



Department of Mines and Petroleum

Department of Water

GUIDELINE FOR GROUNDWATER MONITORING IN THE ONSHORE PETROLEUM AND GEOHERMAL INDUSTRY



July 2016

ENDORSEMENT

Groundwater monitoring in the vicinity of onshore petroleum and geothermal activities is a vital tool to demonstrate the ongoing protection and management of valued water resources. Current best practice by operators ensures that groundwater monitoring commences prior to on-ground disturbance activities, through the life of the activity and then beyond site decommissioning and rehabilitation. This approach will ensure that adequate 'checks and balances' are in place, facilitating responsible development practices.

The Department of Mines and Petroleum and the Department of Water recognise that there is a high level of public interest in protecting groundwater resources. Industry has also sought clear advice and guidance on the matter. This Guideline has been developed in collaboration by these two agencies, as an initiative of DMP's Reforming Environmental Regulation program. Additional input from other Government agencies, industry bodies, petroleum companies, stakeholders and interested community members during the consultation period also helped shape this Guideline.

The purpose of this Guideline is to promote effective groundwater monitoring programs for onshore petroleum and geothermal activities to satisfy the requirements of the Petroleum and Geothermal Energy Resources (Environment) Regulations 2012. It also articulates community and government expectations relating to the petroleum and geothermal industry's protection and management of groundwater resources.

This Guideline has been endorsed by the Department of Mines and Petroleum and the Department of Water.



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1 INTRODUCTION

Groundwater resources can support environmental values (such as ecosystem health) and provide beneficial uses (such as providing potable water supply or supporting agricultural, recreational or industrial activity). Protection of these values and uses relies on an understanding of the groundwater resource and maintaining or improving existing water quality and quantity.

Most onshore petroleum wells in Western Australia intersect groundwater resources while targeting oil and gas in deeper geological formations. Petroleum wells are constructed to rigorous standards to ensure that the environment, including groundwater resources, is protected. As with all industries and land uses, it is acknowledged that risks do exist and these must be appropriately regulated and mitigated.

There is a high level of public concern and interest in protecting groundwater resources, irrespective of quality or use. Questions may arise as to whether operational petroleum activities are impacting groundwater quality and quantity. Groundwater monitoring data can help provide answers. Groundwater monitoring is considered good practice for the onshore petroleum industry and provides evidence to counter future claims of groundwater contamination. It also provides reassurance to local communities, stakeholders and landholders that their groundwater resources are being actively monitored to demonstrate that there has not been any impact.

However, given the sheer size of Western Australia, many aquifers have sparse information available with water quality and quantity largely unknown. The information obtained through groundwater monitoring will also be used to enhance the knowledge of the State's groundwater resources.

Both surface and subsurface petroleum activities have several potential risk sources and pathways which may impact groundwater resources. By far the most immediate of these risks is from the surface management of hydrocarbons, chemicals and wastewater. Subsurface risks include contamination from well integrity failure or accidental subsurface chemical movement from the well through fractures, or other conduits, into aquifers. While the petroleum industry acknowledges these risks do exist, the combination of robust regulations and industry best practice mitigation ensure that these risks are minimised to 'As Low As Reasonably Practicable' (ALARP).

2 PURPOSE

Baseline groundwater monitoring is used to establish groundwater conditions before petroleum activities commence and, when transitioned into surveillance monitoring, can determine whether groundwater has been affected by petroleum activities. This Guideline aims to establish good practice requirements for groundwater monitoring for onshore petroleum and geothermal activities in Western Australia, and has been issued by the Department of Mines and Petroleum (DMP) with input from the Department of Water (DoW). This guideline is not intended to be applied prescriptively, but rather applied on a case by case basis using a risk based approach.

The purpose of this Guideline is to provide guidance to operators on:

- identifying situations where groundwater monitoring is considered appropriate for onshore petroleum activities, and
- outlining the general requirements and considerations that can be applied to groundwater monitoring using a risk based approach.

3 SCOPE

This Guideline applies to monitoring of groundwater resources for onshore petroleum or geothermal activities regulated under the *Petroleum and Geothermal Energy Resources Act 1967*, the *Petroleum and Geothermal Energy Resources (Environment) Regulations 2012* and the *Petroleum and Geothermal Energy Resources (Resource Management and Administration) Regulations 2015*.

This Guideline focuses on aspects of designing a groundwater monitoring program relevant to new onshore petroleum activities. Other literature is available on more general aspects of groundwater monitoring such as *Groundwater Sampling and Analysis – A Field Guide* (Geoscience Australia, 2009).

In this Guideline, reference to the term ‘petroleum activities’ collectively refers to both petroleum and geothermal activities including:

- drilling
- well construction
- well work-over
- injection
- well production testing
- hydraulic fracture stimulation
- construction and installation of a facility
- operation or modification of a facility
- storage and processing of petroleum
- decommissioning of a well or facility.

‘Baseline groundwater monitoring’ refers to the measurement of groundwater levels and collection of groundwater samples to determine water quality prior to the commencement of petroleum activities. It does not include monitoring of produced water, surface waters, wastewater storage or discharge, or monitoring of discharge or emissions from petroleum and geothermal activities.

‘Surveillance monitoring’ refers to monitoring that occurs after commencement of a petroleum activity is not considered to be representative of ‘baseline’ conditions. Any data collected after commencement of a petroleum activity should be directly compared to baseline data and relevant standards to determine whether changes have occurred.



Groundwater samples are collected using monitoring bores. It should be noted that there is a fundamental difference between water 'bores' and petroleum 'wells'. Water bores are constructed to access groundwater. In contrast, petroleum wells are more robust structures, designed to transfer petroleum and geothermal resources from deeper geological formations to the surface while preventing any contact with groundwater.

Other innovative monitoring methods may also be available. This Guideline does not prevent the use of innovative approaches that can alternatively meet the overall objectives of groundwater monitoring for onshore petroleum and geothermal projects. Innovative approaches that allow for the adoption of best groundwater management practices and will be considered on a case by case basis.

Other types of environmental monitoring may be required in an environment plan on a case-by-case basis, under r.14 of the Petroleum and Geothermal Energy Resources (Environment) Regulations 2012, to evaluate potential environmental impacts and risks to specific environmental values and sensitivities.

This Guideline does not replace, remove or negate other monitoring or reporting requirements under other laws, regulations or policies. In some cases, Ministerial conditions may also form part of a project's approval which identify specific groundwater monitoring requirements (eg. approvals under the *Environmental Protection Act 1986*).

4 GUIDANCE

4.1 Activities requiring groundwater monitoring

Groundwater monitoring requirements are determined on a case-by-case basis depending on the scale and nature of the petroleum activity, the level of risk and the sensitivity and values of the surrounding environment (including aquifers). Petroleum activities with a higher risk of adversely impacting groundwater resources or sensitive environments will require a more intensive baseline and surveillance groundwater monitoring program. This could consist of multiple monitoring bores at various locations and depths in the aquifer, together with higher sampling frequency and the sampling of additional chemical parameters.

Development of an appropriate groundwater monitoring program is likely to require the advice of a suitably qualified hydrogeologist or other appropriate professional. Advice should be sought from DoW and other relevant departments where appropriate (eg. water service providers, health or environment agencies).

An intensive groundwater monitoring program is likely to be considered appropriate for petroleum activities in areas:

- in proximity to potable water supplies such as a Public Drinking Water Source Area (PDWSA), PDWSA water bore, or an Aboriginal community drinking water bore
- in proximity to environmental sensitivities such as conservation category wetlands, groundwater dependent ecosystems, waterways, or areas protected by statutory mechanisms such as State forest, national parks, nature reserves, etc.

- with certain geology having potential to rapidly mobilise groundwater contaminants such as faults and karst geology
- with important groundwater values and beneficial uses (current and future) where the groundwater resource has important social or economic values (such as local water supply, stock water, irrigation water, or is used to support nearby wetlands or recreational areas)
- in proximity to populated areas, culturally significant areas and/or there is significant public concern or perceived risks
- where there is a known risk of groundwater contamination
- with higher operational risks, or where the proposed petroleum activity has a high level of complexity, uncertainty or risk.

A less intensive groundwater monitoring program may be appropriate for petroleum activities that pose low risks to groundwater, or where there are no sensitive or water-dependent environments or water users in the vicinity of the proposed activity.

There may also be some petroleum activities where groundwater monitoring is not considered appropriate, for example:

- seismic, geological and aerial surveys
- construction and operation of pipelines
- small scale geothermal wells (if licensed by DoW).

An existing groundwater monitoring program should be reviewed where a petroleum activity is transitioning from an exploration into a production phase. New groundwater monitoring bores may be needed to consider additional or cumulative risks to groundwater from field development and/or from production facilities.

The Environmental Protection Authority (EPA) may also require additional baseline information on groundwater should an environmental impact assessment be required under the *Environmental Protection Act 1986*. Environmental Protection Bulletin No.22 Hydraulic fracturing for onshore natural gas from shale and tight rocks (available at www.epa.wa.gov.au) provides further details on the EPA's information requirements.

4.2 Review of existing information

Prior to construction of a groundwater monitoring bore, a review of existing information available for the site and surrounding areas should be undertaken (commonly referred to as a desktop review). This will allow petroleum operators and regulators to understand the existing groundwater quality, current and historical land uses, potential contamination pathways, and sensitive receptors. This assists with the effective design of the baseline groundwater monitoring program and assessment of results.

The review should include, but not be limited to, the following:

- location and site description
- current and historic land and water uses
- hydrogeological and hydrological setting
- existing bores and available monitoring data.

The type of information that should be considered as part of the review is outlined in the following sections.

Location and site description

This includes a description and maps of:

- the location where the petroleum activities will take place at the surface and in the sub-surface
- aquifers that are intersected by the proposed activities (and connected aquifers)
- features with the potential to create pathways for dynamic water flow (eg. faults, abandoned bores, karst limestone)
- the nearest towns, population centres or properties
- the surrounding environment, including surface waters (eg. waterways, floodplains, wetlands), culturally important areas, sensitive environments (eg. groundwater dependent ecosystems such as wetlands and cave systems) and protected areas (eg. PDWSAs, State forest, national parks, nature reserves, or other areas under statutory protection).

Current and historic land uses

Current and historic activities at the site should be listed and, where possible, located on a site plan. This particularly includes an analysis of any land uses that have (or had) the potential to contaminate groundwater resources in the vicinity of the site.

Particular consideration should be given to land uses that contribute or provide a pathway for pollutants, including bores and wells (groundwater or petroleum), agriculture, mining, industrial, or commercial land uses, feedlots, scrap or storage yards, petrol stations, waste dump/landfill, waste processing facilities/septic systems, etc. Up-gradient land uses could also be investigated through landholder consultation, as these have the potential to contribute pollutants over time.

Reference should be made to the contaminated sites database at the Department of Environment Regulation to determine if there are any known contaminated sites in the vicinity of the proposed activities. Licensed and, where possible, unlicensed groundwater users (eg. stock and domestic/garden bores, PDWSA water bores or Aboriginal community drinking water bores) should be identified on maps and/or tables. Information on the location of licensed water bores can be obtained from the (DoW). Consultation with neighbouring landholders will be required to identify unlicensed private bores, especially those used as a private water supply.

Operators must consult with public water service providers where activities are situated:

- in a PDWSA,
- within 5 km of a PDWSA, or
- within 5km of a public water bore.

Where the activity is within 5km of a bore supplying an Aboriginal community, the relevant public water service provider is the Housing Authority.

Hydrogeological and hydrological setting

Petroleum operators need to understand the geology, hydrogeology, hydrology and environment of the proposal area in order to develop a conceptual model of the area.

Specific information, where available, includes:

- the distribution of geological formations, unconfined and confined aquifers, aquitards and aquicludes present in the area
- aquifer characteristics including transmissivity, permeability and water quality
- lateral and vertical variation in water levels/pressures, groundwater flow directions and rates of flow
- location of recharge and discharge areas for aquifers
- interconnection between aquifers
- existing surface water resources
- potential groundwater-dependent ecosystems
- springs and soaks
- location of existing faults, fractures, solution channels or other geological features
- abstraction volumes and target aquifers for licensed and unlicensed water bores.

This information should be presented in written form and supported using maps and figures where appropriate. DoW can provide advice such as locations of known water resources, depths of aquifers, appropriate monitoring locations, parameters and sampling regimes.

Existing water bores and monitoring data

Existing groundwater monitoring data should be gathered and analysed as part of the initial desktop review with the aim of:

- characterising and assessing groundwater chemistry prior to the proposed operations, including identifying existing groundwater contamination
- collecting and assessing data on groundwater levels and pressures
- identifying groundwater monitoring sites and data that is suitable for use in the baseline monitoring program
- identifying bores that need to be protected and require baseline monitoring information (eg. private and public drinking water bores, including PDWSA water bores and Aboriginal community drinking water bores).



Where data is not available within the area of proposed activities and potential impacts it may be possible to obtain relevant regional data from connected aquifers.

Existing landholder water bores can also be used in the baseline monitoring program if they are suitable and accessible. An assessment of bore suitability for monitoring should be undertaken, including construction details of wells (eg. depth, casing sizes, materials, screen locations and size, grouting/formation packing, etc.), their lithological and geophysical logs, and other key data such as static water levels/pressures.

4.3 Designing a monitoring program

A groundwater monitoring program should include the following key aspects:

- objectives for monitoring
- commencement and duration of monitoring
- relevant approvals
- monitoring sites and bore design
- frequency of monitoring
- sampling equipment and methods
- water monitoring parameters.

Objectives

The monitoring objectives should be clearly stated in the monitoring program as they help define the monitoring requirements and inform the planning and design of the broader monitoring program.

The overriding objective for baseline monitoring in relation to petroleum activities is to establish a reference groundwater condition so that any future potential impacts from the activity can be measured against the original reference condition.

Any other objectives should be realistic in terms of identifying and measuring changes in groundwater quality and quantity, and reflect desired outcomes for groundwater resources, groundwater values and the environment. Further guidance can be obtained from the National Water Quality Management Strategy: *Guidelines for groundwater quality protection in Australia* (Australian Government, 2013).

Commencement and duration

The design of a baseline monitoring program should consider the expected spatial and temporal variations in the parameters to be monitored. The Australian guidelines for monitoring groundwater recommend two years of baseline water quality sampling to adequately characterise groundwater variability (ANZECC and ARMCANZ, 2000). This allows for some understanding of annual variation in groundwater levels and in water quality parameters between wet and dry seasons. Understanding natural variation is important for distinguishing natural fluctuations from a change due to contamination.

While two years of baseline groundwater monitoring is considered useful to understand extremes in annual variation, this may not be practical for some petroleum exploration activities where:

- the groundwater bore will be used as a water supply for the petroleum activity and will be inherently linked to petroleum regulatory approvals
- land access agreements have not been finalised
- the exact location of the petroleum well or facility is not confirmed.

A groundwater monitoring bore should be constructed with baseline samples collected as soon as reasonably practicable following approvals, landholder agreements and prior to commencing the spudding of a new petroleum or geothermal well (or construction of a facility). This will ensure that baseline samples can be obtained well before petroleum activities commence.

Baseline monitoring technically ends once drilling starts or a facility becomes operational (ie. storing or processing hydrocarbons). Cessation of the baseline monitoring program does not mean the groundwater monitoring program should be discontinued. Monitoring at the same bore/s should continue but in the form of 'surveillance' monitoring to detect any change compared to the baseline condition or relevant standard over time.

Surveillance groundwater monitoring should continue for at least the duration of the petroleum activity. For petroleum wells where there have been no external well failures or serious spill incidents, then monitoring can cease following well decommissioning. For petroleum wells where there has been an external well failure or a serious spill incident prior to decommissioning, then monitoring should continue for two years after well decommissioning to account for any potential lag in groundwater movement from the well to the monitoring bore.

Relevant approvals

Table 1: A guide to the approvals required for groundwater monitoring activities and water supply.

| Purpose | Land Tenure | Action | Approvals |
|--|--------------|----------------|---|
| Groundwater monitoring and water supply for a petroleum activity | Private land | Construct bore | <ul style="list-style-type: none"> • a 26D licence to construct a water bore under the <i>Rights in Water Irrigation Act 1914</i> from the DoW • a 5C licence to take water under the <i>Rights in Water Irrigation Act 1914</i> from the DoW • approval via an environment plan under the Petroleum and Geothermal Energy Resources (Environment) Regulations 2012 • landholder agreement. |

| Purpose | Land Tenure | Action | Approvals |
|-----------------------------|--------------|-----------------------|--|
| Groundwater monitoring only | Private land | Construct bore | <ul style="list-style-type: none"> • non-artesian monitoring bores are exempt from requiring a 26D licence under the Rights in Water and Irrigation Exemption (Section 26C) Order 2012 • monitoring bores constructed into confined aquifers required a 26D licence under the <i>Rights In Water and irrigation Act 1914</i> from the DoW • exempt from approval under the Petroleum and Geothermal Energy Resources (Environment) Regulations 2012 • if at any time in the future, the operator wants the monitoring bore to become a water supply bore, then a 5C licence to take water must be sought from the DoW • landholder agreement. • approval should be sought from the relevant Government authority (as land custodian) to construct new bores or monitor existing bores. |
| | | Monitor existing bore | |
| | Public land | Construct bore | |
| | | Monitor existing bore | |

Approval to either construct a *new* bore or to monitor an *existing* groundwater bore on *public* land is subject to approval from the relevant Government authority. For example, bores located in national parks will require approval from the Department of Parks and Wildlife. The operator should seek approval in writing from the relevant authority. For *new* bores on *public* land, the relevant Government authority will advise on approvals required.

Approval to construct a *new* bore on *private* land for the purpose of monitoring groundwater is subject to agreement with the landholder. New non-artesian monitoring bores constructed on *private* land for the sole purpose of groundwater monitoring are exempt from the 26D licence requirement under the Rights in Water Irrigation Exemption (Section 26C) Order 2012 and approvals under the petroleum environment regulations but still require landholder consent (note that artesian monitoring bores do not fall under this exemption). This allows the operator to construct monitoring bores well in advance of planned petroleum activities to develop a baseline understanding of groundwater and to aid in developing models. If at any time in the future the operator wants the monitoring bore to become a water supply bore, then a 5C licence to take water must be sought from DoW.

Similarly, approval to access and use *existing* groundwater bores on *private* land for monitoring purposes is subject to landholder approval only.

Approval to either construct a new bore or use an *existing* bore on *private* land can be negotiated with the landholder and incorporated into the landholder access agreement (further details at APPEA et al., 2015). This allows private landholders to have their groundwater bores tested, and provides reassurance that their water supply is being actively monitored and protected. If the intention is to use an existing licensed bore, the licensee must notify DoW as soon as possible as changes to the licence terms and conditions may be required.

Where approval is sought to construct a *new* bore on *private* land for the dual purposes of providing a water supply and for monitoring groundwater (associated with a petroleum activity), it will require:

- a 26D licence to construct a water bore under the *Rights in Water Irrigation Act 1914* from the DoW
- a 5C licence to take water under the *Rights in Water Irrigation Act 1914* from the DoW
- approval via an environment plan under the Petroleum and Geothermal Energy Resources (Environment) Regulations 2012
- landholder agreement.

Planning is essential to obtain the relevant approvals and allow time to undertake baseline groundwater monitoring prior to commencing petroleum activities.

Details of any bores and groundwater monitoring program should be included within an environment plan for the relevant petroleum activity to be assessed under the Petroleum and Geothermal Energy Resources (Environment) Regulations 2012. Production activities include requirements for baseline groundwater monitoring, details of which should be included in the field management plan which is regulated under the Petroleum and Geothermal Energy Resources (Resource Management and Administration) Regulations 2015.

Monitoring sites and bore design

The number and location of groundwater bores used for baseline and surveillance monitoring needs to be determined on a case by case basis but will primarily depend on the level of risk associated with the proposed petroleum activity and the sensitivity and values of the surrounding environment and groundwater. The scale of petroleum activities (eg. processing plants, multiple wells, or field development programs) may also influence the number and location of groundwater monitoring bores. DoW can provide advice in this regard.

Some activities may require deep and shallow monitoring bores depending on the depths of aquifers that are currently being utilised or are likely to be utilised in the future. In these cases, bores will need to be drilled to different depths to monitor water quality parameters that have various densities and/or solubilities in water.



Some chemicals float on groundwater, some mix within the aquifer and others will sink to the bottom of the aquifer.

As a minimum requirement, it is recommended to locate at least one monitoring bore down-gradient (ie. hydraulic gradient) of the proposed petroleum activities. Where external factors are likely to influence groundwater over the duration of the petroleum activity (ie. nearby land use), an up-gradient monitoring bore is appropriate to characterise groundwater moving through the site (DoW, 2006).

Additional monitoring bores with flow meter logs may be needed to determine the direction of groundwater flow where flow direction remains unknown. This would require multiple bores (ideally three) spread out radially and preferably equidistant from the petroleum well.

The location of new monitoring bores generally depends on hydrogeological factors but should be as close as possible and down-gradient of the petroleum well to allow early detection of any contamination and no closer than 15 metres for safety reasons. The Petroleum and Resources Safety Divisions within DMP should be contacted to discuss any safety aspects in relation to the bore location on site.

The exact location of the bore should also consider other factors, such as layout of site infrastructure, proximity to vehicle tracks, and proximity to drainage sumps or soak-wells. If the monitoring bore is located too far away from the petroleum well there is a greater risk that other external factors will affect groundwater quality or that surveillance monitoring will not detect any potential well leaks within a suitable timeframe.

Water bores must be drilled in accordance with the *Minimum Construction Requirements for Water Bores in Australia* (National Uniform Drillers Licensing Committee, 2012).

Where available, details of existing water monitoring bores should be provided including construction details (eg. depth, casing sizes, materials, screen locations and size, grouting/formation packing, etc.), lithological and geophysical logs, and other key data such as static water levels and existing water quality data. The bores also need to be constructed from materials that would not influence the water quality parameters of interest.

Frequency of monitoring

The frequency of groundwater monitoring is determined on a case by case basis and undertaken in accordance with monitoring objectives and professional advice.

Monitoring frequency is usually related to how dynamic the monitored environment is (ie. how fast hydrological or chemical changes are likely to occur). In aquifers, the rate of change in water quality and water levels is generally slow compared to surface waters, although in unconfined aquifers, seasonal variations in chemistry and water levels are common. Groundwater abstraction and tidal influences in coastal areas can also affect water levels. In most confined aquifers changes in water quality over several weeks are normally minimal.



Frequency of monitoring also depends on chemical parameters being monitored. Highly water soluble chemicals (including salts) are mobile in groundwater and will generally require monthly monitoring. In contrast, insoluble or soil-binding chemicals (including hydrocarbons and persistent chemicals) are less variable over time and half-yearly monitoring may be acceptable.

Monthly sampling is recommended as an initial baseline frequency for areas where little is known about groundwater quality and it is necessary to establish baseline groundwater quality and levels.

Once petroleum activities commence baseline monitoring transitions into surveillance monitoring. Quarterly sampling is usually adequate for surveillance monitoring where the general objective is to track any deviation from the baseline condition over time. The frequency of surveillance monitoring should also be tailored to suit the type of petroleum activity being undertaken. For example, more frequent monitoring when hydraulic fracturing is occurring or less frequent monitoring when a well or facility is in care and maintenance.

Sampling equipment and methods

DMP encourages petroleum operators to engage an appropriately qualified consultant or independent professional to undertake the monitoring program. Independence is important where there are public trust issues around transparency or there may be potential liabilities regarding surrounding land uses and related contamination issues.

Sampling equipment and methods are to be consistent with Australian/New Zealand Standards (AS/NZS 5667, Water quality – Sampling). The method of pumping groundwater to obtain a sample (eg. bailing, high flow pumping or low-flow purge pumping) is determined by the water quality parameters of interest.

Water levels and pressures should be measured within aquifers at the same time as water samples are collected. It may be appropriate, or easier in some cases, to install continuous recording data loggers.

Water monitoring parameters

Chemical analysis of water quality is an integral part of the baseline groundwater monitoring program. If particular chemicals are required outside of the general parameter suite, DMP will inform the petroleum operator or include them as conditions of approval.

Field analysis parameters are measured to help characterise groundwater quality and to help interpret changes in groundwater quality. A list of parameters is included in Table 2 as a suggested minimum.

Sampling should be undertaken in accordance with the Australian Standard (AS/NZS 5667) using a National Association of Testing Authorities (NATA) registered laboratory to undertake chemical analyses using NATA-accredited analysis methods. If a NATA registered laboratory is not available, evidence to support data quality should be presented in the report.

A flow cell should be used to measure field analysis parameters (ie. with no air contact) at the time that samples are collected during the baseline monitoring program. Water levels can be measured manually or using a data logger.

Table 2: General field analysis parameters.

| Field analysis parameters |
|--|
| Water level (m AHD) – water levels/pressures should be measured within aquifers, surface water systems and groundwater-dependent ecosystems at the same time as water samples are collected. It may be appropriate, or easier in some cases, to install continuous recording data loggers. |
| Temperature (°C) |
| Conductivity – compensated to 25°C, or if uncompensated – report the value measured and the temperature; report complete units (e.g. mS/cm, not mS) |
| pH |
| Redox potential (Eh) |
| Dissolved oxygen (mg/L and %DO) |
| Bicarbonate (HCO_3^-) |

The list of water quality parameters for laboratory analysis presented in this Guideline is generic (Table 3). It is not mandatory for operators to sample all parameters. The parameters selected for a groundwater monitoring program should be determined on a case-by-case basis using the results from the desktop review and risk assessment.

Results of the desktop review should help to identify relevant current and historical land uses, environmental sensitivities and groundwater values and uses which will influence which parameters should be selected. For example, where historic land uses indicate some potential risk for groundwater contamination, a range of parameters should be sampled depending on that previous land use (including parameters outside the suite of chemical parameters presented in Table 3).

Results of the risk assessment (undertaken via an environment plan) should also provide information about which parameters are related to the current petroleum activity and can pose a risk to the environment or human health. This information can help to determine specific parameters that should be included in the monitoring program.

Table 3: Potential water quality parameters for laboratory analysis.

| Laboratory analysis parameters |
|---|
| <i>Physico-chemical:</i> |
| Total dissolved solids – determined gravimetrically @ 180°C |
| Turbidity |
| Total hardness (as CaCO_3) |
| Total alkalinity (as CaCO_3) |
| Hydroxide (as CaCO_3) |

Laboratory analysis parameters

Total Nitrogen (mg/L)

Total Kjeldahl Nitrogen (TKN) (mg/L)

Total Phosphorus (TP)

Ions:

Calcium (Ca^{2+})

Magnesium (Mg^{2+})

Sodium (Na^+)

Potassium (K^+)

Ammonia (NH_4^+)

Phosphate (PO_4^{3-})

Carbonate (CO_3^{2-})

Bicarbonate (HCO_3^-)

Chloride (Cl^-)

Sulphate (SO_4^{2-})

Nitrite (NO_2^-)

Nitrate (NO_3^-)

Silica (SiO_2)

Hydrocarbons:

Methane

Ethane

Propane

Total Recoverable Hydrocarbons (TRH)

Benzene

Toluene

Ethylbenzene

Xylene

Phenol

Polycyclic Aromatic Hydrocarbons (PAH)

Volatile Organic Compounds (VOC)

Metals: (Filter and acidify samples in field)

Aluminium

Arsenic

Laboratory analysis parameters

Barium

Beryllium

Boron

Cadmium

Chromium

Cobalt

Iron

Lead

Manganese

Mercury

Molybdenum

Nickel

Selenium

Vanadium

Zinc

Other parameters as appropriate (for example)

Arsenic (As^{3+} , As^{5+})

Bromide (Br^-)

Chromium (Cr^{3+} , Cr^{6+})

Iron (Fe^{2+})

Fluoride

Lithium (Li^+)

Naturally Occurring Radioactive Material (NORM)

Pesticides – organochlorines / organophosphates

Radon (Rn)

Selenium (Se^{4+} , Se^{6+})

Stable isotopes of carbon (C) and hydrogen (H) within methane (CH_4) – undertaken to determine origin or source of the hydrocarbon

Age dating – to provide information on the relative age of groundwater (e.g. ^{13}C / ^{14}C – Carbon 14 dating, Tritium ^3H / ^3He).

Measurement of oxygen 18 and deuterium (^{18}O / ^2H) – to provide an indication of the connection of groundwater within the saturated unit (aquifer) with rainfall recharge.

Uranium

4.4 Interpreting monitoring data

Interpretation of groundwater monitoring data should consider the following:

- assessment of groundwater levels and pressures including lateral and vertical variation, groundwater flow directions and, where possible, rates of flow
- physico-chemical characterisation of the water resources sampled
- establishment of baseline levels of water quality parameters in groundwater and description of any variation or trends since the petroleum activity commenced and the possible reasons for variation
- determination of any exceedances of relevant guidelines
- identification of any contaminants and suspected or known sources of contamination.

Relevant guidelines should be referenced depending on environmental values and groundwater uses in vicinity of the petroleum activity, including the:

- Australian Drinking Water Guidelines (NHRMC, NRMMC, 2011) – for use where petroleum activities occur within or in proximity to groundwater used for drinking water supplies
- Water Quality Guidelines for the Protection of Aquatic Ecosystems (ANZECC and ARMCANZ, 2000) – for general use in relation to the protection of aquatic ecosystem health and beneficial uses
- Contaminated Sites Guidelines (Department of Environment and Conservation) – for use in conjunction with the *National Environment Protection (Assessment of Site Contamination) Measure 1999* (NEPC, amended 2013) for determining whether a site is likely to be classed as contaminated
- Various water quality protection guidelines and notes available at DoW (www.water.wa.gov.au).

Analysis and interpretation of the data should also indicate any abnormalities, peculiarities or information necessary to interpret the data (eg. problems encountered with the operation of monitoring equipment). This includes identifying whether the water quality parameter was below analytical limits.

Results should be compared to the appropriate guideline for water quality and presented in tables, highlighting any results that exceed the guideline value. When operations commence, surveillance monitoring data should be interpreted against baseline data to determine whether there has been any significant change in groundwater conditions and the possible reasons for that change.

As a matter of urgency, DMP, DoW, the Department of Health, the Department of Environment Regulation and relevant water service providers must be contacted where any exceedances of drinking water guidelines (ie. in relation to a potable water supply) or contaminated site guidelines are identified from groundwater

monitoring. The operator may also be required to notify regulatory agencies where it is a specific requirement of Ministerial conditions, licence requirements or an environment plan.

Generally, the DMP and DoW should be notified if trends in groundwater quality or quantity are detected that deviate from the baseline condition.

4.5 Provision of Information

Submitting reports to DMP

The groundwater monitoring report should be submitted to DMP's Environment Division (petroleum.environment@dmp.wa.gov.au). The report should include results of the desktop review, relevant details of the monitoring bore, the monitoring data and a summary analysis of those results.

Where baseline monitoring data has been collected and a report compiled prior to approval for a related petroleum activity, it can be submitted as an appendix to an environment plan. Otherwise, the report can be submitted post-approval in annual environmental reports.

Surveillance groundwater monitoring data should be submitted with a summary analysis of results compared to baseline groundwater data, via annual environmental reports to DMP. An incident report should be submitted to DMP where groundwater contamination has been identified.

Groundwater monitoring data in these reports should be presented in tables and graphical format, with raw data in appendix and summary data in the body of report. Bore construction details should also be provided in the appendix, including bore diagrams, geophysical logs, geological logs, etc.

Submitting data to the DoW

Operators are encouraged to submit raw groundwater monitoring data to DoW (datain@water.wa.gov.au) as the Government's custodian of groundwater data and information.

All submitted data must have sufficient metadata to clearly and unambiguously identify every attribute, for example:

1. Measurement location coordinates in latitude and longitude in decimal degrees with a minimum of six significant decimal places in GDA94.
2. For each set of analyses:
 - laboratory name and address
 - site and sample identification (ie. site name, sample number)
 - sampling details (date, time, depth/reference point, top of casing/ground level, collection method, collection instrument)
 - sample treatment details (filtered/unfiltered, preservation such as HNO₃)

- analytical method code for each analyte
- units for each analyte
- how a result is expressed for each analyte (e.g. as N or as CaCO₃)
- the form of each analyte, if applicable (ie. total or filtered)
- the limit of reporting or detection limit for each analyte.

For field results include site, date, time and sample details as above, on a suitable form. This also needs to include, for each bore sampled, a record of pumping time and stable water quality parameters (EC, temperature, pH, dissolved oxygen and redox potential) prior to taking a sample. This provides evidence that the groundwater sample is representative of the water being sampled from the aquifer. Also, document the instrument used to measure each parameter, specify the parameter being measured and the units reported for each result.

Submitting reports to the landholder

DMP supports openness and transparency regarding monitoring results. In the interest of maintaining a positive stakeholder relationship, the operator is encouraged to provide the groundwater monitoring report to the landholder. The terms of the operator releasing the report to the landholder can be negotiated in the land access agreement.

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The lower half of the page features a series of thin, light-colored wavy lines that create a sense of movement and depth. These lines are layered and curve across the page, adding a modern, abstract aesthetic to the green background.

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Published May 2016
DMPMAY16_4265