6

Site management

Site management

6.1 Introduction

Management of risk associated with contaminated soil and groundwater at former gasworks is the primary objective of any site assessment and management programme. Risk assessment provides the framework for making decisions about the assessment and management of contamination.

Some questions fundamental to the risk management process include:

- does the site pose an unacceptable risk to human health or the environment?
- is action required to reduce the risk to within acceptable boundaries?
- does the uncertainty associated with the assessment of risk warrant either further investigation or management to minimise the risk?
- what action is the most appropriate, giving consideration to environmental and human health risk reduction, cost, possible future use of the site, practicality, and social and political concerns?
- is ongoing site management or monitoring required?

This module covers the following:

- ➔ intrinsic remediation
- ➔ containment systems
- ➔ remedial treatment systems
- ➔ disposal of gaswork contaminants to landfill
- ➔ monitoring

Additional information on site management can be found in Section 5 of the Users' Guide, including:

- ▲ the evaluation, selection and implementation of site management options (Section 5.3)
- ▲ legislation (Section 5.4)
- ▲ land use controls (Section 5.5.1)
- ▲ management controls (Section 5.5.2)
- ▲ intrinsic remediation (Section 5.5.3)
- ▲ containment options (Section 5.5.4)
- ▲ remedial treatment systems (Section 5.5.5)
- ▲ disposal of contaminants to landfill (Section 5.5.6)
- ▲ site management plans (Section 5.6)

6.2 Intrinsic remediation

This form of treatment may be used alone or in combination with other forms of clean-up or site control. Intrinsic remediation is most commonly used in combination with methods such as capping and installation of a cut-off wall.

If intrinsic remediation is used, detailed fate and transport modelling will probably be needed in support of land use and discharge consents, together with detailed site monitoring and the development of a site management plan.

A summary of the key issues associated with the use of intrinsic remedial options is given in Table 6.1.

Table 6.1. Intrinsic remediation

Remedial Status	Currently in use in New Zealand for a wide range of contaminated sites Widely used overseas for the management of contaminated sites, and commonly used on gasworks sites in conjunction with other remedial techniques
Contaminant Type	Organic contaminants primarily Mobile tar waste should be removed from site
Advantages	No site disturbance Low cost
Disadvantages	Only suitable for sites where adverse human health and environmental effects are limited Long-term management and monitoring programme required
Achieve Clean-up Levels	Will result in reduced contaminant concentrations No active clean-up
Downstream Effects	Changes in site use may require more active remediation of the site
Timeframe	Long timeframe, depending on the level and type of contamination and the site conditions (5 to 20+ years)
Cost	Not given/available
Resource Consent Requirements	Air discharge consent for vapours and odours may be required Consent for discharges to stormwater and groundwater may be required
Long-term Site Management Plan Issues	Management plan should address potential change in site end use or subsequent below ground works on site Long-term groundwater/surface water monitoring requirements

Additional information on intrinsic remediation can be found in Section 5.5.3 of the Users' Guide.

6.3 Containment methods

The use of containment systems prevents or reduces the migration of contamination, while the contamination remains on-site. As a consequence, the liability associated with the contamination will remain. In addition, it will be necessary for a site management plan to be developed and land use control measures to be applied to the site. These measures will ensure the continued integrity of the containment system and that adverse human health and environmental effects do not arise in the future.

Containment methods include:

- capping systems
- cut-off walls
- groundwater interception
- on-site repository

6.3.1 Capping systems

Infiltration, resulting in leaching of contaminants, and direct contact with the contaminated soil can be minimised by installation of a low permeability cap at the site. The cap may be constructed from soil, clay, synthetic membranes, asphalt or concrete. Compacted clay caps are most commonly used where a clear site is available; the design of such systems drawing heavily on landfill design principles. Capped sites are most often redeveloped for commercial/industrial and recreational purposes, although they have been used for medium and high density residential purposes.

The key elements of cap containment system are shown schematically in Figure 6.1 and a summary of capping technology issues is given in Table 6.2.

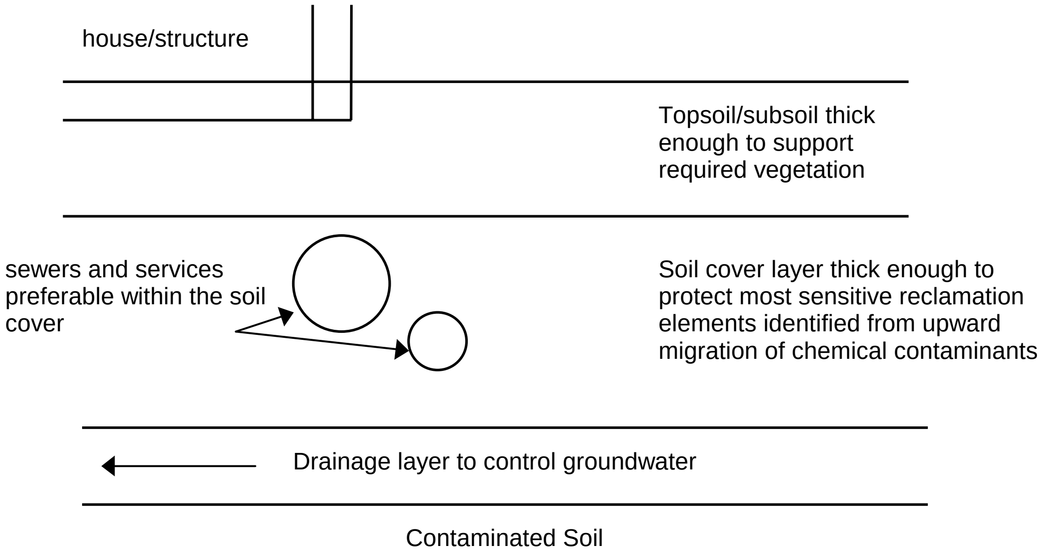


Figure 6.1 Capping technology

In conjunction with cut-off drains up-gradient of the site to divert clean groundwater around the site, the cap prevents permeation of surface water and limits migration (leaching) of soil contaminants.

Table 6.2 Capping systems

Remedial Status	- Currently in use in NZ - Widely utilised overseas, and is commonly used in conjunction with other remedial and management approaches. Approach commonly used on gasworks sites
Contaminant Type	- All contaminant types - Not appropriate for containment of mobile tar waste on site - this should be removed from site
Advantages	- Ideal where landfill access is limited - Reduces recharge to groundwater - Reduces human exposure to surface contaminants
Disadvantages	- Long-term liability issues associated with leaving contamination in-situ - Long-term management plan required
Achieve Clean-up Levels	- Direct contact to contaminants prevented by placement of cover
Downstream Effects	- No direct effects. Changes in land use may require more active remediation of the site
Timeframe	- Relatively short (weeks to months)
Cost	- Refer Table 6.23
Resource Consent Requirements	- Consent to discharge contaminants to groundwater may be required

6.3.2 Cut-off walls

Off-site migration of groundwater and free phase hydrocarbon can be minimised by construction of cut-walls surrounding the contaminated zone. A cut-off wall may be constructed using clay, a bentonite/clay or soil mixture, cement grout, HDPE or steel sheet piling. Ideally such cut-off walls should be keyed into a low permeability strata underlying the site to minimise underflow. The cut-off wall can be installed either in a trench if the wall is relatively shallow, or by injection of grout through closely spaced boreholes to create a low permeability barrier, if the total depth of the wall is significant.

The key elements of a cut-off wall are shown schematically in Figure 6.2 and summarised in Table 6.3.

Table 6.3. Cut-off walls technology

Remedial Status	Currently in use in NZ Widely used overseas for containing contaminated groundwater on variety of sites, including gasworks sites
Contaminant Type	All contaminant types Principally aimed at preventing off-site migration of groundwater contamination
Advantages	Avoids excavation and treatment, removal or disposal of contaminated soil and groundwater
Disadvantages	Possible disposal of excavated contaminated soil following wall construction Aggressive soil or groundwater may attack cut-off wall materials Excavated cut-off walls generally only applicable in unconsolidated materials - cannot be installed into bedrock High level of quality assurance required to ensure integrity of cut-off wall
Achieve Clean-up Levels	Clean-up levels not achieved - migration of groundwater contamination off-site is prevented or limited
Downstream Effects	Changes in site use may require more active remedial works
Timeframe	Medium term (weeks to months)
Cost	Refer Table 6.23
Resource Consent Requirements	An earthworks consent likely to be required A consent to discharge contaminants to groundwater may be required
Long-term Management Plan Issues	Plan should ensure the integrity of the cut-off wall is maintained Long-term groundwater monitoring will be required Plan should address future excavations given that contamination will remain on site

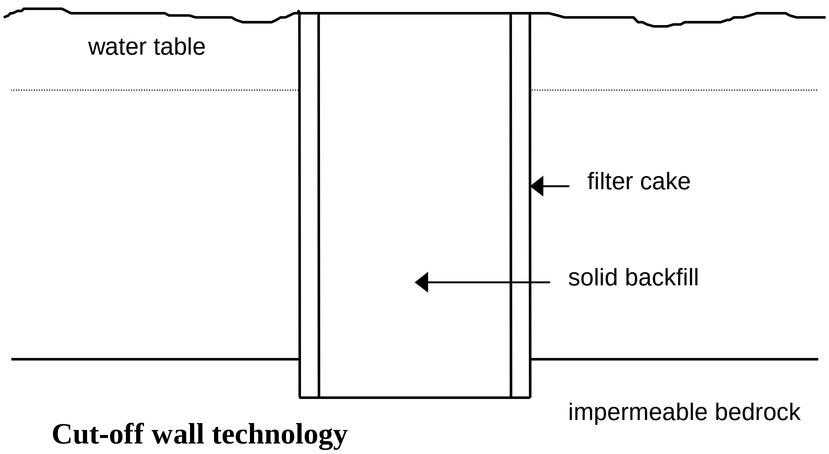


Figure 6.2 Cut-off wall technology

6.3.3 Groundwater interception

An interception trench or a series of groundwater extraction wells installed downgradient of a contaminated area may allow the interception of contaminated groundwater moving off-site. Groundwater may then be extracted and treated before disposal or re-injection. In this way a hydraulic barrier to contaminant migration can be established. The trench or extraction wells must be designed to take into account the presence of free phase hydrocarbons (both dense non-aqueous phase liquids (DNAPLs) and light non-aqueous phase liquids (LNAPLs), and the specific hydrogeological conditions encountered at the site e.g. the trench must be installed to a depth that minimises the underflow of contaminated water. Although the object of such systems is to contain the groundwater contamination plume, they can also be used as part of a groundwater remediation system.

The key elements of a hydraulic control system are shown schematically in Figure 6.3 and summarised in Table 6.4.

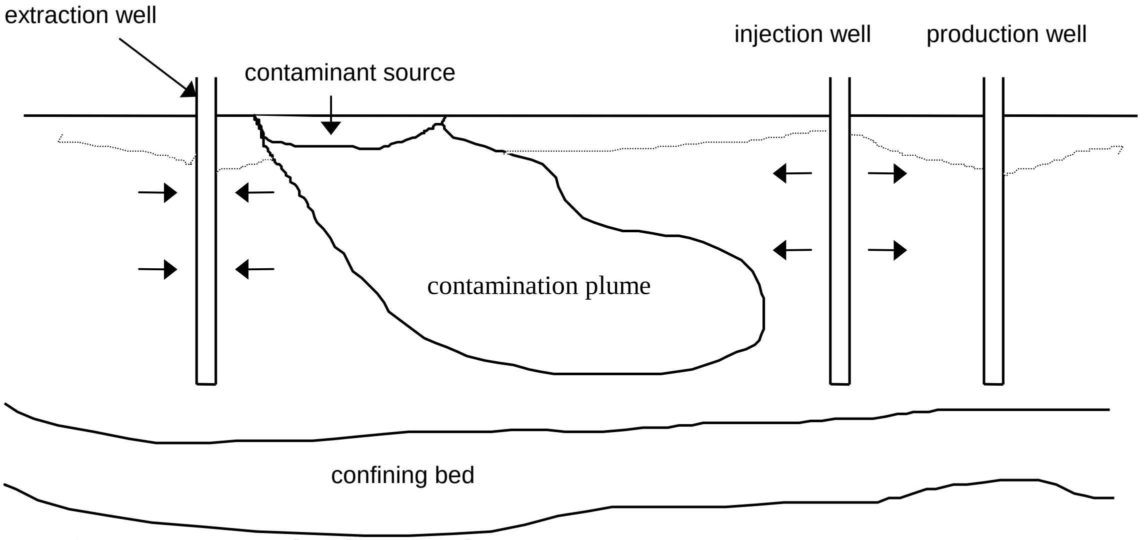


Figure 6.3 Hydraulic control system

Table 6.4 Groundwater interception

Remedial Status	• Currently in use in NZ • Widely used overseas for management of contaminated groundwater (US and Europe) in conjunction with pump and treat technologies. Approach has been used extensively on gasworks sites
Contaminant Type	• All contaminant types • Principally aimed at preventing off-site migration of groundwater contamination
Advantages	• Excavation, removal and disposal of contaminated soil is not necessary • Clean-up of groundwater achieved as part of remediation
Disadvantages	• High level of equipment maintenance required • Contaminated groundwater must be treated and disposed • System prone to mechanical failure
Achieve Clean-up Levels	• Clean-up of contaminated groundwater migrating from the site achieved • Generally only a short-term option. Expensive to run for a long time
Downstream Effects	• Changes in site use may require more active remedial works
Timeframe	• Long term (as long as contamination source(s) are present on-site)
Cost	• Not given/available
Resource Consent Requirements	• A consent may be required to extract groundwater • A consent may be required to discharge groundwater to stormwater or sewer or reinject to groundwater
Long-term Management Plan Issues	• Long-term groundwater monitoring will be required • Plan should address future below surface maintenance works given that contamination will remain on-site • Plan should ensure a regular maintenance schedule for pumps

6.3.4 On-site repositories

To obtain sufficient integrity of containment or to allow aggregation of wastes in one area of the site (thus freeing other area of the site for redevelopment), wastes may be excavated and placed in a secure repository constructed at the site. A secure repository may be considered as a purpose-designed landfill, and may include a low permeability liner and cap and leachate collection and treatment. Repository construction and design draws very heavily on landfill design and construction principles. Mechanisms for the ongoing management and maintenance of the repository are essential.

A summary of the key issues associated with construction and operation of an on-site repository system is given in Table 6.5.

Table 6.5 On-site repository

Remedial Status	• Currently in use in NZ • Widely used overseas for remediation of gasworks sites (US and Europe)

Contaminant Type	• All contaminant types • Not appropriate for disposal of mobile tar waste
Advantages	• Highly effective. Restrict area requiring management
Disadvantages	• Long-term liability issues • Need to ensure long-term performance of repository • Long-term management plan required • Leachate management required
Achieve Clean-up Levels	• Achieve clean-up levels
Downstream Effects	• Treatment/disposal of leachate • May sterilise part of the site i.e. cannot be used for other activities
Timeframe	• Short to medium timeframe (months) • Construction of repository could be incorporated into site redevelopment works
Costs	• Refer Table 6.23
Resource Consent Requirements	• Consents to discharge contaminants to ground may be required • Land use consent may be required • Earthworks consent may be required
Long-term Site Management Plan Issues	• Ensure integrity of repository is maintained • Long-term groundwater monitoring likely • Restrictions on future land use likely

Additional information on containment systems can be found in Section 5.5.4 of the Users' Guide.

6.4 Remedial treatment systems

6.4.1 Stabilisation and solidification

The use of solidification/stabilisation reduces both the mobility of the contaminants and the exposure pathways through which adverse effects can occur.

6.4.1.1 In-situ

Cementing agents may be added to the contaminated soil to bind the contaminants and prevent the movement in leachate or groundwater. Binding agents include lime, cement, pozzolanic fly ashes and organic polymers. The binder can be applied via large diameter augers, or other treatment processes. Overlapping zones are needed to ensure all the soil is treated.

This method is suitable for low permeability soils and where there is heavy metal contamination, which is not amenable to thermal treatment or bioremediation. It does not result in any reduction in contaminant concentrations, but rather in the formation of a solid mass in which contaminants are strongly bound (both physically and chemically). Following treatment the site may be suitable for a restricted range of future land uses. Other compounds, such as high levels of sulphates, some metal salts, phenols, coals, and oil and grease, present in the soil can interfere with the setting of the binder. Such techniques have been used in the United States and Europe for the treatment of contaminated soil, but application to gasworks sites is unknown. There has been no significant application of this technology in Australia or New Zealand.

The in-situ stabilisation process is shown schematically in Figure 6.4 and the key issues associated with this technology are given in Table 6.6.

Table 6.6 Stabilisation and solidification

IN-SITU

Remedial Status	• Not currently in use in NZ • Has been used commercially overseas (US and Europe), but generally not used for full-scale remediation of gasworks sites
Contaminant Type	• Ideal for metals - interference by other gasworks contaminants, particularly organics and sulphates
Advantages	• Highly effective for metals
Disadvantages	• Contamination not destroyed - mobility is reduced or minimised • Possible restrictions on future land use • Limited in highly heterogeneous soils • Effectiveness of stabilisation and solidification may decrease over time
Achieve Clean-up Levels	• Clean-up levels not achieved - contaminants immobilised
Downstream Effects	• None, provided integrity of stabilisation works remains intact
Timeframe	• Short to medium term, works can be incorporated into site redevelopments (weeks to months)
Cost	• Refer Table 6.23
Resource Consent Requirements	• Consent to discharge contaminants to ground/groundwater may be required
Long-term Management Plan Issues	• Integrity of stabilised material needs to be maintained • Long-term groundwater monitoring required. • Restrictions on future land use likely
EX-SITU	
NZ/Remedial Status	• Currently in use in NZ (has been utilised primarily for timber treatment wastes and dredged material, although some gasworks wastes have been stabilised) • Has been used commercially overseas (US and Europe), but generally not utilised for full-scale remediation of gasworks sites
Contaminant Type	• Ideal for metals - interference by other gasworks contaminants
Advantages	• Highly effective for metals • Effective at treating a wide variety of soil types
Disadvantages	• PAHs, cyanides and sulphur compounds will affect waste binding and retard the setting and therefore physical strength of the cement matrix • Careful control of stabilisation process required
Achieve Clean-up Levels	• Achieve clean-up levels through removal of contamination from site
Downstream Effects	• None provided integrity and stabilisation works remain intact
Timeframe	• Short term, excavation works can be incorporated into site redevelopment (weeks)
Cost	• High cost, except for hotspot mix asphalt (Refer Table 6.23)
Resource Consent Requirements	• Earthworks consent may be required
Long-term Management Plan Issues	• No long-term management plan, unless residual contamination remains on-site

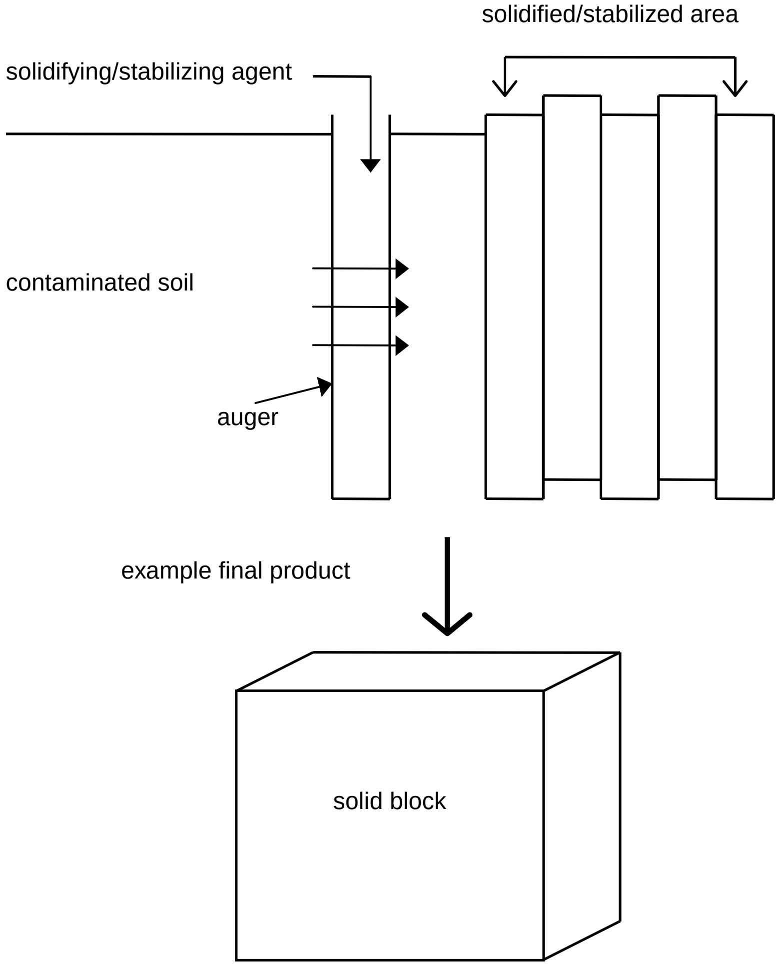


Figure 6.4 In-situ solidification/stabilisation

6.4.1.2 Ex-situ

Frequently waste materials must be stabilised before to disposal to landfill, or placement in another form of secure waste repository, to comply with the relevant leachate test criteria. In waste from gasworks sites, free tar from tar wells or gas holders is the primary waste stream which may require stabilisation. Other waste streams possibly requiring stabilisation include heavy metal contaminated soil and spent oxide.

Such wastes may be stabilised using cementing reagents to form a solid mass for disposal. Stabilisation of tars requires careful control to ensure adequate setting of the stabilised material. An alternative form of stabilisation for tar and heavily tar contaminated soil is the use of such materials in hot or cold mix asphalt.

As discussed above (Section 6.4.1.1) some contaminants may interfere with the setting of the binder and this must be considered when evaluating the technology.

The key issues associated with this remedial technology are given in Table 6.6.

6.4.2 Bioremediation

A range of bioremediation techniques been developed in recent years and these may be classified in terms of the microorganisms used and the physical arrangement of the system. Although increasing attention has been focused on in-situ techniques such as bioventing, in practice gasworks wastes are generally difficult to degrade and therefore the more intensive ex-situ bioremediation methods are probably more applicable.

Bioremediation has been widely applied to the degradation of a range of organic contaminants, particularly petroleum contaminants. However, the application of bioremediation to the treatment of soils from gasworks sites has been more difficult. A number of bioremediation trials have been conducted internationally and in New Zealand with limited success. Some of the key factors which have arisen in this work include:

- robustness of processes under field conditions
- removal efficiencies obtainable may not be sufficient to comply with the nominated landfill acceptance criteria
- plateau in contaminant removal, possibly associated with limited bioavailability.

The soil acceptance criteria nominated for benzo(a)pyrene and other heavier PAHs are generally relatively low, however these components are also some of the most difficult to degrade. Successful bioremediation of gasworks wastes has generally relied upon:

- relatively low initial concentrations of the heavier PAHs (such that 30% to 70% removal is sufficient)
- the nominated criteria are based on total PAH concentrations such that the higher removal achieved for the lighter PAHs can offset the lower removal of the heavier PAHs
- comparatively high acceptance criteria are nominated for a non-sensitive end use e.g. commercial or disposal to landfill (i.e. remediate highly contaminated soils to a level acceptable within a landfill).

Gasworks wastes may contain heavy metals in addition to the primary organic contaminants, and some of the organic contaminants, particularly 4, 5 and 6 ring PAHs and their breakdown products, are toxic to many bacteria strains. Biological processes may therefore be inhibited by specific contaminants. Where particular wastes contain both organic and heavy metal contaminants at significant concentrations, bioremediation may not feasible.

6.4.2.1 In-situ

In-situ bioremediation techniques are generally based on stimulation of contaminant degradation by the naturally occurring microorganisms in the soil and groundwater by the addition of oxygen and nutrients. Oxygen is supplied by injecting air or oxygen-saturated water through wells or sub-surface vents (bioventing) to areas of contamination above the water table. Below the water table the oxygen can be supplied as hydrogen peroxide dissolved in water or as slow release solids, or by air injection or sparging. Some of the emerging areas in the application of in-situ bioremediation include the use of bioaugmentation - the use of alternative electron acceptors and the addition of carbon sources to act as co-substrates for the organisms. Bioventing, involving the injection of air only, has been the most widely implemented in-situ bioremediation technique.

In-situ methods have had some success in permeable soils where the contaminant is a light hydrocarbon product, including lighter PAHs (such as those predominant in creosote). Heavier products and 4, 5 and 6 ring PAHs are less suited due to lower bioavailability, and metals cannot be treated.

Further, based on the organic contaminants present (i.e. 4, 5 and 6 ring PAHs) anaerobes or methanothrophs may provide more effective degradation, especially where co-metabolism of these contaminants can occur.

Resource consents are likely to be required for the implementation of the bioremediation works and on completion of the works, given that some form of residual contamination may remain in-situ. If residual contamination remains, following completion of the bioremediation works, liability issues may also remain.

A summary of the key issues associated with in-situ bioremediation works is given in Table 6.7.

Table 6.7 In-situ bioremediation (soil and groundwater)

Remedial Status	• Currently used in New Zealand but limited mainly to petrochemical/oil industry sites • Has been used commercially overseas (US and Europe) for full-scale remediation of gasworks sites.
Contaminant Type	• Organic only (less suited to heavy end PAHs)
Advantages	• Minimal site disturbance • High level of public acceptance • Effective on soluble light end PAHs and BTEX
Disadvantages	• Ineffective on inorganic contaminants • may be inhibited by the presence of heavy metals, oxides, cyanides or low pH conditions which are common on gasworks sites • Not suitable for low permeability heterogeneous soils
Achieve Clean-up Levels	• Effective at cleaning up monocyclic aromatics and light molecular weight PAHs. Limited success with 4, 5 and 6 ring PAHs
Downstream Effects	• Degradation of some PAHs may form toxic recalcitrant compounds
Timeframe	• Medium to long-term timeframe, with remediation timeframes generally longer than ex-situ bioremediation techniques • Remediation timeframe dependent on organic compounds present, site geology and other environmental factors (i.e. climate)
Cost	• Refer Table 6.23
Resource Consent Requirements	• Land use consent may be required • Consent to discharge inoculant (i.e. nutrients) to soil and or groundwater may be required
Long-term Site Management Plan Issues	• None (should acceptable clean-up levels be achieved)

6.4.2.2 Ex-situ

More recalcitrant compounds usually require a more intensive process such as land farming, soil biopiles, composting or soil slurry reactors. Breakdown is stimulated by providing oxygen and, if necessary, nutrients such as nitrogen and phosphorus. Some work has focused on the addition of microorganisms (bioaugmentation) although generally biostimulation is proposed for the remediation of gasworks materials and other similar hydrocarbons.

Oxygen is supplied either by turning the soil regularly to expose it to the atmosphere ***(landfarming)*** or by creating aerated piles ***(biopiles)***. In biopiles, air is supplied to covered piles of soil via a perforated pipe network. The moisture, oxygen and nutrient contents can be closely monitored and controlled to ensure optimum conditions and hence rapid hydrocarbon degradation.

Soil amendments, such as organic matter, may be added to improve the soil structure and moisture retention.

Composting is the degradation of contaminants using naturally present communities of microorganisms supplemented with organic material. The interaction between various microorganisms allows degradation by a range of mechanisms, with different microorganisms contributing at different stages of the degradation process. Composting is often more effective than simpler bacterial processes. The addition of large volumes of organic matter results in increased areas required for treatment and can increase costs in disposal of treated material.

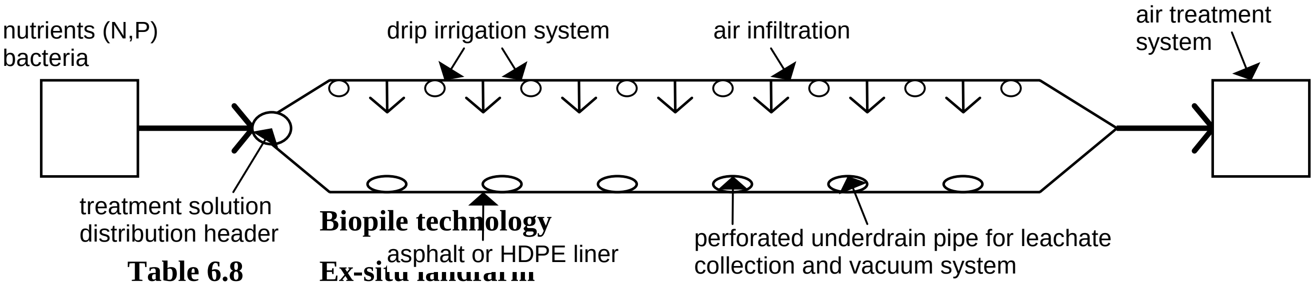
Soil slurry reactors can be used as a starting point for bacterial systems, allowing optimal delivery of nutrients, surfactants and organisms (if required), improved system control and a higher rate of degradation. Slurry bioreactors are used for pilot trial work but rarely for full scale remediation due to the cost associated with such systems. Soil slurry reactors do not generally increase the overall removal efficiency, but rather they increase the rate of degradation.

Fungal systems and the use of white rot fungi have the potential to degrade many compounds resistant to bacterial degradation or which inhibit other microorganisms. The processes are largely based on extra-cellular enzyme activity and the generation of free radicals, which are powerful oxidants, by the fungi. The free radical chemistry of white rot fungi degradative processes is relatively non-specific, degrading a wide variety of compounds. This contrasts with many bacteria whose degradative enzymes are highly substrate specific, and therefore chemical specific. Fungal systems have been applied to PCP contaminated soils and hence conceivably could be applied to gasworks contaminated soils.

Remediation of contaminated soil requires the addition of an inoculum, separately prepared, and provision of a growth medium (e.g. wood chips) as the fungi are not generally capable of using the compounds of concern as a sole carbon or energy source (i.e. co-metabolism). This is a sensitive process, with moisture content and temperature important variables. Contamination by wild fungi has also been reported as a problem. The biodegradation processes of white rot fungi can be used in a slurry bioreactor system, although a variation on a soil biopile or landfarming technique is more common.

Operation of an ex-situ bioremediation system is likely to require a number of resources consents, including a land use consent and an air discharge consent.

A schematic of a biopile system is shown in Figure 6.5 and a summary of the key issues associated with the operation of an ex-situ bioremediation system is given in Tables 6.8 through to 6.12.



Biopile technology

Table 6.8 Ex-situ landfarm

Remedial Status	• Currently used in New Zealand and has been used with limited success on gasworks contaminated soils • Commercially used overseas (US and Europe) for remediation of selected gasworks contaminated soils
Contaminant Type	• Organic only (less suited to heavy molecular weight PAHs)
Advantages	• High level of public acceptance • Allows photodegradation of UV sensitive heavy end PAHs • Allows volatilisation of light end PAHs and monocyclic aromatics • Allows easy aeration of contaminated soils
Disadvantages	• Metals and cyanides may be toxic and inhibit degradation rates • Sensitive to feed stock and to soil grain size - sandy soils preferred • May create odours and vapours • Requires effective stormwater control and leachate management
Achieve Clean-up Levels	• Generally more effective than in-situ bioremediation especially due to the photodegradation of PAHs • Degradation rates for 4, 5 and 6 ring PAHs may still be slow
Downstream Effects	• Degradation of some PAHs may form toxic, recalcitrant compounds • Disposal of treated soil
Timeframe	• Medium to long term timeframe (depends on organic compounds). Remediation times typically in the order of 12 months
Cost	• Refer Table 6.23

Resource Consent Requirements	• Land use consent may be required • Consent to discharge contaminants to ground may be required • Earthworks consent for excavation works may be required • Air discharge consent for vapours and odours may be required
Long-term Site Management Plan Issues	• None (should acceptable clean-up levels be achieved)

Table 6.9 Biopile remediation

Remedial Status	• Currently in use in NZ, but limited to petrochemical and oil industry sites • Used commercially overseas (US and Europe) for remediation of gasworks contaminated soils
Contaminant Type	• Organic only (less suited to heavy end PAHs)
Advantages	• Allows control of environmental factors limiting biodegradation • High level of public acceptance • Can be used to increase volatilisation of light end PAHs and BTEX through heating or forced venting
Disadvantages	• Limited success on low permeability soils • Sensitive to feed stock/soil grain size - sandy soils preferred • Ineffective on inorganic contaminants and may be inhibited by presence of heavy metals or low pH conditions
Achieve Clean-up Levels	• Effective at cleaning up monocyclic aromatic and light molecular weight PAHs • Limited success with 4, 5 and 6 ring PAHs
Downstream Effects	• Degradation of some PAHs may result in the formation of toxic recalcitrant compounds • Disposal of treated soil
Timeframe	• Medium to long-term timeframe (depending on the organic compounds present). Generally remediation times between 12 and 18 months for typical gasworks contaminants
Cost	• Refer Table 6.23
Resource Consent Requirements	• Land use consent may be required • Consent may be required for discharges to land • Earthworks consent for excavation works may be required • Air discharge consent for vapours and odours may be required
Long-term Site Management Plan Issues	• None (should acceptable clean-up levels be achieved)

Table 6.10 Compositing bioremediation

Remedial Status	• Currently, limited use in New Zealand • Has been used commercially overseas for treatment of gasworks contaminated soils, but primarily limited to pilot scale projects
Contaminant Type	• Organic only, used especially for contaminants that must be co-metabolised
Advantages	• High level of public acceptance • Allows cometabolism of recalcitrant 4, 5 and 6 ring PAHs • Suitable for the bioremediation of low permeability soils
Disadvantages	• May create odour and air discharge issues • Sensitive to feed stock/soil grain size - sandy soils preferred • Involves a significant increase in the volume of material which must be disposed
Achieve Clean-up Levels	• Effective at cleaning up monocyclic aromatic and light molecular weight PAHs • Allows cometabolism of 4, 5 and 6 ring PAHs, however may still be limited success with degrading these compounds due to bioavailability
Downstream Effects	• Degradation of some PAHs may form toxic, recalcitrant compounds • Disposal of treated soil
Timeframe	• Medium to long timeframe (depends on organic compounds present. Generally remediation times between 12 and 18 months for typical gasworks contaminants

Cost	• Not given/available
Resource Consent Requirements	• Land use consent may be required • Consent may be required for discharges to ground • Earthworks consent for excavation works may be required • Air discharge consent for vapours and odours may be required
Long-term Site Management Plan Issues	• None (should acceptable clean-up levels be achieved).

Table 6.11 Soil slurry bioremediation

Remedial Status	• Used for agricultural wastes and to remediate PAH contaminated soil at a former coal carbonisation site[1] in New Zealand • Has been used commercially overseas (US and Europe), but limited primarily to treatment of wastes containing high concentrations of recalcitrant compounds i.e. 4, 5 and 6 ring PAH's
Contaminant Type	• Organic only, used especially for contaminants that must be cometabolised
Advantages	• Allows optimal delivery of oxygen and nutrients • Can be utilised with surfactants to enhance bioavailability of contaminants i.e. 4, 5 and 6 ring PAHs • Increased degradation rates
Disadvantages	• High energy inputs and generally treats small quantities of soil at one time • Sensitive to feed stock/soil grain size - sandy soils preferred • Mixture has to be transferred in and out of slurry phase • Generally the most costly bioremediation system
Achieve Clean-up Levels	• Effective remediation system as maximises the contaminant water interface and therefore may result in faster degradation of low solubility contaminants i.e. 4, 5 and 6 ring PAHs
Downstream Effects	• Requires management and treatment of surplus liquids from the slurry bioreactor • Disposal of treated soil
Timeframe	• Short to medium remediation timeframes but treat small quantities of soil. Generally remediation times between 1 and 3 months for typical gasworks contaminants
Cost	• Refer Table 6.23
Resource Consent Requirements	• Land use consent may be required • Earthworks consent for excavation works may be required • Air discharge consent for vapours and odours may be required
Long-term Site Management Plan Issues	• None (should acceptable clean-up levels be achieved)

Table 6.12 Fungal bioremediation

Remedial Status	• Currently not in use within New Zealand • Limited commercial application overseas, primarily pilot scale and trial remediation, but not necessarily on gasworks sites
Contaminant Type	• Has been shown to treat a wide range of monocyclic aromatic and PAHs in trials and limited remediation projects overseas
Advantages	• Able to degrade many compounds resistant to bacterial degradation • Potential high level of public acceptance
Disadvantages	• Limited background information on limitations of the technology • Sensitive to feed stock/soil grain size - sandy soils preferred • Requires intensive management of environmental factors and therefore is costly
Achieve Clean-up Levels	• Based on current literature technology appears able to clean-up both monocyclic aromatics and light and heavy PAHs

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[1] The operating parameters of the sluury-phase bioreactor are important, particularly the solids concentrations which should not exceed 30%. By adhering to this value, the range of soils suitable for treatment by this method can be extended. Further information is available from the US EPA.

Downstream Effects	• Unknown, degradation may result in the formation of more toxic compounds
Time Fame	• Medium to long term timeframe (depending on the organic compounds present) • Typical remediation times between 12 and 18 months
Cost	• Not given/available
Resource Consent Requirements	• Land use consent may be required • Earthworks consent for excavation works may be required • Air discharge consent for vapours and odours may be required
Long-term Site Management Plan Issues	• None (should acceptable clean-up levels be achieved)

6.4.3 Thermal desorption

Thermal desorption is a proven technology for the treatment of PAH contaminated soil from gasworks sites although careful control is required to achieve destruction or removal of contaminants. Thermal desorption generally involves heating of the soil to approximately 450°C in a rotary kiln or retort. Both direct and indirect fired thermal desorbers have been used for the treatment of gasworks wastes. Following desorption of the volatile contaminants, the hot gases may pass to an afterburner for destruction. More recently some configurations have allowed for recovery of the volatilised material by condensation, giving a concentrated oil or tar for disposal or recycling.

There is some evidence that direct fired thermal desorbers allow more effective heat penetration, however directly heated units generate relatively large gas volumes. Therefore, recovery of the desorbed material is only practical where indirectly heated thermal desorption has been used. Thermal desorption has not yet been applied to the treatment of gasworks wastes in New Zealand, although it has been used for the treatment of soil contaminated by other materials in Australia and has been tested for the treatment of wastes from several Australian gasworks sites. Although Australian trials of thermal desorption applied to gasworks sites have been successful, the low cost of landfill disposal has precluded its use on a commercial scale.

Operation of a thermal desorption system is likely to require several consents, namely a land use consent and an air discharge consent.

A summary of the key issues associated with the operation of a thermal desorption system is given in Table 6.13.

Table 6.13 Thermal desorption

Remedial Status	• Not currently available in NZ (may be available within next 2 to 5 years) • Has been used commercially overseas (Australia, US and Europe) for treating a wide range of wastes including gasworks contaminants
Contaminant Type	• Generally limited to organics
Advantages	• Minimises damage to soil - does not create an ash • System has good public acceptance (USA) • System more mobile and energy efficient than incinerators
Disadvantages	• Sensitive to feed stock and soil grain size - sandy soils preferred • Low pH conditions may corrode system components • Air pollution control methods must be capable of dealing with dioxins and furans if secondary combustion used • Soil is sterilised after heating which limits the end uses to situations not requiring biological activity.
Achieve Clean-up Levels	• Achieve clean-up levels, but dependent on organic contaminants present and soil type • Limited application to inorganic contaminants

Downstream Effects	• Emissions require treatment • Materials may require further treatment for inorganic contamination • Waste water may have to be treated if wet scrubbers are used to treat air emissions • Disposal of treated material
Timeframe	• Short treatment timeframe, but treatment limited to approximately 50 tonnes per day with a mobile unit
Cost	• Refer Table 6.23
Resource Consent Requirements	• Earthworks consent may be required to excavate materials on site • Land use consent may be required to establish mobile unit on site • Air discharge consent required for atmospheric discharge
Long-term Management Plan Issues	• No long-term management plan required, unless residual contamination remains on site

6.4.4 Incineration

The use of centralised incineration processes for waste disposal is well established. However due to the cost and transport requirements, such an approach is usually reserved for highly contaminated waste streams. Therefore, centralised incineration is not generally applicable to the treatment of contaminated soils from gasworks sites. However, it may be applied to concentrated waste streams. In particular, incineration has been applied to free tars recovered from abandoned tar wells and gas holders. Incinerators are generally available for the destruction of waste solvents and may be used for the incineration of free tars (although some blending with other wastes may be required to reduce the viscosity of the tars).

6.4.4.1 Mobile on-site incineration

The use of mobile high temperature incinerators for the treatment of hazardous wastes is well established in the United States. Approximately ten former gasworks sites have been remediated using high temperature incineration in the United States and it is one of the few technologies deemed reliable and effective for the treatment of gasworks wastes.

A range of process configurations have been proposed for mobile incinerators however the most common design includes a rotary kiln operating at approximately 1,000°C, together with an afterburner usually sized to ensure effective dioxin destruction (i.e. 1,500°C for 1.5s). To comply with relevant emission standards comprehensive emission control systems are usually required, often incorporating wet scrubbers and bag-house filters.

Operation of a mobile on-site incinerator is likely to require a number of consents namely a land use consent and an air discharge consent.

A summary of the key issues associated with the operation of an incinerator is given in Table 6.14.

Table 6.14 Incineration

Remedial Status	• Not currently available in NZ • Has been used commercially (US and Europe) for treatment of gasworks wastes and is generally the preferred approach especially for recalcitrant wastes
Contaminant Type	• Can be used for treatment of a wide range of organic and inorganic contaminants i.e. directly or indirectly through volume reduction
Advantages	• Reduces the volume of material requiring disposal • Complete destruction of organic contaminants possible • Material handling can be minimised if mobile incineration units are used

Disadvantages	• Poor public perception of incineration • Involves large inputs of energy • Non-combustible contaminants concentrate in ash and therefore ash requires appropriate disposal • Requires treatment of air discharges and requires air discharge consents • Low pH conditions may corrode system components • Air pollution control measures must be capable of dealing with dioxins/furans if secondary combustion
Achieve Clean-up Levels	• Can achieve a high level of clean-up especially for combustible organic compounds
Downstream Effects	• Emission treatment required • Disposal of ash (likely to have elevated heavy metal concentrations) • Waste water may have to be treated if wet scrubbers are used to treat air emissions
Cost	• Refer Table 6.23
Resource Consent Requirements	• Earthworks consent may be required to excavate materials on site • Land use consent may be required to establish mobile unit on-site • Air discharge consent required for atmospheric discharge
Long-term Management Plan Issues	• No long-term management plan required, unless residual contamination remains on site

6.4.4.2 Cement kilns

The burning of a range of hazardous wastes in cement kilns has been proposed for many years. However, to date most cement kiln operators have only burnt less hazardous wastes such as tires and oils. Burning solid wastes in a cement kiln requires some modification to the normal arrangement, however such approaches have been used successfully in Europe. Cement kilns operate at conditions similar to those found in incinerators, with the advantage of a much larger thermal mass and the ability to bind metals contained in the wastes within the cement matrix. Trial burns of gasworks wastes in a cement kiln have been proposed in Australia, although these were abandoned due to possible public concern.

The key factor preventing the use of cement kilns to treat gasworks waste in New Zealand is obtaining an air discharge consent. There are significant air quality concerns associated with the running of cement kilns.

A summary of the key issues associated with the operation of a cement kiln for the treatment of gasworks waste is given in Table 6.15.

Table 6.15 Cement kiln incineration

NZ/Remedial Status	• Not currently available in NZ (although cement kilns do exist) • Has been used commercially overseas (US and Europe) for treatment of a wide range of wastes including gasworks contaminants
Contaminant Type	• Generally limited to organics, but can treat some metals
Advantages	• Reliable and robust • Recovery of calorific value of waste • Effective destruction
Disadvantages	• May need to transport contaminated waste some distance • Non-combustible contaminants concentrate in ash and therefore ash requires appropriate disposal • Requires treatment of air discharges and requires air discharge consents • Air pollution control methods must be capable of dealing with dioxins/furans if secondary combustion used
Achieve Clean-up Levels	• Can achieve a high level of clean-up, especially for combustible organic compounds
Downstream Effects	• Emission treatment required • Waste water may have to be treated if wet scrubbers are used to treat air emissions
Timeframe	• Short treatment timeframe but volume treatable is limited.

Cost	• Not given/available
Resource Consent Requirements	• Earthworks consent may be required • Air discharge consent may be required
Long-term Management Plan Issues	• No long-term management plan required, unless residual contamination remains on-site

6.4.5 Soil washing

6.4.5.1 In-situ soil flushing

In soil flushing a wash solution is injected into the soil in-situ to mobilise contaminants. The wash liquor is then collected at drains or recovery wells downgradient of the contaminated zone. It is then treated and often recycled back through the contaminated zone. The washing solution may be water where the contaminant is soluble, although a surfactant is likely to be required if the contamination includes less soluble constituents. Several washings may be needed to effectively remove contaminants, and the process may be inhibited by areas of lower permeability and high organic content which causes strong sorption.

It is applicable to a wide range of contaminant types including free and dissolved product, and avoids the need for excavation and therefore disturbance. The process generates contaminated water and requires a treatment process at the surface to enable the disposal or reuse of the wash water. If surfactants are left in the soil, any residual contamination may spread as the surfactants will tend to increase their mobility. Ensuring a uniform flow of the wash solution through the soil can be difficult and therefore this technique is best suited to permeable soils.

Operation of an in-situ soil washing system is likely to require a number of discharge consents, namely a consent to discharge washing fluid (such as a solvent). On completion of the remedial works it may prove necessary to apply for a consent to discharge contaminants depending on the level of residual contamination remaining.

A schematic of the workings of an in-situ soil washing system is given in Figure 6.6 and a summary of the key issues associated with in-situ bioremediation works is given in Table 6.16.

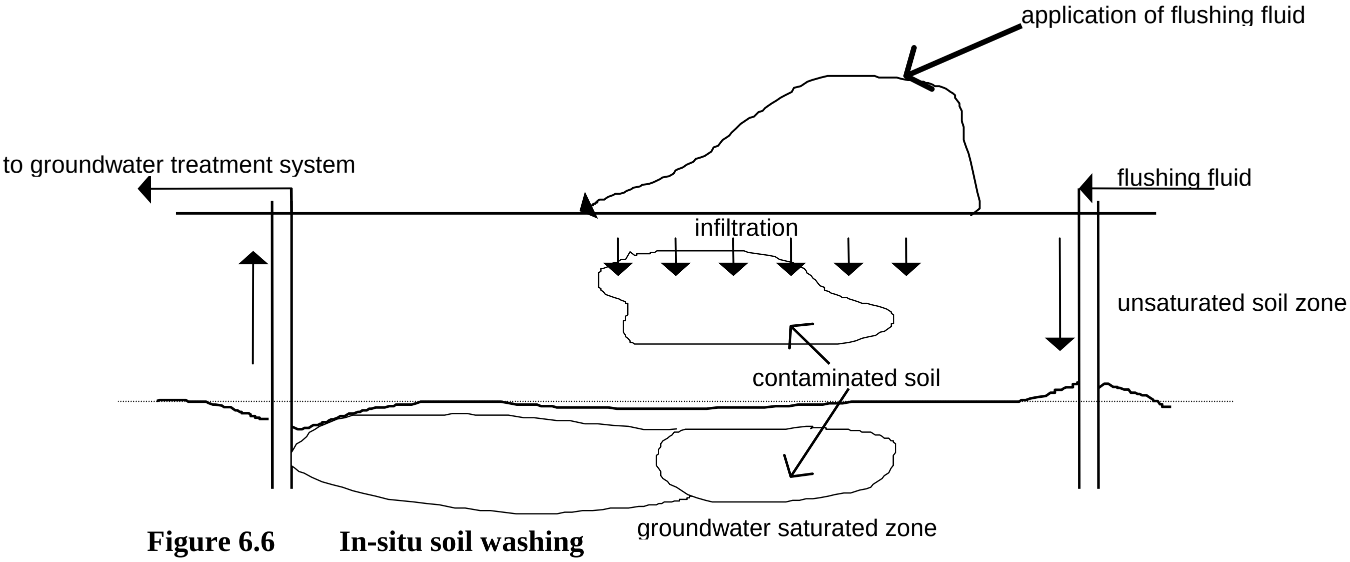

Figure 6.6 In-situ soil washing

Table 6.16 In-situ soil flushing

Remedial Status	• Not currently used in NZ • Has been tested overseas (US and Europe) on gasworks sites, but limited commercial applications
Contaminant Type	• Generally used to treat organics - can be used to treat metals
Advantages	• Works undertaken in-situ
Disadvantages	• Not applicable to low permeability soils • Incomplete treatment in heterogeneous soils • Difficult to validate effectiveness of method • Complex mix of organic and metal contaminants causes difficulties in establishing appropriate flushing fluids • Site hydrogeology must permit capture of groundwater • Treatment and discharge of contaminated groundwater • Bench scale studies have been successful, but field applications have not been that successful (Anderson 1993)
Achieve Clean-up Levels	• Achieve clean-up levels, but dependent on contaminants present and the soil flushing fluid used
Downstream Effects	• Abstraction and treatment of contaminated groundwater • Disposal of sludges from water treatment • Use of surfactants will result in difficult treatment of abstracted groundwater
Cost	• Refer Table 6.23
Timeframe	• Medium to long term timeframe(months to years)
Resource Consent Requirements	• Consent to discharge contaminants to ground or groundwater may be required • Consent to discharge treated groundwater to stormwater, sewer or to groundwater may be required
Long-term Management Plan Issues	• Long-term groundwater monitoring required

6.4.5.2 Ex-situ soil washing

Soil washing is a generic term that has been applied to both size classification processes and surfactant based particle scrubbing systems. Some soil washing systems include both of these processes. Size classification processes are based on the phenomenon that contaminants tend to bind preferentially to fine particles within the soil. Wet size classification processes, known as soil washing, can be used to separate the cleaner coarse materials from the more contaminated fine fraction. This process can be effective in reducing the volume of contaminated material for disposal. Soil scrubbing systems usually incorporate size classification, but may also include high turbulence, attrition processes to remove contaminants from coarse to medium size particles, often with the assistance with surfactants. Generally soil washing processes involve a large amount of plant and equipment, including mixers, clarifiers, cyclones and attrition scrubbers. Simpler soil washing techniques have been proposed but these are generally less effective.

Soil washing is generally limited to soils with a low fines fraction as the process relies on volume reduction. Dewatering and disposal of the fines fraction can be the most difficult element of the process. Test work for the East Perth gasworks indicated soil washing was not viable if the fines content was greater than 17%.

A summary of the key issues associated with the use of ex-situ soil washing techniques is given in Table 6.17.

Table 6.17 Ex-situ soil washing

Remedial Status	• Currently not in use in NZ, although technology available in New Zealand • Has been used commercially overseas (Australia, US and Europe) on petrochemical and gasworks sites
Contaminant Type	• All contaminant types (except for tar waste) • Solvent extraction for organic contaminants

Advantages	• Reduce volume of contaminated material requiring treatment • Can be combined with biological degradation of contaminants
Disadvantages	• Limited to soils with a low % of fines • In soils in which contaminants strongly bound (clay) the residual contamination may still be high after treatment
Achieve Clean-up Levels	• Can achieve clean-up levels, but dependent on contaminants present and soil type
Downstream Effects	• Treatment and disposal of fine grained contaminated materials • Treatment of volatiles from solvent washing • Disposal and/or treatment of washing solution
Timeframe	• Short to medium (months)
Cost	• Refer to Table 6.23
Resource Consent Requirements	• Earthworks consent may be required to excavate material • Land use consent may be required to establish washing unit • Air discharge consent may be required for use of solvents and treatment of washing solution • Discharge of contaminants to ground may be required if treated material is disposed of on-site
Long-term Management Plan Issues	• No long-term management plan requirements, unless residual contaminants remains in-situ

6.4.6 Groundwater treatment

The principal gasworks related contaminants of concern in groundwater are naphthalene and other light PAHs, phenolic compounds (cresol and phenol), BTEX and the inorganic constituents e.g. ammonia, sulphate, cyanide.

In selecting an appropriate groundwater treatment method, consideration must be given to:

- the capability of removing contaminants of concern
- reliability and maintenance requirements
- cost effectiveness
- compatibility with site conditions
- conformance with regulatory requirements.

In general, two primary groundwater treatment options exist:

- in-situ treatment
- pump and treat (ex-situ treatment).

6.4.6.1 In-situ treatment

In-situ treatment is practically limited to biological destruction of organics or the transfer of contaminants from a dissolved phase into a gaseous phase i.e. sparging for volatile organics only. However, inorganic contaminants can be treated by changes to the pH conditions in the soil and/or groundwater, especially in situations where low or high pH conditions exist. Changes in pH conditions result in a reduction in the solubility and mobility of the contaminants.

In-situ bioremediation of contaminated groundwater, like bioremediation of contaminated soils, aims to optimise conditions for bacterial growth and replication. Natural biodegradation can be assisted by the addition of nutrients and oxygen if required. Oxygen may be added by a range of techniques including air sparging and injection of hydrogen peroxide. As with other in-situ processes, delivery of nutrients and oxygen can be difficult in practice due to heterogeneous soil conditions, so these types of remediation technologies are limited in low permeability soils.

In general the consent requirements for in-situ treatment options are minimal, with a high level of public acceptance of in-situ bioremediation technologies.

6.4.6.2 Ex-situ treatment

Pump and treat is the most common approach to remediation of residual organics and inorganics within groundwater. This remediation approach involves extraction of groundwater followed by treatment and disposal or re-injection of treated groundwater. Generally, the groundwater is extracted using conventional groundwater extraction systems such as extraction wells and trenches.

A range of treatment processes may be considered depending on the contaminants present in the groundwater and the requirements for disposal (e.g. sewer disposal, trade waste bylaws, surface water discharge or re-injection to groundwater). Disposal of groundwater to sewer is frequently the preferred option due to the stringent acceptance criteria usually applicable for disposal to surface water or re-injection.

Some form of treatment may, however, be required prior to disposal to sewer or groundwater. A number of treatment options exist and these include:

- air stripping (volatile organics)
- carbon adsorption (organics and some inorganics)
- biological treatment (organics)
- UV oxidation (organics)
- chemical addition and pH adjustment (inorganics).

The most commonly used techniques involve air stripping (volatile organics only) and biological treatment of organics and these are relatively inexpensive. The latter is effective on the majority of dissolved organics detected in groundwater on gasworks sites. However these systems remove light end PAHs less efficiently, and the more costly carbon adsorption or UV oxidation technologies required to remove these contaminants. Both these systems have high removal efficiencies for heavier end PAHs given both the polarity of these molecules and their sensitivity to UV oxidation.

An advantage of using carbon adsorption is the excellent adsorption potential for specific inorganics; these include arsenic, chromium and mercury. However carbon adsorption is usually used as a final treatment (polisher) due to the high treatment cost.

Groundwater treatment of inorganics on gasworks sites is generally limited. However, inorganics are generally treated using standard lime clarification techniques, with the addition of chemical reagents e.g. arsenic removal through the addition of iron and lime.

If free phase hydrocarbons are associated with the groundwater, care must be taken to remove this material. If LNAPL is present, product recovery systems such as those used at petroleum contaminated sites may be used (e.g. skimmer pumps, passive skimmers, total fluids pumps). If DNAPLs are present, specialised extraction systems must be used. In general the viscosity of free phase hydrocarbons encountered at gasworks sites is significantly greater than that found at petroleum contaminated sites, making recovery of product more difficult.

The extraction of groundwater may require a consent from the regional council. Likewise the treatment works and the discharge of treated water may also require consent from Local and Regional Councils. A summary of the key issues associated with the treatment of abstracted groundwater is given in Tables 6.18 through to 6.22.

Table 6.18 Water treatment - air stripping

Remedial Status	• Currently used on petrochemical and oil industry sites in NZ • Has been used commercially overseas (US and Europe) for full scale remediation of aquifers contaminated with volatile organic compounds
Contaminant Type	• Limited to only volatile organic compounds
Advantages	• Low cost and low maintenance requirements • High removal efficiencies for monocyclic aromatics
Disadvantages	• Low removal efficiencies for light molecular weight PAHs • Sensitive to hydraulic loading and air temperature
Achieve Clean-up Levels	• Effective at cleaning volatile organic compounds especially monocyclic aromatics
Downstream Effects	• Treatment of volatile air emissions
Timeframe	• Short to medium timeframe, depending on the level and type of contamination and the site conditions (weeks to months)
Cost	• Refer Table
Resource Consent Requirements	• Consent for abstraction of groundwater may be required • Discharge consent for air emissions may be required • Consent for discharges of treated groundwater to stormwater, council sewers and/or reinjection to groundwater may be required
Long-term Site Management Plan Issues	• None provided full site clean-up is achieved

Table 6.19 Water treatment - activated carbon adsorption

Remedial Status	• Currently only limited use in New Zealand • Has been used commercially overseas (US and Europe) for the full scale remediation of contaminated aquifers, including gasworks sites
Contaminant Type	• A wide range of volatile and semi-volatile inorganics and selected inorganics (i.e. arsenic, cyanide)
Advantages	• High removal efficiencies for monocyclic aromatics, PAHs and phenols • Tolerant of fluctuations in hydraulic loading • No air emissions, contaminants strongly bound to activated carbon
Disadvantages	• Intolerant to high levels of suspended solids and oil and grease • High operation costs • Spent carbon requires either regeneration or disposal
Achieve Clean-up Levels	• Effective at cleaning a wide range of contaminants in a relative short time
Downstream Effects	• Contaminants not destroyed, only transferred from water to activated carbon. Spent carbon requires either regeneration or disposal
Timeframe	• Short to medium timeframe (weeks to months)
Cost	• Refer to Table 6.23
Resource Consent Requirements	• Consent for abstraction of groundwater may be required • Consent for discharges of treated groundwater to stormwater, council sewers and/or reinjection to groundwater may be required
Long-term Site Management Plan Issues	• None, provided full site clean-up is achieved

Table 6.20 Water treatment - ex-situ biological treatment

Remedial Status	• Currently used in New Zealand for a wide range of petrochemical and oil industry sites • Has been used commercially overseas (US and Europe) for full-scale remediation of petrochemical sites, some limited application to gasworks sites
Contaminant Type	• A wide range of volatile and semi-volatile organics
Advantages	• Positive public perception • Limited emissions with contaminants degraded • Excellent for removal of phenols • Proven technology
Disadvantages	• High capital operating and maintenance costs • High monitoring requirement • High potential for malfunctions
Achieve Clean-up Levels	• Effective at cleaning a wide range of organic contaminants. Ineffective at treating inorganic contaminants.
Downstream Effects	• No major effects
Timeframe	• Medium to long timeframe depending on the types of contaminants and loadings (months to years)
Cost	• Not given/available
Resource Consent Requirements	• Consent for abstraction of groundwater may be required • Air discharge consent may be required • Consent for discharges of treated groundwater to stormwater, council sewers and/or reinjection to groundwater may be required
Long-term Site Management Plan Issues	• None, provided full site clean-up is achieved

Table 6.21 Water treatment - UV oxidation

Remedial Status	• Currently limited application in NZ • Has been used commercially overseas (UK and Europe), especially for treatment of aquifers contaminated with halogenated organics and PAH's
Contaminant Type	• A wide range of volatile and semivolatile organics (very effective on monocyclic aromatics and PAHs)
Advantages	• Involves complete oxidation of organic molecules and catalyses oxidation/complexing of inorganics • Provides the highest removal efficiencies
Disadvantages	• High capital operating and maintenance costs
Achieve Clean-up Levels	• Effective at cleaning a wide range of organic contaminants • Oxidises or catalyses complexion of inorganics
Downstream Effects	• No major effects
Timeframe	• Short to medium timeframe depending on hydraulic setting
Cost	• Refer Table 6.23
Resource Consent Requirements	• Consent for abstraction of groundwater may be required • Consent for discharges of treated groundwater to stormwater, council sewers and/or reinjection to groundwater may be required
Long-term Site Management Plan Issues	• None, provided full site clean-up is achieved

Table 6.22 Water treatment - pH adjustment and chemical treatment

Remedial Status	• Widely used for industrial wastewater treatment in NZ • Has been used commercially overseas (US and Europe) in both for ex-situ and in-situ applications, but application to gasworks sites has been limited.
Contaminant Type	• A wide range of inorganic contaminants
Advantages	• Can provide very high removal efficiencies for a wide range of contaminants. • Proven technology
Disadvantages	• Can involve large inputs of raw materials
Achieve Clean-up Levels	• Effective at cleaning a wide range of inorganic contaminants. Involves complexion and precipitation of inorganics
Downstream Effects	• No major effects
Timeframe	• Short to medium timeframe depending on hydraulic setting (weeks to months)
Cost	• Refer Table 6.23
Resource Consent Requirements	• Consent for abstraction of groundwater may be required • Consent for discharges of treated groundwater to stormwater, council sewers and/or reinjection to groundwater may be required
Long-Term Site Management Plan Issues	• None, provided full site clean-up is achieved

Additional information on remedial treatment systems can be found in Section 5.5.5 of the Users' Guide.

Table 6.23 gives an indication of the costs of all the remedial options discussed above.

Table 6.23 Ball park remedial costs

Management/ Treatment Method	Cost in $NZ[1] (Stinson et al 1992)	Cost in $NZ[1] (CIRIA 1996)	$NZ Costs 1996
Groundwater monitoring (assume 10 wells, 6 monthly monitoring and analysis for BTEX, PAHs and Cyanide)			10,000/yr
Capping (Clay)			50-75/m^3
Clay wall			230/m$^{2(2)}$
Soil/bentonite slurry wall	45 - 115/m^3	110 - 180/m^2	
Cement/bentonite slurry wall	45 - 115/m^3	110 - 180/m^2	
Injection grout wall	130 - 570/m^2	630/m^3	
Steel pile wall	690+/m^2	180+/m^2	
On-site repository (clay lined)			100-150/m3
Ex-situ stabilisation/solidification		100 - 120/long ton	120/t (soil)[3] 900/m^3 (tar waste)[4]
In-situ stabilisation/solidification	430 - 1,400/short ton	470 - 630/short ton	
In-situ bioremediation	220+/m3		
Landfarming	70 - 115/m^3	115 - 190/short ton	150/long ton (soil)[4] 500/m3 (tar waste)[3]
Biopiles	140 - 220/m^3	150 - 250/m^3	
Soil slurry bioremediation		85 - 215/m^3	
Thermal desorption	115 - 500/short ton	60 - 600/short ton	250/long ton

Incineration (fixed system)		100 - 170/short ton	
In-situ soil washing	70 - 170/m^3	150 - 310/m^3	
Ex-situ soil washing	70 - 300/short ton	35 - 320/m^3	
Water - air stripping			0.50 - 3.00/1000 US gal
Water - activated carbon	0.22 - 2.52/1000 US gal		
Water - UV oxidation	70 - 150/1000 US gal		
Water - pH adjustment/chemical	0.07 - 0.28/1000 US gal		

1. Costs have been converted into NZ($) from US dollars (0.70) and UK pounds (0.45).
2. Costs include transportation, off-site disposal of excavated material and supervision.
3. Costs allow for off-site disposal following treatment.
4. Costs allow for off-site disposal following treatment (will depend on heavy metal concentrations).

6.5 Disposal of gasworks contaminants to landfill

Excavation and off-site disposal of contaminated soil to an appropriate landfill has been the most common means of remediating former gasworks sites in New Zealand, Australia, UK and the United States. Site remediation by excavation and off-site disposal is relatively quick and may be cost effective depending on the cost of landfilling. Off-site disposal of contaminated soil in an appropriately designed landfill is seen as a reliable and secure means addressing concerns associated with contaminated sites. However, it is unlikely that highly contaminated material could be disposed of off-site without some form of pretreatment.

Other matters associated with the disposal of contaminated soil to landfill include:

- availability of appropriate landfills
- requirements for pretreatment in order to comply with leachate requirements
- risk associated with transport of hazardous wastes
- residual liability
- public perception.

When considering the disposal of contaminants as a site management option, it is important to consult the regional council and the territorial authority to discuss any regulatory requirements.

6.5.1 Gasworks waste types, composition and nature

The general philosophy to the landfilling of gasworks wastes can be found in Section 5 of the Users' Guide.

Waste materials generated at a former gasworks and which may require landfilling will tend to fall into two broad categories:

- contaminated soils and fill materials, including oxides and tar clumps
- building rubble and demolition materials (monolithic materials) which may be heavily contaminated with tar.

At a majority of the gasworks sites in New Zealand free tar may still be contained on site in some form of below ground structure (such as a tar well). This material should not be landfilled without some form of pre-treatment, such as bioremediation or stabilisation.

When assessing the level of contamination at the gasworks it is likely that the contaminated soils will fall into two broad categories:

- low level contaminated materials which meet the landfill acceptance criteria for Class 1 and 2 landfills

- high level contaminated materials, which exceed the landfill acceptance criteria and either require pre-treatment before landfilling or disposal in a purpose-built repository.

6.5.2 Landfill type and processes

In general the landfill principles and the practice in New Zealand has resulted in the identification of three classes of landfills, as follows:

Class 1	Represents the formation of small, specially developed and lined cells within a Class 2 site
Class 2	A site that is suitable for co-disposal of limited quantities of wastes containing relatively low concentrations and quantities of hazardous constituents
Class 3	An appropriately sited, engineered and operated landfill of older design receiving municipal waste only.

Classification criteria for the landfills are summarised in Table 6.24.

A comprehensive set of New Zealand specific landfill engineering guidelines was produced by the University of Canterbury (CAE 1992). It is noted that there are many sites in New Zealand currently used for waste disposal, that do not conform even to the standard of a Class 3 landfill. Such uncontrolled waste disposal sites are not considered suitable for the disposal of gasworks contaminated wastes.

A list of some of the criteria for distinguishing various landfill classes is given in Table 6.24.

Table 6.24 Landfill classification

Class	Landfill Design and Operation Criteria
1	• Meets Class 2 criteria • Accepts hazardous wastes to be mixed with mature refuse if appropriate, and disposed of in discrete cells with low permeability capping and lining material • Has leachate capture and either recirculation, treatment, or disposal to sewage treatment facility.
2	• Meets Class 3 criteria • Has an appropriately designed and operated leachate and groundwater quality surveillance programme which indicates insignificant levels of groundwater contamination and will be regularly monitored for potentially hazardous constituents following acceptance • Applies cover on a daily basis and low permeability intermediate and final cover • Has adequate low permeability/attenuating lining materials and appropriate subsoil conditions as evaluated by a detailed hydrogeological investigation • Is further than 3 km from any significant point of water abstraction and use within the same hydrogeological catchment.
3	• Is securely fenced and has personnel in attendance during all times of operation capable of assessing whether documentation with wastes is adequate. Additionally, personnel must be available who can decide how to evaluate specific wastes and determine the required disposal option, and who are fully instructed in the requirements for safe handling of the particular waste both for themselves and other landfill users. Where wastes are proposed to be accepted, appropriate testing (concentration and leachability of constituents) should be carried out. • Has at least a 4m depth of well compacted refuse available above the site base • Has acceptable control of stormwater, and applies cover at least on a weekly basis • Is further than 1 km from any significant point of water abstraction and use • Closure includes a low permeability protective cap • Is further than 500 m from residential areas • Is located and engineered so that extreme meteorological events will not cause significant mobilisation of wastes by such processes as erosion, wave action, and stormwater run-off • Has in place appropriate operational, quality assurance, emergency response, and post closure management plans.

This should be considered to be indicative of desirable site characteristics for the various classes rather than rigidly specific. In some cases the particular features of a landfill may make certain criteria unnecessary for that particular landfill (e.g. impermeable geological features may obviate the need for engineered lining requirements). For many disposal cases, more detailed consideration in accordance with risk assessment principles should be undertaken before wastes with potentially hazardous constituents are accepted into a particular landfill.

Conformity with the classification criteria should be considered to be indicative only and subject to confirmation. The three classes allow for a graduation in landfill quality commensurate with graduated levels of waste strength. As the waste strength increases, the controls placed on the landfill in terms of management and engineering become more rigorous. **On no account should waste materials be diluted to allow them to be placed in a lower class of landfill site.** This issue of dilution should also be borne in mind when undertaking/assessing the results of pre-treatment works of heavily contaminated gasworks materials, such as bioremediation. Such pre-treatment may result in reduced contaminant concentrations through dilution/substrate bulking and not as a result of chemical and/or other processes.

Processes within the landfill itself, which can essentially be considered to be a ‘bio-reactor’, will reduce the contaminant concentrations of the soils and waste materials landfilled. Attenuation is one of the principal contaminant reducing processes within the landfill, which can be broadly defined as a reduction in the aqueous phase concentration of a contaminant, and may be a result of physical, chemical and biological processes (Williams 1996).

Physical processes (dilution by dispersion, and matrix diffusion) would seem to offer the least complicated and thus the most quantifiable and predictable of the reactions. However, when consideration is given to chemical and biological processes, then these reactions are complicated by the chemical and micro-biological heterogeneity of the landfill. As a consequence, quantification of these processes is very complex and beyond the scope of these guidelines.

Biological and chemical processes in the landfill can reduce cyanide concentrations through a number of reactions (DoE 1978), including :

- conversion to volatile hydrogen cyanide
- conversion to complex cyanides, some of which may be only marginally soluble
- hydrolysis (in aqueous solution) to ammonium formate
- the formation of thiocyanate in the presence of certain sulphur compounds
- biodegradation.

In general the above reactions will result in the destruction of cyanide or conversion to relatively harmless substances, particularly where the cyanide contaminated waste has been landfilled with domestic waste.

Likewise BTEX, PAHs and phenolic contaminated gasworks wastes that may be deposited in a landfill will be subject to biodegradation. Whilst quantification of these processes is not practical or possible, both laboratory and field experiments have shown these contaminants to actively biodegrade (DoE 1978). However, it is important to note that the landfill system should not be overloaded with high levels of contamination. At high concentrations the contaminants can act as biocides which can result in sterilisation of the microbial population of the landfill and prevent further biodegradation occurring.

6.5.3 Leachability testing

All landfills generate a leachate which, depending on the nature of the wastes deposited and the way in which the landfill is operated, will contain a range of organic and inorganic contaminants at varying concentrations. The range and concentration of the contaminants forming the leachate will vary over the operational and closed life of the landfill. However, the leachate may become sufficiently contaminated that there is the potential for the leachate to adversely affect the environment outside the landfill.

Laboratory based leaching tests have been developed in the United States and Europe to simulate/model the leaching processes within a landfill. A previous review and evaluation of leach test protocols (MoH 1993) identified and recommended the United States Environmental Protection Agency's Toxicity Characteristic Leaching Procedure (TCLP) as the standard leach test procedure for New Zealand.

In the United States the TCLP is primarily used for the assessment of whether a waste displays the characteristic of toxicity and must be rated as such under section 40 of the Code Federal Regulations (OFRNARA 1993). A waste is considered to possess the characteristic if the concentrations of any one of forty toxic pollutants in the test extract exceed specified regulatory levels. However, for gasworks waste there are only a small number of the contaminants of concern listed by the federal hazardous regulations, as summarised in Table 6.25.

The TCLP does provide a good indication of whether contaminants are likely to leach from contaminated soils that are to be landfilled. It can be used to establish possible contaminant concentrations in leachate generated from landfilled contaminated soils. One negative aspect to the leach test work is the cost involved in undertaking the TCLP on contaminated soils, particularly gasworks contaminated soils because of the large number of potentially soluble contaminants.

Table 6.25 USEPA maximum concentrations of contaminants for the TCLP test

Contaminant	TCLP Leachate Concentration (mg/l)
Arsenic	5.0
Benzene	0.5
Cadmium	1.0
o-Cresol	200.0
m-Cresol	200.0
p-Cresol	200.0
Cresol	200.0

The TCLP protocol requires that all wastes for testing pass through a 9.5 mm sieve, and makes no provision for the testing of waste that is monolithic in nature i.e. concrete and brick contaminated materials. In keeping with the draft Health and Environmental Guidelines for Selected Timber Treatment Chemicals (MoH/MfE 1993) it is recommended that monolithic waste be broken down to the size that meets the TCLP requirements.

Interpretation of TCLP extract contaminant concentrations in the New Zealand context is more sharply focused on the way in which such information can be used to indicate the likelihood of adverse effects on the environment resulting from disposal of a waste in a landfill. The significance of the TCLP extract concentration for a particular waste is dependent on three factors:

- the limitation of the TCLP technique in providing information on the **rate** at which leaching occurs, i.e. the test can be interpreted as providing information on the average leaching rate over a period, but the test cannot predict the maximum concentration of a constituent in landfill leachate arising from the deposition of a specific waste
- the levels of constituent attenuation in the landfill and leachate dilution in receiving water that can reasonably be expected before the constituent impacts on the environment
- the requirement of the Resource Management Act 1991 that discharges should not cause adverse effects at their point of impact. Depending on the point of discharge, an acceptable waste constituent concentration may vary from a water quality standard protective of sensitive aquatic life (if the leachate were to enter surface water of designated value in a regional plan), to levels based on the

drinking water standards, or a wastewater treatment plant's ability to remove or assimilate the substance.

Of the three factors, the third is the only one which is defined (or has the potential to be defined) in regulation. Only estimates can be made of the effect that the other two factors have on the concentration of a waste substance at the point of impact. Such estimates require knowledge of typical landfill attenuation and receiving water dilution factors, and also some information about the rate at which leaching will occur over the waste's lifetime in a landfill.

6.5.4 Landfilling of low level gasworks wastes

The process and management of landfilling gasworks contaminated materials will tend to be controlled by the operating practices of the landfill and the consent conditions that apply to the landfill. However, there are a number of operational issues that should be considered when co-disposing of contaminated wastes to landfill to ensure that optimum contaminant degradation occurs, wherever possible. A number of the key issues are set out below and discussed further in Lowe 1996:

- the circulation of fluids, landfill gas and leachate within the landfill should not be impeded
- contaminated materials should be brought into the closest contact possible with the co-disposal medium to ensure that degradation processes are optimised
- the contaminated waste materials should not be placed directly into leachate or areas of the landfill cell that will become completely saturated by leachate, and should be placed at least 2 m above the maximum anticipated leachate level and underlain by at least 2 m of normal solid waste
- large bodies of mainly inert materials, such as contaminated soils, will tend to create a barrier to movement of fluids through the landfill. As a consequence, creation of large horizontal barriers that cause the perching of leachate, should be avoided wherever possible
- gasworks wastes deposited in any given landfill cell should not exceed 1 percent of the total cell volume (CAE 1992).

6.5.5 Landfilling of high level gasworks wastes in repositories

A repository may be located at the former gasworks site or a specially constructed landfill repository at the landfill site. Construction and operation of an on-site repository will utilise standard landfill design techniques, comprising a fully engineered, lined and capped facility. Consents are likely to be required by the territorial authorities and regional councils for the construction and operation of a repository. The principal features of an on-site repository are described below.

Lining and Capping

The base and side walls of the repository should be lined with an engineered liner, as shown in Figures 6.7 and 6.8. The choice of lining system depends on site specific variables, such as site hydrogeology, site re-use, availability of natural clay etc. The base of the repository should be graded to allow any leachate generated to drain to a collection sump During infilling, a vertical sand blinding/drainage layer should be installed between the liner and the placed materials. The repository should be capped, with the cap overlapping the side walls of the repository. A sand blinding layer should be placed below the cap, which will also act as a filter blanket and a capillary break (see Figure 6.7).

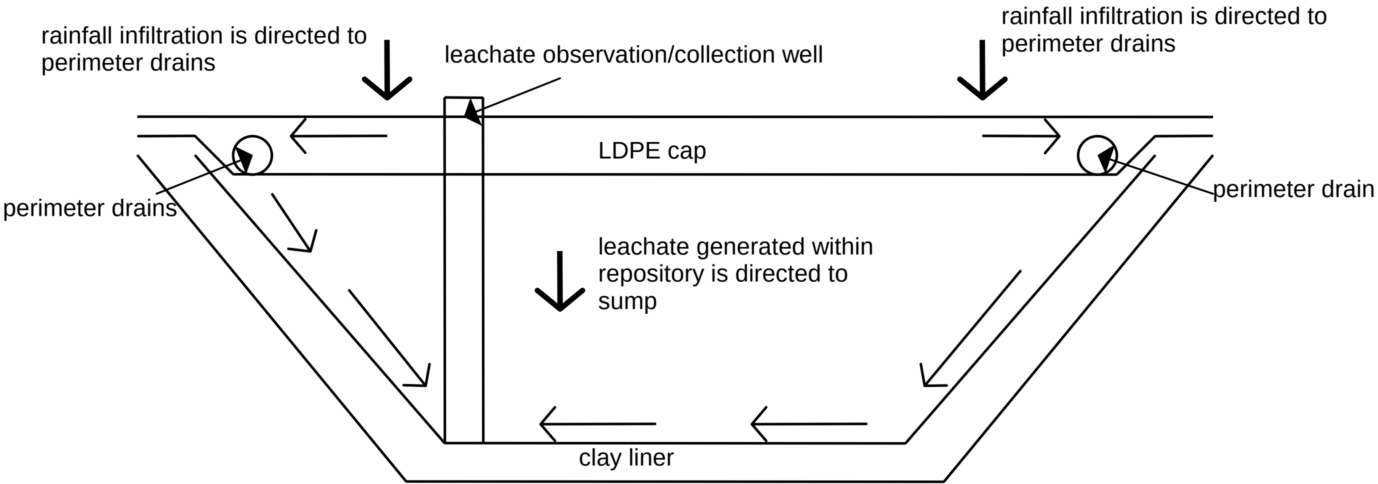

Figure 6.7 Schematic cross section of repository

Placement and Compaction of Fill Materials

Given the range of materials that will be placed within the repository and to enable adequate material compaction to be achieved, it is necessary to screen and split the materials into broad categories (such as granular and cohesive) and to place and compact the materials in discrete layers.

The soil/fill materials should be laid in relatively thin layers, in the order of 250 mm (although the layer thickness will probably be in the order of 500 mm or greater for monolithic materials), and compacted to a nominal highways compaction specification. Such a high level of compaction is required for the following reasons:

- reduce soil/fill settlement within the repository
- compaction of contaminated fill has been shown to significantly reduce the leachability of the contaminants (Cairney 1992), principally through a reduction in material permeability (as shown in Table 6.26).

Table 6.26 Leachate generated from uncompacted and compacted tar wastes

Parameters	Wastes Finely Ground but Uncompacted (mg/l)	Wastes Compacted to Highways Standards (mg/l)
Naphthalene	24 to 84	< 1
Acenaphthylene	10 to 12	< 1
Acenaphthene	2 to 7	2 to 7
Fluorene	7 to 19	<1 to 3
Anthracene	7 to 15	< 1
Phenathrene	5 to 20	<1 to 3
Fluoranthene	5 to 18	<1 to 3
Pyrene	6 to 27	<1 to 4
Benzo anthracene	7 to 43	< 1
Chrysene	7 to 16	< 1
Benzo(b)fluoranthene	7	<1 to 3
Benzo(k)fluoranthene	< 10	-
Indeno(1,2,3-cd)pyrene	< 30	< 1
Dibenzo(a,h)anthracene	< 30	< 1
Benzo(g,h,i)perylene	< 30	< 1
Toluene extract	46 to 96	1 to 6
Phenol	420 to 610	<1 to 1.9
Sulphates	80 to 312	30 to 95

Leachate Control and Drainage

It is likely that the repository should only generate a very small volume of leachate for the following reasons:

- repository infilling will be undertaken in a manner that minimises the ingress of surface water. This will be principally achieved through phased infilling and the control of stormwater ingress into the repository
- the use of a low permeability cap and collection of surface infiltration through the grass cover will result in little or no infiltration into the repository.

Internally within the repository, any generated leachate should ultimately drain to the base of the repository and collect in the leachate sump (as shown in Figure 6.8). Periodically collected leachate should be removed from the sump via leachate abstraction/monitoring wells and disposed of in an appropriate manner off site. Surface infiltration (stormwater) on to the repository cap should be collected and discharged to the local stormwater system.

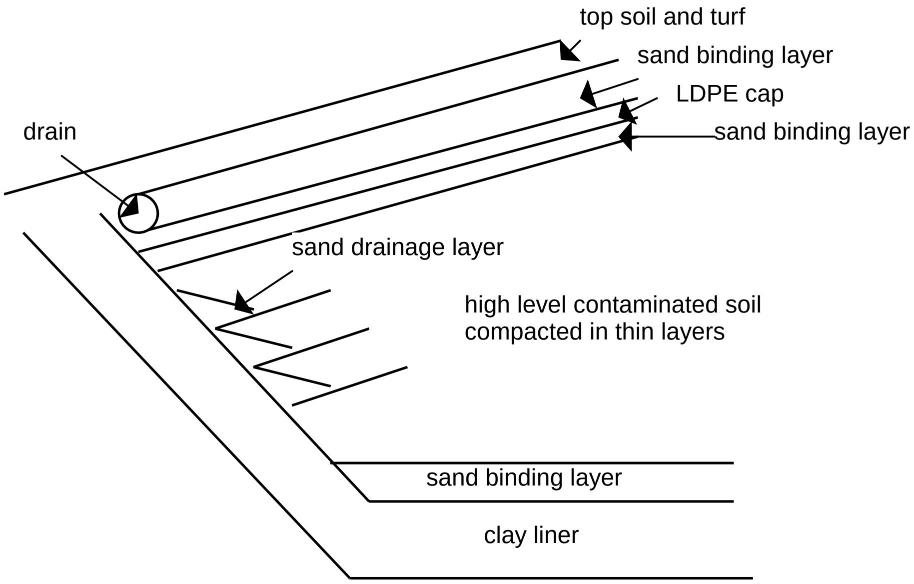

Figure 6.8 Schematic cross section of a repository lining system

Vapour Management

Excavation and placement of high level contaminated soil and fill materials that contain elevated concentrations of relatively volatile compounds (i.e. BTEX compounds, light end PAHs and phenols) could result in the short-term generation of hydrocarbon vapours.

A significant amount of this vapour should vent passively during placement of the materials. However, following capping of the repository, some vapours may still be generated and, given the completely sealed nature of a repository, it may be necessary to allow the vapours to vent. This can be achieved through the installation of vent pipes within the repository cap. Depending on the volume of vapour generated and vapour contaminant concentrations, it may be necessary to treat the vapour to prevent any adverse effects.

Additional information on the disposal of gasworks contaminants to landfill can be found in Section 5.5.6 of the Users' Guide.

6.6 Monitoring

The information in this section can be considered to be a check list for the implementation of environmental monitoring. Because each gasworks site will have its own site-specific environmental monitoring requirements, only generic issues are discussed.

The issues covered by this section comprise:

- post-investigation/pre-remediation environmental monitoring
- remediation environmental monitoring
- post remediation environmental monitoring
- monitoring determinands
- monitoring frequency.

6.6.1 Post investigation/pre-remediation monitoring

6.6.1.1 Groundwater

Prior to implementing remedial works, and following on from investigation works, it may be necessary to establish seasonal variations in the groundwater flow direction at the site or variations in groundwater levels as part of the remediation design. This monitoring would also assist in deciding between remedial options. Groundwater quality data will also have to be obtained over a period to allow for variations in quality and extent of contamination plumes, as these factors are obviously critical to a remedial design.

For example, if a passive/management remedial option is being considered, i.e. one that allows for intrinsic remediation of groundwater contamination and management of risks, then data on the migration of groundwater contamination will need to be established at least over a one-year seasonal cycle in order to ensure that potential adverse effects are unlikely to arise.

6.6.1.2 Surface water

Should the gasworks site lie close to a surface water course which receives run-off from the site (i.e. perhaps up to 20 m to 50 m depending on topography) or reticulated stormwater generated by the site be discharged to a nearby surface water course, then it may be necessary to establish quality data for the water course prior to starting remedial works. This data will assist in establishing whether the site poses any potential risk and will determine background concentrations before any high level short term discharges that may occur during remedial works. Obviously, any discharges will need a consent from the regional council.

6.6.1.3 Atmospheric monitoring

If excavation-type remedial works are planned for the site, it would be prudent to establish background air quality data (i.e. dust and hydrocarbon vapour) before starting the works. This monitoring will be particularly important if the gasworks site lies in a residential area and dust, vapour or odour could pose a potential human health or environmental risk or nuisance. Equally commercial or industrial areas could be affected by atmospheric contamination.

6.6.2 Remediation monitoring

During remedial works it will be necessary to undertake a range of monitoring to ensure that potential adverse human health and environmental effects do not arise. In addition, the monitoring will, depending on the nature of the remedial works, indicate the effectiveness of the remedial works and whether further works are required to meet the required clean-up levels. The typical range of environmental parameters monitored during remediation monitoring are discussed in the following section.

Given the likely range of environmental parameters that may be monitored during remedial works and the number of regulatory authorities that have a mandate to ensure that adverse effects do not arise from the works, it is advisable to detail the remedial works and the monitoring requirements in a Remediation Management Plan. This Plan can then be used as a working document during the remedial works by regulators, contractors, site owners, consultants etc.

Remedial works may take a few days to a number of weeks or months to complete. Obviously the monitoring frequency should reflect the duration of the remedial works.

Consents will obviously be needed for the remedial works and the consent conditions will stipulate the monitoring frequency and determinands that should be covered by the monitoring.

6.6.2.1 Groundwater levels and quality

Regular monitoring of groundwater levels may be necessary during the remedial works, particularly where pump and treat or barrier remedial options are used. This will ensure that the design principles of the remedial system are being achieved and, if necessary, allow modifications to the remedial system to be made, e.g. changes in pumping rates.

Depending on the length of remedial works (i.e. how long areas of the site are left exposed to recharge) and the nature of the remedial works (i.e. pump and treat or in-situ bioremediation), it may be necessary to consider assessing groundwater quality on a number of occasions during the course of the remedial work. However, the routine analysis of the groundwater samples during the remedial operation may be limited to contamination indicator parameters (such as total petroleum hydrocarbons, dissolved oxygen etc.), obviously the choice of parameters will be dictated by the remedial works.

6.6.2.2 Surface water monitoring

If there are surface water courses in close proximity to the site and/or site stormwater discharges to a nearby surface water course, and depending on the nature of the remedial works, it may be necessary to undertake routine surface water sampling and analysis to confirm that there have been no adverse effects.

6.6.2.3 Trade waste/sewer discharge

Contaminated surface water from the gasworks site or contaminated groundwater abstracted as part of remedial works may be discharged to sewer, if treatment and discharge to stormwater or re-injection to groundwater is inappropriate. As a consequence, and in most cases, it will be necessary to routinely monitor stormwater discharges to sewer.

6.6.2.4 Atmospheric monitoring

Remedial works at a gasworks site are likely to generate both dust and vapour emissions which could result in adverse off-site effects and nuisance. As a consequence it will usually be necessary to routinely monitor dust emissions and vapour (such as volatile hydrocarbons). It may be necessary to do this daily during commissioning and redevelopment.

6.6.2.5 Noise monitoring

Any remedial or construction works, or similar, will have to comply with local council noise requirements and, given the location of most gasworks sites within urban areas these requirements could be quite onerous. Actual standards and monitoring requirements will have to be confirmed and agreed with the local council prior to commencement of works.

6.6.3 Post-remediation monitoring

A summary of possible monitoring requirements include:

Groundwater

Verification monitoring and sampling, on completion of remedial works, will require revised groundwater contours to be derived for the site and detailed quality data to prove the effectiveness of the remedial works.

Long-term groundwater monitoring requirements will typically comprise groundwater level monitoring and quality monitoring of selected key indicator parameters. The selection of key parameters will be based on the original site investigation data. Often the determinands measured and the frequency of sampling will be gauged against trigger levels, i.e. if the contamination levels exceed set trigger levels then more detailed monitoring will be undertaken.

Surface Water

Where stormwater run-off from the former gasworks site and where contaminated groundwater enters a nearby surface water course, it may be necessary to undertake verification sampling following completion of the remedial works and to include the water course in the long-term monitoring plan.

Soil

Depending on the choice of remedial works utilised, it may be necessary to undertake verification soil sampling and analysis to prove the residual level of soil contamination. Soil samples may be collected from the base and side walls of an excavation where “excavate and landfill” remedial methods have been used, or it may be necessary to drill boreholes to recover soils where in-situ remedial methods have been utilised. Often this soil sampling work will be done in tandem with the remedial works to determine the depth and extent of contamination and hence excavation works.

Generally, it may not be necessary to analyse the soil samples for the full range of gasworks contaminants, but rather key indicator parameters.

6.6.4 Monitoring determinands and frequency

The choice of monitoring determinands and monitoring frequency will be dictated by a combination of factors, including the nature and extent of the contamination, the remedial methods used, and the nature of potential adverse effects. A summary of “typical” monitoring determinands and monitoring frequencies is given in Tables 6.27 through to 6.30.

6.6.4.1 Determinands

The determinands measured to establish surface water, groundwater quality etc. are likely to comprise a range of “indicator” parameters and, if necessary, more detailed and comprehensive “quantitative” parameters. Indicator parameters may include determinands which can be measured in the field with hand held meters, such as pH and conductivity measurements in water or total volatile organics in air, or a visual description, such as the presence of sheens on a surface water course.

Quantitative measurements will typically entail the collection of soil, water or atmospheric (air) samples and analysis in the laboratory.

The choice of determinands measured will be controlled by a number of factors, including:

- nature of the contamination and nature of remedial and management option(s)
- sensitivity of the receiving environment and nature and magnitude of the potential adverse effect(s)
- monitoring frequency, and
- reason for monitoring (i.e. part of a routine monitoring programme or verification samples collected on completion of remedial works).

6.6.4.2 Monitoring frequency

The frequency at which the monitoring should be undertaken will be controlled by a combination of factors:

- proposed remediation or management strategy
- potential for adverse effects to arise and the magnitude/significance of the adverse effect(s), and
- possible seasonal variations in the parameters of concern.

It is likely that before commissioning a remedial or management option some form of long-term monitoring will be undertaken to identify seasonal variations or trends and then factored into the remedial/management design. During the initial stages of the remedial works it may be necessary to undertake short-term daily or weekly monitoring to ensure that adverse effects are not arising and that the remedial system is performing. More medium-term monitoring (perhaps monthly) may be undertaken once a remedial system is up and running to ensure that the system is performing in the long-term and to enable changes to the system to be made (such as pumping rates).

On completion of remedial works, long-term monitoring may be undertaken to ensure that the level of clean-up has been achieved, allowing for seasonal fluctuations in contamination levels, and that some form of contamination “rebound” has not occurred, particularly with in-situ remediation techniques.

In establishing the monitoring frequency contingency measures should be allowed for catastrophic type events, such as earthquake and flood events, should they arise.

Table 6.27 Post investigation/pre-remediation monitoring

MEDIUM	POSSIBLE DETERMINANDS		AIMS AND FREQUENCY
	INDICATOR PARAMETERS	QUANTITATIVE PARAMETERS	
GROUNDWATER	• Depth to groundwater and product thickness (if present). • Conductivity • pH • Dissolved oxygen (important if assessing bioremediation rates)	• Total petroleum hydrocarbons • Volatile organics • Semi-volatile organics • Total cyanide • Total sulphate • Heavy metals • Total colony forming units (important for assessing bioremediation rates)	To determine seasonal changes in groundwater elevations, groundwater flow direction and contamination patterns. The monitoring frequency will be determined by the proposed remediation method/strategy and the proposed programme between completion of the site investigation works and remediation.
SURFACE WATER	• Flow rates • Conductivity • pH • Dissolved oxygen • Visual signs of sheens, turbidity or discharges to surface water course	• Total petroleum hydrocarbons • Volatile organics • Semi-volatile organics • Total cyanide/free cyanide • Total sulphate • Heavy metals • Suspended solids	To determine seasonal/major storm event changes in water quality, especially where groundwater is in hydraulic continuity with surface water courses and/or when stormwater discharges from the site into surface water courses. In addition, baseflow and stormflow changes in surface water quality may be investigated. The frequency of monitoring will be determined by the potential for contamination to enter surface water courses and the magnitude of potential impacts.
AIR	• Total volatile organics • Total particulate matter	• BTEX • Naphthalene (and isomers) etc. • Hydrogen sulphide • Hydrogen cyanide	Long-term monitoring to determine seasonal changes in vapour/gas concentrations around the site (only where elevated vapour/gas concentrations have been detected on site) Short-term daily monitoring to determine background concentrations of vapour/gases and dust, prior to undertaking remedial works (generally only required where the site is to be excavated).
SEWER/TRADE WASTE	• Generally not required	• Generally not required	Generally not required
SOIL	• Generally not required	• Generally not required	Generally not required

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Table 6.28 Remediation monitoring

MEDIUM	POSSIBLE DETERMINANDS		AIMS AND FREQUENCY
	INDICATOR PARAMETERS	QUANTITATIVE PARAMETERS	
GROUNDWATER	• Depth to groundwater and product thickness (if present). • Conductivity • pH • Dissolved oxygen (important if assessing bioremediation rates)	• Total petroleum hydrocarbons • Volatile organics • Semi-volatile organics • Total cyanide • Total sulphate • Heavy metals • Total colony forming units (important if assessing in-situ bioremediation rates)	The frequency of monitoring will be determined by the remediation options used on site, and the length of time over which the remedial works are being operated. Typically short-term daily monitoring of indicator parameters will be carried out during commissioning of the remedial works, to ascertain performance and allow modifications to the remedial design to optimise remediation rates Groundwater samples may be collected and tested for quantitative indicators of groundwater quality at intermittent time intervals (i.e. once every two months) to determine remediation progress.
SURFACE WATER	• Visual evidence of sheens discharges into surface water, or courses turbidity • Flow rates • Conductivity • pH • Dissolved oxygen	• Total petroleum hydrocarbons • Volatile organics • Semi-volatile organics • Total cyanide/free cyanide • Total sulphate • Heavy metals • Suspended solids	The frequency and scale of monitoring will be determined by the remediation options used on site and the length of time over which the remedial works are being operated. Typically short-term daily monitoring of several indicator parameters will be carried out during commissioning of the remedial works, to ascertain performance and allow modifications to the remedial design to optimise remediation rates and minimise discharges to surface water courses (i.e. stormwater run-off). Surface water samples may be collected and tested for detailed parameters at intermittent intervals (i.e. once every two months) to determine remediation progress and compare surface water quality pre and post remediation. After commissioning the remediation system, routine monitoring of the remediation systems and remediation progress is likely to be carried out (i.e. monthly to two monthly).
AIR	• Total volatile organics • Total particulate matter	• BTEX • Naphthalene (and isomers) • Hydrogen sulphide • Hydrogen cyanide	The frequency of monitoring will be determined by the remediation options utilised on site and the length of time over which remedial works are being undertaken. Typically short-term daily monitoring will be carried out during commissioning of the remedial works (i.e. excavate and cart off site), to allow monitoring of dust/gas concentrations and allow measures to be adopted to mitigate any adverse effects. After remediation commissioning, or completion of the remedial works a period of short-term daily monitoring is generally carried out to allow comparison of dust/vapour/gas emission pre and post remediation.

SEWER/TRADE WASTE	• Flow rates • Conductivity • pH	• Total petroleum hydrocarbons • Volatile organics • Semi-volatile organics • Total cyanide/free cyanide • Total sulphate • Heavy metals • COD/BOD	Only required if stormwater and or groundwater from the site is to be discharged to sewer/trade waste. The frequency of monitoring is likely to be determined by the regulatory authority in charge of waste water treatment. Where stormwater/groundwater is contained/stored prior to discharge the regulatory authority may require testing prior to discharge. Continuous discharges will be tested according to a frequency specified in the trade waste permit.
NOISE		• Quantitative noise monitoring	The need and frequency of monitoring will be determined by the remedial options used. Excavation type works may require almost continuous/daily monitoring to ensure compliance with territorial authority noise level requirements, whilst mechanical systems may only require commissioning monitoring to ensure compliance.

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Table 6.29 Post-remediation verification monitoring

MEDIUM	POSSIBLE DETERMINANDS		AIMS AND FREQUENCY
	INDICATOR PARAMETERS	QUANTITATIVE PARAMETERS	
GROUNDWATER	• Depth to groundwater and product thickness (if present). • Conductivity • pH • Dissolved oxygen (important if assessing bioremediation rates)	• Total petroleum hydrocarbons • Volatile organics • Semi-volatile organics • Total cyanide • Total sulphate • Heavy metals • Total colony forming units (important if assessing bioremediation rates)	The frequency of monitoring will be determined by the nature of remedial works undertaken at the site. Typically verification groundwater monitoring is carried out after completion of the remedial works (i.e. when a groundwater treatment system has been in operation) and/or at 6 monthly intervals for the first year. One year after completion of the remedial works, further groundwater monitoring is covered by the long-term management plan.
SURFACE WATER	• Visual evidence of sheens, discharges into surface water courses or turbidity • Flow rates • Conductivity • pH • Dissolved oxygen	• Total petroleum hydrocarbons • Volatile organics • Semi-volatile organics • Total cyanide/free cyanide • Total sulphate • Heavy metals • Suspended solids	The frequency of monitoring will be determined by the remediation options utilised on site and whether the surface water course was being impacted prior to remediation. Typically surface water monitoring is carried out on completion of the remedial works and at frequent intervals for the first year. Based on the analytical results received for the first year the frequency of monitoring will be reviewed. Generally, one year after completion of the remedial works, further surface water monitoring is covered by the long-term management plan
AIR	• Total volatile organics • Total particulate matter	• BTEX • Naphthalene (and isomers) • Hydrogen sulphide • Hydrogen cyanide	Generally post remediation air quality monitoring is limited. Short-term daily monitoring may be carried after completion of remedial works, especially where large scale excavation works have been undertaken, to allow comparison of pre and post remediation dust/vapour and gas concentrations.
SEWER/TRADE WASTE	• Generally not required	• Generally not required.	Generally not required.
SOIL		• Total petroleum hydrocarbons • Volatile Organics • Semi-volatile organics • Total cyanide • Total sulphate • Heavy metals	Generally associated with large scale excavation works to verify that the majority of contamination has been excavated and removed from site. Sampling is carried out on completion of the excavation works and prior to backfilling. Backfilling of the excavations may not be carried out until receipt of the analytical results. Where in-situ remedial techniques have been undertaken it may be necessary to drill boreholes to obtain soil verification samples.

Table 6.30 Long-term monitoring

MEDIUM	POSSIBLE DETERMINANDS		AIMS AND FREQUENCY
	INDICATOR PARAMETERS	QUANTITATIVE PARAMETERS	
GROUNDWATER	• Depth to groundwater and product thickness (if present). • Conductivity • pH • Dissolved oxygen	• Total petroleum hydrocarbons • Volatile organics • Semi-volatile organics • Total cyanide/free cyanide • Total sulphate • Heavy metals	The frequency of monitoring will be determined by the nature of remedial works undertaken at the site, and potential downgradient impacts. Annual long-term monitoring is generally required indefinitely where remedial management options have been adopted i.e. cut-off walls, capping etc. Annual long-term monitoring may be carried out for the first couple of years after completion of any physical/chemical or biological remedial works to ensure contamination is not migrating off-site. It will be necessary to have a review process to assess the collected data after a number of years (for example 5 years) and redesign the monitoring programme.
SURFACE WATER	• Visual evidence of sheens, discharges into surface water courses or turbidity • Flow rates • Conductivity • pH • Dissolved oxygen	• Total petroleum hydrocarbons • Volatile organics • Semi-volatile organics • Total cyanide/free cyanide • Total sulphate • Heavy metals	The frequency of monitoring will be determined by the remediation options utilised on site, whether stormwater discharges from the site are still entering surface water courses and whether groundwater is in hydraulic continuity with an adjacent stream. Annual long-term monitoring is generally required indefinitely where remedial management options have been adopted i.e. cut-off walls, capping etc and the surface water courses are in close proximity. It will be necessary to have a review process to assess the collected data after a number of years (for example 5 years) and redesign the monitoring programme.
AIR	• Total volatile organics • Total particulate matter	• BTEX • Naphthalene (and isomers) • Hydrogen sulphide • Hydrogen cyanide	Generally long-term air quality monitoring is limited. Monitoring may be carried out in the rare cases where highly elevated vapour/gas concentrations were detected in the site investigation and where the risk level is high.
SEWER/TRADE WASTE	• Generally not required	• Generally not required	Generally not required.
SOIL	• Generally not required	• Generally not required	Generally not required.

6.7 References

1. Anderson W. C. (Ed.) 1993. Innovative Site Remediation Technology: Soil Washing/Flushing. American Academy of Environmental Engineers (Annapolis) 1993.

2. ANZECC 1992. Australia Water Quality Guidelines for Fresh and Marine Waters.

3. ANZECC 1992. Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites. Australian and New Zealand Environment and Conservation Council National Health and Medical Research Council.

4. Cairney T. 1987. Reclaiming Derelict Land. London Blackie.

5. Cairney. T. 1992. Environmentally Secure Encapsulation of Contaminated Land. In: Polluted and Marginal Land 1992 - Proceedings of the Second International Conference on Construction on Polluted and Marginal Land.

6. Centre for Advance Engineering (CAE) 1992. Our Waste: Our Responsibility; Towards Sustainable Waste Management in New Zealand. Project Report. Centre for Advanced Engineering, University of Canterbury. December.

7. CIRIA 1996. Remedial Treatment for Contaminated Land:

   Volume II: Decommissioning, Decontamination and Demolition
   Volume V: Excavation and Disposal
   Volume VI: Containment and Hydraulic Measures
   Volume VII Ex-situ Remedial Methods for Soil, Sludges and Sediments
   Volume VIII: Ex-situ Remedial Methods for Contaminated Groundwater and other Liquids
   Volume IX: In-situ Methods of Remediation

8. Department of Environment (DoE) 1978. The Behaviour of Hazardous Wastes in Landfills. HMSO. London.

9. EPRI 1996. Personal Communication Iswhar Muraka. October.

10. Lowe. M. 1996. Intrinsic Processes for the Stabilisation of Landfill Sites. In: Proceedings of the First International Conference on Intrinsic Bioremediation. London. March.

11. Luthy. R.G., Dzombak. D., Peters. C., Roy. S., Ramaswami. A., Nakles. D. and Nott. B. 1994. Remediating Tar-Contaminated Soils at Manufactured Gas Plants. Environment Science and Technology. Vol. 28. No. 6.

12. Ministry of Health/Ministry for the Environment (MoH/MfE) 1993. Draft Health and Environmental Guidelines for Selected Timber Treatment Chemicals.

13. Office of the Federal Register National Archives and Records Administration (OFRNARA) 1993. Code of Federal Regulations. Protection of Environment. 40 Parts 260 to 299.

14. OIEWG 1996. Guidelines for the Assessment and management of Petroleum Hydrocarbon Contaminated Sites. Oil Industry Working Group. 2nd Internal Draft. June.

15. Shell 1992. Shell Development Westhollow Research Centre, Soil Remediation Workshop, Houston: Environmental Science Department.

16. Stinson, M.K., Skovronek, H.S., Ellis, W.D. 1992: EPA Site Demonstration of Remedial Processes. Journal of Air and Waste Management Association, June.

17. Taylor. B.B and Lee. L.S. 1991 In: Proceedings of the EPRI/GRI Technology Transfer Seminar on Management of Manufactured Gas Plant Sites. Atlanta, Georgia.

18. USEPA 1988. Technology Screening Guide to the Treatment of CERCLA Soils and Sludges. USEPA Office of Solid Waste and Emergency Response/Office of Emergency and Remedial Response..
19. USEPA 1992. Contaminants and Remedial Options at Wood Preserving Sites. Ohio Risk Reduction Engineering Laboratory Office of Research and Development.
20. USEPA 1978. Proceedings of the Symposium on Soil and Groundwater Remediation, Houston, Texas 1977, Washington.
21. Williams G.M. 1996. The UK Research Base for Reliable Application of Intrinsic Remediation. In: Proceedings of the First International Conference on Intrinsic Bioremediation. London. March.