

Comprehensive Plan for Habitat Restoration Projects Pursuant to Reopener for Unknown Injury

1. INTRODUCTION

Presented here is a comprehensive, multi-phase plan to restore shorelines in Prince William Sound and the Gulf of Alaska affected by the *Exxon Valdez* Oil Spill (Comprehensive Plan). This Comprehensive Plan aims to accelerate removal of lingering subsurface oil from those shorelines by: (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 and, as appropriate, alternative technologies such as tilling and physical removal; (4) pilot testing of candidate bioremediation technologies; (5) evaluating potential remediation alternatives in a draft restoration implementation plan; and (6) implementing the chosen remediation option(s). Public involvement is an important component of the Comprehensive Plan, most notably during the phases in which prioritization, of contaminated beaches for remediation, pilot testing, and evaluation of remediation options occur.

A summary of current knowledge regarding locations where lingering *Exxon Valdez* oil is now likely to be found and in what states of preservation appears immediately below this section. It is followed by a more detailed description of the six phases of the Comprehensive Plan. Execution of the Comprehensive Plan is explained in Section 4, where both a timeline and a decision-tree document linking the six program elements with evaluation checkpoints appear. The first two phases are expected to proceed in parallel, with the remaining phases following in sequence. A summary of cost estimates is contained in Section 5 for each of the program elements.

This Comprehensive Plan is supplemented by six appendices. Appendices A–E provide more technical detail for several of the program elements; Appendix F consists of spreadsheets detailing the estimated costs of implementing this Comprehensive Plan.

2. CURRENT STATUS OF OIL ON IMPACTED BEACHES

2.1. Geological Setting

The shorelines impacted by the oil spill in Prince William Sound (PWS) are unusual in several respects, largely because of the uplift that occurred during the 1964 Alaska earthquake. Uplift from 1.5 to 10 m raised formerly subtidal sediments into the intertidal zone. These subtidal sediments were often poorly sorted, meaning they included a wide variety of sediment sizes. Exposure to wave action after the uplift tended to transport the smaller sized particles of surface sediments either landward, forming pebble-cobble berms, or downslope toward the subtidal, where wave energy is much lower. This process leads to beach “armoring”, with larger clasts, cobbles and boulders on the surface of these beaches protecting smaller-grained sediments beneath them. Armoring stabilizes beaches by protecting the underlying sediments from reworking from wave energy and is one of the key factors contributing to the persistence of

subsurface oil. A similar process probably occurs in the spill zone outside PWS, where exposure to much larger waves may lead to shorelines composed of even larger particles, including large boulders, with oil trapped within the interstices.

Remediation of oil in gravel beaches and other coarse substrates poses challenges because they are highly porous, allowing deep oil penetration, and because rates of natural sediment reworking and replenishment are variable but generally slow. Armored beaches are particularly challenging, with their own unique feature combinations that have led to the persistence of oil for over 17 years:

- (1) Many of the sites are sheltered from significant wave action. Even those that are relatively exposed show sediment reworking mostly in the upper intertidal zone.
- (2) Many sites are not true “beaches” in the sense of sediment accumulations formed by wave action. Instead, they are rocky rubble shores – steeply sloping shores where the coarse-grained clasts consist of debris that has accumulated on the slope under the influence of gravity. These clasts show little evidence of reworking, such as sorting or rounding, or the formation of depositional berms at the high-tide line.
- (3) Even the sites that are true beaches have unique characteristics. They are underlain by gently sloping surfaces of wave-carved bedrock platforms that were probably uplifted and covered by a veneer of gravel. The only truly active parts of these beaches are the high-tide and storm berms. The rest of the intertidal zone is composed of flat platforms with a stable surface armor.
- (4) Most of the surface sediments are very coarse, dominated by clasts that are cobble (64-256 millimeters [mm]) and boulder (>256 mm) in size. The grain size of the gravel typically increases seaward.

2.2. Current Oil Distribution

Exxon Valdez oil has been identified at 78 distinct locations within the spill-affected region since 1998 (Fig. 1). Most of these locations were discovered during an extensive survey conducted in 2001 (Short *et al.* 2004), and include a variety of exposure aspects and geomorphological characteristics. Within PWS, oiled shorelines range from sheltered to very exposed. Outside PWS, oil has been found on beaches that are directly exposed to the open ocean (Irvine *et al.* 1999). On individual beaches, oil may be found throughout the intertidal range, although surface oil occurs most often in the upper intertidal zone, while subsurface oil is more frequent at mid-tide elevations (Fig. 2; Short *et al.* 2004, 2006a).

Surface oil occurs most often as weathered asphalt pavements, the thickest of which enclose softer and less weathered interiors, or as more liquid deposits of surface oil residues. The asphalt pavements are typically found on or between the cobbles and boulders that often armor beaches, whereas the surface oil residues typically contaminate the finer-grained sediments that often lay immediately beneath or between the surface armoring.

Subsurface oil is typically found as a band of oiled sediments ranging from < 1 cm in thickness to 20 cm or more, beginning a few cm below the armor if present. The transition from

clean sediments that overlie the oiled sediments beneath is usually very abrupt, occurring within 0.5 cm of vertical sediment depth. Most of the subsurface oil is contained within relatively few large patches, with 20% of subsurface oil patches containing 90% of the subsurface oil (Fig. 3). Most of these patches are found beneath boulder/cobble armored beaches on gently dipping slopes of the middle intertidal or within a thick sediment veneer overlying a bedrock platform (Hayes and Michel 1998, 1999, Short *et al.* 2004). Oil patches are occasionally found in association with other geomorphological features, such as along the bedrock margins of pocket beaches, near boulder or bedrock outcrops, or beneath mussel beds.

The subsurface oil is usually less weathered than surface oil. Especially when the concentrations of oil are high, the oil often retains a substantial proportion of the polycyclic aromatic hydrocarbons (PAH, the most toxic components of crude oil) found in the oil when spilled, as well as a complement of normal alkanes (*n*-alkanes, *i.e.* saturated hydrocarbons that have carbon atoms linked in chains; see Appendix B). Because these *n*-alkanes are easiest for microbes to degrade, their presence indicates that rates of microbial decomposition have been slow. The variability in the extent of weathering changes of subsurface oil indicates that local conditions or factors have important effects on microbial decomposition rates.

An estimated 56 tons of subsurface oil remained on beaches within PWS in 2001 (Short *et al.* 2004), but the actual amount is almost certainly greater. The estimates of lingering oil provided by the 2001 survey are limited in four ways. First, only beaches within PWS were considered, so although oil is known to persist at some locations outside PWS (Irvine *et al.* 1999), the extent of this contamination is not known. Second, the 2001 survey focused mainly on beaches that had been described as heavily or moderately oiled during surveys conducted from 1990 through 1992. Given the amount of oil discovered during the 2001 survey, it is almost certain that additional oil remains on other beaches that were oiled in 1989 but did not meet the selection criteria of the 2001 survey. Third, the 2001 survey only considered the upper half of the intertidal zone, and a follow-up study in 2003 (Short *et al.* 2006a) confirmed that the oil may often be found in the lower intertidal as well (Figure 2). Fourth, surface oil was not included in the estimates. Allowing for these sources of underestimation, the actual amount of oil remaining is probably between 100 – 200 tons (Short *et al.* 2004). Moreover, although substantial amounts of oil remain on some of the beaches impacted by the spill, the precise location of most of it is not known. Hence, one of the tasks of this Comprehensive Plan is to develop an efficient method for finding the bulk of the lingering oil. A probabilistic mapping approach is presented below in Section 3.1 to address this task.

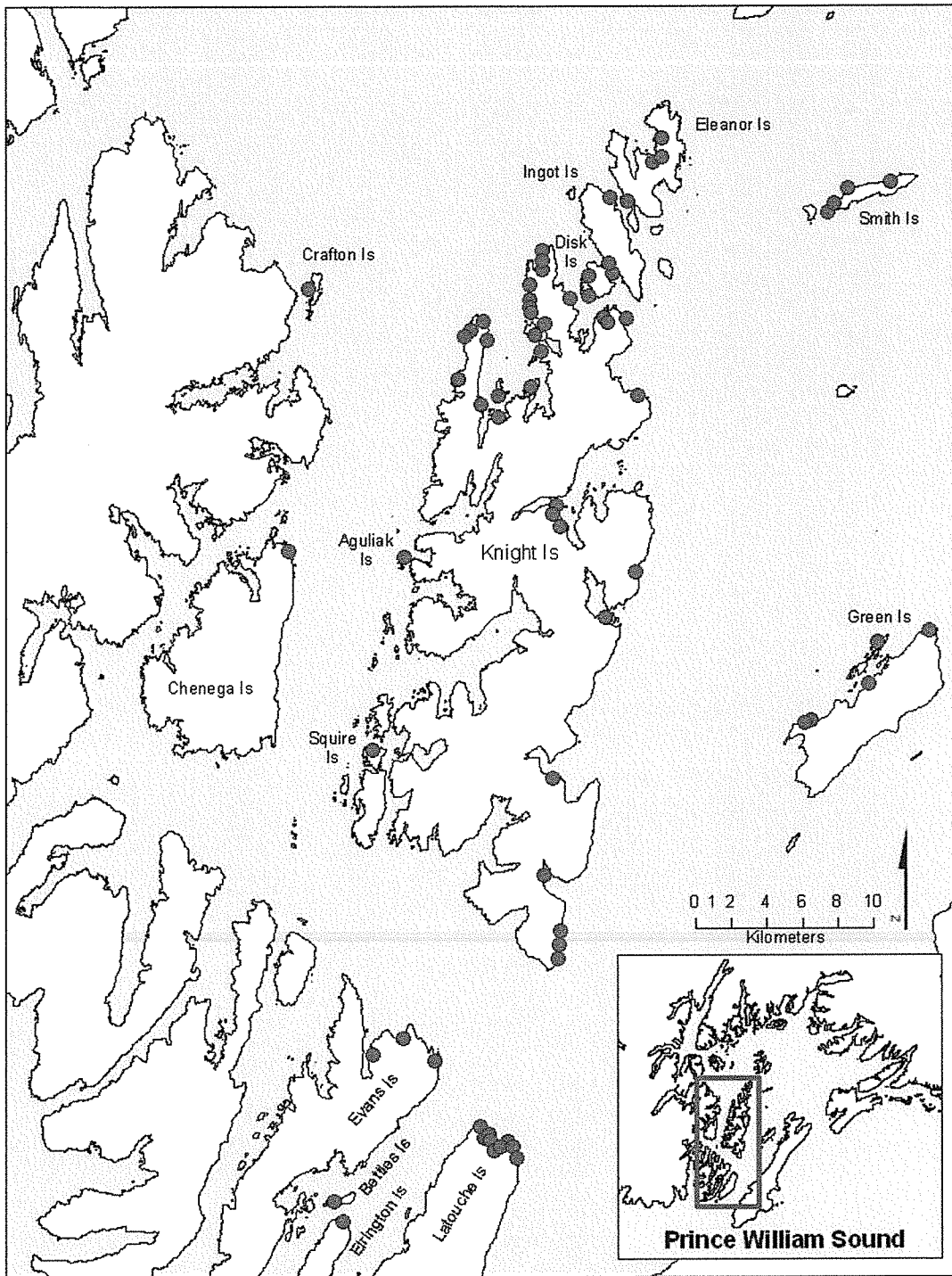


Figure 1. Map of the spill zone showing locations of all known surface and subsurface oil deposits. Filled red circles indication locations where subsurface oil has been found since 1998 (figure continued on following page).

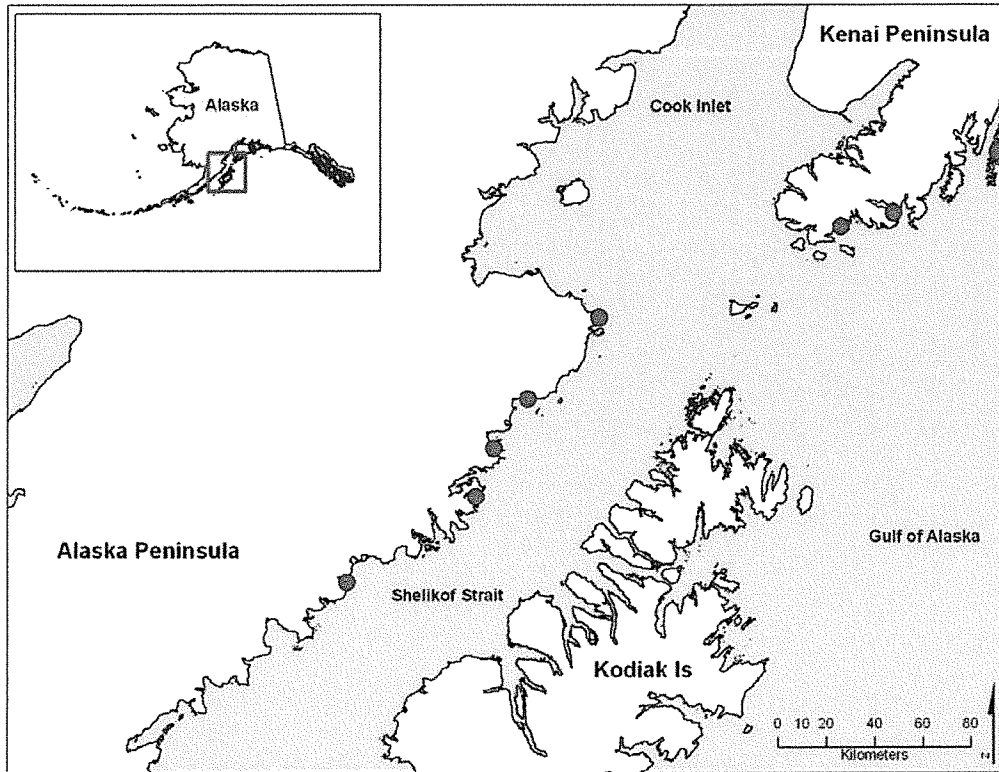


Figure 1 (continued).

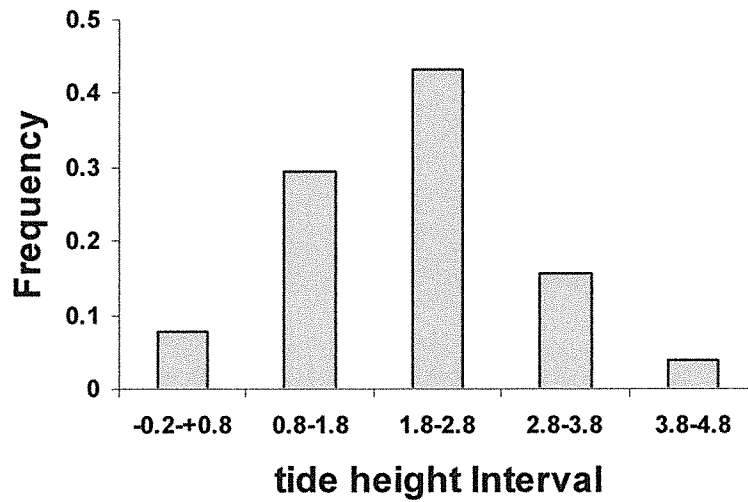


Figure 2. Frequency distributions of surface and subsurface oil with respect to tidal elevation.

A careful evaluation of how the larger patches of less-weathered oil are associated with shoreline oiling history and geomorphological characteristics, will provide insight into the factors promoting the preservation of oil in some patches. These factors are evaluated in Section 3.2.

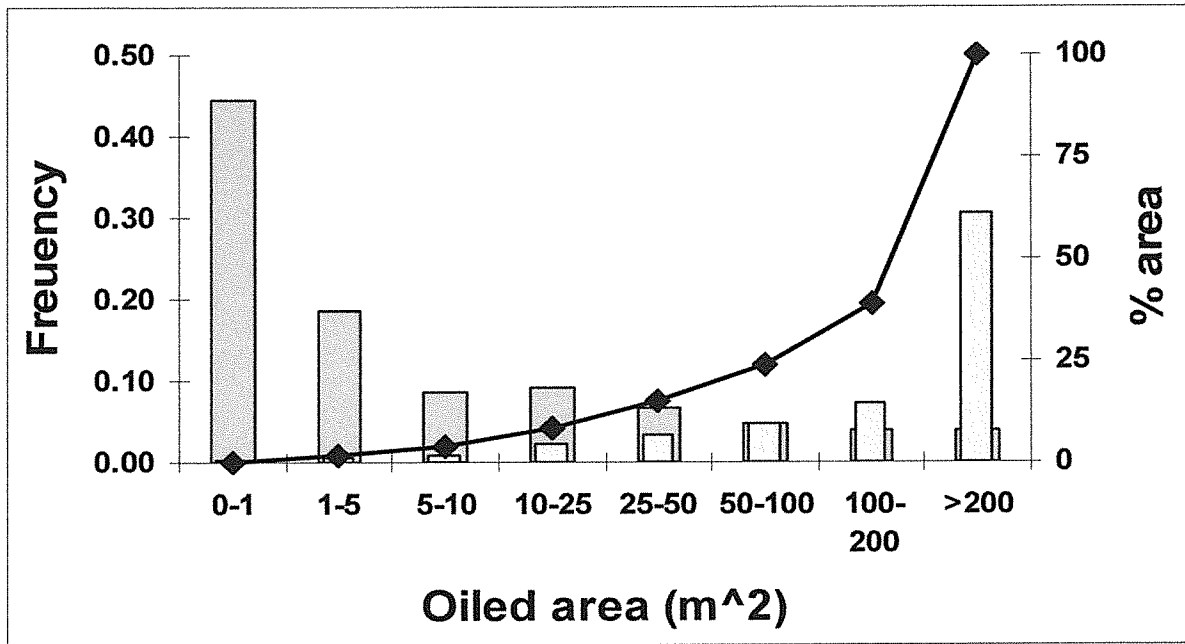


Figure 3. Frequency distribution of oiled beach sediment areas vs. patch size bins. Grey bars depict the proportion (left-hand axis) of oiled patch area within the area intervals indicated beneath them. Yellow bars depict the proportion (right-hand axis) of total oiled area associated with the area intervals indicated. Solid line connecting black diamonds shows the cumulative oiled area for the sum of the patch size intervals below and to the left.

3. RESTORATION PROGRAM ELEMENTS

The Comprehensive Plan plan consists of the following elements: (1) finding the remaining oil, (2) identifying factors limiting natural recovery, (3) evaluating removal technologies, (4) pilot testing of remediation technologies, (5) developing the final restoration plan and environmental assessment of that plan, and (6) implementation of the restoration plan.

3.1. Finding the Remaining Oil

An efficient plan for locating the remaining oil is essential because it is impractical to excavate every beach initially impacted to determine whether subsurface oil remains. Instead, a probability-based approach can locate most of the remaining oil at much lower cost. The

probability-based plan described below will provide a basis for assigning a probability of finding subsurface oil to each shoreline segment that was initially oiled. These assignments will then be used to prioritize selection of shorelines for remediation, beginning with shorelines where the probability of finding large patches of relatively unweathered oil is greatest, and proceeding in accordance with some stipulated criteria for minimum likely patch size and weathering state. In addition, the amounts of any oil left unremediated can be estimated and compared with the amounts subjected to treatment, and the likely locations of all the remaining oil can be mapped for consideration of remediation alternatives.

The probability-based model of oiling location and intensity will be developed iteratively, proceeding along the following six steps, which are depicted in Figure 4. This series of steps amounts to an adaptive sampling scheme, where future sampling is conditioned on information as it is acquired.

Step 1. Construct a preliminary probability model from existing information. This model has three objectives: (1) to determine whether geomorphological features can be found that are associated with lingering oil, (2) to determine the likely maximum extent of oil that would qualify for remediation efforts, and (3) to identify locations where oil is most likely to be found. This preliminary model will be based primarily on comparison of the extent of maximum oil penetration observed during the comprehensive shoreline cleanup assessment team (SCAT) surveys of the entire spill zone during fall, 1989, with shoreline geomorphology (as mapped in 2000 by NOAA using the Environmental Sensitivity Index (ESI) shoreline categories and other shoreline geomorphology data). Locations of relatively un-weathered patches of subsurface oil larger than a stipulated threshold will be added to this map, and the results examined statistically for significant associations. Most of this oil location data will be gleaned from records acquired during the 2001 and 2003 surveys of oil in PWS conducted by the Auke Bay Laboratory (ABL) (Short *et al.* 2004, 2006a).

Step 2. Design a statistically rigorous sampling plan to guide collection of additional field data necessary to refine the preliminary probability model. The sampling plan will address both between-beach and within-beach sampling strategies, incorporate criteria regarding minimum patch size and oil weathering state. The design of this sampling plan will be sufficiently flexible that it can be readily refined as data are acquired from other sources, including oiled locations that might be identified by the public (see Appendix A for details). A process will be established for collecting information from the public regarding locations where oil has been encountered so that this information may be used in the development of the sampling plan. See Appendix E for details regarding input from subsistence users.

Step 3. Conduct the field sampling in PWS and the northern Gulf of Alaska. The field survey objectives are to: (1) provide a statistically rigorous basis for assigning oil encounter probabilities to all shorelines oiled initially; (2) gather ancillary data for estimating the volume and surface area of the subsurface oiled sediments more accurately and precisely; and (3) gather additional data on the geomorphological characteristics associated with lingering oil, including patch sizes and oil weathering states, to refine the probability model to improve prediction of oil volumes and surface areas as well as location at a smaller spatial scale.

Step 4. Construct a refined probabilistic model of the spatial extent of lingering oil. The final results will include a spatial database, an assessment of the uncertainty of the predictions, and an evaluation of assumptions.

Step 5. Develop and apply criteria to prioritize beaches with lingering oil for remediation. Criteria will include the likely amount and weathering state of lingering oil present, assessment of the risks to resources and resource uses and the potential for reduction of those risks, the ability of remediation to meet restoration endpoints (based on the results of studies on the effectiveness of the tested treatment technologies; see Section 3.5), and cost estimates of the selected remediation technology (Section 3.3). Public input, is expected to play a significant role in this prioritization process. Prioritization will be based in part on data collected through the Subsistence Use, Food Safety and Risk Communication component of the plan described in Appendix E, GIS overlap maps generated from such data, and input from the work group established pursuant to that project. The risk assessment process will explicitly address uncertainties both with the remediation effectiveness and the reduction of risks to resources and resource uses. This process will provide prioritization criteria, maps and tabular data on the beaches ranked in order of remediation priority.

Step 6. During remediation, additional field data on the actual presence and distribution of lingering oil on each treated beach will be used to continually refine the model predictions and update the maps. It may be appropriate to repeat the prioritization process using the newly refined model results (Fig. 4).

Finding the Lingering Oil

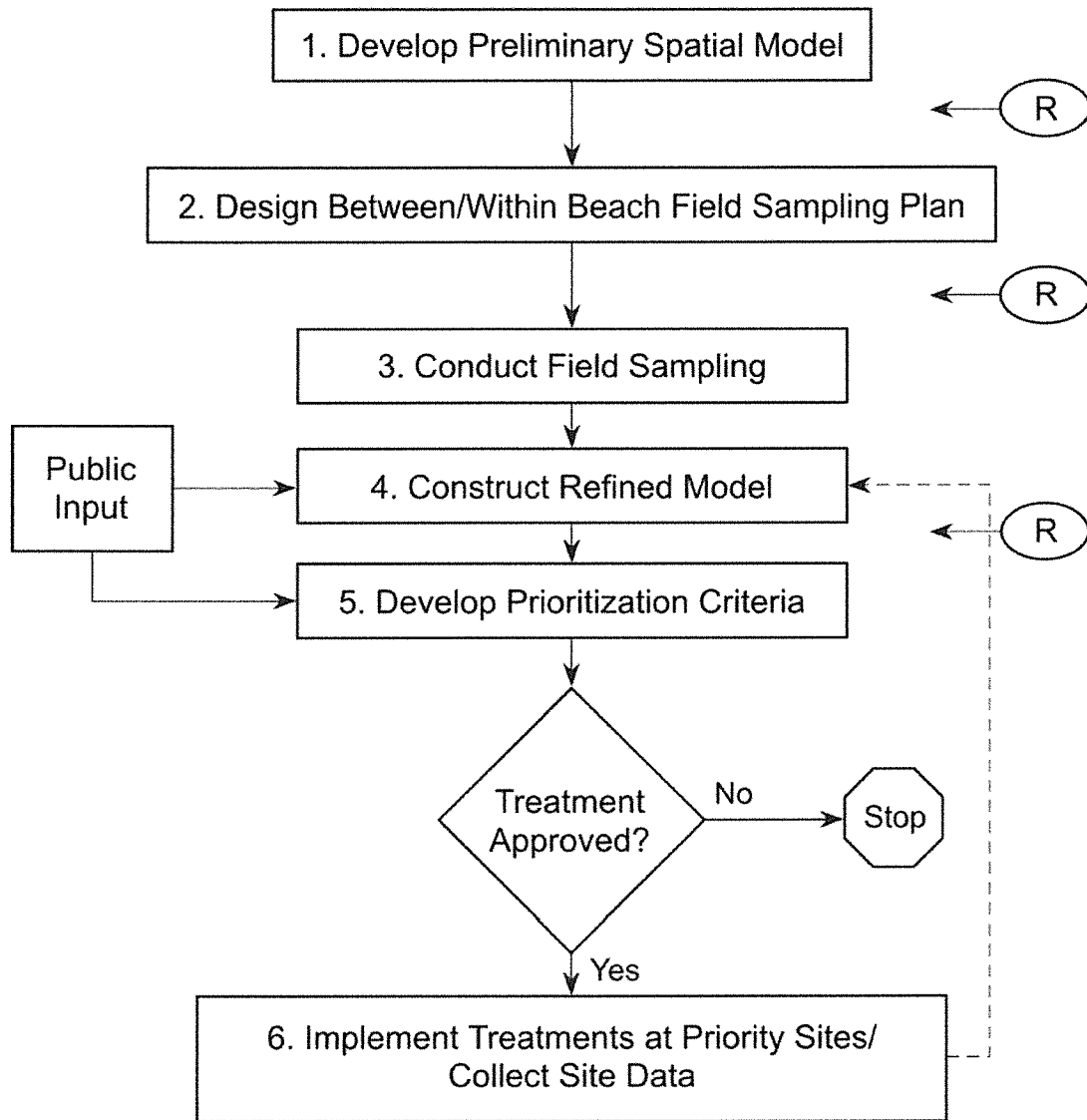


Figure 4. Flowchart of finding lingering oil. The circled R indicates when a report would be prepared to document the results and decisions.

3.2 Identifying Factors Limiting Natural Recovery

Oil is removed from shorelines because of physical disturbances that disperse the oil into the adjacent water column or subtidal sediments, or because of processes *in situ* such as microbial degradation that either convert the oil into more mobile (polar) components or mineralize it. Physical disturbances were undoubtedly important during the years immediately following the spill. Wave action, especially during winter, could disturb surficial sediments on exposed shorelines, exposing underlying subsurface oil to more vigorous physical conditions that promote dispersive removal. Bioturbation, or the mixing of surface sediments by biota searching for prey living in near-surface sediments, is another way subsurface oil could become exposed and dispersed. Sea otters and sea stars are capable of excavating pits in the intertidal zone to depths of several tens of centimeters in search of prey, and some sea ducks and infauna such as worms can mix sediments nearer the surface. However, nearly all of the oil susceptible to loss through physical disturbance was probably removed within the first few years following the spill. Based on recent work indicating that the oiled surface area of beaches has not changed significantly since 2001 (Short *et al.* 2006b), it is unlikely that physical disturbance processes still play a major role in reducing oil burdens on beaches. This leaves *in-situ* processes as the most likely mechanisms for reducing the amount of oil remaining.

Oil stranded on shorelines provides a ready source of carbon for resident microbes, which may convert many of the oil components into carbon dioxide, water, or simpler organic compounds that are readily dispersed into the ambient air and water. The oil components most easily degraded by microbes include the aliphatic and aromatic hydrocarbons, which account for about half the mass of the oil and include the most toxic components, the polycyclic aromatic hydrocarbons (PAH). Hence, natural microbial degradation can be an effective means of detoxifying the oil by degrading the toxic PAH into simpler, less harmful products that no longer pose a contact-contamination threat to biota. Not all oil components are easily degraded by microbes, but the viscosity of the recalcitrant fraction is so high it resembles solid, friable materials that eventually become eroded into progressively finer particulates by wave action. The bioavailability of hydrocarbons in these fine organic particles is typically very low, and these particles eventually become dispersed into the adjacent water column.

The existence of highly weathered deposits of surface and subsurface oil on some of the contaminated beaches shows that microbial degradation can be effective in the spill region. This suggests that some factors, such as low temperature, which might otherwise be considered as limiting, can be discounted, and that at least at some locations, adequate nutrients were available to support microbial degradation. Identification of the factors that limit microbial degradation rates is thus crucial for evaluating whether a bioremediation strategy might be effective.

3.2.1. Candidate Factors Limiting Oil Degradation Rates

The factors most likely responsible for slow microbial degradation of subsurface oil fall into two broad categories, denoted hereafter as “nutrient limitation” and “phase boundary effects.” Nutrient limitation refers to the requirement of microbes for inorganic nutrients such as nitrogen, phosphorus, and oxygen to support their consumption of oil. Phase boundary effects refers to processes that may occur on the surfaces of oil parcels that serve to isolate the bulk of the oil from the surrounding media, be it air, water, or sediment. For example, the formation of a

hard outer skin on asphalt pavements slows the decomposition rate of oil beneath it, leading to some pavements that enclose less viscous and less weathered interiors. Stable emulsions, such as those occurring along Shelikof Strait, form thick deposits that are slow to weather (Irvine *et al.* 1999).

3.2.2. Processes Promoting Nutrient Limitation

Hydraulic stagnation refers to the likely existence of places within beaches where the flow of subsurface interstitial water, driven mainly by tidal pumping, is slow. Such stagnant water probably occurs in sediments immediately adjacent to underlying bedrock, adjacent to bedrock margins of pocket beaches, and next to boulder or bedrock outcrops. Once exhausted from such stagnant water, re-supply of oxygen and inorganic nutrients may be too slow to sustain the prolonged microbial activity needed for biophysical oil dispersion or biochemical oxidation. Hydraulic stagnation is probably an important factor because it can explain the sharp horizontal boundary often found between oiled subsurface sediments and the much cleaner sediments overlying them (Appendix B).

An inadequate supply of nutrients from the ocean, exacerbated by local depletion caused by competition from other flora such as eel grass or algae, could also retard the microbial degradation of oil. Microbial degradation rates in the environment (especially within PWS) are most likely limited by nitrogen, phosphorus, and/or oxygen (Appendix B). The ambient concentrations of nitrogen in seawater within PWS are near thresholds of limitation (Appendix B), and oxygen penetration into subsurface sediments may be sensitive to local characteristics of the sediments. A feasible mechanism through which the flux of dissolved oxygen to the lingering oil zones could be increased is addition of hydrogen peroxide (H_2O_2), which quickly decomposes to dissolved oxygen and water in aqueous solution. Addition of hydrogen peroxide would follow the same approach as addition of nutrients as discussed in detail in Appendix B.

3.2.3. Processes Promoting Phase-Boundary Effects

Phase-boundary effects include a wide range of processes that can limit the interactions of hydrocarbon-degrading microorganisms with the oil-water interface. Since most of the components of the lingering oil have limited solubility in water, microbial degradation requires direct contact with the oil-water interface, and anything that interferes with this contact will inhibit microbial degradation. One example of a phase-boundary effect is the formation of a "skin" that is enriched in viscous, less-degradable compounds and acts as a barrier to interphase mass transfer (Berger and Mackay, 1994), inhibiting microbial activity at the oil-water interface. Alternatively, fine sediment particles may coat the oil trapped in pores or adhere to sediment surfaces, providing a mineral barrier. Mineral fines are attracted to weathered oil by electrical charges and may provide a mechanism for natural removal of oil from coarse substrates (Bragg and Owens 1995). Water flow transports the mineral particles to the oil film; if the moving water exerts sufficient shear, the oil film can be broken into small, sediment-coated droplets, and the oil-mineral aggregates can be washed away. If the oil is too viscous or the shear force too weak, the oil cannot be desorbed and dispersed. The lingering oil may be too viscous or deep to allow formation of droplets, but the mineral particles could still be attracted to the oil-water interface and form a physical barrier that limits microbial attachment and degradation of the oil. Other processes that could block microbial interaction with the oil-water interface are also conceivable.

Finally, if oil is present in small, oil-filled pores, the microbial degradation rate could be limited by the areal extent of the oil-water interface.

3.2.4. Approaches to Hypothesis Testing

A better understanding of the nutrient levels (including oxygen) and the hydrodynamics of beaches that contain lingering oil will clarify the factors that limit microbial degradation. Knowing how these factors interact will facilitate selection of the most appropriate remediation technology. A field study will be conducted to determine actual oxygen and nutrient concentrations as a function of tidal cycling and to collect data (*e.g.*, water level, temperature, salinity) to support hydrodynamic modeling of beaches in the impacted region. Hydrodynamic modeling studies, constrained by actual geomorphological characteristics (including sediment grain size distributions and variability), coupled with measurement of the subsurface transport of a conservative tracer, will be used to evaluate the likelihood of hydraulic stagnation, as well as provide a basis for adapting nutrient delivery technologies to beaches in the impacted region (see Section 3.3).

3.2.4.1. Modeling

Successful remediation will require a more detailed understanding of water flow in these beaches and the various physical processes that affect it. The three major processes are the filling and draining of the beach due to tide and waves, the physical controls on water flow in the beach imposed by beach geomorphology (*i.e.*, profile and sediment properties), and buoyancy of the freshwater on and behind the beach. Construction of a physically-based model will facilitate evaluation of the effects of these processes and the determination of which process is dominant at a particular beach. To evaluate the fidelity of the model, two complementary approaches will be pursued. First, detailed hydraulic data from two beaches within PWS, a lentic (low energy) beach and a lotic (high energy) beach, will be obtained from a field study (Section 3.2.2.2. below and Appendix B) to calibrate the model and provide insight into the actual hydrodynamics of water flow at these beaches. Data for this model will be provided by a rigorous tracer study (Appendix B). Second, easily measured data, such as tidal level variation with time, observed values of wave runup, and large-scale beach profiles will be used to analyze the general behavior of beach hydrodynamics. This is equivalent to conducting sensitivity analyses on the beaches analyzed in the first approach.

The modeling will provide information on: (1) where the oil would most likely be located within an oiled beach, a result that could be incorporated in the statistical model of oil occurrence (Appendix A), (2) whether bioremediation is plausible from a hydraulic point of view, (3) the washout rate of nutrients from the beach, which affects the biodegradation rate of oil, and (4) where to apply the nutrients or oxygen, and at what flow rate, concentration, duration, and frequency.

3.2.4.2. Field measurements

The field study that is described in Appendix B will specifically test the hypothesis that the persistence of oil in some intertidal shorelines is due to limited transport rates for important co-substrates (*e.g.*, nutrients and/or oxygen). Measurement of dissolved oxygen and nutrient

concentrations in oil-contaminated sediments will provide information that will be used to evaluate the potential for rate limitation by these substrates. Data will also be collected to validate a hydrodynamic model of solute transport in the intertidal zone, which will be used to predict the transport rates of nutrients and oxygen to the contaminated sediments under natural and enhanced (engineered) conditions. Measurements of water level and sediment permeability will provide inputs to the model, and the rate of solute transport will be measured using a conservative tracer. Comparison of the observed tracer transport to the model predictions will show whether stagnant regions exist in the subsurface sediments within the experimental domain. Once fully developed, the model will be used to determine the optimum method for applying the required amendments on beaches selected for bioremediation treatment.

Accumulation of mineral coatings at the oil-water interface will be investigated by collecting sediment samples and examining them using scanning electron microscopy.

3.2.5. Evaluation of Limiting Factors

Hydrodynamic modeling of intertidal shorelines will be used to estimate the supply rates of nutrients and oxygen to contaminated subsurface sediments, and the maximum potential rates of oil biodegradation will be estimated based on the stoichiometric requirements (see Appendix B). In addition, the pore-water concentrations of these substrates will be compared to the expected concentrations necessary to support maximum hydrocarbon biodegradation rates (*e.g.*, 2 mg O₂/L and 3-5 mg N/L). If either of these factors appears to be rate limiting, bioremediation will be implemented by providing the limiting substrates at faster rates through engineered manipulation of beach hydrodynamics. Hydrodynamic modeling, coupled with the results of the conservative tracer study, will be used to evaluate a variety of amendment application procedures and compare their expected effectiveness. The simplest and most effective procedure will be selected for pilot-scale testing.

If nutrients and/or dissolved oxygen are found to be available in sufficient quantity, some other factor must be responsible for the persistence of the lingering oil. Phase-boundary effects are likely, but more difficult to address through engineered manipulation of the shoreline hydrodynamics. Mineral barriers, if they exist, would be most difficult to overcome using nonintrusive methods. Persistence of the oil due to limited oil-water interfacial area (*e.g.*, existence of oil-filled small pores) might be addressed by treatment of the contaminated sediments with a surfactant to mobilize the oil and increase its surface area, which would promote microbial degradation.

3.3. Evaluating Remediation Technologies

Once the factors limiting natural recovery have been identified, candidate technologies to overcome these limitations will be evaluated. Evaluation methods and criteria will be formulated, largely on the basis of modeling of water and nutrient flow in the intertidal sediments with and without candidate treatment methods. There are three steps in this program:

- (1) Identify candidate technologies to overcome limiting factors
- (2) Develop and apply evaluation methods and criteria for the most promising technologies

- (3) Make the recommendation as to whether or not to proceed with pilot testing of selected technologies

The evaluation process will be similar to that used by Michel *et al.* (2006) in that the candidate technologies will be described and evaluated as to their potential effectiveness to remove the subsurface oil for the range of settings in PWS and the Gulf of Alaska. The results of the technology evaluation will be documented in a report describing the basis for selection of recommended technology(ies). Costs will be estimated for both a field-scale pilot test and full-scale implementation of the recommended technology(ies), based on available data for the shoreline segments selected for treatment. Although bioremediation is anticipated to be appropriate for most beaches, other treatment technologies will also be considered based on the results of the field study of limiting factors. In cases where it is determined that bioremediation methods are not effective, then other technologies, such as physical reworking and physical removal, will be evaluated. Physical removal is the likely technology for subsurface oil outside PWS where the oil often occurs as thick accumulations of stable emulsion under and between large boulders. Bioremediation is not likely to be effective on these types of oil residues. Physical reworking and removal technologies have been used in past oil spill cleanups, and their likely effectiveness and impacts are well documented. It is possible that a combination of technologies may be necessary based on site-specific conditions. If it is expected that substantial amounts of oil are likely to be left in place once this evaluation has been made, alternative means of addressing this habitat loss will be examined.

3.4. Pilot Testing of Candidate Remediation Technologies

Pilot tests of selected technologies in the field are critical to optimizing the methods and evaluating effectiveness. Field tests provide the opportunity to study processes that cannot be addressed at the smaller scale of laboratory systems or through application of simplified models. Tests will be conducted at representative sites, considering the variability among sites. Environmental conditions during the tests will be documented (*e.g.*, temperature, storms, oil spills). The success of the selected treatment technology will be evaluated by measuring changes in the concentration and composition of the oil in treated sediments relative to untreated sediments. If necessary, the treatment methods will be refined or additional methods will be tested. A detailed description of the pilot tests focused on bioremediation technologies is provided in Appendix D. A similar approach will be used if other technologies are selected for pilot testing.

The field pilot tests will be designed to estimate the variation that exists between treated and control areas to allow evaluation of the statistical significance of any differences that are observed. A statistically valid evaluation of treatment effects will be provided by treating several independent areas and performing similar measurements on independent control areas that will not be subjected to the treatment. The criterion used to define “independence” of the treatment and control areas is that they must be clearly delineated and spatially separated. To the extent possible, treated and control areas will be set up close to one another on the same shoreline segment, such that they are similar with respect to shoreline geomorphology, wave exposure, and oil composition. Within these blocks representing similar environmental conditions, the areas that are treated and those that remain untreated will be randomly assigned. Several times during the study, samples will be collected from predetermined, randomly selected locations within each

block, and analysis of variance (ANOVA) will be used to evaluate the differences in oil concentration and composition over time and between treatments and controls.

The pilot test plan will also include monitoring programs to detect any potential impacts to natural and socio-economic resources. All the required permits will be obtained prior to execution of these studies, including permits from the Alaska Department of Natural Resources, Alaska Department of Environmental Conservation, U.S. Forest Service, and upland property owners. Permitting will be addressed more specifically in the study planning and scheduling.

The pilot testing will be summarized in a report that documents the test methods, results, recommendations, and costs to implement the recommended remediation technologies.

3.5. Restoration Plan and Environmental Evaluation

The decision regarding the implementation of remediation will be based on an analysis of the costs and benefits of the recommended restoration strategy, following the requirements of the National Environmental Policy Act (NEPA). An Environmental Assessment will be conducted where the proposed remediation plan will be evaluated in comparison with alternative actions including natural recovery (the “no-action” alternative) and other feasible treatment options. The proposed action and the alternatives will be described. The existing environment will be described and include selected sites both in and outside of PWS. The priority sites for restoration will have been identified, as described in Section 3.1; thus, there will be quantitative data on the number of sites and the specific areas to be restored. The environmental consequences of the proposed remediation plan and alternative actions will be assessed. This assessment will address impacts to environmental resources, socio-economic resources (including subsistence use), and cultural resources. Issues such as waste management, human health and safety, and compliance with other environmental review and permitting requirements will also be addressed.

The Draft Restoration Plan and NEPA documentation will be released for public review and comment. Public meetings will be held to solicit public input to the plan. The views of subsistence users, expressed individually and through the Subsistence Use, Food Safety and Risk Communication Project work group, will be important to the determination of remediation priorities and the propriety of using specific remediation techniques in areas where subsistence resources are located. The draft plan will be revised based on the comments received, and a Final Restoration Plan and associated NEPA documentation will be completed.

3.6 Implementation of Final Restoration Plan

The final restoration plan is likely to consist of a combination of bioremediation and physical reworking/removal technologies. The areal extent of the contaminated sediments to be treated will be based on the results of the additional field studies. For planning purposes, the estimates of the volume of oil provided by Short *et al.* (2004 and 2006a) and converted to estimates of the area of oiled sediments by Michel *et al.* (2006) are used to indicate the scope and costs. Michel *et al.* (Table 6; 2006) estimate that 14,369 m² of oiled sediments described as lightly oiled residue (LOR), moderately oiled residue (MOR), and heavily oiled residue (HOR) are in the 42 segments where subsurface oil was found by Short *et al.* (2004). These areas represent about 12 percent of the total amount of subsurface oil in PWS based on the 2001

survey (Michel *et al.*, 2006). Based on the 2003 survey data, Short *et al.* (2006a), estimate that there was an additional 36 percent oil in the lower intertidal zone that was not included in the oil estimates from the 2001 survey. Thus, it is estimated that there could be as much as 160,000 m² of oiled sediments in PWS. Michel *et al.* (2006) estimated that 47 percent of the patches of subsurface oiled sediments were greater than 100 m², which they used as a minimum area for treatment. However, during the environmental assessment, some sites would not be selected for remediation, because of advanced degree of weathering of the residual oil or unacceptable impacts to environmental, socio-economic, and cultural resources. It is estimated that two-thirds of the sites would be selected for remediation, estimated to cover 75,200 m² in PWS. It is assumed that 90 percent of the selected sites in PWS with subsurface oil would be targeted for bioremediation (estimated to be 67,680 m²), and 10 percent of the sites in PWS would be targeted for physical technologies (estimated to be 7,520 m²).

Because data on sites to be remediated outside PWS are limited, this plan assumes that the area within the Gulf of Alaska selected for treatment will be approximately 13,600 m². The Department of the Interior has identified fourteen sites outside PWS that likely contain lingering EVO. These sites are located in Kenai Fjords and Katmai National Parks, Kachemak Bay State Park, on the Pye Islands within the Alaska Maritime National Wildlife Refuge and on the Kenai Peninsula in an area where the uplands are owned by the Port Graham Corporation. The geometric mean of the areal extent of the lingering oil available for six of these sites is 340 m². Assuming that ten of the fourteen sites would be selected for remediation in the prioritization process and that these sites represent one-fourth of the total number of sites to be remediated outside PWS, 40 sites and 13,600 m² would be the subject of treatment outside PWS.

The restoration plan will include a program to monitor the effectiveness of the treatments and any adverse impacts. The effectiveness monitoring will be conducted after the first, second, and fourth year of treatment. The methods will be similar to those described in Brodersen *et al.* (1999). The effects monitoring will be conducted during implementation of the treatment methods (Appendix D). Subsistence foods sampling will be conducted after treatment. (Appendix E).

4. PLAN EXECUTION

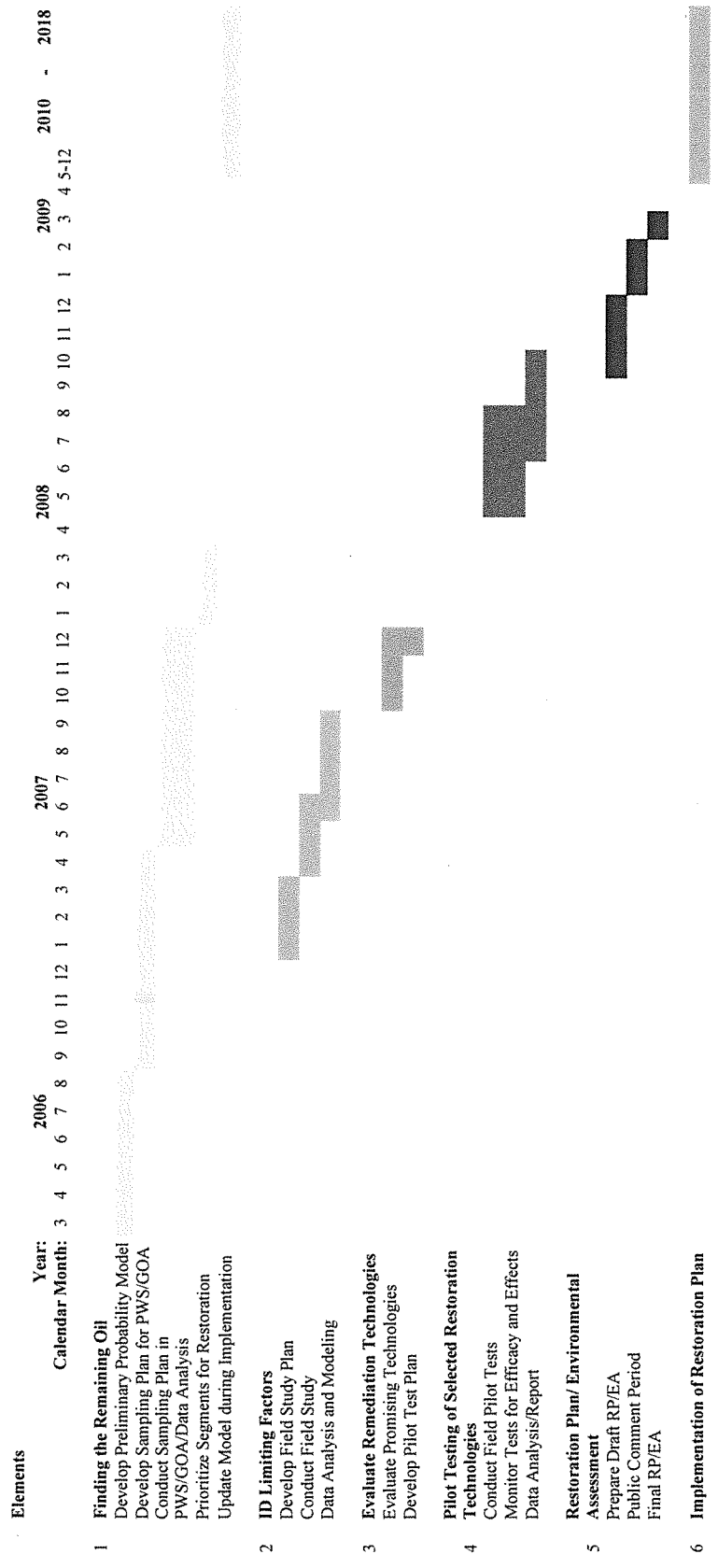
This Comprehensive Plan will be executed through a series of phases, with decisions regarding later phases contingent on results of those completed. Figure 5 shows a proposed timeline for each program element. Comprehensive Plan execution will begin with the first two elements simultaneously: finding the lingering oil and identifying the factors that promote persistence. These two elements are not contingent on each other, so they may proceed in parallel. Similarly, the compilation of subsistence use data, pursuant to the Subsistence Use, Food Safety and Risk Communication component of the Comprehensive Plan, may also proceed in parallel. In contrast, successive Comprehensive Plan elements depend on these results, so evaluation and decision points are built into the implementation plan. This implementation plan is summarized in the two flowcharts appearing in Figures 4 (Finding the Lingering Oil) and 6 (Treatment Technology Evaluation). Implementation of the plan for finding the remaining oil is summarized in Section 3.1 above. The remainder of the implementation plan is summarized below, with reference to Figure 6.

Identification of the factors limiting the natural removal of the oil is the necessary first step toward treatment technology evaluation. This process begins with enumeration of the factors that contribute to oil persistence and have been summarized as hypotheses in Section 3.2.1. Tests of these hypotheses will be constructed and field programs will be designed and executed to provide data for evaluating these hypotheses (Fig. 6), and the results will be used to identify candidate remediation technologies. For example, models of groundwater flow, informed by actual measurements of the temperature, salinity, oxygen, and nutrient contents as summarized in Section 3.2.2 above, will impose restrictive constraints that lead to elimination of all but a very few limiting factors. Determining whether these potentially limiting factors are understood well enough to consider treatment options is the first major decision point of the plan for treatment technology evaluation. If these factors are not understood well enough to proceed, then new hypotheses will be formulated and methods developed to test them. For example, it may be determined that some physical reworking or removal of oiled sediments are needed under certain conditions. In the unlikely possibility that no feasible methods are identified, this Comprehensive Plan will terminate with completion of the plan for finding the lingering oil (Fig. 4). However, physical methods will always be a consideration that would be carried forward in the decisionmaking process.

If the limiting factors can be identified with sufficient confidence, the next step is to evaluate treatment options. This involves selecting treatments that are feasible given the constraints imposed by the physical environment, the level of disturbance likely to be associated with treatment, the anticipated costs, and public acceptance. If feasible treatments cannot be identified, the Comprehensive Plan would again terminate. But if feasible treatments are identified, the Comprehensive Plan will proceed to the design of specific treatment technologies, their selection and application at a pilot-scale field test as described in Sections 3.3 and 3.4 above. The efficacy of these technologies will be measured as described in Section 3.4, and compared with minimum expectations to determine whether to proceed to full-scale implementation, the next major decision of the flowchart in Figure 6. Technologies that are not adequately effective or that will have unacceptable effects on natural resources or resource uses will not be pursued, and if other candidate approaches that have not been tested are available, they will be considered for pilot-scale implementation and evaluation. If no treatment technology can be shown to be effective, the restoration plan would again terminate if no alternative means of addressing these habitat losses have been identified.

If an effective combination of treatment technologies is found, implementation will be evaluated in light of the environmental benefit, likely costs, and public input, particularly with respect to the use of specific treatment techniques in areas where subsistence resources are located. Input from the Subsistence Use, Food Safety and Risk Communication work group and individual subsistence users will be considered for this purpose. If full-scale implementation is approved, the efficacy and the impacts of implementation will be monitored. As implementation progresses, information and experience on the ground will be used to refine the means by which subsequent implementation measures are carried out and to update documentation of the locations of lingering oil.

Figure 5. SUBSURFACE LINGERING OIL RESTORATION TIMELINE



Treatment Technology Evaluation

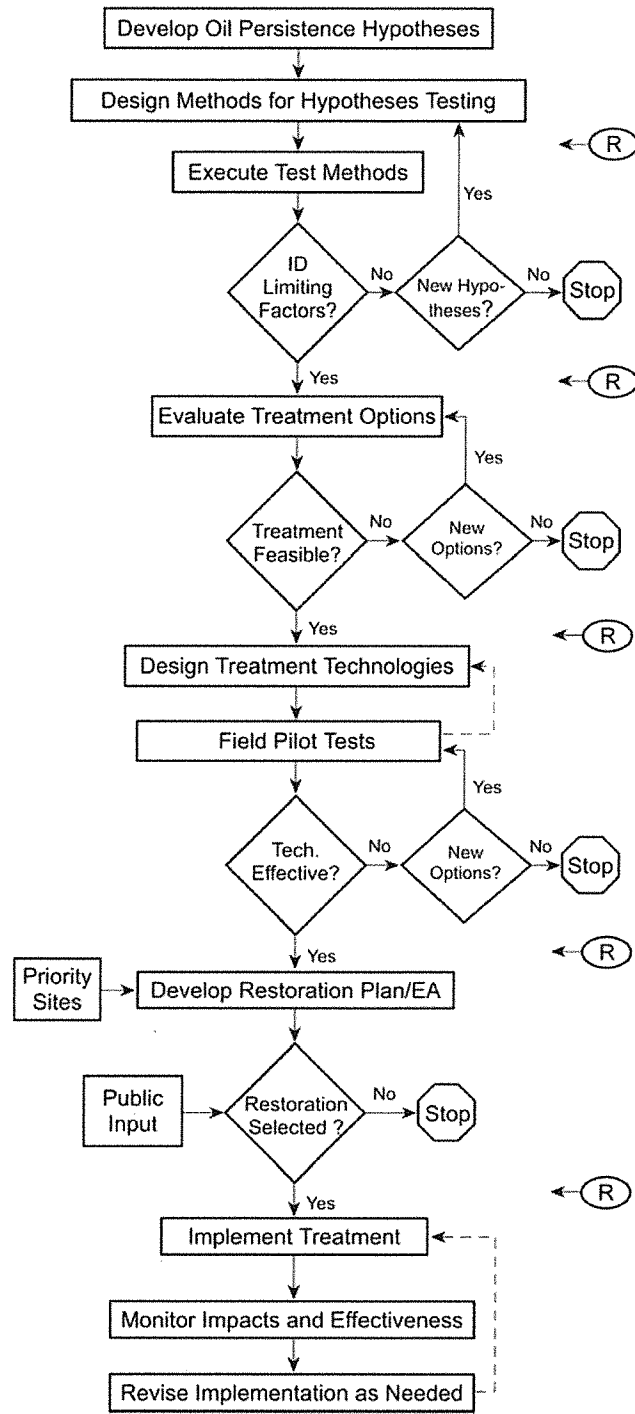


Figure 6. Flowchart of remediation technology evaluation. The circled R indicates when a report would be prepared to document the results and decisions.

5. COST ESTIMATES (See Appendix F for details)

Finding the Remaining Oil

Preliminary Model Development:	\$46,325
Sampling Plan Development:	\$40,875
Field Sampling	\$1,171,750
Model Refinement:	\$163,500
Shoreline Prioritization:	<u>\$99,735</u>
Subtotal	\$1,522,185

Identification of Limiting Factors

Field Studies on Limiting Factors:	\$367,087
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Evaluating Remediation Technologies

Identification and Evaluation of Technologies:	\$99,980
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Pilot Testing of Candidate Remediation Technologies

Pilot Tests:	\$2,579,922
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Final Determination on Restoration Strategy

Cost/Benefit Analysis, Final Determination:	\$470,935
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Implementation of Final Restoration Plan

Remediation:	\$80,027,877
Subsistence Use, Food Safety and Risk Communication:	\$ 7,172,996

Total Costs of Comprehensive Plan	\$92,240,982
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