GROUNDWATER ASSESSMENT TOOLBOX PROJECT FOR SSD/SSI

Groundwater assessment toolbox for major projects in NSW - Overview document

Technical guideline

January 2022

Published by NSW Department of Planning and Environment

dpie.nsw.gov.au

Title: Groundwater assessment toolbox for major projects in NSW - Overview document

ISBN: 978-1-76058-518-1

First published: January 2022. Version 1.

Authors (EGi):

Shaun Davidge, Andrew Davidson, Thomas Neame

Contributors (Department of Planning and Environment)

Fabienne d'Hautefeuille, John Paul Williams, Llyle Sawyer

Recommended citation:

DPE (2022). Groundwater assessment toolbox for major projects in NSW - Overview document. Technical guideline prepared for the Water group, NSW Department of Planning and Environment

---

Preamble

The NSW Department of Planning and Environment – Water saw the need for a Groundwater Assessment Toolbox (GAT). The primary aim of the toolbox is to create a collaborative, transparent, and enabling environment for the preparation and reviewing of groundwater assessments in New South Wales (NSW), in particular, for state-significant developments (SSD) and state-significant infrastructure (SSI) projects. Collectively, both types of project assessment are referred to as either SSDs or 'major projects' for the rest of this guideline document.

The specific objectives of the GAT are to:

> **Objective 1**: Provide a framework to investigate, assess the impacts on, manage and monitor groundwater resources and their interaction with surface water resources within the footprint of a major project
>
> **Objective 2**: Clarify the department's expectations (minimum requirements) from groundwater documentation including groundwater modelling that is prepared for major projects and used to support and inform the impact assessment
>
> **Objective 3:** Identify practical approaches for the assessment of cumulative groundwater impacts.

To assist with understanding how the components of the GAT and the NSW Aquifer Interference Policy interact, the department has developed this *Groundwater Assessment toolbox for major projects in NSW - Overview document*.

This technical guideline presents the minimum requirements for groundwater reporting, including modelling for major projects in NSW. The guideline is not intended to duplicate or replace pre-existing national best-practice guidelines, notably the *Australian groundwater modelling guidelines* (AGMG; Barnett et al., 2012).

The GAT comprises five elements:

> **Element 1 – Groundwater Assessment toolbox for major projects in NSW - Overview document**
>
> The department has provided this over-arching technical guideline to give an overview of the task-specific elements listed below.
>
> **Element 2 – Guidelines for groundwater documentation for SSD/SSI projects (major projects)**
>
> The main objective of the groundwater documentation guideline is to clarify and inform the requirements for groundwater assessment and documentation required for major projects in NSW. These projects can include activities located above the water table and below the water table.
>
> This guideline communicates the expectations of the NSW Government and minimum requirements for the groundwater investigations conducted to inform a groundwater impact assessment, as well as the groundwater impact assessment itself. Following project approval, the role of the NSW Government continues, providing guidance on and review of post-approvals monitoring and management plans and compliance reporting.
>
> **Element 3 – Minimum requirements for groundwater modelling**
>
> This technical guideline presents the minimum requirements for groundwater modelling for major projects in NSW. It is not intended to duplicate or replace pre-existing national best-practice guidelines, notably the *Australian groundwater modelling guidelines* (AGMG; Barnett et al., 2012). Rather, it is a complementary document that describes further modelling requirements specific to major projects in NSW (MGMR-MP).

The guidelines presented in this document incorporate elements from guidance developed by agencies in other countries at state and federal levels, as well as multinational and international standard-setting and scientific organisations.

Element 4 – Information paper on cumulative groundwater impact assessment

The fourth element of the toolbox comprises a technical information paper on the recommended approaches for assessing cumulative groundwater impacts.

The information paper presents:

- how to assess if a project should consider cumulative impacts
- the regulatory framework for water management
- aspects to consider when identifying cumulative impacts on water resources
- case studies of groundwater cumulative impact assessment in NSW.

Further, key recommendations are provided to assist project proponents with planning their approach to predict, apportion, and manage cumulative impacts of projects according to the requirements of the planning approval and water licensing processes in NSW.

Element 5 – Aquifer Interference Policy

The fifth element of the toolbox is the NSW Aquifer Interference Policy. This policy relates to all projects that intersect the water table or take water from aquifers.

Unless an exemption applies, all projects that take water from surface or groundwater sources must be licensed under the *Water Act 1912* or *Water Management Act 2000*.

This policy covers:

- water licensing requirements
- requirements for meeting water sharing plans (WSP)
- reporting and accounting requirements for water take
- minimal impact considerations for aquifer interference activities
- gateway process for approval of mining and petroleum projects
- assessment process for aquifer interference activities

Acknowledgment of Country

The Department of Planning and Environment, and Environmental Geochemistry International, acknowledge the Traditional Owners and Custodians of the land on which we live and work and pay respect to Elders past, present and future.

Contents

Tables

Figures

Acronyms

Acronym	Explanation
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
ACT	Australian Capital Territory
AGMG	Australian groundwater modelling guidelines
AIP	NSW Aquifer Interference Policy 2012
ASTM	American Society for Testing and Materials
BLM	Bureau of Land Management [USA]
BLR	Basic Land Rights
BSAL	Biophysical strategic agricultural land
CLC	Confidence-level class [for groundwater models]
COA	Conditions of approval
CSG	Coal seam gas
CSS	Culturally significant sites
DPIE	NSW Department of Planning, Industry and Environment (known as of 21 December 2021 as the NSW Department of Planning and Environment)
EIS	Environmental impact statement
EP&A	Environmental Planning and Assessment [Act, USA]
EP&A Act	*Environmental Planning and Assessment Act 1979* (NSW)
ET	Evapotranspiration
et al.	And others
etc.	And other similar things
GAT	Groundwater Assessment Toolbox
GDEs	Groundwater-dependent ecosystems
GIA	Groundwater impact assessments
GMMP	Groundwater monitoring and modelling plan

Acronym	Explanation
GMP	Groundwater modelling plan
GMTP	Groundwater Modelling Toolbox Project
GUI	Graphical user interfaces [for modelling software]
GW-PET	Groundwater model assessment procedures and evaluation tool report
Hydrogeological conceptual model	A description of the hydrogeology using maps, sections, schematic diagrams and other means.
HES	High environmental sensitivity [project]
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
LMCM	Low- to medium-complexity [groundwater] model
LMES	Low- to medium-environmental sensitivity [project]
m	Metre
MDBC	Murray–Darling Basin Commission
MGMR-MP	Minimum Groundwater Modelling Requirements for Major Projects in NSW – Technical Note
NARCliM	NSW/ACT Regional Climate Modelling
NDEP	Nevada Department of Environmental Protection
NSW	New South Wales
PEST	Parameter Estimation and Uncertainty Analysis [software]
RMS	Root mean square
SEARs	Secretary's Environmental Assessment Requirements
SEPP	State environmental planning policy
SSD	State-significant development
SSI	State-significant infrastructure
TSF	Tailings storage facilities
USGS	United States Geological Survey
vs	Versus

Acronym	Explanation
VWP	Vibrating wire piezometer
WAL	Water access licence
Water Act	*Water Act 1912* (NSW)
WM Act	*Water Management Act 2000* (NSW)
WMP	Water management plan
WRDMAP	Water Resources Demand Management Assistance Project (China – UK)
WSP	Water sharing plan

1 Introduction

1.1 Purpose and objectives

This *Groundwater Assessment toolbox for major projects in NSW - Overview document* explains how the elements of the Groundwater Assessment Toolbox (GAT) – including the NSW Aquifer Interference Policy (AIP) – relate to each other and how to use them to assess impacts on groundwater arising from a major project.

It is intended to clarify minimum requirements for the applicant and increase the reach of the proponent's application documents through improved transparency and documentation practices. It also intends overall to increase the efficiency of the processes at the different stages of the development by providing guidance on not only which documents are required, but at which stage of the application to prepare them.

The following four documents, along with this overarching GAT Technical Guideline, provide the framework for assessing groundwater impacts from projects in NSW, with a particular focus on major projects:

1. *Guidelines for groundwater documentation for SSD/SSI projects*
2. *Minimum groundwater modelling requirements for major projects in NSW – technical note* (MGMR-MP)
3. *Cumulative groundwater impact assessment approaches – information paper*
4. *NSW Aquifer Interference Policy* (AIP).

The relationship of these documents to each other is presented in Figure 1.

overview of technical guidelines forming the Groundwater Assessment Toolbox. Explanation as per main text.

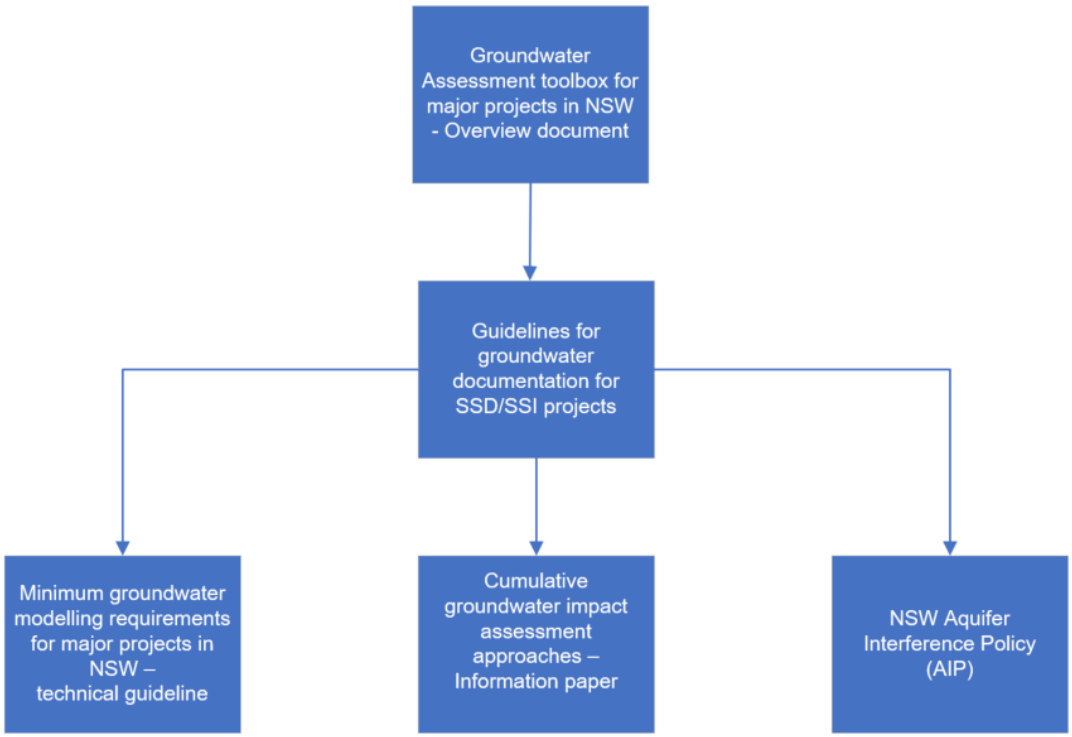

Figure 1: Relationship between this guideline and other documents of the GAT

While the GAT was primarily developed to assess major projects, it is recommended that in some cases it also be used for other projects (such as projects under other planning development pathways) that may impact on groundwater quality or quantity. The AIP provides the regulatory context on which projects will require detailed assessment.

Major projects are assessed under the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act). If a major project is determined to be a state-significant development (SSD) or state-significant infrastructure (SSI), it must be assessed using the *Guidelines for groundwater documentation for SSD/SSI projects*.

Projects that may require assessment using these tools are those that include 'water-affecting activities', or in the term used under the AIP, projects with activities that interfere with the aquifer. Examples of water-affecting activities for SSD/SSI projects that have the potential to affect receptors include:

- water supply developments (surface water and/or groundwater)
- excavation (for example, open cut mine, underground mine, quarry)
- tunnelling (for example, road, rail and other services)
- building dewatering (for example, large high-rise developments)
- conventional and non-conventional petroleum exploration, pilot and production
- solid and putrescible waste landfilling
- tailings storages
- waste (rock) storage
- water storage (above or below ground)
- irrigation.

1.2 Structure of this guideline

This guideline provides an over-arching summary of the groundwater documentation process, and therefore touches on the content of the regulatory framework and the supporting guidelines and policies, including the AIP.

This guideline is focused on the process of groundwater assessment, documentation and compliance of the groundwater component of major projects. Figure 1 shows that the *Minimum groundwater modelling requirements for major projects in NSW* (MGMR-MP); *Cumulative groundwater impact assessment approaches* and *NSW Aquifer Interference Policy* (AIP) are all supporting documents to this process. Accordingly, while these guidelines/policies are important parts of the assessment process, they are not the subject of their own summary, rather their application is described in the main guideline (*Guidelines for groundwater documentation for SSD/SSI projects*).

This over-arching guideline contains the following sections:

Section 2 – Regulatory overview

This section provides a summary of legal instruments that apply to major projects, and discusses which agencies are responsible for assessing the compliance of the project.

Section 3 – Groundwater assessment for major projects

This major section provides guidance on the process of groundwater assessment and post-approval management and monitoring.

The section summarises the expectations of the NSW Government and requirements for the groundwater investigations conducted to inform a groundwater impact assessment, as well as the groundwater impact assessment itself. Following project approval, the role of the NSW

Government continues, providing guidance on and review of post-approvals monitoring and management plans and compliance reporting.

Section 3.1 – Groundwater investigations

This sub-section presents a summary of the minimum requirements for what must be included in a groundwater investigation for a major project. More detailed information of these topics can be found in Part A of the *Guidelines for groundwater documentation for SSD/SSI projects*.

Section 3.2 – Groundwater impact assessments

The sub-section explains how, once the groundwater investigations are underway or completed, the proponent should assess the risks to groundwater and the potentially consequent impacts.

This section includes description of:

- what constitutes an impact
- the concept of minimal harm
- the groundwater assessment process
- what should be in a groundwater monitoring plan
- data collation
- modelling requirements.

Section 3.3 – Water management plans

Major projects are required to submit a water management plan (WMP) as part of the approvals process. This section discusses the strategies, plans, reports and other documents the proponent will need to prepare prior to commencement. It is important to understand that these are minimum reporting requirements and regulatory agencies may require additional documentation.

Section 3.4 – Water compliance reporting

A key component of water management is self-reporting on performance of project risk and impact management. This sub-section details the steps and reports required to demonstrate compliance with regulations policies and the permits provided for the project.

Section 4 Best practice in presentation

Consistency, transparency and concise presentation of issues in reporting are keys to assisting regulatory agencies to assess the proposed project. To assist proponents to understand best practice in presentation, this section of the guideline collates the recommendations and expectations of the department.

Section 6: References

This section contains a list of *ALL* references that are drawn on in any of the GAT documents.

2 Regulatory overview

The *Environmental Planning and Assessment Act 1979*, *Water Act 1912* (Water Act), the *Water Management Act 2000* (WM Act), the AIP, and the WSPs form the regulatory framework for groundwater use and irrigation planning in NSW, including management of cumulative impacts. These regulatory instruments are summarised below, in order of precedence as they relate to groundwater impact analysis.

The NSW Department of Planning and Environment's Water group provides advice for major projects to meet the requirements of the WM Act and the AIP. Major projects include projects declared state-significant development (SSD) and state-significant infrastructure (SSI).

Further detailed information on the regulatory framework (water-focused) for NSW SSD/SSI projects is provided in Appendix D of the *Guidelines for groundwater documentation for SSD/SSI projects*.

Relevant legislation, references and information:

- *Environmental Planning and Assessment Act 1979*
- *Water Management Act 2000*
  - Principles
  - Objects
- Water Sharing Plans
- NSW Aquifer Interference Policy
- Aquifer Interference Policy Fact Sheets 1 to 6 (refer *Guidelines for groundwater documentation for SSD/SSI projects* - Appendix C)
- NSW Government assessing groundwater applications fact sheet
- the department's role in assessing major projects
- National Partnership Agreement on Coal Seam Gas and Large Coal Mining Development
- Significant impact guidelines 1.3: Coal seam gas and large coal mining developments – impacts on water resources

2.1 Agency roles

It is important to identify early in the project planning and definition phase which agencies require consultation. Interactions between legal instruments and agencies can be complex and may require the proponent to engage with multiple agencies.

NSW Department of Planning and Environment – Water, the Natural Resources Access Regulator, WaterNSW and the NSW Environment Protection Authority each play a role in the implementation of the regulatory framework for water management in NSW.

When the project affects matters in the *Environment Protection and Biodiversity Conservation Act 1999*, the Australian Government Department of Agriculture, Water and the Environment and the Australian Government Office of Water Science will also have an interest in the permitting process.

If your project involves the extraction of coal seam gas or coal resources, submissions to the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) will be required.

Interactions with agencies can range from ‘in consultation with’, where the proponent and the agency agree on the course of action; to ‘to the satisfaction of’, where the proponent must demonstrate independently that they understand the risk and how to manage the effect on the relevant agency and get the endorsement from that agency.

It is recommended that professionals in major project approvals be engaged early to identify the specific permitting pathway for the project.

The regulatory context for SSD and SSI projects, and the roles and responsibilities of each of these agencies, is summarised in Table 1 (reproduced from Section 2 Guidelines for Groundwater Documentation for SSD/SSI Projects).

Table 1: Regulatory context for SSD/SSI infrastructure projects

Regulator/agency	Relevant Acts, roles and responsibilities	Involvement in the SSD/SSI process

Department of Planning and Environment – Planning and Assessment	*Environmental Planning and Assessment Act 1979*
	• Issues the Secretary's environmental assessment requirements (SEARs)
	• Assesses the project and provides a recommendation for determination to the consent authority (which is the Minster for Planning and Public Spaces, or the Independent Planning Commission in the circumstances outlined in the State Environmental Planning Policy (State and Regional Development) 2011)
	• Approves management plans required under development consents/approvals.
	• Manages compliance with and reporting required under *Environmental Planning and Assessment Act 1979* and SEARS.
		• Coordinates and leads the whole-of-government assessment
		• Seeks advice from relevant agencies on:
		  ○ the SEARs
		  ○ the EIS
		  ○ conditions of consent/approval
		• Administers management plan assessments and determination process
		• Manages compliance under the EP&A Act; may seek advice from agencies.

Department of Planning and Environment – Water	*Water Management Act 2000* • Manages the state's surface and groundwater resource • Develops and implements water sharing plans • Manages regional and metropolitan water supply and usage.	• Provides advice to the department on the SEARs • Provides advice and recommendations to the department regarding impacts and water licensing at different stages of the assessment and determination process, including following project approval • Provides advice on relevant draft development conditions of approval.

Regulator/agency	Relevant Acts, roles and responsibilities	Involvement in the SSD/SSI process
Natural Resources Access Regulator (NRAR)	Natural resources management legislation including: • *Water Management Act 2000* • *Natural Resources Access Regulator Act 2017* • *Dams Safety Act 2015* • Other relevant legislation • Ensures effective, efficient, transparent and accountable compliance • Informs, educates and engages to promote understanding of water laws and users' responsibilities • Monitors and audits the use of groundwater and surface water.	• Provides advice to the department on water licensing for SSD/SSI projects • Administers water licensing for SSD/SSI projects, major utilities, state-owned corporations, government agencies • Assesses breaches of natural resource management legislation from SSD/SSI projects • Provides advice on relevant draft development conditions of approval.
WaterNSW	• Owns and operates state water infrastructure • Operates and manages the Greater Sydney drinking water catchment • Administers all water dealings for rural landholders or industry (licensing, approvals, trades, metering, billing) • Monitors groundwater and surface water, and maintains relevant databases.	• Provides data to project proponents • Provides advice to the department on water issues in the Sydney Catchment area • Provides advice on draft development consent conditions.

NSW Environment Protection Authority (EPA)	*Protection of Environment Operations Act 1997*
	• Environmental regulator, focuses on water quality, contamination/ pollution
	• Partners with business, government and community to reduce pollution and waste, protect human health, and prevent degradation of the environment
	• Compliance and investigations; issues orders, fines and prosecutions.
		• Provides advice to the department on:
		  ○ SEARs
		  ○ Point source water quality and pollution issues
		  ○ Draft conditions
		• Issues Environment Protection Licences (EPL).
		• Has a specific role as regulator on CSG developments

Regulator/agency	Relevant Acts, roles and responsibilities	Involvement in the SSD/SSI process
Australian Government Department of Agriculture, Water and the Environment	*Environment Protection and Biodiversity Conservation Act 1999* • Environmental regulator	• Assesses and determines applications to carry out a controlled action under the EPBC Act
Australian Government Office of Water Science	*Environment Protection and Biodiversity Conservation Act 1999* • Liaises with the Australian Government regulators on requests for advice • Prepares secretariat support and supporting analysis documentation for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC)	• Reviews requests for advice for adequacy of an EIS/ Groundwater Impact Assessment (GIA)
Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC)	*Environment Protection and Biodiversity Conservation Act 1999* (Section 505D) • Provides independent scientific advice to the Australian Government Environment Minister on the impact that coal seam gas and large coal mining development may have on Australia's water resources	• Reviews requests for advice • Provides advice to Australian Government regulators on potential impacts of coal seam gas and large coal mining development

2.2 *Environmental Planning and Assessment Act 1979*

Part 4, Division 4.1 and Part 5.1 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) provides a streamlined approval process for the assessment and determination of state-significant development and state-significant infrastructure respectively.

Under the Environmental Planning and Assessment Regulation 2000, the Secretary of the Department of Planning and Environment must consult with relevant public authorities when preparing the Secretary's Environmental Assessment Requirements (SEARs) for an SSD or SSI project. The Planning and Assessment group consults with the Water group on water resource impact assessment and management requirements when preparing the SEARs for SSD/SSI proponents. Upon public exhibition of the EIS, the Water group is further consulted and is asked to assess the EIS and any supplementary specialist studies, and to provide relevant draft consent conditions (or confirm the proponent's statement of commitments), should the project be approved.

An additional process – a gateway process – will apply to SSD applications for mining or coal seam gas extraction on strategic agricultural land as defined in a relevant strategic regional land use plan.

2.3 *Water Management Act 2000* and *Water Act 1912*

The interaction with and use of water in NSW are regulated by the *Water Management Act 2000* (WM Act) or the *Water Act 1912* (Water Act). The WM Act governs water approvals and licensing for water sources in areas where water sharing plans (WSPs) have been enacted for those sources. The Water Act applies to water sources where a WSP has not been enacted or does not extend to the specific types of licences or approvals.

WSPs establish rules for sharing water between the environmental needs of river or aquifers and water users, and between different types of water use such as domestic supply, stock watering, industry, and irrigation. Water access licences entitle licence holders to:

- specify shares in the available water within a particular water management area or water source (the share component)
- take water at specified times, rates, or circumstances from specified areas or locations (the extraction component).

The WM Act defines aquifer interference activities as activities that involve the:

- penetration of an aquifer
- interference with water in an aquifer
- obstruction of the flow of water in an aquifer
- taking of water from an aquifer while carrying out mining, or any other activity prescribed by the regulations
- disposal of water taken from an aquifer while carrying out mining, or any other activity prescribed by the regulations.

The WM Act requires water users to hold and comply with the conditions of:

- water access licences (WAL) to take water
- water management work approval to construct and use
    - water supply works (for example, a pump, bore, or dam)
    - specified flood works at specified locations
- water use approvals to use water for particular purposes at particular locations
- controlled activity approvals to carry out any works within 40 metres of a river, lake, or estuary, being waterfront land.

To take water for a particular purpose, proponents may need to obtain a WAL nominating water supply work(s).

There are three main categories of approvals that may be granted to proponents:

1. **Water supply work approvals** authorise holders to construct and use water supply works at specified locations (for example, to install and operate a pump, dam, or bore)
2. **Water use approvals** authorise holders to use water for a particular purpose, such as irrigation, at a particular location
3. **Flood work approvals** confer rights on their holders to construct and use flood works at specified locations.

Major projects have different conditions for water allocation. Section 2.2.1 of *Guidelines for groundwater documentation for SSD/SSI projects* outlines specific exemptions applicable to major projects.

2.4 Aquifer Interference Policy (AIP)

Using the definitions in the WM Act, The NSW Aquifer Interference Policy (AIP) details the types of projects and activities that constitute aquifer interference. WSPs are the main tool for water sharing management at the source scale; the AIP is the water management tool for impacts on the water users, including the environment.

The AIP is applied by proponents of aquifer interference activities in preparing applications and used by the Department of Planning and Environment to assess those applications. The AIP requires proponents of high-risk activities to plan their projects based on an 'account for, mitigate, avoid/prevent, and remediate' approach. Importantly, the AIP defines minimal impact considerations for proposed projects, which include assessment of cumulative impacts. In addition, the AIP provides specific requirements (section 2.2) for dealing with perpetual inflow volumes for projects that continue to take groundwater after the activity has ceased.

Section 3.2 of the AIP outlines the framework for assessing the impacts of aquifer interference activities on water resources, in particular how the project will demonstrate:

- the ability to obtain licences for water take; or
- that water take can be prevented if a licence cannot be granted
- how minimal impact considerations from AIP Section 3.2.2 can be met
- where impacts are greater than predicted, the proponent has adequate remedial mitigation plans in place to address these impacts.

2.5 Bore dealing impact assessment

Where water is taken primarily for consumptive use from a bore or borefield, the intent is that these activities be assessed, and licensing requirements applied in the same way as water supply works. The assessment criteria of bore(s) for consumptive use differs to the AIP criteria.

The potential impact of groundwater extraction is managed through the assessment of all applications for groundwater dealings (trade) and water supply work approvals (bores). Either WaterNSW or the Natural Resources Access Regulator receives applications and then refers them, as required, to the department's Water group for hydrogeological assessment. The NSW Government has a fact sheet about the process for assessing groundwater work approval applications (NSW Department of Industry, 2018).

The assessment criteria applied for groundwater source and aquifer type is discussed further in *Guidelines for groundwater documentation for SSD/SSI projects – Appendix D*.

3 Groundwater assessment for major projects

The overarching groundwater assessment and reporting workflow of a project through pre-approval, impact assessment, monitoring and management, and compliance reporting, is presented in Figure 2 below.

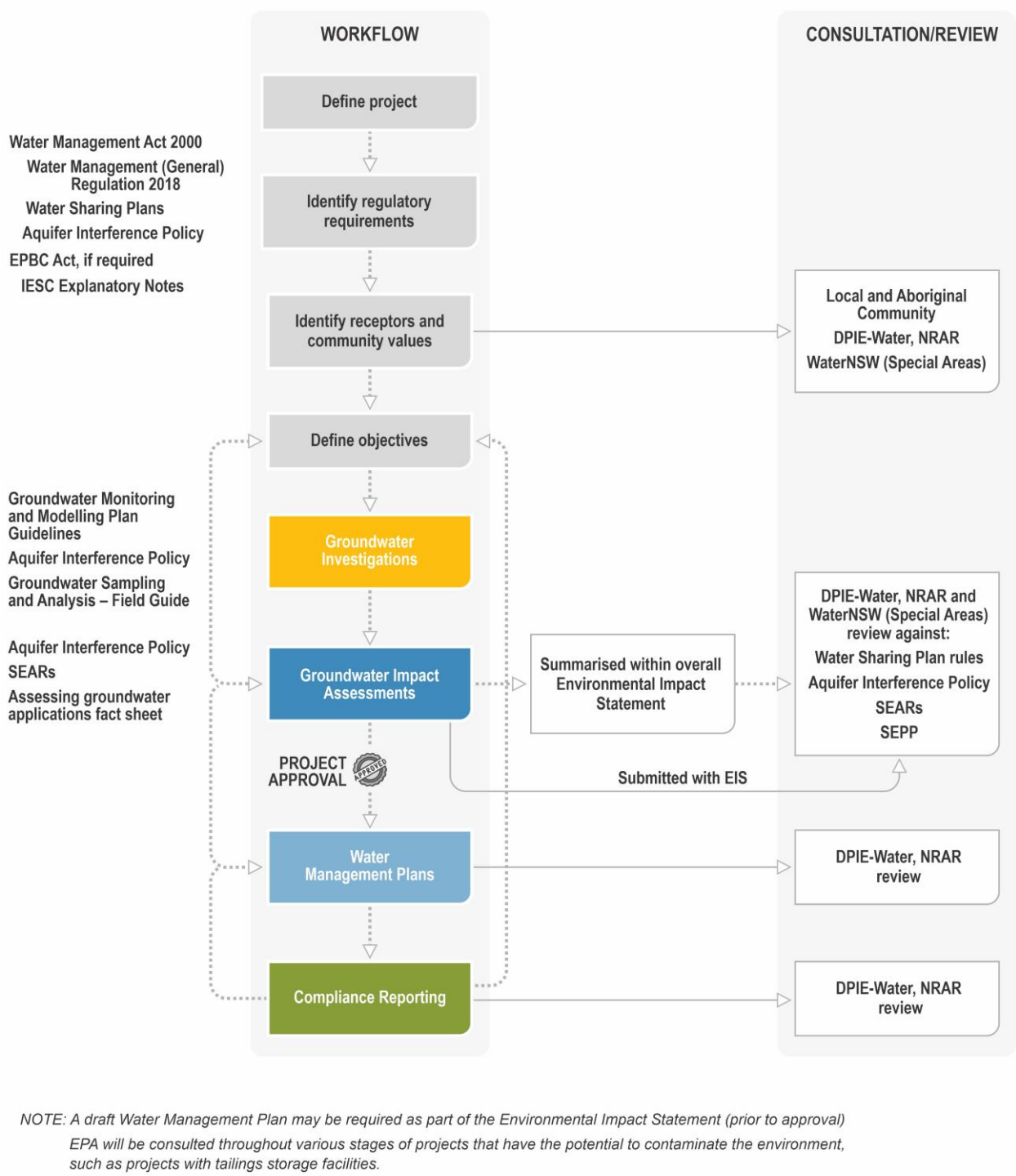

Figure 2: Groundwater assessments and reporting workflow for SSD and SSI projects

For a project progressing through this approval process, to document the groundwater assessment, there are four main stages required, these are:

Part A – Groundwater investigations

Part B – Groundwater impact assessments

Part C – Water management plans

Part D – Water compliance reporting.

3.1 Part A – Groundwater investigations

The steps involved in assessing impacts to groundwater from a major project are:

1. Data collation and assessment
2. Desktop assessment
3. Define baseline conditions
4. Preliminary hydrogeological conceptual model
5. Preliminary risk assessment
6. Gap analysis
7. Groundwater monitoring and modelling plan
8. Field investigations and establishment of monitoring network
9. Review hydrogeological conceptual model
10. Report on findings of 1 to 9.

To guide the development of the plans and reports in steps 1 to 9, Section A2 of *Guidelines for groundwater documentation for SSD/SSI projects* details the data requirements. These are

summarised in Section 3.1.1.

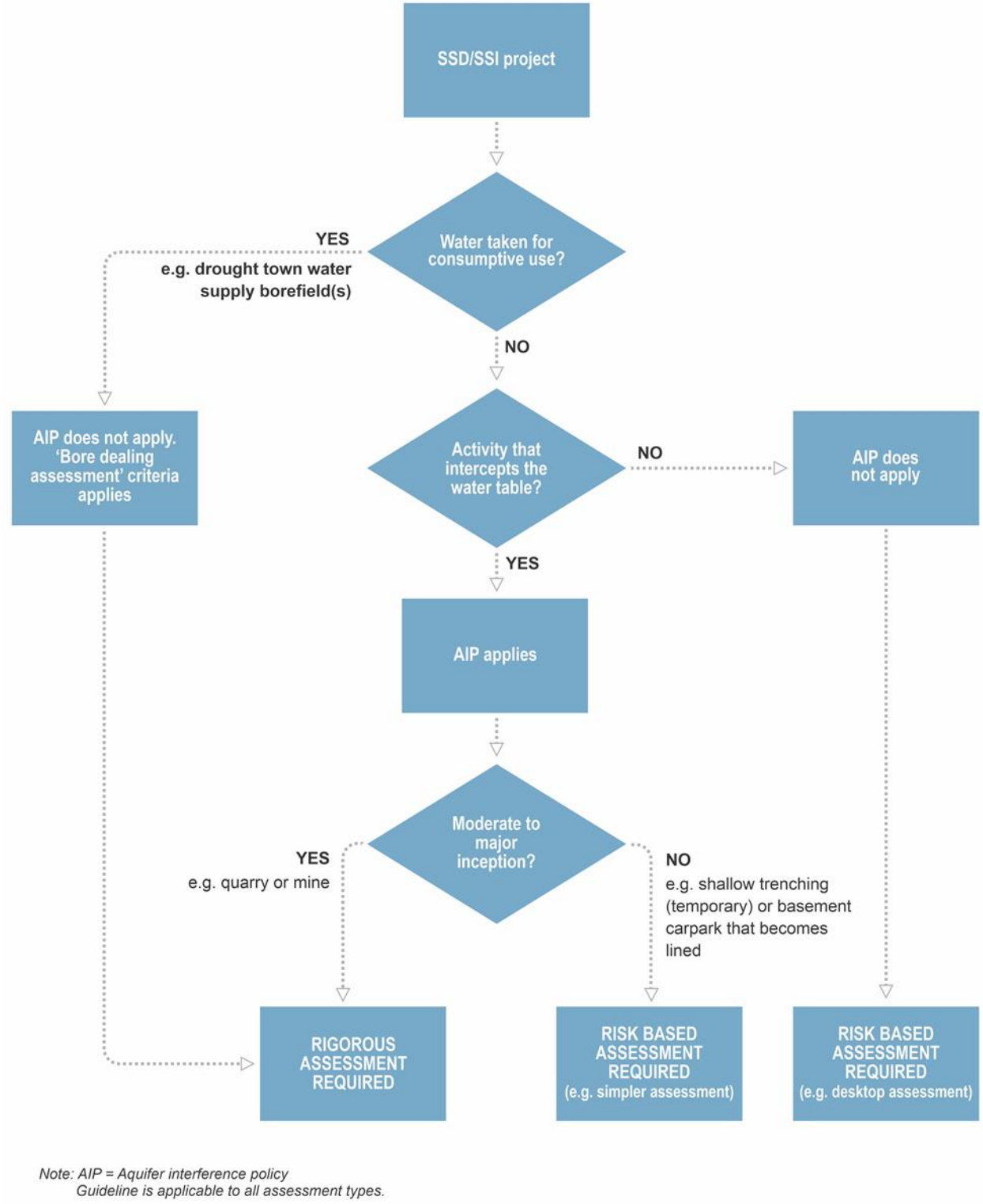

Figure 3 presents a workflow for selecting the type of groundwater assessment required for the project.

Figure 4 illustrates the typical stages of groundwater investigations conducted to inform groundwater assessments where a groundwater system may be impacted.

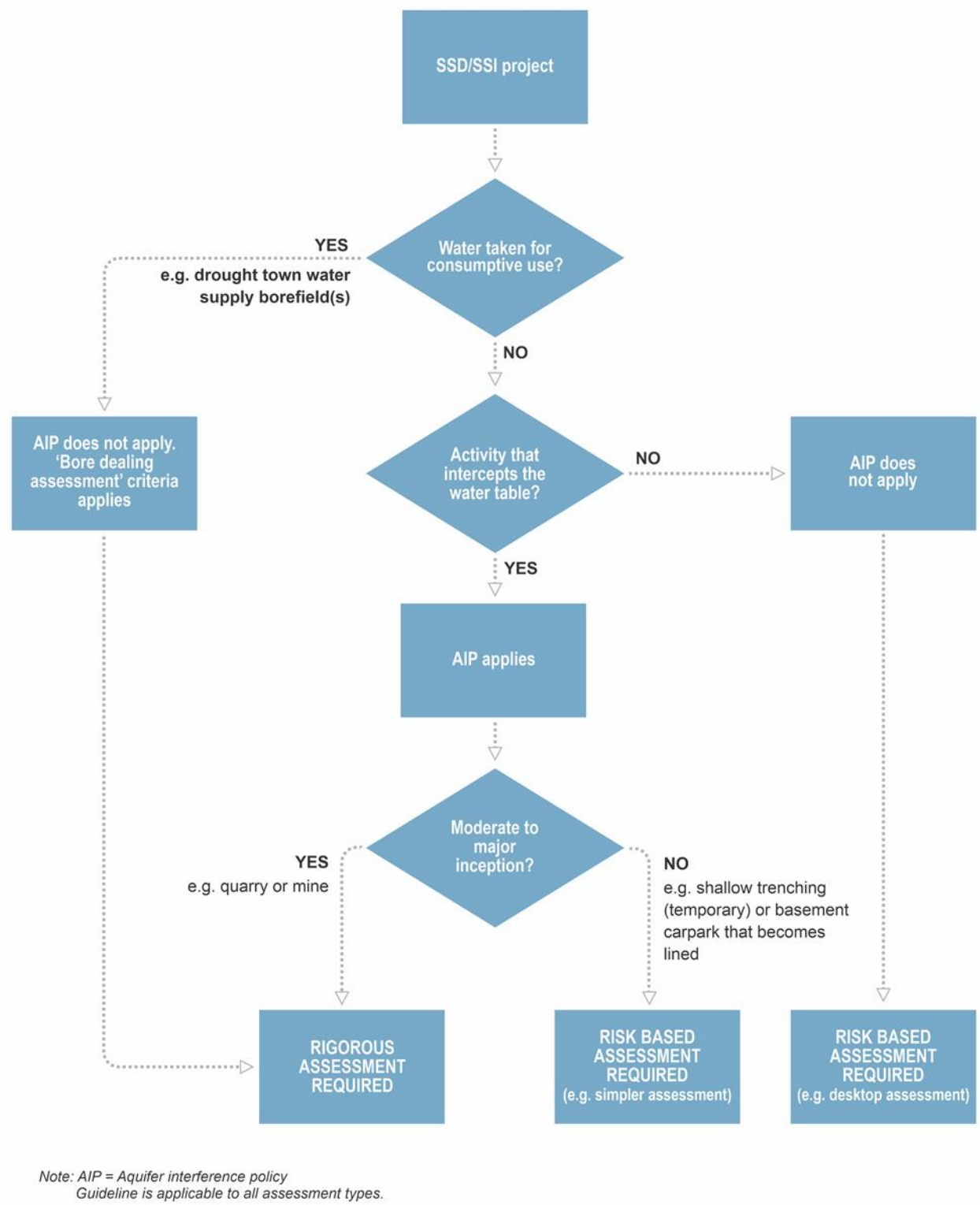

Figure 3: Type of groundwater assessment required

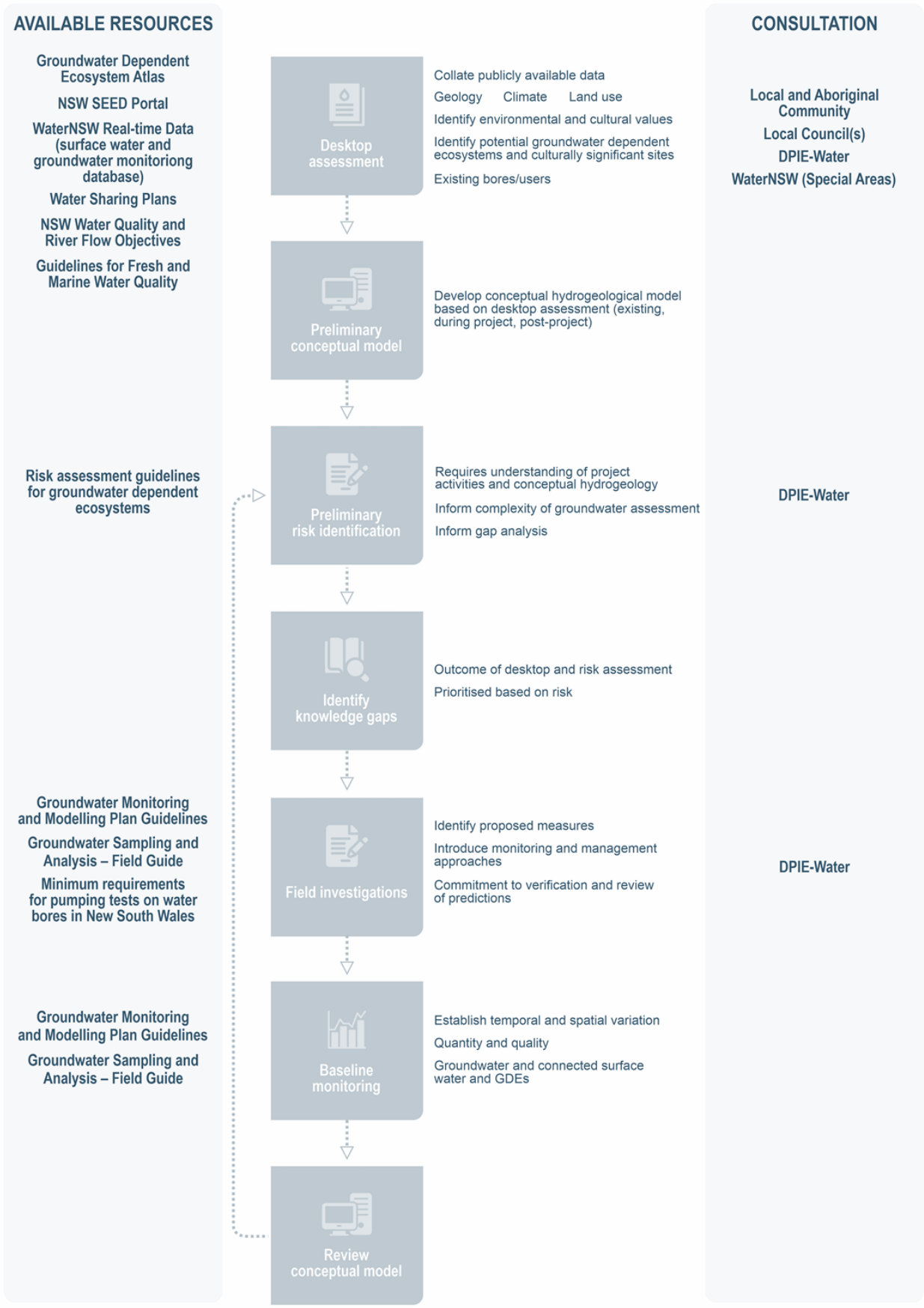

Figure 4: Typical stages of groundwater investigations to inform groundwater impact assessments

3.1.1 Data collation and assessment

The following data are either mandatory and/or instrumental for the department to process your application.

For projects that the proponent does not expect to intersect the water table, you must ensure that:

- sufficient groundwater data (spatially and vertically) are available to demonstrate that the proposed activities will not intersect the water table
- sufficient baseline temporal monitoring data is obtained to demonstrate that the proposed activities will not intersect the water table under varying climate and/or surface water flow conditions.

For projects that intersect the water table, you must ensure that:

- Sufficient groundwater (and related surface water) data are available to:
  - define baseline conditions (see point 2 below)
  - describe the hydrogeological conceptual model)
  - assess the potential changes to groundwater and surface water resources due to future operations.
- A minimum of two years of baseline monitoring data is typically required to capture two seasonal cycles. It is recognised that climatic variation may be significant over periods in excess of two years; however, there may be practical limitations to collecting data for longer periods.
- Any publicly available data for longer historical periods across the region and within the same groundwater source(s) are considered and referenced in the groundwater impact assessment (GIA).

If it is not possible to collect two years of baseline data, an additional risk assessment and gap analysis must be conducted to document the impact on the project and a future monitoring plan developed.

Refer to Table 2 in *Guidelines for groundwater documentation for SSD/SSI projects* for more detail on data requirements.

Figure 5 presents categories of understanding of a groundwater system on the basis of available data and information; the more data and information collated, the greater the understanding.

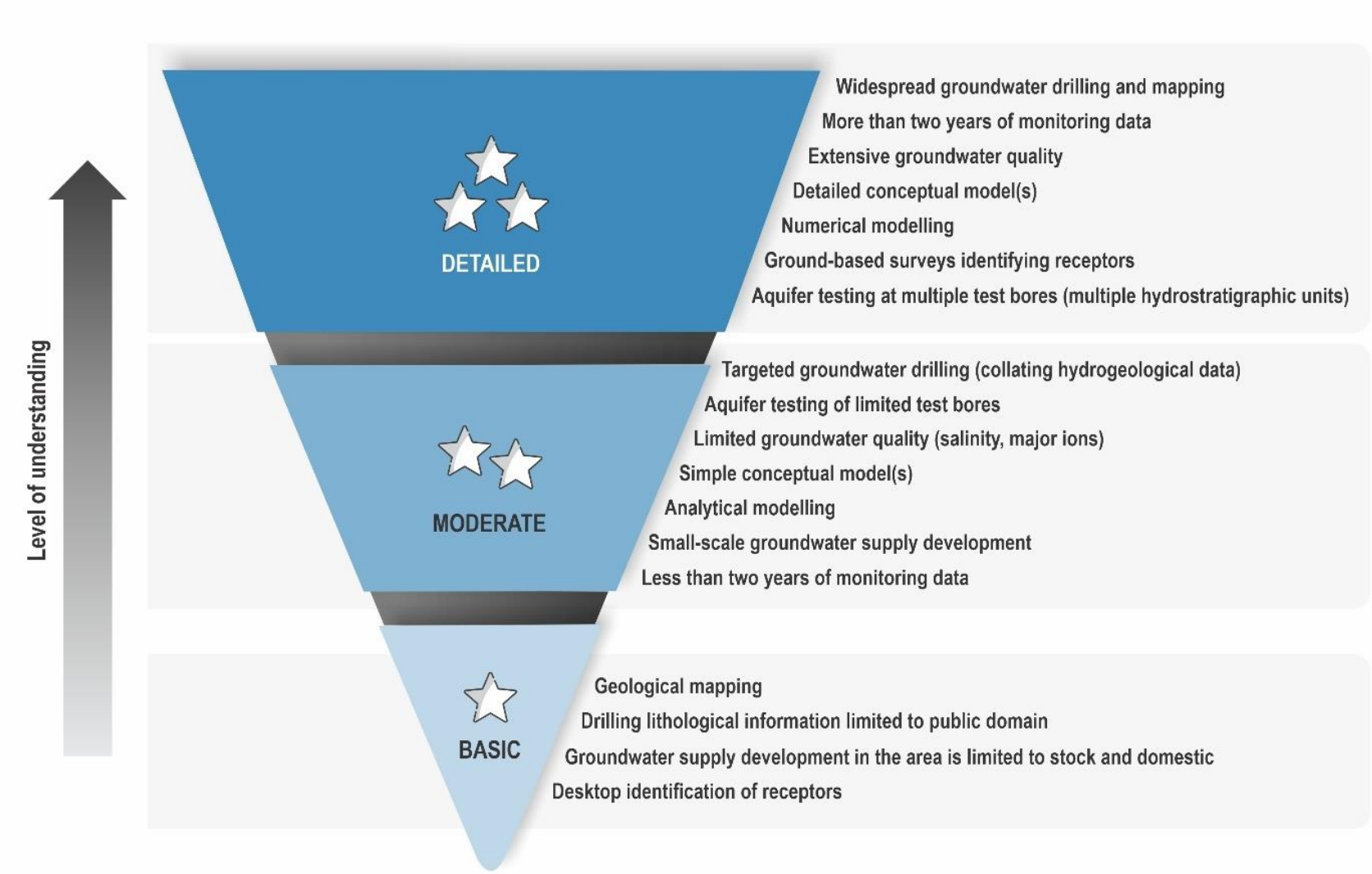

Figure 5: Information complexity and related data sources (adapted from Howe and Dettrick 2010)

3.1.2 Desktop assessment

The proponent must conduct a desktop assessment where publicly available and project data sources are collated, assessed for quality and where data relevant to the project is documented and made available to regulators. The desktop assessment should include collation of all relevant available data, information and past technical studies undertaken in the early stages. This informs the preliminary assessment of the hydrogeological setting and design of future investigations.

All data collected should be presented in a database that clearly identifies the source and categorises the data reliability as Poor, Moderate or High, as detailed in Section A.3.3 *Guidelines for groundwater documentation for SSD/SSI projects*.

Extra effort applied at this stage will avoid unnecessary replication where data and monitoring infrastructure already exist.

The outcome of the desktop assessment is the preliminary hydrogeological conceptual model. If insufficient information is present to develop this model, the proponent will need to conduct and document field investigations to address gaps.

Refer to Section A.3 *Guidelines for groundwater documentation for SSD/SSI projects* for more detail.

The following desktop-based information is used to inform the baseline assessment and hydrogeological conceptualisation:

- Geographical information: topography, climate, drainage and surrounding land use
- Geological information: comprising the local stratigraphy (including a stratigraphic column), lithology and mapped geological structural features to at least the depth of the proposed project
- Hydrogeological information and data: local hydro-stratigraphic units, existing groundwater development, aquifer management, regional monitoring networks, groundwater levels/pressure and quality, bore search, environmental and cultural values, and vulnerability of the aquifers
- Groundwater receptors: groundwater users, potential groundwater-dependent ecosystems (GDEs), culturally significant site and connected groundwater and surface water sources.

As part of the desktop assessment and through consultation with stakeholders (including local community, Aboriginal community, council, the department's Water group), the proponent should identify environmental and cultural values for the surface water and groundwater sources in the project area. Establishing the values early on allows the development of management objectives and informs the impact assessment.

Guidelines for *Groundwater documentation for SSD/SSI projects* Section A.3.3 provides a list of publicly available datasets relevant to NSW projects. In addition to these sources, proponents can request specific groundwater and surface water data from WaterNSW.

3.1.3 Baseline condition assessment

Using data collected during the data collation and baseline assessment, report on the baseline condition of climate, groundwater, and surface water for the project area.

3.1.4 Preliminary hydrogeological conceptual model

The preliminary hydrogeological conceptual model is generally based on a number of assumptions and will need to be continually updated as new data and information is gathered. The hydrogeological conceptual model should be presented graphically through the use of cross-sections and three-dimensional (3D) block diagrams, with supporting descriptive text and charts to

describe the hydrodynamics. Refer Part B *Guidelines for groundwater documentation for SSD/SSI projects* for further detail.

The preliminary hydrogeological conceptual model should be developed as an outcome of the desktop assessment, to identify:

- hydro-stratigraphic units including:
  - their extent (spatially and vertically)
  - characteristics (aquifer or aquitard), hydraulic conductivity, storage parameters
  - water quality
  - water pressure (or total head)
  - recharge and discharge features
- mechanisms for recharge and discharge
- geological structures and conceptual boundaries
- interpreted directions and magnitude of groundwater flow/flow pathways
- surface water-groundwater interactions
- water sources (highly productive vs less productive)
- environmental and cultural values, and potential receptors (social, economic, environmental and cultural)
- existing bores (monitoring, investigation, operating/production, private and government owned)
- climate variability
- existing groundwater development and use in the area (for example, irrigation areas, town water supply borefields)
- activities or infrastructure likely to be intersecting groundwater (for example quarries, mines, tunnels)
- sources of potential contaminants (for example, waste storages, water treatment plants).

3.1.5 Preliminary risk assessment

Following the development of the preliminary hydrogeological conceptual model, a qualitative risk assessment should be developed, which will inform the requirements for the type and density of data required to estimate baseline conditions, further develop the hydrogeological conceptual model and inform the GIA. The principles of risk assessment should be considered and are well documented. For example, international standard (ISO) 31000:2018 provides guidance on risk management, framed around the principles, framework and process of risk identification and management.

Risks, including cumulative, at a scale appropriate to the project and affected groundwater system, should be identified. Section 3.3 *Cumulative impacts information paper* provides more details of cumulative impacts that should be considered in this risk assessment.

3.1.6 Gap analysis

Knowledge gaps will have been identified as an outcome of the preliminary risk identification and preliminary hydrogeological conceptual model developed in the desktop stage of the assessment.

For an SSD/SSI-scale project, a field investigation program is typically required to fill knowledge gaps and develop a monitoring network to collect baseline data.

Refer to Table 4 in *Guidelines for groundwater documentation for SSD/SSI projects* for examples of data gaps and field investigations that can be used to address them.

3.1.7 Groundwater monitoring and modelling plan

The groundwater monitoring and modelling plan (GMMP) would typically be developed following the desktop assessment and development of the preliminary hydrogeological conceptual model. A GMMP, developed in consultation with the NSW Government, ensures the data requirements, such as the establishment of a baseline and a history of data, that cannot be met retrospectively, are considered at the exploration phase of a mining or petroleum project.

A GMMP is required for all onshore petroleum projects, projects that have identified cumulative impacts and all projects that meet the AIP guidelines.

For projects that have identified potential cumulative impacts, Section 6.3 *Cumulative impacts* provides more detail on monitoring and mitigation plans and activities required to address these impacts. The responsibility for monitoring and mitigation of cumulative impacts may be shared among multiple parties or, in instances where cumulative impacts are between a project's activity and natural conditions, the responsibility may reside with a single operator.

For mining and petroleum projects, a groundwater monitoring and modelling plan (GMMP) must be developed in the early stages of the project (as part of exploration drilling activities) in accordance with the GMMP guideline (former DPI Office of Water 2014).

GMMPs are required as a standard condition of licence for exploration drilling under the *Mining Act 1992* and *Petroleum (Onshore) Act 1991*. GMMPs document proposed groundwater, and related surface water, monitoring programs to inform:

- assessment of baseline and regional conditions
- hydrogeological conceptualisation
- time series data for future groundwater model calibration.

A GMMP is a live document that needs to be developed and updated as a project progresses, in consultation with the department's Water group, to ensure the groundwater monitoring requirements, which can have a long lead time, are adequately planned and underway when required.

3.1.8 Field investigations and establishment of monitoring network

The GMMP guides the development of a comprehensive monitoring network. Section A8 of *Guidelines for groundwater documentation for SSD/SSI projects* provides a discussion of examples of monitoring that can be used to collect data to assess groundwater impacts. The Water Act requires that field investigations and monitoring be conducted by appropriately qualified personnel.

The aims of field investigations are to:

- fill identified knowledge gaps
- validate assumptions
- replace forecast values with measured
- quantify the water balance
- provide model input and calibration data
- identify seasonal trends and variability
- demonstrate compliance with licence conditions
- improve understanding of the regional groundwater system.

3.1.9 Review hydrogeological conceptual model

As field-based data is collected and assessed, the assumptions and input data used to develop the preliminary hydrogeological conceptual model and risk assessment should be reviewed. As more

data is collected, knowledge gaps should be reduced, increasing understanding, reducing conceptual uncertainty and potential risks. Refer to Section A.9 for more detail.

3.1.10 Report on findings of groundwater investigations

The outcomes of the desktop assessment, field investigations, baseline conditions and understanding of the hydrogeological conceptual model is sometimes documented within the GIA or as an appendix to the GIA report.

The department's Water group requires the information to be provided as part of the GIA/EIS as it is the supporting evidence and basis of the impact assessment.

3.2 Part B – Groundwater impact assessments (GIA)

This chapter discusses:

- Overview
- Context setting
- Hydrogeological conceptual model
- Impact assessment
- Risk assessment review
- Mitigations, management and monitoring
- Licensing considerations.

3.2.1 Overview

A GIA should:

- be clear, concise, transparent, written in plain English and self-contained for ease of use
- (if appropriate) meet the requirements of the AIP, including use of the aquifer interference assessment framework
- meet the requirements of the SEARS, relevant water sharing plans and water resource plans
- address other relevant legislative and policy requirements
- be scientifically robust, evidence-based assessments supported by diagrams and graphics
- demonstrate an understanding of the water environment, water affecting activities and potential impacts.

The GIA must consider the Source – Transport – Receptor model of impact assessment.

The recommended stages of a GIA are listed in Figure 6, along with available resources for some stages and guidance on when consultation with stakeholders, including the department's Water group, should occur. It is recommended that these stages form the basis for the GIA report structure for ease of the department's review. Each stage is discussed further in the following sections.

The findings of the desktop assessment and groundwater investigations conducted by the proponent (refer Part A of this guideline), including baseline monitoring, should be documented in the GIA report, setting the context and the basis for undertaking the impact assessment.

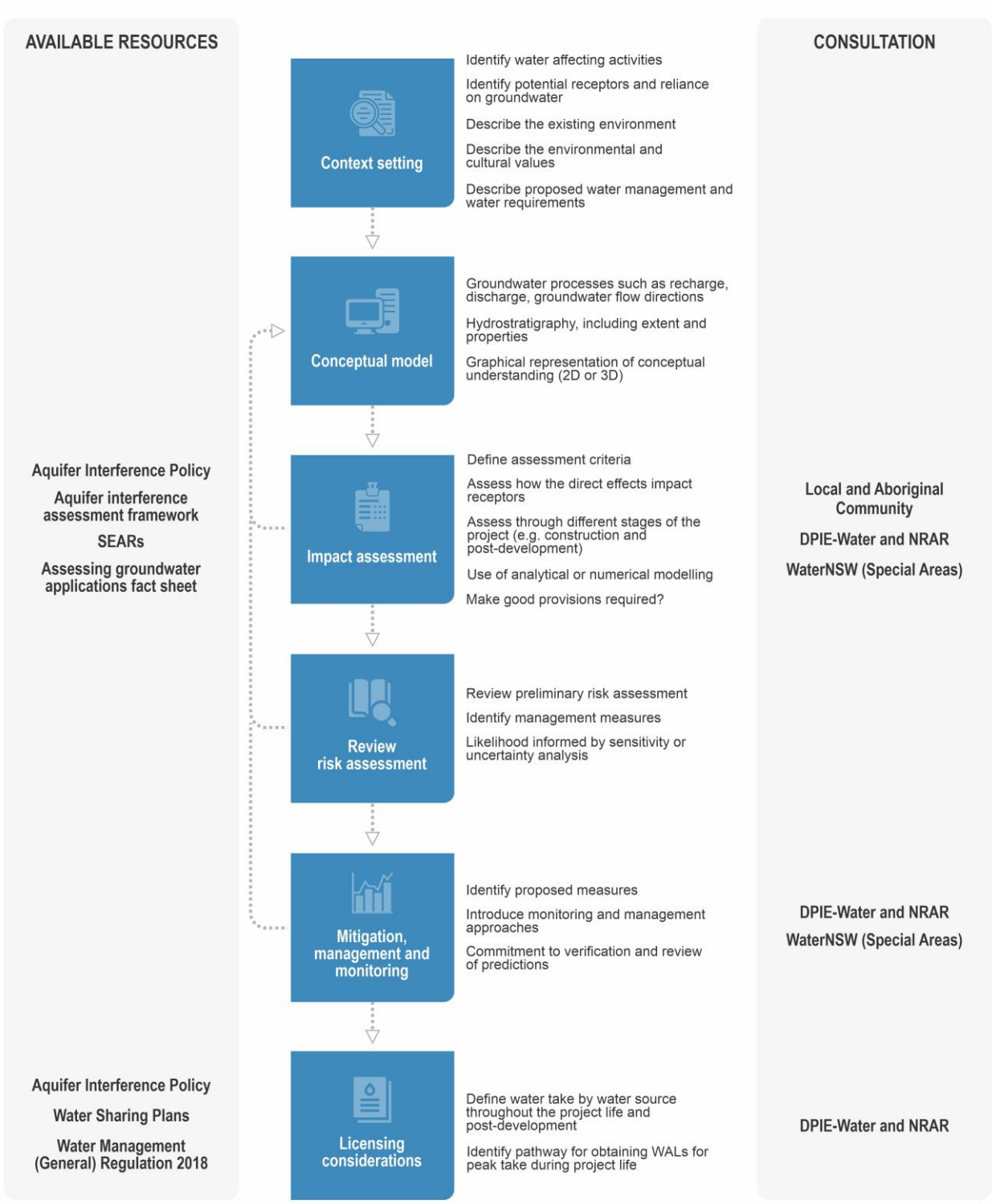

Figure 6: Groundwater impact assessment flow chart

3.2.2 Context setting

Context setting places the project into a regional context, focusing on hydrogeology but also providing an overview of topography, climate, geology and hydrology. The development of a robust hydrogeological conceptual model is a key component of this stage of the assessment (discussed in more detail in the next section). It is important at this stage to engage stakeholders and communicate the proposed project, environmental context and management actions.

Once the context has been established, management objectives should be set to manage and mitigate the identified impacts. Further detail is provided in B.2 of Guidelines for *Groundwater documentation for SSD/SSI projects*.

3.2.3 Hydrogeological conceptual model

Following completion of the groundwater investigations, including updates of preliminary hydrogeological conceptual model, the hydrogeological conceptual model should be finalised and documented.

Proponents are required to provide graphical representation of the hydrogeological conceptual model in the GIA report, through the use of 2D cross-sections and /or 3D block diagrams.

The GMMP guidelines, AIP and *Australian groundwater modelling guidelines* (Barnett et al 2012) provide guidance on the requirements of a hydrogeological conceptual model. The proponent should consider developing conceptual models for the pre-development, development and post-development stages of a project.

Table 2 presents a summary of the information to be documented.

Table 2: Hydrogeological conceptual model components

Component	Information to be documented
Climate	Variation in rainfall, temperature and evaporation
	Supporting charts/figures showing seasonal variation and describing recent and historical climate trends
	Supporting charts and maps showing locally monitored rainfall data recorded during the baseline period used to inform the conceptual understanding
Water sources	Alluvial, porous rock, fractured rock – as defined in relevant water sharing plans
	Identifying highly productive vs less productive sources
	Identifying if it is a highly connected systems
	Supporting maps showing water source extents
Geology	Description of regional and local geology
	Stratigraphic column
	Supporting maps showing surface geology (regional and local scale) and mapped geological structures
	Supporting maps showing extent of proponent geological model and location of mineral drillholes (if relevant)

Component	Information to be documented
Hydro-stratigraphic units	Description of aquifers/aquitards
	Spatial and vertical extent, with consideration of boundaries such as geological structures
	Boundaries such as geological structures (faults, folding, shear zones, intrusions)
	Supporting maps showing spatial extent, depth, elevation and thickness of hydro stratigraphic units
Hydraulic properties	Location, type and number of aquifer tests
	Supporting maps showing spatial coverage of aquifer tests identified by hydro-stratigraphic unit
	Range in estimate hydraulic properties (Kv, Kh, Ss, Sy) from measured data
	Range in hydraulic properties (Kv, Kh, Ss, Sy) from literature reviews
	Results of aquifer test analysis appended to the GIA for quality assurance
Groundwater monitoring network	Location and type (for example, VWPs or standpipe) per hydro-stratigraphic unit
	Presentation through the use of tables providing the location (coordinates), screened interval, screened lithology, GW identification number (as provided by WaterNSW) and proponent identification (if desired)
	Supporting maps showing the spatial coverage of the monitoring network, identified by hydro-stratigraphic unit and identifying use of proponent installed bores, landholder bores and government bores, where applicable
Topography and drainage	Identification and description of watercourses, including seasonal variation and stream gauge data if available
	Topographic and geomorphic information including stream locations and bed elevations
	Supporting maps showing topography and drainage lines in the project area
	Description of surface water quality, through the use of supporting charts and maps showing the location of surface water monitoring/sampling locations
Groundwater levels and flow direction	Spatial, temporal and vertical variation in groundwater elevation and gradients
	Supporting maps showing mapped depth to water table, water table and groundwater elevation for various unconfined and confined hydro-stratigraphic units, showing locations of measured data and inferred groundwater flow directions
	Supporting charts/figures showing seasonal variation and response to recent and historical climate trends

Component	Information to be documented
Groundwater levels and flow direction	Supporting charts/figures showing vertical gradients
	Supporting QA/QC information for monitoring data, including VWPs and/or pressure transducer data loggers (such as correction for barometric effects, density effects, instrument drift)
Groundwater quality	Spatial, temporal and vertical variation in groundwater quality
	Supporting maps showing variation in salinity for various hydro-stratigraphic units
	Supporting laboratory reports and sampling methodologies for quality assurance purposes
	Supporting charts/figures showing statistical variation and trend analysis
Recharge and discharge processes	Estimates of inputs and outputs to the local and regional groundwater system, including description on processes and estimates of quantities
	Description of recharge (for example, rainfall infiltration, irrigation, surface water), discharge (for example, baseflow, groundwater pumping, coastal), throughflow
	Supporting data used to derive estimates (for example chloride mass balance or literature)
	Groundwater age, residence time through the use of isotope analysis
Receptors	Location and type of receptors (social, economic, environmental/ecological and cultural)
	Supporting maps showing mapped GDEs sourced from water sharing plans and BoM GDE Atlas
	Supporting maps showing field-based mapped GDEs, derived through consultation/collaboration with ecological specialists
	Supporting maps showing cultural receptors identified through consultation
	Supporting maps showing the location of existing bores monitoring, investigation, operating/production, private and government-owned), including licensed users and stock/domestic users
Surface water-groundwater interaction	Description of surface water-groundwater interaction through assessment of water quality, field observations and stream flow data
	Supporting charts and maps
Existing groundwater development	Location and description of existing activities, such as irrigation areas, quarries, mines
	Supporting maps showing the location of the identified activities in proximity to the proposed project and receptors

Component	Information to be documented
Proposed project activities	Location and description of proposed water-affecting activities for the project, including sources of potential contamination (for example, waste storages, water treatment plants, tailings storage facilities)
	Supporting maps and charts presenting the proposed activities at key stages of the project (for example, construction, operations, changes to the water management system, post-development, rehabilitation)

Notes: Kh = horizontal hydraulic conductivity, Kv = vertical hydraulic conductivity, Ss = specific storage, Sy = specific yield

3.2.4 Impact assessment

Once the water-affecting activities and potential receptors have been identified, through the hydrogeological conceptual model and risk assessment, proponents need to assess the potential impact of the activities on the identified receptors and estimate the water take from each relevant water source (as an annualised volume).

Direct effects encompass the changes to physical and/or quality aspects of groundwater due to aquifer interference activities, or the changes to the physical characteristics of aquifers affected by these activities.

Direct effects of water-affecting activities can result in adverse impacts on receptors. The assessment of potential receptor exposure to adverse changes in groundwater and connected systems (quantity, quality, groundwater and surface water interactions and physical disruption of aquifers) requires the following:

- Knowledge of the location of receptors within the landscape
- An understanding of the receptor reliance on groundwater
- An understanding of the capacity for receptors to adapt to altered groundwater regimes (resilience and resistance)
- An understanding of the spatial and temporal scale of direct effects at the location of identified receptors.

Section B.4 of *Guidelines for groundwater documentation for SSD/SSI projects* Table 7 to Table 11 present example water-affecting activities and potential effects typically associated with major aquifer interference projects in NSW (open cut mining including quarries, underground mining, petroleum projects and tunnels), the potential duration of the effect and associated impact on a receptor.

Section B.4.2 of *Guidelines for groundwater documentation for SSD/SSI projects* contains details of the assessment approach to be used.

Impact assessment criteria are presented in 4.3 of *Guidelines for groundwater documentation for SSD/SSI projects*.

Proponents should clearly document the assessment criteria used in the impact assessment. The assessment of project-related impacts to water resources and water users should consider:

- management objectives based on environmental and cultural values and NSW water quality objectives
- the requirements of the:
  - WM Act
  - relevant water sharing plans
  - AIP (if relevant)

- state environmental planning policies (SEPP) (such as Sydney Drinking Water Catchment) 2011 (if relevant)
- IESC guidelines (if relevant)
- *Australian groundwater modelling guidelines* (Barnett et al 2012) (if relevant).

3.2.5 Risk assessment review

Following evaluation of the project activities and potential impacts on groundwater, connected surface water and associated receptors associated with these activities, the preliminary risk assessment completed during the groundwater investigation should be updated. At this stage, the proponent's knowledge of the groundwater system as described in the hydrogeological conceptual model will be much more advanced (following completion of the field investigations and groundwater assessment).

Once the risks and uncertainties are considered and documented, the proponent must develop strategies to minimise the risks. The risk rating for an identified hazard should then be reviewed with consideration of mitigation and management strategies (control measures). Mitigation, management and monitoring is discussed further in the next section

3.2.6 Mitigations, management and monitoring

Recommended management, mitigation and monitoring measures should be identified as part of the risk assessment, as controls to manage and reduce the likelihood of a potential adverse impact to a receptor from occurring. Water management strategies can take a number of forms and these strategies should be summarised in the GIA report.

As part of this process, the model should be reviewed, and new information incorporated to improve understanding of the groundwater system.

A high-level summary of the technically feasible and measurable management and mitigation measures must be reported in the GIA.

At this stage of the process, the proposed management measures should be SMART (specific, measurable, achievable, realistic and time-bound):

Following project approval, the proponent will then prepare a follow up and detailed WMP(s) or updated GMMP to document:

- mitigation and management requirements for the project (through various stages). For example, make-good strategy, or biodiversity offsets
- monitoring program, including network, with consideration of project water-affecting activities (for example, sludge lagoon(s), water storages, tailings storages) and receptor location
- trigger action response plan(s) (TARP), which will define contingency plans and remedial measures.

3.2.7 Licensing considerations

Any take of water is licensed by the water source for where the water is taken. These takes must be licensed and the total annual volume of water estimated to be taken from each water source (incidental take) as a result of an aquifer interference activity (during and post-development) and/or a bore/borefield must be clearly reported in the GIA/EIS.

Section 3.2.3 of the AIP requires that proponents hold water entitlements equivalent to the predicted maximum annual water take prior to the commencement of the project, regardless of when the water will be taken.

Relevant guidelines, references and information:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality – Management Framework; Guideline Values
- Groundwater Monitoring and Modelling Plans – Information for prospective mining and petroleum activities
- Water Sharing Plans
- NSW groundwater-dependent ecosystems information
- Minimum requirements for pumping tests on water bores in New South Wales (DPIE 2019)
- Risk assessment guidelines for groundwater-dependent ecosystems (Serov et al 2012)
- Minimum Construction Requirements for water bores in Australia (NUDLC 2020)
- Groundwater Sampling and Analysis – A Field Guide (Sundaram et al 2009).

3.2.8 Groundwater modelling

The AIP requires that all projects that take water from aquifers model the impact of that take from aquifers. Major project proponents are required to use groundwater models to estimate direct and induced surface and groundwater takes due to their proposed and/or ongoing activities. The modelling assessment must clarify potential impacts to the aquifer and aquifer values. **Error! Reference source not found.** presents examples of major projects that require a groundwater model.

Table 3. Examples of major projects in NSW that require preparation of a groundwater model

Mines and quarries	Infrastructure and energy production	Residential, commercial, and services
Mining exploration and operation: Underground coal mines (long wall, bord and pillar, drive shafts), hard rock mineral mines (open cut and underground), open cut coal mines, and underground mineral sand mines.	**Power stations:** Solar farm, hydroelectric, transmission lines, substations, wind farm, and battery farms.	**Residential:** Subdivisions, basement car parks, and tower blocks
Quarries: Sand dredge (rivers or coastal dunes), hard rock, gravel (river dredge), and limestone.	**Roading infrastructure:** Motorways, tunnels, road cuttings, and bridges.	**Commercial:** Transport depots, intensive farming (piggeries, chickens, fish), abattoirs and industrial estates.
Gas: Coal seam, and conventional	**Railway infrastructure:** Overground railway lines, underground railway lines, underground stations, tunnels, and bridges.	**Services:** Hospital, and correctional facility.
n/a	**Utilities:** Water supply (pipelines groundwater supply bore fields), and waste management facilities (landfill).	n/a

Groundwater modelling guidelines already exist at the national level, principally the *Australian groundwater modelling guidelines* (AGMG; Barnett et al., 2012).

The department has prepared a technical note – *Minimum groundwater modelling requirements for major projects in NSW* (MGMR-MP). The MGMR-MP is intended to supplement the AGMG and comprises a superset of groundwater modelling requirements for NSW. In particular, the MGMR-MP adds the following guidance to that contained in the AGMG:

- guidance on how to apply the requirements of the AIP to the modelling process
- where applicable, incorporation of the stipulations of the IESC.

Most importantly, the MGMR-MP gives clear direction on the department's requirements for planning, documentation and presentation of the results of the modelling process. Under the MGMR-MP, a groundwater modelling report must be developed to provide transparency and consistency to the broader community related to how models are used to assess potential groundwater impacts of proposed major project and projects that are subject to the AIP.

As stipulated in the MGMR-MP, numerical groundwater models must follow the following sequence:

- Conceptualisation
- Numerical model implementation
- Reporting
- Review
- Archiving.

Minimum requirements of the MGMR-MP for groundwater modelling are:

- A groundwater monitoring and modelling plan (GMMP) be prepared and submitted to the department's Water group prior to starting the modelling project.
- Develop a document for a robust conceptual model of the site, the project, and other neighbouring projects. The conceptual model may be developed as a series of maps, cross-sections, block models, and tables of aquifer characteristics.
- A mathematical model can then be developed to develop quantitative predictions.
- The model shall be calibrated to find model parameter values (and ranges of values) that are useful for predictions of future conditions, not just to reproduce past data.
- A sensitivity analysis during calibration is carried out to evaluate the relative sensitivity of model predictions of the various model input parameters and boundary conditions on both model calibration and predictive outputs.
- Estimates shall be made of all water likely to be taken from any water source during or following the activity, including indirect takes (leakage or recharge).
- Where recharge and/or evapotranspiration are large components of the system water balance, the modelling process should include assessment of climate change.
- Where predictive uncertainty may have a significant impact on the environment or other authorised water users, the modelling should include uncertainty analysis.
- The technical report must describe the basis for the model, key assumptions, modelling approach, limitations, and the study findings, conclusions, and recommendations.
- Modelling archives should be provided to the department and must include documented data analysis, modelling data and software program files (if they can be provided in accordance with copyright or distribution agreements).
- 3rd-party independent review should be conducted and reported, to ensure the modelling has been conducted consistent with the MGMR-MP.

- The completed model provided to the department must be fit for purpose to the satisfaction of the department.

3.3 Part C – Water management plans (WMP)

Under the minister's conditions of approval (CoA) issued for SSD/SSI projects under the EP&A Act, proponents are required to submit a range of post-approval reports to the department.

The WMP should demonstrate how the proposal will be capable of complying with statutory obligations under all water-related licences and approvals.

WMPs should be practical and binding, providing clear direction to personnel responsible for its implementation. The plans should detail all relevant CoAs and management measures upfront, referencing how (and where) they are addressed in the plan (or sub-plans).

The recommended stages of a WMP development (with a groundwater focus) are listed in Figure 7, along with available resources for some stages and guidance on when consultation with stakeholders, including the department's Water group, should occur. Each stage is discussed further in sections C.2 to C.10 of *Guidelines for groundwater documentation for SSD/SSI projects*.

Figure 7: Water management plan workflow

3.4 Part D – Water compliance reporting

When the project has been approved and is underway, to demonstrate compliance with CoAs, the project is required to prepare reports on the ongoing operations and the impact of the operations on the groundwater resource. Often these reports are submitted as part of the project annual return.

Annual environmental reports are post-approval documents typically required by the CoAs under the EP&A Act. Large, complex projects may require more frequent reports to multiple agencies, as detailed in the CoA. Typically, groundwater compliance reports require a review of groundwater performance against established baseline conditions or trigger levels. Best practice is to ensure that data be collected, analysed and reported in accordance with the CoA.

Figure 8 illustrates the typical workflow/stages in the preparation of water compliance reporting. These are discussed in the Sections D.3.to D.10 of *Guidelines for groundwater documentation for SSD/SSI projects* and can be used by the proponent to form the structure of the compliance report.

Figure 8: Typical water compliance reporting workflow

4 Best practice in presentation

The department requires that best practices are used during the application of groundwater impact analysis.

Key recommendations are provided below. These recommendations should be considered by project proponents during early stages of project planning to improve the prediction capability of the models and reduce the likelihood of permit delays due to incomplete groundwater or cumulative impact assessments.

- Include cumulative impact analysis as part of the design of a study. It is very difficult to account for retroactively.
- Develop the approach for a conceptual model and an analytical or numerical model prior to commencing baseline data collection. Submit approaches for review and collaborate with the department and other agencies to confirm the scope of the required technical study and groundwater model. Coordinate a meeting with the department and other agencies to discuss the approach.
- Collaborate with the department from initial scoping through final submittals for the proposed project.
- Define the spatial scope of cumulative impact studies on the extent of potential resource impacts, rather than the boundaries of the project.
- Consider the timing of impacts, as impacts to water resources, especially groundwater, may be delayed compared to operational periods for projects.
- Consider the degree of uncertainty in the hydrogeological system when establishing the area for analysis and determining whether other projects need to be incorporated into the analysis.
- Collaborate on planning with internal and external stakeholders, including adjacent projects while performing cumulative impact analyses.
- Conduct a qualitative risk assessment during conceptual model development since it can be used to navigate the challenging process of determining the area of analysis.
- Incorporate receptors (for example, GDEs, BLR bores) into the conceptual model and understand whether impacts from other projects are predicted to intersect these features.
- Communicate and apply regulatory agency standards to resource studies and use open-source models, standard methods, common analyte lists, etc.
- Collaborate by sharing data collection and modelling as this provides decision-makers with alternatives to planning rather than relying on precautionary worst-case scenarios.
- Formulate predictions based on data collection and evidence (for example, measurements, raw data, collected information, etc.).
- Disclose and document the conceptualisation, methods, results, and sensitivity analyses to ensure a transparent presentation of cumulative impact analyses.
- Create a monitoring plan to update the analysis and predictions as required. Include mitigation in the event impacts are measured.
- Apportion responsibility for mitigation measures among multiple operators based on the degree of their respective individual impacts when the cumulative impacts are additive.
- Apportion responsibility for mitigation measures among multiple operators equally when the cumulative impacts are non-additive.

4.1 Presentation

With improvements in technology and digital platforms, some proponents are submitting EIS and supporting reports via online and downloadable report formats, sometimes supported by online web maps.

Such online visualisation of EISs, including GIAs, is encouraged by the department's Water group.

Presentation of the impact assessment results, groundwater management plan information and annual reports (or other compliance reports) needs to be clear, concise, transparent and written in plain English. More detail is presented in B.4.4 of *Guidelines for groundwater documentation for SSD/SSI projects*.

This includes (but is not limited to):

- Description of the groundwater system:
  - Clearly present the hydrogeological conceptual model using maps, sections, schematic diagrams and words
  - Clearly define assumptions, limitations and simplifications made in the assessment methodology
  - Clearly identify the ecosystems environments that may potentially, wholly or partially, rely on groundwater and also known GDEs that are predicted to be impacted
- Description of predicted operational impacts:
  - Present quantitative water balances for pre-development, construction and operational phases of the project (and if appropriate, post-development, until the groundwater systems recover or reach a new equilibrium)
  - Where applicable, present the predicted range in water table/potentiometric/groundwater level decline, under varying scenarios, or consider alternative conceptualisations
  - Using AIP criteria and GDE risk assessment (Serov et al 2012), describe the predicted effect that causes the impact (such as lower water table) and then how the impact will manifest
  - Where a project will not intersect the water table, the GIA must provide clear explanation and sufficient data to demonstrate that the activities will not intersect or interact with the water table
  - Where applicable, present cumulative impacts using maps to show predicted groundwater level (including water table), maximum drawdown and elevation. Use hydrographs to present predicted groundwater level change with time. Identified receptors should also be identifiable on maps.
  - Clearly justify and define the significance of the predicted impact(s), based on management objectives, environmental and cultural values, ecological significance, DoE (2013) Significant Impact Guidelines (where applicable).
- Description of post-operational impacts:
  - Use conceptual diagrams (such as cross-sections or 3D diagrams) to illustrate the predicted post-development hydrogeological conditions, including impacts on groundwater sources and/or connected surface water sources and/or at receptors
  - Describe predicted groundwater level recovery following completion/closure/decommissioning of the development.

4.2 Transparency

To give the community and regulators confidence, it is important that all data, assumptions, impacts, models, timeframes and uncertainties are made available to the department. In particular, follow the guidance presented in the GAT documents.

4.2.1 Minimum expectations for report content

The appropriate level of documentation will vary depending on the scope of the study objectives, the phase of the project and the complexity of the model simulations. At a minimum, all reports must present:

- the objectives of the study
- a description of the work that was done
- logical arguments to convince the reader that the methods and analyses used in the study are valid
- results and conclusions.

4.2.2 Maps, graphs, charts and tables

For all data deliverables within a report at all stages of the development, the department requires that the data used to develop the deliverable (map, graph, chart, table, etc.) be provided in an acceptable electronic format, together with a bibliography of all data files that have been provided. Example data submission files would be MS Excel, shape files, DXF, and any templates or automation scripts for commercially available software that was used to create the graphs, charts or maps.

4.2.3 Groundwater modelling report

4.2.3.1 Structure of the groundwater modelling report

In addition to the main GIA report, a stand-alone groundwater modelling report must be provided to provide transparency and consistency to the broader community and describe how the mathematical model(s) have been applied to assess the potential groundwater impacts of the project. Table 4 gives a recommended report structure for groundwater modelling reports presented to the department.

Table 4. Example model report structure (compiled from ASTM, 2013; Barnett et al., 2012)

	Title	Description
1	Report title	The title should reflect the model and project objectives rather than just the study location.
2	Executive summary	The detailed model report includes a brief, executive-style report to summarise the major findings of the study for non-technical audiences.
3	Introduction and model objectives	Clearly state the modelling objectives, the purpose and goals of the study, and the applicability of the model as part of the study. Discuss what types of predictions are to be made with the model. Include the target confidence level.
4	Conceptualisation	This section describes the current level of understanding of the aquifer system and how this is translated into a conceptual model to address the model objectives. Include a general setting of relevant information on the regional characteristics of topography, geology, hydrology, and land use. Present a regional map with the study area defined. Present and discuss data set origins, strength, deficiencies and their effects on the conceptual model. Include reference to a data inventory.
5	Model design	The model design section specifies the model confidence level and the technical details of the groundwater model such as domain, spatial and temporal discretisation, parameter distributions, implementation of stresses and boundary conditions, and model code and software. Discuss the selection criteria for the model code. Identify the code and whether any custom or altered code is used. Present the simplifying assumptions inherent to the code, the limitations to the code, and the governing equations that the code solves.
6	Model calibration	Summary of how model parameters are changed within predefined constraints to match observations. This requires a clear description of the parameterisation, objective function and constraints, as well as the calibration methodology and sensitive analysis. Discuss comparison of calibration simulations to site-specific information using qualitative and quantitative techniques. Discuss and present the simulation's overall water budget and mass balance. Discuss additional insight gained from the calibration regarding the conceptual model and resulting changes, if any, to the conceptual model.
7	Predictive modelling	Description of the use of the model to address the model objectives by exploring aquifer behaviour under different stresses. Detail and justify the changes made to permit the calibrated model to simulate these predictions. Present results of any predictive simulations in graphical form.
8	Uncertainty analysis	Presentation of the uncertainty associated with the predictions, based on, at least, heuristic descriptions of measurement uncertainty associated with parameters, results of sensitivity analysis, stresses and calibration targets and structural model uncertainty, associated with the conceptual and mathematical model.
9	Model limitations	States the limitations of data and code, the reliability of different outcomes of the model and how further data collection or research may improve reliability.
10	Conclusions and recommendations	Summary of model findings and recommendations for further analysis. Draw conclusions related to the study objectives. Discuss how uncertainties inherent to the model affect conclusions derives from the model.
11	References	Full references of cited literature and data sources.
12	Appendices	Maps, graphs and tables containing detailed information on the model that is important to fully document the model.

4.2.3.2 Reporting of cumulative impacts

The modelling report must present a clear and unambiguous description of the predicted cumulative impacts of the project.

Transparent presentation of cumulative impact assessments depends on disclosure and documentation of the conceptualisation, methods, results, and uncertainty analyses undertaken with the groundwater model.

Within the modelling report, these disclosures take the form of a:

- presentation of the conceptual model for cumulative impacts evaluation, along with a description of the environmental context
- listing of the impacts of a project, along with a quantitative description of the magnitude and duration of those impacts
- presentation of the information used to inform the impacts evaluation
- listing of the cumulative impacts forecasted, along with presentation of the spatial-temporal extents (for example, mapping of predicted potentiometric surface changes during operations and post-closure, extents of drawdown at one or more discrete time steps and maximum extent of drawdown, recovery curves for groundwater levels or fluxes at critical locations)
- clear presentation of the level of confidence and uncertainties associated with the analysis, as well as suggestions to reduce uncertainty in future models (for example, data gathering, additional testing, model validation, etc.).

A summary of the cumulative impacts must also be presented and discussed in the GIA. The GIA would typically contain the following discussion of cumulative impacts:

- a listing of the impacts of a project, along with a quantitative description of the magnitude and duration of those impacts
- a map of the resource boundary showing the project location within the boundary
- a tabulation of past, current, and reasonably foreseeable future actions with those actions tied to a specific location represented on the resource boundary map
- a presentation of the conceptual model for cumulative impacts evaluation, along with a description of the environmental context
- an account of the cumulative impact implications for resource management and legal compliance
- a presentation of mitigative measures and controls, along with:
    - an assessment of their effectiveness in offsetting impacts
    - the ownership of the mitigation and the accountability protocol for its implementation
- a presentation of a monitoring plan to verify and update the cumulative impact analysis as needed, including modelling.

For more details, refer to the *Cumulative groundwater impact assessment approaches* information paper.

4.3 Timing of reports

Project proponents must work with the department's Water group to determine the need for interim reports or whether study status, issues and preliminary results, and feedback from the department's Water group and project stakeholders must be obtained by other means.

Consultation or interim reporting must be considered at the following model stages, or more frequently after:

1. conceptualisation and model design
2. calibration and sensitivity analysis
3. predictive modelling and uncertainty.

Staged reporting or consultation makes it possible to re-direct a modelling project and allows the overall report to be prepared progressively throughout the study. A staged reporting or consultation approach increases the opportunities for progressive reviews, which should improve the quality of the final report.

4.4 Government agency and third-party reviews

Resource management decisions are seldom made by a single decision-maker and typically have implications for other resources and their decision-making authorities.

Review by state and federal government agencies – some not necessarily responsible for regulating water resources – along with public review and comment, assists in establishing the completeness of the dataset used and improves confidence that the implications of the cumulative impacts have been recognised. Academic and professional organisations could also contribute to impact assessment reviews.

Assessment of methodologies and validation of forecast results should be accomplished via third-party reviews that compare the evaluation to industry standards plus past observations and forecast results for similar resource management scenarios.

Review of GIAs must include:

- data completeness
- methodological correctness of evaluation tools and models
- validation and benchmarking of forecasts
- multidisciplinary assessment of evaluation conclusions and their implications.

5 Conclusion

This technical guideline is intended to give proponents clarity when preparing project application documents, groundwater impact assessments (including modelling) and environmental impact statements.

This is not a stand-alone document and proponents must refer to the other documents that make up the Groundwater Assessment Toolbox for more detailed guidance when considering the risks of proposed projects.

More information on how the NSW Government sets water policy and assesses the risks of major projects is available online.

Contemporary information on projects, the status of the NSW Water Strategy, water data and other relevant information about water is available online at Water (https://www.water.nsw.gov.au/)

6 References

List of all references used in GAT documents:

AECOM, 2018. Tahmoor South Project Environmental Impact Statement.

AGE, 2020. Report on Boggabri, Tarrawonga, Maules Creek Complex groundwater model update. Prepared for Boggabri, Tarrawonga, Maules Creek (BTM).

Agriculture and Resource Management Council of Australia and New Zealand and the Australian and New Zealand Environment and Conservation Council (ANZECC and ARMCANZ) 2000, National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia.

Anderson, M., Woessner, W., 1991. Applied groundwater modelling – simulation of flow and advective transport, 1st ed. Academic Press.

Anderson, M.P., Woessner, W.W., Hunt, R.J., 2015. Applied groundwater modelling – simulation of flow and advective transport, 2nd ed. Academic Press.

ASTM International, 2008. Standard guide for developing and evaluating groundwater modelling codes (Withdrawn 2017).

ASTM, 2013. D5718-13 Standard guide for documenting a groundwater flow model application. ASTM International, West Conshohocken, PA.

ASTM, 2014. D5610-94 Standard guide for defining initial conditions in groundwater flow modelling, Significance. ASTM International, West Conshohocken, PA.

ASTM, 2016. D5609-16 Standard guide for defining boundary conditions in groundwater flow modelling. ASTM International, West Conshohocken, PA.

ASTM, 2017. D6170-17 Standard guide for selecting a ground-water modelling code. ASTM International, West Conshohocken, PA.

ASTM, 2018. D5981/D5981M Standard guide for calibrating a groundwater flow model application. ASTM International, West Conshohocken, PA.

Australian and New Zealand Guidelines (ANZG) for Fresh and Marine Water Quality 2018, Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia, available at https://www.waterquality.gov.au/anz-guidelines

Australian Government, 2020. Bioregional Assessment Program [online document]. URL https://www.bioregionalassessments.gov.au/bioregional-assessment-program

Axler, R., Yokom, S., Tikkanen, C., McDonald, M., Runke, H., Wilcox, D., Cady, B., 1998. Restoration of a mine pit lake from aquacultural nutrient enrichment. Restor. Ecol. 6, 1–19.

Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A 2012, The Australian groundwater modelling guidelines, National Water Commission.

Barnett, B., Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A., Boronkay, A., 2012. Australian groundwater modelling guidelines, Waterlines Report Series. Canberra.

Barnett, B., Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A., Boronkay, A., 2012. Australian groundwater modelling guidelines, Waterlines Report Series. Canberra.

Basuki, K., 2007. Hydrologic considerations for permitting and liability release.

Biesaga, C.A., 2019. Setting the strategic direction for the Great Artesian Basin. Oral presentation. NCGRT/IAH Australasian Groundwater Conference 2019.

BioNet Atlas, http://www.bionet.nsw.gov.au/

BLM, 1996. Record of Decision and Plan of Operations Approval, Cortez Pipeline Deposit. U.S. Bureau of Land Management (BLM).

BLM, 2008. Groundwater modelling guidance for mining activities. Instruction memorandum. Bureau of Land Management (BLM). Reno, Nevada.

BLM, 2019. Final Environmental Impact Statement for the Mount Hope Project. U.S. Bureau of Land Management (BLM).

Boak, R., Bellis, L., Low, R., Mitchell, R., Hayes, P., McKelvey, P., Neale, S., 2007. Hydrogeological impact appraisal for groundwater abstractions. Science report- SCo40020/SR1.

Bredehoeft, J., 2005. The conceptualization model problem – Surprise. Hydrogeol. J. 13, 37–46.

Broadstock, B., 2011. Impact of groundwater pumping on stacked water sources. NSW Government.

Bureau of Meteorology (BoM) Australian Groundwater Explorer, Climate Data Online, http://www.bom.gov.au/climate/data/

Bureau of Meteorology (BoM) Australian Groundwater Explorer, Groundwater Dependent Ecosystems Atlas, Australian Government, http://www.bom.gov.au/water/groundwater/gde/map.shtml

Bureau of Meteorology (BoM) Australian Groundwater Explorer, http://www.bom.gov.au/water/groundwater/explorer/

CDM Smith Australia 2018, Central Queensland Coal Project Supplementary Environmental Impact Statement, Chapter 10 – Groundwater.

CDWR, 2016. Best management practices and guidance documents [online document]. URL https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents

CEQ, 1997. Considering cumulative effects under the National Environmental Policy Act. Council on Environmental Quality (CEQ).

Cuddy, S., Chan, G.S., Pos, R., 2013. Hydrogeological assessment submissions, conservation. Authority guidelines for development applications.

Department of Agriculture, 2019. Great Artesian Basin Strategic Management Plan.

Department of Environment (DoE) 2013, Significant impact guidelines 1.3: Coal seam gas and large coal mining developments – impacts on water resources. Commonwealth of Australia, December 2013.

Doherty, J., 2015. Calibration and uncertainty analysis for complex environmental models. Watermark Numerical Computing, Brisbane, Australia.

Doherty, J., Moore, C., 2020. Decision support modelling: Data assimilation, uncertainty quantification, and strategic abstraction. Groundwater 58.

DPIE, 2021. AdaptNSW: Understanding and adapting to climate change in New South Wales [online document]. URL https://climatechange.environment.nsw.gov.au/Impacts-of-climate-change/Water-resources/Groundwater-recharge-and-surface-runoff (accessed 28 June 2021).

Dube, M., Duinker, P., Greig, L., Carver, M., 2013. A framework for assessing cumulative effects in watersheds: an introduction to Canadian case studies.

EMM, 2021. Guidelines for groundwater documentation for SSD/SSI projects. Prepared for NSW Department of Planning, Industry and Environment – Water.

Environment Canterbury, Pattle Delamore Partners Ltd, 2000. Guidelines for the assessment of groundwater abstraction effects on stream flow. Roo/11 ISBN 1-86937-387-1. First Edition.

eSPADE information system, https://www.environment.nsw.gov.au/eSpade2Webapp

European Communities, 2010. Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance Document No. 26. Guidance on Risk Assessment and the Use of Conceptual Models for Groundwater. Luxembourg.

Franke, O.L., Reilly, T.E., Bennett, G.D., 1987. Definition of boundary and initial conditions in the analysis of saturated ground-water flow systems – an introduction, in: Techniques of Water-Resources Investigations of the United Stated Geological Survey, Book 3: Applications of Hydraulics. United States Geological Survey.

Hill, M., Tiedeman, C., 2007. Effective groundwater model calibration. Wiley, Hoboken, New Jersey.

Howe P and Dettrick D 2010, Framework for assessing potential local and cumulative effects of mining on groundwater resources – Report 15 Guidelines for conducting a groundwater effects assessment. Australian National Water Commission.

Howe, P., 2011. Framework for assessing potential local and cumulative effects of mining on groundwater resources – project summary report.

IAAC, 2019. Tailored impact statement guidelines template for designated projects subject to the Impact Assessment Act and the Nuclear Safety and Control Act. Practitioner's guide to the Impact Assessment Act.

IAEA, 2005. Guidebook on environmental impact assessment for in situ leach mining projects. International Atomic Energy Agency, Vienna Austria.

IEPMC, 2019a. Independent Expert Panel for Mining in the Catchment Report: Part 1. Review of specific mining activities at the Metropolitan and Dendrobium coal mines. Prepared for the NSW Department of Planning, Industry and Environment.

IEPMC, 2019b. Report of the Independent Expert Panel for Mining in the Catchment: Part 2. Coal mining impacts in the Special Areas of the Greater Sydney Water Catchment.

Institute of Geologists of Ireland, 2013. Guidelines for the preparation of soils, geology and hydrogeology chapters of environmental impact statements.

Intergovernmental Committee on Surveying and Mapping, Elevation and Depth, Foundation Spatial Data (ELVIS), https://elevation.fsdf.org.au/

Jantunen, J., Kauppila, T., Räisänen, M.L., Komulainen, H., Kauppila, P., Kauppinen, T., Törmä, H., Leppänen, M., Tornivaara, A., Pasanen, A., Kemppainen, E., Raunio, A., Marttunen, M., Mustajoki, J., Kauppi, S., Ekholm, P., Huttula, T., Makkonen, H., Loukola-Ruskeeniemi, K., Ministry of Employment and the Economy, F., 2015. Environmental Impact Assessment Procedure for mining projects in Finland, MEE guidelines and other publications.

Keifer, G., Effenberger, F., 1997. Considering cumulative effects under the National Environmental Policy Act, Angewandte Chemie International Edition.

Kolm, K.E., Van Der Heijde, P.K.M., 1996. Conceptualization and characterization of envirochemical systems. IAHS-AISH Publ. 237, 267–275.

Kuells, C.J., Wilhelm Bittner, A.F., 2013. Strategic assessment of water resources for the Erongo Uranium Province.

Lumb, A.M., 1982. Procedures for assessment of cumulative impacts of surface mining on the hydrologic balance. Open File Report 82-334.

McCullough, C., Hunt, D., Evans, L., 2009. Sustainable development of open pit mines: creating beneficial end uses for pit lakes, in: Mine Pit Lakes: Characteristics, Predictive Modeling, and Sustainability. Kentucky.

Middlemis, H., Merrick, N., Ross, J., 2001. Groundwater flow modelling guideline. Murray–Darling Basin Commission. November 2000. Aquaterra Consulting Pty Ltd. South Perth, Western Australia.

Middlemis, H., Peeters, L., 2018. Information guidelines explanatory note: Uncertainty analysis – guidance for groundwater modelling within a risk management framework.

Middlemis, H., Walker, G., Peeters, L., Hayes, P., Moore, C., 2019. Groundwater modelling uncertainty; implications for decision-making. Flinders University – The National Centre for Groundwater Research and Training.

Milne, P., Grierson, S., 2008. When is enough, enough? Dealing with cumulative effects under the Resource Management Act. Report to Ministry for the Environment (New Zealand).

Moran C, Vink S, Straughton G and Howe P 2010, Framework for assessing potential local and cumulative effects of mining on groundwater resources – Report 3 Framework for risk-based assessment of cumulative effects to groundwater from mining. Australian National Water Commission.

Moreau, M., Cameron, S., Daughney, C., Gusyev, M., Tschritter, C., 2014. Envirolink Tools Project — Capture zone delineation — Technical report, GNS Science Report 2013/57.

National Groundwater Information System (NGIS).

National Uniform Drillers Licensing Committee (NUDLC) 2020, Minimum Construction Requirements for Water Bores in Australia; Fourth edition, Australian Government National Water Commission.

National Water Quality Management Strategy (NWQMS) 2013, Guidelines for Groundwater Quality Protection in Australia, Australian Government.

NDEP, 2018. Listing of accepted codes for groundwater and geochemical modelling at mine sites. Nevada Division of Environmental Protection. Bureau of Mining Regulation and Reclamation.

NDEP, 2018. Listing of accepted codes for groundwater and geochemical modelling at mine sites. Nevada Division of Environmental Protection. Bureau of Mining Regulation and Reclamation.

Nevada State Engineer, 2009. Diamond Valley water resource management.

Nevada State Engineer, 2020. Order of determination of the relative rights in and to all waters of the Diamond Valley hydrographic basin.

Newman, C.P., 2018. Guidance for hydrogeologic groundwater flow modelling at mine sites. Nevada Division of Environmental Protection, Bureau of Mining Regulation and Reclamation, Carson City, Nevada.

NSW Department of Environment, Climate Change and Water (DECCW) 2006, NSW Water Quality and River Flow Objectives, https://www.environment.nsw.gov.au/ieo/index.htm, NSW Government.

NSW Department of Finance, Services and Innovation (DFSI) Spatial Services 2014, 5 metre Resolution Digital Elevation Model, NSW Government. https://www.ga.gov.au/scientific-topics/national-location-information/digital-elevation-data

NSW Department of Planning and Environment 2017, Preparing an Environmental Impact Statement. Draft Environmental Impact Assessment Guidance Series June 2017.

NSW Department of Planning, Industry and Environment (DPIE) 2012, NSW Aquifer Interference Policy, NSW Government Policy for the licensing and assessment of aquifer interference activities, NSW Government.

NSW Department of Planning, Industry and Environment (DPIE) 2013a, Aquifer Interference Policy Fact Sheet 3, Accounting for water, NSW Government.

NSW Department of Planning, Industry and Environment (DPIE) 2013b, Aquifer Interference Policy Fact Sheet 4, Assessing the impacts, NSW Government.

NSW Department of Planning, Industry and Environment (DPIE) 2014, Groundwater Monitoring and Modelling Plans – Information for Prospective Mining and Petroleum Exploration Activities.

NSW Department of Planning, Industry and Environment (DPIE) 2018, Water Resource Plans Fact Sheet – Assessing groundwater applications, September 2018.

NSW Department of Planning, Industry and Environment (DPIE) 2019, Minimum requirements for pumping test on water bores in New South Wales PUB 19/540.

NSW Department of the Environment and Energy (DEE)

NSW Department of the Environment and Energy (DEE) 2019, Australian Wetlands Database, https://www.environment.gov.au/water/wetlands/australian-wetlands-database, Australian Government.

NSW Department of the Environment and Energy (DEE) Protected Matters Search Tool (PMST): http://www.environment.gov.au/epbc/protected-matters-search-tool

NSW Department of Urban Affairs and Planning (DUAP) 1996a, Extractive Industries – Dredging and Other Extraction in Riparian and Coastal Areas, EIS Guideline.

NSW Department of Urban Affairs and Planning (DUAP) 1996ba, Extractive Industries – Quarries, EIS Guideline.

NSW Department of Urban Affairs and Planning (DUAP) 1996c, Roads and Related Facilities, EIS Guideline.

NSW Department of Urban Affairs and Planning (DUAP) 2000, Coal mines and associated infrastructure, EIS guideline.

NSW Government, 2008. Impacts of underground coal mining on natural features in Southern Coalfield.

NSW Government, 2011. Water Management (General) Regulation 2011 under the *Water Management Act 2000*.

NSW Government, 2014. New South Wales coal industry profile. Volume 1.

NSW Government, 2020. Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2020 under the *Water Management Act 2000*.

NSW Government, 2021. *Environmental Planning and Assessment Act 1979* No 203. NSW Government.

NSW Government, Mining Exploration and Geoscience, Geological Survey of NSW, online geological data, https://resourcesandgeoscience.nsw.gov.au/miners-and-explorers/geoscience-information/geological-survey-of-nsw

NSW Office of Water, 2012. NSW Aquifer Interference Policy.

NSW Office of Water, 2014. Groundwater Monitoring and Modelling Plans – Information for prospective mining and petroleum exploration activities. NSW Department of Primary Industries.

Office of Surface Mining, 2002. Permitting hydrology. A technical reference document for the determination of probably hydrologic consequences (PHC) and cumulative hydrologic impact assessments (CHIA).

Ontario, 2021. Technical guidance document for hydrogeological studies in support of Category 3 applications [online document]. URL https://www.ontario.ca/page/technical-guidance-document-hydrogeological-studies-support-category-3-applications

Poeter, E.P., Hill, M.C., Lu, D., Tiedeman, C.R., Mehl, S., 2014. UCODE_2014, with new capabilities to define parameters unique to predictions, calculate weights using simulated values, estimate parameters with SVD, evaluate uncertainty with MCMC, and More. Integrated Groundwater Modeling Center.

Punkkinen, H., Räsänen, L., Mroueh, U.-M., Korkealaakso, J., Luoma, S., Kaipainen, T., Backnäs, S., Turunen, K., Hentinen, K., Pasanen, A., Kauppi, S., Vehviläinen, B., Krogerus, K., 2016. Guidelines for mine water management, VTT Technology.

Saayman, I., 2005. Guideline for involving biodiversity specialists in EIA processes, Republic of South Africa, Provincial Government of the Western Cape, Department of Environmental Affairs & Development Planning, Cape Town.

Scientific Information for Land Owners (SILO) Data Drill, https://www.longpaddock.qld.gov.au/silo/datadrill

Scott, M., Beckers, J., Klebek, M., Environment, A., Development, S.R., 2013. Managing regional cumulative effects on groundwater resources – Case studies. https://doi.org/10.13140/2.1.1009.9846

Serov P, Kuginis L, Williams JP 2012, Risk Assessment Guidelines for Groundwater Dependent Ecosystems, Department of Primary Industries, Office of Water, NSW Government.

SIMEC, 2020. Tahmoor Coal Pty Ltd Water Management Plan: Tahmoor North Western Domain Longwalls West 1 and West 2.

SMCRA, 2012. *Surface Mining Control and Reclamation Act of 1977* (SMCRA). US.

Stantec, 2021a. Cumulative groundwater impact assessment approaches. Information paper prepared for the Water group, NSW Department of Planning, Industry and Environment as part of the Groundwater Modelling Toolbox Project.

Stantec, 2021a. Minimum groundwater modelling requirements for Major Projects in NSW. Technical note prepared for the Water group, NSW Department of Planning, Industry and Environment as part of the Groundwater Modelling Toolbox Project.

Stantec, 2021b. Groundwater model assessment procedures and evaluation tool (GW-PET). Technical note prepared for the Water group, NSW Department of Planning, Industry and Environment as part of the Groundwater Modelling Toolbox Project.

Sundaram B, Feitz A, Caritat P de, Plazinska A, Brodie R, Coram J and Ransley T 2009, Groundwater Sampling and Analysis – A Field Guide. Geoscience Australia, Record 2009/27 95 pp.

Sydney Catchment Authority (SCA) 2015, Neutral or Beneficial Effect on Water Quality Assessment Guideline, NSW Government.

Thomann JA, Werner AD, Irvine DJ, Currell MJ 2020, Adaptive management in groundwater planning and development: A review of theory and application. Journal of Hydrology, volume 586.

Todd, by D.K., 1980. Groundwater hydrology (2nd edn). Wiley, New York.

UN/ECE, 2000. Guidelines on monitoring and assessment of transboundary groundwaters. UN/ECE Task Force on Monitoring and Assessment.

USACE, 2016. Cumulative effects evaluation process for nationwide permits.

US-EPA, 1970. US-EPA.

USGS, 2013. Water resources of the Upper Humboldt River Basin. USGS Sci. Investig. Rep.

van der Heijde, P.K.M., Kanzer, D.A., 1997. Ground-water model testing: systematic evaluation and testing of code functionality and performance. Environ. Prot.

Watermark Numerical Computing, 2018. PEST – Model-independent parameter estimation. User manual, 7th ed.

WaterNSW, Online groundwater database located at https://realtimedata.waternsw.com.au/water.stm

WaterNSW, The NSW Water Register, https://waterregister.waternsw.com.au/water-register-frame, NSW Government.

Wels, C., Mackie, D., Scibek, J., 2012. Guidelines for groundwater modelling to assess impacts of proposed natural resource development activities. British Columbia Ministry of Environment.

Whitehaven Coal, Idemitsu Boggabri Coal, 2019. Boggabri – Tarrawonga – Maules Creek Complex Water Management Strategy.

World Meteorological Organisation, 2012, International glossary of hydrology.

WRDMAP, 2010. China – UK WRDMAP Integrated Water Resources Management Document Series. Thematic Paper 1.1: Groundwater flow modelling.

Ye, M., Pohlmann, K.F., Chapman, J.B., Pohll, G.M., Reeves, D.M., 2010. A model-averaging method for assessing groundwater conceptual model uncertainty. Ground Water 48.

Younger, P.L., Sapsford, D.J., 2004. Evaluating the potential impact of opencast coal mining on water quality (Groundwater Regulations 1998): An assessment framework for Scotland.

Zingelmann, M., Bittner, A., Winker, F., Muresan, M., Ellerton, J., 2016. Cumulative groundwater impact of mining in the Kalahari Manganese Field and the need for a strategic environmental assessment approach. Min. Meets Water – Conflicts Solut. 43–44.