PROPOSAL FORM

THIS FORM MUST BE SUBMITTED BY THE PROPOSED PRINCIPAL INVESTIGATOR (S) AND SUBMITTED ALONG WITH THE PROPOSAL.

By submission of this proposal, I agree to abide by the Trustee Council's data policy (*Trustee Council Data Policy**, adopted March 17, 2008) and reporting requirements *(Procedures for the Preparation and Distribution of Reports***, adopted June 27, 2007).

PROJECT TITLE: ______Pilot studies of bioremediation of the Exxon Valdez oil in Prince William Sound beaches

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** www.evostc.state.ak.us/Policies/reporting.cfm

FY11 INVITATION
PROPOSAL SUMMARY PAGE

Project Title: Pilot studies of bioremediation of the Exxon Valdez oil in Prince William Sound Beaches

Project Period: 2011-2012

Primary Investigator(s): Michel Boufadel, Temple University, Jacqui Michel, Research Planning Inc

Study Location: EL056C, SM006B, Montague Island

Abstract:
Oil from the Exxon Valdez persists on initially polluted beaches and contains a considerable fraction of the toxic compounds polycyclic aromatic hydrocarbons (PAHs). The results of the "Oil biodegradation" project by Albert Venosa revealed that more than 80% of the total PAHs (TPAHs) biodegrade within six months when exposed to an environment rich with dissolved oxygen and nutrients. Results from the "Limiting factors" project by Michel Boufadel revealed that the nutrient concentration was an order of magnitude lower than needed for optimal oil biodegradation. It was also found that the dissolved oxygen concentration at oiled pits was, in general, less than 1.0 mg/L. Therefore, anoxic conditions exist, which means that aerobic biodegradation of oil is not occurring. Therefore, both oxygen and nutrient limitations are occurring. While the Venosa study demonstrated oil biodegradability, the actual rate of oil biodegradation in the field when provided with sufficient oxygen and nutrient can be evaluated only through a pilot study of bioremediation, as we are proposing herein. Due to the high dilution for chemicals applied onto the beach surface, we evaluated the delivery of oxygen and nutrient solutions into the beaches subsurface through tracer studies. The tracer experiments revealed that the tracer delivered into the subsurface travelled distances of meters with minimal dilution. Therefore, we are proposing herein to pursue the same approach for delivering solutions of hydrogen peroxide, sodium nitrate, and sodium tripolyphosphate. Sediment samples will be obtained at various times from various locations and will be analyzed for oil composition. Surrogate measures for oil biodegradation include microbial population and the nutrient concentration. The selection of the beaches for the study will be made based on the "Limiting Factor project" and the "Spatial oil distribution" project by Jacqui Michel. Findings from the latter project will be relied upon to upscale the pilot scale results of this study.

Estimated Budget:
EVOS Funding Requested: $1,586,785
(breakdown by fiscal year and must include 9% GA)

Non-EVOS Funds to be used:
(breakdown by fiscal year)

Date: 01/07/2011

Summary of the results of the project: “Factors responsible for limiting the degradation rate of Exxon Valdez oil in Prince William Sound beaches”.

PI: Michel C. Boufadel

Contract: No. AB133F-07-CN0099

It is customary for PIs to have a section summarizing the work that was done in prior funding. However, as this proposal is closely related to our prior work, and we are citing the prior work extensively in this proposal, we would be providing the summary in the body of the proposal. Therefore, the summary will not be provided herein to minimize redundancy.

Thirteen journal publications have resulted so far from this project, and all of them acknowledged support from the EVOSTC. Two additional articles are submitted, and five are in preparation for submission by April 01, 2011.

The papers that are published/in press/accepted are:

1) Li, H. (Postdoctoral Fellow**), M. C. Boufadel**, Long-term persistence of oil from the Exxon Valdez spill in two-layer beaches, ***NATURE geosciences***, *3*, 96-99, 2010.
2) **Boufadel, M. C.**, Y. Sharifi, B.Van Aken, B. A. Wrenn, and K. Lee, Nutrient and oxygen concentrations within the sediments of an Alaskan beach polluted with the *Exxon Valdez* oil spill, ***Environmental Science and Technology***, *44* (19), p 7418–7424, 2010.
3) Xia, Y.(Graduate Student), H. Li., and **M. C. Boufadel**, Factors affecting the persistence of the Exxon Valdez oil on a shallow bedrock beach, ***Water Resources Research***, 46, W10528, 17 PP., 2010 doi:10.1029/2010WR009179.
4) Guo, Q. (Graduate Student), H. Li., **M. C. Boufadel**, and Y. Sharifi, Hydrodynamics in a gravel beach and its impact on the Exxon Valdez oil spill, ***Journal of Geophysical Research, Oceans,*** 115, C12077, doi:10.1029/2010JC006169, 2010.
5) Sharifi, Y. (Graduate Student), B. V. Aken, and **M. C., Boufadel**, The effect of pore water chemistry on the biodegradation of the Exxon Valdez oil spill , ***Journal of Water Quality, Exposure and Health***, Springer, DOI 10.1007/s12403-010-0033-4, 2010.
6) **Boufadel, M. C.** and A. D. Bobo, High pressure delivery of tracer simulating nutrients for the bioremediation of the Exxon Valdez oil, ***Groundwater Monitoring and Remediation***, in press, 2011.
7) Xia, Y. (Graduate Student) and **M. C. Boufadel**, Beach geomorphic factors for the persistence of subsurface oil from the Exxon Valdez spill in Alaska, ***Environmental Monitoring and Assessment,*** in press, 2011**.**
8) Bobo, A. (Graduate Student), H. Li, and **M. C. Boufadel**, Groundwater flow in a tidally influenced gravel beach in Prince William Sound, Alaska, ***Journal of Hydrologic Engineering, ASCE***, accepted, 2011.
9) **Boufadel M. C.**, A. Bobo, and Y. Xia, Feasibility of deep nutrients delivery into a Prince William Sound beach for the bioremediation of the Exxon Valdez oil spill, ***Ground Water Monitoring and Remediation***, accepted, 2011.
10) Li, H. (Postdoctoral fellow), A. D. Venosa, and **M. C. Boufadel**, A universal nutrient application strategy for the bioremediation of oil polluted beaches, ***Marine Pollution Bulletin,*** 54, 1146-1161, 2007.
11) Li, H.(Postdoctoral fellow), **M. C. Boufadel**, and J. W. Weaver, Tide-induced seawater-groundwater circulation in shallow beach aquifers, ***J. of Hydrology***, 211-224, 2008.

12) Li, H. (Postdoctoral Fellow), **M. C. Boufadel**, and J. W. Weaver, Numerical simulations of the bank-storage effects of unconfined aquifers abutting open water bodies with rising water level, ***Ground Water***, 46(6), 841-850, 2008.
13) Abdollahi-Nasab, A. (Graduate Student), **M. C. Boufadel**, Li, H., and J. W. Weaver, Saltwater flushing by freshwater in a laboratory beach, ***Journal of Hydrology***, 386,1-12, 2010.

Journal articles 10 through 13 provided a foundation for the numerical simulations of our field results from the PWS. In other words, they allowed us to "build our case", to validate our approach.

The following two articles reporting field results from Prince William Sound are already submitted:
14) Abdollahi-nasab, A. (Graduate Student), H. Li, and **M. C. Boufadel**, The role of freshwater for the persistence of the Exxon Valdez oil in a wave-exposed beach in Alaska, ***Journal of Environmental Engineering, ASCE***, submitted
15) Li, H., and **M. C. Boufadel**, A tracer study and its implications for the persistence of oil from the Exxon Valdez in a gravel beach in Prince William Sound, Alaska, USA, ***Marine Pollution Bulletin***, submitted 2011.

I. NEED FOR THE PROJECT

A. Problem Statement

The 1989 Exxon Valdez oil spill polluted around 800 km of intertidal shorelines within Prince William Sound, Alaska (Bragg et al. 1994; Neff and Stubblefield 1995; Neff et al. 1995). Recent studies by scientists from the National Oceanic and Atmospheric Administration (NOAA) (Short et al. 2004; Short et al. 2006) estimated that between 60 and 100 tons of subsurface oil persists in many initially-polluted beaches in Prince William Sound (PWS). The persistence of oil was noted by other studies (Li and Boufadel 2010; Michel and Hayes 1999; Page et al. 2008; Taylor and Reimer 2008). Short et al. (2004) found that the oil contains a relatively high percentage of Polycyclic Aromatic Hydrocarbons (PAH) known to be toxic to the fauna and flora (Carls et al. 2001). Short et al. (2006) reported that sea otters and harlequin ducks foraging the beaches in northern Knight Island would encounter subsurface lingering Exxon Valdez oil.

The Exxon Valdez Trustee Council funded three projects in relation to the lingering oil. They are: 1) "Distribution of Subsurface Oil from the *Exxon Valdez* Oil Spill", led by Dr. Jacqui Michel, 2) "Factors responsible for limiting the degradation rate of Exxon Valdez oil in Prince William Sound beaches" led by Dr. Michel Boufadel, and 3) Oil biodegradability led by Dr. Albert Venosa.

The "oil distribution" project (Michel et al., 2010) provided a detailed assessment on the oil distribution at various beaches in PWS, and a probabilistic model on the areal distribution of oil. The work also provided correlations between oil persistence and geomorphic and hydrologic parameters (slope of beach, freshwater, armoring, etc.). The "oil distribution" project would be used as a basis for scaling up the results of the pilot study that we are proposing herein.

Our work (Boufadel and coworkers) investigated the factors affecting the persistence of oil in six beaches in PWS (Fig.1). Four of the beaches were lentic and the remaining two were lotic (i.e., exposed to waves). On each beach, they set up a transect passing through the oiled area of the beach and a transect in the clean area. The publications explaining the hydrologic-geomorphic factors on each beach are as follows: Beach 1 (Li and Boufadel, 2010), Beach 2 (Bobo et al., 2010), Beach 4 (Xia et al., 2010 and Guo et al., 2010), Beach 5 (Xia and Boufadel, 2010). We found that, with the exception of Beach 2, all the beaches that we studied are heavily polluted, with oil content varying between moderate oil residue (MOR) to heavy oil residue (HOR). The oil content at Beach 2 was light oil residue (LOR).

We found that, in general, the beaches can be viewed as consisting of two layers: an upper layer that has a high permeability underlain by a layer that has a permeability that is 100 to 1,000 folds smaller than that in the upper layer. Oil was present in the lower layer just a few inches (0.10 m) below the interface of the two layers (Fig. 2). In addition, on four of the six beaches (Beach 1, 2, 4, and 6, Fig. 1), the water table remained above the interface of the two layers in the clean transect while it dropped into the lower layer in the oiled transect. The water table remained above the interface of the two layers due to a large freshwater groundwater flow into the beach especially during low tide.

At Beach 5 (Fig. 1), no freshwater was found. But the clean transect had a steep slope (11%) in comparison with the oiled transect (7%). In addition, the armor on the clean transect was much weaker than that on the oiled transect. Xia and Boufadel (2010) argued that these two factors enhanced water exchange between the sea and the pore water in the beach causing either the washout of the oil or its accelerated weathering and biodegradation (in comparison with the oiled transect). The role of armoring and its effect on oil weathering was thoroughly discussed in Michel and Hayes (1999), Hayes and Michel (1999), Hayes et al., (2009, and Michel et al. (2010).

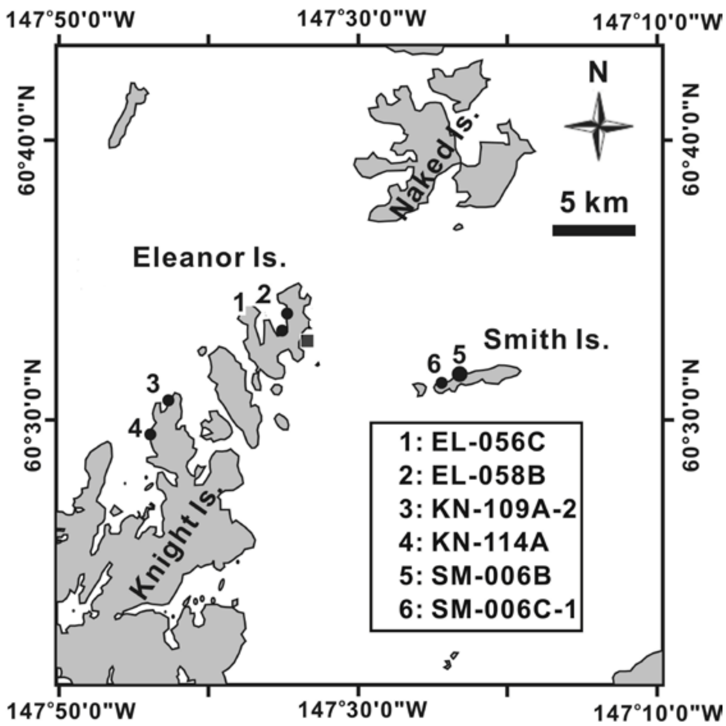

Figure 1: Location of beaches (filled circles with numbers next to them) in Prince William Sound investigated in the Limiting Factor Study by Boufadel. Sites 1 through 4 were in sheltered areas whereas sites 5 and 6 were exposed to waves from a 60 km fetch. For the Oil Biodegradation project by Albert Venosa, oiled sediments were taken from sites 4, 5, and from PWS3A4 (the square symbol on the west side of Eleanor Island).

The data at Beach 3 suggest a random distribution of oil at the 1.0-m scale- in other words, there is no clear correlation between the large-scale hydrology or geomorphology and oil persistence (manuscript in preparation).

In Summer 2009, we measured the concentration of nutrients and dissolved oxygen (DO) in the lower layer of two beaches: Beach 1 (Boufadel et al., 2010) and Beach 6 (Sharifi et al., 2010), Fig. 1. We found that the levels of nitrogen and phosphorous were approximately 0.40 mg-N/ L and 0.033 mg-P/L, respectively. Our nitrogen value is similar to that found by Bragg et al., (1994) and Atlas and Bragg (2009). The optimal values for nitrogen are 2.0 to 10 mg-N/L

(Venosa et al., 1996; Boufadel et al., 1999; Du et al., 1999, Zhu et al., 2001), and those for phosphorus vary from 0.2 to 1.0 mg/L. Thus, the measured concentration of both nitrogen and phosphorus are approximately an order of magnitude lower than the optimum.

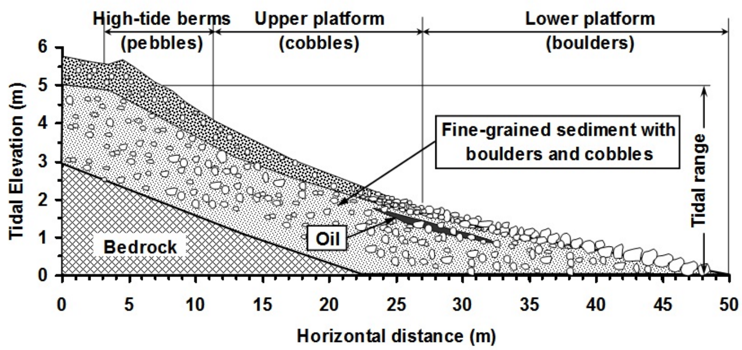

Fig. 2: Persistence of oil in the lower layer of beaches in Prince William Sound. Copyright Nature Publishing Group, from Li and Boufadel (February, 2010).

To accurately measure the oxygen concentration in the lower layer, we placed sensors in the pits and filled the pits and awaited 9 weeks before conducting measurements. Driving sensors into the beach is almost an impossible task (Page et al., 2008). We found that the DO varied from higher than 3 mg/L in the clean locations to less than 1 mg/L in the oily pits (Li and Boufadel, 2010; Boufadel et al., 2010; Sharifi et al., 2010). In addition, while the ammonia concentration was more or less uniform in the beach (at about 0.25 mg-N/L), the nitrate concentration at oily pits was around 0.04 mg/L, an order of magnitude smaller than the average, which suggests that nitrification of ammonia to nitrate was not occurring, a situation due to the low DO. This indicates that anoxic conditions exist in the oiled areas and they prevent the aerobic biodegradation of oil (or slow it down tremendously).

Pore water moving within the beach loses its dissolved oxygen due to biochemical oxygen demand from biogenic material and the oil. The pattern of pore water flow within tidally influenced beaches is very dynamic with water from the sea filling the beach near the high tide line and propagating seaward within the beach (Attai-Ashtiani et al., 1999, 2001; Boufadel, 2000; Li et al., 2008). Thus, the DO tends to decrease going seaward, as illustrated in Figure 3.

In our work on Beach 1 (Boufadel et al., 2010) and Beach 6 (Sharifi et al., 2010), we found the DO to vary from 3.0 mg/L to 9.0 mg/L in the clean transects. The latter value being the same as the DO value measured in the open water near the beaches, which indicates that the 3.0 mg/L can only result from the consumption of oxygen by biodegradation (i.e., oxidation) of biogenic matter (as no oil was present there). Therefore, for the low DO values at the oiled areas, one cannot rule out a combination of biodegradation of biogenic matter and of the hydrocarbons.

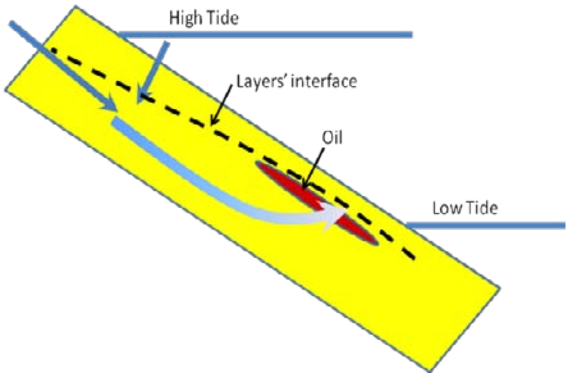

Figure 1: Schematic of water flow within an oiled transect. The beach fills from the landward side and from the sea near the high tide line (large blue arrows). As water moves seaward within the beach (curved arrow), it loses its dissolved oxygen and nitrate. Measurements above the oil layer in the upper layer would provide high dissolved oxygen values due to the large permeability of the upper layer. Copyright American Chemical Society (from Boufadel et al., 2010).

The biodegradation of the Exxon Valdez oil under oxygen-rich (i.e., aerobic) nutrient-rich conditions was demonstrated in Venosa et al. (2010) where more than 80% of the total PAHs (TPAH) degraded within 170 days. In that study, oiled sediment samples were taken from Beach 1, Beach 4, and PWS3A4 (see Figure 1) and they were put in microcosms and supplied with nutrients whenever the nitrogen concentration dropped below 5.0 mg/L. The excavation of the sediments from the beaches, their transport from Alaska to Ohio (where the experiments were conducted), and their mixing in large 55 gallons drums to homogenize them (Albert Venosa, personal communication) made the oil more physically accessible to the ambient water in the microcosm and its abundant content of DO and nutrients (i.e, the mixing minimized mass-transfer resistance). Venosa et al (2010) addressed this point and stated that the microcosm results could be viewed as upper limits for field biodegradation. In other words, the extent of biodegradation in the field would be, most likely, smaller than that found in the microcosms. Unfortunately, the extent of field biodegradation cannot be inferred from that of the microcosms and can be obtained only through a pilot study, which is the objective of this proposal.

The main objective of this proposal is to conduct pilot studies of bioremediation of the EVOS through delivery of hydrogen peroxide and nutrients.

B. Relevance to the 1994 Restoration Plan Goals

The proposed research will consist of the field trials to confirm the factors limiting natural recovery and demonstrate the effectiveness of the proposed technologies to speed natural recovery through addition of oxygen and nutrient.

If this the technology that we are proposing is effective, it would lead to development of a comprehensive bioremediation plan that will restore habitats that are adversely impacted by the lingering oil. The benefits of this research to the evaluation and implementation of bioremediation in PWS is consistent with the EVOSTC objective of determining whether remediation of specific shorelines would protect or restore injured resources.

Michel et al. (2006) evaluated various cleanup technologies for the EVOS, and ranked bioremediation highest amongst the active technologies. Natural attenuation was ranked highest due to a high penalty assigned to the disruption of the environment. In comparison with mechanical removal of the oiled sediments, bioremediation has three salient advantages: 1) It is not too disruptive to the environment and does not increase the exposure of sensitive species during remedial operations, 2) It does not require locating the oil accurately (say to within centimeters), as the delivery methods (if done properly) would ensure complete coverage of the oiled areas, and 3) unlike mechanical removal where large volumes of contaminated sediments would need to be transported out of the PWS, bioremediation occurs in-situ.

The primary beneficiaries of this research would be natural resources in PWS that have not yet fully recovered from the EVOS due to exposure to the lingering oil and the human communities that depend on these resources for their livelihood and quality of life.

II. PROJECT DESIGN

A. Objective:

The main objective of this proposal is to conduct pilot studies of bioremediation of the EVOS through delivery of hydrogen peroxide and nutrients.

We propose to conduct pilot studies of bioremediation on beaches with oil content that is moderate oil residue (MOR) to heavy oil residue (HOR), and we will ensure that the oiled areas receive sufficiently high concentrations of oxygen and nutrients. The method of delivery and the chemical composition of the solutions are key parameters and are discussed next.

B. Procedural and Scientific Methods

Method of Delivery

With the exception of the zone near the high tide line, the net movement of pore water applied onto the beach surface is seaward in any beach subjected to tide (Boufadel et al., 2006, Li et al., 2007, Brovelli et al., 2007). Therefore, solutions applied onto the beach surface would tend to be washed out to sea. Due to the two layers configuration in the beaches of PWS, where the upper layer has a permeability that is 100 to 1,000 times that of the lower layer, solutions applied onto the surface tend to dilute and wash out to sea rapidly. This was indeed noted by Xia et al. (2010) who conducted numerical simulations (based on field results) and found that 1% of the hypothetical applied nutrient concentration reaches the oil after 2 days. Therefore it is highly likely that surface application is not promising except in situations where the oil layer is very shallow and the surface application is in localized form (i.e. placing the solution directly on the oil).

Based on the findings in the field studies in 2007 and 2008, we conducted tracer studies in 2009 at two beaches in PWS (Beach 1 and Beach 6), where a conservative tracer (lithium in a lithium bromide solution) was delivered directly into the lower layer. We found that, in comparison with the surface application, subsurface delivery result in much lower dilution due to two factors: 1) The porosity of the lower layer is 5 to 10% of the total volume while that of the upper layer is more than 30% (Bobo et al., 2011). This implies that in the absence of any pore water movement, the dilution in the upper layer is 3 to 6 times that in the lower layer. 2) As the permeability is proportional to the cube of the porosity, e.g., the Kozeny-Carmen equation (Bobo et al., 2011) a ratio of 3 to 6 in porosity results in a difference of 30 to more than 200 folds in the permeability (the modeling gave a ratio of 1,000 folds in permeability in some cases). Therefore, subsurface delivery is considerably superior to surface application. Air sparging (i.e, injecting air) is not promising due to the shallow depth of the bedrock. Thus, injected air would float by buoyancy to the surface near the injection well and the impact will be very limited (Wong et al., 1997).

For the reasons mentioned above, we propose to follow the same approach that we conducted in Summer 2009, which is to deliver the solutions to the lower layer of the beaches. We will report our prior findings on the topic as we present our approach (below) to minimize redundancy.

Chemical Composition

We will ensure that the chemical solutions delivered into the beaches (subsurface injection or release) have the maximum concentrations of oxygen and nutrients permissible by the logistics, environmental concerns, and safety. Using seawater from the Sound near the beach of interest, the delivered solution will have a concentration of hydrogen peroxide H_2O_2 of 100 mg/L, and will be amended with the compounds lithium nitrate ($LiNO_3$) and sodium tripolyphosphate ($Na_5P_3O_{10}$) to obtain concentrations of 50 mg/L of nitrogen and 5.0 mg/L of phosphorous. This ratio of N:P meets the expected stoichiometric requirements for hydrocarbon degradation and has been shown to support rapid biodegradation of phenanthrene, whereas lower N:P ratios (i.e., higher phosphorus concentrations) resulted in slower biodegradation of PAHs (Garcia-Blanco, 2004). Other cations would be considered for the nutrient compounds based on cost. Examples include sodium nitrate ($NaNO_3$) or potassium nitrate (KNO_3).

Hydrogen peroxide was selected as the source of oxygen for this study because it is water soluble, decomposes to oxygen and water as the only products (Pardieck et al., 1992), and is an efficient source of oxygen (0.47 grams of O_2 are produced per gram of H_2O_2). Other alternative oxygen sources, such as calcium and magnesium peroxides (e.g., PermeOx® and ORC®), produce less oxygen per gram of compound and produce insoluble residual products (e.g., calcium and magnesium hydroxide), which may reduce the permeability of the formation and make subsequent treatment more difficult. Hydrogen peroxide has been widely used to provide oxygen to support bioremediation of hydrocarbon-contaminated groundwater and subsurface sediments (API, 1987; Fogel et al., 1988; Piotrowski, 1989). Although hydrogen peroxide decomposition can be catalyzed by common minerals and enzymes that are likely to be present in the beach subsurface, it is reasonably stable in the absence of sediments (Lawes, 1990). The concentration that will be used (100 mg/l) was selected because the maximum solubility of oxygen in seawater at $15^{o}C$ is about 40 mg/l (Metcalf and Eddy, 1991). Higher concentrations may lead to the formation of oxygen gas bubbles that could reduce the permeability of the formation (Spain et al., 1989; Fiorenza and Ward, 1997).

Table 1: Chemical and hydraulic parameters for the bioremediation study

Concentration of peroxide in solution	100 mg/L
Concentration of nutrients in solution	50 mg/L of N and 10 mg/L of P
Injection flow rate. Type D Beach	1.0 liter per minute
Pressure in injection well. Type D Beach	Less than 7.0 m (of water)
Release Flow Rate. Type S Beach	0.20 liter per minute

C. Description of the Pilot Studies

A main parameter for the selection of beaches for the bioremediation study is the depth of the bedrock. This is because beaches with deep bedrock allow high pressure injection of chemicals into the beach while shallow beaches require slow release (Boufadel and Bobo, 2011; Boufadel et al.,2011, GWMR, Submitted Manuscript). For this reason, we classify (for the purpose of this proposal) beaches as belonging to Type D (for Deep bedrock) or Type S (for Shallow bedrock). We consider a beach to be of Type D if the bedrock is at least 1.5 m deep, and we consider a beach to be of Type S if the bedrock is less than 0.80 m deep. Evidently, these criteria are only for the purpose of this proposal as a bedrock depth of 1.5 m is viewed by a variety of researchers as “shallow”. Examples of type D beaches include (Figure 1): Beach 1, Beach 2, the left transect of Beach 4 (Guo et al., 2010), and Beach 3 (Boufadel et al., manuscript in preparation). Examples of type S beaches include the right side of Beach 4 (Xia et al., 2010), Beach 5 (Xia and Boufadel, 2011), and Beach 6 (Sharifi et al., 2010). Readers interested in a detailed analysis of the geomorphology of the Prince William Sound Shorelines are urged to consult the works of Michel and Hayes (1999), Owens et al. (2008), Hayes et al. (2009), and Michel et al. (2010).

Type D: Deep bedrock (i.e., the bedrock is at least 1.5 m deep).

On this type of beaches, high pressure injection (HPI) of the solutions (Table 1) into the lower layer will be pursued. Boufadel and Bobo (2011) found that within 24 hours, the 10% contour of the solution’s concentration covers an approximate area of 12 m^2 elongated in the seaward direction (Figure 4). Therefore, at beaches where the oil coverage is larger than 12 m^2, multiple injection wells will be used. The advantage of HPI is two folds: 1) It accelerates the movement and therefore the delivery of the solutions to the oiled areas and 2) It spreads the solutions laterally (i.e., along the shore), as the natural hydraulic gradient is negligible in the along shore direction (Li and Boufadel, 2010; Xia et al., 2011). However, the combination of the HPI with the tidal hydraulics result in a comet shape of the plume (note at 21 hour, the “tail of the comet” extends seaward). Therefore, one could explore bioremediating a large area seaward of the injection well provided the solutions are not too diluted. In other words, the HPI acts as a manifold spreading the solutions along the shore which subsequently travel seaward due to tidal hydraulics. The installation of each injection well would mimic the approach adopted by

Boufadel and Bobo (2011), with the difference that an engineering firm will be hired to conduct the installation.

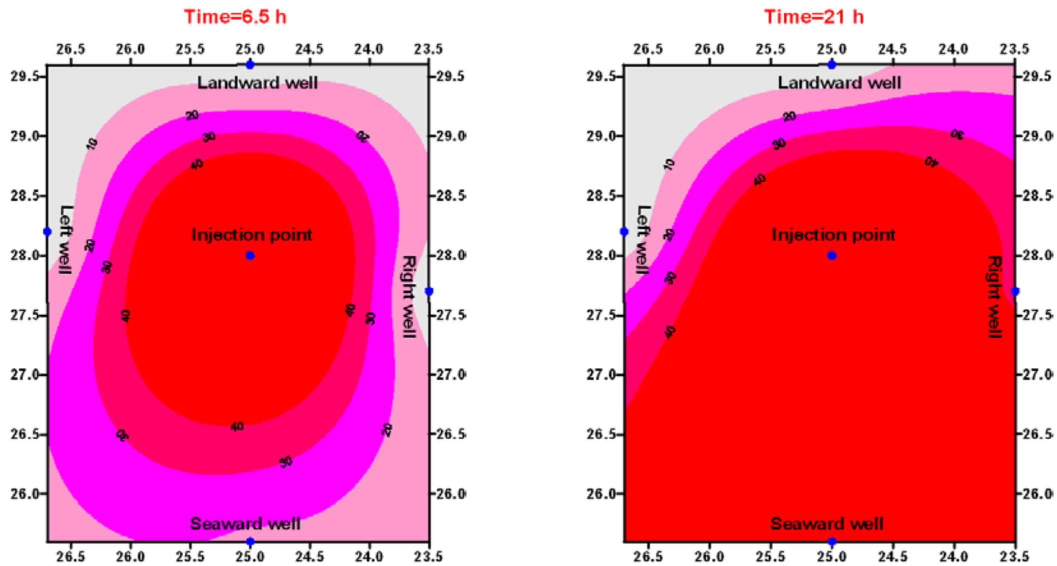

Figure 4: Empirical contours of lithium concentration as percentage of the maximum after 6 hours and 21 hours of high pressure injection (HPI) at Beach 1 (Figure 1). The edge of the plume was delineated where the concentration is 10% of the maximum. The figure indicates that at t=21 hours, the injected plume occupies an approximate area of 12 m^2 (4.0 m cross shore X 3.0 m along shore). Copyright Groundwater Monitoring and Remediation, Boufadel and Bobo (2011).

The approach is as follows: a pit will be excavated down to a depth of 1.50 m while minimizing the disturbance of the beach during the excavation. Then, a well, screened at the bottom 0.30 m will be placed into the pit (Figure 5). The pit will then be filled until the depth of 0.60 m and then a 0.10 m-thick layer of bentonite (clay) will be placed, after which, the pit will be completely filled with the excavated sediments. The primary role of the bentonite layer is to create a sealing "blanket" to keep the injection from short- circuiting around the pipe and upwelling to the surface. Another added benefit would be to "anchor" the pipe into the ground during injection. Based on our experience with excavation in Type D of beaches, we expect the pit diameter at the surface to be less than its depth, and thus the diameter of the bentonite layer to be less than 1.0 m.

The design injection flow is 1.0 liter per minute (0.26 GPM) and the maximum operating pressure in the injection well should be less than 7.0 m of water. Note that the maximum injection flow and the maximum pressure are 3.0 liters per minute and 20.0 m (Boufadel and Bobo, 2011), so our selection (one third of the maxima) provides a sufficient safety factor. These are the same conditions under which Boufadel and Bobo (2011) conducted their tracer study.

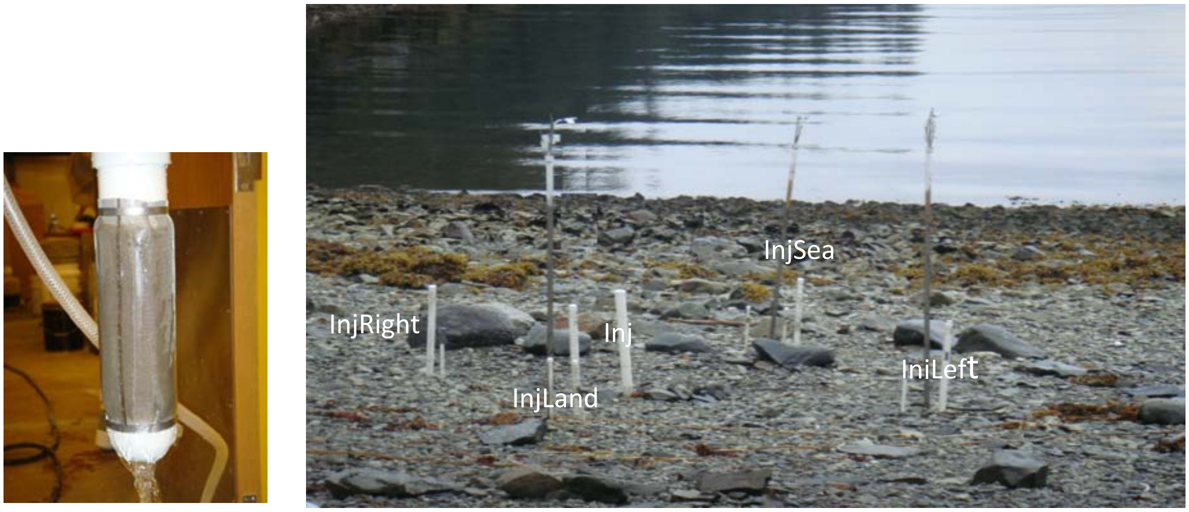

Figure 5: Left panel. The screen that covers the tip of the injection well (length of screen is approximately 0.30 m long, a foot). Right panel: Photograph of the HPI at Beach 1 (Figure 1). Copyright Groundwater Monitoring and Remediation, From Boufadel and Bobo (2011).

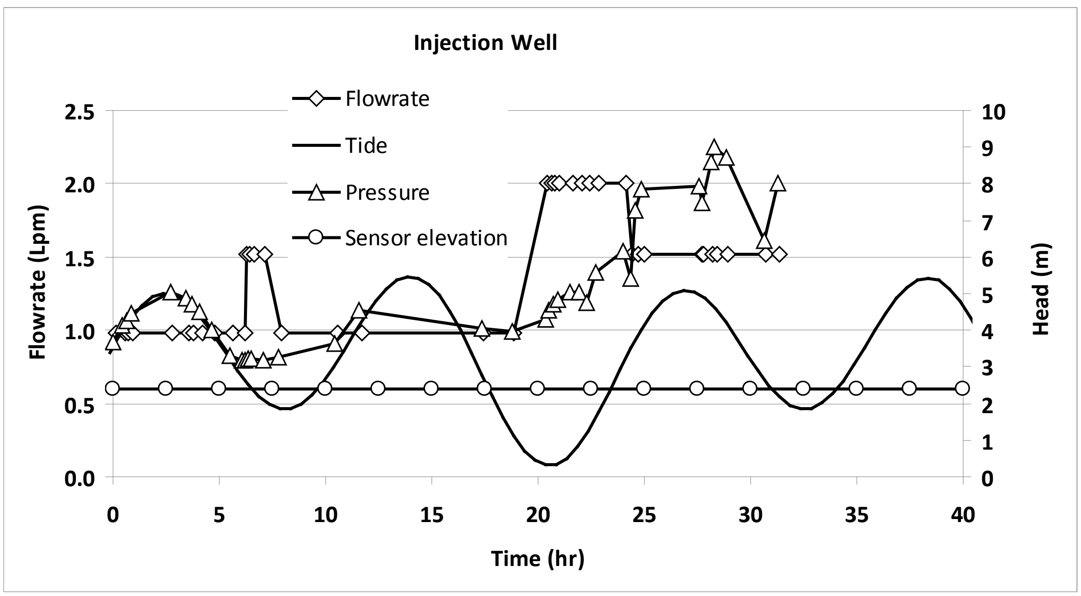

Figure 6: Variation of the pressure as function of time and the flow rate (liter per minute, LPM) for the high pressure injection (HPI) of solution. The pressure remained less than 4 m of water when the injection flow rate was set at 1.0 LPM. For this reason, a design flow rate of 1.0 LPM is proposed. Copyright Groundwater Monitoring and Remediation, from Boufadel and Bobo (2011).

Type S: Shallow bedrock (i.e., the bedrock depth is less than 0.80 m).

The installation would emulate the installation reported in Boufadel et al. (2011, Ground Water Monitoring and Remediation, Submitted Manuscript) for the delivery of lithium bromide under ambient pressure condition. The approach was termed ambient pressure release (APR). Trenches will be dug parallel to the shoreline down to the maximum possible depth. They would be 1.0 to 2.0 m landward of the oiled areas, and thus, the trenches could a few meters long.

Then, HDPE manifolds (Figure 6) will be placed at the bottom of the trenches and the pits will be filled with the excavated material.

Figure 6: Photo of a 1.0 m trench with the manifold placed parallel to the shoreline before refilling the trench. A more rigid system is being proposed for the delivery of chemicals in this study.

Figure 7 reports the results of the tracer of the APR conducted by Boufadel et al. (2011, GWMR, submitted manuscript). The figure indicates that the applied tracer moved upward (towards the beach surface) as it moved seaward and downward as it moved landward. Considering that the delivery would be done into the lower layer and that the oil is in the top part of the lower layer (see Figure 3 for illustration), it is best to apply the bioremediation solution deep into the beach landward of the oil and rely on the tide to bring it to the oil layer from below. This is an important point as all the studies (e.g., Atlas and Bragg, 2009) dealing with the Exxon Valdez oil spill considered only the downward movement of solutions into the beaches (i.e., did not account for the upward movement).

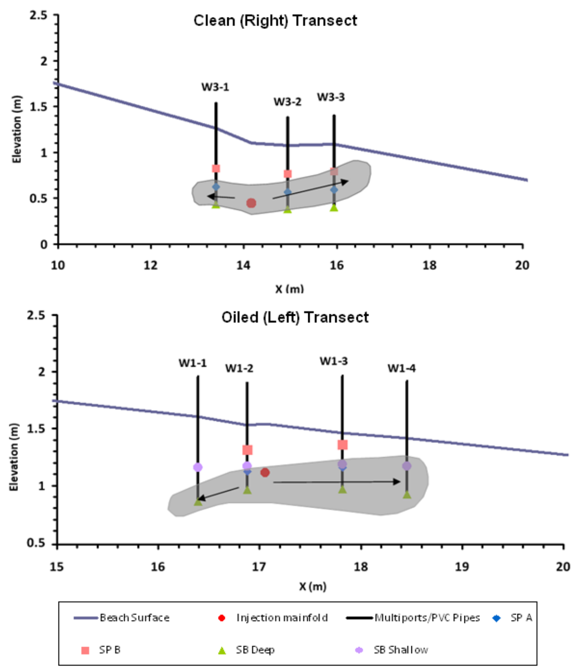

Figure 7: Empirical contours of lithium concentration as percentage of the maximum after 60 hours of ambient pressure release (APR) at Beach 6 (see Figure 1). The manifolds are represented by the filled circle at approximately x=14 m in the top panel and x=17 m in the lower panel. The edge of the plume was delineated where the concentration is 10% of the maximum. The figure indicates that the released plume upwells as it moves seaward and downwells as it moves landward. From Boufadel et al. (2011, submitted manuscript to GWMR).

Beach Selection

We will conduct the pilot studies on four beaches. Two in the northern PWS and two in the southern PWS. Those in the northern PWS would be, most likely, the ones we worked with before: EL056C (147° 34’ 17.42” W, 60° 33’ 45.57” N) and SM006B (147º 23' 6.41" W, 60º 31' 39.10" N). The selection of the beaches in the southern part of the PWS is made to allow generalization (i.e., scale up) of the results. The southern beaches would, most likely, contain oil that is more weathered than those in the north of the PWS due to the larger travel distance of the spill in open water prior to impact on shorelines.

For the estimation of volumes and masses of nutrients, we consider that each beach that we are going to treat contains oil patches that have a combined area of 25 m^2 and thickness of 0.10 m, a volume of oiled sediments of 0.25 m^3. This is what we observed at Beach 1 (Boufadel and Bobo, 2011). (Beach 5, has much more than that, more like 100 m^2 in areal coverage). Consider that we need to get the oxygen to the lower layer to occupy that volume in the subsurface. The porosity of the lower layer was estimated to be between 0.05 and 0.1 (Bobo et al., 2011). We will consider it to be 0.1. Thus, the volume of pore water would be 2.5X0.1=0.25 m^3.

Assuming a H_2O_2 concentration of 100.0 mg/L, filling the 0.25 m^3 requires:

$$0.25 m^3 X 100{,}000 \frac{mg}{m^3} = 25{,}000 mg = 25\ g$$

This amount of hydrogen peroxide would produce 11.8 g O_2 (0.47 grams O_2 are produced per gram of H_2O_2). Hydrogen peroxide is available at a concentration of 30%, which has a density of 1.11 g/ml. So, 75 ml (83.3 g) of 30% hydrogen peroxide would provide 25 g of pure hydrogen peroxide. We can consider that this is the volume that needs to be added to a beach per day. For a duration of 90 days for one beach, the needed volume of hydrogen peroxide (H_2O_2) 30% solution is: 0.075L/day X 90days=6.75 L. As the hydrogen peroxide is delivered in 55 gallon drums, we would distribute the hydrogen peroxide into 10-liter bottles, and provide one 10-L bottle to each beach. (Note that a 55 gallon of hydrogen peroxide from FMC costs around $500).

Using the same argument for the nutrient mass computation, we have that the total volume of water to replenish per beach is : 0.25 m^3/day X90 days=22.5 m^3, which gives around 100 m^3 for the four beaches. Based on the delivery concentration of 50 mg/L and 10 mg/L for nitrogen and phosphorus, respectively, the needed mass is 100X0.05=5 kg of N and 100X0.01=1.0 kg of phosphorus. These are small numbers that reflect the low porosity in the lower layer in the beaches. Nevertheless, the "safety factors" would consist of purchasing more peroxide and nutrients and would not affect the operation.

Metrics for evaluating the performance

Piezometers and multiport sampling wells used extensively in the Limiting Factors study (Li and Boufadel, 2010; Xia et al., 2010; Guo et al., 2010, Sharifi et al., 2010) will be used herein at locations far from the oiled area (at least 4.0 m from the edge of the oiled area). The piezometers reading will provide the water table within the beach and the tide level. The multiport sampling wells will be used to draw pore water samples for the measurement of the concentration of nutrients, salinity, and lithium, as done before.

We will establish a sampling grid in association with each delivery method. The nodes of the grid will be spaced approximately 1.0 m and will be randomly sampled without replacement. . (We will also explore combining samples to minimize field variability).

Collection of Sediment Samples (around 75 sediment samples per beach).
Sediment samples will be collected at one-month intervals (starting with time zero) by digging a pit through the oil-contaminated region during low tide and obtaining a 10 cm thick sample from the elevation that the oil is encountered. This is because it would not be possible to sample at various depth without downward contamination. Duplicate sediment samples will be collected to measure three parameters: (1) the concentration and composition of oil, (2) the concentrations of nutrients and the conservative tracer, and (3) the concentration of oil-degrading bacteria. Samples for oil analysis will be collected in clean, solvent-rinsed glass jars. Samples for nutrient analysis will be collected in clean, acid-washed plastic bottles. Samples for microbial analysis will be collected in sterile 50-ml plastic centrifuge tubes. Appropriate procedures will be used to decontaminate or disinfect all other equipment used to collect samples. The oil and nutrient

samples will be stored frozen and shipped back to Temple University for analysis. One of the duplicate microbiological samples will be analyzed on board the research vessel by most-probable number analysis (MPN) as described below, and the second will be frozen and shipped to Temple University for molecular biological analysis of the microbial community.

Chemical Analytical Procedure for Oil

The most important response variable for this study will be the concentrations of oil and specific oil components in the treated sediments. These concentrations will be measured by collecting sediment samples from the oil-contaminated zone (without replacement) and extracting the oil with dichloromethane (DCM). The mass of extracted oil will be measured gravimetrically by evaporating an aliquot of the solvent to dryness and weighing the residue, and its composition will be measured by gas chromatography with detection by mass spectrometry (GC-MS). The GC-MS analysis will target 17α(H),21β(H)-hopane and alkyl-substituted and unsubstituted 2-through 4-ring polycyclic aromatic hydrocarbons (PAH). Because these compounds represent a relatively small fraction of the oil mass, thin-layer chromatography with flame ionization detection (TLC-FID) using an Iatroscan instrument will also be used to analyze the four main fractions of the extracted oil (aliphatics, aromatics, resins, and asphaltenes). The combination of gravimetric analysis, GC-MS, and Iatroscan will provide information on the concentration and composition of the oil at varying levels of detail. Biodegradable constituents will be normalized to hopane to minimize variability. All oil analyses will be conducted at the Auke Bay lab, which has an extensive expertise in dealing with oil from the Exxon Valdez.

Chemical Analysis of the Nutrients in Sediment Samples

Measurement of the nutrient concentrations is essential to ascertain whether the nutrient are reaching the oiled sediments. When normalized to the lithium values, nutrient concentrations could a surrogate measure for oil biodegradation within the sediment.

The sample containers used to collect nutrient samples will be preweighed to allow estimation of the relative amounts of water and dry sediments for every sample. Each sample bottle will also be weighed after the sample is collected to determine the total mass of sample collected. Ammonium and nitrate will be extracted from one of the duplicate sediment samples from each location by adding 50 grams of a 2 M potassium chloride solution to the entire sample, mixing for 1 hour, allowing the sediments to settle for 10 minutes, and then filtering the supernatant solution through 0.45-micron filters. The other duplicate sample will be used to measure the concentrations of adsorbed and total phosphorus using a sequential extraction procedure involving 1 M ammonium chloride (exchangeable phosphates), sodium hydroxide (iron and manganese adsorbed), and hydrochloric acid (calcium phosphates). The extracts will be filtered and analyzed as described below. After extraction, the samples will be dried and reweighed to determine the total mass of dry sediments.

The nutrient compounds will be measured using AutoAnalyzer3 (Seal Analytical, Mequon, WI). The frozen samples will be defrosted and kept in the fridge (below 4 °C) in batches of 76 samples, at the time of analysis the samples will be taken out of the fridge, hand shaken for 15

seconds and passed through 0.45 micron PTFE membrane filters (Puradisc^{TM}, Whatman, Florham, NJ) into the AutoAnalyzer3 cups. The segmented flow method will be used in Autoanalyzer3 and the concentrations will be detected by colorimetric analysis. Ammonia will be measured using the Berthelot reaction where a blue-green colored complex forms and gets measured at 660 nm wavelength. Nitrate in the solution will be reduced to nitrite by a copper-cadmium reactor column (Grasshoff et al., 1999; Seal Analytical, 2008).The nitrite will then react with sulfanilamide under acid condition to form a purple azo dye. The color will be detected in 550 nm wavelength (Grasshoff et al., 1999; Seal Analytical, 2008). Phosphate will be measured following the Murphy and Riley method until a blue color is formed by reaction of orthophosphate, molybdate ion and antimony ion followed by reduction with ascorbic acid at a pH<1. The blue complex is read at 880 nm wavelength (Grasshoff et al., 1999; Seal Analytical, 2008). The soluble silicate is determined in this method based on reduction of siliconmolybdate in acidic solution to molybdenum blue by ascorbic acid. The complex will be read at 820 nm wavelength (Grasshoff et al., 1999; Seal Analytical, 2008).
The salinity of the same pore-water samples will be measured using a digital refractometer (Salinity-300035, Sper Scientific, Scottsdale, AZ). The samples will be filtered and about 1.5 mL of sample will be poured into the measuring cup of the instrument and the salinity will be determined based on the refraction index of the sample. The refractive index of the samples is affected by the density of each sample which would be different depending on the salinity.

Measurement of Microbial Activity (Sediment and pore water samples)

Two microbiological factors in the beach sediments will be evaluated to characterize oil biodegradation:

1. The size of the alkane- and PAH-degrading microbial communities by most-probable number (MPN) analysis.
2. The structure of the microbial community in different beach layers, which will provide information about the specific pathways and potential of oil biodegradation, e.g., aerobic, denitrification, sulfate reduction, and methanogenesis.

MPN: The size of the alkane- and PAH-degrading microbial communities will be determined using the most-probable number procedure that was developed by Wrenn and Venosa (1996). Because this is a viable counting procedure, the samples must be analyzed as quickly as possible after collection to minimize the potential for the community structure to change during storage. Therefore, the samples will be analyzed on board the research vessel.

The samples will be analyzed by aseptically transferring 5 g of sediment to a sterile 50-ml centrifuge tube followed by addition of 40 ml of sterile phosphate-buffered saline (PBS) solution. The sediment slurries will be mixed by shaking at 200 rpm on a bench-top shaker for 1 hour, the sediments will be allowed to settle, and the supernatant will be used to prepare a dilution series for inoculation into replicate tubes containing selective culture medium. The diluted samples will be incubated for two (alkane degraders) or three (PAH degraders) weeks, and the number of positive wells per dilution will be scored based on color formation. The only difference between this method and that described by Wrenn and Venosa (1996) is that, instead of 96-well microtiter plates, the diluted samples will be inoculated into sterile screw-cap test tubes that can be more easily shipped back to Temple University for incubation and scoring.

D. Coordination and Collaboration with Other Efforts

The personnel in this project have diverse and complementary backgrounds as one notes from their attached biographies.

Dr. Boufadel is a Professional Engineer (environmental engineering) with expertise in hydraulics and and fate and transport of contaminants, especially in tidally influenced beaches. He will be responsible for the overall management of the project. Dr. Jacqui Michel is a geochemist with extensive expertise in oil spill work. She is arguably one of the foremost experts on remediating oil spills. She will provide input on the selection of the beaches for the pilot study and will make recommendation for the scaling up of the results to other beaches (i.e. to provide guidelines on the applicability of the results to other beaches). Dr. Brian Wrenn is an environmental engineer with extensive expertise in chemical and biological processes. He is the author of numerous articles on the bioremediation of hydrocarbons through nutrient amendment. He will be the lead person on the experimental techniques in this study and will supervise the lab studies for ATP quantification and MPN. Mr. Rich McManus is a Professional Engineer, and brings to the group more than three decades of practical experience in remediating hazardous material. He will contribute to the technological aspect of the pilot study. Dr. Jeff Short was the supervisory research chemist at the Alaska Fisheries Science Center, National Marine Fisheries Service from 1982 through November 2008. He has worked on the Exxon Valdez oil spill until his retirement and has published numerous seminal papers on the spill. He will provide input on various aspect of the study, especially on oil chemistry analysis. Dr. Erik Cordes is a microbial ecologist. He has been working on oil seeps in the Gulf of Mexico and is currently leading research on the Gulf Spill. He will provide technical input on the microbial analysis and the ecological impact of bioremediation. Dr. Benoit van Aken will explore using qPCR to quantify hydrocarbon degraders. All chemical analyses of oil will be conducted at the Auke Bay lab (NOAA) whose personnel (e.g., Dr. Jeep Rice) have been conducting oil analysis for the EVOS since 1989.

E. Budget Justification

A major part of the budget is going to subcontracts to setup the field studies (Glacial Alaska), to assist in the engineering design (Rich McManus, Farallon consulting), to allow scale-up of the results (Jacqui Michel, Research Planning Inc), and to analyze the oil (Auke Bay lab). The personnel at Temple University was budgeted at $281k due to the “short fuse” of the project where junior personnel (e.g., students) cannot produce within such a short period. The breakdown of the budgets of the subcontractors are attached.

MICHEL C. BOUFADEL, Ph.D.

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Education: 1998, Ph.D., Environmental Engineering, University of Cincinnati
1992, M.S., Environmental Engineering, University of Cincinnati
1988, B.S., Hydraulic Engineering, Jesuit University at Beirut,Lebanon.

Professional Activities (partial list)

Member: Committee on "The Deep Well Horizon oil spill impacts on the Gulf Ecosystem Services", National Research Council of the National Academies, 01/2011-present.
Member: Science Advisory Board Hydraulic Fracturing Research Plan Panel, US EPA, 12/10-present.
Vice President, Groundwater Quality Committee, American Society of Civil Engineers. (2010-2012).
Panelist, National Science Foundation, Water Sustainability and Climate (Earth Science Division), 2010.
Panelist, National Science Foundation, Water Resources and Soils (Environmental Engineering Division), 2010.

Five Closely Related Publications:

1) Li, H. (Postdoctoral Fellow**), M. C. Boufadel**, Long-term persistence of oil from the Exxon Valdez spill in two-layer beaches, ***NATURE geosciences****, 3,* 96-99, 2010.

2) Xi, Y.(Graduate Student), H. Li., and **M. C. Boufadel**, Factors affecting the persistence of the Exxon Valdez oil on a shallow bedrock beach, ***Water Resources Research***, VOL. 46, W10528, 17 PP., 2010 doi:10.1029/2010WR009179

3) **Boufadel, M. C.**, Y. Sharifi, B.Van Aken, B. A. Wrenn, and K. Lee, Nutrient and oxygen concentrations within the sediments of an Alaskan beach polluted with the *Exxon Valdez* oil spill, ***Environmental Science and Technology***, *44* (19), p 7418–7424, 2010.

4) Guo, Q. (Graduate Student), H. Li., **M. C. Boufadel**, and Y. Sharifi, Hydrodynamics in a gravel beach and its impact on the Exxon Valdez oil spill, ***Journal of Geophysical Research, Oceans,*** 115, C12077, doi:10.1029/2010JC006169, 2010.

5) Sharifi, Y. (Graduate Student), B. V. Aken, and **M. C., Boufadel**, The effect of pore water chemistry on the biodegradation of the Exxon Valdez oil spill , ***Journal of Water Quality, Exposure and Health***, DOI 10.1007/s12403-010-0033-4, 2010.

Five Significant Publications:

1) **Boufadel, M. C.** and A. D. Bobo, High pressure delivery of tracer simulating nutrients for the bioremediation of the Exxon Valdez oil spill, ***Groundwater Monitoring and Remediation***, in press.

2) Xia, Y. (Graduate Student) and **M. C., Boufadel**, Beach geomorphic factors for the persistence of subsurface oil from the Exxon Valdez spill in Alaska, ***Environmental Monitoring and Assessment,*** in press**.**

3) Abdollahi-Nasab (Graduate Student), A., **M. C. Boufadel**, Li, H., and J. W. Weaver, Saltwater flushing by freshwater in a laboratory beach, ***Journal of Hydrology***, 386,1-12, 2010.

4) Li, H. (Postdoctoral fellow), Q. Zhao, A. D. Venosa, and **M. C. Boufadel**, A universal nutrient application strategy for the bioremediation of oil polluted beaches, ***Marine Pollution Bulletin,*** 54, 1146-1161, 2007.

5) Ryan, R. J. (Postdoctoral fellow), and **M. C. Boufadel**, Lateral and longitudinal variation of hyporheic exchange along a mountain stream, ***Environmental Science and Technology***, 41, 4221-4226, 2007.

Current Projects.

Project Title: "Factors affecting the lingering of the Exxon Valdez oil in the beaches of the Prince William Sound, Alaska"
Exxon Valdez Trustee Council 05/2007-05/2011
Sole Principal Investigator $1,620,000

Project Title: "Evaluation of the ecology at the banks of the Delaware River"
Department of Environmental Protection, Pennsylvania 10/2010-09/2012
Principal Investigator, 66% effort $50,000

Project Title: "Evaluation of the persistence of the Deep Well Horizon oil in the beaches of the Gulf of Mexico"
United States Coast Guard 12/2010-12/2011
Principal Investigator, 90% effort. $250,000

Project Title: "Delineating the floodplains in the Wissahickon Watershed"
Commonwealth of Pennsylvania 01/2011-01/2013
Co-Principal Investigator, Dr. Featherstone is PI.
Amount of Funding to Boufadel is: $50,000

Project Title: "Regulations and laws related to the Marcellus Shale exploitation and their impact on public health"
Robert Woods Johnson Foundation 01/2011-01/2012
Principal Investigator, 85% effort. $100,000

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EDUCATION

Ph.D., Department of Geology, University of South Carolina (USC), Columbia (1980).

M.S., Department of Geology, USC, Columbia (1976).

B.S., Department of Geology, USC, Columbia (1974).

PROFESSIONAL CREDENTIALS

Adjunct Faculty, School of the Environment, USC (2005-present)

Phi Beta Kappa

First in graduating class (August 1974), USC

Carolina Geological Society (1975-present)

Distinguished Alumni Achievement Award, College of Science and Mathematics, USC (2002)

Member, Ocean Studies Board, National Academies (2001-2004)

Chair, NRC Committee on Spills of Emulsified Fuels: Risks and Response (2002)

Chair, NRC Committee on Dispersants Effectiveness and Effects (2005)

Member, NRC Committee on Oil in the Sea III (2003)

Member, NRC Committee on Spills of Nonfloating Oils: Risks and Response (1999)

Lifetime Associate, National Academies

Member, Science Advisory Panel to the U.S. Commission on Ocean Policy (2004-2005)

Co-creator of the concept of Environmental Sensitivity Index (ESI) mapping; has mapped many shorelines, including Prince William Sound, Southeast Alaska, Southern Alaska Peninsula, Cook Inlet and Kenai Peninsula, and Bristol Bay

Wrote the Shoreline Assessment Manual (three versions) for NOAA, which includes SCAT procedures and recommended cleanup methods for all shoreline types

Has responded to hundreds of oil spills, providing recommendations for shoreline cleanup, including manual, mechanical, chemical, *in-situ* burning, and biological technologies

Has been the NOAA SCAT Coordinator for the Deepwater Horizon oil spill since April 2010

FIVE RECENT PUBLICATIONS RELATED TO THE PROPOSED PROJECT

Michel, J., Z. Nixon, M.O. Hayes, J. Short, G. Irvine, D. Betenbaugh, C. Boring, and D. Mann. 2010. Distribution of Subsurface Oil from the *Exxon Valdez* Oil Spill. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 070801), National Oceanic and Atmospheric Administration, Juneau, AK. 121 pp. + app.

Hayes, M.O., J. Michel, and D.V. Betenbaugh. 2010. The intermittently exposed, coarse-grained gravel beaches of Prince William Sound, Alaska: Comparison with open-ocean gravel beaches. J. Coastal Research 26(1):4-30.

Michel, J., Z. Nixon, and L. Cotsapas. 2006. Evaluation of oil remediation technologies for lingering oil from the *Exxon Valdez* oil spill in Prince William Sound, Alaska. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 050778), National Marine Fisheries Service, NOAA, Juneau, AK, 47 pp. + appendices.

Michel, J. and M.O. Hayes. 1999. Weathering patterns of oil residues eight years after the *Exxon Valdez* oil spill: Marine Pollution Bulletin 38: 855-863.

Hayes, M.O. and J. Michel. 1999. Factors determining the long-term persistence of *Exxon Valdez* oil in gravel beaches: Marine Pollution Bulletin 38: 92-101.

FIVE OTHER SIGNIFICANT PUBLICATIONS

Michel, J., Z. Nixon, J. Dahlin, D. Betenbaugh, M. White, D. Burton, and S. Turley. 2009. Recovery of interior brackish marshes seven years after the Chalk Point oil spill. Marine Pollution Bulletin 58: 995-1006.

Michel, J., Dunagan, H., Boring, C., Healy, E., Evans, W., Dean, J.M., McGillis, A. and Hain, J. 2007. Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf. U.S. Department of the Interior, Minerals Management Service, Herndon, VA, MMS OCS Report 2007-038, 254 pp.

Michel, J., M.O. Hayes, C.D. Getter, and L. Cotsapas. 2005. The Gulf War oil spill twelve years later: Consequences of eco-terrorism. Proc. 2005 International Oil Spill Conference, American Petroleum Institute, Washington, DC. (CD-ROM).

Michel, J., D. Etkin, T. Gilbert, J. Waldron, C. Blocksidge, and R. Urban. 2005. Potentially Polluting Wrecks in Marine Waters: An Issue Paper Presented at the 2005 International Oil Spill Conference. American Petroleum Institute, Washington, D.C. 76 pp.

Wolfe, D. A., M. J. Hameedi, J. A. Galt, G. Watabayashi, J. Short, C. O'Clair, S. Rice, J. Michel, J. R. Payne, J. Braddock, S. Hanna, and D. Sale. 1994. The fate of the oil spilled from the T/V EXXON VALDEZ. Environmental Science and Technology 28(13): 560A-568A.

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Educational Background:

Ph.D. 1992. Environmental Science in Civil Engineering. University of Illinois at Urbana-Champaign.

M.S. 1984. Biological Oceanography. University of Miami, Coral Gables, FL.

B.S. 1980. Biochemistry/Chemistry. University of Illinois at Urbana-Champaign.

Professional Experience:

Temple University, Philadelphia, PA — 2010 to present
Senior Scientist

Southern Illinois University Edwardsville, National Corn-to-Ethanol Research Center (NCERC), Edwardsville, IL — 2007 to 2010
Research Director

Washington University, Department of Civil Engineering / Environmental Engineering Science Program, St. Louis, MO — 1998 to 2007
Assistant Professor

Environmental Technologies & Solutions, Inc., Rochester, NY — 1995 to 1997
Vice-President

University of Cincinnati, Dept. Civil & Environmental Engineering — 1992 to 1995
Postdoctoral Research Associate

Professional Activities:

- National Academy of Sciences (National Research Council): Understanding Oil Spill Dispersants - Efficacy and Effects (2005)
- American Society of Civil Engineering: Natural Attenuation Task Committee (1999-2000)

Publications:

(1) Five Closely Related Publications

Boufadel, M.C., Y. Sharifi, B. Van Aken, **B.A. Wrenn**, and K. Lee. 2010. Nutrient and oxygen concentrations within the sediments of an Alaskan beach polluted with the *Exxon Valdez* oil spill. Environmental Science & Technology 44: 7418-7424.

Wrenn, B.A., K.L. Sarnecki, E.S. Kohar, K. Lee, and A.D. Venosa. 2006. Effects of nutrient source and supply on crude oil biodegradation in continuous-flow beach microcosms. J. Environmental Engineering 132: 75-84.

Wrenn, B.A., M.T. Suidan, K.L. Strohmeier, B.L. Eberhart, G.J. Wilson, and A.D. Venosa. 1997. Nutrient transport during bioremediation of contaminated beaches: evaluation with lithium as a conservative tracer. Water Research 31: 515-524.

Wrenn, B.A. and A.D. Venosa. 1996. Selective enumeration of aromatic and aliphatic hydrocarbon degrading bacteria by a most-probable-number procedure. Canadian J. Microbiology 42: 252-258.

Venosa, A.D., M.T. Suidan, **B.A. Wrenn**, K.L. Strohmeier, J.R. Haines, B.L. Eberhart, D. King, and E. Holder. 1996. Bioremediation of an experimental oil spill on the shoreline of Delaware Bay. Environmental Science & Technology 30: 1764-1775.

(2) Five Significant Publications

Mukherjee, B. and **B.A. Wrenn**. (in press). Effects of physical properties and dispersion conditions on the chemical dispersion of crude oil. Environmental Engineering Science

Wrenn, B.A., A. Virkus, B. Mukherjee, and A.D. Venosa. 2009. Dispersibility of crude oil in fresh water. Environmental Pollution 157:1807-1814.

Yan, B., **B.A. Wrenn**, S. Basak, P. Biswas, and D.E. Giammar. 2008. Microbial reduction of Fe(III) in hematite nanoparticles by *Geobacter sulfurreducens*. Environmental Science & Technology 42: 6526-6531.

Li, Z., **B.A. Wrenn**, and A.D. Venosa. 2005. Effect of iron on the sensitivity of hydrogen, acetate, and butyrate metabolism to fatty-acid inhibition in vegetable-oil-enriched freshwater sediments. Water Research 39: 3109-3119.

Li, Z., **B.A. Wrenn**, and A.D. Venosa. 2005. Anaerobic biodegradation of vegetable oil and its metabolic intermediates in oil-enriched freshwater sediments. Biodegradation 16: 341-352.

RICHARD W. MCMANUS, P.E.
Principal Engineer

B.S. Civil Engineering, 1975
University of Massachusetts, Amherst
M.B.A. University of California, Berkeley, 1984

Mr. McManus serves as Farallon Consulting's Principal Engineer overseeing all engineering design and remediation project management performed by the firm. He is a senior engineer with over 35 years of experience in environmental engineering design, remediation program management, work plan development, remediation engineering and cost estimating, cleanup construction management, and environmental investigations.

Specific to the EVOS Lingering Oil pilot scale remediation program, Mr. McManus has experience in the design and implementation of full-scale in situ bioremediation in Alaska, and has designed and directed remediation projects in remote locations in Alaska. He has also designed and implemented cleanup projects at sites in Alaska and around the United States involving a variety of in situ technologies, including bioremediation, air sparging, soil vapor extraction, chemical oxidation, ozone injection, resistive electric heating, and hot water/steam injection. Mr. McManus has also served as a design engineer for remediation projects in Washington, Oregon, Texas, and California. On these projects he has been responsible for remediation approach development, cost estimating, drawing and specification development, project bidding, construction oversight, and project closure documentation. His relevant project experience is summarized below.

PROJECT EXPERIENCE

- Developed detailed design for implementation of in situ bioremediation of diesel-contaminated soil at a remote Aleutian Island project site that was inaccessible to standard construction equipment. The project involved performance of treatability studies to determine an appropriate reagent injection approach, and design and construction of a treatment equipment building, pumps, controls, piping, and injection wells. Treatability studies determined that bioremediation of the diesel fuel could be accelerated by injection of hydrogen peroxide to stimulate indigenous bacteria. Treatment was implemented over one treatment season and reduced diesel contamination concentrations to below target cleanup levels.
- Directed the remediation design for petroleum hydrocarbon remediation at a tank farm in Sand Point, Alaska at the scene of a 164,000-gallon diesel fuel spill. The project design included recycling of treated waste to avoid the cost of off-site disposal and significantly reduced project costs. Prepared cost estimates for alternative remediation approaches for client and insurance company review. Implemented an organic waste stabilization process to convert oil-contaminated soil into structural fill for use in tank farm reconstruction. Treated material was used to reconstruct berms around the tank farm and bring the facility up to current codes and standards

- Developed remediation design for cleanup of contamination at remote logging camp sites in Southeast Alaska. Prepared drawings and contract specifications for cleanup construction. Managed bidding and contractor selection and directed construction oversight.
- Directed source determination investigation to locate source of benzene in city of Fairbanks water supply. Set up onsite laboratory to measure contaminant concentrations in groundwater samples during monitoring well drilling program Real-time data was used to determine well placement as drilling progressed. Drilling program conclusively established contamination source to be fuel storage tanks associated with adjacent power generating plant.
- Directed remedial investigations and cleanup design of abandon military facilities on St. Lawrence Island, Alaska. Project design called for asbestos abatement, building demolition, fuel spill cleanup, and site restoration. Design was done on fast track basis to meet federal funding deadlines.
- Designed, prepared cost estimates, and directed implementation of waste segregation and minimization approach for remediation of auto recycling yard in Anchorage, Alaska. Innovative approach involved the use of screening and soil washing to separate PCB contaminated fine soil fractions from less contaminated coarse fractions and debris. The approach reduced off-site disposal requirements and minimized project costs.
- Served as lead on-site technical representative in managing response to 160,000-gallon fuel spill at Alaskan fish cannery. Coordinated initial response activities with US Coast Guard Emergency Response On Scene Coordinator. Directed response activities to limit contaminant migration and associated impacts. Developed and implemented sampling plan to document extent of spill impact. Developed site cleanup work plan that incorporated innovative on-site treatment technologies to greatly reduce site cleanup costs.
- Served as the Program Manager for the City of Saint Paul, Alaska in a large municipal utilities upgrade program that involved moving of a city-owned fuel farm, municipal dock improvements, road improvements, and water and waste water service improvements. Directed the design, bidding, and construction oversight of a new and relocated municipal fuel farm. The facility held over one million gallons of fuel, and included a transfer line and dock distribution equipment.
- Directed the design, bidding, and construction management of water storage, treatment, and supply systems upgrade for the North Slope community of Wainwright, Alaska. The program included replacing a 300,000 gallon insulated water storage tank that had been damaged in an overfilling incident, upgrading water treatment facilities, and constructing a utilidor to serve running water to buildings in the community center.

PROFESSIONAL CERTIFICATIONS AND REGISTRATIONS

Registered Civil Engineer, Alaska (CE-5067), 1981, Washington (Reg. 35032), Oregon (72394PE), Utah (5336093-2202)
40-Hour OSHA Health & Safety Certification (29 CFR 1910.120)
8-Hour OSHA Health & Safety Annual Update Certification
8-Hour OSHA Supervisor Training

ENVIRONMENTAL TECHNOLOGY PATENTS

Volatile Organic Compound Monitoring – Patent Number 7,281,439
Passive Acid Tar Neutralization Process – Patent Number 5,814,206
DCR Transportable Treatment Unit – Patent Number 5,609,836

Jeffrey W. Short
19315 Glacier Highway
Juneau, Alaska 99801
(907) 789-0579 (h)
(907) 789-6065 (w)
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jshort@oceana.org

Professional Experience:

Pacific Science Director, Oceana (November 17, 2008 to December 30, 2010). My main focus was to foster and coordinate the collaborative development and articulation of the scientific rationale for ocean policy recommendations of the Pacific Team of Oceana. My responsibilities included ensuring that policy recommendations have a firm scientific basis, identifying the most compelling scientific arguments for these recommendations, and providing scientific advice regarding advocacy and litigation priorities. As supervisor of the Pacific Team's scientific staff, I was also responsible for the scientific defense of Oceana's advocacy positions at scientific, litigation and policy venues relevant to Pacific and Arctic Ocean issues, including their articulation in media ranging from op/ed articles and news releases to peer-reviewed scientific manuscripts, and for supporting these activities through grant writing. Finally, I promoted our contacts with the scientific community engaged in ocean and climate research, with relevant government agencies and with other environmental organizations.

Supervisory Research Chemist, Alaska Fisheries Science Center, National Marine Fisheries Service (1982 through November 2008). My four basic responsibilities include acting as principal investigator (PI) on research projects, managing the Center's marine chemistry laboratory, advising the government's legal team on the long-term fate and effects of the1989 *Exxon Valdez* oil spill, and reviewing research products that touch on the environmental chemistry of oil for the Center and for numerous peer-reviewed environmental journals.

- **Research Project Principal Investigator.** This includes conceiving, designing, securing funding, executing, analyzing and publishing results for environmental research projects, usually in collaboration with numerous colleagues and support staff. Most of my work has been on the *Exxon Valdez* oil spill. Major projects included: (1) assessment of the initial distribution and persistence of the spilled oil in seawater; (2) discovery and elucidation of a cryptic toxicity mechanism through which oil pollution is nearly 1,000-fold more toxic to fish eggs than previously thought; (3) definitive refutation of alternative hydrocarbon pollution sources advanced by scientists employed by Exxon Corp. as plausible causes of biological effects in the *Exxon Valdez* impact area; (4) discovery of a natural hydrocarbon trophic tracer in the marine food web of the northern Gulf of Alaska; and (5) quantitative measurement of the amount and loss rate of *Exxon Valdez* oil lingering in beaches 12 years or longer after the incident. Each of these was funded at $500K to $5M, and I played the leading role on all but the second. A summary of these projects appeared in *Science* as a review article I co-authored in 2003 (See Peterson, C.H et al.). A list of salient publications from these efforts is attached.

- **Manager, AFSC Marine Chemistry Laboratory.** I presided over a major expansion of the AFSC marine chemistry laboratory in the aftermath of the *Exxon Valdez* spill, when the government urgently needed additional capacity capable of meeting the stringent standards imposed by impending litigation. Staff increased nearly tenfold from two, and successfully qualified as one of only three such facilities nationally to participate, generating revenues of $500K - $1M annually. Today the facility is internationally recognized, specializing in the environmental analysis of hydrocarbons, biogenic lipids in support of nutritional ecology studies, and high-precision characterization of the marine carbonate buffer system in support of incipient studies on ocean acidification.

- **Scientific Advisor to the *Exxon Valdez* Legal Team for the Governments of Alaska and the United States.** The civil settlement between Exxon Corp. and the governments of Alaska and the US created a $900M fund administered by the *Exxon Valdez* Trustee Council that supported scientific studies, habitat acquisition and other impact offsets. I was one of four scientists selected to design the Council's scientific review policy and administrative structure, and I have since provided policy guidance on request on numerous occasions. Other implemented advice includes publication of the 1993 symposium presenting the initial findings of the Exxon Valdez oil spill impacts as a book, establishment of and support for the annual Alaska Marine Science Conference begun in 1993, and (until recently) retention of the peer-review system for proposal evaluation.

Education:

- Bachelor of Science, Biochemistry and Philosophy, University of California at Riverside, 1973

- Master of Science, Physical Chemistry, University of California at Santa Cruz, 1982

- Doctor of Philosophy, Fisheries Biology, University of Alaska at Fairbanks, 2005

Selected Activities and Honors:

- Bronze Medal, U. S. Department of Commerce, "For scientific research and publications describing the long-term, insidious effects of oil pollution on fish embryos at parts per billion levels"

- Appointment as Visiting Professor for the Key Laboratory of Oil Spill Identification and Damage Assessment Technology, State Oceanic Administration, Qingdao, People's Republic of China

- Appointment to the Governor's Sub-Cabinet Adaptation Advisory Group on Climate Change in Alaska

- Coordinating scientist for an on-going, privately-funded $470K study of the impacts of polycyclic aromatic hydrocarbons and toxic metals on the Athabasca River system from tar sands mining, in conjunction with the University of Alberta and Queen's University in Canada

Biographical Sketch - Dr. Erik E Cordes

Professional Preparation
- Southampton College, Marine Science / Biology, B.S. 1993
- Moss Landing Marine Laboratories, Marine Science, M.S. 1999
- Penn State University, Biology, Ph.D. 2004

Appointments
- 2008-present Assistant Professor, Biology Department, Temple University
- 2005-2008 Postdoctoral Fellow (NSF Ridge2000), Harvard University. Microbial ecology of Juan de Fuca Ridge hydrothermal vent chimneys.
- 2005-2008 Postdoctoral Researcher, Penn State University. Supported on MMS contract to investigate the biology and ecology of *Lophelia pertusa* in the Gulf of Mexico
- 2000-2004 Research Assistant, Penn State University. Supported as NOAA Nancy Foster Scholar, Penn State University Graduate Fellow, Center for Environmental Chemistry and Geochemistry Fellow, as well as NSF, NOAA/NURP, OE, and MMS funding.
- 1999-2000 Research Associate, Moss Landing Marine Laboratories. Supported as senior personnel on North Pacific Research Initiative grant to study *Primnoa reseadiformis*.
- 1999-2000 Biological Consultant, ABA Consulting, Moss Landing CA
- 1998-2000 Adjunct Faculty, Hartnell College, Salinas CA
- 1998-1999 Museum Curator, Moss Landing Marine Labs
- 1995 Research Assistant, Moss Landing Marine Labs. Supported on Navy contract to assess the impact of trawl disposal on deep-sea soft-bottom communities.

Current Research
- 2010-2011: NSF Rapid program (P.I.): *Collaborative Proposal: Acute response of benthic hardbottom communities to oil exposure in the deep Gulf of Mexico*
- 2010-2011: NOAA Natural Resources Damage Assessment (co-P.I.): *Mississippi Canyon 252 Incident NRDA Tier 1 for Deepwater Communities*
- 2008-2012: Minerals Management Service and NOAA Office of Ocean Exploration Contract Award (co-P.I.): *Deepwater Program: Exploration and Research of Northern Gulf of Mexico Deepwater Natural and Artificial Hard Bottom Habitats with Emphasis on Coral Communities: Reef, Rigs and Wrecks*

Publications – 5 most relevant (* indicates undergraduate co-author)

Cordes EE, Becker EL, Fisher CR. (2010) Temporal shift in nutrient input to cold-seep food webs revealed by carbon, nitrogen, and sulfur stable-isotope signatures of associated communities. Limnol Oceanogr 55: 2537-2548.

White HK, Reimers CE, Cordes EE, Dilly GF, Girguis PR. (2009) Examining the relationship between power production and community ecology in plankton-fed microbial fuel cells. ISMEJ 3: 635-646. doi:10.1038/ismej.2009.12

Cordes EE, Arthur MA, Shea K, Fisher CR (2005) Modeling the mutualistic interactions between tubeworms and microbial consortia. PLoS Biol 3: 497-506. doi:10.1371/ journal.pbio.0030077.

Cordes EE, Bergquist DC, Shea K, Fisher CR (2003) Hydrogen sulfide demand of long-lived vestimentiferan tube worm aggregations modifies the chemical environment at deep-sea hydrocarbon seeps. Ecol Lett 6: 212-219. doi:10.1046/j.1461-0248.2003.00415.x.

Andrews AH, Cordes EE, Mahoney MM, Munk K, Coale KH, Cailliet GM, Heifetz J (2002) Age, growth and radiometric age validation of a deep-sea, habitat-forming gorgonian (*Primnoa resedaeformis*) from the Gulf of Alaska. Hydrobiologia 471: 101-110. doi: 10.1023/A:1016501320206

Publications – 5 other significant (* indicates undergraduate co-author)

Cordes EE, Cunha MM, Galeron J, Mora C, Olu-Le Roy K, Sibuet M, Van Gaever S, Vanreusel A, Levin L. (2010) The influence of geological, geochemical, and biogenic habitat heterogeneity on seep biodiversity. Mar Ecol 31: 51-65. doi:10.1111/j.1439-0485.2009.00334.x

Olu K, Cordes EE, Fisher CR, Desbruyeres D (2010) Biogeography and potential exchanges among the Atlantic Equatorial Belt cold-seep faunas. PLoS ONE 5: e11967. doi:10.1371/journal.pone.0011967
Cordes EE, Bergquist DC, Fisher CR (2009) Macro-ecology of Gulf of Mexico cold seeps. Ann Rev Mar Sci 1: 143-168. doi:10.1146/annurev.marine.010908.163912
Cordes EE, Carney SL, Hourdez S, Carney RS, Brooks, JM, Fisher CR (2007) Cold seeps of the deep Gulf of Mexico: Community structure and biogeographic comparisons to Atlantic equatorial belt seep communities. Deep-Sea Res I 54: 637-653. doi:10.1016/j.dsr.2007.01.001
Cordes EE, Hourdez S, Predmore BL*, Redding ML*, Fisher CR (2005) Succession of hydrocarbon seep communities associated with the long-lived foundation species *Lamellibrachia luymesi*. Mar Ecol Prog Ser 305: 17-29.

Synergistic Activities

1. Member of the Steering Committee of the Census of Marine Life Chemosynthetic Ecosystems (ChEss) project, and Chair of the advisory committee for the Rutledge Marine Lab on the Isles of Shoals, New Hampshire. This marine lab is targeted at public education, primarily for elementary school children.
2. Advisor for 4 graduate students (including an NSF Bridge to Doctorate Fellow and an NSF Students as Teachers Fellow) and 6 undergraduates at Temple University. Also served as the mentor for a total of 8 undergraduate students during graduate studies while at Penn State, 5 undergraduates during post-doc at Harvard, and 8 different undergraduates are included as co-authors on publications.
3. Reviewer for 18 different journals, 12 proposals to NSF and NOAA as well as proposals to the scientific funding agencies of the U.K. and Chile.
4. Serving as the “Expert Scientist” for GLOBE’s FLEXE Forum program including leading a workshop for 20 High School teachers titled “Bringing Deep-sea Science into the Earth Science Classroom” in Ocean Springs, MS in July 2009.
5. Involved with public outreach by contributing content for websites (NOAA’s “Ocean Explorer”, “Deep-Sea News”, WHOI “Dive and Discover”) and having research on the Gulf oil spill featured on television (CNN, Dan Rather Reports, FOX Philadelphia), radio (NPR, BBC), print articles (Associated Press, New York Times, Philadelphia Inquirer, Science), and websites (Nature, Science, Discovery, National Geographic).

Graduate and Post-doctoral Advisors

M.S. Advisor	James Nybakken (MLML)
Ph.D. Advisor	Charles Fisher (PSU)
Post-doctoral Advisor	Peter Girguis (Harvard)

Recent Collaborators and Co-authors

Monika Bright (University of Vienna, Austria), Jim Brooks (TDI Brooks), Robert Carney (LSU), Maria Cunha (University of Aveiro, Portugal), Daniel Desbruyeres (IFREMER, France), Nicole Dubilier (MPI Bremen, Germany), Joelle Galleron (IFREMER, France), Chris German (WHOI), Stephane Hourdez (CNRS, France), Mandy Joye (U. Georgia), Deborah Kelley (U. Washington), Lisa Levin (Scripps Insitution of Oceanography), Ian MacDonald (Florida State University), Steve Macko (University of Virginia), Camillo Mora (Scripps Institution of Oceanography), Karine Olu-Le Roy (IFREMER, France), Harry Roberts (LSU), Steve Ross (UNC Wilmington), Tim Shank (WHOI), Myriam Sibuet (IFREMER, France), Paul Tyler (Southampton University), Saskia Van Gaever (Ghent University, Belgium), Ann Vanreusel (Ghent University, Belgium).

Benoit Van Aken, Ph.D.
Assistant Professor, Department of Civil and Environmental Engineering
Temple University
1947, N. 12th Street, Philadelphia, PA 198122
215-204-7087 - bvanaken@temple.edu

Education

1989 Master in Economics (MS), **Catholic University of Louvain, Louvain, Belgium**
1995 Engineer in Chemistry and Biochemistry (MS), **Catholic University of Louvain**
2000 Ph.D. in Biological Engineering, **Catholic University of Louvain**

Professional Activities

Professional Experience:

08/2009 - present	**Assistant Professor:** Civil and Environ. Eng., Temple University
08/2005 – 08/2009	**Assistant Professor:** Civil and Environ. Eng., West Virginia University
06/2003 – 08/2005	**Associate Research Scientist:** Civil and Environ. Eng., Univ. of Iowa.
06/2002 – 08/2002	**Visiting Scholar:** Biochemistry, Univ. of Washington.
09/2000 – 06/2003	**Postdoctoral Research Assistant:** Civil and Environ. Eng., Univ. of Iowa.
08/1997 – 12/1997	**Visiting Scholar:** Division of Microbiology, Univ. of Helsinki, Finland.
09/1998 – 04/1999	**Visiting Scholar:** Chemistry and Biochemistry, Utah State Univ., Logan, UT.
09/1995 – 10/2000	**FDS Graduate Research Assistant:** Biological Eng., Univ. of Louvain.

Significant Awards and Projects:

2010 - 2012	**PA Department of Environmental Protection:** Evaluation of the ecology at the banks of the Delaware River
2010 - 2015	**NIEHS Superfund Basic Research Program:** Phytoremediation to Degrade Airborne PCB Congeners from Soil and Groundwater Sources
2009 - 2010	**NASA WV Space Grant Consortium:** Photocatalytic Reactor for the Removal of Pharmaceuticals, Pathogens, and Resistance genes in Recycled Wastewater
2007 - 2009	**DoE:** Selenium Removal from Mine Influenced Water (MIW) using Nano-Magnetite.
2005 - 2010	**NIEHS Superfund Basic Research Program:** Phytoremediation to Degrade Airborne PCB Congeners from Soil and Groundwater Sources
2005 - 2008	**SERDP Grant:** Phytoremediation for the Containment and Treatment of Energetic and Propellant Material Releases on Testing and Training Ranges
2003 - 2005	**NSF Grant:** Involvement of an Endosymbiotic *Methylobacterium* sp. in the Biodegradation of Explosives RDX and HMX inside Poplar Tree
2002 - 2006	**MW Keck Foundation Grant:** Catabolic Enzymes and Metabolic Pathways in Phytoremediation
2002 - 2005	**SERDP Grant:** Metabolic Routes and Catabolic Enzymes Involved in Phytoremediation of the Nitro-Substituted Explosives
1996	**Prize for the Best University Studies:** Ass. of Engineers – Univ. of Louvain
1995 - 2000	**FDS Graduate Fellowship:** Fund for Scientific Development, Univ. Louvain

Professional Affiliations:

American Society for Microbiology (ASM)
American Society of Plant Biology (ASPB)
American Chemical Society (ASC)
Association of Environmental Engineers and Science Professors (AEESP)
American Society for Engineering Education (ASEE)

Reviewing Activities:

Associate Editor: West Virginia Academy of Sciences
Panelist: National Science Foundation (NSF), Environmental Engineering – Biological
Journal reviewer: Environmental Science and Technology, Applied and Environmental Microbiology

Closely Related Publications

Boufadel MC, Sharifi Y, **Van Aken B**, Wrenn BA, Lee K (2010). Nutrient and oxygen concentrations within the sediments of an Alaskan beach polluted with the *Exxon Valdez* oil spill. *Environ. Sci. Technol*. **44**:7418-7424

Sharifi Y, **Van Aken B**, Boufadel MC (2010). The effect of pore water chemistry on the biodegradation of the Exxon Valdez oil spill. *J. Wat. Qual. Exp. Health.* doi: 10.1007/s12403-010-0033-4

Correa PA, Lin L., Just CL, Hu D, Hornbuckle KC, Schnoor JL, **Van Aken B** (2010). The effects of individual PCB congeners on the soil bacterial community structure and the abundance of biphenyl dioxygenase genes. *Environ. Int*. **36**:901-906

Van Aken B, Peres CM, Lafferty-Doty S, Moon Yoon J, Schnoor JL (2004). *Methylobacterium populi* sp. nov.: A novel aerobic, pink-pigmented, facultatively methylotrophic, methane-utilizing bacterium isolated from poplar trees (*Populus deltoides* x *nigra* DN34). *Int. J. Sys. Evol. Microbiol.* **54**:1191-1196

Van Aken B, Moon Yoon J, Schnoor JL (2004) Biodegradation of Nitro-Substituted Explosives TNT, RDX, and HMX by a Phytosymbiotic *Methylobacterium* sp. Associated with Populus (*Populus deltoides* × *nigra* DN34). *Appl. Environ. Microbiol.* **70**:508-517

Significant Publications

Van Aken B (2009). Transgenic plants for the enhanced phytoremediation of explosives. *Curr. Opin. Biotechnol*. **20**:1-6

Brentner LB, Mukherji ST, Merchie KM, Yoon JM, Schnoor JL, **Van Aken B** (2008). Expression of glutathione *S*-transferases in poplar trees (*Populus trichocarpa*) exposed to 2,4,6-trinitrotoluene (TNT). *Chemosphere.* **73**:657-662

Van Aken B (2008). Transgenic Plants for Phytoremediation: Helping Nature to Clean-Up Pollution. *Tr. Biotechnol.* **26**:225-227

Flokstra BR, **Van Aken B**, Schnoor JL (2008). Microtox® toxicity test: Detoxification of TNT and RDX contaminated solutions by poplar tissue cultures. *Chemosphere*. **71**:1970-1976

Van Aken B, Moon Yoon J, Just CL, Schnoor JL (2004). Metabolism and mineralization of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) inside poplar tissues (*Populus deltoides* × *nigra* DN34). *Environ. Sci. Technol.* **38**:4572-4579

Collaborators & Co-Authors

Agathos, Spiros, Catholic Univ. of Louvain, Belgium; **Boufadel, Michel**, Temple Univ.; **Doty, Sharon**, Univ. of Washington; **Hornbuckle, Keri**, Univ. of Iowa; **Hu, Dinfei**, Univ. of Iowa; **Just, Craig**, Univ. of Iowa; **Lee, Kenneth**, Bedford Institute of Oceanography, Fisheries and Oceans, Canada; **Lin, Lianshin**, West Virginia Univ.; **Schnoor, Jerald**, Univ. of Iowa, Iowa City; **Vesper Dorothy**, West Virginia Univ.; **Wrenn Brian**, Southern Illinois Univ.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

National Marine Fisheries Service
Alaska Fisheries Science Center
Auke Bay Laboratories
Ted Stevens Marine Research Institute
17109 Point Lena Loop Road
Juneau, Alaska 99801-8344
Fax (907) 789-6094

January 3, 2011

Dr. Michel Boufadel
Professor and Chair
Department of Civil and Environmental Engineering
Center for Natural Resources Development and Protection
1947 North 12th Street
Philadelphia, PA 19122

Re: GCMS Analyses of Sediment Samples from EVOS Prince William Sound Remediation Studies

Dear Dr. Boufadel:

Our chemistry laboratory will support your proposed EVOS remediation study with the supporting analytical chemistries that you need, estimated earlier by you to be in the 150-sample range, possibly more.

For sediment analyses we will provide the following services:

1. State of the art GCMS analyses for 44 PAH including the 2-5 ring compounds along with important methylated isomers.
2. State of the art GCMS analyses for biomarkers (including terpanes, hopanes, steranes, and isoprenoids). These biomarkers are among the most recalcitrant compounds to degrade, making them useful in source identification, but more importantly, useful in evaluating degradation/weathering from various treatments.
3. GC/FID analyses for 30 alkanes including C9 to C36. Like the biomarkers, these compounds can be very useful in evaluating weathering/degradation over time or by treatment.
4. Quality assurance procedures, including standards and inter-laboratory comparisons of samples provided by NIST.
5. Archiving of the GCMS and collection site data (from chain of custody forms) into the EVOS hydrocarbon database.
6. Modeling of the data for determination of weathering status and comparison to previous sediment samples from the Exxon Valdez spill area. If some sites have

all ready been analyzed from earlier collections, these will be definitely be compared across time prior to and post treatment.

7. Interpretations and a report will be provided of the chemistry as needed, in support of EVOS reporting requirements and scientific publications.
8. FOIA ready package will be prepared for response to expected FOIAs (100% of all chemistry data produced in our laboratory has been subject to previous FOIAs, and this data would be expected to be subject to FOIA also).
9. We will provide the chem-clean collection jars that receive the samples in the field, along with shipping containers.

We will charge $750 per environmental sample provided and provide the services listed above. We will not charge for standards or quality assurance samples that are run in the various strings of samples; those costs are part of the $750 fee per sample. If biomarkers and alkanes (#2 and #3 above) are NOT desired, the price will be lowered to $600 per sample. There are little additional sample preparation costs for these analyses, but they do require additional GC runs (and different standards) to be made for the biomarker and alkane analyses. No charges will be made for any full-time, permanent staff salary that participate in the analyses, reporting, FOIA response, or participation in future publications. The charges above will provide for the operating costs of conducting the analyses and reporting. In addition to the samples provided by you, we would require a chain of custody sheet with appropriate collection data completed. If a field staff person is needed to aid in collection of samples, travel costs would be in addition, but not salary.

In addition, we discussed briefly the possibility of passive samplers. These sample the water, and are a measure of "bioavailability". The cost for passive sampler analyses is $300 each for un-armored and $350 each for armored samplers. Passive samplers are analyzed for PAH only. We would clean the passive samplers (and armored carriers), ship samplers with shipping containers, and provide chemical analyses as above. We would provide training in deployment, if needed, or possibly provide a staff person to aid if this becomes a sampling tool needed by your project.

We look forward to servicing your project needs. More information on remediation of contaminated beaches in Prince William Sound is a worthy project supported by our agency. We appreciate the opportunity to be a part of the project. I can be reached at 907-789-6020 (jeep.rice@noaa.gov).

Sincerely,

Stanley D Rice 3 Jan 2011

Stanley Rice, Ph.D.
Program Manager, Habitat and Marine Chemistry Studies

EXXON VALDEZ OIL SPILL TRUSTEE COUNCIL
DETAILED BUDGET FORM FY 11

Budget Category:	Proposed FY 11	TOTAL PROPOSED
Personnel	$281,160.0	$281,160.0
Travel	$37,600.0	$37,600.0
Contractual	$803,610.0	$803,610.0
Commodities	$33,000.0	$33,000.0
Equipment	$0.0	$0.0
Indirect *(will vary by proposer)*	$ 300,396.2	$300,396.2
SUBTOTAL	$1,455,766.2	$1,455,766.2
General Administration (9% of subtotal)	$131,019.0	$131,019.0
PROJECT TOTAL	$1,586,785.2	$1,586,785.2
Other Resources (Cost Share Funds)	$0.0	$0.0

COMMENTS: In this box, identify non-EVOS funds or in-kind contributions used as cost-share for the work in this proposal. List the amount of funds, the source of funds, and the purpose for which the funds will be used. Do not include funds that are not directly and specifically related to the work being proposed in this proposal.

FY11

Project Title:Pilot studies of bioremediation
Lead PI: Michel Boufadel

FORM 4A
NON-TRUSTEE AGENCY
SUMMARY

***EXXON VALDEZ* OIL SPILL TRUSTEE COUNCIL**
DETAILED BUDGET FORM FY 11

Personnel Costs:		GS/Range/	Months	Monthly		Personnel
Name	Project Title	Step	Budgeted	Costs	Overtime	Sum
Michel Boufadel	Project director		4.0	19000.0		76,000.0
Brian Wrenn	Senior Scientist		5.0	14880.0		74,400.0
Postdoctoral fellow			12.0	5580.0		66,960.0
Two graduate students			24.0	2200.0		52,800.0
Eric Cordes	Assistant Professor		1.0	11000.0		11,000.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
						0.0
	Subtotal		46.0	52660.0	0.0	
					Personnel Total	$281,160.0

Travel Costs:	Ticket	Round	Total	Daily	Travel
Description	Price	Trips	Days	Per Diem	Sum
Travel from Philadelphia to PWS of four personnel	600.0	16	120	200.0	33,600.0
Travel to present the results at a national conference	800.0	2	12	200.0	4,000.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
				Travel Total	$37,600.0

FY11

Project Title:
Lead PI:

FORM 4B
PERSONNEL & TRAVEL DETAIL

EXXON VALDEZ OIL SPILL TRUSTEE COUNCIL
DETAILED BUDGET FORM FY 11

Contractual Costs: Description	Contract Sum
Treatment system construction, mobilization, installation, and removal by Glacial Alaska (or equivalent)	446,965.5
Research Planning Inch (Jacqui Michel)	82,532.0
Rich McManus, Farallon Engineering	49,112.5
Oil analysis, Auke Bay lab, 300 samples @ $700 a sample	210,000.0
Jeff short, one month	15,000.0
If a component of the project will be performed under contract, the 4A and 4B forms are required. **Contractual Total**	$803,610.0

Commodities Costs: Description	Commodities Sum
Shipment of material through land carrier (e.g., ABF) from philadelphia to anchorage	15,000.0
Rental of trucks and cars for transportation	4,000.0
Publications of articles	8,000.0
Purchase of two computers for conducting simulations for data interpretation	6,000.0
Commodities Total	$33,000.0

FY11

Project Title:
Lead PI:

FORM 4B CONTRACTUAL & COMMODITIES DETAIL

***EXXON VALDEZ* OIL SPILL TRUSTEE COUNCIL**
DETAILED BUDGET FORM FY 11

New Equipment Purchases: Description	Number of Units	Unit Price	Equipment Sum
			0.0
No equipment purchase			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
			0.0
		New Equipment Total	$0.0

Existing Equipment Usage: Descriptior	Number of Units	Inventory Agency

FY11

Project Title:
Lead PI:

FORM 4B
EQUIPMENT DETAIL

EXXON VALDEZ OIL SPILL TRUSTEE COUNCIL
DETAILED BUDGET FORM FY 11

Research Planning, Inc.
Budget for subcontract with Temple University
EVOS Remediation Trials
AB133F-11-RP-0016
16-Dec-10

2011

Personnel		Hours	Rate	Total	
	J. Michel	240	104	24,960.00	
	Z. Nixon	192	52	9,984.00	
	Total Salary Cost			34,944.00	
	Overhead (125%)			43,680.00	
	Total Personnel Cost			78,624.00	
Travel					
	Air Transportation			1,900.00	JM - 1 rt Al
	Lodging/Per diem			1,408.00	2 days AK,
	Ground Transportation			300.00	
	Total Travel Cost			3,608.00	
Other Direct Cost					
	Prt/Reproduction			100.00	
	Communications			50.00	
	Mailing/Shipping			50.00	
	Misc			100.00	
	Total ODC			300.00	
	Total 2011			82,532.00	

laska, 2 rt Philadelphia
4 days Phil.

Table 1
Pilot Treatment System Design Cost Estimate
Lingering Oil Removal Pilot Project
Prince William Sound, Alaska
Farallon PN: 506-002

Task 1: Pilot Treatment System Design

Labor	Unit		Rate		Cost
Principal I Engineer/Geologist/Scientist	50	hour @	$180	per hour =	$9,000
Senior I Engineer/Geologist/Scientist	25	hour @	$150	per hour =	$3,750
Project I Engineer/Geologist/Scientist	180	hour @	$93	per hour =	$16,740
Clerical Level 1	10	hour @	$70	per hour =	$700
Drafter	36	hour @	$75	per hour =	$2,700
			Task 1 Estimated Total		**$32,890**

Task 2: Pilot Treatment System Fabrication and Mobilization Coordination

Labor	Unit		Rate		Cost
Principal I Engineer/Geologist/Scientist	40	hour @	$180	per hour =	$7,200
Project I Engineer/Geologist/Scientist	95	hour @	$93	per hour =	$8,835
			Estimated Labor Subtotal		**$16,035**

Other Direct Costs (ODCs)	Unit		Rate		Cost
Field Truck	2	day @	$60	per day =	$120
Field Truck Mileage	90	miles @	$0.75	per mile =	$68
			Estimated ODC Subtotal		**$188**
			Task 2 Estimated Total		**$16,223**
			ESTIMATED PROJECT TOTAL		**$49,113**

Table 2
Construction Cost Estimate Summary
Lingering Oil Removal Pilot Project
Prince William Sound, Alaska
Farallon PN: 506-002

Construction Cost Summary

	Quantity	Unit	Unit Cost	Cost
Treatment System Fabrication	3	per beach	$ 23,432	$ 70,295
Equipment Mobilization	3	per beach	$ 16,883	$ 50,649
Treatment System Installation and Testing	3	per beach	$ 74,351	$ 223,052
Treatment System Removal and Site Restoration	3	per beach	$ 34,323	$ 102,969
Total				$ 446,966

Construction Cost Estimate

			Project Cost	Total with Markup
$397,615.50	**Base Bid**		$330,946.04	$397,615.50
				Total P&O
				$66,669.46

Item 1, Treatment Equipment System Fabrication at Glacier Shop

		Men	Days	Hours	Qty	Units	Labor Rate	Mat Unit	Equip Unit	Subs Unit	Total Labor	Total Mat
LABOR												
Supervisor	ST	1	20	2	40	HR	45.20				1,808.00	
Labor	ST	2	20	8	320	HR	44.37				14,198.40	
			Total Labor		360	MH						
MATERIALS												
8'x10' Containers					3	ea		2850.00				8550.0
1/2" Sched 80 PVC Pipe					1000	LF		0.25				250.0
1/2" Sched 80 PVC Couplers					100	ea		1.70				170.0
1/2" Sched 80 PVC 90's					100	ea		0.94				94.0
1/2" Sched 80 PVC 45's					100	ea		0.94				94.0
12 each, Metering Pumps (Plus Spares)					24	ea		261.00				6264.0
Static Inline mixers					24	ea		300.00				7200.0
Submersible Salt Water Pumps (Plus Spares)					6	ea		1000.00				6000.0
Control Panels					3	ea		1000.00				3000.0
Unistrut					120	LF		3.00				360.0
Unistrut Bolt & Clamps					1	ea		50.00				50.0
Plywood & Lumber for Work Benches					1	LS		500.00				500.0
Misc Valves & Fittings					1	ea		1500.00				1500.0
Solar Power (Includes Batteries)					3	ea		3000.00				9000.0
					0	ea		0.00				0.0
EQUIPMENT												
					0	EA			0.00			
					0	EA			0.00			
SUBCONTRACTORS												
					0	EA				0.00		
					0	EA				0.00		
				Subtotals							$16,006.40	$43,032.0

Item 2, Treatment System Installation Phase Mobilization/Demobilization

		Men	Days	Hours	Qty	Units	Labor Rate	Mat Unit	Equip Unit	Subs Unit	Total Labor	Total Mat
LABOR												
Project Management	ST	1	7	1	7	HR	45.20				316.40	
Travel (GES Crew)	ST	4	7	8	224	HR	44.37				9,938.88	
	ST	0	0	0	0	HR	0.00				0.00	
			Total Labor		231	MH						
MATERIALS												
Perdiem					35	ea		90.00				3150.0
Lodging					35	ea		180.00				6300.0
Round Trip Air Fares					5	ea		1000.00				5000.0
					0	ea		0.00				0.0
EQUIPMENT												
Misc. Rental Equipment (Whittier)					1	LS			3000.00			
					0	DY			0.00			
SUBCONTRACTORS												
Barge Line (Freight Charges)					1	EA				15000.00		
					0	EA				0.00		
				Subtotals							$10,255.28	$14,450.0

Item 3, Treatment System Installation at Smith, Eleanor, and Montague Islands

Labor	Mat	Equip	Subs	Total	Total

		Men	Days	Hours	Qty	Units	Rate	Unit	Unit	Unit	Labor	Mat
LABOR												
Supervisor/Operator	ST	1	21	8	168	HR	45.20				7,593.60	
Supervisor/Operator	OT	1	21	2	42	HR	65.24				2,740.08	
Labor	ST	4	21	8	672	HR	44.37				29,816.64	
Labor	OT	4	21	2	168	HR	63.98				10,748.64	
			Total Labor		1050	MH						
MATERIALS												
Perdiem					105	ea		90.00				9450.0
Lodging					0	ea		0.00				0.0
Stainless Steel Well Points					12	ea		350.00				4200.0
1/2" ID HDPE Tubing					6000	lf		0.84				5040.0
5/8" PP Tees					100	ea		5.65				565.0
5/8" PP 45's					100	ea		3.53				353.0
5/8" PP unions					100	ea		2.96				296.0
5/8" x1/2" Connectors					100	ea		2.35				235.0
2" Sched 80 PVC Pipe					1000	LF		1.26				1260.0
2" Sched 80 PVC Couplers					50	ea		4.18				209.0
Type 1 Catch Basin With Grates					3	ea		300.00				900.0
Float & Level Switches					12	ea		150.00				1800.0
3000 Gallon Poly Tanks					3	ea		1500.00				4500.0
Expendables (PPE ect.)					3	ea		1000.00				3000.0
Bentonite Chips					40	BGS		6.90				276.0
Hydrogen Peroxide 30%					870	Gal		0.40				348.0
					0	ea		0.00				0.0
EQUIPMENT												
120 Excavator					1	MO			4500.00			
Misc. Hand Tools					1	MO			3000.00			
Diesel Fuel & Oil					600	Gal			4.00			
					0	EA			0.00			
SUBCONTRACTORS												
Crew Boat Rental (Lodging)					21	DY				1675.00		
Landing Craft / Barge Rental					10	DY				1600.00		
					0	EA				0.00		
					Subtotals						$50,898.96	$32,432.0

Item 4, Treatment System Removal and Site Restoration

		Men	Days	Hours	Qty	Units	Labor Rate	Mat Unit	Equip Unit	Subs Unit	Total Labor	Total Mat
LABOR												
Supervisor/Operator	ST	1	15	8	120	HR	45.20				5,424.00	
Supervisor/Operator	OT	1	15	2	30	HR	65.24				1,957.20	
Labor	ST	4	15	8	480	HR	44.37				21,297.60	
Labor	OT	4	15	2	120	HR	63.98				7,677.60	
			Total Labor		750	MH						
MATERIALS												
Perdiem					35	ea		90.00				3150.0
Lodging					23	ea		180.00				4140.0
Round Trip Air Fares					5	ea		1000.00				5000.0
					0	ea		0.00				0.0
EQUIPMENT												
Misc. Rental Equipment (Staging in Cordova / Valdez)					1	LS			3000.00			
120 Class Excavator (on island)					0.5	MO			4500.00			
Diesel Fuel & Oil					300	Gal			4.00			
					0	DY			0.00			
SUBCONTRACTORS												
Crew Boat Rental (Lodging)					12	DY				1675.00		
Landing Craft / Barge Rental					6	DY				1600.00		
					0	EA				0.00		
					Subtotals						$36,356.40	$12,290.0

Table 3
Construction Cost Estimate Detail
Lingering Oil Removal Pilot Project
Prince William Sound, Alaska
Farallon PN: 506-002

Pilot Treatment System Installation and Startup Engineering Support

Labor	Unit	Rate	Cost
Principal I Engineer/Geologist/Scientist	80 hour @	$180 per hour =	$14,400
Senior I Engineer/Geologist/Scientist	20 hour @	$150 per hour =	$3,000
Project I Engineer/Geologist/Scientist	10 hour @	$93 per hour =	$930
Staff I Engineer/Geologist/Scientist	290 hour @	$82 per hour =	$23,780
Clerical Level 1	20 hour @	$70 per hour =	$1,400
			$0
		Estimated Labor Subtotal	**$43,510**

Other Direct Costs (ODCs)	Unit	Rate	Cost
Transportation (round trip)	2 each @	$1,000 per each =	$2,000
Per diem	26 day @	$90 per day =	$2,340
Misc. materials	1 each @	$1,500 per each =	$1,500
		Estimated ODC Subtotal	**$5,840**
		Task 3 Estimated Total	**$49,350**
		ESTIMATED PROJECT TOTAL	**$49,350**