

Hydrogeological assessment (groundwater quality) guidelines

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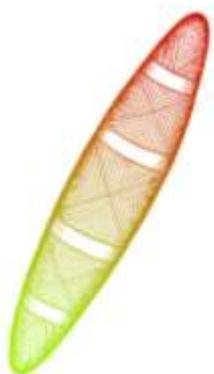
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EPA acknowledges Aboriginal people as the first peoples and Traditional custodians of the land and water on which we live, work and depend. We pay respect to Aboriginal Elders, past and present.

As Victoria's environmental regulator, we pay respect to how Country has been protected and cared for by Aboriginal people over many tens of thousands of years.

We acknowledge the unique spiritual and cultural significance of land, water and all that is in the environment to Traditional Owners, and recognise their continuing connection to, and aspirations for Country.



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Glossary

<p>Aquifer</p>	<p>A geological structure or formation or an artificial land fill permeated or capable of being permeated permanently or intermittently with water. (s4, Environment Reference Standard).</p>
<p>Background level</p>	<p>In relation to the land environment [which includes groundwater], means the level or range of levels of an indicator (measured in geologically similar land containing a measurable level of that indicator), outside the influence of any waste or contaminant. (s4, Environment Reference Standard)</p>
<p>Bore</p>	<p>Any bore, well or excavation or any artificially constructed or improved underground cavity that is used, or could be used for the purpose of:</p> <ul style="list-style-type: none"> a) the interception, collection, storage, or extraction of groundwater b) groundwater observation, or the collection of data concerning groundwater c) the drainage or desalination of any land d) the disposal of any matter below the surface of the ground (except bores that form part of a septic tank system) e) the recharge of an aquifer.
<p>Contaminated land (noting groundwater is a part of the Environment Protection Act 2017 definition of land)</p>	<p>Land is contaminated if waste, a chemical substance or a prescribed substance is present on or under the surface of the land, and the waste, chemical substance or prescribed substance:</p> <ul style="list-style-type: none"> a) is present in a concentration above the background level; and b) creates a risk of harm to human health or the environment. <p>(s35, Environment Protection Act 2017. Note also s35(2))</p>
<p>Bore development</p>	<p>A process of removing fine sand, silt and clay from the aquifer around the bore screen and breaking down drilling mud on the borehole wall. Development maximises the hydraulic connection between the bore and the formation and removes impurities. (modified from NUDLC, 2020)</p>
<p>Diffuse source</p>	<p>A source of contaminants which is not an identifiable single point of discharge.</p>
<p>Domestic and stock use</p>	<p>In relation to water, means use for—</p> <ul style="list-style-type: none"> a) household purposes; or b) watering of animals kept as pets; or c) watering of cattle or other stock; or d) irrigation of a kitchen garden

	<p>but does not include use for dairies, piggeries, feed lots, poultry or any other intensive or commercial use.</p> <p>(modified from Water Act 1989)</p>
Exposure pathway	<p>the course a substance takes from a source area(s) to a receptor. Each exposure pathway includes a source area(s), an exposure route and a point of exposure, and usually a transport/exposure medium or media.</p>
Geochemistry	<p>The chemistry related to the relative abundance, distribution, and migration of the Earth's chemical elements and their isotopes.</p>
Groundwater	<p>Any water occurring in or obtained from an aquifer and includes any matter dissolved or suspended in any such water. For this guideline, and consistent with the Environment Reference Standard clause 13(2), water within a landfill cell is not considered to be groundwater.</p> <p>(s4, Environment Reference Standard)</p>
Household purposes	<p>A supply for drinking, washing, cooking, heating or sanitary purposes</p>
Hydraulic conductivity	<p>A measure of the ease with which water can move through a porous or fractured medium (i.e., is a measure of the properties of water and the medium).</p>
Hydrogeochemistry	<p>The chemistry of groundwater and surface waters, particularly the relationship between the chemical characteristics and quality of waters and the local and regional geology.</p>
Hydrostratigraphic unit	<p>Sections of a geological formation that exhibit similar hydraulic properties, regardless of their composition.</p>
Migration pathway	<p>Natural geologic features or cultural features (including drains and infrastructure alignments) which allow the movement of a liquid, solid or vapor.</p>
Non-aqueous phase liquid (NAPL)	<p>An organic or inorganic liquid that:</p> <ul style="list-style-type: none"> a) is not miscible with water; and b) can exist in groundwater in various forms; and c) is commonly present as a measurable thickness (phase-separated) or sheen; and d) may be identifiable analytically (in soil or groundwater) when solubility has been reached or observed to be present within the unsaturated soil, rock profile or aquifer matrix. <p>(s4, Environment Protection Regulations 2021).</p>
Permeability	<p>The ability of a porous or fractured medium to transmit a fluid (i.e., is a measure of the property of the medium only).</p>

Pollution	<p>Any emission, discharge, deposit, disturbance or escape of—</p> <ul style="list-style-type: none">a) a solid, liquid or gas, or a combination of a solid, liquid or gas, including but not limited to smoke, dust, fumes or odour; orb) noise; orc) heat; ord) a thing prescribed for the purposes of this definition— <p>but does not include a thing prescribed not to be pollution for the purposes of this definition.</p> <p>(s3, Environment Protection Act 2017)</p>
Saturated zone	Area below the water table in which the soil is completely saturated with groundwater.
Unsaturated zone	The portion of the subsurface above the groundwater table. The soil and rock in this zone contains air as well as water in its pores.
Water table	The surface of saturation in an unconfined aquifer at which the water pressure is equal to atmospheric pressure.

1. Introduction

EPA Victoria recognises the need to protect the quality of groundwater both as a resource and as part of the natural environment. Many activities can pose a risk of harm to groundwater itself, and contaminated groundwater can pose a risk of harm to human health and other parts of the environment. Understanding the hydrogeological setting is an important first step in the minimisation of risks of harm to human health and the environment.

Hydrogeological assessment is a systematic study of geology, hydrogeology and geochemistry to provide the necessary information to determine the status of groundwater quality and evaluate the potential for pollution to occur, move and impact upon human health and the environment.

A hydrogeological assessment (HA) is required to assess the risks of harm to groundwater posed by any activity, including past, present, and future activities. An HA is required to understand the risk of harm posed by potential or existing groundwater contamination and to inform remedial activities. An HA may also be undertaken voluntarily as a 'due diligence' study to inform determination of the environmental liabilities of a site or business. EPA expects that an HA will be undertaken in any circumstances where previous, current, or proposed activities have or may pose a risk of harm with respect to groundwater.

An essential component of an HA is the development of a clear conceptual model of the hydrogeology, potential pollution that may be caused by an activity or contamination that has resulted from an activity, and the risks of harm to human health and the environment.

The purpose of undertaking an HA is to achieve a robust conceptualisation of the three-dimensional sub-surface environment (geology, hydrogeology, geochemistry and hydrogeochemistry), as a basis upon which to integrate information regarding:

- aquifer characteristics
- groundwater - surface water interactions
- past, current, and proposed potentially polluting activities
- extent and degree of existing or potential contamination.

The HA aims to inform the:

- potential for past, current, and proposed activities to pose a risk of harm to groundwater (with respect to environmental values)
- risk of harm posed to human health and/or environment by contamination (existing or potential)
- fate and transport of groundwater contaminants
- groundwater remediation feasibility (considering the nature of contamination and aquifer characteristics).

This guideline provides the preferred practice for HAs with a groundwater quality aspect. Other organisations may also request an HA which needs to consider groundwater quality when implementing other legislation or regulations. Two examples include:

Local government has obligations to consider environmental protection, including groundwater, when considering planning applications, and permits for proposals such as service station construction, or when considering the requirements of an Environmental Audit Overlay on potentially contaminated land. Further detail may be found in the Planning Practice Note 30, Potentially Contaminated Land (PPN30).

Rural water authorities and the **Department Environment Land Water and Planning** may need to evaluate the impact of pollution on water resources, to design and review regional surface water and groundwater monitoring strategies, groundwater dewatering activities or to assess the potential impacts of issuing a licence to take and use water, to reinject into the aquifer or in the assessment of an Environment Effects Statement (EES). For example, the Water Act 1989 requires consideration of quality issues, and there are times when EPA is a referral authority for licensing decisions by water authorities.

This guideline provides a useful reference in the absence of guidelines specific to those organisations.

Example activities that may require an HA

- a change in land use or development
- landfilling
- waste storage and handling
- wastewater storage and irrigation
- dewatering of groundwater to facilitate excavation / construction etc.
- groundwater reinjection / artificial aquifer recharge (including managed aquifer recharge, aquifer storage and recovery etc.)
- petroleum or chemical storage and handling
- site contamination assessment / remediation
- a baseline assessment
- a regulatory action, such as:
 - a license, permit or registration application
 - a notice to investigate or take environmental action
 - a Site management order
 - a Financial Assurance proposal
- performance of duties, such as
 - Duty to manage contaminated land
 - Duty to take action to respond to harm caused by pollution incident

1.1. Guideline purpose

The purpose of this guideline is to:

- encourage consistency and improve standards of HA data collection, reporting and analysis
- inform industry and the community about EPA expectations for the content of an HA report
- promote an approach to HA that is commensurate with potential risks of harm to human health and the environment.

This guideline describes the basics of groundwater pollution and contamination; how a site conceptual hydrogeological model is developed; the process of an HA; the collection of groundwater data; and what an HA report should contain.

1.2. Intended audience

The guideline is intended for use by qualified and experienced hydrogeologists¹.

HAs require comprehensive understanding of geology, hydrogeology and hydrochemistry, and should be undertaken by qualified and experienced hydrogeologists.

Nevertheless, a wide cross-section of stakeholders may refer to this guideline to inform their duties under the Environment Protection Act 2017 (the Act), activities, or requirements. These include:

- Officers of regulatory and protection authorities (EPA, Department of Jobs, Precincts and Regions (DJPR), Department of Transport (DOT), Department of Environment, Land, Water and Planning (DELWP), Municipal Councils, Community Services, Water Authorities, etc.). To provide guidance to clients and assist the agency to be confident that appropriate assessments have been undertaken to define the groundwater environment of the locality, and potential for risk of harm to human health and the environment
- Site owners or occupiers conducting or specifying HAs (e.g., as part of a licensing application or requirement, land transfer “due diligence”, and contaminated site investigations or in response to EPA Notices or environmental audit recommendations). To provide some certainty about the requirements of the regulatory authority and a benchmark for consultants submitting fee proposals
- Consultants undertaking HAs on behalf of site owners or occupiers requiring confirmation of the appropriate scope of HAs
- The wider community with an interest in the protection of the groundwater environment.

¹ This means someone who demonstrates scientific knowledge of, and a proven ability and familiarity with hydrogeology, through formal or informal training or through past professional performance.

2. Understanding groundwater and pollution

This section summarises the potential influence that activities, pollution sources, groundwater movement and chemical processes may have on the extent and magnitude of contaminated groundwater. Identifying these aspects is a key part of the HA.

2.1. Risks of harm

The general environmental duty (section 25 of the Act) requires that a person who is engaging in an activity that may give rise to risks of harm to human health or the environment from pollution and waste, must minimise those risks, so far as reasonably practicable. Section 2.2 indicates there are many activities which create a risk of harm to groundwater.

Where there is a chance that pollution may occur as a part of an activity, or when contamination is identified or suspected, a qualitative or quantitative risk assessment should be undertaken to evaluate the significance of the risk of harm to human health and the environment. The risk assessment may include modelling groundwater flow and the transport and fate of contaminants in the groundwater flow system.

Risks of harm must be assessed with respect to the applicable environmental values determined in accordance with the ERS. Section 3.6 provides a more detailed discussion of environmental values.

Where there may be a risk of harm to aquatic ecosystems (such as in a lake or stream receiving groundwater discharge), a multidisciplinary team is required to ensure robust characterisation and quantification of risk. This process requires site-specific assessment of impact, considering environmental values of the discharge zone and the interface, to assess if a risk of harm is created to receiving waters and ecosystem.

2.2. Pollution and contaminated groundwater

It is important to understand what is meant by pollution and contamination as these are defined differently and are not interchangeable. The Act defines pollution as including any emission, discharge, deposit, disturbance or escape of a solid, liquid or gas (or combination thereof). As groundwater is a component of land (as defined in the Act), "contaminated groundwater" holds

Risks of harm to groundwater

The Act defines groundwater as a sub-set of the environment. As such, an activity may give rise to risks of harm to groundwater itself.

The Act defines harm, in relation to human health and the environment, as "an adverse effect...(of whatever degree or duration)". "Risk", in the context of "risk of harm" means "chance".

An activity may present a "chance of an adverse effect on groundwater" if the activity has the potential to cause changes in the groundwater (including changes in dissolved matter that makes up groundwater).

This would be typically measured against background levels (concentrations).

For water-based ecosystems and species, levels above background are considered to create a chance of an adverse effect. Such circumstances would therefore represent "contaminated groundwater" and trigger duties under the Act.

Once contaminated, groundwater may become the avenue through which an activity poses risks of harm to human health and other parts of the environment.

the same definition as “contaminated land”² - where a substance is present above background levels and creates a risk of harm (chance of an adverse effect) to human health and the environment. For a substance to exceed the naturally occurring concentrations there must have, at some point in the past, been an ‘emission, discharge, deposit, disturbance or escape of... a solid, liquid or gas’ therefore explaining the presence of the elevated concentrations. As such, pollution is the action that may, consequently, lead to a state of contamination.

Contaminated groundwater can be a source of pollution to off-site receptors – through migration and discharge of groundwater itself or volatilisation and migration of contaminants into the unsaturated soil above groundwater.

2.2.1. Pollution sources

Many activities can cause pollution to groundwater. Sources of pollution can be from industrial or agricultural activities and practices, sudden releases from spills or accidents, gradual releases from long-term leaks, disturbance of land or materials (for example acid sulphate soils or moving an existing plume of contamination) or contaminated soil, soil gas or groundwater.

Pollution may be from a point source or from a wider, diffuse source area. A large number of point sources in an area, such as septic tanks, can combine to give an impact that is similar to a diffuse source. Natural processes may also lead to elevated analyte concentrations (background levels) that, without an understanding of the hydrogeological setting, may be interpreted as contamination. It is therefore important to collect baseline groundwater data to adequately characterise variability (if applicable) for distinguishing between natural fluctuations and changes due to pollution or contamination.

The Environment Reference Standard (ERS) explains how background levels are to be used when setting environmental quality indicators and objectives to ensure that the natural characteristics of waters are considered. Publication 2033 provides guidance on how to determine background levels.

The type of release (for example, spills at the surface, leakage from underground tanks, injection through bores, seepage from lagoons or containment facilities), or type of land or water disturbance can affect the concentration and extent of released substances and can affect whether the pollution causes contamination.

Asking yourself the following questions will help to develop an understanding of how pollution sources may impact on the groundwater system:

- Where and how does groundwater occur at the site?
- What is the current groundwater quality and what is the background groundwater quality? For example, is groundwater likely to be, or already contaminated?
- What are the potential or likely sources of pollution?
- Has contaminated soil or contaminated soil vapour been identified? Could this indicate a source of pollution to groundwater?

² Refer to glossary and [EPA Publication 1940: Contaminated land: Understanding section 35 of the Environment Protection Act 2017](#) for more details.

- What are the risks of harm to human health and the environment posed by the activity, pollution or contamination? Is there the potential for contamination to be mobilised in air, land or water and therefore be a pollution source to other receptors?

All aquifers are at risk from pollution via subsurface structures such as bores, pits, drains, pipelines, underground services and sewer systems, and old mine shafts. The underground service alignment / trench may also provide a pathway for pollution. Additionally, the exchange of groundwater between shallow and deep aquifers via poorly constructed or improperly decommissioned boreholes, or natural features such as fractures, can increase the spread of substances within an aquifer and make clean up difficult.

For a pollution source located above the water table to impact groundwater, the substances released must first migrate through the unsaturated zone. The gas phase in the unsaturated zone can also be impacted by contaminated soil and/or groundwater and presents a potentially significant risk to human health and safety due to migration of volatile contaminants. The transfer of contaminants between liquid, solid and gaseous phases is largely an equilibrium process. As such, contaminants present in the gas phase can migrate and cause contamination of groundwater elsewhere. Hence, a study of the unsaturated zone often needs to be included in the HA.

Contaminants with relatively low water solubility can be present as a separate phase in the aquifer. The presence of non-aqueous phase liquid (NAPL) is an uncontrolled source of contamination which can significantly impact the soil, water and gas phases of an aquifer. In accordance with the Environment Protection Regulations 2021 (the Regulations), NAPL must be removed so far as reasonably practicable to minimise risks of harm to human health and the environment. Further guidance on this issue is provided in "The clean up and management of contaminated groundwater" (EPA Publication 2001).

Because of the potential for increased contamination, aquifers contaminated with NAPL require a very high level of care in assessment and monitoring. NAPL-contaminated sites should only be investigated using appropriate techniques by hydrogeologists, or environmental consultants, with specialised training in NAPL assessment.

2.2.2. Contamination migration

When a contaminant enters groundwater, its movement is determined by the physical and chemical characteristics of the aquifer, groundwater flow paths, and the properties of the contaminant itself. Other factors, such as utilities in the subsurface, drilling practices and poorly constructed bores could also create a preferential pathway for migration.

Contaminant concentrations can vary widely with space and time due to a range of physical, chemical, and biochemical processes, including source inputs, dispersion, diffusion, adsorption, biodegradation and volatilisation.

Aquifers are usually heterogeneous, the physical properties (porosity, hydraulic conductivity, aquifer thickness etc.) often vary over relatively short distances. This means that assessment of the pattern and rate of groundwater flow is critical, with measurement of hydraulic parameters,

such as hydraulic conductivity, often required to have confidence in understanding the site's groundwater flow system.

To effectively understand how groundwater and matter in groundwater moves, it is important to understand how water enters aquifers (recharge), how it leaves aquifers (discharge) through wells or discharge to rivers, wetlands, oceans, and vegetation, and how it flows between recharge and discharge zones (see Figure 1). Whether a source is continuous or instantaneous / discontinuous can also influence the way a plume develops (refer Figure 2).

Identifying how and where groundwater interacts with the land surface and with surface water is very important and should be a component of every HA. Natural and human related processes that affect groundwater movement need to be considered in the HA (e.g., dewatering, subsurface utilities, tidal interactions, changes in recharge, rainfall and climate).

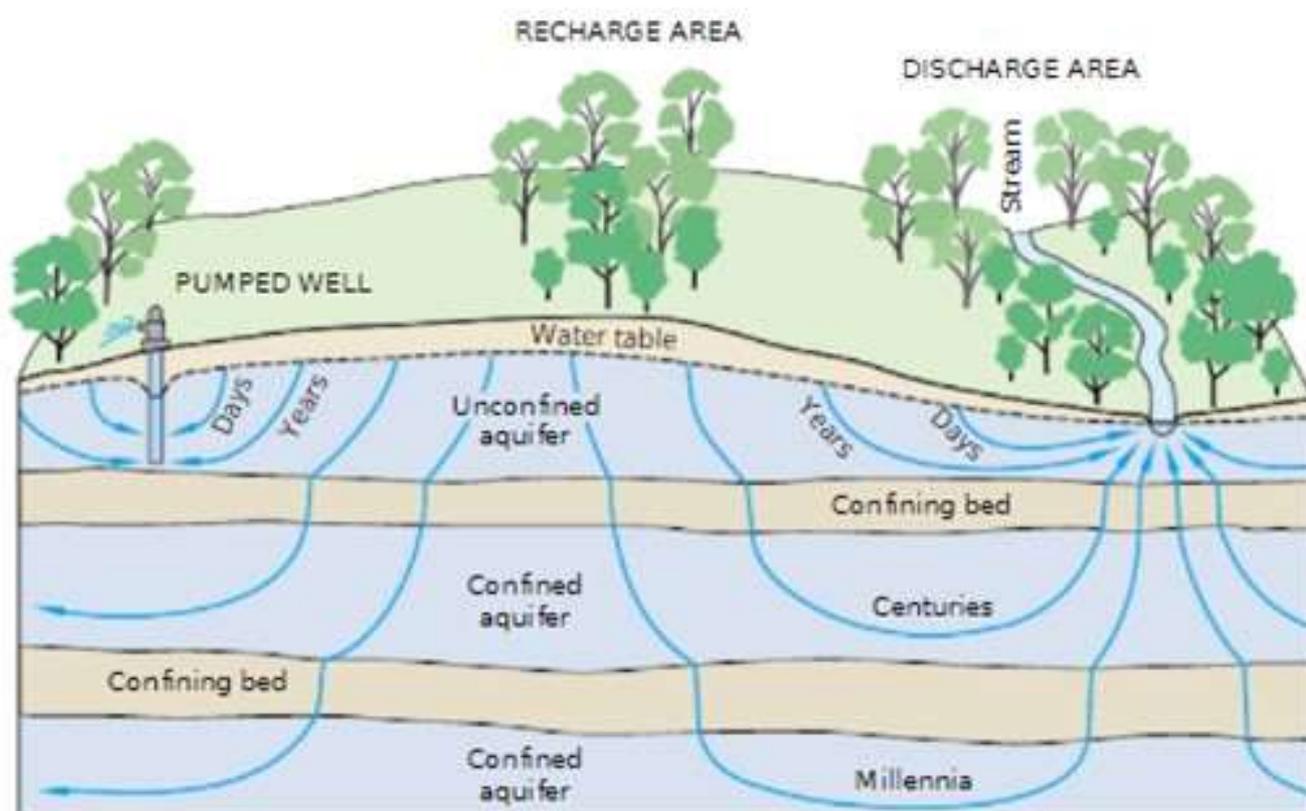


Figure 1: Cross section of a groundwater flow system (from T.C. Winter et al, 1998)

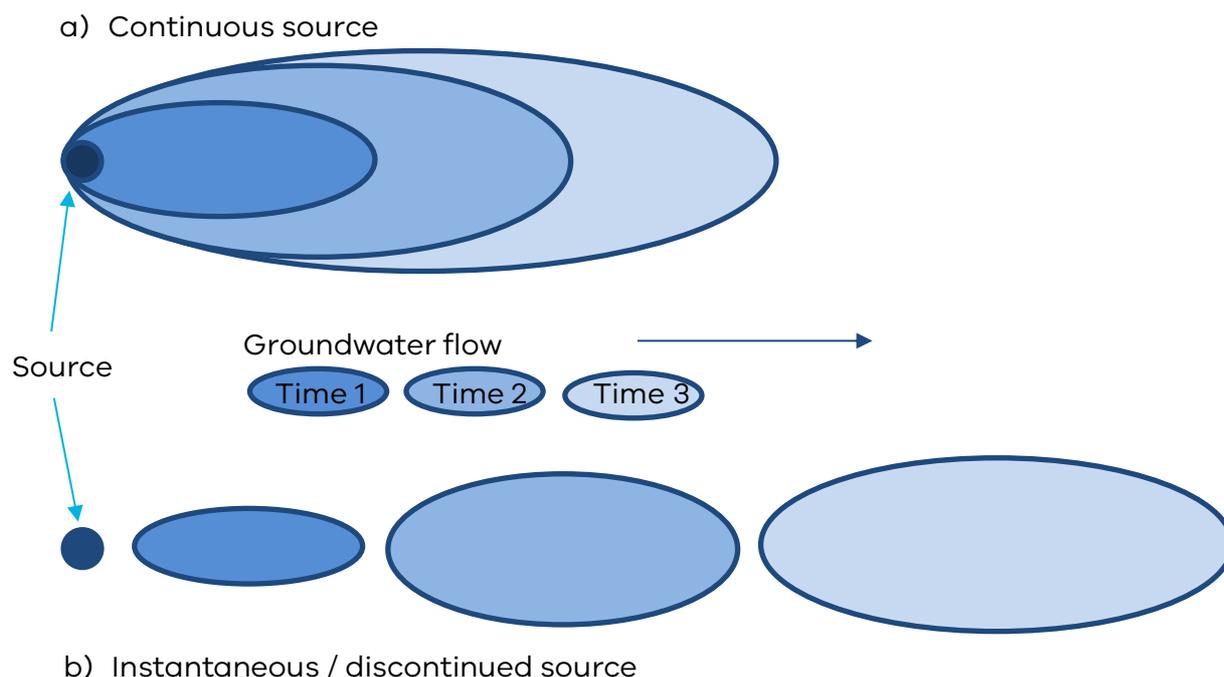


Figure 2 - Conceptual plume development based on source type (adapted from Lane et. al. 1999)

2.2.3. Considerations for activities which impact groundwater flow

There are many activities (for example groundwater extraction, groundwater injection, construction of underground structures) which can cause a change in the direction or rate of groundwater flow.

For example, changes in groundwater flow properties could:

- result in pollution and a requirement to restore (refer section 31 of the Act)
- cause another person in management or control of land to have duties under the Act, for example where existing contamination is moved to below their property
- cause a duty holder's existing management activities to become ineffective.

To help guide assessment when an activity has the potential to change groundwater flow properties, ask yourself questions such as the following:

- Are there existing contaminant plumes that may be moved or changed by the activity?
- Will the injection or release of water into groundwater change the geochemistry?
- Will changes in groundwater level expose or inundate acid sulphate soils or soil contamination or change vapour migration pathways?
- Will the extraction or injection change base flow parameters to nearby water courses?
- Will changes in baseflow cause changes to the natural stream geochemistry?

Where an activity discharges or causes a substance to be discharged to an aquifer, an A18 permit may need to be held (refer to the Regulations and EPA's website for further details of permissions).

2.3. Groundwater remediation

Wherever groundwater remediation is required (for example, pump and treat, multiphase extraction, in-situ enhanced biodegradation, reactive barrier systems), or where 'monitored natural attenuation' is the approved management option, site hydrogeology and contaminant behaviour must be well understood. Understanding these factors will help ensure the feasibility of remedial or management strategies can be determined and demonstrated and ensures that situations are improved in a timely manner and not worsened by remediation or management.

The provision of a groundwater remediation feasibility assessment in accordance with EPA Publication 2001, relies on a sound HA.

EPA Publication 2001 The clean up and management of contaminated groundwater provides details on EPA's expectations for groundwater remediation. The CRC Care National Remediation Framework also provides useful information on groundwater remediation (refer to <https://www.remediationframework.com.au/>).

3. The hydrogeological assessment process

3.1. Aims and objectives

Clear objectives must be determined before commencing the HA, dictated by the nature of the problem and local conditions. The scope of the HA must be site-specific, and risk based. The scope may change as more information becomes available and there is increased understanding of the potential risk.

The HA involves a phased approach, with the scope depending on the nature and scale of the problem, or activity, and the expected risks of harm.

All relevant stakeholders³ should be consulted to ensure the scope of the HA is adequate – in particular, the field investigation and data analysis components.

Typically, the HA would address questions such as the following:

- What is the potential for an activity or a pollution source at or near the site to contaminate groundwater?
- Is groundwater at the site contaminated, and if so, what is the nature and extent of groundwater contamination?
- What is the level of risk posed by the activity, pollution source or contamination and how might this change over time?

³ For example, consider whether an environmental auditor, planner, EPA Authorised Officer or another stakeholder will need to review the HA.

These questions can be answered by:

- reviewing the site history – identifying contaminants of concern⁴, activities, and potential for pollution
- assessing the hydrogeological setting – identifying aquifers, aquitards and their configuration and properties, groundwater flow directions and rates, groundwater quality (including groundwater segment⁵), groundwater background levels⁶ and migration pathways
- measuring contaminant levels in the groundwater in individual aquifers and aquitards at the site
- determining environmental values of groundwater and potential receptors such as wetlands, streams and groundwater users, likelihood of these uses becoming realised, and the likelihood and consequence of risks being realised (for example where there are complete exposure pathways).

Conceptual Site Model (CSM)

A CSM is a broad representation of the biological, physical and chemical processes that control the ways contaminants move from sources through environmental media to receptors.

Conceptual Hydrogeological Model (CHM)

A CHM is the portion of the CSM that represents the geological framework and the movement of groundwater (and contaminants) within that framework.

The HA may not initially include all the hydrogeological work necessary at a site. The HA may evolve as greater understanding of the hydrogeology, pollution pathways, contaminants, and risks of harm to human health and the environment related to groundwater at the site is developed.

3.2. Undertaking hydrogeological assessments

Sufficient work must be done in all HAs to establish a conceptual hydrogeological model (CHM) that represents the hydrogeological setting, the movement of groundwater and contaminants, and the interactions between groundwater and the surface (the CHM assesses migration pathways).

The CHM can then be used to inform the conceptual site model (CSM) of contamination in groundwater that migrates to exposed human and environmental receptors to inform the assessment of risk e.g., to groundwater users or terrestrial, riparian or aquatic environments where groundwater discharges, or receptors of vapour from groundwater contamination, etc. (the CSM expands upon the migration pathways to assesses exposure pathways).

⁴ Substances that are identified for evaluation based on their historical, current, or proposed use at a site, or based on their detection, mobility, toxicity, or persistence in the environment.

⁵ In accordance with the Environment Reference Standard (ERS).

⁶ Refer Publication 2033 - Background levels: Identifying naturally occurring concentrations (in press at time of publication)

The CHM must be based on sound hydrogeological principles and be technically and scientifically defensible. It must be capable of modification as additional information becomes available.

Appendix A outlines the minimum requirements for the CHM section of the HA. It is important that the CHM is communicated effectively. As such, it is recommended that a graphical summary of the CHM is developed to complement the desktop study findings.

Completion of HAs follows a phased approach:

1. The development of an initial conceptual hydrogeological model through a desktop study.
2. Revision of the conceptual hydrogeological model through field investigation.
3. Detailed assessment and extension of knowledge.

Each subsequent phase of the HA should build upon the CHM for the site. The following flowchart provides a high-level process for how hydrogeological assessments should proceed.

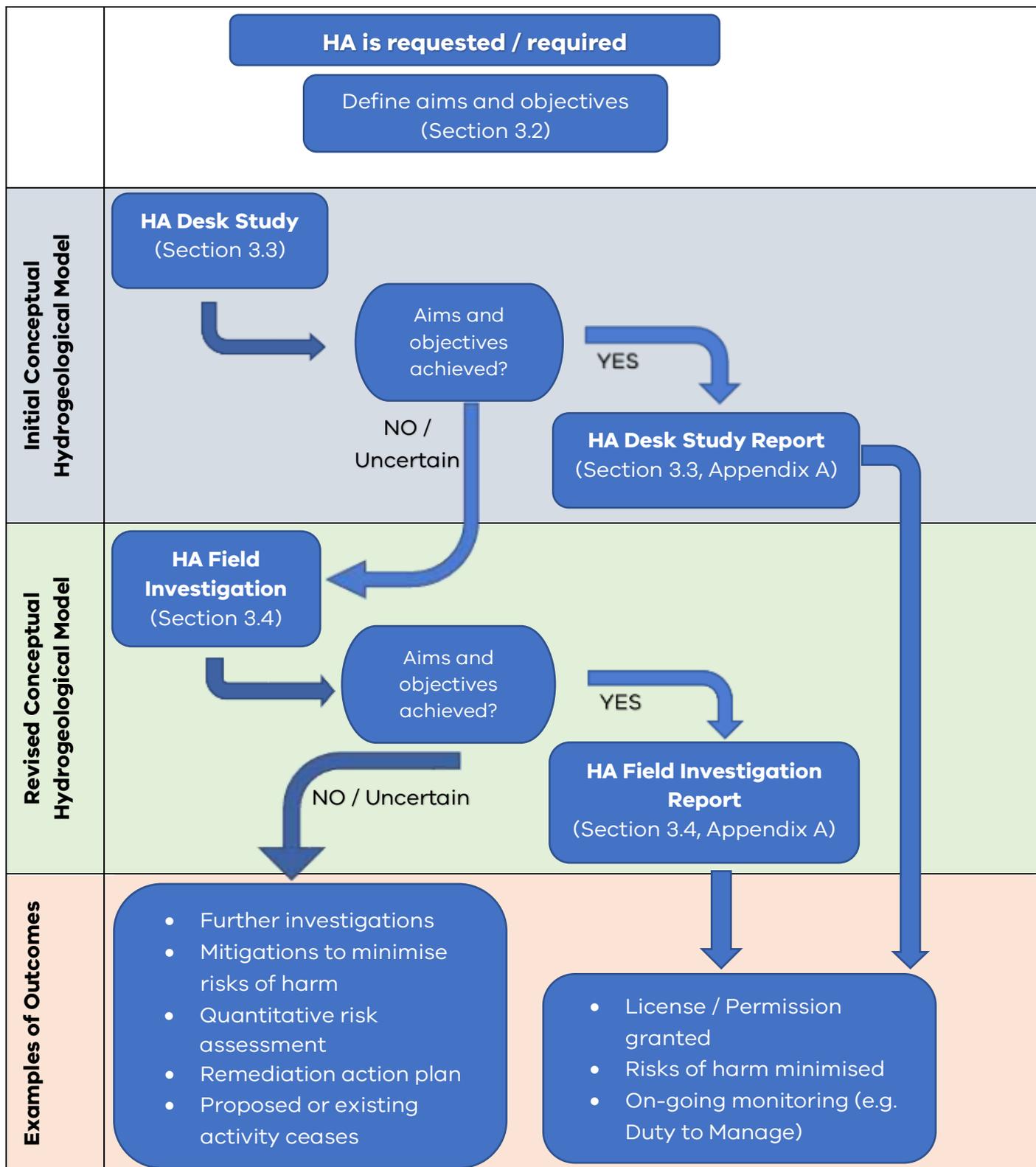


Figure 3 – Flowchart of hydrogeological assessment process

Regardless of the scale and complexity of the task, all HAs should develop an initial conceptual hydrogeological model through an assessment of the:

- hydrogeology of the site and surrounding region
- aquifer properties (physical, geochemical and hydrogeochemical) and groundwater flow directions, paths, and rates
- segment classification and confirmation of environmental values (as per the ERS)
- potential for activities / pollution pathways that may cause groundwater contamination
- description of background groundwater quality and distribution and concentration of existing contamination
- expected fate and transport of groundwater contaminants (if relevant)
- risks of harm to human health and the environment.

All HAs should include a desktop study to build an initial conceptual hydrogeological model of groundwater flow, quality, pollution pathways and contamination, and an initial assessment of risks of harm to human health and the environment.

Depending on the objectives of the HA, it may also comprise:

- field investigation and testing to improve the conceptual hydrogeological model (if necessary)
- reassessment of risks of harm (if necessary)
- reporting of data, conceptual hydrogeological model, conceptual site model and analysis of the hydrogeological conditions and risks of harm at a site.

The minimum requirement for the contents of an HA report is listed in Appendix A. At complex sites it is often appropriate to prepare an HA report and a separate land contamination assessment report, especially where the site is undergoing development or redevelopment in stages, or where a plume of contaminated groundwater underlies multiple sites.

The conclusions from the HA may be any of the following:

- no further action (i.e., groundwater is unlikely to be contaminated and risk of future pollution is minimal)
- ongoing management of groundwater contamination⁷, including containment or monitoring, where risk from groundwater contamination is minimised or has been minimised after clean up
- further HA, monitoring and possibly aquifer clean-up trials where significant groundwater contamination is present, and / or
- further groundwater clean-up to minimise risks of harm to human health and the environment.

⁷ The presence of contaminated groundwater will likely trigger duties under Section 39 of the Act. Refer also to EPA Publication 1940 – Contaminated Land: Understanding Section 35 of the Act.

The HA should demonstrate that the environmental values are not, or will not, be threatened due to site activities (to be measured, determined or assessed against background levels⁸, specific indicators and objectives for groundwater in accordance with clause 16 and Table 5.4 of the ERS 2021) and that any risks of harm are minimised so far as reasonably practicable. If there have been regional impacts on the aquifer from off-site activities, these should also be considered in the HA, along with any other site-specific and geological or aquifer specific issues to support the conclusion.

3.2.1. Dealing with uncertainty

Groundwater systems are inherently complex. A conceptual hydrogeological model is just one potential solution based on the data collected at a site, and while additional data can reduce uncertainty, it does not remove uncertainty entirely.

The HA should include an assessment of data gaps, uncertainty and variability. Section 4.4 of NEPM, Schedule B2 provides useful guidance on considering these three aspects and suggests that in developing a CSM, the following questions be addressed:

- How representative the available data is likely to be?
- What the potential sources of variability and uncertainty are?
- How important the identified gaps are to the objectives and reliability of the site assessment?

The data gap assessment should discuss the implications of assumptions, data limitations, uncertainty and variability on the conclusions formed through the HA. Recommendations for further work should also be informed by this section of the HA.

3.3. Hydrogeological desktop study

All HAs should commence with a desktop study. The HA desktop study should review current and historical information about a site, plus any relevant hydrogeological data such as information from bores previously installed at the site. As a minimum, the HA should assess for groundwater receptors (registered bores, surface water systems, groundwater dependant ecosystems, etc.) within 2 kilometres radius of the site⁹, but this radius should be extended where there is a potential for risks of harm to extend further. The potential presence of unregistered bores should also be considered. Where practicable, the information collected during the desktop study should be confirmed through site inspection.

The outcome of a desktop study is generally an initial conceptual hydrogeological model (CHM). An initial CHM is used to inform a conceptual site model (CSM) and should be able to answer the question, 'Is the risk of harm to human health and the environment minimised?' If the question can't be answered, or the answer is 'no', then further work is needed, such as field investigations (refer Section 3.4).

⁸ See also EPA Publication 2033 Background levels: Identifying naturally occurring concentrations

⁹ It is acknowledged that this radius could identify a significant volume of bores. It is expected that the discussion will be appropriately focused on the most relevant of the resulting dataset to evaluate risks of harm.

The HA desktop study should either result in a desktop study report or provide input to a field investigation work plan. If there is no further investigation, a desktop study report is prepared to reflect the content in the Hydrogeological Assessment Reports section of this guideline and the minimum requirements in Appendix A.

If no further work is proposed there must be a clear and defensible argument presented in the report that the activity does not pose a risk of harm to human health or groundwater, that groundwater is not polluted or contaminated, or that groundwater is unlikely to become so.

If that activity does pose a risk of harm, or if groundwater is, or is likely to be, contaminated, further assessment is necessary to evaluate movement and fate of contaminants and further define the risks of harm to human health and the environment to appropriately design mitigation measures.

3.4. Hydrogeological field investigation

3.4.1. General assessment

If the initial CHM (or subsequent CSM) does not meet the objective of the desktop study due to a lack of data, or if groundwater at the site is suspected of being contaminated or of becoming contaminated due to an activity, then a field investigation is required.

The scale and detail of a field investigation will vary depending on the hydrogeological setting, the type of problem or activity, the nature of contaminants being addressed, and the potential risk of harm posed to human health and the surrounding environment posed by groundwater contamination. Further information regarding groundwater data collection from field investigations can be found in the following sections.

Clear objectives, and a work plan, should be developed prior to commencing the field investigation. The work plan should account for the site's physical features, the location of underground structures (such as fuel tanks or services) and the characteristics of the contaminants of concern. Activities at the site should be carried out in a manner that avoids creating pathways for pollution or expanding any existing contaminated zone.

Before carrying out fieldwork, the potential physical and chemical hazards of the site should be assessed in terms of meeting health and safety requirements for all personnel (including contractors) who will be working on the site, as well as minimising any effects of the proposed work on the environment.

The results of the field investigation may confirm the initial CHM developed during the desktop study or may be used to update the CHM to reflect actual site conditions.

The data to be collected during field assessment will vary depending on the objectives of the HA. Most HA field assessments will require activities to:

- Characterise the site geology and identify hydrostratigraphic units that act as aquifers or aquitards. In many cases it may be necessary to determine the hydraulic properties of the aquifers, and sometimes the aquitards
- Measure groundwater levels to estimate the rates and directions of lateral and vertical groundwater movement
- Measure variability in groundwater quality geographically, within and between aquifers

- Map the areas and / or activities (on- and off-site) which could lead to pollution and contamination.

3.4.2. Contamination assessment

Where contamination is identified or the objective of the HA is to determine the contamination state of groundwater, field assessment should also:

- map the lateral and vertical extent (and variation over time) of groundwater contaminants
- gather information to assess plume movement, stability, growth or contraction
- identify areas of contaminant migration and places where contaminants may accumulate (for example, including high and low-permeability materials).

Other methods that may be used to better define contaminant migration and fate at a site include:

- geophysics (surface and down-hole) and geochemical assessment of aquifer matrix
- unsaturated zone or soil gas monitoring (active or passive)
- environmental isotopes (such as isotopes of oxygen, hydrogen, carbon, and nitrogen) and tracers to characterise, date or 'fingerprint' groundwater or contaminants
- monitored natural attenuation (MNA) and natural source zone depletion (NSZD)
- microbial studies (including compound specific isotope analysis (CSIA), genetic analysis or microcosm analysis)
- soil core solvent extraction
- solid-core diamond drilling
- other and developing techniques such as in-situ monitors and loggers, cone penetrometers, and high-resolution site characterisation (HRSC) methods.

Monitoring of the unsaturated zone may also provide data on contaminant transport. Sampling fluids, soils, and vapours in the unsaturated zone can provide information on the potential for groundwater contamination long before contamination is detected in groundwater-monitoring bores.

3.4.3. NAPL assessment

Where NAPL may be present, or there is a risk of cross-contamination of aquifer zones and water samples, the drilling method and bore locations must be chosen to reduce such risks, and the work should be undertaken by personnel experienced in such work. Figure 4 shows conceptualisation of light NAPL (LNAPL) and dense NAPL (DNAPL) released into the environment.

Field assessments should consider:

- bore design to ensure assessment and characterisation (type, thickness, distribution, colour, viscosity, etc.) of NAPL
- methods to assess the extent and distribution (and variation over time) of NAPL within the unsaturated zone and saturated zones
- LNAPL or DNAPL sampling, physical parameters (including transmissivity) and chemical composition, and monitoring.

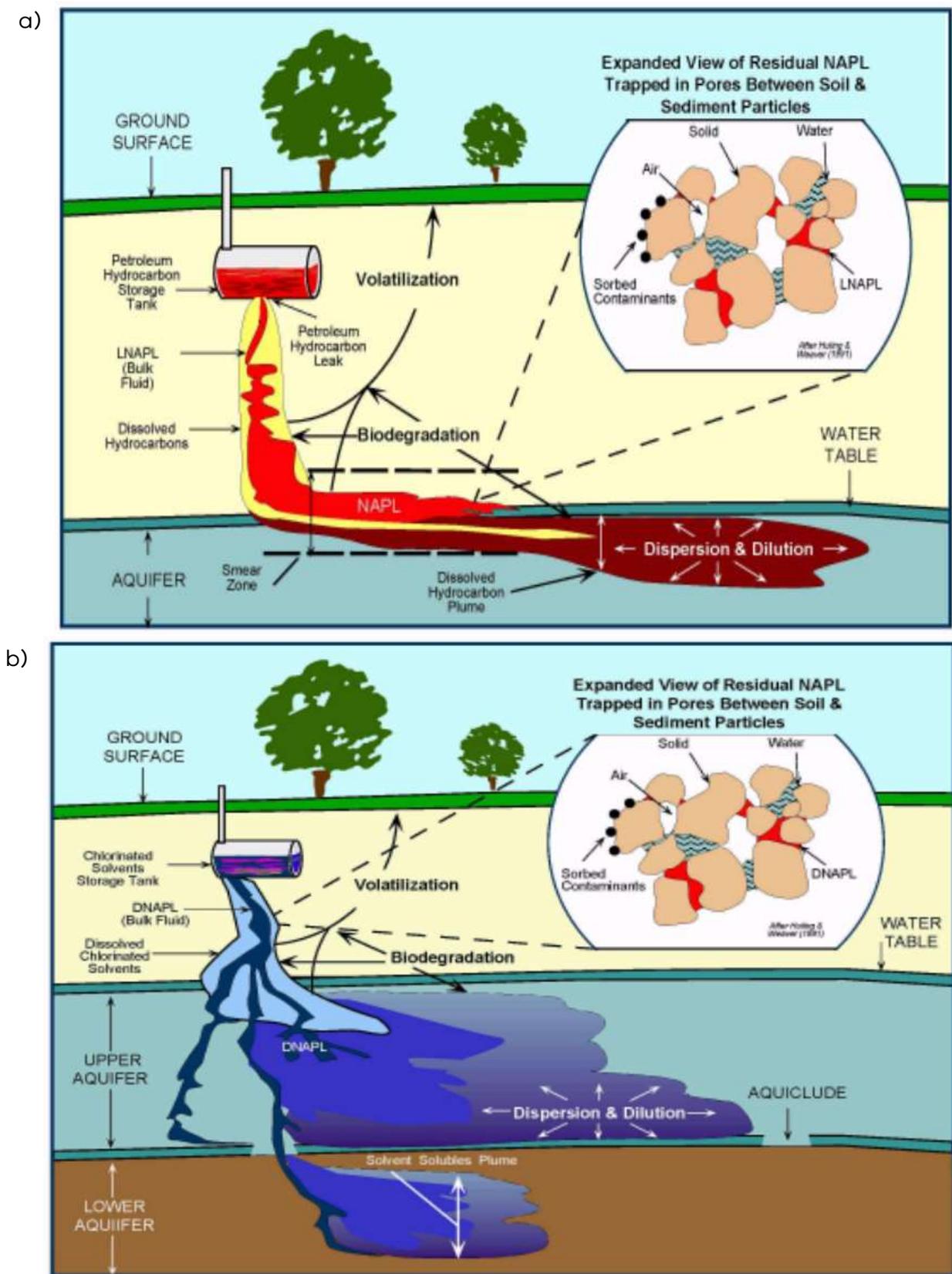


Figure 4 - a) Conceptualisation of LNAPL fate and transport (from Pope and Jones, 1999a), b) Conceptualisation of DNAPL fate and transport (from Pope and Jones, 1999b)

3.4.4. Groundwater bore network

The groundwater bore network should cover the study area and the aquifers and aquitards of concern and should have a sufficient number of bores to characterise the flow system laterally and vertically in the context of the HA objectives (in many instances this may require more than three bores). Although the number of bores and locations, depths and screen intervals are site-specific, most hydrogeological site investigations are likely to require at least:

- one bore located up-gradient on site (and possibly off site) to indicate the quality of groundwater entering the site
- two or three bores to monitor each aquifer located near, but down-gradient of and lateral to each main pollution / contaminant source.

Having at least three bores installed at a site (in a triangular pattern) will enable groundwater flow direction to be estimated (noting the potential issues presented in Figure 5). Where the objective of the HA can be satisfied with less than three bores, the HA report should include clear justification and discuss limitations.

The initial bores should be:

- located with consideration to background, source contribution¹⁰, receptors and anticipated groundwater flow direction
- screened appropriately to prevent cross aquifer contamination (refer Section 3.5.1) and target the most likely zone of risk to, or contamination of, groundwater (for most HAs, this will be across the water table aquifer¹¹ to locate 'floating' NAPL and to identify contaminants derived primarily from surface leakage into the uppermost aquifer)
- installed with similar construction techniques¹² to minimise sources of variation in the data.

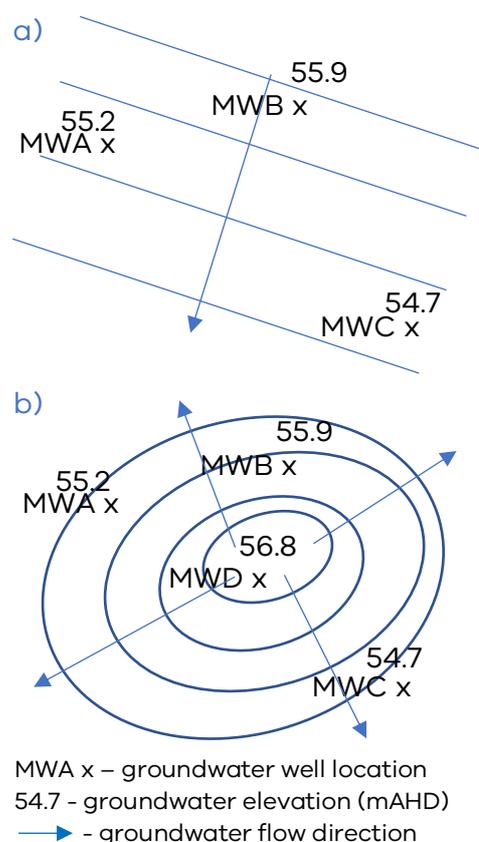


Figure 5 - The "three bore problem". Predicted groundwater contours with a) three bores, and b) after adding a fourth bore (adapted from Lane et. al. 1999)

¹⁰ Note that with Dense NAPL (DNAPL) sites, great care is required in siting, drilling and installing bores to avoid cross-contamination. To gain an understanding of the hydrogeological profile and implications for DNAPL assessment, the initial drilling locations should not be in potential DNAPL source areas.

¹¹ Noting that well screens should be as short as possible to still achieve the project aims and should not cross multiple aquifer units or connect confined aquifers to unconfined aquifers or to the unsaturated zone.

¹² Consider using techniques that assist in providing additional information about hydraulic parameters of the aquifer.

Further information regarding bore installation can be found in Section 3.5.1 below and the Groundwater Sampling Guidelines (EPA Publication 669).

Sites with significant pollution sources, groundwater contamination, high ecological or health risk, or complex hydrogeology may require a significant quantity of groundwater bores to characterise the hydrogeological system or assess the lateral and vertical extent of contamination on and off site and develop an appropriate CHM.

As information is gathered, further phases of field investigation and data analysis may be required to reduce uncertainty and to achieve delineation such as that outlined in Figure 6. Areas of remaining uncertainty should be included where data is presented (e.g., highlighted on contamination extent maps) and captured in the CHM. A comprehensive, multi-stage drilling program may be needed to investigate the unsaturated zone, to monitor multiple aquifers or to monitor different depths within one aquifer, depending on the nature of the site activities, the problem, the site hydrogeology, and whether NAPL may be present. The use of drilling techniques that provide a “core sample” of the geological profile should be considered, as this can provide detailed information on the geology and structures such as faults and joints¹³.

It is important to recognise that the bore network requirements may change over time. For example:

- bores may need to be added due to changing requirements or to fill identified data gaps
- bores may need to be removed if they have failed, no longer provide required information, or have been superseded by newer bores
- the initial investigation bores might not suit long-term monitoring requirements at the site, and additional bores, or bores in different locations, could be required to achieve this purpose.

The possibility of retaining bores for long-term monitoring should be considered when designing a bore network. Investigation bores that are not to be used for future monitoring must be properly decommissioned in accordance with the requirements under the Water Act 1989 (see also Section 3.5.1 below).

To provide reliable information, the bore network must be maintained. This includes re-development, refurbishment, and potentially, re-drilling when indicators show that bore performance is reducing.

¹³ A similar result can be achieved using a down hole camera to retrospectively capture this information prior to well construction.

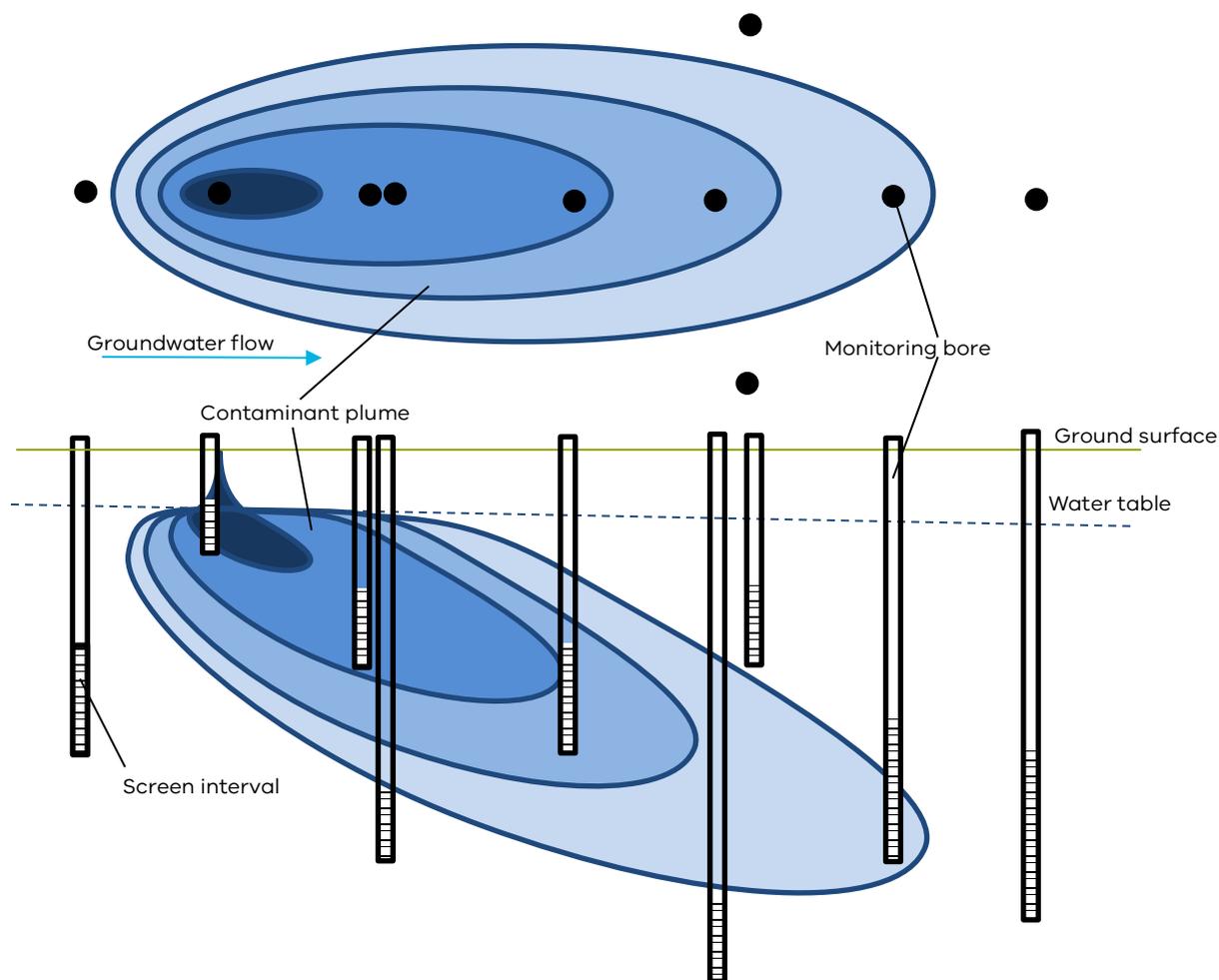


Figure 6 - Example of a contaminant plume with a high degree of lateral and vertical delineation

3.5. Groundwater data collection

Groundwater data is usually obtained from bores installed for the purpose of data collection, but might also be obtained from springs or seeps, water supply bores, sumps and drains, or existing bores which have been installed for another purpose¹⁴. Where interaction between groundwater and surface water environments needs to be defined, wetlands, lakes and streams should also be sampled. Only groundwater from a properly designed, installed, maintained, and sampled bore is representative of groundwater quality in the aquifer. Groundwater from other sampling points represents the groundwater quality at the point of use or point of discharge.

¹⁴ While it is noted that there are many places from which to collect groundwater data, information collected from anything other than a groundwater bore designed for that purpose should be used with caution.

The Groundwater Sampling Guidelines (EPA Publication 669) provide detailed information on the installation of monitoring bores, collection of groundwater data and other aspects of groundwater monitoring.

Where groundwater data is being collected for other regulators, there may be other standards which also apply.

3.5.1. Investigation and monitoring bore installation and decommissioning

Drilling bores for investigation, monitoring or extraction of groundwater is controlled under the Water Act 1989. A bore construction license (BCL) must be obtained from the relevant water authority before installing, altering, or decommissioning investigation, monitoring or extraction bores. The driller must be licensed¹⁵ to drill and install water bores. Typically, the water authority will also require bores to be constructed and decommissioned in accordance with Minimum Construction Requirements for Water Bores in Australia (NUDLC 2020, or the latest version). Refer to DELWP (e.g., <https://www.water.vic.gov.au/groundwater/understanding-groundwater>) or the relevant rural water corporation for further information on their requirements.

Installation of investigation or monitoring bores to provide detailed geological data, water level data and groundwater samples is critical where an HA requires field data. The main success factors are:

- choice of bore design and drilling method to suit the site-specific conditions and the HA objectives (refer to the Groundwater Sampling Guidelines for more details)
- correct placement of filter pack and seals in the bore annulus and the casing collar at ground surface
- choice of screen length (which should be as short as the project aims allow) and proper installation of casing and screens to ensure water levels and groundwater samples represent discrete intervals at the site and to prevent cross linking of hydrogeological layers
- 'development' of the bore to ensure the bore is operational, is suitable for the purposes of obtaining a representative sample of water from the aquifer and groundwater samples are free of suspended sediment (refer to the Groundwater Sampling Guidelines for further details), and
- protection and identification of the bore to preserve the asset and maintain its integrity.

To prevent cross-aquifer contamination, and to ensure that water level (hydraulic head) measurements are meaningful, bore screens must be restricted to a single aquifer. If they extend across multiple aquifers (or even multiple flow zones or fractures within the same aquifer) cross-contamination of multiple aquifers can occur, allowing released substances to spread further. Furthermore, the data obtained can be difficult to interpret and could misrepresent the nature,

¹⁵ There are different license levels for different aquifer scenarios. The Minimum Construction Requirements for Water Bores in Australia (NUDLC 2020, or the latest version) outlines the license requirements. Ensure the driller is appropriately licensed for the proposed work. Stop and reassess if aquifer conditions are different than initially considered.

extent, and significance of contamination. Appropriate drilling and bore installation methods must be employed when drilling through multiple aquifers or when targeting a lower aquifer.

It is critical that the process of investigation itself does not provide pathways for contaminant migration.

Problems such as suspended sediment in water samples, altered water chemistry and interference with chemical analyses are often caused by poor bore design, poor construction and inadequate bore development. It is not appropriate to rely on purging during bore sampling to augment or substitute for inadequate bore development.

All bores should be developed when they are constructed. Water or air should not be added to a bore during development that is to be used for groundwater monitoring (refer EPA Publication 669). Where a wet drilling technique has been utilised (e.g., water boring, diamond coring), or where water was added to aid the drilling process (e.g., to consolidate a running sand layer) the development should remove at least the same volume of water added or lost during drilling (preferable more than twice the volume to account for mixing effects). Groundwater level measurements and groundwater samples should not be collected immediately after bore development.

The minimum requirements for documenting a monitoring bore network are:

- The unique bore identifier from the licensing authority (and the local identifier) recorded on the bore cap and used in all HA and monitoring reports¹⁶ (e.g., bore numbering should include the "WRK" number from the BCL, not just "MW1")
- Detailed bore logs¹⁷ describing the geology, contamination observations, water intersections and levels, and soil sample intervals
- Bore drilling and construction details¹⁸ for all completed and failed bores (see the example in Appendix B), and
- Surveying of the elevation of the water level measuring point (usually the high point on the inner PVC casing), the ground surface elevation at the bore, and the bore location, by a qualified surveyor. The survey point on the bore casing should be marked and used when assessing depth to groundwater levels.

Bores that are not required or are damaged must be decommissioned in accordance with conditions imposed by the relevant water authority.

¹⁶ It is noted that this may be difficult at the time of installation, and perhaps even during the first sampling round. As such, this requirement should be achieved as soon as practicable during subsequent use of the bore network. Nevertheless, the registered bore identifier (i.e., the WRK number) should be linked the local bore identifier used (e.g., MW1) in the HA report produced.

¹⁷ Refer to AS 1726-2017 Geotechnical Site Investigations for bore logging guidance.

¹⁸ Refer also to EPA Publication 669 Groundwater Sampling Guidelines

Bores retained for ongoing data collection and monitoring must be maintained. Maintenance includes ensuring the area around the bore is kept clear, the bore is clearly identified and bore head works and the bore casing are protected from damage and maintained to ensure the integrity of the surface seal. Surface water must be prevented from ponding around the bore. It may be necessary to periodically clean out the bore or redevelop to remove sediment build-up or encrustation.

Bores on sites with public access must be locked to prevent tampering.

When monitoring bores are no longer required, they must be decommissioned. This removes a potential pathway for pollution of groundwater and prevents bores becoming “orphaned” where the licence holder responsible for their up-keep is not able to be identified.

3.5.2. Hydraulic properties

In all but the most basic HA, it is necessary to obtain data on the hydraulic properties of the aquifer system (e.g., hydraulic conductivity, effective porosity, hydraulic gradient). Knowledge of aquifer hydraulic properties is necessary to estimate groundwater flow velocities, flow volumes, and travel times.

Common techniques for estimating the hydraulic properties of aquifers are usually based on solutions to groundwater flow equations simulating the response of an aquifer to pumping stress. Approaches include multiple-bore pumping tests, single-bore pumping tests, slug tests (rising head, falling head or displacement tests), constant-head tests and tracer testing. The detail and rigour of aquifer testing should increase proportionately with increasing risk of harm (for example, a slug test may be appropriate to obtain estimates of hydraulic conductivity, but a pumping test or tracer test may be required to assess whether a sensitive receptor is at risk). These types of techniques may also need to be used to justify instances where environmental values are not considered to apply (e.g., low aquifer yield).

3.5.3. Monitoring procedure

Monitoring activities usually include groundwater level measurement and sample collection for field and laboratory testing.

A monitoring work plan is required to ensure consistency of measurements, sampling methods, handling and transport between monitoring events, and safety of field personnel undertaking monitoring.

Measurement and sampling should be undertaken in accordance with EPA publication 669, Groundwater sampling guidelines, and IWRG701, Guide to the sampling and analysis of waters, wastewaters, soils and wastes.

Consideration should be given to any special data collection requirements that may apply for the assessment. For example, a water authority may require specific information to be provided in a specific format.

Level measurement

Groundwater level measurements are essential to determine groundwater and contaminant flow directions and rates. The following factors need to be considered when collecting and evaluating water level data:

- Water levels in new bores may take some time (days) to stabilise after bore installation and development
- Water levels need to be measured and reported relative to ground level and to a common datum, preferably Australian Height Datum (AHD)
- Water levels in all bores at a site should be measured on the same day and before purging or sampling occurs at any bore
- More frequent measurement may be required where water levels fluctuate rapidly – for example under the influence of pumping, or tides, or close to an intermittent recharge source
- Special conditions in bores that can affect the accuracy of levels, which include:
 - Presence of light NAPL floating on the water. This requires special care in measuring the water level elevation and NAPL thickness because of density differences
 - Highly saline or hot groundwater may require correction of any measurements for density effects
 - Effervescent water such as in mineral water areas or at landfills may be problematic to monitor. Specialist expertise should be sought in this regard.

Groundwater sampling

Background water quality information is required for every HA. The HA may also include a program targeting specific contaminants and degradation products identified in the HA desk study.

EPA publication 669, *Groundwater sampling guidelines*, should be consulted on issues relating to the design and conduct of the sampling and testing program.

Groundwater samples must represent water quality within the aquifer rather than water that has been standing in the bore casing. Groundwater must be removed and analysed with minimum physical and chemical disturbance, temperature change or exposure to sunlight and the atmosphere.

Regardless of the method chosen to purge a bore prior to sampling, it is recommended that the same sampling method should be used in each bore and each time it is sampled, unless a different method is required for a specific analysis. Where methods are changed, there should be a transition period where both old and new methods are used to ensure implications for data consistency are able to be understood. Furthermore, where sampling methods are depth specific, the depth of sampling should be recorded and replicated for every monitoring event.

All water extracted from a well during purging is “waste” under the EP Act and is required to be disposed of appropriately to a lawful place to protect occupational health and safety risks and prevent pollution of surface water, land, air or groundwater. Particular care must be taken for contaminated sites.

Chemistry determination

The choice of analytes should consider the objectives of the HA and include contaminants likely to be found on site. They should be determined from the site history and may include many contaminants such as metals, total petroleum hydrocarbons (TPH), volatile hydrocarbons and chlorinated organics.

All bores should also have a basic field analysis performed, including electrical conductivity (EC) or total dissolved solids (TDS) content in groundwater (used to indicate its quality), pH, Eh dissolved oxygen and temperature. Other parameters that are useful to characterise groundwater chemistry and quality include major ions (calcium, magnesium, sodium, potassium, chloride, carbonate / bicarbonate and sulphate), and minor or trace ions (such as nitrate) and metals. These parameters should be analysed in the laboratory. All field and laboratory equipment should be appropriately calibrated.

Each group of chemical parameters may require a different sampling or sample preservation technique or require a specific volume of groundwater to be analysed. Sample techniques are discussed in EPA publication 669, while guidance on sample volumes, preservation and storage can be provided by the specific analytical laboratory completing the analysis or also in EPA publication IWRG701, Guide to the sampling and analysis of waters, wastewaters, soils, and wastes.

The choice of laboratory test method and the specified reporting limit should be defined in the project planning stage. Care is required to ensure that reporting limits are sufficiently low to enable interpretation of the results (for example, by comparison with ecosystem protection water quality criteria). Analyses should be undertaken by laboratories that are NATA-certified for the specified analysis.

It may also be necessary to characterise the background concentration of naturally occurring organic hydrocarbon compounds and any potential impact from off-site sources of contamination.

Quality assurance and quality control: QA/QC

The HA relies on good quality data. HA data can be in various forms and can range in quality depending on the data types, source, analysis methods and the expertise of the person collecting and interpreting the data.

In essence, quality assurance (QA) means planning to obtain representative data, whilst quality control (QC) means checking to determine if such data were obtained.

Important considerations for groundwater quality parameter measurement

- Dissolved Oxygen (DO) should be measured in mg/L (not percent) as it is difficult to later convert %DO into mg/L DO and most uses of the information require it to be in mg/L
- Field redox (Eh) should be converted relative to the standard hydrogen electrode (SHE), or the type of electrode used recorded so that conversion can be performed later if required. Converting Eh relative to the SHE enables data to be compared more readily between events, between sites and with literature.

A key part of field QA is the preparation and use of a work plan or quality plan. The work plan should include:

- project scope and planning
- project staff, qualifications and supervisor (reviewer)
- reference to standard operating procedures for key activities
- field record sheet examples
- sample integrity protocol, including chain-of-custody forms
- laboratory (and any other relevant) accreditation, and
- data quality objectives.

QC is a separate and complex process but, at the minimum, would involve collecting field splits that are sent to a second laboratory. Equipment blanks would be required where sampling equipment is reused after decontamination. Further description of QA/QC procedures may be found in the NEPM Schedule B (2) Guideline on Site Characterisation - Appendix C.

The HA report should include sufficient information on QA/QC (including records) to enable an independent review or audit of the validity of all data.

A data validity statement should be prepared by the assessor and included in the HA report.

3.5.4. Data management

All data, including original field record sheets (or outputs from electronic record collection), should be retained for subsequent checking and review. For small projects, storing electronic data in a spreadsheet may be sufficient. However, once ongoing monitoring occurs, it may be preferable that the data is stored in a relational database, ideally linked with a geographic information system (GIS) to allow rapid data retrieval, analysis and display.

Copies of original bore installation reports and site plans showing bore locations and surveyor's reports should be incorporated in the database or integrated into a single document or folder that is updated as field investigations continue.

It is essential that the data is owned by the client/site owner (or supplied to the client/site owner in a readily editable electronic format), so that the complete temporal data set is readily accessible and usable, regardless of the consultant engaged at any time.

Data is best able to be used when it can be related to data from other sources. As such, it is helpful to record as much "meta data" (e.g., location, bore construction details, depths, aquifers monitored (the Victorian Aquifer Framework (VAF), etc.) as possible. This will enable the data to be useful if required for other project / assessments. Other regulators may have specific requirements for data provided to them (e.g., data for input to DELWP's Water Measurement Information System (WMIS)).

3.6. Environmental values

Different environmental values apply to different groundwater segments. The ERS defines groundwater segments and environmental values based on the background level of total dissolved solids (TDS).

The HA needs to consider the environmental values based on the groundwater segment (TDS) for groundwater below the site and its surrounds. Given that groundwater often discharges to surface water, the environmental values of surface water (e.g., those listed in Table 5.5 of ERS) at or near the site may also need to be considered. The collective environmental values of all waters are described in Table 5.1 of the ERS.

It is not always easy to identify the background TDS level. Care should be taken to ensure the TDS (whether adopted from measurements or literature) is representative of the natural background levels (e.g., TDS could be influenced by an anthropogenic source, such as a leaky water pipe). Where there is limited information about background TDS, a conservative approach must be adopted (for example, taking the lowest TDS level identified through a desktop study or from initial site assessment). Conversely, an appropriate statistical method (e.g., adopting an average, median or percentile threshold) may be used to determine the TDS level where sufficient information is available to support such a method. Whatever method is chosen, the conclusion needs to be scientifically robust and justified.

The environmental values are benchmarks against which risks of harm to human health and the environment must be measured and all applicable environmental values (as determined by the segment) must be considered during risk assessment phases. In accordance with ERS, the only circumstances where an environmental value may not apply to groundwater are where:

- there is insufficient aquifer yield to sustain the environmental value
- the application of that groundwater, such as for irrigation, may be a risk to the environmental values of land or the broader environment due to the soil properties, or
- the background water quality level exceeds (or is less than, in the case of indicators such as pH, dissolved oxygen and many biological indicators) the relevant objective specified in ERS Table 5.4 and as a result the environmental value cannot be achieved.

Environmental values of groundwater

- Water dependent ecosystems and species
- Potable water supply (desirable)
- Potable water supply (acceptable)
- Potable mineral water supply
- Agriculture and irrigation (irrigation)
- Agriculture and irrigation (stock watering)
- Industrial and commercial
- Water-based recreation (primary contact recreation)
- Traditional Owner cultural values
- Buildings and structures
- Geothermal properties

Refer also to Table 5.3 of the ERS

In each of these cases, the HA will need to provide appropriate spatial and temporal data to support the assessment. EPA Publication 1992¹⁹ provides guidance on further information that EPA expects to be considered when justifying that an environmental value does not apply.

While not specifically documented in the ERS, the groundwater environmental value may also not apply when groundwater does not meet with the definition of the environmental value - i.e., when groundwater is not mineral water as defined in ERS (and the site is not within a known or mapped mineral water area), or where groundwater temperature is not within the range defined by the ERS (30 to 70°C).

Further discussion on how environmental values can be incorporated into the risk assessment is provided in Section 3.8.1.

The HA should demonstrate that the environmental values are not, or will not, be threatened due to site activities (to be measured, determined, or assessed against specific indicators and objectors for groundwater listed in Table 5.4 of the ERS 2021) and that any risks of harm are minimised so far as reasonably practicable. If there have been regional impacts on the aquifer from off-site activities, these should also be considered in the HA, along with any other site-specific and geological or aquifer specific issues.

The ERS discusses the purpose and intent of each environmental value and provides environmental objectives and indicators used to measure the risk of harm against each environmental value. Additional guidance for specific environmental values is provided in the following sections.

3.6.1. Water dependent ecosystems and species

For water dependent ecosystems and species, consideration includes the point at which groundwater interacts with the surface waters or the ecosystems that are dependent on groundwater. This aims to ensure that groundwater quality does not adversely affect natural ecosystems that require access to groundwater to meet all or some of their water requirements

Aquifer Yield

Assessment of aquifer yield can be subjective. For example, a yield of 0.01 L/sec seems very low, but if the desired use only needs 100 L per day 0.01 L/sec yield will provide over 800 L per day so is more than adequate.

Care needs to be taken that the indication of insufficient yield is not due to variations in the aquifer being monitored and that it is not a temporary effect or a problem that could be overcome through engineering or better well construction or development.

It may be inappropriate to conclude that there is insufficient yield if groundwater is being extracted on a neighbouring property

As indicated in Publication 1992 Guidance to the Environment Reference Standard, "*insufficient aquifer yield can be considered as any porous media with a hydraulic conductivity less than 0.0001 m/day*".

¹⁹ EPA Publication 1992, Guide to the Environment Reference Standard, Section 7.2.2 a)

on a permanent or intermittent basis to maintain their communities of organisms, ecological processes, or ecosystem services.

There is state-wide mapping of groundwater dependent aquatic, riparian and terrestrial ecosystems that should be considered as part of the HA. It should be noted that although there is nation-wide mapping of subterranean groundwater dependent ecosystems, information for subterranean GDEs in Victoria had not been collated for the nation-wide mapping exercise at the time of this publication.

The ERS indicates that this environmental value also applies to subterranean waters with a hydrogeological setting conducive to the presence of troglofaunal and stygofauna. Stygofauna are any fauna that live in groundwater systems or aquifers, such as caves, fissures, and small cavities. Troglofauna are small cave-dwelling animals associated with caves and spaces above the water table. Hydrogeological settings conducive to the presence of these organisms includes aquifers with geologies that have abundant small spaces, or pore or void space greater than a millimetre which would allow organisms to move freely. Alluvial, karst and fractured rock aquifers are considered the most inhabitable subsurface groundwater ecosystems for stygofauna (Bold et.al., 2020).

Assessing if troglofauna and stygofauna are present within from these environments is challenging (much more difficult than assessing large cave systems or digging in streambeds) and as such the documentation of their biodiversity has lagged behind the general study of subterranean fauna (Clark et.al., 2021). The absence of data should not be interpreted as the absence of subterranean GDEs in Victoria.

Although not specifically outlined in ERS, the adoption of background levels as the primary objective enables risks of harm to groundwater itself to be assessed (e.g., rather than only considering risk to groundwater on the basis that it discharges to surface water or reaches a receptor).

3.6.2. Potable water supply

The presence of a reticulated water supply does not mean groundwater would not be used for potable water supply or that this environmental value does not apply. Clause 16 of the ERS outlines situations when this EV may not be applicable based on background levels.

There remain significant areas in Victoria that rely on groundwater for potable water and there are also unexpected pockets near towns that are not connected to reticulated water. The effects of climate change may also result in an increasing reliance on groundwater. Historically, groundwater bores installed for domestic water supply did not need to be registered and as such, may not appear on public records.

3.6.3. Potable mineral water supply

The ERS defines potable mineral water as “groundwater that is safe to drink and in its natural state contains carbon dioxide and other soluble matter in sufficient concentration to cause effervescence.”

The potable mineral water environmental value may be considered as not applicable in circumstances where groundwater below the site and in the vicinity of the site (for example,

within a 2 km radius) is not mineral water as defined. While published maps of mineral water occurrence can be included as a line of evidence that could be adopted to support this, it should not be assumed that all mineral water resources in Victoria are mapped. In circumstances where groundwater is not mineral water as defined, but the site is within a mapped mineral water area, it would be appropriate to consider the environmental value as being applicable.

3.6.4. Agriculture and irrigation (irrigation)

Use of groundwater for irrigation could include farm scale watering of crops, recreational parkland or sports fields, residential scale watering of grass, vegetable gardens or fruit trees and anything in between. The growing popularity of container and pot-based gardening (i.e., gardening that is not in the ground) means that this use could be likely in even highly urbanised areas.

Table 5.4 of ERS suggests that the Australian and New Zealand guidelines (ANZG) for fresh and marine water quality is the primary resource for objectives, but consideration should also be given to the objectives outlined in Table 4.3 for the environmental value production of food, flora and fibre.

3.6.5. Agriculture and irrigation (stock watering)

The TDS of groundwater can be used to further define the sort of stock that groundwater may be able to support. For example, ANZG suggests that groundwater with a TDS above 3,000 mg/L is unsuitable to support chickens whereas sheep can cope with water with a TDS of up to 10,000 mg/L. This can aid in assessing the likely risk of harm against this environmental value.

It may be reasonable to refer to land zoning restrictions, such as prohibitions on keeping stock, to conclude that the risks of harm against this environmental value are unlikely. It may be reasonable to conclude that highly urbanised areas with elevated TDS are unlikely to keep stock simply due to small land area, but semi-urbanised and rural areas may have small flocks / herds to maintain grounds or as pets.

Example: A site assessment of an urban area identified that background groundwater TDS was 2,500 mg/L and therefore suitable to support a wide range of stock. A review of the local planning laws indicated that stock were allowed to be kept depending on the size of the lot, and that the minimum land size for which a permit to carry animals (other than dogs and cats) was 500 m². The area of the land was 840 m² and surrounding lot sizes were all less than 1,200 m². Under the local planning rules, this would only allow five poultry or fowl. Consideration of risk of harm against this environmental value therefore adopted objectives related to the watering of poultry and fowls.

3.6.6. Industrial and commercial

Water is used in many industrial and commercial processes, and groundwater can be a cost-effective source of such water. Any industrial or commercial process that uses water in some way, could source that water from groundwater. The industrial use of groundwater in Victoria is generally restricted to process (washing) waters, cooling or heating, and dust suppression. Groundwater is used by several factories for general washing purposes as well as to wash equipment and production areas at some dairies and abattoirs. On farms, some washing of

vegetables utilises groundwater. Large facilities in Anglesea, Portland, and in the Latrobe Valley use groundwater in industrial cooling towers. Geothermal groundwater is used to heat shire offices and recreational centres across the State. In addition, extremely saline (greater than seawater concentration) groundwater in the north of the State is pumped to the surface and evaporated to produce table salt for human consumption. Typically, however, the range of industrial and commercial uses of groundwater decreases sharply as TDS increases.

Some industrial and commercial uses of groundwater also need to be considered under other environmental values (for example bottling of groundwater for potable use, or extraction of geothermal groundwater for spas, etc.).

It may be reasonable under some circumstances to conclude that the risks of harm against this environmental value are unlikely where land zoning would not allow a commercial or industrial activity, however, care would need to be taken to ensure that small scale commercial activities (dog washing for example) are not unintentionally overlooked.

The water quality required for industrial and commercial uses can be highly variable, and it is unlikely to be feasible to develop criteria relevant to all industrial or commercial uses. In addition, the groundwater will likely have other environmental values which require a more conservative assessment and as such will drive management requirements.

Example: A proposed site activity had the potential to introduce metal contamination into groundwater. A review of the site setting indicated that industrial or commercial use of groundwater was possible but limited to small scale commercial purposes. Due to the groundwater TDS, potable commercial uses were considered unlikely. Due to the non-volatile nature of the contaminant, the most sensitive exposure pathway was primary contact. To assess risks of harm against this environmental value, it was considered reasonable to adopt conservative objectives based on primary contact exposure.

3.6.7. Water-based recreation (primary contact recreation)

As defined in the ERS, this environmental value considers water quality that is suitable for primary contact recreation (swimming, diving, water skiing, caving and spas), secondary contact recreation (boating and fishing) and for aesthetic enjoyment).

Groundwater may discharge to a local water body that could be used for water-based recreation. In rural areas, local water bodies are likely to be unofficial swimming holes for children. Equally, groundwater may be extracted to fill a swimming pool²⁰ or a temporary wading pool, or even a dam used for recreational fishing or boating. It is feasible that groundwater may be used to run a sprinkler, in which children may play during summer.

Similarly to other extractive water uses, the presence of a reticulated water supply should not be assumed to discount this environmental value. The use of groundwater to supplement reticulated water supplies for these types of uses is relatively common.

²⁰ During the millennial drought, some swimming pool retailers included a "first fill" using groundwater to help new pool owners who otherwise would not have been able to fill their new pool under prevailing water restrictions.

3.6.8. Traditional Owner cultural values

For Traditional Owners, Country is embedded with culture, stories, songlines including ceremonial places and sites of significance. These 'cultural values' that are embedded in Country, connect everything and everyone. There are no distinctions between water, land, and air.

Assessing risks of harm against this environmental value requires careful consideration of the interconnections of water, land and air – for example, not just considering the direct effect on a target species, but the effects on the environment, food sources and predatory species connected to that target species. Developing a conceptual model which outlines and visualises these interconnections can be a useful tool in building an understanding of the cultural landscape.

Even in highly disturbed areas, culture, stories and songlines will remain. Efforts to minimise risk of harm and ensure activities don't maintain existing contamination in such areas can contribute to the healing of Country.

To give effect to the recognition of Traditional Owner cultural values in the ERS, assessment of Traditional Owner cultural values of groundwater should consider relevant state programs, strategies, or national guidance to inform objectives. Reference sources include the Victorian Aboriginal cultural heritage registers and information system (ACHRIS)²¹, the Cultural Water Strategy²², Water is Life²³, Aboriginal Waterway Assessments²⁴ and the Victorian Waterway Management Strategy. The Aboriginal Heritage Regulations 2018 (Part 2, Division 3) also outlines areas of cultural heritage sensitivity (which include old waterways, ancient lakes and identifiable geological areas and formations). Advice may also be sought from First Peoples - State Relations on specific engagement with Registered Aboriginal Parties (RAPs) and/ or other Traditional Owner groups (including referencing their Country Plans), from Catchment Management Authorities and / or from DELWP.

In addition to this, consideration of the advice in the ANZG chapter on Cultural and Spiritual Values may assist in measuring risk of harm against this environmental value. As indicated in ANZG, cultural values for any element of the environment cannot be ascertained in the absence of engagement and consultation with Traditional Owners.

²¹ Further information, including an online map of recognised Traditional Owner boundaries and mapped areas of cultural heritage sensitivity can be found on the Aboriginal cultural heritage register and information system (<https://achris.vic.gov.au>)

²² O'Donnell E, Godden L and O'Bryan K, (2021), *Cultural Water for Cultural Economies*, Final report of the Accessing water to meet Aboriginal economic development needs Project. Published by University of Melbourne, 2021.

²³ DELWP (2022), Water is Life – Traditional Owner access to water roadmap, Draft for consultation, State of Victoria Department of Environment, Land, Water and Planning, 2022.

²⁴ Available through the DELWP hosted Aboriginal water program website (<https://www.water.vic.gov.au/aboriginal-values/the-aboriginal-water-program>)

It is acknowledged that engagement with the RAP or other Traditional Owner group is an evolving process. However, it is important to consider that any activities undertaken may be on a landscape that has a story and Aboriginal history. As a minimum, assessments should identify whether there are issues, areas or sites of relevance and concern to Traditional Owners and a process to ensure appropriate engagement is undertaken to form indicators and objectives to minimise the risks of harm with respect to this environmental value. The existence of a Cultural Heritage Management Plan, or that the site in question is identified on ACHRIS as being on or near an area of cultural sensitivity or waterway will be indicative that there are matters of cultural concern. However, the primary source of information is the relevant RAPs or other Traditional Owner groups.

It is not appropriate to simply consider Traditional Owner cultural values using the other environmental values as a proxy. ANZG (<https://www.waterquality.gov.au/anz-guidelines/guideline-values/derive/cultural-values>) outlines a process to determine whether the existing water quality guidelines can support assessment of risks of harm with respect to this environmental value but emphasises that the process does not replace the need to consult with Traditional Owners.

3.6.9. Buildings and structures

The ERS indicates that the objective for this environmental value is that groundwater is not corrosive to or otherwise adversely affecting structures or buildings. This is often measured using the Australian Standard AS 2159, 2009: Piling-Design and Installation. While the purpose of criteria in that standard is to inform choices for the construction materials to be used, it does provide a useful benchmark for assessing risk of harm.

When measuring risks of harm against this environmental value, consideration may also be given to other conditions that may adversely affect the integrity of structures, for example, conditions that may lead to chemical permeation into services such as drinking supply lines or migration along utility lines (especially through slab penetrations).

3.6.10. Geothermal properties

The addition of Geothermal properties as an environmental value provides a benchmark against which risk of harm to this use could be measured. This environmental value applies to groundwater with a temperature that is between 30 and 70°C. The environmental objective and indicator to measure whether Geothermal properties are threatened should be considered as follows: the groundwater temperature should not be changed such that it is detrimental to existing and/or future geothermal groundwater uses (and should consider physical and chemical changes that may be induced by any temperature change). This guidance should be read in conjunction with other relevant guidance, such as the *Geothermal Groundwater Licensing Guidelines* (DELWP, 2020).

Example: A groundwater geothermal scheme proposed to extract groundwater from an aquifer with groundwater at 55°C. After use, the groundwater was to be re-injected into the aquifer at a temperature of 25°C and was modelled to result in a cool water plume (at a temperature below 30°C) extending off-site, which had the potential to impact upon another geothermal user. When considering the risk of harm posed by this activity against the geothermal properties environmental value, it was clear that re-injecting groundwater at a reduced temperature posed

a threat to the environmental value (the temperature may become below the lower limit of the range defined in the geothermal properties environmental value). The geothermal scheme was redesigned so that waste heat could be captured and applied to the used groundwater to reheat it to 40°C prior to reinjection. While a plume of cooled groundwater would still result (40°C compared to the natural 55°C), the environmental value of geothermal properties was maintained, and the reduction in heat would not impact upon other nearby geothermal users. It was considered that the risk of harm was minimised.

3.7. Groundwater modelling

The HA may require groundwater modelling to demonstrate or predict an outcome, to support a conclusion on the likelihood of pollution reaching groundwater or future extent of contamination in groundwater, or to test plausibility of various CHMs. Groundwater models can also be useful to:

- assess the impacts of dewatering, pumping or injection schemes
- design a groundwater monitoring network
- design, evaluate, and optimise a proposed remediation scheme
- estimate the possible fate and migration of contaminants.

Groundwater modelling is a specialised field and should only be undertaken by specialist practitioners who are themselves, or as a minimum advised by, experienced hydrogeologists to select the most appropriate modelling approach for the groundwater problem at hand. This guideline does not describe how to undertake modelling but provides an overview of groundwater modelling and considerations for the reporting of any modelling undertaken.

Detailed explanation of the numerous types of computer programs available for flow and transport problems is also beyond the scope of this guideline. The Australian Groundwater Modelling Guidelines (Barnett et. al. 2012) is a handy reference, noting that it has a focus on regional flow models for groundwater resource management rather than site-scale models more relevant to contaminated sites. There are numerous resources that can be referenced for solute transport modelling (e.g., Batu 2006, Konikow, 2010, etc.).

There are many options for modelling and not all involve complex computer software. For example, BioScreenAT is an Excel based solute transport program. It is a deterministic, lumped parameter model and is based on analytical solutions. On the other hand, MODFLOW is a computer program for numerical modelling of groundwater flow. It can be run in both deterministic and stochastic mode and can include distributed parameters. It is often used on conjunction with MT3D to model solute transport.

Groundwater flow models are used to estimate groundwater levels, flow rates and flow paths. Solute transport models are used to estimate the movement and concentration of contaminants dissolved in groundwater. Groundwater dewatering models are used to estimate the volumes of water to be extracted to achieve desired dewatering outcomes and the drawdown impacts that are expected to accompany the dewatering operation.

Significant care should be taken to ensure that the model chosen is fit for purpose and of an appropriate standard to inform the decisions it needs to inform (e.g., Barnett et. al. 2012 outlines difference classes of model what was information is needed to achieve that class).

Analytical and numerical models must be based on a reliable conceptual hydrogeological model. Relevant guidance (e.g., Barnett et al, 2012) should be adopted as a point of reference for preferred practice groundwater modelling. The concepts of building and calibrating a robust models presented in Barnett et. al 2012) are applicable to all models.

Groundwater model terminology

Numerical – uses a mathematical approximation to the complex equations describing groundwater flow and solute transport to estimate groundwater levels and solute concentrations at a two- or three-dimensional grid of points throughout the area of interest.

Analytical – uses one or more mathematical functions (which describe changes in groundwater conditions) that are combined to obtain estimates at the point of interest (or receptor).

Probabilistic (or stochastic) - uses inputs that vary in accordance with a probability distribution to take into account the impact of random events or actions in predicting the potential occurrence of future outcomes

Deterministic - uses input parameters that are fixed, with no random variation in predicting the potential occurrence of future outcomes

Lumped Parameter - assumes that the whole aquifer is homogeneous - uses the same hydrogeological parameters with no spatial variation

Distributed parameter- can account for heterogeneity and can have different hydrogeological parameters allocated to portions of the acquire being modelled.

It is critically important that the model developed is underpinned by the conceptual hydrogeological model that focusses on the physical hydrogeology of the site, and environments and background chemistry of groundwater.

In many cases, the basic data available and the scale of decisions addressed in an HA do not warrant the use of complex numerical models, and simpler analytical models may be the most efficient, appropriate and economical approach to test scenarios.

When a numerical model is developed to assess contaminant migration or remediation scenarios, additional field or laboratory data on key hydraulic parameters that influence the rate of groundwater movement are usually required. Aquifer and solute properties, which affect contaminant advection, sorption, and other attenuation factors, may also need to be understood for the modelling to achieve required objectives.

Modelling results can be visually impressive when printed out or plotted as smooth curves and contours in full colour with animation. However, model results can also be misleading. The accuracy of the resulting model is no better than the accuracy of the data that went into the model, the appropriateness of the model design and the accuracy of the conceptual hydrogeological model.

Model results must not be solely relied on to predict contaminant distribution, remedial pumping rates, travel times, or capture of contaminant plumes. Model predictions must be viewed as estimates, dependent on the quality and uncertainty of the input data. Where models are used as predictive tools, field monitoring must be incorporated to verify model predictions and to trigger re-modelling where required.

The model, whether analytical or numerical, should be described in sufficient detail that a reviewer can determine the appropriateness of the model for the site or problem that is simulated. All model inputs need to be justified with assumptions outlined and discussed. There needs to be sufficient factual material to provide adequate 'weight of evidence' to support interpretations and conclusions. Model results should be reported with clear uncertainty analysis and error bands, and details of the sensitivity of the model to changes in key variables. The model report should provide sufficient information for another modeller or reviewer to develop the same model and generate the same output. This requires that all aspects of the model development and simulation runs be fully documented.

The requirement for independent review of the model should be considered at the outset. Not all models need to be reviewed, but it is good practice to include milestone review steps in all groundwater modelling processes (even if the reviewer is "in house"). Third party or independent review would be recommended instances where the model is used to inform regulatory decision making (including environmental effects statements), where environmental effects or risks of harm could be significant and where the hydrogeology is complex.

3.8. Risk assessment

Risk assessment can be performed at many levels and will depend on the objectives of the HA. The assessment of risk can involve a qualitative analysis of the potential for undesirable effects caused by groundwater contamination or may be a more rigorous quantitative process involving detailed analysis of the transport and fate of contaminants, interaction with receptor organisms, toxicity of chemicals of concern, exposure assessment and a detailed characterisation of the significance of the risk of harm to human health and/or the environment.

In most scenarios, it may be appropriate to start with a qualitative risk assessment, and then expand to a quantitative risk assessment if further work is required to better define the risks or where doubt remains.

Where risks need to be measured against the environmental value of water dependent ecosystems and species maintenance, and contamination has been identified, it may be necessary to undertake more detailed assessment of the potential impact on the ecosystem.

A quantitative risk assessment may be required where an environmental value includes a sensitive use, such as for potable supply, and there is evidence of groundwater contamination. A multidisciplinary approach is required for quantitative risk assessment or ecological risk assessment, and discussion of such assessments is beyond the scope of this guideline. Schedule B4 and B5a of NEPM provides useful guidance on performing risk assessments and the contents of risk assessment reports. The risk assessment should provide sufficient information for another risk assessor or reviewer to perform the same assessment and generate the same output. This requires that all aspects of the risk assessment and simulation runs be fully documented.

A groundwater impact (qualitative risk) assessment generally uses a 'source–pathway–receptor' model²⁵ (or CSM) and involves multiple lines of evidence and components such as the following:

- assessing the pollution source and nature (solubility, partitioning, toxicity and so on) of the chemicals of concern
- identifying existing and potential uses of groundwater and the 'receptors' that may be affected
- estimating likely groundwater flow paths and rates, and potential exposure of the receptors to the contaminants
- assessing the likely impact on water quality and environmental values of the groundwater by reference to water quality criteria
- evaluating the volatilisation pathway for organic contaminants to impact on human health, or
- obtaining evidence of natural source zone depletion and attenuation of contaminants, plume stability and reductions in contaminant mobility (including for example reductions in NAPL transmissivity).

3.8.1. Assessing risk against environmental values

In assessing whether risks of harm are minimised, the HA may discuss the uses, attributes or functions represented by the environmental values of groundwater in terms of being existing or likely / unlikely to be realised in the future.

Uses, attributes or functions of groundwater may be considered:

- 'Existing' where an existing receptor (e.g., bore, spring, creek) or use is, or could plausibly be, impacted by the activity, pollution or contamination under existing or reasonably foreseeable conditions (including altered groundwater flow resulting from groundwater abstraction, injection or other means)

²⁵ Refer to NEPM Schedule B4, Section 2.3.3 for examples of source-receptor-pathway models.

- ‘Likely’ to be realised in circumstances including:
 - (i) use of groundwater in the same hydrogeological setting nearby or elsewhere in Victoria, and
 - (ii) where the existing and likely future land uses both at the site and in the vicinity of the site are compatible with the environmental values of groundwater.

In determining whether a use, attribute or function is ‘existing’ or ‘likely’, consideration should be given to both registered and unregistered bores. Where a bore is installed and registered for a use, that use must be considered as existing unless there is evidence to the contrary. Bores registered for drought relief are considered to represent an existing use, even if they are not in use at the time of the assessment.

Where a bore is registered for stock and domestic use, it may be used for purposes that include human consumption (e.g., through drinking or food preparation). This may include circumstances where the TDS would otherwise indicate potable water use is unlikely (it is also possible that the bore is located within a pocket of fresher groundwater). As such, the use of stock and domestic bores should be assumed to include potable water consumption, unless there is evidence to the contrary. Where the bore use is recorded as “unknown” or groundwater depth is less than 3 m (bores less than 3 m deep are exempt from licensing under the Water Act 1989), all relevant extractive uses (based on TDS) should be considered as existing unless there is evidence to the contrary.

4. Hydrogeological assessment reports

This section presents guidance on documentation and data presentation for reporting consistency and to enable efficient report and data review. The HA should be tailored to the aim and objections and consideration should be given to the needs of third-party reviewers (e.g., environmental auditors, planners, EPA etc.). The analysis and interpretation of hydrogeological data is the most critical step in any HA.

Some questions that the HA report might seek to answer are as follows (as appropriate to the site):

- Hydrogeological setting
 - What are the groundwater flow directions, flow paths, and flow rates in the aquifer(s) and aquitard(s)?
 - What are the regional and local groundwater flow systems relevant to the site, and recharge and discharge areas?
 - What and where are the interactions between groundwater and the surface?
 - To what extent are different aquifers interconnected and what is the role of low-hydraulic conductivity zones?
- Groundwater quality
 - What is the ‘background’ groundwater quality?
 - What is the ambient or regional groundwater quality?
- Pollution and contamination
 - What are sources of groundwater pollution and / or contamination, what are the pathways of contaminant migration and what are the receptors of contamination?
 - What is the vertical and lateral extent of the contaminated groundwater and how is this defined?

- How do the levels of contamination compare to environmental quality indicators and objectives (refer ERS)?
- Are emerging contaminants present or potentially present?
- Are LNAPL or DNAPL contaminants present in dissolved, residual, sorbed or separate phases?
- Are volatile contaminants present that could pose a potential vapour intrusion risk either on-site or off-site under current or future land uses including presence of future basements?
- What are the spatial and temporal trends in contaminant concentrations?
- Which aquifers and aquitards are affected by contamination?
- Do contaminants exhibit evidence of natural attenuation in the aquifer and, if so, over what time frames?
- Risk Assessment
 - Are environmental values threatened by an existing or proposed activity or contamination?
 - How likely are environmental values to be realised?
 - What and where are the receptors of the contaminated groundwater and when are these receptors likely to be affected?
 - Is the current and future risk of impact on receptors low?
- Conclusions
 - Has the current HA assessed all the site issues or is more work required?
 - What are the assumptions, uncertainties and limitations of the data utilised and what are the implications for the conclusions?

4.1. Content

The suggested content of an HA report is:

- Summary
- Introduction
- Site overview
- Methods and results
- Conceptual hydrogeological model
- Hydrogeological risk assessment
- Conclusions and recommendations
- References and appendices.

HA data interpretation requires the collation, presentation and quality review of geological information, groundwater level measurements and groundwater chemistry data.

The extent and means of data analysis for the HA report varies depending on the site hydrogeology and the potential risk posed by the activity or potential contamination.

The data analysis methods that may be included in a report include potentiometric surface and water table maps; hydrogeological cross-sections; groundwater hydrographs; calculation of groundwater flow rates; geochemical stability modelling; Piper plots, Stiff diagrams, and other data visualisations to analyse groundwater geochemistry; contaminant distribution maps;

contaminant trend analysis (graphs etc.); mass balance calculations; degradation pathways and rates; contaminant retardation calculations; natural attenuation capacity calculations; natural source zone degradation estimates; and contaminant plume transport estimates by analytical and numerical models.

If numerical or analytical groundwater flow or solute transport modelling is undertaken, it should be reported in sufficient detail that a reviewer can determine the appropriateness of the model for the site or problem that is simulated. In addition, the model report, together with model journal, should provide sufficient information for another modeller or reviewer to develop the same model and generate the same output. The model parameters and assumptions should be transparent and reproducible.

Throughout the assessment, the validity of the conceptual hydrogeological model that has been developed to that point should be questioned. In the case where further investigations are required or more data is collected, the CHM (and any CSM that is derived from it) must be revisited to determine how the understanding of the hydrogeology, groundwater contamination, and risk associated with the site has evolved.

Appendix A outlines the minimum requirements for HA report content.

5. References

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6. Further information

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Southern Rural Water Groundwater Atlas. (<http://www.srw.com.au/water-systems/other-water-sources/groundwater/>)

Victoria Unearthed. (<https://mapshare.vic.gov.au/victoriaunearthed/>)

Visualising Victoria's Groundwater. (vvg.org.au)

Contact EPA

epa.vic.gov.au

Ph 1300 372 842 (1300 EPA VIC)

Head office:

200 Victoria Street
Carlton 3053

West Metro

Level 2, 12 Clarke Street
Sunshine 3020

South West

West 1, 33 Mackey Street
North Geelong 3215

Southern Metro

Level 3, 14 Mason Street
Dandenong 3175

North East

27–29 Faithfull Street
Wangaratta 3677

Gippsland

8-12 Seymour St
Traralgon 3844

North Metro

Building One,
13a Albert Street
Preston 3072

North West

Level 1, 47–51 Queen Street
Bendigo 3550

Appendix A: Hydrogeological assessment report content

This also provides cross references to the sections of the guideline where the subject is discussed.

Section	Text Content	Supporting Information	Section discussed
Summary	Concise description of purpose, activities, findings.		
Introduction			
<ul style="list-style-type: none"> □ Purpose / objective □ Background □ Scope 	<p>The purpose of the HA and the parties with an interest in the HA.</p> <p>Further information on the background to the HA and its relationship to other studies may be necessary.</p>	<p>Locality plan.</p> <p>Site plan.</p>	Section 3.1, 3.2, 3.3
	<p>The scope of the assessment and whether it is based on a desktop study, includes information from a site inspection or from more detailed field investigations and laboratory testing.</p>	<p>Table that lists sequence of events / activities and resources used.</p> <p>Appendix – work plan (for complex sites).</p>	
Site Overview			
<ul style="list-style-type: none"> □ Description □ Setting □ History □ Previous Studies □ Summary 	<p>A brief description of the site locality and features, the geographic setting in terms of climate, topography, surface water drainage, vegetation and land use (this is elaborated upon in discussion of conceptual hydrogeological model).</p>	<p>Plans showing setting and relevant features.</p>	Section 3.3
	<p>Details on the history of the site and surrounds, existing or proposed activities at</p>	<p>Plan and/or aerial photographs showing relevant historical features.</p>	

Section	Text Content	Supporting Information	Section discussed
	<p>the site, and potential contaminants of concern relevant to the HA.</p> <p>Identify any previous studies, investigations, remediation activities, etc. of groundwater or soil contamination relevant to the HA.</p> <p>A clear summary statement of the potential for site activities to pollute groundwater or presence of groundwater contamination.</p>	<p>Plan showing existing or proposed activities areas.</p> <p>Table that lists historical sequence of previous investigation events/activities at the site.</p> <p>Section(s) that discuss all relevant historical findings or present historical results.</p>	
Methods and results			
<ul style="list-style-type: none"> □ Desktop study <ul style="list-style-type: none"> ➤ Data sources ➤ Data quality ➤ Data summary 	<p><u>HA desktop study</u></p> <p>Scope of desktop study, information sources and data sets discovered in the desktop study; comment on data quality, relevance and reliability, discuss implications of any data quality issues / data gaps, and present a data summary.</p>	<p>Summary of desktop study data, including statistical analysis.</p> <p>Appendix – spreadsheets, data from State groundwater databases, climatic data.</p>	Sections 3.3
<ul style="list-style-type: none"> □ Field study <ul style="list-style-type: none"> ➤ Scope ➤ Methods ➤ Results 	<p><u>HA field study</u></p> <p>Scope of field investigation work, methods used (drilling, geophysical, water sampling, water level measurement, hydraulic testing etc.) and any field results (factual) or observations.</p> <p>Bore construction details (summary table).</p>	<p>Plan showing bore locations.</p> <p>Tabulation (detailed) of bore construction and survey data, tabulation of water level data.</p> <p>Appendices – Bore logs, geophysical logs, pumping test data and analysis, water sampling field records, bore construction licence, elevation and location survey, equipment calibration detail.</p>	Sections 3.4 and 3.5,

Section	Text Content	Supporting Information	Section discussed
<ul style="list-style-type: none"> □ Data gap and uncertainty assessment 	<p>Laboratory testing of water samples, test methods and detection limits. Collation of results.</p>	<p>Tabulated water quality results including field parameters. Laboratory test reports NATA-certified.</p>	<p>Section 3.5</p>
	<p>The means used to ensure quality assurance and quality control, and a commentary on data validity.</p>	<p>Appendix – work plan, tabulation of QC data, data validation report.</p>	<p>Section 3.5</p>
	<p>Outline data gaps, assumptions, uncertainty and variability. Discuss the implications of data limitations and assumptions of the conclusions formed through the HA.</p>	<p>Tabulated data gaps. Uncertainty assessment.</p>	<p>Section 3.2.1</p>
<p>Conceptual Hydrogeological Model</p>			
<ul style="list-style-type: none"> □ Setting □ Geology/aquifers □ Groundwater flow systems □ Groundwater chemistry 	<p>Local setting in terms of topography, surface water drainage, the position of the locality in the landscape, land use and vegetation. Climatic averages to identify potential recharge periods.</p>	<p>Topographic plan. Tabulation of monthly rainfall and pan evaporation data. Stream stage/flow hydrographs.</p>	<p>Section 3.2</p>

Section	Text Content	Supporting Information	Section discussed
<ul style="list-style-type: none"> ❑ Environmental values ❑ Groundwater resource utilisation ❑ Summary 	<p>The geology and relationships between aquifers at the regional and local scale.</p> <p>Comment on whether aquifers are confined or unconfined.</p> <p>Comment on the protection potentially offered to aquifers by the soil profile, unsaturated zone and aquitards; or conversely the opportunity for downward seepage through soil fissures, permeable soil etc.</p>	<p>Geological map.</p> <p>Tabulated geological column showing main aquifers, aquitards and properties (hydraulic conductivity, transmissivity, storativity, aquifer thickness, effective porosity, etc.).</p> <p>Hydrogeological cross-sections showing the levels of surface facilities, geology, aquifer/aquitard units, subsurface structures (e.g., trench, utilities, etc.), intervals (depths) monitored in bores and water level.</p>	<p>Sections 2.4 and 3.4.1</p>
	<p>The groundwater flow systems through the distribution of groundwater potentials, water table depth and morphology, directions and rates of groundwater flow, and seasonal fluctuations. Comment on vertical gradients.</p> <p>Describe any interpreted/inferred recharge, discharge and interactions between surface water and groundwater.</p>	<p>Figures showing the water table and/or potentiometric levels and principal flow lines (map view and cross-section).</p> <p>Tabulations and hydrographs of groundwater level data.</p>	<p>Sections 2.4, 3.2 and 3.4.4</p>
	<p>Describe the natural water, groundwater chemistry/quality and relate to the interpreted geology and flow systems. Include a discussion on TDS and major ion chemistry, as a minimum.</p>	<p>Summary table of water chemistry data/statistics or ratios.</p> <p>Contour and other plots of water chemistry data (Stiff diagrams, Schoeller plots, Piper diagrams etc.).</p>	<p>Sections 3.5, 3.6</p>
	<p>Identify the groundwater segment based on TDS concentration and list the environmental values of the groundwater by reference to ERS.</p>	<p>Tabulate the environmental values identified.</p>	<p>Section 3.6</p>

Section	Text Content	Supporting Information	Section discussed
	<p>Discuss the development and utilisation of the groundwater resource and its potential for future development and use.</p> <p>Identify the location of sensitive receptors/users (such as bore owners, surface water bodies, wetlands, groundwater dependant ecosystems (GDEs)).</p>	<p>Tabulate the registered bores research.</p> <p>Plan showing the location of the nearest existing receptors including known water supply bores.</p>	<p>Sections 3.3 and 3.6</p>
	<p>Conceptual hydrogeological model (CHM) summary: A concise summary of the CHM which draws all the concepts discussed together. This can be useful for inclusion in site assessment and review or auditing reports by others.</p>	<p>Graphical conceptual hydrogeological model. Diagrams and tables as required.</p>	<p>Section 3</p>
Hydrogeological Risk Assessment			
<ul style="list-style-type: none"> <input type="checkbox"/> Description of activities and potential or existing contamination <input type="checkbox"/> Impact assessment <input type="checkbox"/> Risk assessment 	<p>Discuss potential activities and sources of pollution or contamination that may impact groundwater.</p> <p>Discuss results and any interpretations of groundwater contamination data. Include description of the processes leading to the observed containment distribution.</p>	<p>Tabulated and contoured data on contamination concentrations and/or ratios of contaminants.</p> <p>Figures showing the magnitude and extent of contaminants in groundwater.</p>	<p>Section 3</p>

Section	Text Content	Supporting Information	Section discussed
	<p>Impact assessment (source-pathway-receptor model): discuss the possible and likely impacts on groundwater receptors by evaluating activities and sources of contamination and the potential for active pathways to exist between the sources and receptors.</p> <p>Discussion could include description of contaminant release mechanism(s), transport and attenuation, reversibility of attenuation reactions etc.</p>	<p>Tabulate the sources in terms of location and chemical properties, the environmental values in terms of water quality criteria and the groundwater flow system (and travel times) providing the pathway. The data used in this discussion should already have been presented earlier in the report.</p>	<p>Section 3.8</p>
	<p>Where a groundwater model is used this generally requires a separate report or appendix to adequately document the work.</p>	<p>Groundwater flow and solute transport model parameters.</p> <p>Appendix – modelling report.</p>	<p>Section 3.7</p>
	<p>As a minimum, assess risk to groundwater by discussing whether each of the environmental values is achieved, maintained or threatened.</p>	<p>Tabulate environmental values and whether each is existing, likely or unlikely.</p>	<p>Section 3.6 and 3.8</p>
	<p>In cases where contamination is serious, and the risks may cause environmental harm, more detailed groundwater risk assessment protocols may be appropriate. This may include site-specific assessment of human health risk (including vapour intrusion risk) or ecological risks.</p> <p>This is generally beyond the scope of most HAs.</p>	<p>Appendix – risk assessment data and analyses.</p>	

Section	Text Content	Supporting Information	Section discussed
Conclusions and Recommendations			
	Provide concise conclusions and recommendations that are aligned but not limited to the objectives of the study and are informed by the data gaps and uncertainty considerations.		
References and appendix			
	References may be provided in footers, as a separate section in the report, or as an appendix. Include other relevant data in appendices or attachments.	Reference list.	
<p><i>Notes:</i></p> <ol style="list-style-type: none"> 1. This is suggested content for a typical detailed HA report. As the scope of the HA, and therefore the report, is dependent on the 'risk of harm' posed to human health and the environment, a detailed assessment that does not include all of these aspects may be sufficient. 2. A report arising from an HA desktop study would follow the same format, but the level of data available will be less than for an HA that includes field investigation. 3. The report for an HA that did not detect any contamination would not require detailed discussion of the 'groundwater contamination assessment'. 4. The report should be signed by the hydrogeologist responsible for the HA. 			

Appendix B: Hydrogeological assessment checklist

This checklist should be used to help ensure that the HA has collated and discussed all important information.

Site reference / address: _____

Information included	Section/page discussed	Please tick off
Introduction <ul style="list-style-type: none"> - Purpose/objective - Background - Scope 		
Site Overview <ul style="list-style-type: none"> - Description (including current activity / proposed activity) - Setting - History - Previous Studies - Summary 		
Methods and results <ul style="list-style-type: none"> - Desktop study <ul style="list-style-type: none"> o Data sources o Data quality o Data summary - Field study <ul style="list-style-type: none"> o Scope o Methods o Results - Data gap and uncertainty assessment 		

Information included	Section/page discussed	Please tick off
Conceptual Hydrogeological Model <ul style="list-style-type: none"> - Setting - Geology / aquifers - Groundwater depth and flow systems (including velocity and direction) - Groundwater chemistry - Groundwater segment and environmental values - Current / future groundwater resource utilisation - Sensitive receptors (surface water, groundwater dependant ecosystems, extraction bores, etc.) - Summary 		
Groundwater Risk Assessment <ul style="list-style-type: none"> - Description of activities and potential or existing contamination - Impact assessment - Migration pathways - Risk Assessment 		
Graphical hydrogeological cross-section(s) of the assessment area showing (as a minimum) geology, groundwater levels, groundwater bores, surface water receptors and any relevant features (e.g., contamination sources, utility services, building structures, etc.)		
A clear and concise executive summary providing all of the above information		
Concise conclusions and recommendations informed by data gaps and uncertainty considerations		

Note that this is the base level of information required for a Hydrogeological Assessment. More complex issues may require additional information. There is no requirement to complete or provide this checklist with an HA, it is presented as an aid to ensure the HA is completed appropriately and provide a potential communication tool to help a person reading an HA identify where key aspects are documented (e.g., where requested or where it is felt that would help navigate a complex HA).

Appendix C: Example bore construction summary

Reg. bore ID	Site bore ID	Installation Date	Northing (MGA)	Easting (MGA)	Drilled depth (m)	Constructed depth (m)	Bore / Casing diameter (mm)	RL natural surface (mAHD)	RL (top of casing) (mAHD)	Screen interval (mbgl)	Filter pack (mbgl)	Annulus (bentonite) seal (mbgl)	Aquifer monitored	Development method	SWL (30-May-2005) (mBTOC)	RWL (30-May-2005) (mAHD)
WRK012345	BH1A	22-May-2005	5814337	380427	7.5	7.0	150 / 25	67.50	67.80	4.5–7.5	4.0–7.5	3.5–4.0	BGA	Pump 30 mins	6.00	61.80
WRK012346	BH1B	22-May-2005	5814338	380428	15.0	15.0	150 / 25	67.50	67.90	12.0–15.0	11.5–15.0	11.0–11.5	BGA	Pump 45 mins	6.35	61.55
WRK0123457	BH2	23-May-2005	5814325	380420	8.0	8.0	100 / 50	70.00	70.40	5.0–8.0	4.5–8.0	4.0–4.5	BGA	Bail 30 mins	6.00	64.40
WRK0123458	BH2	23-May-2005	5814334	380472	9.5	9.0	100 / 50	73.00	73.55	6.5–9.5	6.0–6.5	5.5–6.0	BGA	Pump 15 mins	6.50	67.05
WRK0123459	BH3	24-May-2005	5814327	380425	20.0	20.0	100 / 50	78.77	79.22	17.0–20.0	16.5–20.0	16.0–16.5	FFA	Bail 25 mins	11.75	67.47

Notes:

BH1A and BH1B are different piezometers installed in bore BH1.

MGA: Map Grid of Australia

mAHD: metres Australian Height Datum.

RL: reduced level (m AHD)

RWL: reduced water level.

mBTOC: metres below top of bore casing

mbgl: metres below ground level.

BGA: Brighton Group Aquifer, FFA: Fyansford Formation Aquifer.



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Environment Protection Authority
Victoria
GPO BOX 4395 Melbourne VIC 3001
1300 372 842



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