Ministry for the Environment
Manatū Mō Te Taiao

Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand (Revised 2011)

MODULE 7
Site management

August 1999

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7 Site management

> This module provides an overview of the options available for site control, management and remediation of petroleum hydrocarbon contaminated sites and the basis for choosing various options. The module also presents guidance on managing environmental issues during underground storage tank (UST) and underground petroleum equipment removal and replacement. A discussion of the current legislation that governs the management of contaminated sites and potential future changes to relevant legislation is provided. In addition, various readily available remedial technologies are described. Advantages and disadvantages of each technology are presented.

Section 7.1 discusses the goals of site management and presents the factors that govern the decision process in determining the level of management required at a site. The current legislation governing contaminated sites is summarised in Section 7.2. The remaining subsections outline specific actions, management practices and technologies available to mitigate a site. Site management techniques such as natural attenuation, land use restrictions, access restrictions, and monitoring are discussed in Section 7.3. Management of environmental issues during UST and underground petroleum equipment removal and replacement are also discussed in Section 7.3. Containment options are discussed in Section 7.4. Both in situ and above ground technologies for remediating contaminated soils are discussed in Section 7.5. Groundwater remediation technologies, including product recovery, are discussed in Section 7.6. Disposal options for contaminated soil and groundwater are discussed in Section 7.7. References for this module are provided in Section 7.8. Comment on issues associated with the management of liquid phase hydrocarbons is given in Section 4.1.1.

7.1 Introduction

> This section discusses the goal of site management, the options available for achieving the goals and the basis for choosing various options.

The fundamental goal of a site management strategy must be to render the site acceptable and safe for the long term. This is the approach embodied in the Australian and New Zealand Environment and Conservation Council (ANZECC) and National Health Medical Research Council (NHMRC) contaminated sites guidelines (ANZECC/NHMRC, 1992). Where human health is deemed to be at risk, or the off-site environment is likely to suffer significant adverse impact, a site should be cleaned up to the extent necessary to minimise such risks in both the short and long terms.

However, in cases where there is no threat, or an acceptable threat, to human health or the environment, it may well be acceptable to devise a strategy whereby the contaminants are contained on site, or planning controls are used to limit the use of the site. There are a large number of options potentially available to manage contaminated sites to achieve these goals.

Once the site investigations and Tier 1 or Tier 2 assessments have been carried out (see Modules 3-6) there will be a body of data available on which to make decisions regarding the level of management, if any, required at the site. The site investigation and risk assessment data will also be used to determine the type of technology that would be the most cost-effective in achieving the management goals. The decision on which approach to take will be governed by multiple factors, including:

- the nature and degree of the contamination

- the intended future use of the site
- the proximity of receptors and the potential pathways to them
- the site characteristics, including geology and soil type, depth to groundwater
- size of the contaminated area
- potential for off site migration
- costs of management or control
- community concern considerations.

Site management options include:

- land use controls
- access restrictions
- management controls
- containment
- remedial treatment systems
- disposal
- monitoring.

In all cases, it will be necessary to ensure that the required consents and approvals are held prior to implementing the management scheme. A discussion of the current legislation governing contaminated sites in New Zealand is given in Section 7.2, and possible resource consent requirements can be found in the discussion of each site management option.

7.2 Legislation

> This section provides an overview of the legislation governing the management of contaminated sites in New Zealand.

7.2.1 The Resource Management Act 1991

The purpose of the Resource Management Act 1991(RMA) is to promote the sustainable management of natural and physical resources. The RMA is the principal statute for the management of land, air, water, soil resources, subdivision of land, the coast, and pollution control. It clearly sets out the resource management responsibilities of individuals, territorial authorities, regional councils and the Government. It sets up a system of policy and plan preparation and administration, including the granting of resource consents which allows the balancing of a wide range of interests and values.

The provisions of the RMA relating to discharges to land, air and water, and the control of the use of land, are of most relevance in managing contaminated sites. Section 30 of the RMA requires regional councils to control discharges of contaminants into or onto land, air or water. They must also control the use of land in order to prevent, or mitigate the adverse effects of the storage, use, disposal, or transportation of hazardous substances.

Section 31 of the RMA requires territorial authorities to control any actual or potential effects of the use, development, or protection of land, which includes preventing or mitigating of any adverse effects of the storage, use, disposal, or transportation of hazardous substances.

7.2.1.1 Resource consent requirements

A number of resource consents may be required for the management of a contaminated site. They include:

- a discharge consent from the regional council for discharges into or onto land, air or water
- a land use consent from the territorial authority.

Resource consents may be necessary to undertake various steps in the site assessment and management process. It is important to contact the regional council and the territorial authority to determine what their particular requirements are, as these may vary throughout the country.

7.2.2 The Health Act 1956

Sections 29 to 35 of the Health Act 1956provide that in certain cases where a nuisance is being caused within the meaning of the Act, an owner or occupier of the premises can be required to abate the nuisance. The primary responsibility for enforcing these provisions rests with the territorial local authority. In the event that the person creating the nuisance fails to comply with an abatement request there are legal remedies available.

A prosecution may be taken for a failure to abate a nuisance. The prosecution may result in an order from a District Court judge requiring an owner or occupier of the premises to abate the nuisance effectively; prohibit the recurrence of the nuisance; both abate and prohibit the recurrence of the nuisance; or to carry out specified works to abate or prevent a recurrence of the nuisance.

If there is default in complying with an order, the territorial local authority, or the Medical Officer of Health on behalf of the territorial local authority and the Ministry of Health, may carry out any works at the expense of the owner and occupier. The costs are deemed to be a charge on the land.

In instances where immediate action for the abatement of a nuisance is necessary in the opinion of the Engineer or Environmental Health Officer of a territorial local authority, those officers may, without notice to the occupier, enter the premises and abate the nuisance. Any costs incurred are recoverable as a debt from the owner or occupier.

7.2.3 The Building Act 1991

The Building Act also addresses site contamination but only where there is an intention to carry out building work. The purpose of the Act is to provide controls relating to the building work and the use of buildings to ensure that buildings are safe and sanitary. Under the associated Building Code F1 *Hazardous Agents on Site*, the objective is to safeguard people from injury or illness caused by hazardous agents or contaminants on a site. There is a requirement that buildings shall be constructed to avoid the likelihood of people within being adversely affected by hazardous agents or contaminants on site. Code F1 requires that sites shall be assessed to determine the presence and potential threat of any hazardous agents or contaminants. The likely effect of these is to be determined taking account of:

- the intended use of the building
- the nature, potency or toxicity of the hazardous agent or contaminant, and
- the protection provided by the building envelope and building systems.

7.2.4 The Health and Safety in Employment Act 1992

The purpose of this Act is to prevent harm to employees and other people (e.g. visitors, contractors) while they are on a work site. All organisations are required to comply with the minimum standards outlined in the Act. To do this, employers need to take all practicable steps to maintain a safe working environment. This includes:

- minimisation, isolation or elimination of hazards (or potential hazards)
- training of staff in safe work practices
- ensuring employees are not exposed to hazards in the course of their work
- informing staff of what to do in an emergency.

Employees are also encouraged to be responsible and look after their own and others safety and health at work. Ways of doing this include:

- observing safe work practices in carrying out their duties
- following instructions given to them by their managers
- being responsible for their own and others' safety and health at work.

7.2.5 Hazardous Substances and New Organisms Act

The Hazardous Substances and New Organisms Act 1996 (HSNO) pulls together the management of hazardous substances into one law that focuses on all of their hazards - to both humans and the environment. HSNO establishes a consistent process for assessing the risk posed by hazardous substances and setting national controls to manage their environmental effects and risks.

The Environmental Protection Authority (EPA) is an independent body established under the Environmental Protection Authority Act 2011, and is responsible for regulating hazardous substances and chemicals under the HSNO Act. The EPA replaces the Environmental Management Risk Authority that was originally established under HSNO.

Both HSNO and the RMA work together to protect human health and the environment from the effects of hazardous substances. Where HSNO sets controls on a national level in recognition of the inherent hazard of certain substances, the RMA controls are set through the local planning process so differences in the sensitivity of the local environment and community needs can be taken into account.

7.3 Site management

> The primary goal of site management is to control site operations and use until such time as an acceptable risk level is reached. Long-term site management options include natural attenuation, access and land use restrictions and/or monitoring. During UST and underground equipment removal and replacement, site operations need to be controlled to mitigate potential impacts from contamination and other on-site activities.

Where a risk management approach is adopted, it may be necessary to prepare a site management plan designed to control site operations and use until such time as an acceptable risk level is reached. The timeframe depends on the type of technology used to remediate the site. The primary purpose of the plan is to ensure that exposure pathways are minimised in the short and long term. A site management plan should include the following elements:

- description of the site characteristics
- description of the contaminant source and characteristics
- description of the potential adverse impact, receptors and pathways
- details of the risk management scheme to be implemented (or in place)
- methods of monitoring the performance of the management technique
- methods for ensuring the management technique is enforced for the period required
- details of an emergency response action plan (including parties to be notified and up-to-date phone numbers) to be implemented if system failure is detected
- consultation procedures with the regulatory authorities
- safety measures required if site works are to be undertaken.

Where a site management plan is in place, or some form of long-term risk management process has been implemented, it is important to ensure that the site is not disturbed or used inappropriately in the future such that the site user, or the environment, is put at risk.

During UST and underground equipment removal and replacement risk management processes and procedures may need to be implemented to manage potential environmental and health and safety risks that may arise during these works. Management options are discussed in Section 7.3.1.

The methods for achieving long-term control of a site can include natural attenuation, land use controls, access restrictions, and monitoring. These options are discussed in Sections 7.3.2 - 7.3.5.

7.3.1 UST and underground petroleum equipment removal and replacement

During the removal and replacement of petroleum storage and dispensing equipment it may, depending on the scale and nature of the works, be necessary to develop an environmental management plan (EMP) to manage potential environmental effects. This section presents typical management practices that should be followed during petroleum storage and dispensing equipment removal and replacement works and that can be incorporated into a site specific EMP, if required.

For the purpose of this guidance petroleum storage and dispensing equipment is considered to comprise:

1. underground petroleum storage system (UPSS) equipment (USTs, below ground lines and fill points) on service stations, commercial sites and production land
2. above ground petroleum storage tanks (typically less than $100m^3$ capacity) and below ground lines on service stations, commercial sites and production land.

The guidance presented could be applied to tank removal and replacement works undertaken on bulk storage facilities; however, given the larger scale and nature of these facilities additional controls may be required.

UPSS equipment and above ground tank and line removal and replacement works typically comprises:

- removal of above ground dispensing equipment
- concrete breaking, excavation, exposure and removal of the below ground equipment (USTs lines, fill points)
- removal of above ground tanks
- removal of petroleum equipment from site for off-site disposal
- excavation of line trench and UST pit bedding materials and possibly natural soils (some of which may be impacted with petroleum hydrocarbons)
- possible removal of perched groundwater and LNAPL from excavations
- soil contamination benchmarking within UST pits, line trench excavations and other excavations
- installation of new UPSS and above ground equipment (if replacement work is being undertaken)
- backfilling excavated voids, re-surfacing and recommissioning (if replacement work is being undertaken).

All works should be undertaken to minimise impacts on the environment and comply with relevant legislative requirements, licences, approvals and notices.

The following sections outline key environmental management practices that should be adopted during petroleum equipment removal and replacement.

7.3.1.1 Petroleum storage and dispensing equipment removal and replacement

The petroleum equipment elements must be removed by an appropriately licensed contractor and in accordance with the Code of Practice for the Design, Installation and Operation of Underground Petroleum Storage Systems (Department of Labour 1992), HSNO, Health and Safety in Employment Act 1992, and any other regional/local rules and regulations.

Following removal of the petroleum equipment, the environmental consultant (or similar) should visually inspect tanks, pipework etc. for any defects which may indicate potential loss of containment and record this information.

The petroleum equipment, particularly the USTs, must be removed and transported off-site as soon as practical for disposal/destruction by an appropriately licensed contractor. Off-site transport and disposal must be undertaken in accordance with the Code of Practice for the Transport and Disposal of Petroleum Tanks and Related Wastes (Department of Labour, 1995) and HSNO.

7.3.1.2 Soil removal and management

During removal of the petroleum equipment it may be necessary to excavate and remove bedding material and hydrocarbon impacted soils from the site. Significantly impacted soil should, wherever possible, be removed from the site, particularly where these soils are likely to exceed the Tier 1 soil guideline values given in Module 4.

Typical soil removal volumes at service stations and commercial sites range between 5m3 to 100m3. Larger volumes sometimes require removal where there has been some form of significant fuel loss at the site or where the soils cannot be placed back in excavated voids because of their poor engineering characteristics.

Soils and bedding materials removed from site must be disposed of to a facility consented to receive such wastes. Each disposal facility is likely to have different rules controlling the disposal of uncontaminated and contaminated soils and these should be established before beginning the removal works. Controls may include:

- sampling and laboratory analyses of representative samples of soil to be disposed
- comparison of analytical results with relevant facility limits
- completion of waste manifest forms to document the soil chain of custody and final disposal location.

It is not anticipated that any excavated materials would be re-used on site; however, should non-impacted soil or bedding material be re-used as backfill this should be benchmarked before being placed in any excavation by the environmental consultant.

During the petroleum equipment removal works, it may be necessary for excavated soil to be temporarily stockpiled on-site before off-site removal. In the event material is temporarily stockpiled on-site, stockpiles should be:

- managed in a manner protective of on-site workers, the public and off-site migration pathways (such as stormwater drains)
- located on concrete hard standing or if necessary sheeted/covered
- kept tidy, less than 4 m in height and with a stable slope.

Stockpiles are generally short term and tend to be removed off-site on the same day or the day following excavation. Where necessary (e.g. for long term stockpiles) hay bales or similar forms of silt containment should be placed around the stockpiled soil and stormwater drains/grates to help prevent surface run-off. The stockpile area should be fenced to prevent public or unauthorised access. Where stockpiled material is odorous, it should be covered with an impermeable material or other form of odour suppression (e.g. application of odour suppressant compounds) to limit the potential release of odours/vapours.

Soils and fill imported to site to backfill excavated voids should comprise clean/uncontaminated materials. The source of imported materials and the volume imported should be documented.

All trucks transporting soils materials to and from site should be covered and vehicles adequately cleaned.

7.3.1.3 Soil benchmarking

Site contamination condition should be benchmarked at the completion of the petroleum equipment removal by sampling from the excavations and the soil results compared to the Tier 1 values presented in Module 4 to determine if further investigation or remedial works are required. The work should be performed by a suitably qualified person, such as an environmental consultant.

The soil sampling exercise should be undertaken in accordance with Module 3 and in particular (and as a minimum) the sampling regime given in Table 3.2. The soil testing should be undertaken in accordance with the Draft Sampling Protocols and Analytical Methods for Determining Petroleum Products in Soil and Water (Oil Industry Environmental Working Group, 1999).

The results of the soil benchmarking work and oversight of the petroleum equipment removal by the environmental consultant (or similar) should be documented in accordance with Contaminated Land Management Guideline No. 1 – Reporting on Contaminated Sites in New Zealand (MfE, 2003), in particular the MfE Checklist for the Removal of Petroleum Underground Storage Tanks.

7.3.1.4 Liquid management

During the petroleum equipment removal and replacement works surface water (i.e. stormwater) should be diverted away from excavations and soil stockpiles.

Where groundwater is encountered in excavations during UPSS removal this groundwater is generally not removed. If the UPSS is being replaced and a high groundwater table exists then specific measures and controls should be used to manage excavation stability and pit dewatering. Dewatering may require a resource consent.

Shallow perched groundwater and stormwater may collect in open excavations. If this water is potentially impacted with petroleum hydrocarbons (or other contaminants) and needs to be removed from site, then care needs to be exercised to remove the water and the water should be disposed of to a licensed waste disposal facility. If LNAPL is encountered during petroleum equipment removal then every effort should be made to remove the LNAPL and this should be disposed of to an approved licensed waste disposal facility. The presence of perched water and LNAPL should be recorded by the environmental consultant. Records on the quantity of water and LNAPL removed from site should be documented in the UST removal/environmental benchmark report (see above).

7.3.1.5 Air quality management

The primary sources of potential hydrocarbon odour may be associated with hydrocarbon vapours released from any on-site degassing of petrol USTs, the walls and floors of open excavations and from soil stockpiles where potentially hydrocarbon impacted soil is exposed. Actual vapour concentrations are dependent on site conditions and activities. Air emission and odour controls can be used to limit the potential flammability/explosion risks and mitigate odour nuisance. Vapour levels should be monitored by on-site contractors to identify and manage any potential hazards.

If considered necessary, the following vapour/odour management procedures could be used:

- undertaking excavation works in a staged manner to limit the exposed surface area of potentially odorous material
- wetting-down of excavations
- application of odour suppressants
- covering any portion of the site that is generating odour

- covering stockpiled soil with sheeting to suppress the potential release of odours
- routinely backfilling excavations.

Petroleum equipment removal and replacement work is generally short duration work and any odour effects will be in temporary.

7.3.1.6 Dust management

Excavation and stockpiling of soils and on-site vehicle movements may generate dust and where appropriate, the generation and impact of dust on the surrounding environment can be minimised by:

- suspending or limiting dust generating activities during periods of high wind
- using water on exposed soils to suppress dust, ensuring that any water used is not allowed to migrate off-site by the stormwater, sewer, or any other means
- covering areas of exposed soil with sheeting
- ensuring trucks transporting soils material to and from site and removing soils are covered and that vehicles are adequately cleaned.

7.3.2 Natural attenuation

Natural attenuation, also referred to as intrinsic bioattenuation, relies on the natural processes of biological degradation, volatilisation, adsorption, and dispersion, which naturally occur at a site, to reduce the level of contamination in the soil and groundwater. In the absence of human intervention, many contaminant plumes will develop until they reach a quasi-steady-state. At steady-state, the contaminant plume is no longer growing and may shrink somewhat over time. Major processes controlling the size of the steady-state plume include:

- release of dissolved contaminants from the source area
- downgradient transport of the contaminants and mixing with uncontaminated groundwater
- volatilisation
- abiotic and biologically mediated transformation of the contaminants of concern.

Soluble components of petroleum products are easily attenuated in most aquifer systems. Benzene, one of the more mobile and carcinogenic components in petrol and diesel, is easily biodegraded in a well-oxygenated groundwater. Typically, dissolved oxygen concentrations of greater than 1 mg/l are required to allow bioremediation of benzene and other petroleum compounds.

Periodic monitoring is recommended to assess the continued effectiveness of natural attenuation. Refer to American Petroleum Institute document on natural attenuation (No. 1628) and ASTM Standard E1739.

Possible resource consent requirements:

- air discharge consent for vapours and odours
- consent for discharges to stormwater and groundwater.

Advantages	Cost-effective. Substantial scientific information available to allow well-founded assessment of viability of natural attenuation.
Disadvantages	May require long-term monitoring. Future land use and use of underlying groundwater may be constrained.
Suitability	No limitations on soil types or hydrocarbons, provided the exposure potential is shown to be acceptable.

7.3.3 Land use controls

Controlling the future use of a site to permit only less sensitive uses is a way of avoiding or reducing exposure to contaminants, and therefore allows higher contaminant concentrations to remain on site, e.g. redevelopment of a site for commercial use rather than residential use. If significant contamination is allowed to remain on site, it must be shown that the contamination will not cause an unacceptable risk to human health and the environment. The land use controls mechanisms available include:

Land Information Memoranda & Project Information Memoranda	Land Information Memoranda, issued under the Local Government Official Information and Meetings Act 1987, and Project Information Memoranda, issued under the Building Act 1991, can be used to release information on site contamination to interested parties.
District plan	Structures or activities such as basements or pools, or their construction, can be controlled using the district plan.
Memorandum of encumbrance	The memorandum creates a nominal mortgage in favour of the local authority and can be made binding on successors in title. It acts as a notification to those searching the title prior to purchase. The memorandum can be used as a condition of a resource consent.
Notation on a district plan	A notation can be placed on the district plan identifying a site as being contaminated. This can be initiated by an individual, company or council.

Another mechanism which is being considered is the use of notation on title, where a notation could be placed against the land title to identify the presence of contamination or to restrict the land use. No decision had been made by the government on this issue at the time this document was completed.

7.3.4 Access restrictions

Access restrictions such as fencing and restrictions on groundwater use are used to minimise potential exposure to a contaminated media. Fencing is used to limit exposure to soil or surface water by sensitive populations such as children and animals. Restrictions on groundwater could be used if a contaminated plume is migrating off site and affecting off-site potable supply wells. Another option for restricting access to impacted groundwater is to provide an alternative water supply to groundwater users. Providing an alternative water supply could involve periodic delivery of bottled or tankered water to be stored on site or constructing a water supply line from an uncontaminated supply well.

7.3.5 Groundwater monitoring

Groundwater monitoring, as part of a management strategy, is recommended if groundwater is or has the potential to be impacted. The objectives of the monitoring programme are to monitor the effectiveness of the management scheme, whether it is natural attenuation or active remediation, and provide assurance that the predictions regarding the fate and transport of the contamination are accurate.

It is recommended that a groundwater monitoring programme include a monitoring well installed upgradient of the site and two or three monitoring wells installed downgradient of the potential source(s) of groundwater contamination. At least one downgradient well can be located outside the contaminant plume to detect migration of the plume. See Section 3.4.6 of Module 3 for descriptions of monitoring wells.

It is suggested that monitoring wells should be sampled quarterly for the first year if contamination is present or groundwater elevations are expected to vary seasonally by more than 0.5 metre. If groundwater elevations are relatively stable, then semi-annual sampling for the first year is recommended. Yearly sampling after the first year is recommended until contaminant levels on the site reach acceptable levels. Note, however, that the monitoring frequency may be amended on the basis of site-specific factors.

The groundwater samples should be analysed for AVOCs if the source of contamination is petrol or diesel as discussed in Section 3.3 of Module 3. If the potential source of the contamination is suspected to be diesel, fuel oil, lubricating oils, bunker fuels, residential fuels, or crude oil, then the groundwater samples should be analysed for TPH. A percentage of the samples, say 10%, could also be analysed for PAHs. The compounds of key interest include BTEX, naphthalene, pyrene and benzo(a)pyrene as discussed in Module 4.

7.4 Containment

Containment at contaminated sites is used to minimise the vertical and horizontal migration of constituents of concern and can be used to isolate the contamination from potential receptors. Containment can be an effective and acceptable site management option but may require long-term monitoring.

In theory, there is no limit to the contaminant concentrations which can be contained on a site provided the integrity of the containment technology can be maintained until contaminant concentrations are reduced to acceptable levels. Containment options for soil at petroleum sites can include dust control, vertical barriers, and asphalt or concrete capping. Containment options for groundwater can include maintaining hydraulic control at the site through groundwater extraction.

7.4.1 Dust control

Dust control measures are used to limit the potential for fugitive dust to migrate off site. Most often, this technology applies to stock piles of excavated material waiting treatment and/or disposal. Dust control can include spraying a contaminated area with water, covering with a high density plastic sheet, or applying a dust suppressant.

7.4.2 Vertical barriers

Vertical barriers, also referred to as cut-off walls, are used to prevent horizontal migration of contamination in either soil or groundwater. They are often used if a sensitive environment such as a stream, used for recreational purposes, is located downstream from a site. Vertical barriers are either comprised of a slurry wall, grout curtain or steel shoring and are most effective when an impermeable layer below the water table is available to key in to. A slurry wall consists of a trench downgradient or around the area of contamination that is filled with a soil (or cement) and bentonite slurry. To form a grout curtain, grout is injected into holes that are drilled in a regular pattern around the contamination (or just on the downstream side). A cut-off wall can also be comprised of interlocking steel shoring that is vibrated into place.

Possible resource consent requirements:

- earthworks consent
- consent to discharge contaminants to groundwater.

Advantages	A moderate cost option if the impermeable layer is at depths less than 10 - 15 metres from the ground surface. Can be used as an interim measure until land use changes.
Disadvantages	Future land use is severely constrained as any containment system must be maintained intact. Liability is not discharged but simply managed. Hydrocarbons are not destroyed but merely prevented from migrating. The long-term integrity of the containment materials is not proven.
Suitability	Not suitable at sites with impermeable layers deeper than 30 metres, or at sites with fractured impermeable layers, such as fractured bedrock or fractured greywacke.

7.4.3 Capping

Capping at petroleum contaminated sites is typically used to isolate the contaminated soil from potential receptors and limit infiltration of rainfall. Limiting infiltration reduces the potential for downward migration of the petroleum hydrocarbons in the soil to the groundwater. Capping also limits upwards migration of vapours.

The most cost-effective caps at petroleum sites are typically comprised of concrete or asphalt. These caps are easily implemented but can be susceptible to weathering and cracking. Other capping materials can include clay and high density polyethylene (HDPE) liners.

Capping can also trap vapours and direct them to areas such as basements. For this reason it may be necessary to consider putting in a venting system.

Possible resource consent requirements:

- consent to discharge contaminants to groundwater.

Advantages	A low-cost option for isolating contaminants and limiting vertical migration.
Disadvantages	Liability is not discharged but simply managed. Caps restrict future land uses. Hydrocarbons are not destroyed. Long-term maintenance required.
Suitability	Suitable at most sites that can be managed long-term. May not be suitable if the site is to be sold and redeveloped.

7.4.4 Hydraulic control

Containment options for groundwater are designed to prevent further migration of the contaminated plume. Plume containment options typically consist of numerous extraction wells strategically placed either within the plume or near the leading edge. The number of wells and spacing between wells needed to maintain capture are a function of the hydrologic properties of the aquifer. Aquifer testing should be performed to obtain site-specific hydrogeologic data prior to designing a well network. See Section 3.4.6 of Module 3 for brief descriptions of aquifer tests and the type of information obtained from each type of test. Hydraulic control is typically combined with an ex situ groundwater treatment option. Several groundwater treatment options for petroleum contaminated sites are discussed in Section 7.6.

7.5 Soil remediation

> Soil remediation technologies are used to reduce the concentration of petroleum hydrocarbons in the subsurface to acceptable levels. Technologies can be implemented either in situ or ex situ. Five cost-effective technologies for remediating petroleum hydrocarbons in soils are described. In addition, their advantages and disadvantages, and suitability are discussed.

Cost-effective in situ technologies for remediating petroleum hydrocarbons in soils include soil vapour extraction (SVE), and bioventing. Cost-effective ex situ technologies for remediating petroleum hydrocarbons in soils include land farming, biopiles, and low-temperature thermal desorption. The five technologies discussed above are the most commonly used treatment technologies for petroleum contaminated sites. Other technologies, not discussed here, are available for remediating sites that have metals and/or chlorinated hydrocarbon contamination in addition to petroleum.

7.5.1 Soil vapour extraction

SVE is used to extract volatile and some semi-volatile organic compounds from unsaturated soils. This process is accomplished by reducing the pressure in the soil vapour space and mechanically drawing large volumes of air through the pores in the soil, which volatilises and strips the volatile and semi-volatile compounds from the soil matrix into the air stream. In this process, hydrocarbon vapours are removed from the soil through horizontal or vertical wells installed in the impacted area. The wells are perforated above the water table and a vacuum is applied to the wellhead to draw the hydrocarbon-laden vapours to the surface where they are discharged. The discharged air may require treatment prior to discharge depending on local regulations. One form of soil vapour extraction is shown in Figure 7.1.

SVE can also be used to volatilise free product from the water table. A vacuum is often applied to an existing groundwater monitoring well by connecting the well to a vacuum pump or blower. A moisture separator, also referred to as a knock-out drum, is installed before the blower to collect moisture that may damage the pump.

A low permeability cover (e.g. asphalt, concrete, or plastic sheeting covered with soil) may be installed to prevent short circuiting of air directly from the surface if the SVE wells are screened within 3 to 10 metres of the surface. Preventing short circuiting results in a larger radius of influence for each well, which decreases the number of wells needed to remediate the site.

There are many factors that influence the effectiveness of SVE systems, including vapour pressure and solubility of the contaminants present, soil moisture, temperature, air permeability of the soil, porosity, and stratigraphy. SVE is most effective with homogeneous, highly permeable soils contaminated with organic compounds that have vapour pressures greater than 1 mm mercury and Henry's Law coefficient values greater than 0.01. Therefore, SVE is effective at sites with gasoline-contaminated soils. More polar compounds and higher molecular weight (greater than 16 carbons) hydrocarbons are not easily removed from the soil using SVE because they are less volatile and more readily sorbed by the soil. Therefore, SVE is generally not as effective at removing contaminants from sites impacted by diesel and fuel oil. However, the use of SVE usually leads to an increase in the oxygen concentrations in the subsurface; this in turn leads to a decrease in diesel and fuel oil concentrations through biological degradation mechanisms.

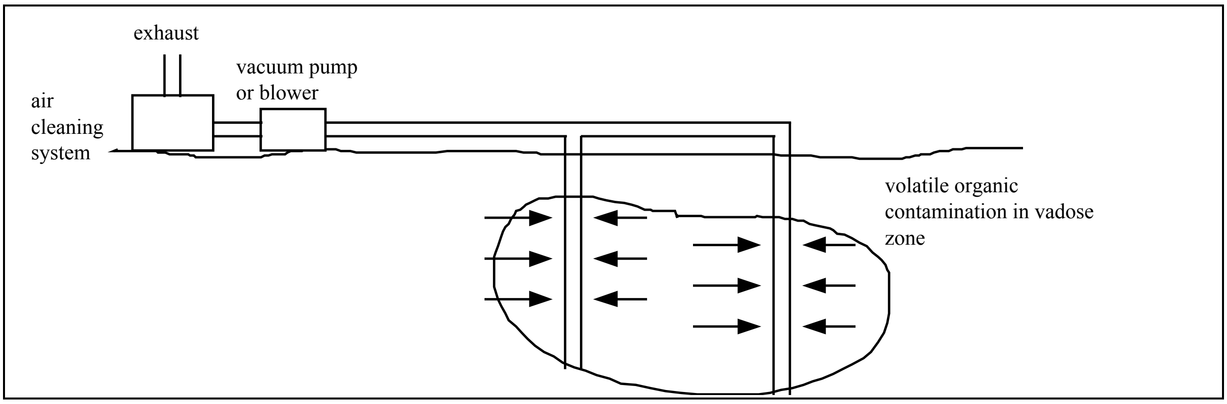

Figure 7.1 Soil vapour extraction

Possible resource consent requirements:

- air discharge consent for vapours and odours
- earthworks consent.

Advantages	Systems are generally easily installed and effective at petrol impacted sites. Can remediate petrol contamination in inaccessible locations (under building or roads). Can be used to remediate free product in existing monitoring wells. Some biodegradation of higher molecular weight hydrocarbons can occur during soil venting.
Disadvantages	Generates contaminated air which may require treatment.
Suitability	Best suited to moderate and high permeability soils contaminated with petrol.

7.5.2 Bioventing

Bioventing enhances natural biodegradation of petroleum hydrocarbons in the unsaturated zone by supplying oxygen to stimulate indigenous soil microorganisms. The micro-organisms aerobically metabolise middle and heavy distillate hydrocarbons into carbon dioxide and water. The stimulation is achieved by injecting air into horizontal or vertical vents installed in the contamination zone, as shown in Figure 7.2. It is usually not necessary to supply nutrients such as nitrogen because the availability of oxygen is typically the reaction rate limiting factor.

In general, bioventing has been found to result in some biodegradation at virtually all sites regardless of site conditions (Leeson et al, 1995). However, bioventing is most effective at sites with moderate to high permeability soils. Horizontal venting systems are effective where contamination is less than 4 metres deep. Typical degradation rates range from 5 to 20 mg/kg/day. Site clean-up averages 1 to 5 years (Miller et al, 1993). No secondary wastes or residuals are generated during the bioventing process.

Possible resource consent requirements:

- air discharge consent for vapours and odours
- earthworks consent.

Advantages	Easily installed, low-cost option that is effective for petrol, diesel and crude oils. Treatment can occur beneath buildings, roads and other surface features without disturbance.
Disadvantages	Timeframe for remediating moderately contaminated sites can take 1 to 5 years. Can result in increased emissions under buildings and into structures.
Suitability	Best suited to permeable soils such as sands and gravels.

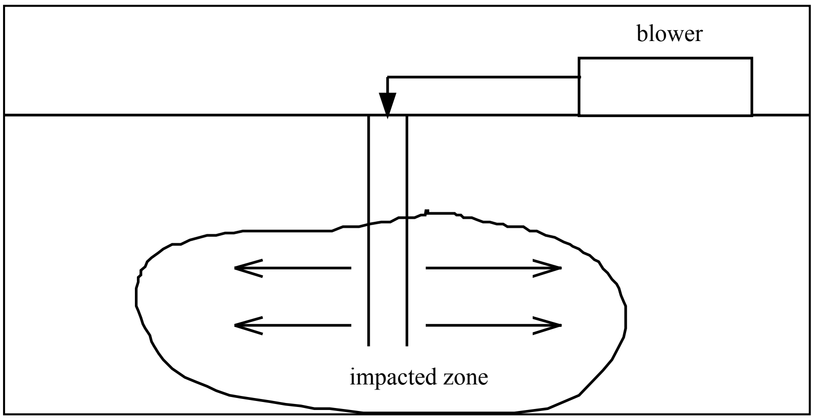

Figure 7.2 Bioventing

7.5.3 Land farming

Land farming is a biological treatment process that reduces the toxicity of organic constituents in soil by enhancing the natural microbial degradation process. For land farming, soil is excavated and place in 0.3 to 0.5 metre lifts on an engineered pad, as shown in Figure 7.3. The soil is periodically sprayed with a nutrient/water mixture, and tilled. Samples are taken to establish the success of the method until the concentrations of contaminants reach the desired clean-up level. Leachate from the spraying process and stormwater run-off are collected in a sump and reapplied over the soil lifts.

Land farming is typically an inexpensive option for remediating soils with petrol, diesel and waste oil, but requires a large area of land. Petrol is easily degraded and takes less time to achieve clean-up levels than diesel and waste oil. Typical clean-up times are three months to one year.

Possible resource consent requirements:

- land use consent
- consent to discharge contaminants to land
- earthworks consent
- air discharge consent for vapours and odours.

Advantages	Low-level technology. Relatively inexpensive depending on design of engineered pad. Proven effectiveness on a wide range of petroleum hydrocarbons.
Disadvantages	Requires a large land area. May need to consider managing odours.
Suitability	Works best on permeable soils, in moderate or warm temperatures.

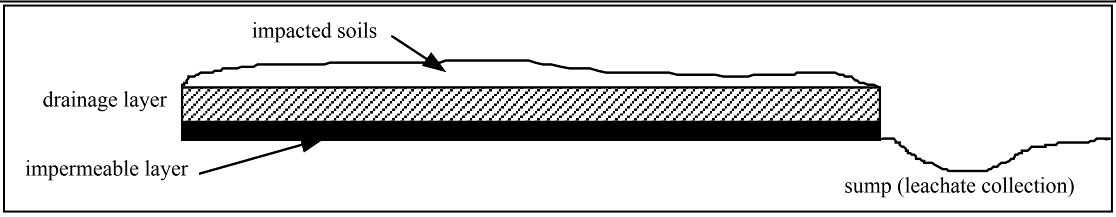

Figure 7.3 Land farming

7.5.4 Biopiles

Biotreatment cells (commonly referred to as biopiles) are designed to reduce the toxicity of organic constituents in soil through enhancing the natural microbial degradation process. Air is forced or pulled through a 2- to 3-metre high pile of impacted soil as shown in Figure 7.4. The biopile treatment process requires less land than land farming but is more capital intensive because perforated piping, a blower and possibly an air treatment system are required.

Possible resource consent requirements:

- land use consent
- consent for discharge of contaminants to land
- earthworks consent
- air discharge consent for vapours and odours.

Advantages	Low-level technology. Proven effectiveness on a wide range of petroleum hydrocarbons. Can be used in colder climates.
Disadvantages	Moderately costly.
Suitability	Suitable for wide range of petroleum hydrocarbons and soil types..

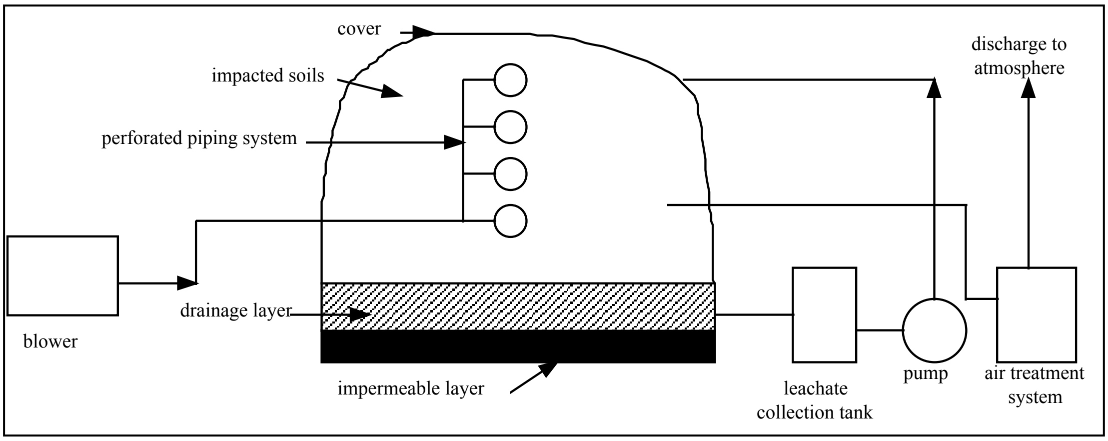

Figure 7.4 Biopiles

7.5.5 Low-temperature thermal desorption

Low-temperature thermal desorption (LTTD) units heat excavated soils contaminated with petroleum hydrocarbons to between 93°C and 315°C to volatilise water and organic constituents to separate them from the soil. The bed temperatures and residence times used in LTTD are sufficient to volatilise, or desorb, selected contaminants, but typically not to oxidise them.

Since the effectiveness of thermal desorption is dependent on the volatility of the organic contaminants, LTTD is generally more efficient for gasoline than diesel and fuel oil contaminated soils. The removal efficiency of LTTD does not depend on the input concentrations of contaminants, but on the residence time of the soil and the operating temperature of the unit. Numerous case studies have demonstrated that greater than 95% removal efficiencies can be achieved by LTTD; greater than 99% removal has been reported in some cases (USEPA, 1992). An LTTD unit can typically remediate a site with 15,000 cubic metres of material within two months.

Particle size distribution and available surface area affect the performance of the LTTD system. Smaller soil particles have a large surface area making more sites available for contamination sorption. Therefore contaminants tend to be adsorbed on smaller soil particles. In general, sandy soils are more effectively treated than clayey soils, which consist of small particles.

Possible resource consent requirements:

- earthworks consent
- land use consent
- air discharge consent.

Advantages	Can remediate large volumes of soils in a short timeframe. Systems are effective for most types of material and hydrocarbon contaminants.
Disadvantages	Transportable units are not yet readily available in New Zealand.
Suitability	Sites with large volumes of petrol and diesel contaminated soils.

7.6 Groundwater remediation

Groundwater remediation technologies are used to reduce the concentration of petroleum hydrocarbons in an aquifer beneath a site to acceptable levels. Acceptable levels are discussed in Module 4. Technologies can be implemented either in situ or ex situ. Six technologies for removing free product and technologies for remediating petroleum hydrocarbons in groundwater are described in this section. In addition, their advantages, disadvantages and suitability are discussed.

The most cost-effective approach for remediating groundwater is to remove the source of contamination before or during remediation. The most likely sources for groundwater contamination include soils saturated with petroleum hydrocarbons and free product floating on the surface of the water table. Technologies for remediating contaminated soils are discussed in Section 7.5. Technologies for remediating free product include recovery trenches, skimming, bailing, vacuum extraction, suction, and bioslurping. These technologies are discussed in Section 7.6.1.

Once the free product has been removed from the water table, remediation of the dissolved and adsorbed phases can begin, if required. In most cases, natural attenuation can adequately mitigate the contaminated groundwater. Contaminated groundwater can be treated either in situ or ex situ. The in situ technologies discussed in this section for remediating petroleum hydrocarbons in groundwater include air sparging and in situ bioremediation. The ex situ technologies discussed for remediating petroleum hydrocarbons in groundwater include air stripping, activated carbon adsorption, spray irrigation, and ex situ biological treatment. The in-situ groundwater treatment technologies are described in Section 7.6.2; the ex situ technologies are described in Section 7.6.3.

7.6.1 Free product removal

Technologies for remediating free product include recovery trenches, skimming, vacuum extraction, suction pumping, bailing, and bioslurping. These technologies are described in this section.

7.6.1.1 Recovery trenches

A trench is excavated on the downgradient side of a product plume to a level deeper than the water table and any expected fluctuations in the water table. Product migrates with the groundwater into the trench and can be removed by pumping from a low point or sump in the trench. Product recovery by trenches is shown in Figure 7.5. Where it is unsafe to leave the trench open (i.e. public access cannot be fully controlled, or the ground conditions are unstable) a perforated pipe drain can be installed and the trench backfilled.

Provided the trench is sufficiently long and correctly placed, complete capture of the plume can be effected by placing an impermeable barrier on the downstream side of the trench and pumping to lower the water table and induce flow into the trench. It is important to ensure that any natural barriers to vertical migration (e.g. an aquiclude or less permeable stratum) are not breached by the trench or this can result in an unwanted spreading of the contaminant.

Trenches are most cost effective where the plume is wide, the water table is shallow, and the product is relatively free flowing.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- earthworks consent
- consent for abstraction of groundwater.

Advantages	Simple to operate and requires no special equipment to install. Can be quick to install and cost effective. Complete plume interception if the trench is long enough.
Disadvantages	Can cause considerable ground disturbance and possible loss of operational land. Requires a collection system. There are health and safety considerations where the trench is open.
Suitability	Free product recovery where the permeability of the ground is high, the water table is near the surface (<4 metres) and groundwater flow velocities are high.

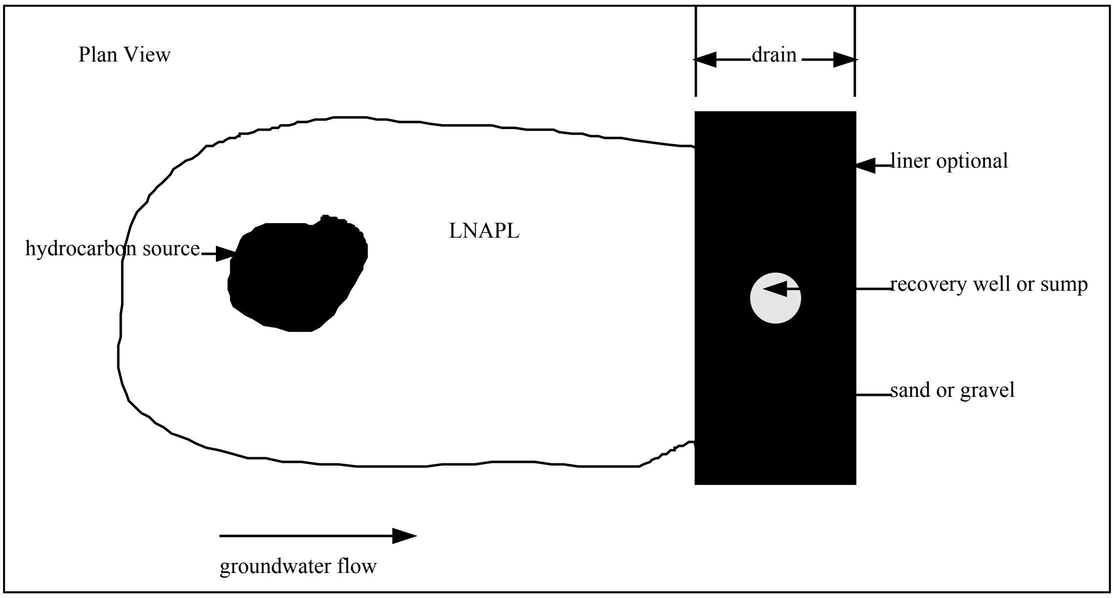

Figure 7.5 Recovery trench

7.6.1.2 Skimming

Passive and active product skimming devices are commercially available. A passive skimmer is a device designed to be installed in a groundwater well to collect small quantities of floating product. It comprises a sealed buoyant tube with a hydrophobic membrane which sits at the water level. The membrane allows petroleum hydrocarbons to pass through while preventing water passage. The hydrocarbon collects in the submerged section of the tube. The skimmer is lifted periodically and the product drained through a valve at the base of the tube.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Active skimming methods include a skimming pump, a one-pump system, and a two pump system. Active skimming requires a power source and a system at the surface for collecting the product or the product/water mix.

Skimming pumps are designed to remove floating product from a recovery well. A skimming pump is designed with a ballast to position the intake of the pump within the layer of floating product. A single-pump is designed to draw down the water table and remove both floating product and the water beneath. A dual-pump system is more sophisticated and comprises a water pump and a hydrocarbon pump. The water pump is used to lower the water table and encourage inflow of product. The hydrocarbon pump is normally fitted with a sensor which will trigger the pump once a sufficient depth of product is present.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, councils sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Passive skimming	
Advantages	Inexpensive and simple to operate. No surface intrusion. Little water, only product recovered. Can be installed in any well of 100 mm diameter or greater. No power needed. Will not cause smearing.
Disadvantages	Small area of influence. Does not enhance recovery rate. Labour intensive.
Suitability	Good for small volumes of free product in relatively low permeability soils, e.g. where product is confined to the backfill around a tank. May require staff on site to empty the skimmer.

Active skimming	
Advantages	Simple to operate once installed although careful setup is required. Pneumatic and single-pump skimming devices generate mostly product with little water. Can cope with fluctuating water tables. Continuous recovery.
Disadvantages	Pneumatic skimming pump has small area of influence. Single-pump system can recover both product and water which must be removed from the site and appropriately discharged. Two-pump system must be operated in conjunction with groundwater treatment. Can require a large diameter well. Requires a power source. Requires a system at the surface to contain the recovered product. Moderately expensive. Two-pump systems can

	smear hydrocarbons in the cone of depression zone.
Suitability	Pneumatic skimming pump suitable for relatively thick, free-flowing product layers. Single- and two-pump systems suitable where soil permeability is moderate and depression of the water table can be achieved.

7.6.1.3 Bailing

Product is removed from the well using a disposable Teflon or stainless steel bailer. If not done with care, this can mix the floating product through the water column.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Quick implementation. No capital cost. Immediate indication of recovery rates.
Disadvantages	High personnel costs. Not continuous. Limited zone of influence hence only small volumes recovered.
Suitability	Good for small volumes of free product where mechanisation is not warranted, i.e. low permeability/yield, low risk of contaminant impact on the environment and staff available on site or nearby.

7.6.1.4 Suction pump

Product is removed from an open trench using a pump with a suction hose. Both product and water are collected and stored in drums or a tank. Removal of the product is typically performed in discrete batches unless recharge of product into the trench is high. This method is most often used during removal of a leaking underground storage tank where the free product is localised around the tank pit.

Disposal of the product/water mixture can be difficult unless there is an oil/water separator and drain system currently operating at a site. If a disposal system is not available on site, then the product/water mixture is typically transported to a depot using an oil tanker where it is properly disposed. The tanker or truck used to transport the oil/water mixture must meet Hazardous Goods Transport requirements for flammable products and must be cleaned before and after use to avoid cross-contamination with other loads. Landfilling the product/water mixture can be difficult and costly because landfills will not generally accept the liquid, or may charge a premium for doing so.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent

- earthworks consent
- consent for abstraction of groundwater.

Advantages	Can be easily implemented during site investigation stage if test pits or tank pits are excavated to the water table.
Disadvantages	Not continuous. Disposal of the collected water and product can be difficult and costly. High removal rates may result in smearing of the product within the capillary fringe.
Suitability	Most often used during removal of a leaking underground storage tank where the product is localised around the tank pit. Can be used to remove all types of petroleum products.

7.6.1.5 Vacuum extraction

Vacuum extraction uses a blower or vacuum pump connected to a wellhead to volatilise the product in the well as well as strip petroleum hydrocarbons from the capillary fringe. The hydrocarbon-laden air is drawn to the surface where it is discharged with or without treatment. Vacuum extraction is most cost-effective at sites contaminated with petrol with existing monitoring wells screened across the capillary fringe. The sites can have low to high permeability soils contaminated with petrol. Low permeability soils may require the use of a liquid ring compressor (which has a higher suction capacity), which requires a water source.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- earthworks consent
- consent for abstraction of groundwater.

Advantages	Systems are generally easily installed and effective at petrol-impacted sites. Can remediate free product in inaccessible locations (under buildings or roads) and will remediate capillary fringe as well. Some biodegradation of higher molecular weight hydrocarbons can occur during vacuum extraction.
Disadvantages	Generates contaminated air which may require treatment.
Suitability	Best suited to moderate and high permeability soils contaminated with petrol but can be effective at sites with low permeability soils. Some success in remediation of diesel has been achieved.

7.6.1.6 Bioslurping

Bioslurping is a combination of vacuum extraction and liquid hydrocarbon removal as shown in Figure 7.6. A slurper spear, positioned near the hydrostatic groundwater level, is connected to a liquid ring vacuum pump (LRVP) at ground level. The LRVP pumps the vapour, product and water emulsion to a liquid/air separator cyclone. The hydrocarbon-laden air can be passed through a biofilter for treatment or discharged to the atmosphere. The liquid phase is typically passed through a coalescing-plate oil/water separator where the bulk of the product is removed. The outlet water contains product in emulsion and must be treated prior to discharge.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- earthworks consent
- consent for abstraction of groundwater.

Advantages	Providing a vacuum at the wellhead will enhance migration of product to the well especially in medium- to fine-grained sediments. Also remediates capillary fringe. Very little disturbance of groundwater table thus reducing smearing. Can be used at sites with petrol, diesel and waste oil.
Disadvantages	High velocity pump systems tend to form emulsions. Generates vapour and water streams that require further treatment.
Suitability	Best suited for low to high permeability sites contaminated with petrol, diesel and/or waste oil.

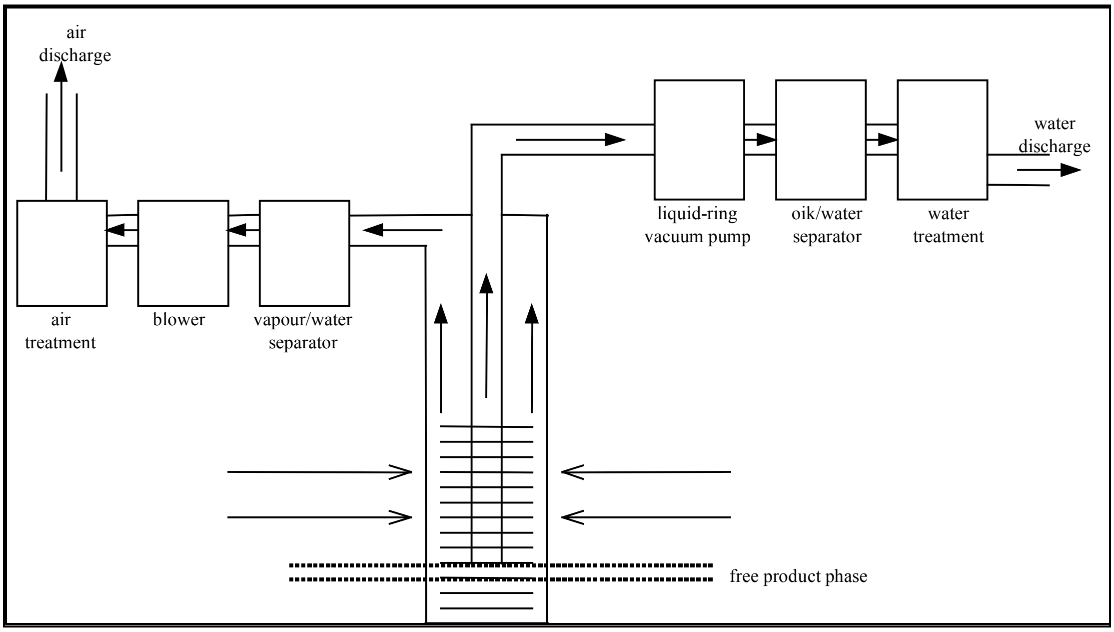

Figure 7.6 Bioslurping

7.6.2 In situ technology

Air sparging and in situ bioremediation technologies are discussed in this section.

7.6.2.1 Air sparging

Air sparging involves the injection of clean air into the saturated zone to strip out VOCs dissolved in groundwater and adsorbed to soils in the saturated zone. The vapour-phase contaminants transferred to the unsaturated zone may then be captured using a soil vapour extraction system or allowed to discharge through the unsaturated zone to the atmosphere. In addition to contaminant removal via mass transfer, the introduction of oxygen may also enhance subsurface biodegradation of contaminants.

The air sparging process creates turbulence and increases mixing in the saturated zone, which increases the contact between groundwater and soil. This results in higher concentrations of VOCs in the groundwater which can be recovered by pumping or can be further stripped by sparging. Air sparging systems are almost always coupled with an SVE system in order to control the subsurface air flow and prevent contaminated soil vapour from migrating to previously uncontaminated areas or entering basements of nearby buildings. The addition of air below the water table may also result in mounding and spreading of contaminated groundwater to uncontaminated areas. Therefore, proper hydraulic control is an important prerequisite for the implementation of this technology.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Generally low to moderate capital and operating costs. Typically remediates groundwater quicker than conventional pump-and-treat systems.
Disadvantages	Air flow may channel along preferential paths leading to incomplete remediation. Layers of fine-grained sediments may form barrier to upward airflow, diverting the flow laterally which can spread contamination.
Suitability	Adequately strips volatile compounds from groundwater and introduces oxygen into saturated zone which enhances natural biodegradation of less volatile compounds.

7.6.2.2 In situ bioremediation

In situ bioremediation is based on stimulating the natural breakdown of petroleum hydrocarbons within the subsurface by enhancing environmental conditions. Groundwater is extracted and treated in a surface mounted bioreactor. The effluent from the reactor, rich in micro organisms, nutrients and oxygen, is then reinjected into the aquifer upgradient of the extraction point. The treated groundwater can also be recirculated through the soil and allowed to percolate to groundwater to promote in situ biodegradation within the soil in addition to the groundwater.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Soil and groundwater treated with one technology. Typically remediates groundwater quicker than conventional pump-and-treat systems.
Disadvantages	Requires close monitoring. Not suitable for low permeability soils. Thorough knowledge of geology and hydrogeology required.
Suitability	Introduces nutrients and oxygen into saturated and unsaturated zone, which enhances natural biodegradation of less volatile compounds.

7.6.3 Ex situ technologies

Four above ground technologies for treating hydrocarbon-impacted groundwater are discussed in this section: air stripping, activated carbon adsorption, spray irrigation and biological treatment.

7.6.3.1 Air stripping

Air stripping uses air to strip volatile organic compounds from extracted groundwater. There are several types of air stripping systems including packed tower and cascading plate systems. The most common is the packed tower. In this type of system, water is released at the top of the tower and made to flow through a packed column against a current of air which is forced up from the bottom. The packed column ensures maximum air-water contact. Volatile organic compounds move into the air stream and are carried out the top of the column. The treated water leaves the bottom of the tower and is disposed. Disposal options for treated groundwater are discussed in Section 7.7. Depending on local authority requirements it may be necessary to treat the air stream prior to discharge to the atmosphere.

The performance of the tower can be affected by iron and manganese, as well as other dissolved compounds, which tend to precipitate out on the column causing clogging and biological slime growths. Other factors which affect performance are the temperature of the air and water, the achieved ratio of air to water, the concentration of the contaminant and the characteristics of the hydrocarbon contaminant. In properly designed and maintained towers, removal efficiencies of 99% have been achieved for BTEX. If necessary, activated carbon can be used just after the air stripping system as a polishing step to reduce organic concentrations to within required limits.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Proven technology that is simple and easy to operate. Relatively low capital and operating cost.
Disadvantages	Fouling of the column may be caused by iron and other dissolved constituents in the groundwater. Stripped vapour may require a discharge to air consent and possible further treatment. Can be affected by low temperature.
Suitability	Volatile contaminants such as BTEX.

7.6.3.2 Activated carbon adsorption

Activated carbon treatment of organics-laden groundwater is a well proven, frequently used technology. It is based on the fact that many organic compounds will preferentially adsorb onto activated carbon. Treatment is effected by passing the groundwater over beds of activated carbon. A separator can be used before the bed if necessary to remove any floating product. Once the absorptive capacity of the carbon is exhausted, it is removed for disposal or regeneration using steam.

The adsorption capacity of the carbon media varies depending on the type of media used, the particle size, the nature of the compounds present, the level of naturally occurring organic matter that compete for adsorption sites, and other water quality parameters such as pH, temperature and total dissolved solids levels. Carbon adsorption favours compounds with low water solubility, high molecular weight, low polarity, and a low degree of ionisation. In general, carbon adsorption is economical at sites with low volume and low concentration waste streams, or as a polishing step for final treatment prior to discharge because of the cost of the carbon and the spent carbon disposal or regeneration costs.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council’s sewers, reinjection to groundwater
- consent for abstraction of groundwater.

Advantages	Proven technology for removing aromatic compounds. Minimises problems with air emissions. Can cope with fluctuations in flow and contaminant concentrations.
Disadvantages	Fouling by high levels of suspended solids a problem. Carbon costs are high and spent carbon must be regenerated or disposed, of which is expensive. There is a lack of regeneration facilities in NZ. Pretreatment is necessary where oil and grease are present in high concentrations.
Suitability	Suitable for aromatics and organic compounds of low volatility where the oil and grease levels are low. Not suitable for oxygenated compounds such as alcohols. Generally used for polishing only due to high costs.

7.6.3.3 Spray irrigation

The natural processes of volatilisation, adsorption and biodegradation are utilised to remove contaminants from water when it is spray irrigated onto land. The water is sprayed from a nozzle to maximise air/water contact and hence volatilisation. Adsorption and biodegradation will occur as the water infiltrates the soils, reducing the contaminant levels still further.

The efficiency of initial removal can be affected by water and air temperature. It is important that the water infiltrates the ground rather than running off, to ensure the fullest possible treatment. Resource consents are likely to be required.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council’s sewers, reinjection to groundwater

- air discharge consent
- consent for abstraction of groundwater
- consent to discharge contaminants to land.

Advantages	Cost effective if land available. Can enhance in situ biodegradation.
Disadvantages	Requires a land area with the capacity to accept the predicted hydraulic loading. Will generally require a consent with an assessment of environment showing impacts on groundwater and surface water quality.
Suitability	Suitable for low contaminant concentrations in low to moderate rainfall areas.

7.6.3.4 Ex situ biological treatment

Treatment systems and technology similar to that used in sewage treatment plants can be used in a scaled down version to facilitate aerobic biodegradation of petroleum hydrocarbons. The contaminated water is passed over or through a biological film in a trickling filter, biotower or rotating biological contactor. Oxygen for the bacteria is provided through contact with air. Activated sludge processes can also be used where the micro-organisms are suspended in liquid and oxygen is provided by aeration. The treated liquid is then passed to a settling chamber and the biological solids removed. A portion of the biological solids are returned to the aeration chamber to maintain the biological population. The sludge must be disposed of separately.

Biological systems are sensitive and must be frequently monitored and controlled to ensure the biological population has optimum conditions for growth. In the event that the microbial population is lost, the restarting process can be slow since the organisms must be acclimatised to the contaminant.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater, council's sewers, reinjection to groundwater
- air discharge consent
- consent for abstraction of groundwater.

Advantages	Proven technology for a wide range of organic compounds. Fewer problems with air emissions.
Disadvantages	Expensive in terms of capital, operating and maintenance costs. Greater potential for malfunction. Sludge disposal required.
Suitability	Suitable for wide range of petroleum hydrocarbons. Best when hydrocarbon concentrations in groundwater are relatively stable.

7.7 Disposal

Disposal options for excavated soil and extracted groundwater are discussed in this section.

Two disposal options for excavated soils are available: landfilling and backfilling. Only treated soils are suitable for backfilling on site. If backfilled, contaminant levels in treated soils must meet appropriate clean-up levels as discussed in Module 4. Landfilling as a disposal option for untreated soils is discussed in Section 7.7.1.

Numerous options are available for disposing of extracted groundwater including disposal to land, reinjection, discharge to surface water bodies, and discharge to the sanitary sewer system. In most cases, extracted groundwater will require treatment prior to disposal. Groundwater disposal options are discussed in Sections 7.7.2 through 7.7.

7.7.1 Landfilling

Once approval is obtained from the landfill operator, the contaminated material is excavated and transported to the landfill. In some cities and towns a hazardous waste manifest is required to be completed before approval is given. It should be noted that the use of this method may become more limited in the future due to the increasing reluctance of territorial authorities to accept such waste at municipal soil waste landfills.

This technology is best suited for sites with contaminated soils at depths less than practical excavation depths. A larger volume of soil than is contaminated is typically excavated because of the need to slope the sides of the excavation. A method for separating uncontaminated soils from contaminated soils should be employed to reduce costs. The costs for the landfilling option will include excavation and transport, as well as the tipping fees at the landfill.

Possible resource consent requirements:

- discharge of contaminants to land.

Advantages	Removes contaminated soil from the site. Applicable to a wide range of contaminant types provided the landfill operator will accept the waste. Very quick.
Disadvantages	Expensive in some areas, especially if the volume to be removed is large. Some pretreatment may be required if contaminant levels high.
Suitability	Suitable for most petroleum-contaminated soils. Most cost effective at sites with contamination at depths shallower than 5 metres.

7.7.2 Reinjection

One option for disposing of treated groundwater is to reinject it back into the aquifer through reinjection wells or trenches. This option would require a fairly detailed evaluation of the hydrogeologic properties of the aquifer system and some modelling to design an effective reinjection system. Reinjection systems can require periodic maintenance, particularly at sites with high levels of iron or manganese in the groundwater, which can cause fouling.

Possible resource consent requirements:

- consent for discharge of contaminants by reinjection to groundwater
- consent for abstraction of groundwater.

Advantages	Can be designed to aid capture of plume. Water returned to aquifer for beneficial usage.
Disadvantages	Expensive. Requires detailed hydrogeologic information and modelling to properly design a system. Long-term maintenance required.
Suitability	Suitable for moderate to high permeability sites for a wide range of extraction rates.

7.7.3 Discharge to surface water bodies

Discharge of extracted groundwater to creeks, streams, or lakes typically requires treatment of the water to ANZECC aquatic standards. Water chemistry parameters should be monitored periodically to ensure minimal deleterious affects from discharge of treated groundwater.

Possible resource consent requirements:

- consent for discharge of contaminants to surface water bodies
- air discharge consent.

Advantages	Low-cost option if lake, stream or creek nearby.
Disadvantages	Monitoring of lake, stream, or creek required to ensure no long-term adverse effects from discharge of water.
Suitability	Suitable for sites with surface water bodies nearby that can withstand hydraulic loading.

7.7.4 Discharge to sanitary sewer or stormwater system

The feasibility of discharging treated or untreated groundwater to the sanitary sewer system or stormwater depends on the characteristics of the water and the capacity of the facility.

Possible resource consent requirements:

- consent for discharge of contaminants to stormwater or sewer
- consent for abstraction of groundwater.

Advantages	Groundwater may not require treatment prior to discharge.
Disadvantages	System may not have capacity.
Suitability	Suitable for sites with wastewater treatment facilities nearby that can withstand hydraulic and constituent loading.

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