OCC | Owens Coastal Consultants

Shoreline In Situ Treatment (Sediment Mixing and Relocation) Tools

OSPR/Chevron Oil Spill Response Technology Workshop, San Ramon, CA

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Dry Mixing

a.k.a. dry tilling
a.k.a. aeration

Objective

- To physically break up stranded oil, which:
  - reduces sediment adhesion and compaction;
  - increases the surface area of the oil for weathering; and
  - Exposes subsurface oil.

Fate of Oil

- The increased surface area and aeration accelerates the natural weathering processes of biodegradation and photo-oxidation.

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

Where do we use Dry Mixing?
• **Above the water line** (i.e. dry), including temporarily exposed intertidal zones. • On **hardened** or **cohesive** 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**.

Wet Mixing

a.k.a. wet tilling

Objective

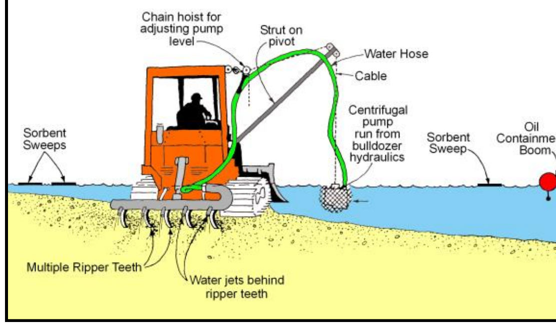
- To cause shallow, underwater agitation to release oil entrained in intertidal and subtidal or river sediments.

Fate of Oil

- Oil is released from the sediment to the water surface, which accelerates natural weathering and removal processes.
- Released oil may be collected for disposal/treatment.

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

"Muck Monster"



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.**

Sediment Relocation

aka surfwashing
aka berm relocation
aka sediment reworking

Objective

- To relocate oiled sediments from one section of a beach to another area where:
  - the physical action of waves or currents is greater, and/or
  - fine particles are present for OPA formation

Fate of Oil

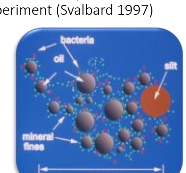
- The physical energy and/or formation of OPA reduces the surface area of the oil, and therefore accelerates the natural weathering processes of biodegradation and photo-oxidation

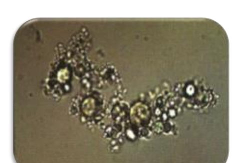
Case	Year	Location	Oil Type	Sediment Type
Amoco Cadiz	1978	France	Crude and fuel oil	Coarse grained beach
Exxon Valdez	1990	Alaska, USA	Medium crude	Sand/pebble/cobble
Fred Bouchard	1993	Florida, USA	Heavy fuel oil	Sand
Apollo Sea	1994	South Africa	Heavy fuel oil	Sand
Sea Empress	1996	UK	Light crude	Cobble
Svalbard Field Trials	1997	Norway	Fuel oil (weathered)	Sand/pebble/cobble
Erika	1999	France	Heavy fuel oil	Sand
Prestige	2002	France	Heavy fuel oil	Sand
Selendang Ayu	2005	Alaska, USA	Fuel oil	Sand/pebble/cobble
Jyeh power station	2006	Lebanon	Heavy fuel oil	Sand
Cosco Busan	2007	California, USA	Heavy fuel oil	Sand/pebble
TK Bremen	2011	France	Fuel oil	Sand
MV Rena	2011	New Zealand	Heavy fuel oil	Sand
Deepwater Horizon	2011/2012	Louisiana, USA	Light crude	Sand

Oil Particle Aggregation

AKA Oil Mineral Aggregation (OMA), Clay Oil Flocculation (COF), Oil-SPM Aggregation

- A natural mechanism in which fine particles interact on exposed oil surface, forming an emulsion, and causing the formation of small oil droplets
- Described in 70's but full significance not appreciated until 1990 on the *Exxon Valdez* response
- Since verified by dozens of lab experiments and a major multi-nation field experiment (Svalbard 1997)

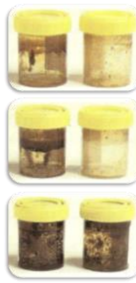




Source: Environment Canada

Oil Particle Aggregates (OPAs)

- Form naturally where suspended particulate matter (SPM), clays or other fine particles are present.
- **Prevent the droplet from coalescing** with other oil droplets
- **Prevent the adhesion** of oil to surface sediments.
- **Increase the oil-water contact area**, therefore enhancing both oil dispersion into the water body and oil biodegradation.



Source: Environment Canada

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 been 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.

The Problem

- Shoreline In Situ Treatment is not generally well known and understood
- Many academic papers exist with good scientific information
- BUT very little for information the public, or to help decision makers in industry or government
- Needed more educational and operational information

API Oil Spill Response Preparedness Program → Shoreline Protection and Cleanup Working Group → TASK E

To aid in the better understanding of, and education on, in-situ treatment techniques, API has supported the development of three tools:

- **Shoreline In Situ Treatment Library**
- **Shoreline In Situ Treatment Fact Sheet**
- **Shoreline In Situ Treatment Job Aid**

energy API

In Situ Treatment Library

An online library containing >150 academic, scientific, technical and operational literature, including links to electronic documents

In Situ Treatment Fact Sheet


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

API TECHNICAL REPORT 1155-2
JUNE 2016

A non-academic **educational guide**, providing an overview of:

- Natural weathering processes, including Oil Particle Aggregate (OPA) Formation
- Why and where the techniques are used
- Advantages and limitations of in situ techniques
- Fate of oil following treatment
- How the techniques are conducted
- Monitoring for effectiveness and effects
- Successful case studies

TACTICS: Dry Mixing

3 Dry Mixing

Why do we use Dry Mixing?

The purpose of dry mixing is to physically disturb the oiled sediment layer 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 OMA 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 rate of biodegradation and photo-oxidation.

Where do we use Dry Mixing?

- Above the water line (i.e. dry).
- 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 subsurface oil on/in a beach.
- Sediment is not removed.
- Waste generation is zero/minimal.

When might Dry Mixing not be recommended?

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

What happens to the oil?

- Oil is broken up into smaller droplets or particles to increase its 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 inches deep: manual raking/mixing using rakes, rotary garden tillers.
- For larger areas or deeper deposits: mechanical tilling/mixing with agricultural or construction equipment:
  - Agricultural equipment: discs, harrows or ploughs – either motorized, or towed with tractor, bobcat or UTV.
  - Construction /earthmoving equipment equipped with rippers, excavators, or backhoes.
- Clean surface sediments overlaying oiled sediments can be removed prior to tilling, and replaced once treatment is completed.
- Beach cleaners can be used 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.
- Continue monitoring until cleanup endpoints are reached (multiple treatments may be required).

Where has Dry Mixing been used successfully? (see "Cases" Section on page 18 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
Fred Bouchard [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

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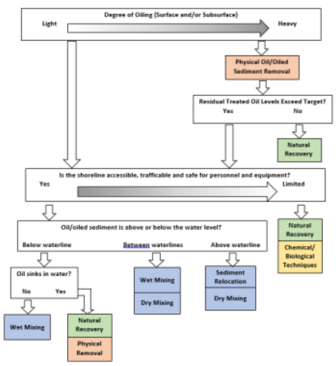
In Situ Treatment Job Aid


Shoreline In Situ Treatment (Sediment Mixing and Relocation) Job Aid

API TECHNICAL REPORT 1155-3
JUNE 2016

A non-academic **operations tool**, to be used during a response by Operations, EU and SCAT for planning and operations, including:

- Decision Guide
- Scope and Application
- Equipment and Personnel Requirements
- Operational and Environmental Considerations
- Sampling and Monitoring, including field testing for OMA formation
- Information Requirements
- Decision Checklists



Shoreline/River Sediment In Situ Treatment Decision Guide

	Dry Mixing	Wet Mixing	Sediment Relocation
Sediment Type *			
Mud	✓	✓	✓
Sand	✓	✓	✓
Mixed Sediment	✓	✓	✓
Pebble	✓	✓	✓
Cobble	✓	✓	✓
Boulder			
Shoreline Location			
Supra-tidal Zone (SUTZ)	✓		✓
Upper Intertidal Zone (UITZ)	✓		✓
Middle Intertidal Zone (MITZ)		✓	✓
Lower Intertidal Zone (LITZ)		✓	
Subtidal (to 3ft water depth)		✓	
River Location			
Above the water line (dry)	✓		✓
Below the water line (wet)		✓	
Oiling Depth			
Surface	✓		✓
Subsurface: <0.2ft (0.5m)	✓	✓	✓
Subsurface 0.2-3ft (0.5-1m)	✓		✓
Subsurface 3-6ft (1-2m)			✓
Subsurface >6ft (2m)			✓
Oil Type			
Volatile		✓	
Light	✓	✓	✓
Medium	✓	✓	✓
Heavy	✓	✓	✓
Solid			
Oil Character			
Pooled		✓	
Emulsion (Mousse)	✓	✓	✓
Surface Residue	✓		✓
Asphalt Pavement	✓		
Tarballs		✓	

Applicability of In Situ Techniques

Equipment and Personnel Requirements: Wet Mixing

Option	Equipment	Personnel
Manual (for small patches of oil)	• Rakes/shovels	• Manual labor
Mechanical	• Tractor-towed agricultural tillers • Bulldozers or motor graders equipped with rippers, excavators, or backhoes.	• Trained equipment operators • Safety spotters for large machinery
Hydraulic	• High volume, low pressure water jets; or low volume, high pressure water jets operated from land or vessel (e.g. landing craft, barge, workboat) • Shallow water dredging equipment (e.g. Mud Cat or Excavator Slurry Pump Attachment)	• Trained equipment operators • Safety spotters for large machinery • Boat crew for vessel operations
Combination	• Mechanical AND hydraulic equipment used in combination • e.g. bulldozer with rippers and water jets	• Trained equipment operators • Safety spotters for large machinery • Boat crew for vessel operations
Optional containment and recovery (where necessary)	• Hard and/or sorbent boom • Skimmers, vacuums, sorbent material • Silt screens (for collecting disturbed sediment in rivers)	• Trained equipment operators, or • Manual labor • Boat crew for vessel operations

Information Requirements for Decision Making: SEDIMENT RELOCATION	
SCAT Data	• Shoreline/riverbank character and width • Sediment type • Oil location (including tidal/river zone), extent and character • Depth of oil burial or penetration • Site access • Sensitive resources (ecology/wildlife, cultural/historic, economic, human use) • Safety concerns
EU Data	• Weather forecast (including wind, rain, snow, predicted storms) • Water conditions (tide, currents, water/river level, ice) • Oil properties (including density, viscosity, volatility) • Resources at Risk (including seasonality) • Approval and permitting requirements for access and treatment
Planning/Logistics	• Available equipment and personnel • Operational limitation (e.g. surface type, shallow water operations etc.) • Transportation and access requirements • Available logistics for waste management
Additional surveys may be required for:	• Site safety • Operating surface • Beach/riverbank dynamics and erosion potential, including longshore or down drift • Specific in-/epi-fauna data (e.g. species diversity, population numbers, etc.) • Beach/riverbank profiles • OMA formation potential test (Appendix A)

Information Requirements for Decision Making: Sediment Relocation

Decision Checklist: Sediment Relocation

Decision Checklist: SEDIMENT RELOCATION

1 **FATE AND PERSISTENCE: Is the oil likely to be removed by NATURAL PROCESSES within an acceptable time frame?**
Consider shoreline/riverbank conditions (exposure, energy, weather), oiling conditions (degree, character, location on the shore/riverbank, burial or penetration) and the potential for natural weathering and removal
YES: Monitor NATURAL RECOVERY of the shoreline
NO: Continue to 2 below

2 **Is the OBJECTIVE to accelerate/enhance the natural recovery of lightly/moderately oiled sediment?**
Consider oiling conditions compared with endpoints/cleanup targets
YES: Continue to 3 below
NO: Consider alternative options, including NATURAL RECOVERY

3 **Can Sediment Relocation be conducted SAFELY?**
Consider shoreline/riverbank conditions, weather and sea/river conditions, shoreline substrate, weight-bearing capacity, trafficability, oil type/properties, transportation requirements, equipment needs, training requirements
YES: Continue to 4 below
NO: Consider alternative options, including NATURAL RECOVERY

4 **Is the shoreline/riverbank ACCESSIBLE?**
Consider the access requirements for personnel/equipment/vehicles, by land, sea or air (SCAT data)
YES: Continue to 5 below
NO: Consider alternative options, including NATURAL RECOVERY

5 **Is the necessary equipment and personnel AVAILABLE to the responders?**
Consider the ability to work in/around water, and to the maximum depth of the oil. Consider sourcing from outside the area, if not locally available
YES: Continue to 6 below
NO: Consider alternative options, including NATURAL RECOVERY

6 **Is Sediment Relocation likely to provide a NET ENVIRONMENTAL BENEFIT?**
Consider potential impacts to wildlife, vegetation, in-/epi-fauna and flora, human use, historical/cultural resources. Consider seasonality, treatment/recovery time, mitigation. Consider waste management and shoreline/riverbank erosion concerns. Compare with other available techniques (potential impacts, invasiveness, duration) including natural recovery. Consider where the treatment will occur (does not necessarily have to be immediately adjacent to oiled area)
YES: Continue to 7 below
NO: Consider alternative options, including NATURAL RECOVERY

7 **Is Sediment Relocation likely to be EFFECTIVE?**
Consider the shoreline/sediment type, oil type and character (SCAT data), weather and sea/river energy/conditions, OMA formation potential (Appendix A). Consider where the treatment will occur (does not necessarily have to be immediately adjacent to oiled area)
YES: Continue to 8 below
NO: Consider alternative options, including NATURAL RECOVERY

8 **Could WEATHER/WATER CONDITIONS negate the need for Sediment Relocation?**
For example, are spring tides, storm-generated waves, or river flood conditions anticipated which would reach the proposed treatment area and promote natural cleaning through water energy, turbulence and/or OMA formation?
YES: Consider re-evaluating the need for treatment after the weather event
NO: Continue to 9 below

9 **Is there any HEAVY or BULK OILING which could be effectively removed manually or mechanically prior to conducting Sediment Relocation?**
Consider degree of oiling and mobilization potential, equipment availability and accessibility, logistics, waste management issues, erosion potential
YES: Plan for bulk/heavy oiling prior to Sediment Relocation, and continue to 10 below
NO: Continue to 10 below

10 **Is the released oil likely to be a concern and to warrant containment and recovery?**
Consider the potential for mobilization of released oil, pre-treatment oiling data, tides and currents, accessibility, equipment availability, logistics, waste management issues
YES: Plan for Containment and Recovery of released oil, and continue to 11 below
NO: Continue to 11 below

11 **Is there CLEAN SEDIMENT (overburden) above the oiled layer which can be temporarily removed, stored and replaced?**
Consider the depth of burial/penetration, the equipment required/available to carry out to move overburden, available storage, and available time
YES: Plan for Overburden Management, and continue to 12 below
NO: Continue to 12 below

12 **Will a field test provide a better understanding of the effectiveness, effects and fate of the oil due to Sediment Relocation?**
Consider the expected outcomes, fate of the oil and sediment, and stakeholder concerns
YES: Conduct a Field Trial prior to approval. If the field trial confirms expectations, continue to 13 below
NO: Continue to 13 below

13 **APPROVAL**
Create a segment/reach specific Shoreline Treatment Recommendation (STR) Form for approval for Sediment Relocation from Command. Include:
- Location of oiled area for treatment
- Description of oiling
- Endpoint criteria
- Equipment and personnel requirements
- Operational and Safety constraints
- Environmental/Ecological constraints
- Monitoring requirements
- Approval sign-off

Library
www.ShorelineInSituTreatment.com

API Documents
http://www.oilspillprevention.org/oil-spill-research-and-development-cente