

CRC for Contamination Assessment and Remediation of the Environment

National Remediation Framework

## **Technology guide: Skimming**

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# National Remediation Framework

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The following guideline is one component of the National Remediation Framework (NRF). The NRF was developed by the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) to enable a nationally consistent approach to the remediation and management of contaminated sites. The NRF is compatible with the *National Environment Protection (Assessment of Site Contamination) Measure* (ASC NEPM).

The NRF has been designed to assist the contaminated land practitioner undertaking a remediation project, and assumes the reader has a basic understanding of site contamination assessment and remediation principles. The NRF provides the underlying context, philosophy and principles for the remediation and management of contaminated sites in Australia. Importantly it provides general guidance based on best practice, as well as links to further information to assist with remediation planning, implementation, review, and long-term management.

This guidance is intended to be utilised by stakeholders within the contaminated sites industry, including site owners, proponents of works, contaminated land professionals, local councils, regulators, and the community.

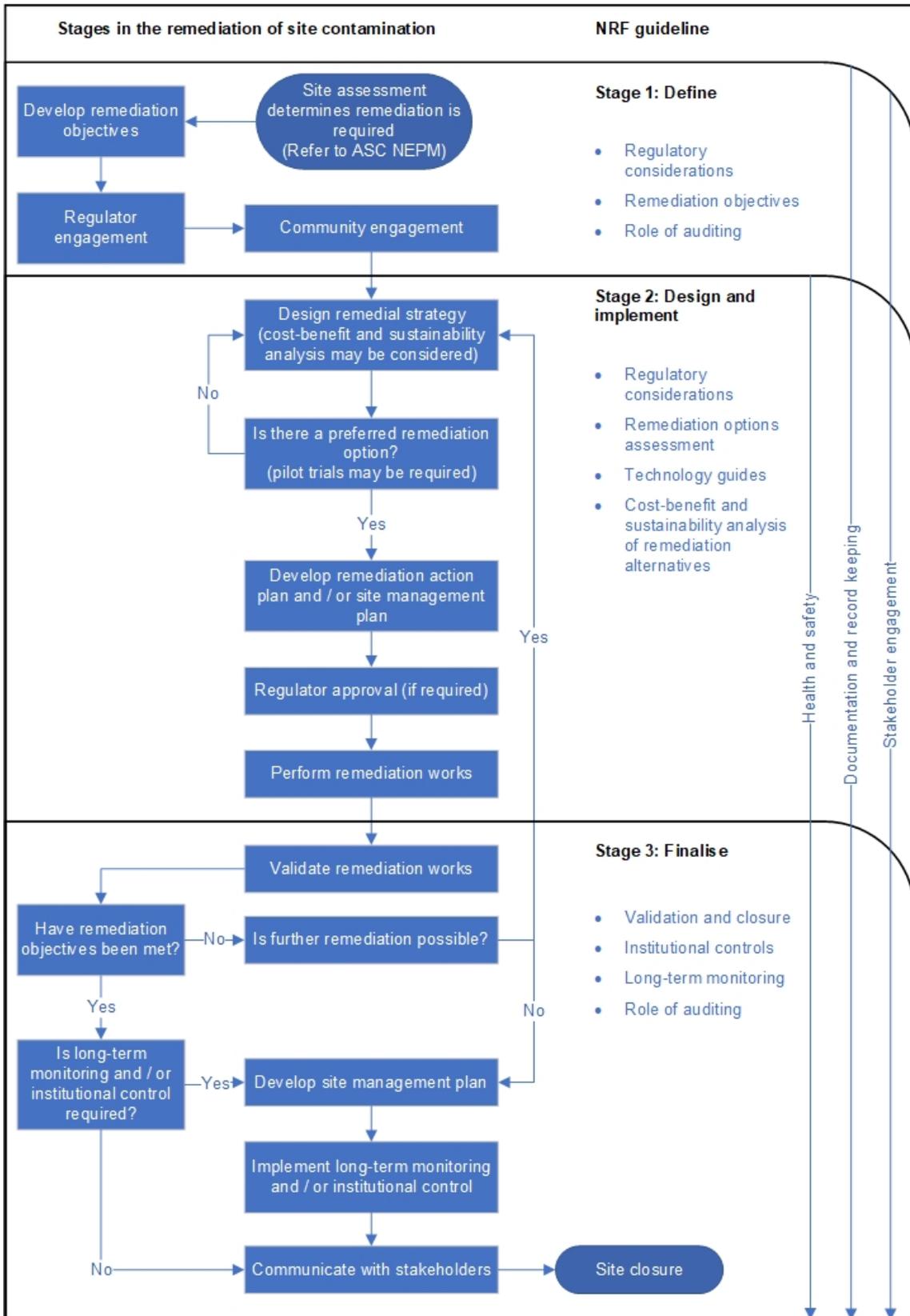
The NRF is intended to be consistent with local jurisdictional requirements, including State, Territory and Commonwealth legislation and existing guidance. To this end, the NRF is not prescriptive. It is important that practitioners are familiar with local legislation and regulations and note that **the NRF does not supersede regulatory requirements**.

The NRF has three main components that represent the general stages of a remediation project, noting that the remediation steps may often require an iterative approach. The stages are:

- Define;
- Design and implement; and
- Finalise.

The flowchart overleaf provides an indication of how the various NRF guidelines fit within the stages outlined above, and also indicates that some guidelines are relevant throughout the remediation and management process.

It is assumed that the reader is familiar with the ASC NEPM and will consult other CRC CARE guidelines included within the NRF. This guideline is not intended to provide the sole or primary source of information.



## Executive summary

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Skimming is a tool for mass recovery of light non-aqueous phase liquids (LNAPLs) and occasionally dense non-aqueous phase liquids (DNAPLs). Skimming uses a pump or hydrophobic belt to extract LNAPL from a well at the air/LNAPL interface and is effective for confined, unconfined and perched LNAPL. Mass recovery technologies, such as skimming, are the most frequently used technologies for LNAPL remediation and, as such, the appropriate design and implementation of such systems is commonplace, and the costs and technical limits are generally well understood. Skimming is often used during emergency or short-term remedial actions to effect immediate mass recovery of LNAPL.

Skimming requires low energy inputs and is not an aggressive LNAPL recovery technology.

The general site conditions affecting LNAPL recovery are the LNAPL:

- LNAPL:
  - Volume;
  - Type;
  - Extent;
  - Depth; and
  - Thickness.
- Hydrogeological conditions such as permeability and groundwater flow

In general, skimming systems are applicable to settings in which the amount of LNAPL is small and exists in open and/or permeable features such as excavations, utility bedding or buried underground open structures. The hydraulic conductivity should be greater than  $10^{-4}$  centimetres per second to ensure a sufficient influx of LNAPL to the skimmer.

In general, LNAPL skimming is applicable to all LNAPL types, although lower viscosity LNAPL (0.5-1.5 centipoise) is much more recoverable than higher viscosity LNAPL (>6 centipoise).

Skimming systems are designed only for mass recovery of LNAPL/DNAPL, and do not address dissolved phase contamination in the short term (although in the longer term, removal of LNAPL would be expected to reduce contaminant loading to an aquifer).

## Abbreviations

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CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
DNAPL	Dense Non-Aqueous Phase Liquid
DTP	Depth to Product
DTW	Depth to Water
LCSM	Light Non-Aqueous Phase Liquid
LNAPL	Light Non-Aqueous Phase Liquids
NAPL	Non-Aqueous Phase Liquid
RAP	Remediation Action Plan

## Glossary

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Aquifer	An underground layer comprising bedrock, unconsolidated natural material, or fill, that is capable of being permeated permanently or intermittently with groundwater, and that allows the free passage of groundwater through its pore spaces.
Baildown test	A controlled field experiment to estimate the hydraulic properties of an aquifer or aquitard. The test involves causing the water level to change suddenly, with the subsequent response in the water level being recorded through time in the control well and one or more surrounding observation wells. Also known as a slug-test or rising-head test.
Concentration	The amount of material or agent dissolved or contained in unit quantity in a given medium or system.
Conceptual site model	A representation of site-related information including the environmental setting, geological, hydrogeological and soil characteristics together with the nature and distribution of contaminants. Contamination sources, exposure pathways and potentially affected receptors are identified. Presentation is usually graphical or tabular with accompanying explanatory text.
Contaminant	Any chemical existing in the environment above background levels and representing, or potentially representing, an adverse health or environment risk.
Contaminated site	A site that is affected by substances that occur at concentrations above background or local levels and which are likely to pose an immediate or long-term risk to human health and/or the environment. It is not necessary for the boundaries of the contaminated site to correspond to the legal ownership boundaries.
Contamination	The presence of a substance at a concentration above background or local levels that represents, or potentially represents, a risk to human health and/or the environment.
Environment(al) protection authority / agency	The government agency in each state or territory that has responsibility for the enforcement of various jurisdictional environmental legislation, including some regulation of contaminated land.
Groundwater	Water stored in the pores and crevices of the material below the land surface, including soil, rock and fill material.

Oleophilic	A substance that readily absorbs or attracts oil or oily material, such as hydrocarbons.
Perched groundwater	Groundwater that occurs above the water table, within the vadose zone, due to an impermeable layer above the water table but below the groundwater.
Practitioner	Those in the private sector professionally engaged in the assessment, remediation or management of site contamination.
Product	A colloquial term for hydrocarbons, particularly light non-aqueous phase liquids. Often used in reference to field measurements, for example "depth to product".
Proponent	A person who is legally authorised to make decisions about a site. The proponent may be a site owner or occupier or their representative.
Remediation	An action designed to deliberately break the source-pathway-receptor linkage in order to reduce the risk to human health and/or the environment to an acceptable level.
Risk	The probability that in a certain timeframe an adverse outcome will occur in a person, a group of people, plants, animals and/or the ecology of a specified area that is exposed to a particular dose or concentration of a specified substance, i.e. it depends on both the level of toxicity of the substance and the level of exposure. 'Risk' differs from 'hazard' primarily because risk considers probability.
Site	A parcel of land (including ground and surface water) being assessed for contamination, as identified on a map by parameters including Lot and Plan number(s) and street address. It is not necessary for the site boundary to correspond to the Lot and Plan boundary, however it commonly does.
Skimming	A tool for mass recovery of LNAPLs (and occasionally DNAPLs) using a pump or hydrophobic belt to extract LNAPL from a well at the air/LNAPL interface
Vacuum-enhanced skimming	variation of skimming that involves applying a low vacuum to the extraction well to induce LNAPL flow into the well for extraction via skimming

## Measurements

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Unit or symbol	Expansion
Cm/s	Centimetres per second
cP	Centipoise
L/min	Litres per minute
m <sup>2</sup>	Square metres
m bgl	Metres below ground level
mm	Millimetre

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# 1. Introduction

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The purpose of this guideline is to provide information on skimming as a treatment technology for the remediation of contaminated sites to assist with selection of remediation options. The document contains information to inform remediation planning and aid compilation of a remediation action plan (RAP).

This guidance is primarily intended to be utilised by remediation practitioners and those reviewing practitioner's work, however it can be utilised by other stakeholders within the contaminated sites industry, including site owners, proponents of works, and the community.

Skimming is one of many technologies available for contamination remediation, and other technologies may be more appropriate. It is assumed that the information presented within will be used in a remediation options assessment to identify and select the preferred technologies for more detailed evaluation. This guideline provides information for both initial options screening and more detailed technology evaluation. Readers are directed to the NRF *Guideline on performing remediation options assessment* for detailed advice on assessing remediation options. In addition, the remediation objectives, particularly the required quality of the groundwater after treatment, are a critical matter and it is assumed that these have been determined and considered in the remediation options assessment and selection process. Readers are directed to the NRF *Guideline on establishing remediation objectives* for more detailed advice.

References to case studies are provided in **Appendix A**.

A number of sources of information were reviewed during the formulation of this document to compile information on potential technologies. These are listed in references, and provide an important resource to readers.

## 2. Technology description

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Skimming is a technology for mass recovery of light non-aqueous phase liquids (LNAPLs), and to a much lesser extent dense non-aqueous phase liquids (DNAPLs) while minimising the recovery of groundwater. Skimming generally requires the least effort in terms of energy inputs and is the least aggressive LNAPL recovery technology.

Skimming can be undertaken passively or actively using a single pump or hydrophobic belt to extract LNAPL from a well at the air/LNAPL interface under natural gradients and is effective for confined, unconfined and perched LNAPL. Typically, small volumes of LNAPL are removed because of limited area of influence in wells, open trenches or excavations. LNAPL mass-recovery technologies such as skimming are widely applied and, as such, the appropriate design and implementation of such systems is commonplace, and their costs and technical limits are generally well understood.

Skimming is often used during emergency or short-term remedial actions to effect immediate mass recovery of LNAPL and is often used in conjunction with another technology (or technologies) as part of a remediation strategy for a site.

It should be noted that when LNAPL is encountered, interaction with regulatory agencies is often required. The level and nature of notification and reporting is different in each jurisdiction. Readers are directed to the NRF *Guideline on regulatory considerations* for more detailed information.

The general site conditions affecting LNAPL recovery are the LNAPL:

- LNAPL:
  - Volume;
  - Type;
  - Extent;
  - Depth; and
  - Thickness.
- Hydrogeological conditions such as permeability and groundwater flow

The following is a summary of features specific to skimming systems:

- Skimming does not provide hydraulic control as it does not involve groundwater extraction and will not reduce the groundwater level and achieve the increased recovery that might result from this;
- Skimming will only recover readily available mobile LNAPL near the skimmer; in the case of hydrocarbons this is likely to be only a small fraction of the total hydrocarbon present (often more than 50% - 70% will remain adsorbed or trapped in the formation), and skimming is unlikely to reduce the risk posed by the contamination;
- Skimmers can be installed in a variety of settings (wells, trenches, excavations);
- Skimming systems generally require 100 mm diameter wells, but can be fitted in 50 mm diameter wells;

- Skimming provides for in-well fluid separation, reducing above ground treatment costs;
- Skimming systems only provide for low recovery rates;
- Skimming systems are typically low in capital, operation and maintenance costs.

Skimmers may also be used in conjunction with other technologies such as water table depression (i.e. pump and treat) and vacuum enhancement to improve recovery rates.

Vacuum-enhanced skimming is a variation on skimming which applies a low vacuum to create a negative pressure (vacuum) gradient around the well to induce LNAPL flow towards the well and enable skimming pumps to remove the LNAPL from the well. A zone of negative pressure around the well causes LNAPL to flow horizontally across the pressure-induced gradient, from a zone of higher pressure outside the well to the zone of lower pressure in the well.

The advantages of skimming are:

- Relatively low capital costs;
- Can be installed in existing groundwater monitoring wells (GMMWs);
- Skimmers are typically powered by compressed air, so running costs are typically lower than for electrically powered equipment;
- Collection of LNAPL with little or no recovery of water, especially when fitted with hydrophobic filters;
- Cycle rates can be easily adjusted to match LNAPL recharge rates to well; and
- Proven and implementable technology.

The disadvantages of skimming are

- Longer time frames for remediation;
- Air-lift based skimmers difficult to use at depths greater than 10 m bgl, due to physical limitations on using high air pressures;
- Air supply to skimmer typically needs to be filtered and dried. Hydrophobic filters can often become blocked with biofilm, requiring extra maintenance;
- LNAPL recharge rates to small diameter wells typically too low to sustain continued LNAPL extraction. Larger diameter wells or sumps may be required;
- LNAPL typically recovered at low rates, as skimming is reliant on natural recharge rate to well;
- Limited to mobile LNAPL pooled near the skimmer or that will flow past the skimmer; will not recover LNAPL adsorbed or trapped in the formation;
- Limited radius of influence; does not create a depression in the groundwater table which can increase the radius of recovery; and
- Does not destroy or treat NAPL, which must be collected and disposed of.

### 3. Feasibility assessment

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Key considerations that will often determine the feasibility of applying skimming systems as a potential remediation option include:

- Whether the physical form (e.g. free phase) of the contaminant is consistent with skimming being effective in recovering the contaminant; and
- Whether reduction in the extent of free phase contaminant is an important regulatory requirement.

A preliminary feasibility assessment for LNAPL skimming would involve the following steps:

- Identification of LNAPL in monitoring well network;
- Measurement of water table and LNAPL fluctuations over time (note – this is particularly important in tidally affected areas);
- Measurement of LNAPL thickness, viscosity and density; and
- Assessment of the volume of mobile LNAPL present in the subsurface and the volume able to be extracted (note – this requires good characterisation of the subsurface soil profile).

#### 3.1 Treatable settings

In general, skimming systems are applicable to settings in which the amount of LNAPL is small and exists in open and/or permeable features such as excavations, utility bedding or buried underground open structures. The hydraulic conductivity should be greater than  $10^{-4}$  centimetres per second (cm/s) to ensure a sufficient influx of LNAPL to the skimmer.

In general, LNAPL skimming is applicable to all LNAPL types, although lower viscosity LNAPL (0.5-1.5 centipoise (cP)) is much more recoverable than higher viscosity LNAPL (>6 cP).

LNAPL removal using skimming equipment is applicable in settings where long-term hydraulic control of the dissolved-phase plume is not required as skimmer operations will not provide such control and a considerable mass of contaminant will remain in adsorbed or trapped form after skimming.

Site conditions and contaminant characteristics direct whether LNAPL skimming is the most appropriate and effective technology for a site including:

- Geological and hydrogeological information/setting.
- LNAPL physical properties (density, viscosity, interfacial tensions, vapour pressure) and chemical properties (constituent solubilities and mole fractions).
- LNAPL extent (vertical and horizontal delineation).
- LNAPL mobility and body stability information.
- LNAPL recoverability information.
- Associated dissolved-phase and vapour-phase plume information.
- LNAPL natural depletion processes.

Skimming systems are designed only for mass recovery of LNAPL/DNAPL, and do not address dissolved phase contamination in the short term (although in the longer term, removal of LNAPL would be expected to reduce contaminant loading to an aquifer).

### 3.2 Bail-down testing

LNAPL recoverability predictions may be regarded as the key 'treatability' studies for assessing LNAPL mass recovery remediation technologies such as skimming. These tests provide data on LNAPL recoverability and transmissivity, which may then be used in computer models such as LDRM (API, 2008) to evaluate different remediation technologies, design and time frames.

The key objectives of recoverability estimates are to enable the following to be undertaken:

- Design of efficient (realistic) LNAPL recovery systems.
- Provision of estimates of recovery performance.
- Provision of estimates of recovery time.
- Preparation of a method to achieve practical goals.

Once the preliminary feasibility assessment is completed and it is concluded that LNAPL skimming appears feasible and sufficient as a remedial method (or is to be used in conjunction with other methods), the next step is to assess the LNAPL recovery rates via bail-down testing in the field, preferably in wells where skimmers are to be placed.

The key objective of bail-down testing is to determine the volume of LNAPL that will be able to be recovered. This can be estimated and reported as a volume of LNAPL recovered as a function of time. Consideration should be given to whether the LNAPL thickness recovers over time, and the rate at which this occurs. The volume of LNAPL released and is present in the formation may also be helpful, although such volume estimates are often very uncertain.

LNAPL transmissivity is a measure of lateral mobility of LNAPL within the groundwater environment, and LNAPL transmissivity can be useful for comparing the relative recoverability from different locations and the choice of a LNAPL recovery system. Transmissivity may also be a possible endpoint criterion for LNAPL mass removal using LNAPL hydraulic recovery systems, including skimmer wells, single-pump wells, dual-pump wells and trenches, although applying such a criterion would need to be agreed with the relevant regulatory authority.

In performance of a bail-down test a volume of hydrocarbon liquid is rapidly removed from the well and the depth to product (DTP) and depth to water (DTW) are measured as a function of time during the fluid recovery period.

Like a rising or falling head permeability test, fluid recovery rates generally vary logarithmically, so measurements should be taken more frequently during the initial period following hydrocarbon removal and the measurement frequency decreases during the later period of the test. The following features are considered generally significant:

- Initial NAPL removal should be rapid and performed in a manner to remove as little water as possible. Peristaltic pumps are preferred since the pump intake can be located to remove only NAPL during the bail-down stage, however

these pumps are limited to less than 10 m bgl working depth. If a bailer is used, then additional precautions are necessary to remove as little water as possible and minimise fluid disturbance during LNAPL removal.

- Following the bail-down stage of hydrocarbon liquid removal, the DTP and DTW are measured as a function of time. Measurements can be taken using interface probes (optical and electrical resistivity), and data are recorded as depth (metres) below top of casing.
- In general, the interface depth measurements are taken more frequently during the initial recovery period and the frequency decreases as recovery time proceeds. If recovery rates are too rapid for (near) simultaneous measurement of DTP and DTW, then a pressure transducer can be placed below the LNAPL and water interface and connected to a data-logger. In this case only the DTP need be measured, and such measurements combined with the data-logger record and LNAPL density can be used to calculate the DTW at desired time intervals;
- When possible, recovery monitoring should continue until LNAPL recovery has ceased. In low LNAPL transmissivity locations, the time for this might be excessive and early termination will be necessary. Reaching the end of recovery is especially important for confined and perched LNAPL conditions, to help verify the site conceptual model for the test.

There are several methods available to analyse the data from bail-down tests to estimate LNAPL conductivity, transmissivity and recoverability many sources have prepared a spreadsheet specifically for bail-down test analysis, which are available in the public domain.

## 4. Design

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When hydraulic control of contaminated groundwater is not necessary, skimmers may be used where significant LNAPL, as quantified by assessing LNAPL transmissivity, is present to initiate LNAPL mass recovery. Skimmers are available for installation in wells of various diameters.

Skimmer equipment can also be used in excavations or trenches which may be open for very short term or emergency recovery operations. For long-term operations, skimmers may be placed in wells and in gravel-filled trenches with sumps. Recovery may be enhanced by application of vacuum at the wellhead, or by use of hydrophobic gravel packs in wells. Recovery rates for long-term operations are generally very low, except for skimmers that are used in open excavations where high recovery rates are achievable.

Skimmers are available for LNAPLs of differing density and viscosity, and these properties should be assessed before deciding on the type of skimmer to use. In addition, skimmers are available which move up and down with fluctuating water tables (these are sometimes referred to as 'floating' skimmers).

If hydraulic control of contaminated groundwater is deemed necessary, then skimmers can be placed in trenches along the full width of the plume at its down gradient edge. The trench can be excavated several feet below the seasonally low water table to allow for fluctuations over time. For longer term operations, the trench can be filled with gravel or sand, with an impermeable partial vertical liner at the down gradient side of the trench which can serve to prevent migration of LNAPL past the trench. A sump can be located at areas where LNAPL is present and at low water table elevations.

### 4.1 Equipment Description

The selection of skimming equipment will be based primarily on the size of the recovery installation (well, trench, excavation), the expected LNAPL recovery rate and the type of LNAPL (e.g. fresh petrol vs weathered diesel).

Two general types of skimming equipment are available. Mechanical skimming equipment actively extracts LNAPL using mobile plant, whereas passive skimming equipment recovers LNAPL using gravity effects over time.

Table 1 summarises the advantages and disadvantages of common types of skimming systems.

**Table 1: Skimmer types and the advantages and disadvantages of each**

	Type of skimmer	Advantages	Disadvantages
Mechanical skimmers	Floating	<ul style="list-style-type: none"> <li>No water is captured.</li> <li>Can effectively skim thin (i.e. &lt;50 mm) layers of LNAPL.</li> </ul>	<ul style="list-style-type: none"> <li>Radius of influence covers small area.</li> <li>The slotted screen can become blocked.</li> <li>Only applicable to shallow LNAPL recovery.</li> </ul>
	Large saucer		
	Small float		
	Pneumatic pump	<ul style="list-style-type: none"> <li>Can effectively skim thin layers of LNAPL.</li> <li>Durable pumps.</li> <li>Adjustable (to minimise water captured).</li> </ul>	<ul style="list-style-type: none"> <li>Radius of influence covers small area.</li> <li>The slotted screen and valves can become blocked.</li> <li>Needs to be adjusted (manually).</li> </ul>
	Belt skimmer	<ul style="list-style-type: none"> <li>Can effectively skim thick layers of LNAPL.</li> <li>Simple operation and maintenance.</li> </ul>	<ul style="list-style-type: none"> <li>Belts have limited capacity; low removal rates</li> </ul>
Passive skimmers	Passive - canister	<ul style="list-style-type: none"> <li>Low cost</li> <li>Simple operation and maintenance</li> </ul>	<ul style="list-style-type: none"> <li>Low recovery potential</li> </ul>
	Absorbent bailer (or sock)	<ul style="list-style-type: none"> <li>Low cost</li> </ul>	<ul style="list-style-type: none"> <li>Low removal rates</li> <li>Requires replacement</li> </ul>

#### 4.1.1 **Mechanical skimmers**

Skimmers typically have a large hydrophobic screen that allows only LNAPL into the pump body. Large floating skimmers can remove LNAPL at a high rate (up to 20 litres per minute (L/min)). These skimmers are generally limited to shallow applications (less than 10 m bgl) and may require large diameter (e.g. up to 500 mm) wells or sumps.

Small float systems require 100 mm diameter or larger wells for operation and are limited to depths of 10 m bgl or less. This type of skimmer typically uses a floating screen inlet to capture the product and is contained in a pump device or bailer. A variation on floating skimmers employs a floating (or depth-controlled) intake equipped with conductivity sensors that activate surface mounted pumps when LNAPL has accumulated to a sufficient thickness.

Belt skimmers use a continuous loop of hydrocarbon-absorbent material that slowly cycles down into and out of the well, soaking up product as it moves through the water surface.

#### 4.1.2 **Passive skimmers**

Passive skimming systems do not actively pump LNAPL, instead they slowly recover it over time via gravity drainage and/or using oleophilic media that absorb hydrocarbons. There are two basic forms of passive skimmers:

- Filter canisters; and
- Absorbent bailers.

Filter canisters are lowered into 50 mm or greater diameter wells so that they contact the layer of LNAPL floating on top of the water surface. The filter is constructed of a hydrophobic material which allows only LNAPL to enter. Gravity causes the liquid hydrocarbons to trickle through the filter and then flow into the bottom of the canister where the product is stored. Canisters can typically store between 2 to 10 litres of LNAPL. The product can be removed automatically by a suction pump or manually by pulling up and emptying the canister.

Absorbent bailers (or socks) are simple skimming devices which are suspended in the well across the surface of the LNAPL layer. Oleophilic material selectively absorbs hydrocarbon product from the water surface and must be periodically removed and disposed of.

## 4.2 **System commencement**

Commissioning skimmer systems, not including treatment systems, are relatively straightforward and of short duration (a few days). The following activities are generally applicable:

- Place the skimmer equipment at proper levels in each well or sump;
- Inspect all mechanical and electrical components of skimmers and collection system, and oil/water separator;
- Monitor the recovery rate of fluids; and
- Sample the fluids collected and inspect them for water content and/or emulsification. Modify skimmer settings as necessary to minimise water production.

### 4.3 Operations and maintenance

After the start up activities have been completed, normal operations and maintenance activities begin. These activities include:

- Measuring the thickness of LNAPL and water in monitor and skimmer wells or sumps;
- Recording the amount of product collected at all recovery points;
- Inspecting all electrical and mechanical components of skimming and collection systems and oil/water separator; and
- Maintaining and repairing all equipment as necessary, or as recommended by equipment supplier.

## 5. Validation

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The following information describes the specific validation appropriate for skimming, to assist validation planning within the RAP. Readers are directed to the NRF *Guideline on validation and closure*, which among other things, provides further information on each of the lines of evidence.

The primary lines of evidence for the validation of skimming are:

- Reduction in contaminant concentration over time; and
- Field measurements.

Groundwater sampling and analysis can be used to determine when concentrations of COC have dropped to the point where remedial objectives have been met, or whether further extraction is no longer efficient. It is important to note that concentrations may rebound to exceed validation criteria, due to diffusion from secondary sources or fluctuations in the water table mobilising contaminants. Contaminated groundwater is likely to persist in areas with lower permeability and transmissivity following the extraction of contaminants from areas of higher hydraulic conductivity and may serve as a secondary source to re-contaminate these areas.

## 6. Health and safety

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The health and safety aspects involved with skimming systems are basically related to potential exposure to hydrocarbon products. Health and safety procedures designed for handling of petroleum products therefore directly apply to the installation, operation and maintenance of skimming systems.

Some of the hazards associated with soil washing and control mechanisms are outlined in Table 3. The list is intended to provide an indication of the hazards potentially associated with soil washing application. They will vary significantly from site to site and the list is not intended as a substitute for a detailed hazard assessment of the operation, which should be provided in the RAP.

Readers are directed to the NRF *Guideline on health and safety* for further information on health and safety on remediation sites, including risk assessment, the hierarchy of controls and suggested documentation.

Table 2 Common LNAPL skimming hazards and suggested controls

Hazard	Sources of hazard	Suggested controls
Site contaminants or chemical exposure	Dermal or inhalation exposure to NAPL	<ul style="list-style-type: none"> <li>• Use of appropriate personal protective equipment (PPE), including gloves protective clothing that are suitable for the task e.g. ensure they provide chemical resistance to the hazardous chemicals.</li> <li>• If necessary, use respiratory protection that is suitable for the task and selected used and maintained.</li> </ul>
Ergonomic risks	Lifting or performing any other movement with too much force and/or in an awkward position, or repeating the lift/movement too often.	<ul style="list-style-type: none"> <li>• Provide conveniently located equipment for the job, like carts, adjustable work stations (operators), and correctly sized tools.</li> <li>• Train workers on ergonomic risks and prevention.</li> </ul>
Fire and explosion	Vapour concentrations exceed the lower explosion level, or flammable and combustible liquid or solid material is present	<ul style="list-style-type: none"> <li>• Use of appropriate hazard rated equipment and storage appropriate for such liquids, including avoiding static electricity hazard.</li> </ul>

Hazard	Sources of hazard	Suggested controls
Electrical Hazards	<ul style="list-style-type: none"> <li>• Working with standard 440V, three-phase electrical service.</li> <li>• Using ungrounded or unguarded electrical equipment.</li> <li>• Working on or testing an electrical system or any electrically powered equipment without properly locking/tagging out energy sources.</li> <li>• Touching (worker or equipment operated by worker) underground and aboveground utilities.</li> </ul>	<ul style="list-style-type: none"> <li>• Because hydrocarbon vapours can be involved, electrical systems should be intrinsically safe and comply with regulatory requirements,</li> <li>• Implement lockout/tagout procedures.</li> <li>• Allow live testing only by employees that are properly trained and qualified.</li> <li>• Ensure workers use proper electrical work practices.</li> <li>• Ensure workers use proper electrical protective equipment and insulated tools while working live.</li> <li>• Locate and mark any underground utilities.</li> <li>• Ensure proper clearance between power lines and elevated equipment (e.g., crane or drill rig booms, scaffolding, etc.) and designate an observer.</li> <li>• De-energize utilities, when necessary</li> <li>• Install ground-fault circuit interrupters (GFCI) when feasible</li> <li>• Routinely inspect electrical cords and equipment</li> </ul>
Mechanical	<ul style="list-style-type: none"> <li>• Contacting or becoming entangled in moving/ unguarded equipment like conveyor, hollow screw mixer, belts, chains, gears, moving parts with protrusions, etc.</li> <li>• Working on any of this moving equipment without isolating the energy source.</li> </ul>	<ul style="list-style-type: none"> <li>• Place guards during operation.</li> <li>• Train workers on hazards, use of guards, who may remove guards, and how to remove guards.</li> <li>• Ensure use of lockout/tagout procedures for maintenance.</li> </ul>

Hazard	Sources of hazard	Suggested controls
Slips, trips and falls	<ul style="list-style-type: none"> <li>• Storing construction materials or other unnecessary items on walkways and in work areas.</li> <li>• Creating and/or using wet, muddy, sloping, or otherwise irregular walkways and work surfaces.</li> <li>• Constructing and/or using improper walkways, stairs, or landings or damaging these surfaces.</li> <li>• Creating and/or using uneven terrain in and around work areas.</li> <li>• Working from elevated work surfaces and ladders.</li> <li>• Working in confined spaces</li> <li>• Using damaged steps into vehicles.</li> </ul>	<ul style="list-style-type: none"> <li>• Keep walking and working areas free of debris, tools, electrical cords, etc.</li> <li>• Keep walking and working areas as clean and dry as possible.</li> <li>• Install handrails, and guardrails on work platforms.</li> <li>• Clean and inspect ladders and stairs routinely.</li> <li>• Perform a Job Hazard Analysis.</li> <li>• Ensure workers use proper PPE, including fall arrest systems.</li> <li>• Train workers on fall hazards and use of ladders.</li> <li>• Use an observer (spotter or signal person) when visibility is limited.</li> </ul>

## Appendix A – Case studies

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Although LNAPL skimming projects have been widely undertaken, both in Australia and internationally, these are not typically subject to academic papers or reporting as case studies and therefore there is very limited case study information on this technology. However, the following case studies include LNAPL recovery via skimming:

- <https://clu-in.org/download/rtdf/napl/cpbpsugarcreek.pdf>
  - Evaluates the performance and cost of LNAPL recovery at a BP Products site in the US
  - LNAPL was recovered using dual pump recovery from up to 15 wells;
  - Over 7 million litres of LNAPL was recovered over 22 years
- [http://costperformance.org/pdf/Pope\\_FT\\_01.pdf](http://costperformance.org/pdf/Pope_FT_01.pdf)
  - The site is Pope Air Force Base in North Carolina, US
  - LNAPL present comprising aviation fuel – the aerial extent was estimated at 6,070 m<sup>2</sup> and there were over 90,000 litres of free product
  - The ground conditions comprised sand overlying silty clay
  - Groundwater was present at depth between approximately 0.6 and 1.5 m bgl
  - LNAPL was recovered by mechanical skimmer and over 3 years, 19,500 litres of aviation fuel were recovered
- [http://costperformance.org/pdf/Shaw\\_AFB\\_SD\\_29\\_30.pdf](http://costperformance.org/pdf/Shaw_AFB_SD_29_30.pdf)
  - The site is Shaw Air Force Base, South Carolina, US
  - 227 litres of aviation fuel were spilled resulting in LNAPL being present on the shallow groundwater table
  - The ground conditions comprised sands and silts
  - Approximately 19 litres of aviation fuel were recovered via the use of mechanical skimmer pumps and passive skimmers

## Appendix B – References

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