Shoreline In Situ Treatment (Sediment Mixing and Relocation) Fact Sheet

API TECHNICAL REPORT 1155-2

JUNE 2016

AMERICAN PETROLEUM INSTITUTE

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Suggested revisions are invited and should be submitted to the Director of Marine and Security, API, 1220 L Street, NW, Washington, DC 20005.

Things You Should Know

- All oil spills are unique events and require response actions based on the conditions encountered.
- There are a variety of different treatment techniques available that may be used to clean up oil on the shoreline.
- Cleanup techniques my be applied individually, in combination, or in sequence, depending on the scenario.
- In most cases, physical removal of mobile bulk oil on the surface is recommended as an initial action, to minimize the potential for oil to remobilize and spread to other areas.
- When choosing cleanup techniques it is important to consider the site-specific conditions, including the natural recovery potential, and changes in natural oil removal rates and weathering processes over time.
- The selected cleanup technique(s) should minimize environmental harm. In certain cases, this may involve natural recovery.
- In situ treatment techniques, such as dry or wet mixing and sediment relocation, are effective and proven tools for shoreline response.
- In situ techniques enhance natural weathering processes, and therefore accelerate the natural recovery of the shoreline.
- There are many benefits to in situ treatment, including rapid cleanup rates, low labor and equipment requirements, no/minimal waste generation, and no removal of shore sediments.
- In situ techniques have been used in many different spill responses and field studies, and have resulted in the successful acceleration of oil removal from shoreline sediments.

Contents

Shoreline In Situ Treatment (Sediment Mixing and Relocation) Fact Sheet

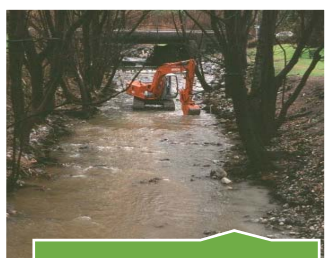
Introduction and Principles of Shoreline In Situ Treatment

When spilled on water, whether at sea, on a lake, or in a river, oil may become stranded on a shoreline or riverbank. If this occurs, there are four basic groups of techniques for shoreline treatment [1], including natural recovery:

Natural Recovery	Removal	In situ	Chemical and Biological
• No intervention • Shoreline recovery may be monitored	• Manual removal • Mechanical removal • Flushing • Washing • Vacuum removal	• **Dry mixing** • **Wet mixing** • **Sediment relocation** • Burning	• Dispersants • Shoreline cleaners • Solidifiers • Bioremediation

This Fact Sheet explains the use of shoreline in situ techniques, including wet and dry **mixing** (also known as tilling or aeration) and **sediment relocation** (also known as surf washing or berm relocation) for oil spill cleanup. Burning is outside the scope of this Fact Sheet.


Dry Mixing


Wet Mixing


Sediment Relocation

The shoreline environment recovers naturally from an oil spill over time in all but a few rare cases. The objective of shoreline treatment is to accelerate the recovery process by enhancing the natural physical removal of oil from the shoreline (see Section 1), and therefore reduce the time and extent of environmental, economic, and other impacts. Unlike removal techniques, dry mixing and sediment relocation do not involve the removal, recovery, or transfer of oil or oiled materials from the treatment location.

Shoreline in situ treatment techniques can be used in a variety of situations, including:

- ✓ Oiled sediments, ranging from mud to cobbles
- ✓ Marine and freshwater (lake and river) environments
- ✓ High and low energy environments
- ✓ Dry and wet (underwater) environments
- ✓ Surface and subsurface oiling.

The many advantages to using shoreline in situ treatment techniques over removal or natural recovery include:

- ✓ Accelerates natural oil removal and weathering.
- ✓ Reduces the persistence of oil on the shoreline.
- ✓ Creates Oil Particle Aggregates (OPA), which accelerate the natural degradation of the oil (see Section 2).
- ✓ Sediment is not removed; therefore:
  - The risk of shoreline/riverbank erosion is minimized.
  - Waste generation and potential impacts due to storage, transportation, treatment, or disposal are minimized.
- ✓ Treatment agents/chemicals are not required.
- ✓ Treatment is rapid compared to other techniques; therefore, the duration of disturbance due to equipment and personnel is reduced.
- ✓ Labor and equipment requirements are low and logistics support is minimal.
- ✓ Can be applied to remote areas with limited access or staging.

Shoreline and weathering processes are key to understanding the role of each shoreline in situ technique in accelerating natural oil removal and weathering. The key processes are explained in Sections 1 and 2. Limitations and considerations for each of the three shoreline in situ treatment techniques are provided in Sections 3 through 5.

This Fact Sheet is organized as follows:

1 Weathering, Persistence, and Fate of Oil on the Shoreline

With no intervention, oil is removed naturally from the shoreline by physical and biological weathering processes:

Process	Timescale	Fate
Evaporation	Hours–Days	Volatile components are transported into the atmosphere
Photo-oxidation	Weeks	Oil is converted to carbon dioxide and water by UV light
Biodegradation	Months	Oil is converted to carbon dioxide and water by micro-organisms
Physical removal by wave and water energy	Hours–Months	Oil is broken up into smaller particles in or on the water, enhancing evaporation, dissolution, dispersion, and OPA formation, all of which enhance biodegradation and photo-oxidation

The major weathering processes are shown in the figure on this page. Many of these processes take place concurrently. The weathering of oil, and therefore the length of time oil persists in the shoreline or nearshore environment, depends on several factors, including:

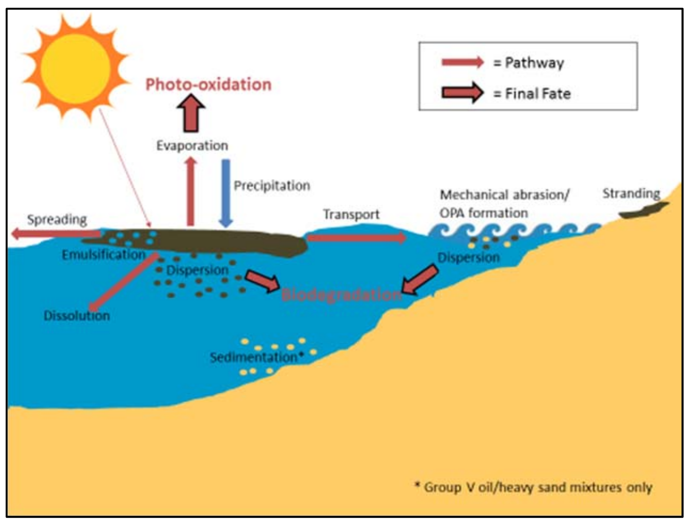
→ Oil properties (e.g. viscosity, specific gravity, solubility, composition, etc.)

→ Oil character and weathering (e.g. fresh oil, oil/water emulsion, tarballs, asphalt pavement)

→ Thickness of the oil (note that photo-oxidation and biodegradation occur only on the exposed surfaces of the oil)

→ Shoreline type (sediment size, porosity, vegetation)

→ Oil penetration into, or burial by, sediment (which inhibits natural weathering and removal processes)



→ Location of stranded oil on the shoreline (sub-tidal, intertidal, or above the high water mark)

→ Environmental conditions (e.g. temperature, precipitation, wave energy, presence of fines).

Key Points:

- The greater the surface area of the oil, the more efficient are the natural processes. Therefore, cleanup techniques that break up oil into smaller particles accelerate natural weathering processes.
- Weathering reduces oil toxicity but increases viscosity, which tends to slow down natural removal processes.

2 Oil Particle Aggregates (OPAs), Natural Dispersion, and Weathering

Oil and Particle Interaction

The formation of Oil Particle Aggregates (OPAs) is a natural process in which fine particles interact on available oil surfaces.[2] This process was described in the 1970s, but its full significance in the break-down of oil in the natural environment was not appreciated until 1990 during the *Exxon Valdez* response. [3] The OPA process has since been verified by dozens of laboratory studies [4] and a major multi-nation field experiment in Norway in 1997 [5]. OPA formation is a significant weathering process because the result is a rapid increase in the surface area of the oil that is available for natural dispersion, biodegradation, and photo-oxidation.

TERMS FOR OPA

There are several different terms that have been used to describe OPA, all of which refer to the same basic process:

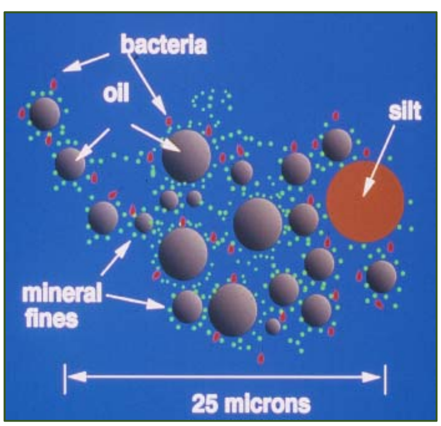
- → COF: Clay Oil Flocculation
- → OMA: Oil Mineral Aggregate
- → OSA: Oil SPM (Suspended Particulate Matter) Aggregation

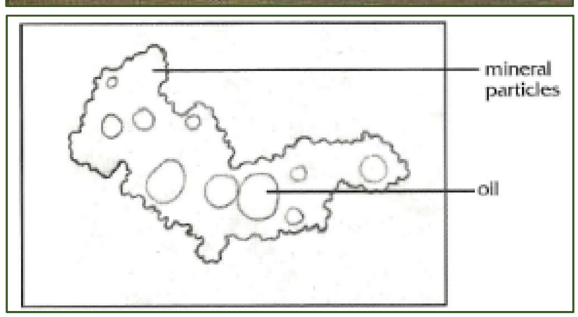
OPA Formation

OPA is an emulsion that forms naturally due to the electrostatic attraction between oil and mineral or organic particles when they mix. Aggregates of oil and fine particles can form naturally where suspended particulate matter (SPM), clays, or other fine particles are present. When particles attach to an oil droplet, they prevent the droplet from coalescing with other oil droplets [2], therefore promoting the formation of stable oil droplets. OPA formation also prevents the adhesion of oil to surface sediments. Because OPAs are not as "sticky" as oil alone, the oil-water contact area is greatly increased when OPAs form, therefore enhancing both oil dispersion into the water body and oil biodegradation [6].

OPA Representation

The following figures illustrate typical OPA structures. The figure below is a schematic representation of oil droplets broken up by the attachment of fine particles, causing an increase in surface area. The photograph on the right is a microscopic image (with schematic representation below) of one aggregate of oil droplets with mineral particles that detached from a large layer of oil. [7]





OPA Requirements

The formation of OPA requires:

→ The presence of oil with polar components

- Polar compounds are found in most crudes and fuel oils
- Polar compounds are not typically found in highly refined products

→ An oil viscosity sufficiently low to allow droplet formation and subsequent aggregation [8]

- Low viscosity oil takes seconds to form OPA
- Highly viscous oil may require days to form OPA
- Extremely viscous and solid oils such as asphalt pavement may not form OPA

→ The presence of water with sufficient ionic strength

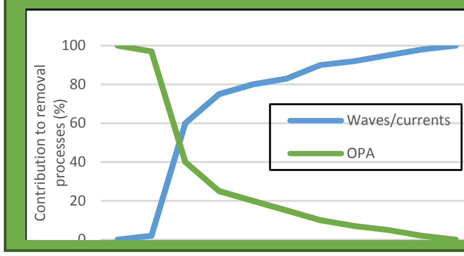
- Readily occurs in both marine and estuarine/brackish environments, where salinity plays a key role in OPA formation
- Also occurs in freshwater environments [9], where calcite and quartz play a role in OPA formation [10]

→ The presence of fine mineral or organic particles

- Fine particles are naturally present in most of the world's water bodies
- The finer the particle, the larger the surface area, which accelerates OPA formation
- The finer the particle, the higher the charge, which increases the attraction to the oil droplets

OPA AND ENERGY

OPA will form even in low energy environments, and can replace the role of wave and current energy in breaking up oil deposits (see graph below). Therefore, even in low energy environments, if the requirements for OPA formation are met, shoreline oil is naturally removed to accelerate biodegradation.



Fate of OPA

→ When an OPA is formed, the surface area-to-volume ratio of the oil is increased by orders of magnitude, accelerating and enhancing the weathering processes of evaporation, dissolution, dispersion, and ultimately biodegradation and photo-oxidation.

→ The particles within the aggregates act as a surfactant, increasing the stability of the oil droplets, and preventing the oil from re-coalescing into larger droplets or oil slicks.

→ Aggregation increases the specific density of the coated droplets, which removes oil from the water surface. However, the aggregates are usually less dense than the particles, and therefore remain in suspension longer and are dispersed farther than un-oiled sediments [11].

→ **The ultimate fate of OPA is the biodegradation, or (to a lesser degree) photo-oxidation of the exposed oil at the particle surface, converting the oil to carbon dioxide and water.**

In Situ Treatment, OPA, Natural Dispersion, and Weathering

- The in situ treatment techniques of mixing and sediment relocation enhance the natural removal processes by physically breaking up oil deposits, therefore accelerating the weathering of the oil and recovery of the shoreline environment.
- Under the right circumstances, and even in low-energy environments, in situ treatment techniques can cause or enhance the formation of OPA, thus further accelerating the removal of the oil and its ultimate conversion to carbon dioxide and water.

3

Dry Mixing

What is Dry Mixing?

The purpose of dry mixing is to physically disturb oiled sediments to:

- Accelerate the physical break up of stranded oil.
- Reduce oiled sediment adhesion and compaction.
- Increase the surface area of the oil for weathering and to enhance OPA formation in sediments.
- For surface oiling: to break up the surface oil layer and to prevent the formation of a weathered oil layer, such as an asphalt pavement.
- For subsurface oiling: to move oiled materials from below the beach surface to the surface, to accelerate removal and weathering processes.
- Increase the exposure of oil to oxygen, sunlight, and water, therefore increasing the rates of biodegradation and photo-oxidation.

Where do we use Dry Mixing?

- Above the water line (i.e. dry), including temporarily exposed intertidal zones.
- On hardened surface oiling.
- On subsurface oiling.
- In locations where shoreline erosion is a concern, and sediment removal must be minimized.
- In remote areas where logistics and waste management are problematic.

What are the advantages of Dry Mixing?

- Accelerates natural removal of oil.
- Exposes and breaks up surface and/or subsurface oil on/in a beach.
- Sediment is not removed.
- Waste generation is zero/minimal.
- Requires minimal logistical support.

When might Dry Mixing not be recommended?

- When equipment could not operate safely or effectively.
- When surface oil may become buried, which would delay natural removal. The depth of mixing can be controlled to mitigate the potential for burial of surface oiling.

What happens to the oil?

- Oil is broken up into smaller droplets or particles to increase the exposed and available surface area, and therefore increase the rate of natural removal by biodegradation and photo-oxidation.
- In the case of buried/penetrated oil, the oil/oiled sediment is brought to the surface of the beach and exposed to sunlight and water, and therefore rates of natural removal by biodegradation and photo-oxidation are accelerated.

How do we conduct Dry Mixing?

- For small patches, less than 6 in. deep: manual raking/mixing using rakes, rotary garden tillers, etc.
- For larger areas or deeper deposits: mechanical tilling/mixing with agricultural or construction equipment:
  - Agricultural equipment: disks, harrows or plows—either motorized, or towed with tractor or UTV (Utility Task Vehicle).
  - Construction/earthmoving equipment equipped with tines, rippers, excavators, or backhoes.
- Dry Mixing can be used as part of a phased response, where initial removal of heavy or bulk oiling prior to mixing is practicable.
- Clean surface sediments overlaying oiled sediments can be removed prior to mixing, and replaced once treatment is completed.
- Beach cleaners can be used after mixing to collect exposed surface oiling, if there are sufficient volumes.

How do we know if Dry Mixing has been successful?

Monitoring should be conducted for:

- Surface and subsurface oiling (SCAT data).
  - Pre-treatment.
  - Post treatment.
- Effectiveness and changes in oil properties during treatment.
- Determining when cleanup endpoints are reached (multiple treatments may be required).

Where has Dry Mixing been used successfully? (see "Cases" section on page 17 for references)

Case	Year	Location	Oil Type	Sediment Type
Amoco Cadiz [a]	1978	France	Crude and fuel oil	Sand
Baffin Island Oil Spill (BIOS) Experiment [b]	1981-1982	Baffin Island, Canada	Medium crude	Sand/pebble/cobble
Exxon Valdez [c]	1990	Alaska, USA	Medium crude	Sand/pebble/cobble
Gulf War spills [d]	1991	Arabian Gulf	Crude	Sand
Barge Bouchard 155 [e]	1993	Florida, USA	Heavy fuel oil	Sand
Apollo Sea [f]	1994	South Africa	Heavy fuel oil	Sand
Sea Empress [g]	1996	UK	Light crude	Cobble
Svalbard Field Trials [h]	1997	Norway	Fuel oil (weathered)	Sand/pebble
Selendang Ayu [i]	2005	Alaska, USA	Fuel oil	Sand/pebble/cobble
Deepwater Horizon [j]	2011/2012	Louisiana, USA	Light crude	Sand

4 Wet Mixing

What is Wet Mixing?

The purpose of wet mixing is to cause shallow, underwater agitation (on shorelines or in rivers) to:

- Release oil from intertidal and subtidal or river sediments.
- Reduce benthic concentrations of oil.
- Enhance OPA formation. [12]

Where do we use Wet Mixing?

- In tidal waters, where oil is in the shallow sub-tidal, or during high tides in the intertidal zone.
- Conducted on a rising tide so that the released oil can be contained and recovered on the water.
- In shallow rivers or on non-tidal shorelines, where oil has mixed with sediment and sunk.
- In low energy environments where additional energy is required to enhance the natural removal and weathering processes.

What are the advantages of Wet Mixing?

- Effective treatment of oil retained in underwater, subtidal and/or intertidal sediments, which could otherwise persist for an unacceptable time frame.
- Released oil may be collected for disposal/treatment, where practicable and safe.
- Sediment is not removed.

When might Wet Mixing not be recommended?

- When equipment could not operate safely or effectively.
- When the oil is denser than the ambient water.
- When treatment could result in oil being driven into the sediment.

What happens to the oil?

- Oil is released from sediments, and floats to the water surface.
- Volatile components of the oil evaporate.
- Less volatile oils can be collected and recovered, using booms, sorbent, skimmers, or vacuums.

How do we conduct Wet Mixing?

- Manual agitation using rakes/shovels.
- Mechanical agitation using agricultural or construction equipment:
  - o Agricultural equipment: disks, harrows or plows—either motorized, or towed with a tractor, backhoe/loader or UTV.
  - o Construction/earthmoving equipment equipped with tines, rippers, excavators, or backhoes.
- Hydraulic agitation using low or high pressure water jets, either from land or on a vessel/floating platform.
- Released oil may be contained by booms and recovered by sorbents, vacuums, and/or skimmers. In some cases, it may not be necessary or safe to recover oil, for example, in the Whatcom Creek incident in which the released gasoline evaporated rapidly when it reached the water surface. [13]
- Silt screens may be installed downstream of a river to collect any sediment that has been suspended due to mixing activities, and prevent movement downstream.

How do we know if Wet Mixing has been successful?

Monitoring should be conducted for:

- Oiling (SCAT) data.
  - o Pre-treatment.
  - o Post treatment.
- Oil/sheen on the water surface at the treatment site.
  - o Pre-treatment.
  - o During treatment.
  - o Post treatment.
- Recovery of any released oil.
  - o Volume and type of waste.

As part of a test prior to implementation, monitoring can include pre- and post-treatment hydrocarbon concentrations in the nearshore water column and/or benthic sediments, at the treatment site, and downstream of river or shoreline currents.

Where has Wet Mixing been used successfully? (see “Cases” section on page 17 for references)

Case	Year	Location	Oil Type	Environment
Wolf Lodge Creek [k]	1983	Idaho, USA	Gasoline	Coarse river sediments
Arco Anchorage [l,m]	1985	Washington, USA	Medium crude	Coarse grained beach
Gulf War spills [d]	1991	Arabian Gulf	Crude	Sand beach
Seki [n]	1994	Fujairah, UAE	Light crude	Sand beach
Chevron pipeline	1996	Hawaii, USA	Heavy fuel oil	Coarse grained beach
Whatcom Creek [o]	1999	Washington, USA	Gasoline	Coarse river sediments
TB Penn 460	2000	Rhode Island, USA	Heavy fuel oil	Fine grained beach
Kalamazoo River [p]	2011	Michigan, USA	Diluted Bitumen	Coarse river sediments
Lac Mégantic	2013	Quebec, Canada	Light crude	Coarse river sediments

5

Sediment Relocation

What is Sediment Relocation?

The purpose of Sediment Relocation is to:

- Move oiled sediments from one section of a beach to an area where the wave or current energy is greater and is sustained for longer periods to accelerate the natural removal of oil.
- To physically break up the oil and therefore increase the surface area available for OPA formation and biodegradation.

Where do we use Sediment Relocation?

- When oil is stranded above the high water mark following a spring tide or storm event, where natural weathering processes due to wave energy and/or OPA formation are minimal.
- When oil is stranded in the upper intertidal zone and can be more quickly broken up with greater energy and/or fine particles in the lower intertidal zone.
- When oil has penetrated into, or buried by, beach sediments below the zone of normal, short-term sediment reworking.
- When oil is stranded on a river bank with falling water levels, where natural weathering processes due to river currents and/or OPA formation are minimal.
- When there is physical energy from waves, tides and currents AND/OR fine particles for OPA formation (even in low energy environments).
- In remote areas where logistics and waste management are problematic.
- In locations where erosion is a concern, and sediment removal must be minimized.

What are the advantages of Sediment Relocation?

- The rapid treatment of oiled beach sediments accelerates natural removal, dispersion, and weathering processes.
- Enables the treatment of beaches with stringent endpoint criteria, such as “No Oil Observed” and “non-detect” oiling levels.
- Enables the efficient polishing of stained or residually oiled beach sediments following bulk oil removal.
- Sediment is not removed.
- Waste generation is zero/minimal and logistical requirements are minimal.
- Treatment is cost-effective and fast compared with removal techniques. [14]

When might Sediment Relocation not be recommended?

- When equipment could not operate safely or effectively.
- When the movement or exposure of oil or oiled sediments could affect resources, such as healthy biological communities in the lower intertidal zone. This can be controlled in some cases by working in the higher intertidal zone, working on a rising tide, or relocating laterally.
- When the oiled sediments would be expected to be naturally cleaned without treatment within an acceptable time frame.
- When oil might be released that could re-oil the beach or adjacent locations. This can be controlled in some cases using containment and recovery equipment to collect the released oil.
- When sediment relocation could cause the oil to become buried.
- When the oil is highly viscous or weathered, e.g. a highly viscous mousse, or an asphalt pavement. In such cases, a test to verify the effectiveness of the treatment is recommended.

What happens to the oil?

- On medium- to high-energy shorelines, the oil is broken up into small particles, which become suspended in the water column and rapidly disperse.
- On shorelines with mineral or organic fines, OPA is formed, naturally dispersing the oil into small droplets, which become suspended in the water column and rapidly disperse.
- Both of these processes may happen together.
- With either of these two processes, the rates of biodegradation and photo-oxidation are accelerated.
- Biodegradation is further accelerated due to the increased concentrations of bacteria and nutrients in the water.

How do we conduct Sediment Relocation?

- Mechanical movement of oiled sediment using construction, excavation and agricultural equipment, such as front end loaders, bulldozers, and backhoes.
- For small patches, manual movement of small volumes of oiled sediment is possible.

How do we know if Sediment Relocation has been successful?

During sediment relocation, monitoring should be conducted for:

- Oiling (SCAT) data.
  - Pre-treatment/Post treatment.
- Oil/sheen on the water surface at the relocation site.
  - Pre-treatment/During treatment/Post treatment.
- Effectiveness during treatment.
- Changes in the beach profile. [15]

As part of a test prior to implementation, monitoring can include pre- and post-treatment hydrocarbon concentrations in the nearshore water column and/or benthic sediments, at the treatment site, and downstream of river or shoreline currents.

Where has Sediment Relocation been used successfully? (see “Cases” section on page 17 for references)				
Case	**Year**	**Location**	**Oil Type**	**Sediment Type**
Amoco Cadiz [a]	1978	France	Crude and fuel oil	Coarse grained beach
Exxon Valdez [c]	1990	Alaska, USA	Medium crude	Sand/pebble/cobble
Barge Bouchard 155 [e]	1993	Florida, USA	Heavy fuel oil	Sand
Apollo Sea [f]	1994	South Africa	Heavy fuel oil	Sand
Sea Empress [g]	1996	UK	Light crude	Cobble
Svalbard Field Trials [h]	1997	Norway	Fuel oil (weathered)	Sand/pebble/cobble
Erika [q]	1999	France	Heavy fuel oil	Sand
Prestige [r]	2002	France	Heavy fuel oil	Sand
Selendang Ayu [i]	2005	Alaska, USA	Fuel oil	Sand/pebble/cobble
Jyeh power station [s]	2006	Lebanon	Heavy fuel oil	Sand
Cosco Busan	2007	California, USA	Heavy fuel oil	Sand/pebble
TK Bremen [t]	2011	France	Fuel oil	Sand
MV Rena	2011	New Zealand	Heavy fuel oil	Sand
Deepwater Horizon [j]	2011/2012	Louisiana, USA	Light crude	Sand

6 Selected Examples

Arco Anchorage, Washington USA (1985) WET MIXING

- Crude oil spilled during this incident penetrated up to 12 in. into coarse-grained sediments within a sheltered, low energy intertidal zone. Wet mixing when the oiled areas were under water released the oil trapped within the pore spaces of the sediments. A bulldozer with ripper teeth combined with a water jet system was found to be the most effective equipment combination to agitate the beach sediments and release the oil. Liberated oil floated to the water surface, and was recovered using sorbents, skimmers and vacuums.[l] Estimates of recovered oil over a six week period were of the order of 10,000 L for every 100 m of treated beach. [m]

Exxon Valdez, Alaska USA (1989) SEDIMENT RELOCATION/DRY MIXING

- Oil remaining on affected shorelines one year after the Exxon Valdez oil spill was still present on the highest parts of the beach, above the limit of normal wave action due to deposition during spring tides. Sediment relocation moved oiled sediments from the dry, back-beach areas into the intertidal zone, where the wave energy and mineral fines broke up the oil. Pre- and post-treatment surveys confirmed that the treatment program was very successful in reducing oil at the treated sites, and that no adverse geological or environmental effects were observed.[15] Intertidal dry mixing was also used in 1990 to expose subsurface oil on selected beaches. [c]

Barge Bouchard 155, Florida USA (1993) SEDIMENT RELOCATION

- Fuel oil stranded on important recreational sand beaches. The objective of the cleanup was to quickly restore the beaches to a pre-spill condition before Labor Day. The sand retained a brown oil stain after mechanical and manual removal of the oiled sediments. Bulldozers and front-end loaders were used to relocate the sediment into the lower intertidal zone. This was successful, depsite low wave-energy conditions at the time, due to the presence of fine particles, and the transport of the cleaned sediment back up the beach occured over a period of only one or two tidal cycles. The No Observed Oil (NOO) endpoints were acheived due to the sediment relocation.[e]

Sea Empress, UK (1996) SEDIMENT RELOCATION

- Stranded emulsion on a coarse sediment beach was found to associate with fine minerals and form OPA during a field test when relocated down the beach. As a result, the planned operational response was modified so that beach sediments on one section of shoreline were relocated to the lower intertidal zone to accelerate oil removal by sediment relocation and to expose subsurface oiled pebbles and cobbles. This action also exposed fine sediments so that the concentration of fines in the nearshore waters was increased, which promoted interaction between oil and sediment fines.[g]

Selendang Ayu, Alaska USA (2005) SEDIMENT RELOCATION

- Fuel oil stranded on mixed sand/pebble/cobble beaches. Sediment relocation and mechanical dry mixing were approved for 8 treatment sites. Monitoring of the treated sites confirmed a net reduction in oiling, the return of beaches to their original profiles, and the reduction of the biological availability of hydrocarbons over the course of the response. Monitoring also confirmed that there were no unanticipated adverse impacts despite the large scale of sediment movement on several of the beaches.[i]

7 FAQs

What are the benefits of using in situ shoreline treatment methods?

There are many benefits, including:

- Reduced treatment time compared with natural recovery and other clean-up techniques
- Minimal labor, equipment, and logistical requirements
- Minimal heavy equipment and responders on the beach
- No removal of sediment
- No generation of waste (unless oil is recovered on water)
- Equipment is typically readily available from the construction and/or agricultural industries

From a purely practical viewpoint, in situ treatment is preferred for remote locations where logistics and waste management are problematic.

Why can't you just remove all of the oil using manual or mechanical means?

Following an oil spill, the complete removal of every last trace of oil is rarely achievable or practical. Decision makers consider the limitations of manual and mechanical shoreline tactics, which:

- Are much slower than in situ methods
- Require more equipment and laborers, therefore greater logistical support
- Produce a large volume of waste, which is especially difficult to manage in remote locations
- Remove a large volume of sediment with the oil, which may contribute to shoreline erosion
- Remove organisms that live in beach sediments

For light oiling conditions, in situ treatment may be sufficient to accelerate natural weathering and removal processes within an acceptable time frame. For higher oil concentrations in populated or accessible areas, manual or mechanical tactics may be preferred initially to remove the bulk surface oil, and then in situ treatment can be applied as part of a polishing process for any remaining oil residues.

How are shoreline treatment methods chosen?

Oil spill response decisions are made by the Incident Command team, with participation and guidance from relevant agencies and stakeholders.

- Treatment methods are recommended by experienced professionals in the Environmental Unit, who assess the net environmental benefit of the available options.
- Field trials may be conducted to evaluate and compare the effectiveness and impacts of different treatment options and can greatly assist the decision process.
- Permits or approvals from the relevant agency(ies) may be required for some treatment methods, including in situ treatment methods.

Mixing: Doesn't the oil just become buried?

Burial of oil can be prevented by limiting the depth of mixing, which can be controlled by the choice and configuration of equipment. [16] In addition, buried oil can be brought to the surface by mixing tactics.

Sediment relocation—Doesn't the oil just sink?

Relocation breaks up oiled sediments, which enhances the formation of OPA, and thereby facilitates the physical removal and natural dispersion by wave and water action.

- Oil Particle Aggregates (OPAs) do not sink provided that both the oil and the fine particles are less dense than the water.
- Breaking waves on even low energy shorelines and river currents keep the OPA emulsions in suspension.
- When the oil is broken up into smaller particles by wave energy and/or OPA formation, dispersion and biodegradation are accelerated [17], and therefore natural removal and weathering is enhanced.
- Monitoring during experimental field studies has shown that oil typically does not accumulate in benthic sediments following sediment relocation. [18]

Sediment relocation—Aren't you just pushing the oil from the beach into/onto the water?

Past spills and studies document that oiled sediments relocated into the water have a short persistence as they are physically broken up, dispersed and biodegraded. [19]

- When the oil is broken up into smaller particles by wave energy and/or OPA formation, dispersion and biodegradation are accelerated, and therefore natural removal and weathering are enhanced. In addition, the relocation of oil from a dry to a wet environment results in increased concentrations of bacteria and nutrients, which further accelerates biodegradation.
- Due to these accelerated processes, aquatic toxicity is minimized. Monitoring conducted during experimental field trials in Norway confirmed that sediment relocation did not elevate toxicity in the nearshore environment to unacceptable levels, nor did it result in consequential alongshore or nearshore sediment oiling. [20]
- In past cases and studies, oil or sheen on the water has rarely been observed, but even when observed, this was minimal and non-persistent, as the oil/sheen rapidly evaporated, dispersed, and/or formed OPA. [21]
- If brown foam is observed adjacent to the relocated sediments, this is a positive indication that the aggregation/OPA process is actively taking place. This foam typically remains for only a few minutes, but may be deposited as a very thin line at the swash.
- In some cases, containment and recovery equipment (booms, sorbents, skimmers, vacuums) may be used to collect anticipated released oil.

Sediment relocation: Doesn't the oil just wash back up onto the beach?

Relocated sediment can be distributed back up the beach over a few tidal cycles; however, this is after the oil has been liberated from the sediment and the oil forms OPA in suspension.

- Some undispersed oil or brown foam may be deposited along the swash line. In such cases, sediment relocation may be repeated one or more times. On the Bouchard 155 operation, some segments required only one relocation pass, whereas others required two or three before oil residues were no longer observed. [e]

- Sorbent materials can be used to collect any free-floating oil or foam both on the water and on the beach; however, past spills and studies have confirmed that little or no residual oil has stranded on the treated or adjacent shorelines following sediment relocation.

Sediment relocation: Doesn't it contribute to shoreline erosion?

Sediment relocation does not remove sediment from the beach, unlike manual and mechanical removal techniques, and therefore reduces the potential for shoreline erosion due to treatment.

- Relocated sediment can be distributed back up the beach over a few tidal cycles. [21]

- Sediment relocation is conducted with consideration of local tides and currents, for example, treatment can be conducted on a rising tide, so that sediment can be quickly and directly redistributed back up the beach.

- On shorelines with significant longshore drift, the sediment can be relocated updrift to ensure that the sediment returns naturally to the area from which the sediment was removed.

- Pre- and post-treatment beach profile surveys help to monitor the recovery of the profile of the beach.

How do these methods impact shoreline wildlife?

Shoreline in situ methods can minimize potential effects on wildlife due to treatment, because they require less heavy equipment, are faster, and more effective in removing the oil than other treatment methods.

- A benefit of in situ tactics is that the treatment is rapid, and therefore, with respect to flora and fauna, the oil exposure time and extent are quickly reduced.

- There may be some short-term localized disturbance of shore sediments, exposure of oiled sediments, and/or small releases of oil/sheen/foam. Such disturbances can be mitigated by planning the treatment to ensure that vegetated areas and lower intertidal zones are avoided, timing the treatment to avoid important migration and/or nesting seasons, and/or using wildlife deterrents, such as scare cannons or visual methods during the physical treatment.

How do these methods impact organisms that live within the beach sediments?

During in situ treatment, there may be some disturbance to organisms that live on or in the sediments.

- In situ treatment equipment can remove or affect fauna, however the disturbance is typically short-lived compared to other treatment methods, and does not remove sediment unlike removal techniques. In addition, there is often rapid recruitment from other non-disturbed areas.

- Disturbances may be reduced by using equipment with low ground pressure (e.g. tracked vehicles).

Where can I find out more about in situ techniques and OPA?

- This Fact Sheet is accompanied by *Shoreline In Situ Treatment (Sediment Mixing and Relocation) Job Aid*, API Technical Report 1155-3.
- A library of papers, case studies, guidance documents and manuals (including the Job Aid) can be found at: www.shorelineinsitutreatment.com

Cases

a. Bellier, P., and Massart, G. (1979). The Amoco Cadiz Oil Spill Operations—An Overview of the Organization, Control, and Evaluation of the Cleanup Techniques Employed. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

b. Owens, E.H., Robson, W., and Foget, C.R. (1987). A Field Evaluation of Selected Beach-Cleaning Techniques. *Arctic 40*(1): 244-257

c. Owens, E.H., Teal, A.R., and Haase, P.C. (1991). Berm Relocation During the 1990 Shoreline Cleanup Program Following the "Exxon Valdez" Spill. *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

d. Benson, R.L., LeGore, R.S., and Pascoe, D. (1993). A Mechanized Approach to Beach Cleanup in Saudi Arabia. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

e. Owens, E.H., Davis, R.A., Michel, J., and Strizke, K. (1995). Beach Cleaning and the Role of Technical Support in the 1993 Tampa Bay Spill. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

f. Moldan, A. (1997). Response to the *Apollo Sea* Oil Spill, South Africa. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

g. Wood, P., Lunel, T., Bailey, N., Lee, K., and Stoffyn-Egli, P. (1997). Clay-Oil Flocculation during Surf Washing at the Sea Empress Incident. *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

h. Owens, E.H., Sergy, G.A., Guénette, C.C., Prince, R.C., Lee. K. (2003). The Reduction of Stranded Oil by In Situ Shoreline Treatment Options. *Spill Science and Technology Bulletin 8*(3): 257-272

i. Shigenaka, G., and Owens, E.H. (2008). M/V Selendang Ayu Response: Mixing and Sediment Relocation on Oiled Coarse Sediment Beaches. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

j. Owens, E.H., Taylor, E., Graham, A., Castle, R.W. (2011). Sand Beach Treatment Studies and Field Trials Conducted During the Deepwater Horizon-Macondo Response Operation. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

k. Graves, N.A. (1985). A Northern Idaho Gasoline Spill and Cleanup Using Steam Bed Agitation. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

l. Miller, J.A. (1987). Beach Agitation for Crude Oil Removal from Intertidal Beach Sediments. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

m. Levine, R.A. (1987). Operational Aspects of the Response to the Arco Anchorage Oil Spill, Port Angeles, Washington. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

n. Owens, E.H, and Sergy, G.A. (2004). Accelerating the Natural Removal of Oil on Shorelines: Part 2: Tilling or Mixing Techniques. *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

o. Owens, E.H., Reiter, G.A., and Challenger, G. (2000). Stream Remediation Following a Gasoline Spill. *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

p. Dollhopf, R., and Durno, M. (2011). Kalamazoo River/Enbridge Pipeline Spill 2010. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

q. Le Guerroue, P., Cariou, G., Poupon, E., and Merlin, F.X. (2003). Recovery of Sunken and Buried Oil in Coastal Water during the Erika Spill. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

r. Kerambrun, L., and Beau, N. (2005). The Prestige Oil Spill Response on the Sandy Beaches in France. *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

s. Fichaut, B. (2008). Massive Use of Berm Relocation and Surfwashing during the 2006 Jyeh Oil Spill (Lebanon): The Accurate Response for Beaches Cleanup. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

t. Kerambrun, L., and Cariou, G. (2014). The *TK Bremen Incident*. Surfwashing Operations as a Cleanup Strategy to Prevent Oil Entering a Small Estuary, the Etel Ria (France). *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

References

1. Owens, E.H., and Sergy, G.A. (2010). *A Field Guide to Oil Spill Response on Marine Shorelines*. Environment Canada, Ottawa.

2. Fitzpatrick, F.A., Boufadel, M.C., Johnson, Rex, Lee, Kenneth, Graan, T.P., et al. (2015). *Oil-particle interactions and submergence from crude oil spills in marine and freshwater environments—Review of the science and future science needs*. U.S. Geological Survey Open-File Report 2015–1076, 33 pp., http://dx.doi.org/10.3133/ofr20151076

3. Bragg, J.R., and Yang, S.H. (1995). *Clay-Oil Flocculation and its Role in Natural Cleansing in Prince William Sound Following the Exxon Valdez Oil Spill. In Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters*, ASTM STP 1219.

4. Owens, E.H., and Lee. K. (2003). Interaction of Oil and Mineral Fines on Shoreline: Review and Assessment. *Marine Pollution Bulletin 47*(9–12): 397–405.

5. Lee, K., Stoffyn-Egli, P., Tremblay, G.H., Owens, E.H., Sergy, G.A., Guenette, C.C., and Prince, R.C. (2003). Oil-Mineral Aggregate Formation on Oiled Beaches: Natural Attenuation and Sediment Relocation. *Spill Science and Technology Bulletin 8*(3): 285–296.

6. Sun, J., and Zheng, X. (2009). A Review of Oil-Suspended Particulate Matter Aggregation—Natural Process of Cleansing Spilled Oil in the Aquatic Environment. *Journal of Environmental Monitoring 11*(10): 1801–1809.

7. Stoffyn-Egli, P., Blenkinsopp, S., Lee, K., and Sergy, G. (2000). *Methods for the Assessment of Oil-Mineral Aggregates*. Environment Canada, Edmonton.

8. Bragg, J.R., and Owens, E.H. (1994). Clay-Oil Flocculation as a Natural Cleansing Process Following Oil Spills: Part 1—Studies of Shoreline Sediments and Residues from Past Spills. *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

9. Lee, K., Stoffyn-Egli, P., and Owens, E.H. (2002). The OSSAII Pipeline Oil Spill: Natural Mitigation of a Riverine Oil Spill by Oil-Mineral Aggregate Formation. *Spill Science and Technology Bulletin 7*(3): 149–154.

10. Omotoso, O.E., Munoz, V.A., and Mikula, R.J. (2002). Mechanisms of Crude Oil-Mineral Interactions. *Spill Science and Technology Bulletin 8*(1): 45–54.

11. Stoffyn-Egli, P., and Lee, K. (2002). Formation and Characterization of Oil-Mineral Aggregates. *Spill Science and Technology Bulletin 8*(1): 31–44.

12. Owens, E.H., and Sergy, G.A. (2004). Accelerating the Natural Removal of Oil on Shorelines: Part 2: Tilling or Mixing Techniques. *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

13. Owens, E.H., Reiter, G.A., and Challenger, G. (2000). Stream Remediation Following a Gasoline Spill. *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

14. Purnell, K.J. (1999). Comparative Costs of Low Technology Shoreline Cleaning Methods. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

15. Hayes, M.O., and Michel, J. (1999). Factors determining the long-term persistence of *Exxon Valdez* oil in gravel beaches. *Marine Pollution Bulleting 38*(2): 92–101.

16. API (in prep.). *Manual of Practice: Mechanical Cleanup of Sand Beaches*. API Report 1151-3.

17. Owens, E.H., Robson, W., and Foget, C.R. (1987). A Field Evaluation of Selected Beach-Cleaning Techniques. *Arctic 40*(1): 244–257

18. Sergy, G.A., Guenette, C.C., Owens, E.H., Prince, R.C., and Lee, K. (2003). In Situ Treatment of Oiled Sediment Shorelines. *Spill Science and Technology Bulletin 8*(3): 237–244.

19. Sergy, G.A., Guenette, C.C., Owens, E.H., Prince, R.C., and Lee, K. (1999). Treatment of Oiled Sediment Shorelines by Sediment Relocation. *Proceedings International Oil Spill Conference,* American Petroleum Institute, Washington DC.

20. Owens, E.H., Sergy, G.A. (2003). Accelerating the Natural Removal of Oil on Beaches: Part 1—Sediment Relocation *Proceedings Arctic and Marine Oil Spill Program (AMOP) Technical Seminar,* Ottawa, ON.

Acknowledgements

This Fact Sheet was prepared by Helen Dubach (Owens Coastal Consultants), Ed Owens (Owens Coastal Consultants), and Bob Castle (RCE Inc.).

energy API®

AMERICAN PETROLEUM INSTITUTE

1220 L Street, NW
Washington, DC 20005-4070
USA

202-682-8000

Additional copies are available online at www.api.org/pubs

Phone Orders:	1-800-854-7179	(Toll-free in the U.S. and Canada)
	303-397-7956	(Local and International)
Fax Orders:	303-397-2740	

Information about API publications, programs and services is available on the web at www.api.org.