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1 Summary

This chapter summarises geological, groundwater and geotechnical investigations, interpretation and design since the Feasibility Stage (Feasibility). The purpose of this chapter is to highlight what facts are known in relation to surface and underground works. Key risks and opportunities at Feasibility, and subsequently in risk workshops, are identified, proposed mitigation measures stated and residual risks specified.

1.1 Introduction

The Project lies within the complex geology of the Lachlan Fold Belt, which comprises undulating tablelands, and steep ravines around the Yarrangobilly River. Several major faults cross the area and are indicated to be present at depth.. Desktop and a detailed field investigations and analysis to date has provided baseline information information, however, several important unknowns remain which is why further investigative drilling and Exploratory Works will be undertaken.

Geotechnical uncertainty with any tunneling project is a reality, but it will be managed contractually through construction by means of classification into broad ground support classes (tunnelling classes (***TCs***)) and an agreed mechanism for determining which class should apply and associated costs and advance rates. See *Supporting Chapter Three - Contracts and legal* for its contractual operation.

1.2 Activities undertaken

Desk studies were performed during Feasibility to develop a preliminary regional geotechnical model. A desktop regional fault study was performed prior to Final Investment Decision (***FID***). Some field mapping was performed during Feasibility.

Further field mapping has been undertaken for the main tunnel alignment and the surface works (access roads) locations and more work will be done.

Geotechnical investigations have been carried out for the underground works, groundwater model and Exploratory Works:

1. **Underground works** - 38 boreholes have been drilled with another 10 boreholes currently underway, with associated in situ and laboratory tests;
2. **Groundwater - Environmental Impact Statement (*EIS*)** - related hydrogeological investigations, with additional drilling and aquifer testing at specific locations with potentially higher risk with respect to groundwater inflows and or environmental impacts along the alignment;
3. **Surface works** - test pits and Drop Cone Penetrometer (***DCP***) tests were performed on a subset of Exploratory Works - Roads (***EWR***). Boreholes were drilled to assess the geological conditions and bridge foundations.

Groundwater monitoring has been undertaken to provide long-term groundwater levels and thermal data. See *Supporting Chapter Eleven - Environment, permits and approvals* for more on groundwater monitoring.

1.3 Geological and geotechnical interpretation

The Project lies within the complex geological province of the Lachlan Fold Belt. It comprises two distinct terrains:

1. **Plateau/Kiandra Tablelands** - mature, undulating tablelands with many streams and boggy areas; and
2. **Ravine** - steep valleys and ravines around the Yarrangobilly River.

The area includes many faults, particularly the Long Plain Fault, the Boggy Plain Fault and the Kiandra Fault. Groundwater occurs within localised flow systems along the alignment profile, and early modelling suggests high construction inflows are possible. The complex geological setting has implications for the engineering geology of the Project area, with a wide range of rock types and geological structures.

The tunnelling is anticipated to encounter a hard rock mass with variably spaced bedding and joints, forming a blocky structure, which may include areas of highly fractured rock with associated high groundwater inflows. The site for the surge shafts and pressure shafts lies within rock with extensive zones which are sheared and fractured in addition to potentially low in situ stress within the uppermost 250 m. The site for the power cavern complex lies within folded sedimentary rocks that include conglomerate, sandstone and siltstone. The rock condition at the power cavern complex is considered favourable.

1.4 Geotechnical Baseline Report

The Project will use a risk-sharing mechanism for the allocation of geotechnical risks between the Employer and the Contractor. The aim is to cater for the inherent variability and uncertainty associated with subsurface conditions and is based on the industry's recognised best-practice.

The Geotechnical Baseline Report (***GBR***) developed for the Project sets out the baseline subsurface geotechnical conditions anticipated by the parties. It includes a range of anticipated tunnel excavation and support measures (at concept level) to be implemented by the Contractor to support the ground under the anticipated geotechnical conditions. See *Supporting Chapter Three* for the contractual treatment and management of the GBR.

2 Activities undertaken

2.1 Desk Studies

Desk studies were performed during Feasibility. The purpose of these was to develop a preliminary regional geotechnical model and to understand how excavations for the original Scheme performed.. A desktop regional fault study was performed by DrQuigs Geological Hazards Consulting from Melbourne University as a subcontractor to SMEC Australia Pty Ltd (***SMEC***) that has defined the major fault locations and orientations, likely mechanisms of movement and likely neotectonic movement.[1]

2.2 Field Mapping

For Feasibility, the geology in the Project area was verified and extended through detailed field mapping. Field mapping was integral to filling knowledge gaps, confirming the previous mapping by others, and identifying drilling targets. Field mapping enabled ground-truth assessments of most of the questions left open by the literature and confirmed geological boundaries as defined by various authors.

Subsequent to Feasibility, additional geological mapping has occurred for both the main tunnel alignment, portal locations and the surface works (access roads).

The hillside surrounding the reference design location for the pressure shafts was mapped to identify any geological conditions that might indicate whether low confining stresses could be expected.[2] This area has limited outcrop and needs further investigation, dependent on the final contractors' location for the pressure shafts and surge shaft. A detailed compilation geological map of the area between the surge shaft and power station complex sites has been prepared covering the current interpretations and included on the Geotechnical Interpretive Report.

It should be noted that geological investigations are continuing and further field mapping will be conducted. During the latest geological investigation, some indications of likely igneous intrusions were noticed by the field teams around 4 km to 5 km from the Tantangara intake but these have not been located on the surface maps as at FID.

[1] Neotectonic in the sense of having been active during the contemporary stress regime, in this case possibly within the past 5 million years.
[2] Because such low stresses have a major impact on tunnel lining.

2.3 Geotechnical Investigations

2.3.1 Overview

Geotechnical investigations have been carried out for the underground works, groundwater model and Exploratory Works. The purpose of these investigations is to reduce ground-related Project risks by:

1. Identifying geological stratigraphy;
2. Identifying key structural features that could impact construction, such as the Long Plain Fault;
3. Allowing measurements of in situ parameters such as in situ stress to be made;
4. Obtaining samples so that material parameters can be measured; and
5. Allowing measure and assessment of groundwater conditions.

2.3.2 Underground Works

Completed and proposed boreholes for the underground works are summarised in Table 1 below. A total of 38 boreholes have been drilled, with another 10 boreholes in the additional testing program. By the end of November 2018, six of these holes were completed. A large scope of in situ and laboratory tests has also been performed to characterise the material properties of the rock and the in situ stress.

Target Structure	Number of boreholes completed	Additional boreholes
Tantangara Intake	3	0
Headrace Tunnel	17	2
Headrace/Pressure Shaft	1	0
Headrace/Pressure Shaft/Cavern	2	0
High-Pressure Tunnel/Cavern	2	3
Tailrace/Cavern	1	0
Tailrace Tunnel	6	0
Talbingo Intake	3	0
MAT/ECVT	3	4
TOTAL	**38**	**10 (6 completed)**

Table 1: Scope of underground geotechnical investigations

2.3.3 Groundwater

Site investigations for reference design have been undertaken by GHD Pty Ltd (***GHD***) and EMM Consulting Pty Ltd (***EMM***).

GHD have undertaken all the geotechnical drilling, testing (including Lugeon Packer Testing and Drill Stem testing) and installation of Vibrating Wire Piezometers (***VWP***), as well as Open Standpipe Piezometers (***OSP***) with the exception of three OSP and two VWP holes installed by SMEC during the feasibility stage investigations.

The details are contained in the Geotechnical Interpretation Report (see the supporting information for this chapter) and the installations summarised in Table 2 below.

Installation Type	Location
Open Standpipe Piezometer	13
Vibrating Wire Piezometer	16
TOTAL	**29**

Table 2: Groundwater installation location summary

EMM Consulting has undertaken hydrogeological investigations specifically for the Environmental Impact Assessment, consisting of open standpipes, test production bores, permeability testing and aquifer pumping tests. EMM Consulting is also undertaking additional drilling and aquifer testing at specific locations with potentially high (RG1) risk (with respect to groundwater inflows and or environmental impacts) along the alignment. The scope of groundwater drilling is summarised in Table 3.

EMM Consulting Scope for EIS	Number of Holes Completed
Production bores, with aquifer pumping tests	6
Monitoring bores, with water level logging equipment and sampling pumps	9
TOTAL	**15**

Table 3: Scope of Groundwater Drilling

2.3.4 Surface Works

The scope of investigations for Exploratory Works is summarised in Table 4. Test pits and DCP tests were performed to assess subgrade conditions or pavements. Boreholes were drilled to assess the geological conditions and bridge foundations.

Road Location	Test Pits	Boreholes	DCP Tests
Ravine Road	24	1	-
Mine Trail	7	8	8
TOTAL	**78**	**17**	**8**

Table 4: Scope of Surface Works Investigations

No site investigations have been performed for the main works surface roads as this was not permitted under existing approvals. Limited site investigations have been performed for the Exploratory Works Roads (***EWR***) Package. In the Reference Design, subsurface stratigraphy, material parameters for slope stability assessments, material utilisation, excavatability, retaining walls and pavement subgrade parameters have been based on a walk-over survey and experience and are not supported by in situ investigations, on-site or laboratory measurements. Site testing and test pits will be conducted under an approved EIS post-FID.

2.4 Groundwater and Thermal Monitoring

Groundwater monitoring has been undertaken at approximately monthly intervals at 63 monitoring points along the alignment to provide long-term groundwater levels and thermal data. These monitoring installations include open standpipes, multi-level VWP (in deeper holes) with either data loggers or thermal loggers installed to monitor the groundwater level and to record formation temperatures. The groundwater monitoring is ongoing at this stage and should be continued throughout construction. See *Supporting Chapter Eleven* for more on groundwater monitoring.

2.5 Known Data Gaps

The scope of investigations performed and planned to date is considered satisfactory.

In a geological framework, this means the big picture is reasonably well-developed, but some important details such as potentially variable stratigraphy around the cavern complex, high groundwater flow features or igneous intrusions/dykes might not be identified. Short summaries of known data gaps are provided below.

2.5.1 General Stratigraphic Variation

Drilling to date encountered diverse ground conditions and lithological rock types. The current drill spacing along the 26 km alignment is sparse; it is generally not possible to correlate units or ground types between adjacent boreholes. Infill drilling is required to provide further information to fill in gaps along the alignment and to better understand specific, previously identified geological features to potentially reduce the level of risks.

2.5.2 Pressure Shaft and Cavern Complex

The area containing the power station cavern and pressure shafts needs further assessment to characterise the ground conditions within the vicinity of the proposed structures and to further assess the in situ stress. Currently, one borehole intersects the Reference Design power station cavern complex, with several boreholes in close proximity. Further boreholes in this area are currently being drilled. Additional information is required to assess the ground conditions and their properties so that a detailed design of this structure can be to be achieved. Further horizontal bores are proposed during the Exploratory Works program to further detail the geological properties of the proposed cavern.

2.5.3 MAT/ECVT Tunnels

The current investigation program incorporates boreholes within the portal locations for both the ECVT and MAT.

2.5.4 Groundwater

There are two main groundwater-related risk items for the Project. Due to the length of tunnels required, there is a risk of groundwater inflows being encountered that affect tunnelling works that are not predicted. Due to the expanse of the Project, and limited potential to install groundwater bores, assumptions are required in the modelling that will need to be monitored during construction.

The second item is the likely direct hydraulic link between flowing streams and the planned tunnel alignment. Given the past knowledge from the Scheme, that major structures are likely to provide the vast majority of the higher inflows of water (ie Nungar, Tantangara and Gooandra Creeks), direct surface impacts to the hydrological regime may result. Further groundwater drilling and monitoring installations with additional off-alignment points are required to address these gaps and further assess potential impacts.

2.5.5 Thermal

To assess potential short-term and long-term environmental impacts of the Project's construction and operation (eg thermal pollution, heat transfers, potential impacts to Yarrangobilly thermal springs), a thermal model was required. The thermal model needs information from the in situ temperature monitoring data and core sample thermal conductivity testing. This information is combined with the geological and groundwater models. Further detailed modelling and confirmation of assumptions from the current drilling program and ongoing monitoring are required.

2.5.6 Igneous intrusions

Igneous intrusions have been mapped in the Project vicinity with two major geological formations in the form of the Shaw Hill Gabbro and the Boggy Plain Suite. Inferred boundaries for these formations have been shown in the geological model. Observations made during the site walkovers suggest that granitic rocks are present elsewhere along the alignment and could impact on the tunnel.

2.5.7 Limestone

Limestone around the Yarrangobilly Caves is just 6 km north of the Project alignment. Structural geology assessment indicates this rock is not anticipated in the tunnels, but its potential for occurrence on the Waterway Alignment cannot be completely ruled out. Further investigation may be required to assess if karstic limestone occurs in the Project area.

3 Geological and geotechnical interpretation

3.1 Geological model

The Project area lies within south-eastern New South Wales within the Lachlan Fold Belt, a geological province of old volcanic belts, sedimentary basins and intrusive rocks that have been affected by several tectonic episodes of orogenesis (mountain-building) and metamorphism. The juxtaposed geological units appear to be mostly aligned in a general north-south direction so that from east to west all the units are encountered in turn while traversing the tunnel alignment. The relative ages are not sequential due to a range of structural movements along faults and by large-scale folding.

The ages of the main rock units range from about 500 million years (Ma) to 360 Ma. Following this period there was a large time hiatus in geological processes until further tectonic activity about 25-20 Ma. During this most recent tectonic activity, there was differential uplift and tilting of the crust, producing two distinct terrains separated by a major geological fault and escarpment caused by movement on the Long Plain Fault and other faults to the east. Figure 1 shows the Project area and the main features of the concept model.

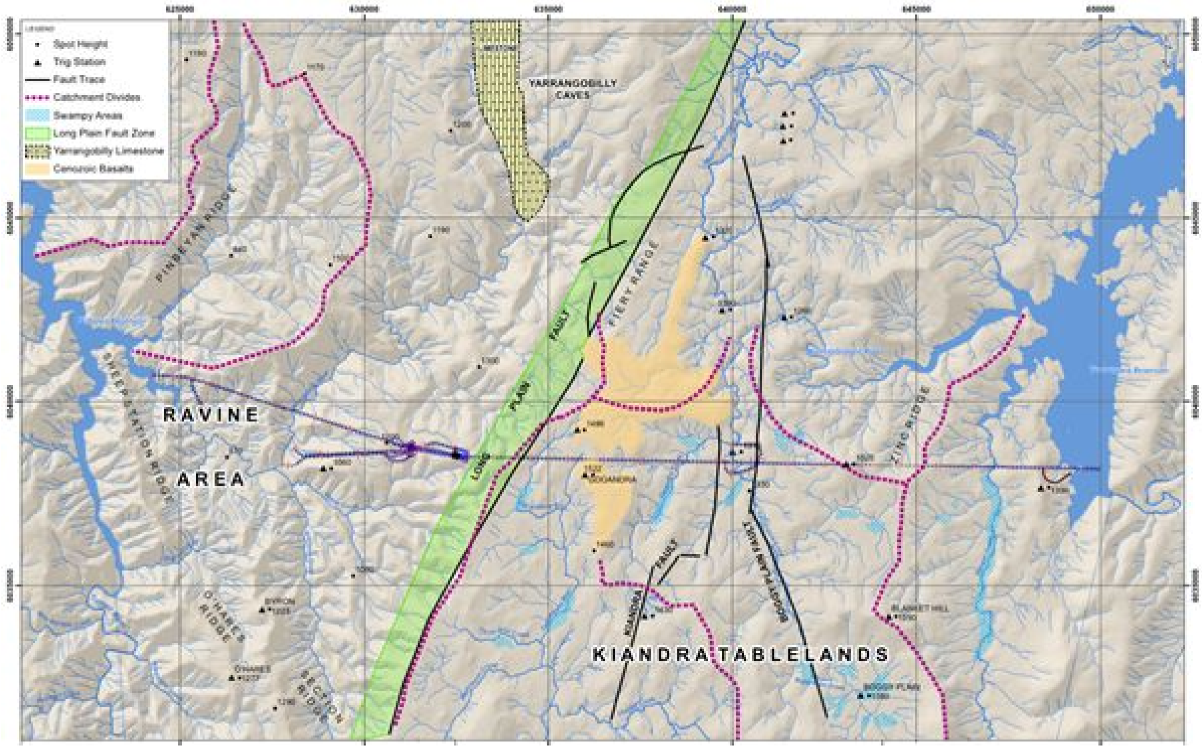

Figure 1: Map Indicating the main terrain types in the Project area

The two terrain types as indicated in Figure 1 are:

1. **Plateau Area (Kiandra Tablelands)** - mature, undulating tablelands in the central and eastern portion of the Project area. The terrain has low relief with a maximum elevation at 1,500 m. The Plateau area is drained to the east by the Murrumbidgee River catchment and its main tributaries are north-flowing meandering streams and associated boggy areas.
2. **Ravine Area** - steep valleys and ravines of the Yarrangobilly River and associated tributaries in the western portion of the Project area. This area has high relief of 500-600 m, with the lowest surface point in the Project area being around 550 m to the west of a well-defined escarpment, with deeply incised streams.

Faults in the Project area were active during the initial tectonic processes hundreds of millions of years ago. There is, however, geomorphic evidence that several of the faults were reactivated 20-25 Ma, with some movements likely within the last 5-10 Ma. Geoscience Australia defines measurable displacement during the contemporary stress regime as Neotectonic. This is generally estimated at 5-10 Ma. The largest fault, the Long Plain Fault, strikes north-northeast and has a dip to the east with the eastern block of older rocks thrust upwards against the younger rocks to the west. The drilling investigations intersected the Long Plain Fault within a zone that may span a width of about 1.7 km, but with intervals of competent rock between more intensely sheared brecciated and fractured material.

Other prominent faults that will be intersected by tunnelling are the Boggy Plain Fault system and the Kiandra Fault. The drilling has not clearly defined these structures but they likely are represented by fractured and sheared rock in discrete bands of 1 to 10 m width.

The western Ravine Area has large fold structures so that some of the younger strata appear folded deeply into the older strata. In the power cavern area one such deep fold is interpreted, a syncline, where competent sedimentary rocks are indicated.

3.2 Groundwater (Conceptual) Model

Groundwater occurs within localised flow systems along the alignment profile. Figure 2 indicates zones of recharge and zones of discharge. Groundwater recharge is mainly via rainfall infiltration. The available information suggests there are two recharge zones (and therefore flow systems) operating along the alignment, one in the Plateau Area and one to the west of the Long Plain Fault, in the Ravine Area.

The discharge zones are base-flow contributions to major creeks and rivers such as the Yarrangobilly River and are strongly controlled by topography. The arrows in Figure 2 indicate hydraulic movement which shows some high gradients such as that evident below the escarpment.

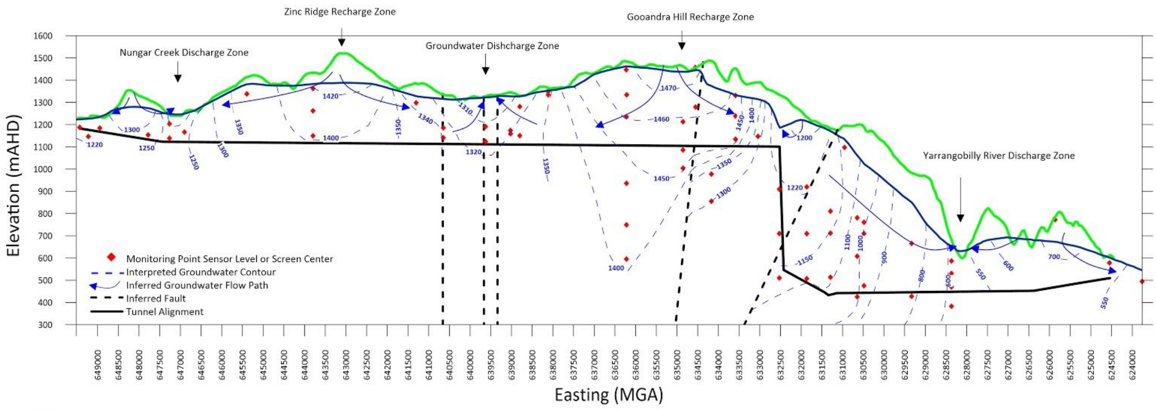

Figure 2: Conceptual groundwater model for the Project alignment

EMM is undertaking numerical modelling for assessment of the shallow environmental impacts. Two primary scenarios are assessed which included a high permeability (worst case) and a low permeability case applying some informed assumptions. Experience provided with tunnelling during the earlier Scheme included some very high groundwater inflows from problematic structures (greater than 30 l/sec) which affected operations, however, the flows dissipated to a manageable level after a period ranging generally from about 1 to 14 days. Accordingly, major structures are likely to provide most of the inflow volumes, which is reflected in the preliminary calculated estimates provided in Table 5 below.

Tunnel Collection Point	Instantaneous Total Cumulative Inflow		Estimated Likely Cumulative Construction Inflow assuming dewatering of structures	
Units	L/sec	L/sec	L/sec	L/sec
Range	Lower	Upper	Lower	Upper
1 TRT and Talbingo Adit	79	264	32	185
2 MAT	85	283	34	198
3 ECVT	20	66	8	46
4 Power Cavern	18	60	7	42
5 Valve Chamber Access Adit (including Headrace Tunnel (***HRT***)	16	52	6	36
6 Mid HRT Adit	240	799	96	559
7 Tantangara Adit (including HRT)	113	376	45	263

Table 5: Preliminary estimate of construction inflows at drainage collection points

3.3 Geotechnical Model

The area of influence of the Project is determined primarily by the alignment of the power waterway, from which all other tunnel features stem. This alignment passes through several geological formations with anticipated highly variable ground conditions.

Each geological formation anticipated in the tunnels is separated into discrete Ground Types that are largely based on fracture spacing differentiated between >300 mm (block and better) and <300 mm (very blocky and worse). Rock type is not used to delineate Ground Types in general because many of the formations are composed of multiple rock types at relatively close intervals. The exception is the powerhouse complex where specific rock types are used to define Ground Types that influence cavern support.

Each ground type is assigned ranges of geological and geotechnical parameters, including:

1. Rock Type;
2. Degree of Weathering;
3. Both intact and rock mass strength and their deformation properties;
4. Defects/discontinuity characteristics and properties: being bedding strata, foliations and joints;

5. In situ stress conditions in the ground;
6. Groundwater flow properties; and
7. Boreability data.

This complex geological setting has implications for the engineering geology of the Project area, with a wide range of rock types and geological structures, a hydrogeological situation with potential impacts due to the planned underground openings and a geomorphological setting that provides an insight into potential issues for the Project works.

Essentially the tunnelling is anticipated to encounter a hard rock mass with variably spaced bedding and joints, forming a blocky structure, that can be supported by standard practices in both drill and blast or tunnel boring machine excavations. Progress will be affected by ground behaviour such as blocks or wedges falling out, or areas of highly fractured rock with travelling or possible chimney failures. Often such behaviour could be associated with high groundwater inflows, due to the passage of water along faults and areas of closely spaced joints. The drilling investigations have provided sufficient data to enable an explanation of the likely range of conditions and behaviours distributed along the tunnel alignments.

The site for the surge shafts and pressure shafts lies within rock with extensive zones which are sheared and fractured in addition to potentially low in situ stress within the uppermost 250 m. While design has taken this into consideration there will be an opportunity to conduct further testing from the access tunnels in order to better appreciate the rock mechanics situation and to optimise the design.

The site for the power station complex lies within folded sedimentary rocks that include conglomerate, sandstone and siltstone, being a different rock formation which indicated much better properties than the surge/pressure shaft site. Overall the rock condition at the power cavern complex is considered favourable and additional planned drilling will help optimise the design of the caverns and associated tunnels.

4 Geotechnical Baseline Report

The Project will use a risk-sharing mechanism for the allocation of geotechnical risks between the Employer and the Contractor. The aim is to cater for the inherent variability and uncertainty associated with subsurface conditions and is based on the industry's recognised best-practice. The key risk allocation principles are:

1. The Employer bears the risk related to the subsurface conditions and;
2. The Contractor bears the risk of production rates and cost of excavation and support in those subsurface conditions foreseen by the GBR and specified in the Baseline Schedule and in the Payment Clauses.

The GBR developed for the Project sets out the baseline subsurface geotechnical conditions anticipated by the parties. It also includes a range of anticipated tunnel excavation and support measures (at concept level) to be implemented by the Contractor to support the ground under the anticipated geotechnical conditions. These measures are referred to as TCs and comprise a suite of typically five to six different classes, ranging from light support (TC1) for good ground to heavy support (TC6) for poorer conditions. The GBR also includes the anticipated baseline distribution of TCs along the tunnels. The TCs are intrinsically related to tunnel construction methodology and vary in concept and scope depending on which methods are selected for each underground structure or section

The GBR also presents the Employer's estimated groundwater inflow as well as the Employer's estimate of the number of locations where water inflows are envisaged and grouting works may be required. The Tenderers will consider these estimated inflows and locations, develop their own estimate and present it as a baseline in their GBR-B, including their estimated costing for grouting works.

See Supporting *Chapter Three - Contracts and legal* for the contractual treatment and management of the GBR.

5 Definitions and Abbreviations

DCP	Drop Cone Penetrometer
EIS	Environmental Impact Statement
EWR	Exploratory Works - Roads
FID	Final Investment Decision
GBR	Geotechnical Baseline Report
OSP	Open Standpipe Piezometers
TC	Tunnelling classes
VWP	Vibrating Wire Piezometers

6 Bibliography

There is no bibliography for this chapter.