Exxon Valdez Oil Spill
Restoration Project Final Report

Priorities, Methods, and Costs for Restoration of Lingering Subsurface Oil from the *Exxon Valdez* Oil Spill in Prince William Sound, Alaska

Restoration Project 15150121

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<u>Study History</u>: The EVOS Trustee Council (EVOSTC) has funded several studies addressing the persistent, lingering subsurface oil from the 1989 *Exxon Valdez* oil spill. These studies have included: (1) locating the remaining lingering oil, using field sampling and modeling; (2) identifying the factors that have slowed the natural removal of the oil; (3) identifying and evaluating candidate bioremediation technologies; (4) evaluating the potential for biodegradation of *Exxon Valdez* oil in laboratory columns (5) pilot testing of candidate bioremediation technologies; and (6) determining the linkage between lingering oil on the shoreline and habitat use by recovering species, namely sea otters and harlequin ducks.

The extensive experience and the in-depth findings of these projects have provided the necessary knowledge to address the current project, which is to provide guidance on sites in Prince William Sound (PWS) known or predicted to contain lingering *Exxon Valdez* oil that are candidates for restoration, and to provide recommendations for the best available technology for restoring these sites. The restoration methods for oiled shorelines have been evaluated in this report by considering only the technical feasibility and predicted disruption of each method, the estimated cost, and the achievable endpoints. There are other factors that the State and Federal trustees should take into consideration to decide which, if any, of the sites should be restored and which methods should be used. These factors include benefits to injured resources, subsistence users, recreational users, and the public in general likely to be gained by restoration, to be balanced against potential ecological costs from disturbances to wildlife and disruption of habitats during implementation. The valuation of these factors is beyond the scope of this project; however, they are critical to the final determination of where and how best to achieve restoration.

<u>Abstract</u>: This new study used the combined knowledge from previous known work on the PWS shorelines affected by the *Exxon Valdez* Oil Spill (EVOS) to identify the best candidate sites and methods for restoration of the habitat where lingering oil is most likely to be found. The study objectives were to:

- Identify the locations of moderate or heavier amounts of lingering subsurface oil,
- Determine the optimal method for restoring each site, and
- Estimate the costs to implement the selected methods.

The investigation relied on three categories of sites: Sites that have been previously surveyed (i.e., known sites); sites that are adjacent to the previously surveyed sites that were not previously surveyed due to the field study design which included survey of 100 meter lengths of shoreline (labeled adjacent model-predicted sites); and non-adjacent model-predicted sites with relatively high probability to have at least moderately oiled residue (MOR) (labeled unique model-predicted sites).

We started with an initial list of 100 sites with at least one pit with MOR or greater oiling based on actual field data or the model predictions. After screening for area of oiling, thickness of the MOR or greater oiled sediment layer, and environmental sensitivity, the list of candidate sites for restoration consisted of 63 sites: 40 known sites, 18 adjacent model-predicted sites, and 5 unique model-predicted sites. Three restoration methods were then evaluated: Monitored Natural Attenuation (MNA), Manual Technique (MT), and Bioremediation Technique (BT). The MNA relies on monitoring the sites every five years to evaluate the depletion of oil concentration with time. The MT requires excavation to remove the oil using sorbents and solidifiers, to treat the sediments prior to re-placement on the beach, and to dispose of sediments that could not be treated on site. The BT requires delivery of chemical amendments to enhance the natural biodegradation of oil, and in particular the biodegradation of the total polycyclic aromatic hydrocarbons (tPAH). In principle, MNA and MT could be applied at all sites, but the success of BT requires beaches with sufficient sediment material to ensure delivery of the amendments to the oiled areas. Special effort was placed on providing guidelines for the MT, as it has not been pilot-tested in the EVOSTC funded projects.

Cost estimates were obtained based on our prior work in PWS and after consultation with Alaskan environmental companies. The cost of MT and BT for the adjacent and unique model-predicted sites was reduced by one third for two non-exclusive reasons: 1) For both adjacent and unique model-predicted sites, there is a likelihood of smaller oil mass on these sites; and 2) For the adjacent model-predicted sites, the cost of mobilization and demobilization is expected to be smaller than estimated based on direct cost when one considers that the nearby known site would be restored. The cost of MNA at 20 sites (in addition to the 10-12 already being monitored as part of the ongoing EVOSTC-funded Gulf Watch Alaska project) was estimated at $2.347M. The cost of MT applied to all sites was estimated at $13.47M, and the cost of a combined MT and BT was estimated at $17.6M. For the latter, it was assumed that the Bioremediation Technique would be conducted for two consecutive seasons followed by MNA, although BT could also be conducted in additional years, which would increase the cost. The cost of MNA was not included directly in this cost, as it would depend on the concentration of the tPAH.

Key Words: Alaska, lingering oil, Prince William Sound, restoration, subsurface oil, treatment methods

Project Data: *Description of data* – multiple sources of data on the location, extent, and characteristics of subsurface oil in Prince William Sound, related spatial data, and the results of bioremediation pilot tests were used as part of this analysis. Publicly available data are generally cited in references. *Format* – Data are held in multiple digital formats including MS Excel spreadsheets and various Geographic Information System (GIS) data formats. *Custodian* - Zachary Nixon, Research Planning, Inc., 1121 Park Street, Columbia, SC 29201.

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ABL	Auke Bay Laboratory
ADEC	Alaska Department of Environmental Conservation
BT	bioremediation treatment
cm	centimeter
ERM	Effects Range Median
EVOS	*Exxon Valdez* oil spill
EVOSTC	EVOS Trustee Council
g	gram
GAC	granular activated carbon
GIS	Geographic Information System
HOR	heavily oiled residue
km	kilometer
LOR	lightly oiled residue
m	meter
MH	man hours
MHW	mean high water
MLLW	mean lower low water
MLW	mean low water
MNA	monitored natural attenuation
MOR	moderately oiled residue
MSL	mean sea level
MT	manual technique
NOAA	National Oceanic and Atmospheric Administration
OF	oil film
NOO	No Oil Observed
PAH	polycyclic aromatic hydrocarbons
ppm	parts per million
PPV	Positive Predictive Value
PWS	Prince William Sound
tPAH	total polycyclic aromatic hydrocarbons

1.0 INTRODUCTION AND OBJECTIVES

Exxon Valdez oil continues to persist in patches at some shoreline sites within the area affected by the spill. As long as the oil persists, particularly the subsurface oil that is only slightly to moderately weathered and still bioavailable, there may be concerns about its effects. Also, users of intertidal resources, including subsistence users, may continue to be concerned about the safety of these resources.

The *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) has funded several studies addressing the presistent lingering subsurface oil. These studies included:

1) Locating the remaining lingering oil, using modeling and field sampling;
2) Identifying the factors that have slowed natural removal of the oil;
3) Identifying and evaluating candidate bioremediation technologies;
4) Evaluating the potential for biodegradation of *Exxon Valdez* oil in laboratory columns;
5) Pilot testing of candidate bioremediation technologies; and
6) Determining the linkage between lingering oil on the shoreline and habitat use by recovering species, namely sea otters and harlequin ducks.

The projects resulted in numerous findings, and some of the salient publications are cited herein. Michel et al. (2010) and Nixon and Michel (2015) developed a series of models to generate spatial data identifying the locations of various degrees of subsurface oil and potential sizes of the patches of the subsurface oil. Other relevant publications revealing the geomorphology of the shorelines in Prince William Sound (PWS) and predictive ability of the model are reported in Hayes et al. (2010) and Nixon et al. (2013). Publications by the Boufadel group in the “Limiting Factors” project highlighted the role of hydrology and geology in subsurface oil persistence (Guo et al., 2010; Xia et al., 2010). In addition, pore-water chemistry measurements and modeling (Boufadel et al., 2010; Li and Boufadel, 2010) revealed that the pore-water nutrient concentration was an order of magnitude lower than needed for maximum oil biodegradation. The major finding in these studies was that the dissolved oxygen concentration in the groundwater measured in oiled pits was the main limiting factor for oil biodegradation; it was around 1.0 mg/L, and concentrations below 2.0 mg/L result in anoxic conditions where the biodegradation rate of oil is essentially zero. Venosa et al. (2010) showed that more than 80% of the total polycyclic aromatic hydrocarbons (tPAHs) biodegrade within six months when exposed to an environment rich with dissolved oxygen and nutrients. Evaluation of the bioremediation technology was conducted in preliminary works in Boufadel and Bobo (2011) and Boufadel et al. (2011), and Boufadel (2014) reported results of the pilot bioremediation studies on four sites.

This new study used the combined knowledge from previous known work along the PWS shoreline to identify the best candidate sites and methods for restoration of the sites where lingering subsurface oil is most likely to be found. Therefore, the study objectives were to:

- Identify the locations of moderate or heavier amounts of lingering subsurface oil as candidates for consideration for restoration;
- Determine the optimal techniques for restoring these candidate sites; and
- Estimate the costs to implement the selected methods.

The restoration methods for oiled shorelines have been evaluated in this report by considering only the technical feasibility and predicted disruption of each method, the estimated cost, and the achievable endpoints. Addressing the technical feasibility, the cost, and the endpoint of methods are necessary steps to identify potential candidate sites for restoration. However, there are other factors that the EVOSTC will need to consider to reach its final decision on which sites and which methods should be used to restore those sites. These factors include benefits to injured resources, subsistence users, recreational users, and the public in general likely to be gained by restoration, to be balanced against ecological costs from disturbances to wildlife and disruption of habitats during implementation. Any active restoration of subsurface oil requires excavation of intertidal sediments, which will cause physical impacts as well as potentially release oil into nearshore waters. The valuation of these factors is beyond the scope of this project; however, they are critical to the final determination of where and how to achieve restoration.

2.0 PROCEDURAL AND SCIENTIFIC METHODS

The work was conducted in two tasks.

2.1 Task 1. Identify the most promising sites in PWS for restoration of the lingering oil.

Throughout this report, we refer to two categories of sites: 1) **Known** sites, meaning lengths of shoreline where the estimated extent and degree of subsurface oil are based on actual field surveys that included the depth and degree of subsurface oil as described in pits that were randomly located within specific shoreline segments; and 2) **Model-predicted** sites, meaning those lengths of shoreline where the estimated extent and degree of subsurface oil are based on models developed by Michel et al. (2010) and Nixon and Michel (2015) and had a high probability of oiling of MOR or greater; therefore, there are no recent data to confirm the presence of subsurface oil at these locations. There are two types of high-probability, model-predicted sites: 1) Those that are **adjacent** to known sites with MOR or greater and have similar geomorphology, thus likely to have similar oiling conditions; and 2) Those that are **unique** sites (greater than 100 meters away from known sites).

Task 1 was completed with the following steps:

1. We used all available data to generate an initial list of the known and high-probability modeled sites of subsurface oil, focusing on the sites with moderate oil residue (MOR) and/or heavy oil residue (HOR).
2. We then reviewed all of the available data for each site, including field data and Shore Zone imagery[1], to determine the likely presence or absence of subsurface oil. This analysis included review of the key geomorphic and hydrologic factors to evaluate each site in terms of the likelihood of oil presence in treatable amounts. We developed screening criteria for both the known and model-predicted sites.

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[1] Shore Zone mapping includes aerial video of the shoreline taken during some of the lowest tides of the year. Thus, it provides the best information on which to remotely visualize the candidate sites. Available at: https://alaskafisheries.noaa.gov/shorezone/

3. For the candidate sites that met our screening criteria, we then determined potential restoration areas and volumes of sediments to be treated. The result of this task was a list of sites, their characteristics, a summary of what is known in terms of actual oil locations, oiling history, and other pertinent data.

In Step 1, the available data that were used to generate the initial list of 100 known and high-probability model-predicted sites included the following sources:

1. Field survey data collected in 2001 and 2003 by personnel from the NOAA Auke Bay; Laboratory (ABL) as described in Short et al. (2004);
2. Field survey data collected in 2007 and 2008 as described in Michel et al. (2010);
3. Field survey data collected in 2012 as described in Appendix B of Boufadel (2014);
4. Field data collected during the bioremediation pilot tests in Boufadel (2014);
5. Field survey based descriptions of surface and subsurface oil at 39 sites surveyed in 2002 by Taylor and Reimer (2008); and
6. Model results from the work of Nixon and Michel (2015).

The field survey data from the first two sources resulted after shoreline segments were examined for surface and subsurface oil using a stratified-random method for both site selection and sampling within a site. Briefly, shoreline segments at sampling sites were partitioned into 12.5 meter (m) along-shore lengths (columns), which were then subdivided into three contiguous rectangles (blocks) bounded by tidal elevation beginning at +0.8 m above mean lower low tide and extending to +3.8 m (Figure 1).

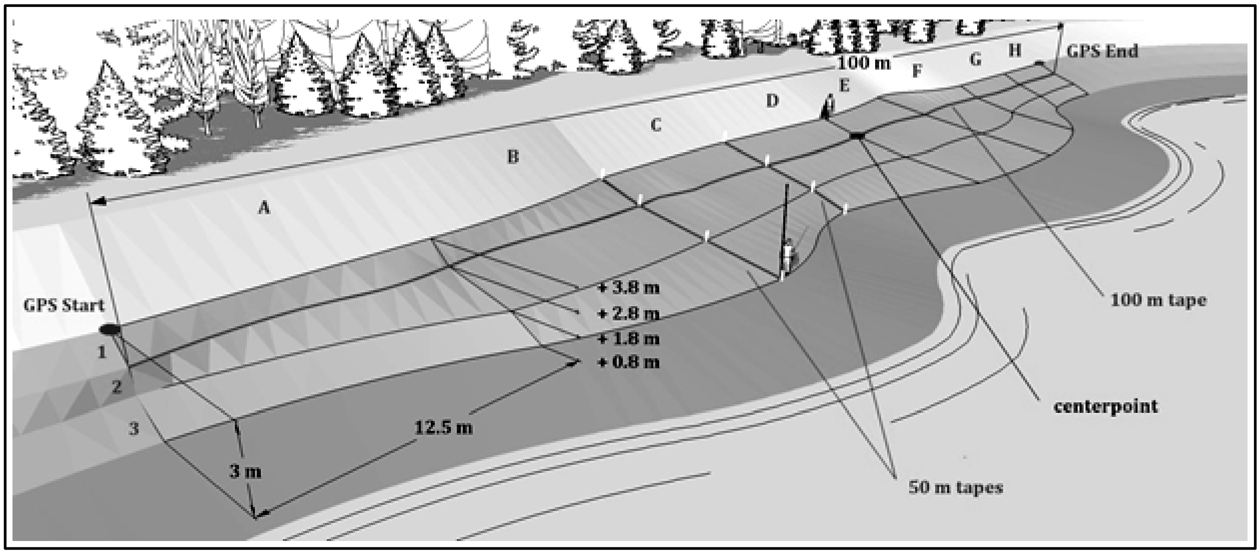


Figure 1. Schematic diagram of 8-column (A-H), 3-row (1-3) sampling grid layout from 2007 showing 3-dimensional blocks at varying tidal elevations. Two 0.25 m^2 pits were excavated to 0.5 m, where possible, in each block. Earlier sampling efforts used slightly different column and block arrangements.

Within each block, two 0.25 m^2 quadrats were randomly located, and pits were excavated to a depth of 0.5 m if possible and examined for the presence of subsurface oil. All observed oil was categorized and described using standardized Shoreline Cleanup Assessment Technique (SCAT) descriptors (Table 1) compatible with those used previously in PWS and described by Gibeaut and Piper (1995). A sketch was made of each segment showing the shoreline geomorphology relative to the distribution of surface and subsurface oil, if present. Samples were taken at selected sites for chemical characterization. This compiled database of field data contained data describing 12,361 subsurface pits excavated across 273 shoreline segments in PWS between 2001 and 2008. Of these, 460 pits (3.7%) had subsurface oil present. Taylor and Reimer (2008) surveyed 39 sites in PWS in 2002. Their paper provides a list of segments with surface oil, summarized data on subsurface oil, and detailed descriptions of the oiling conditions for several segments.

Table 1. Subsurface oil categorical descriptors used in SCAT data.

Category	**Description**
Oil Film (OF)	Continuous layer of sheen or film on sediments
Light Oil Residue (LOR)	Sediments lightly coated with oil residue; pore spaces not filled with oil or oil residue
Medium Oil Residue (MOR)	Heavily coated sediments; pore spaces not filled with oil or oil residue
Heavy Oil Residue (HOR)	Pore spaces partially (or completely) filled with oil or oil residue; oil may or may not flow from pore spaces

In 2012 field data were collected at two types of beaches (Boufadel, 2014): 1) Beaches that were known to be contaminated based on the results of previous surveys; and 2) Beaches that had not been previously surveyed but where contamination was expected based on geomorphological modeling by Nixon et al. (2013). For the segments identified by the geospatial model, aerial photos of the relevant beaches in which the most likely locations for oil contamination were circled in red ink. At each site, pits were excavated in areas where subsurface oil was thought to be most likely, based on the oiling in similar geomorphic settings. Pits were excavated systematically, usually in transects oriented approximately perpendicular and/or parallel to the shoreline. If oil was observed in one or more of the initial pits, subsequent pits were dug surrounding the contaminated pits in an attempt to determine the areal extent of the oil patches. If no oil was found, new pit locations were identified by extending the systematic approach, often by adding new transects parallel to the original transects. The detailed information on subsurface oil distribution obtained during these studies was used to delineate potential areas for additional treatment.

The list of candidate sites included the four locations where Boufadel (2014) conducted pilot-scale studies during 2011 and 2012 to determine whether bioremediation technologies could be used to increase the rate of degradation of subsurface oil at these sites: EL056C on Eleanor Island; LA015E on Latouche Island; PWS3A44 on Perry Island; and SM006B on Smith Island. The subsurface oiling condition at the termination of the tests was used to determine the need for further treatment.

In addition to the field data described above, we used the predictive modeling results of Michel et al. (2010) and Nixon and Michel (2015) to identify additional candidate sites. We used field data from sources 1 and 2 above (i.e., field survey data collected in 2001 and 2003 by personnel from the NOAA Auke Bay Laboratory as described in Short et al. (2004), and field survey data collected in 2007 and 2008 as described in Michel et al. (2010), along with other geological and hydrological factors, to develop a geospatial model that predicted the likelihood of the presence of subsurface oil at all shoreline segments in PWS. The model results from Michel et al. (2010) generated a suite of models that predict the presence or absence of subsurface oil with specific characteristics, including relative oiling intensity and across-shore areal coverage, across all shoreline locations in PWS. Each model outputs a score that ranks all shoreline locations from least to most likely to have oiling that meets the model-specific characteristics (e.g., MOR or greater). We divided the continuous scores output by the model-specific cutoff value into positives (potential sites) and negatives (not potential sites) at the 90% Positive Predictive Value (PPV). The PPV is defined as the proportion of known oiled sites that are correctly predicted as being oiled, or as true positives. The 90% PPV represents the model score cutoff above which 90% of sites known to be oiled with model-specific characteristics are correctly predicted to be oiled with those model-specific characteristics. Note that this cutoff is different from the cutoff that yields the maximum overall accuracy. This is because cutoffs can be defined differently depending upon the application and the relative cost of false positives and negatives. Finally, we defined a model-predicted site as an aggregation of shoreline locations with output from the selected model above the cutoff that are adjacent by less than 50 m (Figure 2). The choice of this distance to aggregate alongshore locations is based upon the logistics of moving and working along the shorelines of PWS. Figure 2 depicts the process of selecting specific shoreline locations meeting the criteria from model output and aggregating these locations into discrete sites. These model-predicted sites were further divided into those that were coincident with or adjacent to previous field-investigated sites by less than 100 m and those that were more than 100 m from any field site (hereafter referred to as "adjacent" and "unique" model predicted sites, respectively). A subset of the unique model-predicted sites were subsequently investigated in the field by Boufadel (2014).

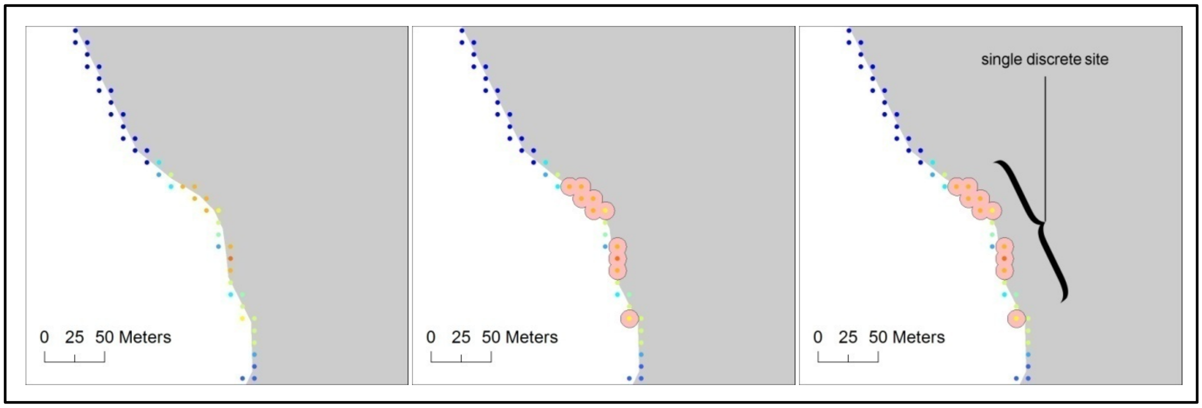


Figure 2. Schematic depicting aggregation of model output into discrete sites. Shoreline locations with model output (left) meeting given criteria are selected – e.g., 90% PPV - (center) and, if contiguous by less than 50 m, considered a discrete site (right). This example might be defined as between 1 and 3 distinct sites depending upon contiguity distance.

Segments with only light oil residues (LOR) or oil film (OF), as defined in Table 1, were not considered for further treatment because LOR and lighter subsurface oiling contained relatively low levels of tPAH (total PAH) and the oil was characterized as highly weathered. The tPAHs are considered to be the cause of most of the chronic toxicity of oil (Di Toro and McGrath, 2000; Di Toro et al., 2000, 2007). Short et al. (2004) reported that LOR samples collected in 2001 contained about half the total oil mass as MOR samples, which contained about half the amount as HOR samples. Two LOR samples from 2007 contained 0.26 and 0.59 micrograms per kilogram, or parts per million (ppm), with the oil characterized as heavily weathered. In contrast, two MOR samples from 2007 contained 34.5 and 41.8 ppm tPAH, with the oil characterized as moderately weathered; and five HOR samples from 2007 contained 15.4 to 250 ppm tPAH, with the oil characterized as slightly to moderately weathered (Michel et al., 2010). Note that these data represent oiling conditions 9-14 years ago. The potential for physical fouling was another consideration for selecting sites with MOR and higher oiling conditions for further analysis. When describing the sediment oiling conditions in excavated pits, LOR was used when the oil formed sheens and films on the water table in the pit, whereas MOR was used when free oil droplets formed. Thus, the risk of physical fouling of furs and feathers during foraging increases with oiling degree.

After careful review of all these data sources, we generated a list of 100 candidate sites for further analysis. The screening criteria for selection of these candidate sites were:

- Any previously field-surveyed site with at least one pit with MOR or higher subsurface oiling conditions, and
- Any adjacent or unique model-predicted site defined by the 90% PPV value as described above.

For each known or model-predicted site, we computed the estimated total intertidal area, and the areal extent of subsurface oiling at least MOR or greater. For known sites, we estimated the site area empirically via the alongshore length of the field site and the average measured intertidal site slope, assuming a 3-m vertical interval. We then estimated the area of subsurface oiling extent by multiplying the site area by the proportion of all excavated pits where MOR or greater was observed. For model-predicted sites where no field data were ever collected, we estimated the site area via the total alongshore length of all shoreline comprising each site, and the average measured intertidal site slope of the nearest field surveyed site, also assuming a 3-m vertical interval. For modeled sites, we estimated the area of subsurface oiling extent by multiplying the site area by the average modeled MOR or greater pit-wise encounter probability.

At the end of Step 1, there were 54 known sites, 23 adjacent model-predicted sites, and 23 unique model-predicted sites, for a total of 100 sites. Maps of these sites are presented in Figures 3 through 13.

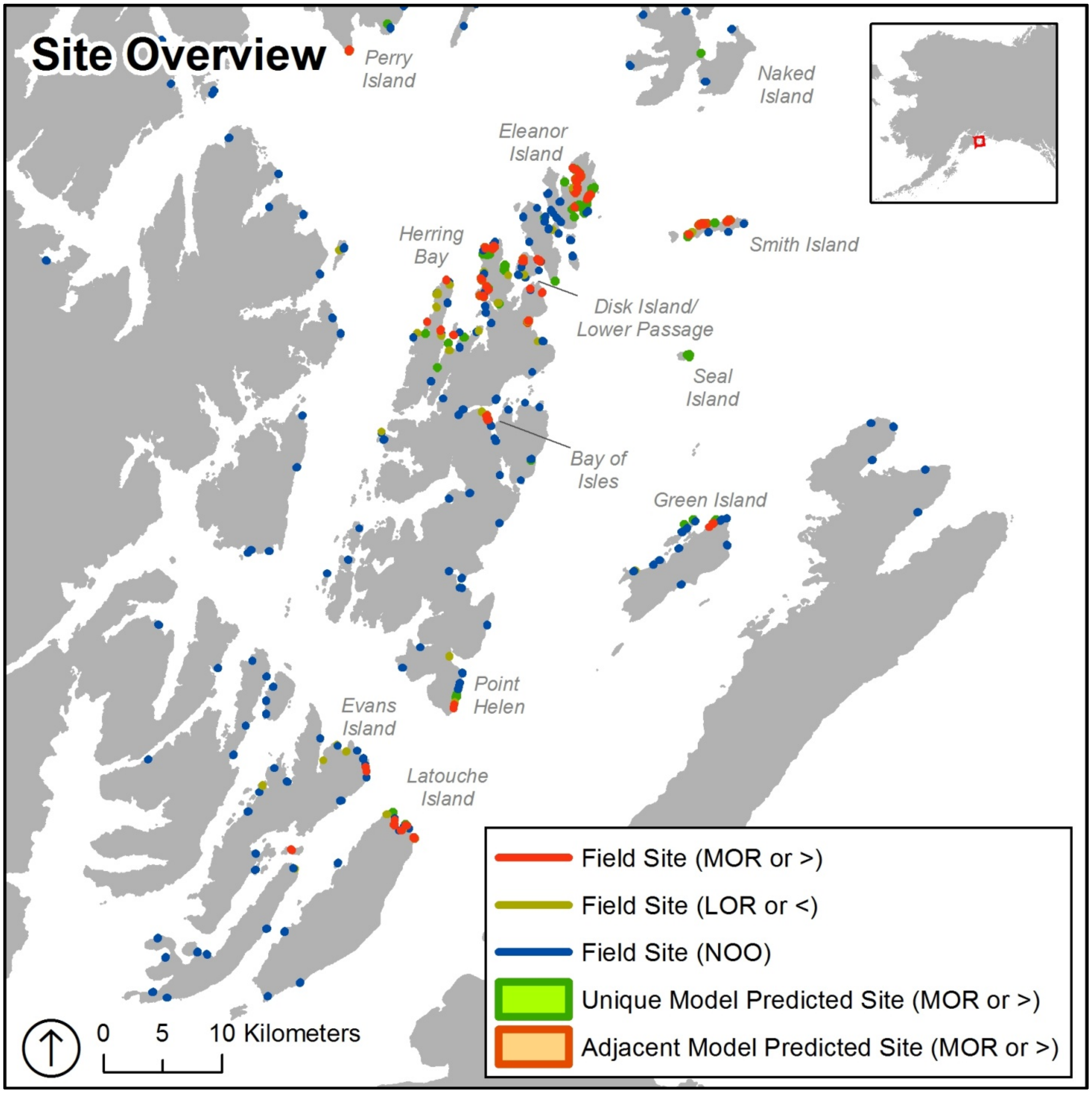


Figure 3. Overview of all known and model-predicted sites evaluated herein as candidates for potential treatment. Only field sites with MOR or greater, or modeled sites predicted to have MOR or greater (either unique or adjacent to field sites) were included in the list of candidate sites.

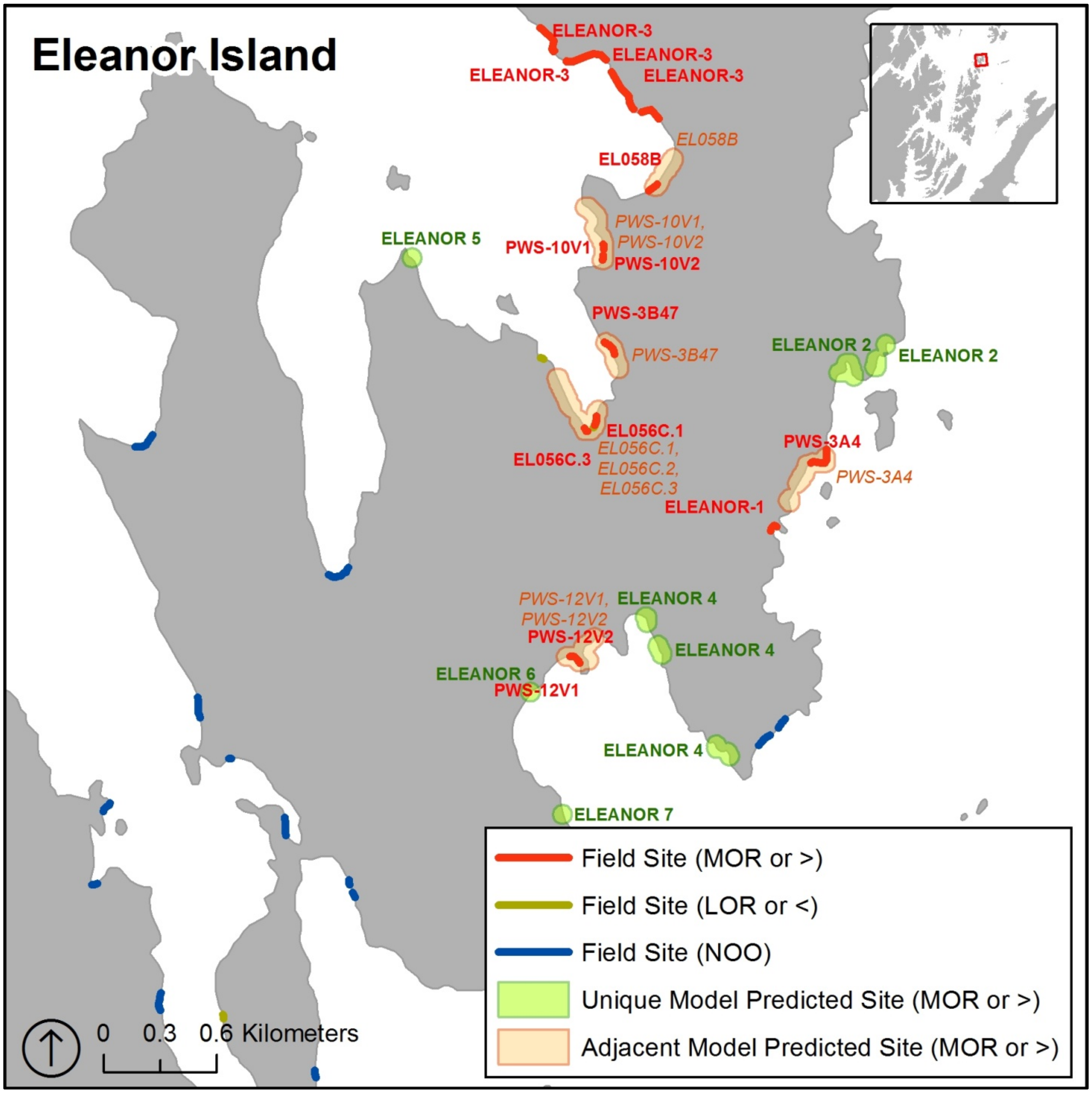


Figure 4. Detailed map of Eleanor Island for known and model-predicted sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

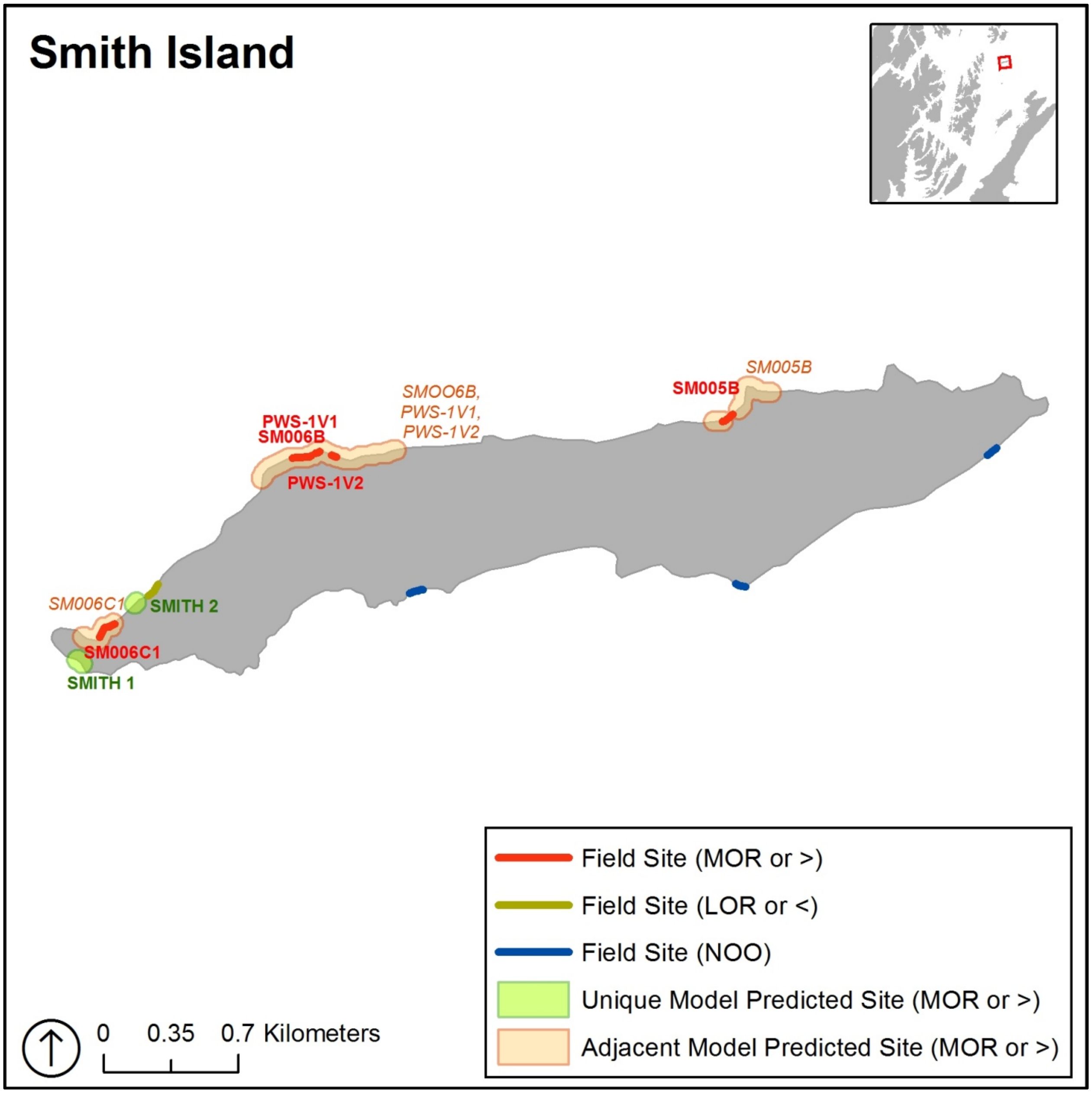


Figure 5. Detailed map for Smith Island for known and model-indicated sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

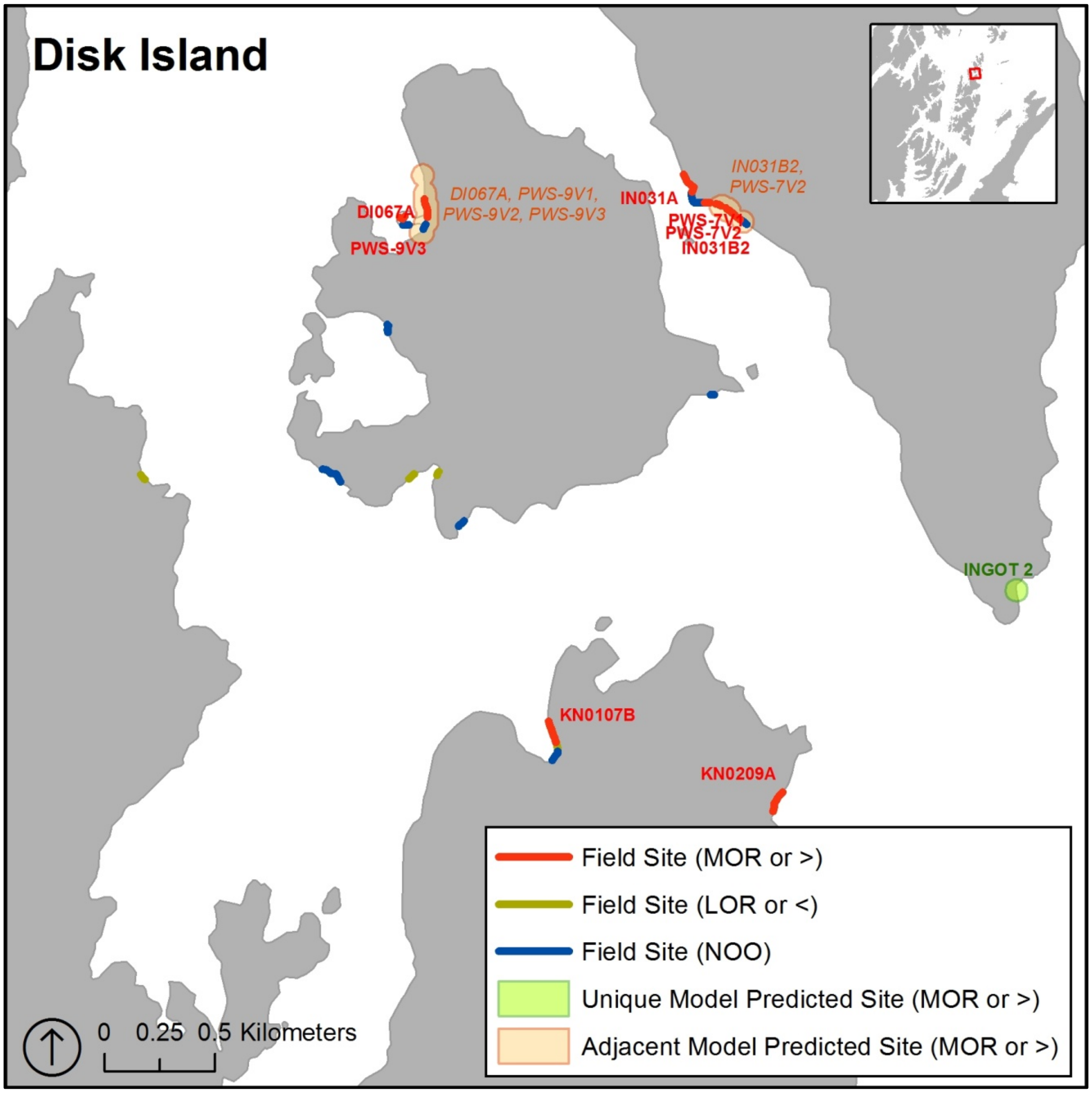


Figure 6. Detailed map for Disk Island and Upper Passage for known and model-indicated sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

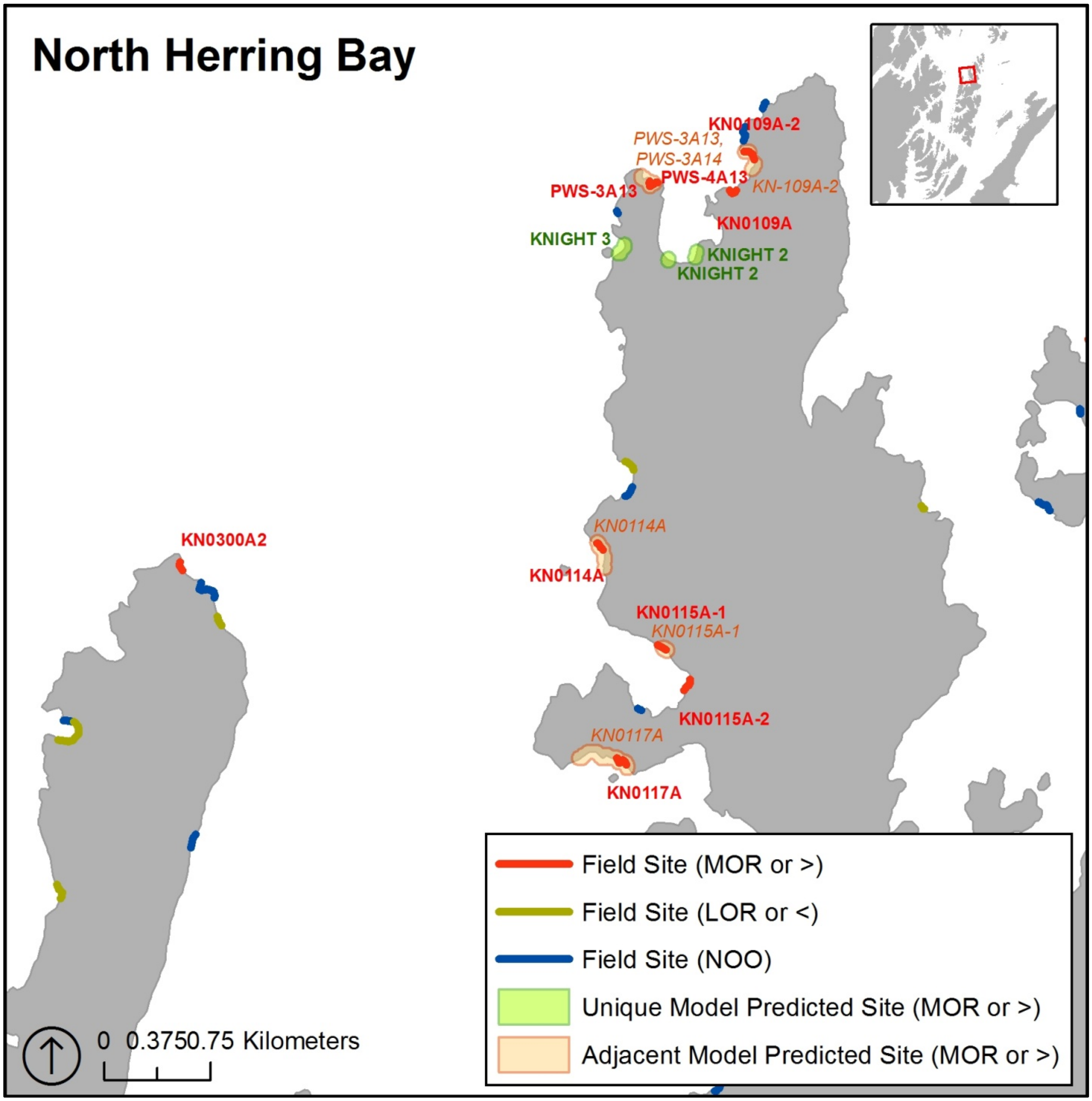


Figure 7. Detailed map for northern Herring Bay for known and model-indicated sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

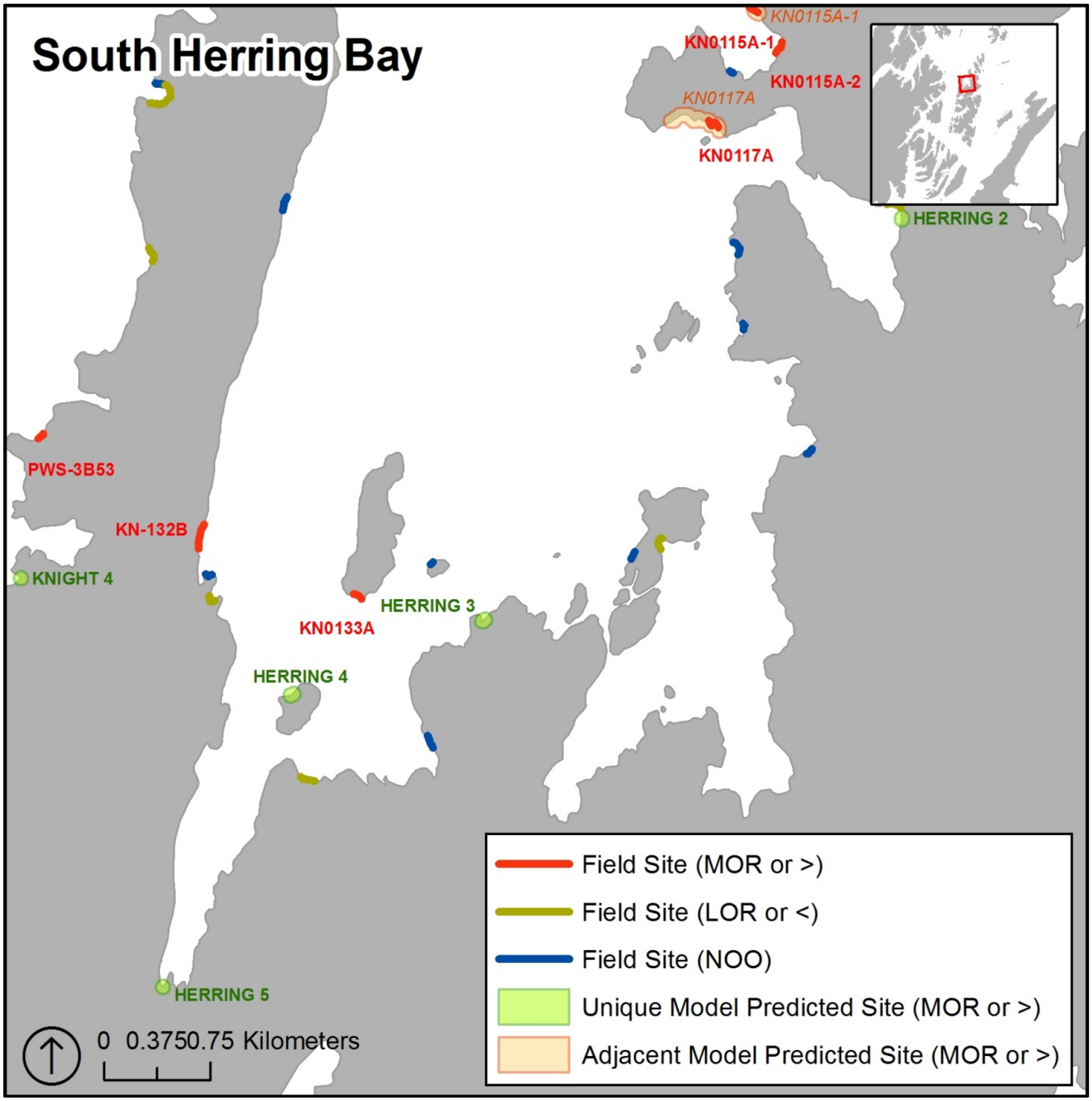


Figure 8. Detailed map for southern Herring Bay for known and model-indicated sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

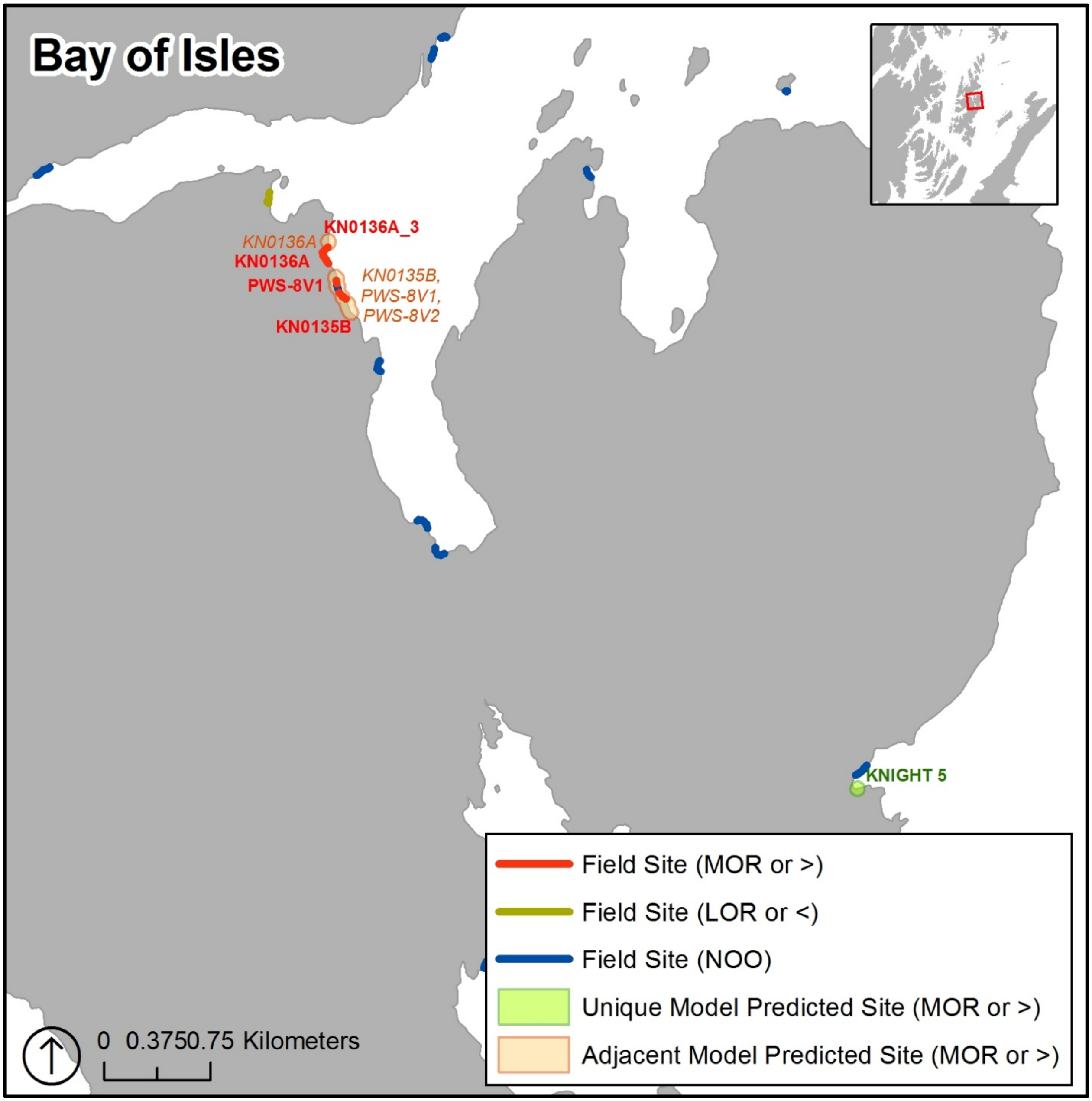


Figure 9. Detailed map for Bay of Isles for known and model-indicated sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

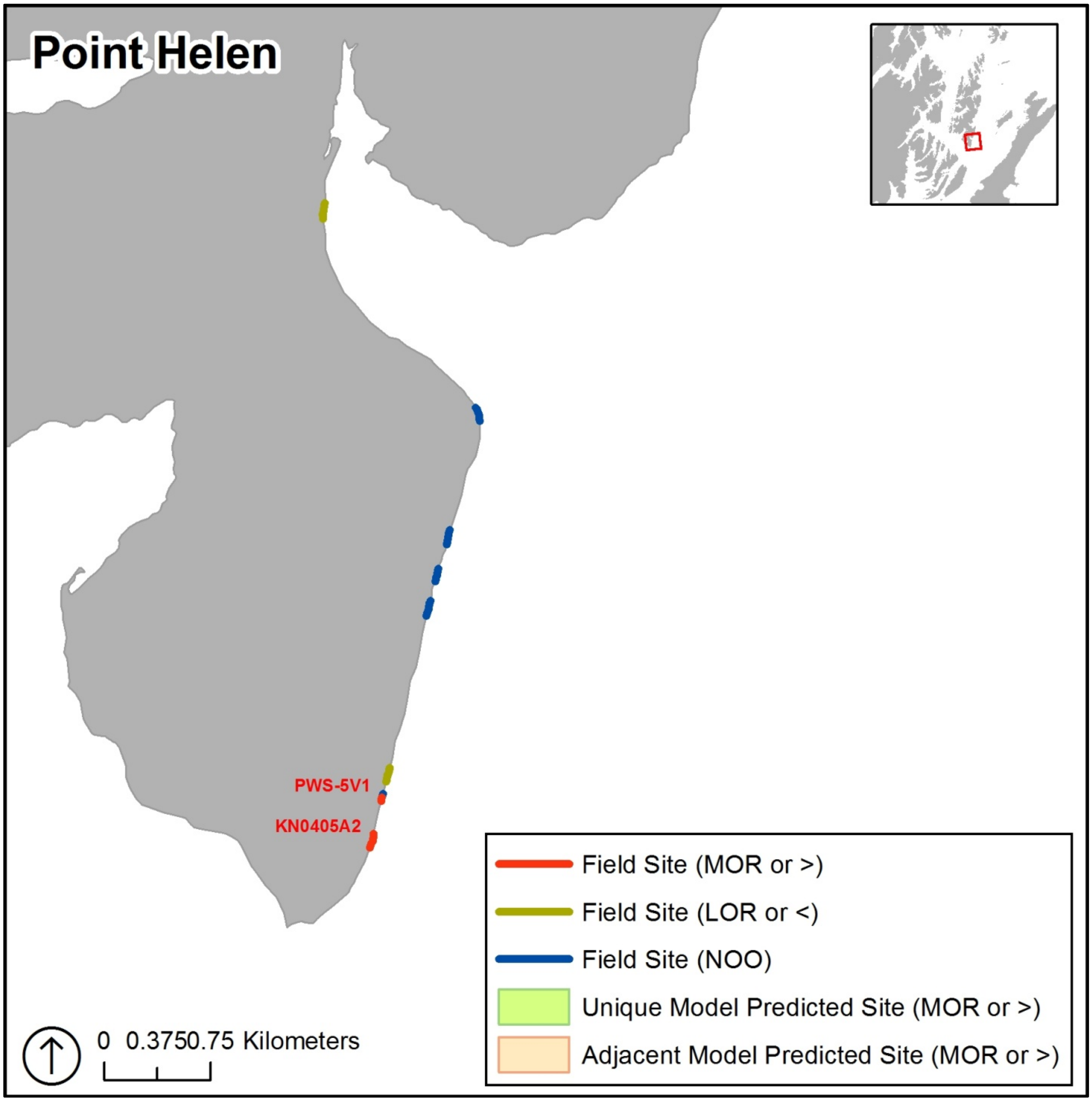


Figure 10. Detailed map for Point Helen for known and model-indicated sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

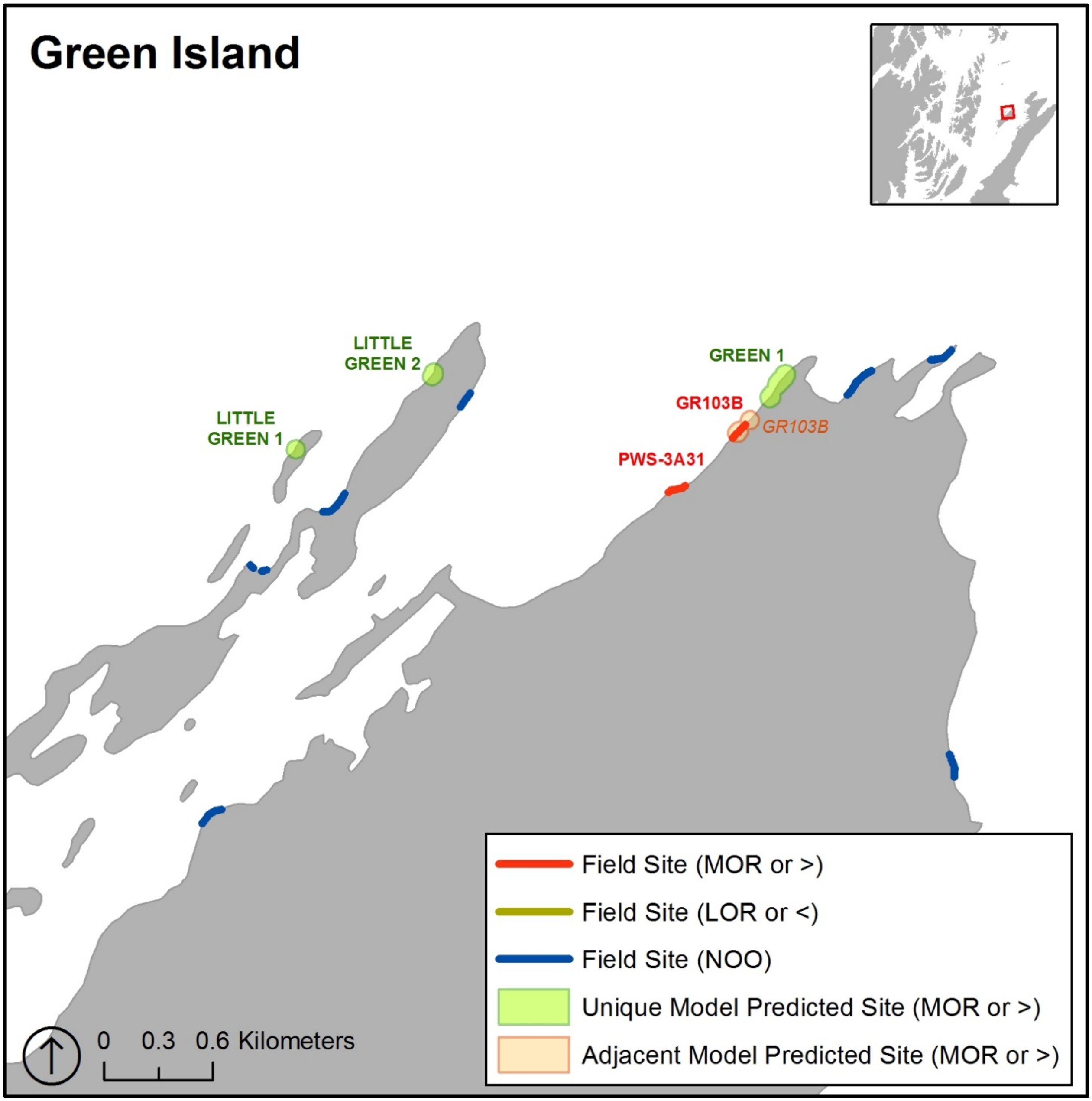


Figure 11. Detailed map for Green Island for known and model-indicated sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

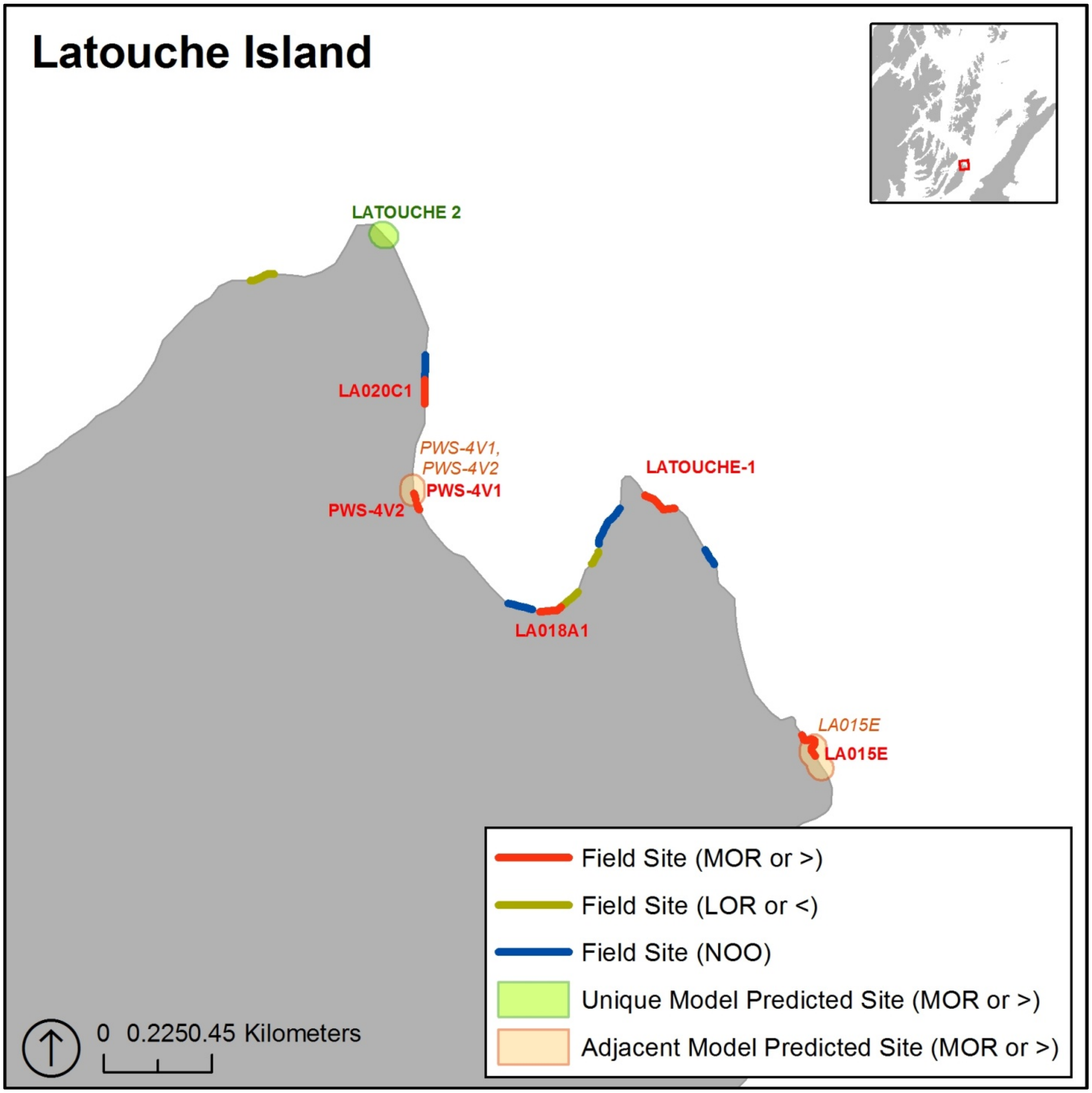


Figure 12. Detailed map for northern Latouche Island for known and model-indicated sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

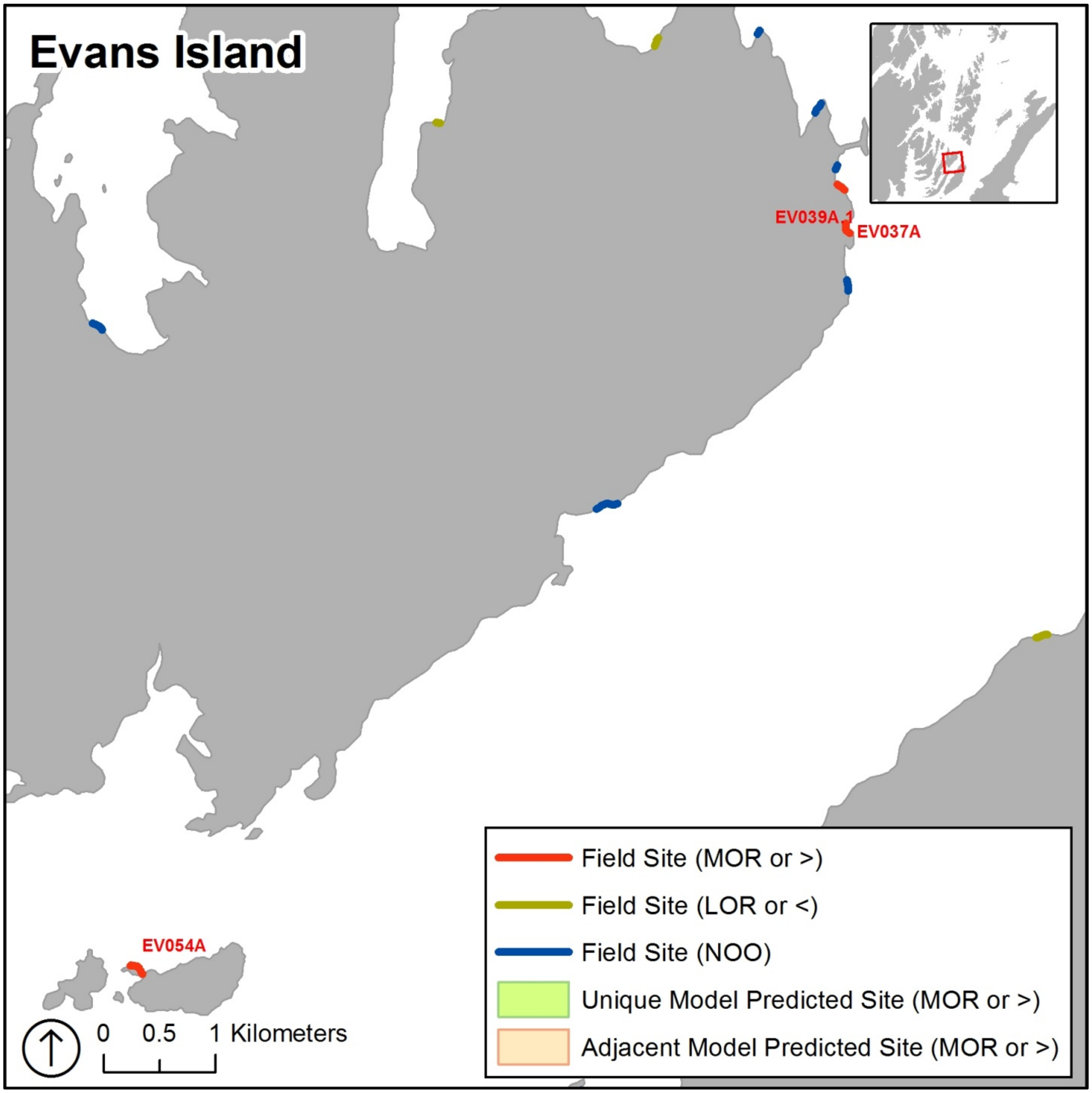


Figure 13. Detailed map for Evans Island for known and model-indicated sites evaluated herein as candidates for potential treatment. Field sites with MOR or greater labeled in red, and unique and adjacent model-predicted sites labeled in green and orange.

For Step 2, we reviewed all of the available information about each of these candidate sites, using the following screening criteria to remove sites from further consideration:

- For the *known* sites with only one MOR pit in the site:
  - With an oil thickness of 5 cm or less, because the volume of oil present was not likely to be enough to warrant disturbances during removal actions. Five sites fell within this category: PWS-7V1, PWS-7V2, PWS-12V2, KN0133A, and EV039A.1.
  - In an area composed of steep, rocky rubble or very large boulders, because the volume of oil present was not likely to be enough to warrant disturbances during removal actions, which would require extensive movement of the large rocky rubble to access small patches of oil underneath. Two sites fell within this category: KN0115A-1 and PWS-11V2.
  - With an oil thickness greater than 5 cm, where additional pit data that indicated that it was an isolated occurrence and available data indicated tPAH concentrations were below 44 ppm, which is the Effects Range Median (ERM = 44.8 ppm). The ERM is the 50th percentile of PAH concentrations in sediment found in the scientific literature to cause adverse ecological effects (Long et al., 1995). One site fell within this category, with a tPAH of 30 ppm in a sample collected in 2007: PWS-3A31.
  - With an oil thickness greater than 5 cm, but where the oiled sediments included a shallow peat layer, because the volume of oil present was not likely to be enough to warrant disturbances to the shallow peat during removal actions. One site fell within this category: PWS-3B53.
  - Where the pit with MOR was in the upper intertidal zone or under very large boulders and isolated from any other oiled pits that had LOR or oil film (OF). Three sites fell within this category: EV054A, KN0107B, and KN0209A.

- The two known sites located on Point Helen, which is difficult to access because of its exposed setting and where the surface sediments consist of very large boulders, making it likely not readily bio-available. The pits with MOR were widely scattered, indicating that the patches were likely small.

- For the 23 *adjacent model-predicted* sites:
  - The site is adjacent to known sites that were removed from further consideration. One site fell into this category: That adjacent to PWS-11V2.
  - The adjacent site did not have in general the same geomorphic characteristics of the field-surveyed site, as determined from Shore Zone imagery. Most often, this was because the adjacent site did not have nearshore breakwaters or tombolos. Four sites fell into this category: Those adjacent to PWS-3A4, PWS-3A44, PWS-10V1, PWS-10V1, and EL058B.

- For the 23 *unique model-predicted* sites (not adjacent to known oiled sites):
  - Sites were removed where the modeled (estimated) area of MOR (or greater) oiled sediments was equal to or less than 20 m^2. This area was selected as a threshold based on review of the distribution of the estimated areas of MOR or

greater for these sites (13 of the 23 had less than 10 m^2; four had between 11 and 20 m^2; and five had 39 to 415 m^2). Thus, only five of the unique model-predicted sites met this threshold and were included. Also, most of the known candidate sites that were retained had more than 20 m^2 of estimated MOR or greater.

- The site is in a highly sensitive area where removal actions would likely disturb sensitive resources; this guideline was applied only to Seal Island, which was one of the model-predicted sites. Seal Island has a large marine mammal haulout and is an important bird nesting area. Further consideration of potential disturbances to sensitive resources should be considered as part of any analysis to select sites and methods for restoration.

At the end of Step 2, there were 63 candidate sites on the final three lists:

1. Forty sites with known field-surveyed oiling conditions that meet the screening criteria described above (Table 2). Note that the site Eleanor 3 is divided into four individual sites designated as Eleanor 3A, 3B, 3C, and 3D in Table 2.
2. Eighteen sites that are adjacent to known field-surveyed sites with similar oiling conditions (Table 3).
3. Five unique sites with model-predicted oiling conditions that meet the thresholds described above (Table 4).

In Step 3, we used these lists to determine potential restoration areas and volumes of sediments to be treated, as follows. For the known sites, the volume of sediments was estimated by multiplying the areal coverage by the oil thickness, both obtained from Michel et al. (2010). For the adjacent model-predicted sites, the thickness of the oil patch was assumed equal to the closest adjacent known site, provided the two sites have similar geomorphology. For the unique model-predicted sites, the thickness was taken as 15 cm, the average value of thickness, reported in Michel et al. (2010).

The result of Task 1 was a final list of sites, their characteristics, and estimated area and volume of sediment for restoration as reported in Tables 2-4.

Table 2. Known sites that are candidates for restoration and the results of the screening analysis.

No.	Location	Name/ Landowner[1]	Area (m^2)	Volume (m^3)	Recommended Technique	Geomorphology	Comments
1	Disk Is.	D1067A	25	0.2	BIO	Gravel flat	Per Table 4 of Boufadel (2014).
2	Disk Is.	PWS-9V3	2	0.1	Manual	Rocky rubble on flat	Area is too small for BIO.
3	Eleanor Is.	Eleanor 1B	5	0.6	Manual	Pocket gravel beach	BIO not feasible per Table 4 of Boufadel (2014).
4	Eleanor Is.	Eleanor 3A	17	2.5	Manual	Rubble/transition	BIO too difficult per Table 4 in Boufadel (2014) and the patches are widely spaced.
5	Eleanor Is.	Eleanor 3B	56	8.4	Manual	Rubble/transition	BIO not feasible per Table 4 of Boufadel (2014).
6	Eleanor Is.	Eleanor 3C	9	1.4	Manual	Rubble/transition	BIO not feasible per Table 4 of Boufadel (2014).
7	Eleanor Is.	Eleanor 3D	1	0.4	Manual	Rocky rubble	BIO not feasible per Table 4 of Boufadel (2014).
8	Eleanor Is.	EL058B	22	1.5	Manual	Gravel beach/rock outcrops	Site investigated in Bobo et al. (2012). Oil entrapped within boulders with little sediments in between. Bioremediation is not recommended.
9	Eleanor Is.	EL056C.3	2	0.2	Manual	Gravel beach	Area too small for BIO.
10	Eleanor Is.	EL056C.1	16.5	1.9	Manual	Gravel beach	Oil is located between boulders and the patches are widely spaced.
11	Eleanor Is.	PWS-10V1	2	0.4	Manual	Gravel beach/ rock outcrops	Area too small for BIO.
12	Eleanor Is.	PWS-10V2	15	1.7	Manual	Gravel beach/rock outcrops	The area is large based on the rectangle, but the terrain is very steep as it is exposed to moderate wave energy. Experience with EL058 during the Lingering Oil study suggests that bioremediation would not be promising.
13	Eleanor Is.	PWS-12V1	8	0.8	Manual	Gravel beach/ rock outcrops	Area is too small for BIO.
14	Eleanor Is.	PWS-3B47	100	3.4	BIO	Gravel beach/rock outcrops	Per Table 4 of Boufadel (2014).

Table 2. *Continued.*

No.	Location	Name/ Landowner[1]	Area (m^2)	Volume (m^3)	Recommended Technique	Geomorphology	Comments
15	Eleanor Is.	PWS-3A4	14	2.0	Manual	Gravel tombolo	Patches are isolated and among boulders.
16	Evans Is.	EV037A/CC	7.5	0.4	Manual	Gravel beach	Area too small for BIO. One area surrounded by clean pits suggesting the oil patch is not much larger than estimated.
17	Green Is.	GR103B	10	0.8	Manual	Gravel beach	Large boulders and many impermeable pits.
18	Ingot Is.	IN031B2	2	0.1	Manual	Angular gravel to rocky rubble	Area too small for BIO.
19	Ingot Is.	IN031A	1	0.01	Manual	Gravel beach/flat	Area too small for BIO.
20	Knight Is., Bay of Isles	KN0135B	1	0.1	Manual	Gravel beach	Area is too small for BIO.
21	Knight Is., Bay of Isles	KN0136A	28		Manual	Gravel flat/marsh	Oil patches are widely spread and surface oil is still present.
22	Knight Is., Bay of Isles	KN0136A_3	11	0.4	Manual	Gravel beach	Patches are very isolated.
23	Knight Is., Bay of Isles	PWS-8V1	1	0.15	Manual	Angular gravel beach	Area is too small for BIO.
24	Knight Is., Herring Bay	KN0300A2	1	0.03	Manual	Gravel beach at bedrock edge	Area too small for BIO.
25	Knight Is., Herring Bay	KN0109A	25	3.3	BIO	Gravel beach	BIO is feasible per Table 4 of Boufadel (2014).
26	Knight Is., Herring Bay	KN0109A-2	14	0.5	BIO	Gravel beach	BIO is feasible per Table 4 of Boufadel (2014).
27	Knight Is., Herring Bay	KN0114A	4	0.6	Manual	Gravel beach	Area too small and BIO not feasible per Table 4 of Boufadel (2014).
28	Knight Is., Herring Bay	KN0115A-2	3	1.15	Manual	Gravel beach	Area too small and BIO not feasible because of large boulders.
29	Knight Is., Herring Bay	KN0117A	139	20.4	Manual	Rocky rubble, small	BIO not feasible per Table 4 of Boufadel (2014).
30	Knight Is., North of Herring Bay	PWS-4A13	2	0.8	Manual	Pocket gravel beach	Area too small for BIO. Very steep. Oil on edge of beach before it becomes made of boulders in the Lower Intertidal zone.

Table 2. *Continued.*

No.	Location	Name/ Landowner^1	Area (m^2)	Volume (m^3)	Recommended Technique	Geomorphology	Comments
31	Knight Is., North of Herring Bay	PWS-3A13	3	0.43	Manual	Pocket gravel beach	Area too small for BIO. Oil patches are between boulders.
32	Latouche Is. Sleepy Bay	PWS-4V2/CC	1	0.1	Manual	Gravel beach	Area too small for BIO.
33	Latouche Is. Sleepy Bay	PWS-4V1/CC	1	0.15	Manual	Gravel beach	Area too small for BIO.
34	Latouche Is. Sleepy Bay	LA020C1/CC	1	0.05	Manual	Gravel beach	Area too small and patchy for BIO.
35	Latouche Is. Sleepy Bay	LA018A1/CC	23	2.7	BIO	Gravel beach	There is one patch of area of 20 m^2. Terrain appears conducive for subsurface flow.
36	Smith Is.	SM006C1	25	4.85	Manual	Gravel beach	BIO not encouraged as per Table 4, Boufadel (2014). Beach morphology (Boufadel et al., 2011) is not conducive to bioremediating a large area.
37	Smith Is.	SM006B	36.7	6.8	Manual	Gravel beach	BIO not encouraged as per Table 4, Boufadel (2014). Beach morphology (Xia et al., 2011) is not conducive to bioremediating a large area.
38	Smith Is.	SM005B	25	0.65	Manual	Gravel beach	BIO not feasible per Table 4, Boufadel (2014). Beach oiling evaluated in Boufadel (2014).
39	Smith Is.	PWS-1V1	1	0.3	Manual	Gravel beach	Area too small and BIO not feasible because of large boulders and thin sediment layer over bedrock.
40	Smith Is.	PWS-1V2	224	36.1	Manual	Gravel beach	Area too small and BIO not feasible because of large boulders and thin sediment layer over bedrock.

Table 3. Model-predicted sites adjacent to known sites that are candidates for restoration as the result of the screening analysis.

Site #	Location/ Landowner[1]	Area of MOR (m^2)	Thickness (cm) Source	Volume (m^3)	Geomorph-ology	Recommended Technique	Comment
ADJ_1	Disk Is.	106	3.2 DI067A	3.4	Gravel beach	BIO	Morphology seems similar to DI067A, thus conducive to BIO, per Table 4 of Boufadel (2014).
ADJ_2	Eleanor Is.	198	10 PWS-12V1	19.8	Gravel beach, no breakwater	Manual	The beach is expected to have a thin veneer of sediments.
ADJ_3	Eleanor Is.	335	10 EL056C.3	33.5	Rock outcrop, boulders	Manual	Partially treated with BIO in 2010/2011. The rest is between boulders on steep terrain.
ADJ_4	Eleanor Is.	143	33.8 PWS-3B47	48.3	Rock outcrop	Manual	PWS3B47 contains oil between boulders in steep terrain.
ADJ_5	Green Is.	3	8 GR103B	0.2	Rubble shore	Manual	Adjacent site was designated for Manual.
ADJ_6	Ingot Is.	4	4.5 IN031B2	0.2	Gravel beach	Manual	Area too small for BIO.
ADJ_7	Knight Is., Bay of Isles between KN0135 and KN0136	42	11 KN0135B	4.6	Rocky rubble	Manual	The patches of oil on the adjacent sites are small and far apart, e.g., PWS8V1 has 1 m^2 of oil. PWS8V2 has one small patch in the upper intertidal zone. The beach is moderately exposed to waves; thus it likely lacks fine substrate due to the absence of a tombolo. The beach is also very steep, based on Shore Zone imagery.
ADJ_8	Knight Is., Bay of Isles "Death" marsh	8	3.3 KN0136A_3	0.3	Rocky rubble	Manual	This site is further north of ADJ_4, and Shore Zone shows large boulder in the beach. Also, the area of MOR is predicted to be 8 m^2, below the area threshold for BIO.
ADJ_9	Knight Is., Herring Bay	181	14.7 KN0117A	26.6	Gravel beach	BIO	Area is large, and site comparable to KN117A, where BIO was proposed.
ADJ_10	Knight Is., Herring Bay	4	35 KN0115A-1	1.4	Rock outcrop	Manual	Area is too small to warrant bioremediation.

Table 3. *Continued.*

Site #	Location/ Landowner[1]	Area of MOR (m^2)	Thickness (cm) Source	Volume (m^3)	Geomorphology	Recommended Technique	Comment
ADJ_11	Knight Is., Herring Bay	42	15 KN0114A	6.3	Rocky rubble	Manual	KN114A is unsuitable for bioremediation (per Table 4 of Boufadel, 2014), and this site has the same geomorphology.
ADJ_12	Knight Is., Herring Bay	9	4 KN-109A-2	0.4	Gravel beach	Manual	BIO is feasible but area is too small.
ADJ_13	Eleanor Is., North of Herring Bay	14	14.3 PWS-3A13	2.0	Gravel beach	Manual	Area sufficient for BIO, but the comparison site, PWS3A13, contains a small oil patch. There is a good chance that the area is smaller than 14 m^2 MOR. Thus, it might not be worthwhile to mobilize BIO equipment.
ADJ_14	Latouche Is., Sleepy Bay/ CC	19	13.3 LA015E	2.5	Gravel beach with tombolos and rock outcrop	Manual	BIO could work, but the amount of oil might not be large, as we noticed in the neighboring site LA015E (Boufadel, 2014) which had less oil in comparison with what was expected probably due to its exposure to waves.
ADJ_15	Latouche Is., Sleepy Bay/ CC	15	15 PWS-4V1	2.2	Gravel protected with rock outcrop	Manual	Although the beach geomorphology is conducive for BIO, it is below the area threshold.
ADJ_16	Smith Is.	277	19.4 SM006C1	53.7	Rocky rubble.	Manual	Terrain not very conducive for BIO. Per Table 4 of Boufadel (2014).
ADJ_17	Smith Is.	300	18.5 SM006B	55.5	Rocky rubble	Manual	Terrain not very conducive for BIO. Per Table 4 of Boufadel (2014). The area is set at 300 m^2 while the model predicted an upper limit of 2,600 m^2.
ADJ_18	Smith Is.	238	21.7 SM005B	51.7	Rock outcrop	Manual	Smith Island beaches tend to have a small amount of sediment between boulders.

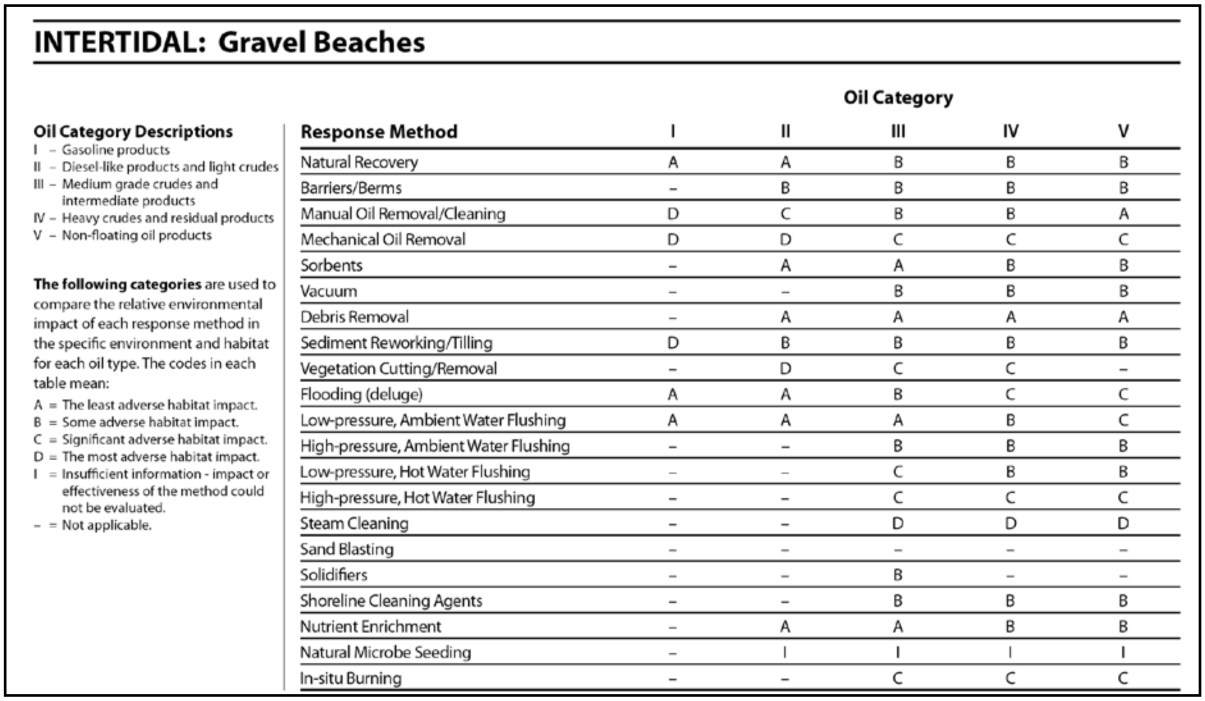
[1] All sites are on U.S. Forest Service lands except where noted; CC = Chenega Corporation

Table 4. Model-predicted unique sites that are candidates for restoration as the result of the screening analysis.

Site #	Location	Area of MOR (m^2)	Thickness (cm)	Volume (m^3)	Geomorphology	Recommended Technique	Comment
PRD_1	Eleanor Island	43	15	6.5	Rock outcrop	Manual	Beach exposed to high wave energy due to the large fetch in front of it. The slope is very steep (25%), as shown in Shore Zone imagery.
PRD_2	Eleanor Island	415	15	62.5	Gravel beach/ rock outcrop	BIO	Shore Zone imagery shows the accumulation of sediment behind bedrock, which could have sheltered the beach causing the persistence of fine substrate and oil.
PRD_3	Green Island	68	15	10.2	Gravel beach	BIO	Shore Zone imagery shows the accumulation of sediment behind bedrock, which could have sheltered the beach causing the persistence of fine substrate and oil.
PRD_4	Knight Island, Herring Bay	39	15	5.9	Gravel beach/ rock outcrop	Manual	Shore Zone imagery shows that terrain is too steep for BIO. The beach is also exposed to moderate wave energy and thus it is likely that only a little amount of fine substrates (sediments) are present.
PRD_5	Smith Island	57	15	8.6	Rocky rubble	Manual	This site is just around the south side of the western tip of Smith Island. Southern exposure. Steep relatively angular rocky talus/rubble at base of cliff/outcrops.

2.2 Task 2. Determine restoration techniques and costs for the priority sites.

Restoration of sites with subsurface oil can be accomplished using a variety of methods to speed the degradation and removal of the oil. Figure 14 lists the options for shoreline treatment of gravel beaches (NOAA, 2010). The lingering oil in PWS shoreline habitats would be similar to a medium crude oil, thus Oil Category III. Of the options listed, the following would be potentially feasible for subsurface oil that has remained in the sediments for more than 25 years: Natural recovery (which we refer to as monitored natural attenuation), manual oil removal, sediment reworking/tilling, and nutrient enrichment (which we refer to as bioremediation because it includes adding oxygen as well as nutrients as the Limiting Factors studies showed that oxygen was also limiting oil biodegradation in the oiled layers). These options have an environmental impact category of A or B. The other methods are considered to be too intrusive (e.g., mechanical oil removal) or not effective on oil that is only in the subsurface (e.g., flooding or flushing methods do not reach the oiled layers). Sediment reworking (also known as berm relocation) and tilling were conducted successfully on nearly 30 exposed gravel beaches in 1989-1991 (Owens et al., 1991; Hayes and Michel, 1999), mostly to treat oil that had penetrated into the sediments in the upper intertidal and supratidal zones. As shown in Figure 15 (from Michel et al., 2010), most of the persistent subsurface oil is in the middle intertidal zone, where sediment reworking would be less effective and more disruptive because most of the sites with subsurface oil have only intermittent exposure to wave energy (thus the rate of sediment reworking would be slow), and the excavated sediments would have to be placed in the lower intertidal (where attached biota would be severely impacted by crushing and smothering). Therefore, only three options were considered further for restoration of shoreline habitats with persistent subsurface oil: Monitored natural attenuation, manual removal, and bioremediation.



INTERTIDAL: Gravel Beaches

Oil Category Descriptions

I – Gasoline products
II – Diesel-like products and light crudes
III – Medium grade crudes and intermediate products
IV – Heavy crudes and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method in the specific environment and habitat for each oil type. The codes in each table mean:

A = The least adverse habitat impact.
B = Some adverse habitat impact.
C = Significant adverse habitat impact.
D = The most adverse habitat impact.
I = Insufficient information - impact or effectiveness of the method could not be evaluated.
– = Not applicable.

	Oil Category				
Response Method	**I**	**II**	**III**	**IV**	**V**
Natural Recovery	A	A	B	B	B
Barriers/Berms	–	B	B	B	B
Manual Oil Removal/Cleaning	D	C	B	B	A
Mechanical Oil Removal	D	D	C	C	C
Sorbents	–	A	A	B	B
Vacuum	–	–	B	B	B
Debris Removal	–	A	A	A	A
Sediment Reworking/Tilling	D	B	B	B	B
Vegetation Cutting/Removal	–	D	C	C	–
Flooding (deluge)	A	A	B	C	C
Low-pressure, Ambient Water Flushing	A	A	A	B	C
High-pressure, Ambient Water Flushing	–	–	B	B	B
Low-pressure, Hot Water Flushing	–	–	C	B	B
High-pressure, Hot Water Flushing	–	–	C	C	C
Steam Cleaning	–	–	D	D	D
Sand Blasting	–	–	–	–	–
Solidifiers	–	–	B	–	–
Shoreline Cleaning Agents	–	–	B	B	B
Nutrient Enrichment	–	A	A	B	B
Natural Microbe Seeding	–	I	I	I	I
In-situ Burning	–	–	C	C	C

Figure 14. Response methods for gravel beaches in the NOAA (2010) publication "Characteristic Coastal Habitats: Choosing Spill Response Alternatives."

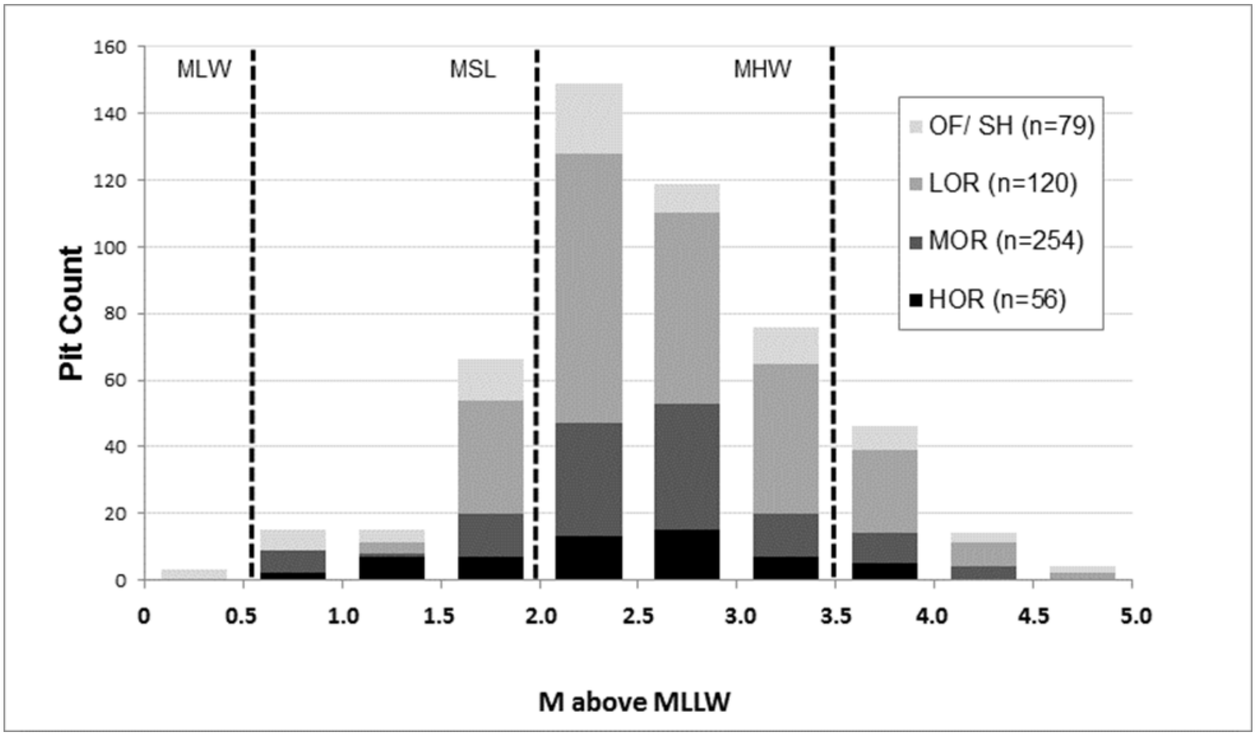


Figure 15. Counts of oiled pits by oiling descriptor by tidal elevation in meters above mean lower low water (MLLW), mean high water (MHW), mean sea level (MSL), and mean low water (MLW) based on data from pits in PWS surveyed in 2001, 2003, and 2007 (n=509). From Michel et al. (2010). Multiply the values in meters by 3.28 to obtain elevation in feet.

The level of disturbance, estimated costs, and achievable endpoints vary for each of the three restoration methods. In general, the sequence of restoration methods by increasing level of disturbance is as follows:

- Monitored natural attenuation (MNA);
- Bioremediation technique (BT); and
- Manual labor technique (MT) to excavate pits using hand tools, collection of the oil released in the pits using sorbents and excavation of oiled sediment for on-site treatment.

The cost of each method, however, does not associate with its degree of intrusiveness. MNA is the least intrusive and the least costly; however, bioremediation, which ranks second in terms of lack of disturbance, could be costly (particularly since the method might need to be applied in multiple years). For manual removal, one needs to consider the disturbance to the shoreline habitat and wildlife users of that habitat during excavation and treatment of oiled sediments, as well as the cost of transportation and disposal of any wastes generated. Some of the sites are in very sheltered setting where it could take years before the sediments are returned to their pre-disturbance distribution. Examples include Bay of Isles and Disk Island. However, many of the sites are in more exposed settings where the sediments are likely to be returned to their pre-disturbance distribution after 1-2 storm events. For example, during the *Exxon Valdez* shoreline treatment program in 1990, berm relocation, which involved the excavation and placement of sediments from the high-tide line to the middle intertidal zone for reworking by wave action and which involves much more extensive sediment disturbance than expected for MT, was conducted at 30 beaches in 1990 and 1991 (Owens et al. 1991). Hayes and Michel (1999) noted that the time required for the beach profile and sediment distribution returned to their original configurations ranged from a few months to over seven years. Factors affecting recovery included degree of exposure to wave action and the grain size of the gravel; beaches with larger boulders took longer to recover. Because no significant amount of sediments will be moved to a different tidal elevation during any of the treatments, it is expected that the sediments will recover within one year or so, depending on their degree of exposure and grain size of the gravel.

In terms of endpoints, MNA and bioremediation do not reduce much of the mass of oil, but rather its bioavailable fraction, such as the tPAHs, which are the most toxic components of oil. The depletion of tPAH due to MNA is expected to be much smaller than that due to the BT. Physical removal would remove total oil but requires dealing with the disposal of wastes.

Restoration of sites requires determining the environmental endpoints, namely, determining the concentrations of oil per water volume and per sediment mass. For sites where the oiled sediments are to be excavated and treated on-site before being returned to the excavation area, a proposed screening endpoint is based on the U.S. Environmental Protection Agency sheen test (40 CFR 435). This test allows up to half of the surface to have a sheen after agitation of the sediments in water. The State of Alaska cleanup standards for soils contaminated with petroleum hydrocarbons (Alaska Administrative Code 18.75.340) include a scoring system based on: depth to groundwater; mean annual precipitation; soil type; potential receptors (e.g., proximity to a public/private water system); and volume of contaminated soil. Applying these screening scores to the largest site would result in a soil cleanup level of 2,000 ppm residual range organics, 100 ppm diesel range organics, and 50 ppm gasoline range organics. Based on chemical analysis of samples collected in 2007 (Michel et al., 2010), two beach sediments described as LOR (defined as sediments lightly coated with oil residue; pore spaces not filled with oil or oil residue) contained 60 and 90 ppm oil that would fall within the residual range organics class. It is proposed to collect representative post-treatment samples for testing to confirm that the sheen test is an adequate field-determined endpoint for the mostly gravel sediments from the intertidal zone. Furthermore, the sheen test will be also used once the sites are backfilled with clean sediment.

We created a matrix of recommended restoration techniques based on these three treatment methods and estimated the costs for each.

2.2.1 Monitored Natural Attenuation Monitoring Plan

MNA may be used for the sites where subsurface oil is present at MOR or higher but where further treatment is determined to be too intrusive. Monitoring may also be recommended for sites where only partial treatment of oil residues was possible. As discussed in American Petroleum Institute (2014), it is best not to treat the sites as homogeneous unit, but to use a groundwater model for pore water flow to interpret the physical, geochemical, and biological measurements. Physical and biological heterogeneity of the contaminated shoreline will tend to increase the complexity of the conceptual site model and increase the information requirements for site characterization.

It is proposed that a MNA monitoring plan include elements of the Lingering Oil component of the EVOSTC project entitled Gulf Watch Alaska, led by the NOAA Auke Bay Laboratory. Under that program, 10-12 sites in PWS will be visited every five years to collect sediment samples for fingerprinting, oil persistence, and weathering. Its priority sites include many of the candidate sites for treatment in this report. The study plan for that program also includes deployment of passive samplers to provide information about the bioavailability of the oil, which would be outside of the MNA monitoring plan recommended herein, which focuses on persistence and weathering.

2.2.2 Manual Technique

The Manual Technique (MT) defined herein relies on using manual or hand-held machinery to excavate the clean overlying sediments to reach the oiled layer. Then, sorbent pads and solidifiers would be used to remove any oil that accumulated on the water table in the pit. The oiled sediments would be then manually removed for treatment by washing in the trommel on site, and subsequently returned to the pit along with the clean excavated sediments to back-fill the pit.

Sorbents are inert and insoluble materials that act through adsorption (i.e., trapping oil on their surfaces), absorption, or a combination of the two (Adebajo et al., 2003; Bayat et al., 2005; NRT, 2009). The NRT (2009) Subpart J also provides a list of sorbent materials as examples including polymers such as polypropylene, polyethylene, and polyurethane (Michel et al., 2008).

Solidifiers are chemical agents that are on the NCP list that change oil from a liquid to a solid. They immobilize the oil and bond the liquid into a solid carpet-like mass with minimal volume increase. They are generally dry, granular, hydrophobic organic polymers. In some cases, polymeric solidifiers are modified with other inorganic or organic additives, which serve as chemical bonding agents (Sundaravadivelu et al., 2015). Solidifiers are expected to work well with the subsurface oil as it is relatively light (Fieldhouse and Fingas, 2009). Their absorbance capacity of oil increases usually with temperature (Fieldhouse and Fingas, 2009), and is sufficiently high at 15^{o}C, the groundwater temperature in PWS in the summer.

Note that after using sorbents to remove any oil floating on the water table, excavation would continue and the process repeated. After reaching a depth below the oil layer (whose thickness would be visible at the walls of the pit), workers could attempt additional application of sorbents or to use solidifiers to recover liquid oil in the pit.

Sediments visibly contaminated with black oil (MOR or HOR) would be washed using a trommel system commonly used to clean sediments. This approach has proven successful for removing organic compounds, such as oil, from coarse sediments (Ross, 1991; EPA, 1995), which make up the majority of sediment in PWS. The fines (smaller than 50 microns in size) would retain the oil and form a sludge that would have to treated off site and/or landfilled. Therefore, the majority of sediments (by mass) would be cleaned and returned to the excavated area, as only a few percent of the mass of sediments occupies sizes below 100 microns (see Figure 6 of Bobo et al., 2012). The water would be recycled in the trommel system until it becomes saturated with hydrocarbons, which could be removed from the water on site using filters made of granular activated carbon (GAC). The GAC medium can be obtained from various sources, such as the Calgon Carbon Corporation which provides Filtrasorb® 300 used in United Water drinking water treatment plants. The usage of the filters is primarily done to ensure that the water does not re-contaminate new sediments in the trommel. However, the filters can be used for complete treatment of the water prior to release on site, if on-site discharge was approved by the Alaska Department of Environmental Conservation (ADEC).

The following guidelines are suggested:

1) Excavation should occur following a falling tide to provide sufficient time for replacing the cleaned sediment into the pit prior to the return of the tide.
2) It would not be necessary to refill the pit with the same sediments that were excavated from it. Thus, previously cleaned sediment from the same site could be used to re-fill (or backfill) the pit.
3) It is best to start from the landward part of the beach and then proceed downhill to ensure that oil that might be mobilized by excavation is removed in the subsequent seaward pit.
4) Clean sediments that are above the oil layer should be stored in a container on one side of the pit (facing landward) and used to refill the pit, preferably in the order that they were excavated. Oiled sediments should be placed on the other side of the pit in containers used to transport them to the barge holding the trommel.
5) Within the pit, sorbents could be used to absorb the maximum amount of oil. The sorbent should be used until it can no longer absorb oil, at which point new sorbents should be used. This is to minimize the amount of waste resulting from the MT activities.
6) It is not advisable to use sorbents in loose form, as it is likely that not all the sorbent particles would be recovered.
7) If solidifiers are used, the operator should ensure that no offsite air transport of the powder occurs. Although the solidifiers are not toxic, they could alter the respiratory function of birds and mammals (Michel et al., 2008).

2.2.3 Bioremediation Technique

The bioremediation technique (BT) relies on injecting amendments into oil-polluted sites, as reported in Boufadel (2014). The delivery of amendments was investigated in Boufadel and Bobo (2011) and Boufadel et al. (2011). The bioremediation would need to be repeated yearly until the tPAH concentration decreases below the required threshold level. Boufadel (2014) observed annual decrease in tPAH concentrations to vary between 12% and 60%. They argued that a value of 16% decrease per bioremediation season could be adopted for design. To the high cost of bioremediation (discussed below), it is advisable that it gets conducted for only two years followed by MNA.

Bioremediation was listed as the recommended restoration method in Tables 2-4 based on the four main factors that affect the feasibility of bioremediation of a beach, as described in Boufadel (2014): 1) the extent of oil (larger than 20 m^2) and its spatial distribution, namely that the oil patch would need to be more or less continuous; 2) the hydraulic conductivity of the sediments (which controls the rate of nutrient transport away from the injection wells); 3) the likelihood that injection wells can be successfully installed in the beach; and 4) the ability to place above-ground bioremediation equipment (e.g., injection pumps, electrical generators, chemical storage and mixing) in an area that is safe from tide and weather. For the first factor, we considered that beaches that have very little oil and/or have a sparse spatial oil distribution would not provide a net environmental benefit that is commensurate with the level of disruption and cost. For the second factor, a small hydraulic conductivity would require a very dense grid of injection wells (e.g., one well every 0.4 m), which causes a lot of disruption to the shoreline habitat and resources using that habitat. The third factor relates mostly to the depth to the bedrock, as beaches with shallow bedrocks (thin veneer) tend to require a high density of wells, because injected water tends to upwell to the surface. The fourth factor relates to the integrity of the equipment and the cost of placing supply solutions far from the bioremediated beach. Overall, the first two factors are the most important. At beaches where the installation of injection wells is problematic, the third factor could be overcome by using injection strips as tested on SM006C-1 (Boufadel et al., 2011), and as conducted in the pilot bioremediation study at SM006B (Boufadel, 2014). Based on these factors, nine sites were determined to be feasible for use of the BT: Five known sites, two adjacent model-predicted sites, and two unique model-predicted sites.

2.2.4 Cost Estimates

Communications were conducted with ADEC with the Office of Water (Director, Michelle Hall) and the Division of Spill Prevention and Response (Ms. Sarah Moore). The ADEC personnel referred our team to companies in Alaska that specialize in transporting and treating contaminated sediments, and we report next the summary of prices that we obtained. The companies are listed in the Acknowledgment.

The estimates for the transport of sediments and/or water to Anchorage ranged from $300 a drum (55 gallons) to $600. The treatment and/or disposal ranged from $200 to $400. The estimates for treating a drum of water ranged from $100 to $300. The cost of incinerating sorbent pads and/or solidifiers was around $400 per drum.

2.2.5 Budget Justification

2.2.5.1 Budget for the Monitored Natural Attenuation

All sites restored using BT would need to be monitored using MNA until the concentration of tPAH drops below the acceptable threshold level. The current component of the Gulf Watch Alaska project of the EVOSTC is budgeted for 2015-2016 at $271,100 to monitor 10-12 sites, most of which are included in the 63 sites herein that may be considered for restoration. For monitoring purposes, it is assumed that the 63 sites could be grouped into approximately 30 representative sites. Based on discussions with the NOAA Auke Bay Laboratory staff, the MNA plan to monitor up to twenty additional sites (for a total of 30 sites) is estimated to be about $400,000 per event. Assuming an annual increase of 3% per year, MNA monitoring costs for the twenty additional sites for year 2020 would be $464,000, year 2025 would be $538,000, year 2030 would be $623,000, and year 2035 would be $722,000, for a total of $2,347,000. It is likely that, over time, the subsurface oil at some sites would decrease to the point that no further monitoring would be required. Therefore, these costs are conservatively high.

2.2.5.2 Budget for the Manual Technique on All Sites

The cost estimate for the project for manual restoration was obtained as the sum of three costs: 1) Cost per unit area of polluted site, 2) Cost *per site*, and thus independent of the area of that site, and 3) Cost of the project design, management, the general operation (boats, treatment systems, barges, etc.), and reporting. We consider herein that all sites would be restored using the Manual Technique (MT), and we consider in the following two subsections the budget for a combined MT and BT restoration approach.

Table B1 (in appendix) shows the costs per square meter of oiled area. It shows that twelve Man Hours (MHs) are needed to restore one square meter; eight MHs are needed for work on the beach, while four MHs are needed to operate the trommel to treat the volume resulting from one square meter. The actual volume of sediments to be treated depends on the thickness of the oil layer, and on the depth of excavation. The thickness of the oil layer varies from a few centimeters up to 22 cm (i.e., 0.22 m) (Michel et al., 2010), and an average value taken herein is 0.15 m. In some cases, the oil layer is near the ground surface; in other cases, it is 0.30 m deep. In addition, one invariably would excavate deeper than the oiled layer to ensure complete remediation. Thus, the depth of excavation could be more than 0.50 m. For estimating the volume that would be transported off site and treated, we assumed that half of the average oil layer thickness would be taken offsite. In ideal situations, only a small portion of the sediments would be transported off site, but in reality, the excavation could contaminate sediments below the oil layer. This gives a volume of 0.075 m^3 per m^2, which is the volume of a half a drum of sediments. The cost of transporting a drum of sediments offsite and for treating it or disposing of it is estimated at $700 (see prevailing rates for treatment).

For the water that would be transported offsite, we estimated the volume to be equal to that of the oiled layer (0.15 m^3). For a given volume of sediment, a much larger volume of water will be used, but that volume will be recycled until the water gets saturated with oil, at which point, it would need to be replenished and/or treated through the granular activated carbon filter, as discussed above.

For costs per site, the following costs were associated with each site: 1) The cost of permitting is estimated at $3,000 per site. This includes preparing and providing maps and schematics to the ADEC; 2) The topographic survey of each site along with general characterization of the terrain is estimated to require 16 MHs (Two people for one day), and is thus estimated at 16×$65=$1,040; 3) The mobilization to a site is estimated to require 16 MHs (Two people for one day), and the demobilization from a site is estimated to require 16 MHs. Thus, $2080 is required for the mobilization to and demobilization from a site; and 4) The management structure of sites is expected to require approximately 24 MHs (three days per site) of the time of a supervisor (hourly rate $125), or $3,000 per site.

Table B2 reports the costs that apply to the whole operation, this includes the cost of renting a boat for the personnel, estimated at $2,500 per day (inclusive of food). Such a boat is expected to house six personnel. It is also assumed that the restoration project occurs in the summer months whose duration is estimated at 90 days. The number of trommels (or sediment cleaning system) to be purchased/rented depends on the number of sites to be considered. If only the forty known sites are to be restored then three trommels would be sufficient. If, in addition, the eighteen adjacent model-predicted sites and five unique model-predicted sites are to be restored using the MT, then the number would increase to six trommels, and thus six barges would need to be rented on a daily basis. Each of the trommels would be operating from a barge moored in the shore zone to have it accessible to loading contaminated sediments and to offloading restored sediments.

The cost of site survey cannot be directly related to the surface area, as some sites are more difficult to survey than others due to logistics and terrain challenges. For example, a site with a clear line of sight would probably take less time than a smaller site with obstructions in the line of sight. By the same argument, mobilization and demobilization to a site would depend on the sea state, the accessibility to a site, and nature of the site terrain (e.g., boulder or gravel).

Community Involvement: Venues for communication with the stakeholders in the restoration (citizens, non-governmental organizations, industry, and relevant government agencies at the State and Federal level) should be considered including: Town hall meetings (at least two, one in Anchorage and another in Cordova), along with visits to impacted sites (maybe before and after restoration), and a web site that gets updated weekly to reflect progress on restoration efforts. The suggested cost is $50,000.

Detailed Designs: For each site, engineering plans would need to be drawn in accordance with engineering designs. These plans would need to be updated regularly depending on the challenges faced at a particular site. The cost is estimated at $100,000 for the forty known (surveyed) sites, at $100,000 for the eighteen adjacent model-predicted sites, and at $20,000 for the five unique model-predicted sites. Although the number of adjacent and unique model-predicted sites is about half of that of the known sites, a larger amount per site is allocated due to the fact that much less information is available on these sites in comparison to the known sites.

Reporting: This task would include writing a comprehensive report that describes the work on all sites along with the observed state of each site. It is estimated at $300,000 for the forty known sites, at $135,000 for the eighteen adjacent model-predicted sites, and $40,000 for the five unique model-predicted sites. The proportions are more or less in direct relation to the number of sites.

An agency fee of 9% is allocated for the entity that would award the project to contractors and provide oversight so that the project gets implemented according to the specifications (engineering and regulatory) within the allocated budget.

The cost is increased by 40% to account for contingencies. These include primarily inclement weather, but also the fact that the work can be only conducted during low tide, which could result in downtimes during normal operating hours.

Therefore, if all 63 sites were restored using the Manual Technique, the cost is estimated to be $13,470,383 (Tables B1 and B2, Appendix).

2.2.5.3 Budget for the Manual Technique on the Recommended Sites

This follows closely the prior section with the difference that the number of sites for MT is 54. That is, thirty-five for known sites, sixteen for adjacent model-predicted sites, and three for unique model-predicted sites, with corresponding areas of 698 m^2, 1651 m^2, and 139 m^2. All costs are more or less proportional to these numbers, with the exception of the Detailed Designs for the unique model-predicted sites, kept at the same value (i.e., for all sites) of $20,000 due to the uncertainty in these sites. Table B1 and Table B3 (Appendix) reports the detailed computation.

Therefore, the cost of applying the Manual Technique to sites recommended for this method in Tables 2, 3, and 4 is $10,549,795.

2.2.5.4 Budget for the Bioremediation Technique

Similar to what was conducted for the MT, the cost estimate for the Bioremediation Technique (BT) was obtained as the sum of three costs: 1) Cost per unit area of polluted site; 2) Cost *per site*, and thus independent of the surface area of that site; and 3) Cost of the overall design, management, general operation (boats, treatment systems, barges, etc.), and reporting.

The "areal" cost is reported by 10m^2 (for example, 5 m × 2 m or 4 × 2.5 m) as using such a "block" approach for bioremediation can be visualized easier than bioremediation for only 1.0 m^2. Ultimately, the cost is normalized per m^2. The detailed computation is reported in Table B4 (Appendix).

The hourly rate of a technician is estimated at $65. After mobilization to a site (addressed in the costs-per-site, below), connections will be made to set up the system placed inland. The crew will connect pipes between the pumps, the water tank, the tank for the amendment, and the injection wells. The crew will also make the cable connections from the generator to the PLC (programmable logic controller) and various pumps and flowmeters. This is estimated to take one day of a crew of three people (thus, 24 MHs). Assuming there are six pits to dig per 10.0 m^2 to place the injection wells (for example, three equally spaced wells at two elevations, at the top and middle of the block), the excavation time is estimated at 24 MHs. The installation of the injection and monitoring wells, and the placement of bentonite above them and then refilling of the pits (Boufadel and Bobo, 2011) is estimated to require 24 MHs. Gabions would need to be placed in the subtidal zone to protect the piping and to hold the water pump intakes submerged. This task is estimated to require 36 MHs as it requires special care in placing the gabions underwater. Placement of pipes and cables in the beach site is estimated to require 12 MHs. The cables are needed for the monitoring wells. Securing the wellheads and connecting the piping are estimated each at 16 MHs. The cost of sorbent booms to be placed around the pits is estimated at $8,000 including cost of disposal. Thus, the estimate per 10m^2 of a beach is $16,385, and thus, $1,638 per m^2. This is less than the MT cost, at $2,538 per m^2 (Table B1).

Table B5 reports the cost of the first year of BT. It also uses the cost per m^2 from Table B4. The cost of propane to power the generators and amendments (hydrogen peroxide, nutrients) per 10 m^2 for 90 days is estimated at $8,000.

The cost of permitting per site is estimated at $4,000. Site survey is estimated to require thirty-two MHs (e.g., a crew of two for two days). The MHs herein is double than that allocated for the MT and it is because the BT requires more accurate estimates of distances than the MT. Mobilization and demobilization are assumed to require each forty-eight MHs due to the major equipment that would need to be offloaded from and loaded onto boats. A supervisor (at $125 per hour) is proposed at each site at forty hours per site. A landing-craft is needed for the BT due to the usage of heavy equipment. It is assumed that it would be rented for five days for mobilization and five days for demobilization. The daily rate is estimated at $5,000, giving a total of $50,000. Maintenance of the sites would require transport using a boat that would cost $2,000 per day. One three-day trip per week is estimated, and thus the total cost is $96,000. The cost of generators, cost of sheds to house the PLC (programmable logic control), cost of tanks, pumps, flowmeters, and pipes is estimated at $300,000. Community involvement is not treated separately in this calculation, as it cost is detailed within the costs of the MT element of the restoration plan. The designs are estimated at $30,000 for the known sites (area = 187 m^2), $50,000 for the adjacent sites (area = 287 m^2), and $30,000 for the two unique model-predicted sites (area=483 m^2). These prices reflect a compromise between the number of sites and the associated areas, along with leveraging of resources assuming that the known and adjacent model-predicted sites have a higher certainty than the unique model-predicted sites.

An agency oversight of 9% is assumed. An additional 40% is assumed as contingency due mostly to inclement weather and to the dependence of the installation and maintenance on the tide level. Finally, a weight factor is introduced to account for the fact that the known sites are known to have had oil (at the level of MOR) in them, and thus the likelihood of finding oil in them during the implementation of additional restoration is considered to be very high. The likelihood of finding oil on the adjacent model-predicted sites and the unique model-predicted sites is smaller compared to the known sites. Thus, both of these types of sites are assigned a weight of 0.66.

Therefore, the total cost of the Bioremediation Technique for Year 1 is $3,712,407 (Table B5). For the second year, the cost drops to $3,330,907 (Table B6), as the cost of equipment needed drops from $300,000 in Year 1 to $50,000 in Year 2. The expenditure of $50,000 is needed in Year 2, and in following years, due to the exposure of equipment to the elements during Year 1. Note that most of the equipment above ground would need to be mobilized off site between the summer of Year 1 and the Summer of Year 2 (and any subsequent summers) to protect the equipment and the environment from large waves and debris during winter. For the cost estimate included herein, it is assumed that the Bioremediation Technique would be conducted for only two years, followed by MNA at these sites. Naturally, the cost would increase if the BT were conducted in additional years. Considering the ongoing effort by the Gulf Watch Alaska project of the EVOSTC, the additional cost for continuous MNA is expected to be small when properly leveraged.

2.2.5.5 Budget Summary

Table 5 reports the various costs based on the pursued options. The MNA and MT for all sites have been computed above, and are thus reported in Table 5. The estimated cost based on the recommendations of Tables 2, 3, and 4 (i.e., MT for some sites and BT for the remainder) is $10,549,795 + $3,712,407 + $3,330,907 = $17,593, 109.

Table 5. Summary of costs for various restoration techniques.

Restoration Technique	**Cost USD**
Monitored Natural Attenuation at 20 sites	$2,347,000
Manual Technique (MT) at all 63 sites	$13,470,383
Manual Technique (MT) at 54 sites + Bioremediation Technique (BT) at nine sites	$17,593,109

3.0 NEXT STEPS

The objectives of this report were to identify the sites in PWS with lingering subsurface oil at levels of MOR or greater where restoration efforts to reduce the amount of oil were feasible and likely to be effective, then to estimate the costs for each method. Only one site was removed from the list based on environmental concerns, namely Seal Island. Other sites were removed from the list based on the thickness of the oiled layer, estimated area/volume of the patches, large size of the surface sediments (which would make manual removal very difficult), and other geomorphological considerations. No site-specific cost/benefit analysis was conducted for any of the 63 sites identified in this report as candidates for restoration. The next steps in the decision-making process to determine which, if any, of these 63 sites should be restored and by what method would include such a site-specific cost/benefit analysis. The Federal and State trustees should consider additional factors, such as benefits to recovering resources, proximity to sensitive fish and wildlife, subsistence use, recreational use, and degree of exposure to waves to speed recovery of disturbed sediments.

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6.0 APPENDICES

Appendix A

Table B1: Cost of Manual Technique per m2

RATE OF SKILLED TECH	65.00	

COST ESTIMATE			LABOR				MATERIAL			OTHER	TOTAL
Description	Qty	Unit	MH/UNIT	MH Total	Rate	Total	Unit/Prc	Qty	Total $		
MANUAL RESTORATION PER 1.0 M2 OF SITE											-
DIGGING PITS	1	M2	4.000	4	65.00	260.00		0	0		
REMOVE OIL FROM PIT USING EITHER SORBENT PADS OR SOLIDIFEF	1	M2	1.000	1	65.00	65.00					
DELIVER SEDIMENTS TO TROMMEL	1	M2	2.000	2	65.00	130.00		0	0		
BACKFILL	1	M2	1.000	1	65.00	65.00		0	0		
COLLECT SORBENT BOOMS	5	M	0.025	0	65.00	8.13		0	0		
TREAT WASTES (assume volume is 50% of 0.15 m X 1.0 m X 1.0 m)	1	M2	2.000	2	65.00	130.00	700.00	1	350		
TREAT WATER (assume volume is 0.15 m3 of water per m2 of sediment)	1	M2	2.000	2	65.00	130.00	700.00	2	1400		
FOREMAN	1	M2	-	0	140.00	-					-
Total				**12**		**788.13**			**1750**		**2,538**

Appendix B

Table B2: Manual Technique. Cost per site and total cost assuming MT used on all sites

Labor per 1 m2 of Manual	788
Solid and water disposal (per m2 of beach)	1,750
Boat rental for lodging per day+food	2,500
Permitting for manual work per site	3,000
Barge rental per day	1,500
Labort Cost for Technician, per hour	65
Labor Cost for Supervisor per hour	125
Cost of survey per site, 16 man hour	1,040
Mobiliization per site, 16 man hour	1,040
Demobilization per site, 16 man hour	1,040
Management, supervisor 3 days per site, 24 MH	3,000

	Surveyed	Adjacent	Predicted	Total Area
Number of sites	40	18	5	
Area (m2)	885	1,938	622	3,445
Duration (day)	90	90	0	Two boats rented each for 90 days sufficient to handle the additional Predicted sites.
Site Surveys (Average 16 Man Hour per site)	41,600	18,720	5,200	
Mobilization and demobilization, 32 MH (16 for mob and 16 for demob)	83,200	37,440	10,400	
Supervisor, Average one per site (24 Man Hour per site, 3 days)	120,000	54,000	15,000	
Permitting.	120,000	54,000	15,000	
Labor for total area	697,259	1,527,396	490,217	
Treatment of solid and water	1,548,225	3,391,500	1,088,500	
Boat rental for lodging per day+food	225,000	225,000	0	
Barges to hold the trommels (3)	405,000	405,000	0	
Trommels, each cost $20K. A total of six would be needed	60,000	60,000	0	
Community Involvement	50,000	0	0	
Detailed designs	100,000	100,000	20,000	
Reporting	300,000	135,000	40,000	
Total	3,750,284	6,008,056	1,684,317	
Agency Oversight, 9%	337,526	540,725	151,589	
Total Cost	4,087,809	6,548,781	1,835,905	
Add in 40% Contingency to bottom line for all summaries	1,635,124	2,619,512	734,362	
Total with contingency	5,722,933	9,168,293	2,570,268	
Adjust for uncertainty	1	0.66	0.66	
Probable Cost	5,722,933	6,051,074	1,696,377	13,470,383

Appendix C

Table B3: Manual Technique. Cost per site and total cost assuming MT used only on sites recommended for Manual Technique in Tables 2, 3, and 4. (i.e., MT not applied on sites where BIO was recommended)

Labor per 1 m2 of Manual	788
Solid and water disposal (per m2 of beach)	1,750
Boat rental for lodging per day+food	2,500
Permitting for manual work per site	3,000
Barge rental per day	1,500
Labort Cost for Technician, per hour	65
Labor Cost for Supervisor per hour	125
Cost of survey per site, 16 man hour	1,040
Mobiliization per site, 16 man hour	1,040
Demobilization per site, 16 man hour	1,040
Management, supervisor 3 days per site, 24 MH	3,000

	Surveyed	Adjacent	Predicted	
Number of sites	35	16	3	
Area (m2)	698	1,651	139	
Duration (day)	90	90	0	Two boats rented each for 90 days sufficient to handle the additional Predicted sites.
Site Surveys (Average 16 Man Hour per site)	36,400	16,640	3,120	
Mobilization and demobilization, 32 MH (16 for mob and 16 for demob)	72,800	33,280	6,240	
Supervisor, Average one per site (24 Man Hour per site, 3 days)	105,000	48,000	9,000	
Permitting.	105,000	48,000	9,000	
Labor for total area	549,878	1,301,203	109,550	
Treatment of solid and water	1,220,975	2,889,250	243,250	
Boat rental for lodging per day+food	225,000	225,000	0	
Barges to hold the trommels (3)	405,000	405,000	0	
Trommels, each cost $20K. A total of six would be needed	60,000	60,000	0	
Community Involvement	50,000	0	0	
Detailed designs	90,000	90,000	20,000	
Reporting	260,000	120,000	20,000	
Total	3,180,053	5,236,373	420,160	
Agency Oversight, 9%	286,205	471,274	37,814	
Total Cost	3,466,258	5,707,646	457,974	
Add in 40% Contingency to bottom line for all summaries	1,386,503	2,283,058	183,190	
Total with contingency	4,852,761	7,990,705	641,164	
Adjusted for uncertainty	1	0.66	0.66	
Probable Cost	4,852,761	5,273,865	423,168	10,549,795

Appendix D

Table B4: Cost of Bioremediation Technique per 10 m2

RATE OF SKILLED TECH	65.00	

COST ESTIMATE			LABOR				MATERIAL			TOTAL
Description	Qty	Unit	MH/UNIT	MH Total	Rate	Total	Unit/Prc	Qty	Total $	
Restoration										-
BIOREMEDIATION PER 10 M2						-				-
CONNECT WATER STORAGE TANK/SWITCHES/PUMPS/CABLES	1	EA	24.000	24	65.00	1,560.00				1,560
HANDDIG PITS	6	EA	2.000	12	65.00	780.00		0	0	780
INSTALL INJECTION AND MONITORING WELLS	6	EA	2.000	12	65.00	780.00				780
SET GABIONS	3	EA	12.000	36	65.00	2,340.00		0	0	2,340
PULL TUBING & WIRING	1	EA	12.000	12	65.00	780.00		0	0	780
SECURE HDPE TO WELL BOXES	1	EA	16.000	16	65.00	1,040.00		0	0	1,040
CONNECT PIPING	1	EA	16.000	16	65.00	1,040.00		0	0	1,040
COLLECT BOOM ADSORBENT	40	M	0.025	1	65.00	65.00		0	8000	8,065
BIOREMEDIATION COST FOR LABOR PER 10 M2				**129**		**8,385.00**				**16,385**

Appendix E

Table B5: Bioremediation Technique (BT). First Year.
For sites recommended for BT in Tables 2, 3, and 4.

Operation cost per **10 m2** of Bioremediation	16,385
Propane and amendments for the summer (90 days)/10 m2	8,000
Labort Cost for Technician, per hour	65
Labor Cost for Supervisor per hour	125
Permitting for bioremediation work per site	4,000
Cost of survey per site, 32 man hour	2,080
Mobiliization per site, 48 man hour	3,120
Demobilization per site, 48 man hour	3,120
Management, supervisor 5 days per site, 40 MH	5,000
Landing Craft	5,000
Cost of boat rental per day for site visits	2,000

	Surveyed	**Adjacent**	**Predicted**	**Total Area**
Number of sites	5	2	2	
Area (m2)	187	287	483	957
Duration (day)	90	90	90	
Labor and waste cost	306,400	470,250	791,396	
Propane and amendments for the summer (90 days)	149,600	229,600	386,400	
Permitting.	20,000	8,000	8,000	
Site Surveys	10,400	4,160	4,160	
Mobilization and Demobilization	31,200	12,480	12,480	
Supervisor, Average one per site	25,000	10,000	10,000	
Landing craft, 5 days for mob, 5 days for demob	50,000	0	0	Landing craft needed
Boat rental for maintaining sites during summer, 16 trips x 3 days a trip	96,000	0	0	due to heavy equipment
Equipment (generators, pumps, PLC)	300,000	0	0	
Community Involvement	0	0	0	
Detailed designs	30,000	50,000	30,000	
Reporting	50,000	30,000	10,000	
Total	1,068,600	814,490	1,252,436	
Agency Oversight, 9%	96,174	73,304	112,719	
Total Cost	1,164,773	887,794	1,365,155	
Add 40% contingency	465,909	355,117	546,062	
Total cost with contingency	1,630,683	1,242,911	1,911,217	
Multiplier to adjust for uncertainty (i.e., oil extent less than computed)	1	0.66	0.66	
Probable Cost	1,630,683	820,321	1,261,403	**3,712,407**

Appendix F

Table B6: Bioremediation Technique (BT). Second Year.
For sites recommended for BT in Tables 2, 3, and 4.

Operation cost per **10 m2** of Bioremediation	16,385
Propane and amendments for the summer (90 days)/10 m2	8,000
Labort Cost for Technician, per hour	65
Labor Cost for Supervisor per hour	125
Permitting for bioremediation work per site	4,000
Cost of survey per site, 32 man hour	2,080
Mobiliization per site, 48 man hour	3,120
Demobilization per site, 48 man hour	3,120
Management, supervisor 5 days per site, 40 MH	5,000
Landing Craft	5,000
Cost of boat rental per day for site visits	2,000

	Surveyed	**Adjacent**	**Predicted**	
Number of sites	5	2	2	
Area (m2)	187	287	483	
Duration (day)	90	90	90	
Labor and waste cost	306,400	470,250	791,396	
Propane and amendments for the summer (90 days)	149,600	229,600	386,400	
Permitting.	20,000	8,000	8,000	
Site Surveys	10,400	4,160	4,160	
Mobilization and Demobilization	31,200	12,480	12,480	
Supervisor, Average one per site	25,000	10,000	10,000	
Landing craft, 5 days for mob, 5 days for demob	50,000	0	0	Landing craft needed
Boat rental for maintaining sites during summer, 16 trips x 3 days a trip	96,000	0	0	due to heavy equipment
Equipment (generators, pumps, PLC)	50,000	0	0	
Community Involvement	0	0	0	
Detailed designs	30,000	50,000	30,000	
Reporting	50,000	30,000	10,000	
Total	818,600	814,490	1,252,436	
Agency Oversight, 9%	73,674	73,304	112,719	
Total Cost	892,273	887,794	1,365,155	
Add 40% contingency	356,909	355,117	546,062	
Total cost with contingency	1,249,183	1,242,911	1,911,217	
Multiplier to adjust for uncertainty (i.e., oil extent less than computed)	1	0.66	0.66	
Probable Cost	1,249,183	820,321	1,261,403	**3,330,907**