8. LAND RESPONSE

The prime focus of oil spill countermeasures activity is in prevention and planning. This is achieved through well-designed equipment, good maintenance and operating procedures, sound training techniques as well as a high degree of awareness and concern at all levels by employees and management. Prevention and mitigation measures planned for the Project include: 24-hour manned automated monitoring, leak detection systems, visual monitoring, and emergency shut down systems for production, storage, and transportation systems. Spill response equipment will be stockpiled at key locations. In addition, the system will be inspected regularly by ground and aerial patrols for signs of leakage or unauthorized encroachment along the land easement that might affect overall system integrity. Other items that may require attention, such as soil erosion, water course changes, road and stream crossings, and the re-growth of brush and trees over the pipeline itself will also be monitored.

Despite best management practices an incident may occur. In the event of an incident the objective of the oil spill response is to assure that actions are efficient and compatible with the balanced environmental, social, and economic needs of the community. The response strategy includes all viable techniques to reduce damage from a spill. No oil spill response option would be ruled out or limited in advance.

This section provides an overview of containment, recovery and treatment options for a spill of oil onto land. Site specific response techniques will be identified in each ASOSRP.

8.1. Introduction

Spills of oil to land require immediate response action to stop the source of the discharge and to limit the spread of material. Immediate response actions and notification procedures are outlined in Section 2. Attention must be paid to fire and safety hazards.

For terrestrial areas, selection of appropriate control and containment techniques is dependent on the:

- nature of the substrate,
- slope of the terrain,
- amount of product, and
- time available to implement the response action.

The quantity and time parameters reflect the reality of constructing a barrier of appropriate size in the time available. These factors can only be judged in the field at the time of the incident.

Should it be impossible to implement the desired method at a desired location due to a lack of time or access, a new control point would be selected further downslope. If containment is still impossible and human safety is in question, the threatened area would need to be evacuated.

The objectives of a program to cleanup or treat a spill that has impacted the land are:

- to confine as much of the spill as possible to restricted, non-porous areas,
- to recover or remediate as much of the spilled material and area as is reasonably feasible, and
- reduce additional impacts to the area while promoting the speediest recovery.

Cleanup of the affected areas should commence as soon as possible after all emergency control actions have been completed.

The steps in cleanup are:

- assess and identify the extent of the problem (usually accomplished by cleanup assessment team surveys);
- plan the cleanup and develop operational strategies in conjunction with a Net Environmental Benefit Analysis (see Sections 1.3.1 and 8.2.1), and with the federal and local authorities and land-owners, and
- conduct and monitor the cleanup.

After removal of pooled oil, residual material can be expected to generate aesthetic concern, interfere with plant growth, and, in some cases, threaten water supplies. There are no defined rules for defining the selection of terrestrial cleanup methods. A soils/groundwater consultant could be used to investigate and recommend appropriate actions and oversee their implementation.

8.2. Assessment and Monitoring

In general, the Supervisor can identify the type of substance released. The properties of a substance and its health hazards can be quickly identified using the Material Safety Data Sheets (MSDSs). If uncertain, it may be possible to identify the material by appearance and location. Preliminary analytical testing of the spilled material may be carried out if deemed necessary.

Vehicular and pedestrian access to the land easement in sensitive areas will be on an as-needed basis and will be restricted to authorized vehicles and personnel involved in the response.

A rough estimate of the total volume of the spill is desirable. Early in the response, the total possible spill volume determines, in part, the level of response plan activation and the requirements of the disposal site. Several quick methods can be used to provide working approximations (see also Section 5, Tracking and Surveillance). Table 8-1 provides an estimation of product loss due to small leaks.

Pipeline/Hose Loss

The volume of material lost can be estimated from the pumping rate, the duration of pumping, and pipeline and hose loss estimates. Calculations of loss are based on pump rate in bbl/min times minutes until shutdown plus loss of the static pipeline and hose contents for segments below the estimated point of breakage.

Volume loss (barrels) =

Pump rate (bbl/min)	x	Time elapsed until shutdown (minutes)	+	Static line & hose contents (barrels/100' segments)

Tank Car Loss

The amount of product lost from the tank car can be estimated by gauging the tank and subtracting the post-spill volume from the pre-spill volume.

Table 8-1. Product Loss Estimations due to Small Leaks

Rate	Estimated Loss
One drop/second	One minute loss is 1/10 ounce One hour loss is 6 ounces One day loss is 1-1/8 gallons One week loss is 7-7/8 gallons One month loss is 34 gallons
Two drops/second	One minute loss is 1/3 ounce One hour loss is 20 ounces One day loss is 3¾ gallons One week loss is 26¼ gallons One month loss is 112½ gallons
Stream breaking to drops	One minute loss is 2 ounces One hour loss is 1 gallon One day loss is 24 gallons One week loss is 168 gallons One month loss is 720 gallons
1/16" stream	One minute loss is 7½ ounces One hour loss is 3½ gallons One day loss is 84 gallons One week loss is 588 gallons One month loss is 2,520 gallons
1/8" stream	One minute loss is 23 ounces One hour loss is 10 gallons One day loss is 240 gallons One week loss is 1,680 gallons One month loss is 7,200 gallons
3/16" stream	One minute loss is 39 ounces One hour loss is 18-3/4 gallons One day loss is 438 gallons One week loss is 3,066 gallons One month loss is 13,140 gallons
1/4" stream	One minute loss is 83 ounces One hour loss is 39 gallons One day loss is 936 gallons One week loss is 6,552 gallons One month loss is 28,080 gallons

8.2.1. Response Priorities and Net Environmental Benefit Analysis

The pipeline route has been chosen to limit the environmental impact in case of a leak, and to avoid where possible sensitive areas such as nature reserves, undisturbed forests, swamps, and human settlements such as Pygmy camps. However, if the oil threatens more than one sensitive area or resource feature, it is necessary to develop priorities and choose appropriate techniques for each area that will not induce additional negative impacts.

The NEBA (see Section 1.3.1) approach accepts that some cleanup or treatment responses have the potential to cause a negative impact on the environment; however, they may be justifiable because of overriding benefits, such as protecting local populations or groundwater, and/or the avoidance of further impact. In some cases, for example, the option with the greatest net environmental benefit may be to allow an oiled area to recover naturally, as when vehicle and foot traffic would do more damage working oil into the plant/soil/active layer than leaving a spill untreated.

Cleanup activities in open land and forest regimes will center on the use of light equipment and land-cleaning techniques, unless the spill presents a threat to human life and must, therefore, be removed rapidly. Depending on the substrate type, biological community, resources and cultural uses present, different types of response options might be chosen. For some areas, such as along heavily used livestock herding routes, the use of heavy equipment may be the most appropriate choice to remove bulk oil. For other areas, the use of equipment may do more harm to the area than leaving the oil in place, such as in heavily vegetated areas.

It is generally beneficial to remove bulk oil from the surface, if it can be done safely and impact to the biological community can be limited. For areas where there is not an extensive biological community, more intrusive techniques to remove bulk oil may be appropriate. If access roads are available and the substrate will support heavy equipment, mechanical recovery can be used to remove oiled material.

Presently, there are no known means for effectively cleaning vegetation. It is likely that a spill will kill low-lying shrubs, grasses, and any plants that absorb oil through its roots. *In-situ* burning, if safe and practicable, would be a preferable option. Large trees with oil on their trunks should be left alone.

Local priorities, response activities and issues will be addressed in the ASOSRPs.

8.3. *Containment*

The objective of surface containment is to prevent the spread of oil on the soil or substrate surface and to prepare it for recovery (Section 8.4) or treatment (Section 8.5). This usually can be achieved using easily available materials (i.e., shovels, earth-moving machinery, trucks, damming materials, sorbents, etc.) to construct berms, dams, barriers, and trenches to divert and contain the flow. Containment and damming to pool the oil are important if the oil is to be pumped and/or sucked up. Several techniques are also discussed to contain and divert subsurface flow. Recovery and treatment methods for remediation of contaminated groundwater, including natural attenuation, are discussed in Section 8.6.

Strategies

- Act quickly.
- Contain and control as near source as possible.
- Protect resources in oil pathway.
- Prevent oil reaching streams, rivers, or groundwater.
- Use the natural features to contain and control flow whenever possible.

Points to Remember

- Always pay attention to fire and health hazards.
- Start containment operations immediately to prevent oil from reaching a watercourse, the groundwater, or otherwise sensitive area or object.
- Evaluate logistical factors (safety, access, availability, etc.) to assess feasibility and to ensure effective and efficient implementation.
- Consider the type of equipment that can be used, as different equipment has different operational capabilities. It is necessary to match planned activities with the available equipment and personnel.
- As much as possible, do not allow vehicles to run over oil-saturated areas.
- Do not flush the oil down clean drains and other inlets.
- Do not use excavators on areas with free oil on the surface.
- Containment is easier on land than on open water.

Methods

A decision guide for choosing containment methods is provided as Table 8-2. Although not a containment technique per se, *in-situ* burning (see Section 8.5.1) is included in Table 8-2 as it may be used as a control technique by rapidly removing the oil. The terrestrial containment techniques are summarized in Table 8-3.

- Earth containment or diversion berm (Section 8.3.1)
- Containment or diversion trench (Section 8.3.2)
- Sorbent barrier (Section 8.3.3)
- Culvert and drain blocking (Section 8.3.4)
- Soil interceptor trench (subsurface flow; Section 8.3.5)
- Slurry walls (subsurface flow; Section 8.3.6)
- Viscous liquid barriers (subsurface flow; Section 8.3.7)

Table 8-2. Terrestrial Spill Containment Technique Selection Guide

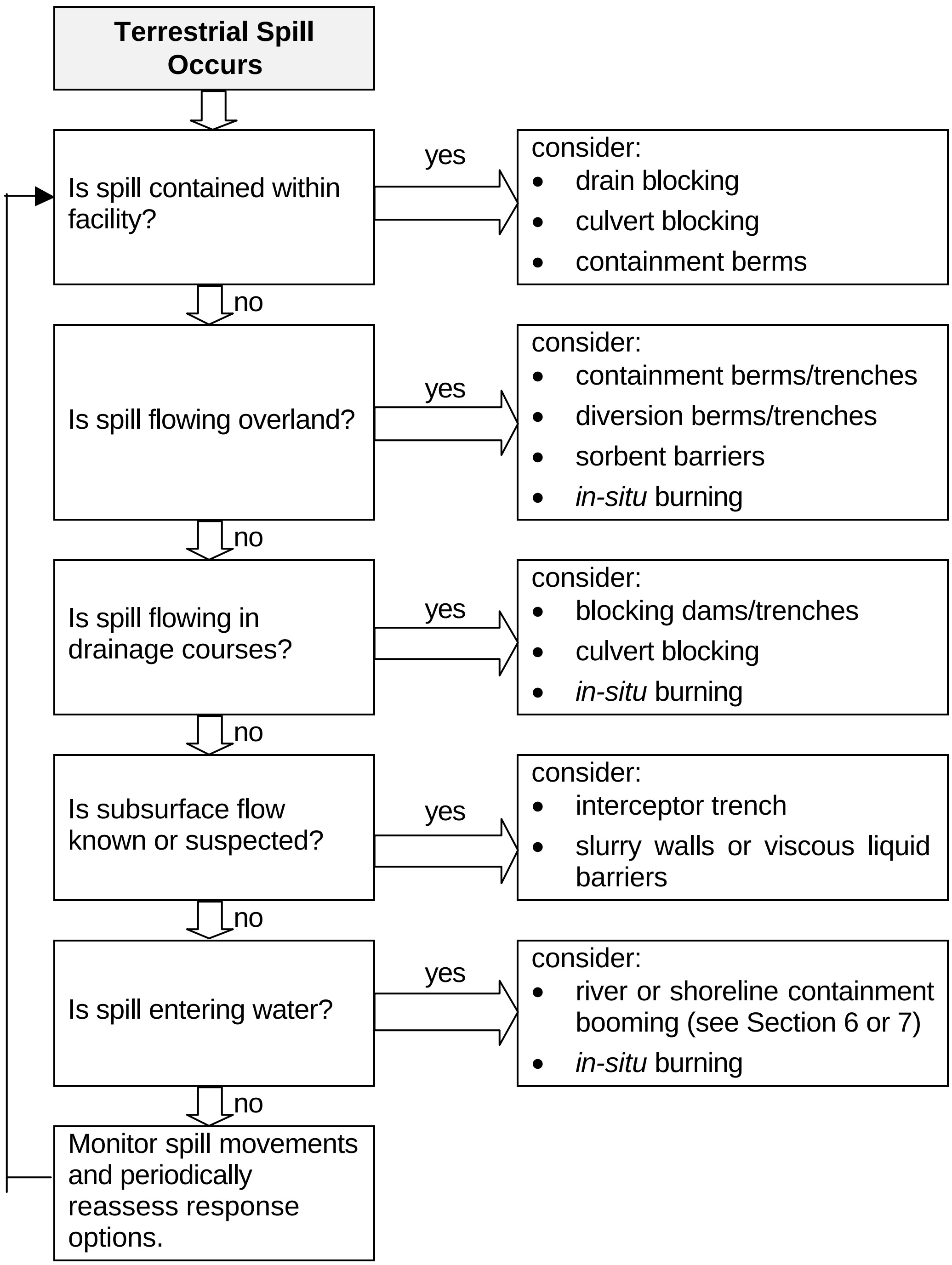


Table 8-3. Summary of Terrestrial Containment and Control Techniques

Technique	Description	Limitations	Potential Environmental Effects
Earth Containment Berm	Low barriers constructed with locally available materials (e.g., earth, gravel, sandbags, etc.) are used to contain surface oil flow. (Figure 8-1)	Steep terrain Accessibility Implementation time Highly permeable soils and low-viscosity oils	Environmental damage inflicted by excavation of berm materials.
Earth Diversion Berms	Low barriers are constructed of available materials (earth, gravel, sandbags, etc.) to direct oil flows to a recovery point or around a sensitive area. (Figure 8-1)	Steep or rugged terrain Accessibility Implementation time Highly permeable soils	Environmental damage inflicted by excavation of berm materials.
Trenches	Dug by machinery to contain and collect oil for recovery or to intercept surface oil flows. Used on most terrain types and redirect them to recovery points or around sensitive areas. Likely would have to be lined to prevent penetration. (Figure 8-2)	Limited accessibility Implementation time Low-viscosity oils on highly permeable soils High water table	Environmental damage inflicted by trench excavation and, if not lined greater oil penetration.
Sorbent Barrier	Low elevation sorbent barriers are used on relatively flat or low-slope terrain to contain or immobilize minor oil flows and recover a portion of the oil; or to limit penetration into permeable soils. (Figure 8-3)	Implementation time Steep slopes	Winds may blow sorbents into the surrounding environment
Culvert Blocking	Boards, sandbags, inflatable plugs, or earthen materials are used to block culverts as a means of containing oil flow into drainage courses that feed into culverts; may also be used to prevent oil from entering tidal channels connected to the ocean through culverts. (Figure 8-4)	Limited accessibility Implementation time Storage area behind culvert Flowing water Culvert size	
Drain Blocking	Sandbags, boards, mats, or other materials are used to prevent oil spilled on roadways and paved areas from entering storm drains or pipes. For curb inlets, position a board over the curb inlet and hold it in place with a sandbag. Street inlets can be similarly blocked with a board or plastic sheeting. (Figure 8-4)	Implementation time	
Soil Interceptor Trench	Trenches are constructed across the migration path to intercept the horizontal movement of spilled oil within the subsoil (Figure 8-5), i.e., floating above the water table and moving with the groundwater.	Rocky ground Water tables > 3 m below the surface Implementation time	Environmental damage inflicted by trench excavation

Slurry Walls	A vertically excavated trench is filled with slurry to contain or divert contaminated groundwater, or to provide a barrier for the groundwater treatment system.	Wall may degrade over time; specific contaminants may degrade wall components.	Environmental damage inflicted by trench excavation
Viscous Liquid Barriers	When injected in the subsurface, certain viscous liquids form impermeable barriers that are biologically and chemically inert that contain or isolate contaminants.		

A terrestrial spill containment guide is provided in Table 8-4 that uses the decision criteria of surface permeability and slope. Additional points to consider based on permeability are listed in below.

Spills on Impermeable Ground, Lined or Paved Surfaces

Fuels, solvents, chemicals, hazardous wastes, and other dangerous, hazardous, or toxic materials are stored in bermed areas underlain with a liner or in some other area/facility equipped to contain leaks/spills and prevent the contamination of the underlying/surrounding soil. Spills from tank trucks may occur on paved roadways. Consider the following when spills occur in these or other impermeable areas.

- Block inlets to drains, pipes, sewage systems, and cable ducts to prevent explosion risk or contamination of sewage treatment plants or watercourses.
- Concentrate the oil so that it can be transferred into containers.
- Use sorbents to limit spreading.

Spills on Permeable Ground

- Flood the area to introduce a water bottom under the oil to float the oil above the sediment surface and reduce penetration.
- Block all inlets, except to oily water drains and let oil enter an oil interceptor via the water drainage system and retain it there.
- Evaluate increasing the spread of oil on the surface to prevent deep penetration of the oil on over-saturated spots. (If oil is spread over a large area to prevent deep penetration, this will result in more oil-contaminated surface material for disposal; however, this may be preferable to a long-term operation of subsoil and groundwater cleanup.)
- Pump out puddles of free oil as quickly as possible (see Section 8.4.2).
- Increase the sorption capacity of the surface layers by spreading sorbents, e.g., minerals, chemicals, straw, peat, sawdust, wood chips, etc.
- Bulldoze or otherwise move any free oil and oil-saturated soil to the nearest natural or artificial impermeable surface.
- Consider burning the oil, if safe and feasible (see Section 8.5.1).

Table 8-4. Terrestrial Containment Guide Based on Substrate Permeability

Surface is Permeable	**Moderate Slope**	• Earth containment berm • Earth diversion berm • Diversion trench • Soil interceptor trench
Surface is Permeable	**Flat or Low Slope**	• Earth containment berm • Sorbent barrier • *In-situ* burning
Surface is Impermeable		• Culvert blocking • Storm drain blocking • Street containment • Sorbents

8.3.1. Earth Containment and Diversion Berms

Earth-moving equipment or manual labor is used to construct berms by forming materials, such as earth, gravel, sandbags, etc., into windrows or ridges to contain oil for removal, or to direct oil flows to a recovery point or around a sensitive area (Figure 8-1). Berms are used primarily on low to moderately sloped terrain.

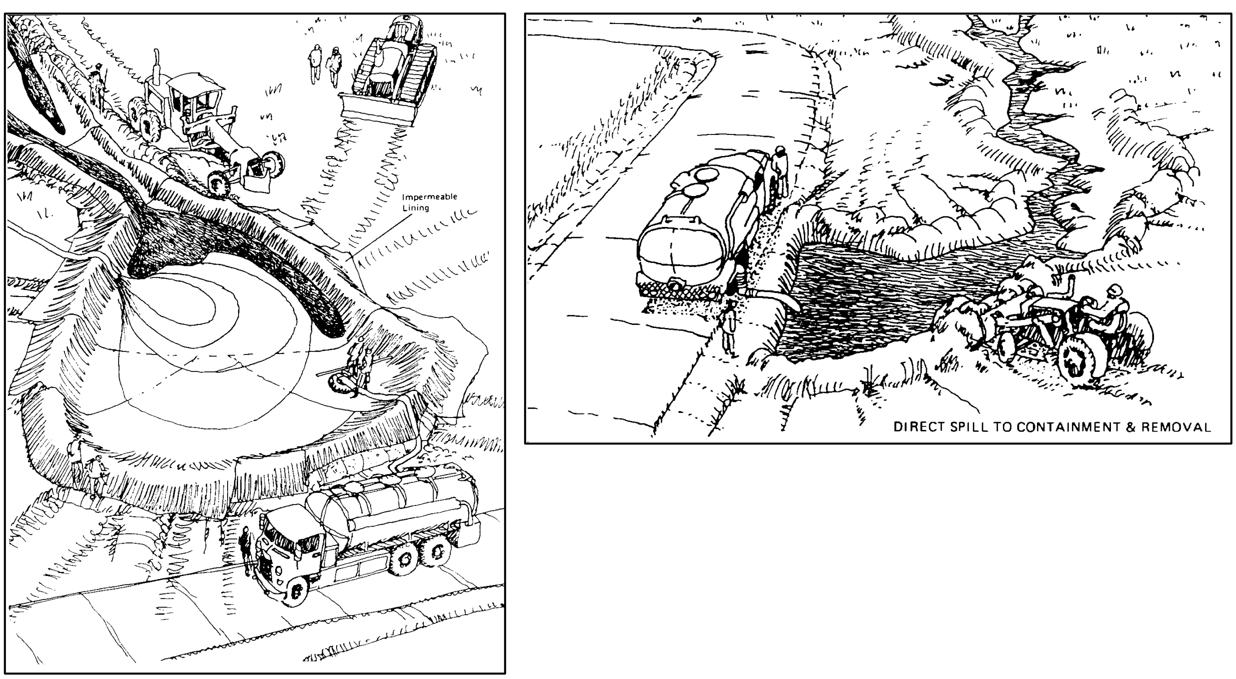
Points to Remember

- The width of containment opening should exceed that of the leading edge of the oncoming oil.
- Berm height and the size of the containment area are dependent upon the physical characteristics of the oil.
- If on-site materials are used, excavate from the downhill side of the berm.
- In areas with a high groundwater table or high soil permeability, the containment area may be flooded and/or lined with plastic sheeting (Figure 8-1, left) to inhibit soil penetration. Oil can be recovered from the water surface by skimming.
- In areas with little gradient, diversion berms can be constructed on each side of the oil flow to limit spread and channel oil to a recovery site (e.g., excavated sump or natural depression).
- Check berms periodically for leakage and adequate height.

Limitations

- Limited accessibility
- Implementation time
- Highly permeable soils and low-viscosity oils
- Rugged terrain
- Environmental damage caused by excavation of berm materials

Figure 8-1. Containment and Diversion Berms.



8.3.2. Earth Containment and Diversion Trenches

A trench is excavated in the path of oil flow to contain oil for recovery or to intercept surface oil flows and redirect oil to recovery points or around sensitive areas (Figure 8-2). The trench should be angled slightly downhill to avoid excessive flow backup. The trench can be dug perpendicular to the slope to contain, rather than divert, the oil flow (Figure 8-2, right). The trench may be partially flooded with water to inhibit sediment penetration and stimulate flow.

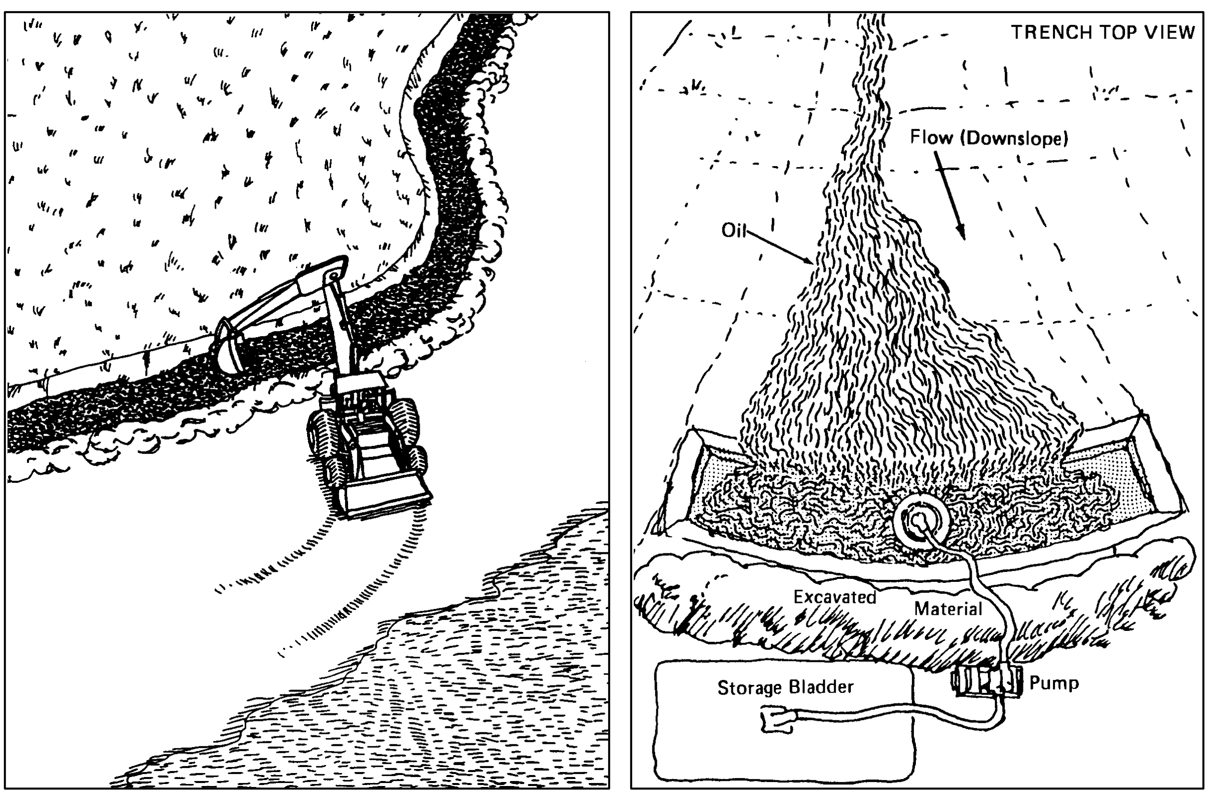
Points to Remember

- The trench must completely intercept the oncoming oil and divert it to the recovery point or well past the sensitive area.
- Trench width and depth is volume dependent.
- Pile excavated materials on downhill side of trench.
- For relatively flat areas, such as wetlands, trench depth should increase slightly towards the recovery or discharge point to maintain adequate flow in that direction.
- Periodically check for adequate flow, blockages caused by trench walls sloughing in, and debris.

Limitations:

- limited accessibility,
- implementation time,
- low-viscosity oils on highly permeable soils,
- high water table,
- environmental damage inflicted by trench excavation.

Figure 8-2. Diversion (left) and Containment (right) Trenches.



8.3.3. Sorbent Barriers

Sorbent materials may be stacked or piled to form a continuous barrier across the entire leading edge of the advancing oil mass with the ends curved toward the oncoming flow to contain minor oil flows and recover a portion of the oil (Figure 8-3). Sorbents used in this manner also tend to immobilize the oil and can be used to limit penetration into permeable soils. Collected oil is recovered by physical removal of spent sorbents or by vacuuming or pumping if quantity exceeds absorption capabilities of the sorbents. The entire spill surface may be covered to immobilize oil.

Artificial or natural sorbents may be used. Roll and granular sorbents generally work best. Minerals, chemicals, straw, peat, sawdust, wood chips, etc., may also be used.

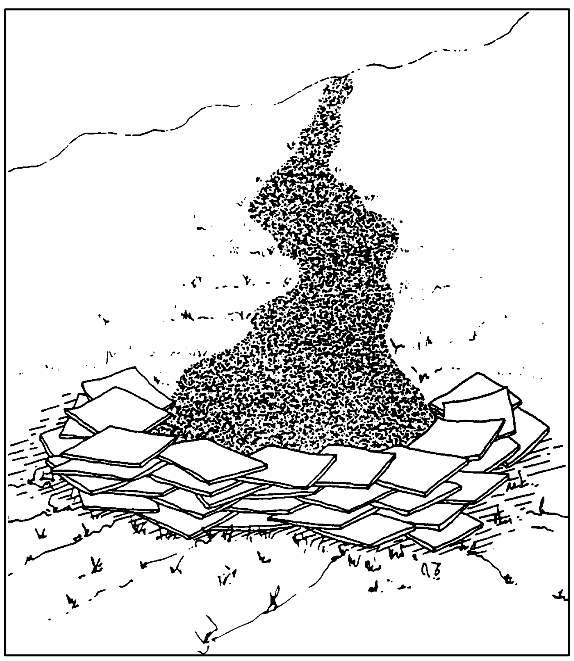
Points to Remember

- Turn sorbents periodically to maximize recovery and replace saturated sorbents. Add additional sorbent material, as necessary.
- Place oiled sorbents in leak-proof containers (drums or plastic bags) for disposal. Minimize manpower and surface disruption during cleanup.

Limitations:

- implementation time,
- steep slopes,
- winds may blow loose sorbents away,
- cleanup/disposal problems.

Figure 8-3. Sorbent Barrier



8.3.4. Culvert and Drain Blocking

Culverts and drains are blocked as a means of containing oil flowing into ditches, creeks, or other drainage courses that feed into culverts, or into sewer systems, pipe and cable ducts, etc. Block the culverts by piling dirt, sand, or similar material over the upstream end of the culvert, thereby creating a containment dam. Sandbags or plywood sheets are also effective (Figure 8-4, top). For drains or similar inlets, position a board or plastic sheeting over the drain and hold it in place with a sandbag (Figure 8-4, bottom). Specially constructed mats can be used expeditiously if they are kept on hand.

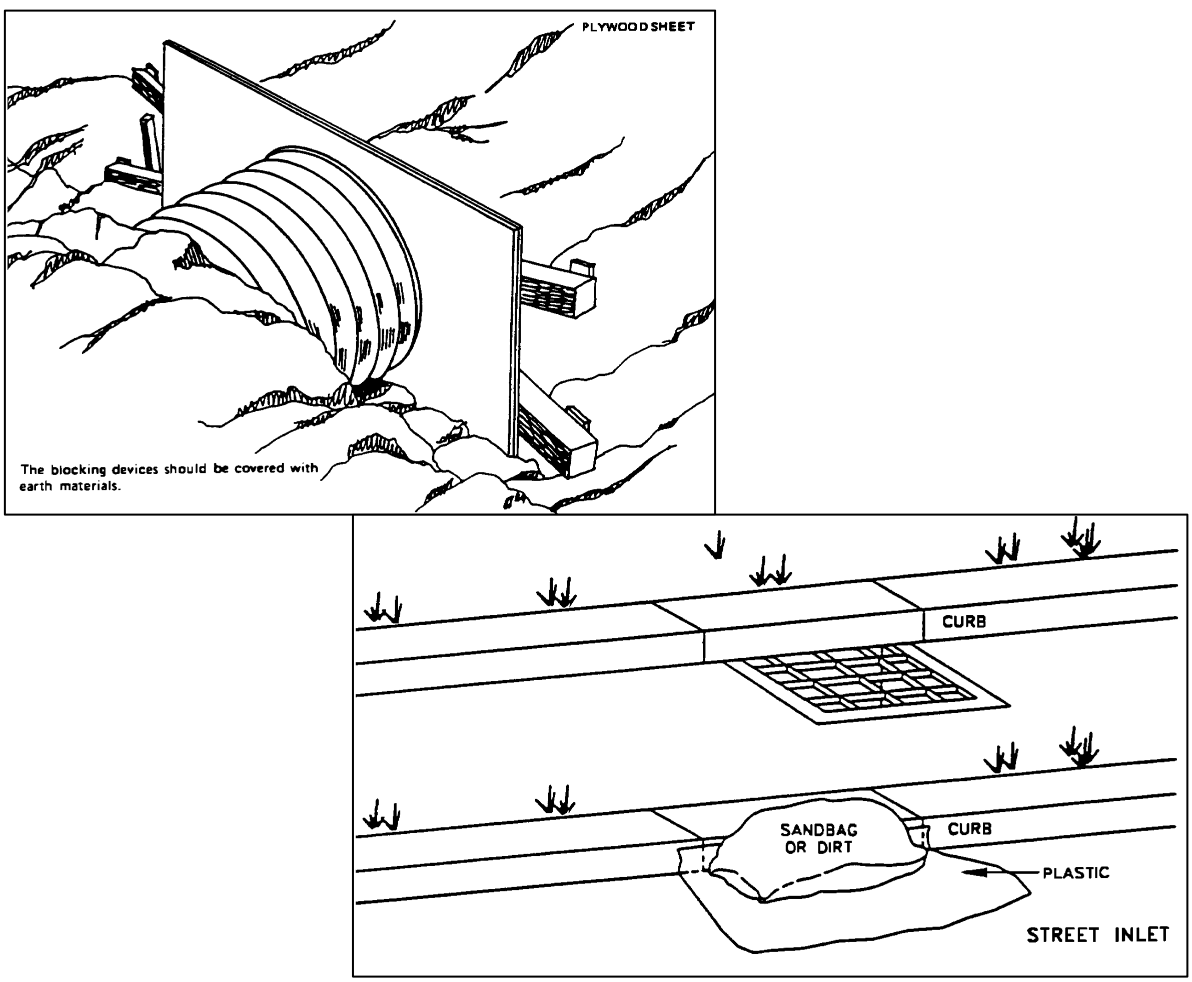
Points to Remember

- If there is little or no storage area upslope from a culvert, it may be advantageous to permit the oil to pass through the culvert and to contain the spill at the culvert outfall.
- Periodically check barrier for leakage.

Limitations:

- limited accessibility,
- implementation time,
- storage area behind barriers,
- flowing water,
- culvert size.

Figure 8-4. Culvert and Storm Drain Blocking Techniques



8.3.5. Interceptor Trench

Trenches are constructed across the migration path to intercept the horizontal movement of spilled oil within the subsoil (Figure 8-5). Trenches can be easily constructed by building contractors with commercially available materials.

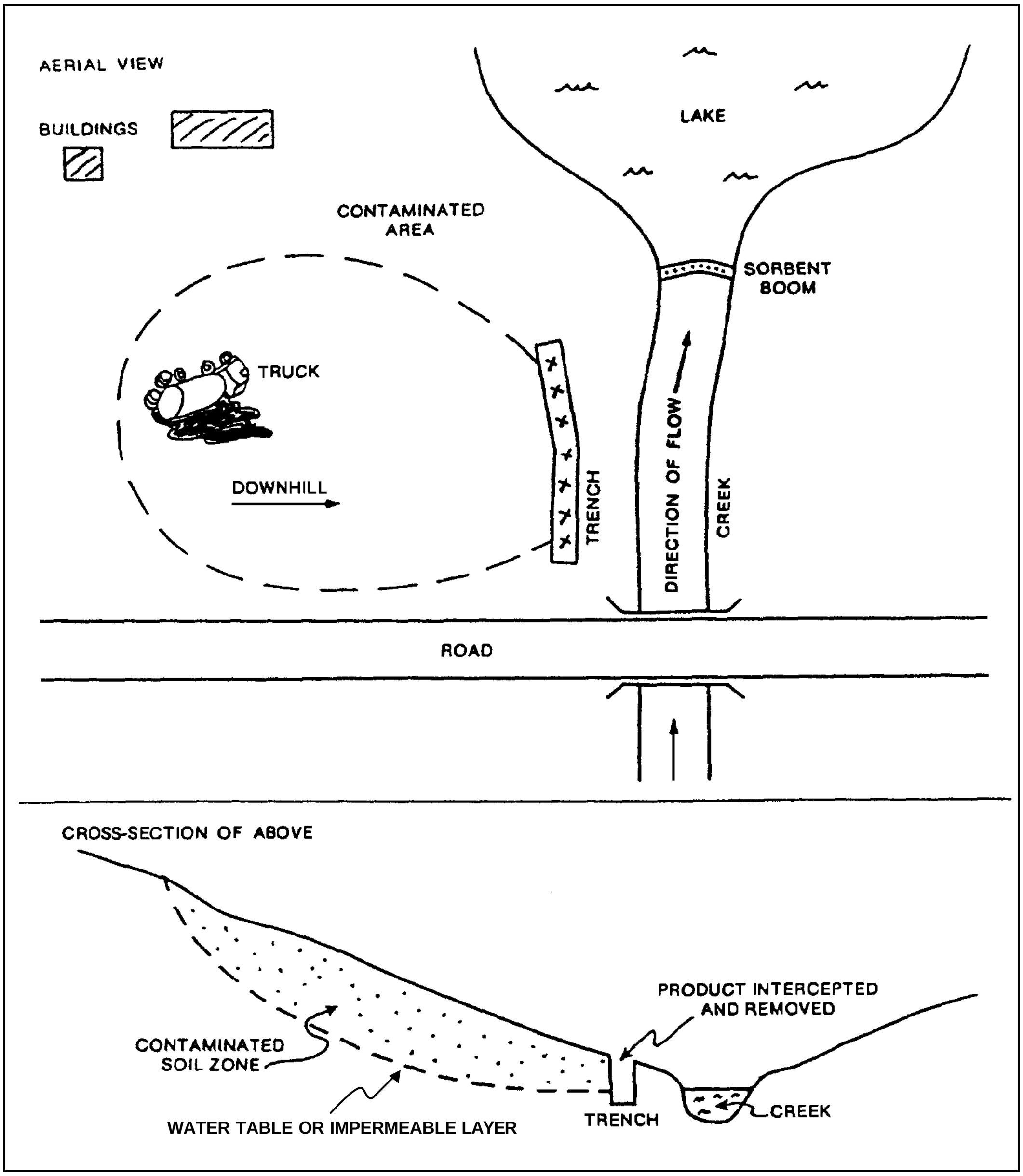
Points to Remember

- Interceptor trenches can be built if the water table is situated less than 3 m (10 ft) below ground surface.
- Oil movement is intercepted when the bottom of the trench is about 1 m (3 ft) below piezometric level.
- Ideally, the depth of the water in the bottom of the trench should be reduced to about 30 to 40 cm (12 to 15 inches), in order to prevent escape of in-flowing oil and to speed up the inflow of further free oil.
- Depending on the depth, the sides of the trench may need supporting, preferably with vertical boarding. For long-term operations, the trench may be backfilled with gravel if some points to collect and pump water and oil are provided.
- A wide trench has no advantages over a narrow trench, other than its volumetric capacity.
- The trench should be long enough to intercept and collect all the oil.

Limitations

- Hydrologists need to be consulted to determine the optimum location for the trench through investigation and sampling.
- Not applicable in rocky ground.
- Not applicable for water tables that are greater than 3 m (10 ft) below the surface, otherwise the water table is too deep for this method to be practical.
- Implementation time is great.

Figure 8-5. Soil Interceptor Trench.



8.3.6. Slurry Walls

Slurry walls are used to contain contaminated groundwater, divert contaminated groundwater from a drinking water intake, or divert uncontaminated groundwater flow. Slurry walls can also provide a barrier and isolate contaminants to improve the efficiency of the groundwater treatment system. These subsurface barriers consist of a vertically excavated trench filled with a slurry. Most walls are constructed of a soil, bentonite, and water mixture that provide a barrier with low permeability and chemical resistance at low cost. The slurry hydraulically shores the trench to prevent collapse and forms a filter cake to reduce groundwater flow.

An alternate configuration for installation is a "hanging" wall in which the wall projects into the groundwater table to block the movement of lower density or floating contaminants such as oils or fuels.

Points to Remember

- Slurry walls contain the groundwater itself within a specific area, thus leaving the contaminant untreated; (treatment methods are described in Sections 8.4 and 8.5).
- Walls are typically placed at depths less than 15 m (50 ft) and are generally 0.6 to 1.2 m (2 to 4 ft) thick.
- Walls may be based 0.6 to 0.9 m (2 to 3 ft) into a low permeability layer such as clay or bedrock to provide an effective foundation with minimum leakage potential.

Limitations

- There is potential for the slurry wall to degrade or deteriorate over time;
- Specific contaminants may degrade wall components.
- Environmental damage inflicted by trench excavation

8.3.7. Viscous Liquid Barriers

Two liquids, colloidal silica and polysiloxane, undergo an extreme increase in viscosity when component additives are mixed. When injected in the subsurface, the viscous liquids form biologically and chemically inert impermeable barriers that can be used to contain contaminated groundwater, divert contaminated groundwater from a drinking water intake, or to divert uncontaminated groundwater flow. These barriers have been successfully constructed in heterogeneous sediments of sands, silts, and clays. They have been used to contain potential sources or to improve "pump-and-treat" efficiency by isolating contaminant sources.

Benefits include:

- Rapid installation
- No excavation required
- Permits a variety of barrier configurations
- Contain plume sources where conventional barrier methods are inadequate

8.4. Physical Recovery and Removal

The appropriate cleanup technique to be used depends primarily on the location of the spill, volume and type of oil, sediment type, slope, level of impact and potential impacts from the candidate cleanup technique(s). Spill circumstances may involve the simultaneous use of several techniques. Risk-based corrective action (RBCA) can be applied to guide decision-making options regarding clean-up options and levels (ASTM Standard E 1739-95; ASTM, 1997).

This section describes physical methods to recover oil and oiled materials and then to remove them from the site for disposal or treatment. *In-situ* cleanup/treatment methods such as burning and bioremediation are described in Section 8.5. Recovery and treatment methods for remediation of contaminated groundwater, including natural attenuation, are discussed in Section 8.6.

Possible recovery and removal strategies include:

- using earth-moving machinery and trucks to excavate materials, with or without replacement of contaminated material/soils (Section 8.4.1);
- recovering dammed, pooled, and contained/concentrated product with vacuum trucks, pumps, and skimming equipment (Section 8.4.2);
- manual recovery (Section 8.4.3);
- collecting with artificial and natural sorbents (Section 8.4.4);
- other physical methods to consider (Section 8.4.5).

8.4.1. Excavation

Oil-saturated soil and oiled sediments are removed mechanically using various types of earth-moving equipment to prevent the contamination of the groundwater. Early and successful excavation can save long-term recovery operations if the oil has not reached the groundwater. It may be the most economic method of recovering high viscosity oils, such as lubes, heavy fuel oils, some crudes, etc., even though it may increase the volume of oil-contaminated material for treatment and or disposal.

Removal of oiled soil and replacement with mixed mineral-organic material has been used for some spills, although this is a disruptive technique. This option may be required when conditions warrant (health hazard, etc.).

Points to Remember

- Soil removal should be on the basis of obviously contaminated soil.
- Excavation can continue to just above the groundwater or to the limit of the machinery.
- If impermeable natural layers are disturbed, oil may penetrate deeper.
- Work below ground will require explosimeter tests and possibly breathing apparatus for workers; people should never work alone.
- Screening systems are utilized to separate debris, such as straw and vegetation, from sediments when large amounts of debris are present.
- Haphazard use of machinery may result in increased oil penetration.

Limitations

- Do not use if excavation will disturb or penetrate an impermeable layer (natural or otherwise) because the latter forms a barrier to the oil.
- Do not use for volatile materials, as this may create a fire hazard.
- Do not use if there is either a risk of damaging underground utilities, e.g., pipes and electric cables, or of undermining foundations, embankments, canals, etc.
- Do not use for large spills; there is a danger of causing more damage; excavation costs also rise steeply with increased depth.
- Do not use if groundwater is not endangered, or if oil has already reached the groundwater.
- Recovered oil/saturated soil may cause disposal problems; it is difficult and expensive to find disposal sites for large quantities of oiled soil.
- It is difficult to undertake where soil contains rocky outcrops.

8.4.2. Pumping

Vacuum Trucks

Oil is recovered from land and water surfaces by using suction generated by the vacuum truck to draw oil from concentrated areas into the truck for transport to reprocessing or disposal facilities.

Points to Remember

- Position the vacuum truck adjacent to area of heaviest oil concentration, such as behind berms, in trenches or sumps, etc. The suction hose nozzle is placed in the oil and maneuvered manually until recovery becomes inefficient.
- Screens should be fitted over the hose nozzle to prevent ingestion of sediments or debris. When recovering oil on water, a duck bill or Manta Ray-type skimmer head should be attached to the suction nozzle. This technique is illustrated in Figure 8-6.
- Vacuum trucks may be left onsite with recovered oil pumped out periodically to tank trucks. This can improve turn-around time in some cases, and a vacuum truck acts as a primary oil-water separator.

Limitations

- Limited access to spill site
- High viscosity oils
- Very thin oil layer
- Heavy debris

Portable Skimmers/Pumps

Portable skimmers and pumps are used to collect small to moderate concentrations of oil, or to pump larger concentrations from areas where larger equipment such as trucks cannot be brought in.

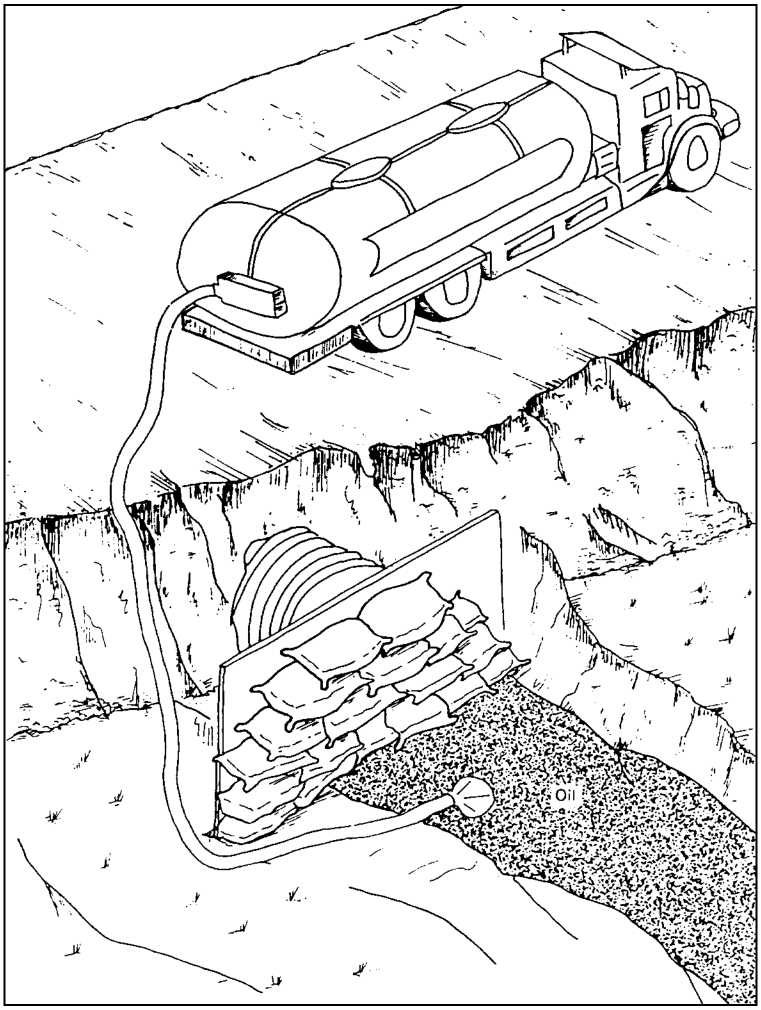
Points to Remember

- Position the skimmer or pump suction hose in the area of heaviest oil concentration behind berms, in trenches, etc., or where flow will drive the oil to the skimmer or hose intake. Continually reposition the intake into area of thickest oil concentration.
- Screen type skimmer heads should be fitted to the suction hose for terrestrial spills to prevent ingestion of sediments or debris.
- Pump the recovered oil to a temporary storage facility such as a tank truck, 55-gallon drums, pillow tanks, or a lined pit.
- When using portable skimmers in shallow water, a hole may have to be excavated in the bottom of the shallow waterway if the skimmer draft is greater than the water depth. Oil can now be forced to the skimmer location by low-pressure water flushing or by deploying a boom around a floating slick and pulling it to the floating skimmer.

Limitations

- Limited accessibility to spill area
- High viscosity oils
- Not useful for sheens
- Adequate means of storage or disposal

Figure 8-6. Vacuum Truck Operation.



8.4.3. Manual Recovery

Manual removal involves the recovery of surface oil, oiled sediment or oily debris by manual methods and placing the material into containers for subsequent disposal. This method is primarily applicable to lightly oiled areas or to remove residual oil during the final cleanup phase.

Points to Remember

- Remove small pools of oil with hand pumps or buckets.
- Remove oiled debris and vegetation with shovels, rakes, or pitchforks. Do not cut or rake healthy unoiled vegetation.
- Remove oil layers on rocky outcrops or cliffs, boulders, manmade structures, etc., by scraping or wire brushing.
- Small quantities of oil or oily debris can be placed in plastic bags and removed for disposal. Fill bags and containers only to the point where they can be easily carried by on person.

- Larger quantities can be placed in barrels or debris boxes for disposal, or lined pits for temporary storage. On or near riverbanks all material must be stored above the high-water line or away from possible flood areas.

Limitations

- Disturbance of vegetation root systems.
- Environmental sensitivity of area to intense human activity.
- It is labor intensive and time consuming.

8.4.4. Collection with Sorbents

- Artificial or natural sorbents (straw, peat, wood chips, sawdust, chemicals, minerals, etc.) may be spread over the ground surface to absorb small pools of oil.
- Sorbent pads or cloths may be used to wipe oil layers on hard surfaces (boulders, man-made structures.
- Sorbents can be used to remove thin films remaining during the final cleanup phase.
- Sorbents can also be used to prevent oiling of walkways and work areas during the cleanup operation.

Limitations

- Sorbents are difficult to collect and some types may be blown away by the wind.
- Collection of sorbents is time consuming.
- Waste generation is high.

8.4.5. Other Methods

- A spill may be absorbed by the vegetative mat and flow beneath it. When this occurs, it may be feasible to flood the area with water; floating some of the oil to the surface where it can be removed with sorbents and small pumps and by hand. Containment and control barriers must be in place around the perimeter of the area to be flooded to avoid further spreading and impacts to other nearby areas.
- It may be possible to "wash" some areas. Large, bare rocks and boulders or man-made objects that are covered with a film of oil can be cleaned with pressurized equipment. Chemical agents, such as Corexit 9580 or other similar products, can be used as a pre-soak to increase the efficiency of cleaning. The ground area surrounding any surface to be cleaned should be covered with sorbents or plastic sheeting to contain and collect the oil before actual cleaning begins. Isolated rocks can be hand-wiped or scraped.
- Large trees with oil on their trunks should be left alone.

Limitations

- Care should be taken not to damage the vegetative layer.
- In general, excessive vehicle traffic and trampling can do more damage working oil into the plant/soil/active layer than leaving a spill untreated.

8.5. Treatment

The following *in-situ* group of methods involves physical, on-site, treatment techniques to alter the character of the oil in order to remove the oil and promote weathering and natural degradation. These treatment methods include:

- *in-situ* burning,
- bioremediation, and
- tilling.

A key feature of this group of techniques is that essentially no oiled materials are generated that require transfer and disposal, and thus waste generation is basically non-existent (see also Waste Management Guidelines in Section 12). Except for burning, *in situ* treatment techniques generally require longer time periods, and there is less certainty about the uniformity of treatment due to the variability in soil and aquifer characteristics.

8.5.1. Burning

Burning can be used where combustible materials, such as logs and debris have been oiled and can be collected and burned. It can also be used where vegetation, such as that found in a wetland or along river floodplains, has been heavily oiled. Burning is primarily applicable to situations where materials are heavily oiled and present either a potential source of released oil, an aesthetic problem, or the possibility of ingestion by animals. Burning can be used in areas with safe access, a sufficient quantity of oiled organic debris and/or vegetation and where local air quality is not an issue. The advantages of burning are that it is rapid, cost effective and non-labor intensive. This is a preferred method where practicable.

Points to Remember

- A plan that provides for safe, controlled burning should be prepared prior to burning.
- Small pools can be burned if there is no danger of the fire spreading.
- In some situations, oiled vegetation may be burned in place if the proper precautions are taken to prevent the fire from spreading beyond the oiled area. The fire should be started at the upwind end and allowed to burn in a downwind direction.
- It may be necessary to section off the burn area with fire breaks to ensure controlled burning.
- Larger logs and debris can be cut into smaller pieces for easier handling.
- Kerosene or diesel fuel can be used to aid in starting the fire, particularly if the material is wet or if it is raining.
- Fans or blowers can be used to sustain or increase combustion of debris piles, which in turn reduces smoke.
- Small, hand-held weed burners can also be used to burn oil off moderately to heavily oiled objects.
- Burning can also be used in marshes or estuarine environments where large areas of grasses or other vegetation have been oiled and natural recovery is not an option and cutting would create too great an impact.
- Once all of the oiled material has been burned, water should be applied to any smoldering areas to ensure that the fire is completely out and that re-ignition is not possible.

Limitations

- Organisms in the vicinity of the burn may suffer adverse thermal impacts.
- Burning should not be conducted during high wind conditions.

8.5.2. Bioremediation — Soils and Sediments

Bioremediation involves the application of a nitrogen and phosphorus fertilizer to the soil to accelerate the oil degradation processes (maintain a high rate of hydrocarbon metabolization) by stimulating the growth of existing natural microbial communities. Terrestrial spills may be treated through bioremediation techniques where nutrients or genetically engineered micro-organisms are applied to areas to accelerate the natural degradation of oil. A number of commercial products are available. Biological processes are typically easy to implement at low cost. Contaminants can be destroyed, and often little or no residual treatment is required, however the process requires more time.

Bioremediation can be used on many substrate types, but is most effective on fine- to medium-grained sediments.

Bioremediation is primarily applicable to areas with light to moderate oil conditions and where the physical and/or ecological impacts from other candidate techniques are considered unacceptable. The method can be used as a polishing technique to treat minor amounts of oil remaining after the initial cleanup is completed, or where light, near-surface oil conditions are present.

In some instances, bioremediation can be enhanced by bioventing techniques in which oxygen is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation. Bioventing uses low airflow rates to provide only enough oxygen to sustain microbial activity. Oxygen is most commonly supplied through direct air injection into unsaturated soil. In addition to degradation of adsorbed fuel residuals, volatile compounds are biodegraded as vapors move slowly through biologically active soil. Bioventing is most applicable where the depth to water exceeds 3 m (10 feet). Where applicable, bioventing can be a low cost remediation method.

Enhanced bioremediation can also be accomplished through the percolation or injection of groundwater or uncontaminated water mixed with nutrients and saturated dissolved oxygen using injection and extraction wells. An infiltration gallery or spray irrigation system is typically used for shallow oiled soils, and injection wells are used for deeper oiled soils.

Limitations

- Potential health problems from inhalation and skin contact may be of concern during the application of a fertilizer. Goggles, a respirator, rubber gloves, and protective coveralls may need to be worn when applying the fertilizers.
- Some fertilizers are very slippery when applied, which can create hazardous walking conditions.
- Bioremediation should be avoided near fish streams or other ecologically sensitive areas.

8.5.3. Land Tilling

Oiled areas are tilled to break up thin asphalt layers or light to moderately oiled sediments as a means of maximizing their exposure to physical, microbial and photochemical degradation processes. Oil is mixed throughout the upper sediment profile, thereby increasing the surface area exposed to weathering. Although this technique is rapid and efficient, the oil is not removed, but broken up and mixed into the top layer of sediments and left to degrade naturally.

Generally, the tilling equipment used is the same as that used for agricultural operations. For small areas, a rototiller or hand tools (shovels, rakes, picks, etc.) can be used to till the surface sediments.

This method is primarily used in low-use areas with light oil conditions existing either as a thin pavement on the surface or coatings on surface and near-surface sediments.

Limitations

- Potential for the release of oil for a period of time
- In some cases oil can be mixed deeper into the sediments and prolong its persistence

8.6. Remediation of Contaminated Groundwater

Many technologies exist for the remediation of groundwater and new methods are continuously being developed. The choice of the correct technology will depend on many factors including contaminant properties and concentration, soil and groundwater characteristics, geologic and hydrogeologic characteristics, and the location of potential receptors including groundwater wells and surface water discharge points. A key decision factor will be the ability of the candidate technique to significantly reduce the remediation time frame in a cost-effective manor. A soils geologist/hydrologist can conduct a risk-based correction action (ASTM, 1997) assessmentto guide decision-making options regarding clean-up options and level of appropriate clean-up.

Treatment technologies for groundwater include *ex-situ* treatment technologies that require groundwater extraction, and *in-situ* methods that allow groundwater to be treated without being brought to the surface resulting in significant cost savings. *In-situ* methods, including natural attenuation, are preferred and should be considered in all cases. *In-situ* processes, however, generally require longer time periods, and there is less certainty about the uniformity of treatment because of the variability in aquifer characteristics and because the efficiency of the process is more difficult to verify.

Several groundwater remediation techniques are discussed in the following sections.

- Natural attenuation (passive bioremediation, Section 8.6.1);
- Bioremediation (active, Section 8.6.2);
- Removal of oil from the water table (subsurface oil) using recovery pump systems (“pump and treat”, Section 8.6.3).

8.6.1. <u>Natural Attenuation</u>

Natural attenuation for petroleum hydrocarbons, particularly benzene, toluene, ethyl benzene and xylene, is well demonstrated as a remedial option for ground water. Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials are allowed to reduce contaminant concentrations to acceptable levels. Natural attenuation is not the same as “no action”, although it often is perceived as such. It has been selected at sites where, for example, it has been determined that active remedial measures would be unable to significantly speed remediation time frames.

A basic assumption underlying a selection of a natural attenuation remedy is that eventually background concentrations will be reached. The primary consideration is, “does this site have enough time to let nature take its course to remediate the plume before receptors, such as drinking water wells, are impacted or the resource needs to be used?" Key decision-making elements then become:

- how fast is the natural process occurring and how do I measure this rate?
- what can be done to take advantage of this rate and what is the value of additional physical removal/treatment techniques?

Therefore, consideration of this option requires that a model (not necessarily a numerical model) be developed to predict the time, distance and direction of plume travel to determine whether natural attenuation is a feasible remedial alternative. The primary objective of site modeling is to demonstrate that natural processes of oil degradation will reduce contaminant concentrations to acceptable levels before potential receptors are impacted.

Since natural attenuation is a naturally occurring process, it requires little costly remedial action other than monitoring. Sampling and sample analysis must be conducted throughout the process to confirm that degradation is proceeding at rates consistent with meeting cleanup objectives.

Natural attenuation is the preferred method where appropriate.

Limitations

- There are costs for modeling contamination degradation rates and for contaminant migration and degradation monitoring. Subsurface sampling and sample analysis to determine the extent of contamination and confirm contaminant degradation rates and cleanup status is potentially extensive.
- Intermediate degradation products may be more mobile and more toxic than the original contaminant.
- Contaminants may migrate before they are degraded.
- The site may have to be fenced and may not be available for reuse until contaminant levels are reduced.
- If free product exists, it may have to be removed.
- Natural attenuation should be used only in low-risk situations.

8.6.2. Bioremediation — Groundwater

As with surface bioremediation discussed in Section 8.5.2, groundwater bioremediation techniques are directed toward stimulating the microorganisms to grow and use the oil as a food and energy source by creating a favorable environment for the microorganisms. Generally, this means providing some combination of oxygen, nutrients (primarily nitrogen and phosphorous), and moisture, and controlling the temperature and pH. Sometimes, microorganisms adapted for degradation of the specific contaminants are applied to enhance the process.

Bioremediation techniques have been successfully used to remediate groundwater contaminated by petroleum hydrocarbons and other organic chemicals. The areal zone of treatment can be larger than with other remedial technologies because the treatment moves with the plume and can reach areas that could otherwise be inaccessible. In most instances, contaminants are destroyed and little to no residual treatment is required.

Feasibility studies would be performed to determine whether bioremediation would be effective in a given situation. For sites contaminated with common petroleum hydrocarbons it is usually sufficient to examine representative soil samples for the presence and level of an indigenous population of microbes, nutrient levels, presence of microbial toxicants, and site-specific aquifer characteristics.

Available *in-situ* biological treatment technologies include co-metabolic processes, nitrate enhancement, and oxygen enhancement with either air sparging or hydrogen peroxide (H_2O_2).

- **Co-Metabolic Processes** —- Co-metabolism is one form of secondary substrate transformation in which enzymes produced for primary substrate oxidation are capable of degrading the secondary substrate fortuitously, even though the secondary substrates do not afford sufficient energy to sustain the microbial population.
- **Nitrate Enhancement** — Nitrate is circulated throughout groundwater contamination zones as an alternative electron acceptor for biological oxidation of organic contaminants by microbes. Nitrate is much more soluble in water than oxygen, and is less reactive and more mobile. Nitrate, however is expensive and , at high concentrations, could be toxic to humans.
- **Oxygen Enhancement with Air Sparging** — Air is injected under pressure below the water table to increase groundwater oxygen concentrations and enhance the rate of biological degradation of organic contaminants by naturally occurring microbes.
- **Oxygen Enhancement with Hydrogen Peroxide** — A dilute solution of hydrogen peroxide is circulated throughout a contaminated groundwater zone to increase the oxygen content of groundwater and enhance the rate of aerobic biodegradation of organic contaminants by microbes. The use of hydrogen peroxide is limited because at high concentrations (above 100 ppm, 1,000 ppm with proper acclimation), it is toxic to microorganisms. Also, hydrogen peroxide tends to decompose into water and oxygen rapidly in the presence of some constituents, thus reducing its effectiveness.

Points to Remember

- Bioremediation processes are typically easily implemented at economical cost.
- Some compounds may be broken down into more toxic by-products during the bioremediation process. In *in-situ* applications, these by-products may be mobilized in groundwater if no control techniques are used. Typically, to address this issue, bioremediation will be performed above a low permeability soil layer and with groundwater monitoring wells downgradient of the remediation area.
- This type of treatment scheme requires aquifer and contaminant characterization and may still require extracted groundwater treatment.
- The rate at which microorganisms degrade the contaminants is influenced by many factors, including: temperature; oxygen supply; nutrient supply; pH; the availability of the contaminant to the microorganism (clay soils can adsorb contaminants making them unavailable to the microorganisms); the concentration of the contaminants (high concentrations may be toxic to the microorganism); and the presence of substances toxic to the microorganism.

8.6.3. <u>Removal of Underground Oil from the Water Table Using Recovery Pump Systems</u>

Recovery pump systems are used to remove the oil from the water table for treatment or disposal. Pumping lowers the groundwater table and forms a depression that will trap the oil so it can be pumped out. A variety of techniques exist for this purpose ranging from the simple to the complicated. The time taken to utilize these techniques is much greater than those that are used for combating surface spills. Because the rate of groundwater movement is very slow and contaminants do not spread or mix quickly, sufficient time should exist for a detailed hydrological survey to be carried out to allow the optimum technique to be used.

"Pump and treat" is a technology commonly used for the remediation of groundwater contaminated by petroleum hydrocarbons, although the practicality of the method for treating non-aqueous phase liquids (NAPLs) and organic solvents is being questioned, which have very low solubility in water and tend to exist as pockets at the subsurface locations to which they have migrated. They dissolve slowly, leading to very slow rates of removal by pumping.

To improve performance, new technologies are being developed to mobilize or solubilize these pockets, which improves the mass removal per pore volume. These include cosolvent flushing and the application of surfactants. Cosolvent flushing involves injecting a solvent mixture up-gradient of the contaminated area to solubilize and mobilize the contaminant plume. The solvent with the dissolved contaminant is extracted down-gradient and treated above ground. The application of surfactants can increase the apparent solubility of the contaminant in water, and reduces interfacial tension between the water and the NAPL, which allows them to be extracted more efficiently.

The technologies most commonly used to treat extracted groundwater contaminated with fuels include air stripping, carbon adsorption, and free product recovery, and bioremediation techniques.

- Air stripping involves the mass transfer of volatile contaminants from water to air. For groundwater remediation, this process is typically conducted in a packed tower or an aeration tank. a spray nozzle at the top of the tower distributes contaminated water over the packing in the column, a fan forces air countercurrent to the water flow, and a sump at the bottom of the tower collects decontaminated water. Packed tower air strippers are installed either as permanent installations on concrete pads, on a skid, or on a trailer.
- Liquid phase carbon adsorption is a full-scale technology in which groundwater is pumped through a series of vessels containing activated carbon to which dissolved contaminants are adsorbed.
- The free product recovery process is used primarily in cases where a fuel hydrocarbon lens more than 20 cm (8 inches) thick is floating on the water table. The free product is generally drawn up to the surface by a pumping system. Following recovery, it can be disposed of, re-used directly in an operation not requiring high-purity materials, or purified prior to re-use. Systems may be designed to recover only product, mixed product and water, or separate streams of product and water (i.e., dual pump or dual well systems).
- A common *ex-situ* biological treatment technology for groundwater is the use of bioreactors. Contaminants in extracted groundwater are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated groundwater is circulated in an aeration basin. In attached systems, such as rotating biological contractors and trickling filters, microorganisms are established on an inert support matrix. The main advantage of *ex-situ* treatment is that it generally requires shorter time periods, and there is more certainty about the uniformity of treatment because of the ability to monitor and continuously mix the groundwater.

Points to Remember

- For construction stability and safety reasons, excavations are usually backfilled with gravel and covered with excavated soil.
- Ditches are used to increase the rate of recovery and are easily made with commercially available materials. Bottoms of ditches should not penetrate the undisturbed water table by more than 80–100 cm (30-40 inches).
- Well shafts should be deep enough to allow the pumps to operate without drawing up sand or picking up surface oil in drainage water.
- The level controls of the pumps should be sensitive enough to form a constant depression of the water table.
- Oil/water separators should be constructed to allow the maximum residence time in order to keep the oil concentrations in the discharged water to a minimum.
- Water re-injection has a flushing effect and improves recovery rate.
- Increasing the mobility of the NAPLs also increases the risk of increasing the contaminant plume.
- Physical barriers may be installed to prevent uncontrolled migration of the contaminants (see Section 8.3.6, Slurry Walls).
- Typically, during pump and treat remediation, 50% of the total project costs are spent to clean up the last few percent of contamination. Significant cost savings can be realized if engineering processes are stopped when they are no longer cost effective and natural processes are relied upon.
- Once this technology has removed the major mass of contamination, a period of monitored natural attenuation or enhanced natural processes should begin.

Limitations

- The efficiency is limited by the low solubility of petroleum hydrocarbons and other factors related to physical hydrogeological conditions.
- Recovery of oil may take a considerable amount of time
- Siting of wells needs careful consideration of the hydrology
- Can be very expensive
- Treatment and disposal of large quantities of water