An Evaluation of Remedial Options for Lingering Oil from the *Exxon Valdez* Oil Spill

Prepared by the Alaska Department of Environmental Conservation

Division of Spill Prevention and Response

For the

Exxon Valdez Oil Spill Trustee Council

Contents

Preamble

This document was prepared by the Alaska Department of Environmental Conservation (ADEC) at the request of the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC). This document consists of an overview of research that was conducted into the causes and impacts of the presence of lingering subsurface oil in Prince William Sound (PWS), as well as other summary documents related to research conducted by EVOSTC. This document was prepared by qualified personnel at ADEC, but is not a regulatory determination.

Executive Summary

The Alaska Department of Environmental Conservation (ADEC) Division of Spill Prevention and Response (SPAR) issued a Cleanup Complete decision for the *Exxon Valdez* Oil Spill (EVOS or Spill) in June, 1992. This decision was based on the success of the response effort initiated after the Spill and several years of additional cleanup and monitoring of oiled beaches in the Spill area. In the early 2000's however, it became apparent that the natural degradation of the remaining oil that had been predicted following the cessation of cleanup efforts was not occurring at the projected rate. The result was pockets of oil that remained at numerous locations, primarily in the subsurface, and most commonly at beaches that had been the most heavily oiled as a result of the Spill. This oil, known as "lingering oil" became the subject of focused, long-term research by the EVOSTC to evaluate why the degradation rate at beaches varied, determine the toxicity level of the lingering oil, and what risk the lingering oil posed to receptors as well as to the recovery of resources that appeared to be underway in the Spill area.

The EVOSTC requested a review by ADEC of the available information to advise the EVOSTC on any potential remediation options may be available. This document provides a summary of some of the work conducted by EVOSTC related to lingering oil, an overview of common methods used to remediate petroleum contamination, as well as recommendations on potential areas of additional study.

1.0 Introduction and Purpose

The location, amount, and chemical composition of lingering oil (LO) present at PWS beaches as a result of the Spill has been the subject of numerous EVOSTC-funded studies over the past 26 years. These studies generally had the following objectives:

- Develop a model to predict where lingering oil was most likely to occur and confirm the results of the model through field visits
- Evaluate near-shore organisms most likely to be impacted by the presence of LO
- Evaluate the factors responsible for limiting the rate of natural degradation of LO
- Evaluate the bioavailability of LO and
- Evaluate methods for reducing the amount of lingering oil

The purpose of this document is to provide a summary of the results of the LO and related studies as they relate to the overall recovery of PWS and also to evaluate what measures could be taken in the future to reduce the amount of LO or reduce the time it may take for the LO to naturally degrade.

1.1 Draft Organization

This Document is organized as follows:

- *Section 1 – Introduction and Purpose.* This section describes the purpose and organization of this document.
- *Section 2 – Background.* This section provides a brief background on LO and its current impacts and a discussion of similar spill events in Alaska and other parts of the world.
- *Section 3 – Remediation Methods for Crude Oil*. This section discusses the treatment technologies that were investigated to reduce the amount of LO by EVOSTC as well as typical remediation methods for petroleum contamination and their applicability to LO.
- *Section 4 –Areas of Additional Study*. This section discusses what additional information could be gathered to support a future recommendations regarding remediation of areas impacted by LO.
- *Section 7- Discussion and Cost Estimates.* This section includes overall discussion of the various concepts proposed to treat LO and a path forward to estimate costs.
- *Section 8 – References*. This section lists the sources of information cited in this Document.

2.0 Background

The *Exxon Valdez* Oil Spill Trustee Council has funded numerous studies to evaluate the locations where LO is present, the factors responsible for the continued presence of LO, and methods to potentially reduce the amount of LO or increase the rate at which is naturally degrades.

Current studies show that the lingering oil is no longer bioavailable and key injured resources are no longer being affected by the lingering oil (Michel, Esler, Nixon, 2016). Sea otters, harlequin ducks, and mussels; the species most likely to be impacted by LO, have met the recovery criteria as defined by EVOSTC, which generally requires a return to conditions that would have been present had the Spill not occurred, as well as cessation of exposure of animals to oil lingering since the Spill. Lacking pre-Spill baseline studies, researchers contrasted a number of metrics between oiled and unoiled areas, including abundance, survival, habitat use, physiology, biomarkers of oil exposure, and population trajectories based on models.

While injured resources have largely recovered, LO will persist in the subsurface at discrete locations in PWS. This paper seeks to present and evaluate potential remediation options for LO.

2.1 Examples from Literature and ADEC Records

Examples of sites in Alaska where petroleum has been removed from a beach or intertidal area are extremely limited and none are similar to the LO situation in PWS. A review of these sites, as well as a few from other areas of the world, indicates varying degrees of success as noted below.

2.1.1 Selendang Ayu

The *Selendang Ayu* grounded on December 8, 2004 near Unalaska Island in the Aleutian chain. The grounding resulted in the release of approximately 320,000 gallons of intermediate fuel oil and 14,000 gallons of other petroleum products that made landfall at hundreds of beach sections in the area of the spill. Spill response activities consisted primarily of the manual removal of tar balls, oiled beach grass, and accumulations of oil on sand. Some oil was buried close to the surface on sandy beaches and was removed by raking the sand to expose the oil, then collecting the oil for disposal. At pebble beaches, oiled material was often pushed back into the active surf zone to allow for the physical washing of the oiled material.

Similar to EVOS, there was a large scale spill response effort following the grounding of the *Selandang Ayu.* Many of the techniques used for the cleanup were developed based on the response efforts to EVOS and appear to have been largely successful at removing the surface oil available at the time.

The Draft Final Natural Resource Damage Assessment (NRDA) Plan for the M/V *Selendang Ayu* Oil Spill dated October 2015 reports finding lingering oil in 21 of 24 subjectively selected beach zones, primarily in the supra-tidal zone, where oil was initially deposited during a storm following the spill. Samples of mussel tissue indicate at least some of the oil remains biologically available at low concentrations at least until 2008 when the study was conducted (IEC, 2015).

To date, there have been no further attempts to remove LO from areas affected by the *Selendang Ayu* spill. As noted in the Draft Final Report "Due to the logistical difficulties associated with site access and the potential for further disturbance of recovering areas via the use of construction equipment, the [*Selendang Ayu* NRDA] Trustees are not pursuing primary restoration" rather compensatory restoration activities are proposed instead. Therefore there are no techniques for removing LO developed for the *Selendang Ayu* that could be adapted to EVOS.

2.2.2 North Slope Crude Releases

There have been a number of crude oil releases on the North Slope and along the pipeline corridor, however the majority of these releases were to gravel pads or tundra. There are a few examples of minor releases adjacent to marine areas, however these releases occurred in winter impacting mostly snow covered areas and were successfully cleaned up following the release.

2.2.3 AMOCO Cadiz

The AMOCO Cadiz ran aground 3 miles off the coast of Brittany, France in 1978 resulting in the largest oil spill to date. Approximately 1.6M barrels of light crude oil were spilled into heavy seas complicating cleanup efforts. Oil that made landfall penetrated the sand to a depth of approximately 50 cm and separated into two or three layers due to the transfer of sand during the storm events at the time and immediately following the spill. An asphalt crust persisted for years in some places, and wildlife and ecological monitoring was conducted for years following the spill. There does not appear to have been any long-term evaluation of the LO from this incident or any methods developed to clean it up, so there are no techniques that might inform remediation of EVOS LO in PWS.

2.2.4 Gulf War Oil Spill

Perhaps the situation most similar to EVOS LO in PWS can be found in the Arabian Gulf as a result of the first Gulf War in 1990-1991. An estimated 10 million barrels of crude oil were released into the Gulf, however little to no spill response was conducted at the time of the release. Twenty years after the release, spill surveys were conducted to identify where oil has persisted and ecological recovery was slow. Large scale remediation projects were executed at three locations with the following goals:

- Increase suitable habitat for grazers and burrowing fauna
- Reduce total petroleum hydrocarbon levels and
- Improve physical processes, such as drainage

The three techniques used to accomplish these objectives were:

- Tilling to expose the oil followed by manual removal (dry tilling)
- Excavation and disposal of oiled sediment (complete removal)
- Tilling and flooding to liberate trapped oil followed by skimming or vacuuming (submerged tilling)

These activities, some conducted by the same organization working on EVOS LO, met with varying degrees of success, mostly based on the specific environment in which the oil was located.

Dry tilling was quite effective in the Gulf. However, PWS LO is located in the intertidal zone in typically saturated conditions. Additionally the Gulf project report indicates “Dry tilling is not an appropriate method when medium to heavy subsurface liquid oiling exists” (Minter et at., 2014) as is the case in PWS.

Complete removal was also quite effective, however this method was conducted on broad tidal flats that were dry at the time of treatment and the Gulf project report indicates “…complete removal may not be an appropriate method when subsurface liquid oiling is patchy…” (Minter et al., 2014) as is the case in PWS. Additional discussion of complete removal is included below in Section 3.2.1.

Submerged tilling met all of the Gulf projects objectives and was most effective at locations where heavy oil was present within tidal flats. Unfortunately this method as executed in the Arabian Gulf does not translate directly to PWS due to the nature of environments that were affected. In the Gulf, large, even, flat expanses of oiled areas were treated by berming the areas then either pumping water into each bermed treatment cell or allowing the tide to come in prior to tilling. The average water depth in the treatment cell was approximately 20 cm and in some cases, large heavy equipment was necessary to effectively mobilize oil into the flooded cell for treatment. In PWS, this activity could only be conducted in areas flooded by the tides, which are large and would require completely different equipment than that used in the Gulf. Additional discussion of submerged tilling is included below in Section 3.2.5.

3.0 Remediation Methods for Crude Oil

The natural processes by which oil weathers or is degraded in the environment include both physical and chemical processes. LO has been identified in discontinuous patches buried in sediments in the intertidal zone of some beaches in PWS, where it was deposited soon after it washed ashore from the Spill. The patches are not visible on the beach surface, as they are buried at average depths between 12 and 18 cm under boulder-armored beaches. One notable exception is an area on Knight Island referred to as KN-102, where peaty soil present at the surface absorbed EVOS oil like a sponge and continues to release that oil in small quantities in the immediate area. Because much of the LO is sequestered in the lower tidal zones or protected by boulder-armored beaches, degradation by physical processes is minimal (Venosa et al., 2010).

The chemical weathering of LO is affected by a number of factors including:

- The presence of oil degrading bacteria
- Nutrient availability
- The presence of oxygen

The presence of oil degrading bacteria has been noted in several previous studies (Venosa et al., 2010. Boufadel et al., 2014) however studies have also shown that the interval in which the LO is present is a nutrient-poor environment that is also low in oxygen (Venosa et al., 2010) therefore, candidate remediation technologies would have to either physically remove the oil from the subsurface or alter the subsurface environment in order to increase the rate of natural degradation.

3.1 Methods Evaluated by EVOSTC

Based on the results of lingering oil research, EVOSTC funded a project in 2015 to provide a list of candidate beaches, a summary of remediation methods that may be available, and a rough cost estimate for each method (Boufadel et al., 2015). Three methods were discussed in the project report and include:

- Monitored Natural Attenuation (MNA),
- Manual Technique (MT), and
- Bioremediation Technique (BT).

A pilot project involving the implementation of BT at four LO sites was conducted in 2011 and 2012 with varying results (Boufadel et al., 2014). The monitoring of natural attenuation has been an ongoing effort conducted by NOAA at five –year intervals. Manual technique has not been evaluated in a pilot study, however Boufadel et al provide a fairly detailed description of what this method would entail in their *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.

The applicability of BT and other non-manual techniques is somewhat limited as discussed in the sections below. Manual techniques potentially offer more promise however pilot studies have not yet been conducted so the discussion in the following sections is directed more towards evaluating the pros and cons of the various manual techniques and discussing their potential implementation as well as some of their limitations.

3.3.1 Bioremediation Technique

As described in Boufadel's *Pilot Studies of Bioremediation of the Exxon Valdez Oil in Prince William Sound:*

> "Bioremediation Technique requires delivery of oxygen and nutrients to enhance the natural biodegradation of oil, and in particular the biodegradation of the total polycyclic aromatic hydrocarbons (tPAH). Bioremediation technique relies on injecting oxygen and nutrients into oil-polluted sites. The bioremediation would need to be repeated yearly until the tPAH concentration decreases below the required threshold level."

A full description of BT and details on its implementation, effectiveness and approximate cost can be found in Boufadel's *Pilot Studies of Bioremediation of the Exxon Valdez Oil in Prince William Sound* and Boufadel et al.'s *Priorities, Methods, and Cost for Restoration of Lingering Subsurface Oil from the Exxon Valdez Oil Spill in Prince William Sound, Alaska.*
In summary, pilot studies of BT recorded annual biodegradation rates between 12% and 72% compared to the natural biodegradation rate of approximately 4% (Short et al., 2007). Bioremediation technique however requires beaches with hydrographic conditions that would allow for the subsurface delivery of nutrients to LO and only nine beaches were identified as potential candidates for BT.

3.3.2 Manual Technique

Manual techniques can vary, however some type of manual removal is likely the most common form of remediation at petroleum contaminated sites in Alaska. This technique is used at most leaking underground storage tank sites as well as a method of spill response for sudden releases resulting from above ground tank or piping failures, truck roll-overs and other sources.

As described in Boufadel and Geng's *Priorities, Methods, and Costs for Restoration of Lingering Subsurface Oil from the Exxon Valdez Oil Spill in Prince William, Sound*:

> "The Manual Technique (MT) … 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."

EVOSTC has not funded any pilot studies for MT. However, based on details in the Boufadel report and a general knowledge of the methods and techniques that would be used for MT, a desktop exercise can be conducted to further evaluate the pros and cons of this technique if it were to be implemented or if EVOSTC were to attempt a pilot study for this method. If implemented as detailed in the Boufadel report, this method would include the following activities:

- Manual or hand-held machinery would be used to remove overlying clean sediments from areas with LO. Oil that accumulated in the excavation would be collected using sorbent pads. Clean sediment would be staged for use as backfill.
- Oiled sediment would be manually collected into containers which would be transported to the trommel stationed on a barge near the site. A trommel is a rotating drum used to separate material by particle size.
- Sediment would be 'washed' in the trommel to separate free oil which would then be collected using sorbents or, if a heavy sludge were produced, collected into containers for disposal.
- Wash water would be recycled until saturated with hydrocarbons at which point it would be filtered through a granular activated carbon filter and discharged at the project site, pending ADEC approval.
- Clean sediment would be transported back to the excavation for use as backfill along with clean overburden. Clean sediment from one excavation could be used to backfill the next excavation.

In the absence of a pilot study, the effectiveness, feasibility, and cost of this method can only be estimated. The cost estimate developed by Boufadel to execute MT at all 63 sites is $13,470,383. A review of the detailed cost estimate and its assumptions as compared to the description provided in the report raises a few issues that could significantly increase the cost including the following:

- The pay rate for skilled labor is set at $65.00/hour. If the true rate were higher than this or if the estimated time or number of personnel necessary to complete the effort were to increase, the cost for labor would also increase.
- The estimate for labor does not appear to include overtime. Assuming this operation would take place during the summer months, it is likely that work would be conducted for at least 12 hours per day or more, which is typical for field work or construction projects in Alaska during the short summer season. Overtime pay could have a significant impact to the overall cost estimate.
- The equipment needs may be underestimated. For instance, the Boufadel cost estimate assumes one vessel for housing workers and then a barge to hold the trommel, however it is likely that a landing craft would also be necessary at each site to transport workers and equipment to and from the beach and transport oiled sediment from the work site to the barge.

- Containers of oiled sediment likely weighing hundreds or thousands of pounds would have to be moved from the work site to the barge. Simply lifting and transporting these containers could require heavy equipment that does appear to be included in the cost estimate.
- The cost estimate includes a 40% contingency on the final estimate, however that contingency is essentially negated by assigning a 0.66 multiplier on the Adjacent and Model-predicted sites to account for uncertainty. For cost estimating purposes, EVOSTC should consider adding back in the contingency.

The tidal cycle is approximately 6-7 hours between high and low tides, however this time period is subject to much local variation. Depending on the location of LO patches relative to mean high water, the amount of time available to conduct manual removal will differ i.e. there will be more time between tides to remove LO from patches closer in elevation to mean high water than from areas further below mean high water. Local variation in the ebb and flow of the tide is likely such that the amount of time available to conduct manual removal from some sites could be extremely limited.

Considering that personnel would have to stage equipment, manually excavate sediment from beneath armored intertidal areas, collect free oil using sorbent pads, collect oiled sediment into a container, transport the container to a vessel, load then unload the container onto the barge, wash the sediment, handle the waste, then return to backfill the excavation and remove equipment from the area, there may simply not be enough time between tides to safely and effectively implement MT at some locations. If clean sediment from previous excavations was available to be immediately backfilled into an existing excavation, this time could be reduced, however it would be very difficult to 'budget' the sediment such that enough was available for backfill at each excavation. If an oil patch was not able to be treated in one tide cycle, that could significantly impact the duration and cost of removal and potentially increase the risk of secondary release.

Assuming cost and timing issues could be adequately addressed, the pros and cons of conducting the activity itself would need to be carefully considered before proceeding with the actual work. Some of the pros include:

- More thorough removal of oil and oiled sediments from the impacted areas.
- Reduced time frame and associated costs for long-term monitoring as the long-term effects will be lessened or eliminated by manual removal.

Cons include:

- Extreme short-term disturbance of the immediate area including intertidal and upland areas.
- High likelihood of remobilizing LO back into the environment impacting water quality and potential bioavailability.
- Risk of spills from the transport and use of petroleum and other products necessary to conduct the cleanup.
- Labor and resource intensive considering manpower, equipment and facilities necessary to house workers and transport workers and equipment to the sites. The collection, handling, transport, and disposal of oily waste would also be time and resource intensive.

- Unknown recovery time for disturbed areas to return to equilibrium.

The cost of MT could vary widely from site to site based on the factors noted above and the impacts to the surrounding area could be significant. If EVOSTC were interested in pursuing MT as described by Boufadel, a pilot project and cost benefit analysis should be conducted to better understand the potential impacts of MT and also get a better estimate of the cost.

A pilot project at one of the more amenable LO sites could probably be conducted for $150,000-$300,000 depending on the size of the oil patch proposed for the pilot study. This would include permitting, labor, transportation, work plan and report preparation, agency review, and waste handling and disposal. Information gathered during the pilot project would then be used to conduct a cost/benefit analysis which would likely cost around $30,000-$50,000 depending on the number of remedial options being considered

3.3.3 Monitored Natural Attenuation

As described in Boufadel and Geng's *Priorities, Methods, and Costs for Restoration of Lingering Subsurface Oil from the Exxon Valdez Oil Spill in Prince William, Sound*:

> "…a MNA monitoring plan could include elements of the Lingering Oil component of the EVOS TC project titled 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."

As noted by Boufadel and Geng, Gulf Watch Alaska is already collecting some of the elements necessary to evaluate MNA as a potential long-term solution to LO however there is likely additional data that could be collected to document the rate of MNA at particular sites where LO is present.

MNA is a common approach at petroleum contaminated sites that pose little or no risk to human health and the environment or where active remediation is unfeasible due to cost or technical constraints. The pros of an MNA approach include:

- Relatively low cost to implement and maintain.
- The LO would remain in place lessening concerns over the impacts from secondary release into the environment resulting from active disturbance.
- Health and safety concerns with MNA are much more easily quantified.

The cons of an MNA approach include:

- The amount of time for all LO to disappear from PWS would be significant, likely several decades at least.
- In the interim, the potential would remain, albeit low, for organisms to come into contact with LO or for some weather or climate event to disturb the LO resulting in a secondary release.

To date, EVOSTC reports spending approximately $1,250,000 for twenty-two years of passive sampling and database upkeep for the monitoring program currently in place at 10-12 sites. This equates to a simple yearly average of approximately $57,000. The monitoring is currently conducted by Gulf Watch Alaska under direction of the National Oceanic and Atmospheric Administration. If this agency were no longer able to conduct the monitoring and EVOSTC contracted this activity with the private sector, there is the potential that costs could go up. If the monitoring were to be expanded to all 63 sites and additional monitoring parameters added, the cost per year would increase to $300,000 to $500,000 per year, however it is unlikely that the same level of monitoring would need to be conducted every year.

ADEC notes that currently there are 23 beaches within the initial spill area that are listed as 'impaired water bodies' under the Clean Water Act. The locations of these beaches are generally included in the 63 sites noted by Boufadel as having heavy or moderate concentrations of LO. If MNA were selected as the most appropriate remedial option, data could be collected for the purposes of complying with Clean Water Act requirements.

3.2 Other Potential Remediation Methods

The *Exxon Valdez* oil spill was an unprecedented event in US waters at the time it occurred. Similarly, the presence of relatively un-weathered subsurface LO in the intertidal zone beneath beaches in a marine environment such as PWS also appears to be an unprecedented situation. There have been many advances in the science of spill response and new techniques are available to responders to clean up spill after they occur, however these advances are all focused on spill response, not on cleanup that occurs decades after the spill. ADEC has been overseeing the investigation and cleanup of petroleum contamination in soil and groundwater for over 25 years and while there are few to no projects in ADEC's records that are similar to the LO situation in PWS, there are a number of traditional remediation methods that are typically considered for petroleum contamination. A number of these methods are discussed in more detail below.

3.2.1 Excavation/Complete Removal

The excavation and treatment or disposal of petroleum contaminated material is likely the most common method of remediation in the State of Alaska. Excavation contractors and equipment are present in both large and small communities, some landfills are permitted to accept petroleum contaminated material for disposal and there are thermal treatment facilities in Anchorage, North Pole, Bethel, and Deadhorse.

Excavation as a remediation method for LO would differ from MT in that the contaminated sediments would be removed entirely and transported to a disposal or treatment facility. While effective, this method would result in significant disruption to the area being excavated, require significant manpower and resources, and also require the transport of contaminated material for long distances over land and water. There would be a high likelihood of secondary release and clean material would have to be obtained to backfill the excavations.

The contaminated sediment from PWS would likely not be suitable for disposal in a landfill so the material would have to be transported to a thermal treatment facility in another part of the State, or a mobile treatment facility would have to transported and set up in a central location. Treatment costs would be nominal assuming 510 cubic meters of sediment would be excavated as noted in Boufadel et al. The more significant costs would be associated with mobilization, executing the work as the tides allow, controlling and responding to secondary releases, and transportation. These costs should be more firmly established by EVOSTC before any significant consideration of complete removal is considered.

3.2.2 In-Situ Chemical Oxidation

In-situ chemical oxidation (ISCO) involves the injection of often proprietary chemicals, including strong oxidizers into a petroleum contaminated area to destroy the contaminants in place. ISCO is typically tailored to the lithology of a site and can be beneficial at reducing contaminant concentrations in both soil and groundwater.

ISCO as a remediation method for LO presents a number of challenges that would likely remove it from further consideration for use in PWS. The chemicals used for most ISCO applications may be unsuitable for use in a marine environment such as PWS and would not likely be appropriate for injection into the intertidal zones at LO sites. Combined with the high cost of obtaining enough commercial product to have an impact on LO and the hazards associated with transporting and handling the chemicals, ISCO would likely be removed from consideration early on in the screening phase if EVOSTC were to conduct additional evaluation of remediation methods

3.2.3 Air Sparging

Air sparging involves the injection of air under pressure into the subsurface to increase aerobic degradation by increasing oxygen levels in groundwater and also volatilizing the lighter end hydrocarbons found in refined fuels such as gasoline. While the presence of oxygen is a limiting factor in the biodegradation of LO in PWS, air sparging would not likely be appropriate in the intertidal zone because of the likelihood that the pressure created by the injection of air would cause a release of LO into the environment.

3.2.4 Vapor Extraction

Vapor extraction is the opposite of air sparging in that a vacuum is placed on wells or piping in the subsurface to extract hydrocarbon vapors from the vadose zone. Because of the lack of hydrocarbon vapors associated with crude oil and the saturated nature of the intertidal zone, vapor extraction is not a viable alternative for LO in PWS.

3.2.5 Submerged Tilling

Submerged tilling, while not a common remedial method, may be worthy of consideration by EVOSTC. Similar to the method described in Section 2.2.4, this method would involve intentionally mobilizing the LO into the water column to be either collected using sorbents or solidifiers, or burned in-situ. The impacts to the surrounding area could be minimized by using a silt curtain to control the migration of oil and contaminated sediment away from the immediate project area as well as sorbent boom to collect any stray oil migrating on the surface. This method would likely result in more complete removal than in-situ techniques and the transport and disposal of oily waste would only involve the spent sorbents or solidifiers, which would retain the oil during transport. Disposal of sorbents or solidifiers may be more economical than would the disposal of oiled sediments.

This technique would cause disturbance of the surface and shallow subsurface, however no sediment would be removed, so backfill would not be necessary. This approach shares some similarities with MT, but differs in that the LO would be mobilized into the water for collection rather than excavating and treating sediments using a trommel as proposed by Boufadel et al.

There would necessarily be impacts to water quality while the operation is taking place, but those impacts could be minimized and would likely be of short duration. While not an entirely novel concept, submerged tilling may be worth further evaluation by EVOSTC.

4.0 Areas for Additional Study

Since the Spill, a large amount of information has been collected to evaluate the impacts of the Spill to the various resources in PWS. Significant effort has been put into the evaluation of LO, and several methods of removing or reducing the amount of LO have been evaluated to an extent. If more detailed information is desired, the following work may be pursued:

- Pilot testing for the Manual Technique (MT) and other manual methods
- A focused feasibility study to further evaluate remediation methods
- A cost/benefit analysis to weigh the potential benefits against the potential cost of remediation.

4.1 Pilot Testing

The 2015 document *Priorities, Methods, and Costs for Restoration of Lingering Subsurface Oil from the Exxon Valdez Oil Spill in Prince William Sounds, Alaska* (Boufadel et al., 2015) provides a summary of much of the LO research that was conducted since 2006 including the modeling effort that generated the list of 63 candidate sites, a review of potential treatment methods including BT, MT, and MNA and rough cost estimates for each technique to be implemented.

In order to proceed with a more objective evaluation of potential remedial methods, a pilot test for MT as well as any of the other methods discussed above, could be conducted at one or more of the 63 candidate sites to provide information critical to deciding whether or not active remediation would result in a benefit to the injured resources and human services of PWS.

4.2 Focused Feasibility Study

The Focused Feasibility Study (FFS) for LO in PWS would evaluate the viable remediation methods for their technical feasibility and likely effectiveness and up to date cost estimates would be produced for each of the proposed techniques. The FFS would incorporate information gathered during pilot studies then screen each of the techniques against some or all of the following criteria:

1. Overall protection of Human Health and the Environment
2. Short- and long-term effectiveness
3. Reduction in toxicity, mobility, or volume of LO
4. Implementability
5. Cost
6. Stakeholder acceptance

Based on the results of this evaluation and considering the scope of any significant remedial undertaking, a detailed cost/benefit analysis could then be prepared.

4.3 Cost/Benefit Analysis

In the *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.* Boufadel et al state that:

> "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."

A detailed cost/benefit analysis would be critical to any decision to move forward with the cleanup of LO in PWS.

Regardless of which remedial action is chosen, the cost benefit analysis will have to consider the costs and benefits to <u>all</u> potentially injured resources including:

1. Animal populations in the affected area
2. Subsistence use

3. Recreation and tourism
4. Commercial fishing
5. Water quality
6. Passive use

If EVOSTC is interested in moving forward with active remediation a detailed analysis of the costs and benefits to each to these resources would be necessary before an informed decision could be made on whether or not to proceed with active remediation at one or more of the LO sites.

5.0 Discussion and Cost Estimates

The presence of LO at some PWS beaches is of concern to EVOSTC and the various stakeholders in the spill affected areas. In an effort to evaluate the causes and potential solutions to the LO issue, significant time and resources have been expended in conducting research into the causes and impacts of LO and potential methods to reduce the amount of LO. Over the course of the last 15 years, research conducted in this area provided the following information regarding LO:

1. The LO remains in some beaches largely due to the geology, which has sequestered the LO in the subsurface beneath beach armoring. This protects the LO from the physical weathering that would be most effective at breaking it down.
2. LO has not experienced significant chemical breakdown or biodegradation due to a lack of oxygen and nutrients in the subsurface.
3. LO does not appear to be bioavailable or negatively impacting water quality.
4. LO does not appear to be impacting the injured resources that are not recovering from the initial spill.
5. LO will continue to impact Human Services, at least through the perception of continued injury, as long as the LO remains.

Research seems to indicate that the mere presence of LO is not causing harm to the ecosystem of PWS or its injured resources, therefore any decision on whether or not to actively remediate areas of LO should be made carefully after fully evaluating the potential costs versus the potential benefits

Boufadel et al. and EVOS LO researchers have developed three potentially viable methods of reducing the amount of LO in the spill affected area, however if EVOSTC would like to proceed with one or a combination of the active methods, more work would be needed to better refine potential issues, costs and effects.

Estimating costs can be difficult without a very specific scope of work upon which to base the cost estimate. If EVOSTC were interested in preparing detailed cost estimates for pilot testing, feasibility study, or cost/benefit analysis, ADEC’s contractors would be well suited to provide these cost estimates if a specific scope of work were to be provided.

6.0 References

Michel, J., Esler, D., Nixon, Z., 2016, Report for the Exxon Valdez Trustee Council. Studies on Exxon Valdez Lingering Oil: Review and Update on Recent Findings- February 2016.

Industrial Economics, Incorporated (IEC, 2015), Natural Resource Damage Assessment Plan for the M/V *Selendang Ayu* Oil Spill, Draft Final, October 2015

Minter, T.G., Hale, J.A., Cormack, C.D., Cotsapas, L., Michel, J. (2014)Tidal Flat and Sand Beach Remediation: Choosing Remediation Techniques to Speed Ecological Recovery of Habitats Still Impacted 20 Years after the Gulf War Oil Spill.

Venosa, A.D., P. Campo, and M.T. Suidan (2010), Biodegradability of lingering crude oil 19 years after the *Exxon Valdez* oil spill, Environmental Science & Technology, 44(19), 7613-7621.

Boufadel, M.C. (2014), Pilot Studies of Bioremediation of the *Exxon Valdez* Oil in Prince William Sound Beaches. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 11100836). New Jersey Institute of Technology, Newark, NJ. 91 pp + appendices.

Boufadel, M.C., *et al.*, 2015. Priorities, Methods, and Costs for Restoration of Lingering Subsurface Oil from the *Exxon Valdez* Spill in Prince William Sound, Alaska

Short, J. W.; Irvine, G. V.; Mann, D. H.; Maselko, J. M.; Pella, J. J.; Lindeberg, M. R.; Payne, J. R.; Driskell, W. B.; Rice, S. D. (2007) Slightly weathered Exxon Valdez Oil persists in Gulf of Alaska beach sediments after 16 years. *Environ. Sci. Technol.* 2007, *41*, 1245– 1250.