MIRAMAR
HOPE BAY LTD.

Landfarm Management Plan
Doris North Project, Nunavut

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1.0 INTRODUCTION

1.1 Overview

The Landfarm Management Plan provides information on how contaminated soil and snow will be handled in a safe and environmentally sound manner at the Miramar Hope Bay Ltd. (MHBL) Doris North Project (Doris North) in Nunavut.

Landfarming is a form of bioremediation that uses naturally occurring micro-organisms contained in the soil (yeast, fungi or bacteria) to metabolize or break down petroleum hydrocarbons. Natural processes include volatilization, aeration, biodegradation and photolysis. End products are micro-organism protein, carbon dioxide and water. Stimulation of microbial growth and activity for hydrocarbon removal is accomplished primarily through the addition of air and nutrients (metabolism of hydrocarbons is mediated predominantly through aerobic microbes).

1.2 Purpose and Scope of the Landfarm Management Plan

The purpose of this document is to provide a consolidated summary of information on the operation of the landfarm treatment area to be used at the Doris North Project both during the operational and reclamation phases to treat hydrocarbon contaminated soil and snow generated by MHBL's operations. These procedures are an integral component of the overall Environmental Protection Plan (EPP) for the proposed Doris North Project and will be periodically reviewed and updated as the Doris North mine moves through construction, operations, and final closure and reclamation.

This Management Plan is a component of the Doris North Environmental Management System and will be updated after the water license has been issued to incorporate any new commitments made by MHBL during the license process and to incorporate any conditions contained within the water license relating to the handling and treatment of hydrocarbon contaminated snow and soil materials. This Management Plan is to be reviewed annually during the first quarter of each calendar year by the mine's environmental staff and updated as needed to reflect changes in operating procedures. The revised Landfarm Management Plan will be made available to the appropriate mine operating staff with appropriate refresher training and sent to the Nunavut Water Board for inclusion in the public registry.

The Landfarm Management Plan is intended to provide the mine's operating staff with a summary of the handling and management procedures for the treatment of hydrocarbon contaminated snow and soil materials developed through the environmental assessment and project design process. It similarly provides a summary of the same to the regulatory agencies and to the land owner who have regulatory interest over the mine facilities.

This Plan is not intended to be a design document for the landfarm treatment facility. The reader is referred to the following sources for design information:

- Design of the Surface Infrastructure Components Doris North Project, Hope Bay, Nunavut, Canada, prepared for MHBL by SRK Consulting Engineers and Scientists, dated March 2007. (Supporting Document S2 to the Revised Water License Application Support Document, April 2007)
    - Sections 4.17 and 5.11 Landfarm.

- Engineering Drawings for Tailings Containment Area and Surface Infrastructure Components, Doris North Project, Nunavut, Canada, prepared for MHBL by SRK Consulting Engineers and Scientists, dated March 2007. (Supporting Document S4 to the Revised Water License Application Support Document, April 2007)
    - Drawing G-02 General Arrangement;
    - Drawings S-13 and S-14 Landfill and Landfarm Typical Plan, Sections and Details.

- Technical Specifications for Tailings Containment Area and Surface Infrastructure Components, Doris North Project, Hope Bay, Nunavut, Canada, prepared for MHBL by SRK Consulting Engineers and Scientists, dated March 2007. (Supporting Document S3 to the Revised Water License Application Support Document, April 2007)
    - Section 10.2.23 Landfarm;
    - General material specifications for fill materials is contained in Section 7;
    - General specifications for geosynthetics is contained in Section 8; and
    - General specifications for fill placement is contained in Section 9.

1.3 Responsibility

- Mine General Manager – The Mine General Manager has overall responsibility for this management plan and will be the party to provide the mine site resources to develop and manage the landfarm facility.

- Surface Superintendent – The mine's Surface Superintendent will have mine site responsibility for the implementation of this management plan and will provide the on-site resources to operate and manage the landfarm facility in accordance with the plan; conduct regular inspections of the landfarm; and provide input to the mine management team on modifications in design and operational procedures to improve operational performance of this facility. The Site Surface Superintendent, through his foremen, will provide daily supervision to site operational personnel on the operation of the landfarm facility including but not limited to: turning of soil within the landfarm, treatment and removal of water and snow accumulations within the landfarm as needed, and the removal of treated soil into the natural environment once cleared by the site's Environmental Coordinator.

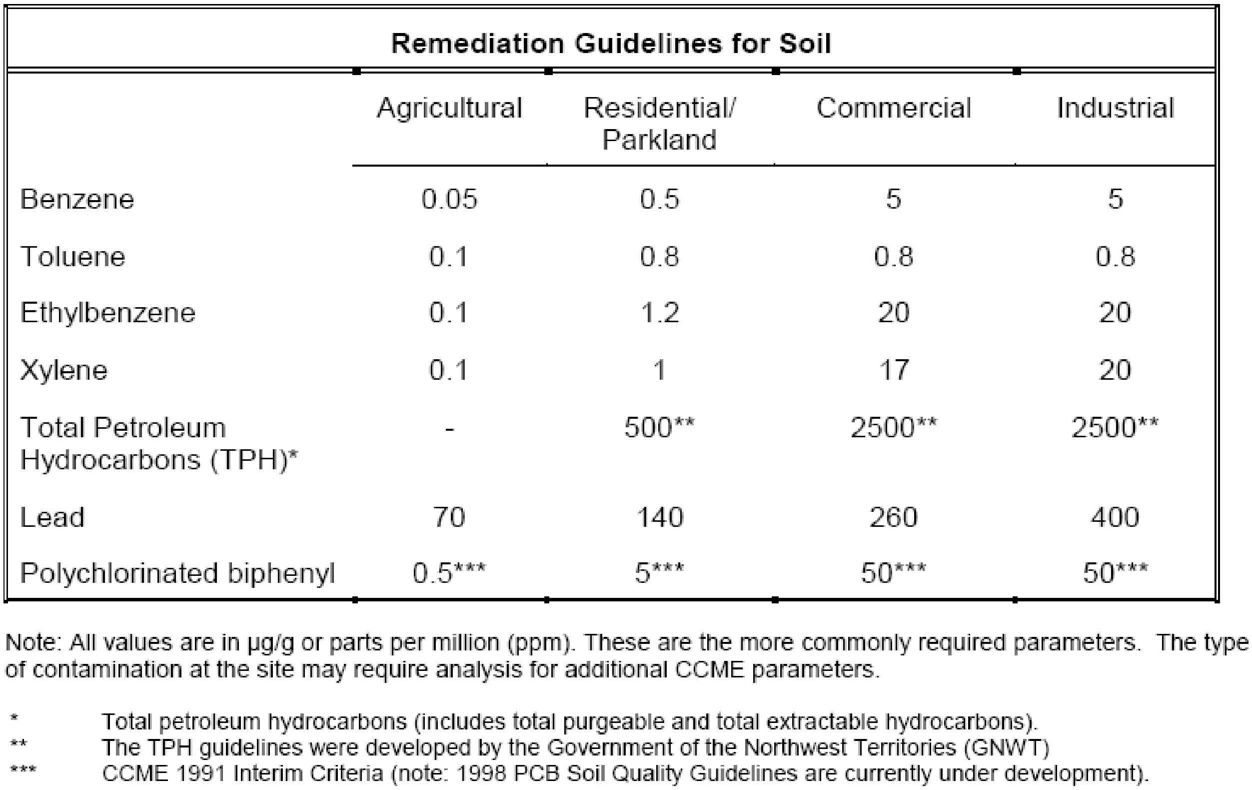
- Environmental Coordinator – The site Environmental Coordinator has responsibility to: keep this management plan updated; provide technical expertise to the site operational personnel on the operation and maintenance of the landfarm; sampling of the contaminated soil and assessment of whether remediation has met applicable regulatory standards; provide operational personnel with direction as to when and where remediated soil should be moved; conduct annual audit of the facility; and provide an audit report to the Surface Superintendent and Mine General Manager.

2.0 APPLICABLE LEGISLATION

Both federal and territorial legislation regulates the management of hazardous materials in Nunavut. Copies of relevant legal documents will be kept on file at the mine site. Management and safety personnel will provide an overview of the applicable regulations to all employees as part of their orientation training and through ongoing training.

The Environmental Protection Service of the Nunavut Department of Sustainable Development has published an “Environmental Guideline for Soil Remediation” that provides guidance as to acceptable levels for the remediation of hydrocarbon contaminated soils in Nunavut. These guidelines are derived from the CCME 1991 Interim Criteria and the CCME 1997 Recommended Soil Quality Guidelines. MHBL will use the industrial remediation guideline as set out in Table 2.1 to determine when soil has been remediated to a level acceptable for removal from the landfarm facility for use in site remediation.

Table 2.1: Nunavut Environmental Guidelines for Soil Remediation



Remediation Guidelines for Soil

	Agricultural	Residential/ Parkland	Commercial	Industrial
Benzene	0.05	0.5	5	5
Toluene	0.1	0.8	0.8	0.8
Ethylbenzene	0.1	1.2	20	20
Xylene	0.1	1	17	20
Total Petroleum Hydrocarbons (TPH)*	-	500**	2500**	2500**
Lead	70	140	260	400
Polychlorinated biphenyl	0.5***	5***	50***	50***

Note: All values are in µg/g or parts per million (ppm). These are the more commonly required parameters. The type of contamination at the site may require analysis for additional CCME parameters.

* Total petroleum hydrocarbons (includes total purgeable and total extractable hydrocarbons).
** The TPH guidelines were developed by the Government of the Northwest Territories (GNWT)
*** CCME 1991 Interim Criteria (note: 1998 PCB Soil Quality Guidelines are currently under development).

Other acts, regulations, and guidelines pertinent to the landfarm treatment of contaminated soil materials and general handling of hazardous materials at the Doris North Project are as follows:

Federal

- Canadian Council of Ministers for the Environment (CCME) 2003 Guidelines for Contaminated Soils – Industrial Sites (attached in Appendix A).

Nunavut

- Consolidation of Environmental Protection Act (RSNWT 1988c E.7)
- Consolidation of the Environmental Rights Act RSNWT 1988 c83 2nd Supp)
- Fire Prevention Act and Regulations
- Environmental Guideline for General Management of Hazardous Waste

3.0 LOCATION AND CONSTRUCTION OF FACILITIES

The landfarm treatment area will be located within the footprint of Quarry 2 (within the footprint of the non-hazardous landfill site). Figure 3-1 shows the location of the Quarry at Doris North and Figure 3-2 is a site arrangement; Figure 3-3 shows a cross section of the facility.

The proposed landfarm will be an area of approximately 50 m by 25 m (1,250 m^2) located within the north end of Quarry 2. A nominal levelling layer of fine crushed quarry rock (surfacing material) (0.1 m thick) will be laid down to provide a base for the landfarm liner. Additional crushed rock will be used to create the bermed area for the landfarm. The low permeability HDPE geomembrane liner, sandwiched between geotextile, will be placed on the floor of the landfarm and continued up into a berm completely surrounding the area. A ramp will be constructed of crushed rock to allow vehicles to enter and exit the landfarm without damaging the containment berm. A thin bedding layer of fine crushed rock (surfacing material) (0.3 m) will be placed on top of the liner to protect it from damage from vehicles delivering contaminated soils to the landfarm. The useable volume within the facility is 1,000 m^3 (25 m by 50 m by 0.8 m). The landfarm facility will be constructed with QA/QC conducted by a geotechnical engineer present during construction. The geotechnical engineer will inspect the placement of the geotextiles and HDPE liner and ensure the integrity of the liner before the bedding layer is placed. No vehicle with a tire pressure greater than 200 kPa will be allowed into the landfarm area once the liner is placed.

The landfarm facility will not be fenced as it is located within the footprint of Quarry 2 and is thus isolated from the surrounding tundra. The landfill floor will be graded to the southeast corner of the Quarry where a pollution control sump will be installed[1]. Typically the landfarm facility will be a closed drainage system with any collected water reporting to the sump within the landfarm which in turn will be treated through an oil water adsorption system before being land applied onto the tundra to the east of Quarry 2. Any spillage or release from the bermed landfarm should drain to the separate landfill sump where it can be intercepted if needed.

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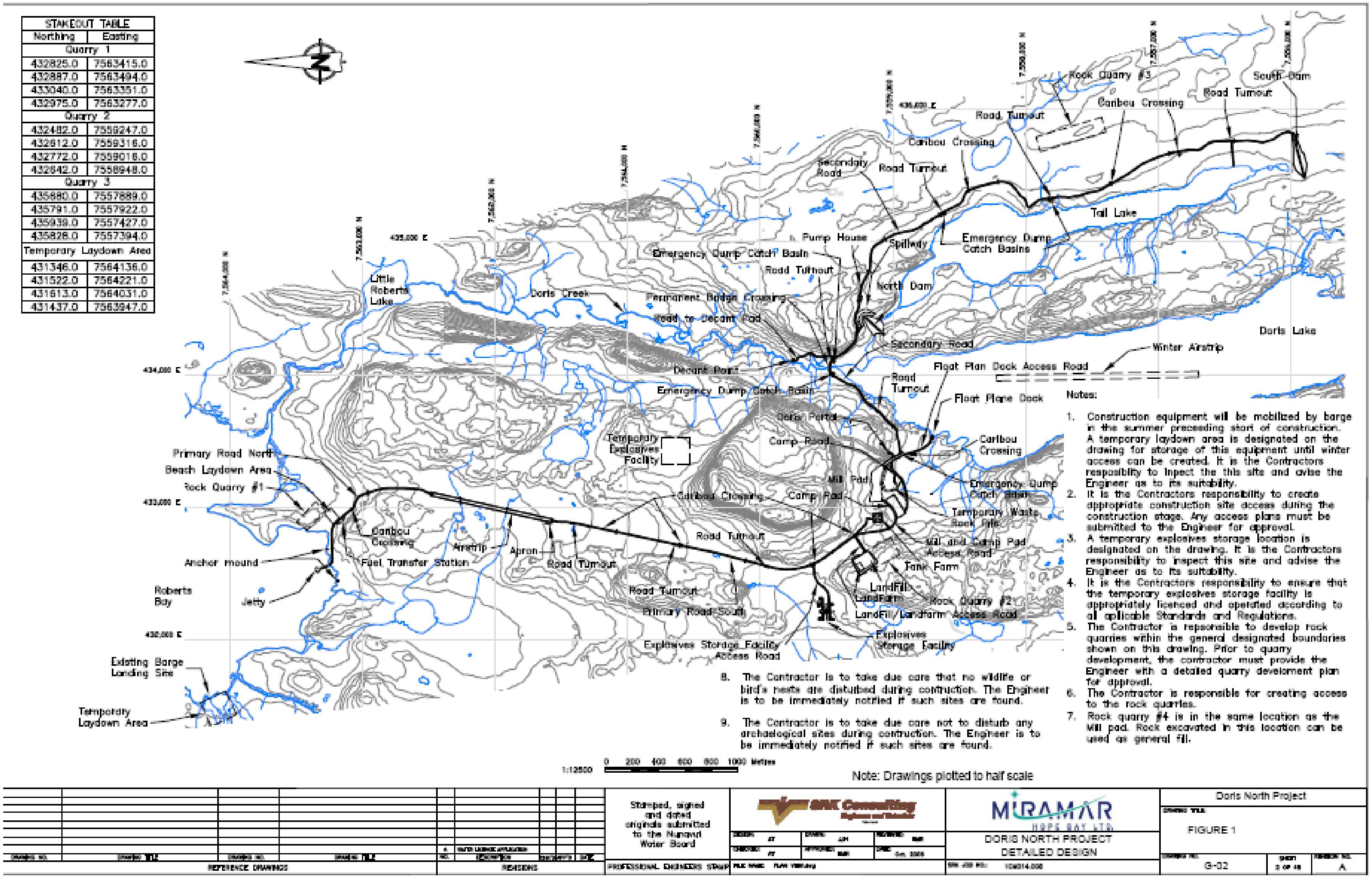
[1] For additional information on the landfill pollution control sump operation see Landfill Management Plan, Supporting Document S10g to the Revised Water License Application Support Document, April 2007.



STAKEOUT TABLE	
Northing	Easting
Quarry 1	
432825.0	7563415.0
432887.0	7563494.0
433040.0	7563351.0
432975.0	7563277.0
Quarry 2	
432482.0	7559247.0
432612.0	7559316.0
432772.0	7559016.0
432642.0	7558948.0
Quarry 3	
435680.0	7557889.0
435791.0	7557922.0
435939.0	7557427.0
435828.0	7557394.0
Temporary Laydown Area	
431346.0	7564136.0
431522.0	7564221.0
431613.0	7564031.0
431437.0	7563947.0

Notes:

1. Construction equipment will be mobilized by barge in the summer preceeding start of construction. A temporary laydown area is designated on the drawing for storage of this equipment until winter access can be created. It is the Contractors resposiblity to inpect the this site and avise the Engineer as to its suitability.
2. It is the Contractors responsibility to create appropriate construction site access during the construction stage. Any access plans must be submitted to the Engineer for approval.
3. A temporary explosives storage location is designated on the drawing. It is the Contractors responsibility to inspect this site and advise the Engineer as to its suitability.
4. It is the Contractors responsibility to ensure that the temporary explosives storage facility is appropriately licenced and operated according to all aplicable Standards and Regulations.
5. The Contractor is reponsible to develop rock quarries within the general designated boundaries shown on this drawing. Prior to quarry development, the contractor must provide the Engineer with a detailed quarry develoment plan for approval.
6. The Contractor is responsible for creating access to the rock quarries.
7. Rock quarry #4 is in the same location as the Mill pad. Rock excavated in this location can be used as general fill.
8. The Contractor is to take due care that no wildlife or bird's nests are disturbed during contruction. The Engineer is to be immediately notified if such sites are found.
9. The Contractor is to take due care not to disturb any archaelogical sites during contruction. The Engineer is to be immediately notified if such sites are found.

Note: Drawings plotted to half scale

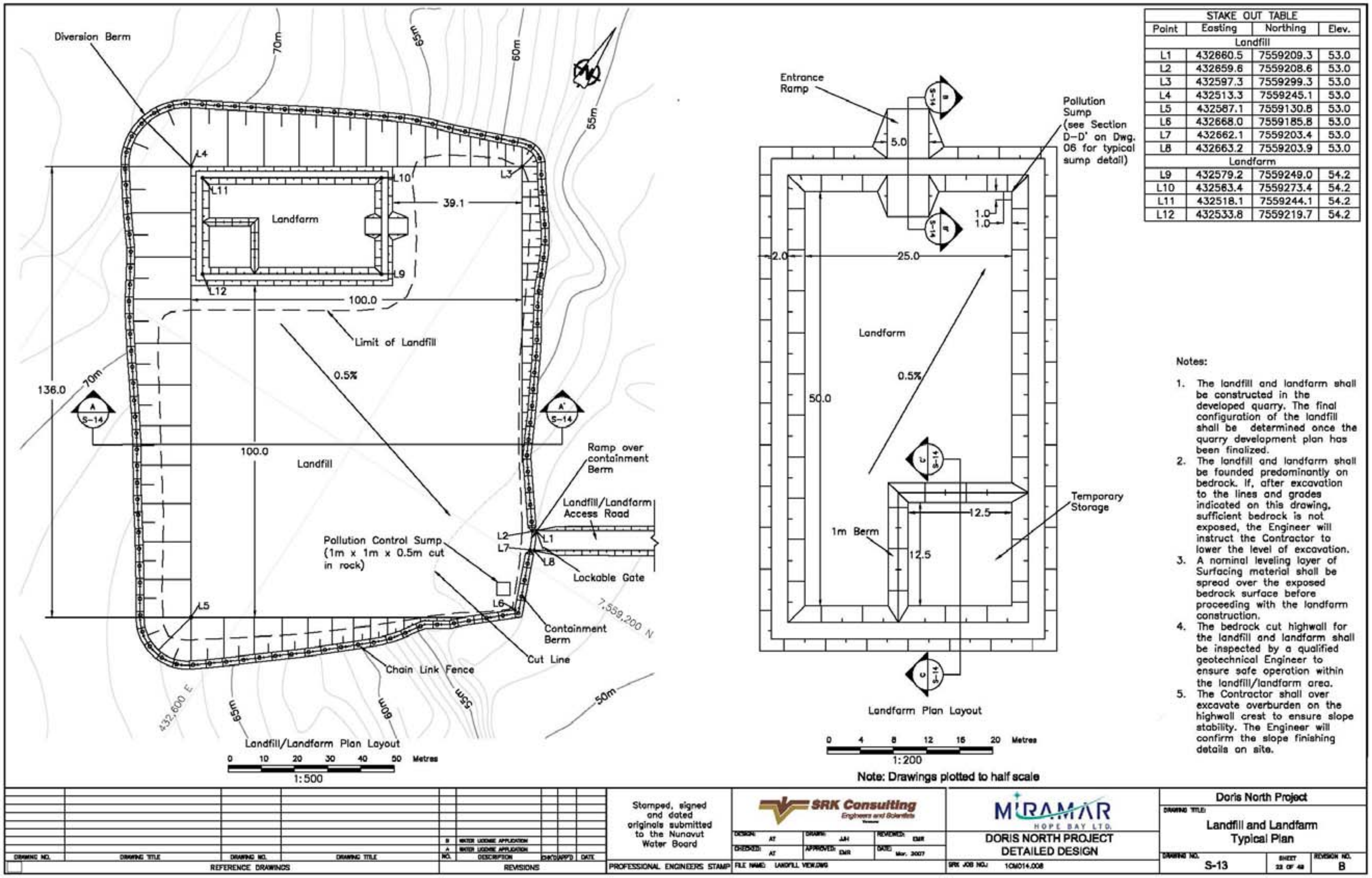
Stamped, signed and dated originals submitted to the Nunavut Water Board

DORIS NORTH PROJECT
DETAILED DESIGN

Doris North Project

FIGURE 1

Figure 3.1: Site Map

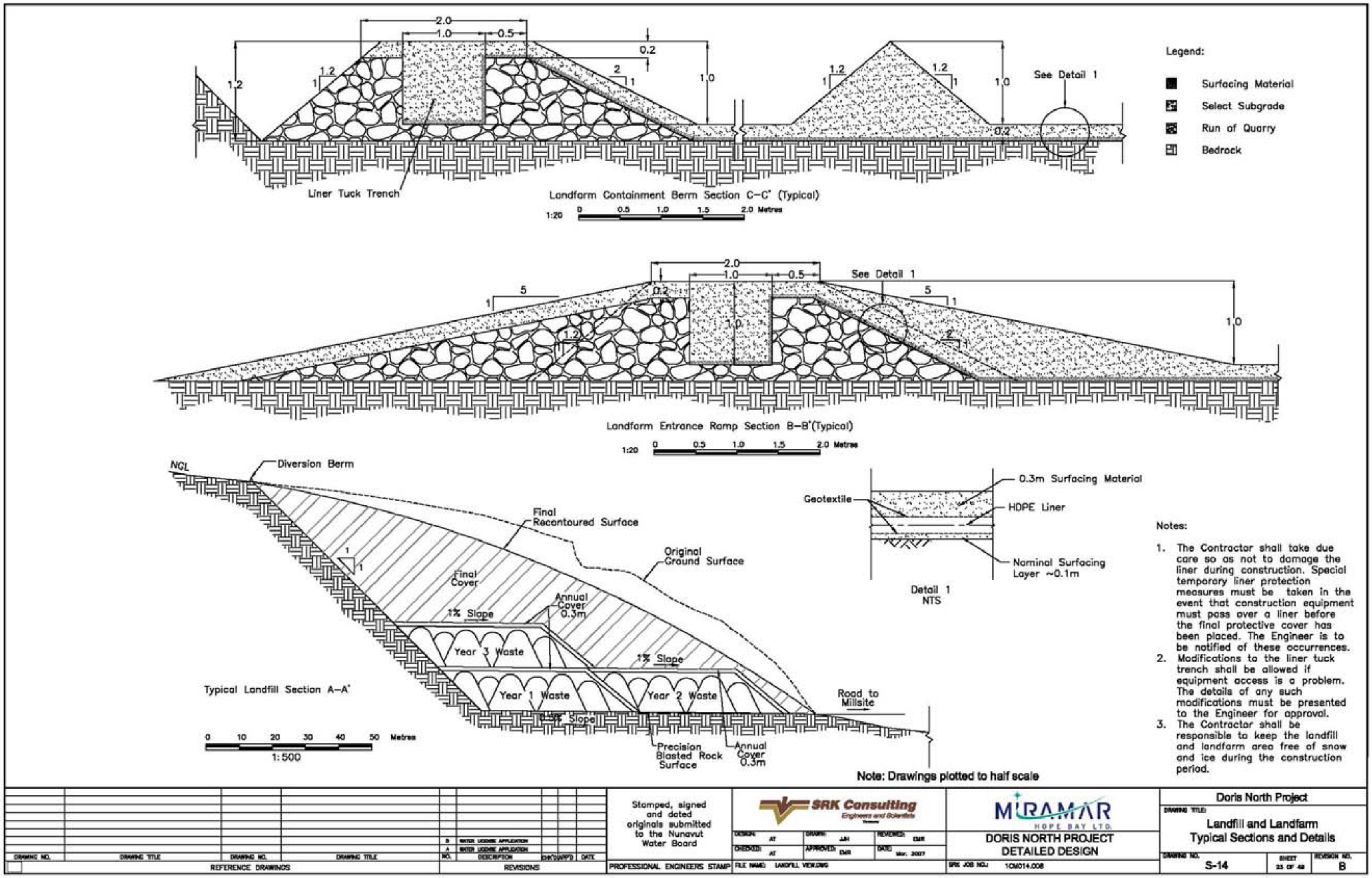


STAKE OUT TABLE			
Point	Easting	Northing	Elev.
Landfill			
L1	432660.5	7559209.3	53.0
L2	432659.6	7559208.6	53.0
L3	432597.3	7559299.3	53.0
L4	432513.3	7559245.1	53.0
L5	432587.1	7559130.8	53.0
L6	432668.0	7559185.8	53.0
L7	432662.1	7559203.4	53.0
L8	432663.2	7559203.9	53.0
Landfarm			
L9	432579.2	7559249.0	54.2
L10	432563.4	7559273.4	54.2
L11	432518.1	7559244.1	54.2
L12	432533.8	7559219.7	54.2

Notes:

1. The landfill and landfarm shall be constructed in the developed quarry. The final configuration of the landfill shall be determined once the quarry development plan has been finalized.
2. The landfill and landfarm shall be founded predominantly on bedrock. If, after excavation to the lines and grades indicated on this drawing, sufficient bedrock is not exposed, the Engineer will instruct the Contractor to lower the level of excavation.
3. A nominal leveling layer of Surfacing material shall be spread over the exposed bedrock surface before proceeding with the landform construction.
4. The bedrock cut highwall for the landfill and landform shall be inspected by a qualified geotechnical Engineer to ensure safe operation within the landfill/landform area.
5. The Contractor shall over excavate overburden on the highwall crest to ensure slope stability. The Engineer will confirm the slope finishing details on site.

Figure 3.2: Landfarm Site Arrangement



Notes:

1. The Contractor shall take due care so as not to damage the liner during construction. Special temporary liner protection measures must be taken in the event that construction equipment must pass over a liner before the final protective cover has been placed. The Engineer is to be notified of these occurrences.
2. Modifications to the liner tuck trench shall be allowed if equipment access is a problem. The details of any such modifications must be presented to the Engineer for approval.
3. The Contractor shall be responsible to keep the landfill and landfarm area free of snow and ice during the construction period.

Note: Drawings plotted to half scale

Figure 3.3: Landfarm Cross Section

4.0 LANDFARM OPERATION

4.1 What Materials Will Be Treated at the Landfarm Facility

The Doris North landfarm facility will only receive hydrocarbon contaminated snow and soil materials generated through MHBL's ongoing mining and exploration activity on the Hope Bay Belt. No material from other sites will be accepted at this facility without the approval of the Kitikmeot Inuit Association (KIA) and the Nunavut Water Board (NWB).

At the Doris North Project and in its regional exploration activity, MHBL's use of hydrocarbons is limited by need to the following products:

- Diesel fuel for generators and for diesel fuelled mobile equipment (vehicles);
- Aviation fuel for helicopters and small aircraft (Jet B);
- Hydraulic oils; and
- Gasoline.

In the event of all spills, MHBL's on-site Environmental Coordinator will be contacted and consulted by the operations personnel and their contractors on clean up and remediation protocols. The Environmental Coordinator will, based on their investigation and understanding of the spill, make a decision on how each spill is to be cleaned up and the affected area remediated. In the event where soil or snow is contaminated by spilled hydrocarbons, the Environmental Coordinator will give direction to the clean up personnel on whether this contaminated soil and/or snow is to be taken to the Doris North landfarm facility and where within the facility it is to be placed. The Environmental Coordinator will ensure that only hydrocarbon contaminated soil and/or snow is taken to the landfarm and that other contaminants such as heavy metals, glycol or heavy oils that are not bio-remedial using the landfarm procedures are not mixed with soils/snow taken to the landfarm. This action is to preserve the remedial performance of the landfarm and prevent generation of large volumes of contaminated soil that cannot be successfully bio-remediated. Alternative methods will be used to address these types of contaminants, up to and including off-site disposal through appropriate remediation/disposal facilities or by placing them underground in stopes to be subsequently backfilled where they will be isolated from surface water by permafrost.

Organic garbage from the camp kitchen and dormitory areas will be burned in a purpose built incinerator to limit the potential for food wastes to attract wildlife. This ash is typically low in metal contaminants due to its source but high in nutrients that can improve the suitability of soil to sustain vegetation. Consequently MHBL intends to take this ash from the kitchen incinerator, place it into drums and then move it to the landfarm where each summer season it will be mixed using a hand rake and/or roto-tiller to blend this material into the soil undergoing remediation. It is estimated that approximately 5 m^3 per year of incinerator ash will be blended with the hydrocarbon contaminated soil undergoing remediation each year.

4.2 Estimated Volumes of Material to be Treated at the Landfarm Facility

MHBL does not plan on having any hydrocarbon spills at the Doris North site, however past experience within the industry suggests that some spills will occur. For planning purposes, MHBL has estimated that the following volumes of hydrocarbon contaminated materials will be generated by its activities at the Doris North site:

- Hydrocarbon Contaminated Soil - estimated volume of 25 m^3 per year (an aggregate area of 5 m by 5 m by 1 m deep); and
- Hydrocarbon Contaminated Snow – estimated volume of 50 m^3 per year (an aggregate area of 5 m by 10 m by 1 m deep). It has been estimated that this 50 m^3 of contaminated snow will melt to create approximately 3,000 litres of water (using a snow water equivalency of 59.2 litres per m^3)[2]. This equivalency represents the high end of measured values rather than an average, specifically 25 cm of snow on the ground being equal to 14.8 mm of snow water equivalent. The higher end value was selected to ensure a conservative assumption on water volume to be collected within the landfarm once the contaminated snow has melted.

The proposed landfarm has a volume of approximately 1,000 m^3 within the bermed area (based on a storage berm height of 0.8 m – from top of fill on top of the HDPE liner to the top of the liner on the berm). Assuming a freeboard allowance of 0.25 m, then this volume decreases to approximately 688 m^3. Consequently the landfarm could contain approximately 364 m^3 of contaminated soil (deducting 324 m^3 for annual precipitation and allowing for a freeboard of 0.25 m). Each cubic metre of contaminated snow is equivalent to approximately 0.06 m^3 of water storage volume.

While remediation rates are very site specific, MHBL has assumed for design purposes that it will require 3 full operating seasons to remediate soils contaminated with light hydrocarbons such as diesel fuel and 6 operating seasons to remediate soils contaminated with heavier hydrocarbon fractions such as motor oil. The designed facility has been constructed in excess of the theoretical volume requirements for a 6 year cycle (6 times 25 m^3) to ensure that capacity is available if and when it should be needed.

In the event of a very large spill the contaminated soils would have to be temporarily stored while a new landfarm cell is constructed. In such an event this contaminated soil could be placed underground while an adaptive management plan was developed such as construction of a second landfarm cell somewhere on site. Such a facility has not been considered by MHBL at this time.

4.3 Water Balance for the Landfarm Facility

A precipitation and temperature profile for the area is taken from the baseline meteorology data compiled for the Doris North Project[3]. The average monthly air temperature is typically above 0°C between June and September with the peak in July, and below freezing between October and May with the coldest temperatures usually occurring in February. The mean annual precipitation adjusted for under-catch is approximately 207 mm with 41% occurring as rain between May and October and 59% as snow through the remainder of the year.

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[2] This equivalency rate was taken from the Concurrent Seasonal Snow Data, 1996 to 2006 reported for Cambridge Bay and Kugluktuk as reported in Table 3.7, Doris North Project Hydroclimatic Parameter Re-Evaluation 2006, Supporting Document S5 to the Doris North Water License Application Support Document, December 2006).

[3] AMEC, 2003. Meteorology And Hydrology Baseline, Doris North Project, Nunavut, Canada, prepared for Miramar Hope Bay Ltd. November 2003, p.D-iii.

The landfarm treatment facility has a footprint of approximately 1,566 m^2 (including the berm footprint) providing a total precipitation collection area of 1,566 m^2 from which water must be collected and treated. Mean precipitation ranges from 94 mm to 207 mm, with only about 41% falling as rain. Annual lake evaporation (typically occurring between June and September) is about 220 mm. Consequently the mean annual volume of precipitation runoff expected to be collected within the landfarm is as follows:

Landfarm (1,566 m^2) 147 m^3 to 324 m^3 (1,566 m^2 x (mean precipitation in mm/1,000))

While it is understood that a lot of this runoff will be lost through wind movement of snow, sublimation and evaporation, for the purposes of estimating the maximum potential volume of water to be treated through the oil adsorption system, these losses have not been considered. Offsetting sublimation and evaporation losses from within the liner of the tank farm and landfarm treatment facilities will be contaminated snow brought to the landfarm treatment facility for remediation (estimated at approximately 3 m^3 per year). Consequently the total estimated volume of water to be treated through the landfarm oil-water adsorption system is between 150 m^3 to 327 m^3 (150,000 to 327,000 liters per year).

All precipitation runoff and snowmelt collected within the landfarm sump will be collected and treated through an F1 “Flow and Plug” Oil Adsorption System (Model F11-C-180-TM-Cx2 as supplied by Terry Ruddy Sales of Edmonton Alberta). A photo and a copy of the operations/maintenance manual for this system are attached as Appendix B). This system consists of a self priming electric pump, a particulate filter, a drum containing TM-100 oil adsorbing media and two activated carbon media containers connected in series. The unit operates at 5 to 7 gpm (19 to 26 lpm). Consequently the maximum discharge time required to treat and release all of the expected water collected within the landfarm will be ~290 operating hours (12 operating days). This system will be operated (i.e. the frequency of pumping) to keep the sump level down so that the soil undergoing remediation does not become saturated with the precipitation and snowmelt water collected within the landfarm (remediation is not effective when the soil is saturated as aeration is prevented).

4.4 How Will Contaminated Soil Be Tested

Early in each summer the soils placed within the landfarm facility will be sampled and analyzed for Benzene, Toluene, Ethylbenzene, Xylene (BTEX), Total Petroleum Hydrocarbons (TPH), polychlorinated biphenyl (PCB), and an ICP-MS 30 element trace metal scan to determine the nature and amount of contamination to be addressed.

Soils with light hydrocarbon fraction products (diesel fuel and Jet B) are expected to be most easily landfarmed and will thus be kept in a separate pile within the landfarm for remediation. Soils contaminated with heavy fraction hydrocarbons, such as motor or hydraulic oils, will be more difficult to remediate and thus these materials will be segregated and treated within a separate pile within the same landfarm facility. Hydrocarbon contaminated snow will be placed within one designated area of the landfarm facility in a location where the snowmelt can be collected in the early summer at the low point within the berm and the resultant contaminated water pumped to an oil water treatment system (an F1 “Flow and Plug” Oil Adsorption System (Model F11-C-180-TM-Cx2 as supplied by Terry Ruddy Sales of Edmonton Alberta).

Additional information on environmental performance sampling (sampling procedures, analytical parameters, frequency and target performance criteria) around this landfarm facility is provided in Section 4.7

4.5 Landfarm Operational Procedures

A record will be kept by MHBL's on-site Environmental Coordinator of the amount of contaminated soil and snow placed in the landfarm and the location of each batch of contaminated soil within the landfarm by contaminant type and length of remediation. The landfarm will be monitored weekly during summer months by the Environmental Coordinator to ensure proper operating conditions of soil moisture and aeration, i.e., moisture content between 15 and 30%, uncompacted soil.

A mixture of ammonium nitrate and corn cobs will be used as a bacterial medium and mixed with the contaminated soil in the first warm weather summer months after the contaminated soil is placed within the landfarm. These corncobs are a commercial packaged product purchased from a supplier in Edmonton. They are dried and ground pellets made from corncobs packaged in 25 kg bags which are then shipped to site for use. An adequate supply will be kept at the Doris North site for use in bio-remediation of hydrocarbon contaminated soils. These corncob pellets add a natural organic nutrient source to enhance the performance of the natural bio-remediation bacteria. Similarly ammonium nitrate fertilizer purchased from a supplier in Edmonton adds a nutrient source to enhance the performance of the natural bio-remediation bacteria that are present in the soil. Based on past experience the following initial rates of bioremediation medium will be added:

- 1 kg of corncob pellets per cubic meter of soil; and
- 0.25 kg of ammonium nitrate fertilizer per cubic meter of soil.

These addition rates are monitored by the on-site Environmental Coordinator and adjusted as needed based on remediation performance over the summer operating season. The medium is hand spread onto the surface of the soil undergoing remediation and mixed in using a hand rake and by a roto-tiller to mix the soil down to a depth of approximately 15 to 20 cm. No medium is added during winter months when bio-remediation is essentially dormant.

The landfarm design incorporates a separate area of approximately 12.5 m^2 for the temporary storage of hydrocarbon contaminated snow over the winter months. In the spring the snow will melt and drain through the internal berm to report to the landfarm sump. This internal berm will not be lined and sufficiently porous to allow the snowmelt water to drain to the landfarm pollution sump.

Soil containing petroleum products will be spread uniformly over the surface of the prepared area. The new contaminated soil will be incorporated into the top 15 to 20 cm of the existing soil base in the landfarm, generally using a manual rake or with roto-tiller, provided that precaution is taken to protect the underlying HDPE liner from the tiller blades. Soils will be tilled monthly over the summer period (June to September) to ensure adequate aeration. Soils will be remediated in separate batches or mixed with soil already undergoing remediation based on the assessment of the on-site Environmental Coordinator. This assessment will consider the nature and degree of contamination of the new soil and the remediation status of soils already in the landfarm. In some circumstances it may be preferable to mix a small volume of lightly contaminated soil in with soil that is nearing completion of remediation to accelerate the overall remediation process by blending the new soil with remediated soil.

Soils will be kept moist with a target soil moisture content of 15% to 30%; water will be applied where necessary and soil moisture content monitored to help ensure it stays within the acceptable range. Bio-remediation performance drops off when soil moisture increases to the saturation point where aeration no longer can take place. The soil also must be dry enough to allow the roto-tiller to mix the soil exposing new material to the air. Soil will be also be watered as required to prevent dust generation; saturation will be avoided. The source of this water will be from the sump located within the landfarm facility and applied using a pump and hose with a spray nozzle or spray bar. Moisture determinations will be made on site using the procedure outlined in ASTM D2216-05 standard test method for determination of water content in soil and rock.

All water collected in the landfarm sump will be pumped to a portable head tank and then treated through an F1 “Flow and Plug” Oil Adsorption System (Model F11-C-180-TM-Cx2 as supplied by Terry Ruddy Sales of Edmonton Alberta). This is a portable unit set up on standard pallets so that they can be moved to the landfarm facility as and when needed. The system consists of a self priming electric positive displacement pump, a particulate filter, a drum containing TM-100 oil adsorbing media and two activated carbon media containers connected in series. The unit operates at 5 to 7 gpm. The unit is designed so that the TM-100 oil adsorbing media will blind off when it reaches its absorbent capacity. The unit will be moved into location soon after the spring snowmelt so that the landfarm can be drained of standing water to prevent saturation of the contained soil undergoing remediation. The unit will then be moved back into the landfarm whenever the sump fills to keep the soils unsaturated.

No allowance has been made to remove uncontaminated snow from the landfarm. It has been designed on the assumption that all snow collected in the landfarm will melt and have to be treated through the oil-water adsorption system. In reality, MHBL will attempt to remove uncontaminated snow from this facility, specifically in areas of drift in the late winter ahead of the spring thaw. A combination of hand shovelling and a small bobcat front end loader will be used to clear this snow where practical. This activity will be directed by the on-site Environmental Coordinator.

All precipitation runoff collected within the landfarm facility is pumped from the internal landfarm sump to the portable head (feed) tank and then pumped through the Oil Adsorption System with the treated water then directed onto the nearby tundra to be land applied in a method that prevents erosion at the point of application. The discharge from the Oil Adsorption System is sampled and analyzed on a once per day basis whenever the system is in operation (see Section 4.7).

Equipment used in the landfarming operation for aeration, etc. will be cleaned off within the landfarm area prior to exiting to ensure that contaminated soil is not transferred away from the landfarm on the wheels and other parts of this equipment.

4.6 Soil Sampling, Applicable Remediation Guidelines, Inspections and Repairs

The Environmental Protection Service of the Nunavut Department of Sustainable Development has a published an “Environmental Guideline for Soil Remediation” that provides guidance as to acceptable levels for the remediation of hydrocarbon contaminated soils in Nunavut. These guidelines are derived from the CCME 1991 Interim Criteria and the CCME 1997 Recommended Soil Quality Guidelines.

MHBL will use the industrial remediation guideline as set out in Table 2.1 (above) to determine when soil has been remediated to a level acceptable for removal from the landfarm facility for use in site remediation.

A record will be kept by MHBL’s on-site Environmental Coordinator of the amount of contaminated soil and snow placed in the landfarm and the location of each batch of contaminated soil within the landfarm by contaminant type and length of remediation. The landfarm will be monitored weekly during summer months by the Environmental Coordinator to ensure proper operating conditions of soil moisture and aeration, i.e., moisture content between 15 and 30%, uncompacted soil.

Soil samples will be collected at least once per year by MHBL and tested for Benzene, Toluene, Ethylbenzene, Xylene (BTEX), Total Petroleum Hydrocarbons (TPH), polychlorinated biphenyl (PCB) and total metals using a 36 element ICP-MS scan. Soil hydrocarbon concentrations will be monitored to ascertain the point where soils are no longer considered contaminated. There are no CCME guidelines for density of soil sampling in landfarms, consequently MHBL proposes that each separate pile within the landfarm be divided into quadrants, and sampled with a target density of one composite of ten samples per 25 m^3 to adequately characterize the soil’s hydrocarbon levels. The soil sampling records will be kept by the Environmental Coordinator and reported to the KIA and the NWB as required (at a minimum as part of the annual reporting). More frequent sampling may be conducted by the Environmental Coordinator especially when soil is nearing the successful remediation levels to verify when soil can be moved out of the landfarm and used in site reclamation.

Remediated soils will be used for reclamation purposes specifically on areas where the existing vegetative cover has been disturbed. The area where the remediated soil is to be used will be opportunistic in that the soil will be used in areas available for progressive reclamation when these soils meet the GN Remediation criteria.

Any required repairs to the landfarm facility will be noted during the weekly inspections conducted by the Environmental Coordinator and arrangements will be made to have the repairs effected promptly. The nature of the repairs required and when repairs were completed will be recorded in the landfarm log. Any unauthorized use of the facility noted on inspections will be reported to the Mine General Manager for corrective action and discussed at Health and Safety Committee meetings.

4.7 Performance and Environmental Monitoring Program

MHBL will implement a monitoring program around the landfarm facility. The objective is to measure both soil and water to verify that remediated soil removed from the landfarm and treated water from the landfarm meets the appropriate remediation criteria. The monitoring program proposed by MHBL is broken down as follows:

1. Contaminated soil within the landfarm will be sampled at the beginning of each summer treatment season to verify the nature and extent of contamination within the soils to be remediated. The soil samples will be collected by MHBL and tested for Extractable Hydrocarbons F1 and F2, Benzene, Toluene, Ethylbenzene, Xylene (BTEX), Total Petroleum Hydrocarbons (TPH), polychlorinated biphenyl (PCB) and total metals using a 36 element ICP-MS scan. MHBL proposes that each separate pile within the landfarm be divided into quadrants, and sampled with a target density of one composite of ten samples per 25 m^3 to adequately characterize the soil's hydrocarbon levels. The soil sampling records will be kept by the Environmental Coordinator and reported to the KIA and the NWB as required (at a minimum as part of the annual reporting).

2. A similar sampling program will be conducted by MHBL prior to any soil being removed from the landfarm for use in reclamation to demonstrate that the soil has been remediated to the GN remediation standards (Industrial) as set out in Table 2.1. The soil samples will be collected by MHBL and tested for Extractable Hydrocarbons F1 and F2, Benzene, Toluene, Ethylbenzene, Xylene (BTEX), Total Petroleum Hydrocarbons (TPH), polychlorinated biphenyl (PCB) and total metals using a 36 element ICP-MS scan. MHBL proposes that each pile of remediated soil be divided into quadrants, and sampled with a target density of one composite of ten samples per 25 m^3 to adequately characterize the soil's hydrocarbon levels. The soil sampling records will be kept by the Environmental Coordinator and reported to the KIA and the NWB as required (at a minimum as part of the annual reporting). Similarly records will be kept and reported as above as to each location where remediated soil is placed along with an estimate of the volume placed in each location.

3. Samples of the precipitation runoff and snowmelt water collected within the landfarm facility liner will be conducted early each summer following the spring melt to determine water quality prior to the start up of the oil adsorption treatment system. The samples will be analyzed for pH, Total Suspended Solids, Total Oil and Grease, Benzene, Toluene, Ethyl benzene and Total Ammonia.

The discharge from the Oil Adsorption system will be sampled and analyzed on a once per day basis whenever the system is in operation. The sample will be taken from the discharge of the Oil Adsorption System prior to this water being land applied onto the tundra. The samples will be analyzed for: pH, Total Suspended Solids, Total Oil and Grease and Total Ammonia. MHBL recommends that the standard that must be achieved for discharge be set as set out in Table 4.1:

Table 4.1: Proposed Discharge Standard for Water Discharged from the lined Fuel Transfer Station, Fuel Tank Farm and Landfarm Facilities

Parameter Being Monitored	Proposed Discharge Standard (mg/L)[1]
pH	**5.0 to 9.0**
TSS	**15.0**
Total Oil and Grease	**5.0**
Total Ammonia	**2.0**

[1] Based on a review of discharge limits used at other mine sites in the NWT for small volume discharges into freshwater

MHBL looked at discharge limits established in other water licenses for relatively new mine sites in the North to determine what discharge standards were being used to protect the freshwater aquatic environment for small volume discharges from surface runoff ponds and fuel containment facilities[4]. Only limited information could be found. At Doris North the treated water released from the fuel transfer station, the fuel tank farm and landfarm will be land applied onto the tundra. The tundra will play a significant role in attenuating contaminants contained in this release. The large dilution available in Doris Lake and Roberts Bay will further attenuate these contaminants. The proposed discharge limits for the release of treated water from these facilities (Table 4.1) were drawn from the data in Table 6.2 in the Water Management Plan. These levels have been selected by the regulatory agencies managing water in the N.W.T. as being protective of water quality in the receiving environment in similar settings.

MHBL will apply the following QA/QC procedures during sampling:

- Use of field blanks: Field blanks are samples of pure water that are subjected to exactly the same procedures as routine samples, following which they are analyzed for the same parameters as the field samples. Any measurement of the parameter of interest, above method detection limits, will indicate any analytical error, impurities in the laboratory distilled water supply, contaminated sample preservatives, or contamination of the sample during the handling process. Combined with the results of other quality control procedures, analysis of field blanks can help identification of sources of contamination. A set of field blanks will be made up once each month and taken into the field when the active SNP stations are sampled. New sample bottles will be used and prepared using distilled water from the normal laboratory water supply. This set will represent all of the parameters routinely analyzed. They will be preserved in the field and submitted to the laboratory identified as field blanks.

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[4] The results of the MHBL review are presented in Table 6.2, Water Management Plan, Supporting Document S10j to the Revised Water License Application Support Document, April 2007.

- Duplicate sampling – Replicate sampling (or sometimes referred to as duplicate sampling) is the collection of more than one sample for a given analysis at a given location. The replicate samples are collected, handled, and analyzed using the standard procedures applied to routine samples. Replicate sampling, combined with the results of other quality control procedures, can help indicate sources of error and are particularly useful in identifying problems with accuracy and sampling methods. Once per operating season, for each active Water License Surveillance Network Program stations (sampling stations prescribed in the Water License), a set of duplicate samples will be taken, representing as many of the routine analyses as possible. Where possible, this should be carried out in conjunction with audit sampling conducted by the designated inspector. Replicate sampling should alternate between the prescribed Water License Surveillance Network Program stations.

These results will be included in the reports provided to the NWB and KIA.

Samples will be delivered to the analytical laboratory as soon as possible after collection. All samples will be stored and transported at a temperature <10 degrees Celsius. Coolers and ice packs are provided for field transportation and samples will be refrigerated as soon as possible following arrival at the laboratory.

A chain of custody form will be completed for each sampling site respectively. The original will be sent to the external laboratory while a copy will be filed accordingly on-site. A follow-up call will be made to the external environmental laboratory ensuring that samples are received[5].

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[5] Sampling program is also included in the Monitoring and Follow-Up Plan, Supporting Document S10m to the Revised Water License Application Support Document, April 2007.

5.0 LANDFARM MANAGEMENT

5.1 General

The focus of management of the landfarm will be safety and environmental responsibility. Employees working in the landfarm will be trained prior to commencement of work so that they are aware of the health and safety risks associated with the landfarm.

5.2 Health and Safety

There are four primary exposure pathways to chemicals within the landfarm:

1. Inhalation;
2. Ingestion;
3. Skin contact; and
4. Eye contact.

Since the facility is outside and concentrations of contaminants will be generally relatively low, inhalation exposure is not likely to be problematic. In special circumstances where contamination is heavy, respirators can be worn to scrub the air of volatile organics. Ingestion, under normal circumstances is very unlikely.

Skin contact will be prevented by issuing suitable personal protective equipment to employees working in the landfarm. Personal protective equipment suitable for petroleum hydrocarbons is listed in the Material Safety Data Sheets for petroleum products that may be transferred to the landfarm in contaminated soil or snow and summarized in Table 5-1.

Eye contact is unlikely under normal circumstances. Where hand work is to be carried out in the landfarm with the risk of eye contact, protective goggles will be required.

Table 5.1: Guidelines for Safe Handling of Contaminated Soil and Snow

Personal Protection	
Ventilation	Use adequate ventilation (normally assured at the landfarm due to being outdoors).
Respiratory protection	Not generally required unless needed to prevent respiratory irritation. Use organic cartridge respirator per MSDS recommendations.
Eye protection	For splash protection, use chemical goggles and face shield
Skin protection	Use gloves resistant to the material being used, i.e., neoprene or nitrile rubber. Use protective garments to prevent excessive skin contact.
Health Hazard Data	
Acute effects of overexposure	Eye: May cause mild irritation, with stinging and redness of eyes.
	Skin: May cause severe irritation. Repeated or prolonged contact may cause defatting of the skin, resulting in dermatitis. Dermal LD50 for diesel fuel is >5 mg/kg (rabbit).
	Inhalation: May cause irritation to nose, throat or lungs. Headache, nausea, dizziness, unconsciousness may occur.
	Ingestion: Swallowing small amounts is not likely to produce harmful effects. Ingestion of larger amounts may produce abdominal pail, nausea and vomiting. Aspiration into lungs can produce severe lung damage and is a medical emergency.

First Aid and Emergency Procedures	
Eye	Flush eyes with running water for at least 15 minutes. If irritation or adverse symptoms develop, seek medical attention.
Skin	Immediately wash skin with soap and water for at least fifteen minutes. If irritation or adverse symptoms develop, seek medical attention.
Inhalation	Remove from exposure. If breathing is difficult, give oxygen. If breathing ceases, administer artificial respiration followed by oxygen. Seek immediate medical attention.
Ingestion	Do not induce vomiting. Seek immediate medical attention.
Fire	
Fire extinguishing media	Dry chemical, foam, or carbon dioxide.

5.3 Landfarm Closure

The landfarm will be decommissioned when the mine is closed, or some time period after closure, depending on requirements for its use during the reclamation period. Remediated soils that test clean (based on the Nunavut Environmental Guideline for Site Remediation – Industrial Standard) will be used for reclamation. Soils that remain contaminated and the underlying fine crushed rock from the landfarm will be placed underground at the time of landfarm decommissioning and be encapsulated by permafrost. The HDPE geomembrane will be cleaned, cut up and disposed of in the non-hazardous landfill. Bedding rockfill (below the geomembrane) will be tested for presence of petroleum hydrocarbons, and if clean, used for reclamation of the adjacent landfill but, if not, placed underground as well. A representative sampling grid will be used to characterize this underlying rockfill material using grid lines set at 10 m intervals with sampling of the rockfill at 50% of the grid intersection nodes.

The site will then be levelled consistent with other reclamation activities at the mine[6].

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[6] Further details in Section 6.1.5.10, Mine Closure and Reclamation Plan, Supporting Document S10l to the Revised Water License Application Support Document, April 2007.

This report, “Landfarm Management Plan, Doris North Project, Nunavut, April 2007”, has been prepared by Miramar Hope Bay Ltd.

Prepared By

Lawrence J. Connell, P.Eng.
General Manager, Environment

REFERENCES

MHBL. 2006. Landfill Design and Management Plan. Plan produced for Miramar Hope Bay Limited by AMEC Earth & Environmental, October 2006.

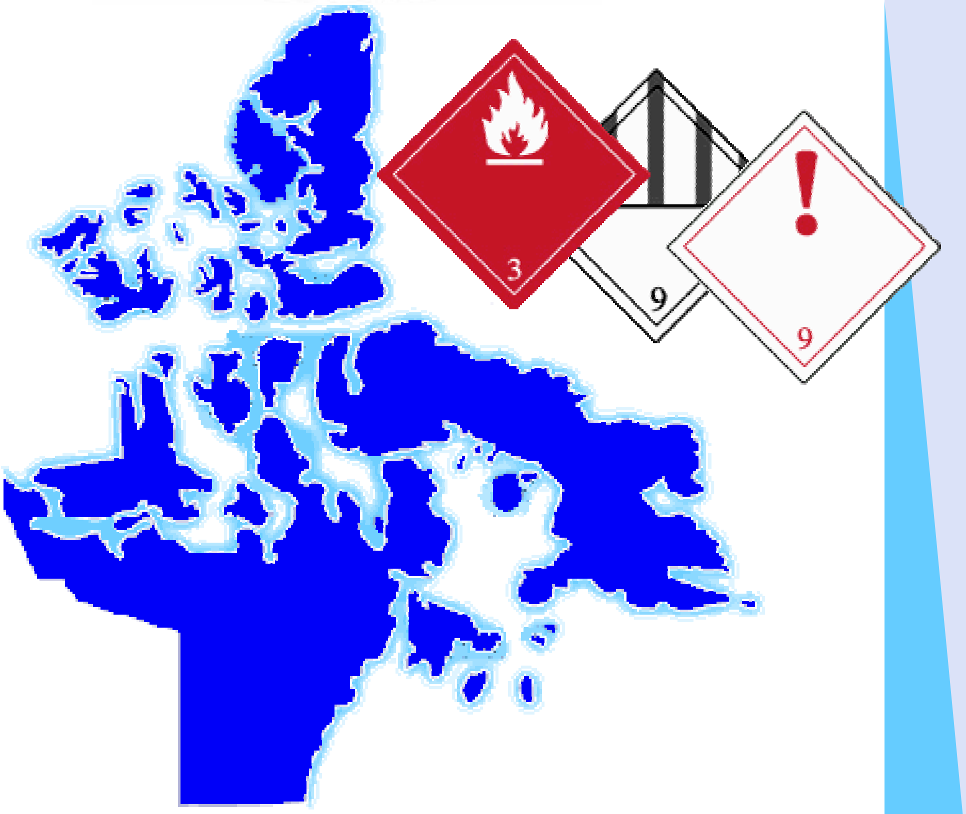
MHBL. 2006. Hazardous Materials Management Procedures.

MHBL. 2006. Mine Closure and Reclamation Plan. Plan produced by Miramar Hope Bay Limited, October 2006

APPENDIX A

Nunavut Environmental Guideline for Site Remediation – January 2002

ENVIRONMENTAL GUIDELINE
FOR
Site remediation



Department of Sustainable Development
Environmental Protection Service

GUIDELINE: CONTAMINATED SITE REMEDIATION

AS AMENDED BY:

USE OF GUIDELINE

A guideline is not law and is therefore not enforceable. It does however, assist an inspector to determine what action(s) may be required of him. Paragraph 2.2(c) of the Environmental Protection Act allows the Minister to develop, co-ordinate and administer guidelines. The Act [subsection 5(1)] makes it an offence to discharge a contaminant into the environment, subject to some exceptions [subsection 5(3)]. When a discharge occurs and it is inconsistent with the guidelines, the discharge is considered an unacceptable risk. The inspector may then consider issuing an order or laying an information.

A guideline allows for some leniency in applying the law. A court would probably be inclined to consider the application of a guideline favorably because the public is aware of the standards they are expected to meet.

This Consolidation is not Law.
It is prepared by Environmental Protection Service,
Department of Sustainable Development
Government of the Nunavut

January, 2002

Guideline for Contaminated Site Redemption

January, 2002

GUIDELINE FOR CONTAMINATED SITE REMEDIATION

1 Introduction

The purpose of this guideline is to help you solve a contamination problem on your property by setting standards for site remediation. This guideline will focus on hydrocarbons because they are the most common type of contaminant in Nunavut. However, the principles outlined here can be applied to other types of site contamination. Section 2.2 of the *Environmental Protection Act* gives the Minister of Sustainable Development the authority to develop, co-ordinate and administer these guidelines (see Appendix).

1.1 Definitions

CCME	Canadian Council of Ministers of the Environment (CCME) is the major intergovernmental forum in Canada for discussion and joint action on environmental issues of national, international and global concern. The 13 member governments work as partners in developing nationally consistent environmental standards, practices and legislation.
Commissioner's Lands	Lands in Nunavut that have been transferred by Order-in-Council to the Government of Nunavut. This includes highways, block land transfers and most lands within municipalities.
Contaminant	Any noise, heat, vibration or substance and includes such other substances as the Minister may prescribe that, where discharged into the environment, (a) endangers the health, safety or welfare of persons, (b) interferes or is likely to interfere with normal enjoyment of life or property, (c) endangers the health of animal life, or (d) causes or is likely to cause damage to plant life or to property.
Contaminated Site	Areas of land, water, ground water, or sediments that have levels of contaminants exceeding the remediation criteria. Contaminant sources can include on-site burial of wastes, non-point chemical releases (small, frequent drips and spills), stockpiling and storage of materials, major spills, and releases during fires. Contamination may also be due to illegal dumping of contaminated soil. Contaminated sites may have short or long-term consequences to people or the environment.
Remediation	The management of the contaminant at a site so as to prevent, minimize, or mitigate damage to human health, property, or the environment. Remediation is a broader term then clean-up in that remediation options can include physical actions such as removal, destruction, and containment, as well as the use of institutional control such as zoning designations or orders.

T.P.H.	Total petroleum hydrocarbons, (includes total purgable and total extractable hydrocarbons).

1.2 Roles and Responsibilities

The Department of Sustainable Development, Environmental Protection Service (EPS), is the main contact concerning remediation of contaminated sites on Commissioner's Land, EPS determines the required level of remediation using the remediation criteria cited in these guidelines. EPS also reviews your remediation plan and monitors the progress of the project. It is your responsibility to remediate the site to acceptable levels. As there may be health or safety concerns to consider, we recommend you also contact the Department of Health, the Office of the Fire Marshal, the municipality and the landowner.

> ***EPS will provide advice on remediation measures, but it is the sole responsibility of the polluter and land owner to provide adequate site remediation.***
> ***(See Environmental Protection Act in Appendix)***

2 Defining The Problem

If you think you have contamination on your property, the first step is to do a thorough site investigation. A thorough investigation may avert unnecessary remediation costs. Depending on the degree and complexity of the contamination, you may require the assistance of a qualified environmental consultant or engineer.

Ask yourself the following questions:

2.1 What is the History of the Site*?*

Thorough historical research will aid in identifying and locating the contaminant(s). It may also aid in assessing responsibility for the contamination. Consider the following:

- Is the site near an existing tank farm, fuel storage area or other contaminant storage site?
- Is it near where a tank farm or fuel storage site previously existed?
- Has there ever been a spill on or near the property?

2.2 What is the Contaminant?

It is essential to identify the contaminant, in order to determine suitable remediation options.

- Common contaminants in Nunavut are diesel fuel, turbo, fuel, gasoline and used oil.
- You should take representative samples with the assistance of an accredited laboratory.

2.3 What is the Degree of Contamination?

Consider the following:

- What is the length, width and depth of the contaminated area?
- What is the soil type?
- Where is the surface and ground water?
- What is the type of permafrost, if any? Is it saturated, unsaturated, continuous or discontinuous permafrost?

2.4 What are the Possible Impacts?

Remember that this contaminated site may affect many people and other living organisms. Determine both the pathway of contamination and all possible receptors of contamination.

Consider the following:

- How did the contamination enter the site?
- Did it enter the ground water?
- Will it affect people through either toxic vapors or soil contamination?
- Could there be any effects on vegetation, wildlife or domestic animals?
- How will the contamination affect adjacent sites?
- What will the site be used for in the future?
- Are there any special factors relating to public use of the area?
- Is it commercial, agricultural or residential land? (Section 2.4.1)

2.4.1 Land Use

Identifying the type of land use will help you assess the extent of human and ecological exposure to contaminants in the soil, and is essential for planning practical remediation programs. The specified land uses considered in this guideline are: agricultural, residential/parkland and commercial/industrial.

Agricultural	All uses of land where the activity is primarily related to the productive capability of the land or facility (e.g. greenhouse) and is agricultural in nature, or is related to the feeding and housing of animals such as livestock.
Residential/ Parkland	Residential: all uses of land in which dwelling on a permanent, temporary or seasonal basis is the primary activity. Institutions, hospitals, schools, daycare and playgrounds are also indicated under this land use. Residential/Parkland is often readily accessible to the public. Parkland: all land uses in which the primary activity is recreational in nature and requires the natural or human designed capability of the land to sustain that activity.
Commercial	All uses of land in which the primary activity is related to the buying, selling or trading of merchandise or services.
Industrial	All land uses in which the primary activity is related to the production, manufacture or storage of materials. The public does not usually have uncontrolled access to this type of land. This does not include institutions

(e.g. schools, hospitals, playgrounds).

Always confirm the required level of remediation with EPS. The type of land found adjacent to the contaminated site may affect the remediation criteria levels that you have to follow.

3 Remediation

Once the problem has been defined (section 2), you can decide on the appropriate remediation options. If you have hired a qualified contractor, they may recommend remediation options to you. General remediation categories include:

On-site/Off-site	Will your remediation be on or off-site? Techniques will vary accordingly.
On-site treatment	The soil must meet the remediation criteria (section 4).
Off-site treatment	Merely moving the spill to a landfill facility is not acceptable. After moving the soil to an acceptable location, you must contain the contaminants, and then treat the soil or water to reduce the contamination to an acceptable level (section 4).
Groundwater	Contaminated groundwater may require treatment. A qualified contractor can advise you on the available options.

3.1 Remediation Guidelines

Remediation in Nunavut is guideline based. The required degree of remediation is determined by CCME 1991 Interim Criteria, CCME 1997 Recommended Canadian Soil Quality Guidelines and the Environmental Protection Service.

Remediation Guidelines for Soil

	Agricultural	Residential/ Parkland	Commercial	Industrial
Benzene	0.05	0.5	5	5
Toluene	0.1	0.8	0.8	0.8
Ethylbenzene	0.1	1.2	20	20
Xylene	0.1	1	17	20
Total Petroleum Hydrocarbons (TPH)*	-	500**	2500**	2500**
Lead	70	140	260	400
Polychlorinated biphenyl	0.5***	5***	50***	50***

Note: All values are in µg/g or parts per million (ppm). These are the more commonly required parameters. The type of contamination at the site may require analysis for additional CCME parameters.

* Total petroleum hydrocarbons (includes total purgeable and total extractable hydrocarbons).

** The TPH guidelines were developed by the Government of the Northwest Territories (GNWT)

*** CCME 1991 Interim Criteria (note: 1998 PCB Soil Quality Guidelines are currently under development).

The chart below may help you to visualize the amount of contaminant it would take to create a level of 1000 PPM. Remember that 1000 PPM is a much greater level than many of the acceptable remediation criteria levels listed above.

Amount of Soil and Gasoline Creating a Level of 1000 PPM

Volume of Soil	***Volume of Gasoline***
5g (typical amount used for chemical analysis)/1 tsp.	.005 ml/ 1/1000 tsp.
4.5 litres/1 gallon bucket	7.5 ml /1.5 tsp.
205 litres/45 gallon drum	400 ml /1 3/4 cups
18,5976 kg/410,000lb (or 140 yd^3, enough to fill a living room that is 10 x 19 x 19 ft.)	205 litres/45 gallon drum

3.2 Decision Considerations

The following should be considered when making your final decision:

Guidelines	(section 3.1).
Permission	You must obtain permission from the local municipality or landlord before using any of their facilities, such as the landfill site or the sewage lagoon.
Time required	How long will the remediation take?
Cost	Is your remediation plan cost effective?
Aesthetics	Does your plan restore the area to an acceptable level of aesthetic quality?
Technology	How effective is the technology being considered?

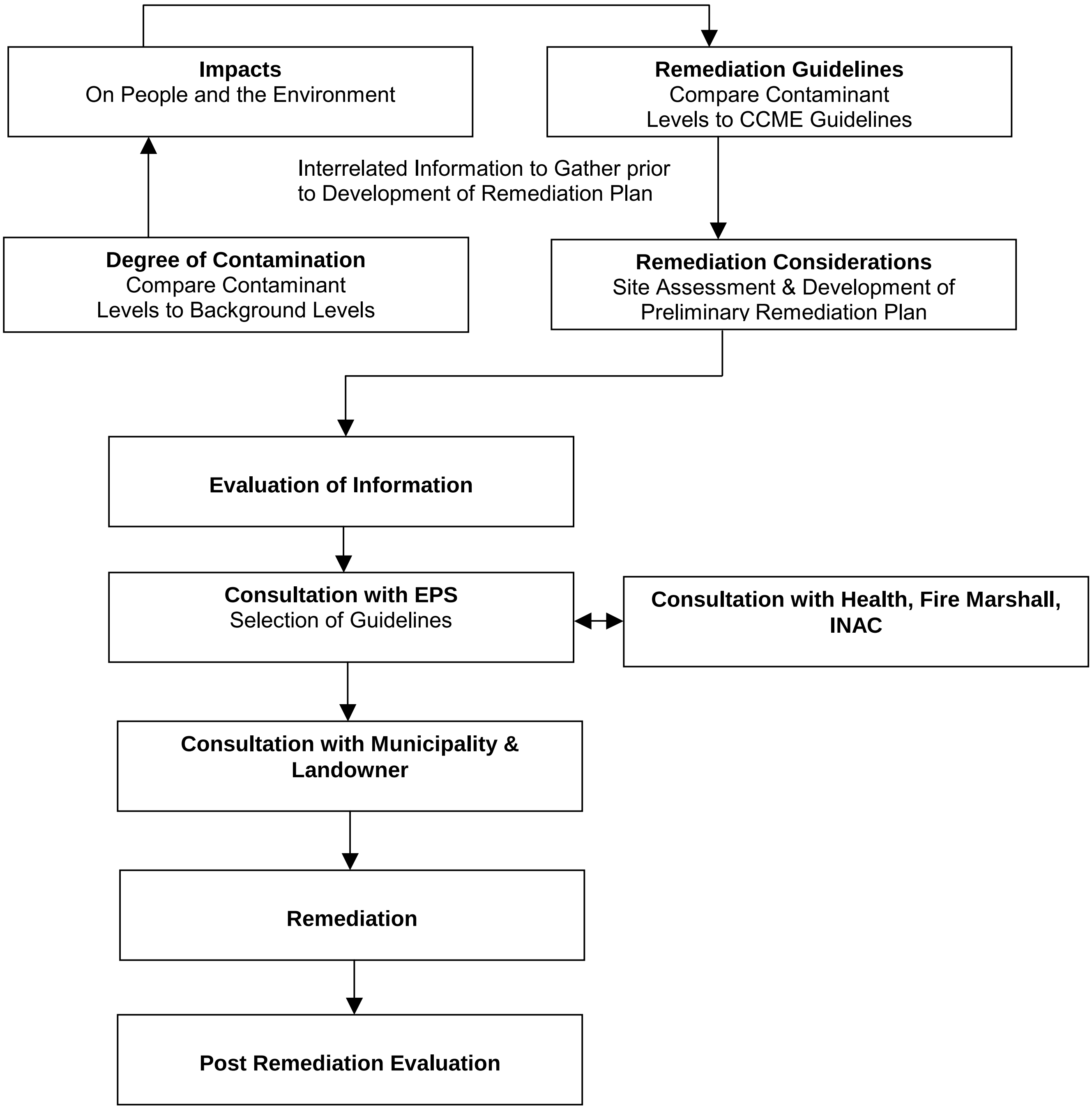


Figure 1: Steps Used in Site Remediation

4 Conclusion

This is a brief introduction to the process of contaminated site remediation.

For more information:

1) Read CCME 1997 Recommended Canadian Soil Quality Guidelines report (see References).

2) Contact the Environmental Protection Service
Department of Sustainable Development
P.O. Box 1000, Station 1195
Iqaluit, Nunavut, X0A 0H0
Phone: (867) 975-5900; Fax: (867) 975-5990

Remember that this document is intended to inform you about some of the basic issues involved in contaminated site remediation. Once you have read this document and verified that you have a contaminated site, you must contact the Environmental Protection Service. You should work with EPS before proceeding through the site remediation process.

5 Bibliography

CCME (Canadian Council of Ministers of the Environment). 1991 Interim Canadian Environmental Quality Criteria for Contaminated Sites . The National Contaminated Sites Remediation Program, Report No. CCME EPC-CS34. Winnipeg, Manitoba.

CCME (Canadian Council of Ministers of the Environment). 1997 Recommended Canadian Soil Quality Guidelines. ISBN 1-895-925-92-4. Winnipeg, Manitoba.

APPENDIX
Environmental Protection Act

The following is a subset of the *Environmental Protection Act*. The complete act can be obtained from any office of the Department of Sustainable Development.

1. In this Act,

"Contaminant" means any noise, heat, vibration or substance and includes such other substances as the Minister may prescribe that, where discharged into the environment,

(a) endangers the health, safety or welfare of persons,
(b) interferes or is likely to interfere with normal enjoyment of life or property,
(c) endangers the health of animal life, or
(d) causes or is likely to cause damage to plant life or to property.

"Discharge" includes, but not so as to limit the meaning, any pumping, pouring, throwing, dumping, emitting, burning, spraying, spreading, leaking, spilling, or escaping.

"Environment" means the components of the Earth and includes:

(a) air, land and water,
(b) all layers of the atmosphere,
(c) all organic and inorganic matter and living organisms, and
(d) the interacting natural systems that include components referred to in paragraphs (a) to (c).

2.2 The Minister may

(a) establish, operate and maintain stations to monitor the quality of the environment in the Territories;
(b) conduct research studies, conferences and training programs relating to contaminants and to the preservation, protection or enhancement of the environment;
(c) develop, co-ordinate and administer policies, standards, guidelines and codes of practice relating to the preservation, protection or enhancement of the environment.

5. (1) Subject to subsection (3), no person shall discharge or permit the discharge of a contaminant into the environment.

(2) REPEALED, R.S.N.W.T. 1988, c. 117 (Supp.), s. 8

(3) Subsection (1) does not apply where the person who discharged the contaminant or permitted the discharge of the contaminant establishes that:
   (a) the discharge is authorized by this Act or the regulations or by an order issued under this Act or the regulations;
   (b) the contaminant has been used solely for domestic purposes and was discharged from within a dwelling-house;
   (c) the contaminant was discharged from the exhaust system of a vehicle;
   (d) the discharge of the contaminant resulted from the burning leaves, foliage, wood, crops or stubble for domestic or agricultural purposes;

(e) the discharge of the contaminant resulted from burring for land clearing or land grading;
(f) the discharge of the contaminant resulted from a fire set by a public official for habitat management of silviculture purposes;
(g) the contaminant was discharged for the purposes of combating a forest fire;
(h) the contaminant is a soil particle or grit discharged in the course of agriculture or horticulture; or
(i) the contaminant is a pesticide classified and labeled as domestic under the *Pest Control Products Regulations* (Canada).

(4) The exceptions set out in subsection (3) do not apply where a person discharges a contaminant that the inspector has reasonable grounds to believe is not usually associated with a discharge from the excepted activity. R.S.N.W.T. 1988, c. 75 (Supp.) S. 5; c. 117 (Supp.), s. 8.

5.1 Where a discharge of a contaminant into the environment in contravention of this Act or the regulations or the provisions of a permit or license issued under the Act or the regulations occurs or a reasonable likelihood of such a discharge exists, every person causing or contributing to the discharge or increasing the likelihood of such a discharge, and the owner or the person in charge, management or control of the contaminant before its discharge or likely discharge, shall immediately:

(a) subject to any regulations, report the discharge or likely discharge to the person or office designated by the regulations;
(b) take all reasonable measures consistent with public safety to stop the discharge, repair any damage caused by the discharge and prevent or eliminate any danger to life, health, property or the environment that results or may be reasonably expected to result from the discharge or likely discharge; and
(c) make a reasonable effort to notify every member of the public who may be adversely affected by the discharge or likely discharge. R.S.N.W.T. 1988, c. 75 (Supp.), s. 5; c. 117 (Supp.), s. 9.

6. **(1)** Where an inspector believes on reasonable grounds that a discharge of a contaminant in contravention of this Act or the regulations or a provision of a permit or license issued under this Act or the regulations has occured or is occurring, the inspector may issue an order requiring any person causing or contributing to the discharge or the owner or the person in charge, management or control of the contaminant to stop the discharge by the date named in the order.

7. **(1)** Notwithstanding section 6, where a person discharges or permits the discharge of a contaminant into the environment, an inspector may order that person to repair or remedy an injury or damage to the environment that results from the discharge.

(2) Where a person fails or neglects to repair or remedy any injury or damage to the environment in accordance with an order made under subsection (1) or where immediate remedial measures are required to protect the environment, the Chief Environmental Protection Officer may cause to be carried out the measures that he or she considers necessary to repair or remedy an injury or damage to the environment that results from any discharge.

If you would like to be placed on a mailing list to receive guideline amendments or for public consultation on Environmental Protection Service legislation please fill this out and mail or fax to:

Environmental Protection Service
Department of Sustainable Development
P.O. Box 1000, Station 1195
Iqaluit, Nunavut, X0A 0H0
Fax: (867) 979-5990

Users of this guide are encouraged to report any errors, misspellings, etc. contained within, to EPS at the above address

Mailing List for Environmental Protection Service Information

Name: ______________________________

Title: ______________________________

Address : ______________________________

____

Phone / Fax Number: ______________________________

APPENDIX B

Flow and Plug Oil Adsorption System

Terry Ruddy Sales

A division of 667762 Alberta Ltd.
9329 62 Avenue
Edmonton, Alberta T6E 0E1
Phone: 780-435-0324, Fax: 780-413-0090

Toll Free: 1-877-435-9690
E-mail: teer@telusplanet.net
Web Page: www.terryruddysales.com

February 02, 2007

Miramar Mining Corporation
300 – 889 Harbourside Drive
North Vancouver, BC
V7P-3S1

Attn. Mr. Larry Connell

Larry,

Enclosed is a photo and a operations/maintenance manual on a oily waste water process system. This system is currently being used at the Boston Camp in Nunaviut Territories.

The system operates at 5 to 7 gpm. without supervision. In the first drum, a product known as technical minerals is used. This media will blind off when it reaches its absorbent capacity. The two drums following contain a water based carbon used for polishing. The discharge should read "non-detectable traces" on testing.

If you have questions, feel free to call out toll free number

Regards

Terry Ruddy

08/14/2

OPERATING &
MAINTENANCE
MANUAL NO. C5121

FOR

Miramar Hope Bay Ltd.
Boston Camp

"FLOW & PLUG"
(Oil Absorption Equipment)

Model No: F11-C-180-TM-Cx2
Maximum Pressure: 10 PSI
Product: Oil Absorption Equipment

Sold & Serviced by:
Terry Ruddy Sales
9329 – 62 Avenue
Edmonton, AB   T6E 0E1
Telephone – 780-435-0324
Fax – 780-413-0090

Miramar Hope Bay Ltd. - Boston Camp

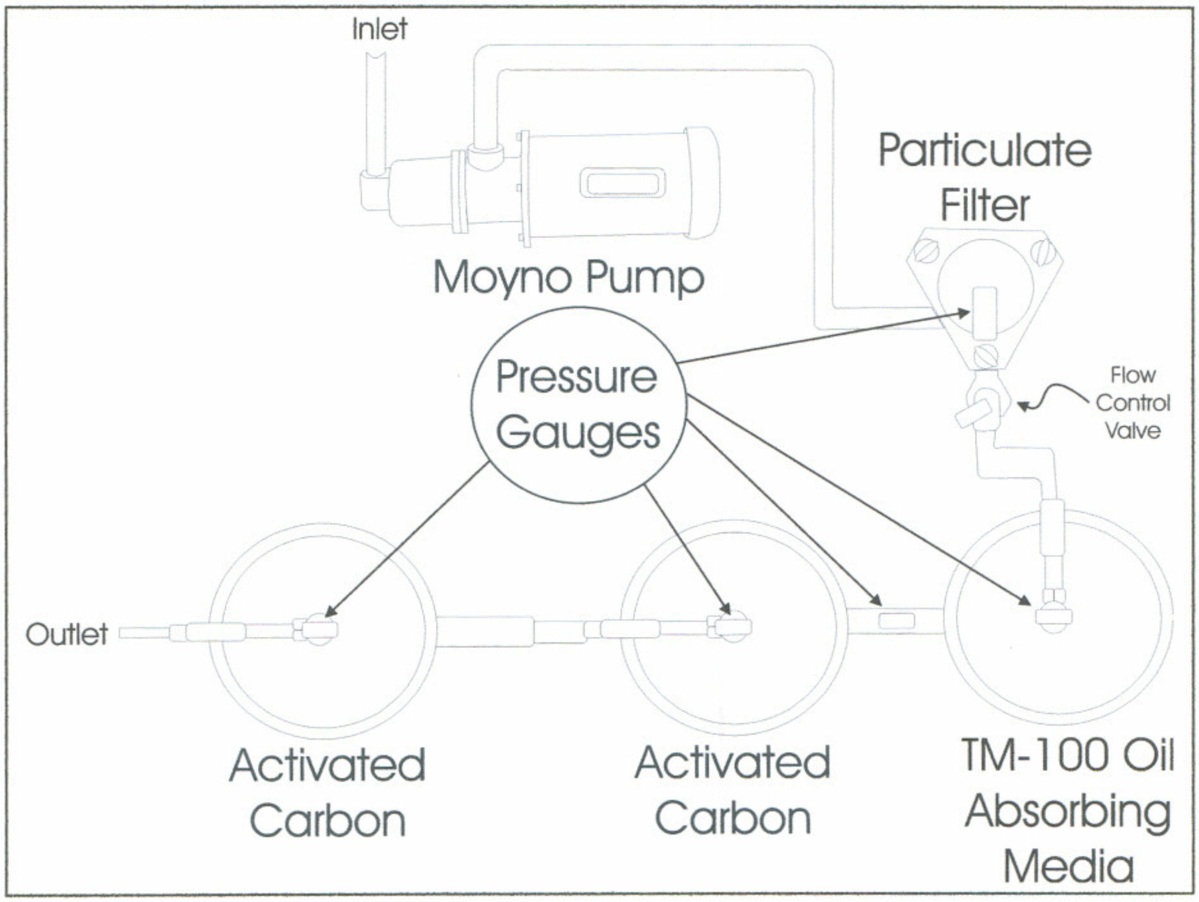
Flow and Plug System
(Oil Absorption Equipment)

General Description

The F-1 "Flow and Plug" Oil Absorption System is the simplest, most efficient and versatile method of removing oil and grease in waste water streams to a level below 15 PPM as regulated by the Ministry of the Environment. (Not recommended for chemical Oil Emulsions).

The F-1 system consists of 4 basic units:
1) a Monyo self-priming electric pump,
2) a particulate filter,
3) the oil absorbing media,
4) two activated carbon media containers connected in series.

Figure 1 – Overview



Overview

1) The Monyo self priming pump, * see separate pages covering installation, operation, trouble shooting and parts breakdown beginning on page

2) The Particulate Filter is a pre-filter to effectively remove any dirt and dust particles, which would prematurely plug the oil absorbing media. It is a bag filter system consisting of the pressure vessel, the micron rated disposable filter bag and restrainer basket (to support the bag filter).

   The disposable filter bag is a triple layered bag having a filter rating of approximately 1 micron. It will hold 1-2 pounds of dry solids before becoming plugged.

   Rapid access to the filter bag ensures a quick and easy clean-up of the vessel, since filtered out contaminants are trapped within the bag. "Spaghetti" (strips of oil absorbing polyproplyene) is added into the clean filter bag to enhance the dirt holding capacity by up to 5 times.

3) The TM-100 Oil Absorbing Media is contained in a removable disposable drum. The drum is specifically coated with epoxy to make it both chemical and abrasive resistant. The TM Media absorbs oils and grease through a partitioning phenomena. A unique characteristic of the media causes a slight swelling of the bed as it removes the hydrocarbons from the contaminated liquid. At a maximum pressure of 8 PSI, stoppage of the pumping action through the system is required as the media is saturated and needs to be replaced thus eliminating the flow of unfiltered liquid into the environment.

4) Activated Carbon, GC 12 X 40, is a virgin activated carbon derived from bituminous coal. Granular in form, it is ideal for many liquid phase applications including the removal of organics from water streams. Its superior absorptive capacity and the surface area make it particularly attractive for use in waste water while its size makes it appealing where low pressure drop is needed.

   The net result is oil/grease readings, in the output water, will be well below 15 PPM. Enabling the water to be sewerable.

   The second Activated Carbon drum, similar to item 4, is added for further polishing the water

WARNING

THIS FILTRATION SYSTEM IS DESIGNED WITH DISPOSABLE F-1 FILTER PRODUCTS OF THE TYPE AND MODEL SPECIFIED IN THE OPERATION INSTRUCTIONS MANUAL AND DRAWINGS. SAFE OPERATION AND PERFORMANCE IS GUARANTEED USING THE SPECIFIC FILTERS. WE WILL NOT GUARANTEE THE PERFORMANCE AND FUNCTION OF THE SYSTEM WITH OTHER MAKES, MODELS OR TYPES. ANY ACCIDENTS OR DAMAGES CAUSED BY USING INCORRECT, NON-SPECIFIED FILTERS AND MEDIA ARE THE FULL RESPONSIBILITY OT THE OWNER OR USER.

Installation

Remove the unit from the shipping crate, being careful not to damage any of the projecting connections.

Caution

Do not attach slings to any nozzles welded to the unit. Be sure not to place slings on the frame of the unit.

Important

Be sure to correctly identify the inlet and outlet connections of the unit to avoid piping the unit backwards. The filter will not perform if the connections are reversed.

Proceed with the required piping. Tighten all bolts evenly and securely. Check to make sure that the filter bag has been installed in the filter vessel before tightening the top cover bolts.

Drain piping should be led away from the unit. The water drain lines can be connected into any common drain system.

After all connections have been made and all bolts tightened securely, the unit is ready to be placed into operation.

Note – Leveling

The F-1 "Flow and Plug" system should be level to 1/8 inch per foot to be conducive to proper operation.

Operation

The system requires a minimum amount of attention after the initial installation. Differential pressure readings should be made and recorded on initial start-up.

Operating Limit Parameters

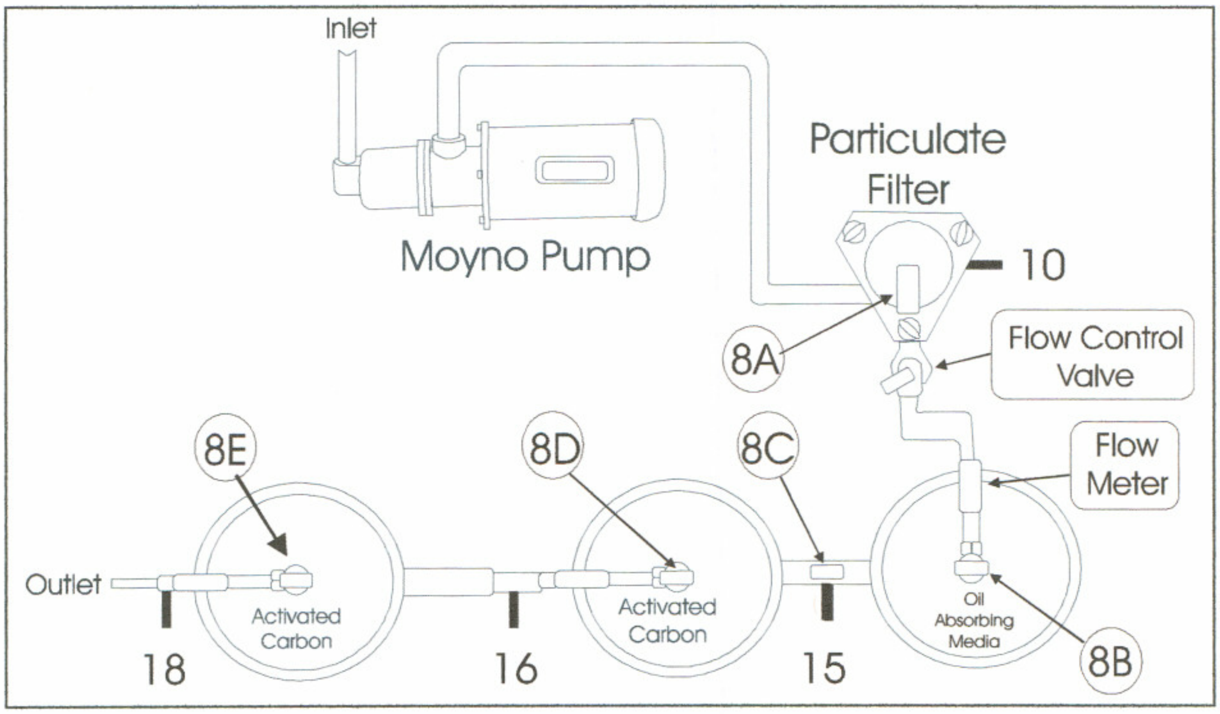
1) Pump must be properly electrically grounded. Read the separate operations and ownership manual starting on page ___.

2) When the differential pressure across the Particulate Filter vessel, as shown on pressure gauge (8A), reaches 15 PSI, the pump needs to be stopped and the filter bag and the "spaghetti" inside the filter bag should be changed.
See CHANGING THE FILTER BAG – Page 7 of these instructions

3) When the differential pressure across the oil absorbing drum (3), as shown by the gauge (8B), reaches 8 PSI, the pump should be shut off, because the absorbing drum is saturated and needs to be replaced.
See INSTRUCTIONS FOR CHANGING OIL ABSORBING DRUM – Page 9 of these instructions

4) Check flow meter (13) and if flow is greater than 19 LPM immediately adjust with flow control valves.

NOTE – **If flow is greater than 19 LPM, treated water quality will worsen, due to speed of flow through system. If excessive flow and or pressure (greater than 15 PSI) is allowed, then damage to and leakage of drums will occur.**

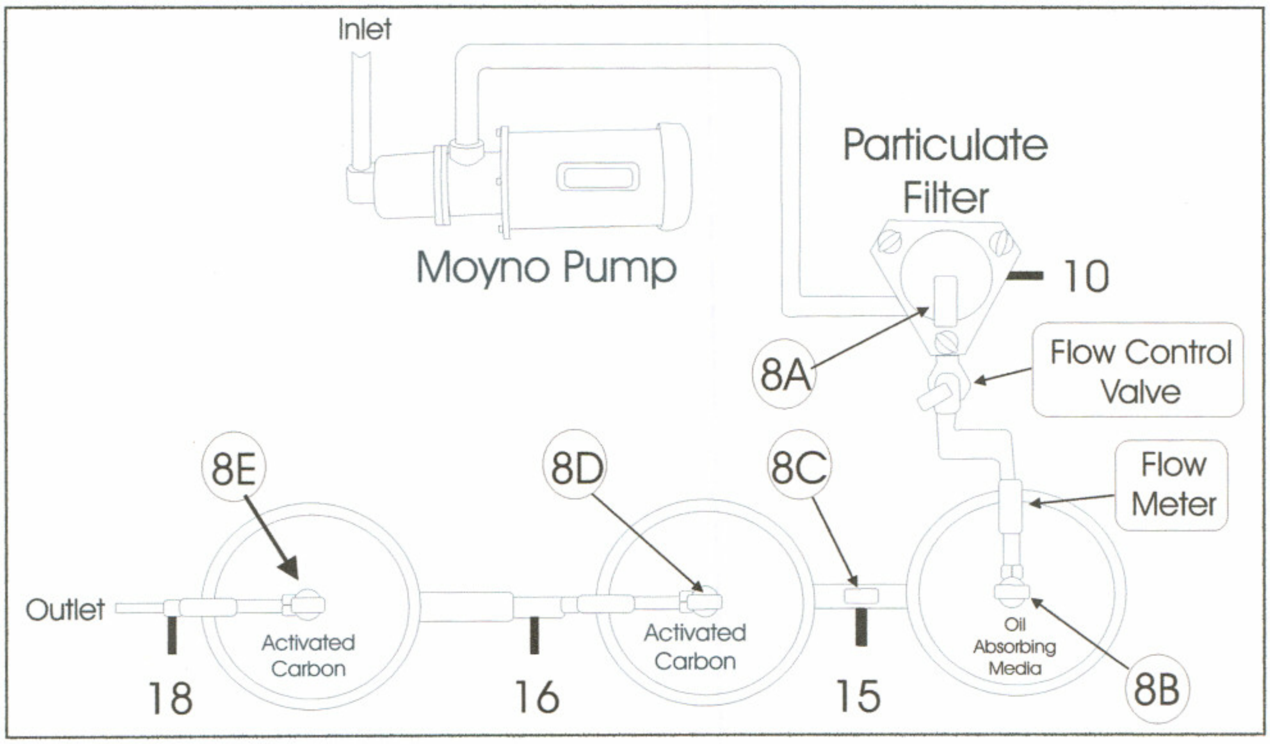


Initial Purging of Air From the Oil Absorption System

1) Connect drain hose to the final carbon absorbing drum (4B).
2) Close all drain valves (10-15-16-18) .
3) Slightly Open flow control valve (11).
4) Allow water to fill the system to purge all air trapped in filters.
5) Allow water to flow approximately 15 minutes after system is filled to ensure all trapped air is removed from filters as well as small particulate matter in the TM-100 Media and Activated Carbon are removed.
6) Observe the pressure gauge readings (8A, 8B and 8C) and record pressures over bag filter, TM Media drum and Activated Carbon drum for further reference.
7) Samples of incoming water may be taken from sampling drain valve, samples of discharge water after filtration may be taken from sampling drain valves (15-16-18).
8) The system is now ready to treat your waste water.

NOTE

The unit should only be drained when changing filter elements OR when no longer in service. The oil absorbing media must be immersed in water to eliminate air pockets which would effect is oil absorbing capabilities.

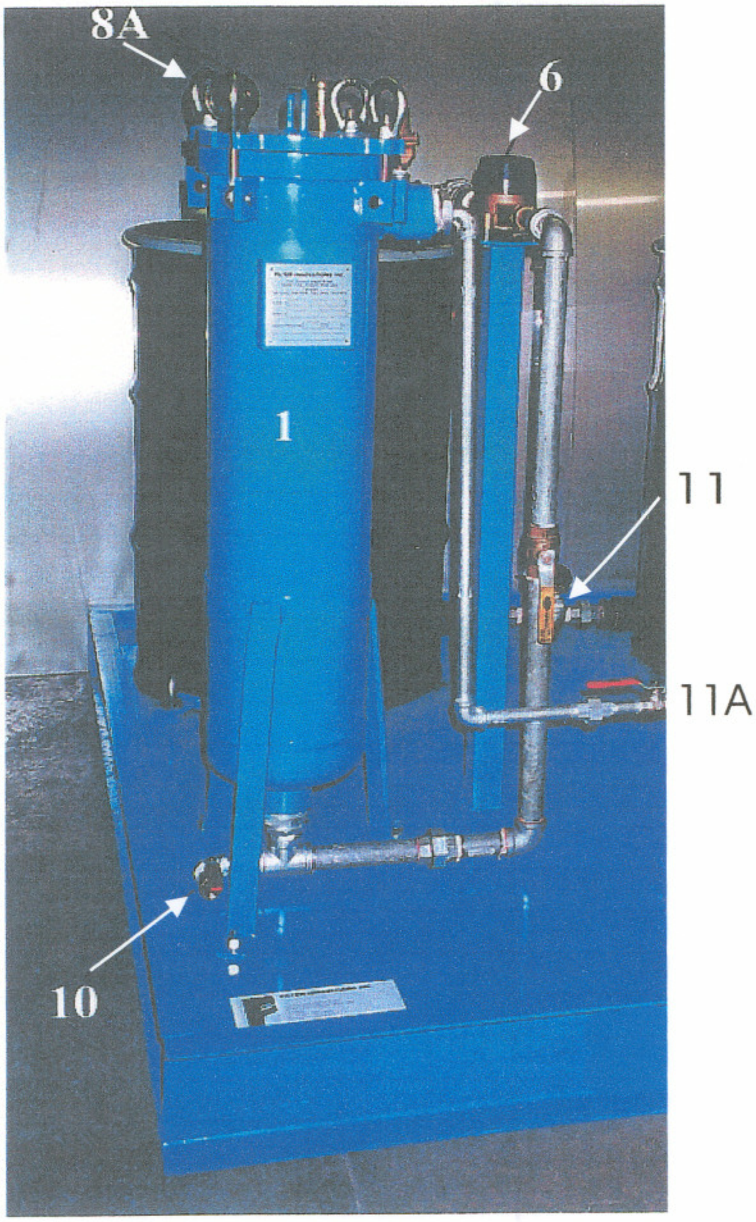


Changing Filter Bag

** CAUTION **
The most important step in changing filter bags, is to make sure that the pressure in the filter vessel is relieved **prior** to opening the unit. This is accomplished by opening the drain valve at the discharge on the filter.

1) Check the pressure gauge (8A) on top of the particulate filter bag. Should this gauge register 15 PSI. or greater, the filter bag is plugged and change-out is required.

Particulate Filter



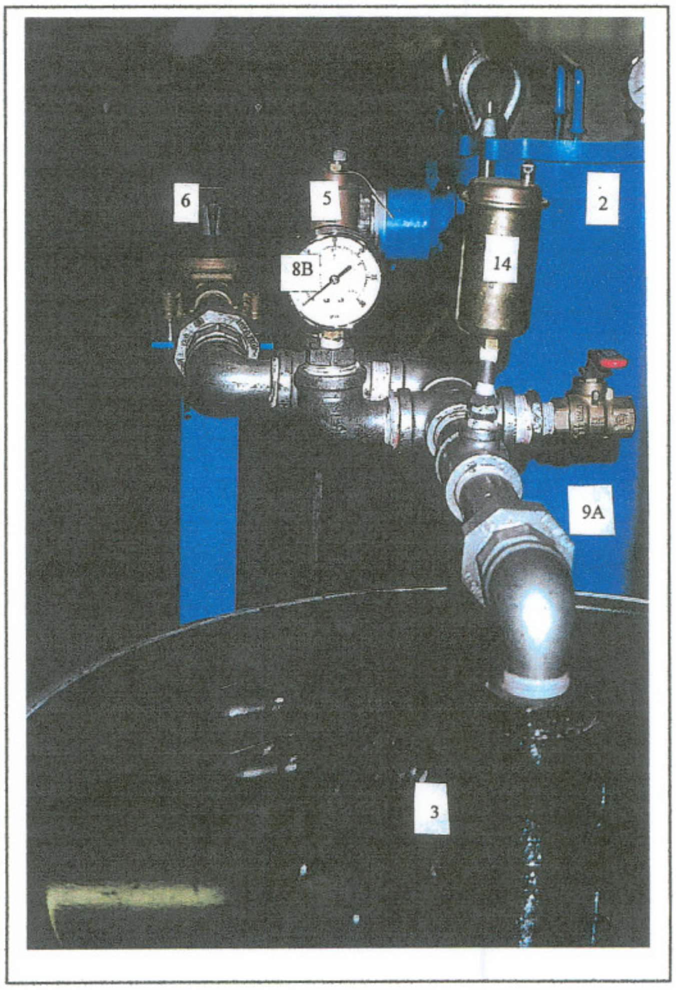
2) Shut the system off by turning pump switch (23) off.
3) Shut off valves before (11A) and after (11) the filter bag vessel
4) Open the filter bag drain valve (10). The product drained from the filter may contain oil and should be piped or collected accordingly. This will also relieve any internal pressure.
5) Wait 5 minutes to allow the water in the filter bag vessel to drain. Check pressure gauge (8A) to make sure there is no pressure in the system.
6) Loosen the bar knobs on the lid so that they are free and the eye bolt assembly can be swung away from the housing.
7) Remove "Spaghetti" from bag filter. Remove and discard saturated filter bag.
8) Insert the clean filter bag into the restrainer basket(already installed) and form the bag to the contours of the basket by pressing against the restrainer basket.
9) Insert new "Spaghetti". Take small handfuls and push firmly to the bottom of bag. Repeat until the filter bag is filled.
10) Check positioning of the O-ring which should be properly seated in the filter. The ring of the filter bag must be seated in the edge provided by the restrainer basket.
11) Replace the hold down device.
12) Close cover carefully. (Do not drop) Tighten the bar knobs evenly and securely. (Slight hand downward force is necessary to compress bag hold down device.)
13) Close the drain valve (10)
14) Partially open the flow control valve (11).
15) Re-open the main flow control valve slightly (11A).
16) Unit is ready to operate. Adjust the flow control valves (11, 11A) accordingly, to the correct flow rate of 5 to 7 gpm.
17) Record in the log book, the **Time/Date and Cubic Meters** processed for the bag filter change.

INSTRUCTIONS FOR CHANGING OIL ABSORBING DRUM

**** CAUTION ****

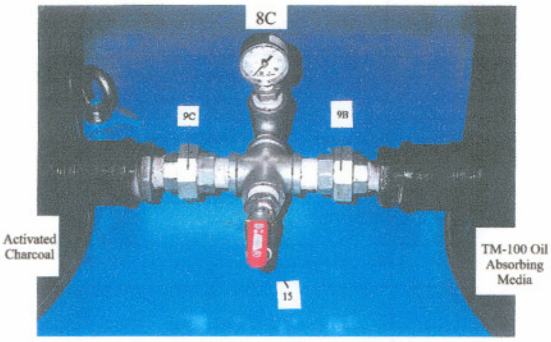
The most important step in changing the oil absorbing drum, is to make sure that the pressure in the drum is relieved **prior** to opening the unit. This is accomplished by opening the drain valves at the discharge on the .

1) Check pressure gauge (8B) to confirm the oil absorbing drum (3) is plugged and requires change-out (8 PSI. maximum).
2) Turn off the electricity to the pump.
3) Close the flow control valve (11A) located at the inlet on the bag filter.
4) Open the drain valve (10) at the bottom of the bag filter to relieve internal pressure
5) Open the sample valve (15) between the T-M drum and the carbon drum (4A) to remove any water which may remain in the drum.
6) Wait 10 minutes to allow any drain water to escape.



7) Undo the union (9A- illustrated on previous page) on the inlet and (9B – illustrated below) on the outlet of the spent drum.

Drum Interconnection



8) Release the drum hold down devices by unscrewing the eye nuts at the base of the drum.

** CAUTION **

NOTE the saturated weight of the drums and media is approximately 500 pounds. The drums need to be handled with proper lifting equipment to remove them from the skid.

9) Remove the spent drum.
10) Replace with the new drum.
11) On the new drum - Remove the 2 inch coupling cap seals on the top centre and bottom side.
12) On the spent drum - Remove the top centre threaded inlet and install this inlet on top centre of the new drum.
13) On the spent drum - Remove the bottom threaded outlet and install this outlet connection to the bottom of the new drum.
14) On the spent drum - Install the 2 inch coupling cap covers which were removed in step 11, above.
15) On the new drum - Install and retighten the unions (9A) on the inlet and (9B) on the outlet of the newly installed TM-100 Oil Absorption Media Drum.
16) Tighten all the drum hold down devices by tightening the eye nuts at the base of the drums.
17) Close the drain valves (10) and sample valve (15).
18) Open the flow control valve (11).
19) Restart the pump. Ensure that the flow rate is at or below 19 LPM. If not adjust the flow control valve accordingly.
20) Record in the Logbook the Time, Date and Cubic Meters processed at the time of this TM-100 Oil Absorption Media change out.

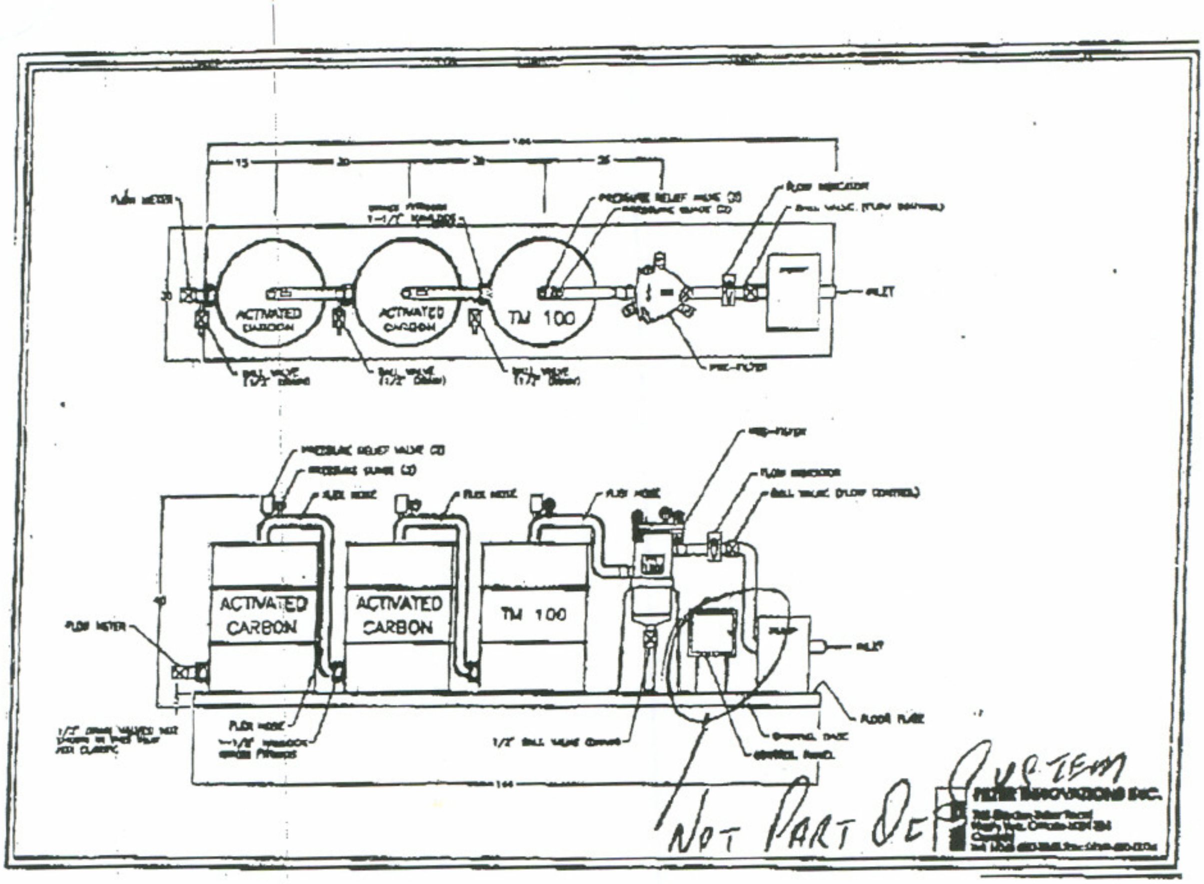
Instructions for Changing the Activated Carbon Drums

** CAUTION **
The most important setp in changing the Activated Carbon Drum is to make sure that the pressure in the system is relieved prior to removing the drums. This can be accomplished by opening the sample valve at the inlet to the Activated Carbon Drum

1) Check the water sample from the sampling valve (16 and 18) If the water quality is the same then the carbon drum (4A) is saturated and needs to be replaced.
2) Turn off the electricity to the pump.
3) Close the flow control valve (11) prior to the inlet of the TM-100 Oil Absorption Drum.
4) Open the Sample Valve (15) at the bottom of the TM-100 drum to relieve any internal pressure and remove any water which may remain in the drums. Wait 15 minutes to allow any drain-water to escape.
5) Undo the union (9C) on the inlet and (9D) on the outlet of the first Activated Carbon Drum.
6) Release the drum hold down devices by unscrewing the eye bolts.
7) Undo the union (9E) on the inlet and (9F) on the outlet of the second carbon drum.
8) Remove the discharge hose.

** CAUTION **
NOTE the saturated weight of the drums and media is approximately 250 pounds. The drums need to be handled with proper lifting equipment to remove them from the skid.

9) Remove the first Activated Carbon Drum (4A)
10) Move the second Activated Carbon Drum (4B) to the position of the first drum (4A).
11) Install a new Activated Carbon Drum in the place left by the just moved drum.
12) Exchange drum lids between the spent drums and the new carbon drum that is now in position two. The inlet connections are now in position on the new drum and the spent drum is now ready to be sealed for safe transportation.
13) Retighten the drum hold down lids securely.
14) The new drum, which has the newly placed inlet lid and outlet connection, is now ready for hook-up.
15) Replace the outlet piping and union (9F) on the second carbon drum.
16) Retighten the union (9F).
17) Transfer the piping between carbon drums one and two.
18) Replace and tighten the union (9E) on the inlet of the second carbon drum.
19) Replace and retighten the union (9C) on the inlet of the drum and (9D) on the outlet of the first carbon drum.
20) Close sampling valve (16) and open flow control valve (11).
21) On restart of the system ensure that the flow is at or under 19 LPM. If not adjust the flow control valve accordingly.
22) Record in the Logbook the Time, Date and Cubic Meters processed for the Activated Carbon Drum changes just made.



NOT PART OF SYSTEM

CONTINUOUSLY REMOVES OILS AND ORGANIC CONTAMINANTS FROM INDUSTRIAL AND NATURAL WATERS

The only waste water discharge systems which permit continuous process operations while allowing you to meet or exceed government regulations for the direct discharge of effluents to sewers or natural watercourse. Each "System" has two important features:

a) It permits the continuous absorption of oil, greases, PCB's, pentachlorophenols and other large molecular weight organics; and

b) Upon saturation it signals and shuts down the discharge systems.

APPENDIX C

Literature Review: Landfarming in the North

CHAPTER 8

Bioremediation of Diesel Contaminated Soil and Tundra in an Arctic Environment

Michael R. Piotrowski, and **Robert G. Aaserude**, Woodward-Clyde Consultants, San Diego, California
Franz J. Schmidt, U.S. Air Force, Brooks Air Force Base, Texas

INTRODUCTION

A United States Air Force station in arctic Alaska operated from 1950 through 1982, when the majority of operations at the facility were curtailed. Several hazardous materials had been used on the station during operation, and spills and leaks of the materials had occurred. Since 1985, site investigations have been conducted to assess residual contamination in areas of the site as part of the U.S. Air Force's Installation Restoration Program (IRP).

As a result of these investigations, several areas on the site have been documented as being contaminated with hazardous substances.[1] One such area is a hillside composed of soil fill and native tundra that became contaminated with diesel fuel as a result of the rupture of a distribution pipeline in 1984. The released diesel fuel affected an area of the tundra hillside covering approximately two acres. Recovery efforts were implemented and resulted in the collection of several accumulations of diesel fuel. However, a portion of the fuel entered the tundra and killed the vegetation. As a result, the two-acre area impacted by the spill became largely denuded.

Although some natural recovery of the vegetation has been observed on the hillside since 1984, most of the two-acre region was apparently still impacted by the spilled diesel fuel in 1989. Diesel fuel contamination was also apparent in the soil fill area adjacent to the location of the pipeline rupture. Therefore, the U.S. Air Force authorized Woodward-Clyde Consultants (Woodward-Clyde) to assess the feasibilities of remedial options for treatment of the hillside and to develop a remediation plan.

During the assessment of remedial options, bioremediation was identified as a feasible approach for treatment of the diesel contaminated soil and tundra. However, there were concerns regarding the effectiveness of that treatment technology under relatively harsh arctic conditions. Furthermore, it was uncertain whether the approach could produce appreciable reductions in diesel fuel concentrations in the affected soil and tundra during the relatively short arctic summers. Finally, because the contaminated tundra is underlain by permafrost, active bioremediation (tilling) of contaminated tundra would likely produce damage to the permafrost. As such, a passive (nontilling) bioremediation approach would be required for the hillside, and there were concerns over the effectiveness of that bioremediation approach.

To address these concerns and uncertainties, Woodward-Clyde developed remediation plans for the contaminated soil and tundra,[2] and these plans were implemented onsite at pilot-scale levels in August 1989. The results of the bioremediation pilot studies that were conducted during the summers of 1989 and 1990 are reported herein.

SITE SETTING

The following paragraphs summarize the pertinent features of the site's physiography, geology and hydrogeology, climate, and tundra ecology. A more complete description of these site aspects can be found in Reference #3.

Physiography

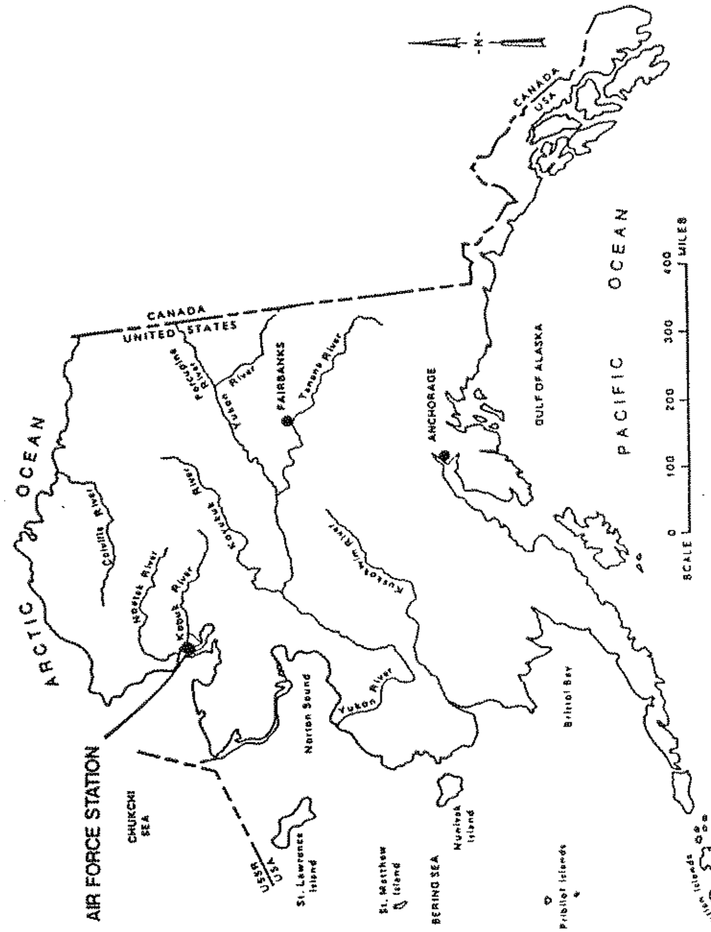
The U.S. Air Force station is located north of the Arctic Circle in northwest Alaska (Figure 8.1). The site is approximately 610 miles northwest of Anchorage and approximately 450 miles west-northwest of Fairbanks. The station is situated on a hill (highest elevation roughly 155 ft above local sea level) approximately four miles south of a small town (population: about 3,600) and roughly 1,500 feet from the coastline of a sound.

Geology and Hydrogeology

The station is located on the remnants of an eroded glacial moraine consisting of mixed clays, silts, sands, and gravels. The regional geology consists of coastal deposits of interbedded marine and terrestrial sediments. Permafrost occurs throughout the region, typically several feet below the tundra surface, and the permafrost layer has been reported to be over 200 ft in thickness.[4] Shallow groundwater forms during the warmer seasons in the silty, organic-rich, tundra layers overlying the permafrost. The groundwater beneath the permafrost is reported to be brackish.[4]

Climate

The climate of the region is arctic with a maritime influence.[5] The average annual daily high and low air temperatures are -2.8°C (27°F) and -10°C (14°F), respectively. However, temperatures in excess of 21°C (70°F) and



SOURCE: INSTALLATION DOCUMENTS and Woodward-Clyde Consultants (1991)

Figure 8.1. Regional location of U.S. Air Force station.

below −23°C (−10°F) have been recorded on individual days. Freezing temperatures typically occur from late September through early June. The mean annual rainfall is 18 cm (7.1 inches) and most of the rainfall occurs in July and August. Snowfall averages 109 cm (43 inches) per year and takes place fairly uniformly over the fall, winter, and early spring.

Tundra Ecology

The tundra is an environmentally sensitive area. It is generally treeless and covered with approximately 1 ft of matted vegetation containing a variety of individual plant species. Vegetative growth and microbial decay take place during the abbreviated spring, summer, and fall seasons. During warmer periods, marshes, small bogs, and other water features may form in many areas of the tundra surface. Persistent water features typically freeze solid during colder periods.

The tundra vegetation is not resilient and can be severely impacted by surface activities. For example, traffic, construction, or excavation can destroy the vegetative cover, expose the underlying soil to erosion and the permafrost to thawing, and may result in the creation of a pock-marked boggy surface. In some cases, long-term damage to the tundra surface can be inadvertently created by careless surface activities.

The microbial ecology of the tundra is essentially confined to the warmer (i.e., unfrozen) seasons. Microorganisms become active with the onset of spring and the thawing of the tundra surface, only to become senescent with the return of freezing temperatures in the fall. An important characteristic of the physiology of arctic microorganisms involves the relationship between changing ambient temperatures and their activity rates.

For most biological systems (including many microorganisms), within a defined temperature range, an increase in temperature of 10°C (18°F) usually results in an increase in the rate of biological activity of between two- and threefold. This temperature/activity relationship has been termed the Q_{10} effect, and most biological systems exhibit Q_{10} values of 2 to 3.[6]

Arctic microorganisms, however, typically exhibit Q_{10} values of approximately 4.[6] That is, for each 10°C increase in temperature with the onset of spring and summer in the arctic, the activity rates of the microorganisms will typically increase approximately fourfold. This capability results in elevated microbial activities during the abbreviated summers characteristic of the arctic. However, the opposite effect is also observed: within a defined temperature range, for every 10°C decrease in temperature, the activity rates of arctic microbes will decline by approximately fourfold. As will be seen, this phenomenon had an influence on the performances of the bioremediation programs implemented at the site.

Bioremediation Approaches and Methods

Two bioremediation approaches were identified as being feasible for treatment of contaminated soil fill and tundra at the site. The approaches, methods of treatment, and sampling plans for the contaminated materials are described below.

Contaminated Soil Fill

The contaminated soil fill was confined to the region immediately downgradient from the location of the diesel fuel spill. The soil exhibited indications that it was heavily contaminated. Because the fill soil could be excavated and quickly replaced with clean fill without appreciably damaging the underlying permafrost, it was decided that this soil could be most rapidly treated by excavating it and biologically treating it in a lined land treatment unit (LTU). With respect to the form of biological treatment to be used for the contaminated fill, the following considerations were taken into account.

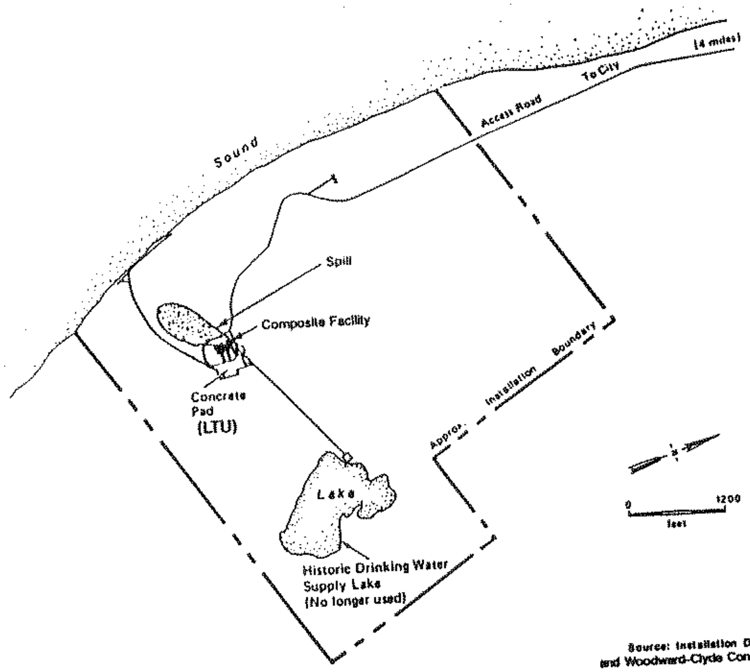
Treatment Considerations

The diesel fuel had been present in the fill material for over five years. Each year after the spill, the contaminated soil had been exposed to a leaching action produced by the annual summer percolation of water through the contaminated region. The leaching action would tend to remove those organic constituents of diesel fuel that are more soluble in water, leaving behind a more insoluble fraction associated with the soil. Because microorganisms generally degrade organic compounds in the aqueous phase, it was reasoned that application of a nontoxic, biodegradable surfactant to the residual contamination in the affected soil may render the residues more accessible to the indigenous microorganisms.

A second issue considered in developing the bioremediation plan for the contaminated soil fill was the need to apply nutrients to the soil. There were no site-specific soil nutrient data available in 1989 upon which to assess potential nutrient requirements for the contaminated soil fill. Therefore, as an initial step in stimulating biodegradation rates of the indigenous microorganisms, we decided to periodically apply a dilute solution of micronutrients (i.e., trace elements and vitamins) to the contaminated soil.

1989 Treatment Methods and Sampling Plan

An onsite, mostly paved area that was formerly occupied by a building was selected as the site of the LTU (Figure 8.2). The concrete and fill base of the area was lined with plastic sheeting (6-mil thick). The excavated soil fill was then spread over the lined pad to a uniform thickness of approximately



Source: Installation Documents and Woodward-Clyde Consultants (1991)

Figure 8.2. U.S. Air Force station site plan and locations of diesel fuel spill and concrete pad.

46 cm (18 inches) in early August 1989. A berm of clean fill material approximately one meter (3 ft) in height was then placed around the perimeter of the LTU to minimize precipitation runoff.

The soil in the LTU was then sampled on August 8, 1989 by collecting nine composite samples and one duplicate sample from randomly selected locations in the LTU. Each composite sample consisted of multiple soil aliquots collected from throughout the soil column in several locations. The samples were analyzed for total petroleum hydrocarbon (TPH) concentrations using method SW3550/418.1 and for soil moisture content using American Society for Testing and Materials (ASTM) method D2216.

All TPH and moisture analyses were performed by ENSECO-Rocky Mountain Analytical Laboratories in Arvada, CO. Strict quality assurance/quality control (QA/QC) procedures (involving collections and analyses of duplicate control samples, single control samples, and method blanks) were followed throughout the entire two-year bioremediation study. Duplicate samples were collected and analyzed for approximately every 10 samples collected, and standard chain-of-custody protocols were followed.

Two composite samples and one duplicate sample were also collected on August 8 and analyzed for microbial content using four methods: total microbial densities using the acridine orange direct count method,[7] viable microbial densities using the standard plate count procedure (e.g., Meynell and Meynell[8]), densities of fluorescent pseudomonads (method by B.B. Hemmingsen, San Diego State University's Applied Microbiology Laboratory, San Diego, CA), and the densities of phenanthrene-degrading microorganisms using a method developed by Bogardt and Hemmingsen.[9] These analyses were performed to establish initial microbial densities (dry weight basis) in the soil, and the samples were analyzed in San Diego State University's Applied Microbiology Laboratory, San Diego, CA.

After sampling, a dilute solution of a nontoxic, biodegradable surfactant (Toxigon 2000, currently distributed as TI-323 by Technologies International, Scottsdale, AZ) was evenly applied to the soil in the LTU using a gas-powered pump, hosing, and a water truck. The dilution used was 1,250 gal of Toxigon 2000 in 5,000 gal of lake water. The original formulation for the surfactant was listed on the U.S. Environmental Protection Agency's National Contingency Plan (NCP) Product Schedule for use as a dispersant in oil spill situations.

Then, approximately 12 gal of a dilute solution of micronutrients (Medina Soil Activator, Medina Agricultural Products, Inc., Hondo, TX) was evenly applied to the surface of the contaminated soil using a backpack spray unit. The soil activator was mixed with lake water at a ratio of one part activator to four parts water.

A bulldozer was then used to mix the soil in the LTU. The mixing action served to distribute the surfactant and micronutrient solutions and deliver oxygen throughout the contaminated soil mass.

At weekly intervals for six weeks (August to September 1989), the contaminated soil was mixed by the bulldozer to deliver oxygen throughout the soil and promote soil drying. After two and four weeks of treatment and prior to mixing, the micronutrient solution was reapplied as described above. After approximately four and six weeks of soil treatment (September 12 and 26, respectively), eight composite soil samples and one duplicate sample were collected on each occasion for TPH and moisture analyses as described above. Two composite samples and one duplicate sample were collected for microbial content analysis after six weeks of treatment. Treatment was suspended in late September, and the soil in the LTU was covered with a layer of plastic sheeting (6-mil in thickness) for the winter.

1990 Treatment Methods and Sampling Plan

In late July 1990, the plastic sheeting was removed from the LTU and the soil was sampled to establish the initial TPH concentrations prior to treatment in 1990. Nine composite samples and one duplicate sample were collected on July 26, 1990 and analyzed for TPH using method SW3550/418.1 and soil moisture content using ASTM method D2216.

Approximately 20 gal of the dilute micronutrient solution (five parts lake water to one-part Medina Soil Activator) were evenly applied to the soil in the LTU using the backpack sprayer. The soil was then mixed with the bulldozer, and thereafter on a weekly basis, for nine weeks. At the end of the nine-week period (September 24, 1990), nine composite samples and a duplicate sample were collected and analyzed for TPH concentration and moisture content using the methods presented previously. No samples were collected for microbial analysis in 1990.

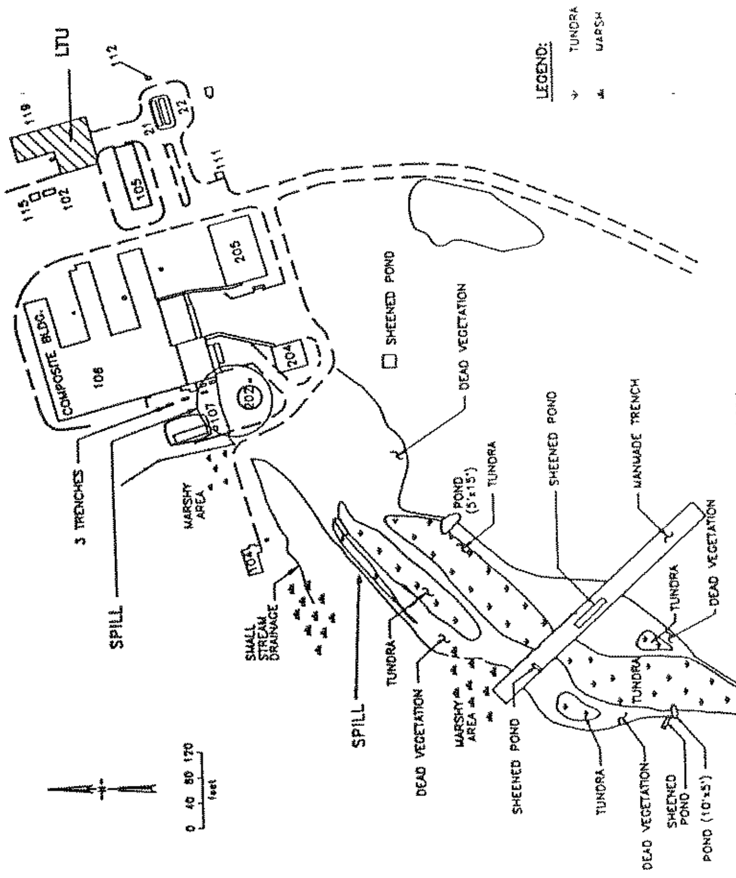
Contaminated Native Tundra

As discussed previously, the contaminated native tundra was confined to a two-acre region downslope from the location of the pipeline leak. Although most of the diesel fuel flowed in three natural channels that ran down the face of the hillside, a portion of the fuel spread over and penetrated the tundra surfaces outside the channels and destroyed the vegetation (Figure 8.3). Because an active bioremediation program (i.e., involving tilling) was likely to inflict damage to the underlying permafrost, an alternative, passive approach was needed to stimulate in situ bioremediation.

Treatment and Sampling Considerations

Based on the considerations presented in the discussion of the bioremediation approach for treatment of the contaminated soil fill, applications of dilute surfactant and micronutrient solutions were deemed necessary to initiate in situ bioremediation. However, no tilling would be conducted. It was also reasoned that the surfactant application would be most useful if it was applied primarily along the three natural channels through which the diesel fuel primarily flowed. Finally, it was concluded that the periodic applications of the micronutrient solution would be most effective in assisting the restoration of the tundra vegetation if the micronutrients were applied to both the channels and the adjacent denuded tundra areas.

With respect to sampling strategy, it was recognized that periodic sampling of the hillside over which the diesel fuel unevenly spread would tend to produce data sets containing large variabilities in tundra TPH concentrations. Randomly collected, replicate composite soil samples, even collected solely from denuded tundra areas, would likely generate samples containing TPH concentrations extending over a large range. Furthermore, because organic-rich tundra typically contains elevated but variable natural organic and moisture contents (compared to soil), calculations of dry weight concentrations of TPH would be strongly influenced by variability in natural organic and moisture contents. Finally, because the passive in situ bioremediation approach was not anticipated to be as effective as the active treatment approach used in the LTU, sampling emphasis in 1989 was placed on the assessment of the performance of the LTU approach. Therefore, a



Source: Woodward-Clyde Consultants (1991)

Figure 8.3. Plan view of extent of diesel fuel spill at the U.S. Air Force station in 1989.

limited-scope sampling plan was adopted for the assessment of the 1989 tundra treatment program. In 1990, the sampling plan for the tundra treatment was similar to the plan for the LTU. Details of the sampling plans are presented below.

1989 Treatment Methods and Sampling Plan

On August 8, 1989, the initial concentrations of TPH in denuded tundra areas on the hillside were estimated by collecting four composite samples and one duplicate sample from randomly selected locations within the denuded areas. The samples were analyzed for TPH and soil moisture content using the methods described previously.

After sampling, approximately 550 gal of the dilute surfactant solution (one 55-gal drum of Toxigon 2000 mixed with 500 gal of lake water) was primarily applied to the three natural channels running down the face of the hillside using a gas-powered pump, hosing, and a water truck. Access to the hillside was limited to the area immediately upslope of the impacted tundra area. Therefore, the surfactant solution was applied from the top of the hill. Denuded tundra areas adjacent to the channels were also sprayed with the surfactant solution, although not to the same extent as the channels.

Approximately 12 gal of the dilute micronutrient solution (one part Medina Soil Activator to four parts lake water) were evenly applied to the denuded areas of the hillside. Micronutrients were applied two more times in 1989, after two and four weeks of treatment.

After four and six weeks of treatment (September 12 and 26, 1989, respectively), four composite tundra samples and one duplicate sample were collected on each occasion from residual denuded areas on the hillside and analyzed for TPH and moisture content as described before. No microbial samples were collected. Treatment of the hillside was then suspended for the winter in late September 1989.

1990 Treatment Methods and Sampling Plan

On July 24, 1990, the hillside was sampled for TPH concentrations and moisture contents in residual denuded tundra areas. Tundra regrowth in several areas treated in 1989 was noted. Nine composite samples and one duplicate sample were randomly collected from locations within the denuded tundra area and analyzed for TPH and moisture content using methods described previously.

After sampling, approximately 600 gal of surfactant solution (one part Toxigon 2000 to 15 parts lake water) were sprayed on the denuded tundra areas with an emphasis placed on applying the solution to the three channels. Approximately 18 gal of the micronutrient solution (one part Medina Soil Activator to five parts lake water) were applied to the denuded hillside areas, with an emphasis again placed upon applying the solution to the three channels.

No further treatments were applied to the hillside. After nine weeks (September 24, 1990), nine composite tundra samples and one duplicate sample were collected from the residual denuded areas of the hillside and analyzed for TPH and moisture content as before.

RESULTS

Environmental Temperatures During the Bioremediation Studies

Air temperatures (daily minimum and maximum) were recorded during the study at a nearby meteorological station operated by the National Weather Service (NWS). The data were obtained from the NWS shortly after collection in each year.[10,11]

1989 Data

For the first four weeks of the study, environmental temperatures largely ranged from 10°C to 17°C (50°F to 63°F; Figure 8.4). However, immediately after the September 12 sampling (day 36 of treatment), environmental temperatures declined appreciably, and ranged from approximately 1°C

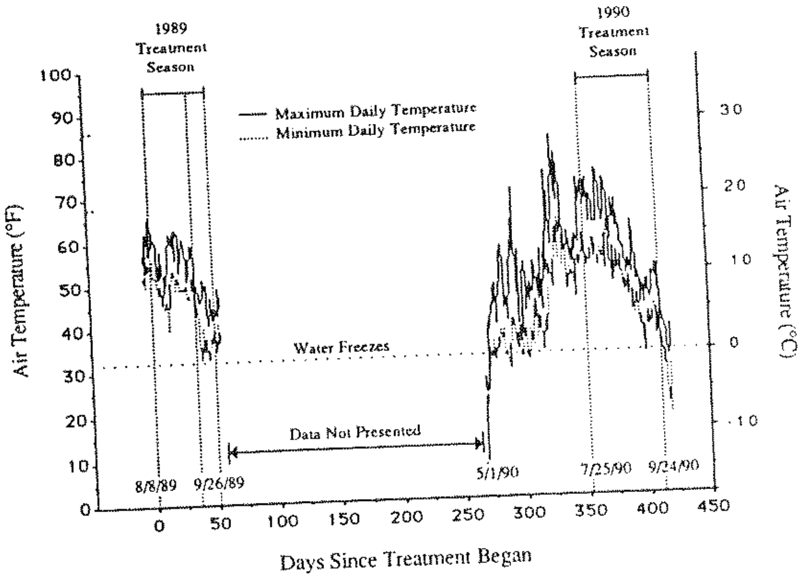


Figure 8.4. Daily maximum and minimum air temperatures in vicinity of the U.S. Air Force station during the 1989 and 1990 bioremediation treatment periods. Vertical dotted lines indicate dates when soil/tundra sample collections were made. (Data source: References 10 and 11.)

(~34°F) to a maximum of 10°C (50°F) for the remaining 14 days of the study.

The average recorded air temperature (±1 standard deviation) from August 8 through September 12, 1989 was 11.6 ± 1.9°C (52.9 ± 3.5°F), whereas the average during the period from September 13 through September 25, 1989 was 5.4 ± 1.3°C (41.7 ± 2.3 °F).

Another indicator of ambient thermal characteristics that is often used in the evaluation of outdoor biological studies is calculation of the cumulative degree-days during the studies. Cumulative centigrade-degree-days (C-degree-days) are calculated as follows:

$$\text{Cumulative C-Degree-Days} = \sum_{i=1}^{i=50} (\text{Average Temperature [°C] on Day i});$$

or on a Fahrenheit basis:

$$\text{Cumulative F-Degree-Days} = \sum_{i=1}^{i=50} ([\text{Average Temperature (°F) on Day i}] - [32°\text{F}]);$$

where i = a day during the 50-day 1989 bioremediation study period.

The freezing temperature (0°C or 32°F) is used as a reference point in the calculation because biological processes (including microbial activity) generally become greatly reduced at the freezing temperature of water.

The cumulative C-degree-days for the entire 50-day study period in 1989 (August 8 through September 25) was 488 C-degree-days (879 F-degree-days) or approximately 10 C-degree-days (~18 F-degree-days) per day (Table 8.1).

For the period August 8 through September 12 (36 days), the cumulative C-degree-day value was 418 C-degree-days (753 F-degree-days) or approximately 12 C-degree-days (~21 F-degree-days) per day, whereas for the period September 13 through September 25 (13 days), the cumulative degree-day value was 70 C-degree-days (126 F-degree-days) or approximately 6 C-degree-days (~10 F-degree-days) per day (Table 8.1).

Therefore, average ambient conditions (as indicated by average and cumulative degree-days) during the first four weeks of the 1989 treatment period were considerably warmer than conditions during the final two weeks of the period. The cold period that occurred during the final two weeks of the 1989 treatment period would have likely reduced microbial activities in the soil, and this may explain why there was no significant reduction in TPH concentrations during this period (Table 8.1).

Table 8.1. Summary of Cumulative and Average Degree-Day Data[a] and Percent Reduction in Contamination Concentration[b] During Portions of the 1989 Bioremediation Treatment Period, Alaska Air Force Station

	First Four Weeks	Last Two Weeks
Number of Treatment Days	36	13
Cumulative C-Degree-Days (F-Degree Days)	418 (753)	70 (126)
Average C-Degree-Day (F-Degree Day)	12 (18)	6 (10)
Percent Reduction in Total Petroleum Hydrocarbon Concentration During Period	44	0

[a] Degree-Day data presented on Centigrade (C-degree-days) and Fahrenheit (F-degree-days) scales. See text for description of calculation method for degree-days.
[b] Measured as total petroleum hydrocarbon concentration; SW3550/418.1 method.

1990 Data

Maximum and minimum daily air temperatures in 1990 are presented in Figure 8.4 starting from May 1. This is done because, although active treatment was not begun until July 24, 1990, the treatment efforts conducted during the previous summer may have produced residual stimulation to the indigenous microorganisms once the soil and the tundra had thawed in 1990. Therefore, the temperature data are presented from the day treatment began in 1989.

Air temperatures essentially increased above the freezing level shortly after May 1. Prior to July 24, air temperatures varied from below freezing to a maximum of approximately 28°C (82°F) and two relatively warm periods were separated by a cooler period (Figure 8.4).

From July 24 through late September, air temperatures generally declined steadily (Figure 8.4). The highest daily air temperature during this period was 23°C (74°F). Soon after the final September 24, 1990 sampling, air temperatures had largely declined below the freezing level.

The cumulative C-degree-days for the entire 1990 treatment period (July 24 through September 24) was 448 C-degree-days (807 F-degree-days), or approximately 7 C-degree-days (13 F-degree-days) per day. Average ambient conditions during the 1990 treatment period (as indicated by cumulative and average daily degree-days) were cooler than the conditions during the 1989 treatment period (Table 8.2).

Precipitation During the Bioremediation Studies

Daily precipitation was also recorded during the bioremediation studies by the NWS station (Figure 8.5). The data were obtained from NWS shortly after completion of each year's treatment period.[10,11]

Table 8.2. Summary of Cumulative and Average Degree-Day Data[a] for the 1989 and 1990 Bioremediation Treatment Periods, Alaska Air Force Station

	1989	1990
Number of Treatment Days	50	63
Cumulative C-Degree-Days (F-Degree-Days)	488 (879)	448 (807)
Average C-Degree-Day (F-Degree-Day)	10 (18)	7 (13)

[a] Degree-Day data presented on Centigrade (C-degree-days) and Fahrenheit (F-degree-days) scales. See text for description of calculation method for degree-days.

1989 Data

August is normally a wet month in the area, and precipitation was recorded at least at trace levels on 27 of 31 days of the month in 1989. Total precipitation during the 1989 study period was approximately 10 cm (3.93 inches), with 6.9 cm (2.71 inches) falling during the August portion of the 1989 study period.

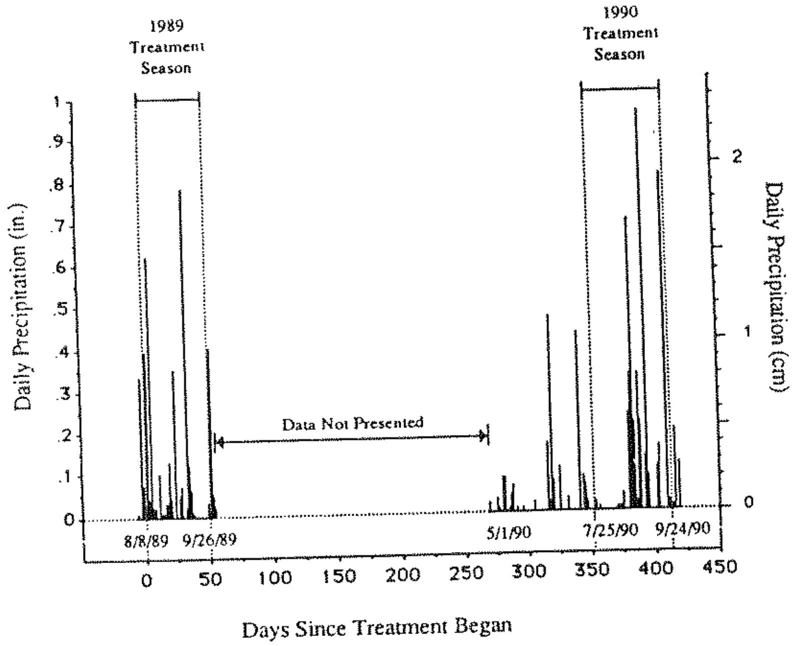


Figure 8.5. Daily precipitation in vicinity of U.S. Air Force station during the 1989 and 1990 bioremediation treatment periods. (Data source: References 10 and 11.)

Table 8.3. Total Petroleum Hydrocarbon Concentrations (Dry Weight Basis) in Soil and Tundra Samples Collected from Land Treatment Unit and Treated Tundra Hillside During the 1989 and 1990 Bioremediation Treatment Periods, Alaska Air Force Station

Sampling Date	No. of Samples	Mean Concentration (mg/kg)	Standard Deviation	Standard Error
Land Treatment Unit				
8 August 1989	9	11,491	4,370	1,457
12 September 1989	9	6,470	1,600	533
26 September 1989	9	6,963	3,210	1,070
25 July 1990	10	4,631	706	223
24 September 1990	10	2,845	661	209
Tundra Hillside				
8 August 1989	5	15,420	12,595	5,633
	4[a]	19,207	10,766	5,383
12 September 1989	5	23,012	42,879	19,176
	4[b]	3,906	4,237	2,119
26 September 1989	5	5,530	3,635	1,626
25 July 1990	10	9,828	7,982	2,524
24 September 1990	10	8,303	7,857	2,485

[a] If sample datum of 271 mg/kg is removed from data set as an apparent outlier.
[b] If sample datum of 99,435 mg/kg is removed from data set as an apparent outlier.

1990 Data

Precipitation was recorded at trace levels or greater on 36 of the 63 days of the 1990 study period. Total precipitation during the 1990 study period amounted to 12.8 cm (5.03 inches), and 12.5 cm (4.93 inches) of this total fell during the final five weeks of the period. On an average daily basis, the 1990 treatment period was wetter than the 1989 period.

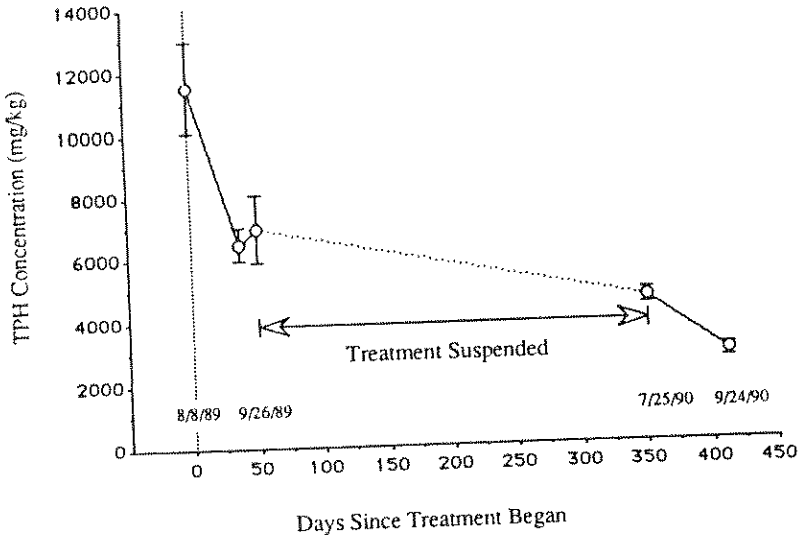
LTU Results

Table 8.3 presents a summary of TPH results for the LTU for the 1989–1990 bioremediation treatment periods.

1989 Total Petroleum Hydrocarbon Concentrations

The average concentration (± 1 standard deviation) of total petroleum hydrocarbons (TPH) in the LTU soil at the beginning of the 1989 study period was 11,491 ± 4,370 mg/kg (dry weight basis). The standard error estimate for the initial data (standard deviation divided by n, where n is the number of replicates collected [n = 9]) was 1,457 mg/kg (Figure 8.6).

After approximately four weeks of biological treatment, the average concentration of TPH in the LTU soil was 6,470 ± 1,600 mg/kg (standard error estimate: 533 mg/kg with n = 9). This average value for TPH concentration represents a 44% reduction from the initial average TPH concentration. A statistical analysis of the initial and four week data (Mann-Whitney U test[12]) indicates that the reduction was significant at the 0.001 probability



Error Bars are ± 1 Standard Error

Figure 8.6. Mean (± 1 standard error) concentrations (dry weight basis) of TPHs in soil samples collected from the LTU during the 1989 and 1990 bioremediation treatment periods conducted at the U.S. Air Force station. TPH measured using SW3550/EPA method 418.1.

level. In other words, there is a 99.9% probability that the difference between the initial and four-week TPH concentrations can be attributed to treatment (versus sampling or analytical errors).

After approximately six weeks of biological treatment, the average TPH concentration in the land-treated soil was 6,963 ± 3,210 mg/kg (standard error: 1,070 mg/kg with n = 9) (Figure 8.6). Statistical analyses (Mann-Whitney U test) of the TPH concentrations in the soil replicates collected initially and at four and six weeks of treatment were performed. The six-week soil TPH concentrations were significantly lower than the initial soil TPH concentrations at the 0.025 probability level. Although the arithmetic mean TPH concentration increased from four to six weeks, the increase was not significant at the 0.05 probability level. This analysis indicates that biological treatment did not induce a significant change in TPH concentration in the soil during the final two weeks of treatment in 1989.

1990 Total Petroleum Hydrocarbon Concentrations

The mean TPH concentration at the beginning of the 1990 LTU study period was 4,631 ± 706 mg/kg (standard error: 223 mg/kg with n = 10). Although this mean TPH concentration value was numerically lower

than the mean value recorded at the end of the 1989 treatment period, a statistical analysis (Mann-Whitney U test) indicates that the concentrations were not significantly different at the 0.05 probability level due to scatter among the data sets. The difference in mean values from the end of the 1989 treatment period to the beginning of the 1990 treatment period suggests that some degree of TPH reduction may have occurred in the LTU soil after it thawed and before active treatment had begun in late July.

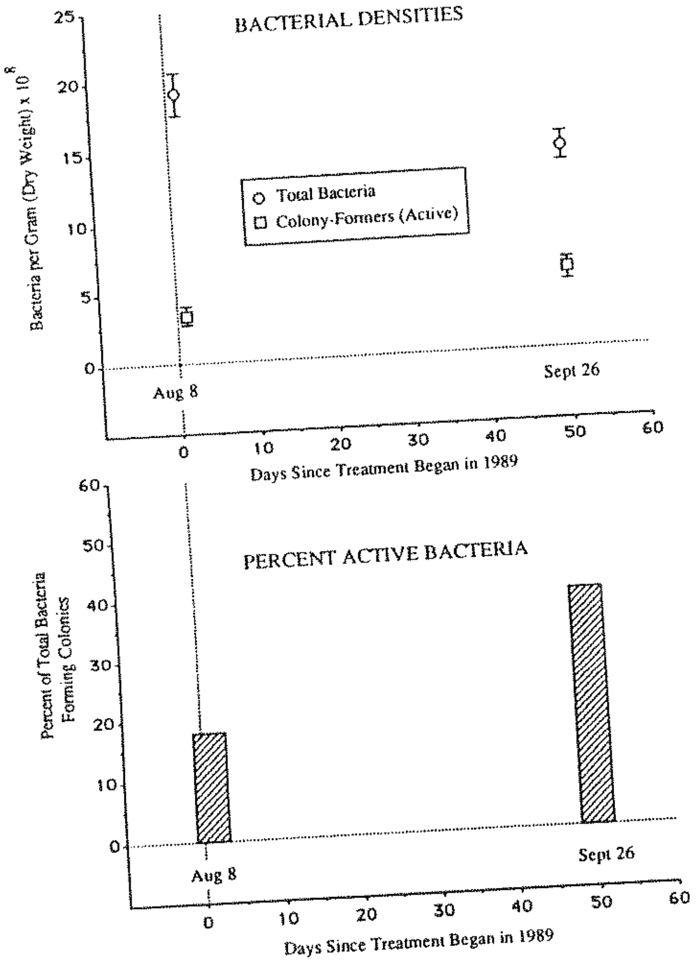
After roughly nine weeks of treatment in 1990, the mean TPH concentration in the LTU soil was 2,845 ± 661 mg/kg (standard error: 209 mg/kg with n = 10). Statistical analysis of the initial and final soil TPH concentrations (Mann-Whitney U test) indicates a significant reduction in mean TPH concentration at the 0.001 probability level.

1989 Microbial Data

The initial average density of total bacteria (i.e., those active, resting, and dead) was 19.1 × 10^8 bacteria/gram dry wt of soil (Figure 8.7, top graph). Of those, roughly 3.4 × 10^8 bacteria/gram or ~18% were active (Figure 8.7, bottom graph). The average density of fluorescent pseudomonads (a group of microorganisms that characteristically possesses the capability to degrade hydrocarbons) was 1.6 × 10^6 bacteria/gram dry wt of soil, and the average density of bacteria capable of degrading phenanthrene (an organic component of diesel fuel) was ~1.4 × 10^7 bacteria/gram (~0.7% of the total number) (Figure 8.8).

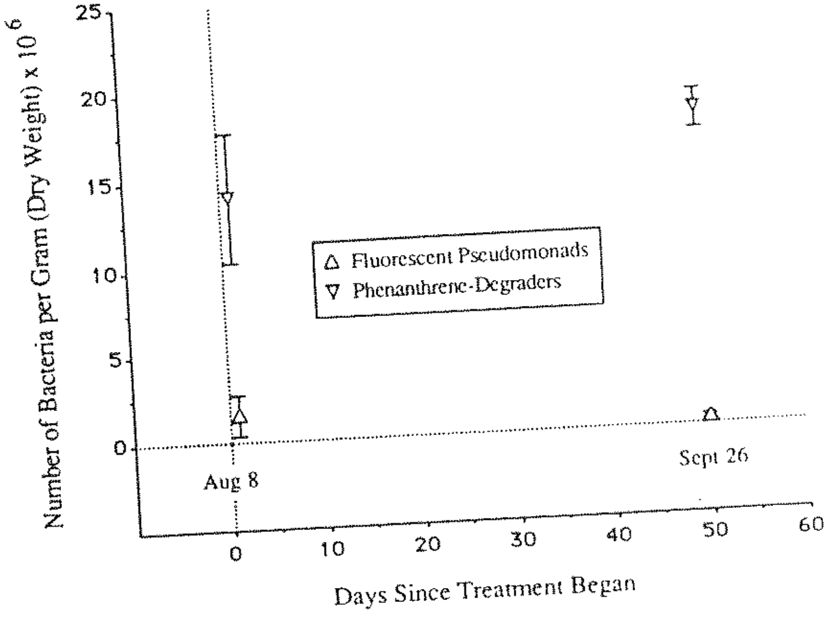
Approximately six weeks after treatment, the average total number of bacteria had declined to approximately 14.3 × 10^8 bacteria/gram dry wt of soil, whereas the average density of active bacteria had increased to 5.6 × 10^8 bacteria/gram (Figure 8.7). Although the average densities were different between sampling periods for each type of microbial analysis, neither change was statistically significant due in part to sample variability (Mann-Whitney U test). However, the percent of total bacteria estimated to be active had increased from ~18% at the beginning of the study to ~40% after six weeks, and the average percent active bacteria in the six-week samples was statistically higher than the average percent active bacteria in the initial samples. This analysis indicates that the bioremediation treatment approach had been effective in stimulating the activity of the indigenous bacteria.

The average density of fluorescent pseudomonads declined to 3.5 × 10^5 bacteria/gram and phenanthrene-degrading bacteria increased in mean density to 1.8 × 10^7 bacteria/gram (~1.3% of the total density) (Figure 8.8). Due to variability in microbial densities between samples, these changes were not statistically significant (Mann-Whitney U test).



Source: Woodward-Clyde Consultants (1991)

Figure 8.7. Mean (±1 standard error) densities (dry weight basis) of total and colony-forming (active) bacteria (top graph) and percent active bacteria (bottom graph) in soil samples collected from the LTU during the 1989 bioremediation treatment period conducted at the U.S. Air Force station. Total bacterial densities estimated using the acridine orange direct count method of Hobbie et al.[7]; colony-forming bacterial densities estimated using the plate-count method (e.g., Meynell and Meynell[8]).



Error Bars = ± 1 Standard Error

Source: Woodward-Clyde Consultants (1991)

Figure 8.8. Densities of specific microbial groups in soil samples collected from the LTU during the 1989 bioremediation treatment period conducted at the U.S. Air Force station. Densities of fluorescent pseudomonads estimated using a method developed by B.B. Hemmingsen, San Diego State University's Applied Microbiology Laboratory, San Diego, CA. Densities of phenanthrene-degrading bacteria estimated using the method of Bogardt and Hemmingsen.[9]

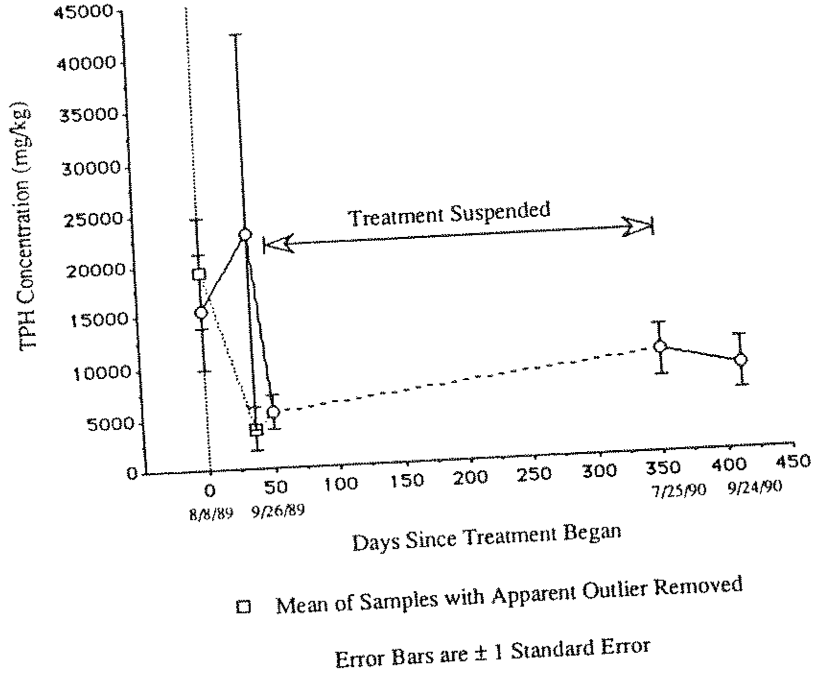
Native Tundra Results

Table 8.3 presents a summary of TPH results for the tundra hillside for the 1989–1990 bioremediation treatment periods.

1989 Total Petroleum Hydrocarbon Concentrations

The average concentration of TPH in the samples collected from the native tundra area at the beginning of the study was 15,420 ± 12,595 mg/kg (standard error: 5,633 mg/kg with n = 5). The large estimate in standard deviation was due in part to one sample that contained a very low TPH concentration (271 mg/kg). If this value is removed from the data set as an outlier, the average initial TPH concentration was 19,207 ± 10,766 mg/kg (standard error: 5,383 mg/kg with n = 4) (Figure 8.9).

As mentioned earlier, a component of the variability observed in tundra samples is variability in natural organic and moisture contents. Soil moisture contents of the tundra data set ranged from 20% to 80% (data not shown), and the highest moisture contents were typically associated with those samples that contained a large fraction of recognizable plant fragments. Upon drying of these naturally organic-laden tundra samples, the water in the plant fragments evaporated, producing a relatively low dry weight to wet weight ratio compared to samples containing low amounts of plant fragments. Thus, when the dry weight concentrations of TPH were calculated for these samples, they were appreciably higher than the samples containing a higher proportion of mineral (nonorganic) debris.



Source: Woodward-Clyde Consultants (1991)

Figure 8.9. Mean (± 1 standard error) concentrations (dry weight basis) of TPHs in tundra samples collected from the treated tundra hillside during the 1989 and 1990 bioremediation treatment periods conducted at the U.S. Air Force station. TPH measured using SW3550/EPA method 418.1.

The presence of plant fragments in the tundra samples also imparts a degree of uncertainty on the results of the analytical method used to quantify TPH (SW3550/EPA method 418.1). The method involves extraction of organic compounds from the sample and analysis of the organic content of the extract using infrared spectroscopy. Although the extraction and cleanup procedures used for the method focus on analysis of nonpolar (presumably petroleum-related) organic compounds, it has been observed that nonpetroleum organic compounds may also be measured by the technique.[13] This is especially true for soil samples that contain an abundance of natural organic materials, such as plant fragments. Therefore, a portion of the "TPH" reported for the tundra samples may be naturally derived organic compounds. The combined potential influences of moisture and natural organic contents on the analytical results of the tundra samples should be taken into consideration during review of the following results.

After approximately four weeks of treatment, the average TPH concentration was 23,012 ± 42,879 mg/kg (standard error: 19,176 mg/kg with n = 5) (Figure 8.9). As in the initial concentration data set for the tundra study, an outlier value (99,435 mg/kg) was identified in the data set. If this value is removed, the mean TPH concentration after four weeks of treatment was 3,906 ± 4,237 mg/kg (standard error: 2,119 mg/kg with n = 4). The difference in TPH concentrations between the initial and four-week samples (with the outliers removed) was statistically significant at the 0.025 probability level (Mann-Whitney U test).

After approximately six weeks of treatment, the average TPH concentration was 5,530 ± 3,635 mg/kg (standard error: 1,626 mg/kg with n = 5). The difference in TPH concentrations between the four- and six-week samples was not significant (Mann-Whitney U test). However, the difference in concentrations between the initial and six-week samples was significant at the 0.05 probability level (Mann-Whitney U test).

1990 Total Petroleum Hydrocarbon Concentrations

The initial mean TPH concentration in the tundra samples collected at the beginning of the 1990 treatment period was 9,828 ± 7,982 mg/kg (standard error: 2,524 mg/kg with n = 10; Figure 8.9). Although the mean TPH concentration was arithmetically higher at the beginning of the 1990 treatment period compared to the end of the 1989 treatment period, the difference was not significant (Mann-Whitney U test). Several samples in the 1990 initial data set were relatively elevated, and these values influenced the mean calculation of that data set.

After approximately nine weeks of treatment in 1990, the average TPH concentration in the tundra samples was 8,303 ± 7,857 mg/kg (standard error: 2,485 mg/kg with n = 10). Statistical analysis indicates that no significant reduction in TPH concentration occurred during the 1990 treatment period.

DISCUSSION

Land Treatment Unit

The 1989 TPH results of the LTU study indicate that land treatment produced roughly a 44% reduction in TPH concentrations during the first four weeks, but that further reductions did not occur during the last two weeks of treatment. The 1990 TPH results indicate that land treatment produced an additional 39% reduction in TPH concentration in the soil during the 1990 study. Thus, the overall reduction in TPH concentration was approximately 75% from August 1989 through September 1990.

Although the 1990 treatment period was approximately three weeks longer than the 1989 treatment period, the percent reduction in soil TPH was lower in 1990 than 1989. The reduced level of TPH reduction observed in the 1990 treatment period may be related to the relatively colder and wetter conditions that occurred during 1990. The 1990 ambient conditions were apparently less conducive for microbial activity compared with the conditions in 1989.

Losses of TPH during the first four weeks of land treatment were probably the result of a combination of biological degradation, volatilization, and leaching. Volatile compounds characteristically comprise approximately 30% of diesel fuel by weight.[14] Therefore, at a maximum, volatilization may have accounted for a loss of 30% of the TPH contamination from the soil. It has been observed that volatilization becomes an important loss mechanism for contaminated soil when environmental temperatures are elevated and soils are relatively dry.[15] These two conditions did not occur during the study. Furthermore, the diesel spill reportedly occurred in 1984, indicating that a major portion of the volatile components may have been already dissipated by 1989. Therefore, the cold, wet nature of the LTU soils during treatment, as well as the age of the diesel spill, suggest that volatilization was not an overly important loss mechanism during the study.

Leaching may have reduced TPH concentrations in the LTU soil. Studies of dissolution and leaching rates of TPH from various soil types are not abundant, although the American Petroleum Institute is currently evaluating this loss mechanism.[15] Although a berm had been installed around the LTU to control runoff, a petroleum sheen was observed in a small flow of water exiting the unit in mid-September,[16] indicating that rainfall and runoff during the first four weeks of treatment may have resulted in some TPH leaching. However, since the majority of organic components in diesel fuel are hydrophobic and because the contaminated soils had been subjected to several years of leaching prior to the beginning of the study, this loss mechanism may not have been significant, even with the initial application of the surfactant solution in 1989.

The other major loss mechanism is enhanced biodegradation. Virtually every organic component in diesel is biodegradable under appropriate environmental conditions.[15] The objective of the land treatment approach used in this study was to create conditions conducive to biodegradation of diesel fuel in soil. It was concluded a priori that the appropriate conditions for this situation included periodic soil mixing to increase contaminant-microbe interaction, enhance oxygen delivery to the soil, and promote soil drying; periodic micronutrient applications to further enhance microbial activity; and addition of a dilute surfactant solution to increase contaminant accessibility to the indigenous microorganisms.

The microbial data indicate that appreciable numbers of hydrocarbon-degrading bacteria were present in the LTU soil throughout the 1989 study period. The combined microbial data also indicate that treatment significantly increased the proportion of active microorganisms in the LTU soil. Furthermore, the average densities of bacteria that were capable of degrading phenanthrene increased during the 1989 study period. These observations indicate that the bioremediation enhancement techniques applied to the LTU soil stimulated microbial activity. The arithmetic mean density of total bacteria presumably declined during the six-week period because the concentration of petroleum hydrocarbons ("food") had also declined over the period.

The objective of enhanced bioremediation is to stimulate microbial activity so that the microorganisms metabolize the targeted organic compounds at a rate greater than would occur naturally. Since microbial activity directly correlates with ambient temperature, climate conditions in the area during the study were anticipated to have a major influence on microbial activity and, hence, the effectiveness of bioremediation treatment. The 1989 and 1990 studies were conducted at the ends of the arctic summers and ambient temperatures, along with microbiological activity, were anticipated to decline during each study period. Indeed, the observation of essentially no appreciable biodegradation during the final two weeks of treatment in 1989, when a period of cold ambient temperatures occurred, is consistent with the theoretical influence that a marked decline in environmental temperatures would have on biodegradation rates.

A second major environmental variable of the 1989/1990 LTU studies was precipitation. As was mentioned previously, August is typically the wettest month of the year in the area. Excavated soils were quite damp when they were placed on the LTU in August 1989, and the precipitation that occurred during that month was more than 2 inches above normal.[11] The 1990 study period also coincided with above-normal precipitation.

Precipitation kept the LTU soil near the saturation point,[16] reducing the effectiveness of soil aeration because oxygen transfer is impeded by the high soil water content. As a result, saturated soils containing elevated levels of organic materials (such as soils containing diesel contamination) often develop anaerobic (no oxygen) conditions because the microbial oxygen consumption rate tends to exceed the rate of oxygen replenishment from the atmosphere. Because petroleum hydrocarbons tend to degrade relatively slowly under anaerobic conditions,[17] the saturated condition of the LTU soil during both study periods may have reduced the rate of diesel fuel biodegradation.

In summary, the results of the 1989/1990 LTU studies indicate that onsite bioremediation produced significant reductions in the concentrations of TPH in the contaminated fill over a relatively short time period, even under the relatively adverse environmental conditions of late arctic summer treatment periods (cold, saturated soil conditions). Presumably, if land treatment is initiated soon after spring thaw, considerably greater reductions in soil TPH concentrations would be realized because treatment would take place under warmer, drier conditions that would be more conducive to elevated biodegradation rates of the petroleum hydrocarbons.

Tundra Treatment

The results of the 1989/1990 bioremediation studies for the tundra area suggest that the bioremediation approach can produce significant initial reductions in TPH concentrations in contaminated tundra. Little additional TPH reduction was observed in 1990. There were several factors associated with the tundra studies that interfere with the evaluation of the treatment approach.

Sampling across the contaminated tundra hillside was focused on those areas that remained denuded. Therefore, with each sampling event, tundra samples were collected in areas more adjacent to the three channels through which the diesel fuel originally flowed. These areas were likely to have higher TPH concentrations than areas at distance from the channels. Therefore, the sampling emphasis placed on denuded areas tended to bias the collection of samples toward those areas containing elevated contamination levels. This could account for the arithmetic increase in tundra TPH concentrations that was observed between the final 1989 sample set and the initial 1990 sample set.

A second influence on the results is the aforementioned variabilities in the contents of natural organic materials and moisture characteristic of tundra samples. These variabilities exerted a large influence on the variability of the calculated dry weight concentrations of TPH in the tundra samples. The outliers identified in the combined data set for the tundra samples may be related to the influences of natural organic materials and moisture contents. As the variability in a sample set increases, the ability of statistical tests to detect significant differences tends to decline.

Third, the negligible additional reduction in TPH concentration observed during the 1990 study may be related to the relatively cool and wet conditions that took place during this period. Such conditions would likely reduce the rate of contaminant biodegradation using a passive in situ approach. In addition, as mentioned for the LTU studies, if treatment is initiated earlier in the summer, a greater degree of TPH reduction may be realized.

Finally, as discussed before, the analytical method may be measuring natural organic components present in the tundra samples. If this is true, the "TPH" concentration would tend to reflect the total organic carbon concentration versus the diesel fuel concentration. The relative importance of this issue could be evaluated by analyzing organic-rich, tundra samples that have not been contaminated by diesel fuel.

The results do indicate a trend of decreasing TPH concentrations in the tundra over time, although the reductions are not statistically significant. One way to assess the overall effectiveness of the bioremediation approach is to monitor the extent of revegetation in the impacted areas over the next few years. The area of the hillside that was impacted by the diesel fuel spill and treated in 1989 showed considerable revegetation during the summer of 1990. Presumably, if the in situ bioremediation approach appreciably enhances the rate of reduction of TPH concentrations on the hillside areas impacted by the spill, the treated areas will revegetate more rapidly than impacted areas that received no treatment because they were inaccessible.

In summary, the passive, in situ bioremediation approach for the contaminated tundra area appears to have produced a significant initial reduction in TPH concentrations. Additional reductions in 1990 were statistically insignificant; however, cold and wet conditions in 1990 may have influenced the 1990 results. In addition, several factors associated with sampling and analysis were identified which could have had bearing on the tundra evaluation. Validation of the effectiveness of the passive, in situ bioremediation approach for treatment of contaminated tundra may best be documented by following revegetation patterns in impacted areas over the next few summers.

SUMMARY AND CONCLUSIONS

Onsite, open-air bioremediation studies conducted over two successive summers (1989 and 1990) at a U.S. Air Force station in arctic Alaska demonstrated that significant reductions in the concentrations of spilled diesel fuel in soil and tundra can be achieved despite the relatively unfavorable environmental conditions of the region.

Active, aboveground, biological treatment of the contaminated soil fill in a land treatment unit produced an average reduction in soil diesel fuel concentration (as measured by total petroleum hydrocarbons) of approximately 75%. During each summer season, TPH concentrations were reduced by approximately 50% by treatment in the LTU.

Passive, in situ biological treatment of the contaminated tundra hillside was not as effective in reducing average TPH concentrations in the affected tundra. However, sampling and analytical difficulties may have reduced our ability to detect significant reductions in TPH concentrations during the two summer periods. Appreciable regrowth of the tundra vegetation in the impacted areas that were treated in 1989 during the summer of 1990 suggest that the passive, in situ bioremediation approach was assisting in the restoration of the affected hillside area.

An assessment of meteorological conditions during the 1989 and 1990 study periods indicates that the bioremediation approaches could produce additional reductions in TPH if the treatment programs are initiated soon after ambient temperatures increase above freezing.

The results of these studies demonstrate that bioremediation technologies may assist the U.S. Air Force in remediating organic contamination problems in Alaska. Because open-air, onsite treatment can be effective for treating contaminated soil and tundra despite relatively unfavorable environmental conditions, the potential exists that the U.S. Air Force may be able to treat contamination problems relatively inexpensively.

ACKNOWLEDGMENTS

These studies could not have been conducted without the support of the U.S. Air Force's Installation Restoration Program. We gratefully acknowledge the assistance of U.S. Air Force personnel in the development, implementation, and evaluation of these studies.

Woodward-Clyde employees who contributed to the success of this project include Robin Spencer, Diana Evans, Jay Clare, Thomas Rogers, Keith Guyer, and Anita Quesada. Desma Hogg of Woodward-Clyde-NZ provided constructive comments on the manuscript.

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Remediation of 25,000 Pounds of Hydrocarbons in One Month

Source: Aeromap U.S. Inc.
Roll No. 91-18C, Exp No. 11-16

1991 Aerial Photograph of Halliburton Geophysical Services (HGS) Pad in Prudhoe Bay, Alaska

INTRODUCTION

Pre-construction view of HGS pad

From October 1989 to August 1999, ***Halliburton*** of Houston, Texas made several attempts to characterize and remediate petroleum hydrocarbon contaminated soil and water within a 9 acre man-made gravel pad in Prudhoe Bay, Alaska. On September 16, 1999, **URS** conducted a site-wide characterization of diesel range organics (DRO) and benzene soil contamination at the gravel pad/tundra interface. A total of 53 test pits were excavated and field screened. Thirteen soil samples were collected for chemical analysis. Based on the analytical results, six areas of the pad totaling approximately 7,400 cubic yards were estimated to be contaminated above Alaska Department of Environmental Conservation (ADEC) cleanup levels. The highest concentrations of DRO contamination were reported in the center of the pad. Approximately 900 cubic yards of benzene contaminated soil with concentrations as high as 37 milligrams per kilogram (mg/Kg) were identified in the northeast portion of the gravel pad. In early 2000, the site was accepted into ADEC's Voluntary Cleanup Program. At that time, ADEC designated a 200 mg/Kg DRO cleanup level for the site based on the presence of benzene in soil. **URS** prepared a Cleanup/Corrective Action Plan to remediate the DRO contaminated soil by in-situ bioremediation/landfarming. The intra-pad water was to be remediated by dewatering and bioremediation.

Mitigation measures in place along perimeter of pad

During July 2000, **URS** and its subcontractor constructed six biocells with french-drain catch basins to remediate the soil and remove the intra-pad water for treatment in temporary holding tanks. The biocells were designed to treat the lower 3 feet of the pad with proprietary enzymes and nutrient inoculations and tilling in place. Prior to beginning the remediation activities, baseline sampling of the biocells and surrounding tundra ponds were conducted by **URS**. The benzene contaminated soil in the northeast portion of the pad was removed by excavation and thermally treated. Following the removal of the benzene contaminated soil, ADEC revised the site-specific DRO cleanup level to 500 mg/Kg.

On July 24, 2000, in-situ bioremediation landfarming utilizing ***Enzyme Technologies, Inc. (ETEC)*** proprietary enzyme and nutrient enchancers began at the site. Simultaneous with landfarming activities, **URS** removed approximately 63,000 gallons of hydrocarbon contaminated water from the catch basins and placed it in temporary holding tanks equipped with low flow aeration manifolds.

The water in the holding tanks was sampled then treated with the same ***ETEC*** products used on the biocells. After two-days of aeration and treatment, the water within the tanks was sampled a second time to evaluate degradation rates of contaminants. The results showed non-detect concentrations of benzene, toluene, ethylbenzene, xylenes (BTEX) and polynuclear aromatic hydrocarbons (PAHs) compounds. The water was then used in the biocells to maintain moisture levels.

The biocells were tilled with a tractor developed by ***ETEC***. The biocells were tilled daily the first week, then three times a week during the second, third, and fourth weeks of landfarming. After 30 days of biocell landfarming, **URS** collected confirmation samples to determine the degradation rates of contaminants in the soil. The biocells were backfilled and the site was returned to its original appearance on September 2, 2000. After 30 days of in-situ landfarming, DRO concentrations had decreased from a high of 2,600 mg/Kg to below the 500 mg/Kg site-specific cleanup level.

French drain and catch basin construction

Benzene contaminated soil excavation

On September 14, 2000, ADEC informed ***Halliburton*** that no further remedial action was required at this site.

Halliburton Company

IN-SITU LANDFARMING: A COST EFFECTIVE SOLUTION

In January 2000, **URS** conducted a remedial alternatives cost analysis for the petroleum hydrocarbon contaminated soil at the former ***Halliburton*** HGS pad site. Five alternatives were considered: excavation and thermal treatment; site encapsulation; soil venting; ex-situ landfarming, and in-situ landfarming.

URS estimated approximately 7,400 cubic yards of soil within the HGS pad was contaminated above ADEC cleanup levels. The contamination was within the lower 3 feet of the pad which also had sunk approximately 1 foot into the underlying tundra. The thermal treatment option included stripping off the top three feet of clean gravel (overburden) and excavating and transporting the contaminated soil to an off-site treatment facility 2 miles away. Treated soil would be returned to the site. The time required to conduct the thermal treatment was 3 months. The encapsulation option included construction costs to place a 20-mil HDPE liner and leave the contamination in place. Monitoring of the surrounding surface waters would have been necessary for a period of 2 to 3 years. However, this option would not allow use of the pad, and the contamination would remain a liability for the foreseeable future.


ETEC tractor tilling Biocell No. 3

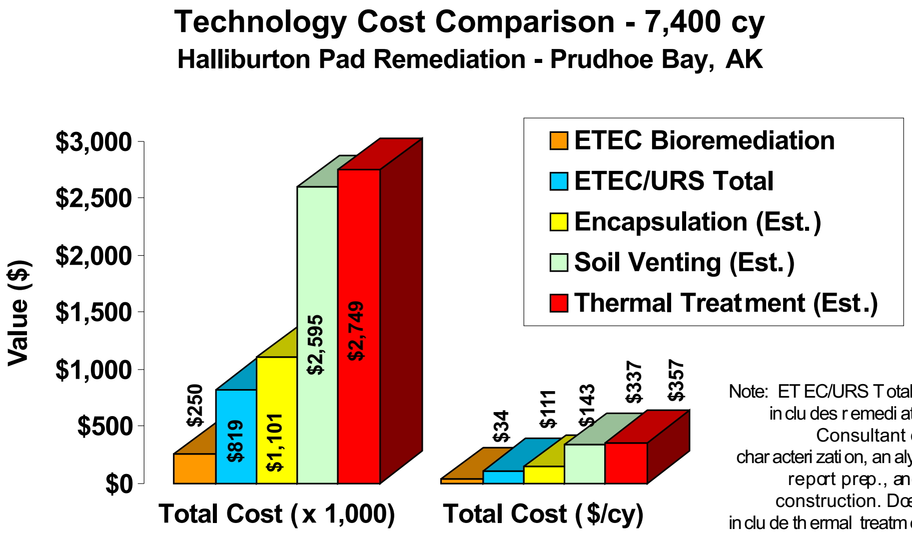
The soil venting option included construction of a treatment system and 2 to 3 years of operation, maintenance, and sampling. The fourth option was ex-situ landfarming. This option would include stripping off the overburden and building off-site treatment cells. The cells would be dismantled at the conclusion of the estimated 2 year treatment period. The fifth option was in-situ landfarming using bioremediation. This option would include stripping off the overburden and building in-place treatment biocells for soil mixing. The cells would be backfilled and the pad would be regraded at the conclusion of the proposed 60-day treatment period and become available for further use.

The results of the cost analysis showed that in-situ landfarming was the most cost effective method for remediating the soil (Figure 1) and provided usage of the property after completion of the treatment activities. The estimated cost for in-situ landfarming, including site construction, plan and report preparation, analytical testing, and project management, was approximately $600,000 or $81.00 per cubic yard. The thermal treatment option was the most expensive.

Since the water within the pad was determined by ADEC as the most probable transport mechanism for the soil contamination, a dewatering program was added to the in-situ landfarming option. The biocells were built with french-drain catch basins to remove the intra-pad water for treatment in temporary holding tanks. The water in the holding tanks was treated with the same product used for the soil biocells. After the water was treated, it was recycled back onto the biocells. The additional cost for dewatering was approximately $184,000.

The final total project cost including characterization activities (sampling, analytical testing, report preparation), remedial alternative cost analysis, Voluntary Cleanup Program application, cleanup/corrective action plan preparation, site construction and remediation activities, thermal treatment of benzene contaminated soil, sampling and analysis, and cleanup action final report preparation was approximately $975,000. The cost to thermally treat 900 cubic yards (cy) of benzene contaminated soil was $156,000. The cost to bioremediate 7,400 cy of DRO contaminated soilwas $250,000.

Figure 1. Cost Comparison Chart for Remedial Options



Note: ETEC/URS Total Cost includes remediation + Consultant costs: characterization, analytical, report prep., and cell construction. Does not include thermal treatment of Benzene contaminated soil.

URS

REMEDIAL METHODOLOGY

Five of the biocells (Cells #1 through #5) were designed to treat 2,800 cy 1,130 cy, 870 cy, 2,375 cy, and 225 cy, respectively. The five perimeter biocells had one french drain catch basin constructed along one edge to remove the intra-pad water. Cell #1 in the central portion of the pad had four catch basins (Figure 2). Each catch basin containing intra-pad water was pumped several times until approximately 2% of the calculated "pad-volume" had been removed and placed into temporary holding tanks. One "pad volume" of water was calculated to be approximately 3.2 million gallons. In addition to the biocell and intra-pad water sampling and analysis, **URS** collected baseline samples of surface water from tundra ponds surrounding the pad. At the completion of all site activities, confirmation samples were collected from one tundra pond designated by ADEC. **URS** also collected baseline samples of intra-pad water placed in temporary holding tanks prior to treatment, and confirmation samples 48-hours following treatment. Soil samples were also collected from the stockpiles of overburden. All of the soil samples were analyzed for DRO, residual range organics (RRO) and BTEX compounds. All of the water samples were analyzed for BTEX and PAHs to assess the total aromatic hydrocarbons (TAH) and total aqueous hydrocarbons (TaqH) concentrations for fresh water aquaculture restrictions per 18 AAC 70. Following the purging of intra-pad water and simultaneous with landfarming, samples were collected from the nine catch basins for further characterization.

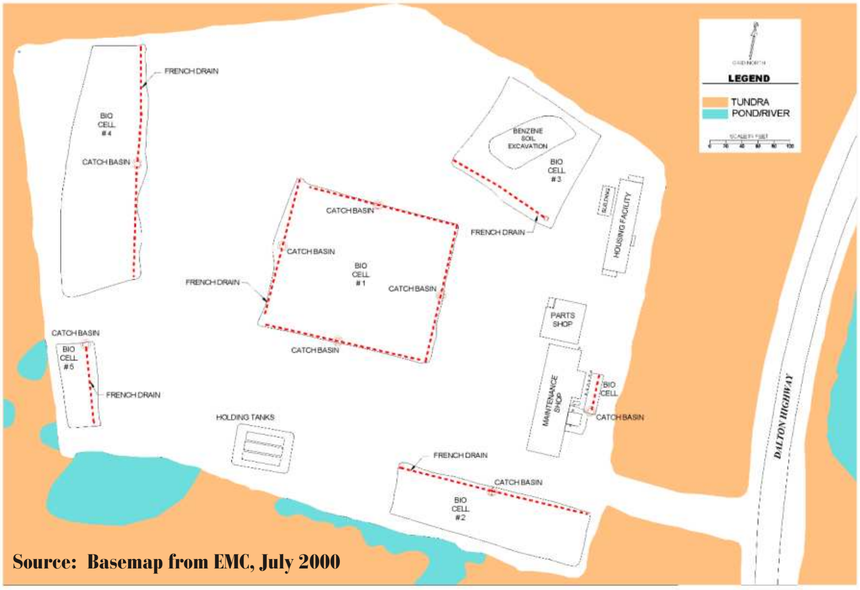
ETEC inoculation of Biocell No. 1

Prior to beginning landfarming activities, **URS** collected baseline samples from each biocell. A total of 25 soil samples were collected: eight samples from the central biocell (Cell #1); five samples from the southeast biocell (Cell #2); four samples from the northeast biocell (Cell #3); six samples from the northwest biocell (Cell #4); and two samples from the southwest biocell (Cell #5). At the completion of the landfarming activities and just prior to backfilling, **URS** collected confirmation samples from the same locations as the baseline samples and analyzed them for same constituents as before, plus PAHs. The biocells were also sampled by ***ETEC*** for nutrients (ammonia and phosphorous) and hydrocarbon plate counts at Day 0, Day 6, and Day 18 of the landfarming process.

On July 23, 2000 the biocells were inoculated with a combination of ***ETEC's Petroleum Consortium*** (EZT-A2), ***Enzyme Accelerator*** (EZT-EA) and ***Custom Blend Nutrients*** (EZT-CBN) bioremediation products. During the initiation of landfarming activities, **URS** removed approximately 63,000 gallons of intra-pad water from the catch basins and contained the water on-site in three temporary holding tanks. The holding tanks were within secondary containment cells. One baseline water sample was collected from each holding tank. Each holding tank had a low-flow aeration manifold to aid the treatment process. Following the baseline sampling of water in the holding tanks, each tank was inoculated with the same product used on the biocells. Once the results of the confirmation samples indicated non-detect concentrations, the water was re-used during the landfarming activities.

To prevent outward migration of hydrocarbons, **URS** encircled the pad with polypropylene absorbant booms. The absorbant booms were in place prior to biocell construction and monitored throughout the remediation activities. At the conclusion of the in-situ landfarming activities, the absorbant booms were retrieved and later incinerated.

Figure 2. Site Map Showing Biocell Locations



Source: Basemap from EMC, July 2000

TREATMENT RESULTS-25,000 LBS. OF CONTAMINATION REMEDIATED IN 30 DAYS

The range of baseline and confirmation concentrations of DRO and RRO for the five biocells are shown in Figure 3 and Figure 4, respectively. The average DRO baseline concentration was 1,388 mg/Kg. The average RRO baseline concentration was 182 mg/Kg. The average decrease in DRO and RRO concentration was 1,126 mg/Kg and 155 mg/Kg, respectively. After thirty days of landfarming using ***ETEC's*** proprietary enzyme and nutrient enhancers, all five biocells exhibited significant decrease in both DRO and RRO concentrations. **URS** estimated that on average approximately 23,300 pounds of DRO contamination and 3,200 pounds of RRO contamination were removed during the in-situ landfarming process.

Placement of temporary holding tanks

The initial intra-pad water results showed total BTEX concentrations as high as 1.854 milligrams per liter (mg/L) from the northwest portion of the central cell and an average of 0.426 mg/L. The highest concentration of BTEX from the baseline holding tank samples was 0.206 mg/L with an average of 0.198 mg/L between the three tanks. Using the total between the cell catch basin samples and the holding tank samples the average total BTEX is 0.369 mg/L for the entire pad. The average amount of total BTEX contaminants removed from the holding tank water in 48 hours was 0.7 pounds.

No PAHs were detected in the confirmation biocell and water samples. A total of approximately 25,000 pounds of petroleum hydrocarbon contamination was remediated from the six biocells following 30 days of in-situ landfarming. None of the surrounding tundra surface water samples contained concentrations of TAH and TaqH that exceed ADEC Arctic cleanup levels. In conclusion, the surface water results showed no complete path exists between the intra-pad water and the surrounding tundra ponds.

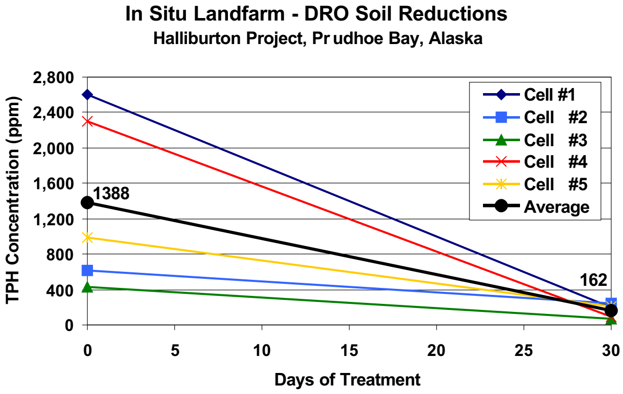


Figure 3. In-Situ Landfarming Bioremediation Treatment Results for DRO in Soil

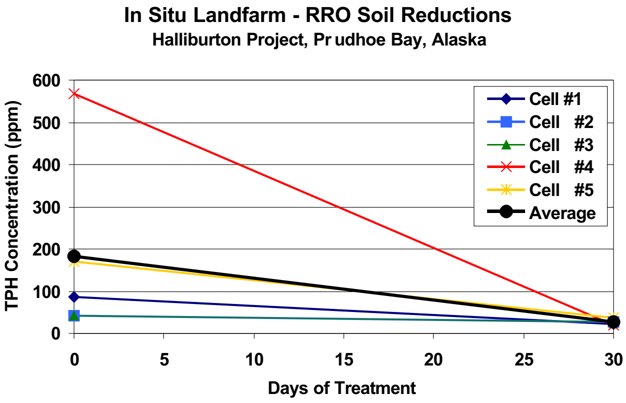


Figure 4. In-Situ Landfarming Bioremediation Treatment Results for RRO in Soil

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TECHNOLOGIES, INC.

Biocell No. 2 with Sagavanirktok River in background

Transferring intrapad water to holding tanks

Post remediation view of HGS pad

Over the past 5 years, URS has brought together several world-class engineering companies, among which are some of the industry's leading environmental, engineering design, process engineering, and program/construction management firms. In Alaska, URS is manifested as the combination of three firms already known individually for their scientific and engineering excellence: Woodward-Clyde Consultants, Dames & Moore Group, and Radian International. Our Anchorage office has a staff of more than 90 professionals who have a wide range of environmental and engineering backgrounds and professional experience. We have satellite offices located in Fairbanks, Ketchikan, Juneau and Homer, which enable us to provide better service to clients throughout Alaska.

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SPECIAL REPORT 98-5

CRREL

Bioremediation of Hydrocarbon-Contaminated Soils and Groundwater in Northern Climates

Charles M. Reynolds, W. Alan Braley, Michael D. Travis,
Lawrence B. Perry, and Iskandar K. Iskandar

March 1998

Abstract: A field demonstration and research project was conducted in Fairbanks, Alaska, to demonstrate, evaluate, and document the construction and operation of three selected bioremediation technologies—landfarming, recirculating leachbeds, and infiltration galleries. Landfarming involves adding water and nutrients to contaminated soil to stimulate microbial activity and contaminant degradation. Infiltration galleries are dynamic in-situ treatment systems designed to stimulate microbial activity and subsequent hydrocarbon degradation by circulating nutrient- and oxygen-amended water through petroleum-contaminated soil. Recirculating leachbeds, in a way similar to slurry reactors, aerate and mix nutrients with contaminated soil, and can be built as on-site bioreactors. Estimated biotreatment costs in the landfarm were between \$20 to \$30 per cubic yard (\$15 to \$23 per cubic meter). Nutrient placement has been demonstrated to be a critical factor, even though the site is tilled and mixed frequently. Success of the infiltration gallery was more difficult to document. Benzene was detected at less than 2 ppb and BTEX levels were less than 5 ppb for water extracted from the pumping well during 1992, which is significantly lower than the 1991 levels. Problems were encountered during the brief operation of the recirculating leach bed, but a similar system has performed well. Relatively simple, low-cost techniques provided significant potential for improving degradation rates.

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Special Report 98-5

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Bioremediation of Hydrocarbon-Contaminated Soils and Groundwater in Northern Climates

Charles M. Reynolds, W. Alan Braley, Michael D. Travis,
Lawrence B. Perry, and Iskandar K. Iskandar

March 1998

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Dr. Charles M. Reynolds, Research Physical Scientist, Geochemical Sciences Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory; W. Alan Braley, Alaska Department of Transportation and Public Facilities, Fairbanks International Airport, Fairbanks, Alaska; Michael D. Travis, formerly of AGRA Earth and Environmental, Inc., Anchorage, Alaska; Lawrence B. Perry, Physical Science Technician, and Dr. Iskandar K. Iskandar, former Chief, Geochemical Sciences Division, Research and Engineering Directorate, CRREL.

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Peter Smallidge, former CPAR Manager, CRREL, and Dr. Edward Smith, Team Leader, U.S. Army Construction Engineering Research Laboratory, assisted in the initial project organization. Acknowledgments are given to Dr. Edward Brown and Lynn Rawls-McAfee, University of Alaska, Fairbanks, for information on the microbial activity data, and to Michael Lily, U.S. Geological Survey, for the water data. Laboratory analyses at CRREL were assisted by Chad S. Pidgeon, Ronald Bailey, Susan Bebeau, Patricia Schumacher, and Dianne Reynolds. Technical review and suggestions to the manuscript were made by Paul Currier and Dr. Charles Racine of CRREL.

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EXECUTIVE SUMMARY

The objectives of the Construction Productivity Advancement Research (CPAR) field demonstration and research project, *Bioremediation of Hydrocarbon Contaminated Soils and Groundwater in Northern Climates*, were to demonstrate, evaluate, and document the construction and operation of three selected bioremediation technologies—landfarming, recirculating leach beds, and infiltration galleries—in cold regions. Before this CPAR program was begun, bioremediation had not been used extensively in cold regions.

Landfarms are lined, bermed areas where soil is treated by adding and mixing water and nutrients. A collection system may be installed inside the liner to collect leachate, which then can be recirculated. In this project, the leachate was recirculated through a mixing tank for nutrient additions and then through spray irrigation lines onto the surface of the landfarm site. The liner surface was sloped to ensure that the liner directed leachate into the collection system.

Infiltration galleries are dynamic in-situ treatment systems designed to stimulate hydrocarbon degradation by enhancing microbial activity. Microorganisms are stimulated by circulating nutrient and oxygen-amended water through soil contaminated by petroleum. The system used in this project included a groundwater pumping well, nutrient addition and aeration capabilities, and an infiltration gallery to encourage transport of the enhanced groundwater back into the soil.

Recirculating leachbeds are similar to slurry reactors. The concept is to develop a lined containment area to serve as an on-site bioreactor. Either a pit, generally resulting from the excavation, a bermed perimeter, or a combination can be used, depending on available materials. In this project, contaminated soil was placed into the bioreactor and, through an inexpensive PVC distribution system, aerated and nutrient-amended water was recirculated into the bottom of the bioreactor, upwards through the contaminated soil, and then through the overlying ponded and aerated water. Skid-mounted mechanical systems included a mixing tank and circulation pumps for water and air.

The products of this project include field demonstrations of each technology, accompanying documentation on design and construction, results of operation in cold regions, and numerous technology transfer activities, such as site visits and tours during the construction and operation of the treatment facility. The designs have been provided to the U.S. Army Engineer District, Alaska, as well as commercial engineering firms.

To date, the Fairbanks bioremediation test site has completed remediating the first batch of contaminated soil in the landfarm. The estimated costs were between $20 to $30 per cubic yard ($15 to $23 per cubic meter). Nutrient placement has been demonstrated to be a critical factor, even though the site is tilled and mixed frequently. Relatively simple, low-cost techniques provided significant potential for improving degradation rates. The project findings include an estimate of the spatial variability in degradation rates within the landfarm and measurements of degradation rates obtainable in a cold region landfarm. These results are significant for developing other low-cost bioremediation systems, such as those using combined treatment technologies. Extension to biotreatment systems that include extremely low inputs, such as natural attenuation, has also been considered.

Processes enhanced by operation of the infiltration gallery were more difficult to document. During the operation in 1992, the benzene and BTEX (benzene,

toluene, ethylbenzene and xylene) concentrations in groundwater samples from the six monitoring wells surrounding the infiltration gallery decreased to below detectable limits. Benzene was detected at less than 2 ppb (µg/g) and BTEX levels were less than 5 ppb (µg/g) for water extracted from the pumping well during 1992, which is significantly lower than the 1991 levels.

Problems were encountered during the brief operation of the recirculating leach bed. The air manifold floated to the surface, but this could be readily solved by using a simple system to anchor the aeration piping to the soil surface. Channeling of water was observed in the soils immediately above the water distribution manifold, possibly causing preferential paths in the flow of nutrients and oxygen through small areas rather than through the entire soil. Channeling would slow the overall rate of remediation. Lastly, it may be necessary to install a heavier liner or to provide better protection by installing a cushion fabric or sand.

Bioremediation of Hydrocarbon-Contaminated Soils and Groundwater in Northern Climates

CHARLES M. REYNOLDS, W. ALAN BRALEY, MICHAEL D. TRAVIS,
LAWRENCE B. PERRY, AND ISKANDAR K. ISKANDAR

INTRODUCTION

Background

Many contaminated-soil sites in cold regions are isolated and remote. These factors, combined with extreme climatic conditions, make bioremediation difficult. Although there are increasing choices of in-vessel bioremediation schemes available, these often rely on extensive equipment needs and large energy inputs. For use at remote sites in cold regions, a cost-efficient and applicable technology would necessarily be characterized by low input and rugged design. Bioremediation encourages natural soil-mediated processes by addressing the limiting factors. It may be a preferred technology for remediating contaminated soils in severe climates, such as the Arctic and sub-Arctic regions of Alaska or other cold regions, and potentially could be used to treat the bulk of the contaminated soils at these remote sites. Although bioremediation of contaminated soils is a proven and frequently used technology in more temperate regions, the constraints imposed by severely cold climates, where the season for optimum bioremediation conditions typically is short, may reduce the cost benefits.

Objectives and rationale for field research

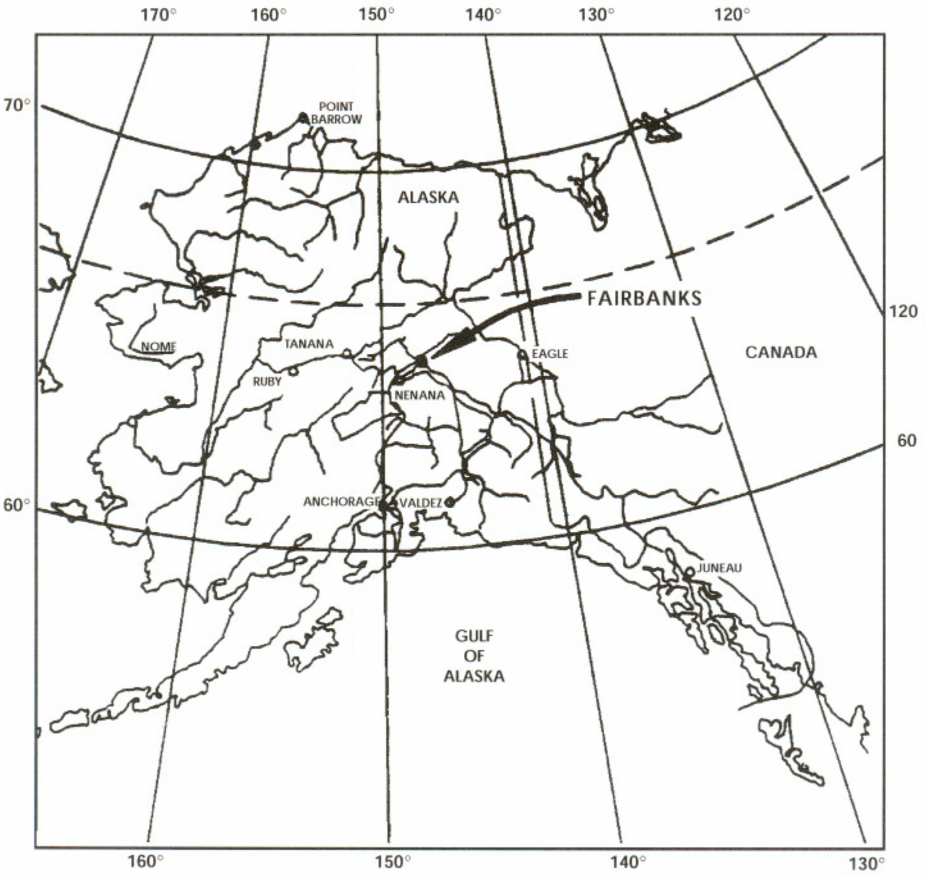
To optimize bioremediation, it is necessary to identify and reduce the factors that limit biodegradation rates. Ways to reduce these limitations are usually found through small-scale laboratory treatability tests, but the success of transferring laboratory results to the field, our ultimate goal, is difficult to quantify. Obtaining a good understanding of the degradation rates at a field site is hindered by the inherent variability in field biological studies.

Landfarms are readily constructed and provide relatively easy sampling, although the soil mixing that is achievable is usually not uniform across an entire landfarm. Regulatory restrictions generally prevent intentional application of petroleum to soils and thereby inhibit studying the effects of different treatments applied to a "uniformly" contaminated soil. To counter this, random samples can be taken and composited, but unless this process is replicated sufficiently, estimates of variability, and therefore estimates of the net effects of treatments taken from the laboratory, can not be made successfully.

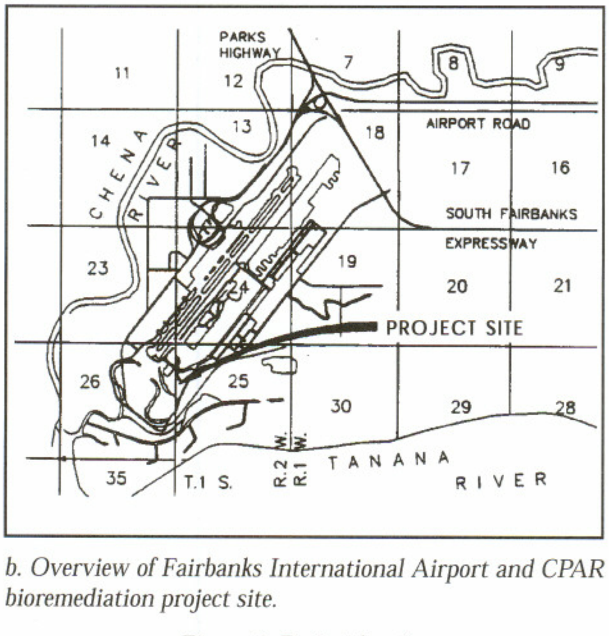
We have incorporated the spatial variability into the monitoring scheme in the landfarm. Process monitoring is more difficult in subsurface systems, owing to the costs of obtaining samples and the limited access to the soil treatment zone. For the infiltration gallery's subsurface system, we used traditional well monitoring techniques. The recirculating leachbed design provided a more aggressive treatment than the infiltration gallery, was a contained system, and provided for better mixing than the infiltration gallery or landfarm.

Project location

The project site, located at the Fairbanks International Airport (FIA) in Fairbanks Alaska, was the previously used crash-fire-rescue (CFR) train-

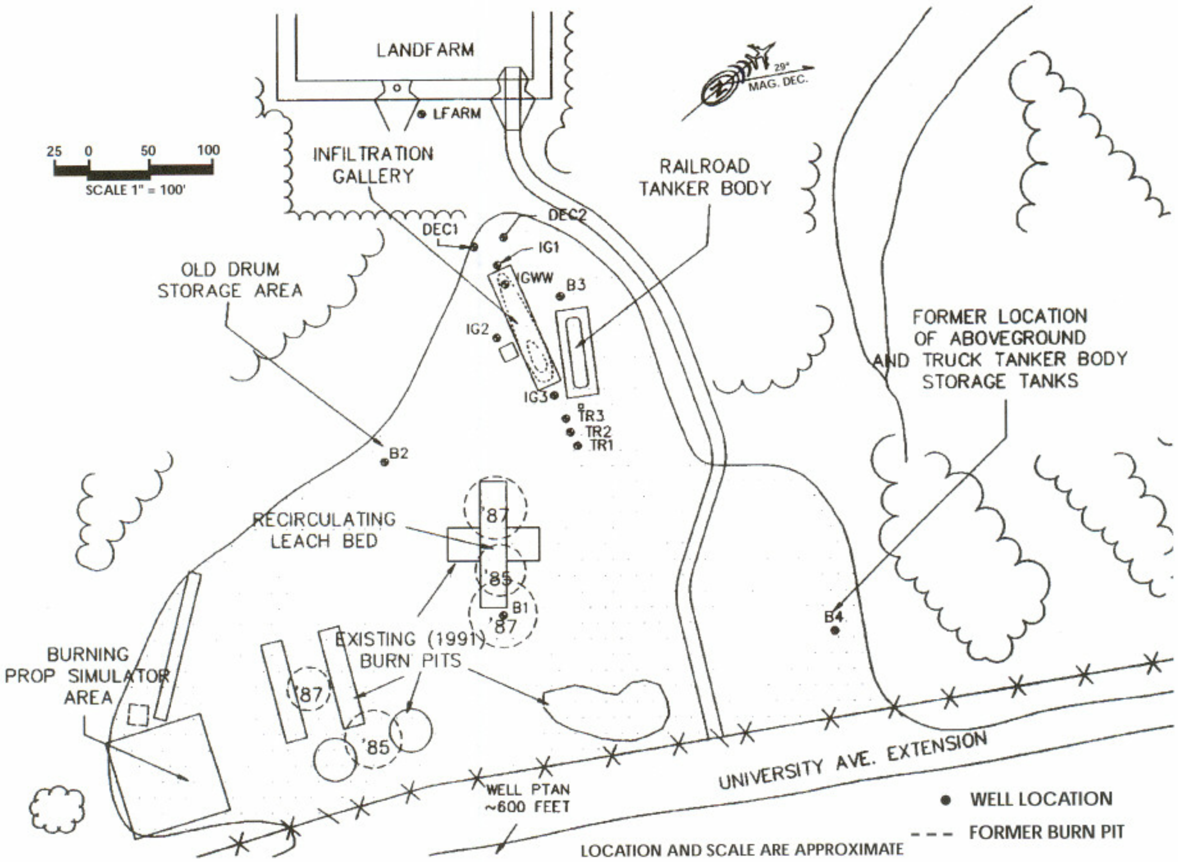


a. Fairbanks, Alaska.



b. Overview of Fairbanks International Airport and CPAR bioremediation project site.

Figure 1. Project location.



c. Fairbanks International Airport CFR training site.

Figure 1 (cont'd).

ing facility. Specifics have been previously documented (Walker and Travis 1990, Braley 1991, Braley 1993, Reynolds 1993, Reynolds et al. 1994). Figure 1 shows the locations of Fairbanks, FIA, and the site of the CFR training facility. FIA is located 3.5 miles (5.6 km) southwest of Fairbanks, Alaska, at latitude 64°49'N. The mean annual air temperature is 26°F (–3.3°C). The mean annual precipitation at FIA is 11.2 in. (28.5 cm), of which approximately half is snowfall that persists on the ground for 5 to 7 months of the year. The site is bounded by the Chena River, Tanana River, and drainage sloughs.

Site history

The CFR facility was used for many years to train personnel from FIA, government agencies, and private firms in fire fighting and rescue techniques appropriate for aircraft disaster. Shallow, unlined burn pits were constructed on the gravel pad and flooded with water and a layer of fuel oil, which was then ignited to serve as a demonstration fire. Following training, fuel remaining in the pits was reignited and permitted to burn. This process allowed unburned fuel to contaminate the soil and groundwater aquifer. Additionally, training included extinguishing burning-prop simulations, which are several fuel nozzles spraying ignited oil above the ground.

Above-ground fuel storage tanks, two truck-tanker bodies, and 55-gal. (208-L) drums, which contained paint and asphalt products, also were located at the site. The two tanker bodies and approximately 500 gal (1900 L) of fuel that leaked from one of the tanker bodies was removed from the site during 1990. An 18,000-gal (68,130-L) railroad tanker body, located at the site within a gravel-berm containment dike, released between 6000 and 10,000 gal (23,000 and 38,000 L) of fuel during May or June 1990 (Fig. 1c).

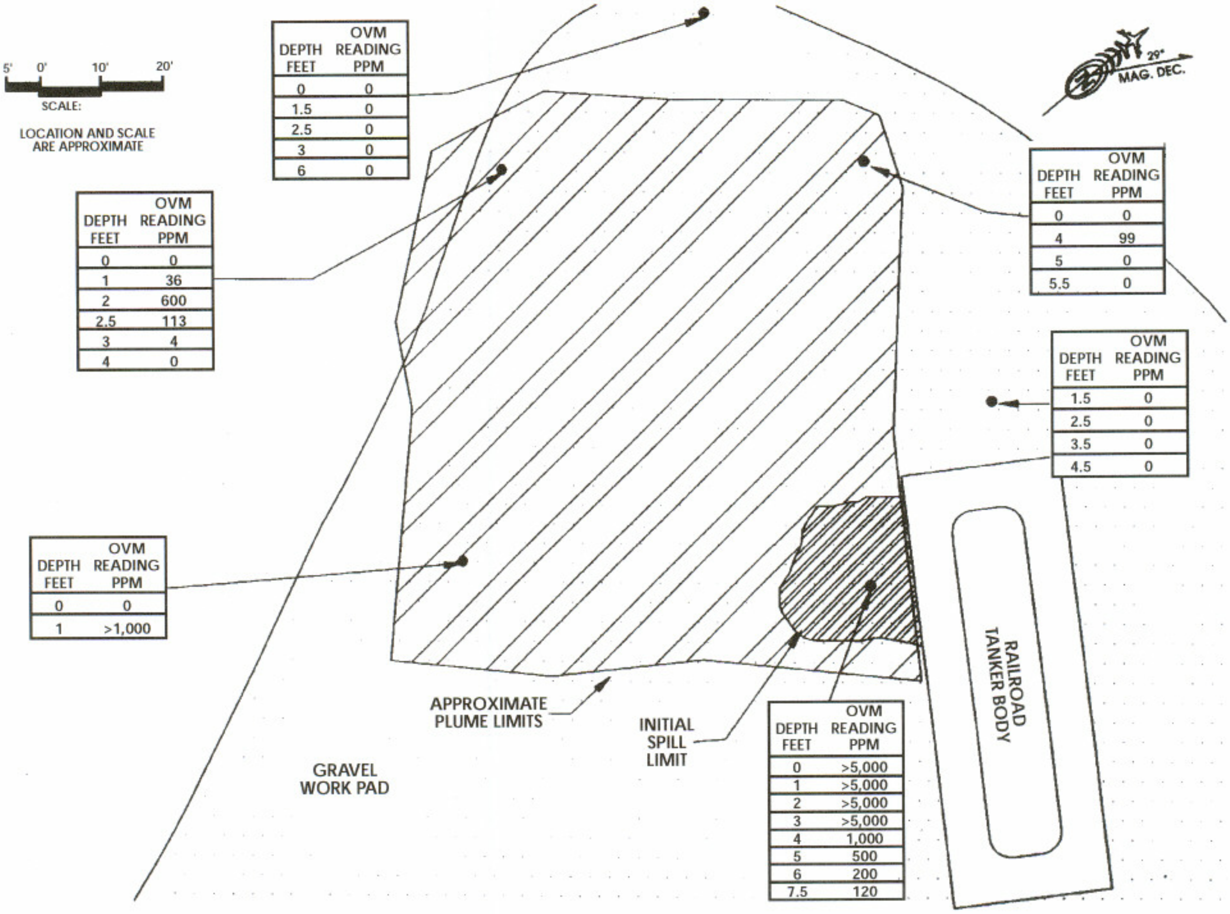


Figure 2. Zone of contaminated soil following tanker spill (OVM is organic vapor meter; 1 ft = 0.3048 m).

Site investigations

Organic vapors in the soils at various depths were analyzed using a hand-held photo-ionization meter to delineate the plume that resulted from the railroad tank car release (Fig. 2). The primary spill covered an area approximately 25 ft (8 m) in diameter and 7.5 ft (2 m) deep. Soils at the groundwater level were contaminated and groundwater was affected by the spill. The fuel oil migrated along the surface of a silt layer located beneath the 2- to 3-ft-thick (0.5- to 1-m-thick) gravel work pad covering the area, resulting in a secondary plume.

During the summer of 1989, a preliminary site investigation (Shannon & Wilson, Inc. 1989) indicated that hydrocarbon contamination was present at the old and new burn pit areas, near the truck tanker body, at the burning prop simulator area, near the railroad tanker body, and at the old drum storage areas (Fig. 1c). The highest concentrations were found in the old and new burn pit areas and at the site of the truck tanker body. Benzene detected in the groundwater was below federal maximum contaminant levels (MCL), and hydrocarbon contamination was primarily confined to the surface soils.

Subsoil and groundwater characteristics

The area that had been used for the fire training activities was generally underlain by gravel that was 2 to 3 ft (0.5 to 1 m) thick. Other portions of the area were underlain by silt, sandy silt, sand, and silty sand. Soil borings and excavations at some locations indicated lenses of sandy gravel. The water table fluctuates 5 to 7 ft (1.5 to 2 m), depending on the stages of the Tanana and Chena Rivers, and has been measured as high as 2 to 3 ft (0.5 to 1 m) from the surface at some locations within the site. July 1989 measurements showed a gradient of approximately 0.25 m per 1000 m toward the northwest (Shannon & Wilson, Inc. 1989). These findings generally agreed with those obtained at a site located approximately 0.5 miles (0.8 km) to the northwest of the CFR area (Dames & Moore 1992), where monitoring over 12 months indicated a gradient of 1.1 to 4.2 ft/mile (0.2 to 0.8 m/km) to the west–northwest.

Four groundwater monitoring wells, denoted B1–B4, were installed at the site in 1989, and during 1991, an additional five monitoring wells, denoted IG1–IG3 and DEC1 and DEC2, were installed in conjunction with the construction of the infiltration gallery. In 1992 three wells, denoted TR1 through TR3, were placed with individual sampling tubes at 1-ft (30-cm) intervals along the length of the well casing. An additional well, PTAN, was installed approximately 750 ft (229 m) up-gradient of the site. During summer 1991, two groundwater pumping wells, IGWW and LFARM, were installed at the site in conjunction with construction of the remediation facilities (Fig. 1c).

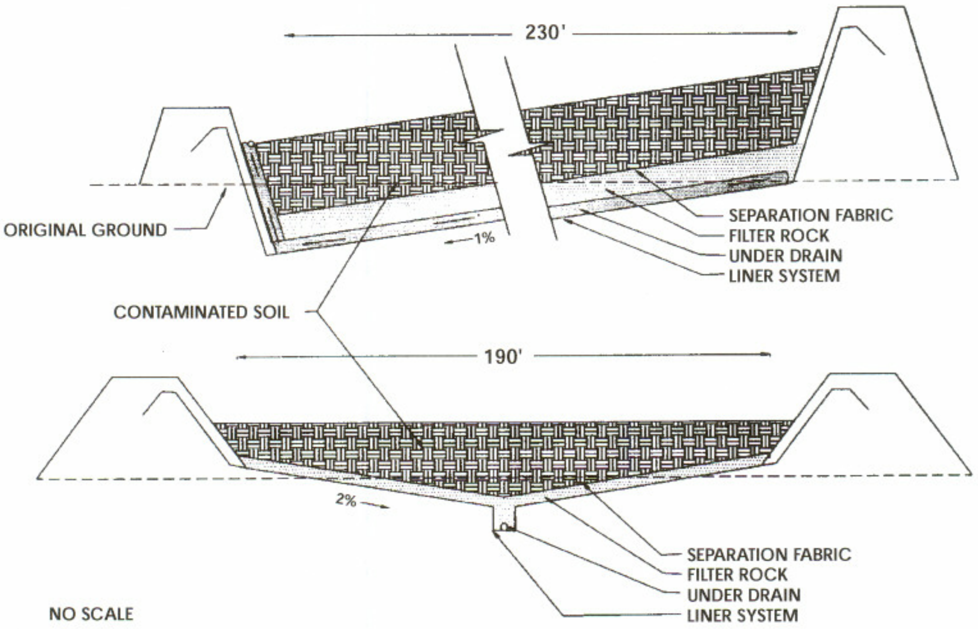
FIELD REMEDIATION PROCEDURES

The treatment technologies used at the site were two ex-situ methods, landfarming and a recirculating leachbed, and an in-situ method, an infiltration gallery, for saturated soils. The design of these systems was completed in early 1991 and a construction contract was awarded in April 1991 (Anonymous 1991). Construction started in late April 1991, but exceptionally high groundwater resulting from heavy snowfalls during the winter of 1990–91 delayed completion. Because of the construction delay, the facilities began to operate during the first two weeks of August 1991.

Landfarm

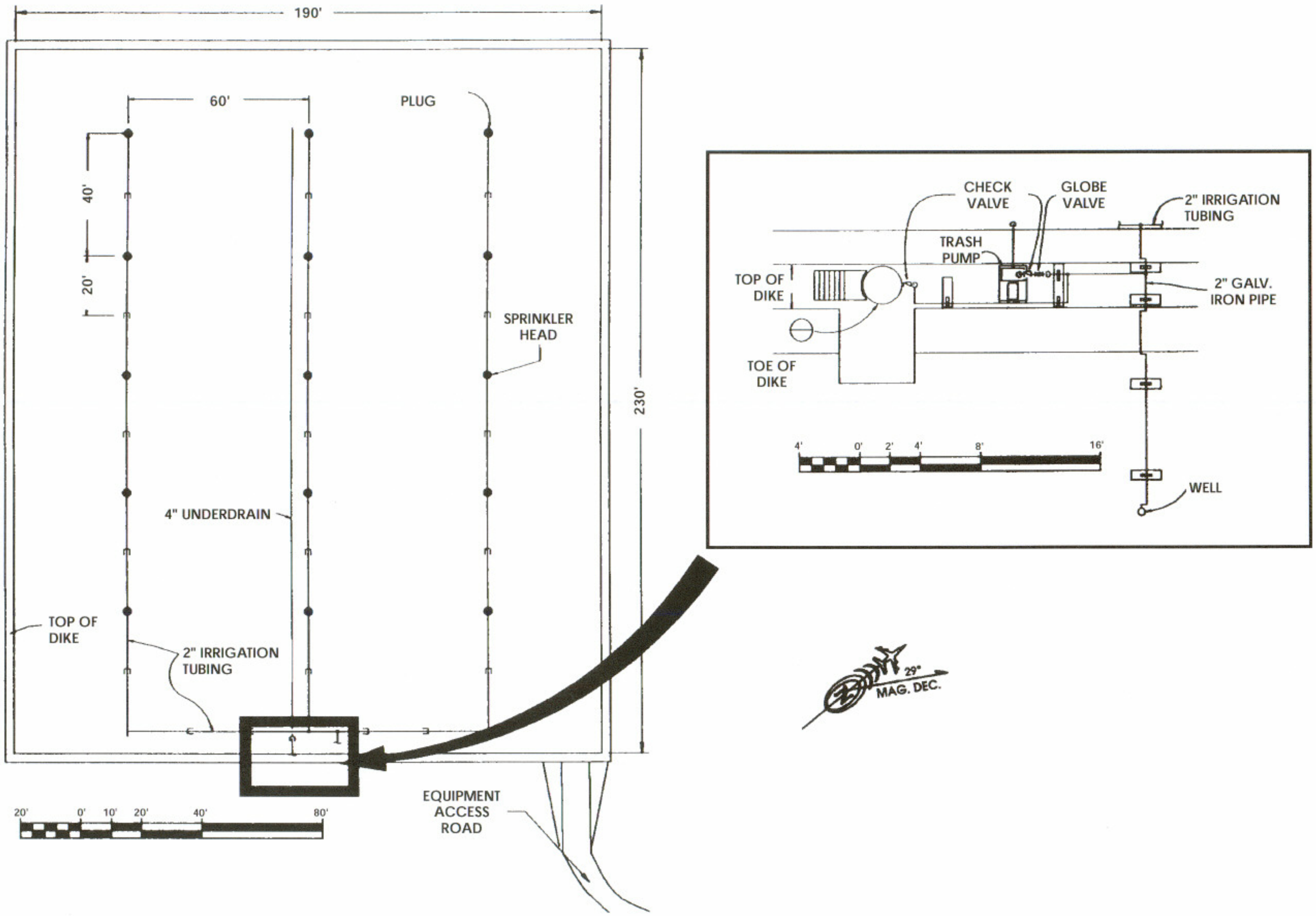
Design

The landfarm is a lined, bermed area that is 190 by 230 ft (58 by 70 m). The liner is 60-mil (1.524-mm-thick) high-density polyethylene (HDPE) and is protected at the top and bottom by 12-oz (4.07-g/m^2) fabric. A 1-ft (30-cm) layer of filter rock covers the liner to aid drainage. To prevent clogging, the filter rock is separated from the overlying contaminated soils by nonwoven geotextile separation fabric (Fig. 3). A system was installed inside the liner to collect and recirculate leachate. Berms are sufficiently high to contain projected annual precipitation. Leachate recirculation is routed through a mixing tank for nutrient additions and then through spray irrigation lines on the surface of the landfarm site. The soil surface under the liner is sloped to ensure



a. Construction specifications.

Figure 3. Landfarm (1 ft = 0.3048 m).



b. Irrigation system.

Figure 3 (cont'd). Landfarm (1 ft = 0.3048 m, 1 in. = 2.54 cm).

that the liner directs leachate into the collection system (Fig. 3a).

Construction

After vegetation was cleared from the landfarm site, the native sandy-silt material was excavated to attain the design contours at the bottom of the landfarm. Excavated material was used to form the surrounding dike. The lowest point in the structure was approximately 2.5 ft (0.76 m) below the original surface of the mineral soils, and the soils in the lower portions of the structure were saturated by groundwater. Construction of the facility was delayed to allow the groundwater elevation to recede.

After the groundwater level receded, the native soils were compacted, a separation fabric was placed atop the sandy-silt in the lower half of the excavation, a 1-ft (30-cm) lift of embankment material was placed over the bottom of the entire excavation, and the berm height was also increased. A layer of 12-oz (4.07-g/m^2) cushion fabric was placed before HDPE liner sections were positioned parallel to the 230-ft (70-m) axis of the landfarm, with seams overlapping 5–6 in. (13–15 cm). Heat-welds were made along the seams and weld integrity was tested. Following weld testing, a cushion fabric was placed over the HDPE liner and a 1-ft (30-cm) layer of filter rock covered with a layer of nonwoven separation fabric was added.

The leachate recovery system was a 4-in. (10-cm) perforated PVC pipe placed in the trench at the center of the landfarm parallel to the 230-ft (70-m) axis. A riser at the lower end of the landfarm was used for pumping water from the leachate system. The riser was connected by a 1-hp (10-kg cal/min) trash pump to a fertilizer mix tank installed on a 2-ft-high (61-cm-high) platform. A 30-ft (9-m) irrigation well for adding supplemental water to the landfarm and a surface irrigation system were installed. Surface irrigation was through 2-in. (5-cm) aluminum pipes and rotating sprinkler heads. The nutrient mixture was gravity fed to the irrigation piping. Water could be delivered to the irrigation system from the well, fertilizer tank, or the drain system (Fig. 3b).

Soil treatment

Approximately 500 yd^3 (382 m^3) of soil, previously stockpiled during cleanup of the fuel spill next to the railroad tanker body, and approximately 3200 yd^3 (2500 m^3) of soil excavated and transported from the old burn pit area were moved into the landfarm. The extent of this excavation in the burn pit area is shown in Figure 4. The contaminated soil was disked weekly with a 2-ft-diam. (60-cm-diam.) disk for aeration and nutrient mixing. The disk mixed the upper 8 to 12 in. (20 to 30 cm) of soil. Each week, 25 lb (11.35 kg) of ammonium nitrate (NH_4NO_3) and 2 lb (0.908 kg) of potassium (potassium sulfate) were mixed with 150 gal (568 L) of water and allowed to flow into the irrigation piping. The well pump was activated to disperse the fertilizer mixture over the landfarm area. Irrigation water was added to the landfarm several times during August to keep the soil's moisture content at 25–85% of field capacity.

The 1992 operational season began in mid-April; a wheeled loader and a large snowblower were used to remove approximately 80 in. (2 m) of snow from the landfarm. An additional 15 in. (38 cm) of snow fell after the winter accumulation was removed. Meltwater, coupled with the moisture from rainfall in late August and September 1991, saturated the material in the landfarm and delayed tillage until 23 June. The rate of fertilizer application was increased to 600 lb (272 kg) of ammonium nitrate, 150 lb (68 kg) of triple super-phosphate, and 50 lb (23 kg) of potassium each month. Applying fertilizer through the irrigation system during 1991 resulted in uneven coverage because of leaky joints in the irrigation pipe, so dry fertilizer was applied in 1992. A tractor-mounted broadcast spreader was used, followed by tillage.

Process monitoring

Landfarming is one of the most commonly used and accepted soil biotreatment techniques in temperate regions (Kuroda and Nusz 1994), yet information on landfarming that would expedite its application to cold regions was sparse. For these reasons, we emphasized characterization of the landfarm and the governing processes within it.

Microbial activity. We characterized the microbial activity at the landfarm by four methods. A most probable number (MPN) sheen screen technique was used to enumerate the oil-degrading population. Radio-respirometry was used to determine the potential to mineralize specific hydrocarbons. Nonspecific microbial activity in the field was estimated by measuring evolved carbon dioxide (CO_2). This was done by alkali-trapping and both gravimetric and gas chromato-

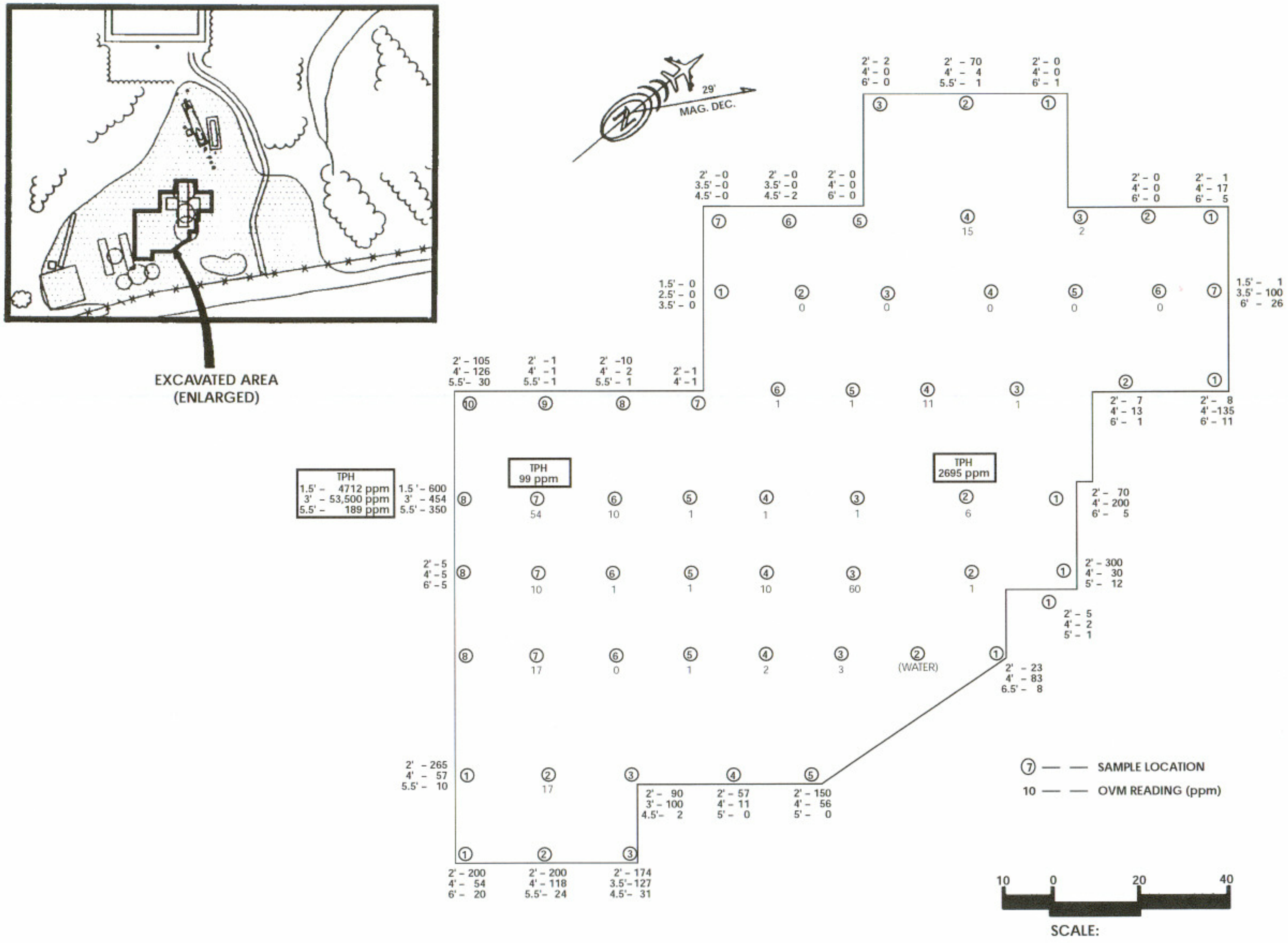


Figure 4. Areas of soil excavation for landfarm treatment (TPH is total petroleum hydrocarbon levels and OVM is organic vapor meter) (1 ft = 0.3048 m).

gram analysis. In August 1991, five composite soil samples were collected at six times and analyzed using radio-respirometric assays and sheen screen techniques. Field measurements of CO_2 evolution were made on seven different occasions.

Contaminant degradation rates. Contaminant degradation was also estimated by measuring dichromate-oxidizable organic carbon and gravimetric total petroleum hydrocarbon (TPH) levels. At approximately monthly sampling intervals, 25 composite samples were collected in a grid pattern and analyzed. Laboratory results were then examined using geostatistical methods. Soil extract hydrocarbon analyses were also performed by an independent testing laboratory on soil samples collected by FIA personnel. During 1991, samples were analyzed for TPH by an infrared method. Soil samples collected during 1992 were analyzed for diesel range petroleum hydrocarbons (DRPH), gasoline range petroleum hydrocarbons (GRPH), and benzene, toluene, ethylbenzene, and xylene (BTEX).

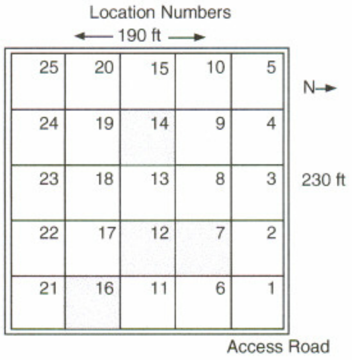
Organic vapor emissions. Headspace gas concentrations were measured for samples collected on 18 August 1992, using an organic vapor meter (OVM) calibrated for benzene. On 20 August 1992, samples were collected for laboratory analysis of DRPH concentrations. No detectable DRPHs were measured in these samples (Table 1). These results indicated that material in the landfarm reached appropriate cleanup levels for closure sampling and disposal.

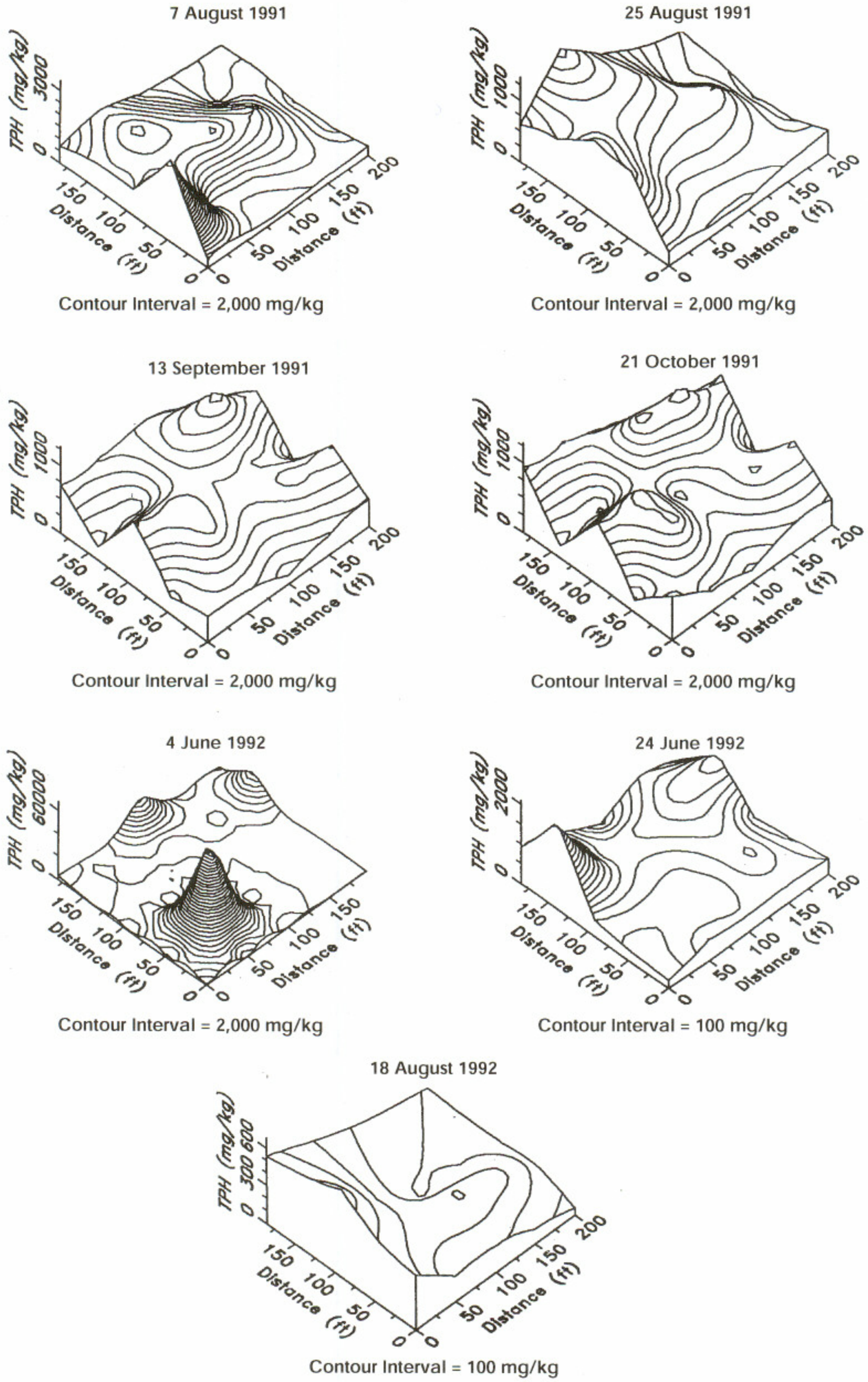
Table 1. Landfarm analytical results.

Date	*TPH (mg/kg)*	*GRPH (mg/kg)*	*DRPH (mg/kg)*	*B (mg/kg)*	*T (mg/kg)*	*E (mg/kg)*	*X (mg/kg)*
			Location 12				
21 Aug 91	1100						
28 Aug 91	1700						
18 Sep 91	770						
01 Oct 91	1100						
15 Jul 92		29*	2300	0.06	0.15	<DL	0.29
20 Aug 92			<DL*				
			Location 14				
21 Aug 91	4000						
28 Aug 91	3500						
18 Sep 91	1000						
01 Oct 91	900						
15 Jul 92		7[†]	55	0.02	0.07	0.03	0.08
20 Aug 92			<DL				
			Location 7				
20 Aug 92			<DL				
			Location 16				
20 Aug 92			<DL				

* Below detection limits.

[†] Light deisel.





7 August 1991

Contour Interval = 2,000 mg/kg

25 August 1991

Contour Interval = 2,000 mg/kg

13 September 1991

Contour Interval = 2,000 mg/kg

21 October 1991

Contour Interval = 2,000 mg/kg

4 June 1992

Contour Interval = 2,000 mg/kg

24 June 1992

Contour Interval = 100 mg/kg

18 August 1992

Contour Interval = 100 mg/kg

Figure 5. Soil TPH levels.

Treatment results

Microbial activity. First year data from the University of Alaska cooperators in this study revealed no increase in mineralization potentials or microbial numbers attributable to the addition of nitrogen, irrigation, or tilling (Rawls-McAfee and Brown 1992). In 1992, 180 soil samples were collected for radio-respirometric assays (Brown et al. 1991) and sheen screen analysis. The results indicated an increase in the mineralization potentials and numbers of microorganism, which is consistent with biodegradation.

Contaminant levels. Soil carbon levels showed a decline in organic carbon and the TPH levels through 1991 and 1992 (Fig. 5). To address the spatial variability issue, CRREL researchers estimated biodegradation rates from a 25-point grid on a 1-acre (4047-m^3) landfarm. A variety of analytical means were used. The simplest and least costly method, using dichromate oxidizable carbon, yielded estimated degradation rates that varied substantially throughout the site.

Three critical observations were noted. First, the degradation of organic carbon was readily measured, even though with a relatively crude technique such as dichromate oxidizable carbon. Second, the measured degradation rates, expressed as half-lives, varied by seven-fold within a 1-acre (4047-m^3) site. Third, there was a pattern in the variability; the center of the site had a much shorter half-life. Sampling locations and results for paired soil hydrocarbon analyses are shown in Table 1. These tests indicated a decline in soil hydrocarbon concentrations through the two seasons.

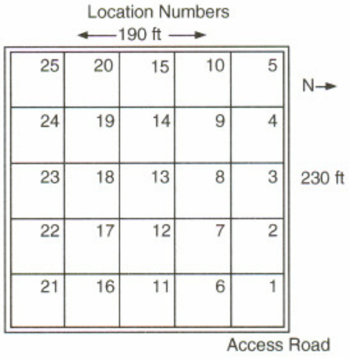
Organic vapor emissions. These results are shown in Table 2. Organic vapors were detected at low concentrations in 4 of the 25 samples analyzed. Additional soil organic vapor analysis typically resulted in low levels.

Infiltration gallery

The infiltration gallery is a dynamic in-situ treatment system designed to stimulate hydrocarbon degrading bacteria by circulating nutrient and oxygen-amended water through petroleum-contaminated soil. The infiltration gallery was installed in the area of the fuel spill next to the railroad tanker body. The soil excavated from this area was moved into the landfarm for treatment, and the infiltration gallery was used to treat the surrounding soil that was less intensively contaminated. The infiltration gallery has a groundwater pumping well located downgradient from the location of the spill. Nutrients are added to water pumped from the well. The water is then infiltrated from a 20- by 100-ft (6- by 30-m) gallery through petroleum-contaminated soils. Oxygen is added to the water within the infiltration gallery by aeration.

Table 2. Results of organic vapor meter survey for the landfarm, 18 August 1992.

Loc.	*Conc. (ppm)*	*Loc.*	*Conc. (ppm)*	*Loc.*	*Conc. (ppm)*	*Loc.*	*Conc. (ppm)*	*Loc.*	*Conc. (ppm)*
1	0	6	1	11	5	16	0	21	0
2	0	7	20	12	0	17	0	22	0
3	0	8	0	13	0	18	0	23	0
4	0	9	0	14	0	19	0	24	0
5	0	10	0	15	0	20	0	25	0



Design

Design views of the infiltration gallery, pumping well, and piping systems are shown in Figure 6. To promote infiltration of water through the sides and bottom of the gallery, it is filled with 2–5 in. (5–13 cm) cobbles and a low percentage of finer materials. The pumping well is designed to draw water from a depth of 15–20 ft (5–6 m) below the original ground surface and to produce 35–45 gal/min (133–170 L/min) of flow. This water is distributed in the infiltration gallery through the system of 4-in. (10-cm) perforated pipes located 1 ft (30 cm) below the surface of the infiltration rock. Nutrients are mixed in a 500-gal (1893-L) tank located in the equipment shed next to the gallery. The nutrient solution is injected into the pumped water stream prior to infiltration using a chemical feed pump. Oxygen is added to the water in the infiltration gallery by 4-in. (10-cm) perforated pipe located near the bottom of the gallery. Air is supplied to the aeration piping by two 10-hp (100-kg cal/min) blowers.

Construction

The gallery was constructed by excavating an area 25 by 100 ft, 6–7 ft deep (7.5 by 30 m, about 2 m deep). High groundwater was encountered during excavation, limiting the depth of excavation. Material removed during the excavation was suspected of having been contaminated by the prior fuel spill and was placed directly into the landfarm. Following excavation, approximately 1 ft (30 cm) of the 2–5 in. (5–13 cm) infiltration rock was placed on the bottom of the gallery. The aeration manifold was then positioned and infiltration rock added to 1 ft (30 cm) below the final grade of the structure. The water distribution piping was then placed and infiltration rock added to achieve the final design grade. A 1-ft (30-cm) berm was placed around the gallery to prevent surface runoff from carrying fines into the infiltration rock. When the gallery was completed, the pumping well was installed and the equipment shelter housing the fertilizer mix tank, blowers, and electrical distribution panel was installed on site.

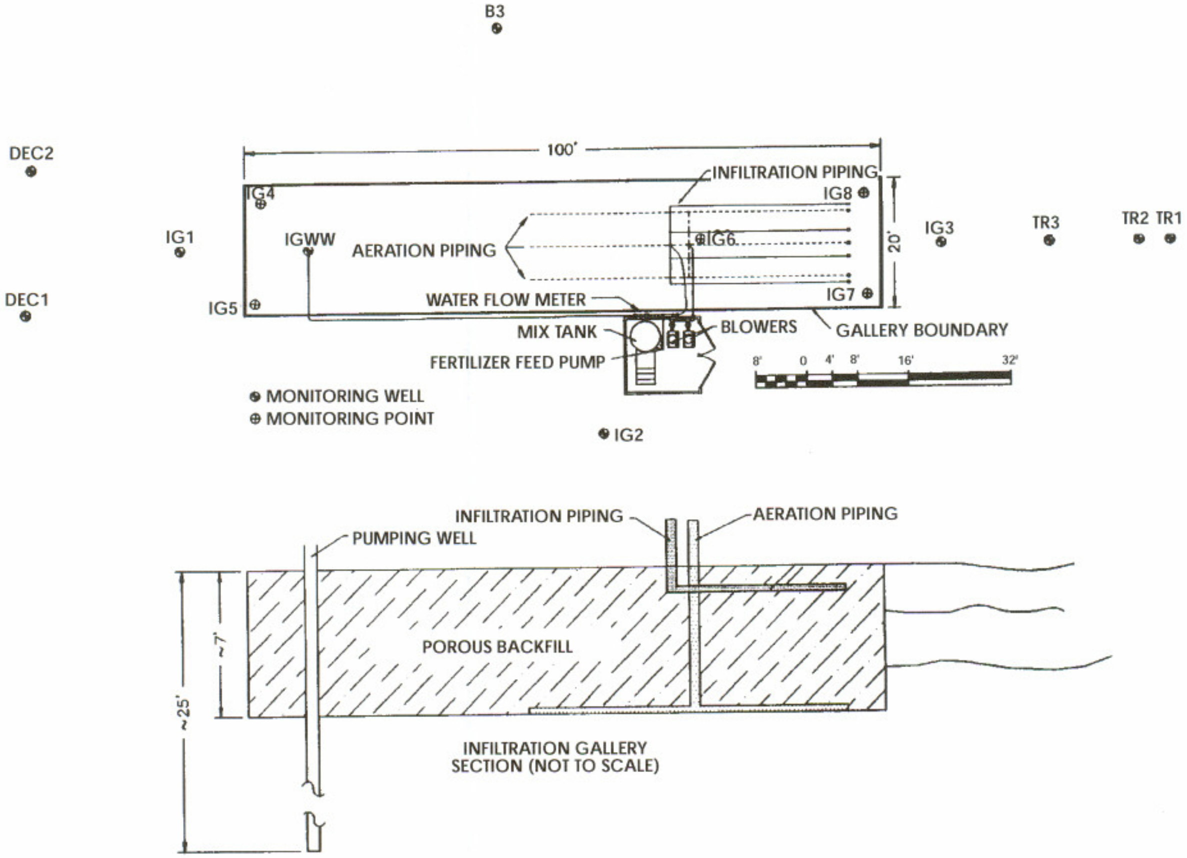


Figure 6. Infiltration gallery and monitoring wells (1 ft = 0.3048 m).

Table 3. Infiltration gallery discharge monitoring.

	Benzene (µg/L)		*Btex (µg/L)*		*NO_3 (mg/L)*	
Date	*1 Dec*	*2 Dec*	*1 Dec*	*2 Dec*	*1 Dec*	*2 Dec*
			a. 1991			
10 Aug	1.0	0.9	1.0	0.9	<DL*	1.38
23 Aug	—	—	—	—	—	—
26 Aug	—	—	—	—	0.05	0.28
03 Sep	<DL	<DL	<DL	<DL	0.43	0.45
10 Sep	—	—	—	—	2.10	4.10
17 Sep	<DL	<DL	<DL	<DL	3.83	7.08
23 Sep	—	—	—	—	7.30	7.85
01 Oct	<DL	<DL	<DL	<DL	2.10	6.78
04 Oct	—	—	—	—	—	—
07 Oct	—	—	—	—	0.80	6.50
			b. 1992			
19 Jun	<DL	<DL	<DL	<DL	0.7	1.1
26 Jun	—	—	—	—	—	—
01 Jul	—	—	—	—	1.7	1.8
06 Jul	—	—	—	—	—	—
09 Jul	0.2	<DL	0.6	<DL	8.6	6.9
16 Jul	—	—	—	—	6.5	5.1
17 Jul	—	—	—	—	—	—
23 Jul	<DL	<DL	<DL	<DL	2.8	2.8
30 Jul	—	—	—	—	0.7	0.7
06 Aug	<DL	<DL	<DL	<DL	2.8	1.2
06 Aug	—	—	—	—	—	—
13 Aug	—	—	—	—	5.38	5.59
18 Aug	—	—	—	—	—	—
20 Aug	<DL	<DL	<DL	<DL	<DL	6.6
24 Aug	—	—	—	—	—	—
28 Aug	—	—	—	—	4.2	3.5
03 Sep	<DL	<DL	<DL	<DL	0.5	0.8
11 Sep	—	—	—	—	<DL	0.6
16 Sep	<DL	<DL	<DL	<DL	0.55	0.8
01 Oct	—	—	—	—	<DL	<DL

* Below detection limits.

Operation

The infiltration gallery operation consists of pumping groundwater at a rate of approximately 40 gal/min (151 L/min) from the pumping well and infiltrating the water through petroleum-contaminated soils surrounding the gallery. A fertilizer solution is prepared in the mix tank, such that when it is injected into the stream of water to be infiltrated, the final concentration of nitrogen is 40 ppm (mg/kg). The N:P:K ratio used in the nutrient solution is 10:1:1.

On 23 August 1991, the system was activated and operated continuously until 7 October. Phosphate fertilizer was not added during 1991. The system was also operated from 23 June through 1 October 1992. During this time, the concentration of ammonium nitrate input was reduced several times because of high concentrations of NO_3 measured in the monitoring wells. Problems were also encountered when the nutrient feed pump clogged several times.

Monitoring

Parameters monitored at the infiltration gallery included soil and groundwater temperatures to a depth of 20 ft (6.1 m), nutrient feed rate and concentrations, pumping well flow rate, and groundwater elevation in and outside the gallery. Groundwater chemistry monitoring included concentrations of Cl, NO_3, PO_4, SO_4, Ca, Mg, Na, K, Fe, Br, F, Pb, O_2, nitrate, TPH, and aromatic hydrocarbons for samples extracted from the six monitoring wells surrounding the gallery and the pumping well. The numbers of hydrocarbon degrading microorganisms and microbial mineralization potential for groundwater samples extracted from several of the infiltration gallery monitoring wells were also measured during both operating seasons. The locations of the wells and points used to monitor the infiltration gallery operation are shown in Figure 6.

Frequent monitoring of benzene, BTEX, and nitrate in the groundwater at monitoring wells DEC1 and DEC2 was required for compliance with the State Waste Treatment/Disposal Permit necessary to operate the infiltration gallery. Table 3 shows the results of this monitoring for 1991 and 1992. If nitrate concentrations exceeded 5 ppm (mg/kg), the permit required action be taken to reduce the concentration; if concentrations exceeded 10 ppm (mg/kg) (federal MCL), the permit required that the system be shut off. The concentration of nitrate was found to rise quickly at the monitoring wells, reaching action levels within 2–3 weeks of startup. The measured concentrations never exceeded 10 ppm (mg/kg). Benzene and BTEX were detected only once in these wells after initial startup in 1991. These measured levels of BTEX were substantially below the federal MCL.

Before the system began operating in 1991, benzene was detected at concentrations of less than 1 ppb (µg/kg) in the monitoring wells sampled. After the system had operated for 10 days, benzene and BTEX were no longer detected in the monitoring wells. After 3 days of operation, benzene levels in the pumping well were measured at 12 ppb (µg/kg). This well was not sampled before startup. The levels of benzene in the pumping well remained near 10 ppb (µg/kg) throughout the 1991 operating season. Benzene and BTEX not being detected in the infiltration gallery monitoring wells during operation tells us that aromatic hydrocarbons were being removed by the infiltration gallery or by microbial degradation.

Before the operation began in 1992, benzene and BTEX levels were found at concentrations similar to those measured prior to operation in 1991(1 ppb [μg/kg]) in the monitoring wells surrounding the gallery. Benzene was not detected and 1.8 ppb (μg/kg) BTEX was detected in the pumping well before operation in 1992. Similar to the 1991 season, benzene and BTEX were generally below detectable limits in the six monitoring wells surrounding the infiltration gallery during the nearly 100 days of operation in 1992. Benzene was detected at less than 2 ppb (μg/kg) and BTEX levels were less than 5 ppb (μg/kg) for water extracted from the pumping well during 1992, which is significantly lower than the 1991 levels.

The size of the microbial population before startup of the infiltration gallery in 1991 was higher (counts of hydrocarbon-degrading microorganisms in groundwater samples collected next to the infiltration gallery) than in samples from other monitoring wells on and off the site. A similar trend was observed in the mineralization potentials. After startup, our estimates of microbial population numbers and mineralization potential declined significantly at the monitoring wells near the infiltration gallery.

The observed rapid transport of nitrate away from the gallery and the decline of microbial population and activity levels showed us that the water being pumped from deeper in the aquifer flows across the surface of the groundwater table some distance from the gallery. As a result, the microbial population possibly was being moved from the site faster than it could regenerate. To quantify the hydrological influence of the infiltration gallery in terms of flow rates, radius of influence, and dilution factors, groundwater tracer studies were developed for the 1992 operating season.

Two groundwater tracer studies, conducted in conjunction with the infiltration gallery, determined the flow pattern and flow rate of the nutrient-enriched water as it moved away from the infiltration gallery and was drawn towards the groundwater pumping well. The primary tracer study introduced sodium bromide into the stream of water flowing to the infiltration gallery, beginning on 21 July 1992. The concentration of sodium bromide at the point of mixing was 4 ppm (mg/kg). Injection was stopped on 1 August 1992. Frequent monitoring of the bromide concentrations in 15 wells and monitoring points surrounding the gallery continued until 13 August 1992.

The second tracer study introduced 1000 L of a 330 ppm (mg/kg) solution of water and sodium fluoride into an injection well that was hydrologically up-gradient of the infiltration gallery. The tracer was injected during a 1-hour, 39-minute period on 8 July 1992. Fluoride concentration was monitored in wells next to the point of injection for several weeks after.

Groundwater sampling

The wells mentioned in the previous paragraph were constructed with PVC pipe. The B, IG, DEC, and TR series wells were constructed with flush-threaded PVC pipe. The screened interval of the wells consists of machine-cut slots in the PVC pipe, with silica sand used as the outside packing. The upper portion of the TR series wells is cased in a 1-ft-diam. (30-cm) pipe that extends above the ground surface, terminating in a lockable sampling shelter. The B, IG, and DEC series wells are sealed with bentonite pellets, and capped at the surface with a cement–bentonite slurry seal. Construction details of the PTAN well are not readily available. We assumed the construction of this well to be similar to that of the IG series wells.

Results

During July 1989, Shannon & Wilson sampled the B series wells for purgeable aromatics and purgeable halogens. From fall 1990 to the present, personnel from the Department of Natural Resources (DNR), Division of Water, sampled groundwater at the site. Initially, only wells PTAN, B1, B2, and B4 were sampled. Well B3 was added during spring 1991. Monitoring at the IG and DEC series wells commenced during August 1991 in conjunction with the startup of the infiltration gallery.

Samples collected by DNR were analyzed by the Alaska Division of Water, Water Quality Laboratory in Fairbanks, Alaska, and by Northern Testing Laboratories (NTL), also located in Fairbanks. Parameters measured by DNR included field measurements of conductivity, dissolved oxygen, temperature, and pH. Analyses by the Water Quality Laboratory include the concentrations of Cl, NO_3, PO_4, SO_4, Ca, Mg, Na, K, Fe, Br, F, Pb, alkalinity, and TPH. Aromatic hydrocarbons and nitrate analyses, which were required for compliance with the water discharge permit needed to operate of the infiltration gallery, were conducted by NTL.

Recirculating leach bed

The recirculating leach bed is a closed-cell system that circulates nutrient-amended water through contaminated soil. Air diffusers add oxygen to the water. The system was designed so that the lined cell and associated piping could be abandoned in place once soils had been remediated. The above-ground mechanical equipment, which is the primary cost associated with this type of system, could then be used at other locations.

Recirculating leachbeds are similar to slurry reactors. The concept is to build a lined containment area to serve as a bioreactor (Fig. 7). Either a pit (generally resulting from the excavation), a bermed perimeter, or a combination can be used, depending on available materials. Contaminated soil is placed into the bioreactor and, through an inexpensive PVC distribution system, aerated and nutrient-amended water is recirculated into the bottom of the bioreactor, upwards through the contaminated soil, and then through overlying ponded and aerated water. Skid-mounted mechanical systems include a mixing tank and circulation pumps for water and air.

Design

The 26- × 26-ft (8- × 8-m) pit was lined with a nominal 20-mil (0.508-mm-thick), woven, black

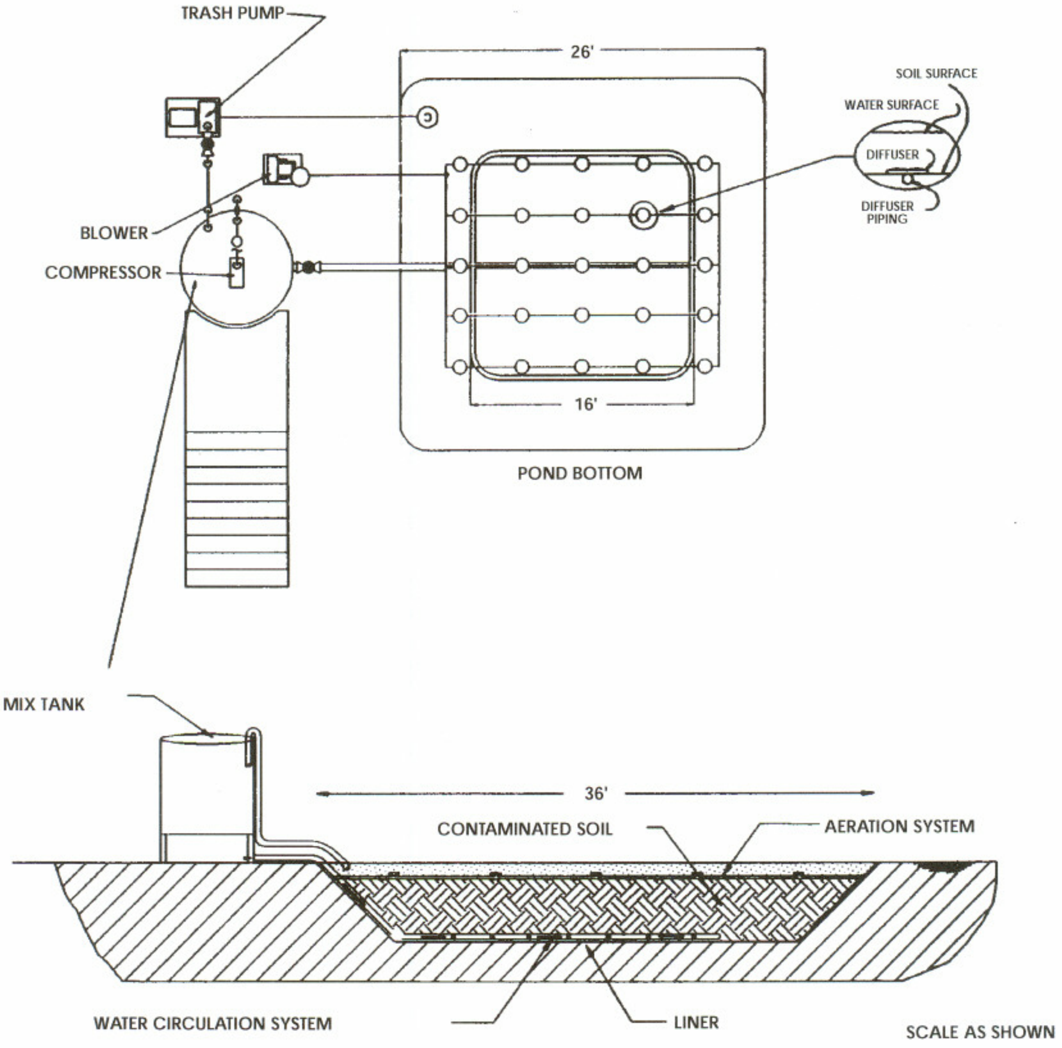


Figure 7. Recirculating leachbed system (1 ft = 0.3048 m).

HDPE scrim, coated on both sides with black HDPE. A water distribution system of 4-in. (10-cm) perforated schedule 40 PVC pipe was placed on top of the liner and covered with contaminated soil. An air header constructed of 4-in. (10-cm) schedule 40 PVC pipe was placed just below the surface of the contaminated soil, with 25 air diffusers attached to the piping located 4 in. (10-cm) above the soil surface. Water is added to the pit, saturating the contaminated soil, and submerging the air diffusers.

Water is circulated through the system using a 1-hp (10-kg cal/min) trash pump to extract water from the surface of the leach bed. The water is pumped to a 1000-gal (3785-L) fertilizer mix tank and is allowed to flow by gravity from the bottom of the tank to the water distribution piping in the bottom of the pit. The water then percolates up through the soil mass carrying nutrients and oxygen to the hydrocarbon degrading bacteria. A 9-kW emersion heater is placed in the tank to elevate the temperature of the circulating water.

Air is supplied to the diffusers by a 2.5-hp (25-kg cal/min) regenerative blower. Aeration was also provided in the mix tank by an air compressor, attached to a single air diffuser located in the bottom of the tank.

Construction

The leach bed was installed at the location of the cross-shaped burn pit (Fig. 1c). Contaminated material in the area was excavated and moved to the landfarm facility and the area was back-filled with mechanically compacted sandy-silt material. The leach bed pit was then excavated and recompacted. The liner was factory seamed and arrived at the site as a single 55- × 55-ft (16.75- × 16.75-m) sheet. The liner was fitted into the excavation and the water distribution manifold was placed at the bottom of the pit. Approximately 150 yd^3 (115 m^3) of contaminated soil that was stockpiled in the landfarm was placed in the pit. The air distribution header was buried by hand at the surface of the contaminated material and the skid-mounted mechanical equipment was moved to the site and plumbed to the air and water distribution systems.

Operation

Beginning on 9 August 1991, water was pumped from the infiltration gallery well to fill the leach bed system. Initially, the air manifold floated to the surface and sandbags were used to anchor it in place. On 12 and 13 August, water continued to be pumped into the pit until the water level was approximately 1 ft (30 cm) above the surface of the contaminated soil. On 17 August the water level had receded and more water was added. After water had to be added several times, it was apparent that the liner system had leaked. Approximately 35,000 gal (132,000 L) of water was pumped into the pit. This is enough to fill the empty pit. Although the cause of the leak has not been verified, several possibilities exist: mechanical damage during placement of the contaminated soil with the backhoe; tearing of the liner at a seam as it was loaded with soil; puncturing of the liner by rocks in the fill material because the liner was not protected by sand or cushion fabric; or cracks in the thin HDPE coating covering the scrim when the liner was folded into the corners of the pit.

Result

Although we encountered problems with the recirculating leachbed at the FIA site, a member of our research team was involved in designing and operating another recirculating leachbed at more northerly location. At this location, TPH levels in a diesel- and waste-oil-contaminated soil decreased from between 300 and 47,000 mg/kg to between 240 and 570 mg/kg in 5 weeks at Anatuvuk Pass, in northern Alaskan. Corresponding values for petroleum and hydrocarbon-degrading microorganisms, as determined by the sheen screen technique (Brown and Braddock 1990), increased from 1.8×10^4/g to 4.5×10^6/g. Final diesel-range organics, after 8 weeks of treatment, were less than 200 mg/kg.

DISCUSSION AND CONCLUSIONS

Landfarm

The results from the landfarm treatment are promising and significant. A seven-fold variability in rates suggested that the slower rates could be improved to match or approach the faster rates. Faster degradation rates would reduce the time and cost required for treatment and consequently reduce the chance of leaching or off-site migration during treatment. At least part of the difference in rates may be ascribable to moisture and nutrient additions. Evidence of this is seen in the pattern of the degradation variability, which appeared to correspond to the pattern of irrigation and fertilization. Owing to the nature of the couplings in the irrigation lines, the center of the site was more heavily treated than the edges.

The greatest operational problem that we encountered in the landfarm so far is the management of excessive soil moisture. Spring snow removal is the only way of limiting water input from precipitation. High soil-moisture content during the early summer may not allow tillage, shortening an already brief operating season. Evaporation of excess moisture may be enhanced by pumping water from the drain system, and spraying it on the surface of the landfarm. However, the pumping rate for the underdrain system is limited by the rate of water percolation through the filter rock to the perforated drainage pipe.

On the basis of testing and observation, landfarming of the petroleum-contaminated soils from the old burn pit site appears to be a viable method of remediation. With appropriate nutrient amendments, the landfarm may be used to remediate 1100 to 1600 yd^3 (841 to 1223 m^3) of material during one summer season.

Infiltration gallery

Because of the difficulty in obtaining sufficient data from an in-situ, saturated system, it is difficult to draw any definite conclusions regarding the operation of the infiltration gallery. However, some general observations can be made. The significant reduction in the iron (Fe) concentrations in the groundwater during operation of the facility tells us that iron is precipitating. This was expected, but, to date, it has not excessively plugged the gallery walls or bottom. There has been some mounding of water in the gallery, indicating that the precipitation of iron is slowing the movement of water away from the gallery.

Dissolved oxygen concentrations at the gallery monitoring wells remained low (less than 10 mg/L) throughout the operating periods. Oxygen concentrations were slightly higher in the wells closer to the gallery, showing the influence of the aeration system. Also, phosphate (PO_4) was not detected at any of the wells during the period when it was added to the infiltration water at a final concentration of approximately 4 mg/L. These factors would be expected to lower the total population of microorganisms and slow their metabolic processes.

Plans are to continue monitoring of groundwater concentrations of aromatic hydrocarbons in wells next to the infiltration gallery. Soil contaminant levels around the gallery will be quantified to see if more treatment is required. Further operation of the infiltration gallery will be based on continued monitoring.

Recirculating leachbed

We encountered three problems during the brief operation of the leachbed. First, the air manifold floated to the surface. This should be anchored using cables and "deadmen" in future installations. Second, "piping" of water was observed in the soils immediately above the water distribution manifold. This will short-circuit the flow of nutrients and oxygen through the entire soil mass, potentially slowing the rate of remediation. Third, it may be necessary to install a heavier liner and to provide better protection for it by installing cushion fabric or a layer of sand.

The more rapid remediation attained with the recirculating leachbed can be used alone or in conjunction with landfarming and could provide an expedient means to treat highly contaminated soil. This would increase the potential for landfarming of the remaining soil without liner requirements.

Because of the relatively small amount of soil that the leachbed can remediate relative to the quantity of contaminated soil located at the CFR site, there are no plans to reconstruct it. Contaminated soils in the pit will be moved to the landfarm in the future. The equipment used with the leach bed may be useful for remediating fuel-contaminated water generated in conjunction with fire training exercises at the new lined fire-training pit recently constructed at FIA.

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13. ABSTRACT (*Maximum 200 words*)

A field demonstration and research project was conducted in Fairbanks, Alaska, to demonstrate, evaluate, and document the construction and operation of three selected bioremediation technologies—landfarming, recirculating leachbeds, and infiltration galleries. Landfarming involves adding water and nutrients to contaminated soil to stimulate microbial activity and contaminant degradation. Infiltration galleries are dynamic in-situ treatment systems designed to stimulate microbial activity and subsequent hydrocarbon degradation by circulating nutrient- and oxygen-amended water through petroleum-contaminated soil. Recirculating leachbeds, in a way similar to slurry reactors, aerate and mix nutrients with contaminated soil, and can be built as on-site bioreactors. Estimated biotreatment costs in the landfarm were between \$20 to \$30 per cubic yard (\$15 to \$23 per cubic meter). Nutrient placement has been demonstrated to be a critical factor, even though the site is tilled and mixed frequently. Success of the infiltration gallery was more difficult to document. Benzene was detected at less than 2 ppb and BTEX levels were less than 5 ppb for water extracted from the pumping well during 1992, which is significantly lower than the 1991 levels. Problems were encountered during the brief operation of the recirculating leach bed, but a similar system has performed well. Relatively simple, low-cost techniques provided significant potential for improving degradation rates.

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