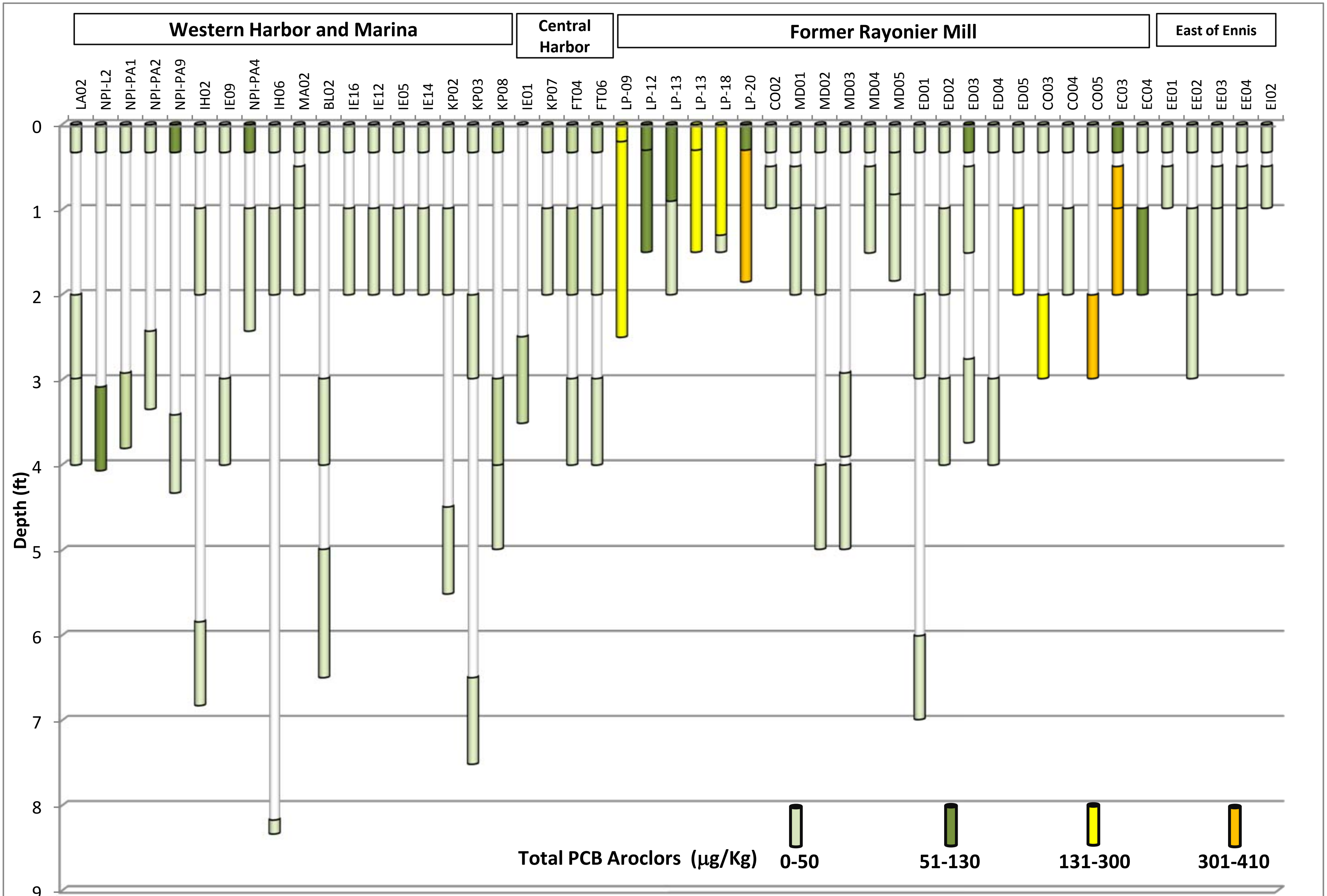


Figure 25. Sediment Core Total PCB Aroclor Concentrations

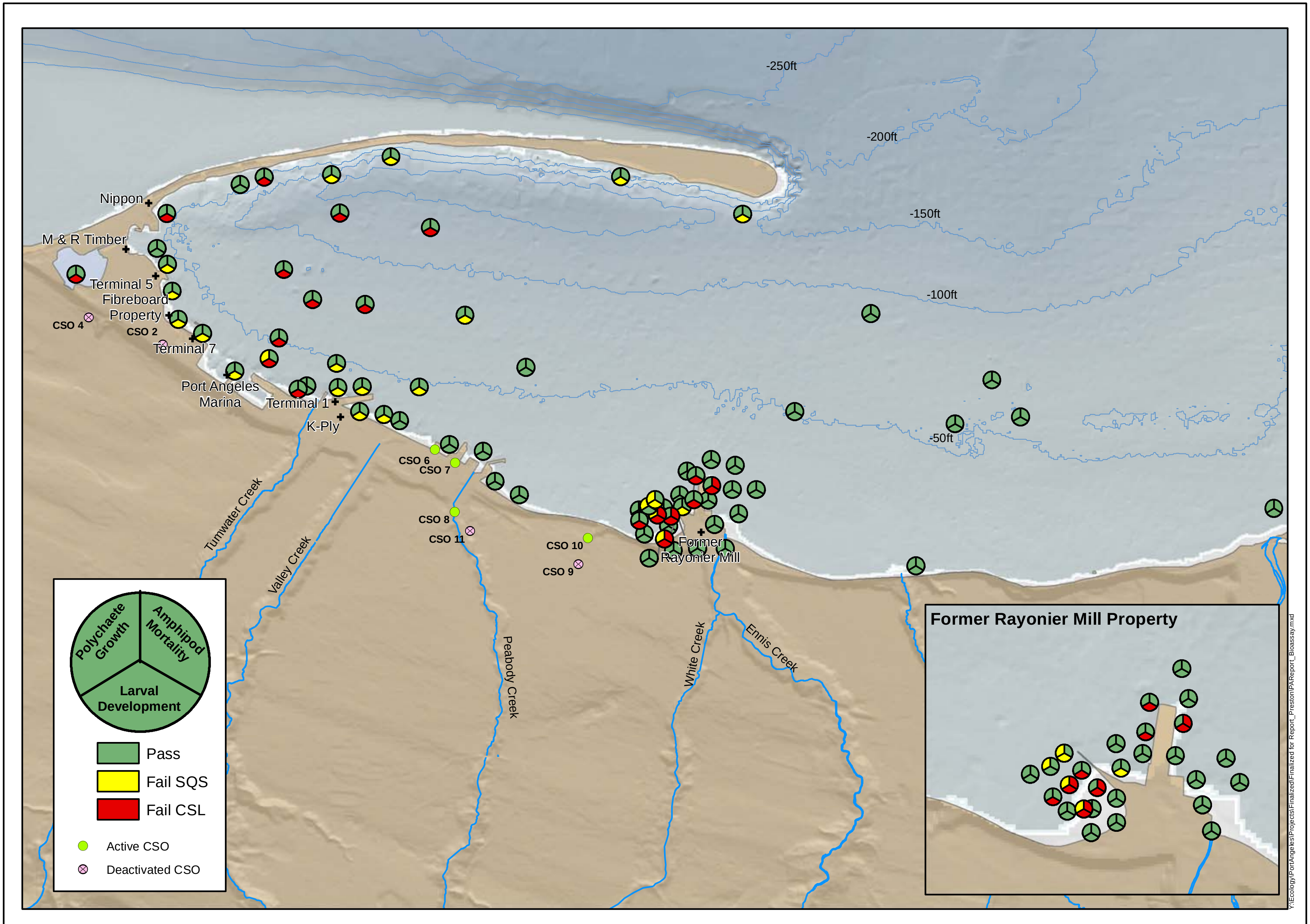


Figure 26. Sediment Bioassay Results

N W E S

0 500 1,000 2,000 3,000 4,000 5,000 6,000
Feet

Scale 1:24,000

Figure 27

Port Angeles Harbor, Washington

Harbor-wide Sub-Areas (from E&E 2008b)

Tables

Table 1. Surface Sediment Data Set Use Matrix

Study	Fines	TOC	Sulfides	Ammonia	Metals	Dioxin/Furan Congeners	PCBs Aroclors	PCB Congeners	Other SMS Analytes	Bioassays
E & E 2012	116	116	116	116	102	85	85	--	92	55
Malcolm Pirnie 2007a	72	81	59	59	59	45	58	--	59	15
Malcolm Pirnie 2007b	72	72	--	--	--	72	--	72	--	--
Anchor 2005	--	4	4	--	4	--	--	--	--	--
Exponent 2008	12	15	15	--	15	15	15	12	12	--

Notes:

Values indicate the number of surface sediment samples used for analysis.

Table 2. Subsurface Sediment Data Set Use Matrix

Study	Fines	TOC	Sulfides	Ammonia	Metals	Dioxin/Furan Congeners	PCBs Aroclors	Other SMS Analytes
E & E 2012	75	75	37	37	69	57	59	75
Malcolm Pirnie 2007a	20	20	--	--	7	7	7	--
Exponent 2008	5	5	4	--	5	4	5	4

Notes:

Values indicate the number of subsurface sediment samples used for analysis.

Table 3. Calculated Background Threshold Values and Port Angeles Harbor Exceedances

Analyte	Number of Data Locations			90th Percentile			Port Angeles Sediment Investigation Surface Sediment Detected Exceedances[1]		
	Puget Sound-wide	Puget Sound Reference Areas	Port Angeles Proximal Area	Puget Sound-wide	Puget Sound Reference Areas	Port Angeles Proximal Area	Puget Sound-wide	Puget Sound Reference Areas	Port Angeles Proximal Area
Metals in mg/kg DW									
Antimony	70	20	13	–	–	0.31*	34%	34%	34%
Arsenic	70	20	15	11	9.7	7.0	8%	15%	42%
Cadmium	70	20	15	0.70	0.79	0.49	34%	29%	44%
Chromium	70	20	15	55	50	39	0%	0%	7%
Copper	70	20	15	40	41	30	16%	16%	41%
Lead	70	20	15	18	17	10	12%	13%	44%
Mercury	70	20	15	0.20	0.23	0.079	17%	13%	53%
Nickel	70	20	15	50	44	37	1%	2%	11%
Silver	70	20	15	0.20	0.25	0.13	2%	0%	29%
Zinc	70	20	15	92	85	70	14%	20%	36%
PCB Aroclors in µg/kg DW									
Total PCB Aroclors[2]	70	20	13	–	–	–	13%	13%	13%
Dioxin/Furan Congener TEQ in pg/g DW									
Dioxin/Furan TEQ (ND = 1/2 DL)	70	20	35	2.2	1.9	0.95	60%	63%	82%
LPAH in µg/kg DW									
Naphthalene	70	20	15	4.6*	4.6*	22*	43%	43%	43%
Acenaphthene	70	20	15	4.6*	4.6*	21*	22%	22%	22%
Phenanthrene	70	20	15	7.9	5.1	21*	72%	72%	72%
Anthracene	70	20	15	4.5*	–	19*	52%	52%	52%
2-Methylnaphthalene	70	20	15	4.6*	4.6*	21*	16%	16%	16%
Total LPAH	70	20	15	11	7.9	18	83%	83%	70%
HPAH in µg/kg DW									
Fluoranthene	70	20	15	12	11	11	76%	79%	79%
Pyrene	70	20	15	12	11	8.6	73%	73%	75%
Benzo(a)anthracene	70	20	15	6.2	4.9	15*	67%	67%	67%
Chrysene	70	20	15	6.9	5.8	17*	72%	72%	72%
Benzo(b)fluoranthene	70	20	15	16	13	10	64%	65%	66%
Benzo(k)fluoranthene	70	20	15	8.8	5.1	23*	64%	64%	64%
Benzo(a)pyrene	70	20	15	10	6.5	8.1*	62%	63%	63%
Indeno(1,2,3-cd)pyrene	70	20	15	4.8	5.5	8.6*	43%	43%	43%
Dibenz(a,h)anthracene	70	20	15	4.6*	–	21*	22%	22%	22%
Benzo(g,h,i)perylene	70	20	15	5.0	5.7	17*	44%	44%	44%
Total HPAH	70	20	15	75	60	49	71%	72%	73%
Phthalate Esters in µg/kg DW									
bis(2-Ethylhexyl)phthalate	70	20	15	46*	46*	–	56%	56%	56%
Phenols in µg/kg DW									
Phenol	70	20	15	480	800	260	0%	0%	3%
Pentachlorophenol	70	20	15	9.3*	9.3*	–	0%	0%	0%

Notes:

1. For instances when the 90th percentile was not determined or below the detection limit, the percentage of detected values is reported.
2. Includes PCB Aroclors 1016, 1221, 1232,1242, 1248, 1254, and 1260.

− = No background concentration determined because there were no detections.

* = 90th percentile value is less than the maximum reported detection limit. The maximum detection limit is reported.

Table 4. Component Loadings for each of the 17 Dioxin/Furan Congeners

Dioxin/Furan Congener	Component1	Component2	Component3
2,3,7,8-TCDD	0.74	0.245	-0.235
1,2,3,7,8-PeCDD	0.944	0.195	-0.164
1,2,3,4,7,8-HxCDD	0.96	0.141	-0.069
1,2,3,6,7,8-HxCDD	0.872	0.176	-0.225
1,2,3,7,8,9-HxCDD	0.892	0.18	-0.256
1,2,3,4,6,7,8-HpCDD	0.722	0.162	-0.432
OCDD	-0.823	-0.439	-0.249
2,3,7,8-TCDF	0.894	0.196	-0.02
1,2,3,7,8-PeCDF	0.951	0.183	0.012
2,3,4,7,8-PeCDF	0.945	0.211	-0.005
1,2,3,4,7,8-HxCDF	0.227	0.831	0.037
1,2,3,6,7,8-HxCDF	0.896	0.256	-0.035
1,2,3,7,8,9-HxCDF	0.747	0.242	-0.184
2,3,4,6,7,8-HxCDF	0.643	0.59	-0.046
1,2,3,4,6,7,8-HpCDF	0.316	0.75	0.13
1,2,3,4,7,8,9-HpCDF	0.037	0.794	-0.1
OCDF	-0.18	0.081	0.939

Key:

Maximum loading for each congener

Table 5. Surface Sediment Metals that Exceed SMS Criteria and Associated Bioassay Results

Region	Location	Study	Arsenic	Cadmium	Mercury	Zinc	Bioassay Result		
			SQS = 57 CSL = 93	SQS = 5.1 CSL = 6.7	SQS = 0.41 CSL = 0.59	SQS = 410 CSL = 960	Larval Development	Amphipod Mortality	Polychaete Growth
			(mg/Kg)						
Lagoon	LA01A	E & E 2012	–	5.90	0.45	–	na	na	na
	LA02A	E & E 2012	–	–	0.59	–	Fail	Pass	Pass
	LA03A	E & E 2012	–	–	0.59	–	na	na	na
	LA01A-01	Exponent 2008	–	6.4	0.57	–	na	na	na
	LA02A-01	Exponent 2008	–	7.6	0.59	–	na	na	na
	LA03A-01	Exponent 2008	–	5.7	0.59	–	na	na	na
	NPI-L1-01	Exponent 2008	–	6.0	0.61	411	na	na	na
Western Harbor	IH01A	E & E 2012	–	7.4	3.50	1600	Pass	Pass	Pass
	IH02A	E & E 2012	69.0	–	1.30	460	Fail	Pass	Pass
	IE09A	E & E 2012	–	–	1.20	860	Fail	Pass	Pass
	IE13A	E & E 2012	–	–	1.90	610	na	na	na
	IE16A	E & E 2012	–	–	1.30	–	na	na	na
	NPI-PA1-01	Exponent 2008	–	–	0.54	–	na	na	na
	NPI-PA2-01	Exponent 2008	–	–	0.43	–	na	na	na
	NPI-PA3-01	Exponent 2008	–	8.1	1.49	1660	na	na	na
	NPI-PA4-01	Exponent 2008	–	6.9	2.65	1330	na	na	na
	NPI-PA6-01	Exponent 2008	–	–	1.26	–	na	na	na
	NPI-PA8-01	Exponent 2008	–	–	0.67	–	na	na	na
	NPI-PA9-01	Exponent 2008	–	–	1.10	–	na	na	na
	NPI-PA10-01	Exponent 2008	–	–	0.66	–	na	na	na
Rayonier	R05LP-06	Malcolm Pirnie 2007a	–	–	0.43	–	Pass	Pass	Pass

Key:

Exceeds SQS criteria

Exceeds CSL criteria

– = concentration below SMS criteria

Key:

Passed SMS criteria

Failed SQS criteria

Failed CSL criteria

na = not analyzed

Table 6. Surface Sediment Organic COPCs that Exceed SMS or LAET Criteria and Associated Bioassay Results

Region	Location	Study	TOC	SMS Exceedances							LAET Exceedances			Bioassay Results		
				Bis(2-ethylhexyl) phthalate	PCBs, Sum of Aroclors	PCBs, Sum of Congeners	2,4-Dimethyl phenol	2-Methyl phenol	4-Methyl phenol	Phenol	PCBs, Sum of Congeners	Butyl benzyl phthalate	Fluoranthene	Larval Development	Amphipod Mortality	Polychaete Growth
				SQS = 47 CSL = 78	SQS = 12 CSL = 65	SQS = 12 CSL = 65	SQS = 29 CSL = 29	SQS = 63 CSL = 63	SQS = 670 CSL = 670	SQS = 420 CSL = 1200	LAET = 130 2LAET = 1000	LAET = 63 2LAET = 900	LAET = 1700 2LAET = 2500			
			wt%	mg/Kg OC			µg/Kg				µg/Kg					
Lagoon	LA03A	E & E 2012	9.2	–	–	na	–	–	–	–	na	73	–	na	na	na
Western Harbor	MA01A	E & E 2012	1.1	49.6	–	na	–	–	–	–	na	–	–	Fail	Pass	Pass
	MA03A	E & E 2012	4.0	–	–	na	–	–	–	610	na	–	–	na	na	na
	MA04A	E & E 2012	8.5	–	–	na	–	–	–	740	na	670	–	na	na	na
	WP-01-SS	Malcolm Pirnie 2007b	4.7	na	na	–	na	na	na	na	372	na	na	na	na	na
	WP-02-SS	Malcolm Pirnie 2007b	10.0	na	na	–	na	na	na	na	219	na	na	na	na	na
	WP-03-SS	Malcolm Pirnie 2007b	3.7	na	na	–	na	na	na	na	173	na	na	na	na	na
	WP-04-SS	Malcolm Pirnie 2007b	5.6	na	na	–	na	na	na	na	148	na	na	na	na	na
	WP-06-SS	Malcolm Pirnie 2007b	6.0	na	na	–	na	na	na	na	240	na	na	na	na	na
	WP-11-SS	Malcolm Pirnie 2007b	6.8	na	na	–	na	na	na	na	2930	na	na	na	na	na
Rayonier	R05IT-07	Malcolm Pirnie 2007a	24.6	–	–	na	–	–	1700	–	na	–	–	na	na	na
	R05LP-03	Malcolm Pirnie 2007a	4.0	67.2	–	na	–	–	–	–	na	–	–	Pass	Pass	Pass
	R05LP-06	Malcolm Pirnie 2007a	18.5	–	–	na	54	200	1300	–	na	–	–	Pass	Pass	Pass
	R05LP-10	Malcolm Pirnie 2007a	10.0	–	–	na	–	–	–	480	na	–	–	Fail	Fail	Fail
	R05LP-13	Malcolm Pirnie 2007a	14.4	–	–	na	–	–	820	–	na	–	–	Fail	Fail	Pass
	R05LP-16	Malcolm Pirnie 2007a	16.5	–	–	na	–	–	840	–	na	–	–	Fail	Pass	Pass
	R05LP-18	Malcolm Pirnie 2007a	23.3	–	–	na	–	–	–	–	na	–	3100	Fail	Pass	Fail
	R05LP-20	Malcolm Pirnie 2007a	13.5	–	–	na	–	–	11000	–	na	–	–	Pass	Pass	Pass
	R05MD-02	Malcolm Pirnie 2007a	15.0	–	–	na	–	–	690	–	na	–	–	Pass	Pass	Pass
	R05MD-04	Malcolm Pirnie 2007a	1.1	–	17.6	na	–	–	–	–	na	–	–	Pass	Pass	Pass
	R05MD-12	Malcolm Pirnie 2007a	1.9	–	–	na	–	–	1400	–	na	–	–	Pass	Pass	Pass
	MD-14-SS	Malcolm Pirnie 2007b	1.3	na	na	16.9	na	na	na	na	–	na	na	na	na	na
	MD-18-SS	Malcolm Pirnie 2007b	4.1	na	na	–	na	na	na	na	352	na	na	na	na	na
	MD-23-SS	Malcolm Pirnie 2007b	0.8	na	na	19.7	na	na	na	na	–	na	na	na	na	na
	LP-03-SS	Malcolm Pirnie 2007b	11.9	na	na	–	na	na	na	na	152	na	na	na	na	na
	LP-04-SS	Malcolm Pirnie 2007b	8.3	na	na	–	na	na	na	na	155	na	na	na	na	na
	LP-08-SS	Malcolm Pirnie 2007b	21.2	na	na	–	na	na	na	na	200	na	na	na	na	na
	ED04A	E & E 2012	5.1	–	–	na	–	–	41000	–	na	–	–	Fail	Fail	Pass
	MD04A	E & E 2012	2.2	–	–	na	–	–	–	760	na	–	–	na	na	na

Key:
- > 3.5% TOC
- Exceeds SQS/LAET criteria
- Exceeds CSL/2LAET criteria

– = concentration below SMS criteria

na = not analyzed

Key:
- Passed SMS criteria
- Failed SQS criteria
- Failed CSL criteria

na = not analyzed

Table 7. Subsurface Sediment COPCs that Exceed SMS or LAET Criteria

Region	Location	Depth Interval (cm)	Study	TOC	SMS Exceedances											
					Cadmium	Mercury	Zinc	PCBs, Sum of Aroclors	2-Methyl-naphthalene	Acenaphthene	Dibenzo-furan	Fluorene	Naphthalene	Phenanthrene	Total LPAH	4-Methyl phenol
					SQS = 5.1 CSL = 6.7	SQS = 0.41 CSL = 0.59	SQS = 410 CSL = 960	SQS = 12 CSL = 65	SQS = 38 CSL = 64	SQS = 16 CSL = 57	SQS = 15 CSL = 58	SQS = 23 CSL = 79	SQS = 99 CSL = 170	SQS = 100 CSL = 480	SQS = 370 CSL = 780	SQS = 670 CSL = 670
				wt%	mg/Kg			mg/Kg OC								µg/Kg
Lagoon	NPI-L2-SC-01	94 -124	Exponent 2008	11.3	7.7	0.7	–	–	–	–	na	–	–	–	–	–
Western Harbor	IE05B	30 - 61	E & E 2012	11.7	–	0.86	–	–	–	–	–	–	–	–	–	–
	IE09B	91 - 122	E & E 2012	78.5	–	–	–	–	–	–	–	–	–	–	–	–
	IH02B	30 - 61	E & E 2012	23.1	12	8.9	1900	–	–	–	–	–	–	–	–	–
	IH06B	30 - 61	E & E 2012	4.9	–	0.53	–	–	–	–	–	–	–	–	–	–
	NPI-PA4-SC-01	30 - 74	Exponent 2008	28.7	na	na	2010	–	na	na	na	na	na	na	na	na
	MA02C	12 - 24	E & E 2012	3.5	–	0.5	–	–	–	–	–	–	–	–	–	–
Ferry Terminal	FT04C	36 - 48	E & E 2012	2.4	–	–	–	–	–	–	–	–	–	–	–	–
Rayonier	EC03B	6 - 12	E & E 2012	2.3	–	–	–	13.5	–	47.8	24.8	40.0	–	117.0	–	690
	EC03C	12 - 24	E & E 2012	2.8	–	–	–	14.7	107.9	176.3	97.1	147.5	226.6	348.9	925	–
	ED05B	30 - 61	E & E 2012	3.7	–	–	–	–	–	–	–	–	–	–	–	–
	R05LP-09	6 - 76	Malcolm Pirnie 2007a	34.4	–	na	–	–	na	na	na	na	na	na	na	na
	R05LP-13	9 - 45	Malcolm Pirnie 2007a	22.7	–	na	–	–	na	na	na	na	na	na	na	na
	R05LP-20	9 - 56	Malcolm Pirnie 2007a	23.9	–	na	–	–	na	na	na	na	na	na	na	na

Key:

> 3.5% TOC

Exceeds SQS/LAET criteria

Exceeds CSL/2LAET criteria

– = concentration below SMS criteria

na = not analyzed

Table 7. Subsurface Sediment COPCs that Exceed SMS or LAET Criteria

Region	Location	Depth Interval (cm)	Study	TOC	LAET Exceedances				
					PCBs, Sum of Aroclors	Butyl benzyl phthalate	Bis(2-ethylhexyl) phthalate	4,4'-DDD	4,4'-DDE
					LAET = 130 2LAET = 1000	LAET = 63 2LAET = 900	LAET = 1300 2LAET = 1900	LAET = 16 2LAET = 43	LAET = 9 2LAET = 15
				wt%	µg/Kg				
Lagoon	NPI-L2-SC-01	94 -124	Exponent 2008	11.3	–	–	–	na	na
Western Harbor	IE05B	30 - 61	E & E 2012	11.7	–	–	–	na	na
	IE09B	91 - 122	E & E 2012	78.5	–	91	–	na	na
	IH02B	30 - 61	E & E 2012	23.1	–	–	–	na	na
	IH06B	30 - 61	E & E 2012	4.9	–	–	2800	na	na
	NPI-PA4-SC-01	30 - 74	Exponent 2008	28.7	–	na	na	na	na
	MA02C	12 - 24	E & E 2012	3.5	–	–	–	na	na
Ferry Terminal	FT04C	36 - 48	E & E 2012	2.4	–	–	–	65	14
Rayonier	EC03B	6 - 12	E & E 2012	2.3	–	–	–	–	–
	EC03C	12 - 24	E & E 2012	2.8	–	–	–	–	–
	ED05B	30 - 61	E & E 2012	3.7	250	–	–	–	–
	R05LP-09	6 - 76	Malcolm Pirnie 2007a	34.4	170	na	na	na	na
	R05LP-13	9 - 45	Malcolm Pirnie 2007a	22.7	260	na	na	na	na
	R05LP-20	9 - 56	Malcolm Pirnie 2007a	23.9	380	na	na	na	na

Key:

> 3.5% TOC

Exceeds SQS/LAET criteria

Exceeds CSL/2LAET criteria

– = concentration below SMS criteria

na = not analyzed

Table 8. COPCs associated with Industries, Harbor-based Activities, and Land Use Types

	Metals	SVOCs	PCBs	Dioxin/furans	Pesticides	Resin Acids	Guaiacols	Tributyltin
Wood Product Facilities	X	X	X	X		X	X	
Creosote-treated Marine Lumber		X		X				
Marine/Shipping Services	X	X	X					X
Petroleum Storage Facilities	X	X						
Commercial Fish/Shellfish Harvesting			X	X	X			
Wastewater Treatment	X	X	X					
Residential	X	X	X					

Source: E & E 2008b

Table 9. Harbor-wide Sub-Areas

Source Region	Sub-Area	Field ID	Location	Potential Sources/Reason of Interest	Surface Sediment: SMS Metal Exceedances[1]	SMS/LAET Organic COPC Exceedances[1]	Maximum Dioxin/Furan TEQ (pg/g)[1]	Maximum Wood Debris (%)[2]	Maximum #2 Diesel Fuel (mg/kg)[2]	Larval Development SMS Failures[1]
Northern Harbor	Ediz Hook Point	EH	Eastern and southeastern point of Ediz Hook	Coast Guard underground storage tank remediation, fuel spills	none	none	na	0	36	1/1
	Fish Pen Area	FP	The marine areas around and at the commercial fish pens along Ediz Hook	Fish pens, boat docks	none	none	na	0	46	1/1
Central Harbor	Barge Area	BA	Mid-western edge of Harbor where large barges are temporary moored	Frequent barge traffic and mooring	none	none	na	10	50	1/1
Western Harbor	Inner Ediz Hook Area	IE	The remainder of Ediz Hook's southern shore	Decaying docks, creosote pilings, BP Bulk Fuel Facility, Nippon Paper Mill, current log booming areas	cadmium, mercury, zinc	none	105	95	120	6/7
	Lagoon Area	LA	The lagoon west of the western edge of the Harbor.	Former log booming area, proximity to Nippon processes	cadmium, mercury, zinc	butyl benzyl phthalate	93.2	80	110	1/1
	Inner Harbor Area	IH	The western edge of Port Angeles Harbor, north of Terminal 7	M&R Timber lumber and wood chips facility, former Fibreboard Mill, wood chips transfer area, historic ship building facility, historic log booming areas, former CSO outfalls	arsenic, cadmium, mercury, zinc	PCB congeners	119	90	320	4/5
	Port Angeles Marina	MA	Large marina directly east of the Inner Harbor Area	Boat marina, boat yard, current log booming areas	none	PCB congeners, butyl benzyl phthalate, phenol	40.9	90	54	4/4
Southern Harbor	Boat Launch & Standard Oil Area	BL	Area to the west and northeast of Terminal 3	Terminals 1 & 3 for large vessels & shipping activity, bulk fuel facility Tumwater Creek outfall	none	none	12.0	30	83	4/5
	K-Ply/Valley Creek	KP	Area between Terminal 1 and Terminal 4	K-Ply Mill, Valley Creek outfall, historic log booming areas, decaying metal dock, Terminal 4 boat dock	none	none	15.4	50	52	4/5
	Landing Pier (Ferry Terminal)	FT	Area east of Terminal 4 and area around Terminal 2 (the Ferry terminal)	Ferry Terminal, Landing Pier, vessel docking, City Walking Pier, Peabody Creek outfall, current CSOs	none	none	15.1	10	62	1/4
	Red Lion Inn	RL	Nearshore areas in front of the Red Lion Inn	This is a highly used public beach area	none	none	14.9	0	15	0/2
Outer Harbor	City of Port Angeles Wastewater Treatment Plant	WW	At the location of the City's WWTP deepwater outfall	Wastewater treatment effluent outfall	none	none	1.4	0	10	0/1
	Outer Harbor	OH	Southeast of the end of Ediz Hook (north of outfalls)	Chosen in order to initially delineate where harbor sediments become more like background sediments in the Strait	none	none	1.3	0	32	0/1
	Eastern Intertidal/Subtidal Shore	EI	Subtidal/intertidal nearshore between Ennis Creek and Morse Creek	Mouths of Lees and Morse creeks	none	none	0.5	0	na	0/2

Notes:

1. Includes results from studies listed in Table 1.
2. Includes results from E & E 2012.

Table 10. Rayonier Mill Sub-Areas

Sub-Area	Field ID	Location	Potential Sources/ Reason of Interest	Surface Sediment					
				SMS Metal Exceedances[1]	SMS/LAET Organic COPC Exceedances[1]	Maximum Dioxin/Furan TEQ (pg/g)[1]	Maximum Wood Debris (%)[2]	Maximum #2 Diesel Fuel (mg/kg)[2]	Larval Development SMS Failures[1]
Log Pond	LP	Rayonier's Log Pond	Former log storage pond	mercury	PCB Aroclors, PCB congeners, bis(2-ethylhexyl) phthalate, 2,4-dimethylphenol, fluoranthene, 2-methylphenol, 4-methylphenol, phenol	59.4	50	--	4/12
Mill Dock	MD	West and northwest of Rayonier's Mill Dock Area	Former dock for Mill operations	none	PCB Aroclors, PCB congeners, 4-methylphenol, phenol	10.7	40	200	2/5
East of Mill Dock	ED	East and Northeast of Rayonier's Mill Dock	Directly east and adjacent to Mill Dock	none	PCB Aroclors, PCB congeners, 4-methylphenol	21.5	70	110	1/4
Nearshore Outfalls	CO	Former nearshore outfall locations along Rayonier's shoreline	Former effluent outfalls for Rayonier operations	none	none	6.4	5	80	1/3
Deep Outfall	DO	Along and at the end of the Rayonier Mill Effluent Outfall pipeline	Former deepwater outfall for Rayonier operations	none	none	1.9	0	--	0/3
Ennis Creek	EC	At the mouth of Ennis Creek	Outfall of Ennis Creek, receives Rayonier stormwater runoff, site of oil leak	none	none	4.0	10	55	0/3
East of Ennis Creek	EE	Intertidal areas directly east of Ennis Creek	Adjacent to Ennis Creek and Rayonier operations	none	none	3.0	0	30	--

Notes:
1. Includes results from studies listed in Table 1.
2. Includes results from E & E 2012.
-- Not Analyzed

Table 11. Potential Primary COPC Sources to Western Harbor and Rayonier Mill Regions

Potential Source Region	Facility	Nearby Sub-Areas[1]	Began Discharge[2]	Ceased Discharge[2]	Principle Discharge To Harbor	Facility Activities	Possible COPCs
Western Harbor	Nippon Paper Induistries	Inner Ediz, Lagoon, Inner Harbor	1921	N/A	Process Wastewater (until 1960s), Stormwater, Air Emisson	Pulp and Paper Production, Hydrosulfite Bleaching, Hog Fuel Burning	metals, SVOCs, PCBs, dioxins/furans
	Merrill & Ring Timber, Inc.	Lagoon, Inner Harbor	1958	N/A	Non-contact cooling water, Stormwater, Air Emission	Lumber and Plywood Mill, Wood Treatment, Former Shipyard	metals, SVOCs, PCBs, dioxins/furans
	Port Angeles Terminal 5	Inner Harbor	2003	N/A	Stormwater	Log Yard, Wood Chip Export Facility	metals, PCBs, SVOCs
	Port Angeles Terminal 7	Inner Harbor	2002	N/A	Stormwater	Lay Berth Facility, Former Wood Chip Export Facility	metals, PCBs, SVOCs
	Fibreboard Paper Products	Inner Harbor	1917	1970	Process Wastewater, Stormwater, Air Emission	Pulp and Boxboard Mill, Bleaching, Hog Fuel Burning	metals, SVOCs, PCBs, dioxins/furans
	Boat Haven Marina and Boat Yard	Port Angeles Marina	--	N/A	Stormwater	Vessel Berthing and Maintenance	metals, PCBs, SVOCs
	City of Port Angeles	Inner Harbor, Port Angeles Marina, Landings/Pier, Red Lion	--	N/A	Stormwater, Municipal Wastewater	Residential/Industrial	metals, pesticides, SVOCs, PCBs, dioxins/furans
Rayonier Mill	Rayonier, Inc.	Log Pond, Mill Dock, East of Mill Dock	1930	1997	Process Wastewater, Stormwater, Air Emission	Pulp and Paper Production, Chlorine-based Bleaching, Hog Fuel Burning	metals, SVOCs, PCBs, dioxins/furans

Notes:

1. Sub-Areas identified in E & E 2012.

2. From E & E 2008a.

N/A = not applicable