ENVIRONMENTAL AUDITING

HYDROGEOLOGICAL ASSESSMENT (GROUNDWATER QUALITY) GUIDELINES

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FOREWORD

Few Victorians would deny the importance of protecting our environment for current and future generations.

Contamination of land can be commonly encountered where land has been used for storage, handling and/or disposal of chemicals and wastes. Frequently, waste and chemical handling at historical industrial premises was not consistent with current practices, leaving a legacy of site contamination that is encountered during redevelopment. Recent trends to redevelop former industrial land, particularly in inner urban areas, have highlighted this issue.

Many organisations are now using a hydrogeological assessment as one of the range of tools available to assist in assessing the condition of the environment they manage. Contaminated land audits also rely on hydrogeological assessment reports.

Similarly, hydrogeological assessment is a critical element in assessing the risk posed to the environment by existing or proposed waste disposal and storage facilities, as well as chemical and petroleum storage handling.

These guidelines provide a detailed overview of the requirements for a hydrogeological assessment. A hydrogeological site assessment that follows these guidelines will provide good quality information to aid owners, developers, potential purchasers and regulators to identify the risk to health and the environment from potential contamination.

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Chairman
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INTRODUCTION

EPA Victoria recognises the need to protect the quality of groundwater both as a resource and as part of the natural environment.

The *State Environment Protection Policy (Groundwaters of Victoria)* (SEPP (GoV)) describes a hydrogeological assessment as a process *'…to determine any*

(a) *existing groundwater contamination and resulting risk to beneficial uses of groundwater, and*

(b) *potential risk to groundwater quality and beneficial uses of groundwater.'*

Hydrogeological assessment (HA) is a systematic study of geology, hydrogeology, geochemistry and contamination at a site. An essential component of an HA is the development of a clear conceptual model of the hydrogeology, the contamination and the potential human health and ecological risks.

An HA may be required in relation to the risk to the groundwater environment, including past, present and future activities such as:

- landfilling
- waste storage and handling
- wastewater storage and irrigation
- petroleum or chemical storage and handling
- site contamination.

The purpose of this guideline is to:

- encourage consistency and improvement in standards of HA data collection, reporting and analysis
- inform industry and the community about EPA expectations of the content of an HA report
- promote an approach to HA that is commensurate with health and environmental risk.

All HAs should provide the basis for making decisions and address the:

- potential for past, current, and proposed activities to affect groundwater quality and protected beneficial uses
- extent and degree of existing contamination
- transport and fate of groundwater contaminants
- risk that groundwater contamination poses to human health and/or the wider environment.

Undertaking an HA requires a range of skills derived from a multidisciplinary team, with the principal expertise being provided by a hydrogeologist.

An HA may also be required by EPA in:

- a works approval application
- a Notice to assess contamination and clean-up required from past activities
- to assess the adequacy of a Financial Assurance proposal
- as part of the EPA licensing process
- in a Notice requiring ongoing management or monitoring of groundwater.

Other organisations may also request an HA when implementing other legislation or regulations. Here are three examples:

> **Local government** has obligations to consider environmental protection, including

groundwater, when considering planning applications, and permits for 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*, Potentially Contaminated Land.*

Catchment management authorities may need to evaluate the impacts of groundwater base flow on streams, or the impact of diffuse sources of pollution on groundwater quality.

Rural water authorities and the Department of Sustainability and Environment may need to evaluate the impact of pollution on water resources, to design and review regional surface water and groundwater monitoring strategies, or to assess the potential impacts of issuing a licence to take and use water.

An HA may also be undertaken voluntarily as a 'due diligence' study to define the environmental liabilities of a site or business.

These guidelines describe the basics of groundwater contamination: how a site conceptual model is developed; the process of an HA; the collection of groundwater data; and what an HA report should contain.

GROUNDWATER CONTAMINATION

This section outlines the influence that contamination source, groundwater movement and chemical processes have on the extent and concentration of groundwater contamination. Identifying these aspects is a key part of the HA.

CONTAMINATION SOURCES

Many activities can cause groundwater contamination. Contaminant sources can be sudden releases from spills or accidents, gradual releases from long-term leaks, or industrial or agricultural practices since the 1800s.

Contaminants 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.

The type of release (for example, spills at the surface, leakage from underground tanks or injection through bores) can affect the concentration and extent of contamination.

To develop an understanding of how contamination sources may impact on the groundwater system, the underlying questions are asked:

- Where and how does groundwater occur at the site?
- What are the likely sources of contamination?
- Is groundwater likely to be polluted?
- Is groundwater polluted?
- What is the level of risk posed by the pollution?

All aquifers are at risk from intentional or accidental contamination via subsurface structures such as bores, pits, drains, pipelines and old mine shafts. Additionally, the exchange of groundwater between shallow and deep aquifers via poorly constructed or improperly decommissioned boreholes, or natural features such as fractures can make contamination worse.

Where the contamination source is above the water table, contaminants have to migrate through the unsaturated zone to the water table. The gas phase in the unsaturated zone above the water table also presents another potentially significant risk to human health and safety due to upward migration of volatile contaminants.

Hence, 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. Such non-aqueous phase liquid (NAPL) in an aquifer is an ***uncontrolled source*** of contamination, and must be removed unless EPA is satisfied that there is no unacceptable risk posed by the NAPL to any beneficial use.

Aquifers contaminated with NAPL require extreme care in assessment and monitoring because of the potential for increased contamination. NAPL-contaminated sites should only be investigated by experienced professionals with specialised training in NAPL assessment and with appropriate techniques.

GROUNDWATER MOVEMENT AND PROCESSES

When contaminants enter groundwater their movement is determined by physical and chemical characteristics of the aquifer, groundwater flow paths, and the properties of the contaminants.

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

Aquifers are usually heterogeneous, the physical properties (porosity and permeability) often changing over relatively short distances, so assessment of the pattern and rate of groundwater flow is critical, with measurement of these important hydraulic properties often required.

So, in order to effectively understand how groundwater and contaminants in groundwater move, 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.

One of the most neglected areas of an HA is identifying how and where groundwater interacts with the land surface and with surface water.

RISK FROM CONTAMINATED GROUNDWATER

Where contamination is identified or suspected, there should be a qualitative or quantitative risk assessment to evaluate the significance of the contamination and the risk to beneficial uses.

Such a site assessment may include modelling groundwater flow and the transport and fate of contaminants in the groundwater flow system.

To assess risk, the protected beneficial uses must be determined. SEPP (GoV) defines segments and beneficial uses based on groundwater salinity (TDS).

Water chemistry parameters are used to assess the background water quality, the relevant 'segment' and protected beneficial uses. Sufficient spatial and temporal data must be collected to determine the protection segment to which groundwater belongs.

Where there may be a risk 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 there is an unacceptable impact on receiving waters and ecosystem.

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 so that the feasibility of remedial or management strategies can be determined and demonstrated, and to ensure that situations are improved and not worsened by remediation or management.

The provision of a groundwater remediation feasibility assessment in accordance with EPA publication 840, *The clean-up and management of polluted groundwater,* relies on a sound HA.

THE HYDROGEOLOGICAL ASSESSMENT PROCESS

The HA involves a phased approach, with the scope depending on the nature and scale of the problem and the expected risks. All stakeholders should be consulted to ensure the scope of the HA is adequate – in particular the field investigation and data analysis components.

Accordingly, the HA may not initially include all of the hydrogeological work necessary at a site, because this could evolve as greater understanding is developed of the hydrogeology, contaminants and risk to groundwater and the environment at the site.

The HA comprises:

- a desk study to build an initial conceptual hydrogeological model of groundwater flow, quality and contamination
- an initial assessment of health and environmental risk
- field investigation and testing to improve the conceptual model, if necessary
- reassessment of risk, if necessary
- reporting of data, conceptual model and analysis of the hydrogeological conditions and potential risks at a site.

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

Regardless of the scale and complexity of the task, the HA includes assessment of the:

- hydrogeology of the site and surrounding region
- aquifer properties and groundwater flow directions, paths and rates
- potential for activities to cause groundwater contamination
- distribution and concentration of existing contamination

- expected transport and fate of groundwater contaminants
- risk to human health and/or ecological receptors in the environment.

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

- no further action (in other words, groundwater is unlikely to be polluted and there is no risk of future pollution)
- ongoing management of groundwater contamination, including containment or monitoring
- further HA, monitoring and possibly aquifer clean-up trials where significant groundwater contamination occurs
- ongoing groundwater clean-up to restore the beneficial uses protected by SEPP (GoV).

UNDERTAKING HYDROGEOLOGICAL ASSESSMENTS

Sufficient work must be done in the HA 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; and identifies potential receptors (groundwater users or environments where groundwater discharges).

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

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.

Typically, the HA would address the following questions:

- What is the potential for groundwater to be contaminated by a source at or near the site?
- Is the groundwater at the site contaminated?
- What is the level of risk posed by the contamination?

These questions can be answered by assessing:

- site history – identifying contaminants of concern, activities, and potential for contamination
- hydrogeological setting – identifying aquifers, aquitards and their configuration and properties, groundwater flow directions and rates, groundwater quality and vulnerability to contamination
- contamination state of the groundwater in individual aquifers and aquitards at the site
- beneficial uses – of groundwater and potential receptors such as wetlands, streams and groundwater users, and likelihood of these uses becoming realised.

HYDROGEOLOGICAL DESK STUDY

Every HA should commence with a desk study. The HA desk study should review current and historical information on a site, plus any relevant hydrogeological data such as information from bores previously installed at the site, and would often involve a site inspection.

The outcome is generally an initial conceptual hydrogeological model (CHM) of the site. This should be sufficient to answer the question, 'Is the risk to groundwater quality low?' If the question can't be answered, or the answer is 'no', then further work is needed, such as field investigations.

The HA desk study should either result in a desk study report or provide input to a field investigation work plan. If there is no further investigation, a desk 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 groundwater is not contaminated or polluted, and is unlikely to become so.

If groundwater is, or is likely to be, contaminated, further assessment is necessary to evaluate movement and fate of contaminants and risks to human health and the environment.

HYDROGEOLOGICAL FIELD INVESTIGATION

If a CHM cannot be developed from the desk study due to a lack of data, or if groundwater at the site is suspected of being contaminated or of becoming contaminated, 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 being addressed and the potential risk to groundwater and the surrounding environment posed by contamination.

There must be clear objectives and a work plan before 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. In particular, activities at the site should be carried out in a manner that avoids expanding the contaminated zone.

Before carrying out fieldwork, the potential physical and chemical hazards of the site should be assessed in terms of health and safety for all personnel (including contractors) who will be working on the site, as well as the effects of the proposed work on the environment. For further information on site safety, refer to the *National Environment Protection (Assessment of Site Contamination) Measure* [NEPM] Schedule B(9)*, Guideline on Protection of Health & the Environment During the Assessment of Site Contamination*.

The initial CHM developed during the desk study must be verified in the field or improved to better reflect the site conditions.

Accordingly, the following field data collection steps should be undertaken:

- Characterise the site geology and identify 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.
- Map the lateral and vertical extent of groundwater chemistry and contaminants.
- Gather information to assess plume movement, stability, growth or decay.
- Identify areas of contaminant migration and places where contaminant may be stored (for example, including high and low-permeability materials).

Where NAPL may be present, or there is potential for cross-contamination of aquifer zones and water samples, the drilling method and bore locations must be chosen to reduce the risk, and the work should be undertaken by personnel experienced in such work.

A field investigation may include a number of investigation methods, including bore installation, groundwater sampling, groundwater level measurement and aquifer hydraulic testing. Other methods that may be used to better define contaminant migration and fate at a site include:

- geophysics (surface and down-hole)
- unsaturated zone or soil gas monitoring
- environmental isotopes and tracers (such as isotopes of oxygen, hydrogen, carbon and nitrogen) to trace, date or 'fingerprint' groundwater or contaminants
- separate-phase (LNAPL or DNAPL) sampling, identification (fingerprint), and monitoring
- soil core solvent extraction
- solid-core diamond drilling
- other and developing techniques such as in-situ monitors and loggers, and cone penetrometers.

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.

The groundwater bore network should cover the study area and the aquifers and aquitards of concern, and should characterise the flow system. Although the number of bores and locations, depths and screen intervals are site-specific, hydrogeological site investigations require at least:

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

The initial bores should be:

- close to the contamination source(s), with a mix of shallow and deeper bores (with caution if DNAPL may be present)[1];
- screened across the water table aquifer to locate 'floating' NAPL and to identify contaminant derived primarily from surface leakage
- installed with similar construction techniques to minimise sources of variation in the data.

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[1] Note that with Dense NAPL (DNAPL) sites, great care is required in siting, drilling and installing bores to avoid cross-contamination. Initially, the drilling should be away from the source.

It must be recognised that sites with significant groundwater contamination, high ecological or health risk, or complex hydrogeology can require numerous bores to assess the extent of contamination on and off site. A comprehensive 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 problem, the site hydrogeology, and whether NAPL may be present. The use of solid-core diamond drilling should be considered, as this can provide detailed information on the geology and structures such as faults and joints.

As information is gathered, further phases of field investigation and data analysis may be required.

It is important to recognise that the investigation bores might not be in the best location for long-term monitoring at the site, and additional bores could be required for 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 of the relevant water authority.

FLOW AND SOLUTE TRANSPORT MODELLING

The HA may require analytical or numerical modelling as well as conceptual modelling. Groundwater flow and solute transport models are used to estimate groundwater flow rates, velocities and flow paths, and the fate of solutes or contaminants. Such analytical and numerical models must be based on the conceptual hydrogeological model.

In many cases, the basic data available and the scale of decisions 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.

If a predictive numerical model is developed to test migration or remediation scenarios, then additional field or laboratory data on hydraulic conductivity distribution, the temporal variations in groundwater flow rates and contaminant behaviour are usually required.

An analytical or numerical model might be used to help:

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

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 conceptual hydrogeological model.

There needs to be sufficient supporting 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.

Model results must not be solely relied on to predict contaminant distribution, pumping rates, travel times, or capture of contaminant plumes. 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.

IMPACT OR RISK ASSESSMENT

Impact or risk assessment can be performed at many levels.

For the purposes of this guideline, impact assessment involves a qualitative analysis of the potential for undesirable effects caused by groundwater contamination. A risk assessment, on the other hand, is 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 risks.

Where ecosystem maintenance is the principal beneficial use 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 beneficial use includes a sensitive use, such as for potable supply, and there is evidence of groundwater pollution. 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.

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

- assessing the source of the contaminant and nature (solubility, partitioning, toxicity and so on) of the chemicals of concern
- identifying existing and potential uses relative to those protected by SEPP (GoV) 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 beneficial uses of the groundwater by reference to water quality criteria
- evaluating the volatilisation pathway for organic contaminants
- obtaining evidence of natural attenuation of contaminants and plume stability.

GROUNDWATER DATA COLLECTION

Groundwater data is usually obtained from bores installed for data collection, but might also be obtained from springs or seeps, water supply bores, sumps and drains. If applicable, wetlands, lakes and streams should also be sampled to better define groundwater interaction with the surface environment.

The installation of groundwater bores and the collection of groundwater data should comply, as a minimum, with the requirements in EPA publication 669, *Groundwater sampling guidelines*.

Drilling bores for investigation, monitoring or extraction of groundwater is controlled under the *Water Act 1989*. A bore construction licence must be obtained from the relevant water authority before installing, altering or decommissioning investigation, monitoring or extraction bores.

Appendix B is an example of a bore construction summary. Typically, the water authority will also require bores to be constructed in accordance with *Minimum Construction Requirements for Water Bores in Australia* [LWBC 2003] and EPA publication 669, *Groundwater sampling guidelines*.

INVESTIGATION OR MONITORING BORES

Installation of investigation or monitoring bores to provide detailed water level data and groundwater samples is critical for a successful HA. The main success factors are:

- choice of bore design and drilling method to suit the site-specific conditions and the HA objectives
- correct placement of filter pack and seals in the bore annulus and the casing collar at ground surface
- choice of screen length and proper installation of casing and screens to ensure water levels and groundwater samples represent discrete intervals at the site
- 'development' of the bore to ensure the bore is operational and groundwater samples are free of suspended sediment
- protection and identification of the bore to preserve the asset and maintain its integrity.

So that water level (hydraulic head) measurements are meaningful, and to prevent inter-aquifer contamination, bore screens must be restricted to a single aquifer. If they extend across multiple aquifers the data is difficult to interpret and could misrepresent the nature, extent and significance of contamination.

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/or 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. Groundwater level measurements and groundwater samples should not be collected immediately after bore development.

The following are the minimum requirements for documenting a monitoring bore network:

- The unique bore identifier from the licensing authority (and the local identifier), recorded on the bore cap and used in all HA and monitoring reports.
- Detailed bore logs describing the geology, contamination observations, water intersections and levels, and soil sample intervals.
- Bore drilling and construction details for all completed and failed bores (see the example in Appendix B).
- 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 position, by a qualified surveyor.

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

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 to remove sediment build-up or encrustation.

Bores on sites with public access must be locked.

HYDRAULIC PROPERTIES

In all but the most basic HA it is necessary to obtain data on the hydraulic properties of the aquifer system. 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) and constant-head tests.

MONITORING PROCEDURE

Monitoring activities usually include groundwater level measurement and sampling 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 publications 669, *Groundwater sampling guidelines*, and 441, *Guide to the sampling and analysis of waters, wastewaters, soils and wastes*.

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 the bore.
- More frequent measurement may be required where water levels may 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 include the following.

- 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 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. Water or air should not be added to a bore that is to be used for groundwater monitoring.

Regardless of the method chosen to purge a bore prior to sampling, generally the same sampling method should be used each time it is sampled, unless a different method is required for a specific analysis.

At contaminated sites, contaminated purge water must be treated and disposed of appropriately to protect occupational health and safety risks and prevent pollution of surface water, land, air or uncontaminated groundwater.

CHEMISTRY DETERMINATION

The choice of analytes should take into account the contaminants likely to be found on site. They should be determined from the site history and may include metals, total petroleum hydrocarbons (TPH), volatile hydrocarbons and chlorinated organics.

All bores should also have a basic analysis performed, including electrical conductivity (EC) or total dissolved solids (TDS) content in groundwater (used to indicate its quality), as well as several other parameters to characterise groundwater chemistry and quality. These include major ions (calcium, magnesium, sodium, potassium, chloride, carbonate/bicarbonate and sulphate), pH, Eh and dissolved oxygen (DO), and minor or trace ions (such as nitrate) and metals.

Each group of chemical parameters may require a different sampling or sample preservation technique. This aspect is discussed in EPA publication 669, while guidance on sample preservation and storage is provided in EPA publication 441, *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 organic compounds.

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.

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
- 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 Data Collection, Sample Design and Reporting*.

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.

DATA MANAGEMENT

All data, including original field record sheets, 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 is preferred 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, so that the complete data set is readily accessible, regardless of the consultant engaged at any time.

HYDROGEOLOGICAL ASSESSMENT REPORTS

This section presents guidance on documentation and data presentation for reporting consistency and to enable efficient report and data review. The analysis and interpretation of hydrogeological data is the most critical step in any HA.

CONTENT

The suggested content of an HA report is:

- Introduction.
- Site overview.
- Methodology and results.
- Conceptual hydrogeological model.
- Groundwater contamination assessment.
- Conclusions and recommendations.
- References and appendices.

Appendix A contains additional guidance on report content.

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 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; contaminant distribution maps; mass balance calculations; degradation pathways and rates; contaminant retardation calculations; 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 must be revisited to determine how the understanding of the hydrogeology, groundwater contamination, and risk associated with the site has changed.

The HA report should seek to answer the following questions (as appropriate to the site):

- 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?
- What is the ‘background’ groundwater quality?

- How and where did contaminants enter the ground and the aquifer system?
- What is the extent of the contaminated groundwater and how is this defined?
- How do the levels of contamination compare to criteria in ANZECC (1992) and ANZECC and ARMCANZ (2000)?
- Are LNAPL or DNAPL contaminants present in dissolved, residual or likely separate phases?
- If present, how do petroleum hydrocarbon levels compare to Dutch Investigation criteria?
- 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?
- What are the protected beneficial uses that may be at risk?
- How likely are any impacted beneficial uses 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?
- Has the current HA assessed all the site issues or is more work required?

APPENDIX A: HYDROGEOLOGICAL ASSESSMENT REPORT CONTENT

SECTION	TEXT CONTENT	SUPPORTING INFORMATION
SUMMARY	Concise description of purpose, activities, findings.	
INTRODUCTION		
❑ **Purpose / objective** ❑ **Background** ❑ **Scope**	The purpose of the HA and the parties with an interest in the HA. Further information on the background to the HA and its relationship to other studies may be necessary. The **scope** of the assessment and whether it is based on a **desk study** includes information from a site inspection or from more detailed field investigations and laboratory testing.	Locality plan. Site plan. Table that lists sequence of events and resources used. Appendix – work plan (for complex sites).
SITE OVERVIEW		
❑ **Description** ❑ **Setting** ❑ **History** ❑ **Previous Studies** ❑ **Summary**	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). Details on the **history** of the site and surrounds, and potential contaminants of concern relevant to the HA. Identify any **previous studies** of groundwater or soil contamination relevant to the HA. A clear **summary statement** of the **potential** for groundwater contamination.	Plans showing setting and relevant features. Plan and/or aerial photographs showing relevant historical features.
METHODOLOGY & RESULTS		
❑ **Desk study** ➢ **Data sources** ➢ **Data quality** ➢ **Data summary**	<u>HA desk study</u> **Scope** of desk study, information **sources** and data sets discovered in the desk study; comment on **data quality** and present a data **summary**.	Summary of desk study data, including statistical analysis. Appendix – spreadsheets, data from State Groundwater Database, climatic data.
❑ **Field study** ➢ **Scope** ➢ **Methods** ➢ **Results**	<u>HA field study</u> **Scope** of field investigation work, **methods** used (drilling, geophysical, water sampling, water level measurement, hydraulic testing etc.) and any field **results** (factual) or observations. Bore construction details (summary table).	Plan showing bore locations. Tabulation (detailed) of bore construction and survey data, tabulation of water level data. Appendices – Bore logs, geophysical logs, pumping test data and analysis, water sampling field records, bore construction licence, elevation and location survey, equipment calibration detail.

SECTION	TEXT CONTENT	SUPPORTING INFORMATION
	Laboratory testing of water samples, test methods and detection limits. Collation of results.	Tabulated water quality results including field parameters. Laboratory test reports NATA-certified.
	The means used to ensure **quality assurance and quality control**, and a commentary on data validity.	Appendix – work plan, tabulation of QC data, data validation report.
CONCEPTUAL HYDROGEOLOGICAL MODEL		
❑ **Setting** ❑ **Geology/aquifers** ❑ **Groundwater flow systems** ❑ **Groundwater chemistry** ❑ **Protected beneficial uses** ❑ **Groundwater resource utilisation** ❑ **Summary**	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.	Topographic plan. Tabulation of monthly rainfall and pan evaporation data. Stream stage/flow hydrographs.
	The **geology** and relationships between **aquifers** at the **regional and local scale**. Comment on whether aquifers are confined or unconfined. 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.	Geological map. Tabulated geological column showing main aquifers, aquitards and properties (hydraulic conductivity, transmissivity, storativity, aquifer thickness and porosity). Hydrogeological cross-sections showing the levels of surface facilities, geology, aquifer/aquitard units, intervals monitored in bores and water level.
	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. Describe any interpreted/inferred recharge, discharge and interactions between surface water and groundwater.	Figures showing the water table and/or potentiometric levels and principal flow lines (map view and cross-section). Tabulations and hydrographs of groundwater level data.
	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.	Summary table of water chemistry data/statistics or ratios. Contour and other plots of water chemistry data (Stiff diagrams, Schoeller plots, Piper diagrams etc.).
	Identify the groundwater segment and list the **protected beneficial uses** of the groundwater by reference to SEPP (Groundwaters of Victoria).	Plan showing the location of the nearest existing receptors including known water supply bores.
	Discuss the development and **utilisation of the groundwater resource** and its potential for future development and use. Identify the location of receptors/users (such as bore owners, surface water bodies, wetlands).	Tabulate the protected beneficial uses.
	Conceptual hydrogeological model **(CHM) summary**: A concise summary of the CHM. This can be useful for inclusion in site assessment and review or auditing reports by others.	Diagrams and tables as required.

SECTION	TEXT CONTENT	SUPPORTING INFORMATION
GROUNDWATER CONTAMINATION ASSESSMENT		
❑ **Description of contamination** ❑ **Impact assessment** ❑ **Risk assessment**	Discuss the results and any **interpretations** of groundwater contamination data. Include description of the processes leading to the observed containment distribution.	Tabulated and contoured data on contamination concentrations and/or ratios of contaminants. Appendix – modelling report.
	Impact assessment (source-pathway-receptor model): discuss the possible and likely impacts on receptors (beneficial uses) of groundwater by evaluating sources of contamination and the potential for active pathways to exist between the sources and receptors. Discussion could include description of contaminant release mechanism, transport and attenuation, reversibility of attenuation reactions etc.	Tabulate the sources in terms of location and chemical properties, the beneficial uses 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.
	Where a groundwater model is used this generally requires a separate report or appendix to adequately document the work.	Groundwater flow and solute transport model parameters. Appendix – modelling report.
	As a minimum, assess whether each of the protected beneficial uses of groundwater is protected, or precluded by contamination.	Tabulate protected beneficial uses and whether each is existing, likely or unlikely.
	In cases where contamination is serious and the risks may cause environmental harm[2], more detailed **groundwater risk assessment** protocols may be appropriate at this stage. This may include site-specific assessment of human health risk or ecological risks. This is generally beyond the scope of most HAs.	Appendix – risk assessment data and analyses.

[2] Section 53ZB (3) of the *Environment Protection Act 1970* states that an environmental auditor appointed under the Act must notify the Authority of any imminent environmental hazard as soon as is practicable after becoming aware of the hazard in the course of conducting an environmental audit.

Environment assessors are encouraged to discuss issues of concern with EPA.

CONCLUSIONS AND RECOMMENDATIONS		
	Provide concise conclusions and recommendations that are aligned but not limited to the objectives of the study.	
REFERENCES		
	References may be provided in footers, as a separate section in the report, or as an appendix.	Reference list.

Notes:

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' presented to groundwater beneficial use, a detailed assessment that does not include all of these aspects may be sufficient.*
2. *A report arising from an HA desk study would follow the same format, but the level of data available will be less than for a 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: EXAMPLE BORE CONSTRUCTION SUMMARY

Registered bore ID	Site bore	Bore construction date	Drilled depth (m)	RL natural surface (mAHD)	RL measuring point (top of casing) (mAHD)	Screen interval (mbgl)	Filter pack (mbgl)	Annulus (bentonite) seal (mbgl)	Aquifer monitored	Development method	Standing water level (30-May-2005) (mBTOC)	RWL elevation (30-May-2005) (mAHD)
S567745/01	BH1A	22-May-2005	7.5	67.50	67.80	4.5–7.5	4.0–7.5	3.5–4.0	BGA	Air lift 30 mins	6.00	61.80
S567745/02	BH1B	22-May-2005	15.0	67.50	67.90	12.0–15.0	11.5–15.0	11.0–11.5	BGA	Air lift 45 mins	6.35	61.55
S567745/03	BH2	23-May-2005	8.0	70.00	70.40	5.0–8.0	4.5–8.0	4.0–4.5	BGA	Air lift 30 mins	6.00	64.40
S567745/04	BH2	23-May-2005	9.5	73.00	73.55	6.5–9.5	6.0–6.5	5.5–6.0	BGA	Pump 15 mins	6.50	67.05
S567745/05	BH3	24-May-2005	20.0	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.

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.

APPENDIX C: USEFUL REFERENCES

Legislation

Environment Protection Act 1970, Victoria.

Water Act 1989, Victoria.

Planning and Environment Act 1987.

Subordinate legislation

All EPA guidelines and policies are available for download from the EPA website: http://www.epa.vic.gov.au/

State Environment Protection Policy (Groundwaters of Victoria), December 1997.

State Environment Protection Policy (Waters of Victoria), June 2003.

State Environment Protection Policy (Contaminated Land), 2002.

Waste Management Policy (Siting, Design and Management of Landfills), December 2004.

Guidelines

National Environment Protection (Assessment Of Site Contamination) Measure, 1999, [NEPM] Schedule A identifies the recommended process for the Assessment of Site Contamination.
Schedule B of the NEPM identifies 10 general guidelines for the assessment of site contamination.

www.ephc.gov.au/nepms/cs/con_sites.html

EPA publication 441, *A guide to the sampling and analysis of waters, wastewaters, soils and wastes.* EPA Victoria, 7th revision, March 2000.

EPA publication 669, *Groundwater Sampling Guidelines*. EPA Victoria, April 2000.

EPA publication 840, *The clean-up and management of polluted groundwater,* EPA Victoria, April 2002.

EPA and DSE 2005. *Planning Practice Note: Potentially Contaminated Land.* www.epa.vic.gov.au/land/contaminated_land.asp

Criteria

ANZECC, 1992. Australian Water Quality Guidelines for Fresh and Marine Waters. National Water Quality Management Strategy, Australian & New Zealand Environment & Conservation Council.

ANZECC and ARMCANZ, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy, Australian & New Zealand Environment & Conservation Council and Agriculture & Resource Management Council of Australia and New Zealand.

Ministry of Housing and Spatial Planning (1994) *Environmental Quality Objectives in the Netherlands.*

Standards

AS 4482.1-2005: *Guide to the investigation and sampling of sites with potentially contaminated soil – Non-volatile and semi-volatile compounds.*

AS 4482.2-1999: *Guide to the sampling and investigation of potentially contaminated soil – Volatile substances.*

General reference

LWBC (Land and Water Biodiversity Committee), 2003. *Minimum Construction Requirements for Water Bores in Australia*, Ed. 2, September 2003. Land and Water Biodiversity Committee.

MDBC, 2000. *Groundwater Flow Modelling Guideline*, November 2000. Murray-Darling Basin Commission

Overview of Victorian Hydrogeology
Department of Conservation and Natural Resources, 1996. Victorian Beneficial Use Map Series.

Leonard JG, 1992. *Port Phillip Region Groundwater Systems – Future use and Management*. Dept. of Water Resources, Victoria.

Leonard JG, 2003. *Groundwater a vital renewable resource*. Chapter 17 in Geology of Victoria, Geological Society of Australia Special Publication 23.

APPENDIX D: USEFUL CONTACTS

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Australian Contaminated Land Consultants Association (ACLCA)

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