Development of Federal Guidelines for

Landfarming Contaminated Soils

- Review of Existing Guidelines -

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ABSTRACT

Among the most cost-effective and practical means of remediating contaminated soils, landfarming is well-suited to Canada due to its simplicity and land-intensive requirements. Despite its frequent application, there is not one set of standard guidelines for the application of landfarming on federal sites. There was an Environment Canada guideline developed in 1993, but since then there has been new research performed and several provincial guidelines developed that should be considered. As a first step in developing these guidelines, this report describes existing landfarming guidelines from Canadian, U.S. and other foreign jurisdictions, other applicable organisations and remediation contractors and researchers were reviewed and compared.

Those provinces with landfarming guidelines generally take the approach of providing numerical constraints or recommendations for landfarming siting, design, operations, and monitoring. The Environment Canada (1993) guidelines also take this approach. Other provinces with no numerical constraints require some type of remediation action plan acknowledged by the appropriate provincial agency.

In the contemplated development of a set of landfarming guidelines for federal contaminated sites, the federal government can use the 1993 Environment Canada guidelines as a basic structure around which additional material from the various recognized sources, where applicable to Canadian site conditions, can be used to enhance the document. Based on the review of the existing guidelines, the following 2-step approach for establishing new federal guidelines is suggested:

Step 1:

- Environment Canada (1993) prescriptive criteria should be considered first.
- In the case where no Environment Canada guideline has been established for a particular criterion, the most stringent existing provincial criterion should be considered.

Step 2:

- Where provincial/territorial criteria vary from the criteria set out in Step 1, each criterion should be evaluated and a justifiable consensus reached as to the most appropriate guideline (whether the most stringent available criterion or not).
- Where a consensus cannot be reached, it is likely due to regional site differences. Site specific allowances should be provided to account for unique climatic or geophysical conditions in various regions in Canada.

TABLE OF CONTENTS

LIST OF TABLES

PREAMBLE

SAIC Canada has been contracted by the Contaminated Sites Division of Environment Canada to undertake a review of existing guidelines for landfarming and, based on this review, to recommend federal guidelines for the use of landfarming at federal contaminated sites in Canada.

This project is comprised of a Guideline Review, Interim Report, Draft Guideline Development, and Final Guideline Development. This document covers the Guideline Review portion of the work; the remainder of this project is to follow.

1 INTRODUCTION

1.1 Landfarming Definition

Landfarming is an *ex situ* contaminated soil bioremediation technique that involves excavating and spreading contaminated material in beds consisting of a thin layer of uniform thickness or windrows. Contaminant bioremediation results from the manipulation of various conditions that stimulate aerobic microbial activity, such as:

- aeration (e.g., tilling);
- moisture content (e.g., irrigation or spraying);
- pH (e.g., buffering or neutralizing by adding lime);
- soil conditioning (e.g., addition of amendments such as bulking agents, nutrients, etc.).

Landfarming is also commonly known as land treatment, land spreading, or cell bioremediation. These later two terms are more specific types of landfarming in that landspreading is always passive (no aeration) and cell bioremediation involves specially-designed and lined treatment cells.

The mechanisms employed during the landfarming process are various degrees of volatilization, dissolution into surface and ground water, sorption to the subsurface soils, and biodegradation, depending upon the contaminant constituents, soil characteristics, and landfarming control methods used. Responsible landfarming remediation manages these mechanisms such that biodegradation is the dominant mechanism; volatilization is minimized; contaminated surface waters are treated or re-circulated; and groundwater contamination is prevented through the use of liners.

1.2 Landfarming Applicability

In Canada, landfarming is primarily used in remediating petroleum-contaminated soils and, to a lesser extent, other hazardous and non-hazardous wastes (GOwen Environmental Limited. 2002; Zimmerman and Robert. 1990; and Andrews Environmental Engineering. 1994). It has been estimated that half of all biodegradable petroleum-contaminated waste generated is remediated through landfarming (Thibodeaux. 1982). A survey of remediation technologies in Canada (SAIC. 2004) revealed 14 out of 35 contaminated sites employed *ex-situ* bioremediation methods (biopiles, compost or landfarming). These 14 sites were split almost evenly between federal, provincial and private industrial sites and were located across the country and in the North.

Landfarming has been proven effective in reducing the concentrations of various constituents of petroleum products ranging from those with a significant volatile fraction, such as gasoline (GOwen Environmental Limited. 2002; USEPA. 1994; Poland, *et al*. 2003), to semi-volatiles such as diesel (Chatham. 2003), to those that are primarily nonvolatile, such as heating and lubricating oils (USEPA. 1994; Poland, *et al*. 2003). Very heavy oils or tar contamination are not suitable for landfarming (Poland, *et al*. 2003).

Among the most cost-effective and practical means of remediating contaminated soils, landfarming is well-suited to remote regions in Canada due to its simplicity, effectiveness and land-intensive requirements.

2 PURPOSE

Landfarming techniques have been used at and recommended for a number of contaminated sites in Canada that fall under the responsibility of the federal government. Despite its frequent application, there are no standard guidelines for landfarming at federal sites. Most of the existing procedures, policies or guidance on landfarming is currently at the provincial/territorial government level. These existing guidelines, therefore, vary widely in their scope, detail and specific parameter values, depending upon the jurisdiction. The purpose of this study is two-fold: (1) to review any existing guidelines, compile numerical and subjective parameters and compare this quantitative and qualitative information and (2) to develop federal guidelines for landfarming at federal contaminated sites. The latter portion of this study is to follow under separate cover.

There is currently much inconsistency in the practical approach to landfarming contaminated soils. The onus is on the property owner to contract a remediation contractor (often adhering to provincial “site professional” criteria) who develops and implements a remediation plan which, in turn, is reviewed and overseen by a regulatory agency. There is the assumption that an engineering professional will use best available technologies and professional expertise in order to remediate the site. The rationale behind this approach is based on the variability of contaminated sites; each site varies in type and extent of contamination, size of contaminated site, geographic/climatic site conditions, etc.

However, adoption of a more systematic and thorough approach, via landfarming guidelines, would lend assurances that landfarming remediation at each federal contaminated site is addressed consistently throughout Canada. By providing a checklist of key parameters or recommendations on landfarm siting, design, construction, operation, monitoring and closure, such guidelines would be beneficial for federal agencies responsible for contaminated sites, as well as for provincial/territorial and local agencies, remediation contractors and other stakeholders. These proposed guidelines would not eliminate existing provincial/territorial regulatory requirements such as the stipulation that a professional engineer develop a remediation plan.

3 SCOPE

This review is limited to existing guidelines, policies and procedures available for landfarming as a technique for contaminated soil remediation. An emphasis was placed locating information related to the use of landfarming in Canadian conditions, however foreign information sources, where applicable, were also reviewed. Information was gathered from a systematic review of Internet sources, contacts with government agencies, and searches of conference proceedings and library materials.

4 GUIDELINE REVIEW

In the search for existing guidelines or policies related to landfarming use, the following sources were contacted or reviewed:

- provincial and territorial Ministries of Environment (Internet searches);
- regional Environment Canada offices (e-mail contact initiated September 8, 2004);
- U.S. Environmental Protection Agency (USEPA) (Internet searches, EC contact);
- other jurisdictions (environment departments of Alaska, Kentucky, Delaware and Australia) (Internet searches);
- U.S. Army Corp of Engineers (Internet search);
- other applicable organizations (Petroleum Alliance of Canada (PTAC), Canadian Association of Petroleum Producers (CAPP), Canadian Petroleum Products Institute (CPPI) and U.S. Department of Energy) (Internet searches, EC contact); and,
- various remediation contractors and researchers (Internet searches, conference proceedings and library materials).

A summary of each of the relevant documents reviewed is provided in this section. A table is provided in Section 6 that offers a comparison of the guidelines reviewed that contain prescriptive elements related to the design, operation, and monitoring of landfarming techniques. Sources with less prescriptive elements were not included in this table; however, were still reviewed for thoroughness and to garner an understanding of various approaches to such guidelines.

4.1 Provincial and Territorial Ministries of Environment

4.1.1 Yukon

Landfarming is specified in the *Contaminated Sites Regulation* of the Yukon *Environment Act* (2002) and guidance is provided in two online documents (Government of Yukon. 2004a; 2004b). The Regulation provides general information and regulatory requirements for contaminated site remediation; landfarming is specifically mentioned as a remediation option. The online documents provide guidance such as siting, construction and operational recommendations for treating petroleum hydrocarbon contaminated soil. See Table 6-1 for the requirements specified in these documents.

4.1.2 Northwest Territories

The *NWT Environmental Protection Act (*R.S.N.W.T. 1988a, c.E-7*)* gives the Government of the Northwest Territories (GNWT) the authority to ensure the environmental protection primarily of Commissioner's Land, municipal lands or lands involving GNWT activities.

Subsequently, the *Environmental Guideline for Site Remediation* (GNWT. 2003) was developed as a guidance document that describes the process used to identify, assess, and remediate contaminated or potentially contaminated sites. This guideline does not specify remediation technologies, only the procedure to be followed by the party responsible for the contaminated site. The responsible party is expected to retain "qualified persons", i.e., a remediation contractor, to manage site remediation and develop a Remediation Action Plan (RAP). Details of such a plan are outlined in the guideline. The GNWT approves the RAP, reviews monitoring reports and authorizes site closure.

In the NWT, only the original contaminated site is addressed; once soil has been excavated and removed from the site, the GNWT does not monitor the excavated soil or its treatment facility (i.e., no permit is required for landfarming). The municipal government and aboriginal stakeholders are obviously concerned with the treatment facility since these parties aid the contractor in siting the facility; however, no guidelines are followed. Once again, it is the onus of the remediation contractor to ensure remediation is complete and to report back to the local government so that the remediated soil and the facility land may be made available upon closure.

There is a document prepared for Indian and Northern Affairs Canada (INAC) in the NWT entitled *Manual for One-Time Landfarming of Hydrocarbon Contaminated Soils* (EBA. 1996) but it does not appear to be widely used or distributed (D. Jessiman, Regulatory Research Specialist, INAC, *Personal Communication.* October, 2004).

4.1.3 Nunavut

No guideline has been developed for contaminated site remediation in Nunavut. Essentially the same procedure is followed as in the NWT under the *Environmental Protection Act (Nunavut)* (R.S.N.W.T. 1988b, cE-7). *Environmental Guideline for Site Remediation* (GNWT. 2003) has been informally adopted by the Government of Nunavut.

4.1.4 British Columbia

British Columbia addresses contaminated sites in the *BC Environmental Management Act (EMA)* (2003) and the associated regulations: *Contaminated Sites Regulations (CSR)* (1996) and *Hazardous Waste Regulations* (1988). Section 56 of *the EMA* specifies that in evaluating remediation alternatives, preference must be given to remediation alternatives that provide permanent solutions to the maximum extent practicable, taking into account several factors, including but not limited to, human health and ecological effects, technical feasibility, and costs.

Elements of a remediation plan are identified in the definition of a remediation plan in the BC Contaminated Sites Regulation (CSR) (1996). Guidance is provided on approaches to site remediation, requirements for site investigations and regulatory requirements, but specific remediation methods are not included (BC. 2004b). British Columbia requires a professional statement indicating that the plan has been prepared in accordance with all requirements in the EMA and the regulations, and certifies that the person signing the statement has demonstrable experience in remediation of the type of contamination at the site for which the statement applies and is familiar with the remediation carried out on the site (CSR Section 63). In addition, as of November 1, 2004, all applications for low to moderate risk sites must be submitted as roster submissions by approved professionals.

Depending on the chemical characteristics of the contaminated soil, permits may be required for landfarming under the BC Hazardous Waste Regulation (1998). Specific requirements for land treatment facilities are listed in Sections 28-32. These include siting and operational requirements, and performance standards. These requirements are included in Table 6-1.

4.1.5 Alberta

A memorandum of understanding (EUB. 2000) between the Government of Alberta and the Alberta Energy and Utilities Board (EUB) has agreed on a harmonization of waste management practices in Alberta. The EUB is responsible for all oil field-related waste practices and where both oil field and non-oil field wastes are considered together, the EUB will act as the “one window” and coordinate the application review with input from the other agency. Oilfield wastes must, first, not contravene any EUB requirement for the management of oilfield wastes and then, second, qualify for acceptance at the AENV-regulated facility. Upon entering the facility, the oilfield waste then becomes a waste regulated by AENV for the purpose of storage, treatment, disposal, or further transportation.

Alberta has drafted the *Code of Practice for the Land Treatment and Disposal of Soil Containing Hydrocarbons (Draft)* (Government of Alberta. 2004) that provides site, design, operational, monitoring, and reporting requirements for landfarming in Alberta. This document has not been finalized and is not widely available. Alberta also adheres to the *Salt Contamination Assessment and Remediation Guidelines* (Government of Alberta. 2001) which provides some information on remediation of contaminated soils. For land treatment information, this document directs the user to the *Oilfield Waste Management Requirements for the Upstream Petroleum Industry Guide 58* (Alberta Energy and Utilities Board (EUB). 1996).

Minimum requirements for the design and operation of techniques and facilities are provided in *Guide 58*. Although this document includes all applicable remediation methods, a section on land treatment provides specifics on siting; contaminant standards for receiving soils; operational pH levels; operational period restrictions, etc.

Table 6-1 provides an itemized comparison of design and operational parameters from both the *Code of Practice* and *Guide 58*. Additional requirements are provided in these guidelines which are too detailed to itemize in their entirety. The *Code of Practice*, in particular, has many specifics on leachate control, leachate release standards, groundwater and soil monitoring requirements, maximum allowable concentrations of soil quality parameters for soil re-use and various regulatory requirements.

4.1.6 Saskatchewan

The Government of Saskatchewan has a brief guideline on landfarming. *Guidelines for Treatment and Disposal of Petroleum Contaminated Soils at Municipal Waste Disposal Grounds* (1994) recommends land application procedures such as soil application rates, areas required for different volumes, tilling recommendations and monitoring requirements.

No siting or design parameters are offered in this four page document. An itemization of these requirements is shown in Table 6-1

4.1.7 Manitoba

Treatment and Disposal of Petroleum Contaminated Soil (Government of Manitoba. 2002) is a concise guideline for landfarming in Manitoba. Siting, operational, soil sampling and closure requirements, as well as requirements for baseline characterization and soil re-use guidelines, are provided (see Table 6-1). Additional requirements such as baseline data collection, inventory control, inspections and monitoring procedures, recordkeeping and reporting are also provided.

4.1.8 Ontario

In the *Guideline for Use at Contaminated Sites* (Government of Ontario. 1996), site specific risk management and risk assessment approaches are recommended due to the variability of contaminated sites. No landfarm siting, design or operational procedures are available.

For any soil remediation process, a Remedial Work Plan (RWP) is required. It is understood that qualified professionals are capable of designing, implementing and operating suitable remediation for the site, and the Ministry of Environment will regulate this process. The remedial work plan (RWP) requires such details as treatability studies; detailed design and implementation plans; and monitoring and verification sampling plans and schedules.

Other specifics provided in the *Guideline for Use at Contaminated Sites* include the following;

- All reasonable and practicable attempts should be made to remove all solid waste products and phase-separated liquid waste products;
- The intentional mixing of on-site contaminated soils with clean soils to meet restoration objectives is not recommended or endorsed, except in a few isolated situations; and
- The ongoing, uncontrolled release of volatile compounds to the air as part of a remedial action is not acceptable. Every effort should be made to recover volatile contaminants and prevent release to the atmosphere.

4.1.9 Québec

The Ministère de l'Environnement has a general guideline for biological treatment processes. *Terrains Contamines – Lignes Directrices pour le Traitement de Sols par Biodégradation, Bioventilation ou Volatilisation* (Gouvernement du Québec. 1999b) provides recommendations for particular characteristics of contaminated soil prior to, and during, remediation. This is a different approach from other provincial guidelines: rather than providing requirements for landfarming engineering parameters, the guideline addresses the inherent constraints of the contaminated soil and biodegradation process. For biodegradation in general, there are numerical constraints on the receiving soils such as:

- total petroleum hydrocarbons < 3%;

- contaminant solubility >1 000 mg/L;
- porosity < 10% ; and
- retention capacity 40-70%.

In addition to soil parameters, some general biological treatment operational parameters are also provided as follows:

- optimal temperature >10 ^{o}C;
- nutrient amendment (C:N:P): 100:10:1;
- soil pH 5 – 9; and
- bacteria count 10^6 CFC/g.

No specific numerical parameters for landfarming siting or design are provided. However, a discussion on landfarming advantages and disadvantages over *in situ* treatment options is presented. Since the above listed parameters would only fit into one Table 6-1 category "Receiving Soil Type Restrictions", this guideline was not included in the comparison.

4.1.10 New Brunswick

The New Brunswick Department of Environment and Local Government has established a *Guideline for Management of Contaminated Sites Version 2* (Government of New Brunswick. 2003). As with all the Atlantic Provinces, New Brunswick uses the Atlantic Risk-Based Corrective Action (RBCA) process for addressing site remediation. Guidelines for landfarming or other remediation methods are not specified. The responsible party is expected to contract a Site Professional to develop a Remedial Action Plan (RAP), details of which are provided in the *Guideline for Management of Contaminated Sites.*

4.1.11 Nova Scotia

Nova Scotia Environment and Labour has established the *Guidelines for Management of Contaminated Sites in Nova Scotia (*Government of Nova Scotia. 1996). These guidelines take a risk assessment approach (Atlantic RBCA) of contaminated sites whereby a site professional is required to design and implement a RAP. No remediation methods are mentioned specifically in this, or other applicable, document.

4.1.12 Prince Edward Island

The *Petroleum Contaminated Site Remediation Guidelines* (Prince Edward Island. 1999) follows the Atlantic RBCA approach to contaminated sites. Minimum monitoring requirements for site closure and on-going management are presented in Appendix C of these guidelines. No remediation methods are addressed in these guidelines.

4.1.13 Newfoundland and Labrador

Newfoundland has soil treatment facilities in much of the province so the disposal of hydrocarbon contaminated soils (> 1000 mg/kg TPH) into municipal landfills is now prohibited. Hydrocarbon contaminated soil must be remediated using Department-approved technology and sites. This policy is expected to be extended to the entire province once similar facilities or services become available. Landfilling of hydrocarbon contaminated soil is permitted in Labrador (Government of Newfoundland and Labrador. 2003).

As with other Atlantic Provinces, the RBCA approach is an option available in Newfoundland and Labrador, as set out in the *Contaminated Sites Cleanup Criteria* (1999).

4.2 Environment Canada Regional Offices

Contact with each of the Environmental Canada regional offices has unearthed three Environment Canada documents related to landfarming:

1. "Appendix 3: Guidelines on the Ex-Situ Bioremediation of Petroleum Hydrocarbon Contaminated Soils on Federal Crown Land" from the *Study on the Use of Landfarming and Surface Impoundments in the Management of Hazardous and Non-Hazardous Waste* (Environment Canada. 1993) (M. Brooksbank, Environment Canada, Ontario Region. *Personal Correspondence*. September 8, 2004).
2. *Study on the Use of Landfarming and Surface Impoundments in the Management of Hazardous and Non-hazardous Waste*. Project Number K2237-1-0009 (GOwen Environmental Limited. 2002) (M. Brooksbank, Environment Canada, Ontario Region. *Personal Correspondence*. September 8, 2004).
3. *Landfarming at Federal Facilities (draft)*. (Environment Canada. 2004) (J.E. Gaskin, Senior Environmental Officer, Environment Canada, Ontario Region. *Personal Correspondence*. October 8, 2004).

"Appendix 3" provides siting, design and operating requirements for landfarming similar in content to some of the provincial guidelines reviewed (e.g. Yukon, Alberta, Manitoba and Saskatchewan). Monitoring and recordkeeping requirements as well as points to consider when decommissioning a site are also provided. See Table 5.1 for these requirements. Regarding characterization of the receiving soils to the landfarm, the guideline provides a table for sampling numbers for various soil volumes being treated. A remedial plan is also recommended in this document; these guidelines list various requirements of the plan.

The GOwen study is a broad look at landfarming: the technology, regulatory framework and practical guidance for federal government departments dealing with contaminated sites located on federal crown land for which they have custodial responsibilities. This study admits the variability of contaminated sites in Canada precludes the approach of establishing a comprehensive set of design specifications, but rather it offers general guidance for federal departments to use when addressing federal contaminated sites. "Appendix 3", as cited above, is also included as an appendix in the GOwen study.

The Ontario Region's *Landfarming at Federal Facilities* is a draft Technical Assistance Bulletin (TAB) that presents the approach taken at Environment Canada's Atmospheric Environmental Service former weather station in Big Trout Lake, Northern Ontario. The TAB is, however, general in nature in that it provides design, operational and cost information that may be applicable to other contaminated sites. Information was sourced from the 1993 Environment Canada document cited above and the U.S. EPA document cited in Section 5.3, as well as from experience at the landfarming operation at Big Trout Lake. As this document is part of the work plan for this current year (J.E. Gaskin, Senior Environmental Officer, Environment Canada, Ontario Region. *Personal Correspondence*. October 8, 2004), it has not been finalized or distributed. Criteria in this document are consistent with that of the Environment Canada (1993) guideline, but additional criteria (e.g. tilling is recommended once or twice per month; leachate/run-off collection should not exceed 60% capacity) is also provided. Under the column "Environment Canada" in Table 6-1, those criteria attributed to this regional document only has been footnoted, otherwise, criteria are attributed to both Environment Canada (1993 and 2004) guidelines.

4.3 U.S. Environmental Protection Agency (USEPA)

An often cited document on landfarming is "Chapter V Landfarming" in the USEPA guideline *How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: a Guide for Corrective Action Plan Reviewers* (USEPA. 1994). This guideline was established prior to most of the other documents cited and appears to have been used in the development of many of the other guidelines reviewed.

USEPA (1994) provides a discussion of advantages and disadvantages to landfarming including an evaluation process flow chart to identify landfarming suitability for a particular contaminated site. Further, soil characteristics suitable for landfarming are recommended, information is provided on contaminant characteristics (volatility, chemical structure, concentration and toxicity). Details are provided on conducting treatability studies to determine soil toxicity, texture, nutrients and contaminant biodegradability. Climatic conditions for effective landfarming are also provided.

The USEPA document provides guidance on landfarm design; and evaluations of landfarm operations and monitoring. Very little siting criteria are available, likely due to the fact that state regulations dictate such matters as buffer zones. This widely used guideline has been included in Table 6-1, for comparison with applicable Canadian criteria.

4.4 Other Jurisdictions

Landfarming guidelines are available on-line from some U.S. States and Australia. As these jurisdictions take vastly different approaches to their guidelines, a comparison table of numerical and subjective recommendations is not useful. An itemized summary of each guideline follows.

4.4.1 Kentucky

Kentucky has a document entitled *Landfarming and Composting of Special Waste* (State of Kentucky. 2004), intended for the remediation of wastewater treatment sludges or other wastes with specific concentration ranges of metals (although hazardous wastes are prohibited). In addition to permitting and other regulatory requirements, various siting, operational and monitoring requirements as follows:

- Site Selection:
  - prohibited on a 1-in-100 year floodplain;
  - > 4 feet (1.2 m) above seasonal high water table and bedrock;
  - on a base of soils with a permeability rate between 0.2 and 6 inches/hour (1.6×10^{-4} – 4×10^{-3} cm/s);
  - < 15% slope;

- buffer zones: residences and occupied buildings – 300 ft (91 m)
  water well – 300 ft (91 m)
  surface water body – 300 ft (91 m)
  karst feature – 300 ft (91 m)
  perennial stream – 300 ft (91 m)
  intermittent stream – 50 ft (15 m)
  ephemeral stream – 50 ft (15 m)
  property line – 50 ft (15 m)
  public road – 50 ft (15 m)

- Operational Requirements:
  - significant reduction in pathogens required (methods and criteria specified);
  - incorporation of contaminants required within 48-hr of land application;
  - various agricultural use restrictions and public access to site is restricted from application zone for a period of one year after each application;
  - application on frozen, snow-covered or ice-covered land or water-saturated soil prohibited;
  - each single surface application , ½ inch (1.3 cm) thickness;
  - identification staking and signage at the site is required; and
  - surface waters or ponding at site prohibited and any surface run-on or run-off controlled.
- Monitoring Requirements:
  - soil sampling a minimum of annually depending on design treatment capacity (parameters specified);
  - soil pH must be maintained at ≥6.5;
  - metals concentration criteria specified; and
  - groundwater and other surface waters monitoring required.

4.4.2 Alaska

Alaska's Contaminated Sites Program is receiving an increase in permit applications for soil remediation in remote areas (State of Alaska. 2002). A guideline for Landfarming and landspreading (State of Alaska. 2000) requires that the landfarm be sited on a slope less than 5% with run-on and run-off control mechanisms installed. Land treatment methods are only recommended for "soils contaminated with gasoline or lightly contaminated with some types of diesel petroleum products." Details on landfarming are lacking since Alaska recommends more sophisticated treatment technologies.

4.4.3 Delaware

Delaware has established a 2-page guideline for landfarming on a very small scale (State of Delaware. 1993). Although brief, this document is detailed and prescriptive in nature:

- Stockpiling:
  - On heavy-duty plastic (specification given);
  - 6-12 inches (15-30 cm) of sand or some brightly colored inert material on top of the plastic; soil pile should be no thicker than 18 inches;
  - soil aggregates should be broken up if possible;
  - if the soil is comprised of more than 50% clay, wood chips or other bulking agents should be added to improve porosity of the soil pile.
- Operations:
  - apply ordinary dry agricultural fertilizer (high in nitrogen and phosphorous content such as 10-10-10 fertilizer) evenly over the top surface of the soil pile at the rate of about 5 lb/100 ft^2 of surface area (2.4 kg/m^2 of surface area);
  - carefully till the soil with a small garden tractor, rototiller, or other suitable tool;
  - increase water content of the soil, if necessary, but ensure that soils are not saturated or flooded by the spraying, because run off may occur; and
  - cover the soil with plastic and secure the edges to prevent erosion and runoff.
- Monitoring:
  - once/month, at minimum, the soil should be checked by removing the top sheet of plastic covering the soil, cultivating the soil and spraying it with more water if needed;
  - new fertilizer should be added monthly;
  - samples should be collected and analyzed to establish whether remediation is complete; and
  - reuse for random fill or other purposes on the same property is permitted upon state approval (additional regulatory approvals are required for reuse at another location).

4.4.4 Western Australia

Western Australia has guidelines for bioremediation technologies (Government of Western Australia. 2004) that includes the following details related to landfarming:

- site selection:
  - flat or gently sloping site;
  - site is located such that, in the event of accidental discharge, contaminated material will not readily access adjacent soil, surface water or groundwater;
  - suitable geological conditions (e.g. soils with low permeability);
  - sufficient distance from surface water bodies (> 50 m);

- o sufficient separation of treatment cell from groundwater (groundwater > 3 m below ground surface);
- o sufficient distance from potential discharge pathways such as drains, soak wells, service trenches; and
- o sufficient distance from odour sensitive receptors, e.g. any occupied (full or part-time) premises (> 50 m).

▪ construction/operation requirements:

- o site must be adequately fenced to prevent public access and appropriate signage should also be provided;
- o liners for waste containment required in accordance with another guideline;
- o stormwater runoff should be diverted so as not to flow onto the treatment facility;
- o leachate runoff should be directed to, and contained within, an impermeable leachate collection system with adequate capacity;
- o leachate may be treated, recycled into the bioremediation area or disposed of at an appropriate off-site location;
- o volatile organic compounds (VOCs) may need to be monitored, controlled and/or treated; and
- o dust emissions should be minimized during construction and operation of a facility via appropriate dust suppression methods (techniques specified).

▪ monitoring requirements:

- o monitoring of air quality and soil contaminant levels during operations and upon closure is required;
- o the natural ground surface beneath the bioremediation area will need to be validated by sampling and analysis to ensure that no leaching of hydrocarbons into *in situ* soil has occurred;
- o groundwater monitoring will be required for those sites where impacted material has leached to underlying soils and the potential exists for groundwater to be impacted.

4.5 U.S. Army Corp of Engineers

The U.S. Army Corp of Engineers has a major document (158 pages) in the form of an Engineering Technical Letter to aid the designer of landfarms. This includes evaluating the suitability of landfarming for a particular site; regulatory requirements; kinds of treatability studies; design requirements; operating parameters; sampling procedures and criteria; recommendations on construction materials; elements of a typical landfarm.

Very specific contaminant information is provided in this guideline. Such information includes the types of waste suitable for landfarming and their treatable ranges of concentration: e.g. petroleum hydrocarbon oil & grease: <100 - 80 000 mg/kg (50 – 99 % degradable). This type of information is also provided for gasoline, diesel fuel, and other various contaminants. Other contaminant issues addressed are how the various heavy metals from specific sources may affect biodegradability (e.g. lead (from tank farm soils, etc.) is not a possible microbicide and not a nutrient, but nickel (from waste oils, etc.) is both a potential microbicide and a nutrient at levels usually encountered). Other factors affecting biodegradability such as moisture content, pH, toxins, temperature, wind and soil type are also discussed. Specifics of these parameters are too complex to itemize; for example, moisture content in the range of 50 – 80% of the field capacity of the solid matrix is recommended but specific numerical values for sandy soil is provided and the various tests to determine soil moisture is described.

This same detailed approach is provided for each aspect of landfarm design. These discussions would prove useful in design, but in many cases the document refers the reader to state regulations for parameter limits (e.g. buffer zones) or site-specific studies for soil characteristics.

Some design requirements as discussed with respect to other guidelines are provided as follows:

- soil application thickness (dependent upon tilling equipment): 45 cm (tractor) or 20-30 cm (rototiller);
- underlying soils permeability: 10^{-2} – 10^{-3} cm/s; and
- slope: <2%, no additional measures; approximately 2% requires broadbase terracing; 6% slope requires conservation bench terracing and 35% requires bench terracing.

Some operational considerations provided are as follows:

- waste loading methods: avoid damaging or compacting liner, equipment considerations provided;
- aeration rates (3 x / week – 1 x / month, as determined by degradation rate, treatability studies);
- Moisture levels: effective levels are 50 - 80 %, but 20 – 80 % will support microbes;
- Nutrients: initial levels of C:N:P should be 400:10:1 or use time-released fertilizer;
- pH control: close to neutral (6 to 8) but can be adjusted to prevent impacts from heavy metals found in some contaminated soils; and
- details on monitoring all parameters discussed and contaminant levels throughout the process are provided; soil sampling typically monthly or bimonthly.

4.6 Other Applicable Organizations

Other organizations with landfarming information are the Petroleum Alliance of Canada (PTAC), Canadian Association of Petroleum Producers (CAPP), U.S. Department of Energy, and the American Petroleum Institute (API).

Although PTAC has some research information on remediation in the petroleum industry, no guidelines for landfarming have been established.

CAPP, in their *Bioremediation Manual* (1998), provides user guidance on the design and operation of bioremediation systems for remediation professionals and deals specifically with hydrocarbon contamination in soils with high salt contents. This manual, however, does not recommend landfarming for hydrocarbon contaminated soils with high salinity.

The U.S. Department of Energy addressed landfarming in *A Framework for Net Environmental Benefit Analysis for Remediation or Restoration of Petroleum-Contaminated Sites* (Efroymson, *et al*. 2003). Although not a guideline for landfarming design and operations, useful design information is provided. Notably, total hydrocarbon concentrations level off after 20 weeks of landfarming remediation (Huesemann. 1995 in Efroymson, *et al*. 2003).

API has several guidance documents addressing remediation in the petroleum industry:

- *A Guide to the Assessment and Remediation of Underground Petroleum Releases* (Publ 1628 E);
- *Operation and Maintenance Considerations for Hydrocarbon Remediation Systems* (Publ 1628E E);
- *Guide for Assessing and Remediating Petroleum Hydrocarbons in Soils* (Publ 1629 E);
- *Evaluation of Limiting Constituents Suggested for Land Disposal of Exploration and Production Wastes* (Publ 4527); and
- *Remediation of Salt-affected Soils at Oil and Gas Production Facilities* (Publ 4663 E).

These publications were not reviewed due to the high cost of obtaining the documents relative to their potential relevance specific to landfarming.

4.7 Remediation Contractors and Researchers

Much of the current research conducted on contaminated soil remediation is more novel and sophisticated than landfarming. However, some pertinent research work has been performed. A summary of this research is provided below.

Landfarming Research

Reynolds, *et al*. (1998) compares landfarming at a contaminated site in Alaska with other bioremediation technologies. Approximately 382 m^3 of soil was treated. The landfarm consisted of a bermed, lined system with leachate collection and recirculation routed through a mixing tank for nutrient additions, then irrigation spraying over the entire landfarm area. In the first year of the study, a nutrient solution of 11.35 kg of ammonium nitrate (NH_4NO_3) and 0.908 kg of potassium sulphate with 568 L of water was applied weekly. Tilling by means of disk aeration was done weekly. In the second landfarming year, nutrient rates were increased to 272 kg of ammonium nitrate, 68 kg of triple super-phosphate and 23 kg of potassium each month. Composite samples were analyzed approximately monthly over the two landfarming years (summers only). Results indicate microbial activity did not increase with the addition of nitrogen, irrigation or tilling in the first year, but increased microorganisms were found in the second year of operations. Further, biodegradation rates varied spatially throughout the site (7-fold variability rate). Researchers believe this variability may be at least partially attributed to localized irrigation and nutrient addition. The greatest operational problem with the landfarm was managing excessive moisture in the soils which had a slow percolation rate through to the collection system. Total hydrocarbons were reduced from over 4000 ppm to 80-400 ppm (variable over site).

A publication by Pepper, *et al*. (Eds.) 1996 extols the benefits of landfarming: the broad land application at appropriate loading rates results in far less pollution than if the material had been concentrated by disposal at a single pile. When loading rates are controlled, the soil has a chance to transform many waste components into plant-available nutrients.

Pepper, *et al*. also explains that the soil environment helps stabilize certain pollutants such as lead, cadmium, zinc, arsenic, etc. by trapping them into their solid phases, preventing leaching. However, metal contaminants are then retained in the soil and are not remediated. Trace metals (particularly Zn, Cu, Cd, Ni, Pb, Hg, Mo, As) are a particular concern. Soils with a high pH have lower plant-available metal concentrations as do low pH soils due to the water solubility of most metals increases as pH decreases. This is why one strategy to reduce metal mobility and toxicity is to lime soils to a neutral or alkaline pH. Metal pollutants do not biodegrade and therefore continue to accumulate in the soil. The degradation, bioavailability and mobility of toxic organic chemicals such as pesticides, polycyclic aromatic hydrocarbons (PAHs), solvents, etc., are largely dependent upon soil type and particularly organic-matter content. The long-term effects of these chemicals, as well as metals, are difficult to predict, particularly since many can accumulate in the soil environment.

Landfarming oily sludges requires that the application of these sludges needs to be optimized (rates should not be so low that excessive land is required, but not so high that soil microbes are overwhelmed and degradation rates are decreased) (Pepper, *et al*., 1996). Nitrogen and phosphorous fertilizers are often added to optimize C:N and C:P ratios. In the early 1980s, land treatment of hazardous oily wastes came under intense scrutiny by the USEPA. Land disposal restrictions begun in early 1992, now prohibit land treatment of hazardous oily wastes. These restrictions have compelled the petroleum industry to look at alternative disposal methods or pre-treatment methods to render oily wastes non-hazardous.

Chatham, 2003, presents findings from a study of several diesel-contaminated sites on the North Slope of Alaska. Two sites (Site 1 and 2) were designed and operated under different conditions within the main site.

At the first site, using a soil thickness of 0.7 m, Site A was the control, Site B had fertilizer and microbial consortium added and Site C had just fertilizer added (2.6 kg/m^3 soil). Soil moisture was maintained at 3-10% (or 15-50% of soil capacity). The treatment period was 41 days. An additional test of these same three sites was also conducted where: Site A was still the control, Site B had low-dose fertilizer added (1.8 kg/m^3 soil) and Site C had high-dose fertilizer added (3.6 kg/m^3 soil). Soil moisture was maintained at 3-10% (or 15-50% of soil capacity) and the treatment period was 75 days.

Results indicate a 77-87 % reduction in contaminant levels over a 2 year treatment period for nutrient-amended soil and the high dose fertilizer increased biodegradation rate substantially over the low dose fertilizer.

The second site studied had sub-sites identified as Control Plot A, B, and C, with a soil thickness of 0.5 m and variability as follows:

- Control: 938 m^3

- Plot A: 1004 m^3 – fertilizer (0.51 kg/m^3in 2 applications)
- Plot B: 1560 m^3 – fertilizer and microbial consortium added (proprietary information)
- Plot C: 8471 m^3 – fertilizer, microbial enzymes and hydrocarbon-degrading bacterial consortium (proprietary information)

Tilling was done four times per week for Control and Plot C and once every 3 days for Plot A and once every five days for Plot B. Moisture was maintained at 30 – 40% for a treatment period of 56 days. Results indicate a 48-71 % reduction in diesel where the greatest biodegradation was found at Plot A (nutrient amendment only) and Plot C (nutrient and bacterial amendment), with no significant difference between the two plots. This demonstrates that indigenous bacteria are capable of supporting biodegradation and microbial amendments are unnecessary. No appreciable degradation occurred in Plots B and the control plot (both were found to have depleted microbe levels).

Zimmerman and Robert (1990) report on research at 32 landfarm sites in west central Alberta contaminated with oil-based drill cuttings. Drill cuttings at a thickness of 5 cm were mixed with surface strippings (topsoil and humus layer). High nitrogen fertilizer (variable, but approx. 1000 kg/ha (0.1 kg/m^2) were added to the cuttings. Cultivation and fertilization occurred 2 times per year over a 2 to 4 year period. Values for pH were between 6.4 and 7.4 (most of sites close to pH 7). These studies found TPH concentrations were reduced from 7.37% to 0.58% after 4 years. If initial TPH were higher (3% - 7%), a 4 year treatment time is required but if initial TPH were lower (0.5% - 2%), then a 2 year treatment time is sufficient.

A research paper (Andrews Environmental Engineering. 1994) based on eighteen case studies of landfarming pesticide contaminated soil in Illinois, contains some general design information. Some pertinent criteria for successful landfarming include:

- siting:
  - 200 ft (61.0 m) from an occupied dwelling
  - 20 ft (6.1 m) from a waterway
  - slope ≤ 5%
  - floodplain ≤ 10 years
- soil spreading:
  - 8 - 60 tons/acre (18 – 135 tonnes/ha) in one pass
  - application rates based on pesticide manufacturer land application rates

A study dealing with air emissions from landfarming has some general design parameters for landfarming oily sludges from the petroleum industry (Thibodeaux and Hwang, 1982). High emission rates will likely occur immediately after application and before the microorganism degradation process can dominate. Some information provided about landfarming in general is as follows:

- Thickness of sludge deposit: fraction of an inch to several inches
- Cultivation period: 2 months
- Application rate: 200 – 600 barrels/acre/year (59 – 177 m^3/ha/year)

ChevronTexaco researchers have been studying landfarming of oil exploration and production wastes since 1992, and have compiled their lessons learned for successful landfarming (McMillen, *et al*. 2002) Researchers have found the following to be true:

- amending contaminated soil with microorganisms is not needed;
- the molecular weight and structure of hydrocarbons determines the biodegradation rate regardless of the age of the spill (i.e., the extent to which the oil is weathered);
- landfarming is suitable for situations where large land areas are available; groundwater is very deep (or liners necessary); starting oil concentrations <5% in soil; long-treatment times are not an issue;
- specialty fertilizers including slow release types are not usually worth the extra cost;
- literature usually recommends C:N:P ratio of 100:10:1, but it is rarely necessary to add the total amount of nitrogen and phosphorus called for because nutrients are recycled during the course of treatment as microorganisms die (and adding this all at once can be toxic to microorganisms and other soil organisms).

A pilot-scale study of the effect of various landfarming design parameters was conducted using a matrix approach on a pilot-scale (Demque, *et al*. 1997). Simulated landfarming sites for untreated soils, biostimulated (nutrient amendment) and bioaugmented (acclimatized microorganism amendment), just biostimulated and chlorinated (sterilized) soils were either untilled, tilled monthly or tilled twice-monthly. Sand contaminated with 10 000 µg/g of diesel and a moisture content of 16.5% was placed 13 cm thick in a lined tank. A commercial fertilizer with a C:N:P ratio of 100:10:0.78 was used. Tilling was done by rototiller on rails for a constant tilling depth. Results indicate biostimulation with commercial fertilizer appeared to be the most important factor whereby total petroleum hydrocarbon concentrations were reduced by 61-83% over tests without biostimulation. Increased tillage rates only slightly reduced the degradation rate of the diesel. Adding microorganisms did not appear to improve the degradation results.

In summary, most researchers studying landfarming were either reporting on one or several landfarming experiences (Zimmerman and Robert, 1990; McMillen, *et al.* 2002; and Andrews Environmental Engineering. 1994), or were studying the effects of various landfarming operational variables (Demque, *et al*. 1997; Reynolds, *et al.* 1998; and Chatham, 2003). The results of these findings may prove useful in the development of landfarming guidelines. In the Discussions and Conclusions (Section 6), key findings of these studies are provided.

5 DISCUSSION AND CONCLUSIONS

In contemplating the development of comprehensive landfarming guidelines for federal contaminated sites, existing guidelines and research findings were reviewed.

Landfarming guidelines are available from several provinces, foreign jurisdictions, Environment Canada, USEPA, and the U.S. Army Corp of Engineers. Although guideline approaches vary, most offer general criteria for siting, operations, monitoring and regulatory requirements. Remediation contractors and researchers have also examined landfarming operational variables or have reported on their landfarming experiences.

The Atlantic Provinces have the option of using a risk-based approach to contaminated sites remediation and endorse the use of the Atlantic RBCA toolkit for this purpose. No specific guidelines on landfarming are offered in these jurisdictions. It should be noted that with the Atlantic RBCA, different jurisdictions use either established criteria or risk assessment approaches in determining site specific remedial objectives. Having set these objectives, the task of selecting a remedial option, one of which may be landfarming, is a separate step that is not linked to the manner in which the remedial objectives are determined.

Ontario mostly takes a risk-assessment approach but also provides limited general guidance (e.g. all reasonable and practicable attempts should be made to remove all solid waste products and phase-separated liquid waste products; the intentional mixing of on-site contaminated soils with clean soils to meet restoration objectives is not recommended or endorsed, except in a few isolated situations; and the ongoing, uncontrolled release of volatile compounds to the air as part of a remedial action is not acceptable and volatile contaminants should be recovered). There has been a shift in recent years for other provinces to take a risk-based approach as well, although Yukon, Alberta, Saskatchewan, Manitoba and Québec each have some form of guideline for landfarming.

Those provinces with landfarming guidelines generally take the approach of providing numerical constraints or recommendations for landfarming siting, design, operations, and monitoring. The exception is the guideline from Québec which is more contaminant-driven, based on research that has determined various constraints and requirements that are most effective for biological treatment processes. The Environment Canada guideline (1993) takes this approach somewhat, but also provides design and operational requirements and recommends a remedial action plan. Other provinces with no numerical constraints require some type of remediation action plan acknowledged by the appropriate provincial agency.

Alberta has two guidance documents with landfarming information: the *Code of Practice for the Land Treatment of Soil Containing Hydrocarbons (draft)* (Government of Alberta. 2004) and the *Oilfield Waste Requirements for the Upstream Petroleum Industry* (Alberta Energy and Utilities Board. 1996); these two documents are complementary except for a difference in site grade (<9% and <5%, respectively) and soil depth (<0.20 m and < 0.15 m, respectively).

For comparison purposes, Table 6-1 is an itemization of prescriptive landfarming parameters that may be useful in the development of landfarming guidelines, including the numerical or descriptive criteria from existing guidelines of each province or territory (where guidelines exist), Environment Canada (1993), and the USEPA (1994). Those sources not included in this table either have no guidelines or have information less prescriptive in nature. Most of the criteria chosen for comparison purposes are those both most common to the guidelines and most important to successful landfarming remediation. Among the guidelines compared in Table 6-1, there is much commonality and, where they differ, there is no one guideline more stringent than the others.

Guidelines from foreign jurisdictions tend to be less stringent; for example Western Australia has residential and water body buffer zones of 50 m, rather than 60 – 500 m in Canada and the state of Kentucky permits a site slope of up to 15%, rather than a maximum of 5 to 9% for Canada.

The U.S. Army Corp of Engineers provides a guideline for landfarming; however, it admits state regulations preclude definitive criteria for all circumstances. Further, treatability or demonstration-scaled studies are prescribed for many of the criteria included in this review (e.g. receiving soil restrictions; pH; moisture content; and nutrient amendments). Most of the criteria provided is in agreement with that of the guidelines reviewed in the comparison table, with the exception of nutrient amendments (C:N:P of 400:10:1 rather than the USEPA value of 100:10:1 to 100:10:0.5). This guideline is intended to aid the landfarm designer and other stakeholders who possess some knowledge of civil engineering, chemistry, chemical engineering, microbiology, and mathematics. Its detail and thoroughness reflect this intent.

From the research materials reviewed, concluding points are as follows:

- Nutrient amendment: Researchers found that adding commercial fertilizers increased biodegradation rates but optimal application rates were necessary (Reynolds, *et al*. 1998; Chatham, 2003; Zimmerman and Robert, 1990; and Demque, *et al.* 1997). Specialty fertilizers, such as time-released, may not be worth the expense (McMillen, *et al*. 2002).
- Microorganism amendment: Adding microbes to the contaminated soil has not been proven to enhance landfarming effectiveness (Chatham, 2003; and McMillen, *et al*., 2002).
- Tilling: Landfarming operations, by definition, all involve tilling the soil. The optimal tilling rate, however, is not well understood. Tilling was done 4 times a week to twice weekly by Chatham (2003), weekly by Reynolds, *et al.* (1998), monthly by Demque, *et al.* 1997, and twice a year by Zimmerman and Robert (1990). However, McMillen, *et al*. (2002) reported that increased tillage rates only slightly reduced the degradation rate of diesel in contaminated soil.
- pH: Neutralizing pH is known to reduce metal mobility and toxicity (Pepper, *et al.* (Eds.) 1996). Researchers sometimes noted pH values were maintained as close to 7 as possible (Zimmerman and Robert. 1990; Demque, *et al*. 1997; and McMillen, et al. 2002).
- Operational concerns: Keeping landfarming sites at the correct moisture level was a concern of some researchers (Reynolds, et al. 1998; Chatham, 2003; and Andrews Environmental Engineering. 1994).
- Design parameters: Andrews Environmental Engineering (1994) presented some siting criteria. These criteria compare with the government guidelines examined in Section 5 as follows:
    - 200 ft (61.0 m) from an occupied dwelling – same as Environment Canada and the Yukon;
    - 20 ft (6.1 m) from a waterway – much closer than all government guidelines;
    - slope ≤ 5% – same as Alberta and less than the others; and

- o floodplain ≤ 10 years – less than that for government guidelines that included this criterion.

It is clear that existing guidelines available for landfarming vary considerably among the jurisdictions considered. Guidelines available from provincial/territorial governments, Environment Canada and U.S. sources do, however, provide numerical and narrative information useful for the development of landfarming guidelines for federal contaminated sites.

Table 6-1 Comparison of Various Requirements in Landfarming Guidelines

Parameter	British Columbia (1988)[i]	Yukon (2004a and 2004b)[ii]	Alberta Environment (2004)[iii]	Alberta EUB (1996)[iv]	Saskatchewan (1995)[v]	Manitoba (2002)[vi]	Environment Canada (1993 and 2004)[vii,viii]	USEPA (1994)[ix,x]
Siting								
Distance from residential zoning		> 60 m	>100 m		>500 m	>500 m	> 60 m	
Distance from water body	> 150 m	> 100 m	>100 m	>100 m		>500 m	> 100 m	
Sensitive areas restriction	within, or adjacent and flowing into, a wetland; within recharge area for an unconfined aquifer (details in Regs. S. 28(1), (7))		As specified in the Alberta *Wildlife Act* or *Migratory Birds Convention Act*					
Underlying native soils (otherwise liner required)	> 5 m of fine grained, consolidated material with permeability $<1x\ 10^{-6}$ cm/s over fractured or permeable bedrock	Sufficiently fine grained soil or clay; hydraulic conductivity $<10^{-5}$ cm/s (> 1m thick)	No coarse-grained soil or coarse-grained soil occurring within 2 m of surface	Hydraulic conductivity low ($\leq 10^{-5}$ cm/s)		Low permeability base		
Site Grade		< 6% slope	< 9% slope	< 5% slope		< 5% slope (1-2% ideal)	< 6% slope	

Parameter	British Columbia (1988)[i]	Yukon (2004a and 2004b)[ii]	Alberta Environment (2004)[iii]	Alberta EUB (1996)[iv]	Saskatchewan (1995)[v]	Manitoba (2002)[vi]	Environment Canada (1993 and 2004)[vii,viii]	USEPA (1994)[ix,x]
Maximum cultivation depth above groundwater table	1 m	3 m	1 m	1 m		3 m	3 m	
Site Identification/ Security		Identification and warning signs; fencing, if warranted		Fencing for prevented access from public and wildlife	Site identified with stakes or flags during operations		Hazard signs posted; access restricted through fencing	
Hydrology	Restricted on land within 25 year floodplain, or surface water control required	Restricted on land within 25 year floodplain					Restricted on land within 50 year floodplain	
Watershed restrictions	Within community; Greater Victoria or Vancouver District watersheds							
Berms and Barriers								
Berm requirements	Design, implement and maintain run-off diversion and collection systems	Natural or engineered of sufficiently low permeability; diversion ditches	Prevention of water flowing onto land or for Class II site, water collected and controlled			Minimum berm height of 0.5 m	Natural or engineered containment system; use if more than 30 inches (0.76 m) rain in landfarming	Use if more than 30 inches (0.76 m) rain in landfarming season expected

Parameter	British Columbia (1988)[i]	Yukon (2004a and 2004b)[ii]	Alberta Environment (2004)[iii]	Alberta EUB (1996)[iv]	Saskatchewan (1995)[v]	Manitoba (2002)[vi]	Environment Canada (1993 and 2004)[vii,viii]	USEPA (1994)[ix,x]
							season[7 only]	
Leachate control	maintain sufficient capacity in leachate or runoff storage; Weekly, or after any catastrophic event, inspect leak detection; leachate control systems; repair, if required; (details in Regs. S 29 (1) (b));	collect and controlled re-application run-off	Collect and treat runoff from 1 in 10 year, 24-hr storm (Class II) or 1 in 25 year, 24-hr storm (Class I)			Capable of handling 24-hr, 10 year frequency storm	means to capture and treat leachate, if required	Use if necessary; design according to state requirements
Barrier requirements	Weekly, or after any catastrophic event, inspect liner and drainage control systems; repair, if required; (details in Regs. S 29 (1) (b));		Maximum seepage rate equivalent to clay liner under 0.3 m head of water, hydraulic conductivity 10^{-7} cm/s, 0.6 m thick (Class I) or 0.3 m thick (Class II)			Minimum compaction thickness of 500 mm	Suggested liner: 20 mil (0.5 mm thick) oil-resistant re-inforced high-density polyethylene geomembrane[7 only]	Use if necessary
Operations								
Receiving soil type restriction	Only receive approved waste	No waste engine oil; < 3% by weight of TPH; single	F1-F4 each < 3% by weight of TPH	< 2 ppm organic halogen; Electrical		If BTEX >100 ppm each, handled	Characterization (quantities, type and level of	>1000 CFU/g of dry soil; soil temperature 10 $^{o}C \leq T \leq 45\ ^{o}C$;

Parameter	British Columbia (1988)[i]	Yukon (2004a and 2004b)[ii]	Alberta Environment (2004)[iii]	Alberta EUB (1996)[iv]	Saskatchewan (1995)[v]	Manitoba (2002)[vi]	Environment Canada (1993 and 2004)[vii,viii]	USEPA (1994)[ix,x]
		source soils only		Conductivity (< 4 dS/m), Sodium Adsorption Ratio (< 6), and metals within Alberta Environmental Protection guidelines		separately	contamination) as per CCME's criteria	10 000 ppm ≤TPH ≤ 50 000 ppm; total heavy metals < 2 500 ppm
pH maintenance		6.5-8.5		6.5 – 8.5			6 – 8 [7 only]	6 - 8
Nutrient amendments							If required[7 only]	C:N:P 100:10:1 to 100:1:0.5;
Moisture content							Adjust as required[7 only]	40%-85% of field capacity
Soil thickness		0-0.5m	0-0.20 m (with barrier); to maximum tillable depth (with no barrier)	0-0.15 m	0-0.15 m		< 0.5 m[7 only]	12 – 18 in. (0.30 – 0.56 m) depending on type of tilling equipment
Tilling		Once per month if > 0.15 m	Once every 4 weeks (with no barrier: full thickness; with barrier: 75% thickness)		First within 48 hrs of deposit; once every 2 weeks; other recommend-ations		At least 1x or 2 x per month[7 only]	specific frequency not mentioned
Application time		Restricted between Oct 31-Apr 1;		Restricted between Oct 15-Apr 30;	Restricted between Nov 1 - Apr 1,		restricted when the soil is saturated with	Ambient temperature between $10^{o}C$

Parameter	British Columbia (1988)[i]	Yukon (2004a and 2004b)[ii]	Alberta Environment (2004)[iii]	Alberta EUB (1996)[iv]	Saskatchewan (1995)[v]	Manitoba (2002)[vi]	Environment Canada (1993 and 2004)[vii,viii]	USEPA (1994)[ix,x]
		during heavy rainfall or when soil saturated or frozen		during heavy rainfall or when soil saturated or frozen	weather permitting (otherwise, stockpiling permitted)		water, ice or snow covering, or when the soil is frozen[7 only]	and 45°C
Operation period				< 5 years			6 months – 2 years, under optimal conditions[7 only]	6 months – 2 years, under optimal conditions
Monitoring and Record Keeping								
Soil, groundwater, leachate monitoring procedures	Groundwater monitoring (details in Regs. S 29 (2), 32 (3)), discharge must meet effluent criteria of Schedule 1.2 (Regs.);	Soil inventory; analytical analyses; operational records required			Initial soil sampling; once per treatment season; site inspection items		> 2 groundwater monitoring wells down gradient sampled no less than twice/year; soil sampling no less than once/4 months during operations	To ensure permit compliance; soil monitoring at least quarterly during season; monitoring plan required

[i] Government of British Columbia. 1988. *Hazardous Waste Regulation* of the *Environmental Management Act*. [SBC 2003]. B.C. Reg. 63/88.

[ii] Government of Yukon. 2004a. *Land Treatment Facilities (Guidelines for Construction, Operation and Decommissioning).* http://www.environmentyukon.gov.yk.ca/epa/landtrecod.shtml

Government of Yukon. 2004b. *Land Treatment Facilities and Landfarming.* http://www.environmentyukon.gov.yk.ca/epa/contamltf.shtml

[iii] Government of Alberta. 2004. *Code of Practice for the Land Treatment of Soil Containing Hydrocarbons (Draft).* Alberta Environment. May, 2004.
[iv] Alberta Energy and Utilities Board. 1996. *Oilfield Waste Management Requirements for the Upstream Petroleum Industry Guide 58.* November, 1996.

[v] Government of Saskatchewan. 1995. *Guidelines for Treatment and Disposal of Petroleum Contaminated Soils at Municipal Waste Disposal Grounds.* Saskatchewan Environment. December, 1995.

[vi] Government of Manitoba. 2002 *Treatment and Disposal of Petroleum Contaminated Soil.* June, 1996 (revised 2002).

[vii] Environment Canada. 1993. "Appendix 3: Guidelines on the Ex-Situ Bioremediation of Petroleum Hydrocarbon Contaminated Soils on Federal Crown Land" in the *Study on the Use of Landfarming and Surface Impoundments in the Management of Hazardous and Non-Hazardous Waste*. Conservation and Protection. June 23, 1993.

[viii] Environment Canada. 2004. *Landfarming at Federal Facilities (draft)*. Tab 30: Tabs on Contaminated Sites. Environment Canada, Ontario Region. Environmental Protection Branch.

[ix] USEPA. 1994. "Chapter V" in *How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers*. (EPA 510-B-94-003; EPA 510-B-95-007; and EPA 510-R-04-002).October 1994.

[x] USEPA has limited siting criteria, as they are prescribed by state legislation or guideline.

6 RECOMMENDATIONS

Environment Canada, in the interest of ensuring a consistent and thorough approach to landfarming practices at federal contaminated sites in Canada, intends to develop comprehensive guidelines.

As a starting point, the Environment Canada 1993 guidelines can be considered. Numerical and narrative criteria for landfarming practices, as presented in this 1993 document and in the other guidelines reviewed here, should now be evaluated and a consensus established for the new guidelines. These imminent guidelines would be applicable to federal sites in all regions of Canada. It is recommended, however, that the guidelines should state that for sites in provinces/territories with existing landfarming guidelines, remediation of non-federal contaminated sites should adhere to those guidelines

Any guideline developed should abide by various federal acts and regulations including the *Fisheries Act*, the *Canadian Environmental Protection Act* and the *Canadian Environmental Assessment Act.*

For discussion purposes, Table 7.1 lists the parameters that are recommended for inclusion in the guidelines. For each of these parameters, the most stringent of the criteria found in the existing Canadian guidelines are shown. As it is difficult to justify using less stringent criteria once established in a particular jurisdiction, the most stringent criteria should be considered first. With justification, a consensus should be reached as to the recommended criteria. Note that these guidelines are not enforceable by legislation and should be considered a tool for ensuring effective remediation. The following approach is suggested in making the final decision on what prescriptive values should be used in the new federal guidelines:

Step 1:

- Environment Canada (1993) prescriptive criteria should be considered first.
- In the case where no Environment Canada guideline has been established for a particular criterion, the most stringent existing provincial criterion should be considered.

Step 2:

- Where provincial/territorial criteria vary from the criteria set out in Step 1, each criterion should be evaluated and a justifiable consensus reached as to the most appropriate guideline (whether the most stringent available criterion or not).
- Where a consensus cannot be reached, it is likely due to regional site differences. Site specific allowances should be provided to account for unique climatic or geophysical conditions in various regions in Canada.

Table 7-1 Comparison Table for Determining Landfarming Guidelines

Parameter	Most Stringent Criterion	Source	Comparison with EC (1993)
Distance from residential zoning	> 500 m[i]	Saskatchewan (1994); Manitoba (2002)	More stringent than EC value of 60 m
Distance from water body	> 500 m[ii]	Manitoba (2002)	More stringent than EC value of 100 m
Sensitive areas restriction	*Alberta Wildlife Act, Migratory Birds Convention Act* Within, or adjacent and flowing into, a wetland	Alberta (2004) British Columbia (1988)	Not mentioned in EC
Underlying native soils (otherwise liner required)	Low hydraulic conductivity ($<10^{-6}$ cm/s), > 5 m thick	British Columbia (1988)	No EC criterion
Site Grade	< 5% slope	Alberta EUB (1996); Manitoba (2002)	More stringent than EC value of 6%
Cultivation depth	Maximum cultivation depth of a minimum 3 m above groundwater table	Yukon (2004a and 2004b); Manitoba (2002); Environment Canada (1993)	EC
Site identification/ security	Fencing or staking and signage	Yukon (2004a and 2004b); Alberta EUB (1996); Saskatchewan (1994); Environment Canada (1993)	EC
hydrology	Restricted on land within 50 year floodplain	EC (1993)	EC
Berm requirements	Natural or engineered containment system, if required	Yukon (2004a and 2004b); British Columbia (1988); Alberta (2004); Manitoba (2002); Environment Canada (1993)	EC
Leachate control	Capable of handling 24-hr, 10 year frequency storm	Manitoba (2002)	No EC criterion value; only: "means to capture and treat

Parameter	Most Stringent Criterion	Source	Comparison with EC (1993)
	Maintain sufficient capacity for leachate; weekly inspections (or after any catastrophic event)	British Columbia (1988)	leachate."
Barrier requirements	Maximum seepage rate equivalent to clay liner under 0.3 m head of water, hydraulic conductivity 10 $^{-7}$ cm/s, 0.6 m thick (Class I) or 0.3 m thick (Class II)[iii] Weekly inspections, or after any catastrophic event	Alberta (2004) British Columbia (1988)	No EC criterion
Receiving soil type restriction	No waste oil < 3% by weight TPH (each fraction) single source soils only Approved waste only F1-F4 each <3% by weight of TPH <2 ppm organic halogen; electrical conductivity < 4 dS/m; SAR <6, metals within Alberta Protection guidelines Total heavy metals <2 500 ppm	Yukon (2004a and 224b); Alberta (2004) Yukon (2004a and 2004b) Yukon (2004a and 2004b) British Columbia (1988) Alberta (2004) Alberta EUB (1996) USEPA (1994)	EC requires waste characterization only
pH maintenance	6.5 – 8.5 6-8	Yukon (2004a and 2004b); Alberta EUB (1996) EC (1996) and USEPA (1994)	Similar or same as EC[iv]
Nutrient amendments	C:N:P 100:10:1 to 100:1:0.5	USEPA (1994)	EC states "ïf required"
Moisture content	40%-85% of field capacity	USEPA (1994)	EC states "ïf required"
Soil depth	Approximately <0.5 m, to	Yukon (2004a and 2004b); Alberta (2004);	EC

Parameter	Most Stringent Criterion	Source	Comparison with EC (1993)
	maximum tillable depth	Environment Canada (1993);	
Application rate	Detailed plans required	Environment Canada (1993)	EC
tilling	At least once per month[v]	Yukon (2004a and 2004b); Alberta (2004); Environment Canada (1993)	EC
Application time	restricted when the soil is saturated with water, ice or snow covering, or when the soil is frozen	Yukon (2004a and 2004b); Alberta EUB (1996); Saskatchewan (1994);Environment Canada (1993)	EC
Operation period	6 months – 2 years, under optimal conditions	Environment Canada (1993); USEPA (1994)	EC
Soil, groundwater, leachate monitoring procedures in guideline	> 2 groundwater monitoring wells down gradient sampled no less than twice/year; soil sampling no less than once/4 months during operations	Environment Canada (1993)	EC

[i] Unless land unavailable, in which case the more moderate Alberta (2004) guideline of 100 m is recommended.

[ii] Unless land unavailable, in which case the more moderate Alberta (2004), Yukon (2004a and 2004b) and Environment Canada (1993) guideline of 100 m is recommended.

[iii] Environment Canada regional document (2004) is more stringent, but not yet finalized, so Alberta (2004) guideline is recommended.

[iv] Both these criteria serve to prevent metals leaching.

[v] Saskatchewan (1994) prescribes tilling within first 48 hours of deposit and once every 2 weeks but research indicates additional tilling does not increase biodegradation rate (McMillen *et al*. 2002).

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