Appendix J – Groundwater impact assessment

Centennial Newstan Pty Ltd

Newstan Mine Extension Project
Groundwater Impact Assessment

June 2020

Executive summary

Newstan Colliery is an existing underground coal mine located in the Lake Macquarie Local Government Area (LGA), approximately 25 kilometres south west of Newcastle and 140 km north of Sydney, NSW. It is owned and operated by Centennial Newstan Pty Ltd (Centennial Newstan).

Newstan Colliery has at various times mined the upper coal seams (Great Northern and Fassifern seams) and lower coal seams (West Borehole, Borehole, Young Wallsend and Yard seams) and produced both semi-soft coking coal and thermal coal for the domestic and export markets. In the lower seams, workings to date have been concentrated to the west of the seam split, which is a defining geological feature of the mine. Mining has been undertaken using a combination of bord and pillar and longwall mining.

Centennial Newstan is now seeking approval for the continuation of mining within the West Borehole seam (Extension of Mining Area) that partially underlies the closed Awaba Colliery. The Newstan Mine Extension Project (the project) proposes to extract up to 25.9 million tonnes (Mt) over a fifteen year period at a maximum production rate of 4 million tonnes per annum (Mtpa) of run of mine (ROM) coal. Bord and pillar mining is proposed using continuous miner methods that will include areas of first workings, partial extraction and total extraction. Once the coal reaches the Newstan Colliery Surface Site it will be handled in accordance with the approved operations for the Northern Coal Logistics Project (SSD-5145), managed by Centennial's Northern Coal Services business unit.

This Groundwater Impact Assessment (GIA) has been prepared to form part of an Environmental Impact Statement (EIS) to support a State significant development (SSD) application (SSD-10333) made under Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The key objective of the GIA is to determine the potential impacts of the project on the groundwater environment by addressing the relevant Secretary's environmental assessment requirements (SEARs) for the project and relevant government agency requirements. In addition, the project was declared to be a controlled action (EPBC 2019/8528), and requires assessment and approval under the EPBC Act.

The groundwater sources in the vicinity of the Project Application Area, which includes the Extension of Mining Area, include the Quaternary alluvium and the weathered and/or fractured sandstone and coal seams. They are classified as 'less productive' in accordance with the criteria specified in the NSW Aquifer Interference Policy (i.e. the yield is typically less than 5 L/s and/or the total dissolved solids concentration is typically greater than 1,500 mg/L).

The alluvial groundwater sources are managed under the Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources. The alluvial aquifer thickness is generally less than 16 m and groundwater ranges in depth from less than 1 m to about 5 m below ground level (bgl). Groundwater flow generally follows topography and provides baseflow to ephemeral creeks in some areas.

The fractured and porous rock groundwater sources are managed under the Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources. The piezometric head within the Permian coal seams tend to reflect the natural topography and proximity to Lake Macquarie, with reduced pressures at major surface drainage areas and in areas of coal extraction. Groundwater flow through the Project Application Area is generally to the east towards Lake Macquarie.

Registered groundwater use in the vicinity of the Project Application Area is low. The majority (50) of registered bores within 2 km of the Project Application Area (69) were registered as monitoring bores or test bores with the remainder generally registered for stock and domestic and/or irrigation purposes and of depth less than 50 m. Only one registered bore (GW202325) is located in the Extension of Mining Area and it is registered as a monitoring bore / test bore.

Potential groundwater dependent ecosystems (GDEs) within the Project Application Area have been mapped based on a search of the BOM Atlas. Lake Macquarie, Muddy Lake and Whiteheads Lagoon are mapped as potential aquatic GDEs. There are no GDEs within the Project Application Area that are classified as 'high priority' in the relevant Water Sharing Plans.

Based on the existing groundwater monitoring program, there is no evidence of impact from existing mining activities at Newstan on alluvial groundwater (or GDEs). There are no known impacts on registered bores from existing mining activities at Newstan. Some groundwater drawdown in the West Borehole seam has been detected by vibrating wire piezometers. Otherwise, groundwater inflows from the porous and fractured rock groundwater source to the existing West Borehole seam workings are relatively low (in the order of 1 ML/day) and there is no evidence of direct hydraulic connection between the existing West Borehole seam workings and the Awaba underground void.

Groundwater quality monitoring has been undertaken at Newstan since 2005. Monitoring data does not show impacts on groundwater quality or beneficial use of groundwater due to mining over this period. Changes to groundwater sources and impacts on groundwater sources as a result of the project have been predicted using a calibrated three dimensional hydrogeological model. The model is based on the conceptualisation outlined in GHD (2020a) and has been used to predict:

- Changes to groundwater inflows into the existing and proposed workings at Newstan Colliery in the West Borehole seam.
- Changes in groundwater level.
- Changes in baseflow to waterways.
- Changes in groundwater inflow into the Awaba underground void and seepage from the Awaba void to underlying strata.
- Changes in seepage from Eraring Ash Dam to underlying strata.

The hydrogeological model has been used to predict impacts directly attributable to the proposed mining at Newstan Colliery within the Extension of Mining Area as well as cumulative impacts attributable to existing and proposed mining at Newstan Colliery and mining at surrounding coal mines including Cooranbong Colliery, Awaba Colliery, West Wallsend Colliery, Teralba Colliery and Newstan workings in the Great Northern seam and Fassifern seam.

There are a number of elements of the regional water balance that have been included and assessed in the water balance model (GHD, 2020b) but are outside the scope of the numerical groundwater model. These inputs and outputs of water to and from the Fassifern Underground Storage and the Awaba underground void other than groundwater inflow/outflow. Potential flows from Eraring Ash Dam to the Awaba underground void via sinkholes is only considered in the water balance model.

The conceptualisation of the fracture zone is based on groundwater monitoring data for Newstan Colliery and Mandalong mine, including recorded mine inflows. It is considered that the empirical conceptualisation of the fracture zone presented by SCT (2019) is overly conservative and not consistent with experience from previous mining at Newstan Colliery. Although the SCT (2019) conceptualisation for enhanced flow from the Awaba underground void to the proposed mine workings in the Extension of Mining Area and from the Eraring Ash Dam to the proposed mine workings is considered to be unlikely, this scenario has still been run using the groundwater model as part of the uncertainty analysis.

There is no groundwater drawdown predicted in the alluvium attributable to the proposed workings at Newstan Colliery. Therefore there are no impacts on GDEs or reduction in baseflow due to the proposed workings predicted. There will also be no impact on groundwater levels or quality in the vicinity of Lake Macquarie City Council's Awaba Biodiversity Conservation Area. Some shallow groundwater drawdown has been predicted from the cumulative impact scenario, however this is all attributable to historical mining in the region (primarily within the Great Northern seam) and it is not exacerbated by the proposed mining in the deeper West Borehole seam.

Based on the model predictions, groundwater inflow into the Newstan Colliery West Borehole seam workings is predicted to peak at 4.0 ML/day in 2029. The hydrogeological model is overestimating current groundwater inflow into the West Borehole seam workings. Therefore estimates of future mine inflows are considered to be conservative. Uncertainty analysis indicates that higher inflows could occur under some scenarios, however these scenarios also substantially over-predict existing inflows and are therefore not considered to be reliable.

The hydrogeological model predicts drawdown of the Permian Coal Measures attributable to the proposed workings within the Extension of Mining Area will extend up to approximately 9.5 km to the north-east and 11 km to the south from the proposed workings. The hydrogeological model predicts cumulative drawdown will extend up to 14 km to the south of the Newstan Colliery West Borehole seam workings. Note that cumulative drawdown is potentially due to a combination of Newstan Colliery workings and surrounding coal mining operations.

Landholder bores within the radius of groundwater depressurisation, within the West Borehole seam and attributable to the proposed workings, have been identified. Of the 286 bores identified, 122 were registered as monitoring bores. The majority of the remainder are shallow bores within Quaternary or Triassic strata and are not impacted by the project. There are ten bores screened within Permian strata. Groundwater drawdown due to the proposed workings is not predicted to exceed 0.6 m at any of these Permian bores.

Since the proposed workings do not impact on GDEs and as drawdown at groundwater supply works is less than 2 m, the predicted impacts are less than the Level 1 minimal impact considerations under the NSW Aquifer Interference Policy and are therefore considered to be acceptable.

The modelling results indicate proposed mining at Newstan Colliery will have no impact on leakage out of the Eraring Ash Dam. Additionally the modelling results indicate the proposed mining will have no impact on the flooded Fassifern workings at Newstan Colliery.

The modelling results indicate that the proposed mining at Newstan Colliery will result in a reduction in groundwater inflow into the flooded Awaba workings. The reduction in groundwater inflow into Awaba is attributable to groundwater drawdown in the strata surrounding Awaba. The maximum reduction in groundwater inflows into Awaba due to proposed mining is 22 m^3/day and occurs between the year 2063 and the year 2175. No increase in leakage out of the Awaba underground void is predicted.

Post mining groundwater contours (at 600 years post mining and steady state) are similar to pre mining contours with no areas of post mining groundwater seepage evident.

Based on previous groundwater quality data and modelling predictions regarding leakage from Eraring Ash Dam and Awaba Colliery underground void, it is considered that groundwater quality impacts attributable to the project will be less than the Level 1 minimal impact considerations under the NSW Aquifer Interference Policy and are therefore considered to be acceptable. The potential for leakage from the Eraring Ash Dam is also discussed in the *Newstan Extension of Mining Project: Surface Water Impact Assessment* (GHD, 2020b).

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1.5 and the assumptions and qualifications contained throughout the Report.

Table of contents

1. Introduction....1
   - 1.1 Background....1
   - 1.2 Extension of Mining Area....2
   - 1.3 Objectives and scope of work....5
   - 1.4 Potential impacts of the project....8
   - 1.5 Limitations....8
   - 1.6 Structure of the report....9
2. Legislation and policy....10
   - 2.1 Legislation....10
   - 2.2 Policies....12
   - 2.3 Guidelines....13
3. Site description....15
   - 3.1 Climate....15
   - 3.2 Topography....17
   - 3.3 Hydrology....17
   - 3.4 Geology....20
   - 3.5 Hydrogeology / groundwater sources....24
   - 3.6 Groundwater use....25
   - 3.7 Groundwater dependent ecosystems....27
4. Groundwater management and monitoring....31
   - 4.1 Groundwater monitoring program....31
   - 4.2 Underground water management....34
5. Impact assessment methodology....43
   - 5.1 Impact prediction....43
   - 5.2 Impact assessment criteria....43
6. Impact assessment....44
   - 6.1 Impact prediction....44
   - 6.2 Impact assessment....48
   - 6.3 Water sharing plan licensing requirements....54
7. Mitigation, management and monitoring....55
   - 7.1 Flow monitoring....55
   - 7.2 Groundwater monitoring....55
   - 7.3 Hydrogeological model....56
   - 7.4 Management plans....56
8. Summary....58
   - 8.1 Summary of potential impacts....58
9. References....59

Table index

Table 1-1 Assessment requirements 5

Table 3-1 Stratigraphic sequence – Newstan Colliery 20

Table 3-2 Results of NSW bore database search 25

Table 4-1 Groundwater monitoring bore details 31

Table 6-1 Landholder bores within radius of drawdown of coal measures attributable to proposed workings 52

Figure index

Figure 1-1 Locality plan 3

Figure 1-2 Conceptual mine layout 4

Figure 3-1 Average climate data (-33.10_151.45) 15

Figure 3-2 Historical annual rainfall record 16

Figure 3-3 Cumulative departure from mean rainfall 16

Figure 3-4 Topography map 18

Figure 3-5 Watercourses within the Project Application Area 19

Figure 3-6 Surface geology mapping 22

Figure 3-7 Location of alluvium within the Project Application Area 23

Figure 3-8 Groundwater bore database search 29

Figure 3-9 Groundwater dependent ecosystems 30

Figure 4-1 Groundwater monitoring network 32

Figure 4-2 Observed underground water transfers at Newstan Colliery 36

Figure 4-3 Observed underground water levels in the Fassifern Underground Storage 36

Figure 4-4 Observed flow from Awaba seepage at SP5 37

Figure 4-5 Awaba underground void water level 38

Figure 4-6 West Borehole seam floor contours 41

Figure 4-7 West Borehole seam depth of cover contours 42

Figure 6-1 Modelled Newstan Colliery West Borehole seam groundwater inflows 44

Figure 6-2 Net leakage from Eraring Ash Dam 46

Figure 6-3 Net groundwater flow into Awaba 47

Figure 6-4 Net groundwater flow into Fassifern Underground Storage 48

Figure 6-5 Landholder bores in incremental radius of coal measures groundwater drawdown 53

Figure 7-1 Recommended additional groundwater monitoring locations 57

Appendices

Appendix A – Supporting assessment requirements

Appendix B – Groundwater modelling report

Appendix C – Groundwater quality

Abbreviations

AHD	Australian Height Datum
ARI	Average Recurrence Interval
bgl	Below ground level
BOM	Bureau of Meteorology
CCL	Consolidated Coal Lease
CDFM	Cumulative departure from mean
Centennial	Centennial Coal Company Limited
Centennial Newstan	Centennial Newstan Pty Limited
CPP	Coal Preparation Plant
DA	Development Application
EC	Electrical Conductivity
EIS	Environmental Impact Statement
EPA	Environment Protection Authority
EPL	Environment Protection Licence
FCT	Flexible Conveyor Train
GIA	Groundwater Impact Assessment
GDE	Groundwater Dependent Ecosystem
GHB	General Head Boundary
GHD	GHD Pty Ltd
GMS	Groundwater Modelling System
ha	Hectares
HARTT	Hydrograph Analysis: Rainfall and Time Trends
kL	Kilolitres
kL/day	Kilolitre per day
km	kilometre
kV	Kilovolt
LDP	Licenced Discharge Point
LGA	Local Government Area
LW	Longwall
m	Metres
MB	Monitoring bore
ML	Megalitre, Mining Lease
ML/day	Megalitre per day
mm	Millimetres
MOP	Mine Operation Plan
Mt	Million tonnes
Mtpa	Million tonnes per annum
Northern Coal Services	Centennial Northern Coal Services Pty Limited
NRAR	Natural Resources Access Regulator
NUDLC	National Uniform Drillers Licensing Committee

Origin Energy	Origin Energy Eraring Pty Limited
RMS	Root Mean Square Error
ROM	Run of Mine
SEARs	Secretary's environmental assessment requirements
SILO	Scientific Information for Land Owners
SMP	Subsidence Management Plan
SRMSE	Scaled Root Mean Square Error
SSD	State significant development
t	Tonnes
TARP	Trigger, Action and Response Plan
USGS	United States Geological Survey
VWP	Vibrating Wire Piezometer
WSP	Water Sharing Plan

Glossary

Aquifer	A groundwater bearing formation sufficiently permeable to transmit and yield groundwater.
Ash	A major by-product of coal-fuelled power generation. Bottom ash is collected from the bottom of the boilers while fly ash is an inert mineral matter collected in dust collection plants.
Australian Height Datum	A common national surface level datum approximately corresponding to mean sea level.
Bord and pillar	A mining system whereby coal is extracted leaving 'pillars' of untouched coal to support the strata above.
Bore	Constructed connection between the surface and a groundwater source that enables groundwater to be transferred to the surface either naturally or through artificial means.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site.
Cumulative Rainfall Departure	Monthly accumulation of the difference between the observed monthly rainfall and long term average monthly rainfall.
Dewatering	The removal or pumping of water from an above or below ground storage, including the mine water within the water collection system of mine workings. Water removed from mine workings is regarded as dewatering unless the workings are flooded and at equilibrium with the surrounding strata (in which case the removal is considered groundwater extraction).
Discharge	The quantity of water per unit of time flowing in a stream, for example cubic metres per second or megalitres per day.
Drawdown	A reduction in piezometric head within an aquifer.
Ephemeral	Stream that is usually dry, but may contain water for rare and irregular periods, usually after significant rain.
Fracture	Cracks within the strata that develop naturally or as a result of underground works.
Goaf	That part of a mine from which the mineral has been partially or wholly removed, including the waste left in the workings.
Groundwater	Subsurface water that occurs in soils and geological formations.
Groundwater extraction	For the purposes of this assessment, groundwater extraction has been defined as the removal of groundwater from a groundwater source or aquifer, either via direct removal for use via a production bore or via incidental flow of groundwater from the aquifer into the mine workings during and after mining. Groundwater extraction includes the pumping of underground water from flooded mine workings in equilibrium with the surrounding strata as well as the removal of water from perched aquifers recharged directly from rainfall infiltration.

Headings	A roadway driven in to the coal seam for access to underground operations by personnel and machinery.
Hydrogeology	The area of geology that deals with the distribution and movement of groundwater in soils and rocks.
Hydrograph	A graph which shows how a water level (either surface or underground) at any particular location changes with time.
Hydrology	The study of rainfall and surface water runoff processes.
Infiltration	The downward movement of water into soil and rock. It is largely governed by the structural condition of the soil, the nature of the soil surface (including presence of vegetation) and the antecedent moisture content of the soil.
Interseam	The strata between coal seams.
Licensed Discharge Point	A location where a licensed operation discharges water to the environment in accordance with conditions stipulated within the site Environment Protection Licence.
Longwall	Longwall mining is a form of underground coal mining where a block of coal is mined using a longwall shearer. The longwall mining method is supported by roadway development, mined using a continuous miner unit.
Outcrop	Where the bedrock is exposed at the ground surface.
Overburden	The strata between the recoverable topsoil and the upper coal seam.
Permian Age	The youngest geological period of the Palaeozoic era, covering a span between approximately 290 and 250 million years.
Roadway	Underground tunnel constructed to enable access to working face.
Run of Mine	Raw coal production (unprocessed).
Runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
Strata	Geological layers below the ground surface.
Structure	The combination or spatial arrangement of primary soil particles (clay, silt, sand, gravel) into aggregates such as peds or clods, and their stability to deformation.
Subsidence	Mining-induced movements and deformations at the ground surface where (i) the vertical downward surface movements are greater than 20 mm, or (ii) the potential impacts on major surface infrastructure, structures or natural features may be significant, notwithstanding that the vertical downward surface movements are less than 20 mm.
Surface Water	Water that is derived from precipitation or pumped from underground and may be stored in dams, rivers, creeks and drainage lines.
Tailings	Fine reject material produced as a result of the coal processing.
Vertical Subsidence	Vertical downward movements of the ground surface caused by underground coal mining.

1. Introduction

GHD Pty Ltd (GHD) was commissioned by Centennial Newstan Pty Limited (Centennial Newstan) to prepare a Groundwater Impact Assessment (GIA) for the Newstan Mine Extension Project (the project). This assessment forms part of an Environmental Impact Statement (EIS) to support a State significant development (SSD) application (SSD-10333) made under Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). Centennial Newstan is a subsidiary of Centennial Coal Company Limited (Centennial), a wholly owned subsidiary of Banpu Public Company Limited.

1.1 Background

Newstan Colliery is an existing underground coal mine located in the Lake Macquarie Local Government Area (LGA), approximately 25 kilometres south west of Newcastle and 140 km north of Sydney, NSW. It is owned and operated by Centennial Newstan.

Mining operations at Newstan Colliery began in 1887. Since then Newstan Colliery has at various times mined the upper coal seams (Great Northern and Fassifern seams) and lower coal seams (West Borehole, Borehole, Young Wallsend and Yard seams) and produced both semi-soft coking coal and thermal coal for the domestic and export markets. In the lower seams, workings to date have been concentrated to the west of the seam split, which is a defining geological feature of the mine. Mining has been undertaken using a combination of bord and pillar and longwall mining.

In August 2014, the underground operations at Newstan Colliery were placed onto care and maintenance due to poor market conditions. In recent years, Centennial Newstan has commenced feasibility investigations into the recommencement of mining at Newstan Colliery. The most recent modification to DA 73-11-98 in January 2019 permits first workings mining within the West Borehole seam in the southern portion of the Newstan Colliery mining lease area. The first workings aim to improve Centennial Newstan's understanding of the geology within the West Borehole seam, including the presence, throw and strike of a major fault zone projected from the historical Newstan Colliery workings.

Centennial Newstan is now seeking approval for the continuation of mining within the West Borehole seam (Extension of Mining Area) that partially underlies the closed Awaba Colliery. The project proposes to extract up to 25.9 million tonnes (Mt) over a fifteen year period at a maximum production rate of 4 million tonnes per annum (Mtpa) of run of mine (ROM) coal. Bord and pillar mining is proposed using continuous miner methods that will include areas of first workings, partial extraction and total extraction. A mix of metallurgical and thermal coal is proposed to be extracted. ROM coal will be delivered to the Newstan Colliery Surface Site via a series of existing underground conveyors. Once the coal reaches the Newstan Colliery Surface Site it will be handled in accordance with the approved operations for the Northern Coal Logistics Project (SSD-5145), managed by Centennial's Northern Coal Services business unit.

Other key features of the project include:

- Utilisation of the Newstan Colliery Surface Site to provide parking, bathhouse, administration and workshop facilities for the underground workforce. A small number of administrative, maintenance and monitoring personnel will also be located at Awaba Colliery Surface Site.
- Transportation of personnel and materials to and from the underground mining area via the existing men and materials drift at Newstan Colliery Surface Site.

- Continued operation of the two existing ventilation fans at Newstan Colliery Surface Site and a ballast borehole located off Forest Road at Awaba.
- Installation and operation of three new ventilation fans at the existing ventilation shaft at Awaba Colliery Surface Site.
- In-seam gas drainage, with gas transferred to a new gas flaring facility to be located within the existing disturbance footprint of Awaba Colliery Surface Site.
- Extraction of underground water via the existing Fassifern Pump Station at Newstan Colliery Surface Site and ongoing groundwater management in accordance with Centennial's *Northern Operations: Regional Water Management Plan*.

If approved, the project will allow for the optimisation of resource recovery from Newstan Colliery while providing ongoing direct and indirect employment opportunities. In addition, the project will provide a number of positive flow-on effects to the local, regional and state economies through additional wages and royalties.

The Project Application Area, which encompasses the existing Newstan Colliery and Awaba Colliery project areas, is shown in Figure 1-1.

1.2 Extension of Mining Area

Bord and pillar mining is proposed to be undertaken using continuous miners and will include first workings, partial extraction and total extraction. Mining will be designed to extract up to 4 Mtpa of ROM coal from within the Extension of Mining Area and a total of 25.9 million tonnes over a fifteen-year mine life. The conceptual mine layout is presented in Figure 1-2.

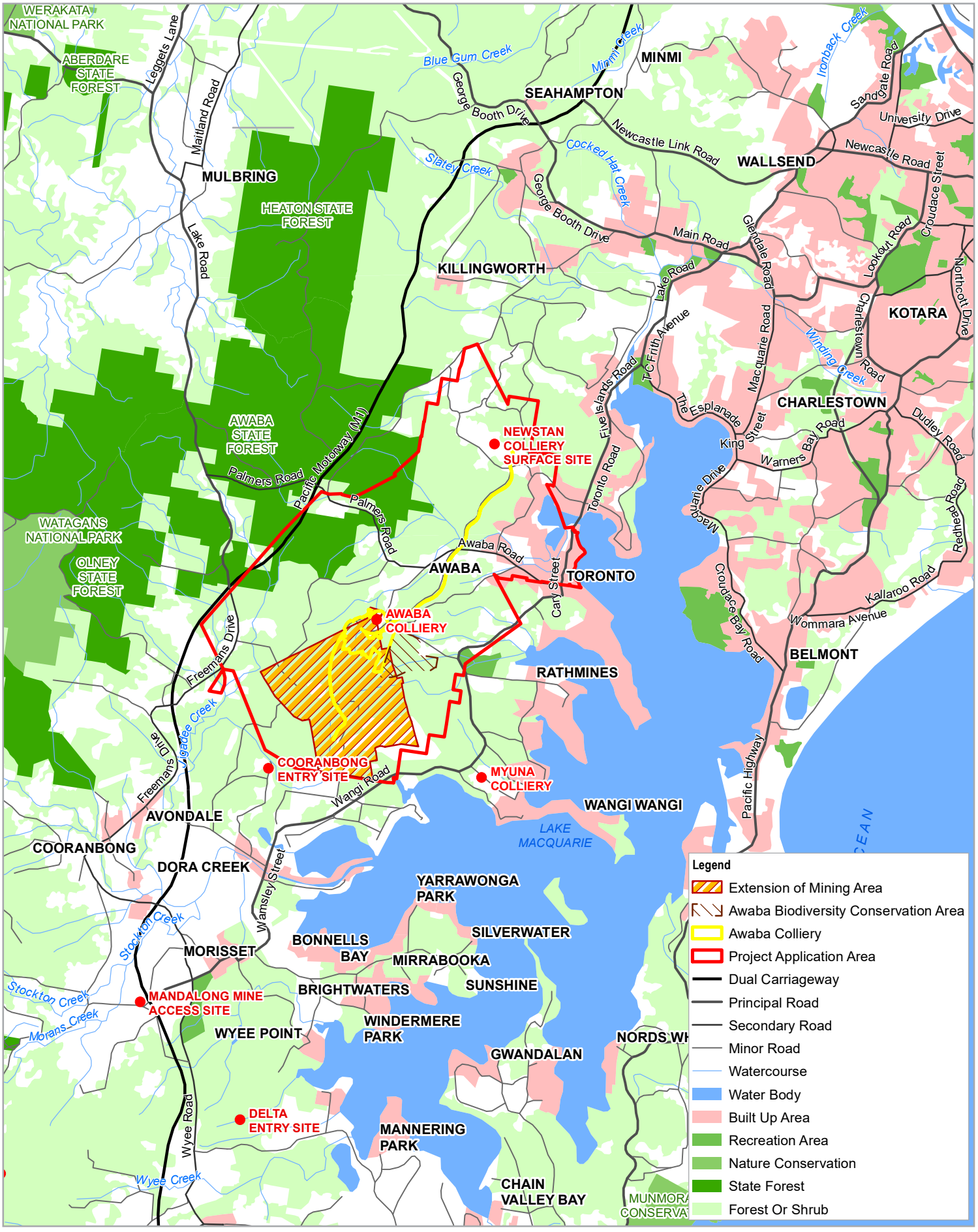
Mining will target the West Borehole seam, which is an agglomeration of the Borehole seam, the Young Wallsend seam and the Yard seam. A mix of metallurgical and thermal coal will be extracted. The depth of cover within the Extension of Mining Area ranges from 140 m in the north west to 320 m in the east. The target seam is overlain by the previous Awaba Colliery mine workings in parts of the Extension of Mining Area with the interburden between the two seams ranging from 100 m to 210 m.

The combination of first workings, partial and total extraction has been adopted to mitigate impacts on sensitive surface features. Total extraction, where all pillars in a panel are removed, is proposed to the south of the existing Awaba Colliery mine workings in areas that have not been subject to mining previously (i.e. single-seam conditions) and in some areas beneath the existing workings (i.e. multi-seam conditions) where sensitive surface features are not present. The total extraction in the multi-seam areas will provide the additional benefit of reducing the long-term liability of pillar failure in the overlying Awaba Colliery mine workings in the Great Northern seam. The maximum void width in total extraction areas is 167 m.

The development of first workings only (i.e. no secondary extraction) will occur beneath certain sensitive surface features in both single-seam and multi-seam conditions. This includes under numerous second and third order streams, the Main Northern Railway, a 132 kV substation, and the Eraring Power Station.

With the presence of the overlying Awaba Colliery mine workings and larger than previously encountered volume of gas within the West Borehole seam and overlying seams, which will be released by the mining process, this mining system allows for greater control of subsidence, particularly with regard to minimising multi-seam subsidence, improved gas management, and superior flexibility to deal with geological anomalies.

Personnel and materials will be transported down the existing men and materials drift at Newstan Colliery Surface Site.



Paper Size ISO A4

0 1 2 3 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

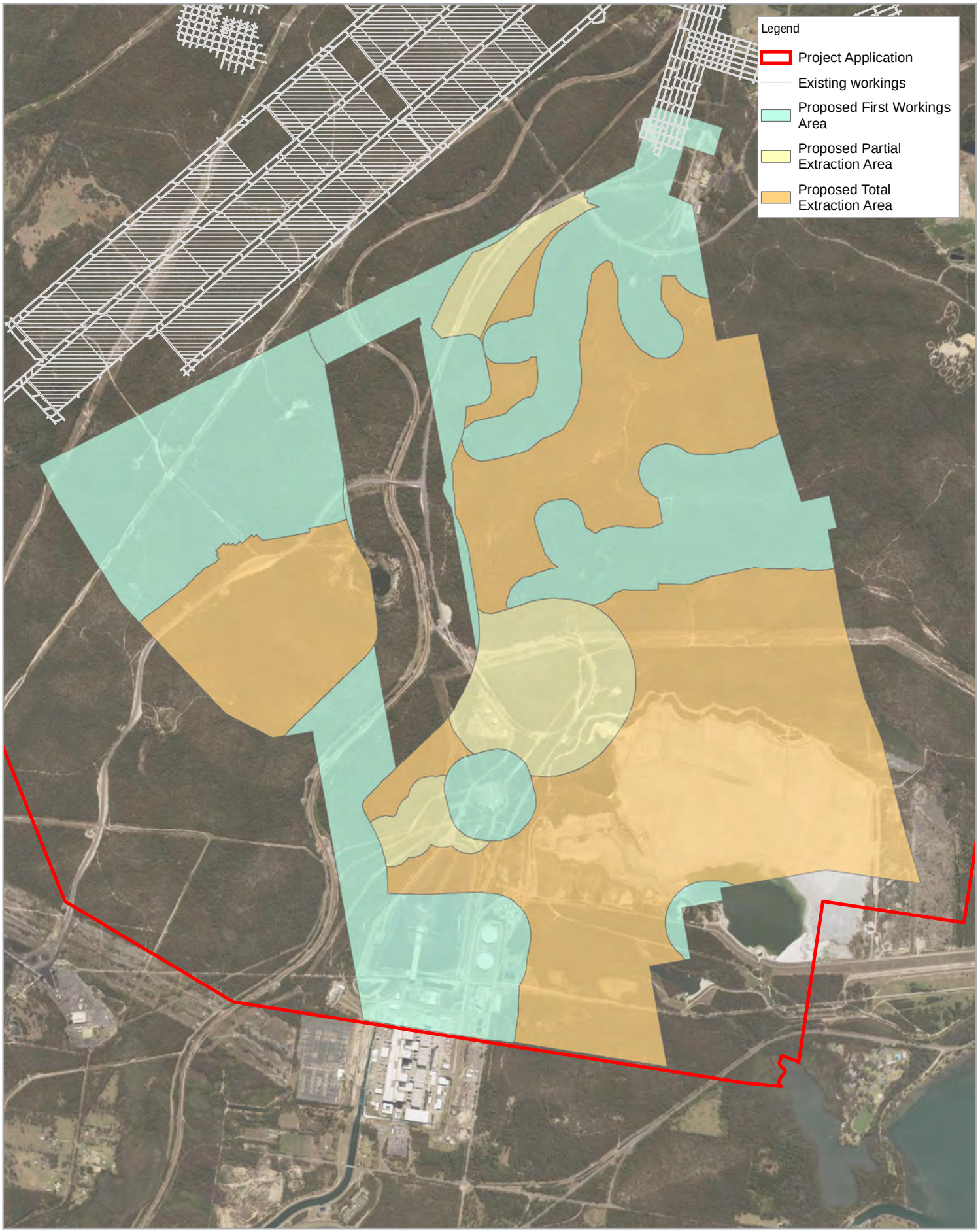
Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

Locality

FIGURE 1-1

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-001_Locality.mxd
Print date: 27 Mar 2020 - 14:20

Data source: Centennial: Consent boundary, 2018, Conservation Area, 2019 Geoscience Australia: 250k Topographic Data Series 3, 2006. Created by: smacdonald



Paper Size ISO A4

0 0.15 0.3 0.45 0.6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

Project No. 22-20265
Revision No. A
Date 24/01/2020

Conceptual mine layout

FIGURE 1-2

G:\22\20105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-002_ProposedMinePlan.mxd
Print date: 06 Feb 2020 - 13:48

Data source: Centennial: Consent boundary, 2016, workings, 2019; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

1.3 Objectives and scope of work

The key objective of the GIA is to determine the potential impacts of the project on the groundwater environment by addressing the relevant Secretary's environmental assessment requirements (SEARs) for the project and relevant government agency requirements. The relevant SEARs and additional requirements are presented in Table 1-1, along with a reference to where each has been addressed in the GIA. In addition, the project was declared to be a controlled action (EPBC 2019/8528), and requires assessment and approval under the EPBC Act (refer to Section 2.1.4). Additional assessment requirements under the EPBC Act are provided in Appendix A, along with a reference to where each has been addressed within this report.

The scope of works for the investigation included:

- A review of available background hydrogeological and mining data.
- Review of relevant statutory requirements and development of impact assessment criteria.
- Identification and description of groundwater sources within the Project Application Area.
- Search of the NSW Groundwater Bore Database to identify licensed groundwater users in the anticipated radius of groundwater drawdown.
- Identification of potential groundwater dependent ecosystems (GDEs) within the Project Application Area.
- Development of a MODFLOW hydrogeological model to predict potential impacts on groundwater sources (quantity) as a result of the proposed underground workings (Appendix B).
- Identification of potential groundwater impacts resulting from the construction and operation of the Project, based on the NSW Aquifer Interference Policy minimal impact considerations.
- Assessment of potential impacts of the Project on GDEs, licensed groundwater users and basic landholder rights.
- Identify licensing requirements.
- Develop measures to avoid, minimised and mitigate potential impacts of the project and provide recommended management, monitoring and reporting requirements.

Table 1-1 Assessment requirements

Assessment requirement	Where addressed
Secretary's Environmental Assessment Requirements	
A comprehensive assessment of potential impacts of the proposed development on surface and groundwater management associated with historic mine workings in overlying coal seams.	Section 6.2
Identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000.	Section 6.3
An assessment of the likely impacts of the development on the quantity and quality of existing surface and groundwater resources including a detailed assessment of proposed water discharge quantities and quality against receiving water quality and flow objectives.	Section 6.2. Discharge quantity and quality addressed in GHD (2020b)

Assessment requirement	Where addressed
An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users.	Section 6.2 (aquifers). Other aspects addressed in GHD (2020b)
Department of Industry	
The identification of an adequate and secure water supply for the life of the project. This includes confirmation that water can be sourced from an appropriately authorised and reliable supply. This is also to include an assessment of the current market depth where water entitlement is required to be purchased.	Section 6.3
Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	Section 6.2 Section 7
Proposed surface and groundwater monitoring activities and methodologies.	Section 4.1 Section 7
Consideration of relevant legislation, policies and guidelines, including the NSW Aquifer Interference Policy (2012), the Guidelines for Controlled Activities on Waterfront Land (2018) and the relevant Water Sharing Plans (available at https://www.industry.nsw.gov.au/water).	Section 2 Section 6.3. Guidelines for Controlled Activities on Waterfront Land (2018) not relevant to this report
Office of Environment and Heritage	
The EIS must map the following features relevant to water and soils including: a. Acid sulfate soils (Class 1, 2, 3 or 4 on the Acid Sulfate Soil Planning Map). b. Rivers, streams, wetlands, estuaries (as described in s4.2 of the Biodiversity Assessment Method). c. Wetlands as described in s4.2 of the Biodiversity Assessment Method. d. Groundwater. e. Groundwater dependent ecosystems. f. Proposed intake and discharge locations.	Groundwater aspects in Section 3.4 Section 3.5 Section 3.7
The EIS must describe background conditions for any water resource likely to be affected by the development, including: a. Existing surface and groundwater. b. Hydrology, including volume, frequency and quality of discharges at proposed intake and discharge locations. c. Water Quality Objectives (as endorsed by the NSW Government http://www.environment.nsw.gov.au/ieo/index.htm) including groundwater as appropriate that represent the community's uses and values for the receiving waters. d. Indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.	Groundwater aspects in Section 3.5 Section 4. Surface water and water quality in GHD (2020b)

Assessment requirement	Where addressed
The EIS must assess the impacts of the development on water quality, including: a. The nature and degree of impact on receiving waters for both surface and groundwater, demonstrating how the development protects the Water Quality Objectives where they are currently being achieved, and contributes towards achievement of the Water Quality Objectives over time where they are currently not being achieved. This should include an assessment of the mitigating effects of proposed stormwater and wastewater management during and after construction. b. Identification of proposed monitoring of water quality.	Section 6.2
The EIS must assess the impact of the development on hydrology, including: a. Water balance including quantity, quality and source. b. Effects to downstream rivers, wetlands, estuaries, marine waters and floodplain areas. c. Effects to downstream water-dependent fauna and flora including groundwater dependent ecosystems. d. Impacts to natural processes and functions within rivers, wetlands, estuaries and floodplains that affect river system and landscape health such as nutrient flow, aquatic connectivity and access to habitat for spawning and refuge (e.g. river benches). e. Changes to environmental water availability, both regulated/licensed and unregulated/rules-based sources of such water. f. Mitigating effects of proposed stormwater and wastewater management during and after construction on hydrological attributes such as volumes, flow rates, management methods and re-use options. g. Identification of proposed monitoring of hydrological attributes.	Section 6.2 for groundwater. Other aspects of hydrology in GHD (2020b)
Environment Protection Agency	
Assess impacts on groundwater and groundwater dependent ecosystems.	Section 6.1 Section 6.2
Describe existing surface and groundwater quality. An assessment needs to be undertaken for any water resource likely to be affected by the proposal. Issues to be discussed should include but are not limited to: − an outline of baseline groundwater information, including, for example, depth to water table, flow direction and gradient, groundwater quality, reliance on groundwater by surrounding users and by the environment	Section 3.5 Section 4.1.1
Lake Macquarie City Council	
Council seeks to ensure that groundwater impacts and risks, and biodiversity impacts on the proposed Awaba Conservation Area have been adequately documented and assessed, and specifically that potential impacts are avoided on biodiversity offsets managed within Council's Awaba Biodiversity Conservation Area. In particular, LMCC requires that potential risks to the Awaba Biodiversity Conservation Area are properly recognised and addressed in the EIS, and ongoing consultation and commitments from Centennial Coal are required.	Section 6.1 Section 6.2 Section 7.2
Baseline subsidence, groundwater and biodiversity monitoring sufficiently detailed to be able to identify future impacts on biodiversity should be undertaken as part of the proposal. This is essential for LMCC to protect its interests in the Awaba Biodiversity Conservation Area and to be able to assess biodiversity impacts more widely.	Section 4

Assessment requirement	Where addressed
The potential for groundwater impacts from the proposed mining, and consequences for natural ecosystems is significant, and must be a priority for the EIS. For example, impacts and groundwater drawdown in the Stockyard and Kilaben Creek catchments is likely, and groundwater dependent ecosystems that may be impacted must be identified.	Section 6.2
The EIS should include surface and groundwater monitoring data within the mining area to determine baseline conditions and to enable post-mining changes to be determined.	Section 4

1.4 Potential impacts of the project

The following potential impacts on groundwater resources have been identified as requiring assessment by the GIA:

- Changes to groundwater inflows into the existing and proposed workings at Newstan Colliery in the West Borehole seam.
- Changes in groundwater level and resulting impacts on groundwater receptors.
- Changes in baseflow to waterways.
- Changes in groundwater quality and resulting impacts on groundwater receptors.
- Changes in groundwater inflow into the Awaba underground void and seepage from the Awaba underground void to underlying strata.
- Changes in seepage from Eraring Ash Dam to underlying strata.

These potential impacts have also been outlined in the conceptual model overview in Section 2.2.4 of the Groundwater Model Report in Appendix B.

1.5 Limitations

This report has been prepared for Centennial Newstan and may on be used and relied upon by Centennial Newstan for the purpose agreed between GHD and the Centennial Newstan as set out in Section 1 of this report.

GHD otherwise disclaims responsibility to any person other than Centennial Newstan arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this Report are based on conditions encountered and information reviewed at the date of preparation of the Report. GHD has no responsibility or obligation to update this Report to account for events or changes occurring subsequent to the date that the Report was prepared. Specifically, this Report does not take into account the effects, implications and consequences of or responses to COVID-19, which is a highly dynamic situation and rapidly changing. These effects, implications, consequences of and responses to COVID-19 may have a material effect on the opinions, conclusions, recommendations, assumptions, qualifications and limitations in this Report, and the entire Report must be re-examined and revisited in light of COVID-19. Where this Report is relied on or used without obtaining this further advice from GHD, to the maximum extent permitted by law, GHD disclaims all liability and responsibility to any person in connection with, arising from or in respect of this Report whether such liability arises in contract, tort (including negligence) or under statute.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Centennial Newstan and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

1.6 Structure of the report

An overview of the structure of the GIA is provided below:

- **Executive summary** provides a brief overview of the project and the key findings of the impact assessment.
- **Section 1** introduces the project by summarising the history of operations at Newstan Colliery and Awaba Colliery, describing the key elements of the project and outlining the objectives and scope of the GIA.
- **Section 2** outlines the statutory context of the project, including the applicability of Commonwealth and State legislation, policies and relevant guidelines.
- **Section 3** provides a characterisation of the existing environment, including land use, topography, climate, hydrogeological environment and regional setting.
- **Section 4** provides details regarding the existing groundwater monitoring network, monitoring results and underground water management.
- **Section 5** sets out the impact assessment methodology.
- **Section 6** provides a summary of predicted impacts on groundwater inflow into the mine workings, groundwater levels and key groundwater receptors and provides an assessment of the potential impacts of the proposed workings on groundwater receptors. This section also outlines the surface water licensing requirements of the project.
- **Section 7** describes the recommended measures to avoid, minimise or mitigate potential impacts to groundwater as a result of the project, as well as describes the management and reporting requirements for the operational phase of the project.
- **Section 8** provides a summary of the key findings of the impact assessment.
- **Section 9** provides a list of the documents and other information sources that were used to prepare the GIA.
- **Appendix A** presents the EPBC assessment requirements and outlines how each requirement has been addressed by the GIA.
- **Appendix B** presents the groundwater modelling report for the project.
- **Appendix C** presents the baseline groundwater quality monitoring results (groundwater level hydrographs are provided in the Groundwater Modelling Report (Appendix B).

2. Legislation and policy

The following section provides a brief overview of the legislation, policies and guidelines relevant to this groundwater impact assessment.

2.1 Legislation

2.1.1 Environmental Planning and Assessment Act 1979

The EP&A Act is the core legislation relating to planning and development activities in NSW and provides the statutory framework under which development proposals are assessed. The EP&A Act aims to encourage the proper management, development and conservation of resources, environmental protection and ecologically sustainable development.

The GIA forms part of an EIS to support development application SSD-10333 under Part 4 of the EP&A Act for the project. The Minister for Planning (or delegate) is the determining authority for the project.

The GIA has been developed to address the groundwater components of the SEARs and accompanying government agency requirements for the project, which are reproduced in Table 1-1, along with a reference to where each requirement has been addressed within this report.

2.1.2 Protection of the Environment Operations Act 1997

The *Protection of the Environment Operations Act 1997* (POEO Act) is administered by the Environment Protection Authority (EPA), which is an independent statutory authority and the primary environmental regulator for NSW. The objectives of the POEO Act are to protect, restore and enhance the quality of the environment, by mechanisms including programs to reduce pollution at the source and monitoring and reporting on environmental quality. The POEO Act regulates and requires licensing for environment protection, including for waste generation and disposal and for water, air, land and noise pollution.

Under the POEO Act, an environment protection licence (EPL) is required for premises at which a 'scheduled activity' is conducted. Schedule 1 of the POEO Act lists activities that are scheduled activities for the purpose of the Act. Licence conditions relate to pollution prevention and monitoring and can control the air, noise, water and waste impacts of an activity.

Newstan and Awaba Collieries are currently licensed for the scheduled activities of "coal works" and "mining for coal" under EPLs 395 and 443 respectively.

2.1.3 Water Management Act 2000

The aim of the *Water Management Act 2000* (WM Act) is to ensure that water resources are conserved and properly managed for sustainable use benefiting both present and future generations. It is also intended to provide formal means for the protection and enhancement of the environmental qualities of waterways and in-stream uses as well as to provide for protection of catchment conditions.

Historically, the *Water Act 1912* was the main legislation for managing water resources in NSW, however, this Act has been progressively phased out and replaced by water sharing plans (WSPs) under the WM Act. Once a WSP commenced, existing licences under the *Water Act 1912* were converted to water access licences (WALs), water supply works and use approvals (controlled activity approvals) under the WM Act. All new WALs and controlled activity approvals are also issued under the WM Act.

Water sharing plans

Fresh water sources throughout NSW are managed via WSPs under the WM Act. Provisions within WSPs provide water to support the ecological processes and environmental needs of groundwater dependent ecosystems and waterways. WSPs also regulate how the water available for extraction is shared between the environment, basic landholder rights, town water supplies and commercial uses. Key rules within the WSPs specify when licence holders can access water and how water can be traded.

The WSP for the Hunter Unregulated and Alluvial Water Sources commenced in August 2009 and regulates the interception and extraction of surface water and alluvium within the defined WSP area. The alluvium within the Project Application Area is located within the North Lake Macquarie extraction management unit of this WSP. Therefore, the interference and extraction of alluvial groundwater throughout the Project Application Area would normally require an access licence under the WM Act.

The WSP for the North Coast Fractured and Porous Rock Groundwater Sources commenced in July 2016. The porous and fractured groundwater sources within the Project Application Area are covered by the Sydney Basin – Lower Hunter / Central Coast Groundwater Source, which is defined under this WSP.

Section 4.41 of the EP&A Act removes the need for a number of approvals under the WM Act when development consent has been granted for a SSD. These are a water use approval under Section 89 of the Act, a water management work approval under section 90 of the Act and an activity approval (other than an aquifer interference approval) under section 91 of the Act.

2.1.4 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is administered by the Commonwealth Department of the Environment and Energy and provides a legal framework to protect and manage nationally important flora, fauna, ecological communities and heritage places defined as ‘matters of national environmental significance’ (MNES). The EPBC Act identifies water resources, in relation to large coal mining development, as a MNES.

An action that ‘has, will have or is likely to have a significant impact on a matter of national environmental significance’ is deemed a ‘controlled action’ and may not be undertaken without prior approval from the Commonwealth Environment Minister. Approval under the EPBC Act is also required where actions are proposed on, or will effect, Commonwealth land and its environment.

The project was referred to the Commonwealth Department of the Environment and Energy due to the potential impacts on MNES, including water resources. The project was declared to be a controlled action (EPBC 2019/8528), and requires assessment and approval under the EPBC Act. Additional assessment requirements under the EPBC Act are provided in Appendix A, along with a reference to where each has been addressed within this report.

2.2 Policies

2.2.1 NSW Aquifer Interference Policy

The NSW Aquifer Interference Policy (AIP) was finalised in September 2012 and clarifies the water licencing and approval requirements for aquifer interference activities in NSW, including the taking of water from an aquifer in the course of carrying out mining.

The Policy outlines the water licensing requirements under the *Water Act 1912* and WM Act. A water licence is required whether water is taken for consumptive use or whether it is taken incidentally by the aquifer interference activity (such as groundwater filling a void), even where that water is not being used consumptively as part of the activity's operation. Under the WM Act, a water licence gives its holder a share of the total entitlement available for extraction from the groundwater source. The WAL must hold sufficient share component and water allocation to account for the take of water from the relevant water source at all times.

Sufficient access licences must be held to account for all water taken from a groundwater or surface water source as a result of an aquifer interference activity, both for the life of the activity and after the activity has ceased. Many mining operations continue to take water from groundwater sources after operations have ceased. This take of water continues until an aquifer system reaches equilibrium and must be licensed.

The NSW AIP requires that potential impacts on groundwater sources, including their users and GDEs, be assessed against minimal impact considerations, outlined in Table 1 of the Policy. If the predicted impacts are less than the Level 1 minimal impact considerations, then these impacts will be considered as acceptable.

The Level 1 minimal impact considerations for less productive groundwater sources are relevant to the groundwater sources at Centennial sites and are as follows:

- **Water table:** less than or equal to 10% cumulative variation in the water table, allowing for typical climatic 'post-water sharing plan' variations, 40 m from any high priority GDE or high priority culturally significant site listed in the schedule of the relevant WSP. A maximum of a 2 m decline cumulatively at any water supply work unless make good provisions should apply.
- **Water pressure:** a cumulative pressure head decline of not more than 40 % of the 'post water sharing plan' pressure head above the base of the water source to a maximum of a 2 m decline at any water supply work.
- **Water quality:** any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity. For alluvial water sources, there should be no increase of more than 1% per activity in the long-term average salinity in a highly connected surface water source at the nearest point to the activity.

2.2.2 NSW State Groundwater Policies

The objective of the NSW State Groundwater Policy Framework Document (NSW Government 1997) is to manage the State's groundwater resources so that they can sustain environmental, social and economic uses for the people of NSW. NSW groundwater policy has three component parts:

- NSW Groundwater Quantity Management Policy.
- NSW Groundwater Quality Protection Policy.
- NSW Groundwater Dependent Ecosystems Policy.

NSW Groundwater Quantity Management Policy

The principles of this policy include:

- Maintain total groundwater use within the sustainable yield of the aquifer from which it is withdrawn.
- Groundwater extraction shall be managed to prevent unacceptable local impacts.
- All groundwater extraction for water supply is to be licensed. Transfers of licensed entitlements may be allowed depending on the physical constraints of the groundwater system.

NSW Groundwater Quality Protection Policy

The objective of this policy is the ecologically sustainable management of the State's groundwater resources so as to:

- Slow and halt, or reverse any degradation in groundwater resources.
- Direct potentially polluting activities to the most appropriate local geological setting so as to minimise the risk to groundwater.
- Establish a methodology for reviewing new developments with respect to their potential impact on water resources that will provide protection to the resource commensurate with both the threat that the development poses and the value of the resource.
- Establish triggers for the use of more advanced groundwater protection tools such as groundwater vulnerability maps or groundwater protection zones.

NSW State Groundwater Dependent Ecosystems Policy

This policy was designed to protect ecosystems which rely on groundwater for survival so that, wherever possible, the ecological processes and biodiversity of these dependent ecosystems are maintained or restored for the benefit of present and future generations. It provides guidance on how to protect and manage groundwater dependent ecosystems in a practical sense.

2.3 Guidelines

2.3.1 Significant impact guidelines

The significant impact guidelines provide over-arching advice on determining whether an action is likely to have a significant impact on a MNES protected by the EPBC Act and requires referral to the Commonwealth Department of the Environment and Energy for assessment and approval. Potential impacts on any MNES are subject to assessments of significance pursuant to the *Significant Impact Guidelines 1.1* (DoE 2013a). If a significant impact is considered likely, a referral under the EPBC Act must be submitted to the Commonwealth Environment Minister.

The *Significant Impact Guidelines 1.3* (DoE 2013b) includes significant impact criteria to assist in determining whether the impacts on a water resource from a proposed action associated with a coal seam gas or large coal mining development are likely to be significant, and therefore whether the action will require referral, assessment and approval. An action is likely to have a significant impact on a water resource if there is the possibility that it will directly or indirectly result in changes to the hydrology or water quality of a water resource.

The significant impact criteria defined by the *Significant Impact Guidelines 1.3* (DoE 2013b) are presented in Appendix A, along with where each aspect has been assessed in this GIA.

2.3.2 IESC information guidelines

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) is a statutory body established under the EPBC Act in 2012. The IESC provides independent scientific advice to Australian government regulators on proposed coal seam gas or large coal mining developments that are likely to have a significant impact on water resources. Information guidelines (IESC 2018) outline the information requirements of the IESC to adequately assess a proposal and provide scientific advice on the potential water-related impacts.

The GIA has been undertaken based on the information guidelines specified by the IESC (2018). Appendix A presents the information requirements as well as a reference to where each requirement has been addressed in this GIA.

The IESC has also published a series of explanatory notes to supplement the information guidelines to provide more detailed guidance on the preparation of environmental impact assessments. These explanatory notes that been utilised where relevant in the groundwater modelling process.

2.3.3 Risk assessment guidelines for groundwater dependent ecosystems

Risk Assessment Guidelines for Groundwater Dependent Ecosystems (NOW, 2012) comprises four volumes and provides a conceptual framework for identifying and assessing ecosystems along with worked examples of assessments and discusses the identification of high probability GDEs and also discussed the ecological value of GDEs. The results from this assessment will be used by others to assess potential impacts of GDEs.

2.3.4 Guidelines for groundwater protection in Australia

The National Water Quality Management Strategy (NWQMS) provides a national framework for improving water quality in Australia's waterways. The main policy objective of the NWQMS is to achieve sustainable use of the nation's water resources, protecting and enhancing their quality, while maintaining economic and social development.

The Guidelines for Groundwater Protection in Australia (ANZECC, 1995) are part of the NWQMS. The objective of these guidelines is to provide a national framework for the protection of groundwater from contamination. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018) are identified as a reference for identifying water quality criteria for developing a strategy for protecting groundwater and the aquatic ecosystem to meet a desired end point.

Protection of groundwater is generally easier when the source of contamination is concentrated at a point rather than spread over a broad area. Additionally, environmental protection measures have been developed to manage and minimise pollution from production of waste. These measures for protecting groundwater include waste avoidance, waste reuse, recycling and waste treatment.

Other groundwater protection strategies can include monitoring and review of performance of protection measures.

3. Site description

The existing geological, hydrogeological and surface water environment within the Project Application Area is outlined in this section.

3.1 Climate

The Science Delivery Division of the Department of Science, Information Technology and Innovation (DSITI) hosts an enhanced climate databased called SILO. SILO contains Australian climate data from 1901 and up to date in two formats: Patch Point and Data Drill. Patch Point data is station data with gaps infilled using the closest nearby record. Data Drill is a synthetic dataset, compiled based on interpolation between nearest weather stations across Australia for any given point.

For this assessment, SILO data were obtained for the grid point located at -33.00N, 151.55E, which is located within the Project Application Area. Average monthly climate data for this point are plotted in Figure 3-1. Evaporation varies seasonally, having higher records in summer compared in winter. The site generally has an average monthly net rainfall deficit except between April and July.

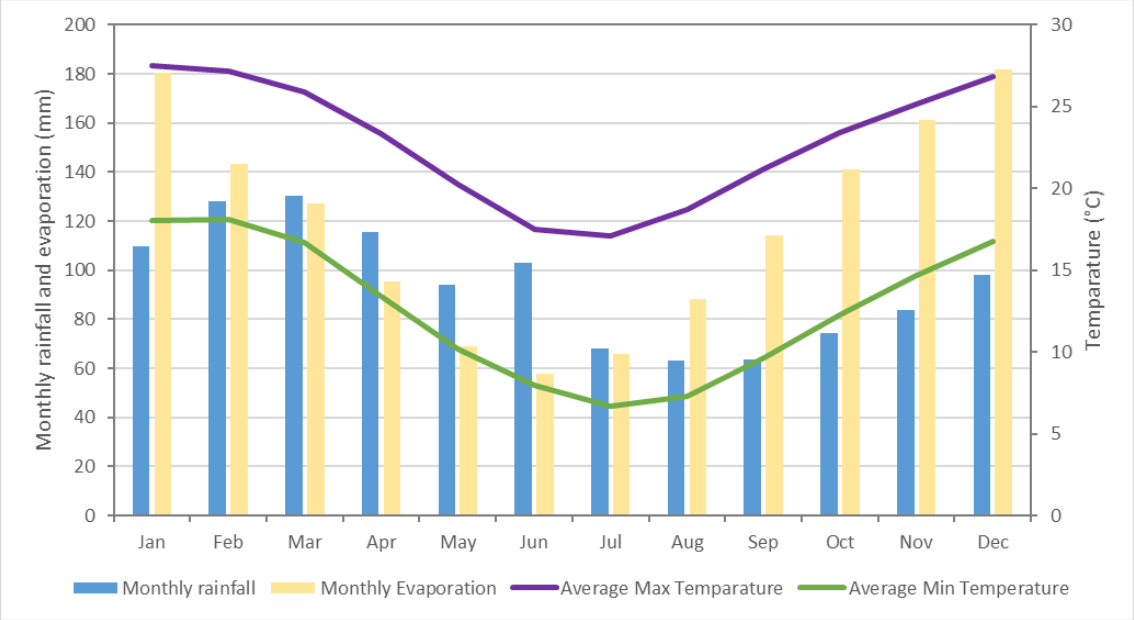


Figure 3-1 Average climate data (-33.10_151.45)

Figure 3-2 presents the historical annual SILO point rainfall data between 1889 and 2019. The annual statistics associated with this data are:

- Minimum rainfall total – 564 mm in 1944.
- Median rainfall total – 1072 mm.
- Average rainfall total – 1118 mm.
- Maximum rainfall total – 2109 mm in 1949.

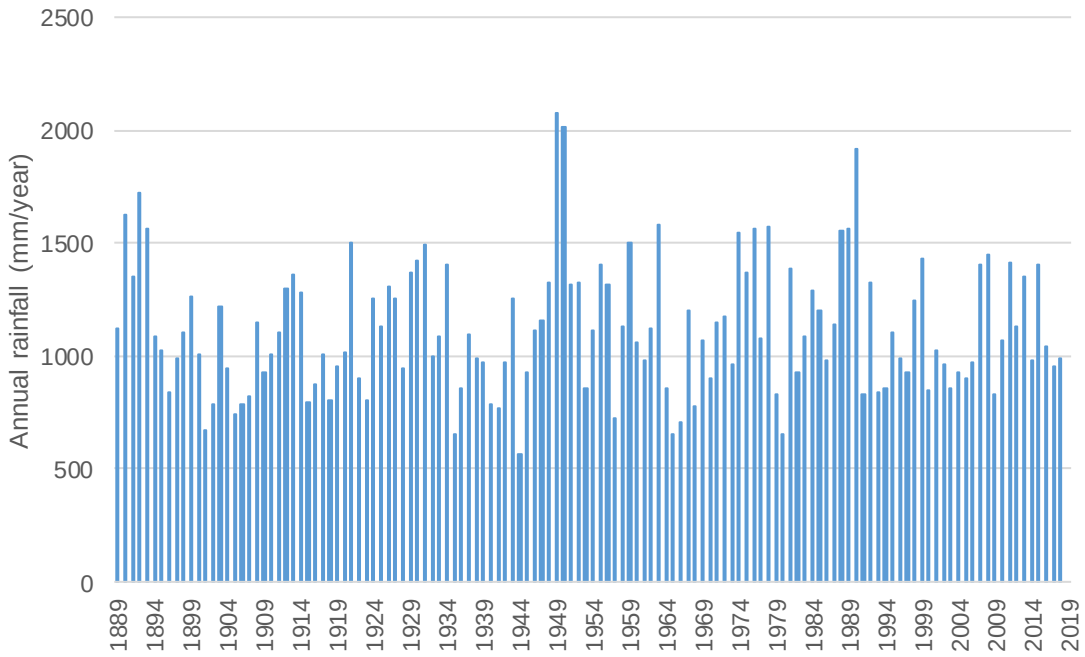


Figure 3-2 Historical annual rainfall record

Cumulative deviation from mean (CDFM) rainfall is the accumulated difference between the average and actual rainfall recorded. Monthly CDFM was calculated using data from 1889 to 2019. The monthly CDFM plot from January 1980 to 2019 is shown in Figure 3-3. The absolute value of the residual mass curve is not important, but rather the slope:

- A positive slope indicates a wetter than average period.
- A negative slope indicates a drier than average period.
- Flat line (no gradient) indicates average rainfall conditions.
- The grade of the slope indicates how much wetter or drier than average the climate is.



Figure 3-3 Cumulative departure from mean rainfall

3.2 Topography

The topography of the Project Application Area generally consists of rolling low hills with short side slopes and numerous closely spaced drainage lines, on predominately coarse grained sediments of the Narrabeen Group and Newcastle Coal Measures. Slope gradients are generally between 10 percent and 25 percent and local relief is from around 20 m Australian Height Datum (AHD) to 110 m AHD.

The elevation rises to the west of the Project Application Area to over 400 m AHD as shown in Figure 3-4.

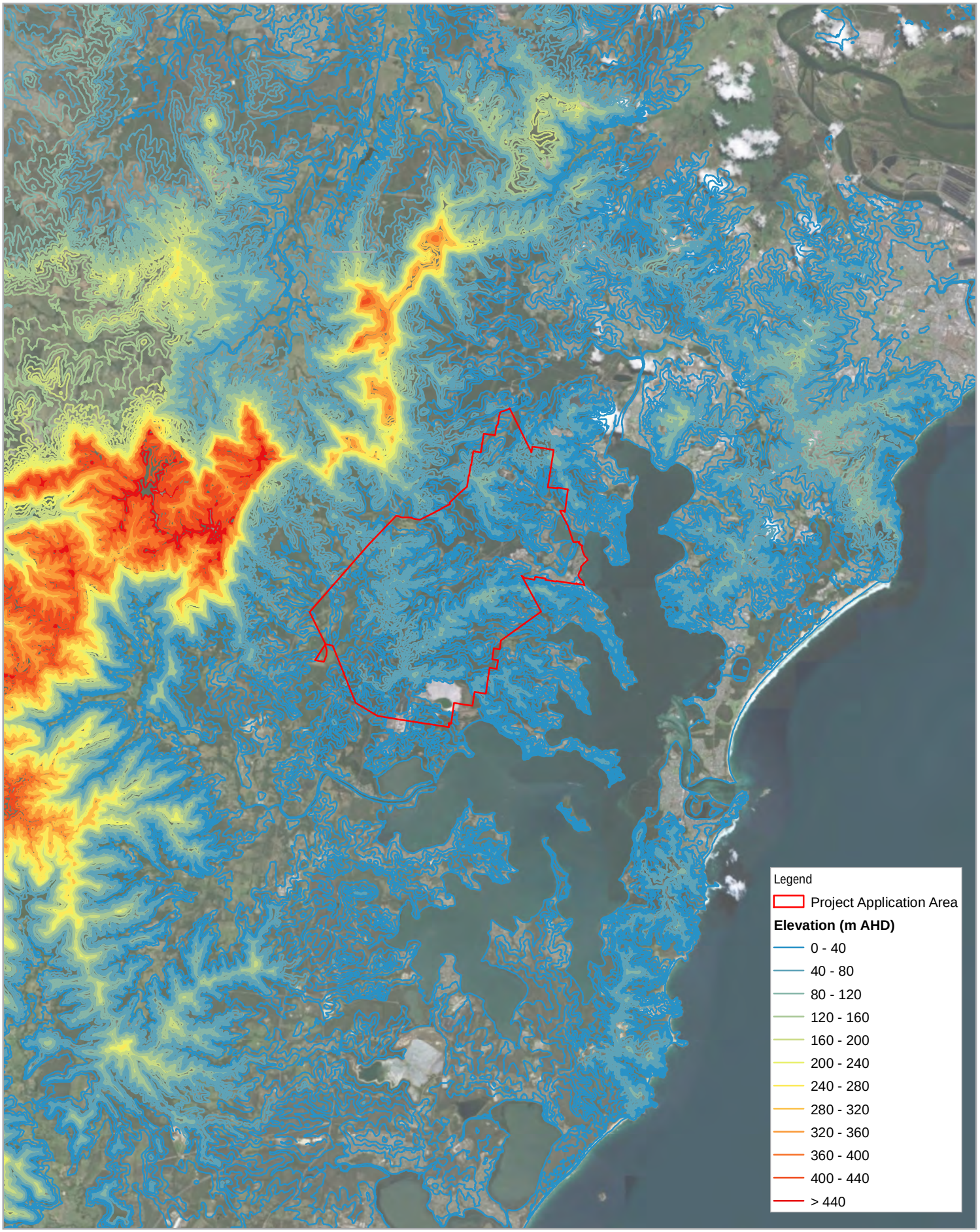
3.3 Hydrology

The Project Application Area is located within the catchment area of Lake Macquarie. Several watercourses traverse the Project Application Area; however, the area encompasses a small proportion of the catchment areas associated with these watercourses. As shown in Figure 3-5, the main creek systems that traverse the Project Application Area are:

- LT Creek, which flows in an easterly direction into Fennell Bay.
- Kilaben Creek and Stockyard Creek, which flow in an easterly direction into Kilaben Bay.
- Palmers Creek and Stony Creek, which flow in an easterly direction into Fennell Bay.
- Lords Creek, and its associated tributaries, which flows in a westerly direction into Jigadee Creek.
- Crooked Creek, which flows in a south-easterly direction into Lake Macquarie.

Creeks that overlie the proposed Extension of Mining Area include Kilaben Creek, Stockyard Creek, Stony Creek and Crooked Creek. Over the proposed Extension of Mining Area, these creeks are ephemeral as concluded in the Aquatic Ecology Impact Assessment (GHD, 2020c).

There are no data regarding creek water levels and flow in the vicinity of the Project Application Area. It has been conceptualised that creeks in the vicinity of the Project Application area, and upstream of the tidal zone, are water gaining streams. Evidence of surface water / groundwater connectivity is discussed further in Section 4.1.1. In the vicinity of Lake Macquarie, there is permanent water in creeks including Dora Creek, LT Creek, Stony Creek, Cockle Creek, Winding Creek and Kilaben Creek.



Paper Size ISO A4

0 1 2 3 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

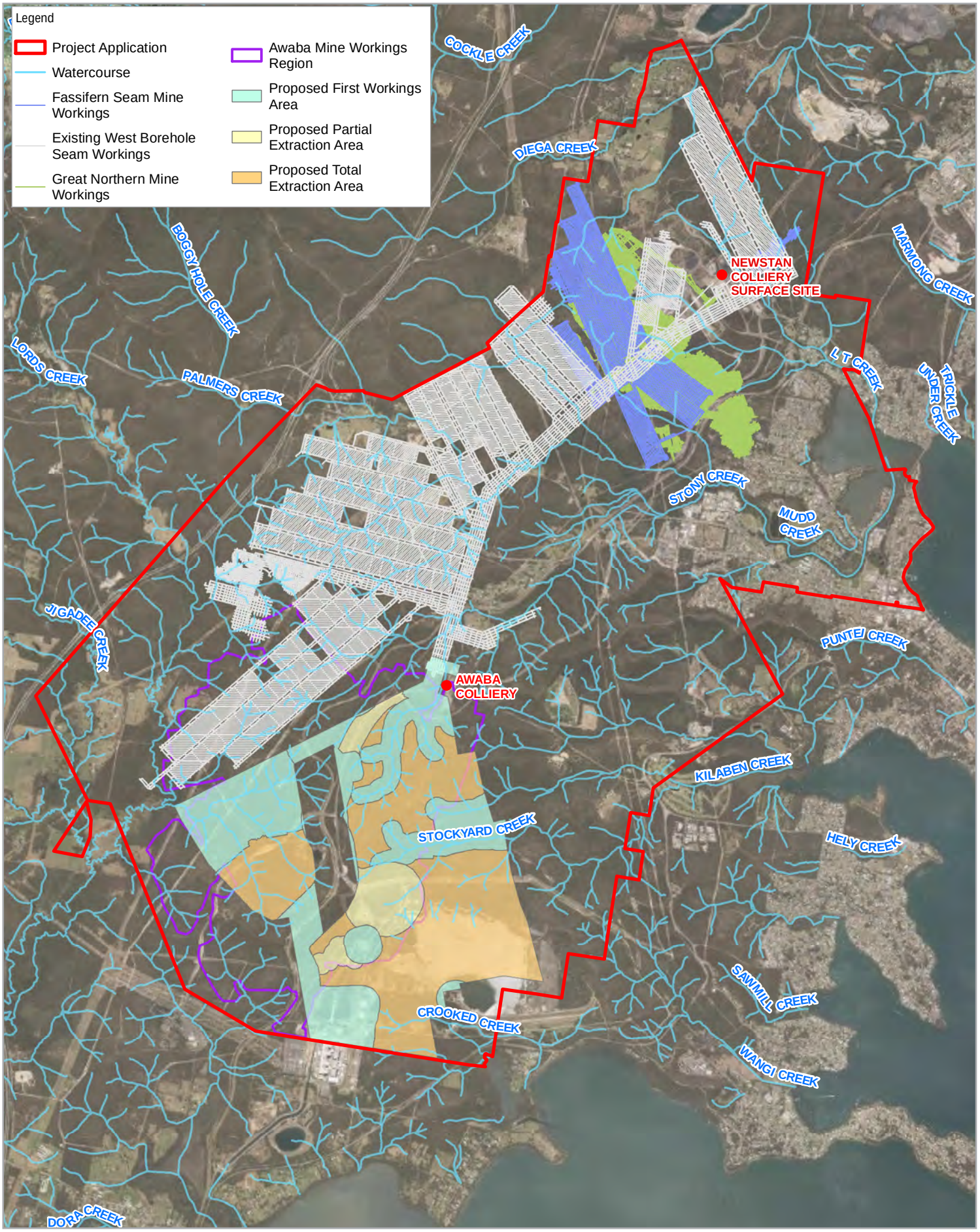
Project No. 22-20265
Revision No. A
Date 28/01/2019

Topography

FIGURE 3-4

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-003_Topography.mxd
Print date: 06 Feb 2020 - 13:49

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 0.4 0.8 1.2 1.6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

Watercourses within the Project Application Area

Project No. 22-20265
Revision No. A
Date 24/01/2020

FIGURE 3-5

G:\22\20105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-004_Watercourses.mxd
Print date: 27 Mar 2020 - 14:28

Data source: Centennial: Consent boundary, 2016, workings, 2019; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

3.4 Geology

The Project Application Area is located in the south-western part of the Newcastle Coalfield, which occupies the north-eastern portion of the Sydney Basin. The stratigraphy of the region consists of material from the Triassic and Permian periods.

The Newcastle Coal Measures are characterised by complex patterns of splitting and coalescence of the various coal seams. This is generally related to the localised presence of alluvial paleochannels within the sedimentary sequence. The West Borehole seam (target seam in the Extension of Mining Area) is contained within the Lambton Formation, the earliest formation of the Newcastle Coal Measures.

The surface lithology in the vicinity of the Extension of Mining Area comprises shallow Quaternary alluvium (associated with the major watercourses) as well as bedrock and surface deposits from the Narrabeen Group and the Moon Island Beach Group of the Newcastle Coal Measures, which dip gently at approximately 1 to 2 degrees to the south-west. The Newcastle Coal Measures subcrop to the west and north of the Project Application Area. The Triassic and Permian rocks that comprise the surface lithology include conglomerate, sandstone, siltstone, claystone, tuff and coal. A surface geology map covering the Project Application Area, including the Extension of Mining Area, is shown in Figure 3-6.

The stratigraphy at Newstan Colliery is listed and described in Table 3-1. This information has been sourced from the Newcastle Coalfields Regional Geology 1:100,000 map (Edition 1 1995) and the Newstan Colliery Life Extension Project Overburden Groundwater Study (Pacific Power International, 1997).

Table 3-1 Stratigraphic sequence – Newstan Colliery

Period	Stratigraphy		Unit / Lithology	Coal seams
	Group	Subgroup		
Quaternary			Alluvium	
Triassic	Narrabeen	Clifton	Conglomerate, sandstone, siltstone, claystone	
Permian	Newcastle Coal Measures	Moon Island Beach	Conglomerate, sandstone, siltstone, tuff, coal	Vales Point, Wallarah, Great Northern
		Awaba Tuff		
		Boolaroo	Sandstone, conglomerate, siltstone, coal, tuff	Fassifern, Upper Pilot, Lower Pilot, Hartley Hill
		Warners Bay Tuff		
		Adamstown	Conglomerate, sandstone, siltstone, coal, tuff	Australasian Montrose, Wave Hill, Fern Valley, Victoria Tunnel
		Nobby's Tuff		
		Lambton	Sandstone, siltstone, claystone, coal, tuff	Young Wallsend, Yard, Borehole
	Waratah sandstone			

The approximate location of the alluvium that is intersected by the Project Application Area is shown in Figure 3-7. Based on a review of available borelogs, the alluvium extends up to about 16 m thick and comprises sandy clays and clayey/silty sands with some gravel.

The alluvium is underlain by a shallow weathered rock aquifer. The shallow weathered zone aquifer includes surficial soils and weathered bedrock. Based on exploration boreholes in the vicinity of the Project Application Area, the shallow weathered zone typically extends to 25 m depth. The shallow weathered rock aquifer also outcrops in areas outside the boundary of the alluvium.

Investigation of the extent of the alluvium along Stony Creek was undertaken by AGE (2008). The extent of the investigation was limited to the upper reaches of Stony Creek, from the headwaters of Stony Creek to approximately 1.1 km downstream. The investigation identified that the boundaries of the alluvium corresponded with the change from the creek floor to the lower slopes of the Stony Creek catchment. Within the extent of the investigation, the width of the alluvium was generally within 30 m of the centreline of Stony Creek. It is likely that the width of the Stony Creek alluvium gradually increases in width as the width of the floodplain increases in width.

The Narrabeen Group comprises variable sequences of interbedded claystones, siltstones and fine to coarse grained sandstones. It includes the Munmorah Conglomerate, which is a low permeability sandstone-dominated formation that typically occurs between 60 and 140 m above the Newcastle Coal Measures (Centennial Mandalong, 2019).

The target coal seam splits in a north-south direction to the east of the Extension of Mining Area into the Young Wallsend, Yard and Borehole seams. Mining is proposed on the western side of the seam split and will target the combined Young Wallsend, Yard and Borehole seams (referred to collectively as the West Borehole seam).

The depth of cover within the Extension of Mining Area ranges from 140 m in the north west to 320 m in the east. Seam thickness ranges from about 2.2 m to more than 5.0 m to the west of the seam split. The target seam is overlain by the previous Awaba Colliery mine workings in parts of the Extension of Mining Area with the interburden between the two seams (Great Northern and West Borehole) ranging from 100 m to 210 m. The West Borehole seam subcrops to the west and north of the Project Application Area while the Great Northern seam subcrops in the vicinity of the western and northern boundaries of the Awaba Colliery workings. Faulting of the Great Northern seam occurs to the south of Awaba Colliery.

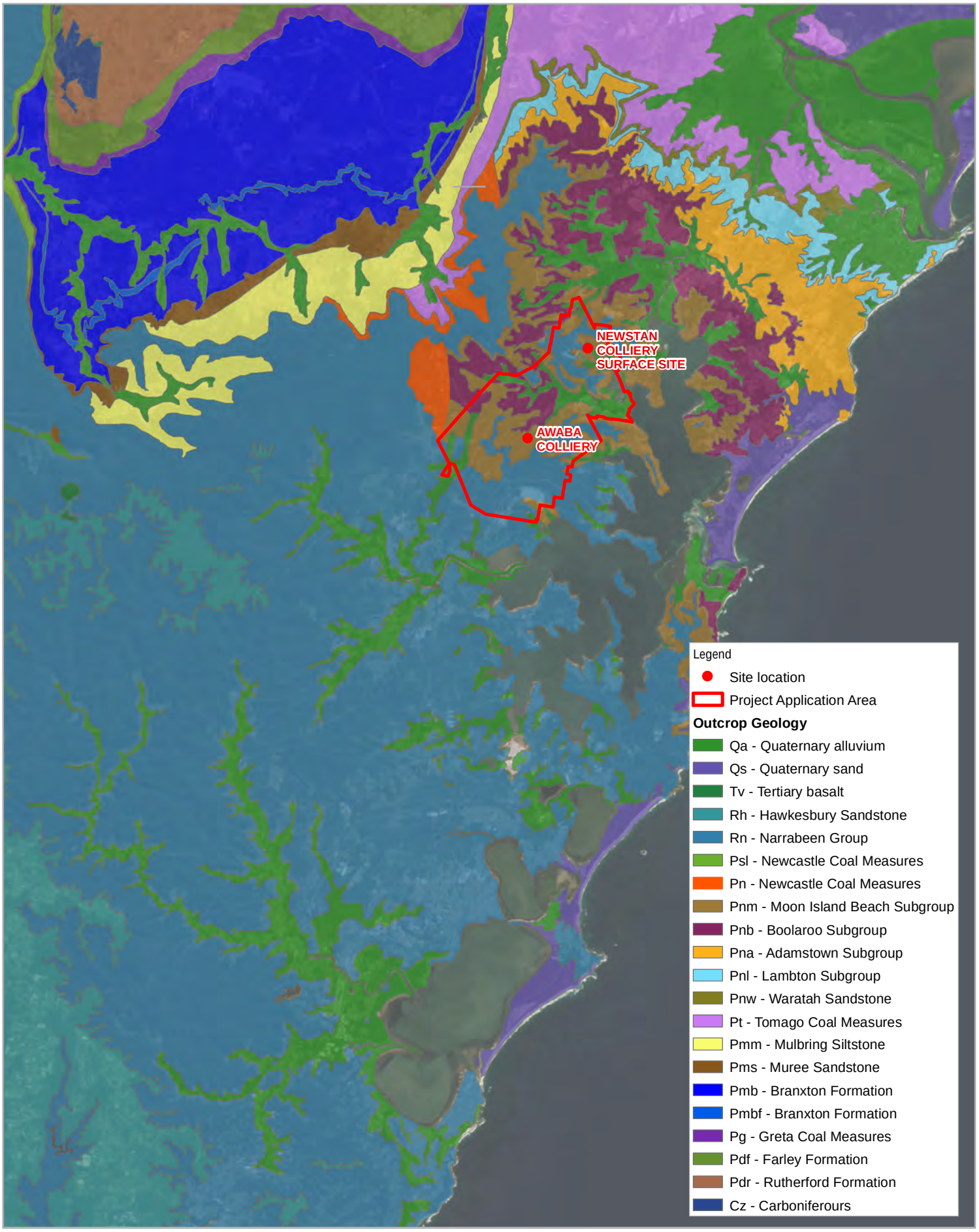
Oceanic Coal's West Wallsend and Teralba Collieries workings are located to the north of Newstan Colliery, and Centennial Mandalong's former Cooranbong workings are located to the south of the Project Application Area. Oceanic Coal's longwalls target the Young Wallsend / Yard seams, while Centennial Mandalong's Cooranbong workings are located in the Great Northern seam.

3.4.1 Geological structures

The location of faults in vicinity of the proposed workings have been mapped and interpreted by MSEC (2019). These faults trend north-west to south-east. A number of these faults were intersected as part of existing mining at Newstan Colliery.

Structure contours at the West Borehole seam roof level provided by Centennial Coal do not indicate any major faulting in the Project Application Area.

These geological features have been incorporated into the numerical groundwater model only through their observed effect on layer geometry. Since the seam roof is continuous throughout the Extension of Mining Area it is not considered that faults would have any substantial influence on groundwater flow or be a conduit for inflow into the mine. Further, the observed groundwater inflows into the existing Newstan Colliery workings do not indicate an influence of geological structures (refer to Section 4.2).



Paper Size ISO A4

0 2 4 6 8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

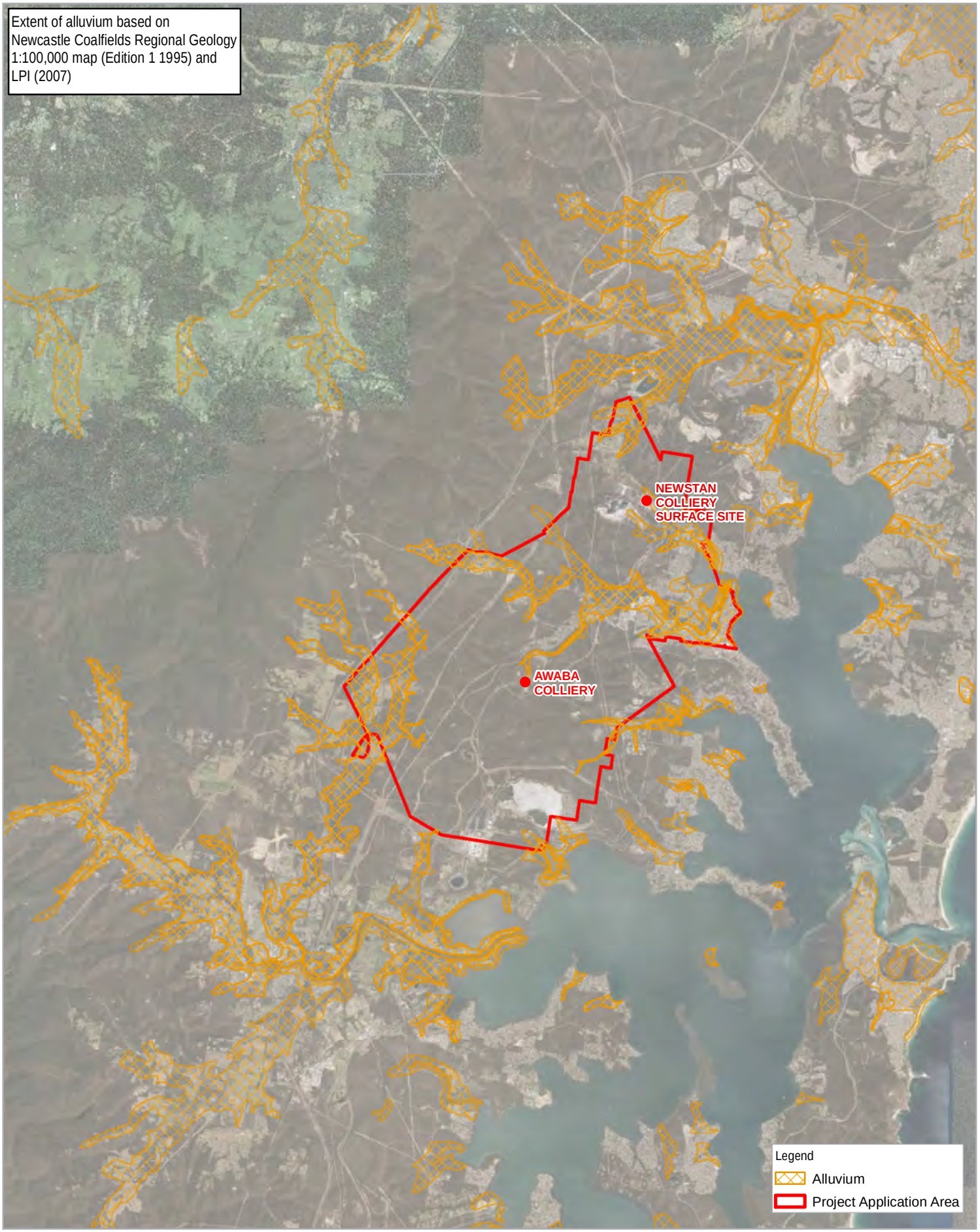
Project No. 22-20265
Revision No. A
Date 16/10/2019

Surface geology mapping

FIGURE 3-6

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-005_RegionalGeology.mxd
Print date: 27 Feb 2020 - 16:54

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1 2 3 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

Location of alluvium within Project Application Area

Project No.	22-20265
Revision No.	A
Date	24/01/2020

FIGURE 3-7

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-006_AlluviumExtent.mxd
Print date: 27 Feb 2020 - 16:55

Data source: Centennial: Consent boundary, 2016; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

3.5 Hydrogeology / groundwater sources

The groundwater sources in the vicinity of the Project Application Area are generally low yielding and predominantly within the Quaternary alluvium, weathered and/or fractured sandstone and coal seams. They would be classified as 'less productive', in accordance with the NSW Aquifer Interference Policy, as yields are generally less than 5 L/s and/or the total dissolved solids (TDS) concentration is typically greater than 1500 mg/L.

3.5.1 Alluvial water sources

The alluvium throughout the Project Application Area (Figure 3-7) forms an unconfined shallow aquifer with groundwater ranging in depth from less than 1 m to about 5 m below ground level (bgl), and aquifer thickness generally less than 16 m. The groundwater flow direction within the alluvium generally reflects the topography. This is demonstrated by the consistent gradient in alluvial groundwater level in Lords Creek bores from upstream site MB11 to downstream sites MB14 and MB17 (levels shown in hydrographs in Appendix B of GHD (2020a). Due to the clay content of the alluvium, yields and beneficial use of this groundwater are generally low as indicated by the registered bore details (refer to Section 3.6). The alluvial groundwater is generally fresh to brackish and slightly acidic. Alluvial groundwater likely provides baseflow to the ephemeral creeks overlaying the Extension of Mining Area (refer to Section 4).

The alluvial water sources within the Project Application Area are covered under the WSP for the Hunter Unregulated and Alluvial Water Sources. This WSP commenced in August 2009 and regulates the interception and extraction of surface water and alluvium within the defined water sharing plan area.

3.5.2 Porous and fractured rock water sources

The porous and fractured rock water sources within the Project Application Area are covered under the WSP for the North Coast Fractured and Porous Rock Groundwater Sources. This WSP commenced in July 2016 and regulates the interception and extraction of groundwater in the fractured and porous rock aquifer within the defined water sharing plan area.

Coal seams

The piezometric head within the Permian coal seams tend to reflect the natural topography and proximity to Lake Macquarie, with reduced pressures at major surface drainage areas and in areas of coal extraction. Where coal seam groundwater has not been depressurised, the groundwater head tends to be in the order of 0-20 m AHD (based on hydrographs in Appendix B and Appendix D of GHD (2020a)) due to the coastal environment. Recharge of coal seams occurs in areas of seam subcrop and groundwater flow is generally to the east towards Lake Macquarie.

Packer testing undertaken as part of the Newstan Colliery exploration program indicates that the hydraulic conductivities of the Young Wallsend seam and overlying seams are generally in the order of 10^{-8} to 10^{-7} m/s or lower. Further results of packer testing are provided in Appendix B.

Overburden and interseam rock

The overburden and interseam strata within the Newcastle Coalfield tend to have very low hydraulic conductivities (in the order of 10^{-11} to 10^{-9} m/s), unless joints or fracturing creates a secondary permeability (Pacific Power International, 1997). Further results of packer testing are provided in Appendix B.

3.6 Groundwater use

The search of groundwater bore database (operated by Water NSW) identified 69 registered bores within approximately 2 km of the Project Application Area. A wider search identified 286 registered bores within the zone of groundwater drawdown within the West Borehole seam attributable to mining within the Extension of Mining Area (refer Section 6.1.2). Of the registered bores within the Project Application Area, the majority (50 bores) were registered as monitoring bores or test bores. One bore was registered for exploration, one bore was registered for dewatering or mining purposes and the remainder (17 bores) were registered for a combination of stock, domestic, irrigation and farming purposes. From the wider search, 122 of the 286 bores were registered as monitoring or exploration bores.

The majority of stock, domestic, irrigation and farming bores are less than 50 m in depth and extract groundwater from the Triassic Narrabeen Sandstone and the shallow Permian Coal Measures and interburden. Only one registered bore (GW202325) is located in the Extension of Mining Area and it is registered as a monitoring bore / test bore.

Registered bore locations within approximately 2 km of the Project Application Area are shown in Figure 3-8 and bore details are provided in Table 3-2.

Table 3-2 Results of NSW bore database search

Bore no	Location		Depth (m)	Purpose	Salinity (ppm)	Yield (L/s)	Strata
	mN	mE					
GW027551	365443	6352249	2.4	Poultry			Sand
GW029567	361864	6340863	3	General use	Very good		Sandstone
GW033618	358945	6343594	30.4	Stock			Shale, sandstone
GW033619	359049	6343596	21.3	Stock	Hard	1.52	Shale, sandstone
GW043431	359665	6345915	38.1	Irrigation			
GW045155	366289	6353092	4.3	Irrigation			Sandstone
GW052381	357498	6346746	35	Stock, domestic			
GW060852	366083	6352905	18.3	Stock, domestic	3001-7000		
GW061202	357061	6344737	50.3	Stock, domestic	1001-3000		Sandstone, siltstone, coal, shale
GW063752	362871	6348578	12.2	Stock, domestic	0-500	0.46	Sand, gravel, coal
GW063947	369396	6345987	22.2	Stock, domestic	1001-3000		Shale, sandstone
GW064025	362740	6348700	12.2	Stock, domestic	0-500	0.9	Sandstone, coal
GW064067	362141	6348845	12.1	Stock, domestic	1001-3000	0.4	Sand, gravel
GW064213	366595	6343917	45.7	Monitoring bore		0.1	Sandstone
GW064214	365965	6344432	45.7	Monitoring bore		0.1	Sandstone
GW078138	356976	6345167	120	Test bore			
GW078486	367252	6345381	5.73	Domestic		90	
GW080426	366772	6353383	23	Exploration			Tuff, coal, sandstone
GW080427	366621	6353279	28	Monitoring bore			Coal, tuff, sandstone, shale

Bore no	Location		Depth (m)	Purpose	Salinity (ppm)	Yield (L/s)	Strata
	mN	mE					
GW080428	366650	6353232	24	Monitoring bore			Gravel, coal, sandstone, shale
GW080494	367738	6349710		Stock, domestic			
GW105161	367850	6343850	5	Domestic			
GW200695	359313	6348500	66	Test bore		2.8	
GW200696	359964	6347393	66	Test bore		1.5	
GW200825	368935	6346345	3.3	Monitoring bore			Fill, clay
GW200826	368962	6346364	3	Monitoring bore			Clayey fill, sandy clay
GW200955	366801	6353226	280	Dewatering, Mining		60	
GW201480	366126	6347135	11.6	Monitoring bore			Sandstone
GW202324	365162	6348895	74.14	Monitoring bore			Coal, shale, sandstone, conglomerate, claystone, mudstone
GW202325	360869	6344024	3	Monitoring bore			Gravelly clay, silty clay, sand
GW202326	364806	6346872	2	Monitoring bore			Sandy clay
GW202327	365681	6343836	3.1	Monitoring bore			Sandy clay, sand
GW202328	365615	6344372	4	Monitoring bore			Sandy clay, silty sand
GW202329	366595	6344766	4	Monitoring bore			Silty sand
GW202330	367311	6345170	4.1	Monitoring bore			Clayey sand
GW202331	365639	6348010	2.8	Monitoring bore			Clayey sand, clayey gravel
GW202338	359356	6347809	102	Test bore	730, 1900, 2300		Coal, sandstone, siltstone
GW202339	359340	6348185	68.5	Test bore	100, 2100		Sandstone
GW202559	364665	6344935	7.5	Monitoring bore			Sand
GW202685	369735	6345316	4	Monitoring bore			Clay
GW202686	369748	6345300	4.4	Monitoring bore			Clay
GW202687	369744	6345305	4.9	Monitoring bore			Clay
GW202798	364598	6344953	9	Monitoring bore			Sand, clay, shale
GW202799	364456	6345369	12.5	Monitoring bore			Sand, sandstone
GW202800	364864	6344964	11	Monitoring bore			Clay
GW202801	364689	6344873	11.7	Monitoring bore			Sandstone
GW202802	364597	6344955	5	Monitoring bore			Shale, clay

Bore no	Location		Depth (m)	Purpose	Salinity (ppm)	Yield (L/s)	Strata
	mN	mE					
GW202803	364689	6344874	8	Monitoring bore			Clay
GW202900	366529	6348534	23.6	Monitoring bore			
GW202901	366340	6348647	29.9	Monitoring bore			
GW202940	361666	6341097		Monitoring bore			Clayey sand, silty clay
GW202941	361591	6341004	5.5	Monitoring bore			Clay, sand, sandy clay
GW202942	361575	6341085	6	Monitoring bore			Silty clay, clay
GW202943	361566	6340704	8	Monitoring bore			Clay, gravel, conglomerate
GW202944	361571	6340770	8.5	Monitoring bore			Gravelly sandy clay, conglomerate
GW202945	361591	6340725	9	Monitoring bore			Conglomerate, coal
GW202946	361568	6340833	8.4	Monitoring bore			Sandstone, conglomerate, coal
GW202947	361596	6340822	9	Monitoring bore			Silty clay, sandy clay
GW202948	361613	6340821	9.5	Monitoring bore			Silty sand, sandy clay
GW202949	361593	6340864	9	Monitoring bore			Silty clay, clay
GW202950	361523	6340829	9	Monitoring bore			
GW202951	361592	6340796	9	Monitoring bore			Fill
GW202952	361618	6340813	19	Monitoring bore			Clay
GW202958	361694	6346816	21.74	Monitoring bore			
GW202963	358946	6343971	38.9	Monitoring bore			
GW202964	359336	6344685	41.25	Monitoring bore			
GW202965	362741	6346266	32.55	Monitoring bore			
GW203292	357414	6347037	88	Stock			Coal, Shale, siltstone
GW203408	362449	6348802	3.7	Monitoring bore			Sand, clay, gravel

3.7 Groundwater dependent ecosystems

Plant Community Types (PCTs) that have a moderate or greater potential to be a Groundwater Dependent Ecosystem (GDE) were identified by RPS (2020) based on a search of the GDE Atlas (BOM 2019). The following PCTs were identified:

- PCT 1588 Grey Ironbark – Broad-leaved Mahogany – Forest Red Gum shrubby open forest on Coastal Lowlands of the Central Coast.
- PCT 1598 Forest Red Gum grassy open forest on floodplains of the lower Hunter.

- PCT 1619 Smooth-barked Apple - Red Bloodwood - Brown Stringybark - Hairpin Banksia heathy open forest of coastal lowlands.
- PCT 1627 Smooth-barked Apple - Turpentine - Sydney Peppermint heathy woodland on sandstone ranges of the Central Coast.
- PCT 1636 Scribbly Gum - Red Bloodwood - Angophora inopina heathy woodland on lowlands of the Central Coast.
- PCT 1638 Smooth-barked Apple – Red Bloodwood – Scribbly Gum grass – shrub woodland on lowlands of the Central Coast.
- PCT 1716 Prickly-leaved Paperbark forest on coastal lowlands of the Central Coast and Lower North Coast.
- PCT 1718 Swamp Mahogany - Flax-leaved Paperbark swamp forest on coastal lowlands of the Central Coast.
- PCT 1737 Typha rushland.

Lake Macquarie, Muddy Lake and Whiteheads Lagoon are mapped as potential aquatic GDEs.

GDE locations, based on potential, are mapped in Figure 3-9. There are no GDEs within the Project Application Area that are listed in Schedule 4 of the WSPs.



Paper Size ISO A4

0 0.55 1.1 1.65 2.2

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

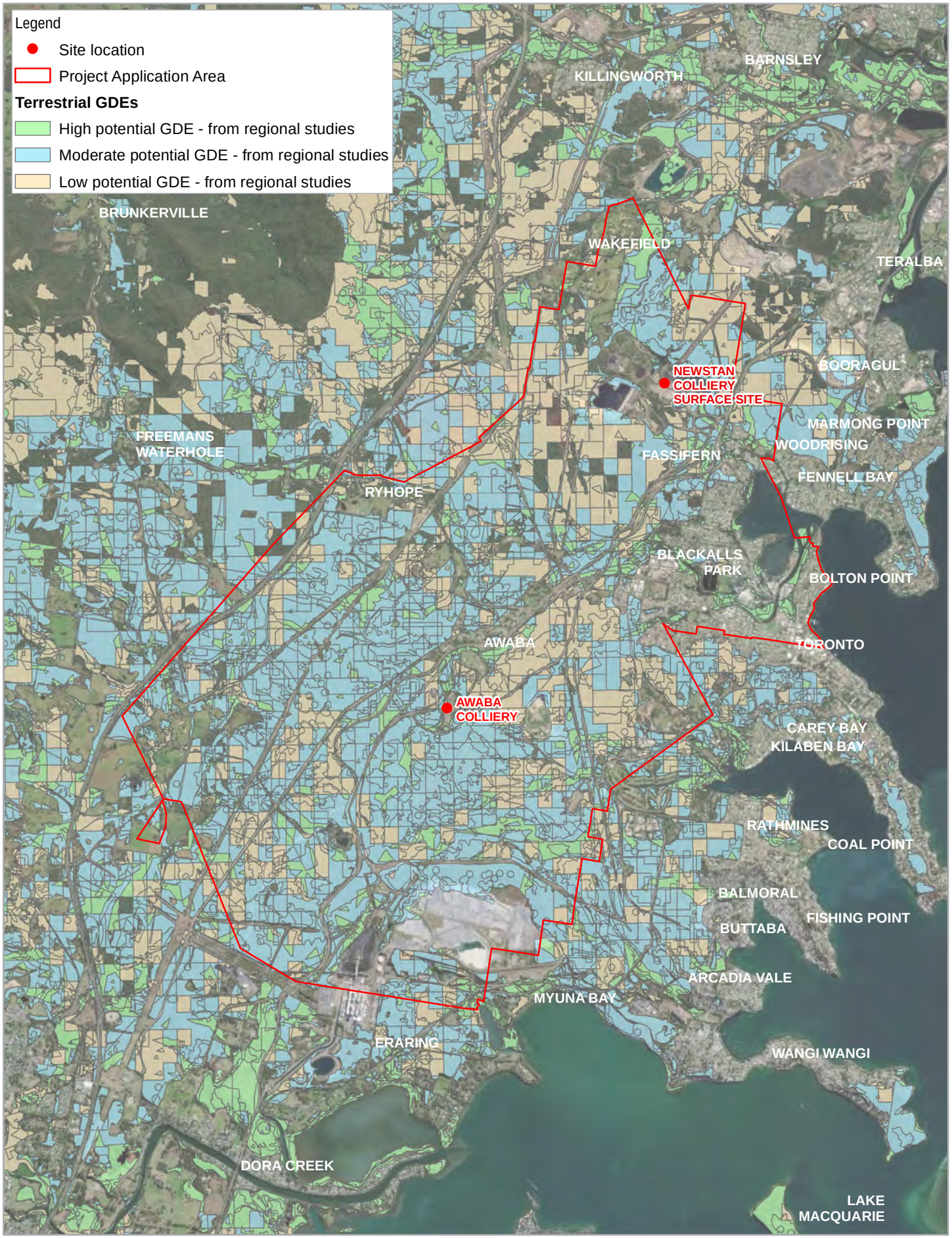
Project No. 22-20265
Revision No. A
Date 24/01/2020

Registered bore locations

FIGURE 3-8

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-008_LandholderBores.mxd
Print date: 27 Feb 2020 - 16:56

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 0.55 1.1 1.65 2.2

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

Potential groundwater dependent ecosystems

Project No. 22-20265
Revision No. A
Date 27/02/2020

FIGURE 3-9

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-009_GDE_Mapping.mxd
Print date: 25 Mar 2020 - 13:13

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald

4. Groundwater management and monitoring

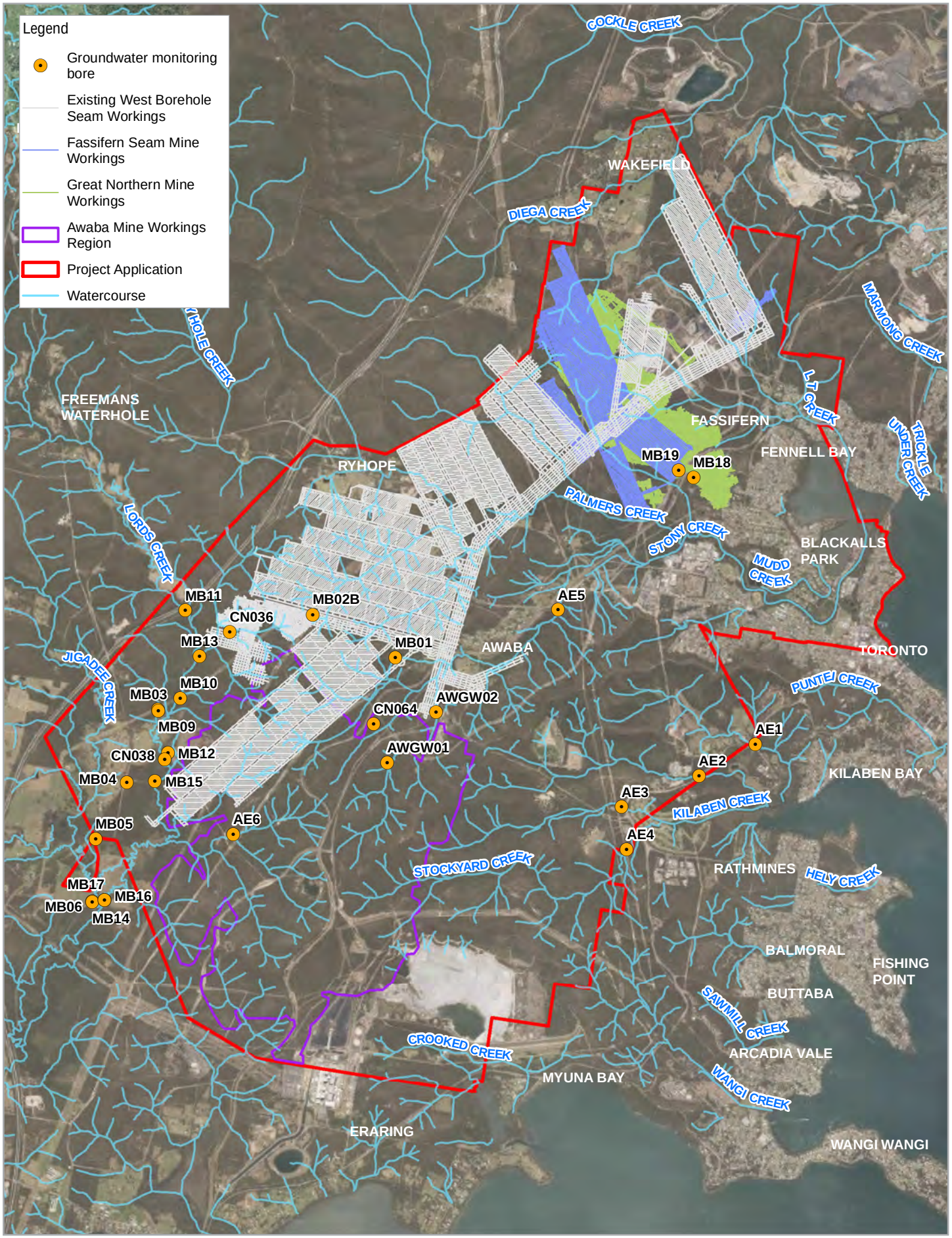
4.1 Groundwater monitoring program

A groundwater monitoring network has been progressively established at Newstan Colliery since 2005 and consists of monitoring bores installed in alluvial and coal seam strata. The bores are generally monitored twice per year for groundwater levels and groundwater quality, although some alluvial bores also contain water level loggers. The coal seam monitoring previously consisted of vibrating wire piezometers (VWPs). Note that the coal seam VWPs (CN036 and CN038) have not been in operation since October 2009.

Monitoring bore locations are shown in Figure 4-1. Monitoring has ceased at MB02 and AE6. Monitoring data were not available from CN064 at the time of this assessment. Details of monitoring bores are summarised in Table 4-1. Further details are provided in Appendix B.

Table 4-1 Groundwater monitoring bore details

Bore	Monitoring period	Lithology
MB02	Mar 11 – Sep 12	Fassifern seam
MB03	Mar 11 – current	Permian Coal Measures
MB04	Mar 11 – current	Great Northern seam/ Fassifern seam
MB05	Mar 11 – current	Great Northern seam
MB06	Mar 11 – current	Great Northern seam
MB09	Mar 11 – current	Lords Creek Alluvium
MB10	Jan 06 – current	Lords Creek Alluvium
MB11	Jan 06 – current	Lords Creek Alluvium
MB12	Jan 06 – current	Lords Creek Alluvium
MB13	Jan 06 – current	Lords Creek Alluvium
MB14	Mar 11 – current	Lords Creek Alluvium
MB15	Jan 06 – current	Lords Creek Alluvium
MB16	Mar 11 – current	Great Northern seam
MB17	Mar 11 – current	Lords Creek Alluvium
MB18	Mar 11 – current	Fassifern storage
MB19	Mar 11 – current	Fassifern storage
AE1	May 09 – Nov 17	Kilaben Creek Alluvium
AE2	Mar 09 – Nov 17	Kilaben Creek Alluvium
AE3	Mar 09 – Nov 17	Kilaben Creek Alluvium
AE4	Mar 09 – Nov 17	Stockyard Creek Alluvium
AE5	Mar 09 – Nov 17	Stony Creek Alluvium
AE6	Mar 09 – Jun 14 Dry throughout monitoring period	Unknown
CN036	Aug 05 – Oct 09	West Borehole seam
CN038	Aug 05 – Oct 09	West Borehole seam
CN064	Jan 2019 – current	Munmorah Conglomerate Fassifern Lower seam Permian Interburden West Borehole seam



Paper Size ISO A4

0 0.45 0.9 1.35 1.8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

Project No. 22-20265
Revision No. A
Date 16/10/2019

Groundwater monitoring network

FIGURE 4-1

G:\22\20105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-010_GWMonitoring.mxd
Print date: 27 Mar 2020 - 14:36

Data source: Centennial: Consent boundary, 2016, workings, 2019, monitoring, 2016; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

4.1.1 Baseline monitoring results

Groundwater level hydrographs for Newstan Colliery alluvial monitoring bores have been plotted with CDFM and are shown in Appendix B. In the hydrographs, groundwater level is plotted in blue and the CDFM curve is plotted in red. Visual review of alluvial groundwater levels indicates that there is response to CDFM (below and above average rainfall) at a majority of the alluvial monitoring bores. Alluvial groundwater levels typically vary by 1 to 2 m.

A statistical comparison between Lords Creek alluvial groundwater levels and CDFM was undertaken by GHD (2014) using the HARTT (Hydrograph Analysis: Rainfall and Time Trends) statistical methodology, to reduce the uncertainty inherent with visual interpretation of time series graphs. HARTT is an Excel based regression model developed by the West Australian Department of Agriculture and Food that involves establishing an underlying time trend in groundwater level by separating the effect of above and below average rainfall (Ferdowsian et al., 2000). In this way, the relationship between groundwater change and atypical rainfall is established and it is possible to identify whether other factors are influencing groundwater level. Where conventional linear regression trend analysis is carried out for groundwater hydrographs, it is not possible to determine to what degree trends are associated with rainfall or other factors.

The analysis indicates that the alluvial hydrographs are reasonably modelled by the HARTT variables (rainfall and linear time trends) and there is a statistically significant relationship between groundwater level and rainfall at most sites. Any statistically significant decreasing trends in groundwater level (independent of rainfall) were not found to be associated with mining since did they not correlate with the schedule of development and extraction of the adjacent mine workings. It is noted that Lords Creek alluvial monitoring bores are not directly underlain by existing Newstan Colliery mine workings, however the West Borehole seam is shallower in this area compared to the Extension of Mining Area.

Decreasing trends in groundwater levels at most of the Lords Creek alluvial bores are evident in recent years. These trends are likely to be primarily attributable to climatic conditions although other factors are possible. It is unlikely that mining at Newstan has caused these trends since they are not evident at MB12 and MB15, which are the closest alluvial bores to the existing Newstan longwalls in the West Borehole seam (Figure 4-1). In addition, decreasing trends in groundwater levels (independent of rainfall) are evident at most of the AE series bores, which suggests there are other factors (other than rainfall and mining) that influence alluvial groundwater levels in the area.

Alluvial groundwater quality is generally slightly acidic. Within Lords Creek, alluvial groundwater quality varies from fresh at MB09, MB14, MB15 and MB17, to brackish at MB11. Monitoring data indicates that alluvial groundwater in Kilaben Creek, Stockyard Creek and Stony Creek is slightly brackish.

Comparison of the major ion chemistry of alluvial groundwater and surface water at some locations in the vicinity of the Extension of Mining Area indicates surface water / groundwater connectivity. Surface waters and alluvial groundwater are generally sodium chloride dominant. In particular there is strong similarity between surface water and alluvial groundwater at sites along Kilaben Creek at the south-eastern boundary of the Project Application Area as shown in Appendix C.

Visual review of groundwater hydrographs for monitoring bores installed in the Permian Coal Measures at Newstan Colliery indicates that groundwater levels at MB04, MB05 and MB06 fluctuate with CDFM. Due to their proximity to the coal seam outcrop, groundwater levels at MB04, MB05 and MB06 may have a stronger influence from rainfall recharge.

Bores MB05, MB06 and MB16 in the Great Northern seam are depressurised due to historical mining at Cooranbong, which commenced in 1980 and was completed in the early 2000s. Dewatering of the Cooranbong workings is ongoing.

Groundwater levels at remaining locations installed in the Permian Coal Measures (MB02 and MB03) are relatively constant with levels generally varying by less than 2 m. Levels within bores MB18 and MB19 installed within the Fassifern Underground Storage are influenced by inputs and outputs of water from the Fassifern Underground Storage.

Groundwater drawdown has been observed at vibrating wire piezometers (VWPs) CN036 and CN038. VWP CN036 overlies existing West Borehole seam workings and CN038 is located within 500 m of the existing West Borehole seam workings. As shown in Appendix B, drawdown at CN038 occurred within two months of installation and drawdown at CN036 occurred within six months of commencement of adjacent longwall mining to the south. With the exception of CN036 and CN038, there is no evidence of groundwater drawdown attributable to mining at Newstan Colliery at monitoring bores installed in the Permian Coal Measures. As stated previously, bores MB05, MB06 and MB16 in the Great Northern seam are depressurised due to historical mining at Cooranbong.

Groundwater quality within the Permian Coal Measures is generally slightly brackish and varies from very slightly acidic to very slightly basic.

4.2 Underground water management

4.2.1 Newstan Colliery

The underground water management features at Newstan Colliery are the Fassifern Underground Storage and the underground workings in the West Borehole seam. The Fassifern Underground Storage is the void formed by previous mining activity in the Fassifern and Great Northern seams at Newstan Colliery and is used to manage water between Newstan Colliery and the Newstan Colliery Surface Site (NCSS).

The Fassifern Underground Storage receives inflows as a result of infiltration from the surface catchment, groundwater inflows into active mining areas and injection transfers from the NCSS. Water levels within the storage are managed by extraction transfers to the Clean Water Plant, which commenced operation at the NCSS in late 2013. The Clean Water Plant employs coagulation, flocculation, sedimentation, filtration and ultra-violet treatment to reduce the concentrations of Total Suspended Solids (TSS) and total (unfiltered) metals. The Clean Water Plant treats water at a maximum rate of 14.5 ML/day. The volume of surface infiltration into the Fassifern Underground Storage was estimated by GHD (2020b).

During periods of above average rainfall when water within the Fassifern Underground Storage rises above 16.6 m below ground level (6.4 m AHD), the storage discharges water by gravity through two 600 mm diameter pipes into Stony Creek via Newstan LDP017. A water monitoring station at Newstan LDP017 was commissioned in 2013 to monitor emergency discharges required for the safety of personnel in the underground workings at Newstan Colliery. The water monitoring station allows for the continuous monitoring of discharge water quality. In the event of poor water quality, water may be contained within the monitoring station and treated or extracted as required in a controlled manner. Since 2013, only one discharge has occurred, which was over 39 days in May 2015 with a total volume of 1289 ML and an average discharge of 3.5 ML/day.

The observed underground water transfers are shown in Figure 4-2 and observed water levels in the Fassifern Underground Storage are shown in Figure 4-3. All monitoring is done using inline meters and recorded within a SCADA system. Where flows are not metered, then these transfers are estimated based on operational conditions. Daily monitoring of the underground water level within the Fassifern Underground Storage is undertaken daily as part of day to day operational reviews.

Figure 4-2 shows that transfers from the West Borehole seam to the Fassifern Underground Storage are typically 1 to 2 ML/day, varying with day to day operations. Given the limited water storage capacity in the West Borehole seam, the average transfer rate is representative of the groundwater inflows into the West Borehole seam workings. This inflow is low considering the size of the existing Newstan Colliery workings in the West Borehole seam, the mining methodology (longwalls) and the longwall void width (230 m). However it is similar to the modelled and observed groundwater inflow into the existing longwall mining area at Mandalong (Centennial Mandalong, 2019). The low inflow suggests low permeability overburden and minimal influence of geological structures on inflows.

The transfers from the Fassifern Underground Storage to NCSS are typically around 11 ML/day, corresponding to the typical treatment rate of the Clean Water Plant at NCSS, with some variation between 0 and up to 15 ML/day with day to day operations.

Recent monitoring by Centennial Newstan indicates that approximately 0.25 ML/day of groundwater inflow to the West Borehole seam workings occurs in Longwalls 22-25, underlying the Awaba underground void. Based on the average interburden thickness between Longwalls 22-25 and the Awaba void of 110 m (MSEC, 2019), a water level in Awaba of 16 m AHD and area of overlap of 1.3 km^2, a bulk hydraulic conductivity of approximately 0.0002 m/day (1.9×10^{-9} m/s) would produce an inflow of 0.25 ML/day. Such a low hydraulic conductivity value suggests that the height of continuous fracturing above Longwalls 22-25 is likely to be much less than estimates from typical empirical methods such as Tammetta (2012). It also suggests that geological structures would be having minimal influence on groundwater inflow.

Groundwater inflow into the existing West Borehole seam workings (sampled at location ‘cut through 19’) is brackish and slightly alkaline, and sodium bicarbonate-chloride dominant. In comparison, water within the Awaba underground void is more magnesium sulfate dominant (sampled at location 13 West 2). These two waters are compared in a piper diagram in Appendix C. The piper diagram was prepared using an average of historical data. This suggests that the groundwater inflow into the Longwall 22-25 area is from the adjacent porous and fractured rock groundwater source rather than via a continuous conduit, such as a continuous fracture or fault, from the Awaba underground void.

Figure 4-3 shows that water levels in the Fassifern Underground Storage have typically been maintained at around between 0 and -5 m AHD since 2017. Note that as part of the development of the numerical hydrogeological model, general head boundary (GHB) cells were used to simulate the flooded Fassifern Underground Storage. Further details regarding the application of GHBs are available in Section 3.5.4 of GHD (2020a). During the calibration phase of modelling, the GHB elevation of the Fassifern Underground Storage was varied in accordance with water level monitoring in the Fassifern Underground Storage shown in Figure 4-3. During the predictive modelling phase, the GHB elevation of the Fassifern Underground Storage was set to 0 m AHD. This level of 0 m AHD is consistent with typically water level in the Fassifern Underground Storage.

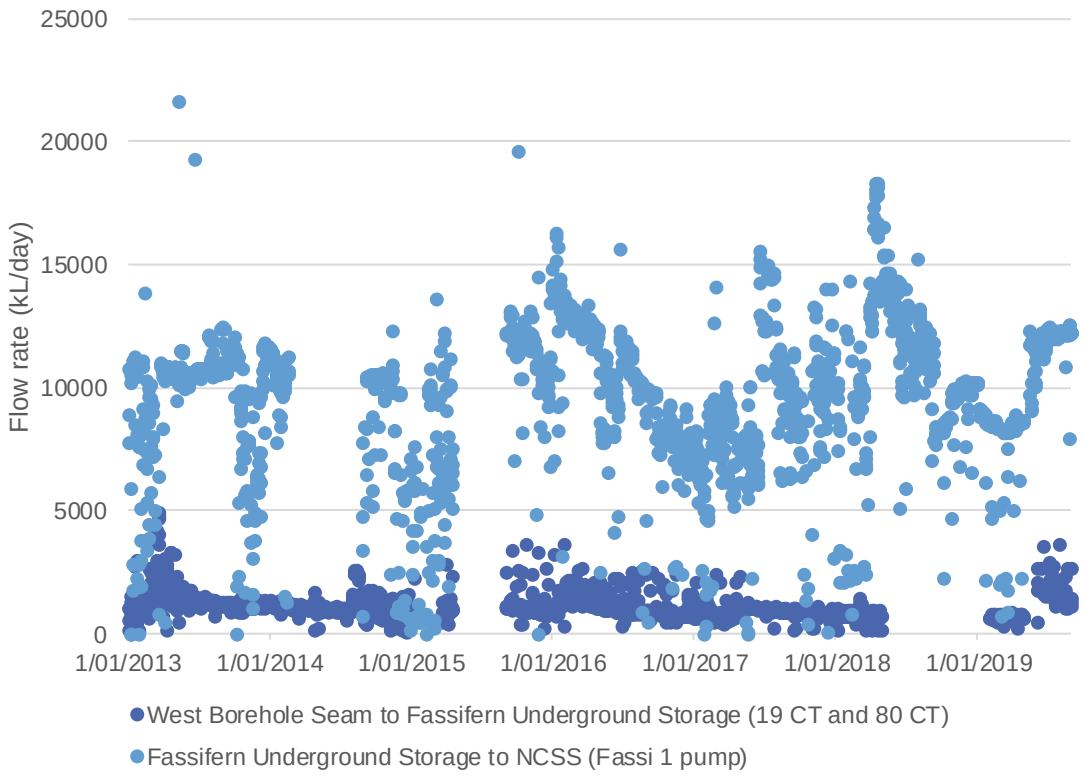


Figure 4-2 Observed underground water transfers at Newstan Colliery

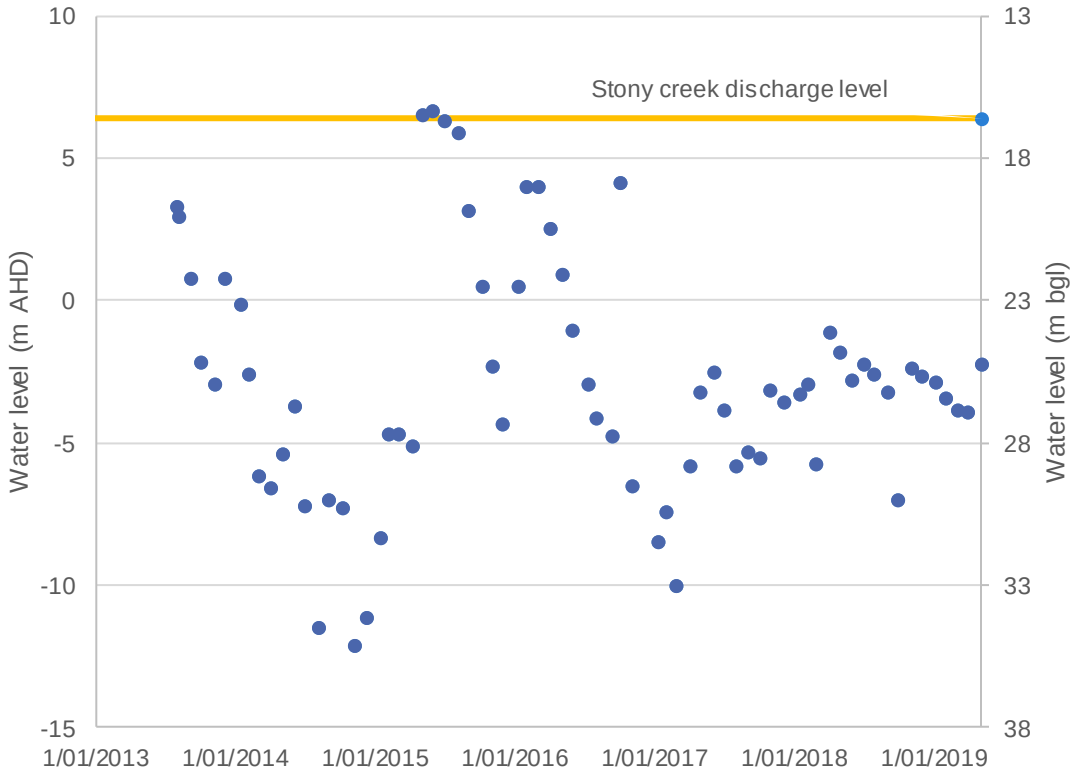


Figure 4-3 Observed underground water levels in the Fassifern Underground Storage

4.2.2 Awaba Colliery

The key underground water management feature of Awaba Colliery is the Awaba underground void, which was formed by previous mining activity in the Great Northern seam at Awaba Colliery. Following the cessation of mining in 2012, water levels in the Awaba underground void recharged due to a combination of inflows of surrounding groundwater and infiltration from the surface. Infiltration is likely to be enhanced at sinkholes.

As water levels in the Awaba underground void equilibrated with the surrounding groundwater, infiltration of water from the surface became the dominant inflow and water from the void began to seep out via a series of natural faults at the south end of the void into an unnamed tributary of Muddy Lake. This area is known as the Awaba seepage. The flow from the Awaba seepage has been observed at a V-notch weir at monitoring location SP5 since 2015 (refer to the Surface Water Impact Assessment (GHD, 2020b)), although this monitoring is also influence by surface catchment runoff. The observed flow, shown in Figure 4-4, is typically 1 ML/day to 2 ML/day and has been declining with water levels under the below average rainfall conditions in 2018 and 2019.

Infiltration to the Awaba underground void and volume of seepage at the Awaba seepage has been simulated in the site water and salt balance model developed as part of this project (Appendix B of GHD (2020b)).

Seepage from the Awaba underground void has also been observed at the Eraring Power Station. Water levels in the underground void are currently managed by pumping water via the 10 South bore and boreholes at Eraring Power Station (the Eraring groundwater manifold) for the purpose of maintaining the water level below about 17 m AHD within the workings. A plot of underground water level in the Awaba underground void interpreted from Centennial Newstan monitoring data is shown in Figure 4-5.

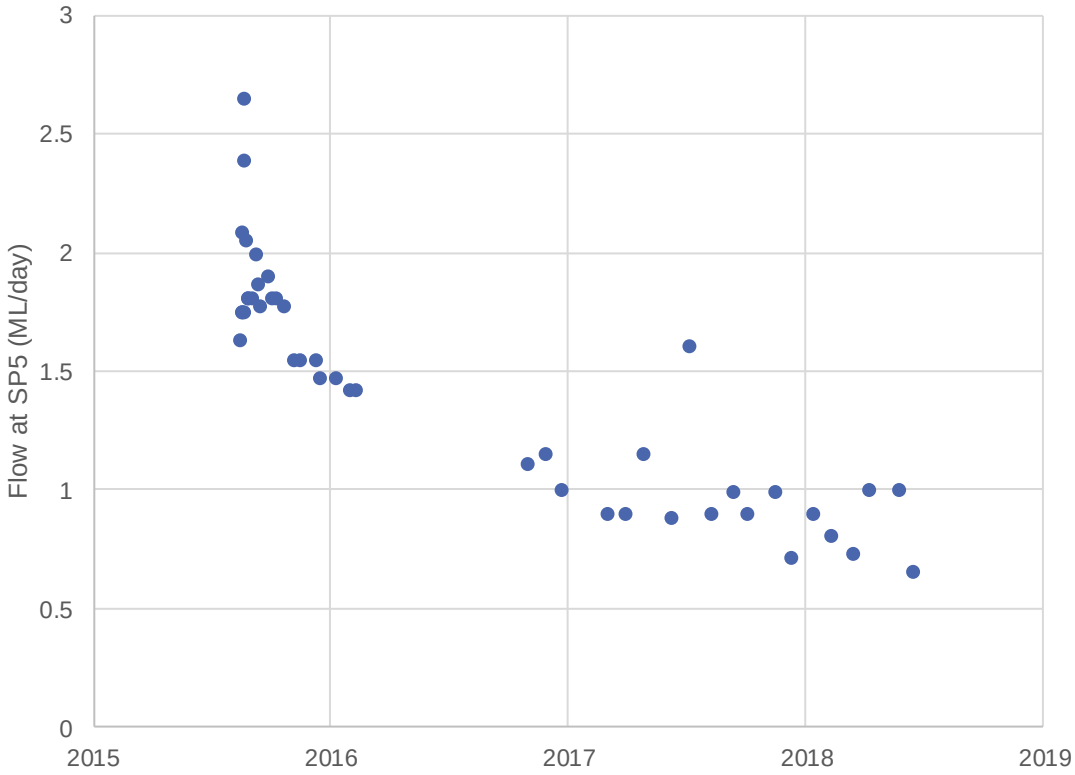


Figure 4-4 Observed flow from Awaba seepage at SP5

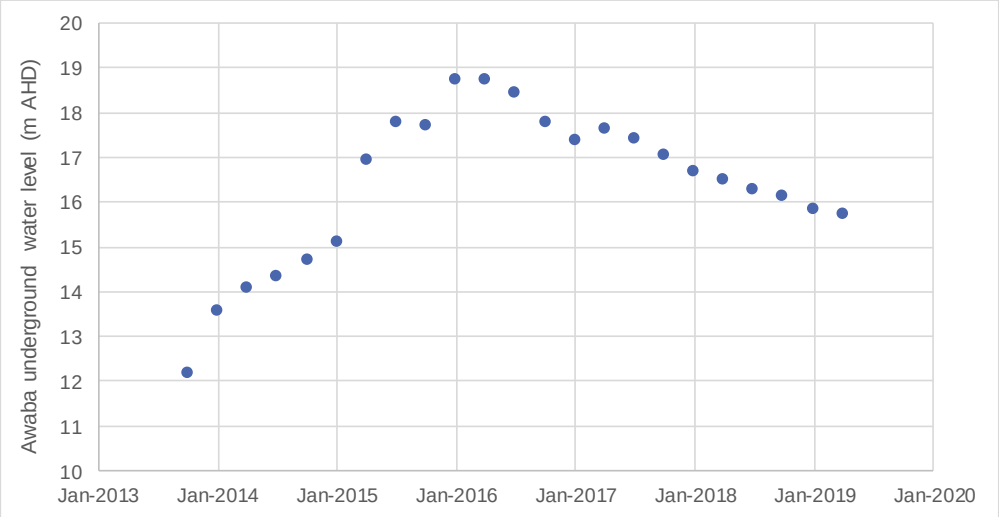


Figure 4-5 Awaba underground void water level

Note that as part of the development of the numerical hydrogeological model, general head boundary (GHB) cells were used to simulate the flooded Awaba Colliery workings. Further details regarding the application of GHBs are available in Section 3.5.4 of GHD (2020a). During the calibration phase of modelling, the GHB elevation of the flooded Awaba Colliery workings was varied in accordance with water level monitoring in the Awaba void shown in Figure 4-5. During the predictive modelling phase, the GHB elevation of the Awaba workings was set to 15.768 m AHD. This level of 15.768 m AHD is consistent with current water level in the Awaba workings.

4.2.3 Newstan Colliery interaction with Awaba underground void and Eraring Ash Dam

The existing Newstan Colliery workings have undermined sections of the Awaba underground void. The existing Newstan Colliery workings that have undermined the Awaba underground void includes longwall mining panels and first workings.

Longwall panels that undermine the Awaba underground void include Longwalls 22-25. As discussed in Section 4.2.1, approximately 0.25 ML/day of groundwater inflow to the West Borehole seam workings occurs in Longwalls 22-25. This volume of groundwater inflow likely includes groundwater inflow from the surrounding West Borehole seam. Therefore this volume of groundwater inflow does not indicate a direct connection between the Awaba underground void and the West Borehole seam workings. This is in contrast to the conceptualisation by SCT (2019). Further details are outlined below.

Conceptualisation of the fracture zone

SCT (2019) approach

SCT (2019) was commissioned by Centennial Newstan to review the proposed mine design in the Extension of Mining Area in the context of potential interactions with fly ash emplaced in the Eraring Ash Dam. SCT (2019) concluded that full extraction within the Extension of Mining Area will provide an enhanced flow pathway into Newstan Colliery from the Eraring Ash Dam and from the Awaba underground void. SCT (2019) calculated flows from the Eraring Ash Dam to the West Borehole seam workings to be in the order of 0.03 to 3 ML/day. These calculations were based on an empirical equation of the height of depressurisation (Tammetta (2012)), based on data from other sites. GHD considers that this conceptualisation by SCT (2019) is too conservative and is not supported by groundwater monitoring data for Newstan Colliery and Mandalong Mine as outlined in more detail below.

The SCT (2019) conceptualisation and flow estimates are based on average and maximum heights of depressurisation, or continuous fracturing, of 180 m and 220 m respectively (calculated from Tammetta (2012)) and hydraulic conductivity of fractured strata above the height of continuous fracturing of 10^{-5} to 10^{-7} m/s. These hydraulic conductivity values were based on the hydraulic conductivity of overburden strata, maximum subsidence and overburden depth relationship from Gale (2010). At a height of 180 m above the mined seam and subsidence of 1 m (which is the subsidence predicted by MSEC (2019) resulting from extraction of the panels under Eraring Ash Dam), the Gale (2010) plot indicates a hydraulic conductivity value of less than 10^{-7} m/s. This is more consistent with observed inflows into existing Longwalls 22-25 as discussed in Section 4.2.

Observed groundwater inflows into Longwalls 22-25 at Newstan Colliery (0.25 ML/day) are lower than would be expected if the actual height of depressurisation or continuous fracturing was in accordance with the Tammetta (2012) empirical equation (i.e. approximately 250 m). With an average interburden thickness between Longwalls 22-25 and the Awaba underground void of 110 m (range 90 m to 140 m), it would be expected that there would be complete drainage of the interburden and direct flow from the Awaba underground void into the Longwall 22-25 goaf. Since this is not the case, it is considered overly conservative and unreliable to apply the Tammetta (2012) height of depressurisation above the proposed panels as proposed by SCT (2019). The thickness of interburden between the Longwall 22-25 and the Awaba void is approximately 90 m to 140 m. Seam floor contours for the West Borehole seam are shown in Figure 4-6. Depth of cover contours for the West Borehole seam (between surface and the West Borehole seam) are shown in Figure 4-7. As shown in Figure 4-6 and Figure 4-7, the elevation of the West Borehole seam dips to the south east from Longwalls 22-25 towards the proposed workings and Eraring Ash Dam and the depth of cover between the West Borehole seam and the surface increases. In the vicinity of the Eraring Ash Dam the depth of cover above the West Borehole Seam is ranges from approximately 240 m to 295 m.

The proposed panels in the Extension of Mining Area have a lower void width (167 m) compared to Longwalls 22-25 (230 m), there is a greater interburden thickness between the proposed panels and Awaba underground void (average of 170 m) as identified above and the panels will only recover up to 75% to 85% of available coal compared to 100% for longwalls (excluding the chain, spine and barrier pillars), thus reducing the equivalent mining height (MSEC, 2019). These aspects of the mine design further reduce the likelihood of the SCT (2019) conceptualisation.

As discussed in Section 4.2.1, the major ion chemistry of groundwater inflow into the existing Newstan Colliery workings has been compared to that for the Awaba underground void. Groundwater inflow into the existing West Borehole seam workings at Newstan Colliery (sampled at location ‘cut through 19’) is brackish and slightly alkaline, and sodium bicarbonate-chloride dominant. In comparison, water within the Awaba underground void is more magnesium sulfate dominant (sampled at location 13 West 2). This suggests that the groundwater inflow into the Longwall 22-25 area is from the adjacent porous and fractured rock groundwater source rather than directly from the Awaba underground void which would be the case under the SCT (2019) conceptualisation.

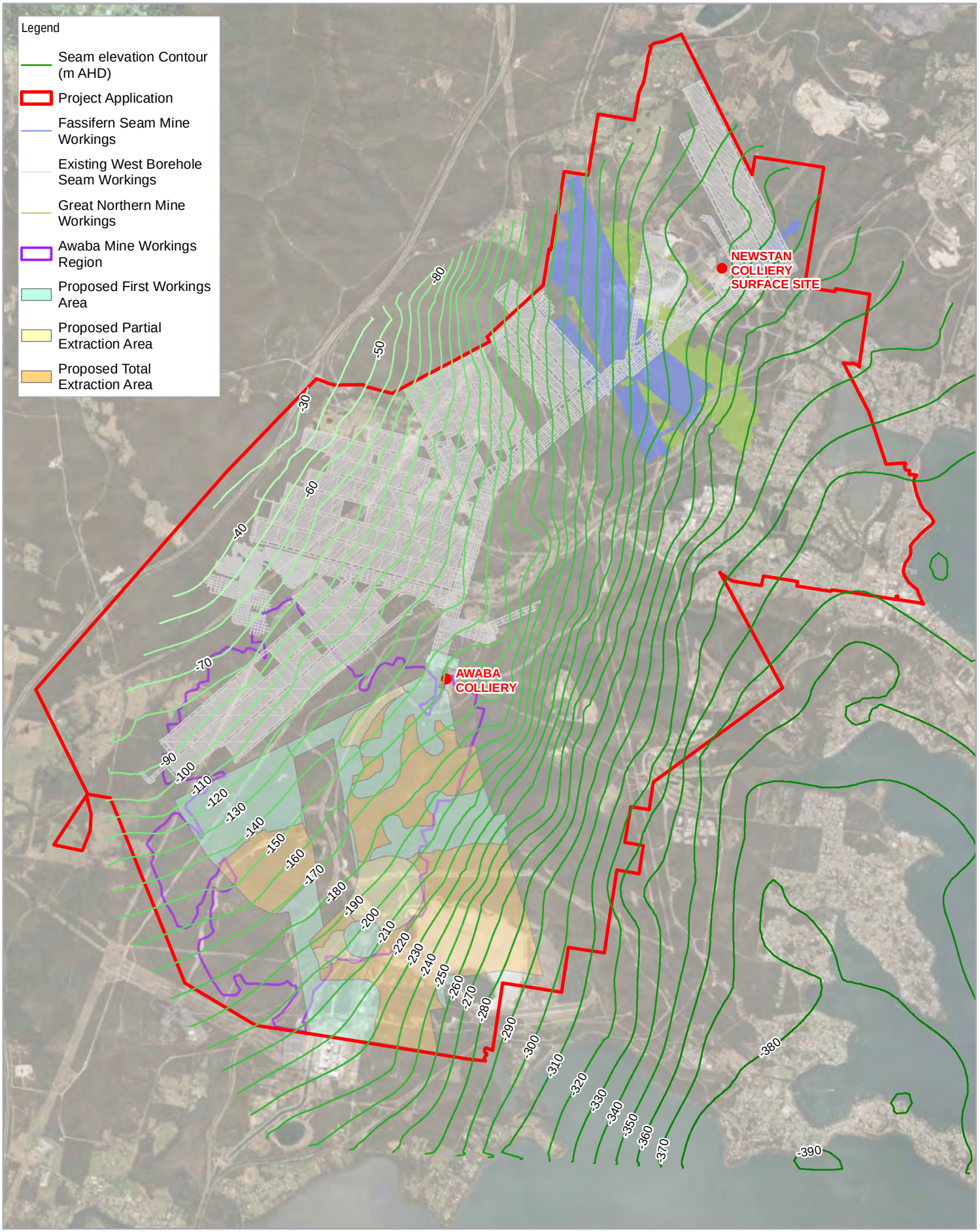
Finally, observed groundwater inflows into the Mandalong Mine longwall mining area (less than 1 ML/day) are low considering the current mine footprint (25 longwall panels have been extracted since 2005). This reflects the low hydraulic conductivity of the fractured overburden, particularly the Munmorah Conglomerate, and provides further evidence that groundwater inflow into mine workings tends to be low throughout the Newcastle Coalfield and less than what would be predicted using the common empirical methods (such as Tammetta (2012)) for calculating the height of continuous fracturing.

GHD approach

The height of depressurisation is simulated in the numerical groundwater model using the stacked drain approach. The height of stacked drains above the West Borehole seam was based on model calibration to groundwater inflows reported into the existing Newstan Colliery workings. This height was found to be approximately 140 m, which is at the lower end of the range calculated using Tammetta (2012) for the lowest mining height in the Extension of Mining Area.

As part of the uncertainty analysis, the SCT (2019) conceptualisation for height of continuous fracturing has been simulated using a stacked drain height of 220 m above all full and partial extraction area. Results are shown in Appendix B, however have not been assessed in this Groundwater Impact Assessment since they are considered very unlikely to occur.

While a direct connection between the Eraring Ash Dam and the underlying Awaba underground void forming due to the proposed workings has not been assessed in this Groundwater Impact Assessment; the potential impacts due to infiltration from the Eraring Ash Dam to the Awaba underground void have been assessed in GHD (2020b) and the site water and salt balance model developed as part of this project (Appendix B of GHD (2020b)). The infiltration from the Eraring Ash Dam to the Awaba underground void may occur due to existing fracturing from the historical Awaba workings discussed in GHD (2020b).



Paper Size ISO A4

0 0.4 0.8 1.2 1.6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

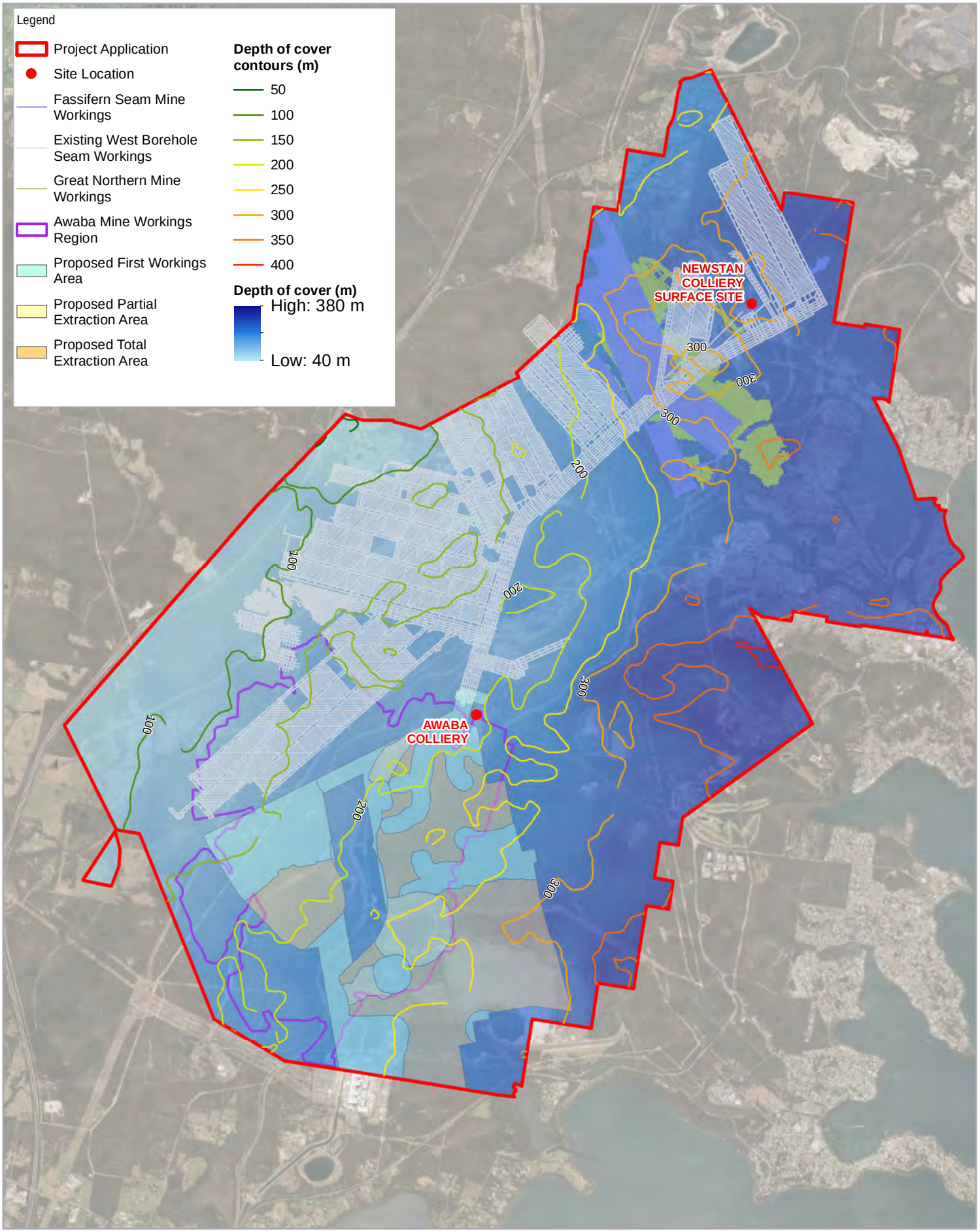
West Borehole Seam
Floor Elevation Contours

Project No.	22-20265
Revision No.	A
Date	24/01/2020

FIGURE 4-6

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-013_WBS_Contours.mxd
Print date: 27 Feb 2020 - 16:59

Data source: Centennial: Consent boundary, 2016, workings, 2019; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald



Paper Size ISO A4

0 0.4 0.8 1.2 1.6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

West Borehole Seam
Depth of Cover

Project No. 22-20265
Revision No. A
Date 24/01/2020

FIGURE 4-7

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-014_WBS_DepthCover.mxd
Print date: 27 Feb 2020 - 16:59

Data source: Centennial: Consent boundary, 2016, workings, 2019; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

5. Impact assessment methodology

Potential groundwater impacts from the project on the groundwater sources identified in Section 3.5 have been predicted by development and calibration of a numerical hydrogeological model. Impacts have been assessed in accordance with the criteria from the NSW AIP.

5.1 Impact prediction

The numerical groundwater model has been used to make predictions for:

- Groundwater inflows into the existing and proposed workings at Newstan Colliery in the West Borehole seam.
- Change in the groundwater flow budget, including flux from the Awaba underground void to underlying strata and flux from the Eraring Ash Dam to underlying strata.
- Drawdown in groundwater sources.
- Changes in baseflow to waterways.

5.1.1 Predictive simulations

Development and calibration of the numerical hydrogeological model is outlined in the *Groundwater Modelling Report* (GHD, 2020a) which is included in Appendix B. As discussed in Section 3.6 of the Groundwater Modelling Report, the numerical hydrogeological model was run until the end of July 2019 as part of model calibration.

To predict potential impacts from proposed mining, the predictive model was run from the end of the calibration model in July 2019 to January 2635; 600 years after the end of mining. This was undertaken to allow assessment of impacts of proposed mining and assessment of post-mining recovery of groundwater levels.

To enable the assessment of impacts a number of models representing various baseline conditions were developed. To assess incremental impacts associated with proposed mining, a 'no proposed mining' scenario was developed. The 'no proposed mining' scenario does not simulate any proposed mining at Newstan Colliery within the Extension of Mining Area. The 'no proposed mining' scenario includes all existing mining at Newstan Colliery, Teralba, West Wallsend, Awaba and Cooranbong. In this scenario existing Newstan Colliery workings are kept in care and maintenance until the end of 2034 (end of mining). Incremental impacts were calculated as the difference in model results between the proposed mining model and the 'no proposed mining' scenario.

To assess cumulative impacts a 'no regional mining' model was developed, where all mining within the model boundary was not represented. Cumulative impacts were calculated as the difference between the predictive model and the 'no regional mining' model.

Uncertainty analysis for hydrogeological model predictions has been undertaken in accordance with the requirements *Information guidelines for proponents preparing coal seam gas and large coal mining development proposals* (IESC, 2018a) and the *Explanatory Note on Uncertainty Analysis in Groundwater Modelling* (IESC, 2018b).

5.2 Impact assessment criteria

The NSW AIP requires that potential impacts on the groundwater sources, including their users and GDEs, be assessed against minimal impact considerations, outlined in Table 1 of the Policy. If the predicted impacts are less than the minimal impact considerations, then these impacts will be considered as acceptable. The Level 1 minimal impact considerations have been adopted for this groundwater impact assessment and are outlined in Section 2.2.1.

6. Impact assessment

6.1 Impact prediction

6.1.1 Groundwater inflow

Predicted groundwater inflow rates into the Newstan Colliery West Borehole seam workings are presented in Figure 6-1. Groundwater inflows are presented for the predictive scenario only.

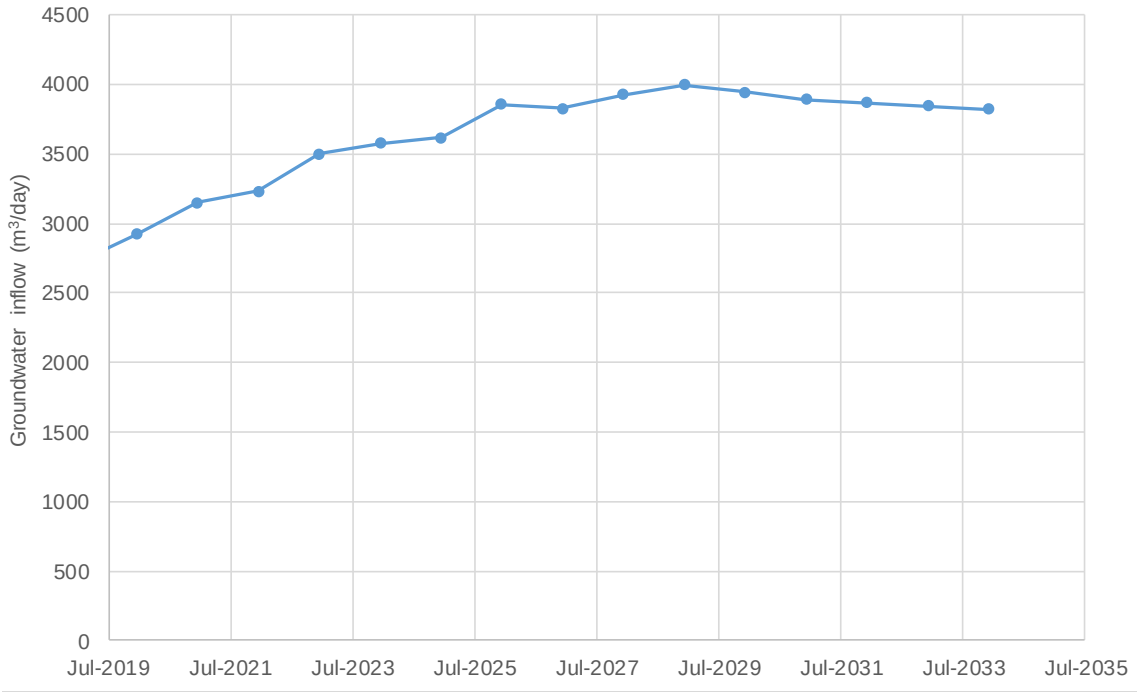


Figure 6-1 Modelled Newstan Colliery West Borehole seam groundwater inflows

Groundwater inflows are modelled to increase from 2.8 ML/day under current conditions to a peak of 4.0 ML/day in 2029. Groundwater inflows are modelled to slightly decrease to 3.8 ML/day in the final year of mining.

Note that the model is over predicting current mine inflows (compared to observed rates). Current observed inflows into the West Borehole seam are 1 ML/day. Therefore, it is likely that the model is over predicting future mine inflows.

Various uncertainty analysis runs are presented in Appendix B. Although most of these runs have reasonable calibration statistics (based on comparison of observed and modelled groundwater levels), the majority considerably overestimate groundwater inflows and are not considered to be reliable. Therefore these predictions are not assessed as part of this impact assessment. It is noted that the modelled groundwater inflows presented in Figure 6-1 are similar to the 50th percentile modelled inflows from the uncertainty analysis reported in Appendix H of GHD (2020a).

6.1.2 Groundwater drawdown

Groundwater drawdown predictions for the end of mining at Newstan Colliery are included in Appendix B. Incremental drawdown contours (attributable to proposed mining) and cumulative drawdown contours have been calculated. Contours of predicted drawdown of the Layer 1 water table and piezometric heads in the Great Northern seam (Layer 4), Fassifern seam (Layer 6) and the West Borehole seam (Layer 10) have been calculated.

As shown in Figure E-1 of Appendix B, cumulative drawdown in the alluvium and regolith is centred on historical/existing Newstan Colliery workings in the Great Northern seam, Cooranbong Mine and Awaba Colliery workings. Note that all these workings are located in the Great Northern seam. Drawdown in Layer 1 is likely attributable to the lower depth of cover above the Great Northern seam.

Model results predict there will be no drawdown in the alluvium and shallow regolith (Layer 1 of the model) due to the proposed mine workings (Figure E-5 of Appendix B).

Modelled drawdown in the Great Northern seam is also centred on Newstan Colliery workings in the Great Northern seam, Cooranbong Mine and Awaba Colliery workings. As shown in Figure E-2 of Appendix B, cumulative drawdown in the Great Northern seam is greatest above existing workings.

Drawdown in the Great Northern seam at the end of mining attributable to the proposed workings is shown in Figure E-6 of Appendix B. Drawdown in the Great Northern seam attributable to proposed workings is negligible.

Cumulative modelled drawdown in the Fassifern seam is similar to cumulative modelled drawdown in the Great Northern seam. As shown in Figure E-3 of Appendix B, cumulative drawdown in the Fassifern seam is greatest above existing workings. Cumulative drawdown in the Fassifern seam is predominantly centred over Awaba, existing workings at Newstan Colliery in the Fassifern seam and Cooranbong.

Drawdown in the Fassifern seam at the end of mining, attributable to the proposed workings, is shown in Figure E-7 of Appendix B. Drawdown attributable to proposed workings is greatest above areas of panel extraction.

Cumulative modelled drawdown in the West Borehole seam is shown in Figure E-4 of Appendix B. Drawdown in the West Borehole seam is centred on the Newstan Colliery workings. The radius of drawdown extends to the north, north-east, north-west and south of the workings.

Drawdown in the West Borehole seam, attributable to the proposed workings, is shown in Figure E-8 of Appendix B. The radius of drawdown attributable to proposed workings extends up to approximately 9.5 km to the north-east and approximately 11 km to the south of the proposed workings.

6.1.3 Baseflow

Changes to baseflow to creeks and Lake Macquarie have been estimated based on the output of groundwater from layer 1 of the model (alluvium and outcrop of fractured and porous rock) to drains.

Model results indicate that there is no impact on baseflow or Lake Macquarie due to the proposed mine workings.

6.1.4 Eraring Ash Dam

The net leakage from the Eraring Ash Dam has been extracted from the cell-by-cell flow output. The results are shown in Figure 6-2.

The results show that there is no difference in net leakage out of the Eraring Ash Dam for the predictive and no proposed mining scenarios. Therefore, modelling results indicate proposed mining at Newstan Colliery will have no impact on leakage out of the Eraring Ash Dam. Note that these predictions are based on the fracture height conceptualisation discussed in Section 4.2.3.

Modelled leakage out of the Eraring Ash Dam reflects changes in rainfall recharge. As discussed in Appendix B, rainfall recharge was set to a constant value for the predictive model period. Therefore, modelled leakage out of the Eraring Ash Dam is constant throughout the prediction and post-closure period of modelling (from July 2019 onwards).

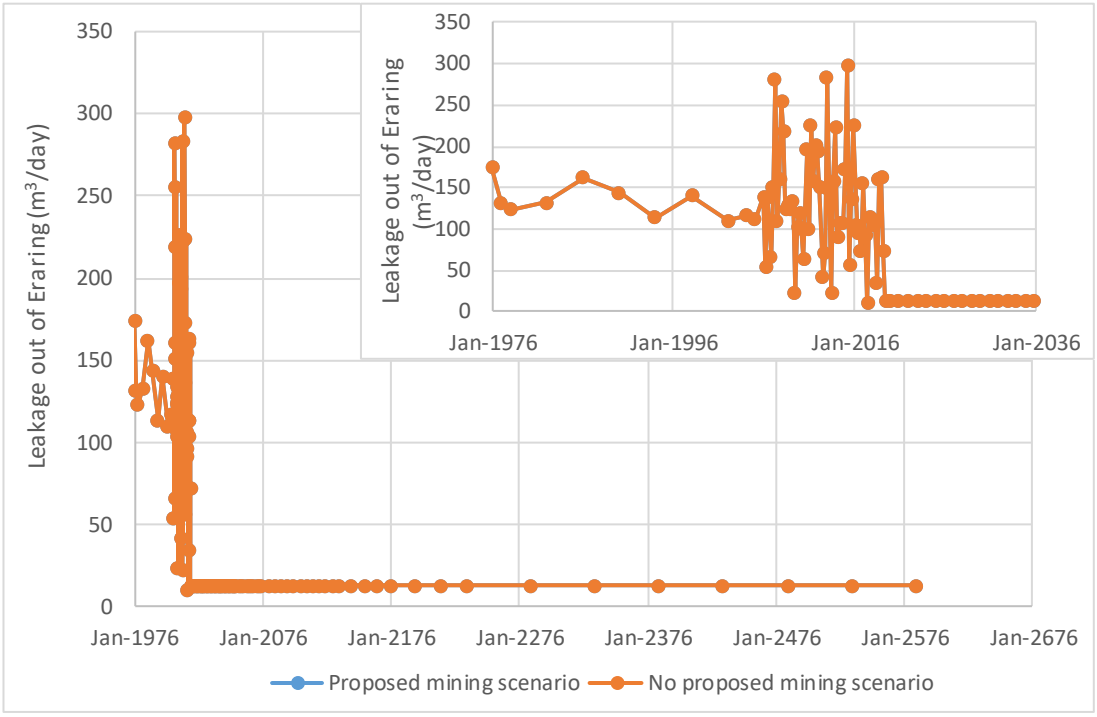


Figure 6-2 Net leakage from Eraring Ash Dam

6.1.5 Awaba workings

Net groundwater flow into Awaba underground void has been extracted from the cell-by-cell flow output and is plotted in Figure 6-3.

The results show that there is a modelled net groundwater flow into the Awaba underground void for existing conditions and throughout the period of proposed mining. Proposed mining at Newstan Colliery is modelled to result in a slight reduction in groundwater inflow into the Awaba underground void. Note that during the period of proposed mining the General Head Boundary (GHB) elevation of the Awaba underground void was set to a constant elevation. The reduction in groundwater inflow into the Awaba underground void is attributable to groundwater drawdown in the surrounding porous and fractured rock groundwater source.

The reduction in groundwater inflow to the Awaba underground void continues after the end of mining. The maximum discrepancy in groundwater inflows into the Awaba underground void between the 'proposed mining' and 'no proposed mining' scenarios is 22 m^3/day and occurs between the year 2063 and the year 2175.

No increase in leakage from the Awaba underground void to underlying strata is predicted to result from mining in the Extension of Mining Area, based on the fracture height conceptualisation discussed in Section 4.2.3.

For further consideration of potential infiltration from the Eraring Ash Dam to the Awaba workings, refer to GHD (2020b) and the site water and salt balance model developed as part of this project (Appendix B of GHD (2020b)).

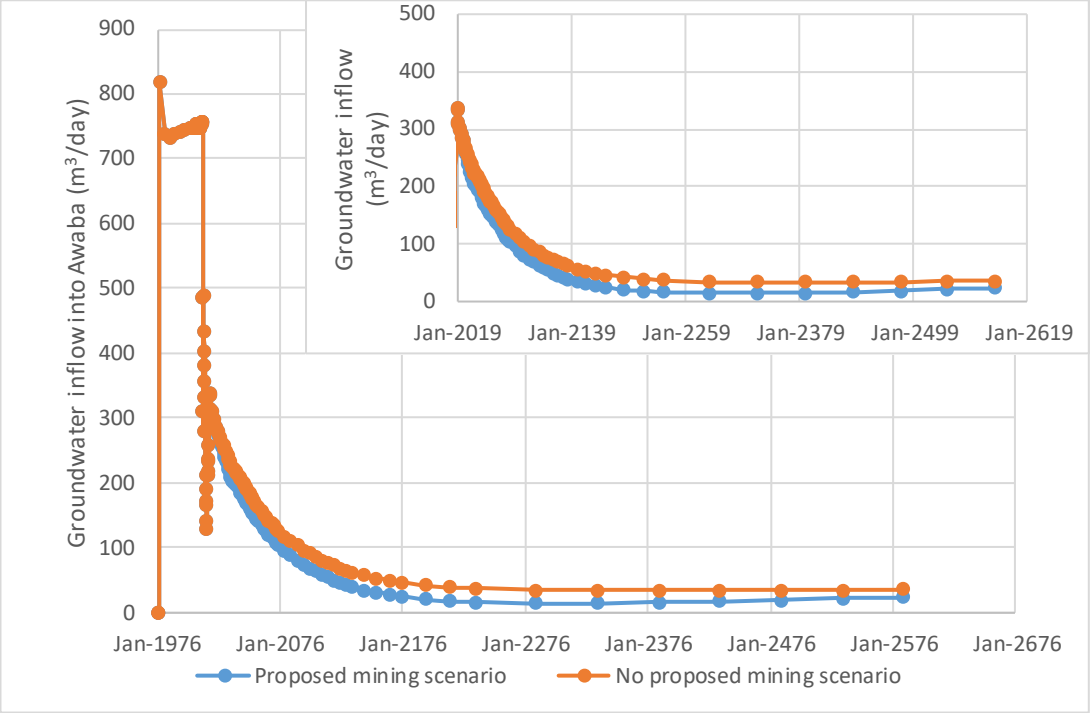


Figure 6-3 Net groundwater flow into Awaba

6.1.6 Fassifern underground storage

Net groundwater flow into the Fassifern Underground Storage has been extracted from the cell-by-cell flow output and is plotted in Figure 6-4.

The results show that there is a modelled net groundwater flow into the Fassifern Underground Storage for existing conditions and throughout the period of proposed mining. The results show that there is no difference in net groundwater flow into the Fassifern Underground Storage due to proposed mining.

Groundwater inflow into the Fassifern Underground Storage reflects the timeline of mining related activities at the Fassifern Underground Storage. From the start of the transient calibration model to the mid-1990s, groundwater inflow into Fassifern workings is influenced by mining. The results indicate an approximate equilibrium in groundwater inflows from 1992 to 2011. The Fassifern Underground Storage started to flood and therefore GHBs were activated in the Fassifern Underground Storage to simulate the managed water level in the Fassifern Underground Storage. From 2011 to July 2019, groundwater flow into the Fassifern Underground Storage is influenced by the GHB elevation. During the predictive modelling phase, the GHB elevation was fixed at 0 m AHD for the period of proposed mining and therefore inflows into the Fassifern Underground Storage are relatively constant over this period. Additional information regarding the use of GHBs in the model is discussed in Appendix B.

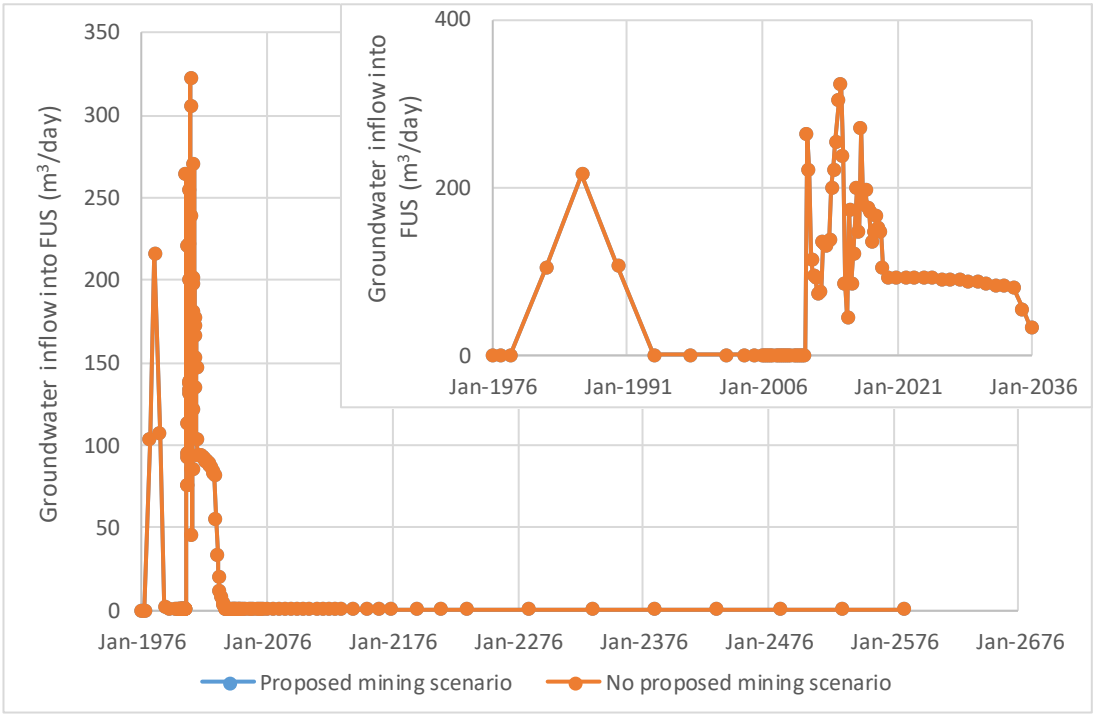


Figure 6-4 Net groundwater flow into Fassifern Underground Storage

6.2 Impact assessment

The assessment of potential impacts on the groundwater resources identified in Section 3.5 is detailed in this section. Details of how each of the Significant Impact Guidelines have been addressed are included in Appendix A.

6.2.1 Alluvium groundwater sources

The alluvial groundwater sources include alluvium associated with creek lines in the vicinity of the Project Application Area including LT Creek, Kilaben Creek, Palmers Creek, Stony Creek, Lords Creek and Crooked Creek and their tributaries.

Incremental impacts

Water table and baseflow

As discussed in Section 6.1.2 and Section 6.1.3, groundwater impacts due to the proposed mine workings do not extend up to the alluvium. Therefore, there will be no impact to the alluvial water table or baseflow to creeklines attributable to the proposed workings. This specifically includes Stockyard and Kilaben Creek catchments. Note that this assessment is based on the predicted change in alluvial groundwater level only and change in outflow to drain cells within ephemeral creeks. It does not consider impacts to creeks associated with fracturing of creek beds which is addressed by MSEC (2019).

As discussed in Section 6.1.2 and 6.1.3, impacts from proposed mining at Newstan Colliery will not extend to the alluvium and outcropping fractured and porous rock. Therefore the proposed mine workings will not impact on GDEs. This includes the GDEs within Lake Macquarie City Council's (LMCC) Awaba Biodiversity Conservation Area.

As there is no drawdown within the alluvial groundwater sources due to the proposed workings, the proposed workings will not impact on high priority GDEs (either vegetation or stygofauna) or impact on any alluvial landholder bores. Therefore the predicted impacts are less than the Level 1 minimal impact considerations under the NSW AIP and are therefore considered to be acceptable.

Since alluvial groundwater sources are unconfined, the criterion for 'Water Pressure' does not apply.

Water quality

As discussed in Section 6.1.2 and Section 6.1.3, impacts due to the proposed mine workings do not extend to the alluvium. Therefore there will be no impact on alluvium groundwater quality due to the proposed workings. It is noted that groundwater quality monitoring, which has been undertaken at Newstan Colliery since 2005, does not show impacts on alluvial groundwater quality or beneficial use of groundwater due to mining over this period.

The beneficial use category of the alluvial groundwater is not expected to change within or outside the Project Application Area and the level of impact is less than the Level 1 minimal impact considerations under the NSW AIP.

Cumulative impacts

Water table

As discussed in Section 6.1.2, drawdown of the water table has occurred due to historical workings. As shown in Figure E-1 of Appendix B, cumulative drawdown in the alluvium and regolith is centred on Newstan Colliery workings in the Great Northern seam, Cooranbong and Awaba workings. However, the proposed workings will not change (or worsen) the existing water table impacts from historical mining.

Groundwater quality

The existing beneficial use categories for alluvium are ‘environmental protection’ as well as ‘domestic’ and ‘agricultural use’.

It is not expected that cumulative drawdown will change these categories either within the Project Application Area or downstream. While no drawdown attributable to mining has been observed at alluvial groundwater monitoring locations (refer to Section 4.1.1), no impacts on groundwater quality have been observed at alluvial groundwater monitoring bores in the Project Application Area. Therefore, it is not expected that drawdown due to regional mining has impacted on groundwater quality.

6.2.2 Porous and fractured rock groundwater sources

The Narrabeen Sandstone and Illawarra Coal Measures groundwater sources are considered to be ‘less productive’ under the NSW AIP since the yields are typically less than 5 L/s and/or the groundwater salinity exceeds 1500 mg/L.

Incremental impacts

Water pressure

As discussed in Section 6.1.2, drawdown attributable to the proposed workings will extend up to 11 km from the proposed workings in the West Borehole seam.

Limited drawdown attributable to the proposed workings is predicted in the Fassifern seam and the Great Northern seam, with drawdown remaining within 500 m of the Project Application Area.

Landholder bores within the radius of drawdown have been identified in Section 6.2.3. Modelled drawdown due to proposed workings is less than 0.6 m at all bores at the end of mining.

Since there are no high priority vegetation GDEs within the radius of drawdown, and drawdown at landholder bores is less than 2 m, the predicted impacts are less than the Level 1 minimal impact considerations under the NSW AIP and are therefore considered to be acceptable.

Since these groundwater sources are confined, the criterion for ‘Water Table’ does not apply.

Eraring Ash Dam

As discussed in Section 6.1.4, proposed mining at Newstan Colliery will have no impact on leakage out of the Eraring Ash Dam.

Awaba Colliery

As discussed in Section 6.1.5, proposed mining at Newstan Colliery will result in a slight reduction in groundwater inflows into the Awaba underground void. This reduction in inflows is due to groundwater drawdown of strata surrounding the Awaba Colliery workings. Further details on the Awaba Colliery water balance are provided in GHD (2020b). Potential interaction between the Eraring Ash Dam and the Awaba underground void are discussed in GHD (2020b) and the site water and salt balance model developed as part of this project (Appendix B of GHD (2020b)).

Fassifern Underground Storage

As discussed in Section 6.1.6, proposed mining at Newstan Colliery will have no impact on groundwater inflow into the Fassifern Underground Storage.

Groundwater quality

The predicted drawdown in the less productive porous and fractured rock groundwater sources is not expected to result in any change in groundwater quality. This is based on results of the existing groundwater monitoring program as well as the prediction that the proposed mining is not expected to change inter-aquifer connectivity and no change in leakage from the Awaba Colliery underground void or Eraring Ash Dam is predicted.

Note that the surface water impact assessment (GHD, 2020b) does predict an increase in leakage from the Eraring Ash Dam to the Awaba underground void, but no increase in infiltration from the surface to the Awaba underground void. This infiltration is via existing sinkholes. The increase in leakage from the Eraring Ash Dam is because the expansion of the Eraring Ash Dam will directly overly the Awaba underground void.

The beneficial use category of the fractured and porous rock groundwater source is not expected to change within or outside the Project Application Area and the level of impact is less than the Level 1 minimal impact considerations under the NSW AIP.

Cumulative impacts

Water pressure

As discussed in Section 6.1.2, drawdown in the West Borehole seam is centred on the Newstan Colliery workings. The radius of drawdown predominantly extends to the north, north-east, north-west and south of the workings. The radius of drawdown extends up to approximately 14 km to the south of the West Borehole seam workings.

Landholder bores within the radius of drawdown attributable to proposed workings have been identified in Section 6.2.3.

Groundwater quality

The beneficial use categories for the fractured and porous rock are domestic and agricultural use.

It is not expected that cumulative drawdown will change these categories either within the Project Application Area or downstream. While no drawdown attributable to mining has been observed at fractured and porous rock groundwater monitoring locations (refer to Section 4.1.1), no impacts on groundwater quality have been observed at fractured and porous rock groundwater monitoring bores in the Project Application Area. Therefore, it is not expected that drawdown due to regional mining has impacted on groundwater quality.

The beneficial use category of the alluvial groundwater is not expected to change within or outside the Project Application Area and the level of impact is less than the Level 1 minimal impact considerations under the NSW AIP.

6.2.3 Landholder bores

Landholder bores identified in the wider search in Section 3.6 were compared to the modelled radius of drawdown discussed in Section 6.2.1 and Section 6.2.2 and presented in Appendix B.

Landholder bores within the incremental radius of drawdown (attributable to the proposed workings) in the West Borehole seam are shown in Figure 6-5. A total of 286 bores are within this incremental radius of drawdown, with 122 registered as monitoring or exploration bores and an additional two bores abandoned. Of the remaining 164 bores, the majority are shallow and screened above the Permian within the Triassic and/or Quaternary strata. There are only 10 bores screened within Permian strata.

Alluvium

As discussed in Section 6.1.2, there is no modelled drawdown in the alluvium attributable to the proposed workings. Therefore the proposed workings will not result in any drawdown at landholder bores within alluvium.

Fractured and porous rock

There is no modelled drawdown in Triassic strata attributable to the proposed workings and therefore no impact predicted on bores screened above the Newcastle Coal Measures.

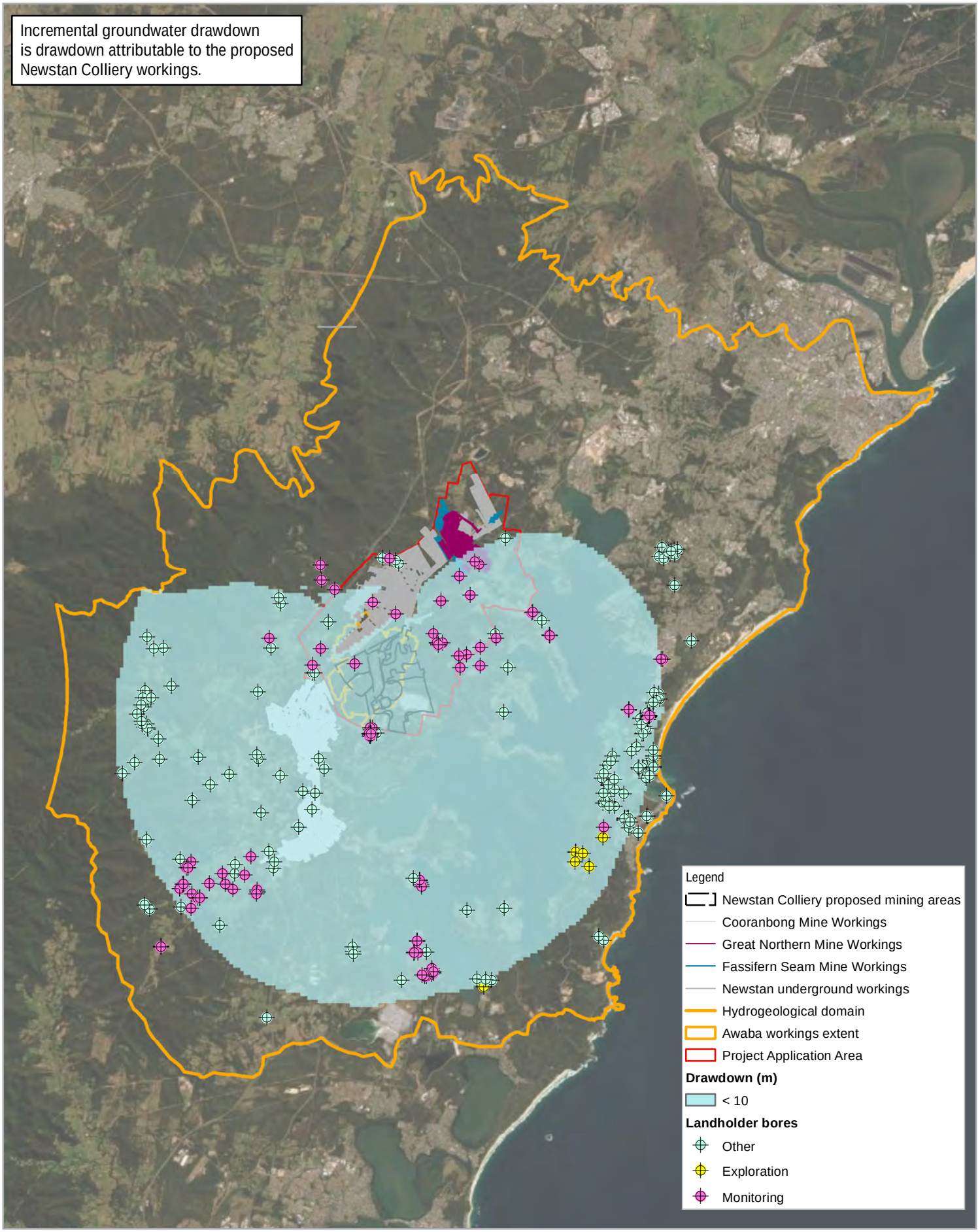
Details of the remaining ten bores screened within the Permian strata are provided in Table 6-1. Predicted maximum drawdown (both incremental and cumulative) is shown in this table for each bore.

Incremental drawdown for the majority of these Permian bores is less than 0.1 m. The maximum incremental drawdown is 0.6 m for bore GW061202, located in the vicinity of the coal seam subcrop to the west of the existing Newstan mine workings. As shown in Appendix H of GHD (2020a), this drawdown is between the 50th and 90th percentile of predictions from the uncertainty analysis.

Cumulative drawdown exceeds 2 m at four landholder bores. This cumulative drawdown is attributable to impacts from existing Newstan Colliery workings and surrounding mining such as Cooranbong Mine workings.

Table 6-1 Landholder bores within radius of drawdown of coal measures attributable to proposed workings

Bore	Depth (m)	Purpose	Strata (interpreted)	Incremental maximum drawdown (m)	Cumulative maximum drawdown (m)
GW043431	38.1	Irrigation	Permian interburden	<0.1	1.23
GW052111	49	Stock and domestic	Great Northern seam	<0.1	36.5
GW052381	35	Water supply	Permian interburden	0.1	2.2
GW053438	53	Irrigation	Great Northern seam	<0.1	44.2
GW061202	50.3	Water supply	Permian interburden	0.6	7.8
GW063947	22.2	Water supply	Great Northern seam	<0.1	<0.1
GW078354	35	Water supply	Permian interburden	<0.1	<0.1
GW078363	36.5	Water supply	Permian interburden	<0.1	0.4
GW078591	42.6	Water supply	Permian interburden	<0.1	0.4
GW203292	88	Stock and domestic	Permian interburden	<0.1	0.9



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

Landholder bores within radius of incremental groundwater drawdown
End of mining - Layer 10:
West Borehole Seam

Project No. 22-20265
Revision No. A
Date 24/01/2020

FIGURE 6-5

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-015_LandholderBoresIncrementalDrawdown_2.mxd
Print date: 25 Mar 2020 - 13:12

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald

6.3 Water sharing plan licensing requirements

The project is predicted to result in an increase in groundwater inflow into the mine workings. Groundwater inflows into the Newstan Colliery West Borehole seam workings are predicted to gradually increase over the period of proposed mining to a peak of 4.0 ML/day in 2029.

A WAL will be required for the Sydney Basin – North Coast Groundwater Source for the interception and extraction of groundwater from the proposed and existing workings in accordance with the WM Act.

It is recommended that Centennial Newstan obtain a licence for 1,460 ML/year (4.0 ML/day multiplied by 365 days) for the Sydney Basin – North Coast Groundwater Source to licence groundwater inflows into the West Borehole seam workings.

Centennial Newstan has previously submitted applications under Part 5 of the *Water Act 1912* for Newstan Colliery. These licence applications include:

- GNS pump station – 2522 ML. The GNS pump extracts water from the Newstan Colliery Great Northern Seam workings.
- 19 cut through pump – 824 ML. The 19 cut through pump extracts water from the West Borehole seam workings.
- Fassi 1 Bore – 2575.5 ML. The Fasi 1 bore extracts water from the Fassifern underground storage.

Following determination of the above valid licence application, Centennial Newstan anticipate that these licences will convert to WALs under the WM Act for the Sydney Basin – North Coast Groundwater Source.

Based on the predicted infiltration of surface water into the Fassifern Underground Workings reported in GHD (2020b), maximum total dewatering of underground workings is predicted to be 13 ML/day (4745 ML/year). This volume includes the modelled groundwater inflows of 4.0 ML/day into the West Borehole seam. Therefore the outstanding applications listed above will be sufficient, once granted, to licence the extraction of groundwater from the underground workings.

Additionally, Centennial Newstan has submitted a number of applications under Part 5 of the *Water Act 1912* for Awaba Colliery. These applications include a number of dewatering boreholes:

- 10 South – 1460 ML
- LDP001 – 73 ML
- LDP002 – 73 ML
- LDP003 – 730 ML
- LDP004 – 730 ML
- LDP005 – 73 ML
- LDP006 – 73 ML
- LDP007 – 183 ML

Following determination of the above valid licence application, Centennial Newstan anticipate that these licences will convert to WALs under the WM Act for the Sydney Basin – North Coast Groundwater Source.

7. Mitigation, management and monitoring

All groundwater impacts attributable to the project have been assessed to be less than the Level 1 impact considerations in the NSW AIP. Therefore ongoing measures should focus on monitoring to validate groundwater model predictions and provide observation data for future model calibration.

7.1 Flow monitoring

The existing flow monitoring program at Newstan Colliery and Awaba Colliery should be continued. The following additional flow monitoring will be installed within 12 months of project approval:

- Water levels in Awaba underground void: an automated pressure transducer and data logger will be installed in at least one groundwater monitoring bore to provide continuous record of water levels in the Awaba underground void.
- 19 cut through and Fassi 1 bore: these existing flow meters will be recalibrated to improve confidence in the estimation and groundwater interception and surface infiltration.
- Any new dewatering pumps installed in the Extension of Mining Area will have individual flow meters installed.

7.2 Groundwater monitoring

The groundwater monitoring program at Newstan Colliery should be continued. This involves biannual monitoring of levels and quality (pH and EC) at the monitoring bores listed in Table 4-1. Groundwater level monitoring within alluvial bores would be improved with the installation of pressure transducers and loggers so that the response in groundwater level to rainfall events can be assessed. Continuous recording of water pressure at the existing VWP (CN064) should continue.

Although no groundwater impacts are predicted in the Awaba Biodiversity Conservation Area, additional groundwater monitoring within the Awaba Biodiversity Conservation Area is recommended to validate these predictions. It is recommended that two additional alluvial monitoring bores are installed to monitor for potential impacts on alluvial groundwater. Proposed locations for these additional monitoring bores are shown in Figure 7-1. Monitoring of these bores is recommended to commence within 12 months of project approval. It is recommended that groundwater monitoring continues at AE2 and AE3 to assist in identification of potential impacts on the shallow groundwater in this area.

It is recommended that loggers are installed in these bores for the continuous monitoring of groundwater levels. It is also recommended that quarterly monitoring of these bores is undertaken. Quarterly monitoring should include manual gauging of groundwater levels and sampling of groundwater quality. Groundwater quality parameters should include electrical conductivity, pH, alkalinity, sulfate, chloride, magnesium, sodium, potassium, calcium, dissolved iron, nitrate, nitrite, total Kjedahl nitrogen, total oxidised nitrogen (NOX), total nitrogen and total phosphorus.

7.3 Hydrogeological model

The hydrogeological model (refer Appendix B) will be reviewed and revised if required every two years. The review of the hydrogeological model will include a comparison of modelling results against groundwater monitoring data and mine dewatering volumes.

7.4 Management plans

7.4.1 Water management plans

A regional water management plan has been developed to provide an overview of the water management requirements across Centennial's northern operations in the Lake Macquarie catchment. Site-specific management plans for Newstan Colliery, Awaba Colliery and Northern Coal Services have also been developed to address specific water management requirements for each of the operations.

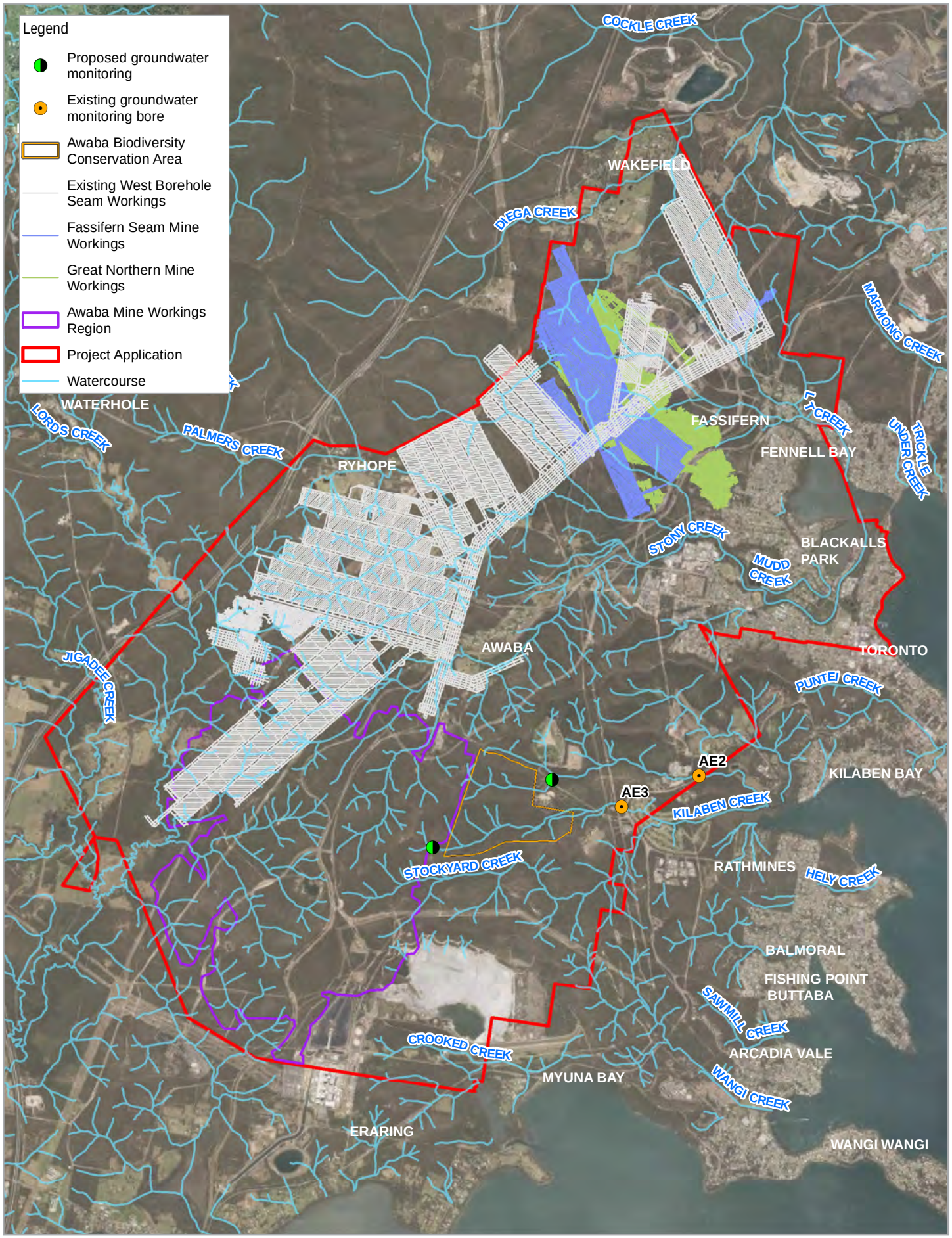
The water management plans ensure that each operation, with respect to water, meets all relevant regulatory requirements. The regional and site-specific water management plans are reviewed every three years or as a result of any regulatory requirements, any significant changes to water management practices or the development of new mining areas.

TARPs are provided in the site-specific water management plans. Additional TARPs will be developed as required to provide guidance on the immediate actions that should be taken in response to any impacts of the project identified as part of the monitoring program. Generally, responses include investigation and monitoring, determination of the risk of impact and remedial measures to be implemented.

Following approval of the project, the site-specific water management plan for Newstan Colliery and Awaba Colliery will be merged and updated to include the water management requirements of the project. The revised management plan will then be implemented.

7.4.2 Extraction plans

Extraction plans will be developed and implemented for each extraction area prior to mining. Generally, extraction plans describe the applicable regulatory framework, mine planning and management and monitoring measures to be implemented to ensure the protection of all surface/subsurface natural and built features and the protection of public safety during extraction. Each extraction plan for the project will include a water management plan to manage potential subsidence-related impacts to water resources.



Paper Size ISO A4

0 0.45 0.9 1.35 1.8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Impact Assessment

Recommended additional groundwater monitoring locations

Project No. 22-20265
Revision No. A
Date 04/02/2020

FIGURE 7-1

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GIA\22-20265-GIA-012_ProposedGWMonitoring.mxd
Print date: 25 Mar 2020 - 13:08

Data source: Centennial: Consent boundary, 2016, workings, 2019, monitoring, 2016; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

8. Summary

The GIA considers the potential impacts of the project on the groundwater environment under the proposed conditions.

8.1 Summary of potential impacts

The predictive simulations indicate the following:

- Existing mining at Newstan Colliery and surrounding mining operations has resulted in depressurisation of the coal seams in the vicinity of Newstan Colliery.
- Cumulative impacts of mining in the vicinity of Newstan Colliery will result in drawdown of the West Borehole seam up to 14 km to the south of the Newstan Colliery mine workings at the end of proposed mining. The majority of this drawdown is attributable to existing mine workings. Drawdown in the West Borehole seam due to proposed workings is limited to 9.5 km to the north-east and approximately 11 km to the south of the proposed workings at the end of mining.
- The proposed workings do not result in impacts to the alluvium or shallow regolith. Impacts on the alluvium and shallow regolith has previously occurred above the existing Newstan Colliery Great Northern seam workings, Awaba and Cooranbong.
- The proposed workings do not impact on GDEs or baseflow to creeks.
- Excluding monitoring bores, incremental modelled drawdown at the majority of landholder bores is predicted to be less than 0.1 m. Maximum incremental drawdown is predicted to be 0.6 m at bore GW061202.
- Negligible change in leakage from the Eraring Ash Dam is predicted due to proposed workings. This is based on the modelling conceptualisation that there will be no seam to surface fracturing.
- Negligible impact on the Fassifern Underground Storage is predicted due to proposed workings.
- The proposed workings will result in a slight decrease in groundwater flow into Awaba. The maximum modelled reduction in groundwater inflow into Awaba is 22 m^3/day and occurs between the year 2063 and the year 2175.

9. References

AGE (2008) *Definition of limit of the Stoney Creek alluvium: Awaba Colliery,* prepared by Australasian Groundwater & Environmental Consultants Pty Ltd for Centennial Newstan Pty Limited.

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

ANZECC (1995) *Guidelines for Groundwater Protection in Australia*, National Water Quality Management Strategy, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

BOM (2019). Groundwater Dependent Ecosystem Atlas, Bureau of Meteorology, retrieved from: http://www.bom.gov.au/water/groundwater/gde/

Centennial Mandalong (2019). Mandalong Mine Water Management Plan, Revision 4, August 2019.

DES (2017) *Groundwater dependent ecosystems,* Department of Environment and Science, Queensland Government, https://wetlandinfo.des.qld.gov.au/wetlands/ecology/aquatic-ecosystems-natural/groundwater-dependent/, accessed 4 February 2020.

DoE (2013a) *Significant Impact Guidelines 1.1: Matters of National Environmental Significance*, Commonwealth Department of the Environment.

DoE (2013b) *Significant Impact Guidelines 1.3: Coal seam Gas and Large Coal Mining Developments: Impacts on Water Resources*, Commonwealth Department of the Environment.

DMR (1995) *1:100,000 Newcastle Coalfield Regional Geology map*, NSW Department of Mineral Resources.

Ferdowsian, R., Pannell, D.J., McCarron, C., Ryder, A. and Crossing, L. (2000). *Explaining groundwater hydrographs: separating atypical rainfall events from time trends*. Sustainability and Economics in Agriculture (SEA) Working Paper 00/12.

Gale, W.J. (2010). 'Review and estimation of the hydraulic conductivity of the overburden above longwall panels. Experience from Australia'. *Proceedings of the 29th International Conference on Ground Control in Mining*. Morgantown, West Virginia, pp. 340-347.

GHD (2014). *Bore 20BL173524 Annual Compliance Report*. Cooranbong Services Site, prepared by GHD Pty Ltd for Centennial Mandalong Pty Limited.

GHD (2020a) *Newstan Extension of Mining Project: Groundwater Modelling Report,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited, reference 2220265.

GHD (2020b) *Newstan Extension of Mining Project: Surface Water Impact Assessment,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited.

GHD (2020c) *Newstan Mine Extension Project: Aquatic Ecology Impact Assessment,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited.

MSEC (2019) *Newstan Colliery: Mine Extension Project – Subsidence Predictions and Impact Assessments for Natural and Built Features due to the proposed 201 to 218 Panels in Support of the Environmental Impact Statement*, draft report, prepared by Mine Subsidence Engineering Consultants for Centennial Newstan Pty Limited, reference MSEC1042.

NOW (2012), *Risk Assessment Guidelines for Groundwater Dependent Ecosystems*, Department of Primary Industries: Lands and Water, NSW Office of Water.

Pacific Power International (1997). *Newstan Colliery Life Extension Project Overburden Groundwater Study*.

RPS (2012) *Flora and Fauna Assessment: Centennial Newstan Proposed LW101 to LW103 Mining Area*, RPS Australia East, Broadmeadow, NSW.

RPS (2020). *Newstan Mine Extension Project: Biodiversity Inventory Report*.

SCT (2019) *Newstan Mine Extension project: Mine Design in Context of Eraring Ash Dam,* prepared by SCT Operations Pty Ltd for Centennial Coal Company Limited, report no. NST4976.

Tammetta, P. (2012) *Estimation of the height of complete groundwater drainage above mined longwall panels,* Groundwater NGWA org pp 1-16.

WaterNSW (2020) NSW Water Register, https://realtimedata.waternsw.com.au/, accessed 29 January 2020.

Appendices

Appendix A – Supporting assessment requirements

A.1 Significant impact criteria

Criteria	Impact
Changes to hydrological characteristics	
Flow regimes (volume, timing, duration, frequency)	Refer to Surface Water Impact Assessment (GHD, 2020b)
Recharge rates	Yes, potential changes to flow budget within the porous and fractured rock groundwater source. No impact to registered groundwater users predicted as a result of the project. No impact to alluvial groundwater levels or baseflow to ephemeral creeks.
Aquifer pressure or pressure relationships between aquifers	
Groundwater table levels	
Groundwater/surface water interactions	
River/floodplain connections	Refer to Surface Water Impact Assessment (GHD, 2020b)
Inter-aquifer connectivity	No change to inter-aquifer flow into or out of alluvium predicted
Changes to water quality	
Creates risks to human or animal health or to the condition of the natural environment as a result of the change in water quality	No change to groundwater quality predicted. No transfer of water from the Eraring Ash Dam or from the Awaba underground void to underlying groundwater predicted
Substantially reduces the amount of water available for human consumptive uses or for other uses, including environmental uses, which are dependent on water of the appropriate quality	
Causes persistent organic chemicals, heavy metals, salt or other potentially harmful substances to accumulate in the environment	
Seriously affects the habitat or lifecycle of a native species dependent on a water resource	No change in groundwater flow to Groundwater Dependent Ecosystems predicted
There is a significant worsening of local water quality (where current local water quality is superior to local or regional water quality objectives)	No change to groundwater quality predicted. No transfer of water from the Eraring Ash Dam or from the Awaba underground void to underlying groundwater predicted
High quality water is released into an ecosystem which is adapted to a lower quality of water	No impact.
Cumulative impacts, timing and scale	
An assessment of the cumulative impacts of all other known projects in the surface or groundwater source area	Cumulative impacts considered in the groundwater model in terms of other historical and existing mine workings
An assessment of the significance of impacts in both the short and long term	
An assessment of the significance of impacts on each of a local and regional scale	

A.2 Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development information requirements

Assessment requirement	Where addressed
Groundwater	
Context and conceptualisation	
Describe and map geology	Section 3.4
Provide hydrogeological data	Section 3.5 Section 4
Define and describe or characterise significant geological structures and associated fracturing in the area and their influence on groundwater	Section 2.2 Appendix B
Provide hydrogeochemical characterisation	Section 3.5 Section 4
Provide site specific values for hydraulic parameters	Section 3.5
Describe recharge, discharge and flow pathways	Section 2.2 Appendix B
Provide time series level and water quality data	Section 4
Assess surface water / groundwater connectivity and inter-aquifer connectivity	Section 4
Analytical and numerical modelling	
Provide a detailed description of all models used	Section 3 Appendix B
Provide an explanation of the model conceptualisation, assumptions and limitations	Section 2.2 Appendix B
Undertaken groundwater modelling in accordance with the Australian Groundwater Modelling Guidelines (Barnett at al. 2012), including independent peer review	Section 1 Appendix B
Consider a variety of boundary conditions	Section 3 Appendix B
Calibrate models with adequate monitoring data	Section 3.6 Appendix B
Undertake sensitivity analysis and uncertainty analysis	Section 3.6 Appendix B Section 5.7 Appendix B
Describe each hydrogeological unit	Section 3.4 Appendix B
Provide an assessment of the quality of the data used in modelling	Section 3.6 Appendix B
Describe existing recharge/discharge pathways and predicted changes	Section 2.2 Appendix B
Undertake an uncertainty analysis	Section 5.7 Appendix B
Describe various stages of the proposed project and incorporate into model	Section 4

Assessment requirement	Where addressed
	Appendix B
Provide a program for review and update of models	Section 7.3
Identify annual water take	Section 6.3
Provide information on the magnitude and time for maximum drawdown	Section 5.2 Appendix B
Undertake model verification with monitoring data	Section 3.6 Appendix B Section 5.7 Appendix B
Impacts to water resources and water-dependent assets	
Provide an assessment of the potential impacts of the proposal	Section 6.2
Describe the water resources and water-dependent assets that will be directly impacted and describe the impact	Section 3.5 Section 3.6 Section 3.7 Section 6.2
Assess cumulative impacts of the project	Section 4 Appendix B Section 6.1 Section 6.2
Describe mitigation and management actions	Section 7
Data and monitoring	
Provide sufficient baseline hydrogeological and hydrogeochemical data, including long term monitoring data	Section 3.5 Section 4
Develop and describe a groundwater monitoring program and targeted field programs	Section 4.1 Section 7.1 Section 7.2

Appendix B – Groundwater modelling report

Centennial Newstan Pty Ltd

Newstan Extension of Mining Project
Groundwater Modelling Report

June 2020

Abbreviations

AHD	Australian Height Datum
ARI	Average Recurrence Interval
bgl	Below ground level
BOM	Bureau of Meteorology
CCL	Consolidated Coal Lease
CDFM	Cumulative departure from mean
Centennial	Centennial Coal Company Limited
Centennial Newstan	Centennial Newstan Pty Limited
CPP	Coal Preparation Plant
DA	Development Application
EC	Electrical Conductivity
EIS	Environmental Impact Statement
EPA	Environment Protection Authority
EPL	Environment Protection Licence
FCT	Flexible Conveyor Train
GIA	Groundwater Impact Assessment
GDE	Groundwater Dependent Ecosystem
GHB	General Head Boundary
GHD	GHD Pty Ltd
GMS	Groundwater Modelling System
ha	Hectares
HARTT	Hydrograph Analysis: Rainfall and Time Trends
kL	Kilolitres
kL/day	Kilolitre per day
km	kilometre
kV	Kilovolt
LDP	Licenced Discharge Point
LGA	Local Government Area
LW	Longwall

m	Metres
MB	Monitoring bore
ML	Megalitre, Mining Lease
ML/day	Megalitre per day
mm	Millimetres
MOP	Mine Operation Plan
Mt	Million tonnes
Mtpa	Million tonnes per annum
Northern Coal Services	Centennial Northern Coal Services Pty Limited
NRAR	Natural Resources Access Regulator
NUDLC	National Uniform Drillers Licensing Committee
Origin Energy	Origin Energy Eraring Pty Limited
RMS	Root Mean Square Error
ROM	Run of Mine
SEARs	Secretary's environmental assessment requirements
SILO	Scientific Information for Land Owners
SMP	Subsidence Management Plan
SRMSE	Scaled Root Mean Square Error
SSD	State significant development
t	Tonnes
TARP	Trigger, Action and Response Plan
USGS	United States Geological Survey
VWP	Vibrating Wire Piezometer
WSP	Water Sharing Plan

Glossary

Aquifer	A groundwater bearing formation sufficiently permeable to transmit and yield groundwater.
Ash	A major by-product of coal-fuelled power generation. Bottom ash is collected from the bottom of the boilers while fly ash is an inert mineral matter collected in dust collection plants.
Australian Height Datum	A common national surface level datum approximately corresponding to mean sea level.
Bord and pillar	A mining system whereby coal is extracted leaving 'pillars' of untouched coal to support the strata above.
Bore	Constructed connection between the surface and a groundwater source that enables groundwater to be transferred to the surface either naturally or through artificial means.
Catchment	The land area draining through the main stream, as well as tributary streams, to a particular site.
Cumulative Rainfall Departure	Monthly accumulation of the difference between the observed monthly rainfall and long term average monthly rainfall.
Dewatering	The removal or pumping of water from an above or below ground storage, including the mine water within the water collection system of mine workings. Water removed from mine workings is regarded as dewatering unless the workings are flooded and at equilibrium with the surrounding strata (in which case the removal is considered groundwater extraction).
Discharge	The quantity of water per unit of time flowing in a stream, for example cubic metres per second or megalitres per day.
Drawdown	A reduction in piezometric head within an aquifer.
Ephemeral	Stream that is usually dry, but may contain water for rare and irregular periods, usually after significant rain.
Fracture	Cracks within the strata that develop naturally or as a result of underground works.
Goaf	That part of a mine from which the mineral has been partially or wholly removed, including the waste left in the workings.
Groundwater	Subsurface water that occurs in soils and geological formations.
Groundwater extraction	For the purposes of this assessment, groundwater extraction has been defined as the removal of groundwater from a groundwater source or aquifer, either via direct removal for use via a production bore or via incidental flow of groundwater from the aquifer into the mine workings during and after mining. Groundwater extraction includes the pumping of underground water from flooded mine workings in equilibrium with the surrounding strata as well as the removal of water from perched aquifers recharged directly from rainfall infiltration.

Headings	A roadway driven in to the coal seam for access to underground operations by personnel and machinery.
Hydrogeology	The area of geology that deals with the distribution and movement of groundwater in soils and rocks.
Hydrograph	A graph which shows how a water level (either surface or underground) at any particular location changes with time.
Hydrology	The study of rainfall and surface water runoff processes.
Infiltration	The downward movement of water into soil and rock. It is largely governed by the structural condition of the soil, the nature of the soil surface (including presence of vegetation) and the antecedent moisture content of the soil.
Interseam	The strata between coal seams.
Licensed Discharge Point	A location where a licensed operation discharges water to the environment in accordance with conditions stipulated within the site Environment Protection Licence.
Longwall	Longwall mining is a form of underground coal mining where a block of coal is mined using a longwall shearer. The longwall mining method is supported by roadway development, mined using a continuous miner unit.
Outcrop	Where the bedrock is exposed at the ground surface.
Overburden	The strata between the recoverable topsoil and the upper coal seam.
Packer testing	A test used to measure the hydraulic conductivity of a section of borehole. The packer test involves lowering an inflatable tube (packer) down a borehole to isolate sections of the borehole above and below the packer. Water is then pumped into the isolated section of interest and the rate at which water is lost from the isolated section of interest to the surrounding formation is used to calculate hydraulic conductivity.
Permian Age	The youngest geological period of the Palaeozoic era, covering a span between approximately 290 and 250 million years.
Roadway	Underground tunnel constructed to enable access to working face.
Run of Mine	Raw coal production (unprocessed).
Runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
Strata	Geological layers below the ground surface.
Structure	The combination or spatial arrangement of primary soil particles (clay, silt, sand, gravel) into aggregates such as peds or clods, and their stability to deformation.
Subsidence	Mining-induced movements and deformations at the ground surface where (i) the vertical downward surface movements are greater than 20 mm, or (ii) the potential impacts on major surface infrastructure, structures or natural features may be significant, notwithstanding that the vertical downward surface movements are less than 20 mm.

Surface Water	Water that is derived from precipitation or pumped from underground and may be stored in dams, rivers, creeks and drainage lines.
Tailings	Fine reject material produced as a result of the coal processing.
Vertical Subsidence	Vertical downward movements of the ground surface caused by underground coal mining.

Table of contents

1. Introduction....1
   - 1.1 Background....1
   - 1.2 Extension of Mining Area....2
   - 1.3 Purpose of this report....3
   - 1.4 Third party review....5
   - 1.5 Previous groundwater modelling....5
   - 1.6 Scope and limitations....5
   - 1.7 Assumptions....6
2. Hydrogeological conceptualisation....9
   - 2.1 Existing hydrogeological setting....9
   - 2.2 Conceptual hydrogeological model....39
3. Groundwater modelling set-up....47
   - 3.1 Software selection....47
   - 3.2 Model complexity....47
   - 3.3 Model domain....49
   - 3.4 Model layers....52
   - 3.5 Boundary conditions....53
   - 3.6 Model calibration....59
4. Predictive simulations....70
   - 4.1 Overview....70
   - 4.2 Predictive model set-up....70
   - 4.3 Model scenarios....71
5. Model predictive results....72
   - 5.1 Flow budget....72
   - 5.2 Predicted effect on piezometric heads....76
   - 5.3 Predicted groundwater inflow rate....77
   - 5.4 Eraring Ash Dam....78
   - 5.5 Awaba workings....78
   - 5.6 Fassifern underground storage....79
   - 5.7 Groundwater seepage....80
   - 5.8 Uncertainty analysis....81
6. Conclusions and recommendations....90
   - 6.1 Model confidence level and set-up....90
   - 6.2 Predictions....90
   - 6.3 Recommendations....90
   - 6.4 Model limitations....91
7. References....92

Table index

Table 1-1 Summary of risk assessment 4
Table 2-1 Stratigraphic sequence – Newstan Colliery 16
Table 2-2 Newstan Colliery groundwater monitoring bore details 30
Table 2-3 Mandalong Mine groundwater monitoring network 32
Table 2-4 Summary of packer test results 37
Table 3-1 Australian Groundwater Modelling Guidelines model confidence level (Barnett *et al*, 2012) 48
Table 3-2 HSUs and model layers 52
Table 3-3 Calibration parameters 60
Table 3-4 Model parameter ranges for calibration 61
Table 3-5 Calibrated model parameters 63
Table 3-6 Calibrated evapotranspiration parameters 64
Table 3-7 Steady-state calibration model flow budget 67
Table 3-8 Transient calibration model flow budget 67
Table 4-1 Model scenarios 71
Table 5-1 Predictive model flow budget 73
Table 5-2 No proposed mining scenario – flow budget 74
Table 5-3 Changes to the flow budget due to proposed mining 75
Table 5-4 Uncertainty analysis – transient model calibration statistics 82

Figure index

Figure 1-1 Locality plan 7
Figure 1-2 Conceptual mine layout 8
Figure 2-1 Average climate data (-33.10_151.45) 11
Figure 2-2 Historical annual rainfall record 11
Figure 2-3 Rainfall cumulative departure from mean 12
Figure 2-4 Topography map 14
Figure 2-5 Watercourses within the Project Application Area 15
Figure 2-6 Surface geology mapping 19
Figure 2-7 Location of alluvium within the Project Application Area 20
Figure 2-8 Geological structures (MSEC, 2019) 21
Figure 2-9 Registered bore locations 26
Figure 2-10 Potential GDEs 27

Figure 2-11 Newstan Colliery groundwater monitoring network 28
Figure 2-12 Mandalong Mine groundwater monitoring network 33
Figure 2-13 Observed underground water transfers at Newstan Colliery 35
Figure 2-14 Observed underground water levels in the Fassifern Underground Storage 36
Figure 2-15 Observed flow from Awaba seepage at SP5 37
Figure 2-16 Schematic conceptual model 43
Figure 2-17 Conceptual cross section 44
Figure 2-18 Conceptual cross section including alluvium 45
Figure 2-19 Hydraulic conductivity, subsidence and overburden depth relationship, from Gale (2010) 46
Figure 3-1 Hydrogeological model domain 50
Figure 3-2 Model domain and mesh 51
Figure 3-3 Regional mine workings 56
Figure 3-4 Awaba underground water level 57
Figure 3-5 Evapotranspiration zones 58
Figure 3-6 Calibration scatter plot 65
Figure 3-7 Modelled mine inflows 66
Figure 3-8 Modelled water table head – end of calibration period 69
Figure 5-1 Modelled Newstan Colliery West Borehole seam groundwater inflows 77
Figure 5-2 Net leakage from Eraring Ash Dam 78
Figure 5-3 Net groundwater flow into Awaba 79
Figure 5-4 Net groundwater flow into Fassifern Underground Storage 80
Figure 5-5 Modelled mine inflows – uncertainty analysis 83
Figure 5-6 Net leakage from Eraring Ash Dam – uncertainty analysis 84
Figure 5-7 Net groundwater inflow into Awaba – uncertainty analysis 85
Figure 5-8 Net groundwater inflow into Fassifern Underground Storage – uncertainty analysis 85
Figure 5-9 Comparison of mine inflows 87
Figure 5-10 Net leakage from Eraring Ash Dam 87
Figure 5-11 Net groundwater inflow into Awaba 88
Figure 5-12 Net groundwater flow into Fassifern Underground Storage 89

Appendices

Appendix A – IESC information guidelines

Appendix B – Hydrographs

Appendix C – Model discretisation, hydrostratigraphy and boundary conditions

Appendix D – Calibration hydrographs

Appendix E – Modelled groundwater drawdown and post mining water table

Appendix F – Risk assessment

Appendix G – Independent third party review

Appendix H – Uncertainty analysis

1. Introduction

GHD Pty Ltd (GHD) was commissioned by Centennial Newstan Pty Limited (Centennial Newstan) to prepare a Groundwater Impact Assessment (GIA) for the Newstan Mine Extension Project (the project). This assessment forms part of an Environmental Impact Statement (EIS) to support a State significant development (SSD) application (SSD-10333) made under Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). Centennial Newstan is a subsidiary of Centennial Coal Company Limited (Centennial), a wholly owned subsidiary of Banpu Public Company Limited.

This report has been prepared to document the development and predictions of a numerical groundwater model used to assess the groundwater impacts associated with the project. The GIA is based on the results of groundwater modelling.

1.1 Background

Newstan Colliery is an existing underground coal mine located in the Lake Macquarie Local Government Area (LGA), approximately 25 kilometres south west of Newcastle and 140 km north of Sydney, NSW. It is owned and operated by Centennial Newstan.

Mining operations at Newstan Colliery began in 1887. Since then Newstan Colliery has at various times mined the upper coal seams (Great Northern and Fassifern seams) and lower coal seams (West Borehole, Borehole, Young Wallsend and Yard seams) and produced both semi-soft coking coal and thermal coal for the domestic and export markets. In the lower seams, workings to date have been concentrated to the west of the seam split, which is a defining geological feature of the mine. Mining has been undertaken using a combination of bord and pillar and longwall mining.

In August 2014, the underground operations at Newstan Colliery were placed onto care and maintenance due to poor market conditions. In recent years, Centennial Newstan has commenced feasibility investigations into the recommencement of mining at Newstan Colliery. The most recent modification to DA 73-11-98 in January 2019 permits first workings mining within the West Borehole seam in the southern portion of the Newstan Colliery mining lease area. The first workings aim to improve Centennial Newstan's understanding of the geology within the West Borehole seam, including the presence, throw and strike of a major fault zone projected from the historical Newstan Colliery workings.

Centennial Newstan is now seeking approval for the continuation of mining within the West Borehole seam (Extension of Mining Area) that partially underlies the closed Awaba Colliery. The project proposes to extract up to 25.9 million tonnes (Mt) over a fifteen year period at a maximum production rate of 4 million tonnes per annum (Mtpa) of run of mine (ROM) coal. Bord and pillar mining is proposed using continuous miner methods that will include areas of first workings, partial extraction and total extraction. A mix of metallurgical and thermal coal is proposed to be extracted. ROM coal will be delivered to the Newstan Colliery Surface Site via a series of existing underground conveyors. Once the coal reaches the Newstan Colliery Surface Site it will be handled in accordance with the approved operations for the Northern Coal Logistics Project (SSD-5145), managed by Centennial's Northern Coal Services business unit.

Other key features of the project include:

- Utilisation of the Newstan Colliery Surface Site to provide parking, bathhouse, administration and workshop facilities for the underground workforce. A small number of administrative, maintenance and monitoring personnel will also be located at Awaba Colliery Surface Site.
- Transportation of personnel and materials to and from the underground mining area via the existing men and materials drift at Newstan Colliery Surface Site.
- Continued operation of the two existing ventilation fans at Newstan Colliery Surface Site and a ballast borehole located off Forest Road at Awaba.
- Installation and operation of three new ventilation fans at the existing ventilation shaft at Awaba Colliery Surface Site.
- In-seam gas drainage, with gas transferred to a new gas flaring facility to be located within the existing disturbance footprint of Awaba Colliery Surface Site.
- Extraction of underground water via the existing Fassifern Pump Station at Newstan Colliery Surface Site and ongoing groundwater management in accordance with Centennial's *Northern Operations: Regional Water Management Plan*.

If approved, the project will allow for the optimisation of resource recovery from Newstan Colliery while providing ongoing direct and indirect employment opportunities. In addition, the project will provide a number of positive flow-on effects to the local, regional and state economies through additional wages and royalties.

The Project Application Area, which encompasses the existing Newstan Colliery and Awaba Colliery project areas, is shown in Figure 1-1.

1.2 Extension of Mining Area

Bord and pillar mining is proposed to be undertaken using continuous miners and will include first workings, partial extraction and total extraction. Mining will be designed to extract up to 4 Mtpa of ROM coal from within the Extension of Mining Area and a total of 25.9 million tonnes over a fifteen-year mine life. The conceptual mine layout is presented in Figure 1-2.

Mining will target the West Borehole seam, which is an agglomeration of the Borehole seam, the Young Wallsend seam and the Yard seam. A mix of metallurgical and thermal coal will be extracted. The depth of cover within the Extension of Mining Area ranges from 140 m in the north west to 320 m in the east. The target seam is overlain by the previous Awaba Colliery mine workings in parts of the Extension of Mining Area with the interburden between the two seams ranging from 100 m to 210 m.

The combination of first workings, partial and total extraction has been adopted to mitigate impacts on sensitive surface features. Total extraction, where all pillars in a panel are removed, is proposed to the south of the existing Awaba Colliery mine workings in areas that have not been subject to mining previously (i.e. single-seam conditions) and in some areas beneath the existing workings (i.e. multi-seam conditions) where sensitive surface features are not present. The total extraction in the multi-seam areas will provide the additional benefit of reducing the long-term liability of pillar failure in the overlying Awaba Colliery mine workings in the Great Northern seam. The maximum void width in total extraction areas is 167 m.

The development of first workings only (i.e. no secondary extraction) will occur beneath certain sensitive surface features in both single-seam and multi-seam conditions. This includes under numerous second and third order streams, the Main Northern Railway, a 132 kV substation, and the Eraring Power Station.

With the presence of the overlying Awaba Colliery mine workings and larger than previously encountered volume of gas within the West Borehole seam and overlying seams, which will be released by the mining process, this mining system allows for greater control of subsidence, particularly with regard to minimising multi-seam subsidence, improved gas management, and superior flexibility to deal with geological anomalies.

Personnel and materials will be transported down the existing men and materials drift at Newstan Colliery Surface Site.

1.3 Purpose of this report

This report has been prepared to document the development and predictions of a numerical groundwater model used to assess the groundwater impacts associated with the project. Groundwater impacts have been assessed in the Groundwater Impact Assessment (GIA) report for the project.

The numerical groundwater model has been used to make predictions, under both approved and proposed conditions, for:

- Groundwater inflows into the existing and proposed workings at Newstan Colliery in the West Borehole seam.
- Change in the groundwater flow budget, including flux from the Awaba underground void to underlying strata and flux from the Eraring Ash Dam to underlying strata. Further to this, the model was used to test the hypothesis posed by SCT (2019) that there will be an enhanced flow pathway between the Eraring Ash Dam and the proposed Newstan Colliery workings.
- Drawdown in groundwater sources.
- Changes in baseflow to waterways.

An uncertainty analysis has been undertaken as part of the groundwater modelling process to meet the requirements of the *Information guidelines for proponents preparing coal seam gas and large coal mining development proposals* (IESC, 2018a) and the *Explanatory Note on Uncertainty Analysis in Groundwater Modelling* (IESC, 2018b). The latter provides additional guidance when undertaking uncertainty analysis.

A hydrogeological risk assessment was undertaken to determine the best approach and level of uncertainty analysis to be undertaken. The uncertainty analysis undertaken is commensurate with the level of complexity of the project and the existing hydrogeological environment. It is important to note that the uncertainty analysis undertaken pertains to the model input parameters and outcomes of scenarios investigated, and not the numerical model itself.

The scope and the outcomes of the risk assessment are appended to this report as Appendix F. A summary of the risk assessment is provided in Table 1-1. The risk analysis was undertaken using Centennial's risk management tools. The risk rating provided in Table 1-1 is based on the likelihood of the risk multiplied by the consequence of the risk. More detail regarding the risk assessment process and the calculation of risk is provided in Appendix F.

1.3.1 Approach

The groundwater modelling described in this report has been undertaken in a staged manner consistent with the recommendations of the Australian Groundwater Modelling guidelines (Barnett et al, 2012). A hydrogeological conceptualisation is presented, based on the review and analysis of available information, which forms the basis for the subsequent model design and construction. The model has been calibrated to available data, to ensure that the choice of parameter values are sensible and consistent with the current hydrogeological knowledge of the site.

Table 1-1 Summary of risk assessment

Step	Risk rating	How incorporated into groundwater model
Groundwater quality (changes in beneficial use due to seepage from Eraring Ash Dam and Awaba underground void to underlying water sources)	Extreme	Groundwater flow model to assess change in flow from Eraring Ash Dam to underlying groundwater and from Awaba underground void to underlying groundwater as a result of mining in the Extension of Mining Area. Extreme risk mitigated by monitoring of seepage into Longwalls 22-25 to improve model calibration. Worst case of hydraulic connection between Eraring Ash Dam and Extension of Mining Area simulated by model.
Groundwater licensing	High	Uncertainty analysis undertaken on groundwater inflow predictions to provide a conservative estimate of groundwater licensing requirements.
Groundwater level within the West Borehole seam	High	Use best available data for model calibration, including metered inflow data into the mine workings and vibrating wire piezometer data. Ensure material properties are within sensible ranges.
Groundwater level within Great Northern seam workings	Medium	Constant heads applied to the Fassifern Underground Storage and Awaba underground void based on measured data.
Groundwater dependent ecosystems (not high priority)	Medium	Drawdown in shallow groundwater in areas not above the Fassifern Underground Storage and Awaba underground void can be predicted by the model. No drawdown modelled above these voids since constant heads applied.
Cumulative impacts from other mine workings	Medium	All active and historical mine workings considered likely to cause groundwater drawdown within the zone of influence of mining in the Extension of Mining Area included in the model
Groundwater levels within the alluvial layers	Medium	Utilise existing monitoring data in model calibration to assist in understanding of alluvial groundwater impacts
Surface and groundwater connectivity	Medium	Utilise existing monitoring data in model calibration to assist in understanding of alluvial groundwater impacts. Uncertainty analysis to be undertaken in absence of baseflow monitoring data.
Groundwater users	Low	Included in the model but no specific action required

1.4 Third party review

SLR has been appointed as an independent third party reviewer for the groundwater modelling works. The independent third party review is included in Appendix G.

1.5 Previous groundwater modelling

As part of this project a new numerical groundwater model has been developed. The current groundwater modelling works build on previous modelling undertaken for Newstan Colliery. In particular, a model of the West Borehole seam workings at Newstan Colliery was constructed to support Modification 8 (GHD, 2018). Current modelling works involve the following updates to the model for Modification 8:

- Larger hydrogeological domain and additional model layers.
- Modelling software changed from MODFLOW-NWT to MODFLOW-USG.
- Inclusion of old flooded mine workings (Fassifern storage and Awaba void).
- Inclusion of the Eraring Ash Dam.
- Recalibration of the model.
- Uncertainty analysis on model inflow predictions.

1.6 Scope and limitations

This report has been prepared for Centennial Newstan and may on be used and relied upon by Centennial Newstan for the purpose agreed between GHD and the Centennial Newstan as set out in Section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Centennial Newstan arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this Report are based on conditions encountered and information reviewed at the date of preparation of the Report. GHD has no responsibility or obligation to update this Report to account for events or changes occurring subsequent to the date that the Report was prepared. Specifically, this Report does not take into account the effects, implications and consequences of or responses to COVID-19, which is a highly dynamic situation and rapidly changing. These effects, implications, consequences of and responses to COVID-19 may have a material effect on the opinions, conclusions, recommendations, assumptions, qualifications and limitations in this Report, and the entire Report must be re-examined and revisited in light of COVID-19. Where this Report is relied on or used without obtaining this further advice from GHD, to the maximum extent permitted by law, GHD disclaims all liability and responsibility to any person in connection with, arising from or in respect of this Report whether such liability arises in contract, tort (including negligence) or under statute.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Section(s) 1.7 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Centennial Newstan and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

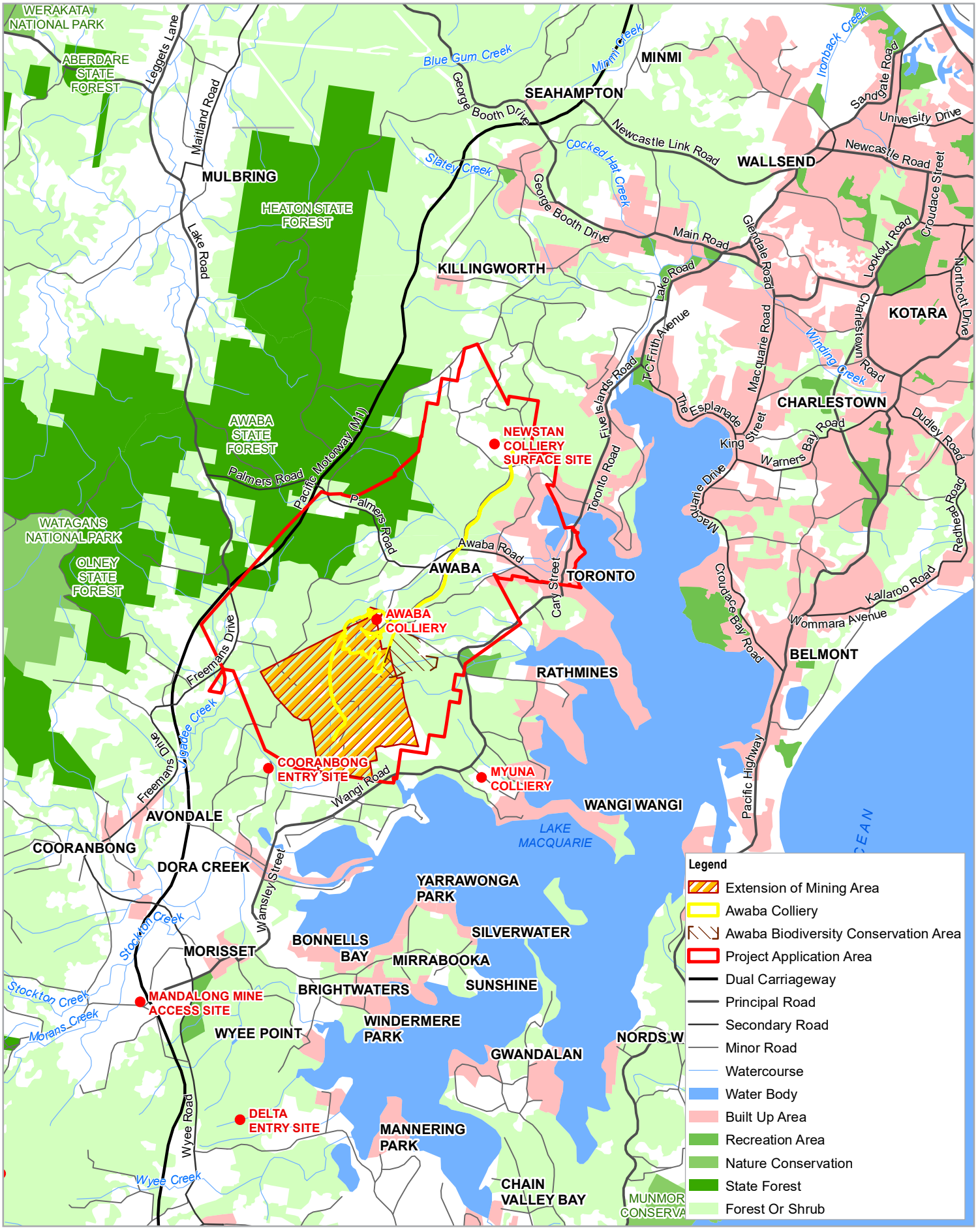
The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

1.7 Assumptions

The report relies on a combination of existing data and site-specific data supplied by the client specifically for the project including but not limited to:

- Surfaces from the mine geological model.
- Borehole logs and other relevant geological data.
- Bore/piezometer construction details and depth.
- Piezometric head measurements.
- Hydraulic testing data.
- Topographical data.
- Underground mine water transfers.
- Data from the previous numerical groundwater model (GHD, 2018) and other hydrogeological studies in the region including AGE (2008), GHD (2013) and RPS (2012).

A numerical groundwater model is a mathematical representation of a complex natural environment where parameters and processes can only be inferred from a finite number of measurements. Simplifications and assumptions are necessary in modelling. Efforts have been made to provide clarity on the data used to support the modelling and associated limitations. Findings presented in this report should be considered in this context.



Paper Size ISO A4

0 1 2 3 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

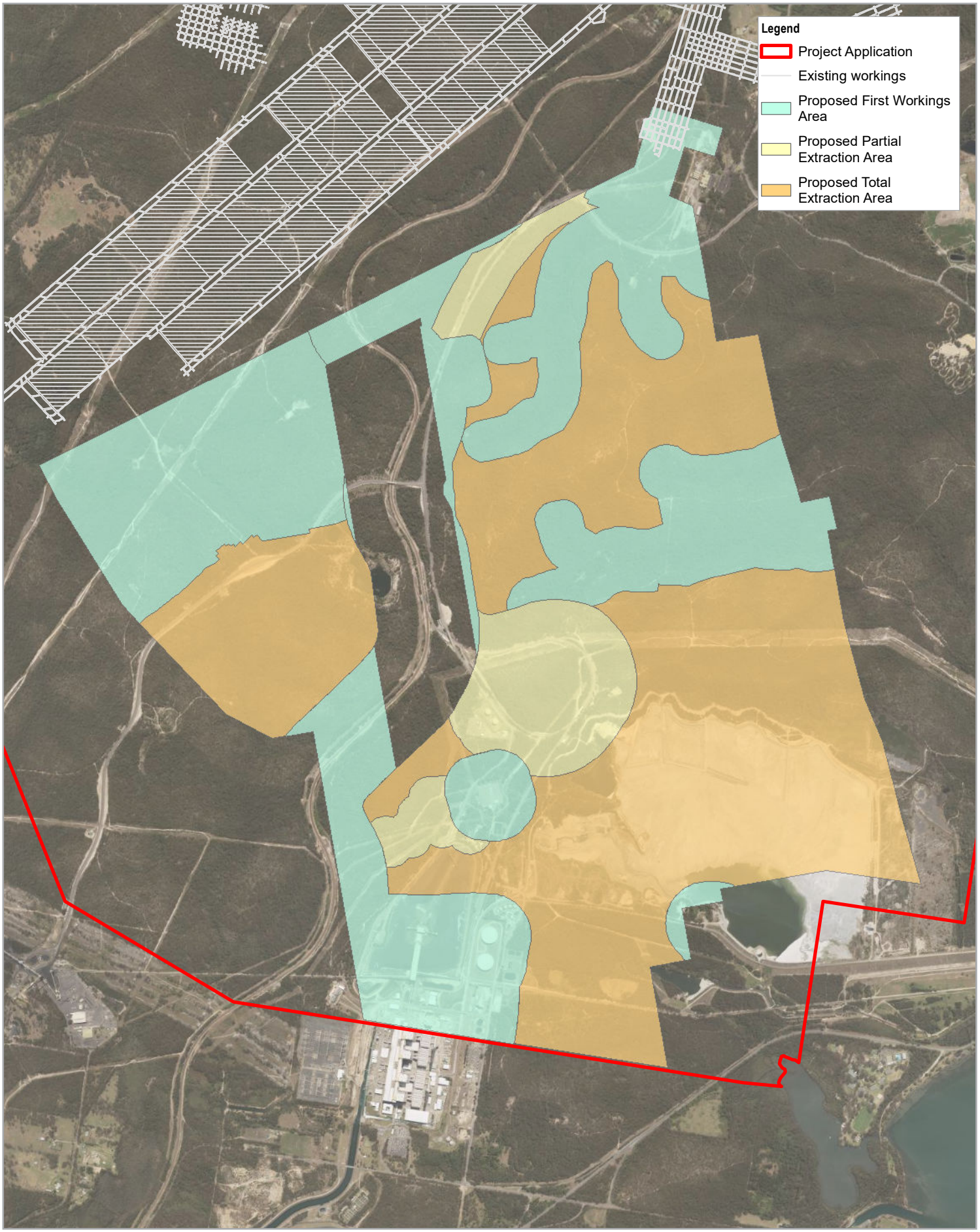
Project No. **22-20265**
Revision No. **0**
Date **27/03/2020**

Locality

FIGURE 1-1

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-001_Locality.mxd
Print date: 27 Mar 2020 - 14:23

Data source: Centennial: Consent boundary, 2018, Conservation Area, 2019 Geoscience Australia: 250k Topographic Data Series 3, 2006. Created by: smacdonald



Paper Size ISO A4

0 0.15 0.3 0.45 0.6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

Conceptual mine layout

FIGURE 1-2

G:\220105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-002_ProposedMinePlan.mxd
Print date: 06 Mar 2020 - 17:44

Data source: Centennial: Consent boundary, 2016, workings, 2019; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

2. Hydrogeological conceptualisation

2.1 Existing hydrogeological setting

The regional and local hydrology and hydrogeology as well as key features of the project area are detailed in this section.

2.1.1 Site setting

Most of the Project Application Area is located in undulating, unpopulated bushland and areas of rural residential land use. Lake Macquarie and the surrounding residential suburbs of Toronto and Rathmines border the Project Application Area to the east. To the south lies Eraring Power Station and associated infrastructure including the Eraring Ash Dam. To the west of the Project Application Area lies the M1 Pacific Motorway with the Main Northern Railway line traversing the area in a north-south direction. Parts of the north-west of the Project Application Area are overlain by the Awaba State Forest.

The proposed Extension of Mining Area is bordered by historical Newstan Colliery mine workings to the north and north-west. Completed longwall and bord and pillar underground workings within the Great Northern and Fassifern seams at Newstan Colliery are now used by Centennial Newstan as an underground water storage (referred to as the 'Fassifern Underground Storage'). Completed and existing longwall and continuous miner underground workings within the West Borehole seam, developed at Newstan Colliery since 1990, are referred to as the 'existing Newstan Colliery workings'.

The western and northern area of the proposed Extension of Mining Area is partially overlain by mine workings from the Awaba Colliery in the Great Northern seam. Completed bord and pillar underground workings within the Great Northern seam at Awaba are partially flooded and referred to as the 'Awaba void'.

Key features within and adjacent to the Project Application Area are described in more detail below and shown in Figure 1-1.

Eraring Power Station

The proposed Extension of Mining Area is partially overlaid by the Eraring Power Station and the associated Eraring Ash Dam. Origin Energy Eraring Pty Limited (Origin Energy) own and operate these assets, which are located on Rocky Point Road at Eraring. Origin Energy is currently seeking approval to augment the Eraring Ash Dam using an alternate placement strategy and landform design to maintain operational flexibility and extend the storage life of the dam in the short to mid-term whilst continuing to support long-term ash placement strategies towards the proposed closure in 2032.

Currently, ash generated at Eraring Power Station is either reclaimed for beneficial reuse or deposited hydraulically via pipelines into the ash dam. The proposed ash dam augmentation would involve the placement of ash in a series of upstream raises or terraces, or through placement from a pipe (or pipes) from the edges of the dam to form a 'beach' extending across the length of the ash dam operational area. The aim of the augmentation is to achieve ash deposition to reduced level (RL) 140 m (Eraring Power Station datum) or approximately 40 m AHD. Potential interaction between the Eraring Ash Dam and the Awaba underground void are discussed in GHD (2020b) and the site water and salt balance model developed as part of this project (Appendix B of GHD (2020b)).

The groundwater model has been used to predict the leakage (if any) from Eraring Ash Dam to underlying strata as a result of mining in the Extension of Mining Area.

Awaba Biodiversity Conservation Area

Part of the proposed Extension of Mining Area is overlain by a biodiversity offset area owned by Lake Macquarie City Council. The site, known as the Awaba Biodiversity Conservation Area, is managed for biodiversity conservation in accordance with the terms of an agreement established under the EPBC Act. Potential impacts on the Awaba Biodiversity Conservation Area have been assessed in the model by predicting drawdown in the alluvium and regolith.

West Wallsend and Teralba Collieries

Various completed and abandoned workings exist throughout the Newcastle Coalfield to the north of the Project Application Area. These include West Wallsend and Teralba Collieries, with workings in the West Borehole, Young Wallsend and Borehole seams. The majority of these completed and abandoned mine workings are now flooded. Historical workings at West Wallsend and Teralba Collieries have been incorporated into the groundwater model.

Mandalong Mine

Mandalong Mine is an underground coal mine located to the south of the Project Application Area and is owned and operated by Centennial Mandalong Pty Limited (Centennial Mandalong), a subsidiary of Centennial. Mined coal can be transferred from underground workings via drift systems to the Cooranbong Entry Site, which is approved as part of the Northern Coal Logistics Project (SSD-5145) and managed by Centennial's Northern Coal Services business unit. Coal transferred to the Cooranbong Entry Site is processed in a coal handling plant before being transferred to Eraring Power Station or to the Newstan Colliery Surface Site.

The active underground mining areas of Mandalong Mine are located in the West Wallarah seam and are dewatered to the Cooranbong Underground Storage (within the Great Northern seam) via a series of collection points and pumps. The Cooranbong Underground Storage is thence dewatered to the Borehole Dam at the Cooranbong Entry Site.

The historical Cooranbong workings within the Great Northern seam have been included in the groundwater model due to their close proximity to the Awaba workings. Groundwater level monitoring data for Mandalong Mine have been used in model calibration.

Myuna Colliery

Myuna Colliery is an underground coal mine owned and operated by Centennial Myuna Pty Limited, a subsidiary of Centennial. The consolidated development consent boundary for the Myuna Colliery (approved under Project Approval 10_0080) abuts the eastern boundary of the Project Application Area. Mining has been undertaken at Myuna within the Wallarah, Great Northern and Fassifern seams. It is not considered that the Myuna workings would interact hydraulically with the Newstan Colliery or Awaba Colliery workings and therefore have been excluded from the groundwater model.

2.1.2 Climate

The Science Delivery Division of the Department of Science, Information Technology and Innovation (DSITI) hosts an enhanced climate databased called SILO. SILO contains Australian climate data from 1901 and up to date in 2 formats: Patch Point and Data Drill. Patch Point data is station data with gaps infilled using the closest nearby record. Data Drill is a synthetic dataset, compiled based on interpolation between nearest weather stations across Australia for any given point.

For this assessment, SILO data were obtained for the grid point located at -33.00N, 151.55E, which is located within the Project Application Area. Average monthly climate data for this point are plotted in Figure 2-1. Evaporation varies seasonally, having higher records in summer compared in winter. The site generally has an average monthly net rainfall deficit except between April and July.

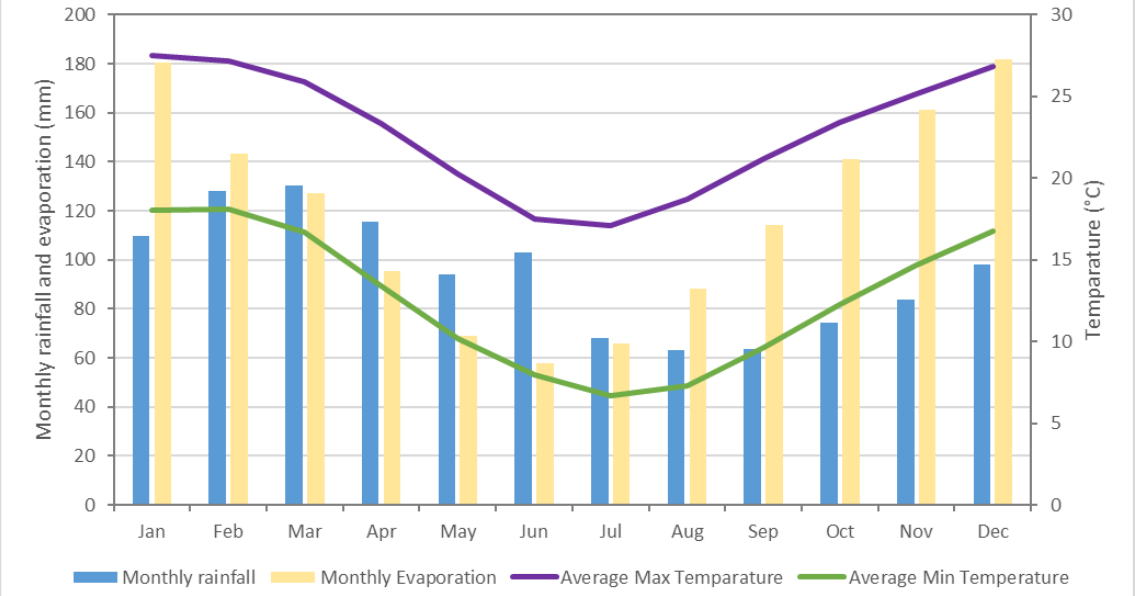


Figure 2-1 Average climate data (-33.10_151.45)

Figure 2-2 presents the historical annual SILO point rainfall data between 1889 and 2019. The annual statistics associated with this data are:

- Minimum rainfall total – 564 mm in 1944.
- Median rainfall total – 1072 mm.
- Average rainfall total – 1118 mm.
- Maximum rainfall total – 2109 mm in 1949.

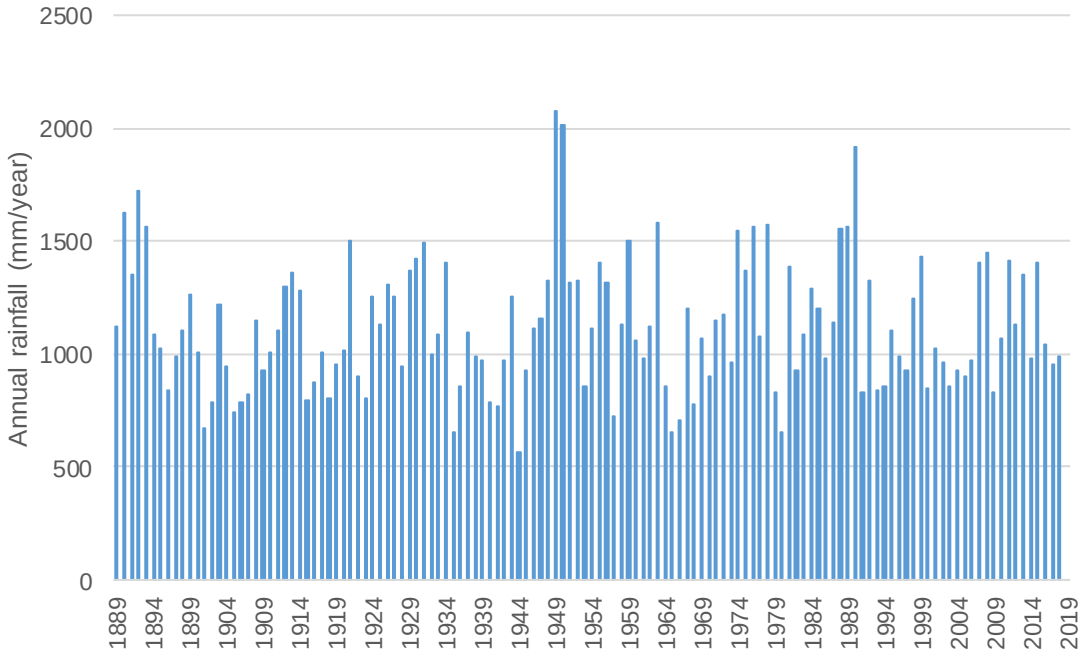


Figure 2-2 Historical annual rainfall record

Cumulative deviation from mean (CDFM) rainfall is the accumulated difference between the average and actual rainfall recorded. Monthly CDFM was calculated using data from 1889 to 2019. The monthly CDFM plot from January 1980 to 2019 is shown in Figure 2-3. The absolute value of the residual mass curve is not important, but rather the slope:

- A positive slope indicates a wetter than average period.
- A negative slope indicates a drier than average period.
- Flat line (no gradient) indicates average rainfall conditions.
- The grade of the slope indicates how much wetter or drier than average the climate is.



Figure 2-3 Rainfall cumulative departure from mean

2.1.3 Topography

The topography of the Project Application Area generally consists of rolling low hills with short side slopes and numerous closely spaced drainage lines, on predominately coarse grained sediments of the Narrabeen Group and Newcastle Coal Measures. Slope gradients are generally between 10 percent and 25 percent and local relief is from around 20 m Australian Height Datum (AHD) to 110 m AHD.

The elevation rises to the west of the Project Application Area to over 400 m AHD as shown in Figure 2-4.

2.1.4 Hydrology

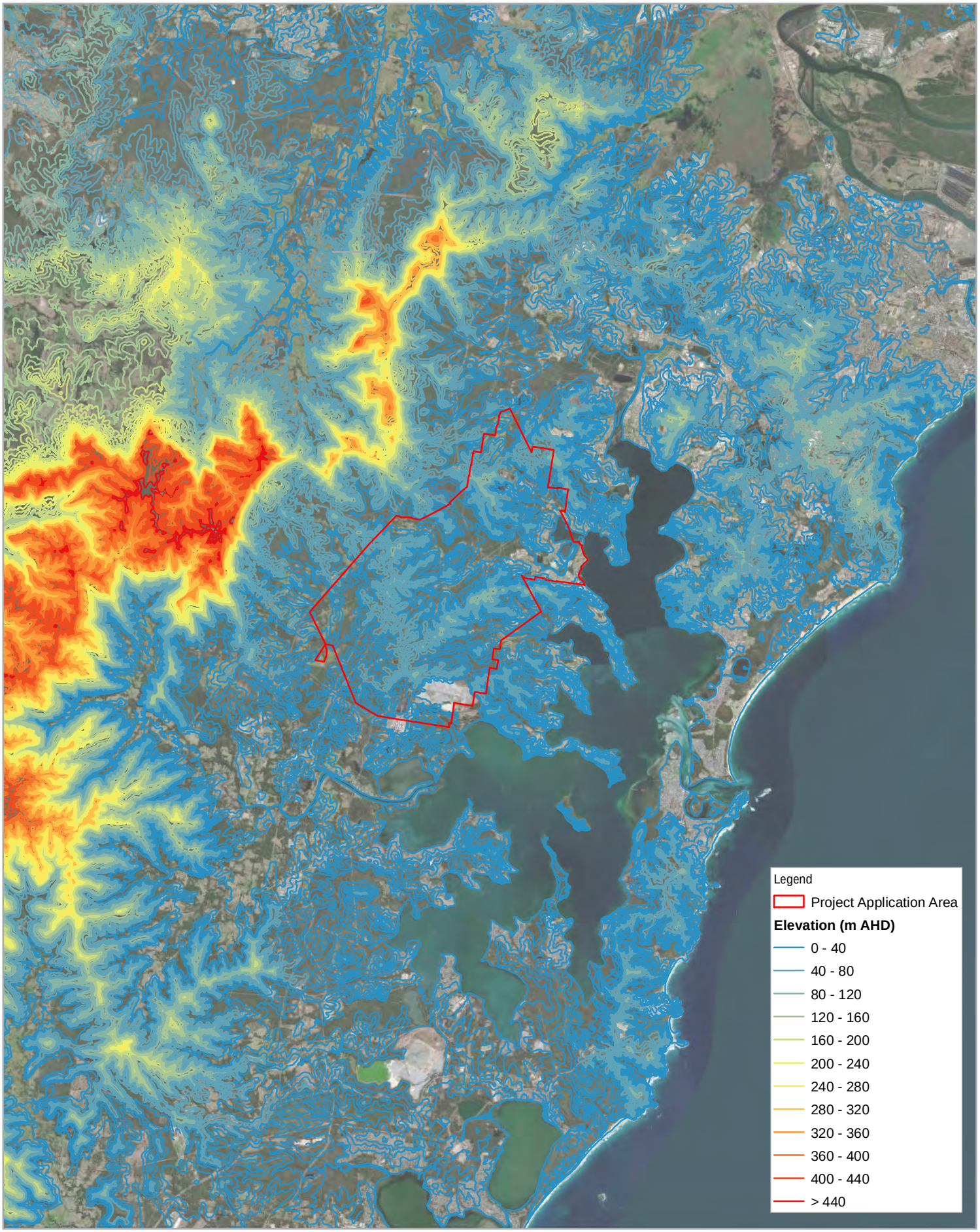
The Project Application Area is located within the catchment area of Lake Macquarie. Several watercourses traverse the Project Application Area; however, the area encompasses a small proportion of the catchment areas associated with these watercourses. As shown in Figure 2-5, the main creek systems that traverse the Project Application Area are:

- LT Creek, which flows in an easterly direction into Fennell Bay.
- Kilaben Creek and Stockyard Creek, which flow in an easterly direction into Kilaben Bay.
- Palmers Creek and Stony Creek, which flow in an easterly direction into Fennell Bay.
- Lords Creek, and its associated tributaries, which flows in a westerly direction into Jigadee Creek.
- Crooked Creek, which flows in a south-easterly direction into Lake Macquarie.

Creeks that overlie the proposed Extension of Mining Area include Kilaben Creek, Stockyard Creek, Stony Creek and Crooked Creek. Over the proposed Extension of Mining Area, these creeks are ephemeral as concluded in the Aquatic Ecology Impact Assessment (GHD, 2020c).

There are no data regarding creek water levels and flow in the vicinity of the Project Application Area. It has been conceptualised that creeks in the vicinity of the Project Application area, and upstream of the tidal zone, are water gaining streams. Evidence of surface water / groundwater connectivity is discussed further in Section 2.1.9. In the vicinity of Lake Macquarie, there is permanent water in creeks including Dora Creek, LT Creek, Stony Creek, Cockle Creek, Winding Creek and Kilaben Creek.

The representation of creeks within the numerical groundwater model is discussed in Section 3.5.2.



Paper Size ISO A4

0 1 2 3 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

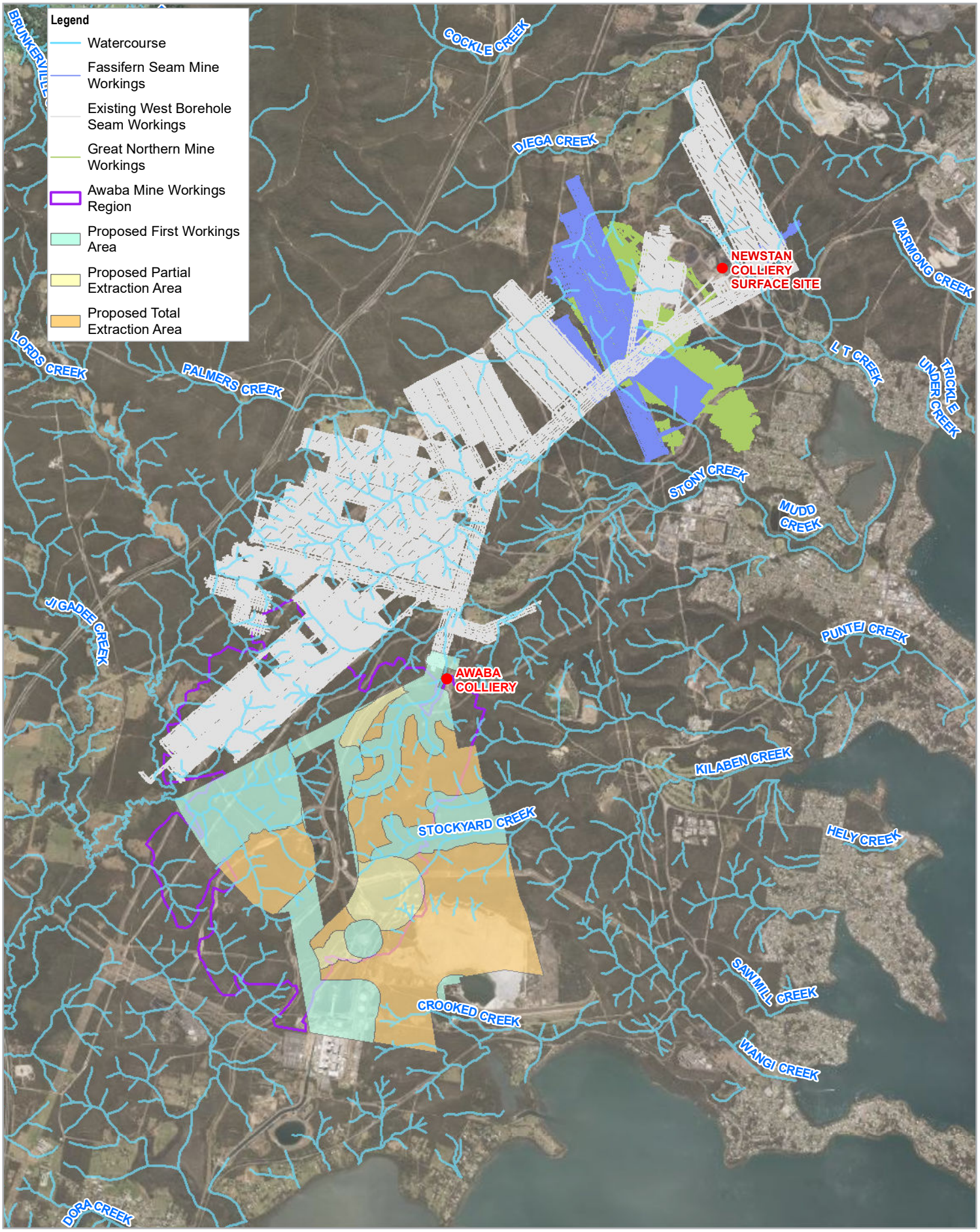
Project No. 22-20265
Revision No. A
Date 28/01/2019

Topography

FIGURE 2-4

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-003_Topography.mxd
Print date: 06 Mar 2020 - 17:44

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 0.4 0.8 1.2 1.6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Watercourses within the Project Application Area

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE 2-5

G:\220105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-004_Watercourses.mxd
Print date: 06 Mar 2020 - 17:44

Data source: Centennial: Consent boundary, 2016, workings, 2019; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

2.1.5 Geology

The Project Application Area is located in the south-western part of the Newcastle Coalfield, which occupies the north-eastern portion of the Sydney Basin. The stratigraphy of the region consists of material from the Triassic and Permian periods.

The Newcastle Coal Measures are characterised by complex patterns of splitting and coalescence of the various coal seams. This is generally related to the localised presence of alluvial paleochannels within the sedimentary sequence. The West Borehole seam (target seam in the Extension of Mining Area) is contained within the Lambton Formation, the earliest formation of the Newcastle Coal Measures.

The surface lithology in the vicinity of the Extension of Mining Area comprises shallow Quaternary alluvium (associated with the major watercourses) as well as bedrock and surface deposits from the Narrabeen Group and the Moon Island Beach Group of the Newcastle Coal Measures, which dip gently at approximately 1 to 2 degrees to the south-west. The Newcastle Coal Measures subcrop to the west and north of the Project Application Area. The Triassic and Permian rocks that comprise the surface lithology include conglomerate, sandstone, siltstone, claystone, tuff and coal. A surface geology map covering the Project Application Area, including the Extension of Mining Area, is shown in Figure 2-6.

The stratigraphy at Newstan Colliery is listed and described in Table 2-1. This information has been sourced from the Newcastle Coalfields Regional Geology 1:100,000 map (Edition 1 1995) and the Newstan Colliery Life Extension Project Overburden Groundwater Study (Pacific Power International, 1997).

Table 2-1 Stratigraphic sequence – Newstan Colliery

Period	Stratigraphy		Unit / Lithology	Coal seams
	Group	Subgroup		
Quaternary			Alluvium	
Triassic	Narrabeen	Clifton	Conglomerate, sandstone, siltstone, claystone	
Permian	Newcastle Coal Measures	Moon Island Beach	Conglomerate, sandstone, siltstone, tuff, coal	Vales Point, Wallarah, Great Northern
		Awaba Tuff		
		Boolaroo	Sandstone, conglomerate, siltstone, coal, tuff	Fassifern, Upper Pilot, Lower Pilot, Hartley Hill
		Warners Bay Tuff		
		Adamstown	Conglomerate, sandstone, siltstone, coal, tuff	Australasian Montrose, Wave Hill, Fern Valley, Victoria Tunnel
		Nobby's Tuff		
		Lambton	Sandstone, siltstone, claystone, coal, tuff	Young Wallsend, Yard, Borehole
	Waratah sandstone			

The approximate location of the alluvium that is intersected by the Project Application Area is shown in Figure 2-7. Based on a review of available borelogs, the alluvium extends up to about 16 m thick and comprises sandy clays and clayey/silty sands with some gravel.

The alluvium is underlain by a shallow weathered rock aquifer. The shallow weathered zone aquifer includes surficial soils and weathered bedrock. Based on exploration boreholes in the vicinity of the Project Application Area, the shallow weathered zone typically extends to 25 m depth. The shallow weathered rock aquifer also outcrops in areas outside the boundary of the alluvium.

Investigation of the extent of the alluvium along Stony Creek was undertaken by AGE (2008). The extent of the investigation was limited to the upper reaches of Stony Creek, from the headwaters of Stony Creek to approximately 1.1 km downstream. The investigation identified that the boundaries of the alluvium corresponded with the change from the creek floor to the lower slopes of the Stony Creek catchment. Within the extent of the investigation, the width of the alluvium was generally within 30 m of the centreline of Stony Creek. It is likely that the width of the Stony Creek alluvium gradually increases in width as the width of the floodplain increases in width.

The Narrabeen Group comprises variable sequences of interbedded claystones, siltstones and fine to coarse grained sandstones. It includes the Munmorah Conglomerate, which is a low permeability sandstone-dominated formation that typically occurs between 60 and 140 m above the Newcastle Coal Measures (Centennial Mandalong, 2019).

The target coal seam splits in a north-south direction to the east of the Extension of Mining Area into the Young Wallsend, Yard and Borehole seams. Mining is proposed on the western side of the seam split and will target the combined Young Wallsend, Yard and Borehole seams (referred to collectively as the West Borehole seam).

The depth of cover within the Extension of Mining Area ranges from 140 m in the north west to 320 m in the east. Seam thickness ranges from about 2.2 m to more than 5.0 m to the west of the seam split. The target seam is overlain by the previous Awaba Colliery mine workings in parts of the Extension of Mining Area with the interburden between the two seams (Great Northern and West Borehole) ranging from 100 m to 210 m. The West Borehole seam subcrops to the west and north of the Project Application Area while the Great Northern seam subcrops in the vicinity of the western and northern boundaries of the Awaba Colliery workings. Faulting of the Great Northern seam occurs to the south of Awaba Colliery.

Geological structures

The location of faults in vicinity of the proposed workings have been mapped and interpreted by MSEC (2019). The location of these interpreted faults are shown in Figure 2-8. These faults trend north-west to south-east. A number of these faults were intersected as part of existing mining at Newstan Colliery.

Structure contours at the West Borehole seam roof level provided by Centennial Coal do not indicate any major faulting in the Project Application Area. The seam floor contours do reflect the mapped paleochannels shown in Figure 2-8. The paleochannel to the east of the proposed workings corresponds with the split of the West Borehole Seam with the Young Wallsend Seam and part of the Yard Seam sitting above the channel and the remainder of the Yard Seam and the Borehole Seam lying below this channel. The paleochannel that passes through the middle of the proposed workings (refer Figure 2-8) is located above the West Borehole Seam.

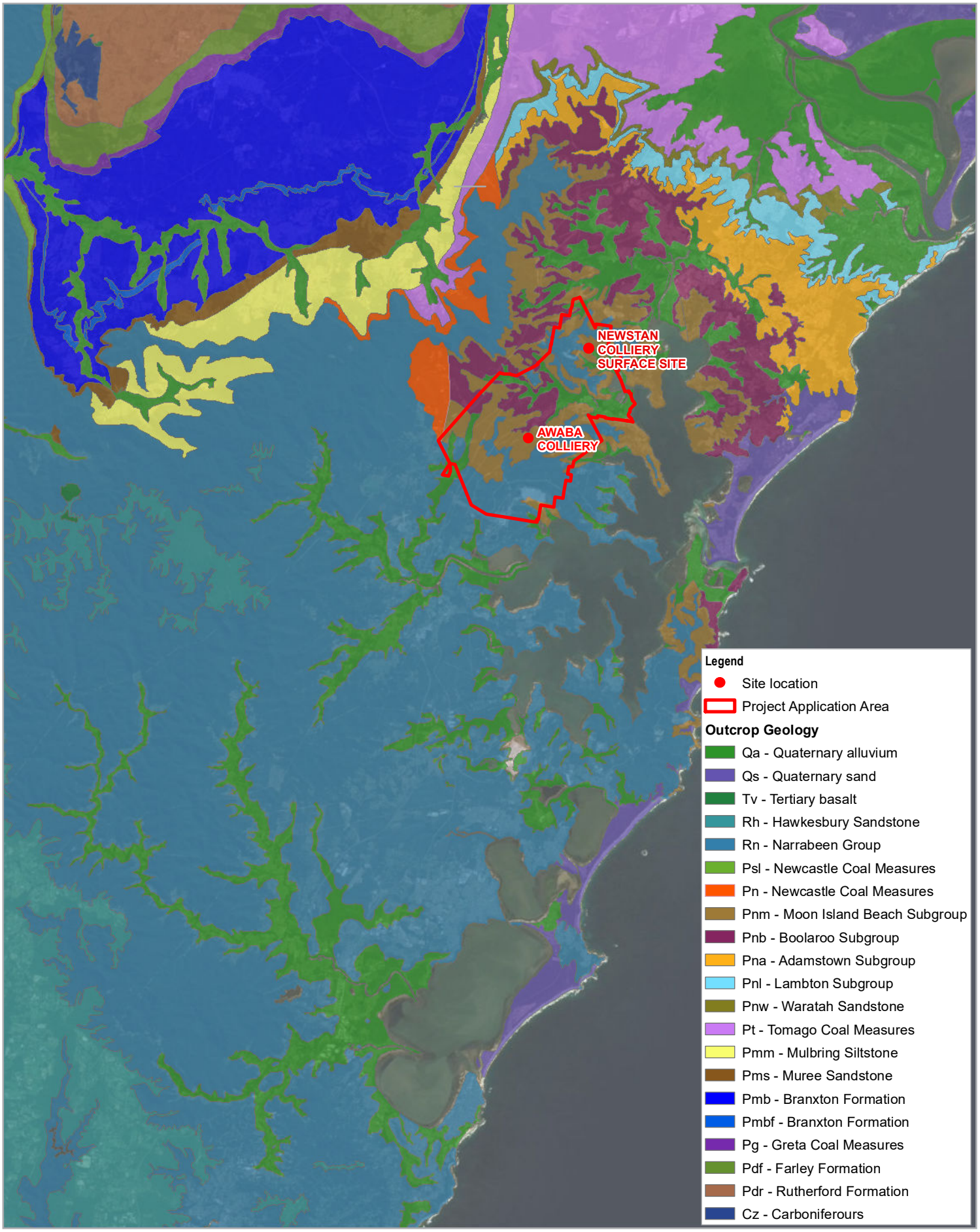
These geological features have been incorporated into the numerical groundwater model only through their observed effect on layer geometry. Since the seam roof is continuous throughout the Extension of Mining Area it is not considered that faults would have any substantial influence on groundwater flow or be a conduit for inflow into the mine. Further, the observed groundwater inflows into the existing Newstan Colliery workings do not indicate an influence of geological structures (refer Section 2.2.3).

2.1.6 Hydrostratigraphy

The groundwater sources in the vicinity of the Project Application Area are generally low yielding and predominantly within the Quaternary alluvium, weathered and/or fractured sandstone and coal seams. They would be classified as 'less productive', in accordance with the NSW Aquifer Interference Policy, as yields are generally less than 5 L/s and/or the total dissolved solids (TDS) concentration is typically greater than 1500 mg/L. A general overview of groundwater sources is provided in this section. More detail and interpretation is provided in Section 2.1.9.

The alluvium throughout the Project Application Area (refer Figure 2-7) forms an unconfined shallow aquifer with groundwater ranging in depth from less than 1 m to about 5 m below ground level (bgl), and aquifer thickness generally less than 16 m. The groundwater flow direction within the alluvium generally reflects the topography. Due to the clay content of the alluvium, yields and beneficial use of this groundwater are generally low as indicated by the registered bore details. The alluvial groundwater is generally fresh to brackish and slightly acidic. Alluvial groundwater likely provides baseflow to the ephemeral creeks overlaying the Extension of Mining Area (refer Section 2.1.9).

The alluvial water sources within the Project Application Area are covered under the Water Sharing Plan (WSP) for the Hunter Unregulated and Alluvial Water Sources. This WSP commenced in August 2009 and regulates the interception and extraction of surface water and alluvium within the defined water sharing plan area.



Paper Size ISO A4

0 2 4 6 8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

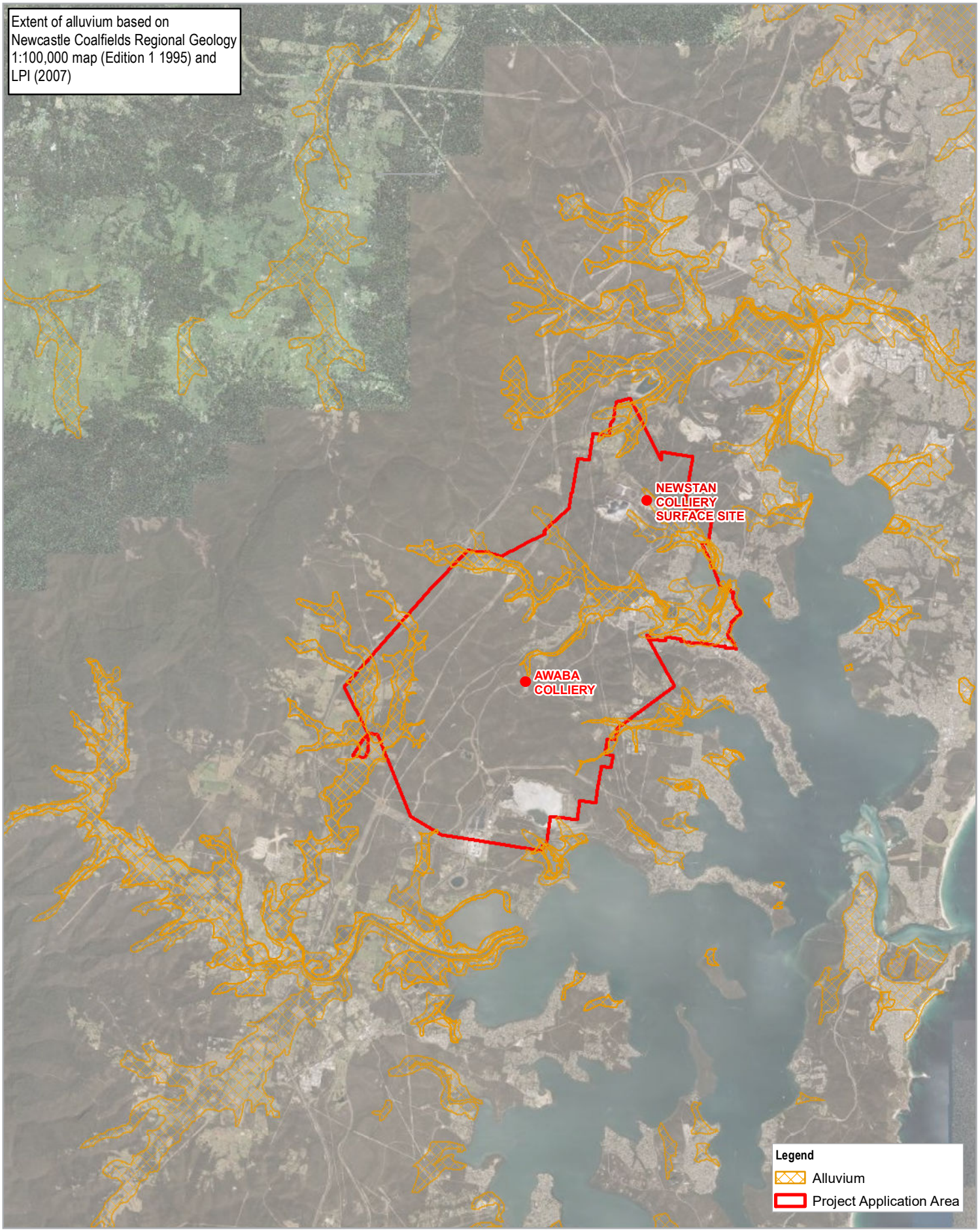
Project No. **22-20265**
Revision No. **A**
Date **16/10/2019**

Surface geology mapping

FIGURE 2-6

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-005_RegionalGeology.mxd
Print date: 06 Mar 2020 - 17:44

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1 2 3 4

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Location of alluvium within Project Application Area

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE 2-7

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-006_AlluviumExtent.mxd
Print date: 06 Mar 2020 - 17:45

Data source: Centennial: Consent boundary, 2016; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

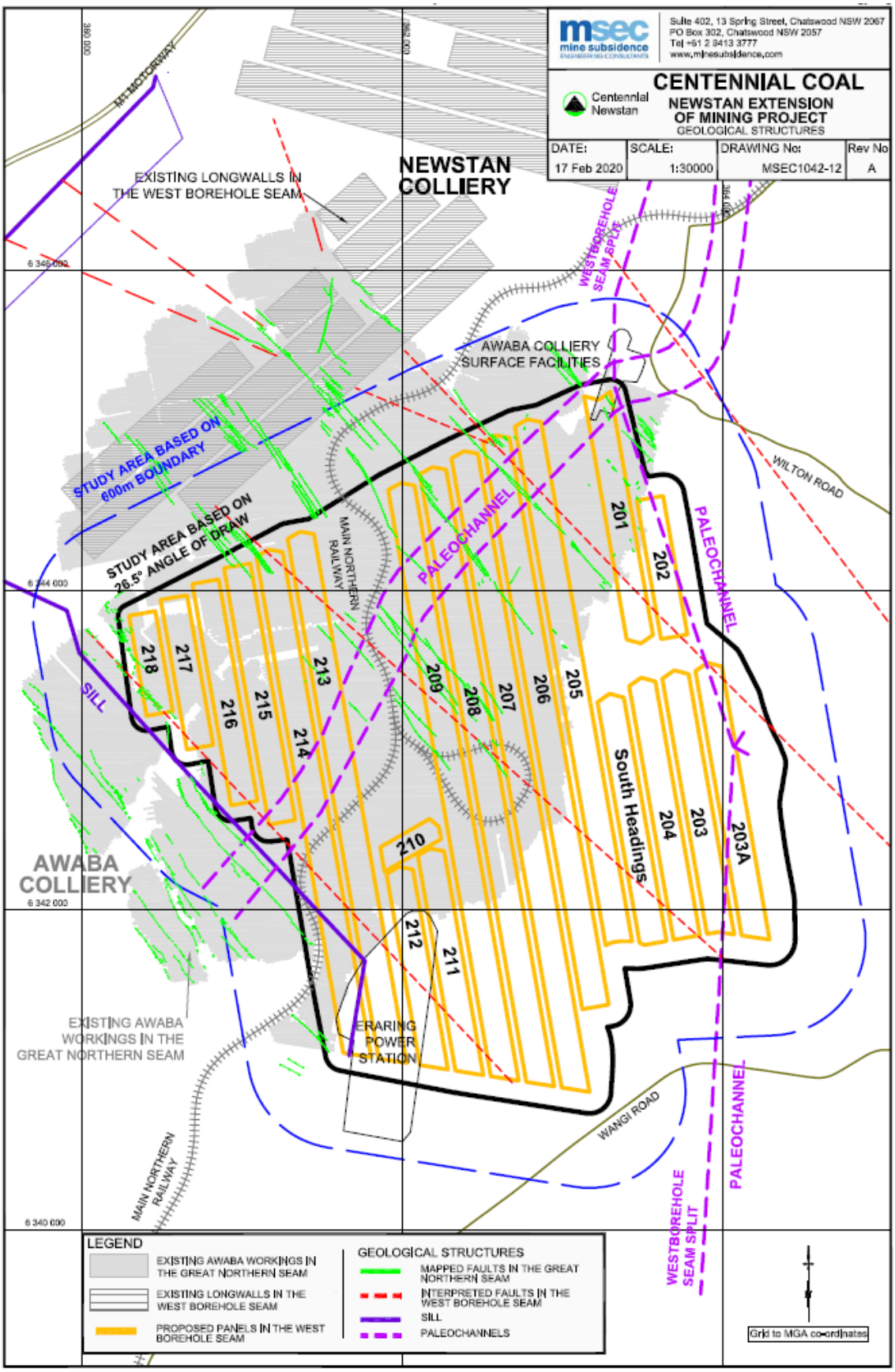


Figure 2-8 Geological structures (MSEC, 2019)

The porous and fractured rock groundwater sources underlying the Project Application Area generally occur within weathered rock and coal seams. They are managed under the North Coast Fractured and Porous Rock Groundwater Sources WSP. The piezometric head within the Permian coal seams tend to reflect the natural topography and proximity to Lake Macquarie, with reduced pressures at major surface drainage areas and in areas of coal extraction. Where coal seam groundwater has not been depressurised, the groundwater head tends to be in the order of 0-20 m AHD due to the coastal environment. Groundwater flow through the Project Application Area is generally to the east towards Lake Macquarie. Recharge of coal seams occurs in areas of seam subcrop to the west and north of the Project Application Area.

Packer testing undertaken as part of the Newstan Colliery exploration program indicates that the hydraulic conductivities of the Young Wallsend seam and overlying seams are generally in the order of 10^{-8} to 10^{-7} m/s. The overburden and interseam strata within the Newcastle Coalfield tend to have very low hydraulic conductivities (in the order of 10^{-11} to 10^{-9} m/s), unless joints or fracturing creates a secondary permeability (Pacific Power International, 1997). The results of packer testing are outlined in Section 2.1.11.

2.1.7 Groundwater use

A search of groundwater bore database (operated by Water NSW) identified 69 registered bores within approximately 2 km of the Project Application Area. A wider search identified 286 registered bores within the zone of groundwater drawdown within the West Borehole seam attributable to mining within the Extension of Mining Area (refer Section 5.2). Of the registered bores within the Project Application Area, the majority (50 bores) were registered as monitoring bores or test bores. One bore was registered for exploration, one bore was registered for dewatering or mining purposes and the remainder (17 bores) were registered for a combination of stock, domestic, irrigation and farming purposes. From the wider search, 122 of the 286 bores were registered as monitoring or exploration bores.

One bore (GW202325) is located within the Extension of Mining Area. This bore is 3 m deep and registered as a monitoring bore / test bore.

The majority of stock, domestic, irrigation and farming bores are less than 50 m in depth and extract groundwater from the Triassic Narrabeen Sandstone and the shallow Permian Coal Measures and interburden.

Registered bore details are provided in the GIA (GHD, 2020a). Registered bore locations are shown in Figure 2-9.

There was limited transient groundwater level monitoring data within the vicinity of the Project Application Area.

2.1.8 Groundwater dependent ecosystems

Plant Community Types (PCTs) that have a moderate or greater potential to be a Groundwater Dependent Ecosystem (GDE) were identified by RPS (2020) based on a search of the GDE Atlas (BOM 2019). The following PCTs were identified:

- PCT 1588 Grey Ironbark – Broad-leaved Mahogany – Forest Red Gum shrubby open forest on Coastal Lowlands of the Central Coast.
- PCT 1598 Forest Red Gum grassy open forest on floodplains of the lower Hunter.
- PCT 1619 Smooth-barked Apple - Red Bloodwood - Brown Stringybark - Hairpin Banksia heathy open forest of coastal lowlands.
- PCT 1627 Smooth-barked Apple - Turpentine - Sydney Peppermint heathy woodland on sandstone ranges of the Central Coast.

- PCT 1636 Scribbly Gum - Red Bloodwood - Angophora inopina heathy woodland on lowlands of the Central Coast.
- PCT 1638 Smooth-barked Apple – Red Bloodwood – Scribbly Gum grass – shrub woodland on lowlands of the Central Coast.
- PCT 1716 Prickly-leaved Paperbark forest on coastal lowlands of the Central Coast and Lower North Coast.
- PCT 1718 Swamp Mahogany - Flax-leaved Paperbark swamp forest on coastal lowlands of the Central Coast.
- PCT 1737 Typha rushland.

Lake Macquarie, Muddy Lake and Whiteheads Lagoon are mapped as potential aquatic GDEs.

GDE locations, based on potential, are mapped in Figure 2-10. There are no GDEs within the Project Application Area that are listed in Schedule 4 of the WSPs.

2.1.9 Groundwater monitoring program

The groundwater monitoring network has been progressively established at Newstan Colliery since 2005 and consists of monitoring bores installed in alluvial and coal seam strata. The bores are generally monitored twice per year for groundwater level and groundwater quality (mainly pH and EC), although some alluvial bores also contain water level loggers. Coal seam monitoring previously consisted of vibrating wire piezometers (VWPs). Note that the coal seam VWPs (CN036 and CN038) have not been in operation since October 2009.

Monitoring bore locations are shown in Figure 2-11. Monitoring has ceased at MB02 and AE6. Details of monitoring bores at Newstan Colliery are summarised in Table 2-2. Screens are located at the base of each bore.

In addition, a groundwater monitoring program has progressively been established at Mandalong since 1997 and includes monitoring bores installed in alluvial and fractured and porous rock groundwater sources. Groundwater monitoring data from Mandalong Mine was reviewed as part of development of the numerical groundwater model and have been utilised in model calibration.

Groundwater monitoring bores at Mandalong Mine are listed in Table 2-3 and locations are shown in Figure 2-12. Note that groundwater monitoring has ceased at a number of monitoring bores at Mandalong Mine. Monitoring bores are subsequently decommissioned if no impacts are observed within the two year period after mining in the vicinity of the bore. Mandalong monitoring bores that have been dry throughout the period of monitoring are not included in this report.

Alluvial groundwater

Groundwater level hydrographs for Newstan Colliery alluvial monitoring bores have been plotted with CDFM and are shown in Appendix A. In the hydrographs, groundwater level is plotted in blue and the CDFM curve is plotted in red. Visual review of alluvial groundwater levels indicates that there is response to CDFM (below and above average rainfall) at a majority of the alluvial monitoring bores. Alluvial groundwater levels typically vary by 1 to 2 m.

A statistical comparison between Lords Creek alluvial groundwater levels and CDFM was undertaken by GHD (2014) using the HARTT (Hydrograph Analysis: Rainfall and Time Trends) statistical methodology, to reduce the uncertainty inherent with visual interpretation of time series graphs. HARTT is an Excel based regression model developed by the West Australian Department of Agriculture and Food that involves establishing an underlying time trend in groundwater level by separating the effect of above and below average rainfall (Ferdowsian et al., 2000). In this way, the relationship between groundwater change and atypical rainfall is established and it is possible to identify whether other factors are influencing groundwater level. Where conventional linear regression trend analysis is carried out for groundwater hydrographs, it is not possible to determine to what degree trends are associated with rainfall or other factors.

The analysis indicates that the alluvial hydrographs are reasonably modelled by the HARTT variables (rainfall and linear time trends) and there is a statistically significant relationship between groundwater level and rainfall at most sites. Any statistically significant decreasing trends in groundwater level (independent of rainfall) were not found to be associated with mining since did they not correlate with the schedule of development and extraction of the adjacent mine workings. It is noted that Lords Creek alluvial monitoring bores are not directly underlain by existing Newstan Colliery mine workings, however the West Borehole seam is shallower in this area compared to the Extension of Mining Area.

Decreasing trends in groundwater levels at most of the Lords Creek alluvial bores are evident in recent years. These trends are likely to be primarily attributable to climatic conditions although other factors are possible. It is unlikely that mining at Newstan has caused these trends since they are not evident at MB12 and MB15, which are the closest alluvial bores to the existing Newstan longwalls in the West Borehole seam (refer Figure 2-11). In addition, decreasing trends in groundwater levels (independent of rainfall) are evident at most of the AE series bores, which suggests there are other factors (other than rainfall and mining) that influence alluvial groundwater levels in the area.

Alluvial groundwater level data for Mandalong also does not indicate a loss of alluvial groundwater due to mining. Groundwater monitoring data for Mandalong indicates that any reduction in alluvial groundwater levels due to mining in the longwall area has been temporary and localised and levels recover as shallow tensile and compressive cracks fill over time (Centennial Mandalong, 2019). It is noted that previous mining at Mandalong has involved extraction of longwall panels of void width 160 m at depths ranging from 150 to 300 m beneath Stockton Creek and Morans Creek alluvium.

Alluvial groundwater quality is generally slightly acidic. Within Lords Creek, alluvial groundwater quality varies from fresh at MB09, MB14, MB15 and MB17, to brackish at MB11. Monitoring data indicates that alluvial groundwater in Kilaben Creek, Stockyard Creek and Stony Creek is slightly brackish.

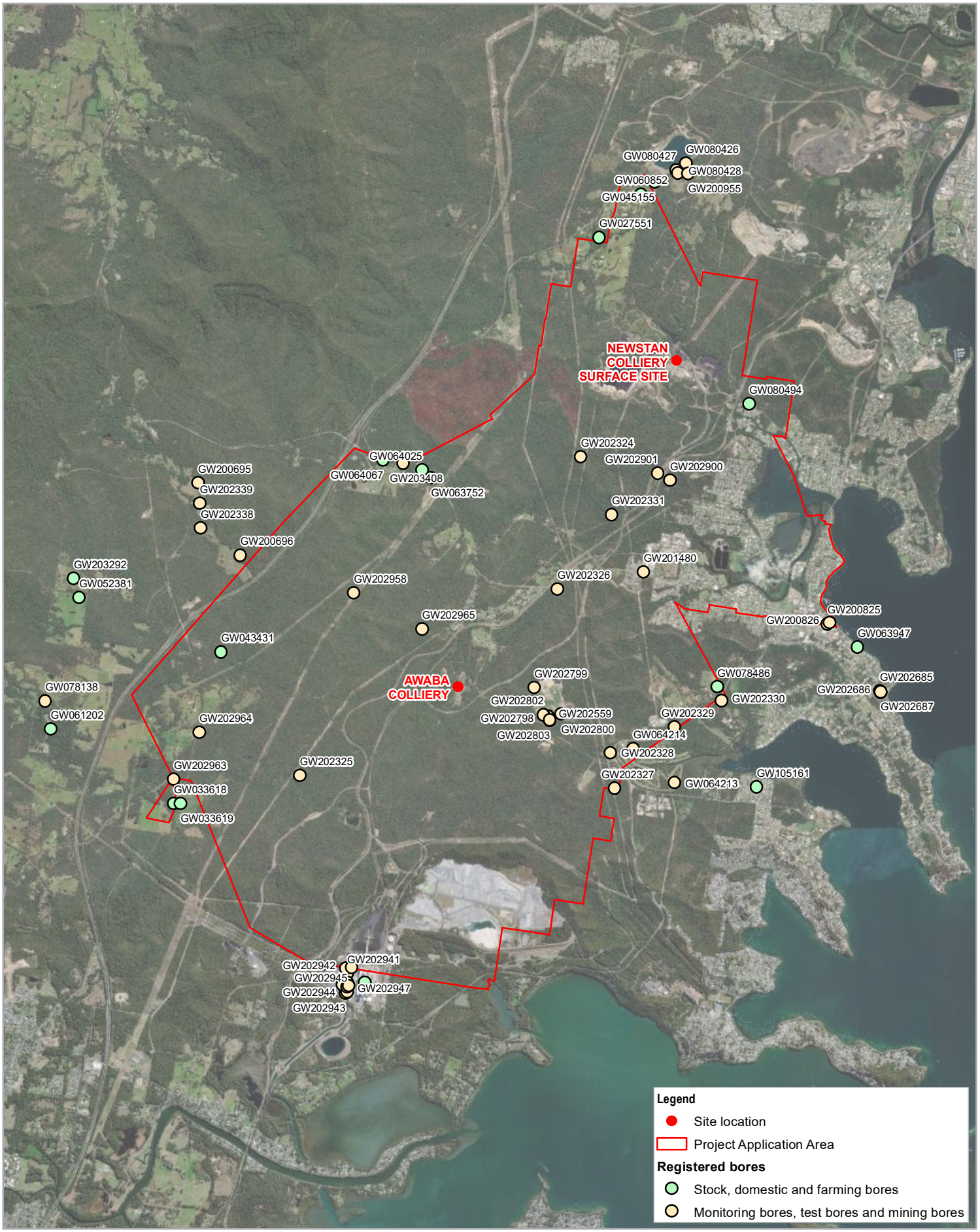
Comparison of the major ion chemistry of alluvial groundwater and surface water at some locations in the vicinity of the Extension of Mining Area indicates surface water / groundwater connectivity. Surface waters and alluvial groundwater are generally sodium chloride dominant. In particular there is strong similarity between surface water and alluvial groundwater at sites along Kilaben Creek. Further detail is provided in Section 4.1 and Appendix C of GHD (2020a).

Porous and fractured rock groundwater

Visual review of groundwater hydrographs for monitoring bores installed in the Permian Coal Measures at Newstan Colliery indicates that groundwater levels at MB04, MB05 and MB06 fluctuate with CDFM. Due to their proximity to the coal seam outcrop, groundwater levels at MB04, MB05 and MB06 may have a stronger influence from rainfall recharge.

Bores MB05, MB06 and MB16 in the Great Northern seam are depressurised due to historical mining at Cooranbong, which commenced in 1980 and was completed in the early 2000s. Dewatering of the Cooranbong workings is ongoing.

There are no monitoring bores at Newstan Colliery installed in the Narrabeen Sandstone (although one of the piezos at CN064 is in the conglomerate). Monitoring data in the Narrabeen Sandstone would be beneficial to characterise groundwater levels and groundwater flow direction in the Narrabeen Sandstone in the vicinity of the Project Application Area.



Paper Size ISO A4

0 0.55 1.1 1.65 2.2

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

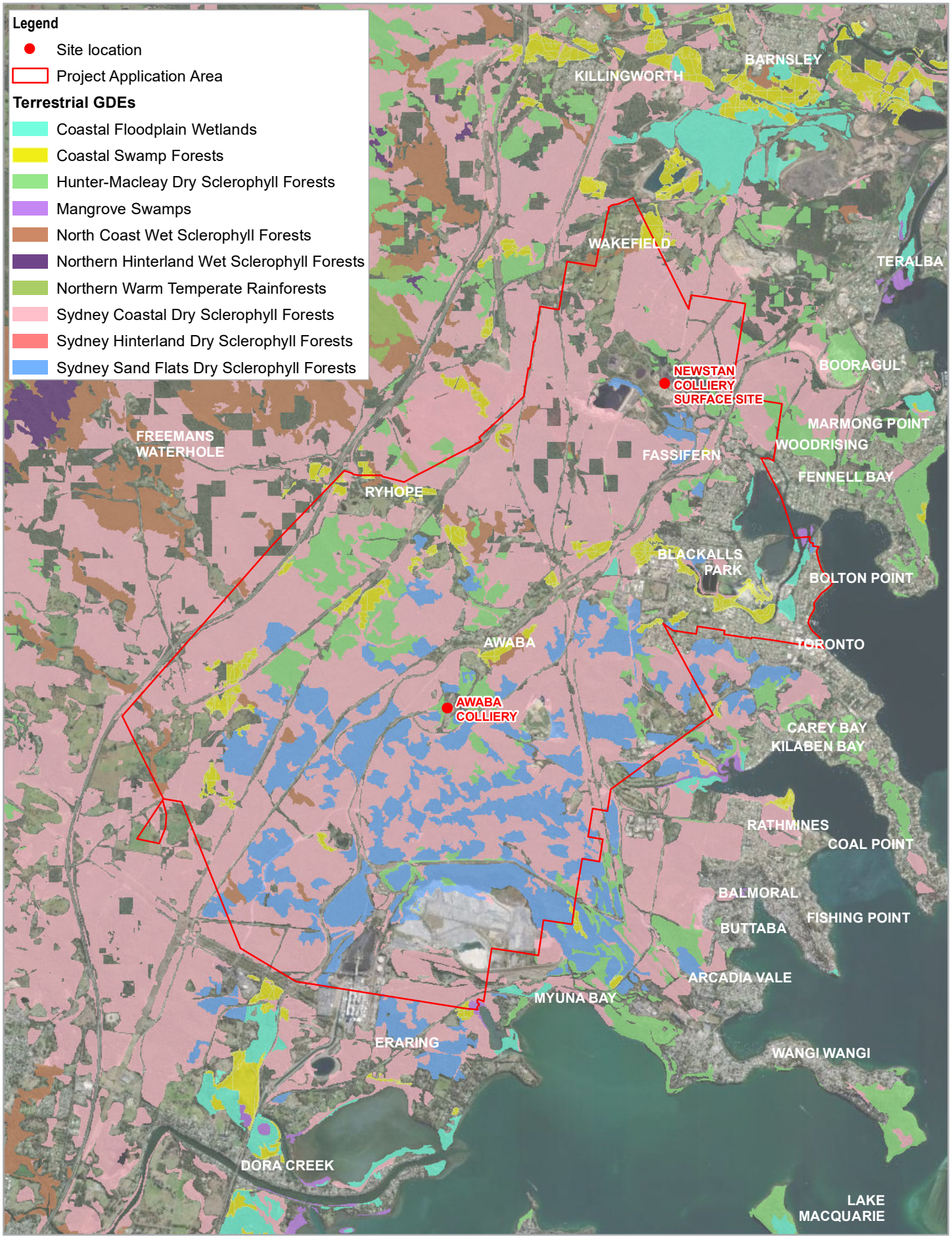
Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

Registered bore locations

FIGURE 2-9

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-007_LandholderBores.mxd
Print date: 06 Mar 2020 - 17:45

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 0.55 1.1 1.65 2.2

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Model Report

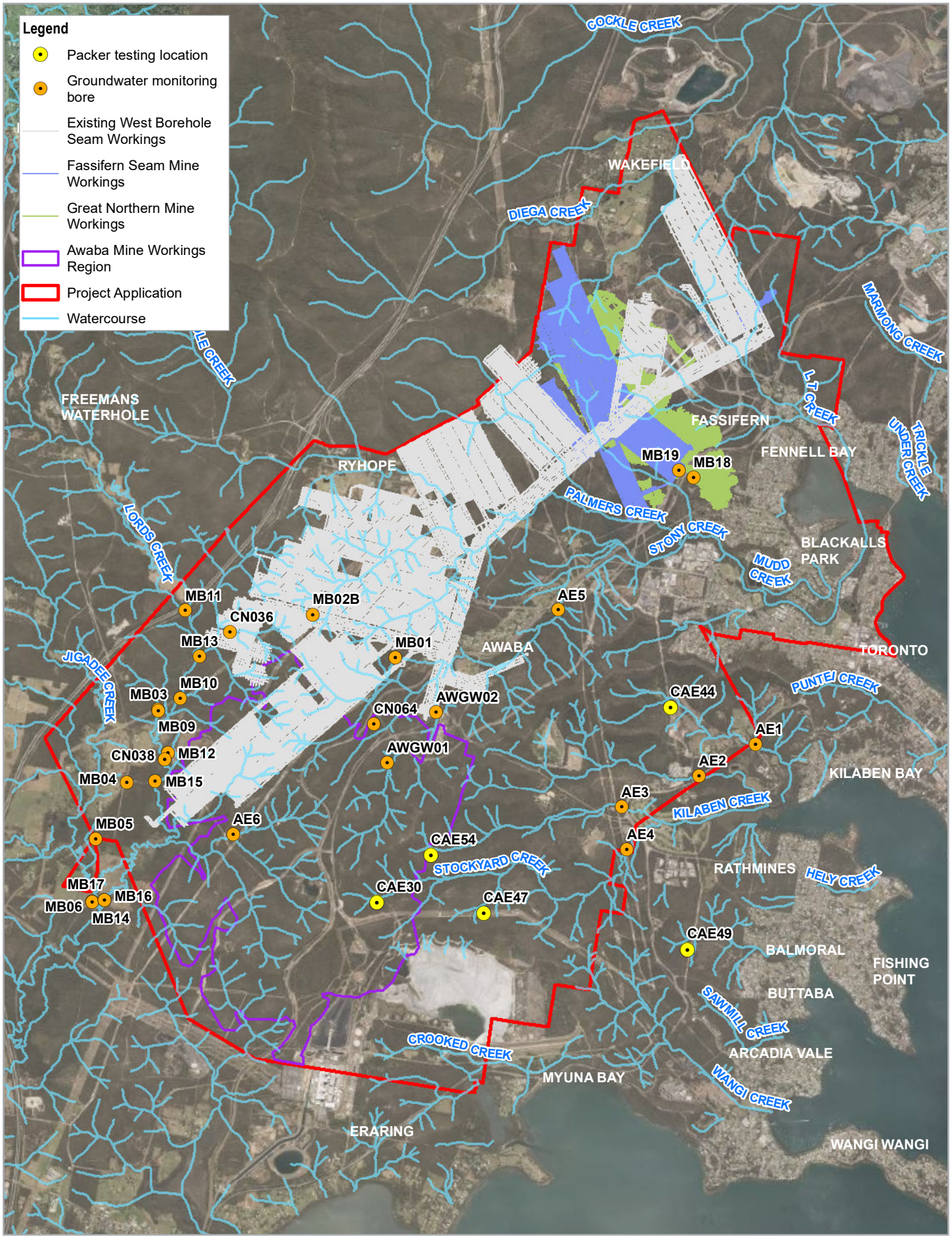
Potential groundwater dependent ecosystems

Project No. **22-20265**
Revision No. **A**
Date **16/10/2019**

FIGURE 2-10

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-008_GDE_Mapping.mxd
Print date: 06 Mar 2020 - 17:45

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 0.45 0.9 1.35 1.8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Project No. **22-20265**
Revision No. **A**
Date **16/10/2019**

Groundwater monitoring network

FIGURE 2-11

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-009_GWMonitoring.mxd
Print date: 06 Mar 2020 - 17:45

Data source: Centennial: Consent boundary, 2016, workings, 2019, monitoring, 2016; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

Groundwater levels at remaining locations installed in the Permian Coal Measures (MB02 and MB03) are relatively constant with levels generally varying by less than 2 m. Levels within bores MB18 and MB19 installed within the Fassifern Underground Storage are influenced by inputs and outputs of water from the Fassifern Underground Storage.

Groundwater drawdown has been observed at CN036 and CN038. CN036 overlies West Borehole seam workings and CN038 is located within 500 m of West Borehole seam workings. As shown in Appendix A, drawdown at CN038 occurred within two months of installation and drawdown at CN036 occurred within six months of commencement of adjacent longwall mining to the south. With the exception of CN036 and CN038, there is no evidence of groundwater drawdown attributable to mining at Newstan Colliery at monitoring bores installed in the Permian Coal Measures. As stated previously, bores MB05, MB06 and MB16 in the Great Northern seam are depressurised due to historical mining at Cooranbong.

Monitoring of porous and fractured rock groundwater at Mandalong generally suggests that complete depressurisation of groundwater occurs up to a height of approximately 120 m above longwalls. Decreasing trends in groundwater levels occur up to a height of approximately 170 m above the longwall panels.

Groundwater quality within the Permian Coal Measures is generally slightly brackish and varies from very slightly acidic to very slightly basic.

Table 2-2 Newstan Colliery groundwater monitoring bore details

Bores	Location		Elevation (m AHD)		Bore Depth (m)	Monitoring period	Screen depth (m)	Lithology
	mE	mN	Ground	TOC				
MB01	362741.2	6346266.9	52.64	53.21	32.6	Jan 06 – May 07 Generally dry	29.5-32.5	Fassifern Seam
MB02	361694.6	634681.3	56.91	57.49	21.7	Mar 11 – Sep 12	18.7-21.7	Fassifern Seam
MB03	359733.0	634681	24.60	25.15	28.8	Mar 11 – current	25.8-28.8	Permian Coal Measures
MB04	359336.6	6344685.8	40.18	40.71	41.2	Mar 11 – current	35.2-41.2	Great Northern Seam/ Fassifern Seam
MB05	358942.3	6343966.4	17.30	17.82	38.9	Mar 11 – current	32.0-38.0	Great Northern Seam
MB06	358899.6	6343172.7	15.44	15.97	54.6	Mar 11 – current	48.6-54.6	Great Northern Seam
MB09	359738.6	6345599.4	24.49	-	4	Mar 11 – current	2.5-4.0	Lords Creek Alluvium
MB10	360015.5	6345750.0	26.37	27.00	6.5	Jan 06 – current	5.0-6.5	Lords Creek Alluvium
MB11	360077.1	6346865.0	32.10	32.58	11.3	Jan 06 – current	9.8-11.3	Lords Creek Alluvium
MB12	359858.7	6345063.5	23.47	24.33	8.8	Jan 06 – current	7.3-8.8	Lords Creek Alluvium
MB13	360259.8	6346287.4	30.16	-	8.2	Jan 06 – current	6.7-8.2	Lords Creek Alluvium
MB14	358899.7	6343169.2	15.4	15.91	13.5	Mar 11 – current	12.0-13.5	Lords Creek Alluvium
MB15	259697.8	6344703.6	21.26	-	8.5	Jan 06 – current	7.0-8.5	Lords Creek Alluvium
MB16	359054.4	6343193.9	-	-	53.8	Mar 11 – current	47.8-53.8	Great Northern Seam
MB17	359055.0	6343197.3	-	-	8.75	Mar 11 – current	7.25-8.75	Lords Creek Alluvium
MB18	366529.3	6348553.6	-	-	-	Mar 11 – current	-	Fassifern storage
MB19	366340.5	6348646.7	-	-	-	Mar 11 – current	-	Fassifern storage
AE1	367311	6345170	-	-	-	May 09 – Nov 17	-	Kilaben Creek Alluvium
AE2	366595	6344766	-	-	-	Mar 09 – Nov 17	-	Kilaben Creek Alluvium
AE3	365615	6344372	-	-	-	Mar 09 – Nov 17	-	Kilaben Creek Alluvium
AE4	365681	6343836	-	-	-	Mar 09 – Nov 17	-	Stockyard Creek Alluvium
AE5	364806	6346872	-	-	-	Mar 09 – Nov 17	-	Stony Creek Alluvium
AE6	360689	6344024	-	-	-	Mar 09 – Jun 14 Dry throughout monitoring period	-	Lords Creek Alluvium
CN036	361214.7	6345960.6	69.99	-	-	Aug 05 – Oct 09	145*	West Borehole Seam
CN038	359897.8	6345203.3	23.71	-	-	Aug 05 – Oct 09	87.9*	West Borehole Seam

Bores	Location		Elevation (m AHD)		Bore Depth (m)	Monitoring period	Screen depth (m)	Lithology
	mE	mN	Ground	TOC				
CN064	362472	6345426.44	-	-	-	Jan 2019 – current	53, 92, 169, 248*	Munmorah Conglomerate Fassifern Lower Seam Permian Interburden West Borehole Seam
AWGW01	362641	6344934	-	33.229	-	-	-	Alluvium
AWGW02	363263	6345575	-	25.291	-	-	-	Alluvium

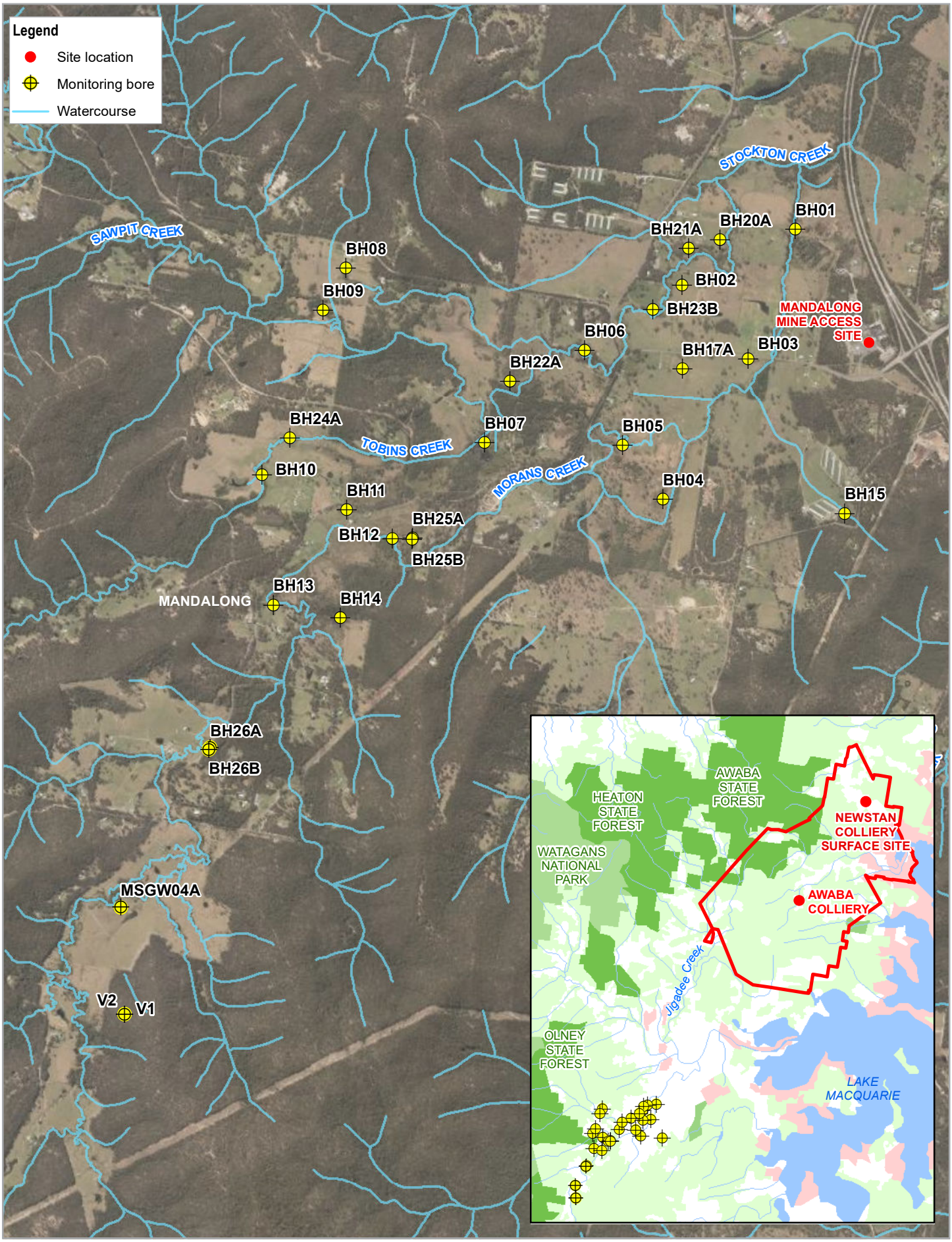
* VWP depth

‘-‘ denotes unknown information

Coordinate projection GDA 1994 MGA 56

Table 2-3 Mandalong Mine groundwater monitoring network

Bore	Monitoring period reviewed	Strata
BH01	2004 – July 2019	Alluvium
BH02	2005 – October 2016	Alluvium
BH03	2005 – July 2019	Alluvium
BH04	2004 – July 2019	Alluvium
BH05	2004 – July 2019	Alluvium
BH06	2004 – October 2016	Alluvium
BH07	2004 – October 2016	Alluvium
BH08	2004 – October 2016	Alluvium
BH09	2004 – July 2019	Alluvium
BH10	2004 – July 2019	Alluvium
BH11	2004 – July 2019	Alluvium
BH12	2004 – July 2019	Alluvium
BH13	2004 – July 2019	Alluvium
BH14	2004 – July 2019	Alluvium
BH15	September 2003 – November 2014	Fassifern seam
BH17A	2005 – October 2016	Alluvium
BH20A	2004 – July 2016	Alluvium
BH21A	2004 – October 2016	Alluvium
BH22A	2005 – October 2016	Alluvium
BH23B	2005 – October 2016	Alluvium
BH24A	April 2010 – July 2013	Alluvium
BH25A	April 2010 – July 2019	Narrabeen Sandstone
BH25B	July 2010 – July 2012	Narrabeen Sandstone
BH26A	October 2011 – July 2019	Alluvium
BH26B	October 2011 – October 2016	Narrabeen Sandstone
MSGW01	July 2011 – July 2019	Mannering Creek alluvium
MSGW04A	October 2011 – July 2019	Morans Creek alluvium
V1/V2	July 2013 – June 2017	Great Northern seam



Paper Size ISO A4

0 0.2 0.4 0.6 0.8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Project No. **22-20265**
Revision No. **A**
Date **16/10/2019**

Mandalong Mine
Groundwater monitoring network

FIGURE 2-12

G:\22\105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-022_Mandalong_GWMonitoring.mxd
Print date: 06 Mar 2020 - 17:46

Data source: Centennial: Consent boundary, 2016, workings, 2019, monitoring, 2016; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Geoscience Australia: 250k Topographic Data Series 3, 2006. Created by: smacdonald

2.1.10 Underground water management

Newstan Colliery

The underground water management features at Newstan Colliery are the Fassifern Underground Storage and the underground workings in the West Borehole seam. The Fassifern Underground Storage is the void formed by previous mining activity in the Fassifern and Great Northern seams at Newstan Colliery and is used to manage water between Newstan Colliery and the Newstan Colliery Surface Site (NCSS).

The Fassifern Underground Storage receives inflows as a result of infiltration from the surface catchment, groundwater inflows into active mining areas and injection transfers from the NCSS. Water levels within the storage are managed by extraction transfers to the Clean Water Plant, which commenced operation at the NCSS in late 2013. The Clean Water Plant employs coagulation, flocculation, sedimentation, filtration and ultra-violet treatment to reduce the concentrations of Total Suspended Solids (TSS) and total (unfiltered) metals. The Clean Water Plant treats water at a maximum rate of 14.5 ML/day.

During periods of above average rainfall when water within the Fassifern Underground Storage rises above 16.6 m below ground level (6.4 m AHD), the storage discharges water by gravity through two 600 mm diameter pipes into Stony Creek via Newstan LDP017. A water monitoring station at Newstan LDP017 was commissioned in 2013 to monitor emergency discharges required for the safety of personnel in the underground workings at Newstan Colliery. The water monitoring station allows for the continuous monitoring of discharge water quality. In the event of poor water quality, water may be contained within the monitoring station and treated or extracted as required in a controlled manner. Since 2013, only one discharge has occurred, which was over 39 days in May 2015 with a total volume of 1289 ML and an average discharge of 3.5 ML/day.

The observed underground water transfers are shown in Figure 2-13 and observed water levels in the Fassifern Underground Storage are shown in Figure 2-14. All monitoring is done using inline meters and recorded within a SCADA system. Where flows are not metered, then these transfers are estimated based on operational conditions. Daily monitoring of the underground water level within the Fassifern Underground Storage is undertaken daily as part of day to day operational reviews.

Figure 2-13 shows that transfers from the West Borehole seam to the Fassifern Underground Storage are typically 1 to 2 ML/day, varying with day to day operations. Given the limited water storage capacity in the West Borehole seam, the average transfer rate is representative of the groundwater inflows into the West Borehole seam workings. This inflow is low considering the size of the existing Newstan Colliery workings in the West Borehole seam, the mining methodology (longwalls) and the longwall void width (230 m). However it is similar to the modelled and observed groundwater inflow into the existing longwall mining area at Mandalong (Centennial Mandalong, 2019). The low inflow suggests low permeability overburden and minimal influence of geological structures on inflows.

The transfers from the Fassifern Underground Storage to NCSS are typically around 11 ML/day, corresponding to the typical treatment rate of the Clean Water Plant at NCSS, with some variation between 0 and up to 15 ML/day with day to day operations.

Recent monitoring by Centennial Newstan indicates that approximately 0.25 ML/day of groundwater inflow to the West Borehole seam workings occurs in Longwalls 22-25, underlying the Awaba underground void. Based on the average interburden thickness between Longwalls 22-25 and the Awaba void of 110 m (MSEC, 2019), a water level in Awaba of 16 m AHD and area of overlap of 1.3 km^2, a bulk hydraulic conductivity of approximately 0.0002 m/day (1.9 x 10^{-9} m/s) would produce an inflow of 0.25 ML/day. Such a low hydraulic conductivity value suggests that the height of continuous fracturing above Longwalls 22-25 is likely to be much less than estimates from typical empirical methods such as Tammetta (2012). It also suggests that the faults shown in Figure 2-8 would be having minimal influence on groundwater inflow.

Groundwater inflow into the existing West Borehole seam workings (sampled at location 'cut through 19') is brackish and slightly alkaline, and sodium bicarbonate-chloride dominant. In comparison, water within the Awaba underground void is more magnesium sulfate dominant (sampled at location 13 West 2). These two waters are compared in a piper diagram in Appendix C of GHD (2020a). This suggests that the groundwater inflow into the Longwall 22-25 area is from the adjacent porous and fractured rock groundwater source rather than via a continuous conduit, such as a continuous fracture or fault, from the Awaba underground void.

Figure 2-14 shows that water levels in the Fassifern Underground Storage have typically been maintained at around between 0 and -5 m AHD since 2017. Note that since 2013, only one discharge from the Fassifern Underground Storage into Stony Creek via LDP017 has been required, which was over 39 days in May 2015 with a total volume of 1289 ML and an average discharge of 3.5 ML/day. This period of discharge corresponds with the period of time water level in the Fassifern Underground Storage was above the Stony Creek discharge level, shown in Figure 2-14.

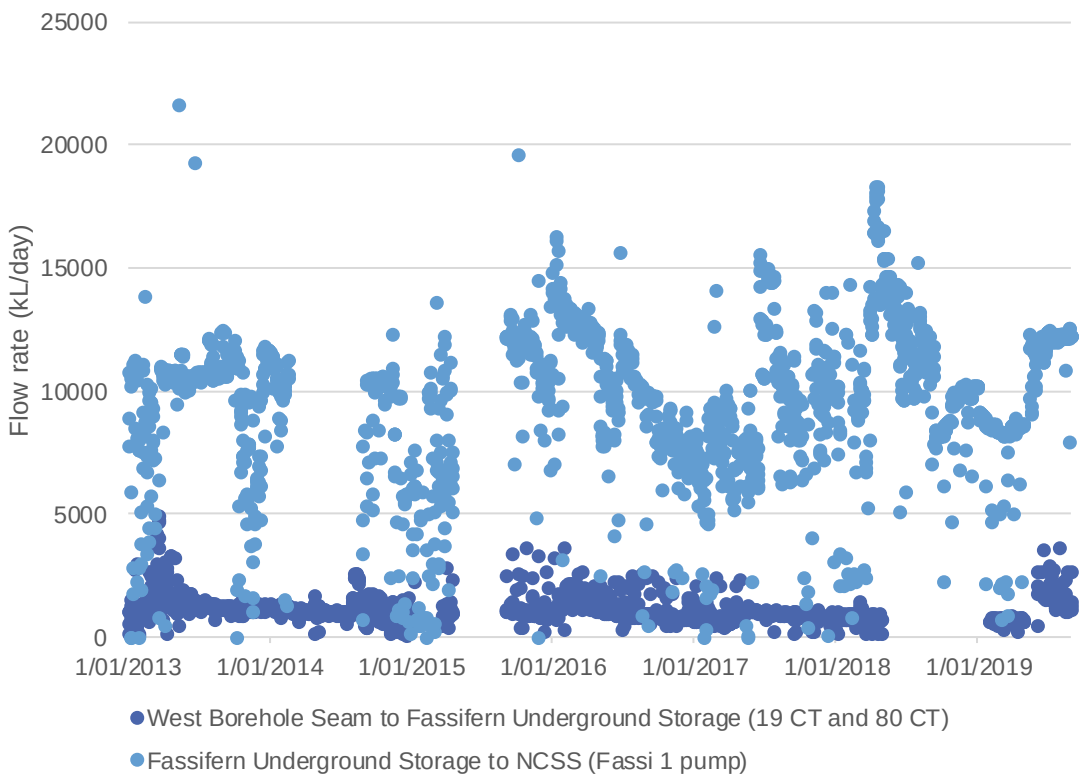


Figure 2-13 Observed underground water transfers at Newstan Colliery

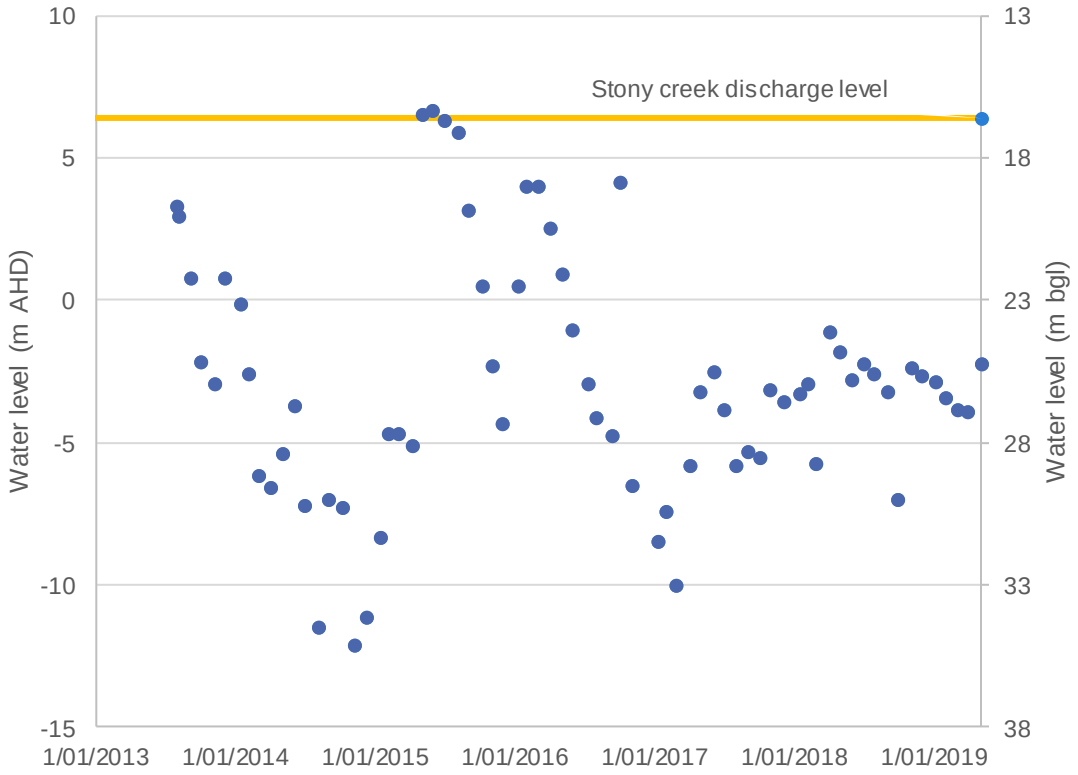


Figure 2-14 Observed underground water levels in the Fassifern Underground Storage

Awaba Colliery

The key underground water management feature of Awaba Colliery is the Awaba underground void, which was formed by previous mining activity in the Great Northern seam at Awaba Colliery. Following the cessation of mining in 2012, water levels in the Awaba underground void recharged due to a combination of inflows of surrounding groundwater and infiltration from the surface. Infiltration is likely to be enhanced at sinkholes.

As water levels in the Awaba underground void equilibrated with the surrounding groundwater, infiltration of water from the surface became the dominant inflow and water from the void began to seep out via a series of natural faults at the south end of the void into an unnamed tributary of Muddy Lake. This area is known as the Awaba seepage. The flow from the Awaba seepage has been observed at a V-notch weir at monitoring location SP5 since 2015, although this monitoring is also influence by surface catchment runoff. The observed flow, shown in Figure 2-15, is typically 1 ML/day to 2 ML/day and has been declining with water levels under the below average rainfall conditions in 2018 and 2019.

Seepage from the Awaba underground void has also been observed at the Eraring Power Station. Water levels in the underground void are currently managed by pumping water via the 10 South bore and boreholes at Eraring Power Station (the Eraring groundwater manifold) for the purpose of maintaining the water level below about 17 m AHD within the workings.

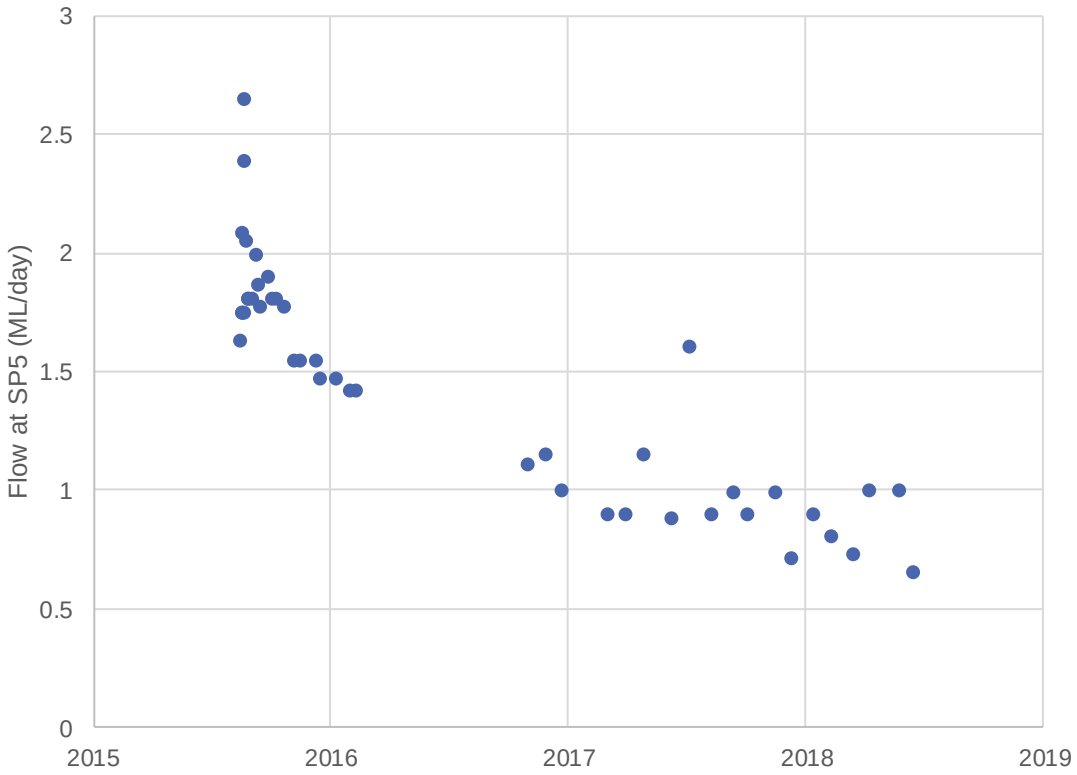


Figure 2-15 Observed flow from Awaba seepage at SP5

2.1.11 Hydraulic aquifer parameterisation

Packer testing results

Packer testing has previously been undertaken at Newstan Colliery by Aurecon. Previous packer testing at Newstan Colliery was undertaken in a number of exploration boreholes including CAE30, CAE44, CAE47, CAE49 and CAE54. These exploration boreholes are shown in Figure 2-11. A summary of the packer testing results is presented in Table 2-4.

Table 2-4 Summary of packer test results

Strata	Depth (m)		Hydraulic conductivity (m/sec)		
	From	To	Minimum	Maximum	Mean
CAE30					
Australasian seam	148	153.5	2.32×10^{-8}	1.34×10^{-7}	6.53×10^{-8}
Australasian seam	150.19	155.69	1.16×10^{-8}	8.72×10^{-8}	5.20×10^{-8}
Australasian seam and Montrose Seam	155.5	161	5.80×10^{-8}	2.08×10^{-7}	9.63×10^{-8}
Wave Hill and Fern Valley Seam	191.5	197	8.12×10^{-8}	1.68×10^{-7}	9.77×10^{-8}
Fern Valley Seam	196.5	202	8.12×10^{-8}	1.54×10^{-7}	1.02×10^{-7}
Nobbys Tuff, West Borehole	226	231.5	5.78×10^{-8}	1.61×10^{-7}	8.98×10^{-8}
CAE44					
Borehole	367.37	369.37	5.43×10^{-9}	3.08×10^{-8}	1.35×10^{-8}
Young Wallsend	354.19	358.19	0	1.72×10^{-8}	7.48×10^{-9}
Fern Valley Seam	325.19	329.19	3.22×10^{-9}	9.02×10^{-9}	5.48×10^{-9}
Fern Valley Seam	266.99	270.99	4.83×10^{-9}	1.53×10^{-8}	9.94×10^{-9}
Wave Hill	258.99	262.99	8.06×10^{-9}	4.31×10^{-8}	1.82×10^{-8}
Australasian seam	197.5	201.5	6.44×10^{-9}	6.03×10^{-8}	2.20×10^{-8}
Hartley Hill	168	172	1.13×10^{-8}	1.90×10^{-8}	1.42×10^{-8}

Strata	Depth (m)		Hydraulic conductivity (m/sec)		
	From	To	Minimum	Maximum	Mean
Jewels and Hartley Hill	163	167	3.20×10^{-9}	6.35×10^{-9}	4.64×10^{-9}
CAE47					
Fern Valley Seam	255.19	260.19	0	1.96×10^{-9}	4.81×10^{-10}
Wave Hill, Edgeworth Tuff, Fern Valley	249.19	254.19	0	4.46×10^{-9}	2.88×10^{-10}
Australasian seam	202.19	207.19	0	2.97×10^{-7}	7.02×10^{-8}
Australasian seam	199.19	204.19	0	2.23×10^{-9}	5.61×10^{-10}
CAE49					
Some Sandstone, Borehole Seam	396.69	399.96	3.03×10^{-8}	1.19×10^{-7}	7.25×10^{-8}
Young Wallsend, Yard, sandstone	384	389	1.91×10^{-8}	3.99×10^{-8}	2.93×10^{-8}
Sandstone, Edgeworth Tuff, Fern Valley	325.19	330.19	1.28×10^{-8}	2.99×10^{-8}	1.89×10^{-8}
Montrose, Tuff, Wave Hill	298.5	303.5	8.93×10^{-9}	1.90×10^{-8}	1.34×10^{-8}
Australasian, Sandstone	250	255	0	1.36×10^{-8}	7.73×10^{-9}
Australasian	244.19	249.19	0	9.52×10^{-9}	5.52×10^{-9}
Tuffite, Hartley Hill	214	219	2.75×10^{-9}	1.02×10^{-8}	6.07×10^{-9}
Jewels and Tuffite	210.5	215.5	0	9.52×10^{-9}	5.24×10^{-9}
CAE54					
Interburden between Fassifern and Lower Pilot Seams	78.94	82.94	0	5.93×10^{-11}	3.83×10^{-12}
Sandstone and Mudstone interburden, Lower Pilot	84.94	88.94	0	8.64×10^{-11}	5.58×10^{-12}
Mount Hutton Tuff, Floraville Seam	90.44	95.94	1.61×10^{-8}	3.09×10^{-8}	2.30×10^{-8}
Sandstone, siltstone and Tuffite interburden between Fassifern and Lower Pilot Seams	66.94	70.94	0	1.73×10^{-10}	2.01×10^{-11}
Sandstone	33.94	37.94	0	1.17×10^{-8}	5.80×10^{-9}
Awaba Tuff, Fassifern Upper Split	39.94	43.94	0	2.37×10^{-10}	1.53×10^{-11}
Sandstone, Conglomerate some Mudstone interburden	115.02	119.39	0	6.47×10^{-11}	4.18×10^{-12}
Sandstone and Conglomerate interburden	118.08	122.94	0	2.38×10^{-10}	4.32×10^{-11}
Siltstone and Sandstone interburden	133.09	137.94	0	2.82×10^{-9}	3.70×10^{-10}
Tuffite (between Jewels and Hartley Hill), Hartley Hill	150.77	155.75	-1.50×10^{-10}	6.41×10^{-10}	3.65×10^{-11}
Warners Bay Tuff, Australasian	160.04	164.93	-7.37×10^{-11}	2.65×10^{-9}	1.70×10^{-10}
Montrose, Siltstone, Mudstone, Tuff	175.06	180.1	0	7.19×10^{-11}	4.65×10^{-12}
Waratah Sandstone immediately below West Borehole	250.15	254.15	5.97×10^{-9}	2.37×10^{-8}	1.27×10^{-8}
Sandstone, siltstone above Nobby Tuff; top 0.5 m of Nobbys Tuff	241.09	245.09	6.47×10^{-10}	1.97×10^{-8}	9.55×10^{-9}
Sandstone, siltstone	235.07	239.07	3.11×10^{-9}	1.18×10^{-8}	6.04×10^{-9}

Strata	Depth (m)		Hydraulic conductivity (m/sec)		
	From	To	Minimum	Maximum	Mean
Sandstone, siltstone, conglomerate	223.13	227.13	0	9.71×10^{-9}	5.32×10^{-9}
Fern Valley, Siltstone	217.08	221.08	4.28×10^{-9}	9.33×10^{-9}	5.69×10^{-9}
Wave Hill, Edgeworth Tuff, Fern Valley	211.11	215.11	1.13×10^{-9}	5.70×10^{-9}	3.72×10^{-9}

2.2 Conceptual hydrogeological model

Based on the hydrogeological environment detailed in Section 2.1, a conceptual hydrological and hydrogeological model has been developed to form the basis of the numerical groundwater model and the water balance model (GHD, 2020b).

Figure 2-16 presents a conceptual hydrogeological model of the Project Application Area and wider region. The conceptual model has been developed to identify the key hydrogeological processes and their interactions. It includes the surface water systems, groundwater systems, flow paths, recharge and discharge processes and the interaction between each component. The key components include:

1. Rainfall, catchment runoff and recharge of groundwater sources.
2. Evaporation from water surfaces and evapotranspiration from vegetation.
3. Operational water flows between the NCSS and Newstan Colliery.
4. Discharges from NCSS to LT Creek.
5. Potential discharges from Newstan Colliery to Stony Creek via Newstan LDP017.
6. Groundwater inflows to Newstan Colliery underground workings.
7. Discharge from Awaba Colliery Surface Site to Stony Creek
8. Surface infiltration into the Awaba underground void.
9. Potential groundwater flows from Eraring Ash Dam to the Awaba underground void.
10. Potential groundwater outflows from the Awaba underground void.
11. Passive seepage from the Awaba underground void to the unnamed tributary of Muddy Lake.
12. Extraction of groundwater from the Awaba underground void to Eraring Power Station via 10 South bore.
13. Potential groundwater flows from Eraring Ash Dam to the Extension of Mining Area.

Each of the above elements are included in the water balance model. However, it was considered that a number of the elements listed above are outside of the scope of the numerical groundwater model. The main exclusions from the groundwater model are catchment runoff, operational transfers to and from the NCSS and Awaba Colliery Surface Site (elements 3, 4 and 7) and inputs and outputs to and from the Fassifern Underground Storage and Awaba underground void other than groundwater inflow/outflow (elements 5, 8 and 12). Potential flows from Eraring Ash Dam to the Awaba underground void via sinkholes is only considered in the water balance model. For the purpose of the groundwater model, the water levels in the Fassifern Underground Storage and Awaba underground void are maintained at a constant level. It is considered that the site water and salt balance model is more suitable to modelling varying water levels in an underground void.

As part of the development of the site water and salt balance model (GHD, 2020b), an infiltration model was developed to estimate the rate of infiltration from the surface to the Awaba underground void. Details regarding the development of the seepage model are outlined in Appendix B of GHD (2020b). The rate of infiltration estimated by the infiltration model was scaled to match the estimated rate of groundwater inflow into the Awaba workings estimated in this report.

The infiltration model was validated using historical pumping data from the Awaba void, and comparing modelled water levels in the Awaba underground void to observed water levels. The infiltration model provided a reasonable fit between modelled and observed water levels in the Awaba underground void. The exception to this was the model was unable to replicate the response to two major rainfall events in 2016, underestimating the response in January 2016 and overestimating the response in August 2016. Additionally, Centennial Newstan rehabilitated a number of sinkholes above the Awaba underground void, which potentially reduced the infiltration of water from the surface. The infiltration model tended to overestimate the water level during 2018 and 2019. This indicates that sinkhole repair undertaken by Centennial Newstan in 2018 may have been effective in reducing infiltration to the Awaba underground void. More details are outlined in Appendix B of GHD (2020b).

Further details on the conceptualisation of the groundwater system are provided in the following sections. Reference is made to the conceptual cross section of groundwater flow shown in Figure 2-17 and Figure 2-18.

2.2.1 Inputs

Inputs to the groundwater system throughout the model domain include rainfall recharge to alluvium and weathered rock, and leakage from Lake Macquarie and permanent streams. These inputs are shown in Figure 2-17 and Figure 2-18. Rainfall recharge, expressed as a percentage of net rainfall, varies according to the permeability of the surface strata. Permanent streams only occur in the lower reaches within the tidal zone, as outlined in Section 2.1.4.

2.2.2 Outputs

The main outputs from the groundwater system include evapotranspiration, baseflow to water gaining streams, outflow to Lake Macquarie and inflow to mine workings, as shown in Figure 2-17. Evapotranspiration varies across the model domain according to the extent of vegetation. The majority of streams within the model domain, including all within the Extension of Mining Area, are considered to be water gaining and as such will receive baseflow from groundwater when the groundwater level rises to the bed elevation.

2.2.3 Groundwater flow

Alluvial groundwater flow generally reflects topography and discharges to connected surface waterways or infiltrates to the regional porous and fractured rock groundwater system. Alluvial groundwater levels respond to rainfall and there is a statistically significant relationship between level and CDFM at many alluvial monitoring bores at Newstan Colliery and Mandalong Mine. Groundwater within the porous and fractured rock system generally flows east from areas of seam subcrop to the west and north of the Project Application Area towards Lake Macquarie. Horizontal flow dominates over vertical flow through the strata unless mining creates a hydraulic gradient towards the mine workings.

2.2.4 Potential impacts

Potential impacts to groundwater from mining are as follows:

- Groundwater inflows into mine workings from the porous and fractured rock groundwater source. It is considered that there is a low risk of loss of alluvial groundwater into underlying strata (and mine workings) based on review of the response of alluvial groundwater levels to previous mining at Newstan Colliery and Mandalong Mine (refer Section 2.1.9).
- Groundwater drawdown at water supply works within the porous and fractured rock groundwater source. Drawdown within alluvial bores is considered to be less risk.
- Groundwater drawdown within alluvium and shallow groundwater sources that support GDEs. Note that alluvial drawdown above the Awaba underground void is not included in the groundwater model since the void is modelled with a constant water level. Changes in infiltration to the Awaba void resulting from pillar failure are included in the water balance model. Nevertheless, the impact of potential drawdown in the alluvium above the Awaba void is assessed in the Groundwater Impact Assessment.
- Reduction or loss in groundwater baseflow to ephemeral streams within the Extension of Mining Area.
- Increase in leakage from the Awaba void to underlying strata and from the Eraring Ash Dam to underlying strata. Further details on the conceptualisation of the fracture zone above areas of secondary extraction within the Extension of Mining Area and the potential hydraulic connection between the Awaba underground void and proposed workings and between the Eraring Ash Dam and proposed workings are detailed below.

2.2.5 Conceptualisation of the fracture zone

SCT (2019) approach

SCT (2019) was commissioned by Centennial Newstan to review the proposed mine design in the Extension of Mining Area in the context of potential interactions with fly ash emplaced in the Eraring Ash Dam. SCT (2019) concluded that full extraction within the Extension of Mining Area will provide an enhanced flow pathway into Newstan Colliery from the Eraring Ash Dam and from the Awaba underground void. SCT (2019) calculated flows from the Eraring Ash Dam to the West Borehole seam workings to be in the order of 0.03 to 3 ML/day. These calculations were based on an empirical equation of the height of depressurisation (Tammetta (2012)), based on data from other sites. GHD considers that this conceptualisation by SCT (2019) is too conservative and is not supported by local groundwater monitoring data for Newstan Colliery and Mandalong Mine as outlined in more detail below.

The SCT (2019) conceptualisation and flow estimates are based on average and maximum heights of depressurisation, or continuous fracturing, of 180 m and 220 m respectively (calculated from Tammetta (2012)) and hydraulic conductivity of fractured strata above the height of continuous fracturing of 10^{-5} to 10^{-7} m/s. These hydraulic conductivity values were based on the hydraulic conductivity of overburden strata, maximum subsidence and overburden depth relationship from Gale (2010). The relationship plot from Gale (2010) is reproduced in Figure 2-19. At a height of 180 m above the mined seam and subsidence of 1 m (which is the subsidence predicted by MSEC (2019) resulting from extraction of the panels under Eraring Ash Dam), the Gale (2010) plot indicates a hydraulic conductivity value of less than 10^{-7} m/s. This is more consistent with observed inflows into existing Longwalls 22-25 as discussed in Section 2.1.10.

Observed groundwater inflows into Longwalls 22-25 at Newstan Colliery (0.25 ML/day) are lower than would be expected if the actual height of depressurisation or continuous fracturing was in accordance with the Tammetta (2012) empirical equation (i.e. approximately 250 m). With an average interburden thickness between Longwalls 22-25 and the Awaba underground void of 110 m, it would be expected that there would be complete drainage of the interburden and direct flow from the Awaba underground void into the Longwall 22-25 goaf. Since this is not the case, it is considered overly conservative and unreliable to apply the Tammetta (2012) height of depressurisation above the proposed panels as proposed by SCT (2019). Further, the proposed panels have a lower void width (167 m) compared to Longwalls 22-25 (230 m), there is a greater interburden thickness between the panels and Awaba underground void (average of 170 m) and the panels will only recover up to 75% to 85% of available coal compared to 100% for longwalls (excluding the chain, spine and barrier pillars), thus reducing the equivalent mining height (MSEC, 2019). These aspects of the mine design further reduce the likelihood of the SCT (2019) conceptualisation.

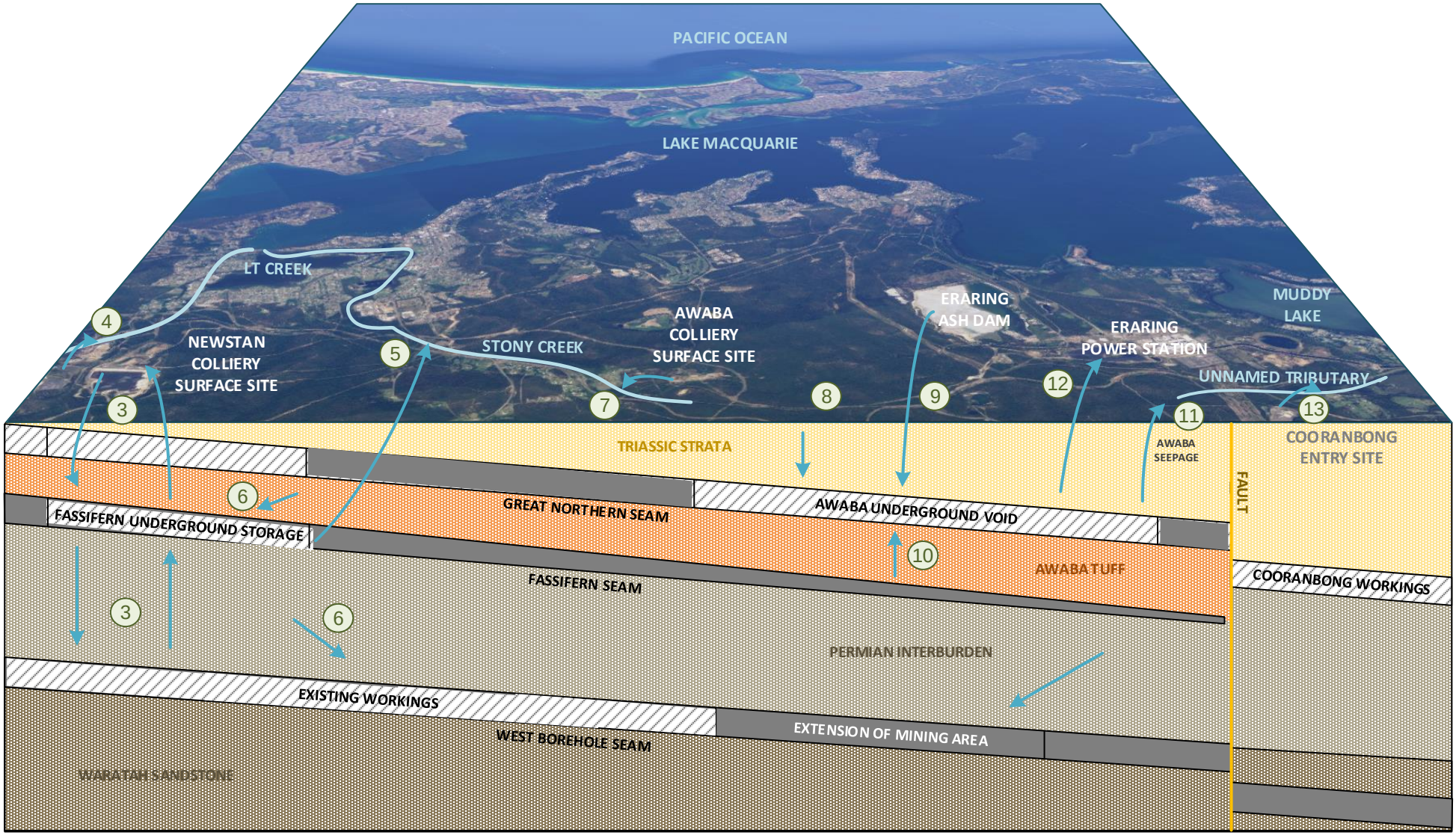
As discussed in Section 2.1.10, the major ion chemistry of groundwater inflow into the existing Newstan Colliery workings has been compared to that for the Awaba underground void. Groundwater inflow into the existing West Borehole seam workings at Newstan Colliery (sampled at location ‘cut through 19’) is brackish and slightly alkaline, and sodium bicarbonate-chloride dominant. In comparison, water within the Awaba underground void is more magnesium sulfate dominant (sampled at location 13 West 2). These two waters are compared in a piper diagram in Appendix C of GHD (2020a). This suggests that the groundwater inflow into the Longwall 22-25 area is from the adjacent porous and fractured rock groundwater source rather than directly from the Awaba underground void which would be the case under the SCT (2019) conceptualisation.

Finally, observed groundwater inflows into the Mandalong Mine longwall mining area (less than 1 ML/day) are low considering the current mine footprint (25 longwall panels have been extracted since 2005). This reflects the low hydraulic conductivity of the fractured overburden, particularly the Munmorah Conglomerate, and provides further evidence that groundwater inflow into mine workings tends to be low throughout the Newcastle Coalfield and less than what would be predicted using the common empirical methods (such as Tammetta (2012)) for calculating the height of continuous fracturing.

GHD approach

The height of depressurisation is simulated in the numerical groundwater model using the stacked drain approach (Section 4.2). The height of stacked drains above the West Borehole seam was based on model calibration to groundwater inflows reported into the existing Newstan Colliery workings. This height was found to be approximately 140 m, which is at the lower end of the range calculated using Tammetta (2012) for the lowest mining height in the Extension of Mining Area.

As part of the uncertainty analysis, the SCT (2019) conceptualisation for height of continuous fracturing has been simulated using a stacked drain height of 220 m above all full and partial extraction area (Section 5.8.1).



Note: Not to Scale

Legend

Receiving waters

Water flow

Centennial Newstan Pty Ltd
Newstan Mine Extension Project
Groundwater Modelling Report

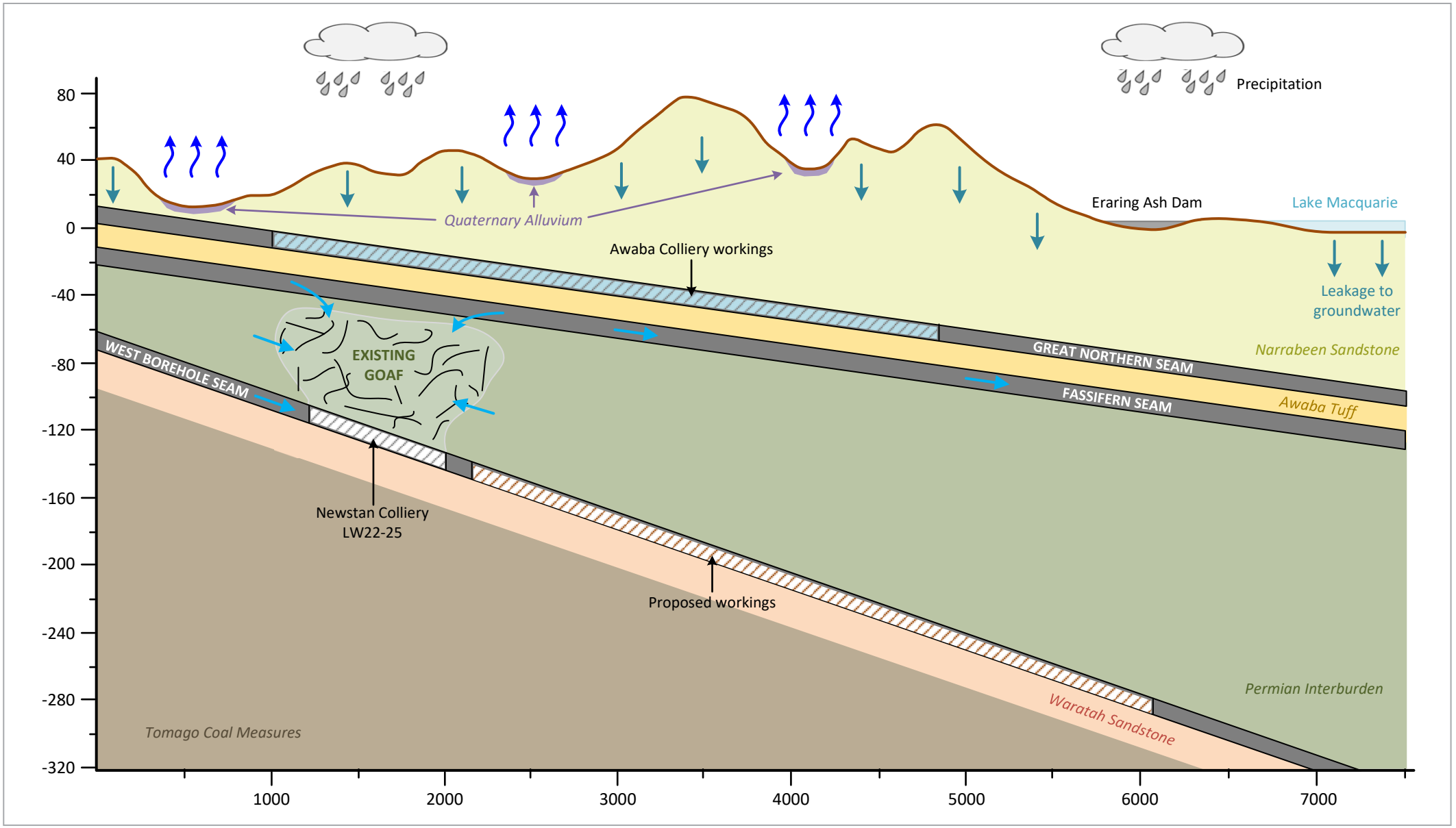
Conceptual hydrogeological model

Project No. 2220265
Revision No. A
Date 22/01/2020

FIGURE 2-16

Created by: Tyler Tinkler

\\ghdnet\ghd\AU\Newcastle\Projects\22\20237\Tech\Visio\2220237-VIS-Newstan_Extension_Project-Conceptual_hydrological_model.vsdx
Print date: 22/01/2020 17:45
© 2020. Whilst every care has been taken to prepare this figure, GHD make no representations or warranties about its accuracy, reliability, completeness or suitability for any particular purpose and cannot accept liability and responsibility of any kind (whether in contract, tort or otherwise) for any expenses, losses, damages and/or costs (including indirect or consequential damage) which are or may be incurred by any party as a result of the figure being inaccurate, incomplete or unsuitable in any way and for any reason.



Recharge

Groundwater flow

Evapotranspiration

Centennial Newstan Pty Ltd
Newstan Mine Extension Project
Groundwater Model Report

Conceptual cross-section

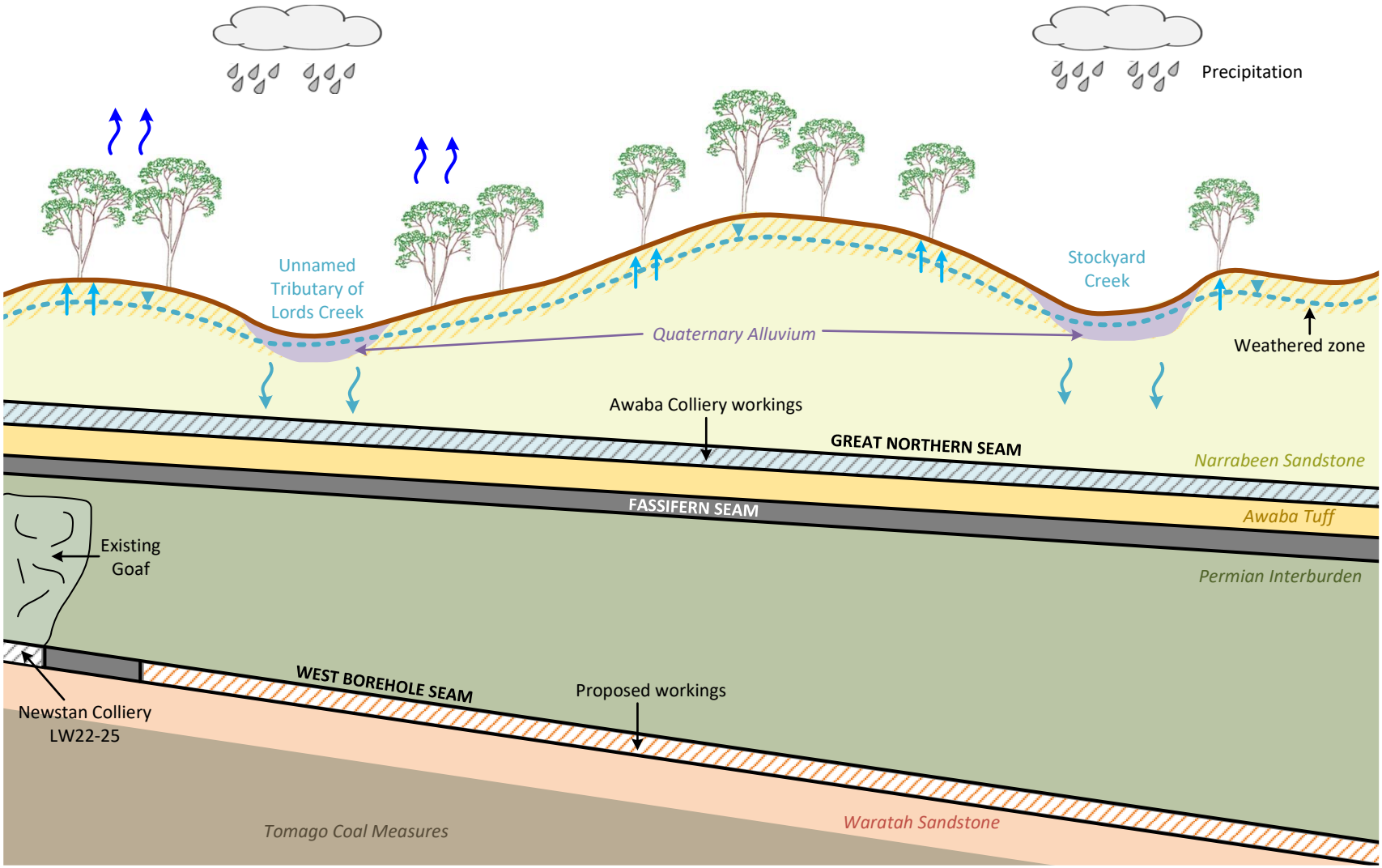
Project No. 2220265
Revision No. A
Date 27/02/2020

FIGURE 2-17

G:\22\20265\Tech\Visio\2220265-VIS-Newstan_Extension_Project-Conceptual_cross section.vsdx
Print date: 27/02/2020 15:20

Created by: SMacDonald

© 2020. Whilst every care has been taken to prepare this figure, GHD make no representations or warranties about its accuracy, reliability, completeness or suitability for any particular purpose and cannot accept liability and responsibility of any kind (whether in contract, tort or otherwise) for any expenses, losses, damages and/or costs (including indirect or consequential damage) which are or may be incurred by any party as a result of the figure being inaccurate, incomplete or unsuitable in any way and for any reason.



Groundwater table

Groundwater uptake by vegetation

Evapotranspiration

NOT TO SCALE

Centennial Newstan Pty Ltd
Newstan Mine Extension Project
Groundwater Model Report

Conceptual cross-section including alluvium

Project No. 2220265
Revision No. A
Date 27/02/2020

FIGURE 2-18

Created by: SMacDonald

G:\22\20265\Tech\Visio\2220265-VIS-Newstan_Extension_Project-Conceptual_cross section_alluvium.vsdx
Print date: 27/02/2020 15:20

© 2020. Whilst every care has been taken to prepare this figure, GHD make no representations or warranties about its accuracy, reliability, completeness or suitability for any particular purpose and cannot accept liability and responsibility of any kind (whether in contract, tort or otherwise) for any expenses, losses, damages and/or costs (including indirect or consequential damage) which are or may be incurred by any party as a result of the figure being inaccurate, incomplete or unsuitable in any way and for any reason.

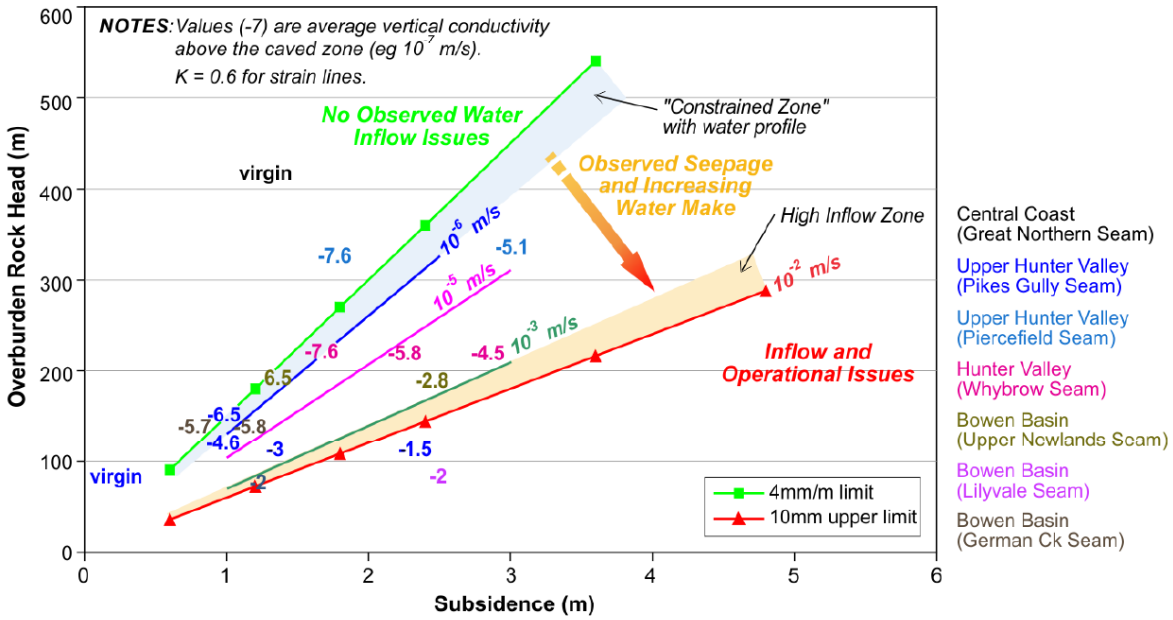


Figure 2-19 Hydraulic conductivity, subsidence and overburden depth relationship, from Gale (2010)

3. Groundwater modelling set-up

3.1 Software selection

MODFLOW-USG (MF-USG) has been selected as the most appropriate groundwater modelling software for this study. MF-USG is an unstructured grid version of the industry standard MODFLOW code developed and maintained by the United States Geological Survey (Panday et al, 2013). Advantages of MF-USG include flexible meshing for efficient refinement of model cells in the area of interest and robust handling of saturation and desaturation of model cells for tracking the location of the water table.

The input data files for the MF-USGs model have been prepared using the graphical user interface GMS Version 10.4.

3.2 Model complexity

The modelling effort required to meet the study objective is guided by the target confidence level and complexity of the model. Confidence in model predictions depends fundamentally on the availability of data, whether or not sufficient data are available to characterise the groundwater flow processes of interest and whether or not sufficient information is available to inform hydrogeological parameters that have the greatest influence on model predictions. Complexity of the model reflects the level of sophistication of modelling techniques such as the mesh design, degree of parameterisation and choice of boundary conditions.

Model characteristics have been compared with the Australian Groundwater Modelling Guidelines (Barnett et al, 2012) shown in Table 3-1. According to the Australian Groundwater Modelling Guidelines (Barnett et al, 2012), this model has a combination of characteristics of a class 2 (medium confidence) model and a class 3 (high confidence) model. This model has been classified as medium to high confidence as this model has been calibrated to transient data, stresses observed as part of existing workings at Newstan Colliery are similar to those expected as part of the proposed workings, and the period of calibration data (2005 to March 2019) is similar to the predictive period (14 years of mining). Results should be interpreted in accordance with the expectation of a medium to high confidence model.

The model calibration is good which adds confidence to the model predictions.

It should be noted that even a well-calibrated model can still have significant uncertainty associated with it, as spatial and temporal distribution of hydraulic parameters and boundary conditions are not fully known and by definition groundwater modelling is a simplification of real world conditions.

Table 3-1 Australian Groundwater Modelling Guidelines model confidence level (Barnett *et al*, 2012)

Class	Data		Calibration		Prediction		Quantitative indicators	
1 (simple)		Not much		Not possible		Timeframe >> calibration		Timeframe > 10x
		Sparse coverage		Large error statistic		Long stress periods		Stresses > 5x
		No metered usage		Inadequate data spread	✓	Poor/no validation		Mass balance > 1% (or one-off 5%)
		Low resolution						Properties < > field values
		Poor aquifer geometry		Targets incompatible with model purpose		Transient prediction but steady-state calibration		No review by Hydro/ Modeller
		Basic / initial conceptualisation						
2 (impact assessment)	✓	Some		Partial performance		Timeframe > calibration		Time frame = 3–10x
	✓	Ok coverage		Some long term trends wrong		Long stress periods		Stresses = 2–5x
	✓	Some data usage / low volumes		Short term record		Ok validation	✓	Mass balance <1%
		Baseflow estimates Some K & S measurements		Weak seasonal match	✓	Transient calibration and prediction	✓	Some properties < > field values
	✓	Some high resolution topographic DEM &/or some aquifer geometry	✓	No use of targets compatible with model purpose (heads & fluxes)		New stresses not in calibration		Review by hydrogeologist
3 (complex simulator)		Lots, with good coverage	✓	Good performance stats	✓	Timeframe ~ calibration	✓	Timeframe <3x
		Good metered usage info	~	Most long term trends matched	~	Similar stress periods	✓	Stresses <2x
	✓	Local climate data	~	Most seasonal matches ok		Good validation		Mass balance <0.5%
		Kh, Kv and Sy measurements from a range of tests	✓	Present day data targets	~	Calibration & prediction consistent (transient or steady state)		Properties ~ field measurements
		High resolution DEM all areas		Head & flux targets used to constrain calibration	✓	Similar stresses to those in calibration	✓	No coarse discretisation in key areas (grid or time)
		Good aquifer geometry					✓	Review by experienced modeller

Note: achieved attributes are shown with a tick.

3.3 Model domain

The hydrogeological model domain is shown in Figure 3-1. The hydrogeological domain defines the extent of the numerical groundwater model. The model domain should be large enough to capture key stresses on the groundwater system and their area of influence, both in the context of past and future activities.

The northern boundary of the hydrogeological model domain follows the outcrop of the Newcastle Coal Measures. The north-western boundary follows Topographic ridgeline, the western boundary follows the Yarramulla Syncline. The south western and southern boundary follows the Dora Creek/Lake Macquarie catchment boundary. The eastern boundary follows the coastline.

The MF-USG grid is shown in Figure 3-2. The grid is a layered quadtree mesh with the same level of cell refinement in all model layers. The grid is refined in the footprint of proposed workings, existing Newstan Colliery workings, Awaba workings, Teralba Colliery workings, West Wallsend Colliery workings, key creek lines in the vicinity of Newstan Colliery and geological contacts such as the edge of the alluvium.

The cell size varies from 50 m in the areas of refinement corresponding to the proposed Newstan Colliery workings to 100 m in areas corresponding to existing mine workings. The cell size increases to 800 m away from the mining areas. The model has 12 layers with 25,202 cells per layer, giving a total of 302,424 cells. It has an area of around 921 km^2.

Model cells were not refined around the geological structures mapped and interpreted by MSEC (2019) and discussed in Section 2.1.5. Note that the cell size in areas corresponding to the proposed workings is 50 m, and 100 m in areas corresponding to the existing workings. Hence there is refinement around geological structures that are within the footprint of the proposed workings.



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

Hydrogeological domain

FIGURE 3-1

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-012_ProposedModelBoundary.mxd
Print date: 06 Mar 2020 - 17:45

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald

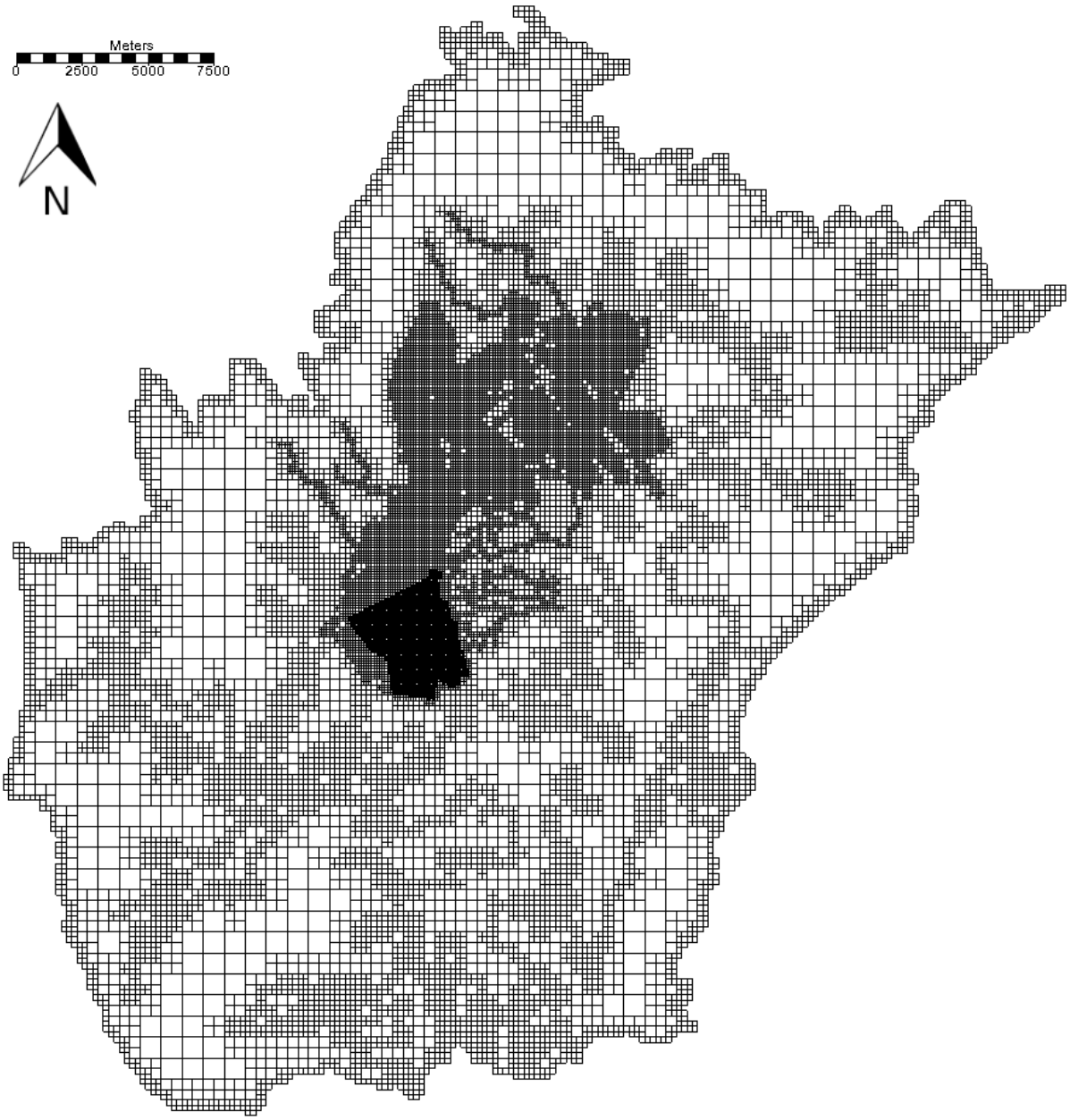


Figure 3-2 Model domain and mesh

3.4 Model layers

The relationship between model layers hydrostratigraphic units (HSUs) is summarised in Table 3-2. As discussed in Section 2.1.5, the West Borehole seam splits to the east of Newstan Colliery into the Young Wallsend, Yard and Borehole seam. Based on discussions with Centennial Newstan, there was insufficient geological data to characterise the thickness or elevation of the Young Wallsend, Yard and Borehole seam. Therefore it was decided to model the Young Wallsend, Yard and Borehole seam as one model layer to the east of the seam split.

There are a number of coal seams between the Fassifern seam and the West Borehole seam that are not explicitly included in the model. These coal seams have been included in the model. Each layer is continuous throughout the model domain, reducing to a minimum thickness of 0.5 m where the HSUs pinch out. The model did not include any geological structural features.

Table 3-2 HSUs and model layers

Model layer	HSU	MF-USG layer type	Typical layer thickness (m)
1	Alluvium and regolith	4 – Convertible Upstream	1
2	Regolith	4 – Convertible Upstream	24
3	Narrabeen Sandstone	4 – Convertible Upstream	20
4	Great Northern seam	4 – Convertible Upstream	3
5	Awaba Tuff	4 – Convertible Upstream	40
6	Fassifern seam	4 – Convertible Upstream	3
7	Permian Interburden	4 – Convertible Upstream	60
8	Permian Interburden	4 – Convertible Upstream	60
9	Permian Interburden	4 – Convertible Upstream	60
10	West Borehole seam	4 – Convertible Upstream	3
11	Waratah Sandstone	4 – Convertible Upstream	40
12	Tomago Coal Measures	4 – Convertible Upstream	200

The elevation of model layers are based on a combination of coal seam elevation contours, exploration bore logs and regional geology mapping provided by Centennial Newstan. In the vicinity of Newstan Colliery, the elevation of the Great Northern seam, Fassifern seam and West Borehole seam are based on these seam elevation contours. To the north and north-west of Newstan Colliery, outside the extent of the seam elevation contours, the elevation of the coal seams were interpolated from the surface elevation at the outcrop of the coal seams to the edge of the seam elevation contours. To the east, west and south of Newstan Colliery, the elevation of the coal seams has been extrapolated based on regional geology mapping.

The ground surface, corresponding to the top of model layer 1, has been assigned using a combination of regional 10 m contours sourced from LPI (2008) and site LiDAR data. In accordance with feedback provided by the independent model reviewer during the model development process, exploration bore logs were reviewed to determine the depth of the alluvium. Along creek lines, the depth of alluvium was interpolated between exploration bore logs, Lake Macquarie and the edge of the alluvium. The base of the alluvium under Lake Macquarie was assigned as -20 m AHD.

Within the vicinity of Newstan Colliery exploration bore logs were reviewed to determine the depth of weathering. Based on this review, the base of Layer 2 was assigned as 25 m below ground level throughout the model domain. As the target seam at Newstan Colliery is the West Borehole seam, there was limited number of exploration boreholes that extended into the Waratah Sandstone. Based on the review of exploration bore logs, the thickness of the Waratah Sandstone was assumed to vary from 47 m at the southern extent of Newstan Colliery to 32 m at the northern extent of Newstan Colliery. Based on the exploration borehole data, the thickness of the Waratah Sandstone was assumed to gradually increase to the south east of Newstan Colliery and gradually decrease to the northwest.

3.5 Boundary conditions

Boundary conditions were applied according to the following:

- General head boundaries (GHBs) were applied to the coal measures, alluvium and regolith based on the conceptualisation of groundwater flow direction.
- No flow boundary conditions are assumed elsewhere, where the boundary is parallel to the expected groundwater flow direction, in locations commensurate with groundwater divides (e.g. seam outcrop) for the aquifer units, and along the perimeters of all aquitard units.
- Lake Macquarie was represented using a GHB in model layer 1. Creeks within the tidal zone were also represented using a GHB in model layer 1. The elevation of the GHB was set to 0 m AHD.
- The mine workings at Newstan Colliery, Teralba Colliery, West Wallsend Colliery, Awaba Colliery and the Cooranbong workings were represented using drain cells.
- Recharge was assigned to the highest active cells and varied temporarily (during transient calibration) based on a fraction of measured rainfall.
- Evapotranspiration (ET) was assigned to the alluvium and the regolith using the EVT package. Groundwater is extracted by ET only where the water table lies above the prescribed ET extinction depth (e.g. along natural topographic low points such as creek lines).
- Rivers using the RIV package were assigned to ephemeral creeklines.

The set-up of the boundary conditions is further discussed in the following sections. Pumping from landholder bores is not simulated in the model as there are a limited number of landholder bores on the western side of Lake Macquarie and potential pumping from these bores are assumed to have negligible effect on model flow budgets.

3.5.1 General head boundaries

GHBs have been applied to the coal measures along the edge of the model domain. Head values have been assigned based on a review of groundwater levels in the coal measures. GHB was assigned as 0 m AHD within the coal seams along the eastern boundary of the model due to the proximity to the Pacific Ocean. Groundwater levels at Newstan Colliery and Mandalong Mine were also reviewed to determine groundwater flow directions and gradient across the model domain. A review of groundwater levels indicated a groundwater low direction from north to south and from west to east. This information was used to assign GHB level along the western and southern model boundary. Conductance values for the GHB were assigned to not restrict flow across the boundary.

The Newcastle Coal Measures outcrop to the north of Newstan Colliery and therefore no flow boundary conditions were applied to the norther boundary of the coal measures. The Narrabeen Sandstone and Permian interburden have been assumed to be aquitards and no flow boundary conditions were applied.

Lake Macquarie was represented as a GHB in model layer 1. This was considered to be a reasonable approach based on the distance between the Lake from the Extension of Mining Area and the unlikelihood for mining induced groundwater drawdown in the vicinity of the Lake. The elevation of the GHB was set to 0 m AHD. GHBs were assigned as 0 m AHD along the eastern boundary of the alluvium and the regolith (model layers 1 and 2) to reflect the Pacific Ocean. GHBs were also assigned as 0 m AHD within model layers 1 and 2 along the north eastern model boundary along the Hunter River. As discussed in Section 3.3, the majority of the southern and western model boundaries are assigned to topographic ridgelines/catchment boundaries. These topographic ridgelines have been assumed to form a groundwater flow divide in the alluvium and regolith. Therefore, no flow boundaries were applied to the southern and western boundaries of the alluvium and regolith. The exception to this is where Deep Creek and Dora Creek passes through the western model boundary. GHBs have been applied to model layer 1 and 2 where Deep Creek and Dora Creek traverses the western model boundary with a GHB elevation equal to the top of model layer 1. The GHBs that represent Lake Macquarie were assigned a conductance of 10,000 m^2/day and GHBs along the model boundary were assigned a conductance of 200 m^2/day. Conductance values are high in comparison to other models in the region.

Perimeter boundary conditions are displayed on a layer basis in Appendix C.

GHBs were also assigned during transient calibration to represent the flooding of historical underground workings. The use of GHBs to simulate flooding of historical workings is discussed further in Section 3.5.4.

3.5.2 Watercourses

River (RIV) cells were applied to watercourses in the model. The river stage elevation was based on topographic data. The river bed elevation was set equal to the river stage elevation. This application of RIV cells allowed baseflow but did not allow leakage from the watercourse to the aquifer. Reaches of watercourses in the vicinity of Lake Macquarie with permanent water were represented by GHBs. GHBs were assigned to 0 m AHD. Watercourses that were partially modelled with GHBs include Dora Creek, LT Creek, Stony Creek, Cockle Creek, Winding Creek and Kilaben Creek. This application of river cells and GHBs was consistent with the conceptualisation of watercourses in the hydrogeological domain as ephemeral, water gaining streams. RIV cells were assigned a conductance of 25 m^2/day.

3.5.3 Recharge

Recharge is assigned to the highest active cells and varied temporarily based on measured monthly rainfall data during the transient calibration. Recharge was calculated as a percentage of the monthly rainfall.

Recharge is conceptually higher along higher permeability alluvium areas than in areas where the regolith outcrops. Recharge zones have been assigned to account for different surface geology across the model domain. Recharge was calculated as a percentage of rainfall available for each month. The percentage of rainfall available for recharge was varied depending on the outcropping geology. Recharge was applied according to surficial lithology: alluvium and Permo-Triassic (regolith). The extent of these zones correspond with layer 1 material properties shown in Figure B-1 (Appendix C).

Rainfall recharge for the steady state model (utilised to gain starting heads) was applied using the average rainfall in the five years prior to the commencement of the transient calibration period, using the same recharge zones and the same fixed percentage of rainfall.

3.5.4 Mining

Drain cells were utilised to simulate historical mining at Newstan Colliery and surrounding mining operations during the transient calibration model. The location of mine workings simulated are shown in Figure 3-3.

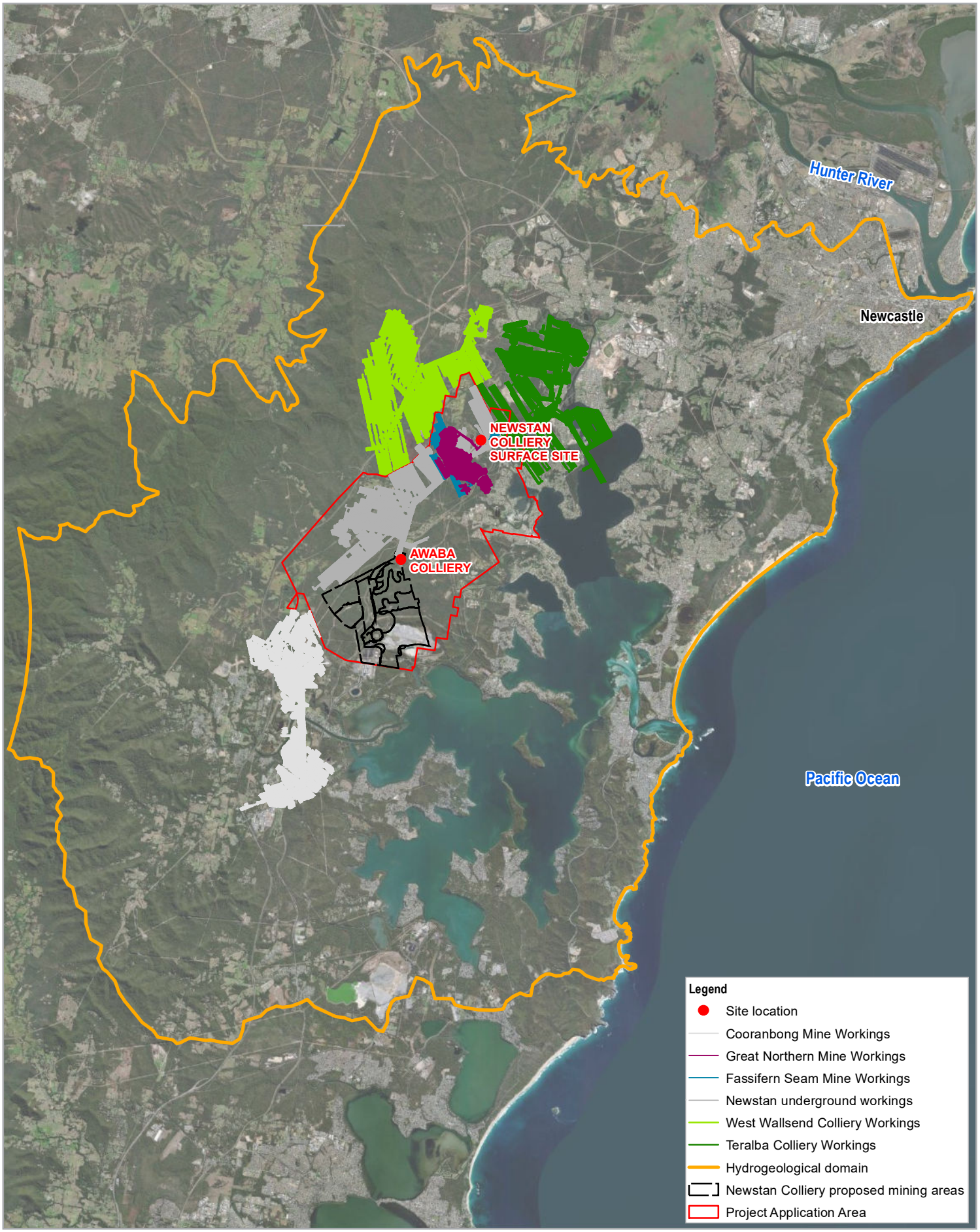
Limited information was available to determine the history of mining at Awaba and Cooranbong, with mining commencing at Awaba and Cooranbong prior to the 1980's. Drain cell elevation was assigned to 0.1 m above the base of Layer 4 (Great Northern seam) and were activated at the commencement of the transient calibration period to represent mining at Cooranbong and Awaba. Cooranbong workings have been assumed to be maintained as fully dewatered throughout mining.

Drain cells to simulate historical mining at West Wallsend Colliery and Teralba Colliery were assigned to Layer 10 (West Borehole seam). The drain cell elevation was assigned to 0.1 m above the floor of the model cell. Drain cells were progressively activated in accordance with the progression of mining at West Wallsend Colliery. The progression of mining at West Wallsend Colliery was based upon Annual Review reports published by Oceanic Coal (2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016a and 2017). Mining sequence data was not available for Teralba Colliery. Therefore all drain cells for Teralba Colliery were activated near the start of the transient calibration model in 1978.

Drain cells were used to simulate historical mining at Newstan Colliery. Drain cells were assigned to Layer 4 (Great Northern seam), Layer 6 (Fassifern seam) and Layer 10 (West Borehole seam). The drain cell elevation was assigned to 0.1 m above the floor of the model cell. Drain cells were progressively activated in accordance with the mining schedule supplied by Centennial Newstan. Drain cells were assigned a conductance of 2500 m^2/day. A trial and error approach was undertaken that involved modifying drain conductance to fit modelled inflows to observed inflows. Changing drain conductance resulted in minimal change to mine inflows. Typical drain conductance in similar models in the region are typically lower (RPS, 2013).

To simulate depressurisation of groundwater sources above the coal seam due to fracturing following longwall mining, drain cells were also activated in Layer 9, Layer 8 and Layer 7 (Permian Interburden). Drain cells in these layers were assigned a conductance of 2500 m^2/day, equal to that of the West Borehole Seam. These drain cells were progressively activated in accordance with the mining schedule supplied by Centennial Newstan.

Following the end of mining at Awaba Colliery and the Fassifern seam workings at Newstan Colliery, these underground workings were progressively allowed to flood with groundwater. Based on available monitoring data the Awaba Colliery workings started to flood in 2013 and the Fassifern seam workings at Newstan Colliery started to flood in 2011. The Fassifern seam workings at Newstan Colliery were referred to as the Fassifern Underground Storage following flooding. Within the transient calibration model, following flooding of these workings, drain cells representing mine workings were deactivated and GHBs were activated. GHBs were assigned to model layer 4 and model layer 6 to represent flooding of Awaba Colliery and the Fassifern Underground Storage. The underground water level in the Awaba underground void and in the Fassifern Underground Storage are monitored and the water levels are plotted in Figure 3-4 and Figure 2-14 respectively. GHB elevations were set in accordance with this monitoring data. Review of leakage from these storages was undertaken to confirm the validity of applying GHBs and whether this boundary condition influences predicted groundwater drawdown in the vicinity of these storages.



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

Regional mining included in model

FIGURE 3-3

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-021_RegionalMining.mxd
Print date: 06 Mar 2020 - 17:46

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald

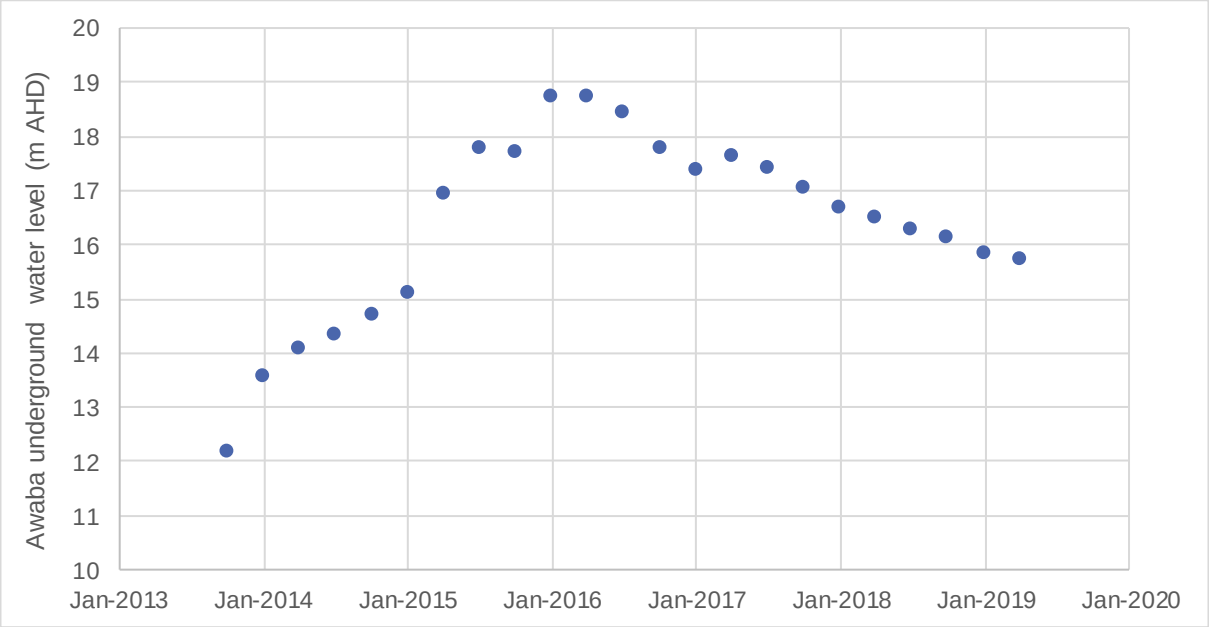


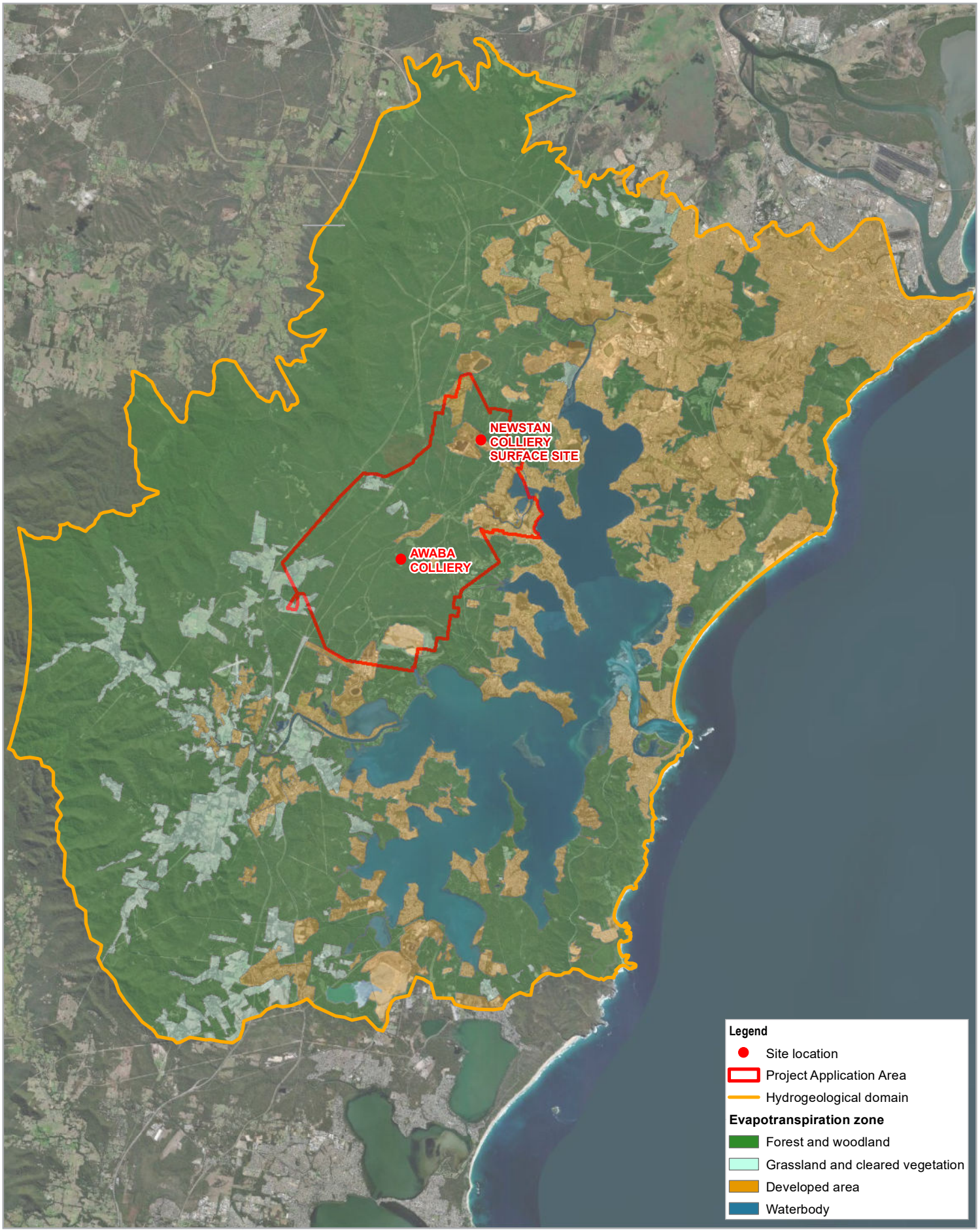
Figure 3-4 Awaba underground water level

3.5.5 Evapotranspiration

Evapotranspiration (ET) was assigned to the model using the EVT package. Groundwater is extracted by ET only where the water table lies above the prescribed ET extinction depth.

Conceptually, ET depth varies depending of the vegetation. The ET extinction depth was varied across the model domain based on the mapped vegetation. Figure 3-5 shows the ET zones that were utilised. The ET zones include forest and woodland, grassland and cleared vegetation, and urban or developed areas. ET was not applied to waterbodies including Lake Macquarie.

The ET surface elevation was set to the top of model layer 1 and was applied to the alluvium and the regolith.



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

Evapotranspiration zones

FIGURE 3-5

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-011_Evapotranspiration.mxd
Print date: 06 Mar 2020 - 17:45

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald

3.6 Model calibration

Model calibration involves changing the value of model parameters within bounds until the model outputs fit historical measurements, such that the model can be accepted as a reasonable representation of the physical system of interest (Barnett et al. 2012). The calibration target was observed groundwater levels with observed groundwater inflows (refer Section 3.6.2) providing a qualitative indication of realistic mine inflow rates.

The calibration implemented a two stage process of running the steady state model first, to obtain a sensible set of initial heads, followed by the transient model to simulate temporal variations in groundwater levels. The transient calibration period commences in January 1976, approximately two years prior to commencement of mining at Teralba Colliery and continues through to the end of July 2019.

The stress periods of the transient calibration model include:

- Two one-year stress periods from January 1976 to January 1978.
- Six four-year stress periods from January 1978 to January 2002.
- One two-year stress period from January 2002 to January 2004.
- Two one-year stress periods from January 2004 to January 2006.
- 54 three-monthly stress periods from January 2006 to July 2019. The three-monthly stress periods cover the period that quarterly groundwater monitoring data is available at Newstan Colliery.

In total the transient model has 65 stress periods.

3.6.1 Calibration parameters

The calibration has been undertaken using the parameter estimation software PEST (Doherty, 2016a, 2016b). PEST was implemented using PEST_HP with parallel processing across multiple PCs on a cloud based network.

Parameters were assigned on a HSU basis. Thirty seven (37) calibration parameters were adopted, as summarised in Table 3-3.

The range of values for the parameters considered for calibration are summarised in Table 3-4. The range of these parameters was based on site observations (Section 2.1.11) and literature values. In addition to these parameters, rainfall recharge to the alluvium was varied between 1% and 6% of observed rainfall, while rainfall recharge to the fractured rock outcrop was varied between 0.2% and 3% of observed rainfall. The evapotranspiration rate was varied between 0.00164 m/year and 0.00356 m/year.

A height of depressurisation of 140 m was adopted to define the stacked drains above existing Newstan longwall panels as outlined in Section 2.2.5.

3.6.2 Calibration targets

The model was calibrated against observed groundwater levels (head). Calibration targets were adopted from the Newstan Colliery and Mandalong Mine groundwater monitoring networks. Calibration was completed against 2141 head measurements collated from 43 standpipe monitoring bores and 3 VWPs. Calibration targets are summarised in Table D-1 in Appendix D. Calibration locations are shown in Figure 2-11 and Figure 2-12.

A weighting strategy was implemented in PEST during the calibration to provide approximately equal contribution to the calibration objective function from head at CN036 and CN038 (that display significant drawdown during the monitoring period), drawdown at CN036 and CN038, and head at the remaining monitoring bores.

Table 3-3 Calibration parameters

Parameter group	PEST name	Description
Horizontal hydraulic conductivity	kh_aluv	Alluvium
	kh_rego	Regolith
	kh_n_sst	Narrabeen Sandstone
	kh_gn_seam	Great Northern seam
	kh_awaba	Awaba Tuff
	kh_fas_seam	Fassifern seam
	kh_iterb	Permian Interburden
	kh_wb_seam	West Borehole seam
	kh_w_sst	Waratah Sandstone
	kh_tcm	Tomago Coal Measures
Vertical anisotropy	kv_aluv	Alluvium
	kv_rego	Regolith
	kv_n_sst	Narrabeen Sandstone
	kv_gn_seam	Great Northern seam
	kv_awaba	Awaba Tuff
	kv_fas_seam	Fassifern seam
	kv_iterb	Permian Interburden
	kv_wb_seam	West Borehole seam
	kv_w_sst	Waratah Sandstone
	kv_tcm	Tomago Coal Measures
Specific storage	Ss_aluv	Alluvium
	Ss_rego	Regolith
	Ss_n_sst	Narrabeen Sandstone
	Ss_gn_seam	Great Northern seam
	Ss_awaba	Awaba Tuff
	Ss_fas_seam	Fassifern seam
	Ss_iterb	Permian Interburden
	Ss_wb_seam	West Borehole seam
	Ss_w_sst	Waratah Sandstone
	Ss_tcm	Tomago Coal Measures
Specific yield	Sy_aluv	Alluvium
	Sy_rego	Regolith
Recharge	R_fac_aluv	Alluvium
	R_fac_rego	Regolith
Evapotranspiration rate	Etrate_veg	Forest and woodland
	Etrate_ind	Urban or developed areas
	Etrate_gras	Grassland and cleared vegetation

Table 3-4 Model parameter ranges for calibration

HSU	Model layer	Horizontal hydraulic conductivity (m/day)		Vertical anisotropy (-)		Specific yield (-)		Specific storage (m^{-1})	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Alluvium	1	1	10	5	20	0.05	0.2	0.00000023	0.000013
Regolith	1 and 2	0.01	1	5	20	0.05	0.1	0.00000023	0.000013
Narrabeen Sandstone	3	0.00001	0.01	5	20	NA	NA	0.00000023	0.000013
Great Northern seam	4	0.0001	0.01	5	20	NA	NA	0.00000023	0.000013
Awaba Tuff	5	0.000001	0.004	5	50	NA	NA	0.00000023	0.000013
Fassifern seam	6	0.0001	0.01	5	20	NA	NA	0.00000023	0.000013
Permian Interburden	7, 8 and 9	2×10^{-7}	0.004	5	50	NA	NA	0.00000023	0.000013
West Borehole seam	10	0.0001	0.01	5	20	NA	NA	0.00000023	0.000013
Waratah Sandstone	11	0.00001	0.01	5	20	NA	NA	0.00000023	0.000013
Tomago Coal Measures	12	0.00001	0.01	5	20	NA	NA	0.00000023	0.000013

Note: NA denotes parameters not changed during model calibration.

3.6.3 Calibration performance

The performance of calibration is often assessed against a predefined value of goodness of fit between observed and computed data, such as the scaled root mean squared (SRMS) error. Other measures of calibration performance are also pertinent, such as low water balance errors, model stability, whether or not the numerical model is behaving in a manner consistent with the conceptual model and representation of key observed hydrological processes, such as water level trends.

Calibrated material properties are summarised in Table 3-5 and Table 3-6.

Table 3-5 Calibrated model parameters

HSU	Model layer	Horizontal hydraulic conductivity (m/day)	Vertical anisotropy (-)	Specific yield (-)	Specific storage (m^{-1})	Recharge (%)
Alluvium	1	5.53837	19.9965	0.05	1.254372×10^{-6}	2.176
Regolith	1 and 2	0.136275	5	0.09998	1.3×10^{-5}	0.228
Narrabeen Sandstone	3	4.462478×10^{-5}	5	0.01[1]	1.548677×10^{-6}	-
Great Northern seam	4	0.01	18.3189	0.01[1]	2.3×10^{-7}	-
Awaba Tuff	5	1.396526×10^{-3}	50	0.01[1]	9.580664×10^{-7}	-
Fassifern seam	6	0.01	20	0.01[1]	1.3×10^{-5}	-
Permian Interburden	7, 8 and 9	6.542498×10^{-6}	5	0.01[1]	1.3×10^{-5}	-
West Borehole seam	10	0.0001	11.7924	0.01[1]	2.3×10^{-7}	-
Waratah Sandstone	11	0.006244156	5	0.01[1]	2.289779×10^{-6}	-
Tomago Coal Measures	12	0.01	5.45374	0.01[1]	4.409449×10^{-7}	-

Note:

1. Value not changed as part of calibration

Recharge expressed in percent of observed rainfall

Table 3-6 Calibrated evapotranspiration parameters

Evapotranspiration zone	Evapotranspiration extinction depth (m)	Evapotranspiration rate (m/day)
Forest and woodland	1.428	0.0016438
Grassland and cleared vegetation	1.0	0.0016438
Urban and developed areas	0.5	0.0016438

Note: evapotranspiration extinction depth not adjusted as part of calibration

Calibrated model parameters are generally similar (within an order of magnitude) to observed material parameters discussed in Section 2.1.11. The most notable discrepancy is for the West Borehole seam, where calibrated hydraulic conductivity is approximately one to two orders of magnitude lower than material properties discussed in Section 2.1.11. However, the calibrated hydraulic conductivity value for the West Borehole seam is within the range of values reported for other seams within the Newcastle Coal Measures (refer Section 2.1.11).

Figure 3-6 presents a scatter plot of observed and computed heads. The root mean squared (RMS) error is 6.4 m and the SRMS is 8.3%, within the 10% target typically adopted for modelling projects. Figure 3-6 provides a split based on each of the main HSUs and indicates a reasonable match between observed and modelled heads for all HSUs. The model is generally under predicting groundwater heads reported at VWPs CN036 and CN038 within the West Borehole seam in the vicinity of existing Newstan mine workings. These VWPs are no longer operational and therefore it is difficult to verify the reliability of the data from these VWPs.

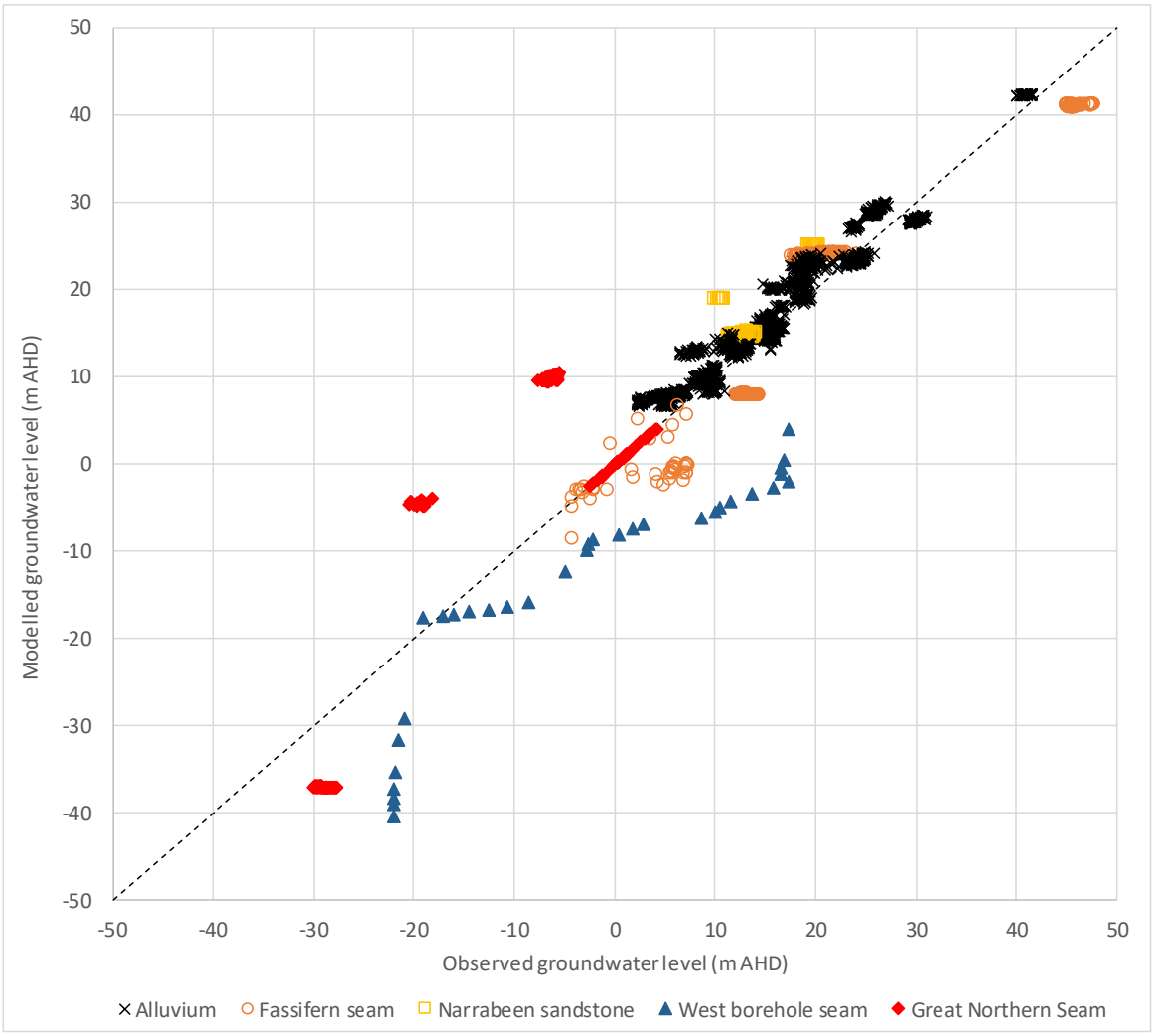


Figure 3-6 Calibration scatter plot

Calibration hydrographs, residual summary, residual histogram and residual plot are presented in Appendix D.

Model calibration has provided replication of both climate induced trends as well as drawdown from Newstan Colliery and Cooranbong (refer to hydrographs in Appendix D). While modelled heads replicate climate induced trends, modelled trends are not as pronounced as observed trends.

Observed groundwater levels at MB19 are influenced by the Fassifern Underground Storage. Varying GHBs in the Fassifern Underground Storage in the transient calibration model has resulted in a good fit between observed and modelled groundwater levels at MB19.

3.6.4 Modelled groundwater inflows

Modelled groundwater inflows into the Newstan Colliery West Borehole seam workings over the calibration period are plotted in Figure 3-7. Inflows have been reported for the mid-point of each stress period. Modelled inflows have been plotted for LW's 22-25 and for the whole of the West Borehole seam workings. As discussed in Section 2.1.10, based on metered flows through the Newstan Colliery water treatment plant, current groundwater inflow into the Newstan Colliery West Borehole seam workings is approximately 1 ML/day. Additionally, as discussed in Section 2.1.10, Centennial Newstan has installed a flow meter down dip of LW's 22-25. Metered data indicates flows into this block of longwalls are constant at 255 kL/day.

As shown in Figure 3-7, the calibrated model is overestimating mine inflows. Current (July 2019) modelled mine inflows into the whole of the West Borehole seam is 2.55 ML/day compared to observed inflows of 1 ML/day, while current (July 2019) modelled mine inflows into LW's 22-25 is 428 kL/day compared to current observed inflows of 255 kL/day. There was no significant rainfall during the period of monitoring inflows into LW22-25.

One possible reason for the overestimation of mine inflows is that the adopted height of depressurisation of 140 m above existing Newstan longwalls panels is larger than the actual height of continuous fracturing. Nevertheless, a height of 140 m was retained for the predictive modelling since it is within the range calculated using the Tammetta (2012) formula (at the lower end of this range).

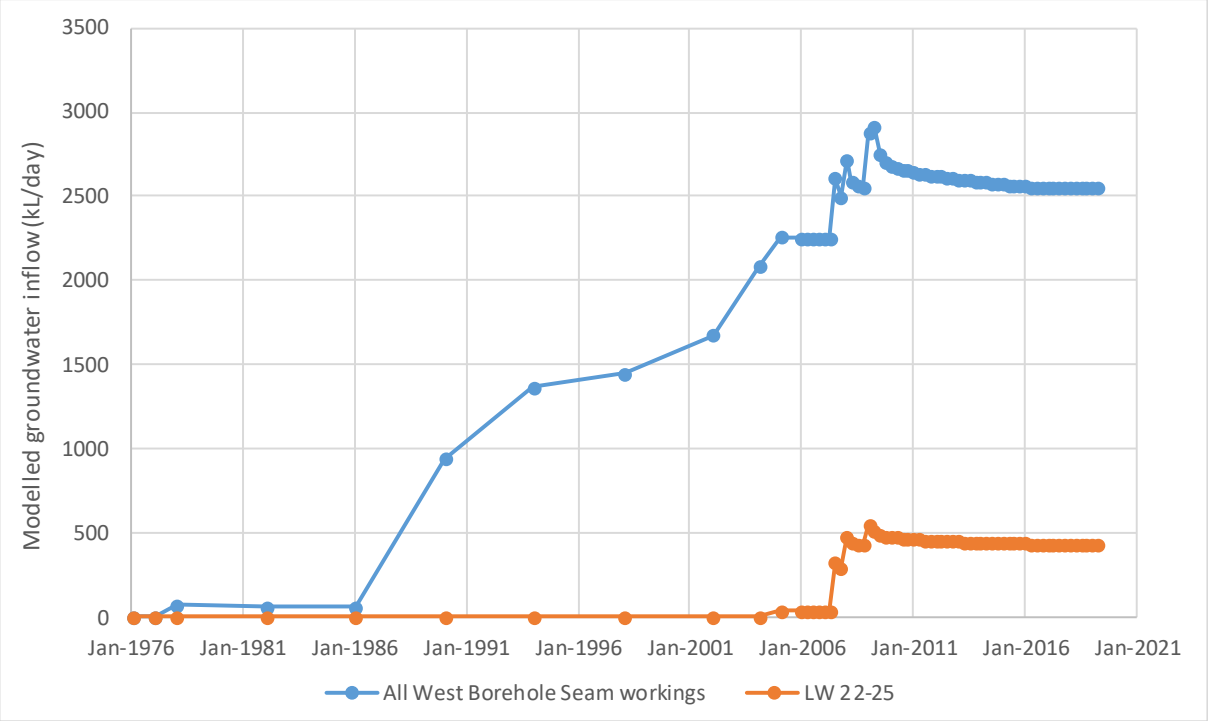


Figure 3-7 Modelled mine inflows

3.6.5 Calibration phase flow budget

Table 3-7 and Table 3-8 present the flow budget for the steady-state and transient calibration models. A cumulative water balance error of less than 0.01% was recorded for the steady-state model and for the transient model, well below the target of 1%.

Table 3-7 Steady-state calibration model flow budget

Component	Flow (m^3/day)
Inflow	
External boundary inflow	20,872
Lake Macquarie leakage	16,245
Recharge	21,751
Total	58,868
Outflow	
Evapotranspiration	46,669
External boundary outflow	3,384
Outflow to Lake Macquarie	8,778
Rivers	38
Total	58,869

Table 3-8 Transient calibration model flow budget

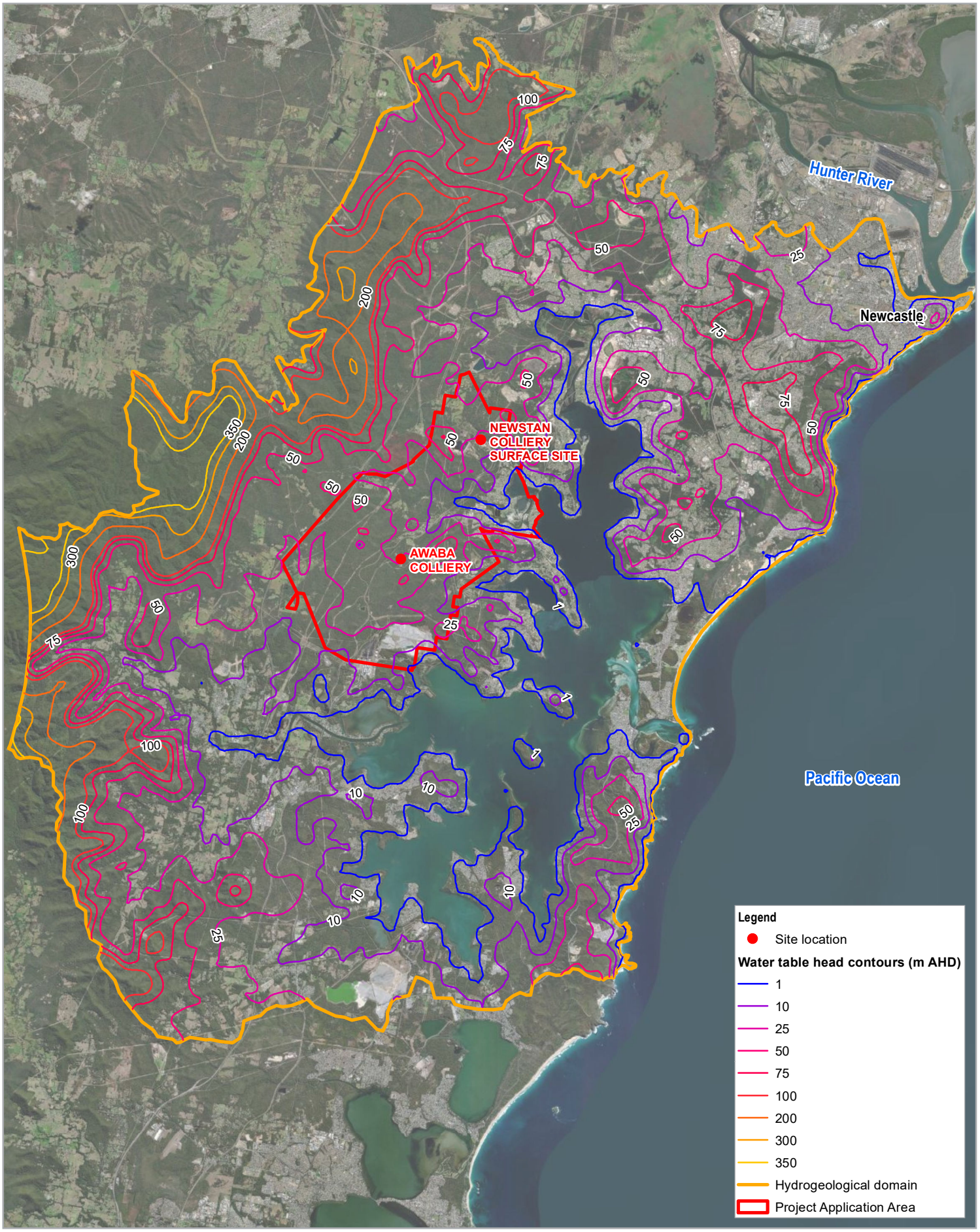
Component	Average flow (m^3/day)
Inflow	
Storage	9438
External boundary inflow	23993
Lake Macquarie leakage	24485
Recharge	21977
Awaba leakage	132
Fassifern Underground Storage leakage	43
Total	**80068**
Outflow	
Storage	2431
Mine inflow – Teralba, West Wallsend and Cooranbong	2499
Mine inflow – Awaba	341
Mine inflow – Newstan Colliery Great Northern seam workings	91
Mine inflow – Newstan Colliery Fassifern seam workings	24
Mine inflow – Newstan Colliery West Borehole seam workings	5101
Evapotranspiration	57547
External boundary outflow	3203
Outflow to Lake Macquarie	8680
Rivers	0
Awaba storage outflow	36
Fassifern Underground Storage outflow	114
Total	**80068**

On the basis of the calibration results, the model has been considered suitably calibrated.

As presented in Table 3-7 and Table 3-8, inflow is dominated by a combination of rainfall recharge, leakage from Lake Macquarie and inflow from external boundaries. Outflow is dominated by evapotranspiration and outflow to Lake Macquarie. Outflow to rivers (or baseflow) is very small in comparison to other outflow components.

3.6.6 Modelled groundwater contours

A contour plot showing the modelled water table at the end of the calibration period has been generated using the calibrated model. The contour plot is shown in Figure 3-8. The modelled water table contours indicate that groundwater flow direction generally reflects the topography. Water table head is elevated along catchment boundaries and decreases towards creek lines and Lake Macquarie. This is consistent with the conceptualisation of shallow groundwater levels discussed Section 2.1.6.



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Water table head
End of calibration period

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE 3-8

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-024_ModelledWaterTable_EndofCalibration.mxd
Print date: 24 Mar 2020 - 11:08

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald

4. Predictive simulations

4.1 Overview

The purpose of predictive modelling is to predict future groundwater conditions at and surrounding Newstan Colliery, including inflow rates into the mine, the magnitude and extent of drawdown of piezometric heads and change in groundwater flow conditions.

The predictive model utilises the calibrated model described in Section 3.6.

4.2 Predictive model set-up

The mine plan provided by Centennial Newstan indicates that mining at Newstan Colliery will resume in the year 2020 and will continue up to the end of 2034. First workings only are undertaken in 2020. The predictive model was run from the end of the calibration model in July 2019 to January 2635; 600 years after the end of mining. This was undertaken to allow assessment of impacts of proposed mining and assessment of post-mining recovery of groundwater levels.

The predictive model was run with:

- One 6 month stress period from July 2019 to January 2020.
- Annual stress periods from January 2020 to the end of 2034.

After the end of mining this was followed by:

- 20 one-year stress periods from January 2035 to end of 2054.
- 10 two-year stress periods from January 2055 to end of 2074.
- 12 five-year stress periods from January 2075 to end of 2134.
- Four ten-year stress periods from January 2135 to end of 2174.
- Three 20-year stress periods from January 2175 to end of 2234.
- Eight 50-year stress periods from January 2235 to end of 2664.

A summary of the stress periods is provided in Appendix C.

Proposed mining was simulated by progressively assigning drain cells in accordance with the mining sequence provided by Centennial Newstan. To simplify the assignment of drain cells, it was assumed that bord and pillar extraction and panel extraction occurred simultaneously.

The proposed mine workings are to be undertaken in the Extension of Mining Area shown in Figure 1-2. First workings will commence in the north-eastern portion of the Extension of Mining Area by developing the mains in a south-west orientation. Each panel will be developed south from the mains, with the mains and associated panels being extended progressively from east to west through the Extension of Mining Area. Partial and full extraction of the panels will generally be undertaken in a sequential manner from east to west, excluding areas where only first workings are proposed. This will be followed by the partial and full extraction of the mains from west to east, again, excluding areas where only first workings are proposed.

As detailed in Section 2.2.5, the height of continuous fracturing (i.e. the Zone A height of fracturing above the panel areas) was assigned as 140 m based on model calibration. This is at the lower end of the range calculated using Tammetta (2012). A height of continuous fracturing of 140 m corresponds to drainage extending into either Layer 8 or Layer 7 of the model.

In areas where proposed workings are bord and pillar workings only, mining was simulated by progressively assigning drain cells to Layer 10 (West Borehole seam) only. In areas of panel extraction, mining was simulated by assigning drain cells from Layer 10 up to and including either Layer 8 or Layer 7. Drain elevations were set to 0.1 m above the cell bottom. Drain conductance was adopted as per the calibration period model, discussed in Section 3.5.4.

The predictive model used constant recharge rates, assigned based on the percentage of long-term average rainfall utilised in the calibration model. The predictive model evapotranspiration was applied as per the model calibration. During proposed mining, the GHB elevation of the Fassifern Underground Storage was set to 0 m AHD and the GHB elevation of Awaba was set to 15.768 m AHD. These GHB elevations are based on typical underground water levels in these storages. Additionally the GHB elevation for Awaba is equal to the current water level in the Awaba storage as shown in Figure 3-4.

It has been assumed that after the end of mining, dewatering of the mine workings will cease. Therefore drain cells were deactivated at the end of mining (end of 2034). Horizontal hydraulic conductivity of layers within the zone of continuous fracturing above existing and proposed Newstan workings (i.e. up to a height of 140 m), as well as within the Newstan mine workings, were increased by 100 times for the post mining model. It was also assumed that at the end of mining, management of groundwater levels in the Fassifern Underground Storage would cease and groundwater levels would be allowed to re-equilibrate. Therefore GHBs in the Fassifern Underground Storage were turned off at the end of mining (end of 2034). It was assumed that Awaba would remain at a constant water level after the end of mining. Therefore GHBs in Awaba were not deactivated at the end of mining. After the end of mining the GHB elevation of Awaba was maintained at 15.768 m AHD.

Mining at Mandalong Mine to the south of Newstan Colliery is proposed to be completed at the end of 2036. Therefore drain cells at Cooranbong were deactivated at the end of 2036.

The initial heads for the operational phase model were based on the piezometric heads computed at the end of the calibration phase model.

4.3 Model scenarios

To enable the assessment of impacts a number of models representing various baseline conditions were developed. To assess incremental impacts associated with proposed mining, a ‘no proposed mining’ scenario was developed. The ‘no proposed mining’ scenario does not simulate any proposed mining at Newstan Colliery. The ‘no proposed mining’ scenario includes all existing mining at Newstan Colliery, Teralba, West Wallsend, Awaba and Cooranbong. In this scenario existing Newstan Colliery workings are kept in care and maintenance until end of 2034 (end of mining). GHB elevations were set as per the predictive model set-up discussed in Section 4.2.

To assess cumulative impacts a ‘no regional mining’ model was developed, where all mining within the model boundary was not represented. A description of the model scenarios is provided in Table 4-1.

Impacts were assessed by comparing results of these model runs with the predictive model run. Note the predictive model run includes existing and proposed mine workings.

Table 4-1 Model scenarios

Modelling period	Predictive model	No proposed mining	No regional mining
Initial heads	Steady state model		
Calibration period	Simulates existing workings at Newstan Colliery and mining at Teralba, West Wallsend, Awaba and Cooranbong		Does not simulate any existing mine workings.
Predictive model Proposed mining: Jan 2020 – Jan 2035 Post closure: Jan 2035 – Jan 2665	Simulates proposed workings at Newstan Colliery.	Does not include proposed mining at Newstan Colliery. Existing workings at Newstan Colliery remain dewatered.	Does not simulate any proposed mining.

Note to table: No mining is simulated for the post closure phase, with the exception of Cooranbong. Mining at Cooranbong finishes at the end of 2036 as discussed in Section 4.2.

5. Model predictive results

Model results are presented and discussed in this section.

5.1 Flow budget

The key aspects of the predictive model flow budget for the proposed mining and post-closure are presented in Table 5-1 according to year.

For comparison the key aspects of the model flow budget for the no proposed mining scenario are shown in Table 5-2.

The magnitude of impact on the flow budget due to proposed mining is shown in Table 5-3.

Table 5-1 Predictive model flow budget

Flow term	Flow budget by year (m^3/day)					
Year	2020	2029	2034	2044	2134	2634
Inflow						
Storage	44664	22353	17867	11110	1381	13
External boundary inflow	18573	18774	18889	18794	18709	18741
Lake Macquarie leakage	17189	17902	18016	18144	18360	18377
Recharge	21751	21751	21751	21751	21751	21751
Awaba leakage	46	44	45	29	40	41
Fassifern Underground Storage leakage	2	2	2	0	0	0
Total	102225	80826	76570	69828	60241	58923
Outflow						
Storage	1113	306	188	2589	653	86
Mine inflow – Cooranbong	622	590	575	0	0	0
Mine inflow – Newstan Colliery Great Northern seam workings	225	171	147	0	0	0
Mine inflow – Newstan Colliery West Borehole seam workings	2924	3996	3819	0	0	0
ET	80310	61560	58148	54181	47351	46589
External boundary outflow	3812	3401	3326	3261	3308	3407
Outflow to Lake Macquarie	12781	10421	10026	9584	8849	8773
Awaba storage outflow	347	290	257	213	79	66
Fassifern Underground Storage outflow	92	90	83	0	0	0
Baseflow	0	0	0	0	0	0
Total	102226	80825	76569	69828	60240	58921

Note:

ET: evapotranspiration

2020 relates to the first year of proposed workings, 2029 is year of peak groundwater inflow (refer to Section 5.3), 2034 is the last year of mining. 2044, 2134 and 2634 relate to 10, 100 and 600 years post closure.

Awaba storage outflow refers to outflow from the model via the GHBs that represent the Awaba storage.

Fassifern Underground Storage outflow refers to outflow from the model via the GHBs that represent the Fassifern Underground Storage.

Table 5-2 No proposed mining scenario – flow budget

Flow term	Flow budget by year (m^3/day)					
Year	2020	2029	2034	2044	2134	2634
Inflow						
Storage	44568	21259	17017	10939	1360	14
External boundary inflow	18573	18723	18765	18702	18709	18740
Lake Macquarie leakage	17189	17902	18016	18145	18359	18376
Recharge	21751	21751	21751	21751	21751	21751
Awaba leakage	46	43	44	28	36	39
Fassifern Underground Storage leakage	2	2	2	0	0	0
Total	102129	79680	75595	69565	60215	58920
Outflow						
Storage	1117	327	205	2271	545	55
Mine inflow – Cooranbong	622	590	576	0	0	0
Mine inflow – Newstan Colliery Great Northern seam workings	225	171	147	0	0	0
Mine inflow – Newstan Colliery West Borehole seam workings	2824	2814	2792	0	0	0
ET	80310	61562	58153	54198	47382	46603
External boundary outflow	3812	3408	3337	3279	3340	3413
Outflow to Lake Macquarie	12781	10421	10026	9584	8850	8774
Awaba storage outflow	347	299	275	232	98	74
Fassifern Underground Storage outflow	92	90	83	0	0	0
Baseflow	0	0	0	0	0	0
Total	102130	79682	75594	69564	60215	58919

Note:

ET: evapotranspiration

2020 relates to the first year of proposed workings, 2029 is year of peak groundwater inflow (refer to Section 5.3), 2034 is the last year of mining. 2044, 2134 and 2634 relate to 10, 100 and 600 years post closure.

Table 5-3 Changes to the flow budget due to proposed mining

Flow term	Flow budget by year (m^3/day or %)					
Year	2020	2029	2034	2044	2134	2634
Inflow						
Storage	96	1094	850	171	21	-1
External boundary inflow	0	51	124	92	0	1
	0%	0.3%	0.7%	0.5%	0%	0.0%
Lake Macquarie leakage	0	0	0	-1	1	1
	0%	0%	0%	0.0%	0.0%	0.0%
Recharge	0	0	0	0		
Awaba leakage	0	1	1	1	4	2
	0%	2.3%	2.3%	3.6%	11.1%	5.1%
Fassifern Underground Storage leakage	0	0	0	0	0	0
Outflow						
Storage	-4	-21	-17	318	108	31
Mine inflow – Cooranbong	0	0	-1	0	0	0
Mine inflow – Newstan Colliery Great Northern seam workings	0	0	0	0	0	0
Mine inflow – Newstan Colliery West Borehole seam workings	100	1182	1027	0	0	0
	3.5%	42.0%	36.8%	0%	0%	0%
ET	0	-2	-5	-17	-31	-14
	0.0%	0.0%	0.0%	0.0%	-0.1%	0.0%
External boundary outflow	0	-7	-11	-18	-32	-6
	0%	-0.2%	-0.3%	-0.5%	-1.0%	-0.2%
Outflow to Lake Macquarie	0	0	0	0	-1	-1
	0%	0%	0%	0%	0.0%	0.0%
Awaba storage outflow	0	-9	-18	-19	-19	-8
	0%	-3.0%	-6.5%	-8.2%	-19.4%	-10.8%
Fassifern Underground Storage outflow	0	0	0	0	0	0
Baseflow	0	0	0	0	0	0

Note:

ET: evapotranspiration

2020 relates to the first year of proposed workings, 2030 is year of peak groundwater inflow (refer to Section 5.3), 2034 is the last year of mining. 2044 relates to 10 years post closure.

Impacts are calculated as: proposed mining model – no proposed mining

Units are m^3/day unless marked as %

The flow budget indicates the following:

- The dominant outflow is via evapotranspiration, accounting for 70% to 80% of model outflow for both the proposed mining and no proposed mining scenarios.

- With the exception of changes to mine inflow to the Newstan Colliery workings, the most notable impact on the water balance due to proposed mining is changes in outflow to the Awaba storage. This change is attributable to groundwater drawdown in the vicinity of Awaba due to mining.
- No change to baseflow to rivers is predicted.

5.2 Predicted effect on piezometric heads

Contours of predicted drawdown of the Layer 1 water table and piezometric heads in the Great Northern seam (Layer 4), Fassifern seam (Layer 6) and the West Borehole seam (Layer 10) are presented in Appendix E. Drawdown contours have been calculated for end of mining conditions at Newstan Colliery. Drawdown attributable to proposed mining have been calculated. This has been calculated as the difference between groundwater heads for the proposed mining scenario and the 'no proposed mining scenario'. Cumulative drawdown has been calculated as the difference between the proposed mining scenario and the 'no regional mining' scenario.

As shown in Figure E-1, cumulative drawdown in the alluvium and regolith is centred on Newstan Colliery workings in the Great Northern seam, Cooranbong and Awaba workings. Note that all these workings are located in the Great Northern seam. Drawdown in Layer 1 is likely attributable to the lower depth of cover above the Great Northern seam.

Model results predict there will be no drawdown in the alluvium and shallow regolith (Layer 1 of the model) due to the proposed mine workings.

Cumulative modelled drawdown in the Great Northern seam is also centred on Newstan Colliery workings in the Great Northern seam, Cooranbong and Awaba workings. As shown in Figure E-2, cumulative drawdown in the Great Northern seam is greatest above existing workings.

Drawdown in the Great Northern seam at the end of mining attributable to the proposed workings is shown in Figure E-6. Drawdown in the Great Northern seam attributable to proposed workings is negligible. It is not considered that the GHB applied to the Awaba Colliery workings has influence drawdown predictions due to the proposed workings since mining in the Extension of Mining Area does not result in an increase in leakage from the Awaba Colliery workings to underground strata (refer Section 5.5).

Cumulative modelled drawdown in the Fassifern seam is similar to cumulative modelled drawdown in the Great Northern seam. As shown in Figure E-3, cumulative drawdown in the Fassifern seam is greatest above existing workings. Cumulative drawdown in the Fassifern seam is predominantly centred over Awaba, existing workings at Newstan Colliery in the Fassifern seam and Cooranbong.

Drawdown in the Fassifern seam at the end of mining, attributable to the proposed workings is shown in Figure E-7. Drawdown attributable to proposed workings is greatest above areas of panel extraction.

Cumulative modelled drawdown in the West Borehole seam is shown in Figure E-4. Drawdown in the West Borehole seam is centred on the Newstan Colliery workings. The radius of drawdown predominantly extends to the north, north-east and north-west of the workings. The radius of drawdown extends up to approximately 14 km to the south of the West Borehole seam workings and extends to the northern, eastern and southern model boundaries. This is considered due to the low storage and hydraulic conductivity and low seepage from the overlying strata. Drawdown at the model boundary is generally low, and interaction with the model boundary is generally facilitated through a general head boundary (with the exception of the north where there is a no flow boundary due to the outcropping of the coal seam); and consequently it is unlikely that predicted impacts within the model domain are restricted by the boundary conditions applied.

Drawdown in the West Borehole seam, attributable to the proposed workings is shown in Figure E-8. The radius of drawdown attributable to proposed workings extends up to approximately 9.5 km to the north-east and approximately 11 km to the south of the proposed workings.

In order to assess the recovery of piezometric head after the end of mining, drawdown in the West Borehole seam, attributable to the proposed workings, 100 years after the end of mining is shown in Figure E-9. The drawdown contours indicate that piezometric head has largely recovered within 100 years of the end of mining. The maximum magnitude of drawdown in the West Borehole Seam due to the proposed workings has reduced from over 150 m to less than 3 m within 100 years of the end of mining. As shown in Figure E-9 the radius of drawdown within the West Borehole seam, 100 years after the end of mining extends up to approximately 5.8 km from the proposed workings.

5.3 Predicted groundwater inflow rate

The groundwater inflow rates are derived from modelled drain inflows for the operational phase of mining. The predicted groundwater inflow into the West Borehole seam at Newstan Colliery is presented in Figure 5-1. As drain cells are activated at the start of each stress period, large areas of the mine are assumed to be instantaneously depressurised by the drain cells. Therefore groundwater inflow has been calculated for each year as average drain inflows calculated using all time steps.

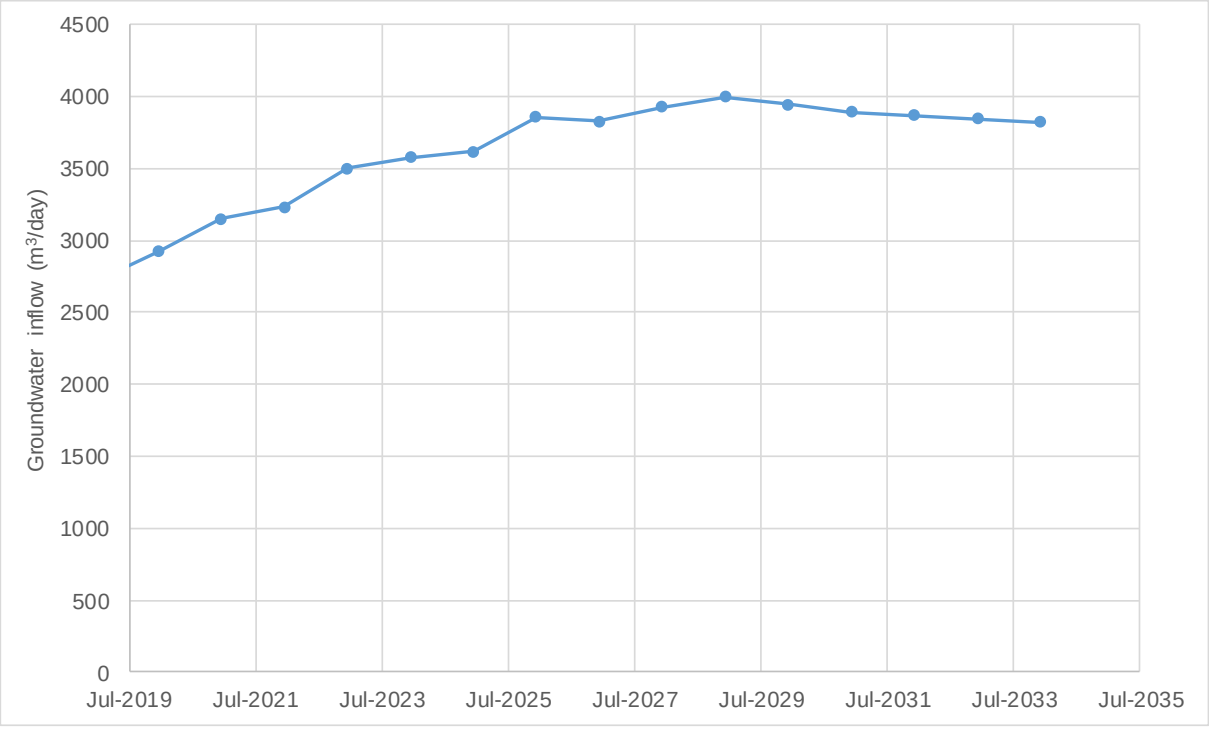


Figure 5-1 Modelled Newstan Colliery West Borehole seam groundwater inflows

Groundwater inflows are modelled to increase from 2.8 ML/day under current conditions to a peak of 4.0 ML/day in 2029. Groundwater inflows are modelled to slightly decrease to 3.8 ML/day in the final year of mining.

Since the calibrated model over-predicts existing groundwater inflows into the West Borehole seam at Newstan, it is likely that the predicted groundwater inflows are conservative.

5.4 Eraring Ash Dam

The net leakage from the Eraring Ash Dam has been extracted from the cell-by-cell flow output. The results are shown in Figure 5-2.

The results show that there is no difference in net leakage out of the Eraring Ash Dam for the proposed and null scenarios. Therefore, modelling results indicate proposed mining at Newstan Colliery will have no impact on leakage out of the Eraring Ash Dam. Additionally the groundwater model has not taken into account the potential for pillar failure at Awaba.

Modelled leakage out of the Eraring Ash Dam reflects changes in rainfall recharge. As discussed in Section 4.2, rainfall recharge was set to a constant value for the predictive model period. Therefore, modelled leakage out of the Eraring Ash Dam is constant throughout the prediction and post-closure period of modelling (from July 2019 onwards).

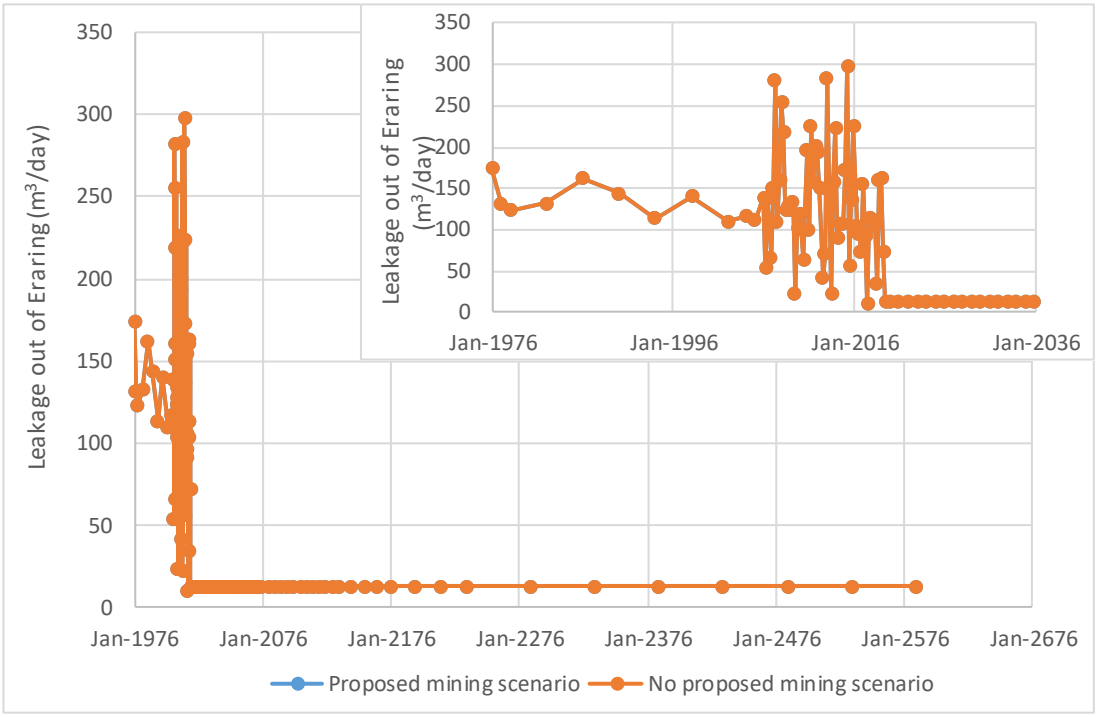


Figure 5-2 Net leakage from Eraring Ash Dam

5.5 Awaba workings

Net groundwater flow into Awaba has been extracted from the cell-by-cell flow output and is plotted in Figure 5-3.

The results show that there is a modelled net groundwater flow into Awaba for existing conditions and throughout the period of proposed mining. The results show that proposed mining at Newstan Colliery is modelled to result in a slight reduction in groundwater inflow into Awaba. Note that during the period of proposed mining the GHB elevation of Awaba was set to a constant elevation. The reduction in groundwater inflow into Awaba is attributable to groundwater drawdown in the strata surrounding Awaba due to mining in the West Borehole seam.

The impact on groundwater inflow to Awaba continues after the end of mining. The maximum discrepancy in groundwater inflows into Awaba between the proposed and null scenarios is 22 m^3/day and occurs between the year 2063 and the year 2175.

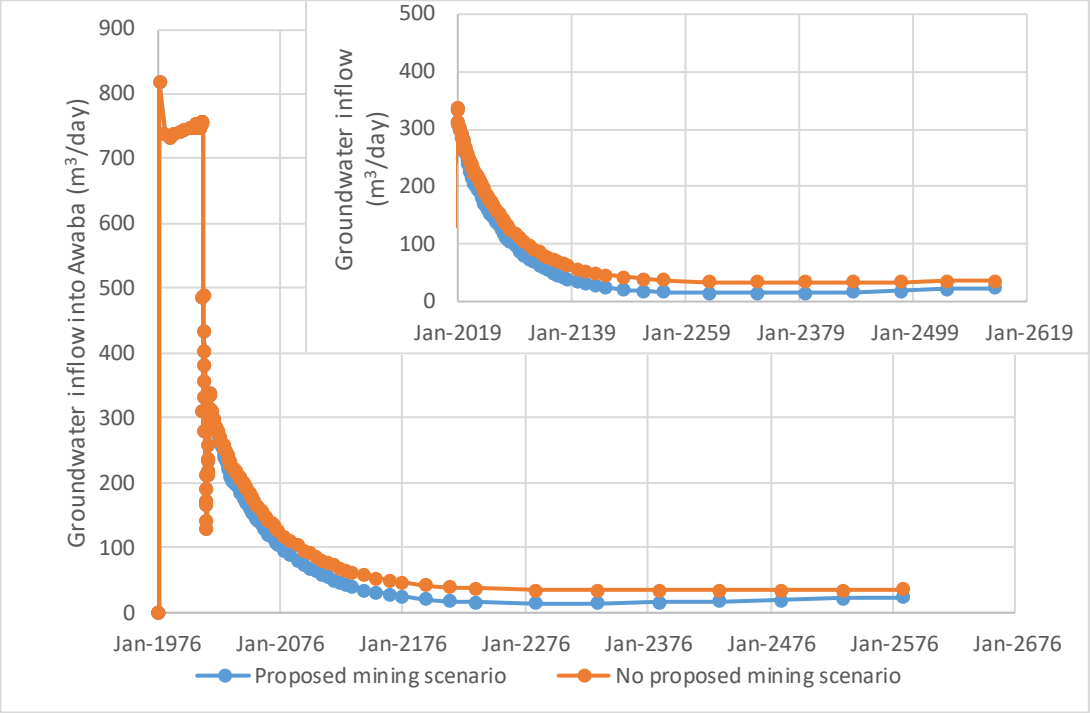


Figure 5-3 Net groundwater flow into Awaba

5.6 Fassifern underground storage

Net groundwater flow into the Fassifern Underground Storage has been extracted from the cell-by-cell flow output and is plotted in Figure 5-4.

The results show that there is a modelled net groundwater flow into the Fassifern Underground Storage for existing conditions and throughout the period of proposed mining. The results show that there is no difference in net groundwater flow into the Fassifern Underground Storage due to proposed mining.

Groundwater inflow into the Fassifern Underground Storage reflects the timeline of mining related activities at the Fassifern Underground Storage. From the start of the transient calibration model to the mid-1990s, groundwater inflow into Fassifern workings is influenced by mining. The results indicate an approximate equilibrium in groundwater inflows from 1992 to 2011. As discussed in Section 4.2, in 2011 the Fassifern Underground Storage started to flood and GHB's were activated in the Fassifern Underground Storage to simulate the managed water level in the Fassifern Underground Storage. From 2011 to July 2019, groundwater flow into the Fassifern Underground Storage is influenced by the GHB elevation. During the predictive modelling phase, the GHB elevation was fixed at 0 m AHD for the period of proposed mining and therefore inflows into the Fassifern Underground Storage are relatively constant over this period.

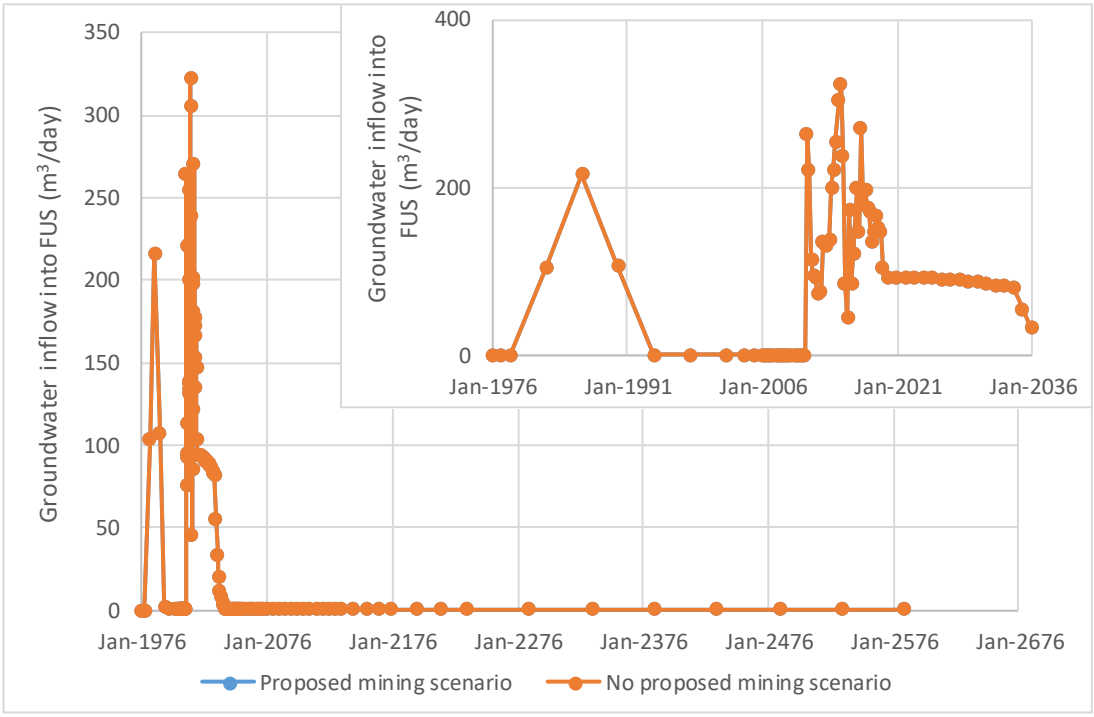


Figure 5-4 Net groundwater flow into Fassifern Underground Storage

5.7 Groundwater seepage

Likely changes in groundwater seepage at Newstan Colliery has been reviewed and the potential for new seepage areas has been assessed.

SCT (2019) identified that a preferential flow path may form between the flooded Awaba Colliery workings and the proposed West Borehole Seam workings due to fracturing of the interburden due to proposed mining. This preferential pathway would result in depressurisation of the Awaba Colliery workings and a reduction in Awaba seepage. As discussed in Section 2.2.5, limited connection has been observed between the existing Newstan workings and Awaba. Therefore a preferential flow path between Awaba and the proposed workings is considered to be unlikely. Therefore it is considered unlikely that the Awaba seepage will cease due to the proposed mining.

However, as discussed in Section 5.5, some reduction in groundwater inflow into the Awaba workings due to drawdown in the Great Northern seam. The maximum reduction in groundwater inflow to the Awaba workings is predicted to be 22 m^3/day. Therefore there may be some reduction in the Awaba seepage. This is further assessed in the water balance assessment in GHD (2020b).

Post mining water table has been reviewed to identify changes in potential areas of seepage following mining. The post mining water table has been plotted for 600 years following the end of mining and from the predicted heads from a post-mining steady state run. The post-mining steady state run includes changes in material properties associated with the underground void and goaf. Post mining water table 600 years after the end of mining is shown in Figure E-10 and post mining steady state water table is shown in Figure E-11.

As shown in Figure E-10 and Figure E-11, the post-mining water table is similar to the modelled water table at the end of calibration, shown in Figure 3-8. Therefore there is no increase in the predicted area of groundwater seepage due to the proposed workings. Additionally, comparison of post-mining water table shown in Figure E-10 and Figure E-11 and topography (refer Figure 2-4) indicates that the water table remains at least 1 m below the ground surface throughout the Project Application Area. This indicates that additional groundwater seepage post-mining is unlikely.

5.8 Uncertainty analysis

Uncertainty analysis for hydrogeological model predictions has been undertaken in accordance with the requirements *Information guidelines for proponents preparing coal seam gas and large coal mining development proposals* (IESC, 2018a) and the *Explanatory Note on Uncertainty Analysis in Groundwater Modelling* (IESC, 2018b).

IESC (2018b) outlines three general approaches to uncertainty analysis with respect to groundwater modelling and these, in order of increasing complexity and computational resource requirements, are: *'(1) scenario analysis with subjective probability, (2) deterministic modelling with linear probability quantification and (3) stochastic modelling with Bayesian probability'*.

Based on the understanding of the groundwater environment within the Newcastle Coalfield, from previous groundwater modelling conducted at Newstan and other sites such as Mandalong, as well as the field hydraulic conductivity testing outlined in Section 2.1.11, it is considered that the uncertainty with regard to aquifer material properties is generally low and the risk of this uncertainty impacting model predictions is low. Therefore it is considered that the 'scenario analysis with subjective probability' or Level 1 approach to uncertainty analysis is sufficient for this groundwater model. The results of the Level 1 uncertainty analysis are outlined in this section. Nevertheless, it is acknowledged that the existing groundwater monitoring within the Extension of Mining Area is spatially limited and therefore some additional uncertainty analysis based on the Level 3 approach has been undertaken. Results of the Level 3 uncertainty analysis are appended as Appendix H.

Based on the Level 1 methodology, 14 uncertainty runs were considered as part of uncertainty analysis. In each of these uncertainty runs, model parameters were varied. The hydrogeological model was run for each uncertainty run under steady state and transient conditions. Model parameters were adopted as per Table 3-5 with parameters varied in each uncertainty run are summarised below:

- Uncertainty run 1: increased horizontal hydraulic conductivity of the West Borehole seam (Layer 10) to 0.01 m/day (which is the highest value within the range of values as part of model calibration shown in Table 3-4). Vertical anisotropy of the West Borehole seam remained unchanged.
- Uncertainty run 2: increased specific storage throughout the model to 0.000013 m^{-1}.
- Uncertainty run 3: increased horizontal hydraulic conductivity of the West Borehole seam (Layer 10) to 0.01 m/day (which is the highest value within the range of values as part of model calibration shown in Table 3-4). Vertical anisotropy of the West Borehole seam remained unchanged. Increased specific storage throughout the model to 0.000013 m^{-1}.
- Uncertainty run 4: modified specific storage of all Permian layers (Layer 4 to Layer 11) to 2.3 x 10^{-7} m^{-1}.
- Uncertainty run 5: Increase hydraulic conductivity of the Permian interburden (Layers 7 to 9). Horizontal hydraulic conductivity was increased to 0.001 m/day. Vertical anisotropy remained unchanged.

- Uncertainty run 6: increased horizontal hydraulic conductivity of Narrabeen Sandstone (Layer 2) to 0.01 m/day. Vertical anisotropy of the Narrabeen Sandstone remained unchanged.
- Uncertainty run 7: increased horizontal hydraulic conductivity of the regolith (Layer 1 and 2) to 1 m/day. Vertical anisotropy of the regolith remained unchanged.
- Uncertainty run 8: decreased horizontal hydraulic conductivity of the regolith (Layer 1 and 2) to 0.01 m/day. Vertical anisotropy of the regolith remained unchanged.
- Uncertainty run 9: increased horizontal hydraulic conductivity of the alluvium to 10 m/day. Vertical anisotropy of the alluvium remained unchanged.
- Uncertainty run 10: decreased horizontal hydraulic conductivity of the alluvium to 1 m/day. Vertical anisotropy of the alluvium remained unchanged.
- Uncertainty run 11: increased rainfall recharge to 3% of historical rainfall for areas where fractured and porous rock outcrops. Increased rainfall recharge to 6% of historical rainfall for alluvium.
- Uncertainty run 12: decreased rainfall recharge to 1% of historical rainfall for alluvium. Rainfall recharge remained constant in areas where fractured and porous rock outcrops.
- Uncertainty run 13: increased horizontal hydraulic conductivity of Narrabeen Sandstone (Layer 2) to 0.01 m/day. Vertical anisotropy of the Narrabeen Sandstone remained constant. Increased horizontal hydraulic conductivity of the regolith (Layer 1 and 2) to 0.5 m/day. Vertical anisotropy of the regolith remained constant. Increased horizontal hydraulic conductivity of the alluvium to 10 m/day. Vertical anisotropy of the alluvium remained constant.
- Uncertainty run 14: decreased horizontal hydraulic conductivity of the regolith (Layer 1 and 2) to 0.01 m/day. Vertical anisotropy of the regolith remained constant. Decreased horizontal hydraulic conductivity of the alluvium to 1 m/day. Vertical anisotropy of the alluvium remained constant.

Parameters modified as part of the uncertainty analysis were selected with consideration of the likely sensitive model parameters. These parameters were determined based on experience and were subject to critique by the third party reviewer, as required by the NSW Aquifer Interference Policy (DPI, 2012). Model parameters were increased or decreased to provide a range of estimated groundwater inflows.

Model results were analysed to identify potential changes to impacts on groundwater receptors. Calibration statistics were reviewed for each uncertainty run. Calibration statistics were used to identify the likelihood of selected parameters of each uncertainty run occurring. Model calibration statistics are shown in Table 5-4.

Table 5-4 Uncertainty analysis – transient model calibration statistics

Model run	Root Mean Squared Error (m)	Scaled Root Mean Squared Error
Best fit model run	6.4	8.3%
Uncertainty run 1	6.8	8.7%
Uncertainty run 2	7.2	9.2%
Uncertainty run 3	6.7	8.6%
Uncertainty run 4	7.0	9.0%
Uncertainty run 5	Did not converge	Did not converge
Uncertainty run 6	7.5	9.6%
Uncertainty run 7	Did not converge	Did not converge
Uncertainty run 8	6.7	8.6%

Model run	Root Mean Squared Error (m)	Scaled Root Mean Squared Error
Uncertainty run 9	6.4	8.4%
Uncertainty run 10	6.5	8.4%
Uncertainty run 11	7.8	10.0%
Uncertainty run 12	6.6	8.5%
Uncertainty run 13	7.2	9.3%
Uncertainty run 14	6.6	8.5%

All uncertainty analysis runs did not result in large changes in calibration statistics. Uncertainty runs that included changing rainfall recharge (run 11), increasing specific storage throughout the model (run 2) and increasing the hydraulic conductivity of Narrabeen Sandstone, alluvium and regolith (run 13) resulted in the largest changes in calibration statistics.

The modelled groundwater inflows into the Newstan Colliery West Borehole seam workings for each of the uncertainty analysis runs have been compared with modelled groundwater inflows for the best fit model scenario and are shown in Figure 5-5. Modelled groundwater inflows are considerably higher than the best fit model run for uncertainty run 1, 2 and 3 with results for run 3 similar to the 90th percentile inflows reported in Appendix H. This indicates that groundwater inflows into the West Borehole Seam may be sensitive to model values for horizontal hydraulic conductivity of the West Borehole seam and specific storage. It is noted that the modelled groundwater inflows into the Newstan Colliery West Borehole seam workings for the best fit model run are similar to the 50th percentile inflows from the Level 3 uncertainty analysis reported in Appendix H.

As discussed in Section 3.6.4, groundwater inflows into the Newstan Colliery West Borehole seam workings are approximately 1 ML/day. Therefore, predictions of mine inflows for the best fit model scenario and the uncertainty analysis runs are considered conservative.

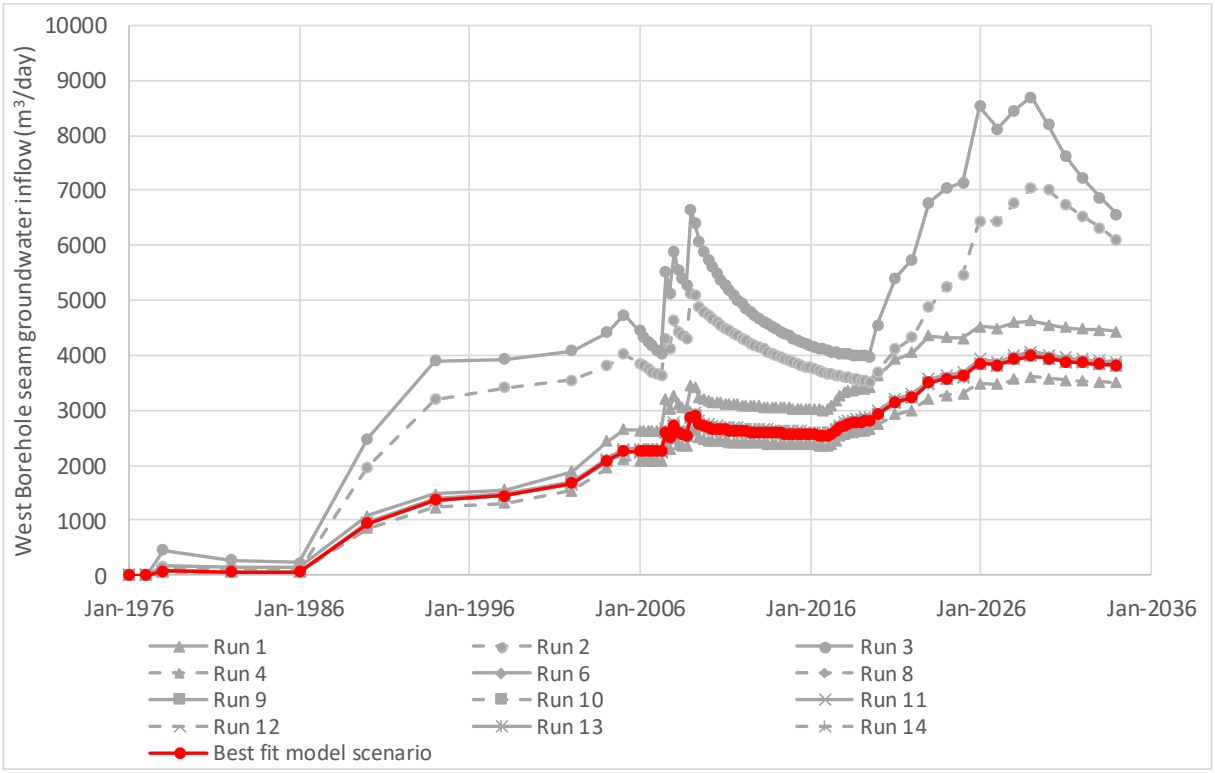


Figure 5-5 Modelled mine inflows – uncertainty analysis

Note to Figure:

Best fit model scenario, uncertainty run 6, 8, 9, 10, 11, 12, 13 and 14 are plotting on top of each other.

The net leakage from the Eraring Ash Dam has been extracted from the cell-by-cell flow output for each of the uncertainty runs and the best fit model run. Net leakage from the Eraring Ash Dam is shown in Figure 5-6.

Modelled leakage out of the Eraring Ash Dam reflects changes in rainfall recharge. As discussed in Section 4.2, rainfall recharge was set to a constant value for the predictive model period. Therefore, modelled leakage out of the Eraring Ash Dam is constant throughout the prediction and post-closure period of modelling (from July 2019 onwards).

As shown in Figure 5-6, modelled leakage out of the Eraring Ash Dam is generally lower for uncertainty run 8. This indicates that modelled leakage out of the Eraring Ash Dam is also sensitive to hydraulic conductivity of the regolith that underlies the Eraring Ash Dam. Modelled leakage out of the Eraring Ash Dam is significantly different for uncertainty run 11 due to the changes in rainfall recharge.

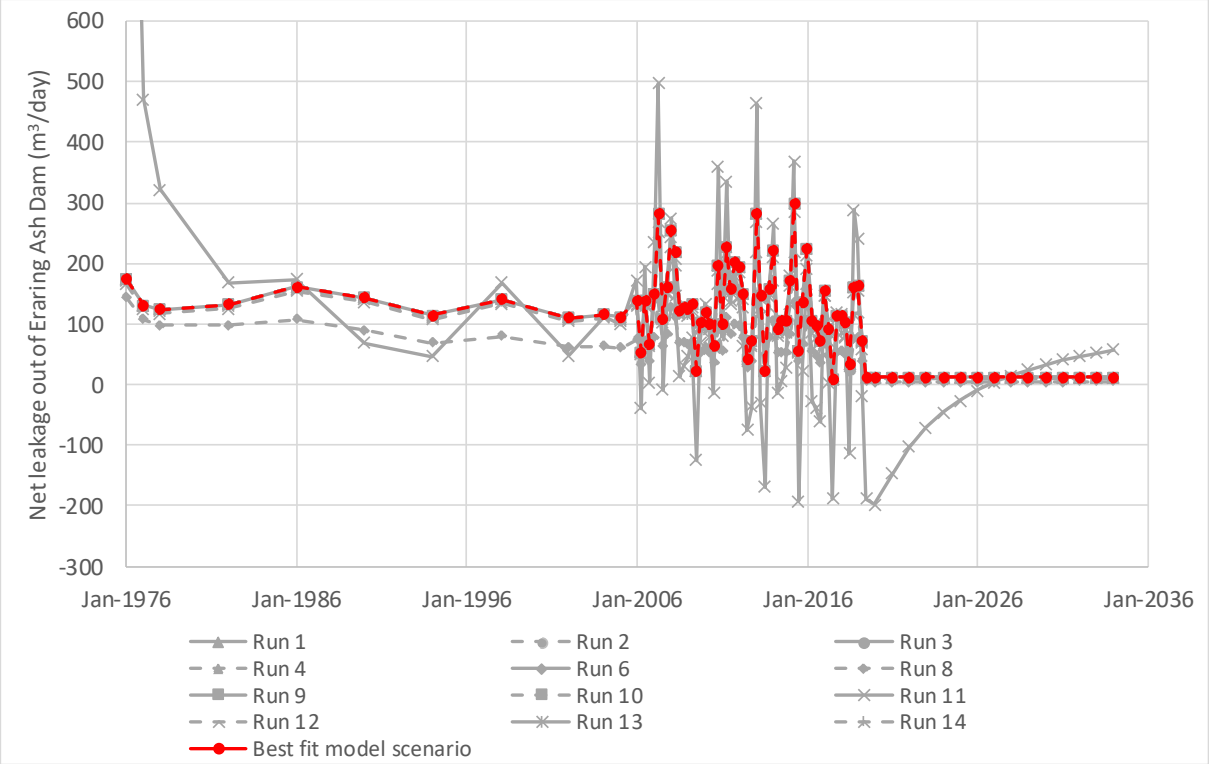


Figure 5-6 Net leakage from Eraring Ash Dam – uncertainty analysis

Net groundwater flow into Awaba has been extracted from the cell-by-cell flow output for the best fit model run and all uncertainty runs and is plotted in Figure 5-7. The results indicate that groundwater flow into Awaba is similar for the majority of the uncertainty runs with the exception of run 6, 11 and 13. This indicates that groundwater flow into Awaba is sensitive to the hydraulic conductivity of the overlying Narrabeen Sandstone and regolith, and rainfall recharge.

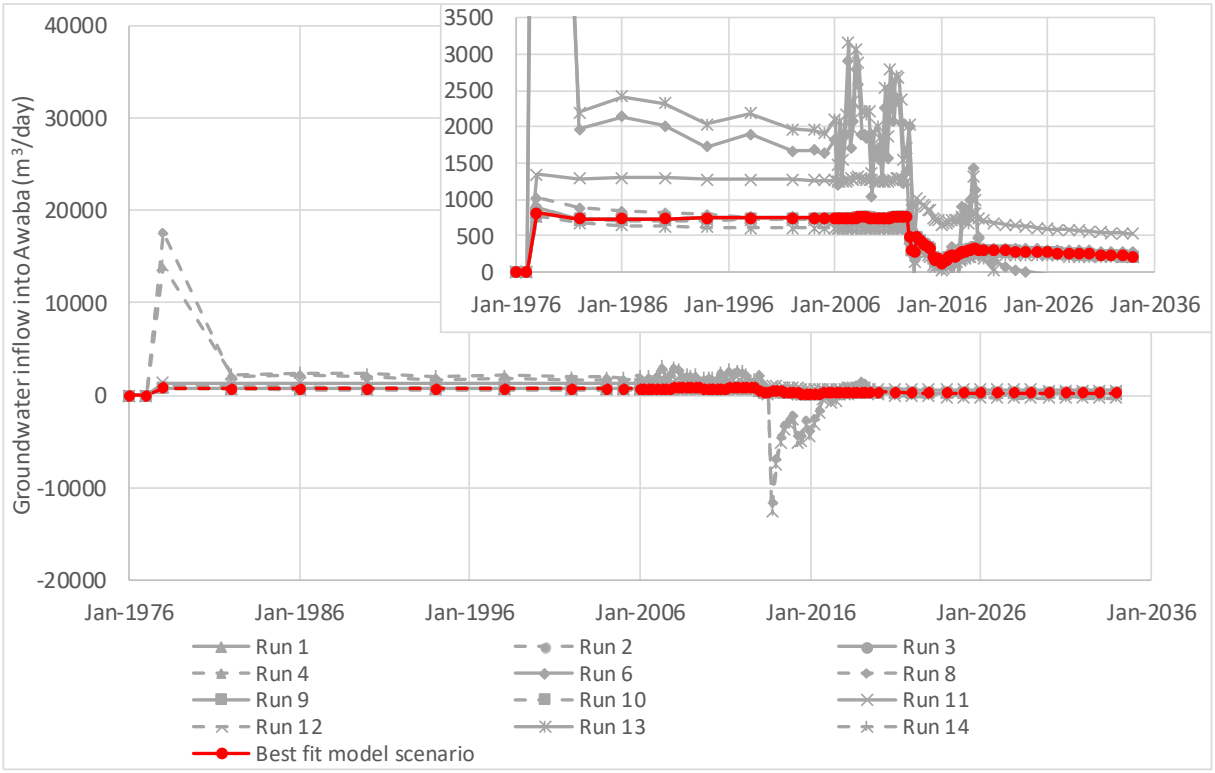


Figure 5-7 Net groundwater inflow into Awaba – uncertainty analysis

Net groundwater flow into the Fassifern Underground Storage has been extracted from the cell-by-cell flow output for the best fit model run and all uncertainty runs and is plotted in Figure 5-8.

The observed modelled trend in groundwater inflow into the Fassifern Underground Storage and its relationship to mining activities is discussed in Section 5.6. The results of the uncertainty analysis indicate that there is minimal change in modelled groundwater inflow into the Fassifern Underground Storage for a range of modelled material properties.

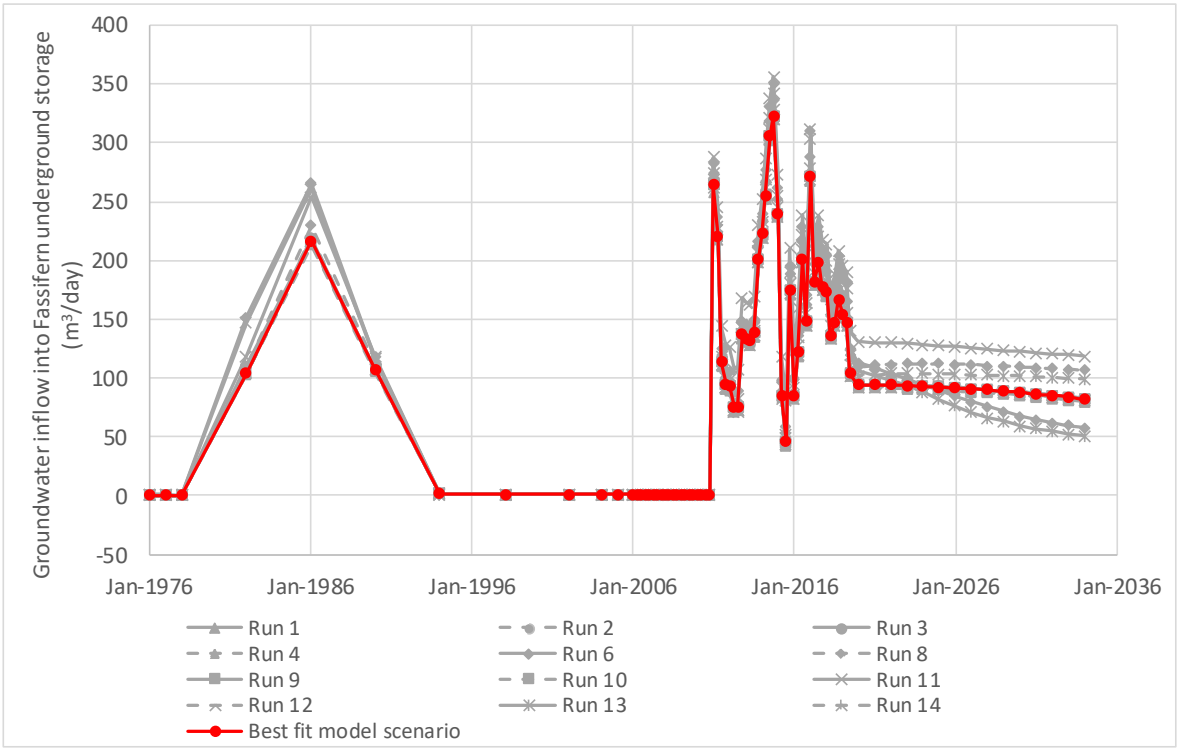


Figure 5-8 Net groundwater inflow into Fassifern Underground Storage – uncertainty analysis

5.8.1 Modified height of continuous fracturing

An additional scenario was undertaken to assess the model sensitivity to increasing the height of continuous fracturing above the proposed mine workings. As outlined in Section 2.2.5, the additional model run simulated continuous fracturing of strata up to 220 m above the proposed mine workings to simulate the conceptualisation of SCT (2019). This height is equal to the upper limit of the Zone A height of fracturing as defined by Tammetta (2012). The Zone A height of fracturing is defined by Tammetta (2012) as the height of strata above the mine workings where groundwater will be fully drained.

A fracture height of 220 m corresponds to fracturing up to the Awaba underground void (since the average interburden thickness is 170 m), and in some areas above the Awaba underground void. However it does not extend to the surface in the vicinity of the Eraring Ash Dam.

To simulate depressurisation of groundwater sources above the coal seam due to fracturing following longwall mining, drain cells were also activated in Layer 9, Layer 8 and Layer 7 (Permian Interburden), Layer 6 (Fassifern seam) and Layer 5 (Awaba Tuff). Similarly to the predictive model, these drain cells were progressively activated in accordance with the mining schedule supplied by Centennial Newstan. Drain cells were not activated in areas directly above the Awaba underground void, as the groundwater level is assumed to be controlled by the water level in the Awaba underground void. Drain cells were activated in Layer 4 (Great Northern seam) and Layer 3 (Narrabeen Sandstone) in cells that were less than 220 m above the West Borehole seam and outside the footprint of the Awaba underground void.

As discussed in Section 2.2.5, observed monitoring data indicates that there is no direct connection between the existing West Borehole Seam workings and the Awaba underground void. The height of the interburden between the proposed workings and the Awaba underground void is greater than for the existing workings. Additionally the void widths as part of the proposed workings are less than the existing longwall panels under the Awaba underground void. Therefore it is considered unlikely that a continuous fracture height of 220 m would develop above the proposed workings and therefore the results of this model run are unlikely to occur.

Mine inflows

Groundwater inflow rates have been are derived from modelled drain inflows for the operational phase of mining. Modelled inflow rate for the modified height of continuous fracturing scenario have been compared to the mine inflow predictions presented in Section 5.3. Comparison of mine inflows is presented in Figure 5-9.

The comparison shows that a fracture height that extends above the Awaba underground void results in considerably higher groundwater inflows. For a continuous fracture height of 220 m, groundwater inflow rates into the West Borehole seam workings are modelled to peak at 6.1 ML/day in 2033.

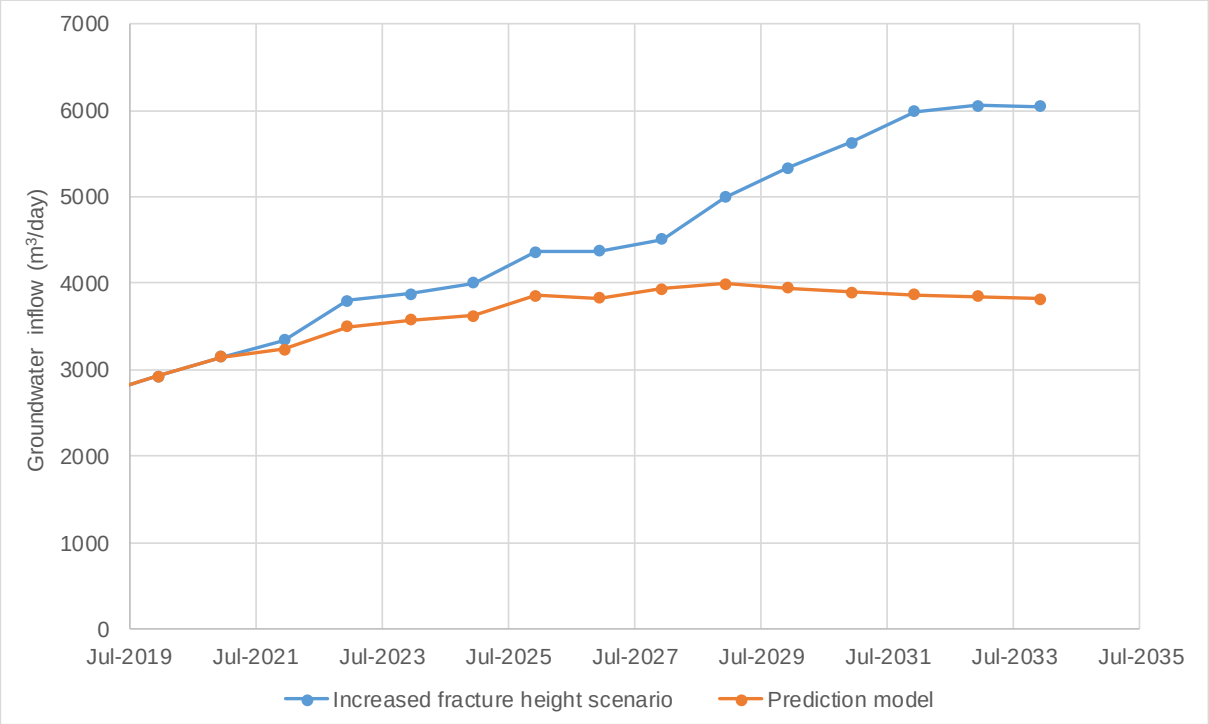


Figure 5-9 Comparison of mine inflows

Eraring Ash Dam

The net leakage from the Eraring Ash Dam has been extracted from the cell-by-cell flow output. Results from the additional model run with increased fracture heights has been compared to model results for the predictive scenario in Figure 5-10.

The results show that there is negligible change in net leakage out of the Eraring Ash Dam for the proposed and increased fracture height scenarios. Therefore, modelling results indicate proposed mining at Newstan Colliery will have no impact on leakage out of the Eraring Ash Dam.

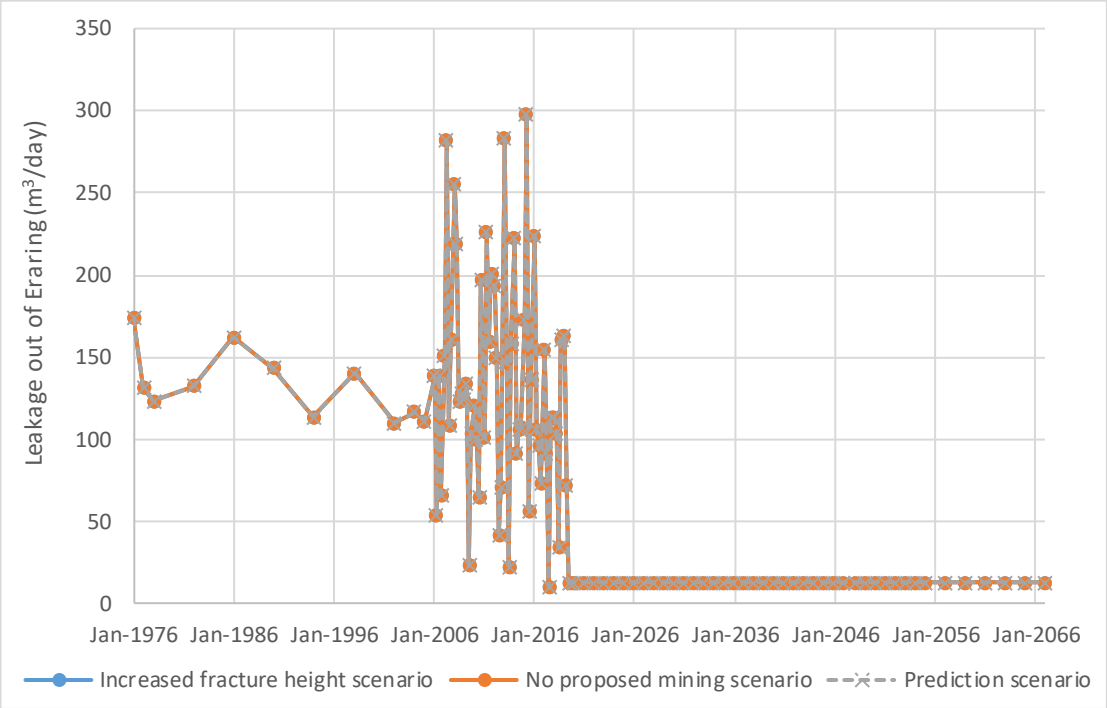


Figure 5-10 Net leakage from Eraring Ash Dam

Awaba underground void

Net groundwater flow into the Awaba underground void has been extracted from the cell-by-cell flow output. Results from the additional model run with increased fracture heights have been compared to model results for the predictive scenario and are plotted in Figure 5-11.

The results show that fracturing up to the Awaba underground void would result in an increase in groundwater flows out of the Awaba underground void. This groundwater flow from the Awaba underground void would report to the West Borehole Seam workings. The modelled volume of groundwater flow out of the Awaba underground void is likely influenced by the presence of a GHB to simulate the flooded Awaba workings. This provides a constant source of groundwater inflow into the model that likely overestimates the rate of seepage out of Awaba. The increased leakage from the Awaba underground void, although unlikely to occur, would likely results in a drop in the water level in the Awaba underground void and a potential reduction in the flow rate at the Awaba seepage.

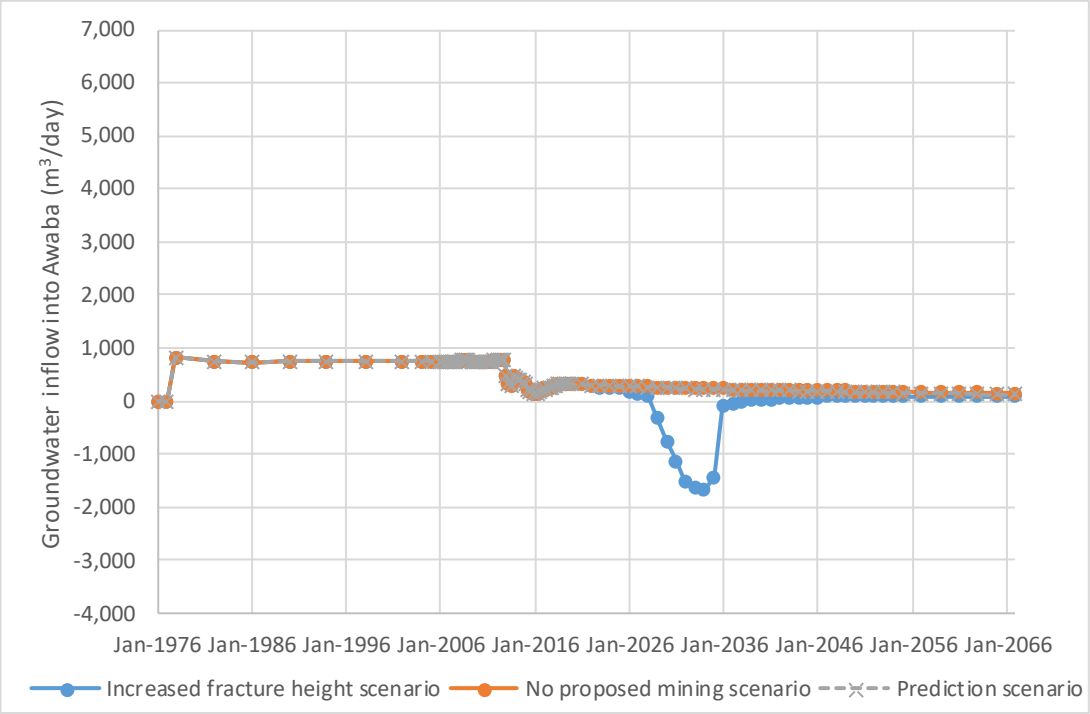


Figure 5-11 Net groundwater inflow into Awaba

Fassifern underground storage

Net groundwater flow into the Fassifern Underground Storage has been extracted from the cell-by-cell flow output. Results from the additional model run with increased fracture heights has been compared to model results for the predictive scenario and is plotted in Figure 5-12.

The results show that fracturing up to the Awaba underground void will have no impact on the Fassifern Underground Storage.

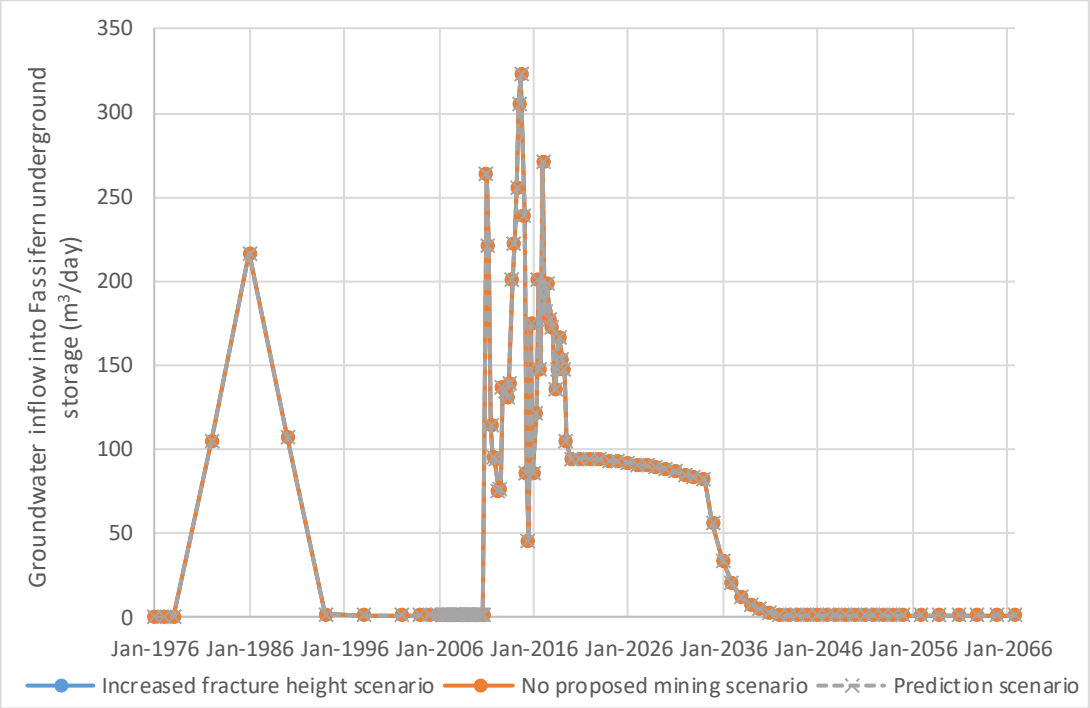


Figure 5-12 Net groundwater flow into Fassifern Underground Storage

6. Conclusions and recommendations

6.1 Model confidence level and set-up

3D numerical groundwater flow model of Newstan Colliery has been developed using the industry standard MODFLOW-USG code. The model simulates the key features of the hydrogeological system of the mine site and surrounding area including hydrostratigraphic units, recharge and discharge mechanisms and spatial and temporal distribution of piezometric heads, as well as representing historical mining.

Model calibration has been undertaken using PEST. The calibrated model is considered to have the characteristics of class 2 confidence level (i.e. moderate confidence), with aspects of a class 3 model, in accordance with the confidence level classification of the Australian Groundwater Modelling guidelines (Barnett et al, 2012). Model confidence should be considered lower for predictions of far-future conditions post-mining, where the groundwater system slowly recovers towards a new dynamic equilibrium over potentially many hundreds of years.

6.2 Predictions

The predictive simulations indicate the following:

- Existing mining at Newstan Colliery and surrounding mining operations has resulted in depressurisation of the coal seams in the vicinity of Newstan Colliery.
- Cumulative impacts of mining in the vicinity of Newstan Colliery will result in drawdown of the West Borehole seam up to 14 km to the south east at the end of proposed mining. The majority of this drawdown is attributable to existing mine workings. Drawdown in the West Borehole seam due to proposed workings extends to 9.5 km to the north-east and approximately 11 km to the south from the proposed workings at the end of mining.
- Proposed mining does not result in impacts to the alluvium or shallow regolith. Impacts on the alluvium and shallow regolith has previously occurred above the existing Newstan Colliery Great Northern seam workings, Awaba Colliery and Cooranbong Mine (based on groundwater modelling). This drawdown is attributable to these existing workings.
- Negligible impact on the Eraring Ash Dam is predicted due to proposed workings. This is based on the modelling assumption that there will be no seam to surface fracturing as discussed in Section 2.1.11. Modelling of the larger height of continuous fracturing conceptualised by SCT (2019) still does not indicate leakage from the Eraring Ash Dam.
- Negligible impact on the Fassifern Underground Storage is predicted due to proposed workings.
- The proposed workings will result in a slight decrease in groundwater flow into Awaba. The maximum modelled reduction in groundwater inflow into Awaba is is 22 m^3/day and occurs between the year 2063 and the year 2100.

6.3 Recommendations

The following is recommended:

- Additional monitoring in the vicinity of the proposed workings is recommended. This includes accessing data from existing VWP CN064.
- The confidence in model predictions would be improved by ongoing data collection and revision of the numerical model.

- Additional monitoring in the Narrabeen Sandstone to verify impacts from proposed mining at Newstan Colliery. Additional monitoring in the Narrabeen Sandstone would also assist in characterising groundwater levels and groundwater flow direction in the Narrabeen Sandstone. This additional monitoring may be achieved by monitoring of suitable landholder bores.

6.4 Model limitations

Numerical groundwater models are a mathematical representation of complex natural systems, developed using a finite numbers of cells whose properties must be inferred from a limited number measurements. Simplifications are necessary in modelling commensurate with the spatial and temporal scales of processes being modelled and the underlying data used to support the development of the model. The outcomes of modelling should be considered within the context these limitations.

7. References

AGE (2008) *Definition of limit of the Stoney Creek alluvium: Awaba Colliery,* prepared by Australasian Groundwater & Environmental Consultants Pty Ltd for Centennial Newstan Pty Limited.

BOM (2019). Groundwater Dependent Ecosystem Atlas, Bureau of Meteorology, retrieved from: http://www.bom.gov.au/water/groundwater/gde/

Centennial Mandalong (2019). Mandalong Mine Water Management Plan, Revision 4, August 2019.

DMR (1995) *1:100,000 Newcastle Coalfield Regional Geology map*, NSW Department of Mineral Resources.

Ferdowsian, R., Pannell, D.J., McCarron, C., Ryder, A. and Crossing, L. (2000). *Explaining groundwater hydrographs: separating atypical rainfall events from time trends*. Sustainability and Economics in Agriculture (SEA) Working Paper 00/12.

Gale, W.J. (2010). 'Review and estimation of the hydraulic conductivity of the overburden above longwall panels. Experience from Australia'. *Proceedings of the 29th International Conference on Ground Control in Mining*. Morgantown, West Virginia, pp. 340-347.

GHD (2013) *Mandalong Southern Extension Project,* prepared by GHD Pty Ltd for Centennial Mandalong Pty Limited.

GHD (2014). *Bore 20BL173524 Annual Compliance Report*. Cooranbong Services Site, prepared by GHD Pty Ltd for Centennial Mandalong Pty Limited.

GHD (2018) *Newstan Colliery Modification 8: Water Resources Impact Assessment,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited.

GHD (2020a) *Newstan Extension of Mining Project: Groundwater Impact Assessment,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited.

GHD (2020b) *Newstan Extension of Mining Project: Surface Water Impact Assessment,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited.

GHD (2020c) *Newstan Mine Extension Project: Aquatic Ecology Impact Assessment,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited.

IESC (2018a) *Information guidelines for proponents preparing coal seam gas and large coal mining development proposals*, Independent Expert Scientific Committee on Coal seam Gas and Large Coal Mining Development.

IESC (2018b) *Explanatory Note on Uncertainty Analysis in Groundwater Modelling*, Independent Expert Scientific Committee on Coal seam Gas and Large Coal Mining Development.

MSEC (2019) *Newstan Colliery: Mine Extension Project – Subsidence Predictions and Impact Assessments for Natural and Built Features due to the proposed 201 to 218 Panels in Support of the Environmental Impact Statement*, draft report, prepared by Mine Subsidence Engineering Consultants for Centennial Newstan Pty Limited, reference MSEC1042.

Oceanic Coal (2009) *West Wallsend Colliery Annual Environmental Management Report 2008*, prepared by Umwelt (Australia) on behalf of Oceanic Coal Australia Limited.

Oceanic Coal (2010) *West Wallsend Colliery Annual Environmental Management Report 2009*, prepared by Umwelt (Australia) on behalf of Oceanic Coal Australia Limited.

Oceanic Coal (2011) *West Wallsend Colliery Annual Environmental Management Report 2010*, prepared by Umwelt (Australia) on behalf of Oceanic Coal Australia Limited.

Oceanic Coal (2012) *West Wallsend Colliery Annual Review 2011*, prepared by Umwelt (Australia) on behalf of Oceanic Coal Australia Limited.

Oceanic Coal (2013) *West Wallsend Colliery Annual Review 2012*, prepared by Umwelt (Australia) on behalf of Oceanic Coal Australia Limited.

Oceanic Coal (2014) *West Wallsend Colliery Annual Review 2013*, prepared by Umwelt (Australia) on behalf of Oceanic Coal Australia Limited.

Oceanic Coal (2015) *West Wallsend Colliery Annual Review 2014.*

Oceanic Coal (2016a) *West Wallsend Underground Annual Review 2015.*

Oceanic Coal (2016b) *Mining Operations Plan Closure of the OCAL Complex*, prepared by SLR Consulting Australia Pty Ltd.

Oceanic Coal (2017) *OCAL Complex Annual Review 2016.*

Pacific Power International (1997). *Newstan Colliery Life Extension Project Overburden Groundwater Study*.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., Hughes, J. (2013) *MODFLOW–USG Version 1: An Unstructured Grid Version of MODFLOW for Simulating Groundwater Flow and Tightly Coupled Processes Using a Control Volume Finite-Difference Formulation*, Chapter 45 of Section A, Groundwater Book 6, Modeling Techniques. Techniques and Methods 6–A45.

RPS (2012) *Tasman Extension Project: Groundwater Assessment,* prepared by RPS Aquaterra for Glouscester Coal Ltd.

RPS (2020). *Newstan Mine Extension Project: Biodiversity Inventory Report*.

SCT (2019) *Newstan Mine Extension project: Mine Design in Context of Eraring Ash Dam,* prepared by SCT Operations Pty Ltd for Centennial Coal Company Limited, report no. NST4976.

Tammetta, P. (2012) *Estimation of the height of complete groundwater drainage above mined longwall panels,* Groundwater NGWA org pp 1-16.

Appendices

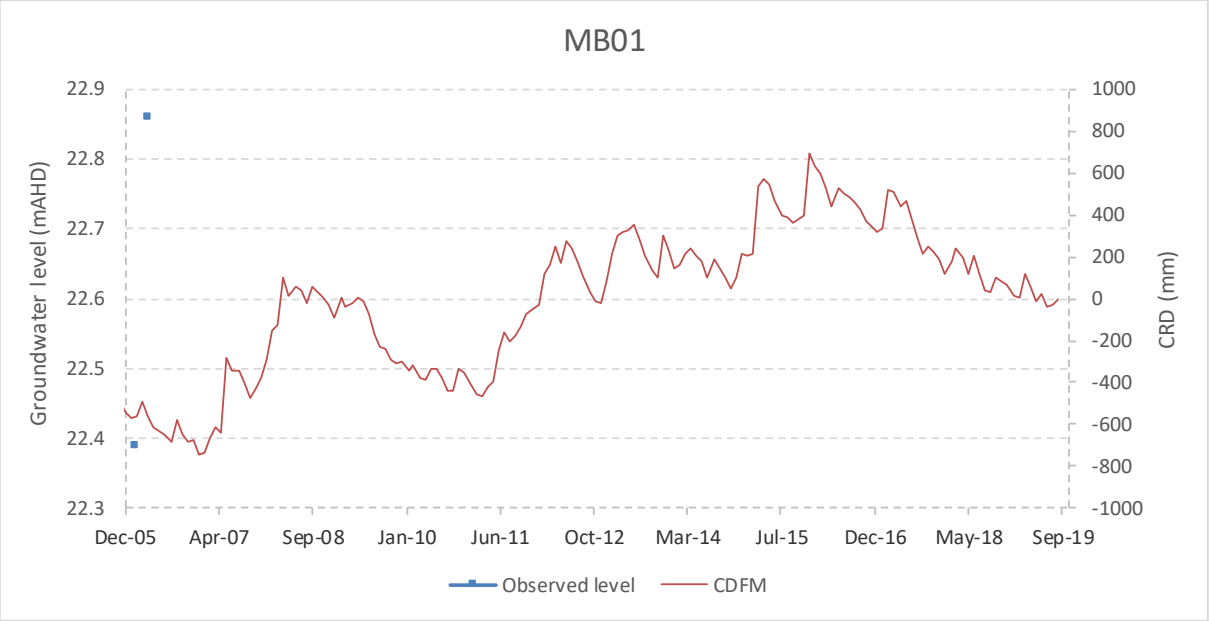
Appendix A – IESC information guidelines

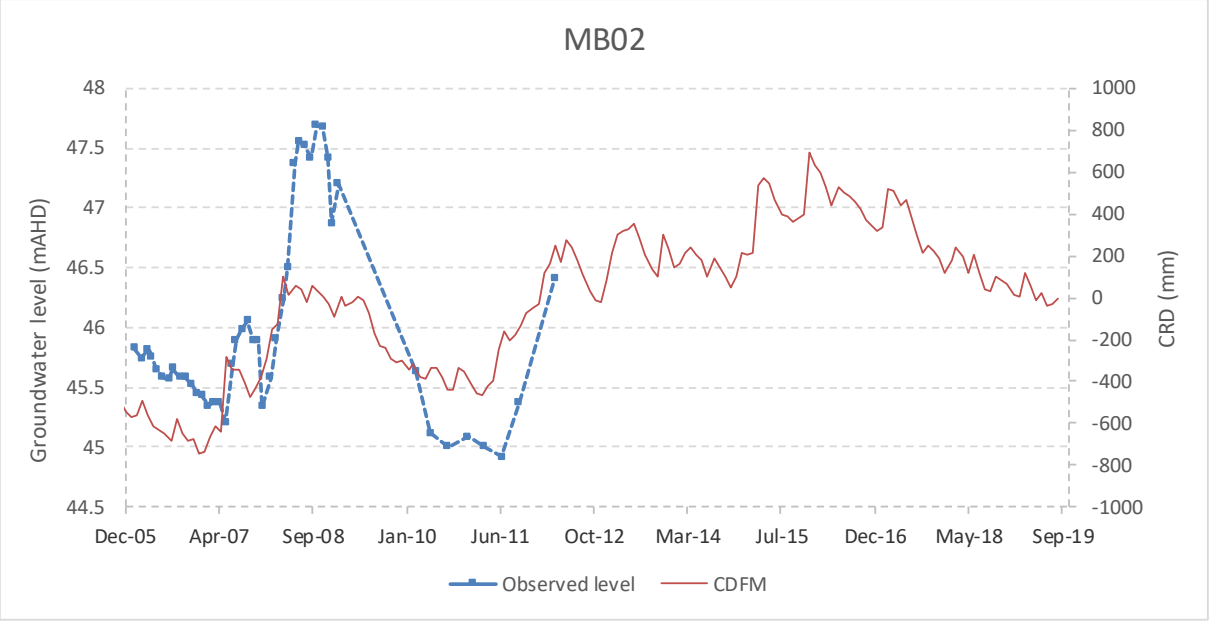
Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development information requirements

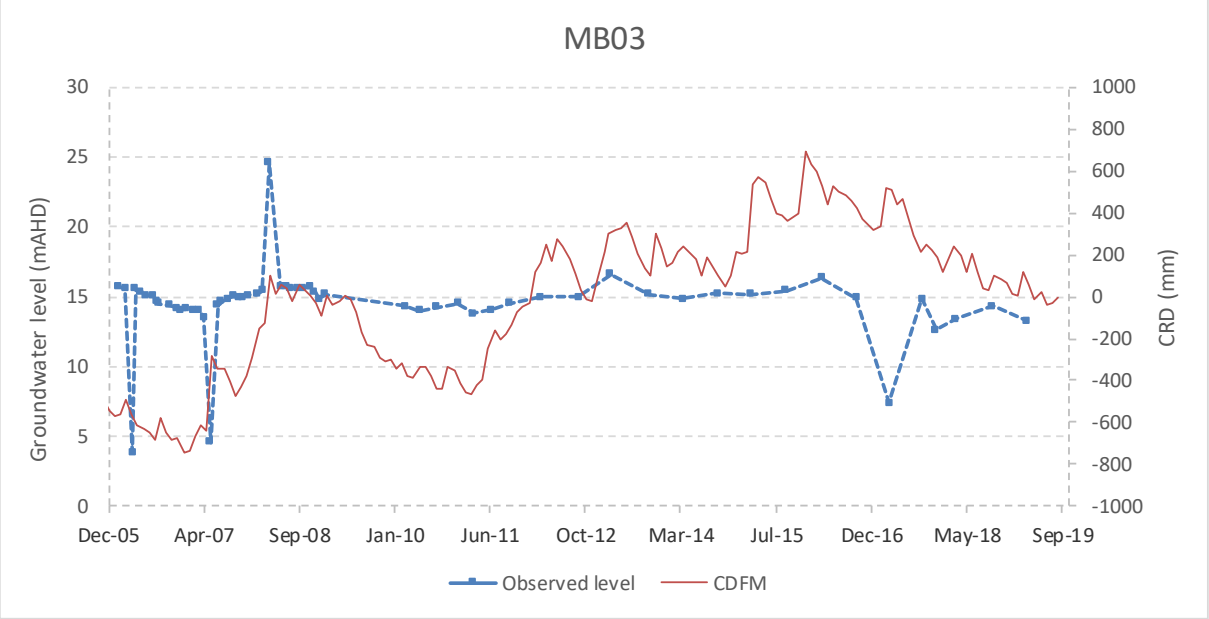
Assessment requirement	Where addressed
Groundwater **Context and conceptualisation**	
Describe and map geology	Section 2.1.5
Provide hydrogeological data	Section 2.1.9 Appendix B
Define and describe or characterise significant geological structures and associated fracturing in the area and their influence on groundwater	Section 2.1.5
Provide hydrogeochemical characterisation	Section 2.1.10 Appendix C of GHD (2020a)
Provide site specific values for hydraulic parameters	Section 2.1.11
Describe recharge, discharge and flow pathways	Section 2.2
Provide time series level and water quality data	Section 2.1.9 Appendix B
Assess surface water / groundwater connectivity and inter-aquifer connectivity	Section 2.2
Analytical and numerical modelling	
Provide a detailed description of all models used	Section 3
Provide an explanation of the model conceptualisation, assumptions and limitations	Section 2.2
Undertaken groundwater modelling in accordance with the Australian Groundwater Modelling Guidelines (Barnett at al. 2012), including independent peer review	Section 1
Consider a variety of boundary conditions	Section 3.5
Calibrate models with adequate monitoring data	Section 3.6
Undertake sensitivity analysis and uncertainty analysis	Section 3.6 Section 5.8
Describe each hydrogeological unit	Section 3.4
Provide an assessment of the quality of the data used in modelling	Section 3.6
Describe existing recharge/discharge pathways and predicted changes	Section 2.2 Section 5
Undertake an uncertainty analysis	Section 5.7
Describe various stages of the proposed project and incorporate into model	Section 4
Provide a program for review and update of models	Section 7.3 of GHD (2020a)
Identify annual water take	Section 6.3 of GHD (2020a)
Provide information on the magnitude and time for maximum drawdown	Section 5.2
Undertake model verification with monitoring data	Section 3.6 Section 5.7
Impacts to water resources and water-dependent assets	
Provide an assessment of the potential impacts of the proposal	Section 6.2 of GHD (2020a)
Describe the water resources and water-dependent assets that will be directly impacted and describe the impact	Addressed in GHD (2020a): Section 3.5 Section 3.6 Section 3.7 Section 6.2

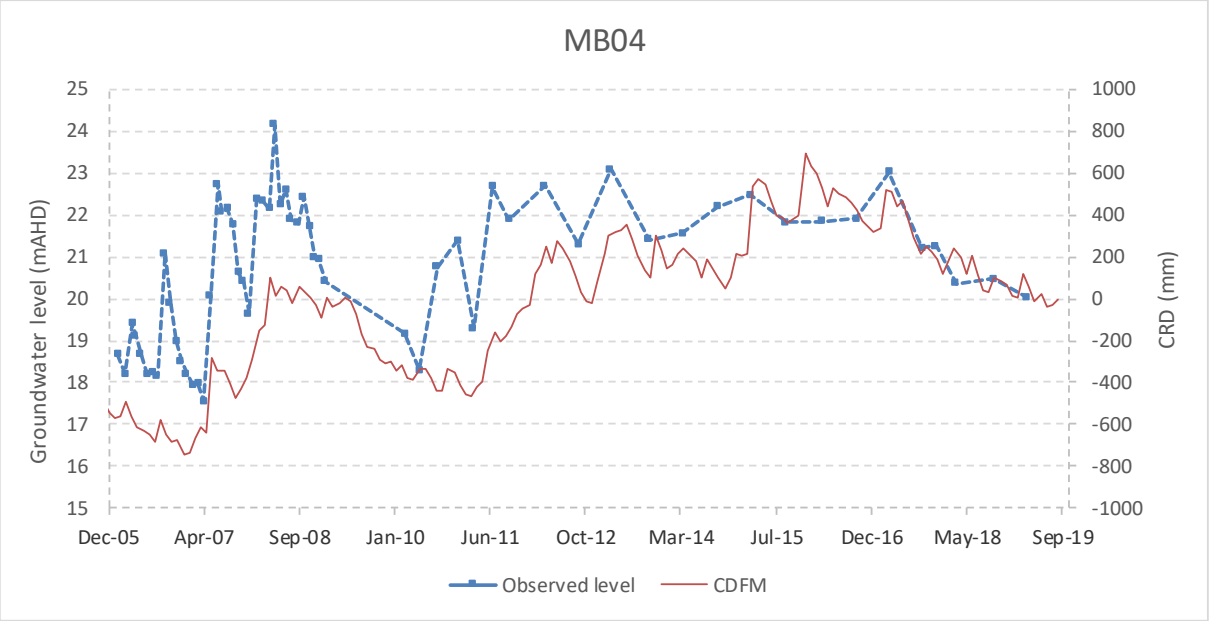
Assessment requirement	Where addressed
Assess cumulative impacts of the project	Section 4 Section 5 Section 6.2 of GHD 2020a
Describe mitigation and management actions	Section 7 of GHD (2020a)
Data and monitoring	
Provide sufficient baseline hydrogeological and hydrogeochemical data, including long term monitoring data	Section 2.1.9 Section 2.1.10
Develop and describe a groundwater monitoring program and targeted field programs	Section 2.1.9 Addressed in GHD (2020a): Section 7.1 Section 7.2

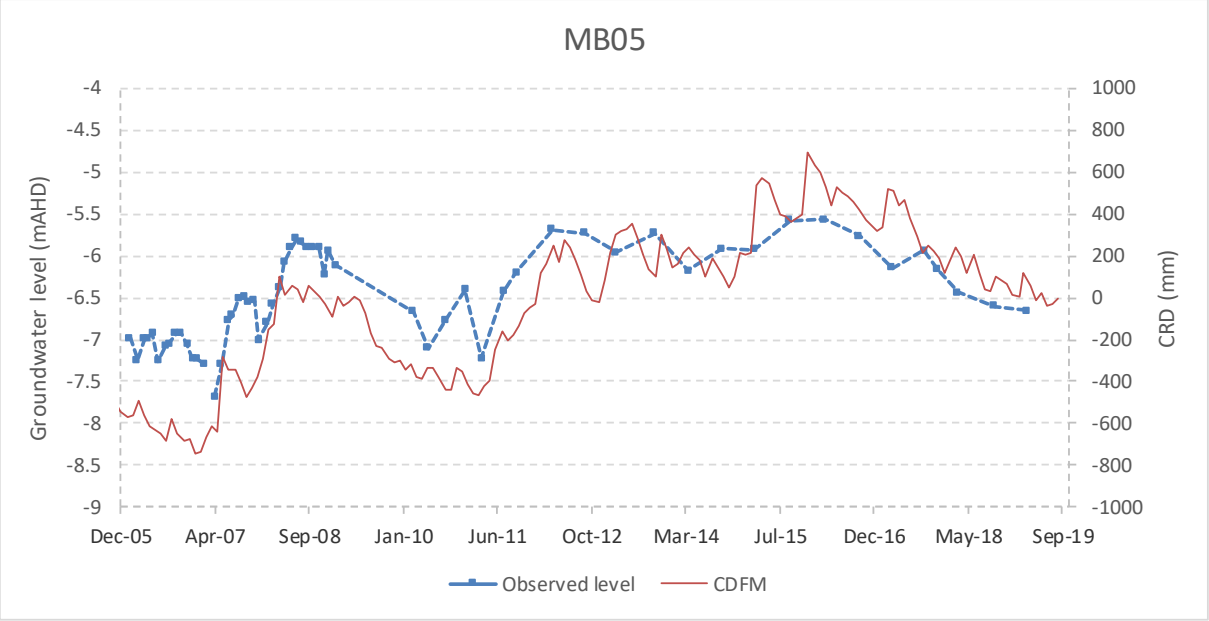
Appendix B – Hydrographs

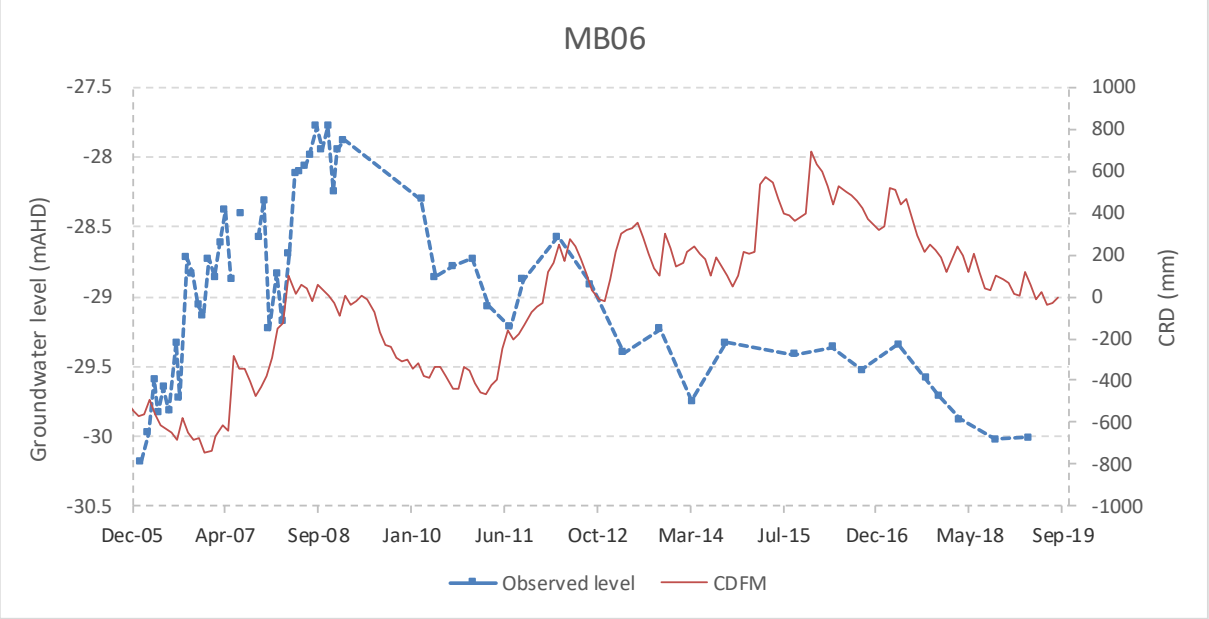

MB01
Groundwater level (mAHD)
CRD (mm)
22.9
22.8
22.7
22.6
22.5
22.4
22.3
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

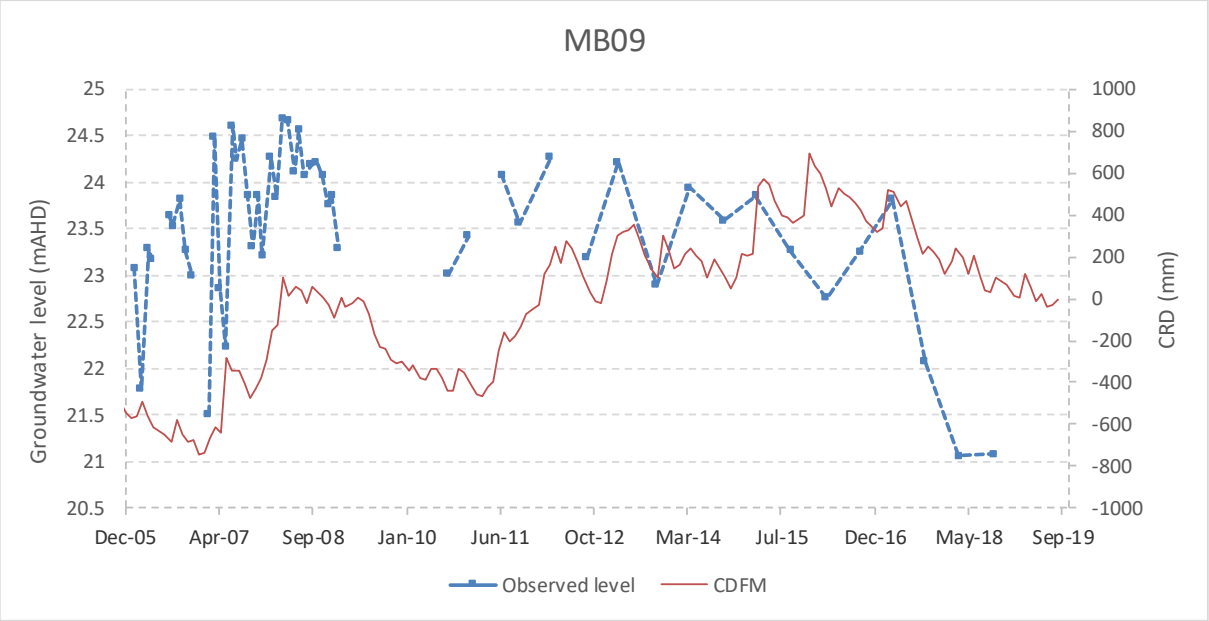

MB02
Groundwater level (mAHD)
CRD (mm)
48
47.5
47
46.5
46
45.5
45
44.5
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

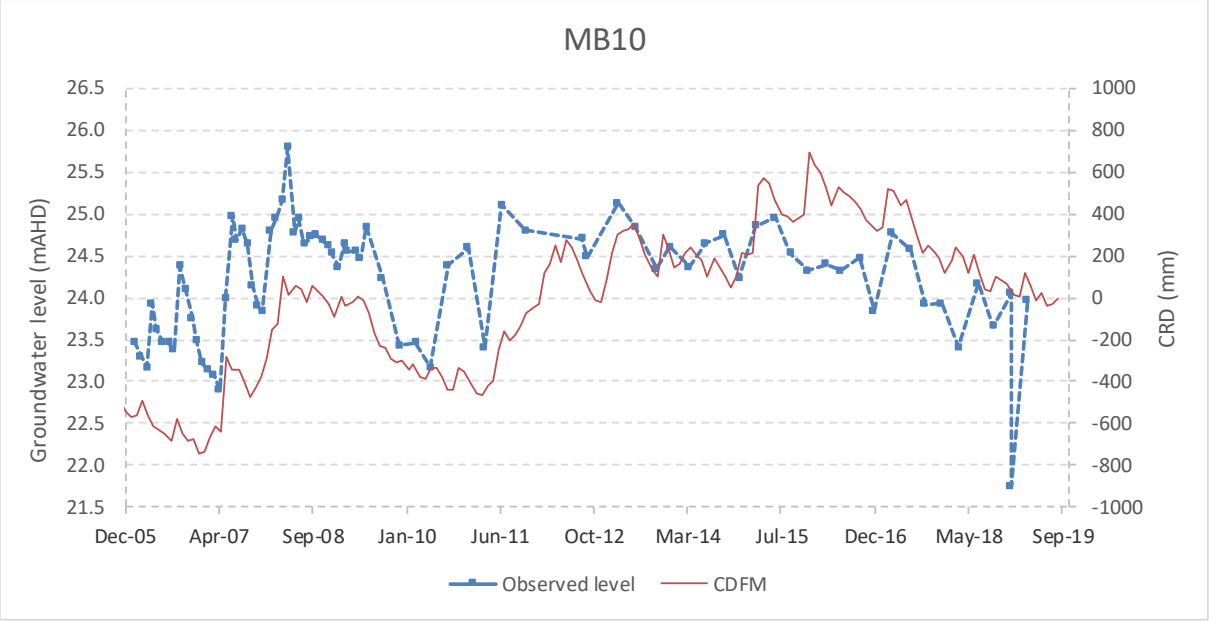

MB03
Groundwater level (mAHD)
CRD (mm)
30
25
20
15
10
5
0
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

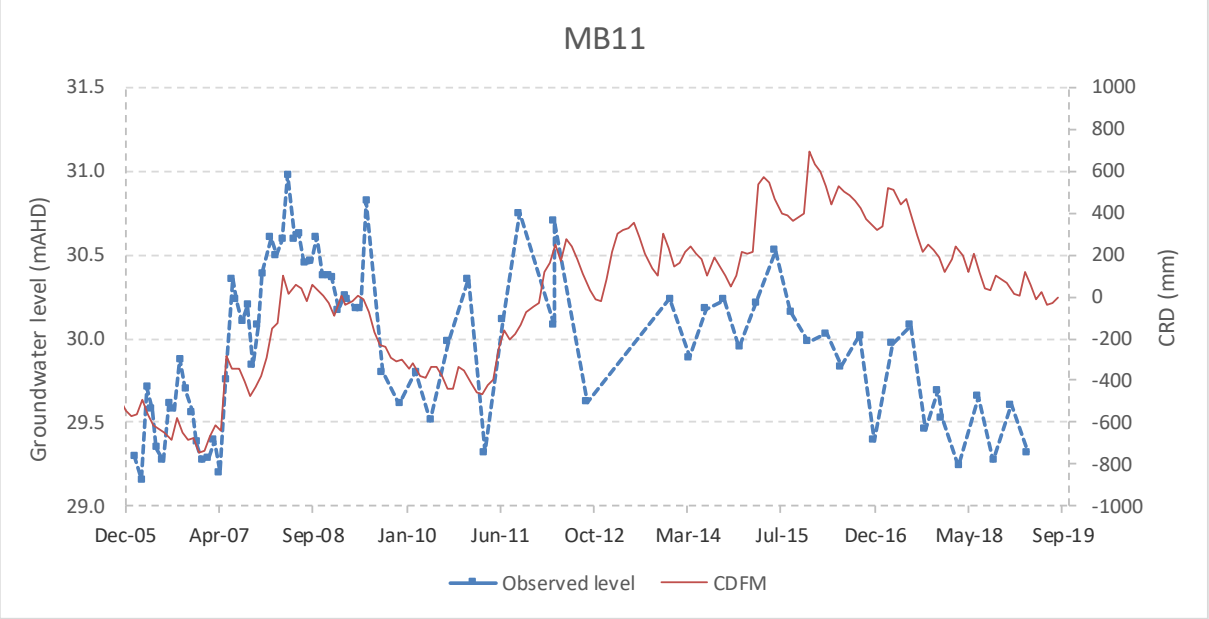

MB04
Groundwater level (mAHD)
CRD (mm)
25
24
23
22
21
20
19
18
17
16
15
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

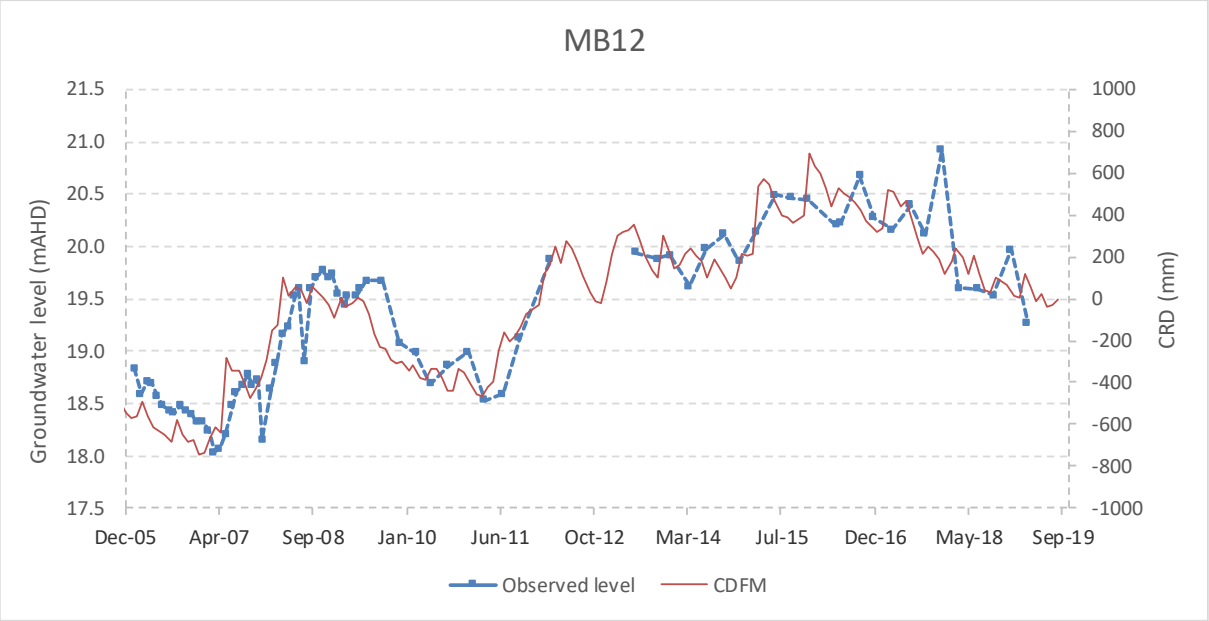

MB05
Groundwater level (mAHD)
CRD (mm)
-4
-4.5
-5
-5.5
-6
-6.5
-7
-7.5
-8
-8.5
-9
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

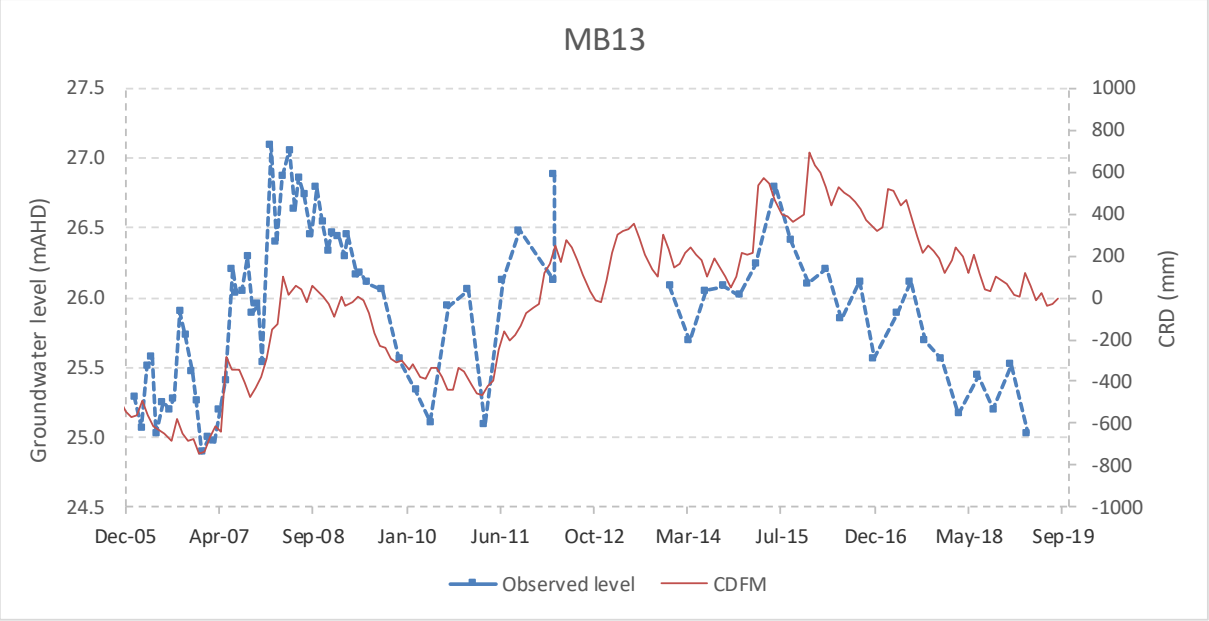

MB06
Groundwater level (mAHD)
CRD (mm)
-27.5
-28
-28.5
-29
-29.5
-30
-30.5
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

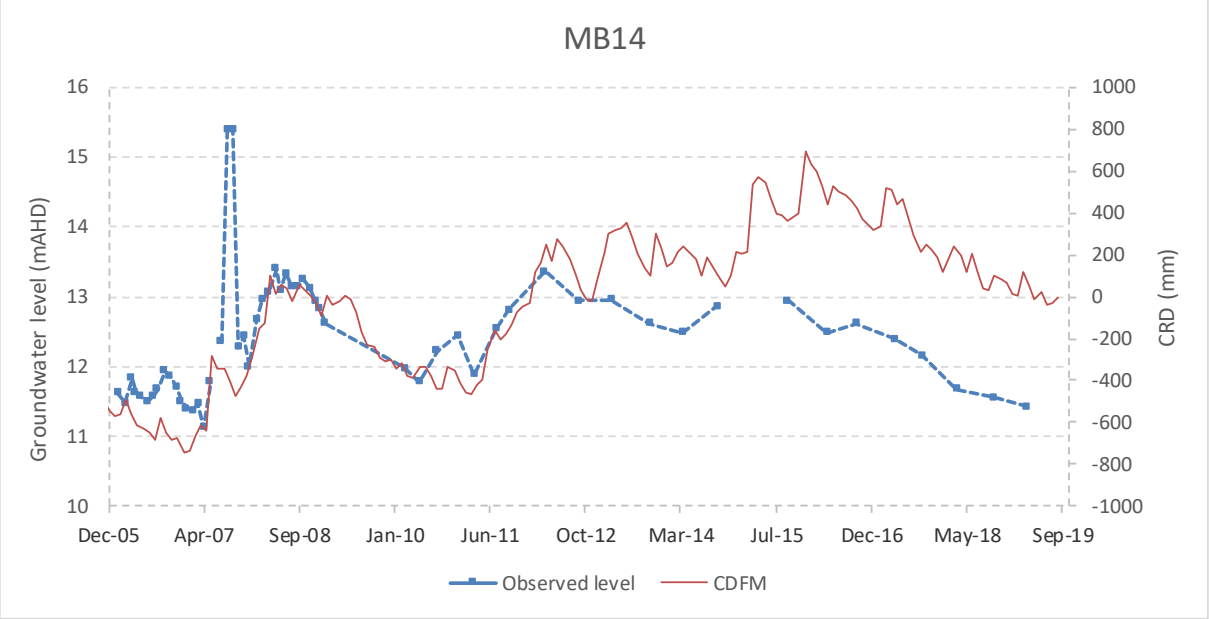

MB09
Groundwater level (mAHD)
CRD (mm)
25
24.5
24
23.5
23
22.5
22
21.5
21
20.5
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

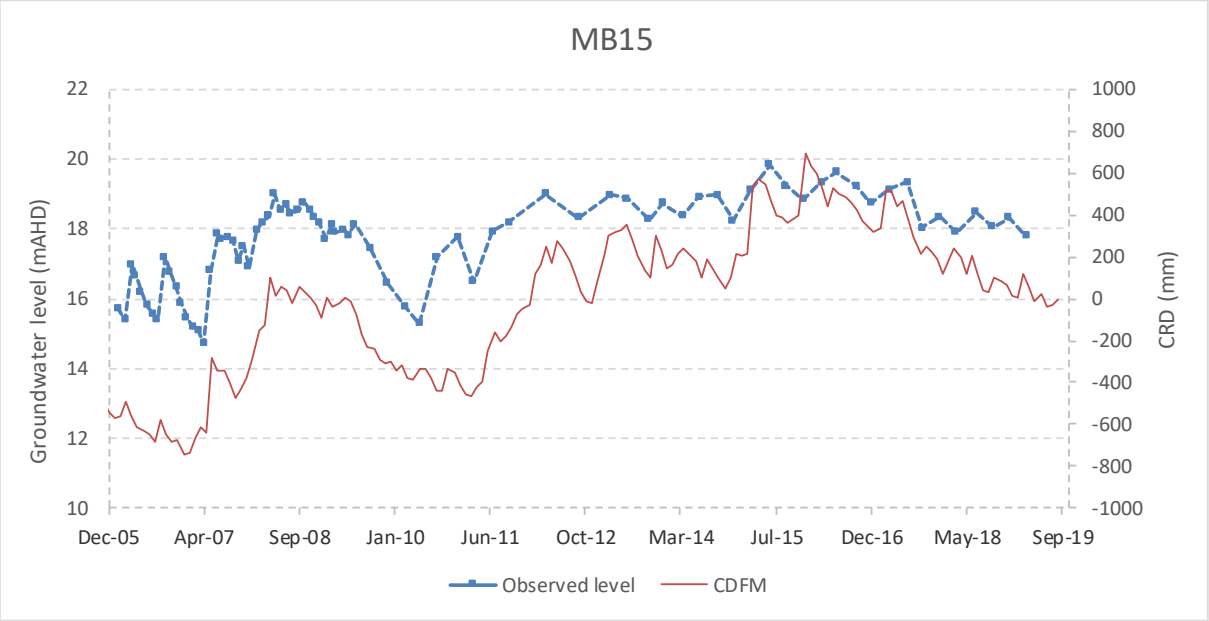

MB10
Groundwater level (mAHD)
CRD (mm)
26.5
26.0
25.5
25.0
24.5
24.0
23.5
23.0
22.5
22.0
21.5
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

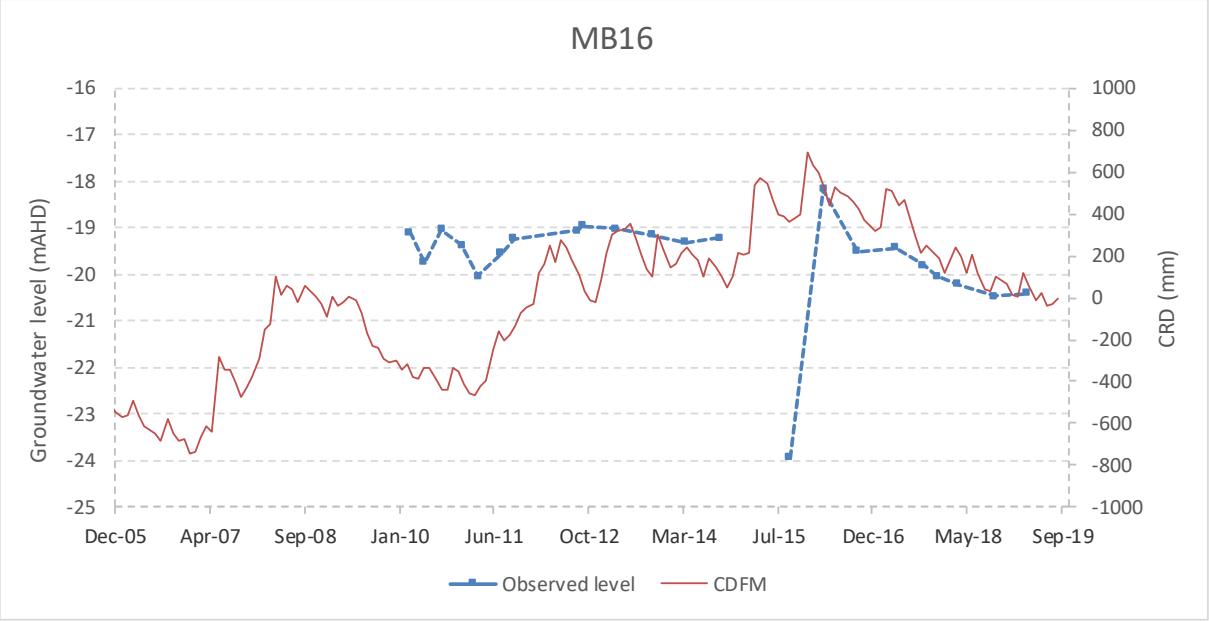

MB11
Groundwater level (mAHD)
CRD (mm)
31.5
31.0
30.5
30.0
29.5
29.0
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

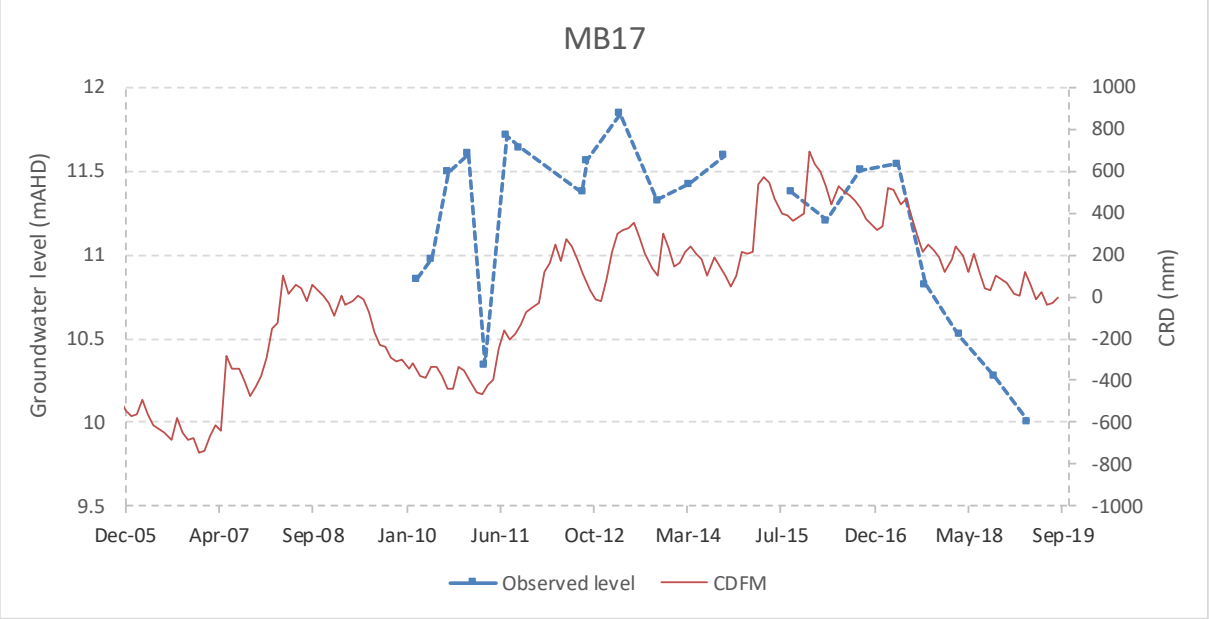

MB12
Groundwater level (mAHD)
CRD (mm)
21.5
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

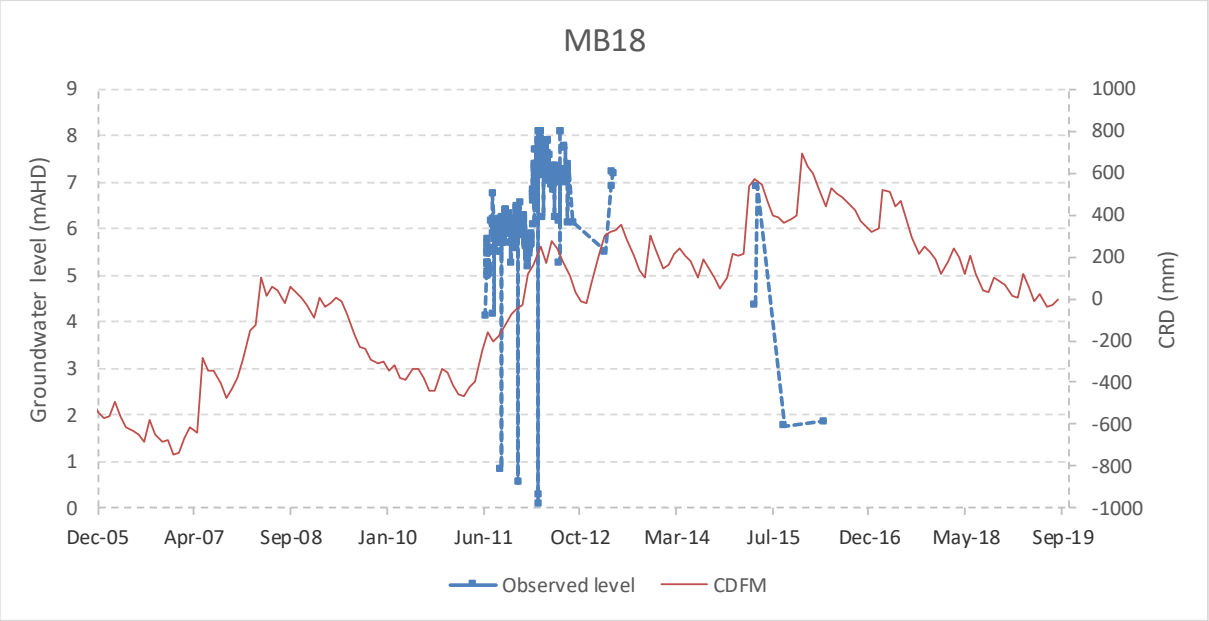

MB13
Groundwater level (mAHD)
CRD (mm)
27.5
27.0
26.5
26.0
25.5
25.0
24.5
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

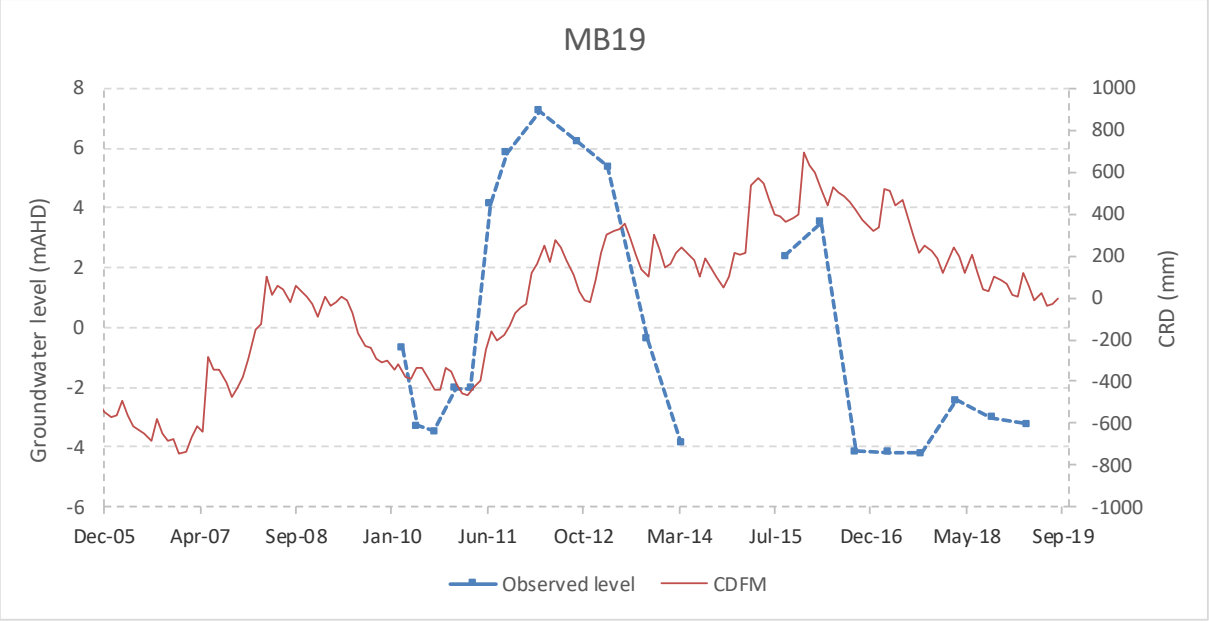

MB14
Groundwater level (mAHD)
CRD (mm)
16
15
14
13
12
11
10
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

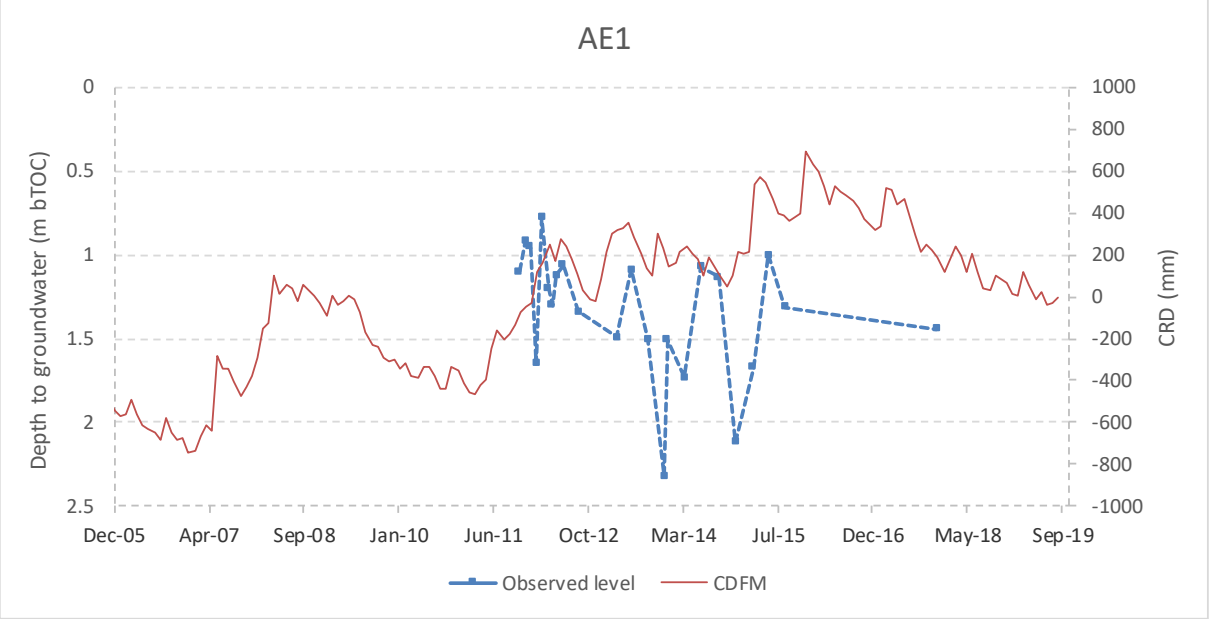

MB15
Groundwater level (mAHD)
CRD (mm)
22
20
18
16
14
12
10
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

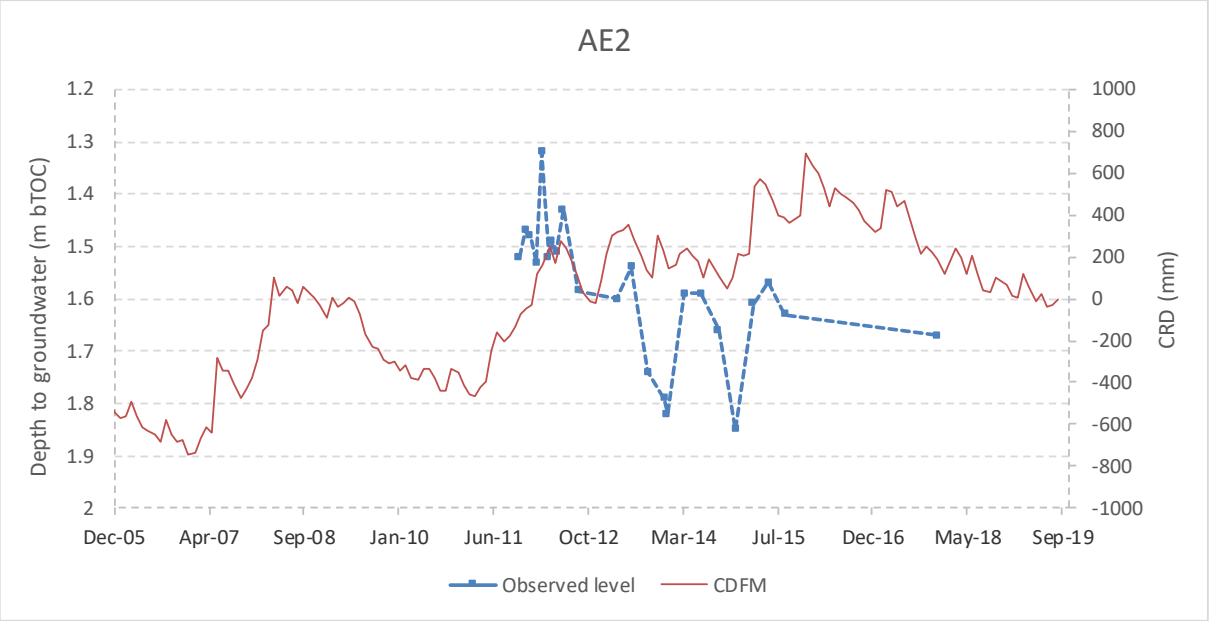

MB16
Groundwater level (mAHD)
CRD (mm)
-16
-17
-18
-19
-20
-21
-22
-23
-24
-25
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

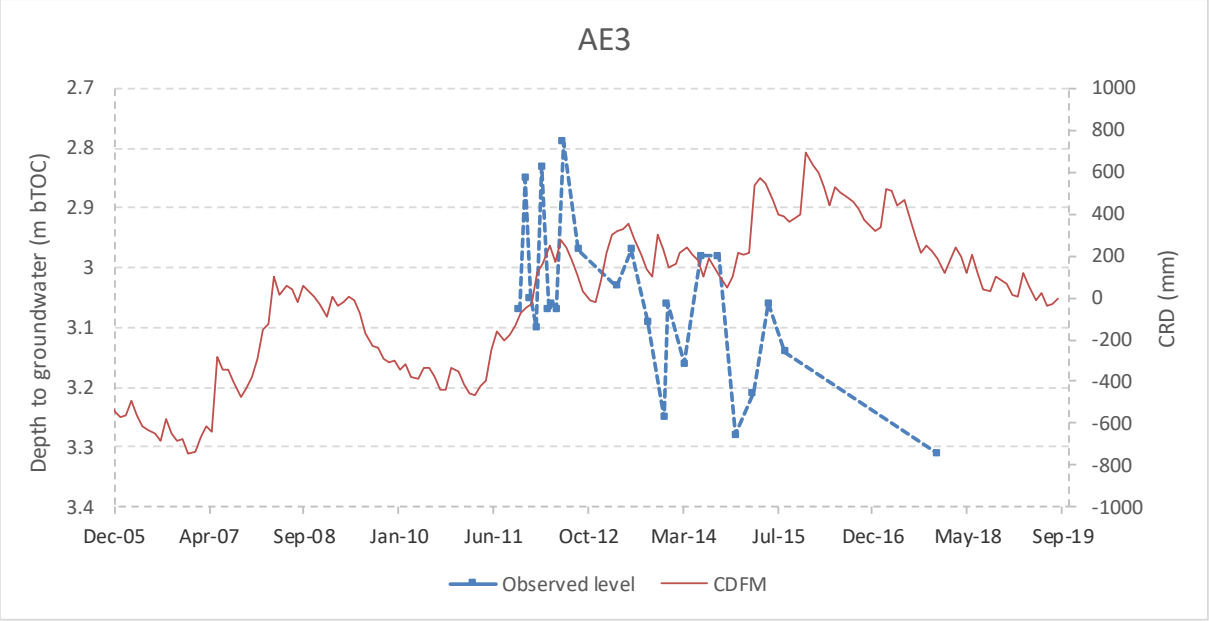

MB17
Groundwater level (mAHD)
CRD (mm)
12
11.5
11
10.5
10
9.5
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

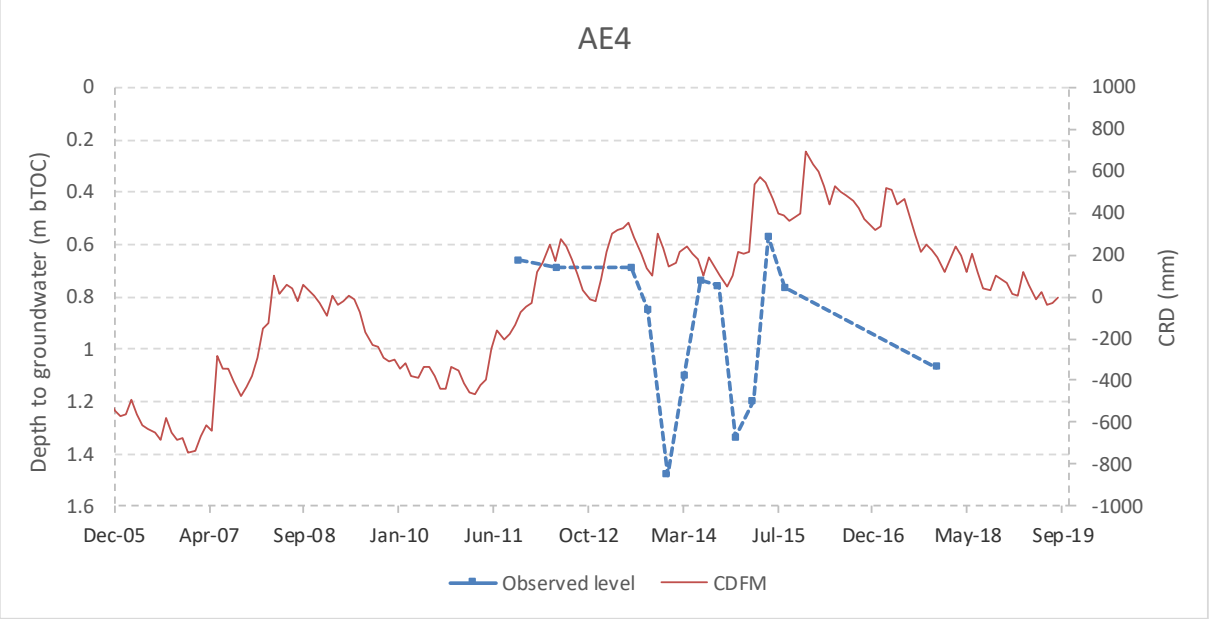

MB18
Groundwater level (mAHD)
CRD (mm)
9
8
7
6
5
4
3
2
1
0
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

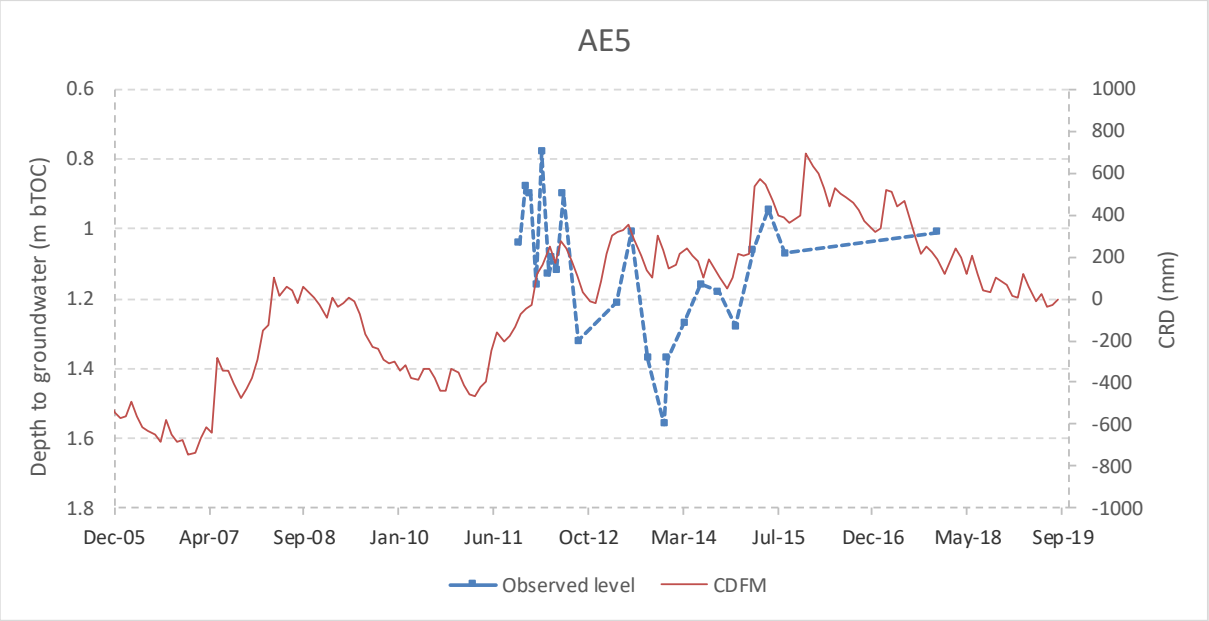

MB19
Groundwater level (mAHD)
CRD (mm)
8
6
4
2
0
-2
-4
-6
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

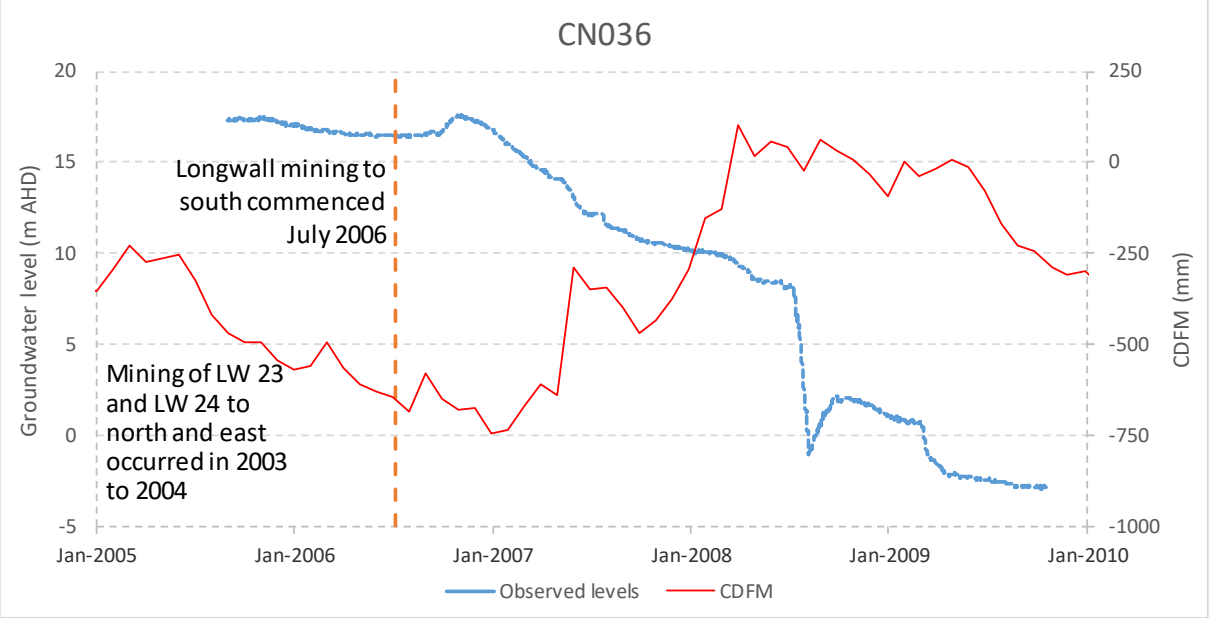

AE1
Depth to groundwater (m bTOC)
CRD (mm)
0
0.5
1
1.5
2
2.5
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM

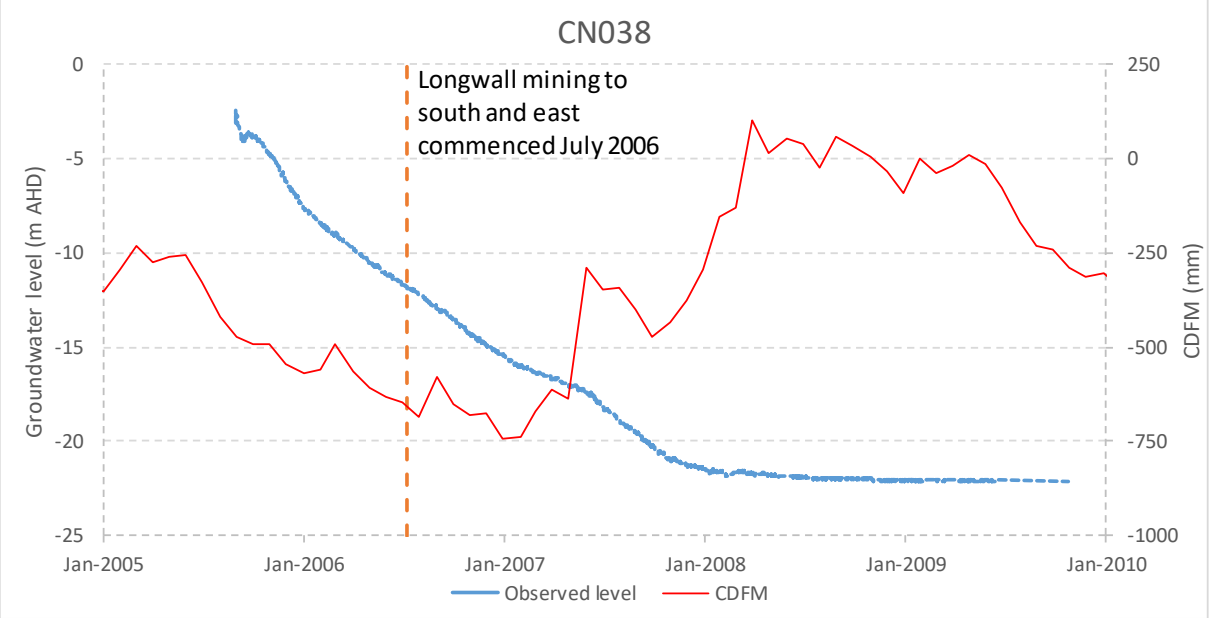

AE2
Depth to groundwater (m bTOC)
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
CRD (mm)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM


AE3
Depth to groundwater (m bTOC)
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
CRD (mm)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM


AE4
Depth to groundwater (m bTOC)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
CRD (mm)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM


AE5
Depth to groundwater (m bTOC)
CRD (mm)
0.6
0.8
1
1.2
1.4
1.6
1.8
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
Dec-05
Apr-07
Sep-08
Jan-10
Jun-11
Oct-12
Mar-14
Jul-15
Dec-16
May-18
Sep-19
Observed level
CDFM


CN036
Groundwater level (m AHD)
CDFM (mm)
20
15
10
5
0
-5
250
0
-250
-500
-750
-1000
Longwall mining to south commenced July 2006
Mining of LW 23 and LW 24 to north and east occurred in 2003 to 2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Observed levels
CDFM


CN038
Groundwater level (m AHD)
CDFM (mm)
0
-5
-10
-15
-20
-25
250
0
-250
-500
-750
-1000
Longwall mining to south and east commenced July 2006
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Jan-2010
Observed level
CDFM

Appendix C – Model discretisation, hydrostratigraphy and boundary conditions

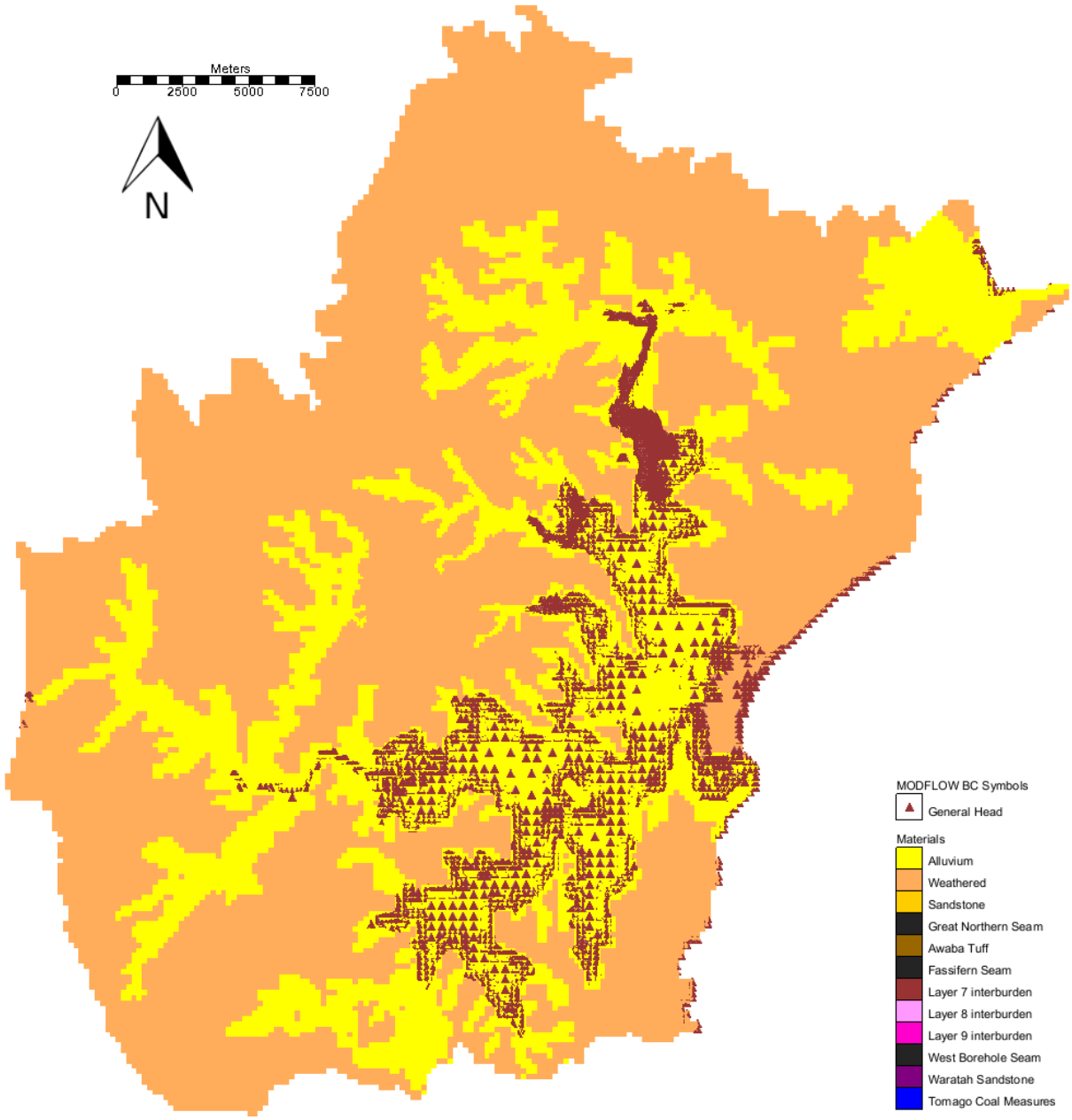


Figure C-1 Layer 1 material distribution and GHB locations

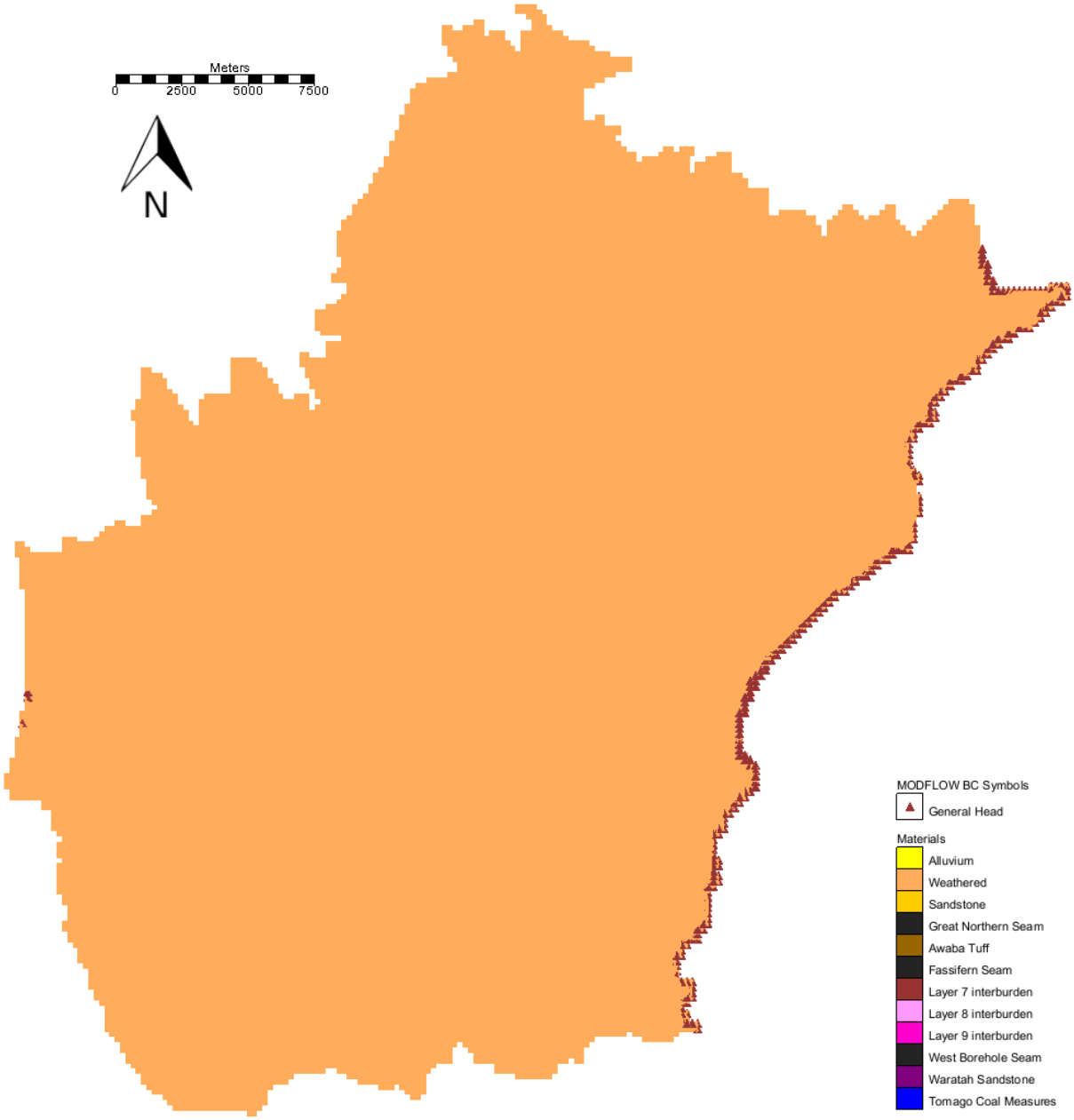


Figure C-2 Layer 2 material distribution and GHB locations

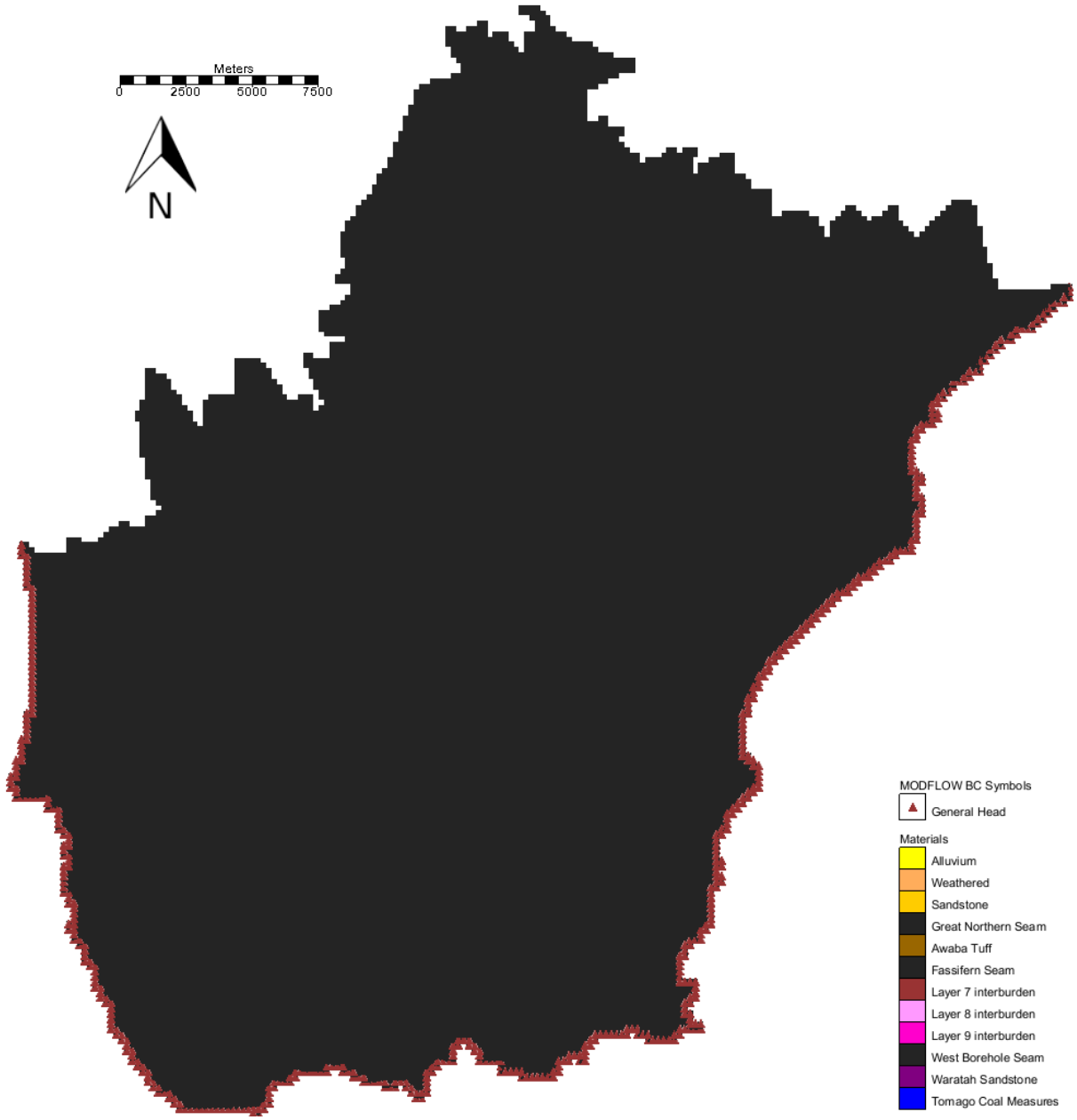


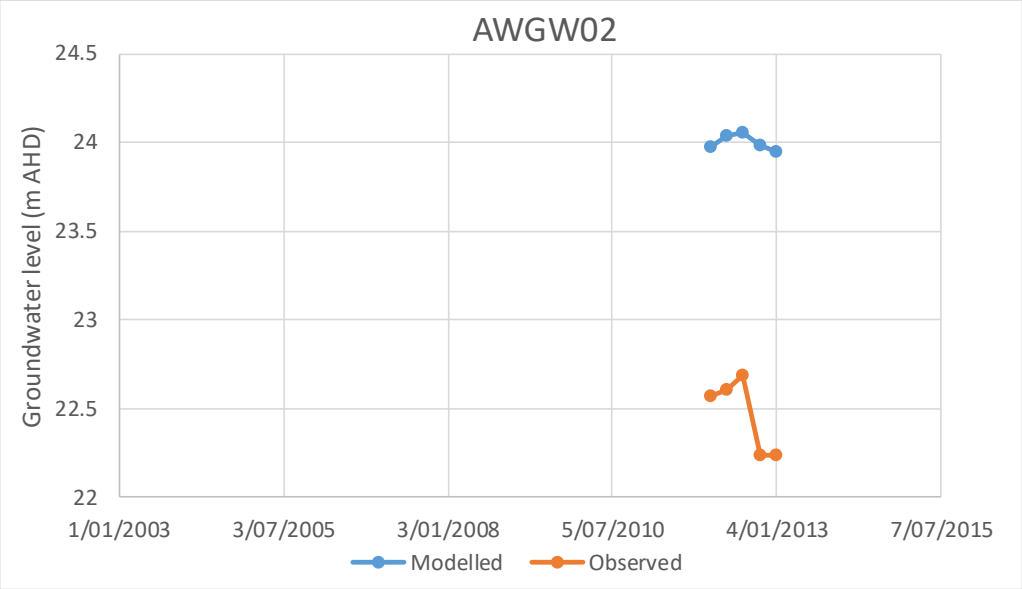
Figure C-3 Typical coal seam material distribution and GHB locations

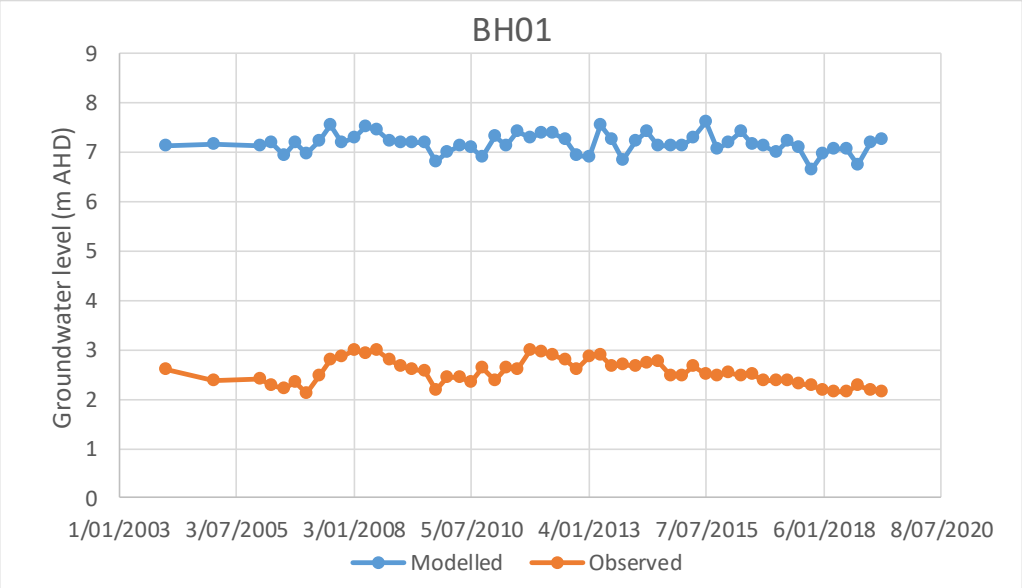
Table C-1 Summary of predictive model stress periods

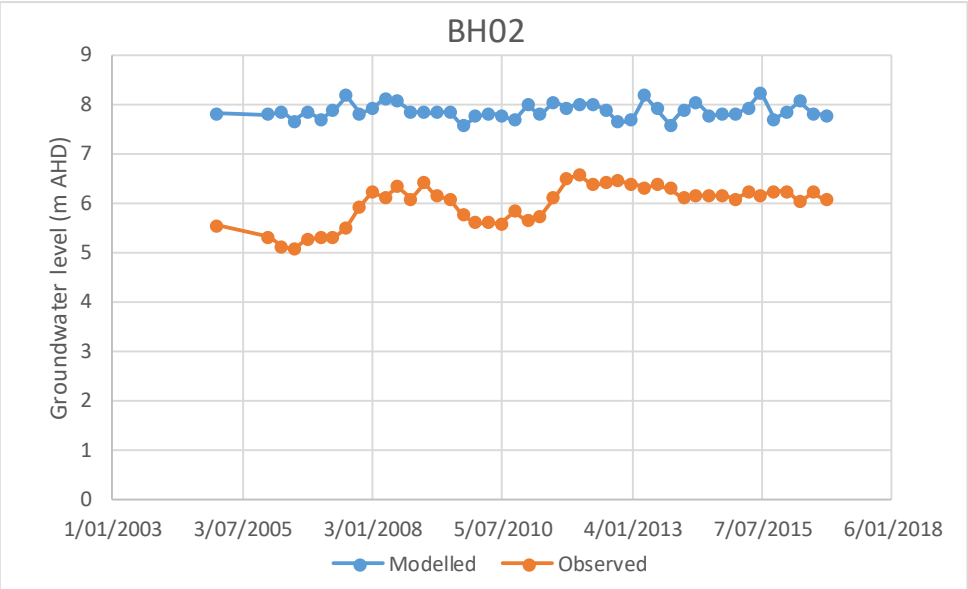
Stress period no.	Start date/time	Length (days)	No. of time steps
1	1/07/2019 12:00:00 AM	184	6
2	1/01/2020 12:00:00 AM	366	12
3	1/01/2021 12:00:00 AM	365	12
4	1/01/2022 12:00:00 AM	365	12
5	1/01/2023 12:00:00 AM	365	12
6	1/01/2024 12:00:00 AM	366	12
7	1/01/2025 12:00:00 AM	365	12
8	1/01/2026 12:00:00 AM	365	12
9	1/01/2027 12:00:00 AM	365	12
10	1/01/2028 12:00:00 AM	366	12
11	1/01/2029 12:00:00 AM	365	12
12	1/01/2030 12:00:00 AM	365	12
13	1/01/2031 12:00:00 AM	365	12
14	1/01/2032 12:00:00 AM	366	12
15	1/01/2033 12:00:00 AM	365	12
16	1/01/2034 12:00:00 AM	365	12
17	1/01/2035 12:00:00 AM	365	12
18	1/01/2036 12:00:00 AM	366	12
19	1/01/2037 12:00:00 AM	365	12
20	1/01/2038 12:00:00 AM	365	12
21	1/01/2039 12:00:00 AM	365	12
22	1/01/2040 12:00:00 AM	366	12
23	1/01/2041 12:00:00 AM	365	12
24	1/01/2042 12:00:00 AM	365	12
25	1/01/2043 12:00:00 AM	365	12
26	1/01/2044 12:00:00 AM	366	12
27	1/01/2045 12:00:00 AM	365	12
28	1/01/2046 12:00:00 AM	365	12
29	1/01/2047 12:00:00 AM	365	12
30	1/01/2048 12:00:00 AM	366	12
31	1/01/2049 12:00:00 AM	365	12
32	1/01/2050 12:00:00 AM	365	12
33	1/01/2051 12:00:00 AM	365	12
34	1/01/2052 12:00:00 AM	366	12
35	1/01/2053 12:00:00 AM	365	12
36	1/01/2054 12:00:00 AM	365	12
37	1/01/2055 12:00:00 AM	731	12
38	1/01/2057 12:00:00 AM	730	10
39	1/01/2059 12:00:00 AM	731	10
40	1/01/2061 12:00:00 AM	730	10
41	1/01/2063 12:00:00 AM	731	10
42	1/01/2065 12:00:00 AM	730	10
43	1/01/2067 12:00:00 AM	731	10
44	1/01/2069 12:00:00 AM	730	10
45	1/01/2071 12:00:00 AM	731	10
46	1/01/2073 12:00:00 AM	730	10
47	1/01/2075 12:00:00 AM	1826	10
48	1/01/2080 12:00:00 AM	1827	25

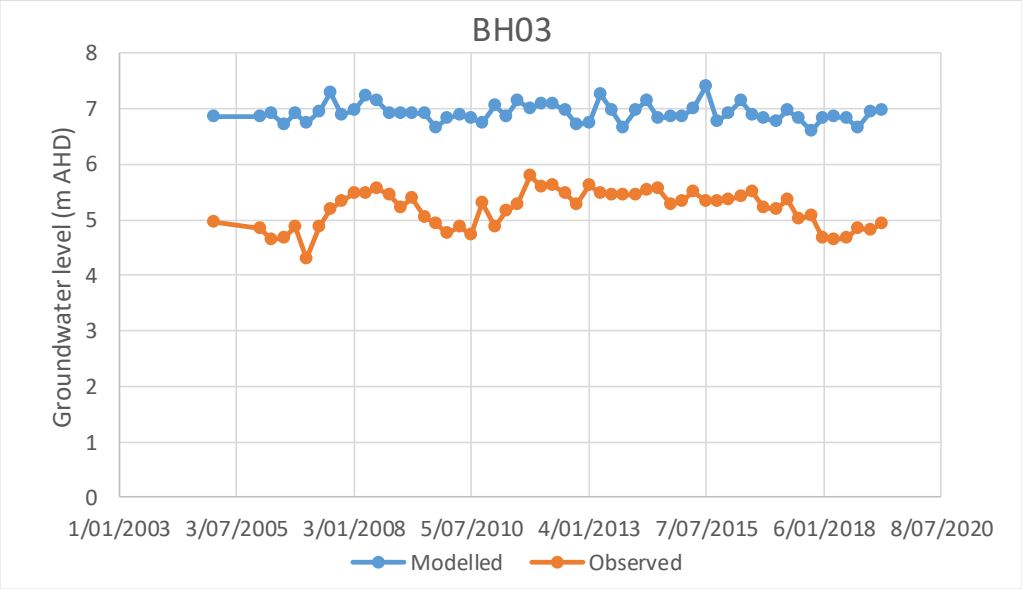
Stress period no.	Start date/time	Length (days)	No. of time steps
49	1/01/2085 12:00:00 AM	1826	25
50	1/01/2090 12:00:00 AM	1826	20
51	1/01/2095 12:00:00 AM	1826	20
52	1/01/2100 12:00:00 AM	1826	10
53	1/01/2105 12:00:00 AM	1826	10
54	1/01/2110 12:00:00 AM	1826	10
55	1/01/2115 12:00:00 AM	1826	10
56	1/01/2120 12:00:00 AM	1827	10
57	1/01/2125 12:00:00 AM	1826	10
58	1/01/2130 12:00:00 AM	1826	10
59	1/01/2135 12:00:00 AM	3653	10
60	1/01/2145 12:00:00 AM	3652	10
61	1/01/2155 12:00:00 AM	3653	10
62	1/01/2165 12:00:00 AM	3652	10
63	1/01/2175 12:00:00 AM	7305	10
64	1/01/2195 12:00:00 AM	7304	10
65	1/01/2215 12:00:00 AM	7305	10
66	1/01/2235 12:00:00 AM	18263	10
67	1/01/2285 12:00:00 AM	18261	10
68	1/01/2335 12:00:00 AM	18263	10
69	1/01/2385 12:00:00 AM	18262	10
70	1/01/2435 12:00:00 AM	18263	10
71	1/01/2485 12:00:00 AM	18261	10
72	1/01/2535 12:00:00 AM	18263	10
73	1/01/2585 12:00:00 AM	18261	10

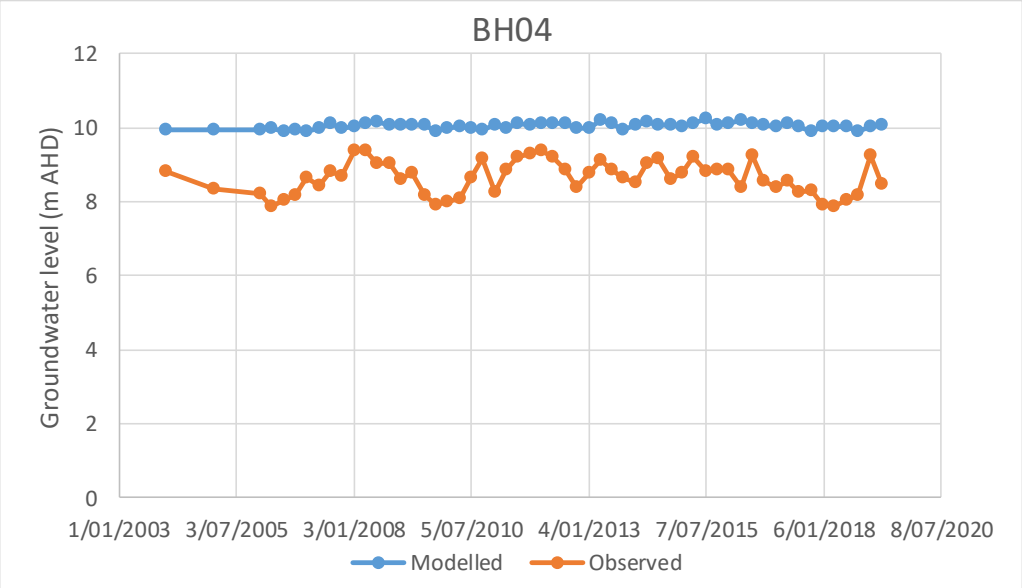
Appendix D – Calibration hydrographs

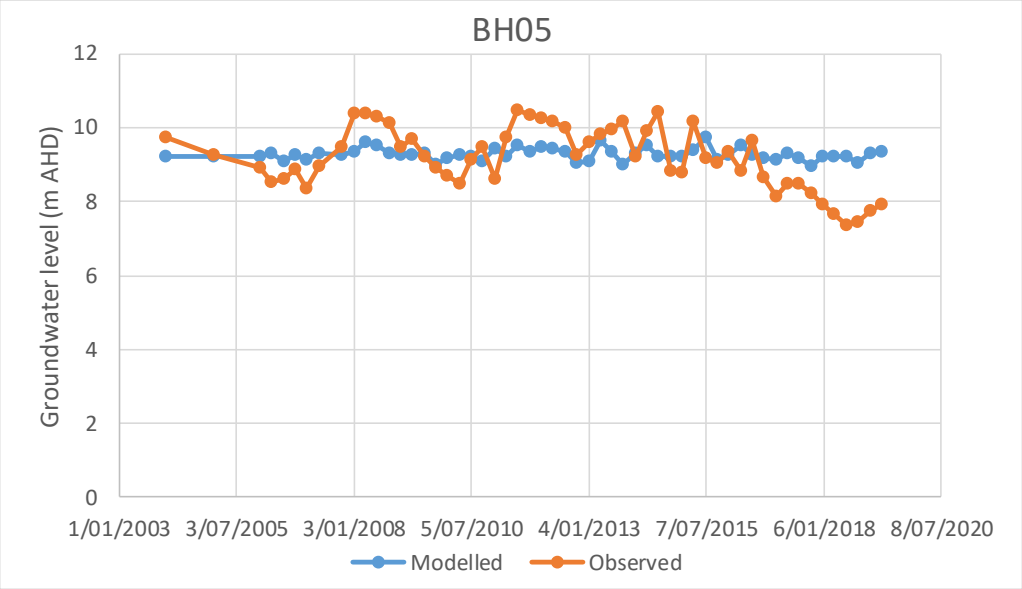

AWGW02
Groundwater level (m AHD)
24.5
24
23.5
23
22.5
22
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
Modelled
Observed

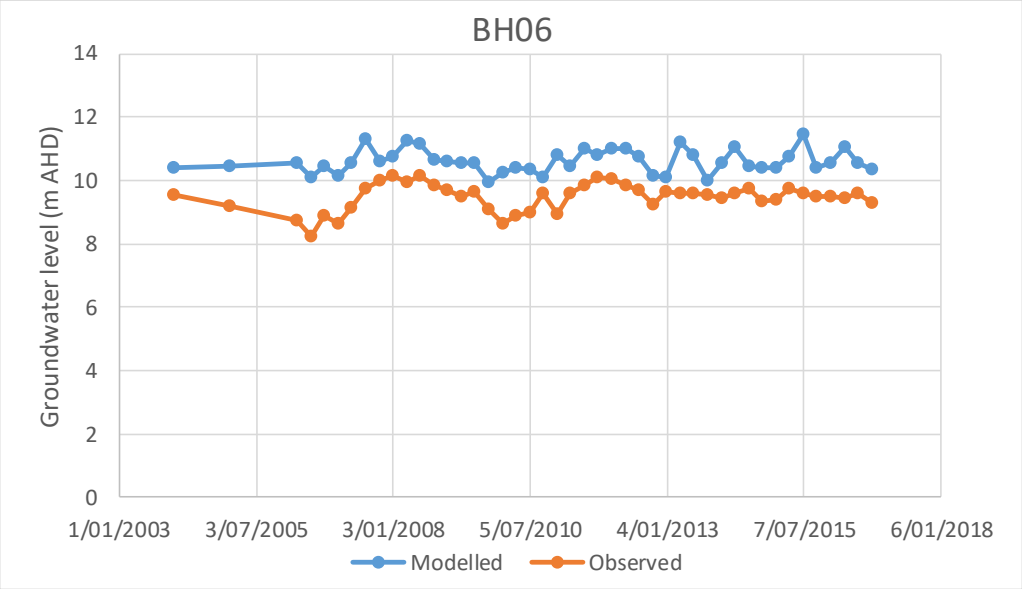

BH01
Groundwater level (m AHD)
9
8
7
6
5
4
3
2
1
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

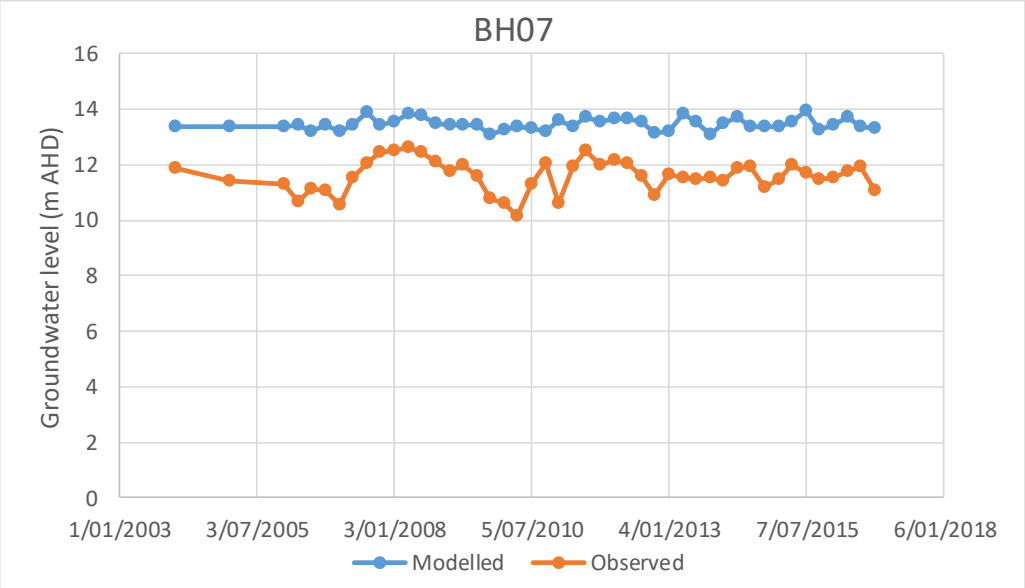

BH02
Groundwater level (m AHD)
9
8
7
6
5
4
3
2
1
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

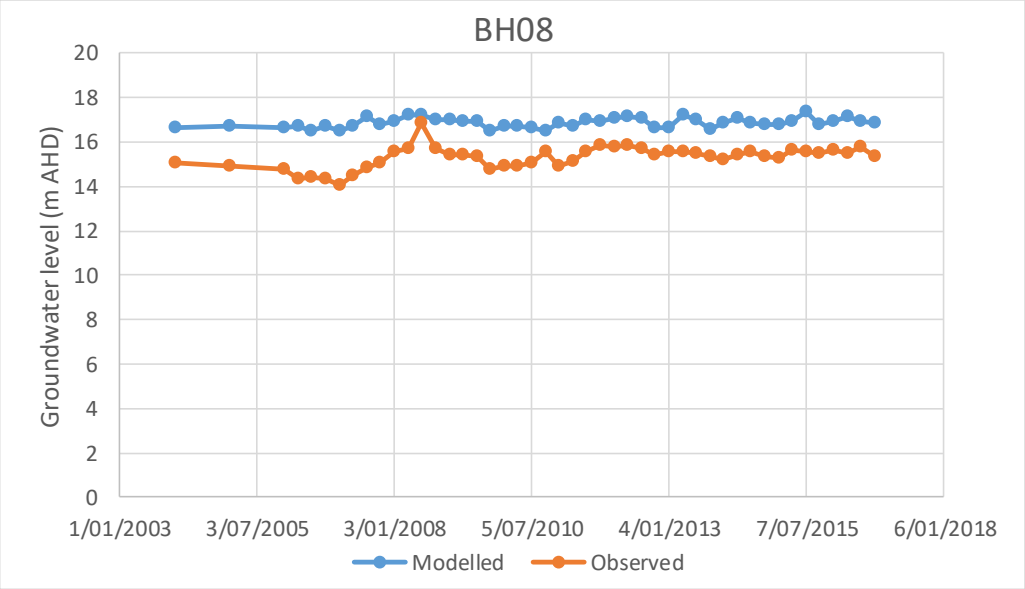

BH03
Groundwater level (m AHD)
8
7
6
5
4
3
2
1
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

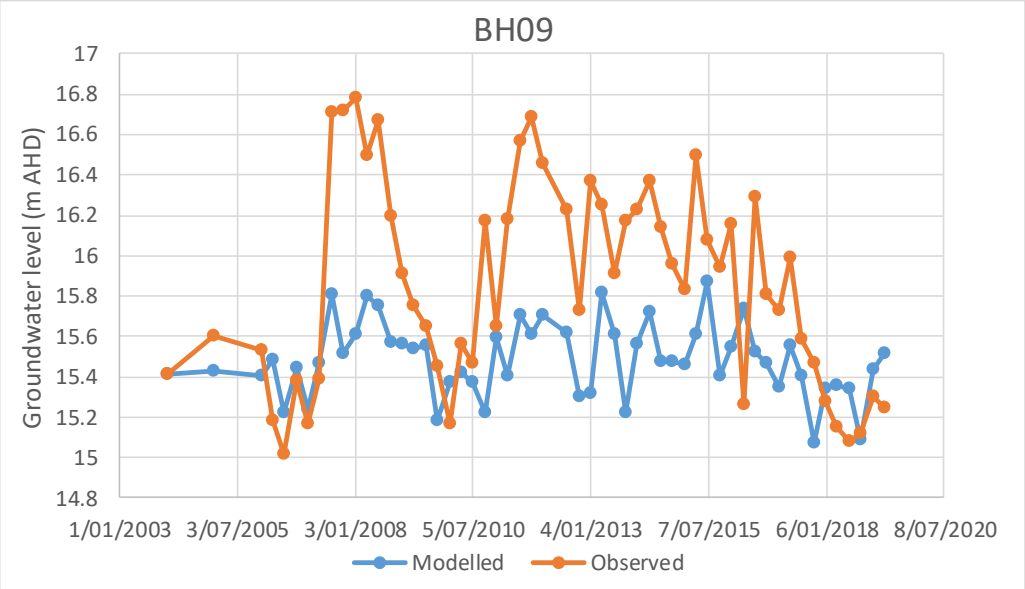

BH04
Groundwater level (m AHD)
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

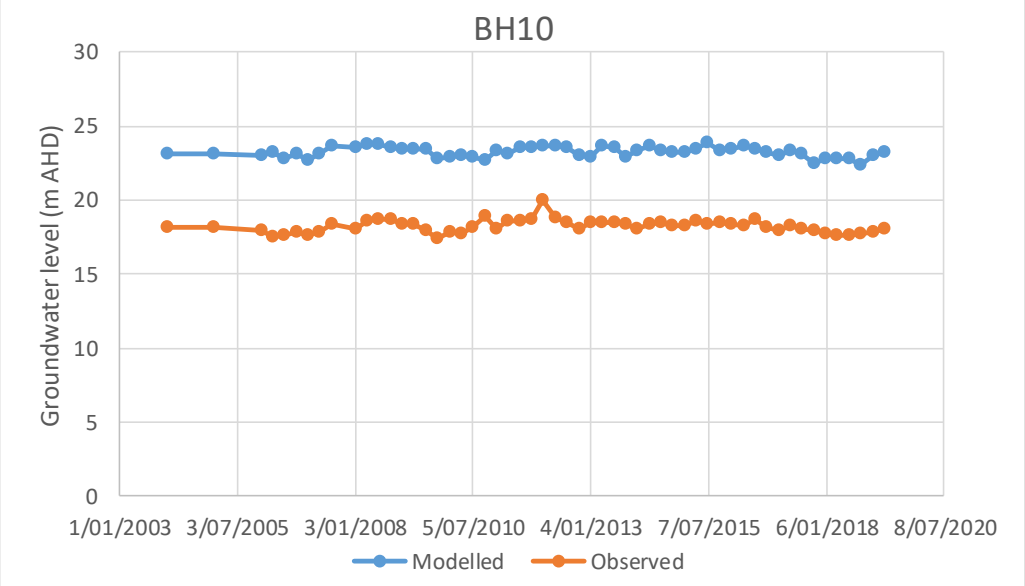

BH05
Groundwater level (m AHD)
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

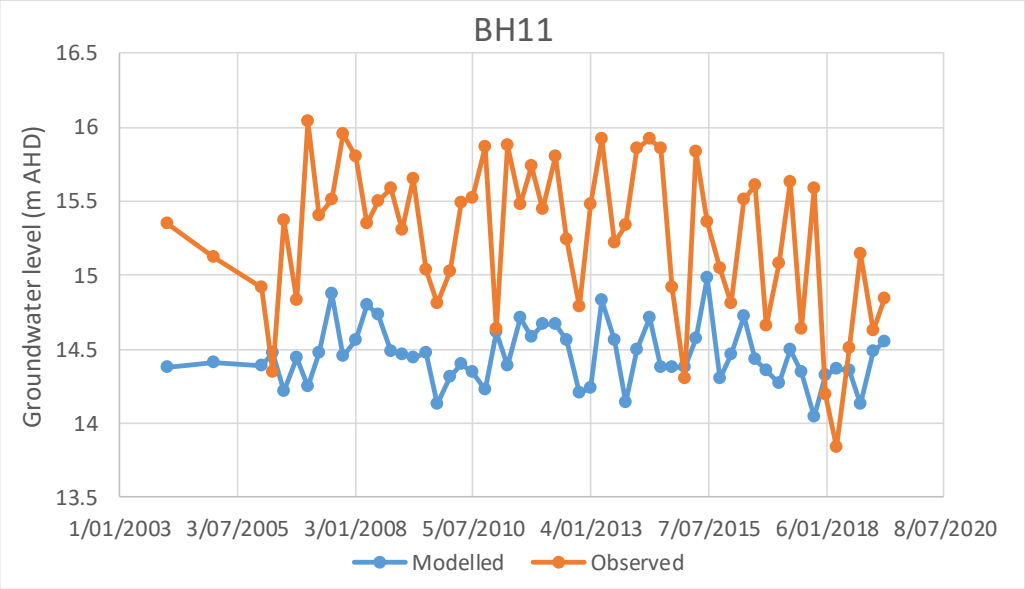

BH06
Groundwater level (m AHD)
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

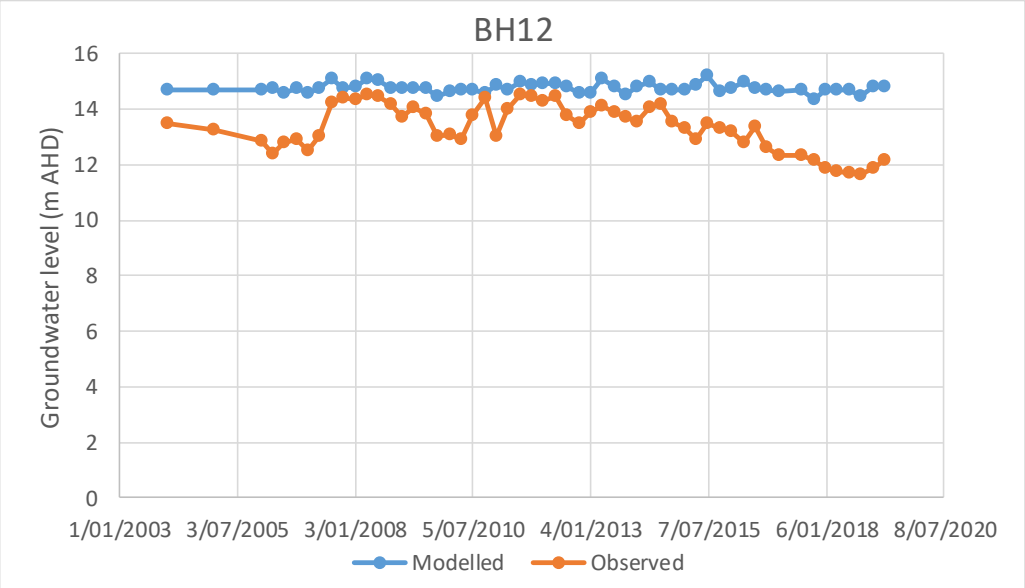

BH07
Groundwater level (m AHD)
16
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

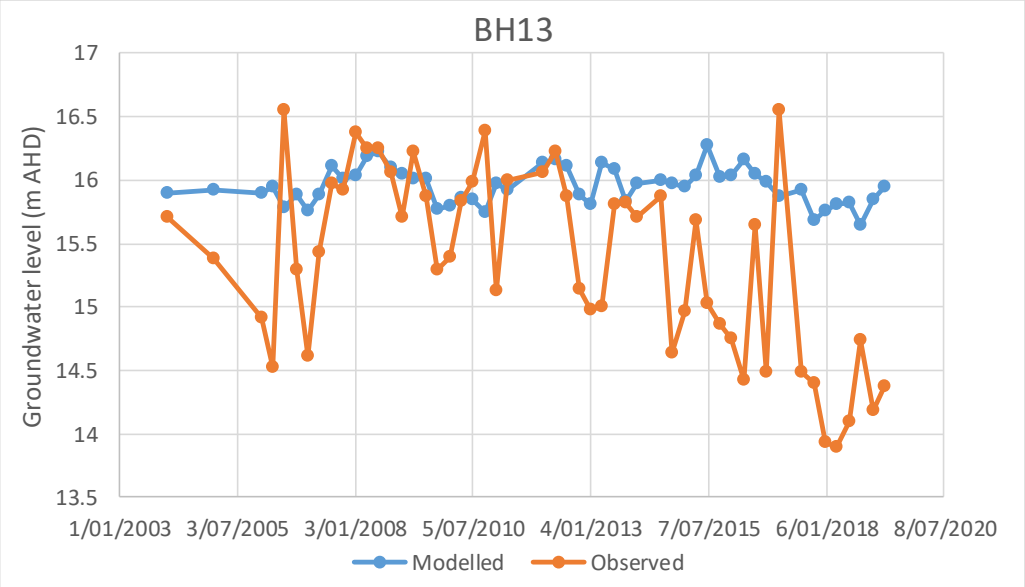

BH08
Groundwater level (m AHD)
20
18
16
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

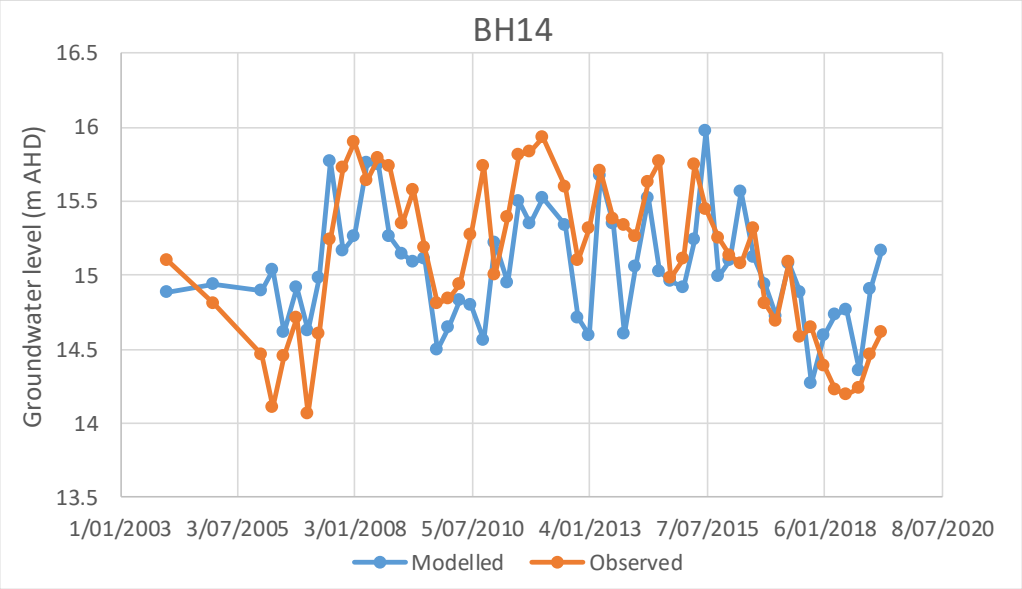

BH09
Groundwater level (m AHD)
17
16.8
16.6
16.4
16.2
16
15.8
15.6
15.4
15.2
15
14.8
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

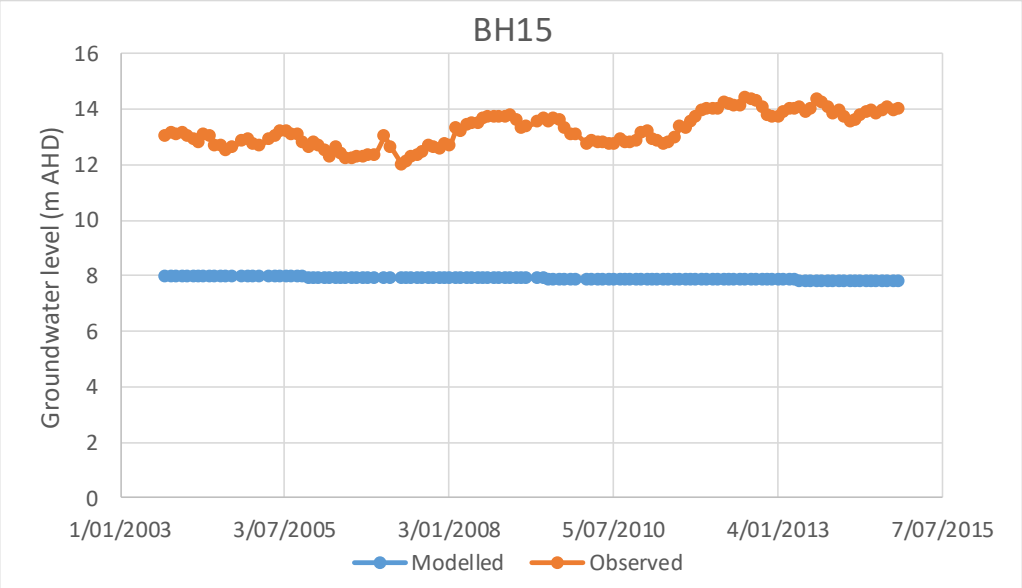

BH10
Groundwater level (m AHD)
30
25
20
15
10
5
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

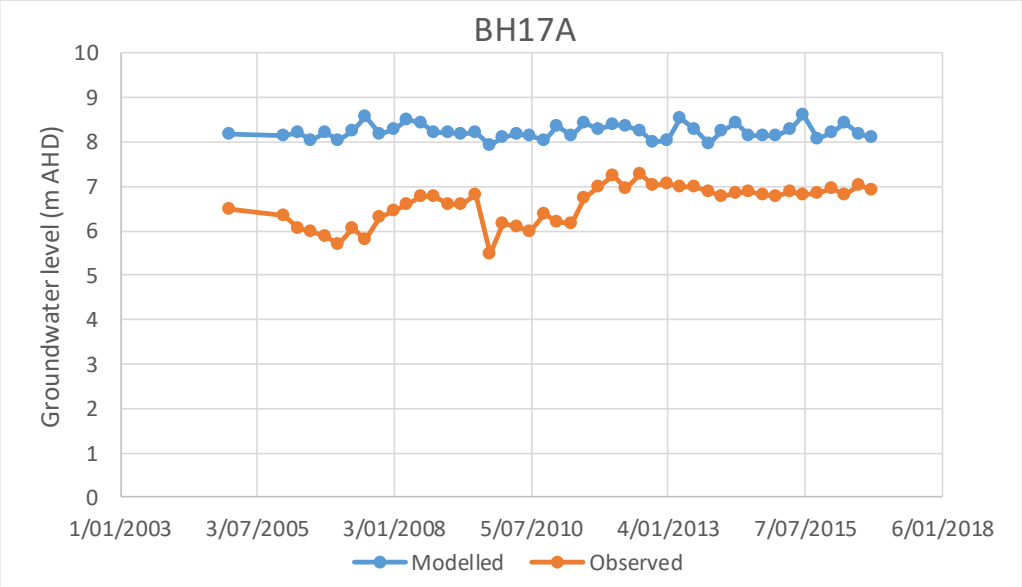

BH11
Groundwater level (m AHD)
16.5
16
15.5
15
14.5
14
13.5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

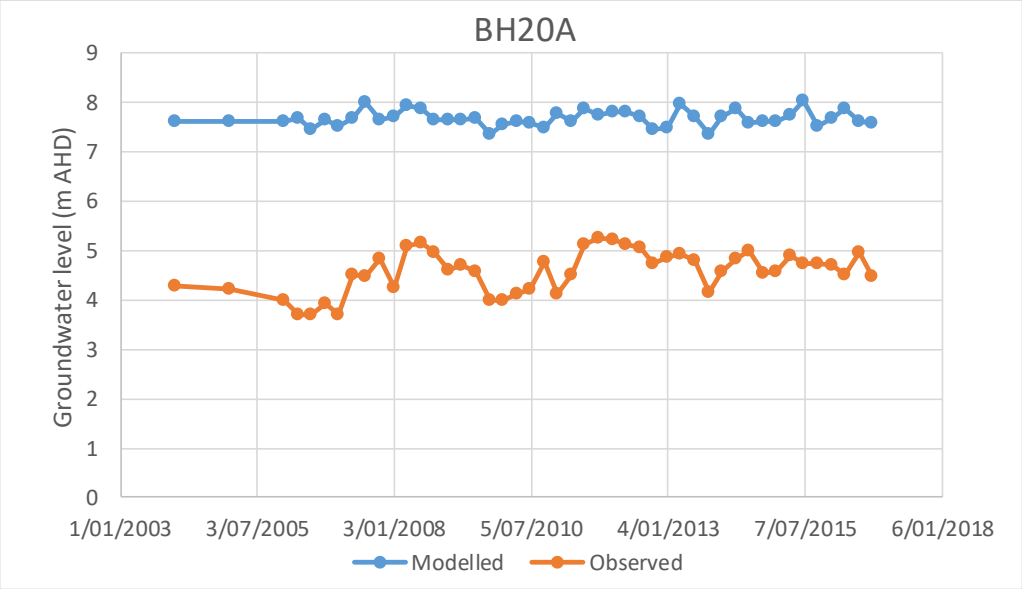

BH12
Groundwater level (m AHD)
16
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

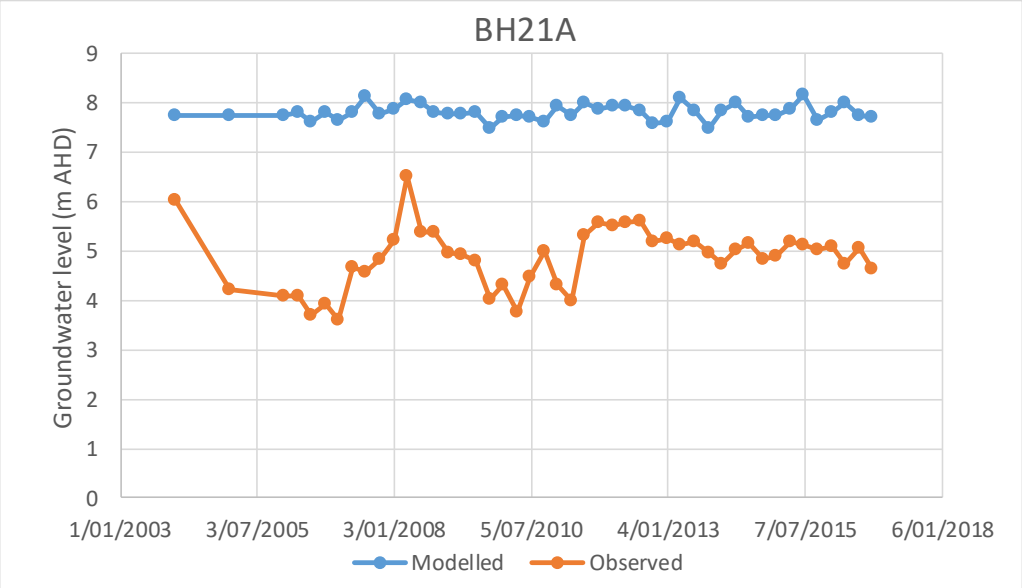

BH13
Groundwater level (m AHD)
17
16.5
16
15.5
15
14.5
14
13.5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

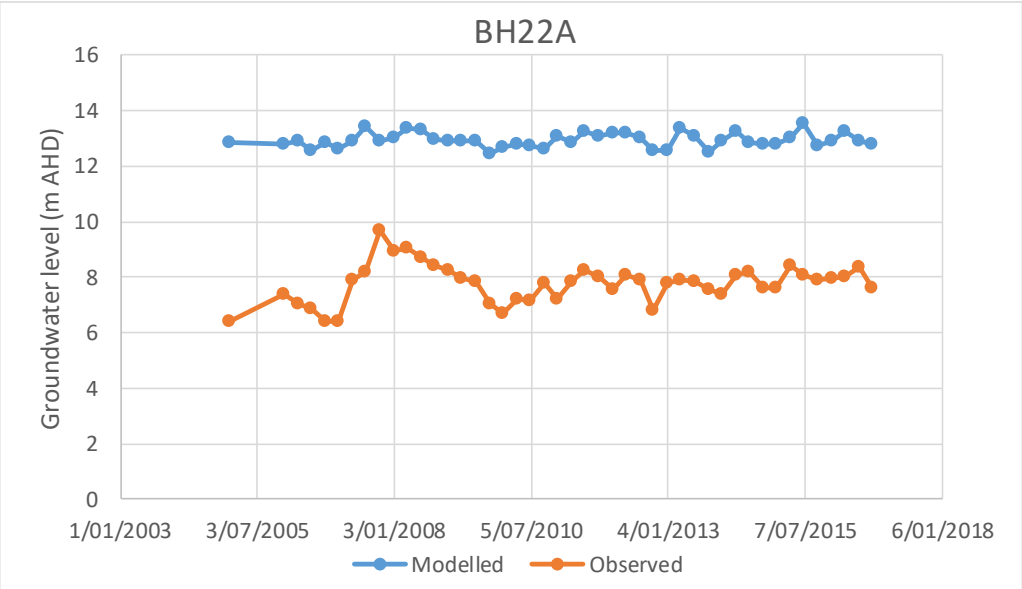

BH14
Groundwater level (m AHD)
16.5
16
15.5
15
14.5
14
13.5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

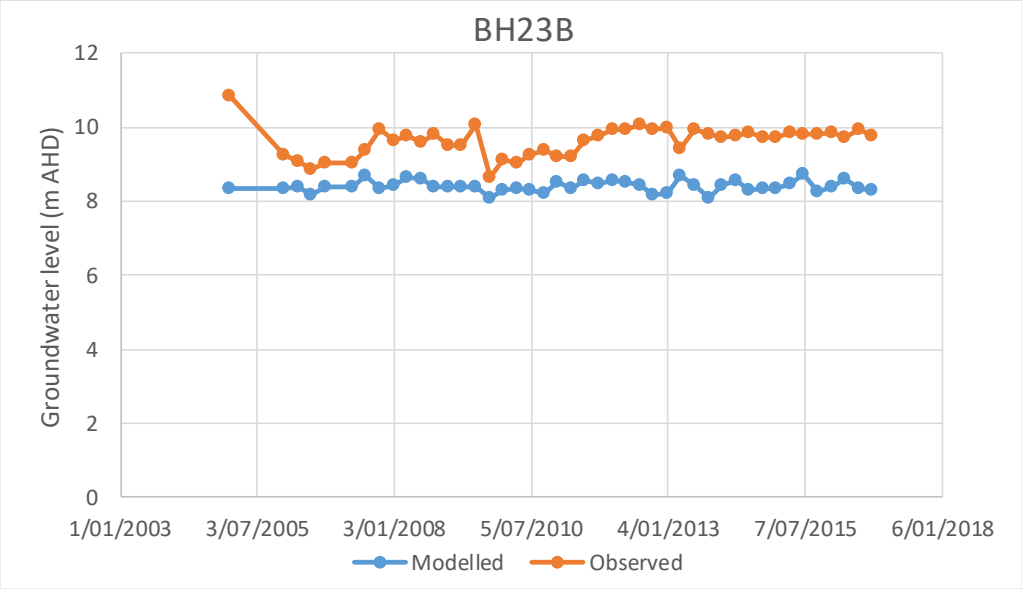

BH15
Groundwater level (m AHD)
16
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
Modelled
Observed

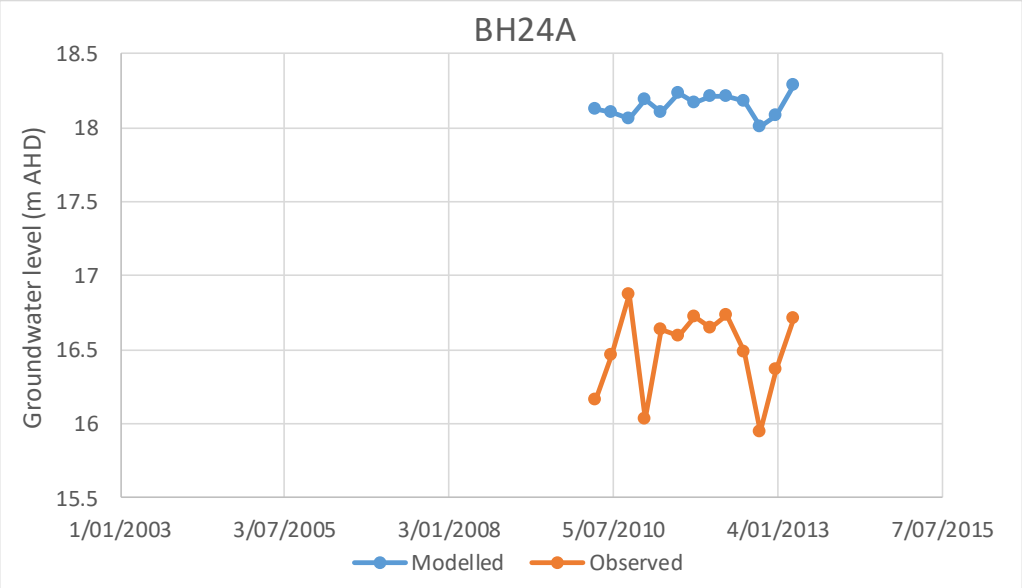

BH17A
Groundwater level (m AHD)
10
9
8
7
6
5
4
3
2
1
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

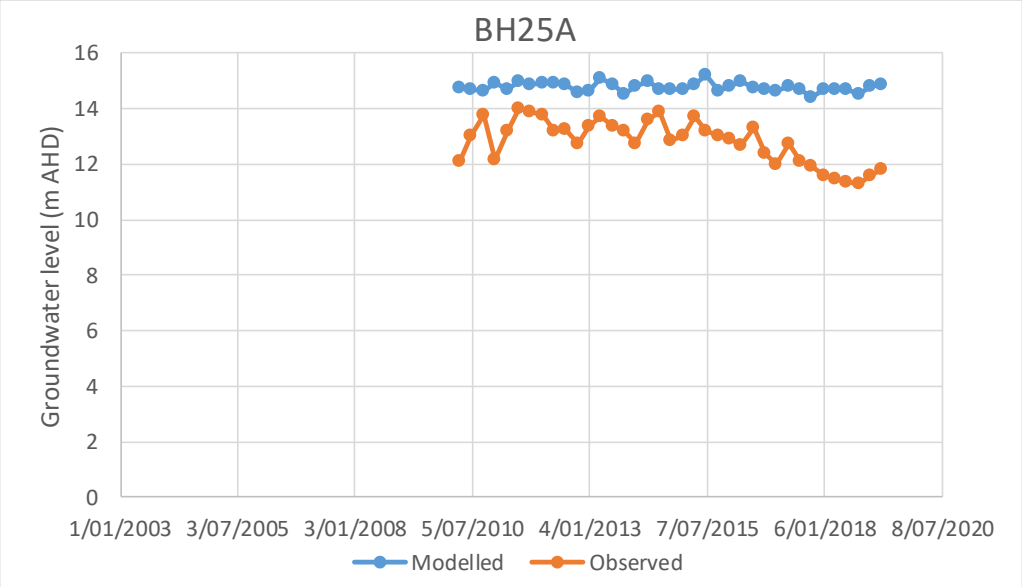

BH20A
Groundwater level (m AHD)
9
8
7
6
5
4
3
2
1
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

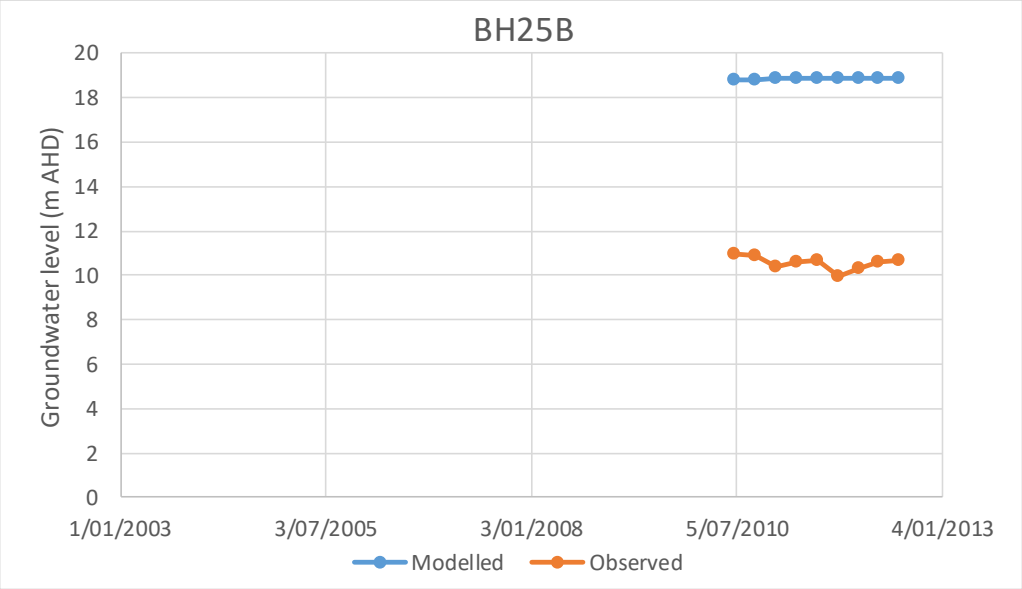

BH21A
Groundwater level (m AHD)
9
8
7
6
5
4
3
2
1
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

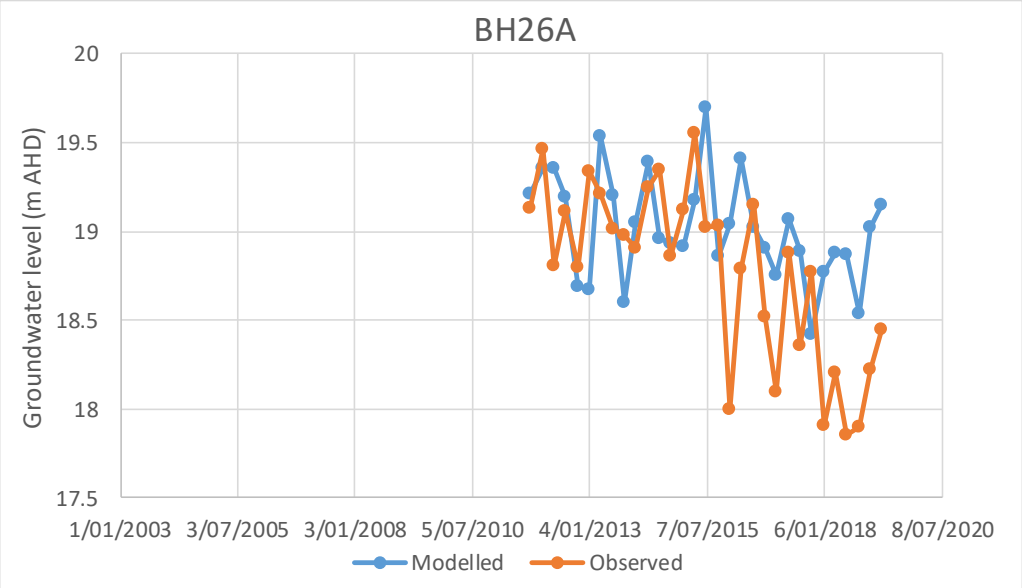

BH22A
Groundwater level (m AHD)
16
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

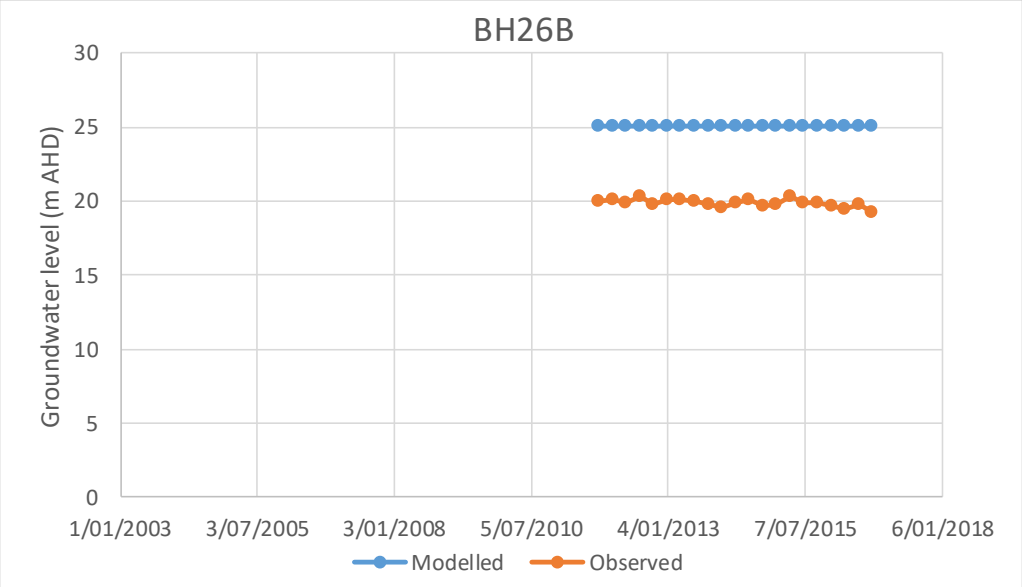

BH23B
Groundwater level (m AHD)
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

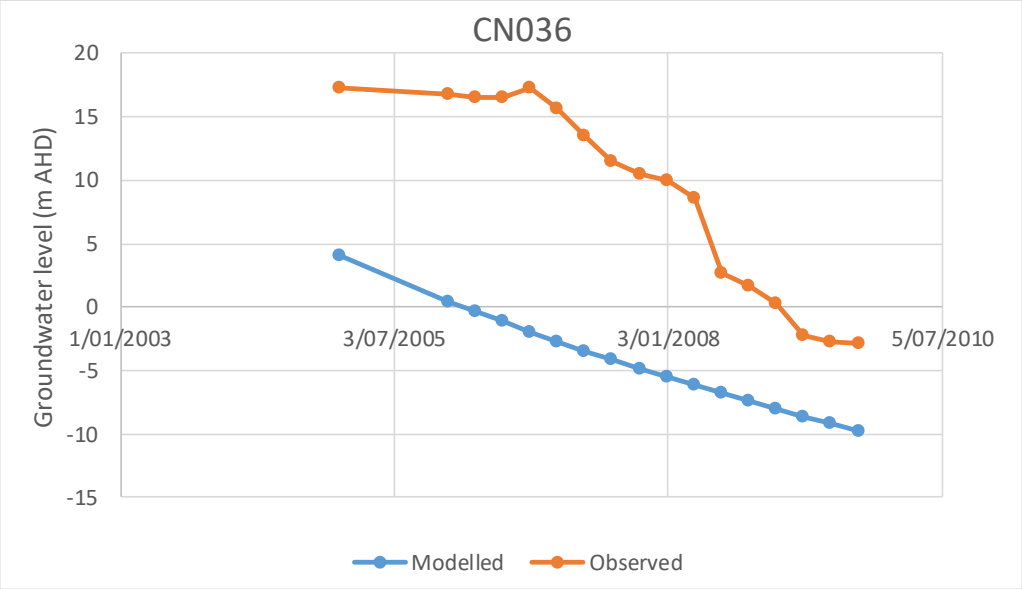

BH24A
Groundwater level (m AHD)
18.5
18
17.5
17
16.5
16
15.5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
Modelled
Observed

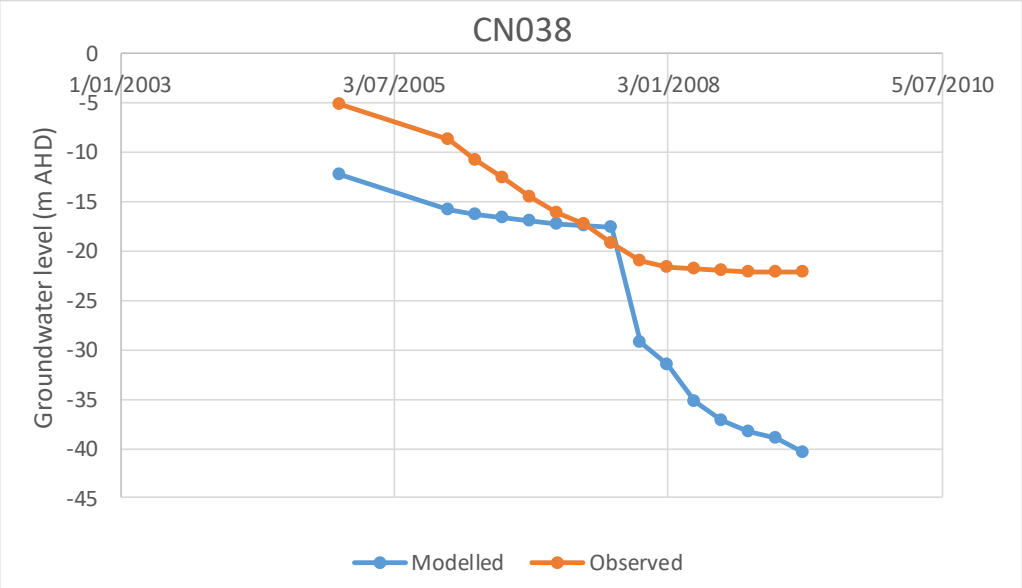

BH25A
Groundwater level (m AHD)
16
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

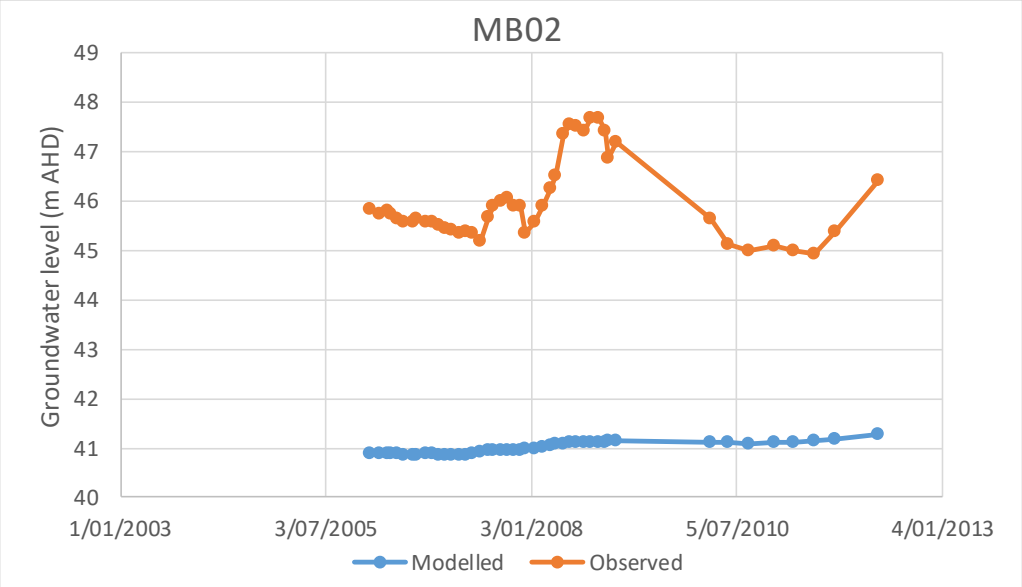

BH25B
Groundwater level (m AHD)
20
18
16
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
Modelled
Observed

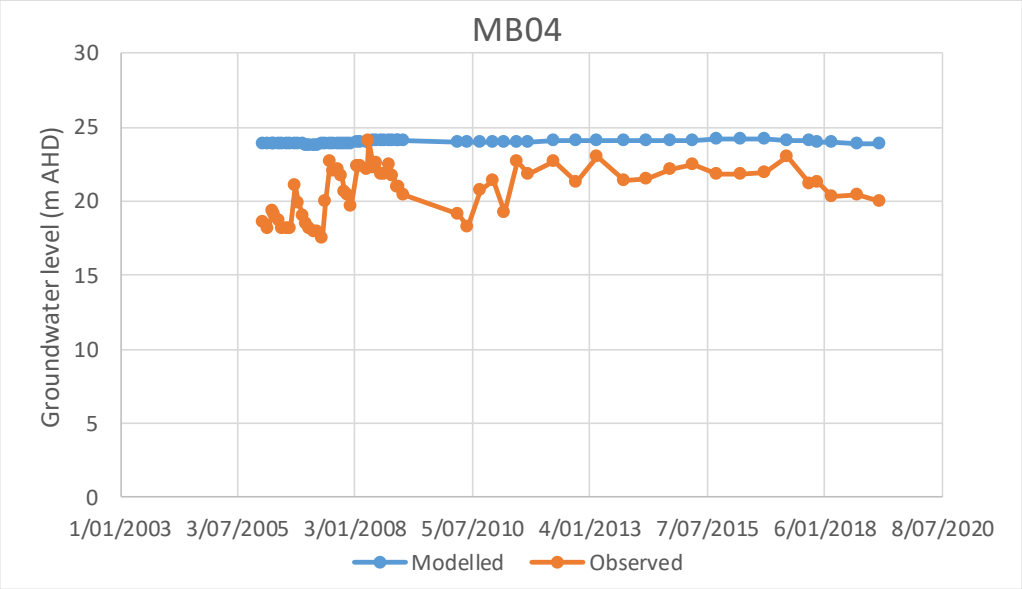

BH26A
Groundwater level (m AHD)
20
19.5
19
18.5
18
17.5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

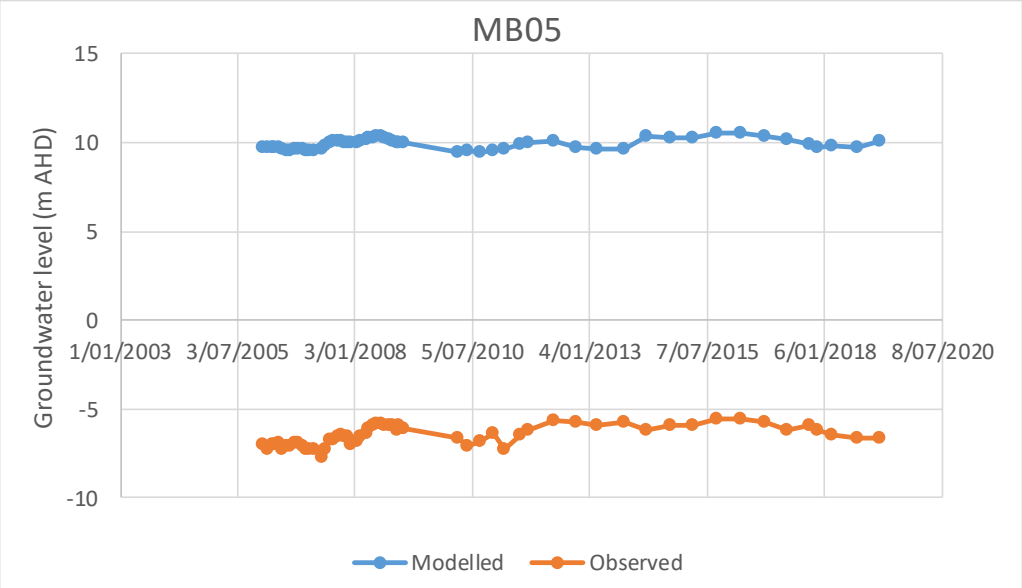

BH26B
Groundwater level (m AHD)
30
25
20
15
10
5
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed

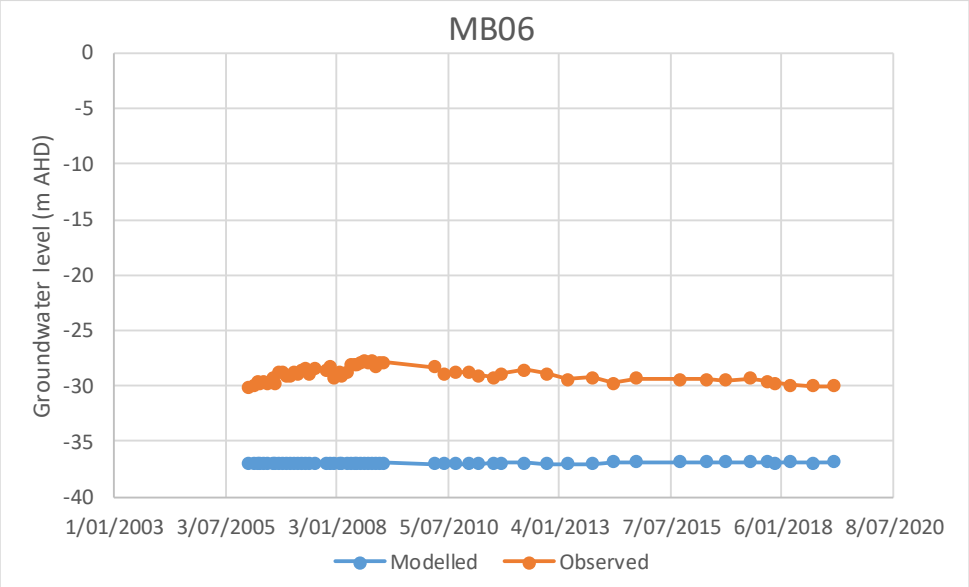

CN036
Groundwater level (m AHD)
20
15
10
5
0
-5
-10
-15
1/01/2003
3/07/2005
3/01/2008
5/07/2010
Modelled
Observed

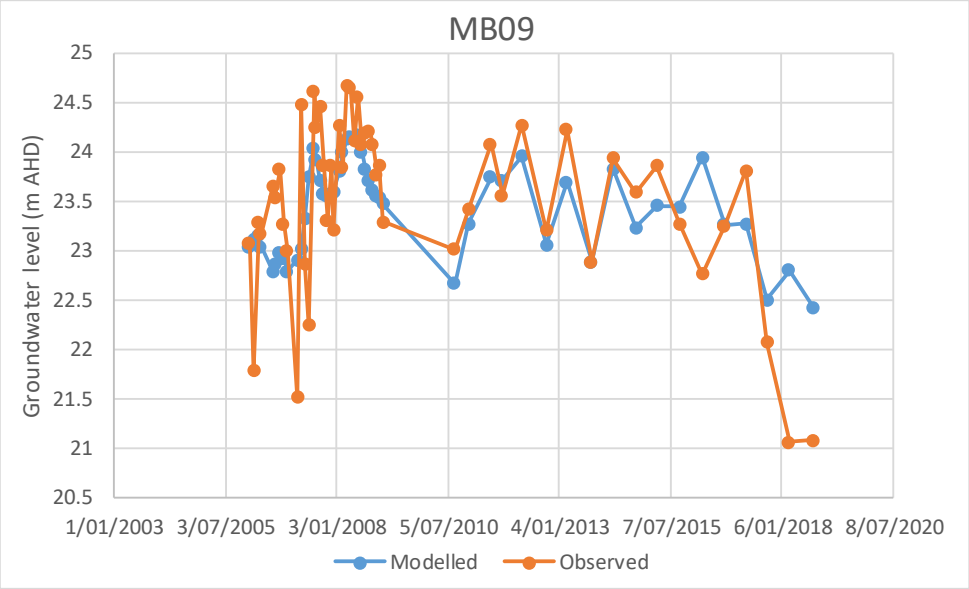

CN038
Groundwater level (m AHD)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
1/01/2003
3/07/2005
3/01/2008
5/07/2010
Modelled
Observed

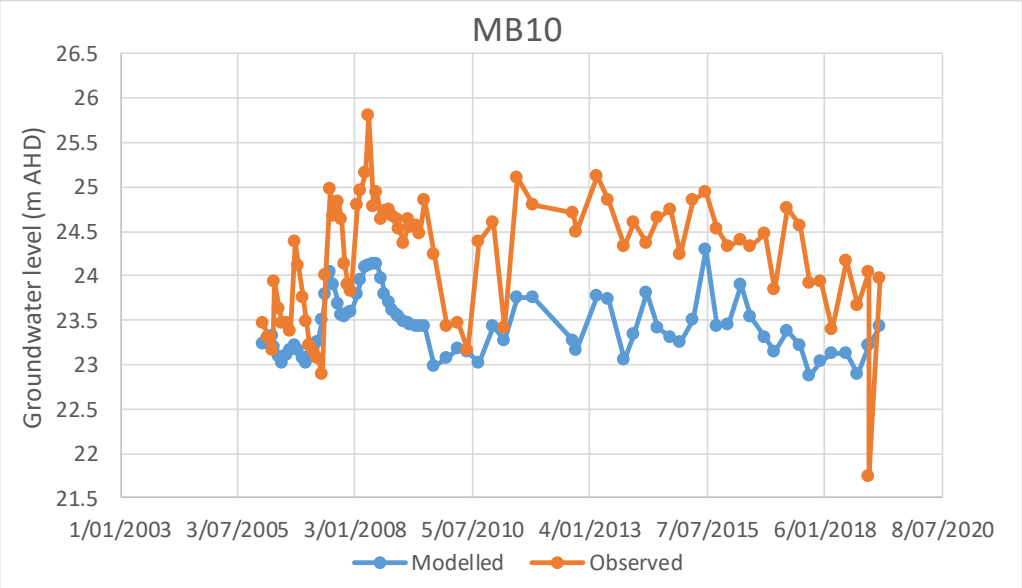

MB02
Groundwater level (m AHD)
49
48
47
46
45
44
43
42
41
40
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
Modelled
Observed

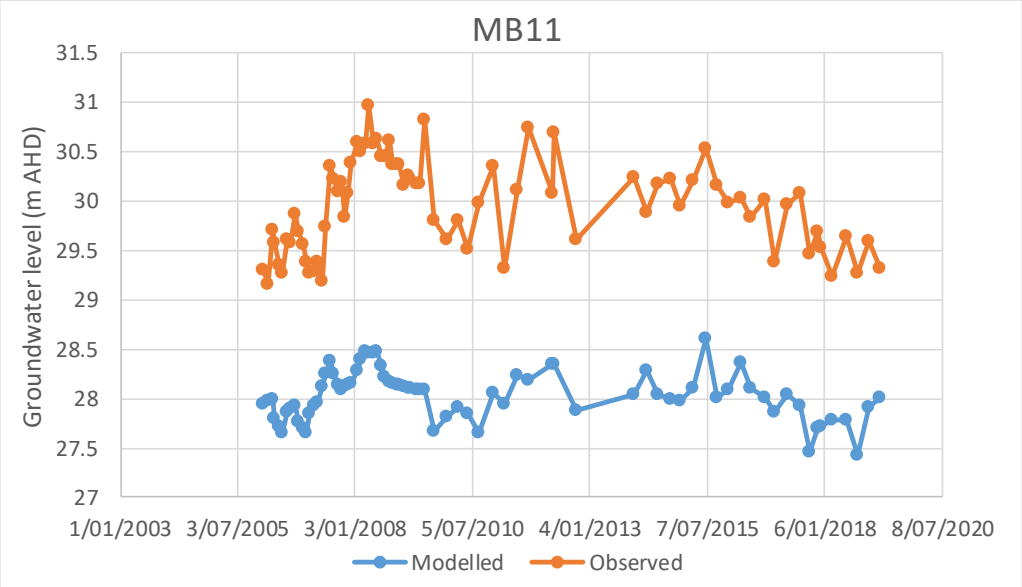

MB04
Groundwater level (m AHD)
30
25
20
15
10
5
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

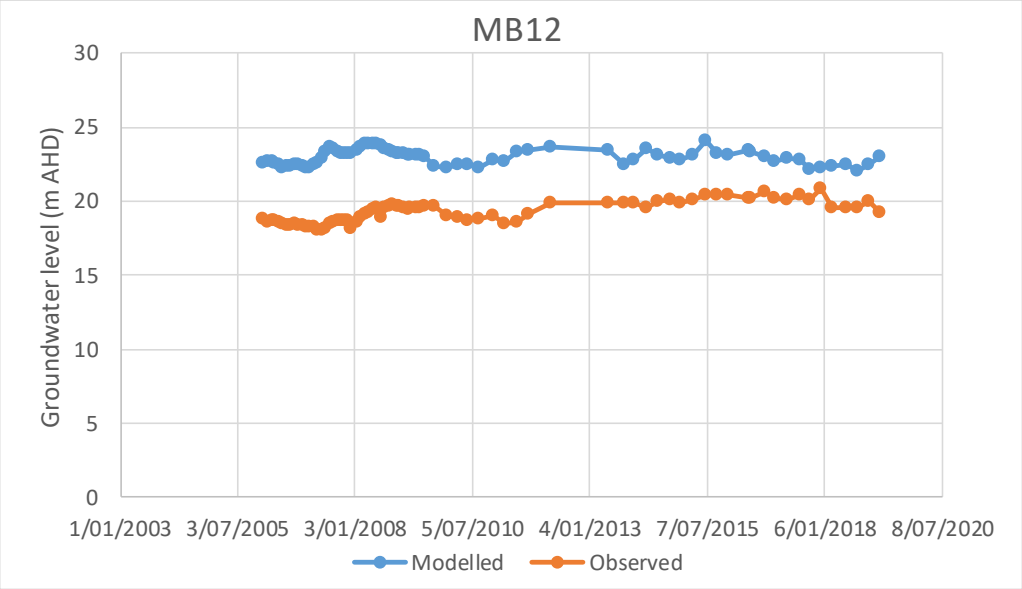

MB05
Groundwater level (m AHD)
15
10
5
0
-5
-10
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

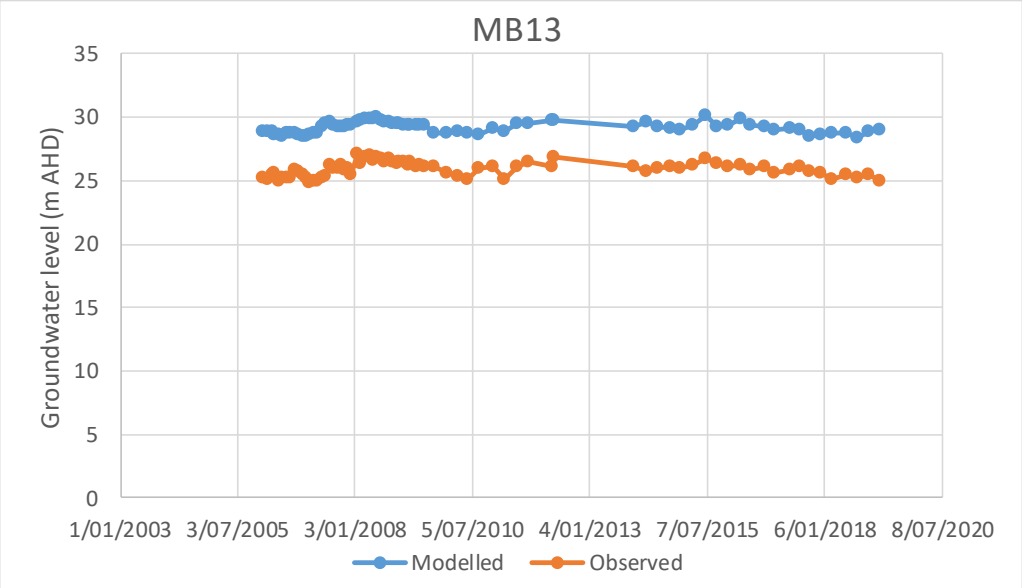

MB06
Groundwater level (m AHD)
0
-5
-10
-15
-20
-25
-30
-35
-40
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

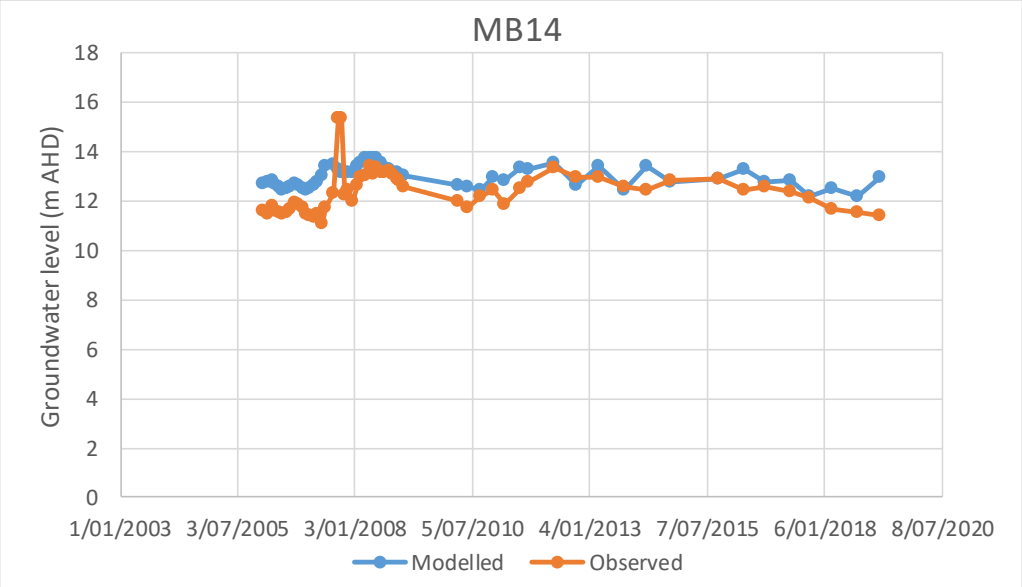

MB09
Groundwater level (m AHD)
25
24.5
24
23.5
23
22.5
22
21.5
21
20.5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

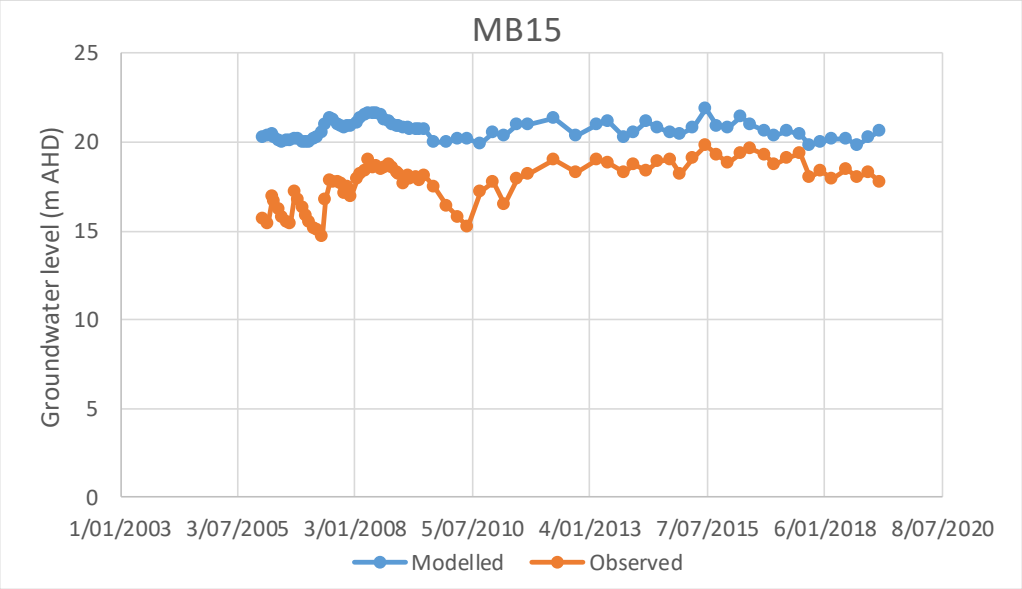

MB10
Groundwater level (m AHD)
26.5
26
25.5
25
24.5
24
23.5
23
22.5
22
21.5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

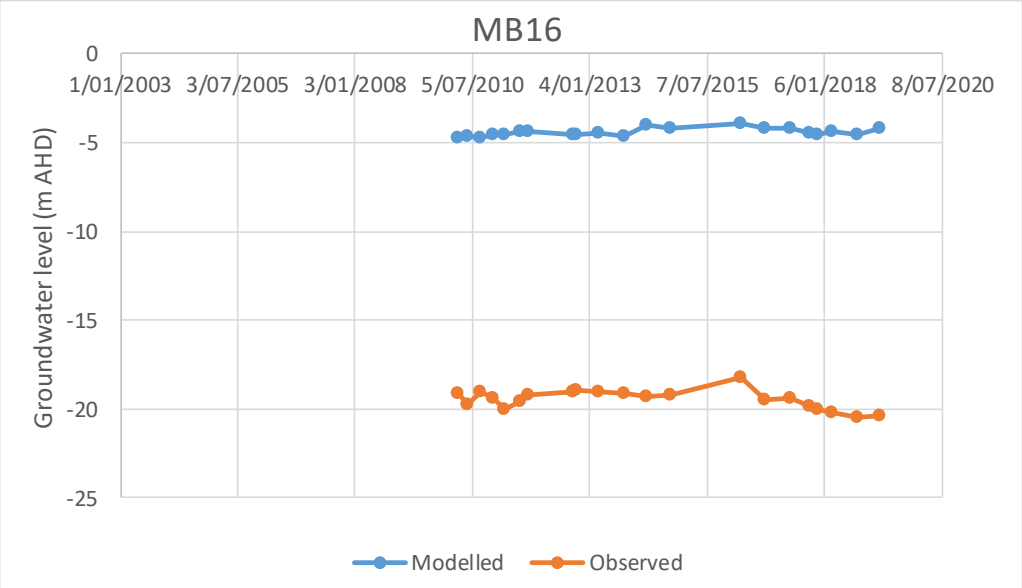

MB11
Groundwater level (m AHD)
31.5
31
30.5
30
29.5
29
28.5
28
27.5
27
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

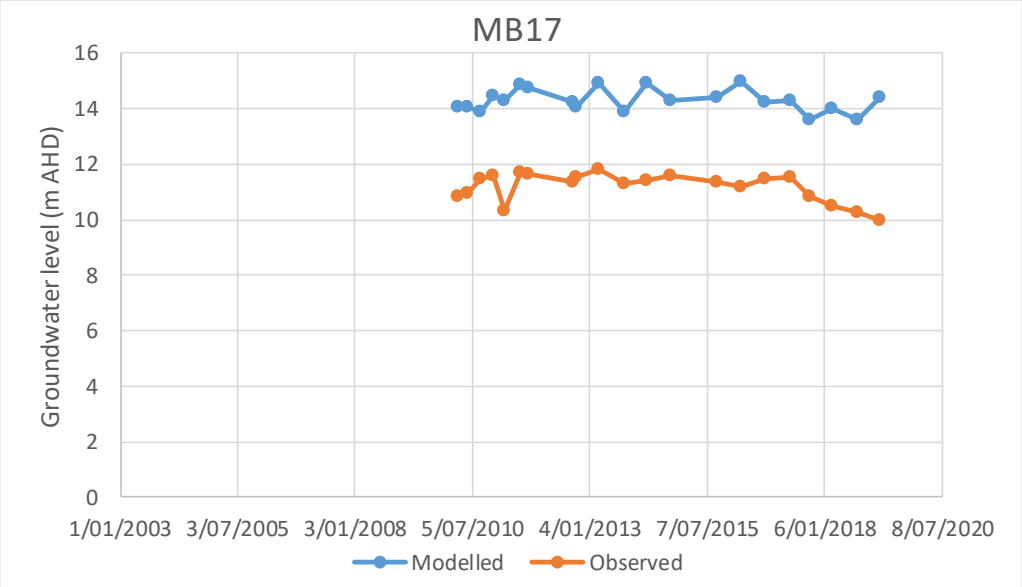

MB12
Groundwater level (m AHD)
30
25
20
15
10
5
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

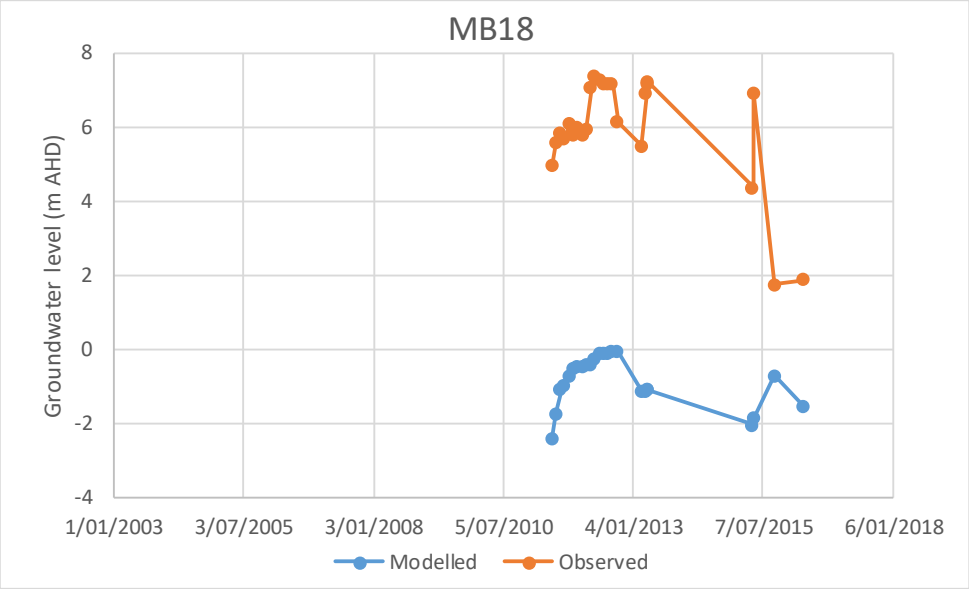

MB13
Groundwater level (m AHD)
35
30
25
20
15
10
5
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

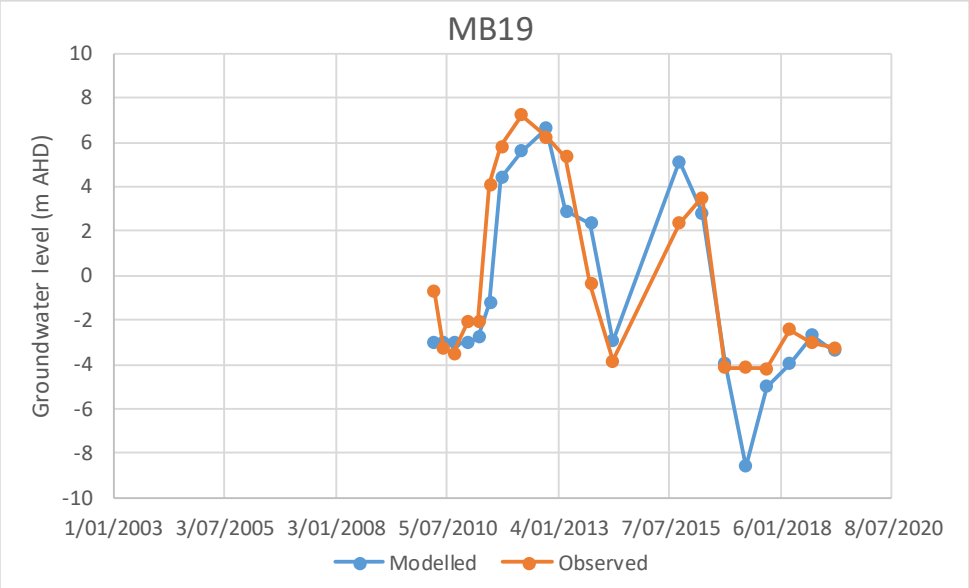

MB14
Groundwater level (m AHD)
18
16
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

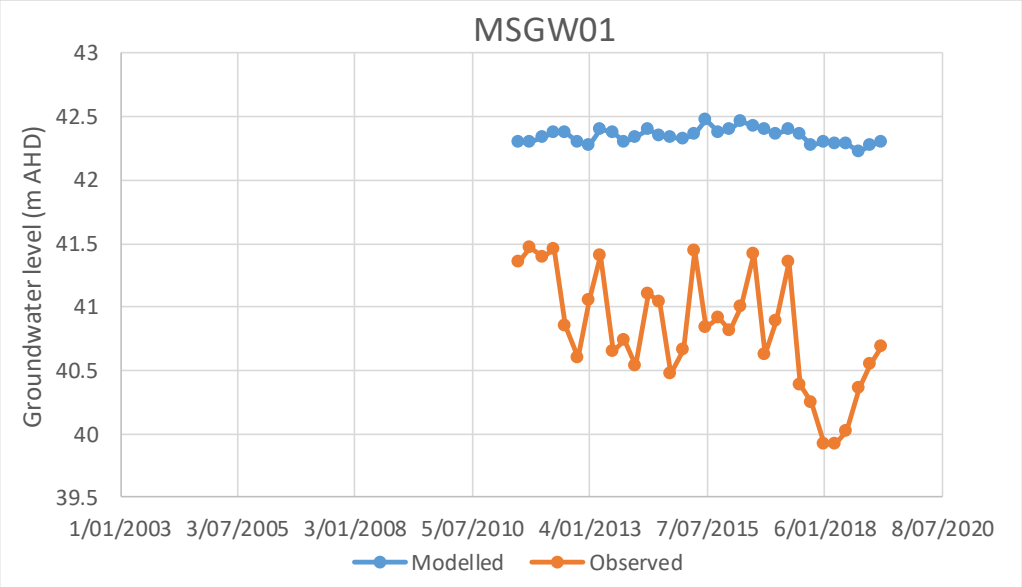

MB15
Groundwater level (m AHD)
25
20
15
10
5
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

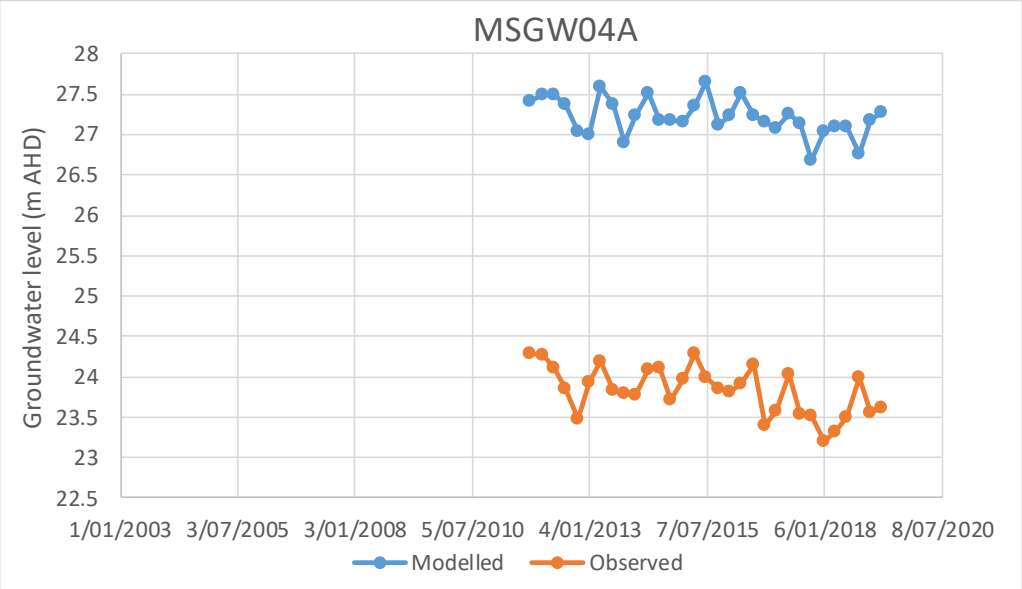

MB16
Groundwater level (m AHD)
0
-5
-10
-15
-20
-25
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

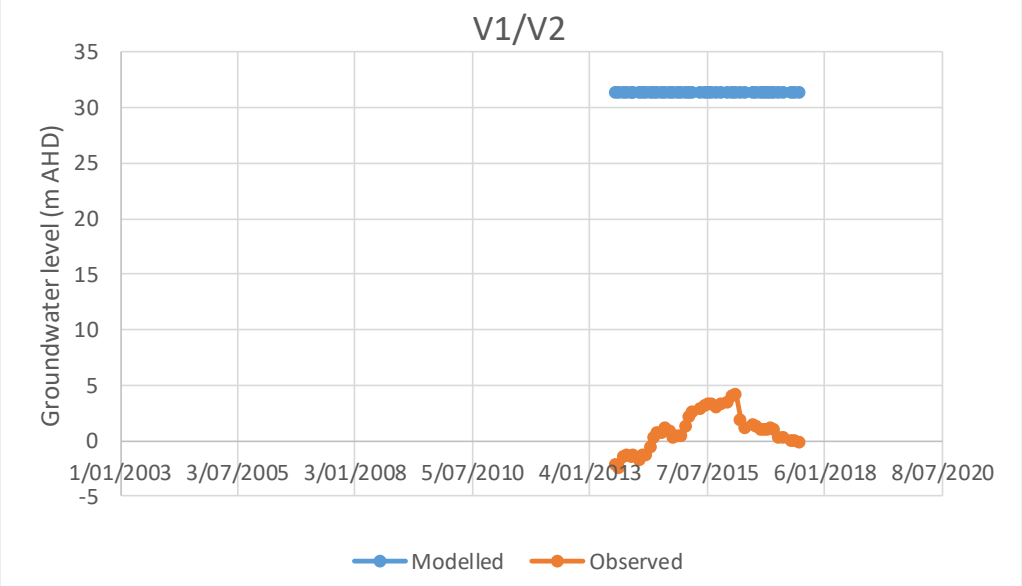

MB17
Groundwater level (m AHD)
16
14
12
10
8
6
4
2
0
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed

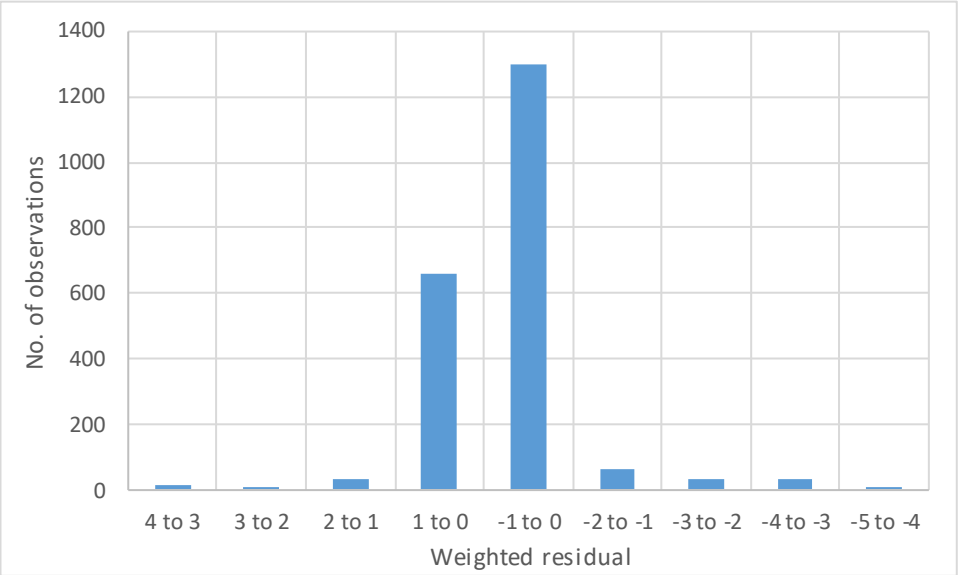

MB18
Groundwater level (m AHD)
8
6
4
2
0
-2
-4
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
Modelled
Observed


MB19
Groundwater level (m AHD)
10
8
6
4
2
0
-2
-4
-6
-8
-10
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed


MSGW01
Groundwater level (m AHD)
43
42.5
42
41.5
41
40.5
40
39.5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed


MSGW04A
Groundwater level (m AHD)
28
27.5
27
26.5
26
25.5
25
24.5
24
23.5
23
22.5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed


V1/V2
Groundwater level (m AHD)
35
30
25
20
15
10
5
0
-5
1/01/2003
3/07/2005
3/01/2008
5/07/2010
4/01/2013
7/07/2015
6/01/2018
8/07/2020
Modelled
Observed


1400
1200
1000
800
600
400
200
0
No. of observations
4 to 3
3 to 2
2 to 1
1 to 0
-1 to 0
-2 to -1
-3 to -2
-4 to -3
-5 to -4
Weighted residual

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
AWGW02	1/01/2012	22.57	23.97774	-1.40634944	0.3658178	-0.51446763
AWGW02	1/04/2012	22.60	24.03424	-1.42972244	0.3658178	-0.523017889
AWGW02	1/07/2012	22.69	24.0554	-1.36536403	0.3658178	-0.499474438
AWGW02	1/10/2012	22.24	23.98793	-1.75249955	0.3658178	-0.641095495
AWGW02	1/01/2013	22.24	23.94791	-1.70980512	0.3658178	-0.625477113
BH01	1/01/2004	2.60	7.145926	-4.541926	0.1093093	-0.496474933
BH01	1/01/2005	2.36	7.164788	-4.800788	0.1093093	-0.524770968
BH01	1/01/2006	2.42	7.149309	-4.725309	0.1093093	-0.516520408
BH01	1/04/2006	2.28	7.216472	-4.932472	0.1093093	-0.539165259
BH01	1/07/2006	2.22	6.934862	-4.710862	0.1093093	-0.514941216
BH01	1/10/2006	2.34	7.186056	-4.842056	0.1093093	-0.529281946
BH01	1/01/2007	2.10	6.968712	-4.864712	0.1093093	-0.531758458
BH01	1/04/2007	2.47	7.219998	-4.745998	0.1093093	-0.518781909
BH01	1/07/2007	2.78	7.573688	-4.789688	0.1093093	-0.523557634
BH01	1/10/2007	2.87	7.189172	-4.315172	0.1093093	-0.471688603
BH01	1/01/2008	3.00	7.285542	-4.281542	0.1093093	-0.46801253
BH01	1/04/2008	2.93	7.520919	-4.586919	0.1093093	-0.501393089
BH01	1/07/2008	2.98	7.453068	-4.469068	0.1093093	-0.488510873
BH01	1/10/2008	2.80	7.223256	-4.419256	0.1093093	-0.483065957
BH01	1/01/2009	2.67	7.21335	-4.53935	0.1093093	-0.496193353
BH01	1/04/2009	2.60	7.197839	-4.593839	0.1093093	-0.502149509
BH01	1/07/2009	2.56	7.216815	-4.652815	0.1093093	-0.508596137
BH01	1/10/2009	2.18	6.80196	-4.61796	0.1093093	-0.50478616
BH01	1/01/2010	2.43	6.992339	-4.558339	0.1093093	-0.498269028
BH01	1/04/2010	2.45	7.122616	-4.668616	0.1093093	-0.510323334
BH01	1/07/2010	2.35	7.090856	-4.736856	0.1093093	-0.517782603
BH01	1/10/2010	2.63	6.919555	-4.285555	0.1093093	-0.468451189
BH01	1/01/2011	2.37	7.329255	-4.955255	0.1093093	-0.541655654
BH01	1/04/2011	2.62	7.1412	-4.5172	0.1093093	-0.493772151
BH01	1/07/2011	2.60	7.428834	-4.824834	0.1093093	-0.52739942
BH01	1/10/2011	2.99	7.297455	-4.303455	0.1093093	-0.470407826
BH01	1/01/2012	2.97	7.38886	-4.41486	0.1093093	-0.482585433
BH01	1/04/2012	2.90	7.381633	-4.477633	0.1093093	-0.489447108
BH01	1/07/2012	2.79	7.278626	-4.484626	0.1093093	-0.490211508
BH01	1/10/2012	2.60	6.9323	-4.3283	0.1093093	-0.473123616
BH01	1/01/2013	2.86	6.911746	-4.047746	0.1093093	-0.442456444
BH01	1/04/2013	2.90	7.550178	-4.646178	0.1093093	-0.507870651
BH01	1/07/2013	2.68	7.27796	-4.59396	0.1093093	-0.502162736
BH01	1/10/2013	2.69	6.839964	-4.145964	0.1093093	-0.453192589
BH01	1/01/2014	2.66	7.230065	-4.566065	0.1093093	-0.499113552
BH01	1/04/2014	2.73	7.427049	-4.693049	0.1093093	-0.512994089
BH01	1/07/2014	2.75	7.136575	-4.382575	0.1093093	-0.479056381
BH01	1/10/2014	2.48	7.146062	-4.662062	0.1093093	-0.50960692
BH01	1/01/2015	2.46	7.141765	-4.682765	0.1093093	-0.511869952
BH01	1/04/2015	2.68	7.298373	-4.614373	0.1093093	-0.504394067

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH01	1/07/2015	2.52	7.632442	-5.113442	0.1093093	-0.55894697
BH01	1/10/2015	2.48	7.057415	-4.578415	0.1093093	-0.500463522
BH01	1/01/2016	2.54	7.214059	-4.670059	0.1093093	-0.510481067
BH01	1/04/2016	2.48	7.435456	-4.956456	0.1093093	-0.541786934
BH01	1/07/2016	2.51	7.175068	-4.661068	0.1093093	-0.509498267
BH01	1/10/2016	2.36	7.124863	-4.760863	0.1093093	-0.520406792
BH01	1/01/2017	2.38	7.000769	-4.616769	0.1093093	-0.504655972
BH01	1/04/2017	2.37	7.240892	-4.866892	0.1093093	-0.531996752
BH01	1/07/2017	2.30	7.104449	-4.800449	0.1093093	-0.524733912
BH01	1/10/2017	2.27	6.64075	-4.36675	0.1093093	-0.47732656
BH01	1/01/2018	2.18	6.965737	-4.781737	0.1093093	-0.522688516
BH01	1/04/2018	2.16	7.070947	-4.906947	0.1093093	-0.536375138
BH01	1/07/2018	2.15	7.08034	-4.92634	0.1093093	-0.538494974
BH01	1/10/2018	2.27	6.760117	-4.491117	0.1093093	-0.490921035
BH01	1/01/2019	2.18	7.199066	-5.015066	0.1093093	-0.548193555
BH01	1/04/2019	2.15	7.274154	-5.120154	0.1093093	-0.559680654
BH02	1/01/2005	5.55	7.814296	-2.264296	0.1219393	-0.276106579
BH02	1/01/2006	5.32	7.801825	-2.481825	0.1219393	-0.302631904
BH02	1/04/2006	5.13	7.862443	-2.732443	0.1219393	-0.333192077
BH02	1/07/2006	5.07	7.662815	-2.592815	0.1219393	-0.316165942
BH02	1/10/2006	5.27	7.853264	-2.583264	0.1219393	-0.315001301
BH02	1/01/2007	5.30	7.697251	-2.397251	0.1219393	-0.292319013
BH02	1/04/2007	5.29	7.88074	-2.59074	0.1219393	-0.315912918
BH02	1/07/2007	5.50	8.186865	-2.686865	0.1219393	-0.32763433
BH02	1/10/2007	5.92	7.820773	-1.900773	0.1219393	-0.231778853
BH02	1/01/2008	6.21	7.915967	-1.705967	0.1219393	-0.208024354
BH02	1/04/2008	6.13	8.130586	-2.000586	0.1219393	-0.243949976
BH02	1/07/2008	6.34	8.065091	-1.725091	0.1219393	-0.21035632
BH02	1/10/2008	6.08	7.84775	-1.76775	0.1219393	-0.215558127
BH02	1/01/2009	6.42	7.845477	-1.425477	0.1219393	-0.173821611
BH02	1/04/2009	6.14	7.834904	-1.694904	0.1219393	-0.20667534
BH02	1/07/2009	6.09	7.855062	-1.765062	0.1219393	-0.215230354
BH02	1/10/2009	5.75	7.568377	-1.818377	0.1219393	-0.221731546
BH02	1/01/2010	5.61	7.760715	-2.150715	0.1219393	-0.262256596
BH02	1/04/2010	5.60	7.816865	-2.216865	0.1219393	-0.270322878
BH02	1/07/2010	5.59	7.777421	-2.187421	0.1219393	-0.266732498
BH02	1/10/2010	5.83	7.682726	-1.852726	0.1219393	-0.225920037
BH02	1/01/2011	5.65	7.983649	-2.333649	0.1219393	-0.284563432
BH02	1/04/2011	5.74	7.789817	-2.049817	0.1219393	-0.249953168
BH02	1/07/2011	6.11	8.05704	-1.94704	0.1219393	-0.237420617
BH02	1/10/2011	6.49	7.924895	-1.434895	0.1219393	-0.174970034
BH02	1/01/2012	6.58	8.010645	-1.430645	0.1219393	-0.174451793
BH02	1/04/2012	6.38	8.001123	-1.621123	0.1219393	-0.197678539
BH02	1/07/2012	6.42	7.902269	-1.482269	0.1219393	-0.180746785
BH02	1/10/2012	6.44	7.636516	-1.196516	0.1219393	-0.145902276

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH02	1/01/2013	6.40	7.683522	-1.283522	0.1219393	-0.156511723
BH02	1/04/2013	6.32	8.175284	-1.855284	0.1219393	-0.226231958
BH02	1/07/2013	6.37	7.906505	-1.536505	0.1219393	-0.187360283
BH02	1/10/2013	6.29	7.577847	-1.287847	0.1219393	-0.15703911
BH02	1/01/2014	6.11	7.891668	-1.781668	0.1219393	-0.217255277
BH02	1/04/2014	6.16	8.055162	-1.895162	0.1219393	-0.231094652
BH02	1/07/2014	6.15	7.774576	-1.624576	0.1219393	-0.198099595
BH02	1/10/2014	6.17	7.791457	-1.621457	0.1219393	-0.197719267
BH02	1/01/2015	6.09	7.79181	-1.70181	0.1219393	-0.207517452
BH02	1/04/2015	6.21	7.937346	-1.727346	0.1219393	-0.210631293
BH02	1/07/2015	6.17	8.23319	-2.06319	0.1219393	-0.251583862
BH02	1/10/2015	6.24	7.7048	-1.4648	0.1219393	-0.178616628
BH02	1/01/2016	6.23	7.85381	-1.62381	0.1219393	-0.19800619
BH02	1/04/2016	6.02	8.058101	-2.038101	0.1219393	-0.248524528
BH02	1/07/2016	6.21	7.808066	-1.598066	0.1219393	-0.194866985
BH02	1/10/2016	6.06	7.770349	-1.710349	0.1219393	-0.208558691
BH03	1/01/2005	4.97	6.869903	-1.895903	0.1102991	-0.209116433
BH03	1/01/2006	4.84	6.854695	-2.010695	0.1102991	-0.221777889
BH03	1/04/2006	4.65	6.920116	-2.271116	0.1102991	-0.250502096
BH03	1/07/2006	4.67	6.72005	-2.04605	0.1102991	-0.225677514
BH03	1/10/2006	4.86	6.907051	-2.043051	0.1102991	-0.225346727
BH03	1/01/2007	4.31	6.747177	-2.433177	0.1102991	-0.268377282
BH03	1/04/2007	4.87	6.934708	-2.060708	0.1102991	-0.227294279
BH03	1/07/2007	5.20	7.301517	-2.102517	0.1102991	-0.231905775
BH03	1/10/2007	5.33	6.888231	-1.559231	0.1102991	-0.171981807
BH03	1/01/2008	5.47	6.98586	-1.51686	0.1102991	-0.167308323
BH03	1/04/2008	5.49	7.224192	-1.735192	0.1102991	-0.191390151
BH03	1/07/2008	5.56	7.160179	-1.596179	0.1102991	-0.176057139
BH03	1/10/2008	5.45	6.926714	-1.477714	0.1102991	-0.162990554
BH03	1/01/2009	5.22	6.919768	-1.700768	0.1102991	-0.187593214
BH03	1/04/2009	5.40	6.907156	-1.503156	0.1102991	-0.165796784
BH03	1/07/2009	5.04	6.927909	-1.883909	0.1102991	-0.207793505
BH03	1/10/2009	4.93	6.656988	-1.727988	0.1102991	-0.190595556
BH03	1/01/2010	4.77	6.823531	-2.049531	0.1102991	-0.226061466
BH03	1/04/2010	4.86	6.877209	-2.013209	0.1102991	-0.222055181
BH03	1/07/2010	4.73	6.834033	-2.100033	0.1102991	-0.231631792
BH03	1/10/2010	5.30	6.740519	-1.441519	0.1102991	-0.158998277
BH03	1/01/2011	4.89	7.051489	-2.162489	0.1102991	-0.238520634
BH03	1/04/2011	5.15	6.849806	-1.695806	0.1102991	-0.187045909
BH03	1/07/2011	5.27	7.137013	-1.863013	0.1102991	-0.205488694
BH03	1/10/2011	5.80	7.002217	-1.203217	0.1102991	-0.132713776
BH03	1/01/2012	5.60	7.096229	-1.497229	0.1102991	-0.165143041
BH03	1/04/2012	5.62	7.090132	-1.466132	0.1102991	-0.161713069
BH03	1/07/2012	5.48	6.984946	-1.500946	0.1102991	-0.165553023
BH03	1/10/2012	5.28	6.714797	-1.435797	0.1102991	-0.158367146

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH03	1/01/2013	5.63	6.755545	-1.126545	0.1102991	-0.124256922
BH03	1/04/2013	5.47	7.274378	-1.800378	0.1102991	-0.198580109
BH03	1/07/2013	5.45	6.990016	-1.536016	0.1102991	-0.169421213
BH03	1/10/2013	5.46	6.666037	-1.207037	0.1102991	-0.133135119
BH03	1/01/2014	5.45	6.962883	-1.508883	0.1102991	-0.166428467
BH03	1/04/2014	5.53	7.143699	-1.609699	0.1102991	-0.177548383
BH03	1/07/2014	5.57	6.846299	-1.277299	0.1102991	-0.140884956
BH03	1/10/2014	5.28	6.857954	-1.576454	0.1102991	-0.173881489
BH03	1/01/2015	5.32	6.856669	-1.532669	0.1102991	-0.169052042
BH03	1/04/2015	5.51	7.013147	-1.501647	0.1102991	-0.165630343
BH03	1/07/2015	5.33	7.422996	-2.091496	0.1102991	-0.230690168
BH03	1/10/2015	5.33	6.781009	-1.447009	0.1102991	-0.159603819
BH03	1/01/2016	5.35	6.927617	-1.573617	0.1102991	-0.17356857
BH03	1/04/2016	5.42	7.151451	-1.729951	0.1102991	-0.190812073
BH03	1/07/2016	5.50	6.886832	-1.390332	0.1102991	-0.153352396
BH03	1/10/2016	5.22	6.840317	-1.616317	0.1102991	-0.178278343
BH03	1/01/2017	5.18	6.776909	-1.592909	0.1102991	-0.175696461
BH03	1/04/2017	5.37	6.965983	-1.591983	0.1102991	-0.175594324
BH03	1/07/2017	5.03	6.831071	-1.797071	0.1102991	-0.19821535
BH03	1/10/2017	5.06	6.606202	-1.542202	0.1102991	-0.170103523
BH03	1/01/2018	4.68	6.838818	-2.159818	0.1102991	-0.238226025
BH03	1/04/2018	4.64	6.857854	-2.213854	0.1102991	-0.244186148
BH03	1/07/2018	4.67	6.838983	-2.169983	0.1102991	-0.239347215
BH03	1/10/2018	4.86	6.663144	-1.801644	0.1102991	-0.198719748
BH03	1/01/2019	4.81	6.953383	-2.139383	0.1102991	-0.235972062
BH03	1/04/2019	4.92	6.98686	-2.06286	0.1102991	-0.227531643
BH04	1/01/2004	8.83	9.960149	-1.131149	0.1093093	-0.123645151
BH04	1/01/2005	8.36	9.962881	-1.603881	0.1093093	-0.175319174
BH04	1/01/2006	8.21	9.953075	-1.744075	0.1093093	-0.190643687
BH04	1/04/2006	7.86	9.978379	-2.119379	0.1093093	-0.23166792
BH04	1/07/2006	8.04	9.902553	-1.863553	0.1093093	-0.203703748
BH04	1/10/2006	8.16	9.966532	-1.807532	0.1093093	-0.19758013
BH04	1/01/2007	8.64	9.905045	-1.266045	0.1093093	-0.138390543
BH04	1/04/2007	8.43	9.972267	-1.543267	0.1093093	-0.168693497
BH04	1/07/2007	8.82	10.1142	-1.2952	0.1093093	-0.141577457
BH04	1/10/2007	8.71	9.995316	-1.286316	0.1093093	-0.140606353
BH04	1/01/2008	9.37	10.03724	-0.66824	0.1093093	-0.073044873
BH04	1/04/2008	9.39	10.13958	-0.75058	0.1093093	-0.082045404
BH04	1/07/2008	9.05	10.14186	-1.09286	0.1093093	-0.119459805
BH04	1/10/2008	9.05	10.0707	-1.0217	0.1093093	-0.111681353
BH04	1/01/2009	8.62	10.06755	-1.44855	0.1093093	-0.158340044
BH04	1/04/2009	8.78	10.05981	-1.28081	0.1093093	-0.140004496
BH04	1/07/2009	8.16	10.06495	-1.90595	0.1093093	-0.208338137
BH04	1/10/2009	7.90	9.915751	-2.016751	0.1093093	-0.220449721
BH04	1/01/2010	8.01	10.0002	-1.9912	0.1093093	-0.217656758

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH04	1/04/2010	8.09	10.01311	-1.92411	0.1093093	-0.210323194
BH04	1/07/2010	8.67	9.993731	-1.324731	0.1093093	-0.144805471
BH04	1/10/2010	9.19	9.951894	-0.762894	0.1093093	-0.08339144
BH04	1/01/2011	8.26	10.06475	-1.80575	0.1093093	-0.197385341
BH04	1/04/2011	8.86	9.997155	-1.138155	0.1093093	-0.124410972
BH04	1/07/2011	9.23	10.11059	-0.88159	0.1093093	-0.096366021
BH04	1/10/2011	9.32	10.07744	-0.75844	0.1093093	-0.082904576
BH04	1/01/2012	9.37	10.1249	-0.7559	0.1093093	-0.08262693
BH04	1/04/2012	9.20	10.13807	-0.93907	0.1093093	-0.102649122
BH04	1/07/2012	8.89	10.11056	-1.22156	0.1093093	-0.133527917
BH04	1/10/2012	8.41	10.00469	-1.59569	0.1093093	-0.174423821
BH04	1/01/2013	8.80	10.00406	-1.20506	0.1093093	-0.131724313
BH04	1/04/2013	9.14	10.1943	-1.0553	0.1093093	-0.115354147
BH04	1/07/2013	8.85	10.11035	-1.26135	0.1093093	-0.137877336
BH04	1/10/2013	8.64	9.952071	-1.313071	0.1093093	-0.143530924
BH04	1/01/2014	8.53	10.08448	-1.55548	0.1093093	-0.170028492
BH04	1/04/2014	9.05	10.15773	-1.10873	0.1093093	-0.121194545
BH04	1/07/2014	9.16	10.05775	-0.89875	0.1093093	-0.098241769
BH04	1/10/2014	8.61	10.05671	-1.44271	0.1093093	-0.157701678
BH04	1/01/2015	8.79	10.04911	-1.26011	0.1093093	-0.137741792
BH04	1/04/2015	9.22	10.10582	-0.88682	0.1093093	-0.096937709
BH04	1/07/2015	8.83	10.24646	-1.41746	0.1093093	-0.154941617
BH04	1/10/2015	8.86	10.05531	-1.19131	0.1093093	-0.13022131
BH04	1/01/2016	8.86	10.10326	-1.24426	0.1093093	-0.136009239
BH04	1/04/2016	8.38	10.18926	-1.81026	0.1093093	-0.197878326
BH04	1/07/2016	9.25	10.10097	-0.85197	0.1093093	-0.093128278
BH04	1/10/2016	8.57	10.07772	-1.50872	0.1093093	-0.164917187
BH04	1/01/2017	8.39	10.0422	-1.6532	0.1093093	-0.180710201
BH04	1/04/2017	8.56	10.10412	-1.54512	0.1093093	-0.168896047
BH04	1/07/2017	8.28	10.05171	-1.77271	0.1093093	-0.19377376
BH04	1/10/2017	8.30	9.886816	-1.587816	0.1093093	-0.173563119
BH04	1/01/2018	7.94	10.0232	-2.0842	0.1093093	-0.227822526
BH04	1/04/2018	7.86	10.02418	-2.16518	0.1093093	-0.236674397
BH04	1/07/2018	8.03	10.01441	-1.98541	0.1093093	-0.217023857
BH04	1/10/2018	8.18	9.910307	-1.731307	0.1093093	-0.189248026
BH04	1/01/2019	9.25	10.04001	-0.79101	0.1093093	-0.086464781
BH04	1/04/2019	8.47	10.05911	-1.59011	0.1093093	-0.173813875
BH05	1/01/2004	9.74	9.224578	0.517422	0.1102991	0.057071191
BH05	1/01/2005	9.28	9.242333	0.039667	0.1102991	0.004375235
BH05	1/01/2006	8.92	9.227727	-0.305727	0.1102991	-0.033721419
BH05	1/04/2006	8.53	9.295769	-0.763769	0.1102991	-0.084243049
BH05	1/07/2006	8.61	9.090077	-0.478077	0.1102991	-0.052731472
BH05	1/10/2006	8.89	9.281998	-0.389998	0.1102991	-0.043016436
BH05	1/01/2007	8.36	9.119543	-0.757543	0.1102991	-0.083556326
BH05	1/04/2007	8.98	9.312885	-0.330885	0.1102991	-0.036496324

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH05	1/10/2007	9.47	9.261524	0.210476	0.1102991	0.023215318
BH05	1/01/2008	10.38	9.358698	1.023302	0.1102991	0.11286931
BH05	1/04/2008	10.37	9.595291	0.776709	0.1102991	0.085670319
BH05	1/07/2008	10.29	9.522923	0.769077	0.1102991	0.084828516
BH05	1/10/2008	10.14	9.290447	0.851553	0.1102991	0.093925547
BH05	1/01/2009	9.47	9.282213	0.189787	0.1102991	0.020933339
BH05	1/04/2009	9.71	9.268561	0.443439	0.1102991	0.048910931
BH05	1/07/2009	9.23	9.290226	-0.058226	0.1102991	-0.006422277
BH05	1/10/2009	8.93	9.013583	-0.081583	0.1102991	-0.008998533
BH05	1/01/2010	8.70	9.184148	-0.482148	0.1102991	-0.0531805
BH05	1/04/2010	8.50	9.243029	-0.741029	0.1102991	-0.081734847
BH05	1/07/2010	9.13	9.201136	-0.069136	0.1102991	-0.00762564
BH05	1/10/2010	9.50	9.106282	0.395718	0.1102991	0.043647347
BH05	1/01/2011	8.61	9.425699	-0.813699	0.1102991	-0.089750284
BH05	1/04/2011	9.75	9.221601	0.530399	0.1102991	0.058502543
BH05	1/07/2011	10.46	9.508013	0.953987	0.1102991	0.105223927
BH05	1/10/2011	10.35	9.372169	0.979831	0.1102991	0.108074497
BH05	1/01/2012	10.26	9.462575	0.799425	0.1102991	0.088175874
BH05	1/04/2012	10.19	9.453953	0.738047	0.1102991	0.081405935
BH05	1/07/2012	9.98	9.347771	0.634229	0.1102991	0.069954901
BH05	1/10/2012	9.26	9.069564	0.192436	0.1102991	0.021225521
BH05	1/01/2013	9.61	9.111122	0.500878	0.1102991	0.055246403
BH05	1/04/2013	9.81	9.642746	0.169254	0.1102991	0.018668567
BH05	1/07/2013	9.96	9.353444	0.608556	0.1102991	0.067123191
BH05	1/10/2013	10.17	9.022314	1.149686	0.1102991	0.126809354
BH05	1/01/2014	9.21	9.325423	-0.113423	0.1102991	-0.012510457
BH05	1/04/2014	9.92	9.507051	0.414949	0.1102991	0.04576851
BH05	1/07/2014	10.45	9.207893	1.244107	0.1102991	0.137223907
BH05	1/10/2014	8.83	9.2175	-0.3905	0.1102991	-0.043071806
BH05	1/01/2015	8.79	9.216369	-0.429369	0.1102991	-0.047359023
BH05	1/04/2015	10.19	9.377881	0.814119	0.1102991	0.089796609
BH05	1/07/2015	9.17	9.719397	-0.552397	0.1102991	-0.060928903
BH05	1/10/2015	9.05	9.136431	-0.089431	0.1102991	-0.009864161
BH05	1/01/2016	9.33	9.285884	0.046116	0.1102991	0.005086554
BH05	1/04/2016	8.84	9.509852	-0.667852	0.1102991	-0.073663488
BH05	1/07/2016	9.64	9.245311	0.396689	0.1102991	0.043754448
BH05	1/10/2016	8.67	9.195446	-0.523446	0.1102991	-0.057735633
BH05	1/01/2017	8.14	9.130225	-0.988225	0.1102991	-0.109000348
BH05	1/04/2017	8.48	9.326734	-0.844734	0.1102991	-0.093173417
BH05	1/07/2017	8.50	9.190364	-0.688364	0.1102991	-0.075925943
BH05	1/10/2017	8.24	8.966745	-0.724745	0.1102991	-0.079938736
BH05	1/01/2018	7.93	9.201987	-1.269987	0.1102991	-0.140078449
BH05	1/04/2018	7.65	9.224911	-1.572911	0.1102991	-0.173490699
BH05	1/07/2018	7.38	9.207507	-1.825507	0.1102991	-0.201351816
BH05	1/10/2018	7.45	9.029728	-1.582728	0.1102991	-0.174573506

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH05	1/01/2019	7.75	9.327714	-1.575714	0.1102991	-0.173799868
BH05	1/04/2019	7.94	9.364058	-1.422058	0.1102991	-0.156851746
BH06	1/01/2004	9.54	10.40285	-0.85885	0.1219393	-0.104727533
BH06	1/01/2005	9.21	10.4466	-1.2326	0.1219393	-0.150302332
BH06	1/04/2006	8.73	10.55251	-1.81851	0.1219393	-0.221747764
BH06	1/07/2006	8.23	10.12139	-1.88739	0.1219393	-0.23014694
BH06	1/10/2006	8.90	10.47504	-1.57104	0.1219393	-0.191571455
BH06	1/01/2007	8.63	10.1723	-1.5383	0.1219393	-0.187579164
BH06	1/04/2007	9.16	10.54644	-1.38244	0.1219393	-0.168573711
BH06	1/07/2007	9.73	11.31824	-1.58424	0.1219393	-0.193181053
BH06	1/10/2007	10.00	10.62892	-0.62492	0.1219393	-0.076202282
BH06	1/01/2008	10.16	10.73424	-0.57024	0.1219393	-0.069534644
BH06	1/04/2008	9.93	11.23769	-1.30369	0.1219393	-0.158970994
BH06	1/07/2008	10.13	11.17612	-1.04212	0.1219393	-0.127075342
BH06	1/10/2008	9.85	10.67893	-0.82493	0.1219393	-0.100591354
BH06	1/01/2009	9.68	10.58422	-0.90022	0.1219393	-0.109772161
BH06	1/04/2009	9.50	10.53789	-1.03389	0.1219393	-0.126071782
BH06	1/07/2009	9.65	10.57515	-0.92115	0.1219393	-0.112324349
BH06	1/10/2009	9.10	9.951169	-0.847169	0.1219393	-0.103303161
BH06	1/01/2010	8.62	10.23093	-1.60693	0.1219393	-0.195947855
BH06	1/04/2010	8.89	10.40933	-1.51533	0.1219393	-0.184778219
BH06	1/07/2010	8.98	10.35074	-1.36674	0.1219393	-0.166659264
BH06	1/10/2010	9.58	10.1225	-0.5385	0.1219393	-0.065664292
BH06	1/01/2011	8.96	10.78835	-1.82435	0.1219393	-0.222459889
BH06	1/04/2011	9.57	10.45843	-0.88443	0.1219393	-0.10784674
BH06	1/07/2011	9.86	11.02386	-1.15986	0.1219393	-0.14143247
BH06	1/10/2011	10.12	10.82314	-0.69914	0.1219393	-0.085252614
BH06	1/01/2012	10.03	10.98939	-0.95539	0.1219393	-0.11649955
BH06	1/04/2012	9.84	10.99652	-1.15252	0.1219393	-0.140537436
BH06	1/07/2012	9.69	10.77482	-1.08082	0.1219393	-0.131794391
BH06	1/10/2012	9.26	10.1289	-0.8649	0.1219393	-0.105465266
BH06	1/01/2013	9.66	10.0958	-0.4318	0.1219393	-0.052653372
BH06	1/04/2013	9.57	11.2209	-1.6469	0.1219393	-0.200821767
BH06	1/07/2013	9.58	10.81596	-1.23196	0.1219393	-0.150224291
BH06	1/10/2013	9.53	10.02305	-0.49405	0.1219393	-0.060244091
BH06	1/01/2014	9.45	10.56223	-1.10823	0.1219393	-0.135136746
BH06	1/04/2014	9.62	11.03635	-1.41235	0.1219393	-0.172220914
BH06	1/07/2014	9.76	10.47858	-0.71458	0.1219393	-0.087135356
BH06	1/10/2014	9.36	10.40991	-1.04991	0.1219393	-0.128025248
BH06	1/01/2015	9.42	10.39173	-0.97273	0.1219393	-0.118613976
BH06	1/04/2015	9.73	10.73411	-1.00011	0.1219393	-0.121952673
BH06	1/07/2015	9.60	11.45484	-1.85084	0.1219393	-0.22569006
BH06	1/10/2015	9.50	10.39539	-0.89139	0.1219393	-0.108695437
BH06	1/01/2016	9.51	10.54696	-1.03296	0.1219393	-0.125958378
BH06	1/04/2016	9.42	11.04662	-1.62262	0.1219393	-0.197861082

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH06	1/07/2016	9.57	10.56232	-0.98832	0.1219393	-0.120515009
BH06	1/10/2016	9.30	10.37867	-1.07467	0.1219393	-0.131044465
BH07	1/01/2004	11.88	13.35856	-1.47856	0.1206059	-0.178323089
BH07	1/01/2005	11.44	13.38112	-1.94112	0.1206059	-0.234110563
BH07	1/01/2006	11.31	13.36222	-2.05222	0.1206059	-0.247509881
BH07	1/04/2006	10.65	13.44475	-2.79475	0.1206059	-0.337063395
BH07	1/07/2006	11.11	13.19198	-2.08198	0.1206059	-0.251099113
BH07	1/10/2006	11.05	13.41675	-2.36675	0.1206059	-0.285444061
BH07	1/01/2007	10.53	13.22859	-2.69859	0.1206059	-0.32546593
BH07	1/04/2007	11.51	13.45457	-1.94457	0.1206059	-0.234526654
BH07	1/07/2007	12.04	13.87279	-1.83279	0.1206059	-0.221045324
BH07	1/10/2007	12.46	13.42858	-0.96858	0.1206059	-0.116816482
BH07	1/01/2008	12.51	13.53233	-1.02233	0.1206059	-0.12329905
BH07	1/04/2008	12.62	13.81865	-1.19865	0.1206059	-0.144564286
BH07	1/07/2008	12.44	13.75283	-1.31283	0.1206059	-0.15833507
BH07	1/10/2008	12.09	13.46563	-1.37563	0.1206059	-0.165909122
BH07	1/01/2009	11.78	13.44274	-1.66274	0.1206059	-0.200536287
BH07	1/04/2009	11.98	13.42246	-1.44246	0.1206059	-0.173969215
BH07	1/07/2009	11.60	13.4467	-1.8467	0.1206059	-0.222722952
BH07	1/10/2009	10.80	13.08876	-2.28876	0.1206059	-0.276038005
BH07	1/01/2010	10.64	13.28461	-2.64461	0.1206059	-0.318955622
BH07	1/04/2010	10.14	13.373	-3.233	0.1206059	-0.389918939
BH07	1/07/2010	11.30	13.33004	-2.03004	0.1206059	-0.244834842
BH07	1/10/2010	12.05	13.20589	-1.15589	0.1206059	-0.139407177
BH07	1/01/2011	10.63	13.59329	-2.96329	0.1206059	-0.357390317
BH07	1/04/2011	11.94	13.36345	-1.42345	0.1206059	-0.171676497
BH07	1/07/2011	12.49	13.71232	-1.22232	0.1206059	-0.147419028
BH07	1/10/2011	11.99	13.55851	-1.56851	0.1206059	-0.189171592
BH07	1/01/2012	12.19	13.67043	-1.48043	0.1206059	-0.178548622
BH07	1/04/2012	12.04	13.66538	-1.62538	0.1206059	-0.19603045
BH07	1/07/2012	11.59	13.53263	-1.94263	0.1206059	-0.234292678
BH07	1/10/2012	10.91	13.17443	-2.26443	0.1206059	-0.273103663
BH07	1/01/2013	11.63	13.19832	-1.56832	0.1206059	-0.189148676
BH07	1/04/2013	11.54	13.84735	-2.30735	0.1206059	-0.27828007
BH07	1/07/2013	11.48	13.54062	-2.06062	0.1206059	-0.248522971
BH07	1/10/2013	11.52	13.10917	-1.58917	0.1206059	-0.19166331
BH07	1/01/2014	11.43	13.46956	-2.03956	0.1206059	-0.24598301
BH07	1/04/2014	11.88	13.71433	-1.83433	0.1206059	-0.221231057
BH07	1/07/2014	11.95	13.35857	-1.40857	0.1206059	-0.169881881
BH07	1/10/2014	11.18	13.3559	-2.1759	0.1206059	-0.262426421
BH07	1/01/2015	11.47	13.35169	-1.88669	0.1206059	-0.227545983
BH07	1/04/2015	12.01	13.54849	-1.53849	0.1206059	-0.185551002
BH07	1/07/2015	11.70	13.9473	-2.2473	0.1206059	-0.271037684
BH07	1/10/2015	11.49	13.28089	-1.79089	0.1206059	-0.215991936
BH07	1/01/2016	11.53	13.43858	-1.91358	0.1206059	-0.230789076

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH07	1/04/2016	11.78	13.72125	-1.94125	0.1206059	-0.234126242
BH07	1/07/2016	11.94	13.40669	-1.46669	0.1206059	-0.176891497
BH07	1/10/2016	11.10	13.33268	-2.23268	0.1206059	-0.269274425
BH08	1/01/2004	15.06	16.68552	-1.62152	0.1206059	-0.195564911
BH08	1/01/2005	14.92	16.69772	-1.77372	0.1206059	-0.213921132
BH08	1/01/2006	14.79	16.66907	-1.87507	0.1206059	-0.226144542
BH08	1/04/2006	14.33	16.74417	-2.41017	0.1206059	-0.29068077
BH08	1/07/2006	14.39	16.48371	-2.08971	0.1206059	-0.252031397
BH08	1/10/2006	14.36	16.69951	-2.33551	0.1206059	-0.281676332
BH08	1/01/2007	14.05	16.50603	-2.45203	0.1206059	-0.295729334
BH08	1/04/2007	14.46	16.71775	-2.25375	0.1206059	-0.271815592
BH08	1/07/2007	14.88	17.14775	-2.26375	0.1206059	-0.273021651
BH08	1/10/2007	15.04	16.83035	-1.78635	0.1206059	-0.215444385
BH08	1/01/2008	15.58	16.93688	-1.35288	0.1206059	-0.163165337
BH08	1/04/2008	15.71	17.23124	-1.51724	0.1206059	-0.182988126
BH08	1/07/2008	16.84	17.24759	-0.40359	0.1206059	-0.048675343
BH08	1/10/2008	15.74	17.02543	-1.28143	0.1206059	-0.154548044
BH08	1/01/2009	15.44	16.98293	-1.53893	0.1206059	-0.185604068
BH08	1/04/2009	15.39	16.93476	-1.54076	0.1206059	-0.185824777
BH08	1/07/2009	15.35	16.92977	-1.57577	0.1206059	-0.190047191
BH08	1/10/2009	14.75	16.50866	-1.75466	0.1206059	-0.211622384
BH08	1/01/2010	14.94	16.693	-1.749	0.1206059	-0.210939754
BH08	1/04/2010	14.90	16.72839	-1.82439	0.1206059	-0.220032234
BH08	1/07/2010	15.07	16.67572	-1.60172	0.1206059	-0.193176914
BH08	1/10/2010	15.58	16.52722	-0.94322	0.1206059	-0.113757916
BH08	1/01/2011	14.90	16.88187	-1.97787	0.1206059	-0.238542831
BH08	1/04/2011	15.10	16.70571	-1.60171	0.1206059	-0.193175708
BH08	1/07/2011	15.55	17.0402	-1.4862	0.1206059	-0.179244518
BH08	1/10/2011	15.87	16.96296	-1.08896	0.1206059	-0.131335023
BH08	1/01/2012	15.78	17.10094	-1.31694	0.1206059	-0.15883076
BH08	1/04/2012	15.83	17.14093	-1.30693	0.1206059	-0.157623495
BH08	1/07/2012	15.69	17.05278	-1.35878	0.1206059	-0.163876912
BH08	1/10/2012	15.42	16.67745	-1.25345	0.1206059	-0.15117349
BH08	1/01/2013	15.54	16.67119	-1.12719	0.1206059	-0.135945787
BH08	1/04/2013	15.54	17.22502	-1.68102	0.1206059	-0.202740964
BH08	1/07/2013	15.49	17.01115	-1.51715	0.1206059	-0.182977272
BH08	1/10/2013	15.36	16.55733	-1.19333	0.1206059	-0.143922663
BH08	1/01/2014	15.20	16.89031	-1.68631	0.1206059	-0.203378969
BH08	1/04/2014	15.44	17.11371	-1.66971	0.1206059	-0.201376911
BH08	1/07/2014	15.54	16.83249	-1.28849	0.1206059	-0.155399522
BH08	1/10/2014	15.37	16.81102	-1.43702	0.1206059	-0.173313119
BH08	1/01/2015	15.32	16.7787	-1.4597	0.1206059	-0.176048461
BH08	1/04/2015	15.62	16.94164	-1.32264	0.1206059	-0.159518214
BH08	1/07/2015	15.55	17.35466	-1.80566	0.1206059	-0.217773286
BH08	1/10/2015	15.51	16.81425	-1.30025	0.1206059	-0.156817847

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH08	1/01/2016	15.64	16.93514	-1.29114	0.1206059	-0.155719128
BH08	1/04/2016	15.50	17.18207	-1.67807	0.1206059	-0.202385176
BH08	1/07/2016	15.75	16.92892	-1.17492	0.1206059	-0.141702308
BH08	1/10/2016	15.37	16.84062	-1.46662	0.1206059	-0.176883054
BH09	1/01/2004	15.41	15.41539	-0.00539	0.1102991	-0.000594512
BH09	1/01/2005	15.60	15.43026	0.16974	0.1102991	0.018722173
BH09	1/01/2006	15.53	15.4057	0.1243	0.1102991	0.013710181
BH09	1/04/2006	15.18	15.48152	-0.30152	0.1102991	-0.033257391
BH09	1/07/2006	15.02	15.22084	-0.20084	0.1102991	-0.022152475
BH09	1/10/2006	15.38	15.44499	-0.06499	0.1102991	-0.00716834
BH09	1/01/2007	15.17	15.23929	-0.06929	0.1102991	-0.007642626
BH09	1/04/2007	15.39	15.46582	-0.07582	0.1102991	-0.008362879
BH09	1/07/2007	16.71	15.80895	0.90105	0.1102991	0.099385022
BH09	1/10/2007	16.72	15.51908	1.20092	0.1102991	0.132460419
BH09	1/01/2008	16.78	15.60705	1.17295	0.1102991	0.129375353
BH09	1/04/2008	16.50	15.79937	0.70063	0.1102991	0.077278872
BH09	1/07/2008	16.67	15.75628	0.91372	0.1102991	0.100782512
BH09	1/10/2008	16.20	15.57176	0.62824	0.1102991	0.069294319
BH09	1/01/2009	15.91	15.55961	0.35039	0.1102991	0.038647709
BH09	1/04/2009	15.75	15.54015	0.20985	0.1102991	0.02314627
BH09	1/07/2009	15.65	15.55167	0.09833	0.1102991	0.010845712
BH09	1/10/2009	15.45	15.18459	0.26541	0.1102991	0.029274489
BH09	1/01/2010	15.17	15.37201	-0.20201	0.1102991	-0.022281525
BH09	1/04/2010	15.56	15.42172	0.13828	0.1102991	0.015252162
BH09	1/07/2010	15.47	15.37171	0.09829	0.1102991	0.010841301
BH09	1/10/2010	16.17	15.2259	0.9441	0.1102991	0.104133399
BH09	1/01/2011	15.65	15.59761	0.05239	0.1102991	0.005778571
BH09	1/04/2011	16.18	15.4085	0.7715	0.1102991	0.085095771
BH09	1/07/2011	16.57	15.70419	0.86581	0.1102991	0.095498081
BH09	1/10/2011	16.69	15.61425	1.07575	0.1102991	0.118654278
BH09	1/01/2012	16.46	15.70345	0.75655	0.1102991	0.083446799
BH09	1/07/2012	16.23	15.6224	0.6076	0.1102991	0.067017745
BH09	1/10/2012	15.73	15.30537	0.42463	0.1102991	0.046836315
BH09	1/01/2013	16.37	15.31469	1.05531	0.1102991	0.116399764
BH09	1/04/2013	16.25	15.81334	0.43666	0.1102991	0.048163214
BH09	1/07/2013	15.91	15.60931	0.30069	0.1102991	0.033165842
BH09	1/10/2013	16.17	15.21937	0.95063	0.1102991	0.104853652
BH09	1/01/2014	16.23	15.56167	0.66833	0.1102991	0.073716211
BH09	1/04/2014	16.37	15.72302	0.64698	0.1102991	0.071361325
BH09	1/07/2014	16.14	15.47817	0.66183	0.1102991	0.072999267
BH09	1/10/2014	15.96	15.47711	0.48289	0.1102991	0.053262342
BH09	1/01/2015	15.84	15.45816	0.37684	0.1102991	0.04156512
BH09	1/04/2015	16.50	15.60759	0.88741	0.1102991	0.097880542
BH09	1/07/2015	16.08	15.87432	0.20068	0.1102991	0.022134827
BH09	1/10/2015	15.95	15.40152	0.54348	0.1102991	0.059945366

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH09	1/01/2016	16.16	15.54991	0.60509	0.1102991	0.066740895
BH09	1/04/2016	15.26	15.73795	-0.47795	0.1102991	-0.052717464
BH09	1/07/2016	16.29	15.52539	0.76461	0.1102991	0.08433581
BH09	1/10/2016	15.81	15.46841	0.34159	0.1102991	0.037677076
BH09	1/01/2017	15.73	15.34794	0.38206	0.1102991	0.042140882
BH09	1/04/2017	15.99	15.55881	0.43119	0.1102991	0.047559878
BH09	1/07/2017	15.59	15.40737	0.18263	0.1102991	0.020143928
BH09	1/10/2017	15.47	15.07106	0.39894	0.1102991	0.044002731
BH09	1/01/2018	15.28	15.34259	-0.06259	0.1102991	-0.006903622
BH09	1/04/2018	15.15	15.359	-0.209	0.1102991	-0.023052516
BH09	1/07/2018	15.08	15.34292	-0.26292	0.1102991	-0.028999845
BH09	1/10/2018	15.12	15.08511	0.03489	0.1102991	0.003848336
BH09	1/01/2019	15.30	15.44039	-0.14039	0.1102991	-0.015484893
BH09	1/04/2019	15.25	15.51269	-0.26269	0.1102991	-0.028974476
BH10	1/01/2004	18.18	23.09595	-4.91995	0.1102991	-0.542666155
BH10	1/01/2005	18.13	23.13508	-5.00908	0.1102991	-0.552497116
BH10	1/01/2006	17.96	23.07185	-5.11585	0.1102991	-0.564273753
BH10	1/04/2006	17.57	23.23421	-5.66821	0.1102991	-0.625198575
BH10	1/07/2006	17.68	22.78098	-5.10498	0.1102991	-0.563074802
BH10	1/10/2006	17.86	23.10799	-5.25199	0.1102991	-0.579289875
BH10	1/01/2007	17.59	22.76205	-5.17605	0.1102991	-0.57091376
BH10	1/04/2007	17.83	23.14025	-5.31425	0.1102991	-0.586157098
BH10	1/07/2007	18.38	23.71721	-5.34121	0.1102991	-0.589130763
BH10	1/01/2008	18.09	23.53853	-5.45253	0.1102991	-0.601409261
BH10	1/04/2008	18.59	23.7926	-5.2066	0.1102991	-0.574283398
BH10	1/07/2008	18.77	23.80492	-5.03892	0.1102991	-0.555788442
BH10	1/10/2008	18.69	23.56489	-4.87889	0.1102991	-0.538137274
BH10	1/01/2009	18.39	23.5087	-5.1227	0.1102991	-0.565029302
BH10	1/04/2009	18.36	23.46679	-5.11079	0.1102991	-0.56371564
BH10	1/07/2009	18.01	23.47037	-5.46437	0.1102991	-0.602715202
BH10	1/10/2009	17.43	22.80153	-5.37553	0.1102991	-0.592916229
BH10	1/01/2010	17.87	22.9571	-5.0911	0.1102991	-0.56154385
BH10	1/04/2010	17.77	23.05072	-5.28472	0.1102991	-0.582899965
BH10	1/07/2010	18.19	22.96958	-4.78358	0.1102991	-0.527624664
BH10	1/10/2010	18.96	22.70951	-3.75351	0.1102991	-0.41400885
BH10	1/01/2011	18.03	23.40321	-5.37721	0.1102991	-0.593101531
BH10	1/04/2011	18.56	23.11384	-4.55784	0.1102991	-0.502725741
BH10	1/07/2011	18.60	23.60299	-5.00699	0.1102991	-0.552266591
BH10	1/10/2011	18.72	23.55467	-4.83867	0.1102991	-0.533701043
BH10	1/01/2012	19.97	23.66735	-3.70135	0.1102991	-0.408255648
BH10	1/04/2012	18.80	23.6898	-4.8938	0.1102991	-0.539781833
BH10	1/07/2012	18.54	23.59436	-5.05836	0.1102991	-0.557932657
BH10	1/10/2012	18.02	23.06214	-5.04614	0.1102991	-0.556584801
BH10	1/01/2013	18.54	22.92471	-4.38871	0.1102991	-0.484070851
BH10	1/04/2013	18.50	23.7082	-5.2122	0.1102991	-0.574901073

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH10	1/07/2013	18.48	23.5559	-5.0799	0.1102991	-0.5603085
BH10	1/10/2013	18.35	22.89437	-4.54837	0.1102991	-0.501681208
BH10	1/01/2014	18.03	23.37806	-5.35206	0.1102991	-0.590327508
BH10	1/04/2014	18.43	23.63945	-5.21345	0.1102991	-0.575038947
BH10	1/07/2014	18.50	23.34028	-4.84428	0.1102991	-0.534319821
BH10	1/10/2014	18.27	23.28195	-5.01595	0.1102991	-0.553254871
BH10	1/01/2015	18.26	23.21231	-4.95631	0.1102991	-0.546676631
BH10	1/04/2015	18.62	23.49348	-4.87248	0.1102991	-0.537430256
BH10	1/07/2015	18.43	23.87616	-5.44516	0.1102991	-0.600596356
BH10	1/10/2015	18.48	23.32664	-4.85064	0.1102991	-0.535021323
BH10	1/01/2016	18.42	23.47142	-5.05542	0.1102991	-0.557608377
BH10	1/04/2016	18.27	23.697	-5.431	0.1102991	-0.599034521
BH10	1/07/2016	18.72	23.47505	-4.75905	0.1102991	-0.524919027
BH10	1/10/2016	18.16	23.30068	-5.14468	0.1102991	-0.567453677
BH10	1/01/2017	17.99	23.03438	-5.04838	0.1102991	-0.556831871
BH10	1/04/2017	18.33	23.38084	-5.05484	0.1102991	-0.557544404
BH10	1/07/2017	18.07	23.11812	-5.05212	0.1102991	-0.55724439
BH10	1/10/2017	18.01	22.49528	-4.48928	0.1102991	-0.495163633
BH10	1/01/2018	17.79	22.80253	-5.01653	0.1102991	-0.553318844
BH10	1/04/2018	17.65	22.86338	-5.21738	0.1102991	-0.575472423
BH10	1/07/2018	17.69	22.85601	-5.17001	0.1102991	-0.570247553
BH10	1/10/2018	17.79	22.42239	-4.63139	0.1102991	-0.510838241
BH10	1/01/2019	17.88	22.99924	-5.12324	0.1102991	-0.565088864
BH10	1/04/2019	18.11	23.24756	-5.14156	0.1102991	-0.567109543
BH11	1/01/2004	15.35	14.3828	0.9642	0.1093093	0.105396066
BH11	1/01/2005	15.13	14.40637	0.72063	0.1093093	0.07877159
BH11	1/01/2006	14.92	14.38678	0.53022	0.1093093	0.057957998
BH11	1/04/2006	14.35	14.47065	-0.12365	0.1093093	-0.0135161
BH11	1/07/2006	15.38	14.22065	1.15635	0.1093093	0.126399855
BH11	1/10/2006	14.84	14.44263	0.39437	0.1093093	0.043108324
BH11	1/01/2007	16.04	14.2521	1.7849	0.1093093	0.195106241
BH11	1/04/2007	15.41	14.48076	0.92624	0.1093093	0.101246683
BH11	1/07/2007	15.52	14.87434	0.64266	0.1093093	0.07024874
BH11	1/10/2007	15.96	14.44917	1.50783	0.1093093	0.164819902
BH11	1/01/2008	15.81	14.55967	1.24733	0.1093093	0.136344819
BH11	1/04/2008	15.35	14.8023	0.5447	0.1093093	0.059540797
BH11	1/07/2008	15.50	14.74	0.757	0.1093093	0.08274717
BH11	1/10/2008	15.59	14.48898	1.09802	0.1093093	0.120023842
BH11	1/01/2009	15.31	14.4685	0.8385	0.1093093	0.091655882
BH11	1/04/2009	15.66	14.44802	1.20898	0.1093093	0.132152806
BH11	1/07/2009	15.04	14.472	0.565	0.1093093	0.061759777
BH11	1/10/2009	14.81	14.12687	0.68013	0.1093093	0.074344561
BH11	1/01/2010	15.03	14.31506	0.71194	0.1093093	0.077821692
BH11	1/04/2010	15.49	14.39499	1.09201	0.1093093	0.119366892
BH11	1/07/2010	15.53	14.35062	1.17638	0.1093093	0.128589321

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH11	1/10/2010	15.87	14.23067	1.63633	0.1093093	0.178866152
BH11	1/01/2011	14.64	14.61798	0.01902	0.1093093	0.002079064
BH11	1/04/2011	15.88	14.38971	1.48729	0.1093093	0.162574688
BH11	1/07/2011	15.48	14.71381	0.76319	0.1093093	0.083423795
BH11	1/10/2011	15.74	14.58119	1.15581	0.1093093	0.126340828
BH11	1/01/2012	15.45	14.67385	0.77315	0.1093093	0.084512516
BH11	1/04/2012	15.81	14.66659	1.14041	0.1093093	0.124657464
BH11	1/07/2012	15.24	14.55748	0.67952	0.1093093	0.074277883
BH11	1/10/2012	14.79	14.20776	0.57924	0.1093093	0.063316342
BH11	1/01/2013	15.48	14.23445	1.24255	0.1093093	0.13582232
BH11	1/04/2013	15.92	14.83383	1.08317	0.1093093	0.118400598
BH11	1/07/2013	15.22	14.56104	0.65596	0.1093093	0.071702555
BH11	1/10/2013	15.34	14.14638	1.19062	0.1093093	0.130145886
BH11	1/01/2014	15.86	14.49614	1.36086	0.1093093	0.148754708
BH11	1/04/2014	15.92	14.71379	1.20321	0.1093093	0.131522091
BH11	1/07/2014	15.86	14.38032	1.47668	0.1093093	0.161414916
BH11	1/10/2014	14.92	14.37889	0.53811	0.1093093	0.058820449
BH11	1/01/2015	14.30	14.37479	-0.07279	0.1093093	-0.007956627
BH11	1/04/2015	15.84	14.57405	1.26295	0.1093093	0.138052231
BH11	1/07/2015	15.36	14.98322	0.37378	0.1093093	0.040857645
BH11	1/10/2015	15.05	14.30012	0.75188	0.1093093	0.082187507
BH11	1/01/2016	14.81	14.46172	0.34528	0.1093093	0.037742329
BH11	1/04/2016	15.51	14.71932	0.78768	0.1093093	0.086100781
BH11	1/07/2016	15.61	14.42865	1.17835	0.1093093	0.128804661
BH11	1/10/2016	14.66	14.35562	0.30138	0.1093093	0.032943649
BH11	1/01/2017	15.08	14.26709	0.80991	0.1093093	0.088530728
BH11	1/04/2017	15.63	14.50235	1.12965	0.1093093	0.123481296
BH11	1/07/2017	14.64	14.3469	0.2901	0.1093093	0.03171064
BH11	1/10/2017	15.59	14.04824	1.53876	0.1093093	0.16820084
BH11	1/01/2018	14.20	14.32572	-0.12872	0.1093093	-0.014070298
BH11	1/04/2018	13.84	14.36804	-0.53104	0.1093093	-0.058047632
BH11	1/07/2018	14.51	14.35334	0.15366	0.1093093	0.016796473
BH11	1/10/2018	15.15	14.13122	1.01578	0.1093093	0.111034241
BH11	1/01/2019	14.63	14.48634	0.14066	0.1093093	0.015375452
BH11	1/04/2019	14.85	14.55515	0.29185	0.1093093	0.031901931
BH12	1/01/2004	13.48	14.70315	-1.22815	0.1102991	-0.135463864
BH12	1/01/2005	13.26	14.71935	-1.46435	0.1102991	-0.161516516
BH12	1/01/2006	12.88	14.70487	-1.82987	0.1102991	-0.201833051
BH12	1/04/2006	12.39	14.76971	-2.38471	0.1102991	-0.263031414
BH12	1/07/2006	12.79	14.57417	-1.78917	0.1102991	-0.197343877
BH12	1/10/2006	12.92	14.75611	-1.84111	0.1102991	-0.203072813
BH12	1/01/2007	12.51	14.60005	-2.09505	0.1102991	-0.231082171
BH12	1/04/2007	13.05	14.78376	-1.73876	0.1102991	-0.191783698
BH12	1/07/2007	14.22	15.12899	-0.91399	0.1102991	-0.100812293
BH12	1/10/2007	14.40	14.74268	-0.34768	0.1102991	-0.038348798

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH12	1/01/2008	14.38	14.83928	-0.46428	0.1102991	-0.051209675
BH12	1/04/2008	14.53	15.08045	-0.55545	0.1102991	-0.061265646
BH12	1/07/2008	14.47	15.01911	-0.55411	0.1102991	-0.061117845
BH12	1/10/2008	14.18	14.78196	-0.60696	0.1102991	-0.066947154
BH12	1/01/2009	13.73	14.77271	-1.04771	0.1102991	-0.115561491
BH12	1/04/2009	14.08	14.75779	-0.68279	0.1102991	-0.075311136
BH12	1/07/2009	13.83	14.77674	-0.95174	0.1102991	-0.104976084
BH12	1/10/2009	13.06	14.48584	-1.43084	0.1102991	-0.157820393
BH12	1/01/2010	13.08	14.67061	-1.59561	0.1102991	-0.175994379
BH12	1/04/2010	12.92	14.72191	-1.80691	0.1102991	-0.199300583
BH12	1/07/2010	13.80	14.68106	-0.88606	0.1102991	-0.097731638
BH12	1/10/2010	14.41	14.59108	-0.18608	0.1102991	-0.02052446
BH12	1/01/2011	13.02	14.8973	-1.8823	0.1102991	-0.207616034
BH12	1/04/2011	14.01	14.69894	-0.69394	0.1102991	-0.076540971
BH12	1/07/2011	14.52	14.98773	-0.47273	0.1102991	-0.052141703
BH12	1/10/2011	14.46	14.85277	-0.39777	0.1102991	-0.043873681
BH12	1/01/2012	14.32	14.94894	-0.63394	0.1102991	-0.069923024
BH12	1/04/2012	14.49	14.94363	-0.45863	0.1102991	-0.050586485
BH12	1/07/2012	13.80	14.83715	-1.04215	0.1102991	-0.114948228
BH12	1/10/2012	13.48	14.5694	-1.0944	0.1102991	-0.120711357
BH12	1/01/2013	13.90	14.60698	-0.71198	0.1102991	-0.078530767
BH12	1/04/2013	14.13	15.11835	-0.99335	0.1102991	-0.109565631
BH12	1/07/2013	13.93	14.83859	-0.91359	0.1102991	-0.100768173
BH12	1/10/2013	13.75	14.50596	-0.76096	0.1102991	-0.083933218
BH12	1/01/2014	13.54	14.80871	-1.27371	0.1102991	-0.140489092
BH12	1/04/2014	14.06	14.99137	-0.93637	0.1102991	-0.103280787
BH12	1/07/2014	14.17	14.69553	-0.53053	0.1102991	-0.058516992
BH12	1/10/2014	13.57	14.70609	-1.14109	0.1102991	-0.125861223
BH12	1/01/2015	13.33	14.70315	-1.37815	0.1102991	-0.152008732
BH12	1/04/2015	12.90	14.85758	-1.95758	0.1102991	-0.215919351
BH12	1/07/2015	13.50	15.20359	-1.70859	0.1102991	-0.188455973
BH12	1/10/2015	13.31	14.63237	-1.32237	0.1102991	-0.145856247
BH12	1/01/2016	13.19	14.77546	-1.59046	0.1102991	-0.175426338
BH12	1/04/2016	12.78	14.99977	-2.22477	0.1102991	-0.245390173
BH12	1/07/2016	13.36	14.73524	-1.38024	0.1102991	-0.152239257
BH12	1/10/2016	12.62	14.688	-2.073	0.1102991	-0.228650076
BH12	1/01/2017	12.32	14.62409	-2.30909	0.1102991	-0.254690595
BH12	1/07/2017	12.33	14.67558	-2.35058	0.1102991	-0.259266905
BH12	1/10/2017	12.17	14.36435	-2.19935	0.1102991	-0.24258637
BH12	1/01/2018	11.89	14.67903	-2.79403	0.1102991	-0.30817905
BH12	1/04/2018	11.75	14.69981	-2.95481	0.1102991	-0.325912943
BH12	1/07/2018	11.71	14.68353	-2.97853	0.1102991	-0.328529238
BH12	1/10/2018	11.63	14.49618	-2.87118	0.1102991	-0.316688627
BH12	1/01/2019	11.86	14.79656	-2.94156	0.1102991	-0.324451479
BH12	1/04/2019	12.16	14.83246	-2.67746	0.1102991	-0.295321482

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH13	1/01/2004	15.71	15.90357	-0.19457	0.1134402	-0.022072067
BH13	1/01/2005	15.38	15.92262	-0.54362	0.1134402	-0.061668383
BH13	1/01/2006	14.92	15.89591	-0.97691	0.1134402	-0.110820905
BH13	1/04/2006	14.52	15.94274	-1.42374	0.1134402	-0.161509407
BH13	1/07/2006	16.55	15.78344	0.76556	0.1134402	0.08684531
BH13	1/10/2006	15.30	15.88198	-0.58298	0.1134402	-0.066133391
BH13	1/01/2007	14.62	15.76158	-1.14258	0.1134402	-0.129614549
BH13	1/04/2007	15.43	15.88817	-0.45917	0.1134402	-0.052088355
BH13	1/07/2007	15.98	16.1152	-0.1362	0.1134402	-0.015450561
BH13	1/10/2007	15.92	16.00565	-0.08665	0.1134402	-0.009829597
BH13	1/01/2008	16.38	16.03741	0.34159	0.1134402	0.038750052
BH13	1/04/2008	16.25	16.19295	0.05605	0.1134402	0.006358325
BH13	1/07/2008	16.25	16.22334	0.02566	0.1134402	0.002910877
BH13	1/10/2008	16.06	16.09545	-0.03645	0.1134402	-0.004134897
BH13	1/01/2009	15.71	16.04337	-0.33437	0.1134402	-0.037931013
BH13	1/04/2009	16.22	16.01119	0.20781	0.1134402	0.023574016
BH13	1/07/2009	15.87	16.00937	-0.14037	0.1134402	-0.015923606
BH13	1/10/2009	15.30	15.77539	-0.47639	0.1134402	-0.054041796
BH13	1/01/2010	15.39	15.80242	-0.41342	0.1134402	-0.046898464
BH13	1/04/2010	15.83	15.85885	-0.02985	0.1134402	-0.003386191
BH13	1/07/2010	15.99	15.84858	0.14042	0.1134402	0.015929279
BH13	1/10/2010	16.39	15.74609	0.64291	0.1134402	0.072931865
BH13	1/01/2011	15.13	15.97188	-0.84288	0.1134402	-0.095616509
BH13	1/04/2011	16.00	15.92407	0.07493	0.1134402	0.008500077
BH13	1/01/2012	16.06	16.13809	-0.07909	0.1134402	-0.008971989
BH13	1/04/2012	16.23	16.16141	0.06759	0.1134402	0.007667426
BH13	1/07/2012	15.87	16.1091	-0.2401	0.1134402	-0.027237002
BH13	1/10/2012	15.14	15.88953	-0.75053	0.1134402	-0.085140303
BH13	1/01/2013	14.98	15.80912	-0.83012	0.1134402	-0.094169012
BH13	1/04/2013	15.00	16.14216	-1.14316	0.1134402	-0.129680345
BH13	1/07/2013	15.81	16.0909	-0.2819	0.1134402	-0.031978804
BH13	1/10/2013	15.82	15.8375	-0.0185	0.1134402	-0.002098644
BH13	1/01/2014	15.71	15.97725	-0.26825	0.1134402	-0.030430344
BH13	1/07/2014	15.87	16.00115	-0.13215	0.1134402	-0.014991128
BH13	1/10/2014	14.64	15.97042	-1.33142	0.1134402	-0.151036604
BH13	1/01/2015	14.97	15.94522	-0.97622	0.1134402	-0.110742631
BH13	1/04/2015	15.69	16.03619	-0.34719	0.1134402	-0.039385317
BH13	1/07/2015	15.03	16.27322	-1.24422	0.1134402	-0.141144615
BH13	1/10/2015	14.87	16.02432	-1.15532	0.1134402	-0.131059778
BH13	1/01/2016	14.75	16.03094	-1.28194	0.1134402	-0.145423581
BH13	1/04/2016	14.42	16.15983	-1.74083	0.1134402	-0.197480173
BH13	1/07/2016	15.65	16.04703	-0.39803	0.1134402	-0.045152619
BH13	1/10/2016	14.49	15.98058	-1.49158	0.1134402	-0.169205193
BH13	1/01/2017	16.55	15.8723	0.6767	0.1134402	0.07676501
BH13	1/07/2017	14.49	15.92783	-1.43883	0.1134402	-0.163221221

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH13	1/10/2017	14.40	15.68033	-1.28133	0.1134402	-0.145354383
BH13	1/01/2018	13.94	15.7607	-1.8217	0.1134402	-0.206654085
BH13	1/04/2018	13.90	15.80726	-1.90826	0.1134402	-0.216473472
BH13	1/07/2018	14.10	15.81911	-1.72011	0.1134402	-0.195129691
BH13	1/10/2018	14.74	15.64604	-0.90704	0.1134402	-0.102894835
BH13	1/01/2019	14.19	15.84362	-1.65462	0.1134402	-0.18770049
BH13	1/04/2019	14.38	15.94919	-1.57019	0.1134402	-0.17812273
BH14	1/01/2004	15.10	14.88794	0.21506	0.1102991	0.023720929
BH14	1/01/2005	14.81	14.94144	-0.12844	0.1102991	-0.014166819
BH14	1/01/2006	14.46	14.89374	-0.43074	0.1102991	-0.047510243
BH14	1/04/2006	14.11	15.03887	-0.92587	0.1102991	-0.102122646
BH14	1/07/2006	14.45	14.6178	-0.1648	0.1102991	-0.018177295
BH14	1/10/2006	14.71	14.92018	-0.20718	0.1102991	-0.022851772
BH14	1/01/2007	14.06	14.63059	-0.56759	0.1102991	-0.062604678
BH14	1/04/2007	14.60	14.98431	-0.38131	0.1102991	-0.042058157
BH14	1/07/2007	15.24	15.76588	-0.52288	0.1102991	-0.057673204
BH14	1/10/2007	15.72	15.17072	0.55228	0.1102991	0.060915998
BH14	1/01/2008	15.90	15.26356	0.63944	0.1102991	0.070529669
BH14	1/04/2008	15.64	15.75655	-0.11355	0.1102991	-0.012524465
BH14	1/07/2008	15.79	15.74567	0.04733	0.1102991	0.005220457
BH14	1/10/2008	15.74	15.26783	0.47517	0.1102991	0.052410833
BH14	1/01/2009	15.35	15.14957	0.20343	0.1102991	0.02243815
BH14	1/04/2009	15.57	15.08581	0.48719	0.1102991	0.053736628
BH14	1/07/2009	15.19	15.10833	0.08467	0.1102991	0.009339026
BH14	1/10/2009	14.81	14.49245	0.32055	0.1102991	0.035356383
BH14	1/01/2010	14.84	14.65099	0.19201	0.1102991	0.021178534
BH14	1/04/2010	14.94	14.83298	0.11002	0.1102991	0.012135109
BH14	1/07/2010	15.27	14.80072	0.47228	0.1102991	0.052092068
BH14	1/10/2010	15.74	14.56484	1.17816	0.1102991	0.129950011
BH14	1/01/2011	15.00	15.21581	-0.21281	0.1102991	-0.023472756
BH14	1/04/2011	15.39	14.95572	0.43728	0.1102991	0.048231599
BH14	1/07/2011	15.81	15.5034	0.3096	0.1102991	0.034148608
BH14	1/10/2011	15.83	15.34791	0.48509	0.1102991	0.053505
BH14	1/01/2012	15.93	15.51885	0.41415	0.1102991	0.045680381
BH14	1/07/2012	15.59	15.33931	0.25369	0.1102991	0.027981784
BH14	1/10/2012	15.10	14.7121	0.3909	0.1102991	0.043115926
BH14	1/01/2013	15.32	14.59325	0.72975	0.1102991	0.080490783
BH14	1/04/2013	15.70	15.6714	0.0316	0.1102991	0.003485452
BH14	1/07/2013	15.38	15.34941	0.03359	0.1102991	0.003704947
BH14	1/10/2013	15.34	14.60161	0.74139	0.1102991	0.081774665
BH14	1/01/2014	15.26	15.05988	0.20312	0.1102991	0.022403957
BH14	1/04/2014	15.63	15.52645	0.10655	0.1102991	0.011752371
BH14	1/07/2014	15.77	15.03096	0.74204	0.1102991	0.081846359
BH14	1/10/2014	14.98	14.95728	0.02572	0.1102991	0.002836893
BH14	1/01/2015	15.11	14.92242	0.19058	0.1102991	0.021020806

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH14	1/04/2015	15.75	15.23758	0.51042	0.1102991	0.056298877
BH14	1/07/2015	15.45	15.9783	-0.5303	0.1102991	-0.058491623
BH14	1/10/2015	15.26	14.9989	0.2591	0.1102991	0.028578502
BH14	1/01/2016	15.13	15.10415	0.02885	0.1102991	0.00318213
BH14	1/04/2016	15.08	15.56622	-0.48322	0.1102991	-0.053298741
BH14	1/07/2016	15.32	15.12604	0.19696	0.1102991	0.021724515
BH14	1/10/2016	14.81	14.94056	-0.12756	0.1102991	-0.014069756
BH14	1/01/2017	14.69	14.72049	-0.02749	0.1102991	-0.003032123
BH14	1/04/2017	15.09	15.08433	0.00367	0.1102991	0.000404798
BH14	1/07/2017	14.58	14.88058	-0.29758	0.1102991	-0.032822812
BH14	1/10/2017	14.65	14.2718	0.3812	0.1102991	0.042046025
BH14	1/01/2018	14.39	14.59226	-0.19926	0.1102991	-0.021978203
BH14	1/04/2018	14.22	14.73939	-0.51639	0.1102991	-0.056957363
BH14	1/07/2018	14.19	14.771	-0.578	0.1102991	-0.063752891
BH14	1/10/2018	14.24	14.35646	-0.11346	0.1102991	-0.012514538
BH14	1/01/2019	14.46	14.90928	-0.44628	0.1102991	-0.049224291
BH14	1/04/2019	14.61	15.16741	-0.55441	0.1102991	-0.061150935
BH15	15/09/2003	13.02	7.978938	5.041062	0.0720249	0.363081986
BH15	15/10/2003	13.13	7.977501	5.152499	0.0720249	0.371108225
BH15	15/11/2003	13.09	7.976017	5.113983	0.0720249	0.368334114
BH15	15/12/2003	13.15	7.974582	5.175418	0.0720249	0.372758964
BH15	15/01/2004	13.05	7.973088	5.076912	0.0720249	0.365664079
BH15	15/02/2004	12.94	7.971577	4.968423	0.0720249	0.35785017
BH15	15/03/2004	12.82	7.97015	4.84985	0.0720249	0.349309961
BH15	15/04/2004	13.09	7.968607	5.121393	0.0720249	0.368867819
BH15	15/05/2004	13.04	7.967109	5.072891	0.0720249	0.365374467
BH15	15/06/2004	12.69	7.96554	4.72446	0.0720249	0.340278759
BH15	15/07/2004	12.69	7.964023	4.725977	0.0720249	0.340388021
BH15	15/08/2004	12.52	7.962436	4.557564	0.0720249	0.328258091
BH15	15/09/2004	12.64	7.960849	4.679151	0.0720249	0.337015383
BH15	15/11/2004	12.85	7.9577	4.8923	0.0720249	0.352367418
BH15	15/12/2004	12.94	7.956146	4.983854	0.0720249	0.358961586
BH15	15/01/2005	12.75	7.954537	4.795463	0.0720249	0.345392743
BH15	15/02/2005	12.71	7.952921	4.757079	0.0720249	0.342628139
BH15	15/04/2005	12.91	7.949821	4.960179	0.0720249	0.357256396
BH15	15/05/2005	13.03	7.948236	5.081764	0.0720249	0.366013544
BH15	15/06/2005	13.21	7.946583	5.263417	0.0720249	0.379097083
BH15	15/07/2005	13.22	7.944983	5.275017	0.0720249	0.379932572
BH15	15/08/2005	13.09	7.943311	5.146689	0.0720249	0.370689761
BH15	15/09/2005	13.07	7.941638	5.128362	0.0720249	0.36936976
BH15	15/10/2005	12.80	7.940008	4.859992	0.0720249	0.350040438
BH15	15/11/2005	12.63	7.938311	4.691689	0.0720249	0.337918431
BH15	15/12/2005	12.83	7.936669	4.893331	0.0720249	0.352441676
BH15	15/01/2006	12.66	7.93497	4.72503	0.0720249	0.340319813
BH15	15/02/2006	12.53	7.933269	4.596731	0.0720249	0.331079091

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH15	15/03/2006	12.27	7.931735	4.338265	0.0720249	0.312463103
BH15	15/04/2006	12.64	7.930042	4.709958	0.0720249	0.339234254
BH15	15/05/2006	12.39	7.928401	4.461599	0.0720249	0.321346222
BH15	15/06/2006	12.22	7.926686	4.293314	0.0720249	0.309225512
BH15	15/07/2006	12.21	7.925002	4.284998	0.0720249	0.308626552
BH15	15/08/2006	12.26	7.923237	4.336763	0.0720249	0.312354921
BH15	15/09/2006	12.27	7.921454	4.348546	0.0720249	0.313203591
BH15	15/10/2006	12.35	7.919723	4.430277	0.0720249	0.319090258
BH15	15/11/2006	12.34	7.917922	4.422078	0.0720249	0.318499726
BH15	15/01/2007	13.04	7.914309	5.125691	0.0720249	0.369177382
BH15	15/02/2007	12.62	7.912439	4.707561	0.0720249	0.33906161
BH15	15/04/2007	12.01	7.908871	4.101129	0.0720249	0.295383406
BH15	15/05/2007	12.09	7.907088	4.182912	0.0720249	0.301273819
BH15	15/06/2007	12.27	7.905322	4.364678	0.0720249	0.314365496
BH15	15/07/2007	12.35	7.903692	4.446308	0.0720249	0.320244889
BH15	15/08/2007	12.45	7.902096	4.547904	0.0720249	0.327562331
BH15	15/09/2007	12.67	7.900577	4.769423	0.0720249	0.343517215
BH15	15/10/2007	12.63	7.899152	4.730848	0.0720249	0.340738854
BH15	15/11/2007	12.60	7.897727	4.702273	0.0720249	0.338680743
BH15	15/12/2007	12.75	7.896397	4.853603	0.0720249	0.349580271
BH15	15/01/2008	12.71	7.895061	4.814939	0.0720249	0.3467955
BH15	15/02/2008	13.31	7.893783	5.416217	0.0720249	0.390102488
BH15	15/03/2008	13.18	7.892665	5.287335	0.0720249	0.380819775
BH15	15/04/2008	13.42	7.891547	5.528453	0.0720249	0.398186274
BH15	15/05/2008	13.50	7.890556	5.609444	0.0720249	0.404019643
BH15	15/06/2008	13.50	7.889637	5.610363	0.0720249	0.404085834
BH15	15/07/2008	13.64	7.888827	5.751173	0.0720249	0.41422766
BH15	15/08/2008	13.73	7.888069	5.841931	0.0720249	0.420764496
BH15	15/09/2008	13.72	7.887372	5.832628	0.0720249	0.420094448
BH15	15/10/2008	13.71	7.886729	5.823271	0.0720249	0.419420511
BH15	15/11/2008	13.75	7.886088	5.863912	0.0720249	0.422347675
BH15	15/12/2008	13.79	7.88548	5.90452	0.0720249	0.425272463
BH15	15/01/2009	13.63	7.884853	5.745147	0.0720249	0.413793638
BH15	15/02/2009	13.32	7.884222	5.435778	0.0720249	0.391511367
BH15	15/03/2009	13.35	7.883639	5.466361	0.0720249	0.393714104
BH15	15/05/2009	13.57	7.882321	5.687679	0.0720249	0.409654511
BH15	15/06/2009	13.68	7.881618	5.798382	0.0720249	0.417627884
BH15	15/07/2009	13.53	7.880918	5.649082	0.0720249	0.406874566
BH15	15/08/2009	13.65	7.880154	5.769846	0.0720249	0.415572581
BH15	15/09/2009	13.58	7.879316	5.700684	0.0720249	0.410591195
BH15	15/10/2009	13.31	7.878437	5.431563	0.0720249	0.391207782
BH15	15/11/2009	13.09	7.877442	5.212558	0.0720249	0.375433969
BH15	15/12/2009	13.08	7.876395	5.203605	0.0720249	0.37478913
BH15	15/02/2010	12.74	7.874032	4.865968	0.0720249	0.350470859
BH15	15/03/2010	12.86	7.872878	4.987122	0.0720249	0.359196963

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH15	15/04/2010	12.82	7.871558	4.948442	0.0720249	0.35641104
BH15	15/05/2010	12.78	7.870234	4.909766	0.0720249	0.353625405
BH15	15/06/2010	12.74	7.868817	4.871183	0.0720249	0.350846468
BH15	15/07/2010	12.75	7.867406	4.882594	0.0720249	0.351668345
BH15	15/08/2010	12.92	7.8659	5.0541	0.0720249	0.364021047
BH15	15/09/2010	12.83	7.864332	4.965668	0.0720249	0.357651741
BH15	15/10/2010	12.82	7.862765	4.957235	0.0720249	0.357044355
BH15	15/11/2010	12.87	7.861105	5.008895	0.0720249	0.360765161
BH15	15/12/2010	13.15	7.859482	5.290518	0.0720249	0.38104903
BH15	15/01/2011	13.21	7.857809	5.352191	0.0720249	0.385491022
BH15	15/02/2011	12.90	7.856143	5.043857	0.0720249	0.363283296
BH15	15/03/2011	12.85	7.85464	4.99536	0.0720249	0.359790304
BH15	15/04/2011	12.75	7.852974	4.897026	0.0720249	0.352707808
BH15	15/05/2011	12.78	7.851373	4.928627	0.0720249	0.354983867
BH15	15/06/2011	12.98	7.849756	5.130244	0.0720249	0.369505311
BH15	15/07/2011	13.35	7.848235	5.501765	0.0720249	0.396264074
BH15	15/08/2011	13.31	7.846717	5.463283	0.0720249	0.393492412
BH15	15/09/2011	13.57	7.845257	5.724743	0.0720249	0.412324042
BH15	15/10/2011	13.70	7.843885	5.856115	0.0720249	0.421786097
BH15	15/11/2011	13.98	7.842519	6.137481	0.0720249	0.442051455
BH15	15/12/2011	14.03	7.841257	6.188743	0.0720249	0.445743596
BH15	15/01/2012	14.03	7.840005	6.189995	0.0720249	0.445833771
BH15	15/02/2012	14.01	7.838814	6.171186	0.0720249	0.444479055
BH15	15/03/2012	14.23	7.837761	6.392239	0.0720249	0.460400375
BH15	15/04/2012	14.19	7.836688	6.353312	0.0720249	0.457596661
BH15	15/05/2012	14.14	7.835698	6.304302	0.0720249	0.454066721
BH15	15/06/2012	14.13	7.83472	6.29528	0.0720249	0.453416912
BH15	15/07/2012	14.39	7.8338	6.5562	0.0720249	0.472209649
BH15	15/08/2012	14.33	7.832857	6.497143	0.0720249	0.467956075
BH15	15/09/2012	14.30	7.831889	6.468111	0.0720249	0.465865048
BH15	15/10/2012	14.06	7.830915	6.229085	0.0720249	0.448649224
BH15	15/11/2012	13.79	7.829851	5.960149	0.0720249	0.429279136
BH15	15/12/2012	13.72	7.828751	5.891249	0.0720249	0.42431662
BH15	15/01/2013	13.70	7.827551	5.872449	0.0720249	0.422962552
BH15	15/02/2013	13.89	7.82631	6.06369	0.0720249	0.436736666
BH15	15/03/2013	13.99	7.825189	6.164811	0.0720249	0.444019896
BH15	15/04/2013	14.03	7.823975	6.206025	0.0720249	0.44698833
BH15	15/05/2013	14.05	7.822835	6.227165	0.0720249	0.448510936
BH15	15/06/2013	13.89	7.821693	6.068307	0.0720249	0.437069205
BH15	15/07/2013	14.04	7.820609	6.219391	0.0720249	0.447951015
BH15	15/08/2013	14.37	7.819491	6.550509	0.0720249	0.471799756
BH15	15/09/2013	14.23	7.818338	6.411662	0.0720249	0.461799314
BH15	15/10/2013	14.08	7.817176	6.262824	0.0720249	0.451079272
BH15	15/11/2013	13.81	7.815925	5.994075	0.0720249	0.431722652
BH15	15/12/2013	13.93	7.814672	6.115328	0.0720249	0.440455888

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH15	15/01/2014	13.74	7.813353	5.926647	0.0720249	0.426866158
BH15	15/02/2014	13.54	7.812025	5.727975	0.0720249	0.412556827
BH15	15/03/2014	13.59	7.81084	5.77916	0.0720249	0.416243421
BH15	15/04/2014	13.78	7.809554	5.970446	0.0720249	0.430020776
BH15	15/05/2014	13.88	7.808332	6.071668	0.0720249	0.437311281
BH15	15/06/2014	13.97	7.807076	6.162924	0.0720249	0.443883985
BH15	15/07/2014	13.86	7.805856	6.054144	0.0720249	0.436049116
BH15	15/08/2014	13.94	7.80458	6.13542	0.0720249	0.441903012
BH15	15/09/2014	14.07	7.80328	6.26672	0.0720249	0.451359881
BH15	15/10/2014	13.97	7.802001	6.167999	0.0720249	0.444249511
BH15	15/11/2014	14.02	7.800649	6.219351	0.0720249	0.447948134
BH17A	1/01/2005	6.50	8.17104	-1.66904	0.1219393	-0.203521503
BH17A	1/01/2006	6.34	8.157636	-1.815636	0.1219393	-0.22139731
BH17A	1/04/2006	6.04	8.222216	-2.180216	0.1219393	-0.265853926
BH17A	1/07/2006	5.99	8.022816	-2.030816	0.1219393	-0.2476362
BH17A	1/10/2006	5.89	8.21286	-2.32086	0.1219393	-0.283003951
BH17A	1/01/2007	5.69	8.053095	-2.361095	0.1219393	-0.287910177
BH17A	1/04/2007	6.07	8.2417	-2.1697	0.1219393	-0.264571612
BH17A	1/07/2007	5.79	8.57019	-2.77819	0.1219393	-0.338770433
BH17A	1/10/2007	6.32	8.181703	-1.859703	0.1219393	-0.226770808
BH17A	1/01/2008	6.47	8.280508	-1.808508	0.1219393	-0.220528127
BH17A	1/04/2008	6.61	8.510319	-1.898319	0.1219393	-0.231479614
BH17A	1/07/2008	6.77	8.441833	-1.669833	0.1219393	-0.2036182
BH17A	1/10/2008	6.77	8.210378	-1.438378	0.1219393	-0.175394749
BH17A	1/01/2009	6.60	8.205835	-1.603835	0.1219393	-0.195570453
BH17A	1/04/2009	6.60	8.194177	-1.592177	0.1219393	-0.194148885
BH17A	1/07/2009	6.82	8.215411	-1.393411	0.1219393	-0.169911506
BH17A	1/10/2009	5.48	7.947562	-2.465562	0.1219393	-0.300648806
BH17A	1/01/2010	6.15	8.121918	-1.969918	0.1219393	-0.240210343
BH17A	1/04/2010	6.08	8.175299	-2.093299	0.1219393	-0.255255331
BH17A	1/07/2010	5.97	8.132675	-2.160675	0.1219393	-0.263471111
BH17A	1/10/2010	6.39	8.041547	-1.649547	0.1219393	-0.201144541
BH17A	1/01/2011	6.20	8.351947	-2.149947	0.1219393	-0.262162946
BH17A	1/04/2011	6.15	8.147031	-1.995031	0.1219393	-0.243272604
BH17A	1/07/2011	6.74	8.430465	-1.688465	0.1219393	-0.205890173
BH17A	1/10/2011	7.01	8.292115	-1.280115	0.1219393	-0.156096276
BH17A	1/01/2012	7.24	8.382957	-1.140957	0.1219393	-0.139127452
BH17A	1/04/2012	6.97	8.373686	-1.401686	0.1219393	-0.170920554
BH17A	1/07/2012	7.27	8.267996	-0.995996	0.1219393	-0.121451015
BH17A	1/10/2012	7.04	8.000435	-0.958435	0.1219393	-0.116870855
BH17A	1/01/2013	7.07	8.048377	-0.976377	0.1219393	-0.119058689
BH17A	1/04/2013	7.01	8.557692	-1.545692	0.1219393	-0.188480539
BH17A	1/07/2013	6.99	8.273293	-1.281293	0.1219393	-0.15623992
BH17A	1/10/2013	6.89	7.953435	-1.061435	0.1219393	-0.129430598
BH17A	1/01/2014	6.77	8.25557	-1.48357	0.1219393	-0.180905428

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH17A	1/04/2014	6.85	8.429667	-1.577667	0.1219393	-0.192379547
BH17A	1/07/2014	6.89	8.131953	-1.239953	0.1219393	-0.151198951
BH17A	1/10/2014	6.82	8.147099	-1.325099	0.1219393	-0.161581591
BH17A	1/01/2015	6.77	8.147236	-1.375236	0.1219393	-0.16769526
BH17A	1/04/2015	6.89	8.302406	-1.410406	0.1219393	-0.171983864
BH17A	1/07/2015	6.83	8.621354	-1.794354	0.1219393	-0.218802199
BH17A	1/10/2015	6.84	8.061137	-1.219137	0.1219393	-0.148660664
BH17A	1/01/2016	6.97	8.213303	-1.241303	0.1219393	-0.151363569
BH17A	1/04/2016	6.80	8.43248	-1.63048	0.1219393	-0.198819525
BH17A	1/07/2016	7.02	8.167771	-1.145771	0.1219393	-0.139714468
BH17A	1/10/2016	6.93	8.125113	-1.193113	0.1219393	-0.145487316
BH20A	1/01/2004	4.29	7.619018	-3.329018	0.1206059	-0.401499279
BH20A	1/01/2005	4.23	7.634198	-3.404198	0.1206059	-0.410566432
BH20A	1/01/2006	4.00	7.621686	-3.621686	0.1206059	-0.436796772
BH20A	1/04/2006	3.69	7.68171	-3.99171	0.1206059	-0.481423857
BH20A	1/07/2006	3.70	7.476015	-3.776015	0.1206059	-0.455409763
BH20A	1/10/2006	3.92	7.669747	-3.749747	0.1206059	-0.452241687
BH20A	1/01/2007	3.70	7.514544	-3.814544	0.1206059	-0.460056589
BH20A	1/04/2007	4.52	7.697511	-3.177511	0.1206059	-0.383226637
BH20A	1/07/2007	4.49	8.001823	-3.511823	0.1206059	-0.423546644
BH20A	1/10/2007	4.83	7.642588	-2.812588	0.1206059	-0.339214763
BH20A	1/01/2008	4.25	7.735385	-3.485385	0.1206059	-0.420358064
BH20A	1/04/2008	5.10	7.946922	-2.846922	0.1206059	-0.343355647
BH20A	1/07/2008	5.16	7.882829	-2.722829	0.1206059	-0.328389297
BH20A	1/10/2008	4.98	7.66914	-2.68914	0.1206059	-0.324326204
BH20A	1/01/2009	4.62	7.666093	-3.046093	0.1206059	-0.367376849
BH20A	1/04/2009	4.71	7.655316	-2.945316	0.1206059	-0.355222546
BH20A	1/07/2009	4.57	7.674976	-3.104976	0.1206059	-0.374478487
BH20A	1/10/2009	3.99	7.355191	-3.365191	0.1206059	-0.405861957
BH20A	1/01/2010	3.98	7.564858	-3.584858	0.1206059	-0.432355097
BH20A	1/04/2010	4.14	7.632142	-3.492142	0.1206059	-0.421172999
BH20A	1/07/2010	4.21	7.595463	-3.385463	0.1206059	-0.40830688
BH20A	1/10/2010	4.78	7.493286	-2.713286	0.1206059	-0.327238354
BH20A	1/01/2011	4.13	7.798448	-3.668448	0.1206059	-0.442436546
BH20A	1/04/2011	4.50	7.610582	-3.110582	0.1206059	-0.375154604
BH20A	1/07/2011	5.12	7.87348	-2.75348	0.1206059	-0.332085989
BH20A	1/10/2011	5.27	7.744507	-2.474507	0.1206059	-0.298440193
BH20A	1/01/2012	5.24	7.828588	-2.588588	0.1206059	-0.312199037
BH20A	1/04/2012	5.14	7.819472	-2.679472	0.1206059	-0.323160186
BH20A	1/07/2012	5.06	7.722414	-2.662414	0.1206059	-0.32110289
BH20A	1/10/2012	4.74	7.446917	-2.706917	0.1206059	-0.326470215
BH20A	1/01/2013	4.88	7.487929	-2.607929	0.1206059	-0.314531676
BH20A	1/04/2013	4.94	7.987871	-3.047871	0.1206059	-0.367591286
BH20A	1/07/2013	4.82	7.726357	-2.906357	0.1206059	-0.35052386
BH20A	1/10/2013	4.17	7.37113	-3.20113	0.1206059	-0.386075229

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH20A	1/01/2014	4.58	7.706408	-3.126408	0.1206059	-0.377063313
BH20A	1/04/2014	4.84	7.871384	-3.031384	0.1206059	-0.365602856
BH20A	1/07/2014	5.00	7.596386	-2.596386	0.1206059	-0.313139522
BH20A	1/10/2014	4.56	7.611854	-3.056854	0.1206059	-0.368674689
BH20A	1/01/2015	4.59	7.611825	-3.021825	0.1206059	-0.364449984
BH20A	1/04/2015	4.90	7.755417	-2.855417	0.1206059	-0.344380194
BH20A	1/07/2015	4.74	8.047764	-3.307764	0.1206059	-0.39893592
BH20A	1/10/2015	4.75	7.527838	-2.777838	0.1206059	-0.335023708
BH20A	1/01/2016	4.70	7.673156	-2.973156	0.1206059	-0.358580215
BH20A	1/04/2016	4.53	7.874743	-3.349743	0.1206059	-0.403998836
BH20A	1/07/2016	4.96	7.62956	-2.67456	0.1206059	-0.322567769
BH20A	1/10/2016	4.48	7.591237	-3.111237	0.1206059	-0.375233601
BH21A	1/01/2004	6.05	7.75268	-1.70268	0.1206059	-0.205353288
BH21A	1/01/2005	4.21	7.767568	-3.557568	0.1206059	-0.429063762
BH21A	1/01/2006	4.09	7.755205	-3.665205	0.1206059	-0.442045421
BH21A	1/04/2006	4.09	7.814418	-3.724418	0.1206059	-0.449186859
BH21A	1/07/2006	3.71	7.612501	-3.902501	0.1206059	-0.470664723
BH21A	1/10/2006	3.92	7.80313	-3.88313	0.1206059	-0.468328466
BH21A	1/01/2007	3.60	7.655203	-4.055203	0.1206059	-0.489081489
BH21A	1/04/2007	4.68	7.830509	-3.150509	0.1206059	-0.379970036
BH21A	1/07/2007	4.57	8.13052	-3.56052	0.1206059	-0.42941979
BH21A	1/10/2007	4.85	7.777939	-2.927939	0.1206059	-0.353126777
BH21A	1/01/2008	5.24	7.86761	-2.62761	0.1206059	-0.316905321
BH21A	1/04/2008	6.51	8.077472	-1.567472	0.1206059	-0.189046403
BH21A	1/07/2008	5.38	8.015956	-2.635956	0.1206059	-0.317911898
BH21A	1/10/2008	5.40	7.80361	-2.40361	0.1206059	-0.289889595
BH21A	1/01/2009	4.98	7.79908	-2.81908	0.1206059	-0.339997737
BH21A	1/04/2009	4.93	7.788392	-2.858392	0.1206059	-0.344738997
BH21A	1/07/2009	4.81	7.807867	-2.997867	0.1206059	-0.361560508
BH21A	1/10/2009	4.04	7.484058	-3.444058	0.1206059	-0.415373784
BH21A	1/01/2010	4.32	7.70761	-3.38761	0.1206059	-0.408565821
BH21A	1/04/2010	3.78	7.767737	-3.987737	0.1206059	-0.48094469
BH21A	1/07/2010	4.47	7.730914	-3.260914	0.1206059	-0.393285533
BH21A	1/10/2010	5.01	7.635258	-2.625258	0.1206059	-0.316621656
BH21A	1/01/2011	4.33	7.930606	-3.600606	0.1206059	-0.434254399
BH21A	1/04/2011	3.99	7.745286	-3.755286	0.1206059	-0.452909723
BH21A	1/07/2011	5.33	8.004451	-2.674451	0.1206059	-0.322554623
BH21A	1/10/2011	5.58	7.878215	-2.298215	0.1206059	-0.277178334
BH21A	1/01/2012	5.53	7.960875	-2.430875	0.1206059	-0.293177916
BH21A	1/04/2012	5.59	7.952363	-2.362363	0.1206059	-0.284914963
BH21A	1/07/2012	5.62	7.855983	-2.235983	0.1206059	-0.269672787
BH21A	1/10/2012	5.19	7.578961	-2.388961	0.1206059	-0.288122839
BH21A	1/01/2013	5.26	7.630146	-2.370146	0.1206059	-0.285853639
BH21A	1/04/2013	5.14	8.11707	-2.97707	0.1206059	-0.359052266
BH21A	1/07/2013	5.19	7.861238	-2.671238	0.1206059	-0.322167117

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH21A	1/10/2013	4.97	7.499574	-2.529574	0.1206059	-0.305081599
BH21A	1/01/2014	4.75	7.839114	-3.089114	0.1206059	-0.372565436
BH21A	1/04/2014	5.02	8.002984	-2.982984	0.1206059	-0.35976553
BH21A	1/07/2014	5.16	7.73159	-2.57159	0.1206059	-0.310148978
BH21A	1/10/2014	4.84	7.745294	-2.905294	0.1206059	-0.350395656
BH21A	1/01/2015	4.90	7.745393	-2.845393	0.1206059	-0.343171241
BH21A	1/04/2015	5.21	7.887458	-2.677458	0.1206059	-0.322917285
BH21A	1/07/2015	5.14	8.173623	-3.033623	0.1206059	-0.365872893
BH21A	1/10/2015	5.03	7.666045	-2.641045	0.1206059	-0.318525662
BH21A	1/01/2016	5.09	7.805588	-2.715588	0.1206059	-0.327515989
BH21A	1/04/2016	4.75	8.00597	-3.25597	0.1206059	-0.392689257
BH21A	1/07/2016	5.05	7.764367	-2.714367	0.1206059	-0.327368729
BH21A	1/10/2016	4.64	7.725086	-3.085086	0.1206059	-0.372079635
BH22A	1/01/2005	6.41	12.84226	-6.43326	0.1219393	-0.784466964
BH22A	1/01/2006	7.40	12.81706	-5.41806	0.1219393	-0.660674227
BH22A	1/04/2006	7.05	12.91769	-5.86869	0.1219393	-0.715623716
BH22A	1/07/2006	6.85	12.59901	-5.75001	0.1219393	-0.701151964
BH22A	1/10/2006	6.42	12.87018	-6.45118	0.1219393	-0.786652115
BH22A	1/01/2007	6.41	12.64235	-6.23335	0.1219393	-0.760090086
BH22A	1/04/2007	7.91	12.91832	-5.00932	0.1219393	-0.610832774
BH22A	1/07/2007	8.17	13.44153	-5.27253	0.1219393	-0.642928407
BH22A	1/10/2007	9.72	12.93897	-3.21997	0.1219393	-0.392640759
BH22A	1/01/2008	8.95	13.04172	-4.09272	0.1219393	-0.499063248
BH22A	1/04/2008	9.04	13.38226	-4.34326	0.1219393	-0.52961391
BH22A	1/07/2008	8.71	13.31989	-4.61089	0.1219393	-0.562248515
BH22A	1/10/2008	8.45	12.97868	-4.52968	0.1219393	-0.552345827
BH22A	1/01/2009	8.26	12.93034	-4.67134	0.1219393	-0.569619743
BH22A	1/04/2009	7.96	12.90055	-4.94155	0.1219393	-0.60256895
BH22A	1/07/2009	7.85	12.92861	-5.07961	0.1219393	-0.619403884
BH22A	1/10/2009	7.06	12.43679	-5.37779	0.1219393	-0.655763733
BH22A	1/01/2010	6.72	12.67914	-5.96014	0.1219393	-0.726775061
BH22A	1/04/2010	7.23	12.81443	-5.58543	0.1219393	-0.681083201
BH22A	1/07/2010	7.18	12.77214	-5.59314	0.1219393	-0.682023353
BH22A	1/10/2010	7.79	12.60321	-4.81421	0.1219393	-0.587041205
BH22A	1/01/2011	7.24	13.08564	-5.84664	0.1219393	-0.712934955
BH22A	1/04/2011	7.84	12.83811	-4.99911	0.1219393	-0.609587774
BH22A	1/07/2011	8.24	13.24541	-5.00641	0.1219393	-0.610477931
BH22A	1/10/2011	8.00	13.08781	-5.08881	0.1219393	-0.620525726
BH22A	1/01/2012	7.59	13.20972	-5.62072	0.1219393	-0.685386437
BH22A	1/04/2012	8.11	13.2079	-5.0989	0.1219393	-0.621756093
BH22A	1/07/2012	7.92	13.05462	-5.13562	0.1219393	-0.626233702
BH22A	1/10/2012	6.84	12.58671	-5.74771	0.1219393	-0.700871504
BH22A	1/01/2013	7.78	12.57392	-4.79492	0.1219393	-0.584688997
BH22A	1/04/2013	7.89	13.38416	-5.49516	0.1219393	-0.670075744
BH22A	1/07/2013	7.84	13.07143	-5.23243	0.1219393	-0.638038642

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH22A	1/10/2013	7.58	12.4865	-4.9075	0.1219393	-0.598416918
BH22A	1/01/2014	7.37	12.92452	-5.55552	0.1219393	-0.677435998
BH22A	1/04/2014	8.10	13.24781	-5.14881	0.1219393	-0.627842081
BH22A	1/07/2014	8.22	12.84065	-4.62165	0.1219393	-0.563560581
BH22A	1/10/2014	7.59	12.81161	-5.21761	0.1219393	-0.636231502
BH22A	1/01/2015	7.65	12.80209	-5.15309	0.1219393	-0.628363981
BH22A	1/04/2015	8.41	13.04596	-4.63696	0.1219393	-0.565427471
BH22A	1/07/2015	8.06	13.53606	-5.47206	0.1219393	-0.667258947
BH22A	1/10/2015	7.92	12.75952	-4.84052	0.1219393	-0.590249427
BH22A	1/01/2016	7.95	12.907	-4.953	0.1219393	-0.603965155
BH22A	1/04/2016	8.00	13.25588	-5.25688	0.1219393	-0.641020057
BH22A	1/07/2016	8.39	12.89957	-4.51057	0.1219393	-0.550015568
BH22A	1/10/2016	7.62	12.78668	-5.16768	0.1219393	-0.630143075
BH23B	1/01/2005	10.86	8.349063	2.506937	0.1233217	0.309159682
BH23B	1/01/2006	9.24	8.335583	0.900417	0.1233217	0.111040937
BH23B	1/04/2006	9.08	8.393882	0.682118	0.1233217	0.084119938
BH23B	1/07/2006	8.86	8.184245	0.671755	0.1233217	0.082841955
BH23B	1/10/2006	9.06	8.382596	0.673404	0.1233217	0.083045313
BH23B	1/04/2007	9.04	8.408113	0.627887	0.1233217	0.07743208
BH23B	1/07/2007	9.39	8.704069	0.681931	0.1233217	0.084096877
BH23B	1/10/2007	9.96	8.362586	1.593414	0.1233217	0.196502491
BH23B	1/01/2008	9.67	8.450329	1.215671	0.1233217	0.14991859
BH23B	1/04/2008	9.78	8.657818	1.118182	0.1233217	0.137896083
BH23B	1/07/2008	9.62	8.602028	1.013972	0.1233217	0.125044731
BH23B	1/10/2008	9.81	8.395856	1.410144	0.1233217	0.173901327
BH23B	1/01/2009	9.54	8.390504	1.145496	0.1233217	0.141264491
BH23B	1/04/2009	9.53	8.379191	1.146809	0.1233217	0.141426413
BH23B	1/07/2009	10.07	8.397696	1.668304	0.1233217	0.205738052
BH23B	1/10/2009	8.66	8.089236	0.566764	0.1233217	0.069894289
BH23B	1/01/2010	9.13	8.30099	0.82501	0.1233217	0.101741619
BH23B	1/04/2010	9.03	8.354606	0.671394	0.1233217	0.082797436
BH23B	1/07/2010	9.25	8.316378	0.929622	0.1233217	0.114642547
BH23B	1/10/2010	9.38	8.209113	1.166887	0.1233217	0.143902465
BH23B	1/01/2011	9.21	8.510667	0.695333	0.1233217	0.085749634
BH23B	1/04/2011	9.21	8.329217	0.876783	0.1233217	0.108126353
BH23B	1/07/2011	9.67	8.58386	1.08214	0.1233217	0.133451323
BH23B	1/10/2011	9.80	8.463109	1.332891	0.1233217	0.164374357
BH23B	1/01/2012	9.97	8.545728	1.420272	0.1233217	0.175150329
BH23B	1/04/2012	9.96	8.539667	1.416333	0.1233217	0.174664565
BH23B	1/07/2012	10.06	8.446602	1.609398	0.1233217	0.198473665
BH23B	1/10/2012	9.95	8.167484	1.778516	0.1233217	0.219329581
BH23B	1/01/2013	9.98	8.212719	1.763281	0.1233217	0.217450775
BH23B	1/04/2013	9.43	8.698344	0.727656	0.1233217	0.08973576
BH23B	1/07/2013	9.93	8.450907	1.475093	0.1233217	0.181910947
BH23B	1/10/2013	9.84	8.102103	1.733897	0.1233217	0.213827091

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH23B	1/01/2014	9.73	8.427779	1.298221	0.1233217	0.160098795
BH23B	1/04/2014	9.80	8.587135	1.208865	0.1233217	0.149079263
BH23B	1/07/2014	9.87	8.322628	1.543372	0.1233217	0.190331228
BH23B	1/10/2014	9.73	8.334386	1.391614	0.1233217	0.171616176
BH23B	1/01/2015	9.72	8.333157	1.382843	0.1233217	0.170534522
BH23B	1/04/2015	9.85	8.472316	1.378684	0.1233217	0.170021627
BH23B	1/07/2015	9.83	8.757595	1.073405	0.1233217	0.132374108
BH23B	1/10/2015	9.84	8.254969	1.581031	0.1233217	0.194975399
BH23B	1/01/2016	9.87	8.396071	1.469929	0.1233217	0.181274114
BH23B	1/04/2016	9.73	8.592549	1.133451	0.1233217	0.139779082
BH23B	1/07/2016	9.94	8.357585	1.578415	0.1233217	0.19465279
BH23B	1/10/2016	9.79	8.317138	1.468862	0.1233217	0.18114253
BH24A	1/04/2010	16.17	18.12427	-1.95627	0.2268723	-0.443823474
BH24A	1/07/2010	16.47	18.1049	-1.6369	0.2268723	-0.371367268
BH24A	1/10/2010	16.88	18.06083	-1.18283	0.2268723	-0.268351363
BH24A	1/01/2011	16.04	18.1939	-2.1559	0.2268723	-0.489113992
BH24A	1/04/2011	16.64	18.10868	-1.47068	0.2268723	-0.333656554
BH24A	1/07/2011	16.60	18.2298	-1.6318	0.2268723	-0.370210219
BH24A	1/10/2011	16.73	18.1755	-1.4475	0.2268723	-0.328397654
BH24A	1/01/2012	16.65	18.21848	-1.57048	0.2268723	-0.35629841
BH24A	1/04/2012	16.74	18.21876	-1.48076	0.2268723	-0.335943427
BH24A	1/07/2012	16.49	18.17917	-1.69117	0.2268723	-0.383679628
BH24A	1/10/2012	15.95	18.01032	-2.06232	0.2268723	-0.467883282
BH24A	1/01/2013	16.37	18.08314	-1.71514	0.2268723	-0.389117757
BH24A	1/04/2013	16.71	18.29439	-1.58639	0.2268723	-0.359907948
BH25A	1/04/2010	12.14	14.74302	-2.60402	0.1344792	-0.350186526
BH25A	1/07/2010	13.01	14.70216	-1.69316	0.1344792	-0.227694802
BH25A	1/10/2010	13.78	14.61581	-0.83681	0.1344792	-0.112533539
BH25A	1/01/2011	12.19	14.91358	-2.72458	0.1344792	-0.366399339
BH25A	1/04/2011	13.19	14.71669	-1.52769	0.1344792	-0.205442529
BH25A	1/07/2011	14.01	14.9988	-0.9898	0.1344792	-0.133107512
BH25A	1/10/2011	13.88	14.86301	-0.98401	0.1344792	-0.132328878
BH25A	1/01/2012	13.81	14.95813	-1.14913	0.1344792	-0.154534083
BH25A	1/04/2012	13.20	14.9523	-1.7533	0.1344792	-0.235782381
BH25A	1/07/2012	13.27	14.84641	-1.57741	0.1344792	-0.212128835
BH25A	1/10/2012	12.76	14.58841	-1.82941	0.1344792	-0.246017593
BH25A	1/01/2013	13.40	14.6303	-1.2313	0.1344792	-0.165584239
BH25A	1/04/2013	13.74	15.13083	-1.39183	0.1344792	-0.187172185
BH25A	1/07/2013	13.39	14.84845	-1.45945	0.1344792	-0.196265668
BH25A	1/10/2013	13.21	14.52539	-1.31639	0.1344792	-0.177027074
BH25A	1/01/2014	12.72	14.82602	-2.10702	0.1344792	-0.283350364
BH25A	1/04/2014	13.61	15.00215	-1.39315	0.1344792	-0.187349697
BH25A	1/07/2014	13.87	14.71018	-0.84118	0.1344792	-0.113121213
BH25A	1/10/2014	12.87	14.7234	-1.8544	0.1344792	-0.249378228
BH25A	1/01/2015	13.01	14.7216	-1.7076	0.1344792	-0.229636682

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH25A	1/04/2015	13.71	14.87167	-1.16267	0.1344792	-0.156354931
BH25A	1/07/2015	13.21	15.2108	-1.9968	0.1344792	-0.268528067
BH25A	1/10/2015	13.06	14.6466	-1.5876	0.1344792	-0.213499178
BH25A	1/01/2016	12.92	14.7905	-1.8665	0.1344792	-0.251005427
BH25A	1/04/2016	12.66	15.01023	-2.35123	0.1344792	-0.316191529
BH25A	1/07/2016	13.35	14.74807	-1.39907	0.1344792	-0.188145814
BH25A	1/10/2016	12.39	14.7049	-2.3159	0.1344792	-0.311440379
BH25A	1/01/2017	12.00	14.64517	-2.64617	0.1344792	-0.355854825
BH25A	1/04/2017	12.72	14.82569	-2.10669	0.1344792	-0.283305986
BH25A	1/07/2017	12.13	14.69454	-2.56554	0.1344792	-0.345011767
BH25A	1/10/2017	11.93	14.38572	-2.45672	0.1344792	-0.33037774
BH25A	1/01/2018	11.60	14.70469	-3.10569	0.1344792	-0.417650707
BH25A	1/04/2018	11.48	14.72293	-3.24393	0.1344792	-0.436241111
BH25A	1/07/2018	11.35	14.70575	-3.35675	0.1344792	-0.451413055
BH25A	1/10/2018	11.28	14.52249	-3.24349	0.1344792	-0.43618194
BH25A	1/01/2019	11.59	14.81803	-3.22903	0.1344792	-0.434237371
BH25A	1/04/2019	11.80	14.84849	-3.04949	0.1344792	-0.410092976
BH25B	1/07/2010	10.94	18.84384	-7.90884	0.2726639	-2.156455475
BH25B	1/10/2010	10.93	18.84244	-7.91744	0.2726639	-2.158800385
BH25B	1/01/2011	10.40	18.84598	-8.45098	0.2726639	-2.304277504
BH25B	1/04/2011	10.59	18.84714	-8.26214	0.2726639	-2.252787645
BH25B	1/07/2011	10.69	18.85254	-8.16754	0.2726639	-2.226993637
BH25B	1/10/2011	9.95	18.85689	-8.91189	0.2726639	-2.42995104
BH25B	1/01/2012	10.30	18.8625	-8.5675	0.2726639	-2.336048306
BH25B	1/04/2012	10.64	18.86853	-8.23353	0.2726639	-2.24498673
BH25B	1/07/2012	10.67	18.87273	-8.20773	0.2726639	-2.237952
BH26A	1/10/2011	19.14	19.21654	-0.08054	0.146921	-0.011833016
BH26A	1/01/2012	19.47	19.35416	0.11184	0.146921	0.016431642
BH26A	1/04/2012	18.81	19.35611	-0.55011	0.146921	-0.0808227
BH26A	1/07/2012	19.12	19.19072	-0.07472	0.146921	-0.010977936
BH26A	1/10/2012	18.80	18.69298	0.10302	0.146921	0.015135799
BH26A	1/01/2013	19.34	18.67531	0.66569	0.146921	0.097803827
BH26A	1/04/2013	19.21	19.53769	-0.32669	0.146921	-0.047997615
BH26A	1/07/2013	19.02	19.2002	-0.1842	0.146921	-0.027062845
BH26A	1/10/2013	18.98	18.60151	0.37949	0.146921	0.055755043
BH26A	1/01/2014	18.91	19.05094	-0.13994	0.146921	-0.020560122
BH26A	1/04/2014	19.25	19.39088	-0.13988	0.146921	-0.020551307
BH26A	1/07/2014	19.35	18.95888	0.39212	0.146921	0.057610655
BH26A	1/10/2014	18.87	18.9299	-0.0639	0.146921	-0.009388251
BH26A	1/01/2015	19.12	18.91681	0.20419	0.146921	0.029999795
BH26A	1/04/2015	19.56	19.17593	0.38007	0.146921	0.055840257
BH26A	1/07/2015	19.03	19.70005	-0.67405	0.146921	-0.099032087
BH26A	1/10/2015	19.03	18.8662	0.1648	0.146921	0.024212578
BH26A	1/01/2016	18.00	19.04047	-1.03947	0.146921	-0.152719951
BH26A	1/04/2016	18.79	19.40836	-0.62236	0.146921	-0.091437741

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
BH26A	1/07/2016	19.15	19.0281	0.1229	0.146921	0.018056588
BH26A	1/10/2016	18.52	18.90499	-0.38399	0.146921	-0.056416187
BH26A	1/01/2017	18.10	18.75397	-0.65297	0.146921	-0.095934992
BH26A	1/04/2017	18.88	19.07259	-0.19159	0.146921	-0.028148591
BH26A	1/07/2017	18.36	18.88544	-0.52444	0.146921	-0.077051239
BH26A	1/10/2017	18.77	18.42469	0.34631	0.146921	0.050880205
BH26A	1/01/2018	17.91	18.77515	-0.86415	0.146921	-0.126961765
BH26A	1/04/2018	18.20	18.87714	-0.67614	0.146921	-0.099339151
BH26A	1/07/2018	17.85	18.8698	-1.0188	0.146921	-0.149683094
BH26A	1/10/2018	17.90	18.53556	-0.63456	0.146921	-0.093230177
BH26A	1/01/2019	18.22	19.02228	-0.80128	0.146921	-0.117724843
BH26A	1/04/2019	18.45	19.1529	-0.7019	0.146921	-0.103123836
BH26B	1/10/2011	20.00	25.03569	-5.03169	0.178504	-0.89817659
BH26B	1/01/2012	20.15	25.04281	-4.88881	0.178504	-0.872671945
BH26B	1/04/2012	19.89	25.0502	-5.1562	0.178504	-0.920402119
BH26B	1/07/2012	20.32	25.05545	-4.73145	0.178504	-0.844582562
BH26B	1/10/2012	19.83	25.05434	-5.22034	0.178504	-0.931851363
BH26B	1/01/2013	20.09	25.05101	-4.95701	0.178504	-0.884845915
BH26B	1/04/2013	20.16	25.05783	-4.89383	0.178504	-0.873568035
BH26B	1/07/2013	20.03	25.06407	-5.03007	0.178504	-0.897887414
BH26B	1/10/2013	19.78	25.06207	-5.27807	0.178504	-0.942156396
BH26B	1/01/2014	19.58	25.0627	-5.4787	0.178504	-0.977969646
BH26B	1/04/2014	19.95	25.06936	-5.11536	0.178504	-0.913112017
BH26B	1/07/2014	20.08	25.07221	-4.98821	0.178504	-0.890415238
BH26B	1/10/2014	19.72	25.07303	-5.34903	0.178504	-0.954823037
BH26B	1/01/2015	19.84	25.0737	-5.2347	0.178504	-0.934414679
BH26B	1/04/2015	20.31	25.07732	-4.76332	0.178504	-0.850271483
BH26B	1/07/2015	19.89	25.0882	-5.1942	0.178504	-0.927185269
BH26B	1/10/2015	19.88	25.09093	-5.20693	0.178504	-0.929457624
BH26B	1/01/2016	19.67	25.09225	-5.41825	0.178504	-0.967179081
BH26B	1/04/2016	19.44	25.09876	-5.65476	0.178504	-1.009397053
BH26B	1/07/2016	19.84	25.1021	-5.2581	0.178504	-0.938591672
BH26B	1/10/2016	19.29	25.10255	-5.80855	0.178504	-1.036849177
CN036	1/01/2005	17.31	4.011366	13.29624029	0.1983977	2.637943758
CN036	1/01/2006	16.79	0.4746502	16.31971361	0.1983977	3.237793971
CN036	1/04/2006	16.52	-0.3426097	16.85813795	0.1983977	3.344616133
CN036	1/07/2006	16.53	-1.145484	17.67120447	0.1983977	3.505926677
CN036	1/10/2006	17.23	-1.933967	19.16631829	0.1983977	3.80255385
CN036	1/01/2007	15.66	-2.699884	18.36148706	0.1983977	3.642877169
CN036	1/04/2007	13.53	-3.428058	16.957505	0.1983977	3.364330329
CN036	1/07/2007	11.49	-4.143722	15.63804026	0.1983977	3.102551533
CN036	1/10/2007	10.47	-4.846852	15.32054565	0.1983977	3.039561326
CN036	1/01/2008	9.93	-5.53014	15.46181	0.1983977	3.067587851
CN036	1/04/2008	8.61	-6.187113	14.79216227	0.1983977	2.934731268
CN036	1/07/2008	2.73	-6.825866	9.55105879	0.1983977	1.894908288

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
CN036	1/10/2008	1.70	-7.453671	9.158529087	0.1983977	1.817031289
CN036	1/01/2009	0.35	-8.063993	8.412513778	0.1983977	1.669023553
CN036	1/04/2009	-2.19	-8.644691	6.459609832	0.1983977	1.281571863
CN036	1/07/2009	-2.68	-9.215857	6.537573739	0.1983977	1.297039724
CN036	1/10/2009	-2.86	-9.777472	6.919132794	0.1983977	1.372740171
CN038	1/01/2005	-5.03	-12.23196	7.204829838	0.2112076	1.521714818
CN038	1/01/2006	-8.71	-15.82143	7.113189331	0.2112076	1.502359647
CN038	1/04/2006	-10.75	-16.27817	5.52675333	0.2112076	1.167292307
CN038	1/07/2006	-12.56	-16.6357	4.07900568	0.2112076	0.861517
CN038	1/10/2006	-14.53	-16.93025	2.39896608	0.2112076	0.506679868
CN038	1/01/2007	-16.14	-17.17973	1.03588589	0.2112076	0.218786973
CN038	1/04/2007	-17.24	-17.39312	0.1487762	0.2112076	0.031422664
CN038	1/07/2007	-19.22	-17.58588	-1.63468778	0.2112076	-0.345258483
CN038	1/10/2007	-21.02	-29.1553	8.14023313	0.2112076	1.719279103
CN038	1/01/2008	-21.65	-31.50647	9.85800772	0.2112076	2.082086151
CN038	1/04/2008	-21.82	-35.26815	13.44478066	0.2112076	2.839639856
CN038	1/07/2008	-21.98	-37.14264	15.16482777	0.2112076	3.202926878
CN038	1/10/2008	-22.05	-38.21496	16.16810752	0.2112076	3.414827186
CN038	1/01/2009	-22.07	-38.92925	16.85609025	0.2112076	3.560134367
CN038	1/04/2009	-22.10	-40.37659	18.27687166	0.2112076	3.860214199
MB02	18/01/2006	45.83	40.8832	4.9468	0.1219393	0.603209131
MB02	27/02/2006	45.74	40.889	4.851	0.1219393	0.59152735
MB02	4/04/2006	45.82	40.89297	4.92703	0.1219393	0.600798392
MB02	21/04/2006	45.75	40.88783	4.86217	0.1219393	0.592889412
MB02	18/05/2006	45.65	40.87928	4.77072	0.1219393	0.581738066
MB02	19/06/2006	45.58	40.86899	4.71101	0.1219393	0.574457073
MB02	26/07/2006	45.57	40.86826	4.70174	0.1219393	0.573326696
MB02	15/08/2006	45.66	40.871	4.789	0.1219393	0.583967116
MB02	21/09/2006	45.58	40.87614	4.70386	0.1219393	0.573585208
MB02	20/10/2006	45.58	40.87299	4.70701	0.1219393	0.573969316
MB02	23/11/2006	45.52	40.86436	4.65564	0.1219393	0.567705296
MB02	20/12/2006	45.45	40.85741	4.59259	0.1219393	0.560017026
MB02	17/01/2007	45.43	40.85714	4.57286	0.1219393	0.557611164
MB02	21/02/2007	45.35	40.86398	4.48602	0.1219393	0.547021959
MB02	22/03/2007	45.38	40.86974	4.51026	0.1219393	0.549977767
MB02	20/04/2007	45.37	40.88858	4.48142	0.1219393	0.546461039
MB02	24/05/2007	45.21	40.9198	4.2902	0.1219393	0.523143813
MB02	28/06/2007	45.69	40.95239	4.73761	0.1219393	0.577700658
MB02	18/07/2007	45.90	40.95581	4.94419	0.1219393	0.60289087
MB02	22/08/2007	45.99	40.95597	5.03403	0.1219393	0.613845893
MB02	20/09/2007	46.06	40.95602	5.10398	0.1219393	0.622375544
MB02	18/10/2007	45.90	40.96069	4.93931	0.1219393	0.602295806
MB02	14/11/2007	45.90	40.96836	4.93164	0.1219393	0.601360532
MB02	10/12/2007	45.34	40.97578	4.36422	0.1219393	0.532169757
MB02	23/01/2008	45.58	40.99928	4.58072	0.1219393	0.558569607

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB02	22/02/2008	45.91	41.02329	4.88671	0.1219393	0.595881801
MB02	1/04/2008	46.25	41.05482	5.19518	0.1219393	0.633496405
MB02	23/04/2008	46.51	41.06859	5.44141	0.1219393	0.663521509
MB02	27/05/2008	47.37	41.08984	6.28016	0.1219393	0.765798063
MB02	24/06/2008	47.56	41.10744	6.45256	0.1219393	0.786820392
MB02	22/07/2008	47.52	41.11449	6.40551	0.1219393	0.781083149
MB02	26/08/2008	47.42	41.11829	6.30171	0.1219393	0.768425854
MB02	23/09/2008	47.69	41.12123	6.56877	0.1219393	0.800990953
MB02	28/10/2008	47.68	41.12555	6.55445	0.1219393	0.799244783
MB02	25/11/2008	47.42	41.12911	6.29089	0.1219393	0.767106471
MB02	16/12/2008	46.87	41.13173	5.73827	0.1219393	0.699720397
MB02	20/01/2009	47.20	41.1356	6.0644	0.1219393	0.739488448
MB02	16/03/2010	45.64	41.10912	4.53088	0.1219393	0.552492154
MB02	2/06/2010	45.12	41.10472	4.01528	0.1219393	0.489620272
MB02	1/09/2010	45.00	41.08492	3.91508	0.1219393	0.477401958
MB02	20/12/2010	45.09	41.11034	3.97966	0.1219393	0.485276795
MB02	16/03/2011	45.00	41.10975	3.89025	0.1219393	0.474374206
MB02	21/06/2011	44.92	41.15635	3.76365	0.1219393	0.458936696
MB02	21/09/2011	45.38	41.18281	4.19719	0.1219393	0.511802243
MB02	30/03/2012	46.41	41.26907	5.14093	0.1219393	0.6268812
MB04	18/01/2006	18.66	23.90499	-5.24499	0.1056038	-0.553890875
MB04	24/02/2006	18.21	23.90666	-5.69666	0.1056038	-0.601588943
MB04	4/04/2006	19.41	23.90763	-4.49763	0.1056038	-0.474966819
MB04	21/04/2006	19.11	23.901	-4.791	0.1056038	-0.505947806
MB04	19/05/2006	18.67	23.88813	-5.21813	0.1056038	-0.551054357
MB04	20/06/2006	18.21	23.87279	-5.66279	0.1056038	-0.598012143
MB04	26/07/2006	18.23	23.86663	-5.63663	0.1056038	-0.595249547
MB04	15/08/2006	18.17	23.86726	-5.69726	0.1056038	-0.601652306
MB04	20/09/2006	21.09	23.86898	-2.77898	0.1056038	-0.293470848
MB04	19/10/2006	19.90	23.86389	-3.96389	0.1056038	-0.418601847
MB04	22/11/2006	19.00	23.85084	-4.85084	0.1056038	-0.512267137
MB04	20/12/2006	18.51	23.83961	-5.32961	0.1056038	-0.562827069
MB04	17/01/2007	18.20	23.83499	-5.63499	0.1056038	-0.595076357
MB04	21/02/2007	17.94	23.83851	-5.89851	0.1056038	-0.62290507
MB04	21/03/2007	17.96	23.84194	-5.88194	0.1056038	-0.621155215
MB04	19/04/2007	17.56	23.85773	-6.29773	0.1056038	-0.665064219
MB04	24/05/2007	20.05	23.89065	-3.84065	0.1056038	-0.405587234
MB04	28/06/2007	22.74	23.92547	-1.18547	0.1056038	-0.125190137
MB04	18/07/2007	22.06	23.9309	-1.8709	0.1056038	-0.197574149
MB04	21/08/2007	22.15	23.92978	-1.77978	0.1056038	-0.187951531
MB04	19/09/2007	21.78	23.92782	-2.14782	0.1056038	-0.226817954
MB04	17/10/2007	20.62	23.92995	-3.30995	0.1056038	-0.349543298
MB04	14/11/2007	20.41	23.93662	-3.52662	0.1056038	-0.372424473
MB04	10/12/2007	19.64	23.94322	-4.30322	0.1056038	-0.454436384
MB04	23/01/2008	22.37	23.96547	-1.59547	0.1056038	-0.168487695

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB04	22/02/2008	22.35	23.9918	-1.6418	0.1056038	-0.173380319
MB04	1/04/2008	22.16	24.02732	-1.86732	0.1056038	-0.197196088
MB04	23/04/2008	24.16	24.04319	0.11681	0.1056038	0.01233558
MB04	27/05/2008	22.23	24.06664	-1.83664	0.1056038	-0.193956163
MB04	24/06/2008	22.62	24.08581	-1.46581	0.1056038	-0.154795106
MB04	22/07/2008	21.88	24.09393	-2.21393	0.1056038	-0.233799421
MB04	26/08/2008	21.81	24.09583	-2.28583	0.1056038	-0.241392334
MB04	24/09/2008	22.44	24.09675	-1.65675	0.1056038	-0.174959096
MB04	28/10/2008	21.71	24.09837	-2.38837	0.1056038	-0.252220948
MB04	25/11/2008	20.98	24.09984	-3.11984	0.1056038	-0.329466959
MB04	16/12/2008	20.94	24.10089	-3.16089	0.1056038	-0.333801995
MB04	20/01/2009	20.41	24.10212	-3.69212	0.1056038	-0.389901902
MB04	16/03/2010	19.17	24.02645	-4.85645	0.1056038	-0.512859575
MB04	2/06/2010	18.30	24.01165	-5.71165	0.1056038	-0.603171944
MB04	2/09/2010	20.76	23.97688	-3.21688	0.1056038	-0.339714752
MB04	20/12/2010	21.39	23.98818	-2.59818	0.1056038	-0.274377681
MB04	16/03/2011	19.30	23.97882	-4.67882	0.1056038	-0.494101172
MB04	22/06/2011	22.68	24.0188	-1.3388	0.1056038	-0.141382367
MB04	21/09/2011	21.89	24.0412	-2.1512	0.1056038	-0.227174895
MB04	27/03/2012	22.69	24.12445	-1.43445	0.1056038	-0.151483371
MB04	20/09/2012	21.31	24.10148	-2.79148	0.1056038	-0.294790896
MB04	6/03/2013	23.08	24.11393	-1.03393	0.1056038	-0.109186937
MB04	26/09/2013	21.41	24.09914	-2.68914	0.1056038	-0.283983403
MB04	26/03/2014	21.56	24.15319	-2.59319	0.1056038	-0.273850718
MB04	26/09/2014	22.20	24.1216	-1.9216	0.1056038	-0.202928262
MB04	17/03/2015	22.49	24.12018	-1.63018	0.1056038	-0.172153203
MB04	23/09/2015	21.82	24.18598	-2.36498	0.1056038	-0.249750875
MB04	29/03/2016	21.84	24.2307	-2.3917	0.1056038	-0.252572608
MB04	27/09/2016	21.91	24.19804	-2.28804	0.1056038	-0.241625719
MB04	21/03/2017	23.02	24.16652	-1.15152	0.1056038	-0.121604888
MB04	11/09/2017	21.22	24.08523	-2.86523	0.1056038	-0.302579176
MB04	21/11/2017	21.26	24.05399	-2.79399	0.1056038	-0.295055961
MB04	12/03/2018	20.36	24.02934	-3.67234	0.1056038	-0.387813059
MB04	24/09/2018	20.47	23.94076	-3.47176	0.1056038	-0.366631049
MB04	19/03/2019	20.04	23.94655	-3.90655	0.1056038	-0.412546525
MB05	18/01/2006	-6.98	9.706931	-16.686931	0.1064954	-1.777081725
MB05	24/02/2006	-7.24	9.728561	-16.968561	0.1064954	-1.80707403
MB05	4/04/2006	-6.98	9.757275	-16.737275	0.1064954	-1.782443131
MB05	21/04/2006	-6.98	9.753701	-16.733701	0.1064954	-1.782062516
MB05	19/05/2006	-6.93	9.711977	-16.641977	0.1064954	-1.77229433
MB05	20/06/2006	-7.26	9.640088	-16.900088	0.1064954	-1.79978197
MB05	26/07/2006	-7.08	9.581956	-16.661956	0.1064954	-1.774422002
MB05	15/08/2006	-7.05	9.582233	-16.632233	0.1064954	-1.771256639
MB05	20/09/2006	-6.93	9.613275	-16.543275	0.1064954	-1.761783019
MB05	19/10/2006	-6.93	9.634132	-16.564132	0.1064954	-1.764004194

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB05	22/11/2006	-7.06	9.611402	-16.671402	0.1064954	-1.775427958
MB05	20/12/2006	-7.23	9.572587	-16.802587	0.1064954	-1.78939856
MB05	17/01/2007	-7.23	9.542514	-16.772514	0.1064954	-1.786195923
MB05	21/02/2007	-7.30	9.564706	-16.864706	0.1064954	-1.796013949
MB05	19/04/2007	-7.68	9.680636	-17.360636	0.1064954	-1.848828222
MB05	24/05/2007	-7.30	9.853418	-17.153418	0.1064954	-1.826760454
MB05	28/06/2007	-6.76	10.04455	-16.80455	0.1064954	-1.78960761
MB05	18/07/2007	-6.71	10.11629	-16.82629	0.1064954	-1.791922821
MB05	21/08/2007	-6.51	10.12185	-16.63185	0.1064954	-1.771215851
MB05	19/09/2007	-6.49	10.07186	-16.56186	0.1064954	-1.763762237
MB05	17/10/2007	-6.55	10.02152	-16.57152	0.1064954	-1.764790982
MB05	14/11/2007	-6.54	9.996202	-16.536202	0.1064954	-1.761029777
MB05	10/12/2007	-7.00	9.987927	-16.987927	0.1064954	-1.809136421
MB05	23/01/2008	-6.80	10.0131	-16.8131	0.1064954	-1.790518146
MB05	22/02/2008	-6.58	10.09092	-16.67092	0.1064954	-1.775376627
MB05	1/04/2008	-6.37	10.21188	-16.58188	0.1064954	-1.765894275
MB05	23/04/2008	-6.08	10.26629	-16.34629	0.1064954	-1.740805019
MB05	27/05/2008	-5.90	10.31694	-16.21694	0.1064954	-1.727029836
MB05	24/06/2008	-5.79	10.34136	-16.13136	0.1064954	-1.717915958
MB05	22/07/2008	-5.84	10.33388	-16.17388	0.1064954	-1.722444144
MB05	26/08/2008	-5.89	10.25854	-16.14854	0.1064954	-1.71974555
MB05	24/09/2008	-5.90	10.18395	-16.08395	0.1064954	-1.712867011
MB05	29/10/2008	-5.89	10.09993	-15.98993	0.1064954	-1.702854311
MB05	26/11/2008	-6.22	10.04533	-16.26533	0.1064954	-1.73218315
MB05	17/12/2008	-5.94	10.01154	-15.95154	0.1064954	-1.698765952
MB05	21/01/2009	-6.11	9.963188	-16.073188	0.1064954	-1.711720907
MB05	16/03/2010	-6.67	9.498373	-16.168373	0.1064954	-1.721857673
MB05	2/06/2010	-7.10	9.537127	-16.637127	0.1064954	-1.771777827
MB05	2/09/2010	-6.78	9.471162	-16.251162	0.1064954	-1.730674323
MB05	20/12/2010	-6.40	9.585607	-15.985607	0.1064954	-1.702393931
MB05	17/03/2011	-7.22	9.683206	-16.903206	0.1064954	-1.800114022
MB05	14/07/2011	-6.43	9.913895	-16.343895	0.1064954	-1.740549962
MB05	21/09/2011	-6.20	9.967428	-16.167428	0.1064954	-1.721757035
MB05	27/03/2012	-5.69	10.10172	-15.79172	0.1064954	-1.681745854
MB05	20/09/2012	-5.73	9.744103	-15.474103	0.1064954	-1.647921098
MB05	7/03/2013	-5.96	9.664278	-15.624278	0.1064954	-1.663914048
MB05	26/09/2013	-5.73	9.674319	-15.404319	0.1064954	-1.640489422
MB05	26/03/2014	-6.18	10.34521	-16.52521	0.1064954	-1.75985918
MB05	26/09/2014	-5.91	10.24004	-16.15004	0.1064954	-1.719905293
MB05	17/03/2015	-5.93	10.25194	-16.17694	0.1064954	-1.72277002
MB05	24/09/2015	-5.58	10.56277	-16.14477	0.1064954	-1.719344062
MB05	29/03/2016	-5.57	10.5575	-16.1275	0.1064954	-1.717504886
MB05	28/09/2016	-5.76	10.32615	-16.08815	0.1064954	-1.713314291
MB05	22/03/2017	-6.15	10.16036	-16.30536	0.1064954	-1.736446161
MB05	12/09/2017	-5.94	9.931231	-15.871231	0.1064954	-1.690213411

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB05	22/11/2017	-6.17	9.767371	-15.937371	0.1064954	-1.697257018
MB05	13/03/2018	-6.44	9.856779	-16.294779	0.1064954	-1.735319333
MB05	24/09/2018	-6.61	9.770694	-16.377694	0.1064954	-1.744149401
MB05	19/03/2019	-6.66	10.05506	-16.71506	0.1064954	-1.780077335
MB06	17/01/2006	-30.18	-36.9693	6.7893	0.1093093	0.742133902
MB06	24/02/2006	-29.98	-36.96849	6.98849	0.1093093	0.763907229
MB06	31/03/2006	-29.59	-36.96743	7.37743	0.1093093	0.806422004
MB06	21/04/2006	-29.83	-36.96759	7.13759	0.1093093	0.780205252
MB06	19/05/2006	-29.65	-36.9694	7.3194	0.1093093	0.800078783
MB06	20/06/2006	-29.82	-36.97244	7.15244	0.1093093	0.781828496
MB06	27/07/2006	-29.33	-36.97491	7.64491	0.1093093	0.835660066
MB06	15/08/2006	-29.73	-36.97497	7.24497	0.1093093	0.791942889
MB06	20/09/2006	-28.72	-36.9739	8.2539	0.1093093	0.902228361
MB06	20/10/2006	-28.83	-36.97322	8.14322	0.1093093	0.890130004
MB06	23/11/2006	-29.06	-36.97435	7.91435	0.1093093	0.865112375
MB06	20/12/2006	-29.13	-36.97594	7.84594	0.1093093	0.857634523
MB06	17/01/2007	-28.73	-36.97721	8.24721	0.1093093	0.901497082
MB06	21/02/2007	-28.86	-36.97642	8.11642	0.1093093	0.887200513
MB06	22/03/2007	-28.61	-36.97471	8.36471	0.1093093	0.914340929
MB06	20/04/2007	-28.38	-36.97163	8.59163	0.1093093	0.939145405
MB06	23/05/2007	-28.88	-36.96485	8.08485	0.1093093	0.883749617
MB06	18/07/2007	-28.41	-36.95406	8.54406	0.1093093	0.93394556
MB06	18/10/2007	-28.57	-36.95764	8.38764	0.1093093	0.916847393
MB06	15/11/2007	-28.31	-36.95859	8.64859	0.1093093	0.945371665
MB06	11/12/2007	-29.23	-36.95894	7.72894	0.1093093	0.84484533
MB06	24/01/2008	-28.83	-36.95792	8.12792	0.1093093	0.888457571
MB06	22/02/2008	-29.18	-36.95496	7.77496	0.1093093	0.849875746
MB06	1/04/2008	-28.69	-36.95035	8.26035	0.1093093	0.902933407
MB06	2/05/2008	-28.11	-36.94769	8.83769	0.1093093	0.966042061
MB06	28/05/2008	-28.10	-36.94639	8.84639	0.1093093	0.966993052
MB06	25/06/2008	-28.06	-36.94551	8.88551	0.1093093	0.971269234
MB06	23/07/2008	-27.98	-36.94608	8.96608	0.1093093	0.980076287
MB06	27/08/2008	-27.78	-36.94933	9.16933	0.1093093	1.002293411
MB06	24/09/2008	-27.94	-36.95233	9.01233	0.1093093	0.985131844
MB06	29/10/2008	-27.78	-36.95583	9.17583	0.1093093	1.003003921
MB06	26/11/2008	-28.24	-36.95815	8.71815	0.1093093	0.952975223
MB06	17/12/2008	-27.95	-36.95961	9.00961	0.1093093	0.984834523
MB06	21/01/2009	-27.88	-36.96175	9.08175	0.1093093	0.992720099
MB06	17/03/2010	-28.30	-36.98328	8.68328	0.1093093	0.949163606
MB06	2/06/2010	-28.86	-36.98204	8.12204	0.1093093	0.887814832
MB06	6/09/2010	-28.78	-36.98523	8.20523	0.1093093	0.896908276
MB06	21/12/2010	-28.73	-36.98025	8.25025	0.1093093	0.901829382
MB06	17/03/2011	-29.07	-36.97635	7.90635	0.1093093	0.8642379
MB06	14/07/2011	-29.22	-36.96685	7.74685	0.1093093	0.846803061
MB06	21/09/2011	-28.88	-36.96466	8.08466	0.1093093	0.883728849

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB06	27/03/2012	-28.57	-36.95959	8.38959	0.1093093	0.917060546
MB06	21/09/2012	-28.91	-36.97528	8.06528	0.1093093	0.881610434
MB06	15/03/2013	-29.40	-36.97694	7.57694	0.1093093	0.828230311
MB06	2/10/2013	-29.23	-36.97643	7.74643	0.1093093	0.846757151
MB06	26/03/2014	-29.75	-36.87611	7.12611	0.1093093	0.778950381
MB06	25/09/2014	-29.33	-36.87492	7.54492	0.1093093	0.824730226
MB06	30/09/2015	-29.42	-36.85503	7.43803	0.1093093	0.81304615
MB06	26/04/2016	-29.36	-36.84991	7.48991	0.1093093	0.818717119
MB06	28/09/2016	-29.53	-36.86119	7.33619	0.1093093	0.801914087
MB06	19/04/2017	-29.34	-36.87009	7.52809	0.1093093	0.822890549
MB06	13/09/2017	-29.58	-36.88109	7.29909	0.1093093	0.797858711
MB06	22/11/2017	-29.71	-36.88811	7.17811	0.1093093	0.784634467
MB06	13/03/2018	-29.88	-36.88545	7.00545	0.1093093	0.765761116
MB06	24/09/2018	-30.02	-36.89032	6.87032	0.1093093	0.750990145
MB06	19/03/2019	-30.01	-36.87959	6.86959	0.1093093	0.750910349
MB09	18/01/2006	23.08	23.03317	0.04683	0.1145445	0.005364121
MB09	24/02/2006	21.78	23.11154	-1.33154	0.1145445	-0.152520637
MB09	4/04/2006	23.29	23.15344	0.13656	0.1145445	0.015642202
MB09	21/04/2006	23.17	23.04427	0.12573	0.1145445	0.014401685
MB09	26/07/2006	23.65	22.78953	0.86047	0.1145445	0.09856214
MB09	15/08/2006	23.53	22.85945	0.67055	0.1145445	0.076807841
MB09	21/09/2006	23.82	22.96901	0.85099	0.1145445	0.097476258
MB09	20/10/2006	23.27	22.9136	0.3564	0.1145445	0.040823674
MB09	22/11/2006	22.99	22.79045	0.19955	0.1145445	0.022857363
MB09	20/02/2007	21.51	22.90721	-1.39721	0.1145445	-0.160042777
MB09	21/03/2007	24.49	23.01626	1.47374	0.1145445	0.16880887
MB09	19/04/2007	22.86	23.33369	-0.47369	0.1145445	-0.054258603
MB09	23/05/2007	22.24	23.74527	-1.50527	0.1145445	-0.17242046
MB09	28/06/2007	24.61	24.04326	0.56674	0.1145445	0.064916973
MB09	17/07/2007	24.25	23.92973	0.32027	0.1145445	0.03668518
MB09	21/08/2007	24.46	23.70784	0.75216	0.1145445	0.086155821
MB09	19/09/2007	23.87	23.57753	0.29247	0.1145445	0.033500842
MB09	17/10/2007	23.31	23.54946	-0.23946	0.1145445	-0.027428836
MB09	14/11/2007	23.86	23.57572	0.28428	0.1145445	0.032562722
MB09	10/12/2007	23.21	23.59497	-0.38497	0.1145445	-0.044096212
MB09	23/01/2008	24.27	23.79796	0.47204	0.1145445	0.054069605
MB09	22/02/2008	23.85	23.99098	-0.14098	0.1145445	-0.016148489
MB09	25/03/2008	24.68	24.1259	0.5541	0.1145445	0.06346913
MB09	23/04/2008	24.66	24.15306	0.50694	0.1145445	0.058067209
MB09	27/05/2008	24.11	24.15935	-0.04935	0.1145445	-0.005652773
MB09	24/06/2008	24.56	24.16481	0.39519	0.1145445	0.045266857
MB09	22/07/2008	24.07	24.00672	0.06328	0.1145445	0.007248378
MB09	26/08/2008	24.19	23.82297	0.36703	0.1145445	0.042041283
MB09	23/09/2008	24.22	23.71414	0.50586	0.1145445	0.057943501
MB09	28/10/2008	24.07	23.61776	0.45224	0.1145445	0.051801623

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB09	25/11/2008	23.77	23.56322	0.20678	0.1145445	0.02368552
MB09	16/12/2008	23.87	23.53078	0.33922	0.1145445	0.038855799
MB09	20/01/2009	23.29	23.47914	-0.18914	0.1145445	-0.021664954
MB09	1/09/2010	23.01	22.6662	0.3448	0.1145445	0.039494957
MB09	20/12/2010	23.42	23.27122	0.14978	0.1145445	0.017156481
MB09	21/06/2011	24.08	23.74697	0.33403	0.1145445	0.038261313
MB09	20/09/2011	23.56	23.71896	-0.15796	0.1145445	-0.018093456
MB09	8/03/2012	24.27	23.95949	0.31151	0.1145445	0.03568177
MB09	21/09/2012	23.20	23.05781	0.14319	0.1145445	0.016401633
MB09	6/03/2013	24.22	23.6999	0.5211	0.1145445	0.05968916
MB09	26/09/2013	22.89	22.88979	0.00121	0.1145445	0.000138599
MB09	26/03/2014	23.94	23.83493	0.10607	0.1145445	0.012149739
MB09	25/09/2014	23.59	23.23449	0.35651	0.1145445	0.040836274
MB09	16/03/2015	23.86	23.45933	0.39867	0.1145445	0.045665472
MB09	22/09/2015	23.27	23.44708	-0.17908	0.1145445	-0.020512636
MB09	30/03/2016	22.76	23.94843	-1.18743	0.1145445	-0.136013623
MB09	27/09/2016	23.26	23.25986	-0.00286	0.1145445	-0.000327597
MB09	21/03/2017	23.82	23.26921	0.54679	0.1145445	0.062631809
MB09	11/09/2017	22.07	22.50085	-0.43485	0.1145445	-0.049809693
MB09	12/03/2018	21.06	22.80079	-1.74179	0.1145445	-0.199512534
MB09	24/09/2018	21.07	22.41821	-1.34421	0.1145445	-0.153971916
MB10	18/01/2006	23.47	23.23488	0.23512	0.0932193	0.021917717
MB10	24/02/2006	23.30	23.28478	0.01522	0.0932193	0.001418797
MB10	30/03/2006	23.17	23.31703	-0.14703	0.0932193	-0.013706031
MB10	21/04/2006	23.93	23.20048	0.72952	0.0932193	0.068005329
MB10	18/05/2006	23.63	23.09907	0.53093	0.0932193	0.049492912
MB10	19/06/2006	23.46	23.02147	0.43853	0.0932193	0.040879451
MB10	26/07/2006	23.46	23.10638	0.35362	0.0932193	0.032964202
MB10	16/08/2006	23.37	23.161	0.209	0.0932193	0.01948283
MB10	21/09/2006	24.38	23.22181	1.15819	0.0932193	0.107965638
MB10	20/10/2006	24.11	23.15349	0.95651	0.0932193	0.089165174
MB10	22/11/2006	23.76	23.0688	0.6912	0.0932193	0.064433166
MB10	20/12/2006	23.49	23.02438	0.46562	0.0932193	0.043404761
MB10	16/01/2007	23.22	23.08791	0.13209	0.0932193	0.012313335
MB10	20/02/2007	23.14	23.20108	-0.06108	0.0932193	-0.005693834
MB10	21/03/2007	23.07	23.25916	-0.18916	0.0932193	-0.017633359
MB10	19/04/2007	22.90	23.49588	-0.59588	0.0932193	-0.055547505
MB10	23/05/2007	24.00	23.80014	0.19986	0.0932193	0.018630805
MB10	28/06/2007	24.98	24.03653	0.94347	0.0932193	0.087949594
MB10	17/07/2007	24.68	23.90489	0.77511	0.0932193	0.072255196
MB10	21/08/2007	24.83	23.67943	1.15057	0.0932193	0.107255307
MB10	19/09/2007	24.64	23.56225	1.07775	0.0932193	0.100467079
MB10	17/10/2007	24.14	23.54596	0.59404	0.0932193	0.055375981
MB10	14/11/2007	23.90	23.57509	0.32491	0.0932193	0.030287876
MB10	10/12/2007	23.83	23.5933	0.2367	0.0932193	0.022065004

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB10	23/01/2008	24.80	23.78308	1.01692	0.0932193	0.09479655
MB10	22/02/2008	24.96	23.95878	1.00122	0.0932193	0.093333008
MB10	25/03/2008	25.16	24.09121	1.06879	0.0932193	0.099631834
MB10	23/04/2008	25.80	24.12055	1.67945	0.0932193	0.15655712
MB10	27/05/2008	24.78	24.13047	0.64953	0.0932193	0.060548719
MB10	24/06/2008	24.95	24.1391	0.8109	0.0932193	0.075591514
MB10	22/07/2008	24.64	23.978	0.662	0.0932193	0.061711163
MB10	26/08/2008	24.73	23.79357	0.93643	0.0932193	0.08729333
MB10	23/09/2008	24.75	23.69344	1.05656	0.0932193	0.098491762
MB10	28/10/2008	24.68	23.6098	1.0702	0.0932193	0.099763273
MB10	25/11/2008	24.63	23.56438	1.06562	0.0932193	0.099336329
MB10	16/12/2008	24.53	23.53773	0.99227	0.0932193	0.092498695
MB10	20/01/2009	24.37	23.4947	0.8753	0.0932193	0.081594836
MB10	23/02/2009	24.64	23.46041	1.17959	0.0932193	0.10996053
MB10	9/03/2009	24.55	23.44896	1.10104	0.0932193	0.102638156
MB10	27/04/2009	24.57	23.43723	1.12777	0.0932193	0.105129907
MB10	19/05/2009	24.47	23.43832	1.03168	0.0932193	0.096172467
MB10	23/06/2009	24.85	23.43801	1.41199	0.0932193	0.131624691
MB10	15/09/2009	24.24	22.98821	1.25179	0.0932193	0.116690963
MB10	14/12/2009	23.43	23.07397	0.35603	0.0932193	0.03318886
MB10	16/03/2010	23.46	23.1725	0.2875	0.0932193	0.026800543
MB10	2/06/2010	23.17	23.14772	0.02228	0.0932193	0.002076926
MB10	1/09/2010	24.39	23.01019	1.37981	0.0932193	0.128624895
MB10	20/12/2010	24.60	23.44023	1.15977	0.0932193	0.108112924
MB10	16/03/2011	23.41	23.27735	0.13265	0.0932193	0.012365537
MB10	21/06/2011	25.11	23.75595	1.35405	0.0932193	0.126223566
MB10	26/10/2011	24.80	23.76068	1.03932	0.0932193	0.096884662
MB10	27/08/2012	24.71	23.27039	1.43961	0.0932193	0.134199408
MB10	20/09/2012	24.49	23.16415	1.32585	0.0932193	0.123594782
MB10	6/03/2013	25.13	23.77865	1.35135	0.0932193	0.125971874
MB10	5/06/2013	24.85	23.74405	1.10595	0.0932193	0.103095863
MB10	26/09/2013	24.34	23.04864	1.29136	0.0932193	0.120379649
MB10	10/12/2013	24.61	23.33825	1.26675	0.0932193	0.118085523
MB10	25/03/2014	24.37	23.81503	0.55497	0.0932193	0.051733904
MB10	20/06/2014	24.65	23.41353	1.23647	0.0932193	0.115262843
MB10	25/09/2014	24.75	23.29861	1.45139	0.0932193	0.135297531
MB10	17/12/2014	24.24	23.25616	0.97984	0.0932193	0.091339979
MB10	16/03/2015	24.86	23.50282	1.35618	0.0932193	0.126422123
MB10	29/06/2015	24.95	24.30096	0.65104	0.0932193	0.06068948
MB10	22/09/2015	24.53	23.43767	1.09033	0.0932193	0.101639778
MB10	21/12/2015	24.32	23.44975	0.87325	0.0932193	0.081403736
MB10	30/03/2016	24.40	23.90634	0.49366	0.0932193	0.04601863
MB10	15/06/2016	24.33	23.54094	0.78706	0.0932193	0.073369167
MB10	27/09/2016	24.48	23.30341	1.17659	0.0932193	0.109680873
MB10	13/12/2016	23.85	23.13825	0.70675	0.0932193	0.065882726

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB10	21/03/2017	24.77	23.37549	1.39451	0.0932193	0.129995218
MB10	27/06/2017	24.57	23.21699	1.35301	0.0932193	0.126126618
MB10	11/09/2017	23.92	22.86874	1.04926	0.0932193	0.097811262
MB10	11/12/2017	23.93	23.03522	0.89478	0.0932193	0.083410747
MB10	12/03/2018	23.41	23.11923	0.28577	0.0932193	0.026639274
MB10	25/06/2018	24.17	23.13311	1.03689	0.0932193	0.096658139
MB10	17/09/2018	23.66	22.885	0.777	0.0932193	0.072431381
MB10	17/12/2018	24.05	23.2215	0.8285	0.0932193	0.077232173
MB10	17/12/2018	21.75	23.2215	-1.4715	0.0932193	-0.137172171
MB10	18/03/2019	23.97	23.42486	0.54514	0.0932193	0.050817558
MB11	18/01/2006	29.30	27.95288	1.34712	0.0932193	0.125577556
MB11	27/02/2006	29.16	27.97412	1.18588	0.0932193	0.11054688
MB11	30/03/2006	29.71	27.98707	1.72293	0.0932193	0.160610294
MB11	21/04/2006	29.58	27.7937	1.7863	0.0932193	0.1665176
MB11	18/05/2006	29.35	27.72151	1.62849	0.0932193	0.151806665
MB11	19/06/2006	29.27	27.65148	1.61852	0.0932193	0.150877269
MB11	26/07/2006	29.61	27.86082	1.74918	0.0932193	0.1630573
MB11	16/08/2006	29.58	27.89541	1.68459	0.0932193	0.157036267
MB11	21/09/2006	29.88	27.93746	1.94254	0.0932193	0.18108218
MB11	19/10/2006	29.70	27.76118	1.93882	0.0932193	0.180735404
MB11	22/11/2006	29.56	27.69608	1.86392	0.0932193	0.17375328
MB11	20/12/2006	29.38	27.65367	1.72633	0.0932193	0.16092724
MB11	16/01/2007	29.27	27.85586	1.41414	0.0932193	0.131825113
MB11	20/02/2007	29.29	27.93012	1.35988	0.0932193	0.126767034
MB11	21/03/2007	29.39	27.95463	1.43537	0.0932193	0.133804158
MB11	19/04/2007	29.20	28.11671	1.08329	0.0932193	0.100983514
MB11	23/05/2007	29.75	28.26032	1.48968	0.0932193	0.138866897
MB11	28/06/2007	30.36	28.37705	1.98295	0.0932193	0.184849171
MB11	17/07/2007	30.23	28.25114	1.97886	0.0932193	0.184467904
MB11	21/08/2007	30.10	28.13228	1.96772	0.0932193	0.183429442
MB11	19/09/2007	30.20	28.09513	2.10487	0.0932193	0.196214466
MB11	17/10/2007	29.84	28.12147	1.71853	0.0932193	0.160200129
MB11	14/11/2007	30.08	28.14568	1.93432	0.0932193	0.180315918
MB11	10/12/2007	30.39	28.15644	2.23356	0.0932193	0.208210855
MB11	23/01/2008	30.60	28.28697	2.31303	0.0932193	0.215618991
MB11	22/02/2008	30.50	28.40082	2.09918	0.0932193	0.195684048
MB11	25/03/2008	30.59	28.47448	2.11552	0.0932193	0.197207251
MB11	23/04/2008	30.98	28.47027	2.50973	0.0932193	0.233955224
MB11	27/05/2008	30.59	28.47013	2.11987	0.0932193	0.197612755
MB11	24/06/2008	30.63	28.47582	2.15418	0.0932193	0.200811109
MB11	22/07/2008	30.45	28.33538	2.11462	0.0932193	0.197123354
MB11	26/08/2008	30.46	28.22186	2.23814	0.0932193	0.208637799
MB11	23/09/2008	30.61	28.1782	2.4318	0.0932193	0.226690645
MB11	28/10/2008	30.38	28.15444	2.22556	0.0932193	0.207465101
MB11	26/11/2008	30.38	28.14422	2.23578	0.0932193	0.208417802

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB11	16/12/2008	30.37	28.13756	2.23244	0.0932193	0.208106449
MB11	20/01/2009	30.17	28.1208	2.0492	0.0932193	0.191024949
MB11	23/02/2009	30.26	28.10582	2.15418	0.0932193	0.200811109
MB11	9/03/2009	30.23	28.10037	2.12963	0.0932193	0.198522575
MB11	27/04/2009	30.18	28.09683	2.07817	0.0932193	0.193725511
MB11	19/05/2009	30.18	28.09584	2.08416	0.0932193	0.194283895
MB11	23/06/2009	30.82	28.09278	2.72722	0.0932193	0.254229485
MB11	15/09/2009	29.80	27.66852	2.13148	0.0932193	0.198695031
MB11	14/12/2009	29.61	27.81829	1.79171	0.0932193	0.167021916
MB11	16/03/2010	29.80	27.90887	1.89113	0.0932193	0.176289777
MB11	2/06/2010	29.51	27.84953	1.66047	0.0932193	0.154787818
MB11	1/09/2010	29.98	27.65779	2.32221	0.0932193	0.216474744
MB11	20/12/2010	30.36	28.06404	2.29596	0.0932193	0.214027738
MB11	16/03/2011	29.32	27.94863	1.37137	0.0932193	0.127838124
MB11	22/06/2011	30.12	28.23305	1.88695	0.0932193	0.17590012
MB11	20/09/2011	30.75	28.18693	2.56307	0.0932193	0.23892754
MB11	26/03/2012	30.08	28.34604	1.73396	0.0932193	0.161638503
MB11	27/03/2012	30.70	28.3463	2.3537	0.0932193	0.219410219
MB11	21/09/2012	29.62	27.88545	1.73455	0.0932193	0.161693502
MB11	10/12/2013	30.24	28.04135	2.19865	0.0932193	0.20495657
MB11	25/03/2014	29.89	28.28018	1.60982	0.0932193	0.150066261
MB11	20/06/2014	30.18	28.04319	2.13681	0.0932193	0.19919189
MB11	25/09/2014	30.23	28.0013	2.2287	0.0932193	0.207757809
MB11	17/12/2014	29.95	27.97372	1.97628	0.0932193	0.184227399
MB11	16/03/2015	30.21	28.11158	2.10042	0.0932193	0.19579964
MB11	30/06/2015	30.53	28.60236	1.92564	0.0932193	0.179506774
MB11	22/09/2015	30.16	28.01774	2.14326	0.0932193	0.199793154
MB11	21/12/2015	29.98	28.09089	1.88911	0.0932193	0.176101474
MB11	30/03/2016	30.03	28.35968	1.67032	0.0932193	0.155706028
MB11	15/06/2016	29.84	28.10825	1.72675	0.0932193	0.160966392
MB11	27/09/2016	30.02	28.00754	2.01246	0.0932193	0.187600072
MB11	13/12/2016	29.39	27.86959	1.52041	0.0932193	0.141731526
MB11	21/03/2017	29.97	28.04491	1.92509	0.0932193	0.179455504
MB11	27/06/2017	30.08	27.92806	2.15194	0.0932193	0.200602297
MB11	12/09/2017	29.46	27.45559	2.00441	0.0932193	0.186849657
MB11	21/11/2017	29.69	27.69954	1.99046	0.0932193	0.185549248
MB11	11/12/2017	29.53	27.72151	1.80849	0.0932193	0.168586136
MB11	12/03/2018	29.24	27.787	1.453	0.0932193	0.135447614
MB11	25/06/2018	29.65	27.78381	1.86819	0.0932193	0.174151327
MB11	17/09/2018	29.27	27.42963	1.84037	0.0932193	0.171557966
MB11	17/12/2018	29.61	27.91379	1.69121	0.0932193	0.157653379
MB11	18/03/2019	29.32	28.01678	1.30322	0.0932193	0.12148523
MB12	18/01/2006	18.83	22.60725	-3.77725	0.0938328	-0.354429868
MB12	24/02/2006	18.59	22.68758	-4.09758	0.0938328	-0.384487323
MB12	30/03/2006	18.70	22.74975	-4.04975	0.0938328	-0.379999301

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB12	21/04/2006	18.69	22.62477	-3.93477	0.0938328	-0.369210408
MB12	19/05/2006	18.56	22.46573	-3.90573	0.0938328	-0.366485504
MB12	20/06/2006	18.48	22.3087	-3.8287	0.0938328	-0.359257565
MB12	26/07/2006	18.43	22.3525	-3.9225	0.0938328	-0.36805908
MB12	16/08/2006	18.41	22.42375	-4.01375	0.0938328	-0.376621321
MB12	20/09/2006	18.48	22.52742	-4.04742	0.0938328	-0.37978067
MB12	19/10/2006	18.43	22.47968	-4.04968	0.0938328	-0.379992733
MB12	22/11/2006	18.39	22.34997	-3.95997	0.0938328	-0.371574994
MB12	20/12/2006	18.32	22.2576	-3.9376	0.0938328	-0.369475955
MB12	16/01/2007	18.33	22.29723	-3.96723	0.0938328	-0.37225622
MB12	20/02/2007	18.24	22.45696	-4.21696	0.0938328	-0.39568908
MB12	22/03/2007	18.03	22.5729	-4.5429	0.0938328	-0.426272936
MB12	19/04/2007	18.07	22.89425	-4.82425	0.0938328	-0.452672789
MB12	23/05/2007	18.21	23.35012	-5.14012	0.0938328	-0.482311749
MB12	28/06/2007	18.48	23.69296	-5.21296	0.0938328	-0.489146529
MB12	17/07/2007	18.61	23.59511	-4.98511	0.0938328	-0.46776673
MB12	21/08/2007	18.67	23.38835	-4.71835	0.0938328	-0.442735898
MB12	19/09/2007	18.77	23.25936	-4.48936	0.0938328	-0.421249129
MB12	17/10/2007	18.68	23.23167	-4.55167	0.0938328	-0.42709585
MB12	14/11/2007	18.72	23.26077	-4.54077	0.0938328	-0.426073072
MB12	10/12/2007	18.15	23.28299	-5.13299	0.0938328	-0.481642721
MB12	23/01/2008	18.63	23.49667	-4.86667	0.0938328	-0.456653175
MB12	22/02/2008	18.88	23.70036	-4.82036	0.0938328	-0.452307779
MB12	25/03/2008	19.17	23.85446	-4.68446	0.0938328	-0.439555905
MB12	23/04/2008	19.23	23.89865	-4.66865	0.0938328	-0.438072408
MB12	27/05/2008	19.52	23.91972	-4.39972	0.0938328	-0.412837959
MB12	24/06/2008	19.59	23.93451	-4.34451	0.0938328	-0.407657451
MB12	22/07/2008	18.90	23.77629	-4.87629	0.0938328	-0.457555847
MB12	26/08/2008	19.60	23.5824	-3.9824	0.0938328	-0.373679663
MB12	24/09/2008	19.71	23.46462	-3.75462	0.0938328	-0.352306432
MB12	28/10/2008	19.77	23.36307	-3.59307	0.0938328	-0.337147747
MB12	25/11/2008	19.71	23.30044	-3.59044	0.0938328	-0.336900967
MB12	16/12/2008	19.74	23.26215	-3.52215	0.0938328	-0.330493126
MB12	20/01/2009	19.54	23.20058	-3.66058	0.0938328	-0.343482398
MB12	23/02/2009	19.44	23.14692	-3.70692	0.0938328	-0.347830609
MB12	9/03/2009	19.53	23.12746	-3.59746	0.0938328	-0.337559673
MB12	27/04/2009	19.54	23.09326	-3.55826	0.0938328	-0.333881428
MB12	19/05/2009	19.59	23.08908	-3.49908	0.0938328	-0.328328404
MB12	23/06/2009	19.67	23.08363	-3.41363	0.0938328	-0.320310393
MB12	15/09/2009	19.67	22.38875	-2.71875	0.0938328	-0.255107871
MB12	14/12/2009	19.08	22.31935	-3.23935	0.0938328	-0.303957216
MB12	16/03/2010	18.98	22.46678	-3.48678	0.0938328	-0.327174261
MB12	2/06/2010	18.69	22.46009	-3.77009	0.0938328	-0.353758026
MB12	1/09/2010	18.86	22.23191	-3.37191	0.0938328	-0.316395689
MB12	20/12/2010	18.99	22.84015	-3.85015	0.0938328	-0.361270278

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB12	16/03/2011	18.53	22.75691	-4.22691	0.0938328	-0.396622716
MB12	22/06/2011	18.59	23.4051	-4.8151	0.0938328	-0.451814219
MB12	21/09/2011	19.12	23.41347	-4.29347	0.0938328	-0.402868226
MB12	8/03/2012	19.88	23.69361	-3.81361	0.0938328	-0.357841628
MB12	5/06/2013	19.94	23.50492	-3.56492	0.0938328	-0.334506354
MB12	2/10/2013	19.88	22.54561	-2.66561	0.0938328	-0.250121597
MB12	10/12/2013	19.92	22.85971	-2.93971	0.0938328	-0.275841162
MB12	26/03/2014	19.62	23.56628	-3.94628	0.0938328	-0.370290423
MB12	20/06/2014	19.98	23.14681	-3.16681	0.0938328	-0.297150586
MB12	25/09/2014	20.12	22.93121	-2.81121	0.0938328	-0.263783649
MB12	17/12/2014	19.86	22.8277	-2.9727	0.0938328	-0.278936705
MB12	16/03/2015	20.14	23.15793	-3.01993	0.0938328	-0.283368427
MB12	29/06/2015	20.49	24.13317	-3.64417	0.0938328	-0.341942602
MB12	23/09/2015	20.46	23.22239	-2.75939	0.0938328	-0.258921235
MB12	21/12/2015	20.45	23.18735	-2.73735	0.0938328	-0.25685316
MB12	26/05/2016	20.21	23.44148	-3.23548	0.0938328	-0.303594083
MB12	15/06/2016	20.23	23.36066	-3.12866	0.0938328	-0.293570865
MB12	27/09/2016	20.68	23.00738	-2.33238	0.0938328	-0.218853699
MB12	13/12/2016	20.28	22.69892	-2.42392	0.0938328	-0.227443152
MB12	22/03/2017	20.16	22.9716	-2.8156	0.0938328	-0.264195575
MB12	27/06/2017	20.39	22.79464	-2.40264	0.0938328	-0.225446391
MB12	11/09/2017	20.12	22.16621	-2.05121	0.0938328	-0.192470737
MB12	11/12/2017	20.92	22.24172	-1.32172	0.0938328	-0.124020662
MB12	12/03/2018	19.60	22.4309	-2.8309	0.0938328	-0.265631217
MB12	25/06/2018	19.60	22.50077	-2.90577	0.0938328	-0.272656477
MB12	18/09/2018	19.53	22.06507	-2.53507	0.0938328	-0.237872666
MB12	17/12/2018	19.97	22.5324	-2.5674	0.0938328	-0.240906279
MB12	19/03/2019	19.27	22.98008	-3.71008	0.0938328	-0.34812712
MB13	18/01/2006	25.29	28.83988	-3.54988	0.0944545	-0.335301998
MB13	27/02/2006	25.07	28.88507	-3.81507	0.0944545	-0.360350377
MB13	30/03/2006	25.51	28.91592	-3.40592	0.0944545	-0.321704334
MB13	21/04/2006	25.57	28.68336	-3.11336	0.0944545	-0.294070738
MB13	18/05/2006	25.02	28.60345	-3.58345	0.0944545	-0.338472835
MB13	19/06/2006	25.25	28.5188	-3.2688	0.0944545	-0.308752739
MB13	26/07/2006	25.20	28.7038	-3.5038	0.0944545	-0.330949537
MB13	16/08/2006	25.28	28.73816	-3.45816	0.0944545	-0.326638635
MB13	21/09/2006	25.90	28.79093	-2.89093	0.0944545	-0.273061232
MB13	20/10/2006	25.73	28.61789	-2.88789	0.0944545	-0.27277409
MB13	22/11/2006	25.47	28.55096	-3.08096	0.0944545	-0.291010413
MB13	20/12/2006	25.26	28.50031	-3.24031	0.0944545	-0.306061731
MB13	16/01/2007	24.89	28.68427	-3.79427	0.0944545	-0.358385724
MB13	20/02/2007	25.00	28.76345	-3.76345	0.0944545	-0.355474637
MB13	22/03/2007	24.97	28.8231	-3.8531	0.0944545	-0.36394248
MB13	19/04/2007	25.19	29.25108	-4.06108	0.0944545	-0.383587118
MB13	23/05/2007	25.41	29.49455	-4.08455	0.0944545	-0.385803965

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB13	28/06/2007	26.21	29.69536	-3.48536	0.0944545	-0.329207797
MB13	17/07/2007	26.03	29.35954	-3.32954	0.0944545	-0.314489903
MB13	22/08/2007	26.05	29.26959	-3.21959	0.0944545	-0.304104635
MB13	20/09/2007	26.29	29.2148	-2.9248	0.0944545	-0.276260405
MB13	17/10/2007	25.89	29.31363	-3.42363	0.0944545	-0.323377123
MB13	14/11/2007	25.95	29.33647	-3.38647	0.0944545	-0.319867195
MB13	10/12/2007	25.54	29.35605	-3.81605	0.0944545	-0.360442942
MB13	23/01/2008	27.09	29.65976	-2.56976	0.0944545	-0.242725293
MB13	22/02/2008	26.40	29.77989	-3.37989	0.0944545	-0.319245685
MB13	25/03/2008	26.87	29.88896	-3.01896	0.0944545	-0.285154237
MB13	2/05/2008	27.06	29.89403	-2.83403	0.0944545	-0.267686773
MB13	27/05/2008	26.63	29.92713	-3.29713	0.0944545	-0.311428634
MB13	24/06/2008	26.86	29.96102	-3.10102	0.0944545	-0.29290517
MB13	22/07/2008	26.74	29.73812	-2.99812	0.0944545	-0.283185806
MB13	26/08/2008	26.45	29.64954	-3.19954	0.0944545	-0.302210823
MB13	23/09/2008	26.79	29.58811	-2.79811	0.0944545	-0.264293969
MB13	28/10/2008	26.54	29.53832	-2.99832	0.0944545	-0.283204697
MB13	25/11/2008	26.34	29.49921	-3.15921	0.0944545	-0.298401475
MB13	16/12/2008	26.46	29.47344	-3.01344	0.0944545	-0.284632848
MB13	20/01/2009	26.44	29.42236	-2.98236	0.0944545	-0.281697203
MB13	23/02/2009	26.30	29.38452	-3.08452	0.0944545	-0.291346671
MB13	9/03/2009	26.45	29.37041	-2.92041	0.0944545	-0.27584575
MB13	27/04/2009	26.16	29.35775	-3.19575	0.0944545	-0.301852841
MB13	19/05/2009	26.18	29.34982	-3.16982	0.0944545	-0.299403636
MB13	23/06/2009	26.11	29.33867	-3.22867	0.0944545	-0.304962281
MB13	15/09/2009	26.06	28.72834	-2.66834	0.0944545	-0.252036614
MB13	14/12/2009	25.56	28.80333	-3.24333	0.0944545	-0.306346984
MB13	16/03/2010	25.34	28.87384	-3.53384	0.0944545	-0.333786949
MB13	2/06/2010	25.11	28.80746	-3.69746	0.0944545	-0.349241588
MB13	1/09/2010	25.94	28.59385	-2.65385	0.0944545	-0.250667969
MB13	20/12/2010	26.06	29.14954	-3.08954	0.0944545	-0.291820832
MB13	16/03/2011	25.09	28.91946	-3.82946	0.0944545	-0.361709576
MB13	22/06/2011	26.13	29.52772	-3.39772	0.0944545	-0.320929808
MB13	20/09/2011	26.48	29.46206	-2.98206	0.0944545	-0.281668867
MB13	26/03/2012	26.12	29.79615	-3.67615	0.0944545	-0.347228763
MB13	27/03/2012	26.88	29.79703	-2.91703	0.0944545	-0.275526493
MB13	10/12/2013	26.08	29.20417	-3.12417	0.0944545	-0.29509179
MB13	25/03/2014	25.69	29.68953	-3.99953	0.0944545	-0.377773446
MB13	20/06/2014	26.05	29.23728	-3.18728	0.0944545	-0.301052811
MB13	25/09/2014	26.08	29.13536	-3.05536	0.0944545	-0.288592379
MB13	17/12/2014	26.02	29.05951	-3.03951	0.0944545	-0.287095276
MB13	17/03/2015	26.24	29.34468	-3.10568	0.0944545	-0.293345327
MB13	30/06/2015	26.79	30.14567	-3.35167	0.0944545	-0.31658018
MB13	22/09/2015	26.42	29.27424	-2.85724	0.0944545	-0.269879061
MB13	21/12/2015	26.10	29.37914	-3.27914	0.0944545	-0.309729398

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB13	30/03/2016	26.21	29.84423	-3.63423	0.0944545	-0.343269232
MB13	15/06/2016	25.85	29.44229	-3.59729	0.0944545	-0.339780084
MB13	27/09/2016	26.12	29.20756	-3.09056	0.0944545	-0.291917176
MB13	13/12/2016	25.57	28.96949	-3.40449	0.0944545	-0.321569265
MB13	19/04/2017	25.90	29.08947	-3.19347	0.0944545	-0.301637484
MB13	27/06/2017	26.12	28.98933	-2.87133	0.0944545	-0.271209925
MB13	12/09/2017	25.69	28.47255	-2.78255	0.0944545	-0.262824258
MB13	11/12/2017	25.56	28.67769	-3.11769	0.0944545	-0.294479725
MB13	12/03/2018	25.16	28.74135	-3.57735	0.0944545	-0.337896662
MB13	25/06/2018	25.44	28.73719	-3.29519	0.0944545	-0.311245392
MB13	17/09/2018	25.20	28.35932	-3.15932	0.0944545	-0.298411865
MB13	17/12/2018	25.52	28.82691	-3.30691	0.0944545	-0.312352398
MB13	18/03/2019	25.03	29.06184	-4.03184	0.0944545	-0.38082527
MB14	18/01/2006	11.62	12.74139	-1.12139	0.1083441	-0.12149599
MB14	24/02/2006	11.48	12.8084	-1.3284	0.1083441	-0.143924302
MB14	31/03/2006	11.83	12.85371	-1.02371	0.1083441	-0.110912939
MB14	21/04/2006	11.64	12.725	-1.085	0.1083441	-0.117553349
MB14	19/05/2006	11.57	12.58581	-1.01581	0.1083441	-0.11005702
MB14	20/06/2006	11.49	12.4683	-0.9783	0.1083441	-0.105993033
MB14	27/07/2006	11.58	12.55102	-0.97102	0.1083441	-0.105204288
MB14	15/08/2006	11.67	12.61737	-0.94737	0.1083441	-0.10264195
MB14	20/09/2006	11.94	12.71126	-0.77126	0.1083441	-0.083561471
MB14	20/10/2006	11.86	12.64987	-0.78987	0.1083441	-0.085577754
MB14	23/11/2006	11.72	12.53612	-0.81612	0.1083441	-0.088421787
MB14	20/12/2006	11.51	12.46997	-0.95997	0.1083441	-0.104007086
MB14	17/01/2007	11.40	12.53383	-1.13383	0.1083441	-0.122843791
MB14	20/02/2007	11.37	12.67952	-1.30952	0.1083441	-0.141878766
MB14	22/03/2007	11.47	12.77063	-1.30063	0.1083441	-0.140915587
MB14	20/04/2007	11.12	13.06975	-1.94975	0.1083441	-0.211243909
MB14	23/05/2007	11.78	13.41741	-1.63741	0.1083441	-0.177403713
MB14	18/07/2007	12.36	13.50912	-1.14912	0.1083441	-0.124500372
MB14	21/08/2007	15.40	13.28135	2.11865	0.1083441	0.229543227
MB14	19/09/2007	15.40	13.16051	2.23949	0.1083441	0.242635529
MB14	18/10/2007	12.27	13.14707	-0.87707	0.1083441	-0.09502536
MB14	15/11/2007	12.43	13.1816	-0.7516	0.1083441	-0.081431426
MB14	11/12/2007	12.00	13.20293	-1.20293	0.1083441	-0.130330368
MB14	24/01/2008	12.67	13.40975	-0.73975	0.1083441	-0.080147548
MB14	22/02/2008	12.96	13.58943	-0.62943	0.1083441	-0.068195027
MB14	27/03/2008	13.07	13.73631	-0.66631	0.1083441	-0.072190757
MB14	2/05/2008	13.40	13.75295	-0.35295	0.1083441	-0.03824005
MB14	28/05/2008	13.09	13.75429	-0.66429	0.1083441	-0.071971902
MB14	25/06/2008	13.34	13.75723	-0.41723	0.1083441	-0.045204409
MB14	23/07/2008	13.15	13.57037	-0.42037	0.1083441	-0.045544609
MB14	27/08/2008	13.15	13.37274	-0.22274	0.1083441	-0.024132565
MB14	24/09/2008	13.24	13.27046	-0.03046	0.1083441	-0.003300161

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB14	29/10/2008	13.13	13.187	-0.057	0.1083441	-0.006175614
MB14	26/11/2008	12.94	13.14123	-0.20123	0.1083441	-0.021802083
MB14	17/12/2008	12.84	13.11407	-0.27407	0.1083441	-0.029693867
MB14	21/01/2009	12.62	13.06766	-0.44766	0.1083441	-0.04850132
MB14	17/03/2010	11.98	12.62933	-0.64933	0.1083441	-0.070351074
MB14	2/06/2010	11.78	12.61503	-0.83503	0.1083441	-0.090470574
MB14	2/09/2010	12.23	12.42945	-0.19945	0.1083441	-0.021609231
MB14	21/12/2010	12.44	12.98836	-0.54836	0.1083441	-0.059411571
MB14	17/03/2011	11.89	12.81668	-0.92668	0.1083441	-0.100400311
MB14	14/07/2011	12.54	13.37953	-0.83953	0.1083441	-0.090958122
MB14	21/09/2011	12.81	13.3007	-0.4907	0.1083441	-0.05316445
MB14	27/03/2012	13.36	13.53359	-0.17359	0.1083441	-0.018807452
MB14	21/09/2012	12.95	12.64844	0.30156	0.1083441	0.032672247
MB14	15/03/2013	12.96	13.43535	-0.47535	0.1083441	-0.051501368
MB14	2/10/2013	12.62	12.47745	0.14255	0.1083441	0.015444451
MB14	26/03/2014	12.49	13.42012	-0.93012	0.1083441	-0.100773014
MB14	25/09/2014	12.86	12.8117	0.0483	0.1083441	0.00523302
MB14	30/09/2015	12.94	12.93229	0.00771	0.1083441	0.000835333
MB14	26/04/2016	12.48	13.33294	-0.85294	0.1083441	-0.092411017
MB14	28/09/2016	12.61	12.81137	-0.20137	0.1083441	-0.021817251
MB14	19/04/2017	12.39	12.84115	-0.45115	0.1083441	-0.048879441
MB14	12/09/2017	12.16	12.19182	-0.03382	0.1083441	-0.003664197
MB14	13/03/2018	11.67	12.54633	-0.87833	0.1083441	-0.095161873
MB14	24/09/2018	11.56	12.20084	-0.63984	0.1083441	-0.069322889
MB14	19/03/2019	11.43	12.97194	-1.54194	0.1083441	-0.167060102
MB15	18/01/2006	15.72	20.28702	-4.56702	0.0926221	-0.423007166
MB15	24/02/2006	15.38	20.36292	-4.98292	0.0926221	-0.461528714
MB15	30/03/2006	16.99	20.41799	-3.42799	0.0926221	-0.31750777
MB15	21/04/2006	16.68	20.28988	-3.60988	0.0926221	-0.334354811
MB15	19/05/2006	16.21	20.13595	-3.92595	0.0926221	-0.363629891
MB15	20/06/2006	15.81	19.99293	-4.18293	0.0926221	-0.387431928
MB15	26/07/2006	15.54	20.05263	-4.51263	0.0926221	-0.417969448
MB15	16/08/2006	15.38	20.1269	-4.7469	0.0926221	-0.439668036
MB15	20/09/2006	17.20	20.22717	-3.02717	0.0926221	-0.280382964
MB15	19/10/2006	16.76	20.17438	-3.41438	0.0926221	-0.316247182
MB15	22/11/2006	16.34	20.04696	-3.70696	0.0926221	-0.343346568
MB15	20/12/2006	15.86	19.96215	-4.10215	0.0926221	-0.379949912
MB15	16/01/2007	15.48	20.00973	-4.52973	0.0926221	-0.419553286
MB15	20/02/2007	15.19	20.16925	-4.97925	0.0926221	-0.461188791
MB15	22/03/2007	15.10	20.27652	-5.17652	0.0926221	-0.47946036
MB15	19/04/2007	14.70	20.58449	-5.88449	0.0926221	-0.545034057
MB15	23/05/2007	16.80	21.01371	-4.21371	0.0926221	-0.390282838
MB15	28/06/2007	17.86	21.35979	-3.49979	0.0926221	-0.324158039
MB15	17/07/2007	17.73	21.25759	-3.52759	0.0926221	-0.326732935
MB15	21/08/2007	17.78	21.03096	-3.25096	0.0926221	-0.301110872

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB15	19/09/2007	17.67	20.89195	-3.22195	0.0926221	-0.298423904
MB15	17/10/2007	17.10	20.85815	-3.75815	0.0926221	-0.348087895
MB15	14/11/2007	17.51	20.88511	-3.37511	0.0926221	-0.312609911
MB15	10/12/2007	16.91	20.90639	-3.99639	0.0926221	-0.370154194
MB15	23/01/2008	17.95	21.12493	-3.17493	0.0926221	-0.294068811
MB15	22/02/2008	18.18	21.3489	-3.1689	0.0926221	-0.293510299
MB15	25/03/2008	18.38	21.53083	-3.15083	0.0926221	-0.291836617
MB15	23/04/2008	19.01	21.59481	-2.58481	0.0926221	-0.239410634
MB15	27/05/2008	18.54	21.62945	-3.08945	0.0926221	-0.28615147
MB15	24/06/2008	18.69	21.65229	-2.96229	0.0926221	-0.274373639
MB15	22/07/2008	18.45	21.48882	-3.03882	0.0926221	-0.281462011
MB15	26/08/2008	18.54	21.27093	-2.73093	0.0926221	-0.252944581
MB15	24/09/2008	18.76	21.13426	-2.37426	0.0926221	-0.219909042
MB15	28/10/2008	18.55	21.01654	-2.46654	0.0926221	-0.228456213
MB15	25/11/2008	18.32	20.94458	-2.62458	0.0926221	-0.243094216
MB15	16/12/2008	18.20	20.90055	-2.70055	0.0926221	-0.25013072
MB15	20/01/2009	17.71	20.83102	-3.12102	0.0926221	-0.289075551
MB15	23/02/2009	18.11	20.77315	-2.66315	0.0926221	-0.246666652
MB15	9/03/2009	17.91	20.75279	-2.84279	0.0926221	-0.263305293
MB15	27/04/2009	17.99	20.71716	-2.73116	0.0926221	-0.252965884
MB15	19/05/2009	17.82	20.71221	-2.89221	0.0926221	-0.26788268
MB15	23/06/2009	18.14	20.70549	-2.56549	0.0926221	-0.237621174
MB15	15/09/2009	17.46	20.04434	-2.58434	0.0926221	-0.239367101
MB15	14/12/2009	16.43	20.02526	-3.59526	0.0926221	-0.333000675
MB15	16/03/2010	15.78	20.17151	-4.39151	0.0926221	-0.406751054
MB15	2/06/2010	15.28	20.15537	-4.87537	0.0926221	-0.451567203
MB15	2/09/2010	17.20	19.93483	-2.73483	0.0926221	-0.253305807
MB15	20/12/2010	17.76	20.52913	-2.76913	0.0926221	-0.256482747
MB15	16/03/2011	16.48	20.40649	-3.92649	0.0926221	-0.363679906
MB15	22/06/2011	17.92	21.03489	-3.11489	0.0926221	-0.288507778
MB15	20/09/2011	18.19	21.03779	-2.84779	0.0926221	-0.263768404
MB15	30/03/2012	19.01	21.37297	-2.36297	0.0926221	-0.218863338
MB15	21/09/2012	18.32	20.38029	-2.06029	0.0926221	-0.190828469
MB15	6/03/2013	18.98	21.0117	-2.0317	0.0926221	-0.188180402
MB15	5/06/2013	18.86	21.14686	-2.28686	0.0926221	-0.211813867
MB15	26/09/2013	18.26	20.23196	-1.97196	0.0926221	-0.182647155
MB15	10/12/2013	18.75	20.52837	-1.77837	0.0926221	-0.164716435
MB15	25/03/2014	18.37	21.20742	-2.83742	0.0926221	-0.262807912
MB15	20/06/2014	18.91	20.78066	-1.87066	0.0926221	-0.173264532
MB15	25/09/2014	18.97	20.57265	-1.60265	0.0926221	-0.148440873
MB15	17/12/2014	18.24	20.4798	-2.2448	0.0926221	-0.20791818
MB15	16/03/2015	19.11	20.79851	-1.69351	0.0926221	-0.15685652
MB15	29/06/2015	19.84	21.85238	-2.01738	0.0926221	-0.186854053
MB15	23/09/2015	19.25	20.89318	-1.64418	0.0926221	-0.15228747
MB15	21/12/2015	18.85	20.83134	-1.98034	0.0926221	-0.183423329

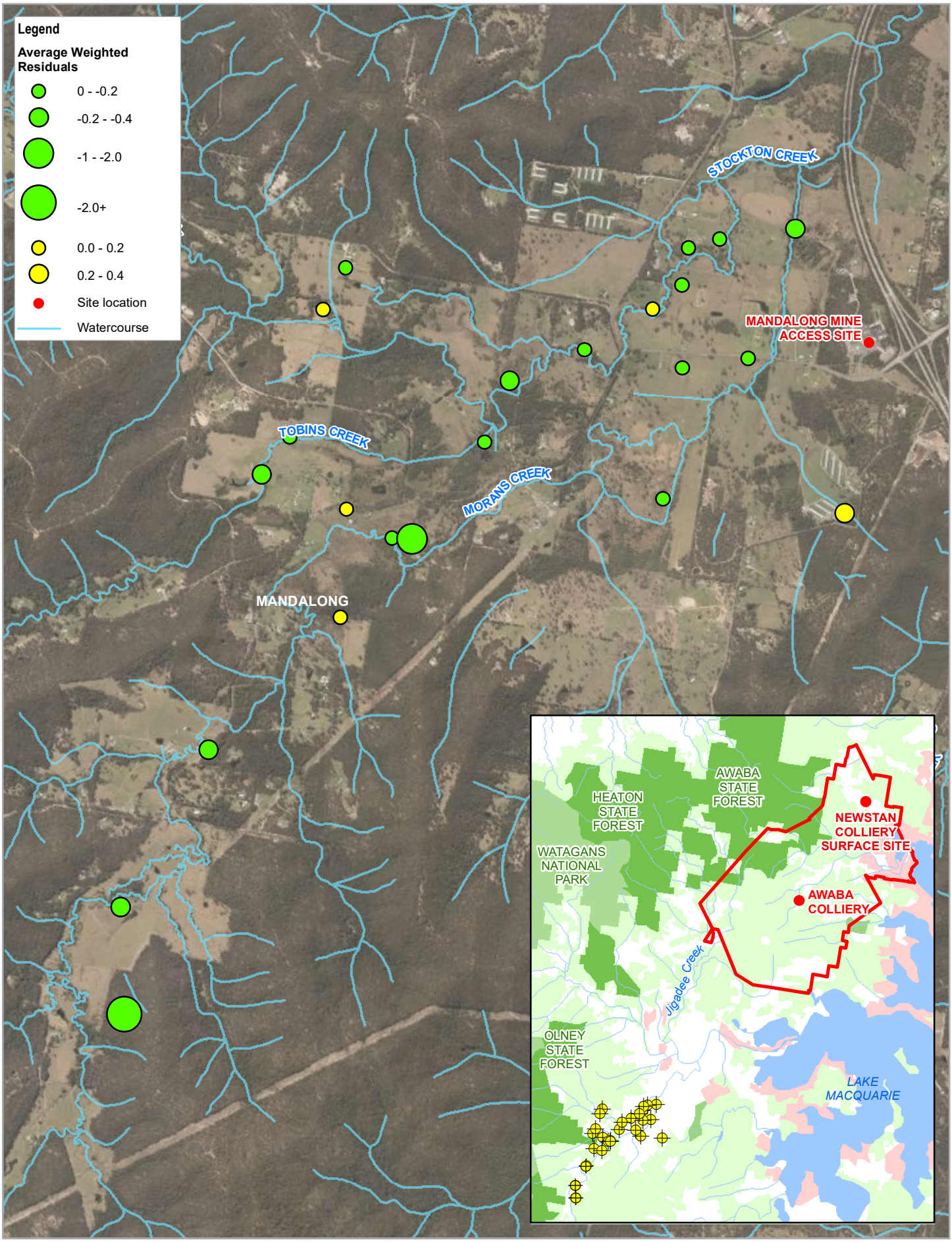
Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB15	30/03/2016	19.35	21.40855	-2.06355	0.0926221	-0.191130417
MB15	15/06/2016	19.63	21.01006	-1.38206	0.0926221	-0.128009355
MB15	27/09/2016	19.24	20.64613	-1.40313	0.0926221	-0.129960903
MB15	13/12/2016	18.74	20.35603	-1.62103	0.0926221	-0.150143268
MB15	21/03/2017	19.12	20.62531	-1.50531	0.0926221	-0.139425034
MB15	27/06/2017	19.33	20.44349	-1.11349	0.0926221	-0.103133827
MB15	11/09/2017	18.03	19.8592	-1.8292	0.0926221	-0.169424418
MB15	11/12/2017	18.35	19.98304	-1.63804	0.0926221	-0.15171877
MB15	12/03/2018	17.90	20.15707	-2.26107	0.0926221	-0.209425142
MB15	25/06/2018	18.48	20.20723	-1.73123	0.0926221	-0.160350227
MB15	18/09/2018	18.06	19.79313	-1.73413	0.0926221	-0.160618832
MB15	17/12/2018	18.32	20.26247	-1.94247	0.0926221	-0.179915728
MB15	18/03/2019	17.80	20.64644	-2.84644	0.0926221	-0.263643364
MB16	17/03/2010	-19.10	-4.685284	-14.409716	0.178504	-2.572191368
MB16	3/06/2010	-19.74	-4.669618	-15.065382	0.178504	-2.689230346
MB16	2/09/2010	-19.04	-4.737908	-14.297092	0.178504	-2.552087538
MB16	21/12/2010	-19.37	-4.57627	-14.78873	0.178504	-2.639846868
MB16	17/03/2011	-20.04	-4.555271	-15.479729	0.178504	-2.763192926
MB16	14/07/2011	-19.54	-4.334532	-15.200468	0.178504	-2.713343732
MB16	21/09/2011	-19.24	-4.332382	-14.902618	0.178504	-2.660176327
MB16	27/08/2012	-19.06	-4.501974	-14.553026	0.178504	-2.597772771
MB16	21/09/2012	-18.96	-4.586372	-14.368628	0.178504	-2.564856998
MB16	15/03/2013	-19.01	-4.441134	-14.563866	0.178504	-2.599707754
MB16	2/10/2013	-19.16	-4.666576	-14.488424	0.178504	-2.586241058
MB16	25/03/2014	-19.31	-4.037473	-15.267527	0.178504	-2.725314029
MB16	26/09/2014	-19.22	-4.201777	-15.013223	0.178504	-2.679919758
MB16	31/03/2016	-18.18	-3.894349	-14.285651	0.178504	-2.550045275
MB16	28/09/2016	-19.51	-4.149505	-15.361495	0.178504	-2.742087689
MB16	19/04/2017	-19.43	-4.194034	-15.232966	0.178504	-2.719144754
MB16	12/09/2017	-19.80	-4.446288	-15.353712	0.178504	-2.740698393
MB16	22/11/2017	-20.05	-4.504316	-15.540684	0.178504	-2.774073635
MB16	13/03/2018	-20.22	-4.398942	-15.818058	0.178504	-2.823585993
MB16	24/09/2018	-20.48	-4.509341	-15.965659	0.178504	-2.849933356
MB16	19/03/2019	-20.42	-4.22074	-16.19426	0.178504	-2.890739539
MB17	17/03/2010	10.86	14.08849	-3.23349	0.178504	-0.57719077
MB17	3/06/2010	10.98	14.07085	-3.09585	0.178504	-0.552621485
MB17	2/09/2010	11.50	13.8723	-2.3773	0.178504	-0.424357464
MB17	21/12/2010	11.61	14.46705	-2.86205	0.178504	-0.510887259
MB17	17/03/2011	10.35	14.27541	-3.93041	0.178504	-0.701593749
MB17	14/07/2011	11.72	14.8636	-3.1486	0.178504	-0.562037568
MB17	21/09/2011	11.65	14.76672	-3.12172	0.178504	-0.557239382
MB17	27/08/2012	11.38	14.22789	-2.85289	0.178504	-0.509252162
MB17	21/09/2012	11.57	14.07789	-2.51289	0.178504	-0.448560816
MB17	15/03/2013	11.85	14.93947	-3.09447	0.178504	-0.552375149
MB17	2/10/2013	11.33	13.9057	-2.5807	0.178504	-0.46066517

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB17	26/03/2014	11.43	14.91411	-3.48911	0.178504	-0.622819952
MB17	26/09/2014	11.60	14.27273	-2.67773	0.178504	-0.477985409
MB17	24/09/2015	11.37	14.39886	-3.02486	0.178504	-0.539949488
MB17	31/03/2016	11.21	15.00516	-3.80016	0.178504	-0.678343609
MB17	28/09/2016	11.51	14.2678	-2.7618	0.178504	-0.492992237
MB17	19/04/2017	11.55	14.31832	-2.77332	0.178504	-0.495048602
MB17	12/09/2017	10.83	13.62225	-2.79725	0.178504	-0.499320202
MB17	13/03/2018	10.52	13.9966	-3.4736	0.178504	-0.620051355
MB17	24/09/2018	10.28	13.62132	-3.34632	0.178504	-0.597331371
MB17	19/03/2019	10.01	14.44057	-4.43557	0.178504	-0.79176681
MB18	15/06/2011	4.97	-2.420538	7.391038	0.1669702	1.234082797
MB18	15/07/2011	5.57	-1.738502	7.313344105	0.1669702	1.221110235
MB18	15/08/2011	5.85	-1.105516	6.955516	0.1669702	1.161363619
MB18	15/09/2011	5.68	-0.9649297	6.649096367	0.1669702	1.110200684
MB18	15/10/2011	6.09	-0.7490946	6.843868794	0.1669702	1.142721868
MB18	15/11/2011	5.79	-0.5489468	6.334280133	0.1669702	1.057635767
MB18	15/12/2011	6.01	-0.4949029	6.501289997	0.1669702	1.085521431
MB18	15/01/2012	5.81	-0.4568034	6.263835658	0.1669702	1.045873642
MB18	15/02/2012	5.95	-0.4219397	6.371757882	0.1669702	1.063893433
MB18	15/03/2012	7.09	-0.4029297	7.49130007	0.1669702	1.250823571
MB18	15/04/2012	7.41	-0.2606996	7.6686996	0.1669702	1.280443999
MB18	15/05/2012	7.26	-0.1301899	7.38835119	0.1669702	1.23363418
MB18	15/06/2012	7.16	-0.098652847	7.26023618	0.1669702	1.212242797
MB18	15/07/2012	7.18	-0.091967605	7.272217605	0.1669702	1.214243337
MB18	15/08/2012	7.20	-0.082211837	7.28654517	0.1669702	1.216635613
MB18	20/09/2012	6.14	-0.063066281	6.201066281	0.1669702	1.035393029
MB18	7/03/2013	5.51	-1.129972	6.637972	0.1669702	1.108343247
MB18	9/04/2013	6.93	-1.116274	8.044274	0.1669702	1.343153717
MB18	16/04/2013	7.23	-1.113889	8.341889	0.1669702	1.392846541
MB18	23/04/2013	7.18	-1.111751	8.294751	0.1669702	1.384975902
MB18	30/04/2015	4.38	-2.051952	6.429952	0.1669702	1.073610114
MB18	8/05/2015	6.93	-1.87553	8.80353	0.1669702	1.469926813
MB18	30/09/2015	1.76	-0.7269076	2.4849076	0.1669702	0.41490542
MB18	26/04/2016	1.87	-1.574063	3.440063	0.1669702	0.57438787
MB19	17/03/2010	-0.69	-3.03712	2.34712	0.182913	0.429318714
MB19	3/06/2010	-3.27	-3.031096	-0.238904	0.182913	-0.043698643
MB19	1/09/2010	-3.48	-3.029521	-0.450479	0.182913	-0.082398456
MB19	21/12/2010	-2.04	-3.015979	0.975979	0.182913	0.178519227
MB19	16/03/2011	-2.03	-2.786671	0.756671	0.182913	0.138404947
MB19	21/06/2011	4.13	-1.230012	5.360012	0.182913	0.980415768
MB19	20/09/2011	5.83	4.403296	1.426704	0.182913	0.26096268
MB19	8/03/2012	7.25	5.613296	1.636704	0.182913	0.299374406
MB19	20/09/2012	6.24	6.629959	-0.389959	0.182913	-0.071328563
MB19	6/03/2013	5.38	2.919973	2.460027	0.182913	0.449970869
MB19	26/09/2013	-0.37	2.346642	-2.716642	0.182913	-0.496909084

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MB19	26/03/2014	-3.84	-2.953336	-0.886664	0.182913	-0.162182354
MB19	23/09/2015	2.38	5.136626	-2.756626	0.182913	-0.504222676
MB19	31/03/2016	3.51	2.842972	0.667028	0.182913	0.122008079
MB19	28/09/2016	-4.15	-3.933331	-0.216669	0.182913	-0.039631572
MB19	22/03/2017	-4.16	-8.613307	4.453307	0.182913	0.814567654
MB19	12/09/2017	-4.19	-4.986661	0.796661	0.182913	0.145719638
MB19	13/03/2018	-2.42	-3.983333	1.563333	0.182913	0.285953898
MB19	17/09/2018	-3.02	-2.676672	-0.343328	0.182913	-0.062799148
MB19	19/03/2019	-3.23	-3.360002	0.130002	0.182913	0.023779053
MSGW01	1/07/2011	41.36	42.29575	-0.93475	0.144606	-0.135170496
MSGW01	1/10/2011	41.47	42.29654	-0.83054	0.144606	-0.1201011
MSGW01	1/01/2012	41.40	42.34403	-0.94803	0.144606	-0.137090864
MSGW01	1/04/2012	41.45	42.3742	-0.9222	0.144606	-0.13335569
MSGW01	1/07/2012	40.86	42.37194	-1.51594	0.144606	-0.21921408
MSGW01	1/10/2012	40.61	42.30036	-1.69436	0.144606	-0.24501469
MSGW01	1/01/2013	41.05	42.27911	-1.22811	0.144606	-0.177592124
MSGW01	1/04/2013	41.41	42.40706	-0.99606	0.144606	-0.144036292
MSGW01	1/07/2013	40.65	42.38081	-1.73481	0.144606	-0.250864004
MSGW01	1/10/2013	40.74	42.29559	-1.55959	0.144606	-0.225526134
MSGW01	1/01/2014	40.54	42.34389	-1.80289	0.144606	-0.260708783
MSGW01	1/04/2014	41.10	42.40467	-1.30367	0.144606	-0.188518556
MSGW01	1/07/2014	41.05	42.35163	-1.30563	0.144606	-0.188801984
MSGW01	1/10/2014	40.47	42.34314	-1.87214	0.144606	-0.270722752
MSGW01	1/01/2015	40.67	42.33151	-1.66551	0.144606	-0.240842806
MSGW01	1/04/2015	41.45	42.36859	-0.92259	0.144606	-0.133412086
MSGW01	1/07/2015	40.84	42.48172	-1.64572	0.144606	-0.237981052
MSGW01	1/10/2015	40.92	42.38165	-1.46065	0.144606	-0.211218812
MSGW01	1/01/2016	40.82	42.40226	-1.58626	0.144606	-0.229382777
MSGW01	1/04/2016	41.00	42.46788	-1.46688	0.144606	-0.212119708
MSGW01	1/07/2016	41.42	42.42283	-1.00683	0.144606	-0.145593699
MSGW01	1/10/2016	40.62	42.40015	-1.77915	0.144606	-0.257275836
MSGW01	1/01/2017	40.89	42.36391	-1.47291	0.144606	-0.212991682
MSGW01	1/04/2017	41.35	42.3953	-1.0443	0.144606	-0.151012088
MSGW01	1/07/2017	40.39	42.35979	-1.96879	0.144606	-0.284698925
MSGW01	1/10/2017	40.25	42.27991	-2.02891	0.144606	-0.293392641
MSGW01	1/01/2018	39.92	42.29978	-2.37878	0.144606	-0.343985956
MSGW01	1/04/2018	39.92	42.29398	-2.37298	0.144606	-0.343147241
MSGW01	1/07/2018	40.02	42.28218	-2.26118	0.144606	-0.326980286
MSGW01	1/10/2018	40.36	42.22147	-1.86047	0.144606	-0.269035199
MSGW01	1/01/2019	40.55	42.2737	-1.7227	0.144606	-0.249112825
MSGW01	1/04/2019	40.69	42.29516	-1.60416	0.144606	-0.231971225
MSGW04A	1/10/2011	24.28	27.40838	-3.12638	0.146921	-0.459330813
MSGW04A	1/01/2012	24.27	27.49234	-3.22034	0.146921	-0.473135509
MSGW04A	1/04/2012	24.10	27.48522	-3.38322	0.146921	-0.497065998
MSGW04A	1/07/2012	23.86	27.3821	-3.5201	0.146921	-0.517176542

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
MSGW04A	1/10/2012	23.49	27.03856	-3.55156	0.146921	-0.521798676
MSGW04A	1/01/2013	23.94	27.00396	-3.06696	0.146921	-0.450600769
MSGW04A	1/04/2013	24.20	27.58588	-3.38888	0.146921	-0.497897571
MSGW04A	1/07/2013	23.84	27.38082	-3.53882	0.146921	-0.519926902
MSGW04A	1/10/2013	23.79	26.89694	-3.10494	0.146921	-0.456180828
MSGW04A	1/01/2014	23.78	27.23624	-3.45924	0.146921	-0.508234931
MSGW04A	1/04/2014	24.10	27.51583	-3.41883	0.146921	-0.502297854
MSGW04A	1/07/2014	24.11	27.18566	-3.07866	0.146921	-0.452319744
MSGW04A	1/10/2014	23.71	27.17488	-3.46788	0.146921	-0.509504328
MSGW04A	1/01/2015	23.98	27.16302	-3.18402	0.146921	-0.467799339
MSGW04A	1/04/2015	24.28	27.36422	-3.08222	0.146921	-0.452842783
MSGW04A	1/07/2015	24.00	27.64543	-3.64343	0.146921	-0.535296306
MSGW04A	1/10/2015	23.86	27.1094	-3.2474	0.146921	-0.47711119
MSGW04A	1/01/2016	23.81	27.23221	-3.42021	0.146921	-0.502500605
MSGW04A	1/04/2016	23.92	27.52405	-3.60205	0.146921	-0.529216716
MSGW04A	1/07/2016	24.15	27.22757	-3.07557	0.146921	-0.451865758
MSGW04A	1/10/2016	23.40	27.16195	-3.75995	0.146921	-0.552415539
MSGW04A	1/01/2017	23.57	27.07252	-3.50052	0.146921	-0.514299829
MSGW04A	1/04/2017	24.03	27.25177	-3.21977	0.146921	-0.473051764
MSGW04A	1/07/2017	23.53	27.14175	-3.60975	0.146921	-0.530348008
MSGW04A	1/10/2017	23.51	26.68557	-3.17357	0.146921	-0.466264014
MSGW04A	1/01/2018	23.19	27.04895	-3.85695	0.146921	-0.566666874
MSGW04A	1/04/2018	23.31	27.096	-3.784	0.146921	-0.555948988
MSGW04A	1/07/2018	23.50	27.10152	-3.59952	0.146921	-0.528845006
MSGW04A	1/10/2018	24.00	26.76215	-2.76015	0.146921	-0.405523943
MSGW04A	1/01/2019	23.55	27.17993	-3.62793	0.146921	-0.533019031
MSGW04A	1/04/2019	23.62	27.2787	-3.6567	0.146921	-0.537245948
V1/V2	29/07/2013	-2.18	31.31879	-33.4946815	0.1233217	-4.130620394
V1/V2	28/08/2013	-2.51	31.31954	-33.8263705	0.1233217	-4.171524838
V1/V2	27/09/2013	-1.43	31.32027	-32.7512096	0.1233217	-4.03893419
V1/V2	30/10/2013	-1.36	31.32106	-32.6798907	0.1233217	-4.030139023
V1/V2	28/11/2013	-1.49	31.32175	-32.8116405	0.1233217	-4.04638663
V1/V2	18/12/2013	-1.29	31.32222	-32.6100383	0.1233217	-4.021524708
V1/V2	29/01/2014	-1.75	31.32322	-33.0763266	0.1233217	-4.079028165
V1/V2	27/02/2014	-1.35	31.32393	-32.6728922	0.1233217	-4.029275957
V1/V2	25/03/2014	-1.35	31.32457	-32.6713392	0.1233217	-4.029084438
V1/V2	29/04/2014	-0.68	31.32544	-32.0004627	0.1233217	-3.946350821
V1/V2	27/05/2014	0.19	31.32612	-31.13171	0.1233217	-3.839214778
V1/V2	26/06/2014	0.60	31.32686	-30.7261126	0.1233217	-3.789195826
V1/V2	29/07/2014	0.74	31.32766	-30.5914668	0.1233217	-3.772591079
V1/V2	26/08/2014	1.14	31.32834	-30.1901954	0.1233217	-3.723105616
V1/V2	30/09/2014	0.81	31.32917	-30.5241574	0.1233217	-3.764290371
V1/V2	28/10/2014	0.27	31.32984	-31.0600316	0.1233217	-3.830375278
V1/V2	25/11/2014	0.34	31.33049	-30.9929587	0.1233217	-3.822103735
V1/V2	22/12/2014	0.41	31.33112	-30.9258658	0.1233217	-3.813829726

Site	Date	Observed (m AHD)	Modelled (m AHD)	Residual (m)	Weight	Weighted Residual
V1/V2	29/01/2015	1.28	31.33199	-30.0540136	0.1233217	-3.706311448
V1/V2	24/02/2015	2.08	31.33259	-29.2529038	0.1233217	-3.607517241
V1/V2	26/03/2015	2.55	31.33329	-28.7795435	0.1233217	-3.549141654
V1/V2	28/05/2015	2.88	31.33479	-28.4501045	0.1233217	-3.508514683
V1/V2	25/06/2015	3.09	31.33549	-28.2487323	0.1233217	-3.483681125
V1/V2	23/07/2015	3.29	31.3362	-28.0451771	0.1233217	-3.458578356
V1/V2	19/08/2015	3.22	31.33688	-28.1124835	0.1233217	-3.466878694
V1/V2	24/09/2015	2.96	31.33778	-28.3809856	0.1233217	-3.499990824
V1/V2	29/10/2015	3.29	31.33864	-28.0487136	0.1233217	-3.459014483
V1/V2	15/12/2015	3.42	31.33978	-27.9166008	0.1233217	-3.442722111
V1/V2	22/01/2016	3.96	31.34071	-27.3779406	0.1233217	-3.37629363
V1/V2	23/02/2016	4.10	31.3415	-27.2432848	0.1233217	-3.35968765
V1/V2	23/03/2016	1.75	31.34222	-29.5901833	0.1233217	-3.649111116
V1/V2	29/04/2016	1.14	31.34315	-30.2006194	0.1233217	-3.724391121
V1/V2	1/07/2016	1.41	31.34473	-29.9313078	0.1233217	-3.691179162
V1/V2	28/07/2016	1.28	31.34539	-30.0652206	0.1233217	-3.707693514
V1/V2	2/09/2016	1.01	31.34627	-30.3369922	0.1233217	-3.741208844
V1/V2	29/09/2016	1.01	31.34692	-30.3387387	0.1233217	-3.741424226
V1/V2	28/10/2016	1.01	31.34761	-30.3394287	0.1233217	-3.741509318
V1/V2	24/11/2016	1.07	31.34824	-30.2734323	0.1233217	-3.733370531
V1/V2	19/12/2016	1.01	31.34881	-30.3417252	0.1233217	-3.741792526
V1/V2	17/01/2017	0.27	31.34946	-31.0796516	0.1233217	-3.832794849
V1/V2	27/02/2017	0.27	31.35038	-31.0805716	0.1233217	-3.832908305
V1/V2	27/04/2017	-0.07	31.35169	-31.4204961	0.1233217	-3.874828365
V1/V2	31/05/2017	-0.07	31.35244	-31.4212461	0.1233217	-3.874920857
V1/V2	27/06/2017	-0.20	31.35303	-31.5572819	0.1233217	-3.89169702



Paper Size ISO A4

0 0.2 0.4 0.6 0.8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

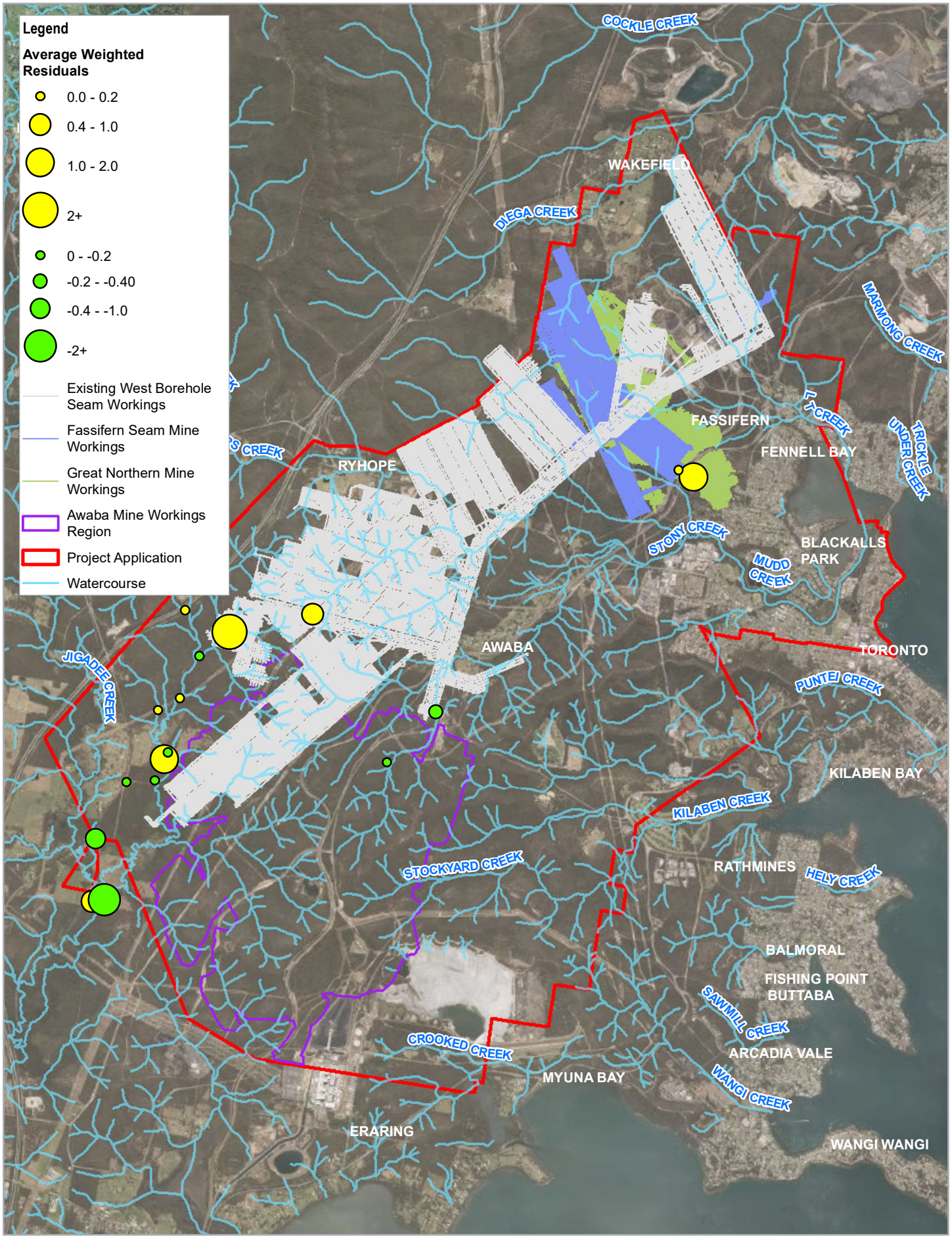
Groundwater model calibration
Average weighted residuals

Project No. **22-20265**
Revision No. **A**
Date **16/10/2019**

FIGURE D-2

G:\22\105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-023_MandalongResidualModelError.mxd
Print date: 06 Mar 2020 - 17:46

Data source: Centennial: Consent boundary, 2016, workings, 2019, monitoring, 2016; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Geoscience Australia: 250k Topographic Data Series 3, 2006. Created by: smacdonald



Paper Size ISO A4

0 0.45 0.9 1.35 1.8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Groundwater model calibration
Average weighted residuals

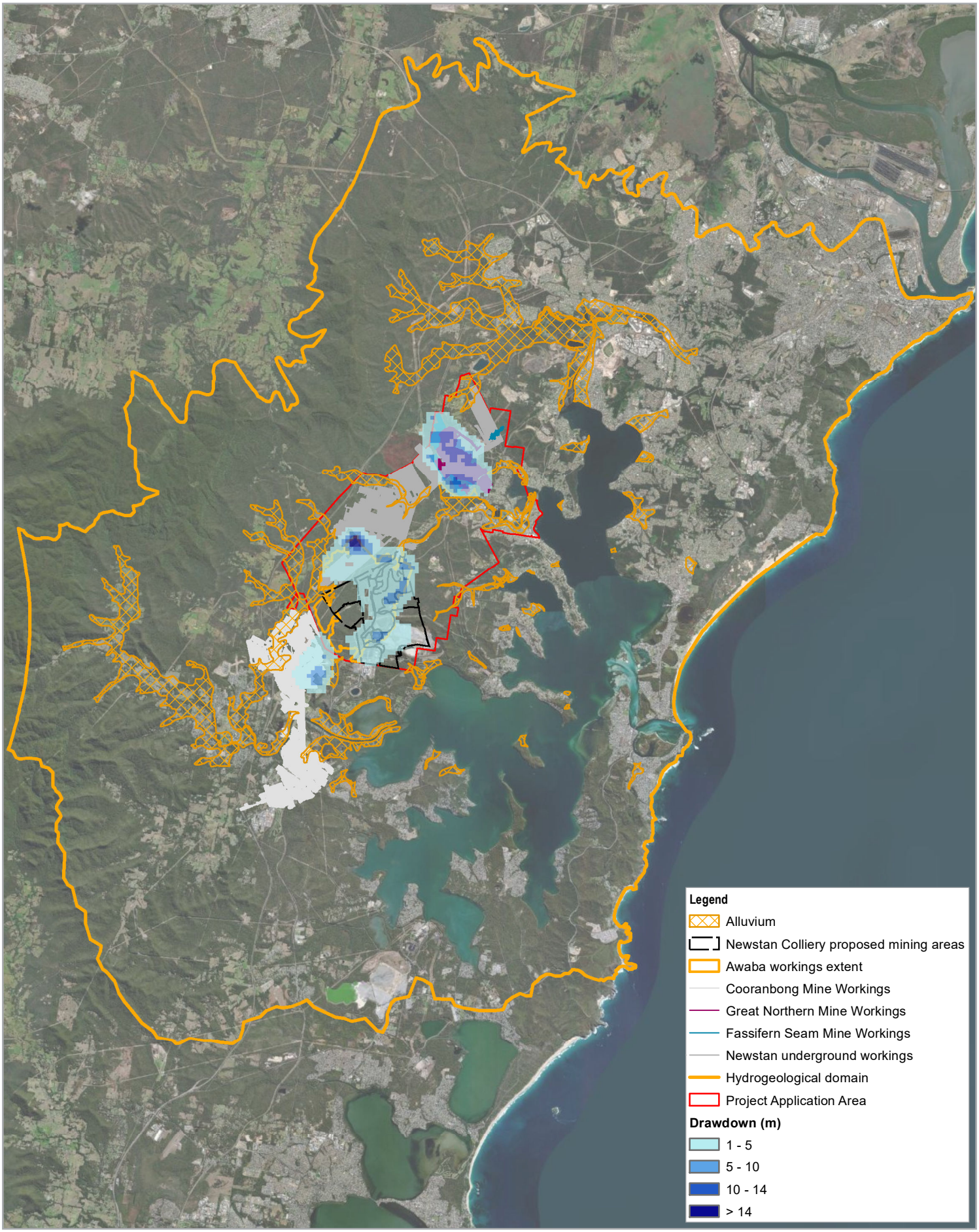
Project No. **22-20265**
Revision No. **A**
Date **16/10/2019**

FIGURE D-1

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-023_NewstanResidualModelError.mxd
Print date: 06 Mar 2020 - 17:46

Data source: Centennial: Consent boundary, 2016, workings, 2019, monitoring, 2016; LPI:DTDB / DCDB, 2017; Sixmaps/LPI_Imagery_Best: © Department of Finance, Services & Innovation 2017. Created by: smacdonald

Appendix E – Modelled groundwater drawdown and post mining water table



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

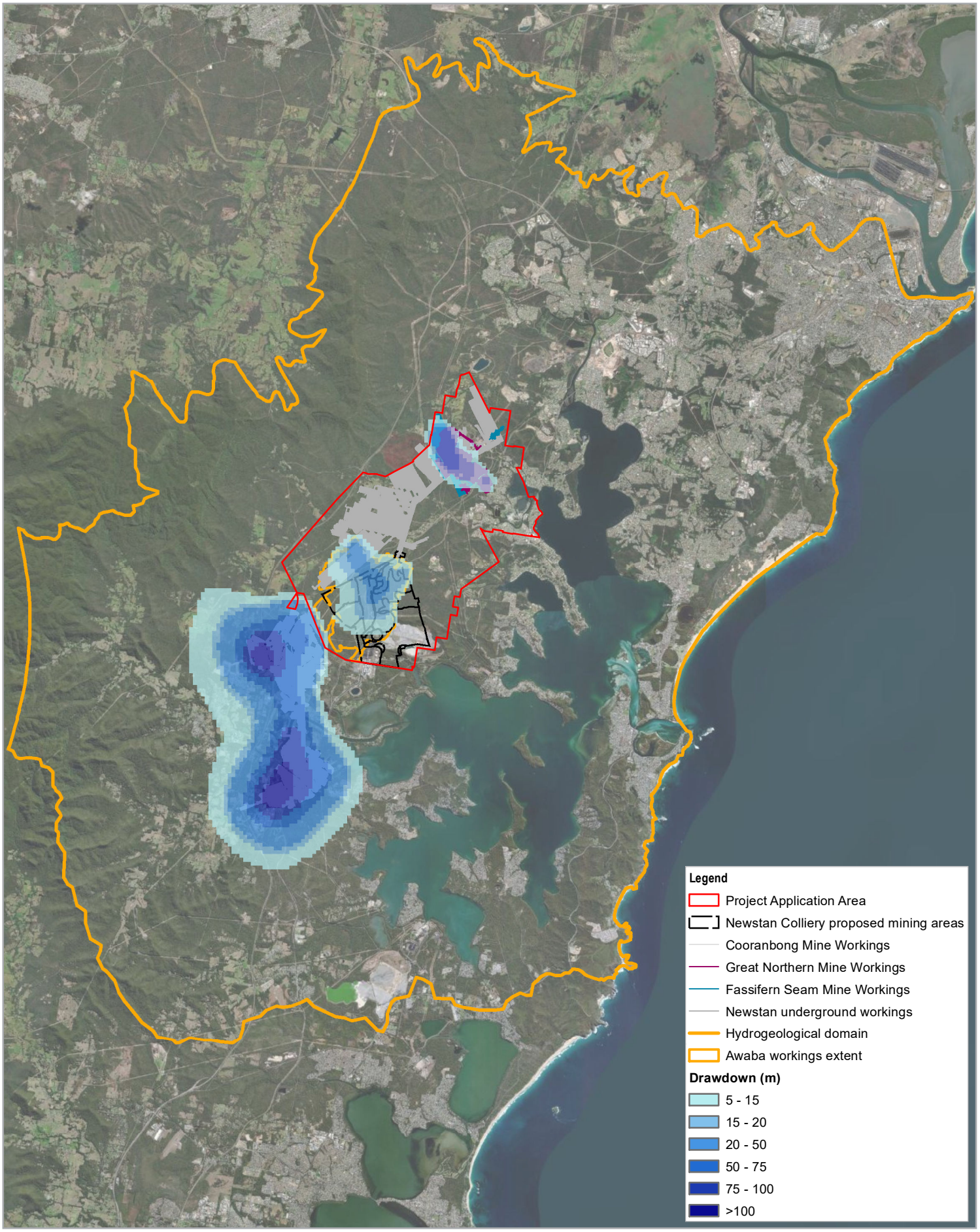
Cumulative groundwater drawdown
End of mining - Layer 1:
Alluvium and regolith

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE E-1

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-013_CumulativeDrawdownEoM_Lyr01.mxd
Print date: 24 Mar 2020 - 10:22

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

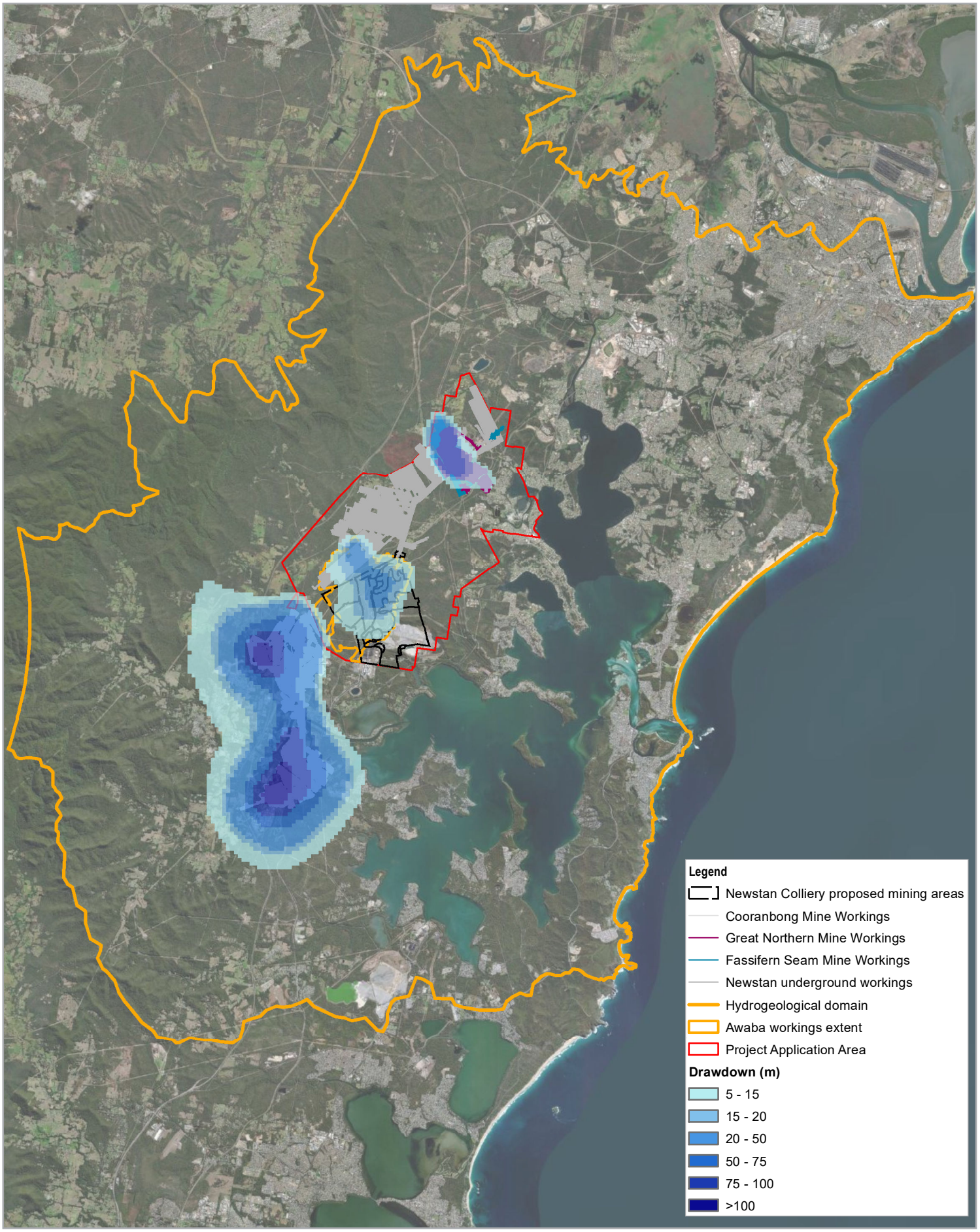
Cumulative groundwater drawdown
End of mining - Layer 4:
Great Northern Seam

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE E-2

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-014_CumulativeDrawdownEoM_Lyr04.mxd
Print date: 24 Mar 2020 - 10:23

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

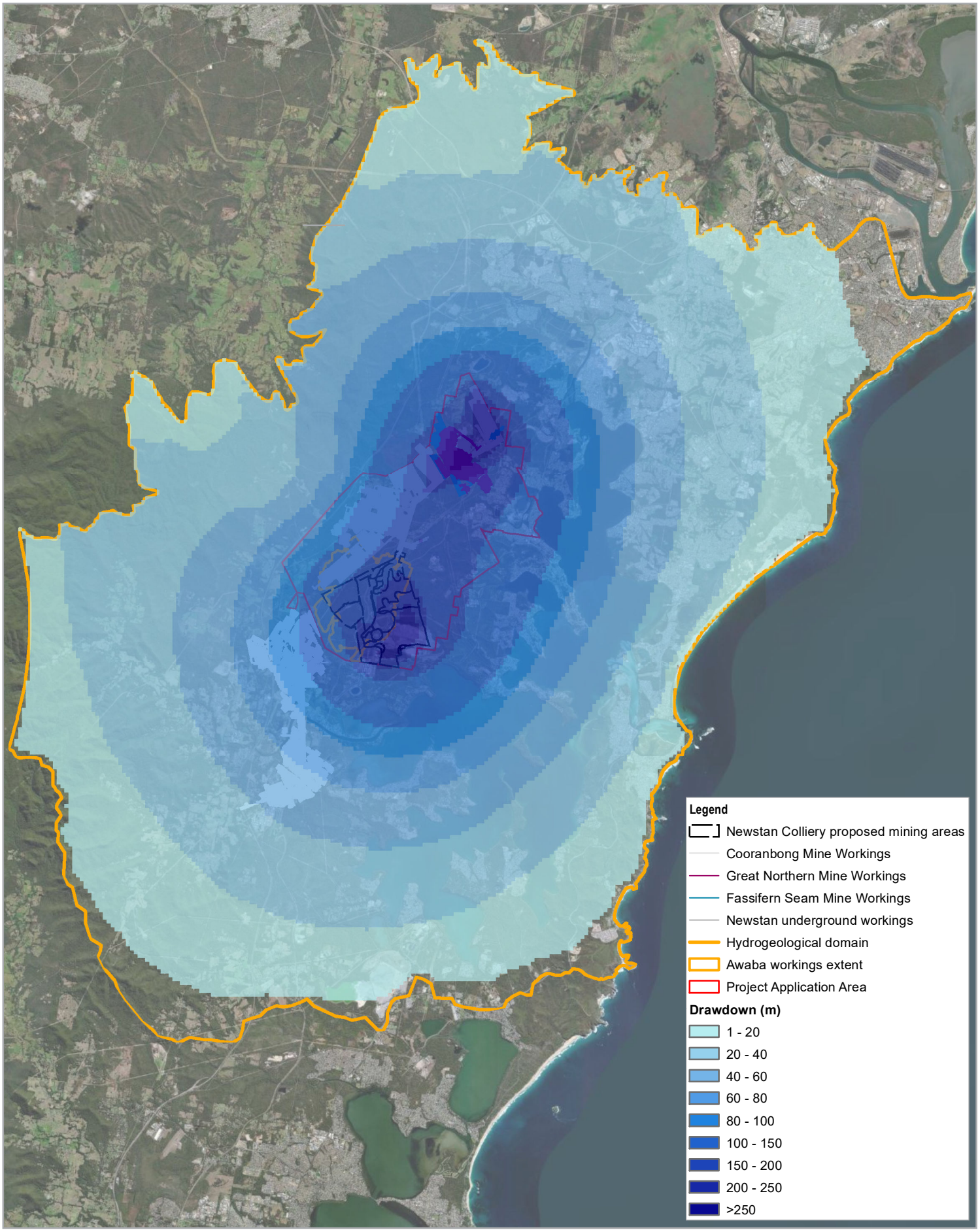
Cumulative groundwater drawdown End of mining - Layer 6: Fassifern Seam

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE E-3

G:\22\01050011\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-015_CumulativeDrawdownEoM_Lyr06.mxd
Print date: 24 Mar 2020 - 10:27

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

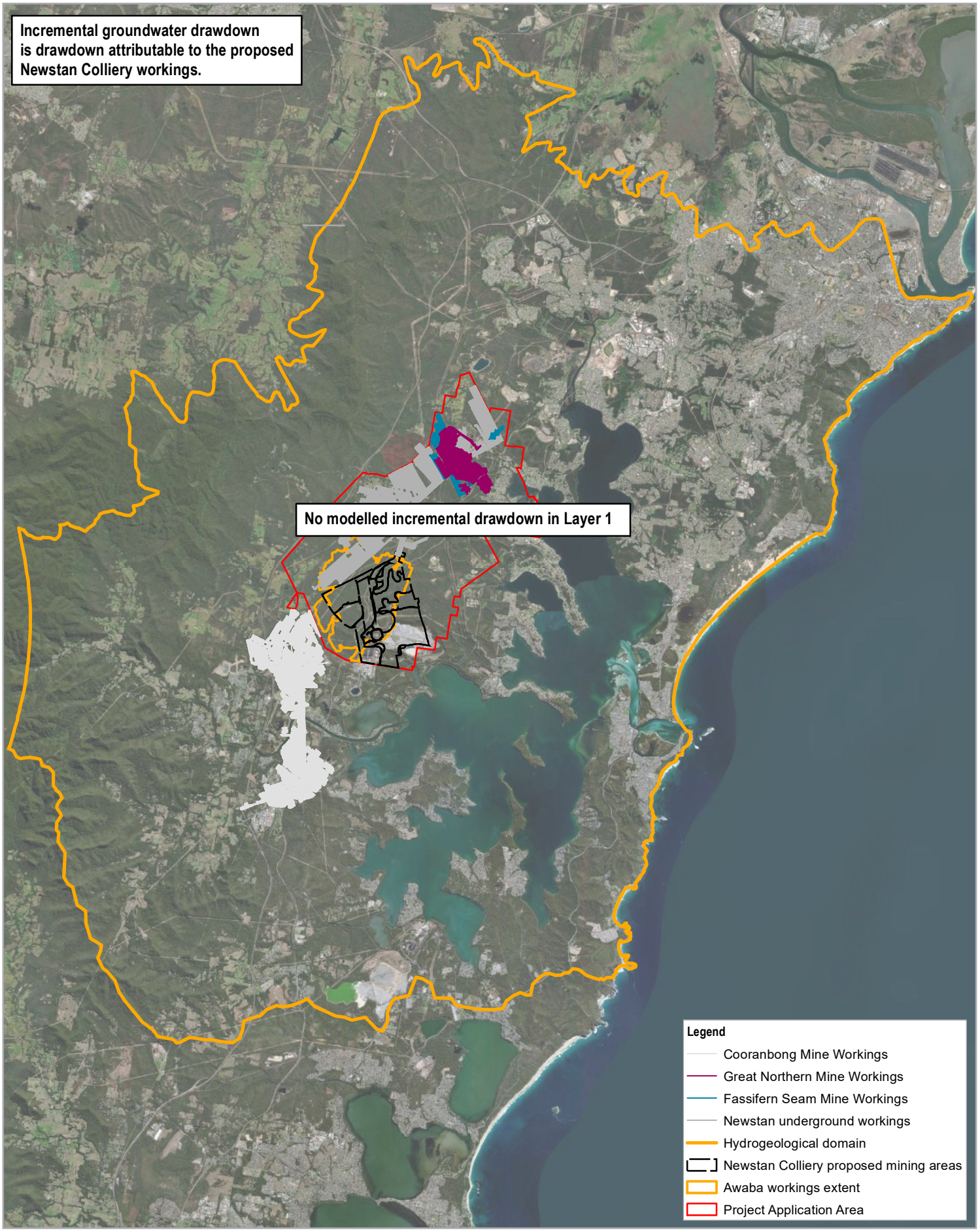
Cumulative groundwater drawdown
End of mining - Layer 10:
West Borehole Seam

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE E-4

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-016_CumulativeDrawdownEoM_Lyr10.mxd
Print date: 09 Apr 2020 - 10:25

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

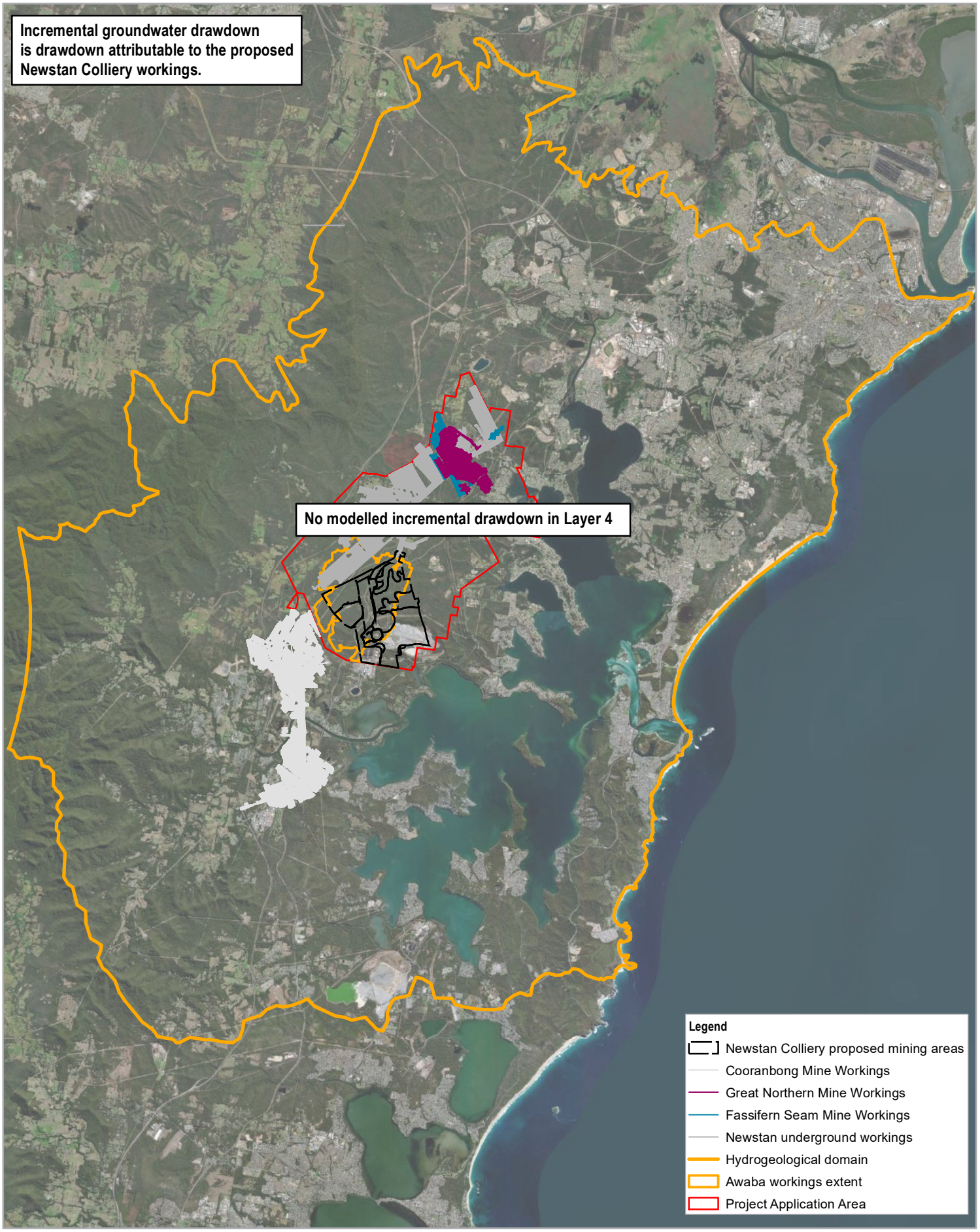
Incremental groundwater drawdown End of mining - Layer 1: Alluvium and regolith

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE E-5

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-017_IncrementalDrawdownEoM_Lyr01.mxd
Print date: 24 Mar 2020 - 10:30

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

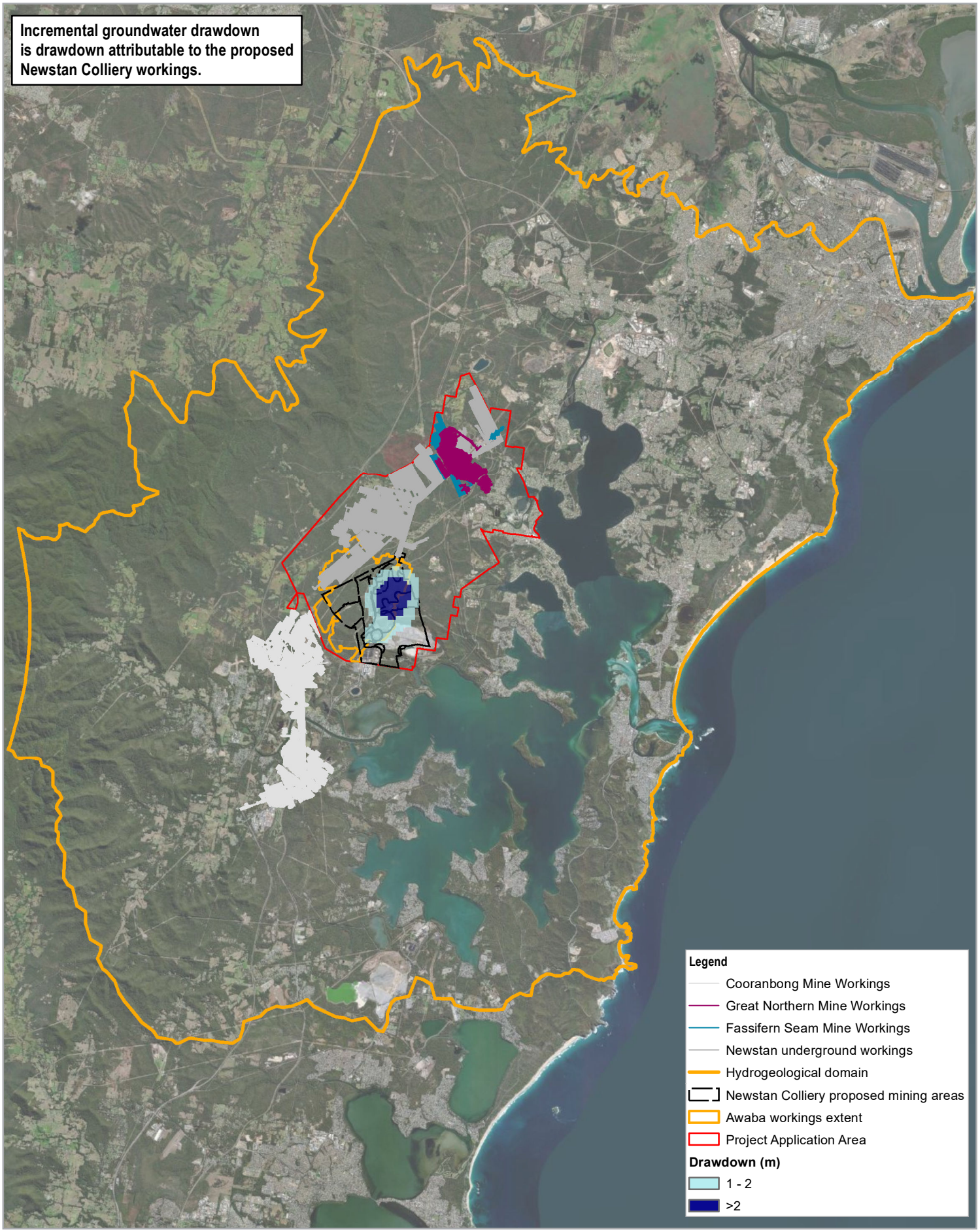
Incremental groundwater drawdown
End of mining - Layer 4:
Great Northern Seam

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE E-6

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-018_IncrementalDrawdownEoM_Lyr04.mxd
Print date: 24 Mar 2020 - 10:31

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

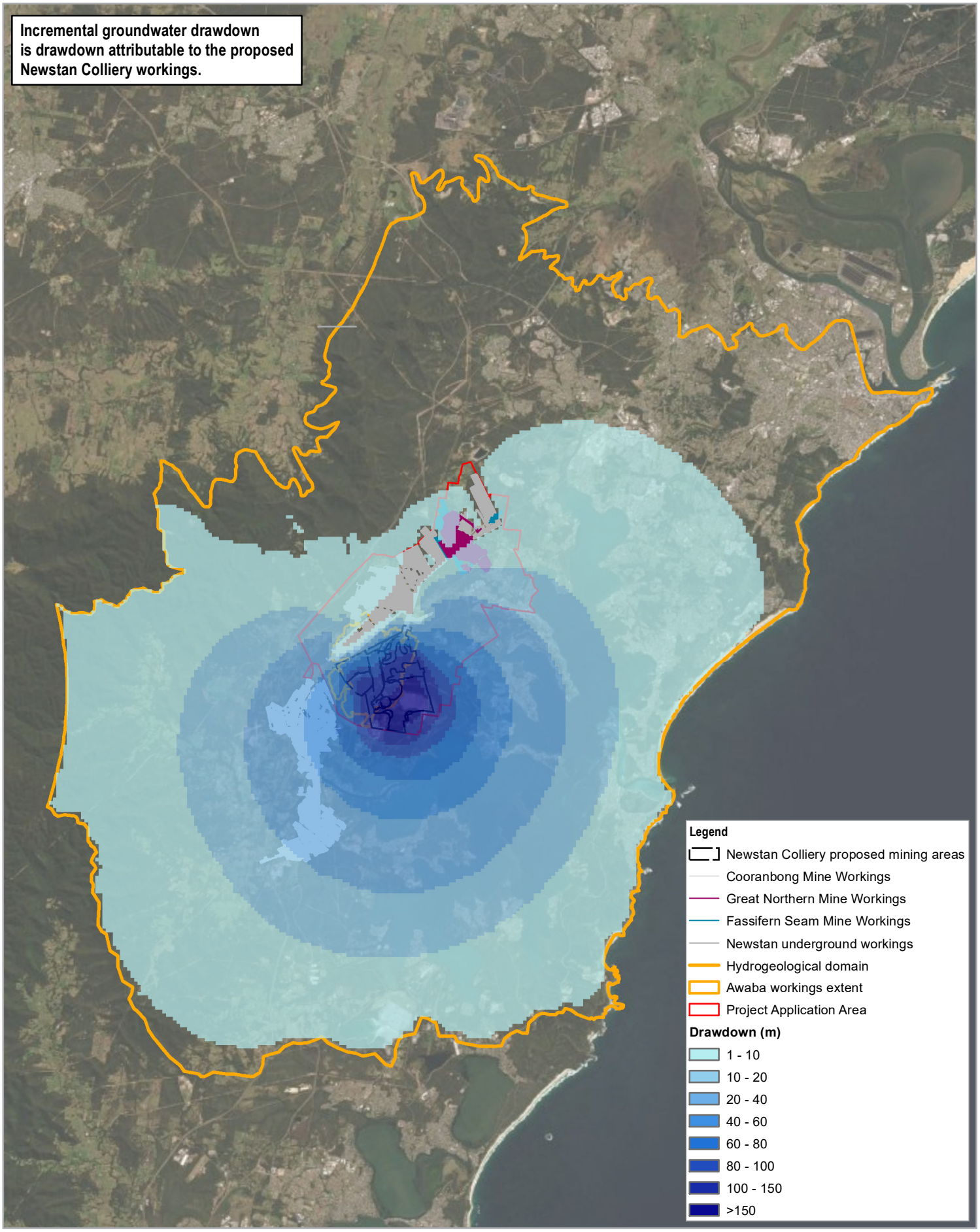
Incremental groundwater drawdown End of mining - Layer 6: Fassifern Seam

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE E-7

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-019_IncrementalDrawdownEoM_Lyr06.mxd
Print date: 09 Apr 2020 - 10:24

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Groundwater Modelling Report

Incremental groundwater drawdown End of mining - Layer 10: West Borehole Seam

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE E-8

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\GMR\22-20265-GMR-020_IncrementalDrawdownEoM_Lyr10.mxd
Print date: 09 Apr 2020 - 10:23

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald

Appendix F – Risk assessment

Administration

Facility Information

Risk Assessment Title:	Newstan Colliery Groundwater Uncertainty Analysis 2019
Revision:	1
Region:	Centennial Coal
Site:	Operations
Department:	
Equipment / Process:	
Stature Risk Assessment No. (Stature Unique ID):	1001238000
Study Lifecycle State:	Risk Assessment In Progress
Document Date:	05-Aug-2019
Potential Hazard No.:	
PULSE Actions Required URL:	
Site Risk Assessment Ref. No. (Optional):	

Originator: 100372
Site Code: SYD
Hazard Type: 4

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

Team Members (hover for instructions):

Scoping Team Members					
Name	**Position**	**Company**	**Industry Start Date**	**E-Mail Address**	**Experience relevant to the role in the risk assessment**
Lachlan Hammersley	Manger of Water Engineering	Centennial Coal	09-Apr-2018	Lachlan.Hammersleuy@centennialcoal.com.au	Engineer

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

Background (hover for instructions):

Newstan Colliery is an existing underground coal mine located in the Lake Macquarie Local Government Area, approximately 25 kilometres south west of Newcastle and 140 kilometres north of Sydney, NSW. It is owned and operated by Centennial Newstan Pty Ltd (Centennial Newstan). Mining operations at Newstan Colliery began in 1887 and upon the introduction of the EP&A Act operated pursuant to continuing use rights in accordance with Part 4, Division 10 of the EP&A Act (continuing use rights). On 14 May 1999 the (then) Minister for Urban Affairs and Planning granted Development Consent DA 73-11-98 under Part 4 of the EP&A Act for the Newstan Colliery Life Extension Area. This approval enabled mining to continue within the existing mining areas as well as the expansion into areas that had not previously been mined. Development Consent DA 73-11-98 has been modified on eight occasions

Centennial Newstan is now seeking approval for the continuation of mining within the West Borehole seam. The Newstan Extension Project proposes to extract up to 25.9 million tonnes (Mt) over a fifteen year period at a maximum production rate of 2.2 million tonnes per annum (Mtpa) using continuous miner methods.

As part of the extension project, the review of hydrogeological conditions and consequences of an increased mining area need to be undertaken. This work was done in 2012-2013 as part of the original mine extension project however due to changes in the mine plan a predictive model revision is required. As part of increased regulations, a risk assessment is necessary to support the revised model.

As part of the groundwater model redevelopment/update, consideration of the most recent standards was considered. As part of the guidelines prepared by IESC on uncertainty analysis in groundwater modelling, a risk assessment methodology is suggested to define how model predictions can aid in decision making processes throughout the EIS process.

Generally the hydrogeological system for the Newstan Extension Project would be deemed moderate to high risk.

The level of effort applied to uncertainty analysis for modelling should be a function of the potential risks being managed.

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

Objective (hover for instructions):

The following Hierarchy of Controls offers a framework for considering the effectiveness of controls. Note that the effectiveness of a control that is intended to reduce a risk decreases from top to bottom of the list. In other words, the closer the control type is to the top of the hierarchy, the more potentially effective the control.

·Eliminate the hazard or energy source (do not use the energy)
·Minimise or replace the hazard or energy source (reduce the amount of energy to a less damaging level or replace the energy with another that has less potential negative consequences)
·Control the hazard or energy using engineered devices (ex. Lock outs, chemical containers, mechanical roof support, gas monitors, etc.)
·Control the hazard or energy by using physical barriers (ex. machine guarding, fences or enclosures, etc.)
·Control the hazard or energy with procedures (ex. Isolation procedures, standard operating procedures, etc.)
·Control the hazard or energy with personal protective equipment (ex. hard hats, boots with toe caps, gloves, safety glasses, welding gear, etc.)
·Control the hazard or energy with warnings and awareness (ex. posters, labels, warning signs, verbal warnings, etc.)

To identify, assess and control the risks to people and environment to safely.....
manage interactions with the groundwater environment within the bounds of sustainable development.

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

Potential Hazards (hover for instructions):

Key hazards for groundwater environment as a result of the Project include:

1. Increased groundwater drawdown impacting on vegetation and groundwater users

2. Groundwater inflow requiring appropriately sized infrastructure to safely manage out of the underground
- Water Treatment Plant at NCSS
- Awaba seepage interactions (risk of increased volumes of seepage)

3. Groundwater quality risks associated with mining and other industrial activities where existing interactions exist.
- Eraring Ash Dam and connectivity leading to excerbating contamination of mine workings

4. Pressure/water levels in surrounding mining areas

5. Reduction or redirection of surface water flow volumes as a result of cracking or increased hydraulic conductivity
- Surface water users or quality may be impacted

6. Cumulative impacts

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

Risk Assessment Methods (hover for instructions):

Risk Assessment Methods

- ☑ Workplace Risk Assessment and Control (WRAC)
- ☐ Fault Tree Analysis (FTA)
- ☐ Safety Integrity Level Analysis to Australian Standard 61508 (SIL)
- ☐ Bow Tie Analysis (BTA)
- ☐ Hazard and Operability Analysis (HAZOP)
- ☐ Failure Modes and Effects Analysis (FMEA)

Newstan Colliery Groundwater Uncertainty Analysis 2019

6. Previous Risk Assessment and other documents to be used and/or referenced

Instructions

Previous Risk Assessments to be used (hover for instructions):

Document Name	Title	Version	Referenced Document Date
	Newstan Extension Project Hydrogeology Model Report (GHD 2013)		
	Newstan Extension Project Groundwater Impact Assessment (GHD 2013)		
	Awaba Water Management Plan (GHD 2018)		
	Newstan Water Resources Assessment - Modification 8 (GHD 2018)		
	AGE (2008) Newstan Colliery - Longwall Panel 25		
	SCT Report - Mine Design in Context of Eraring Ash Dam		
	MSEC Subsidence Assessment - Newstan Extension Mine Plan (2019)		
	Ismet Canbulat - Preliminary assessment of the impact of the proposed workings in the WBH Seam on previously mined Awaba workings located in the Great Northern Seam		

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

Venue and Time (hover for instructions):

Date	Description	Location	Start Time	End Time	Comment
1. 06-Aug-2019	Scoping session	Newstan	9:30 AM	10:00 AM	
2. 06-Aug-2019	Risk Assessment	Newstan	12:30 PM	2:00 AM	

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

Team Selection (hover for instructions):

Name	Position	Company	Industry Start Date	E-Mail Address	Role	Experience relevant to the role in the risk assessment	Pulse User No.	Attendance	
								1. 06-Aug-2019	2. 06-Aug-2019
Lachlan Hammersley	Manger of Water Engineering	Centennial Coal	09-Apr-2018	Lachlan.Hammersleuy@centennialcoal.com.au	Risk Assessment Owner	Engineer	100372	P	P
Peter Corbett	General Manager Mine Technical Support	Centennial Coal	11-Mar-1992	peter.corbett@centennialcoal.com.au	Facilitator	Engineer	111	A	P
Stuart Gray		GHD							
Ken Mills		SCT							

Newstan Colliery Groundwater Uncertainty Analysis 2019

WRAC Analysis Incident Builder

Instructions

WRAC Analysis Incident Builder (hover for instructions):

Step	Events				
	Events	caused by	Hazards / Causes	resulting in	Consequences / Outcomes
1. Groundwater levels within the alluvial layers	1.1. Depressurisation or reduction in level that exceeds the acceptable impact	caused by	1. Model conceptualisation does not reflect natural system adequately 2. over estimation of model parameters 3. under estimation of model parameters 4. insufficient baseline data / monitoring less than adequate 5. mine design is less than adequate 6. impacts of geological structures	resulting in	1. Legal / non-compliance 2. Environmental impacts (eg GDEs) 3. Social impact 4. Business impact
2. Groundwater levels within the GNS (Awaba)	2.1. Groundwater level changes that result in an unacceptable impact	caused by	1. Model conceptualisation does not reflect natural system adequately 2. over estimation of model parameters 3. under estimation of model parameters 4. insufficient baseline data / monitoring less than adequate 5. mine design is less than adequate 6. impacts of geological structures	resulting in	1. Legal / non-compliance 2. Environmental impacts (eg GDEs) 3. Social impact 4. Business impact
3. Groundwater level within the WBH (mine workings)	3.1. Depressurisation or reduction in level that exceeds the acceptable impact	caused by	1. Model conceptualisation does not reflect natural system adequately 2. over estimation of model parameters 3. under estimation of model parameters 4. insufficient baseline data / monitoring less than adequate 5. mine design is less than	resulting in	1. Legal / non-compliance 2. Environmental impacts (eg GDEs) 3. Social impact 4. Business impact

Instructions

WRAC Analysis Incident Builder (hover for instructions):

Step	Events				
	Events	caused by	Hazards Causes	resulting in	Consequences Outcomes
			adequate		
			6. impacts of geological structures		
4. Surface and groundwater connectivity	4.1. Reduction in surface flow volumes into alluvial or further vertically	caused by	1. Model conceptualisation does not reflect natural system adequately	resulting in	1. Legal / non-compliance
			2. over estimation of model parameters		2. Environmental impacts (eg GDEs)
			3. under estimation of model parameters		3. Social impact
			4. insufficient baseline data / monitoring less than adequate		4. Business impact
			5. mine design is less than adequate		
			6. impacts of geological structures		
5. Groundwater bores - external users	5.1. Depressurisation of private bores located within or potentially effected by the proposed mining operations - greater than 2m	caused by	1. over estimation of model parameters	resulting in	1. Legal / non-compliance
			2. mine design is less than adequate		2. Environmental impacts (eg GDEs)
			3. impacts of geological structures		3. Social impact
					4. Business impact
	5.2. Inability to confirm compliance for impacts against all identified groundwater users.	caused by	1. Existing monitoring system less than adequate	resulting in	1. Legal / non-compliance
			2. inability to gain access arrangements with property owners/bore owners		2. Environmental impacts (eg GDEs)
					3. Social impact
					4. Business impact
6. Groundwater dependent ecosystems	6.1. Depressurisation of groundwater level that could result on an impact to a GDE beyond the level of acceptance - GENERAL	caused by	1. Model conceptualisation does not reflect natural system adequately	resulting in	1. Legal / non-compliance
			2. over estimation of model parameters		2. Environmental impacts (eg GDEs)
			3. under estimation of model parameters		3. Social impact
			4. insufficient baseline data / monitoring less than adequate		4. Business impact
			5. mine design is less than adequate		
			6. impacts of geological structures		

Instructions

WRAC Analysis Incident Builder (hover for instructions):

Step	Events				
	Events	caused by	Hazards Causes	resulting in	Consequences Outcomes
	6.2. Depressurisation of groundwater level that could result on an impact to a GDE beyond the level of acceptance - LISTED OR HIGH PRIORITY	caused by	1. Model conceptualisation does not reflect natural system adequately 2. over estimation of model parameters 3. under estimation of model parameters 4. insufficient baseline data / monitoring less than adequate 5. mine design is less than adequate 6. impacts of geological structures	resulting in	1. Legal / non-compliance 2. Environmental impacts (eg GDEs) 3. Social impact 4. Business impact
7. Groundwater quality	7.1. Change in beneficial use category for aquifer	caused by	1. Model conceptualisation does not reflect natural system adequately 2. over estimation of model parameters 3. under estimation of model parameters 4. insufficient baseline data / monitoring less than adequate 5. mine design is less than adequate 6. Design of external infrastructure	resulting in	1. Legal / non-compliance 2. Environmental impacts (eg GDEs) 3. Social impact 4. Business impact
8. Groundwater licensing	8.1. Inadequate groundwater license volumes	caused by	1. Model conceptualisation does not reflect natural system adequately 2. over estimation of model parameters 3. under estimation of model parameters 4. impacts of geological structures 5. mine design is less than adequate	resulting in	1. Legal / non-compliance 2. Environmental impacts (eg GDEs) 3. Social impact 4. Business impact
	8.2. Inadequate surface water license volumes	caused by	1. Model conceptualisation does not reflect natural system adequately	resulting in	1. Legal / non-compliance 2. Environmental impacts (eg GDEs) 3. Social impact

Instructions

WRAC Analysis Incident Builder (hover for instructions):

Step	Events				
	Events	caused by	Hazards Causes	resulting in	Consequences Outcomes
			2. over estimation of model parameters		4. Business impact
			3. under estimation of model parameters		
			4. impacts of geological structures		
			5. mine design is less than adequate		
9. Water and Salt Balance	9.1. Groundwater volumes results in change in the site water balance predicting in an increased discharge requirement beyond approved/acceptable limits	caused by	1. Model conceptualisation does not reflect natural system adequately	resulting in	1. Legal / non-compliance
			2. over estimation of model parameters		2. Environmental impacts (eg GDEs)
			3. under estimation of model parameters		3. Social impact
			4. mine design is less than adequate		4. Business impact
	9.2. Groundwater quality results in change in the site salt balance predicting in an increased salt concentration in discharges beyond acceptable limits	caused by	1. Model conceptualisation does not reflect natural system adequately	resulting in	1. Legal / non-compliance
			2. over estimation of model parameters		2. Environmental impacts (eg GDEs)
			3. under estimation of model parameters		3. Social impact
			4. mine design is less than adequate		4. Business impact
10. Cumulative impacts	10.1. Project interactions with external factors result in an groundwater impact that is beyond acceptable limits	caused by	1. Model conceptualisation does not reflect natural system adequately	resulting in	1. Legal / non-compliance
			2. over estimation of model parameters		2. Environmental impacts (eg GDEs)
			3. under estimation of model parameters		3. Social impact
			4. insufficient baseline data / monitoring less than adequate		4. Business impact
			5. mine design is less than adequate		

Instructions

WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
7. Groundwater quality	There is a risk to Operations from ::: Change in beneficial use category for aquifer ::: Caused by: Design of external infrastructure or insufficient baseline data / monitoring less than adequate or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.	7.1.a. Working group established with Eraring over potential connection between Awaba and Ash Dam 7.1.b. Groundwater quality monitoring sufficient for GNS & alluvial 7.1.c. Salt considered as indicator for quality from groundwater sources	**B** (Pb)	4 (F)	**22 (E)**	10. Additional monitoring required WBH seam (LW22 or similar) 11. Salt balance to incorporate hydrogeo flow and salt sources to identify risk associated with activity.
8. Groundwater licensing	There is a risk to Operations from ::: Inadequate groundwater license volumes ::: Caused by: impacts of geological structures or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.	8.1.a. Licence application submitted 8.1.b. Evaluation of pit water managment conceptualised through water balance 8.1.c. FUS side seepage calibrated on historical information	**B** (Pb)	3 (F)	**17 (H)**	12. Hydrogeology model to consider conservative groundwater make predictions. 13. Uncertainity in rainfall volumes to be evaluated in supporting water balance 5. Use Winton Gale (2009) literature for understanding range of hydraulic conductivity
9. Water and Salt Balance	There is a risk to Operations from ::: Groundwater quality results in change in the site salt balance predicting in an increased salt concentration in discharges beyond acceptable limits :::	9.2.a. Rainfall uncertainty considered 9.2.b. Awaba model calibrated to Awaba seepage flow and rainfall response to groundwater level 9.2.c. Fassifern underground storage calibrated to rainfall response	**B** (Pb)	3 (E)	**17 (H)**	14. Re-evaluate model for varying rainfall interaction percentages (eg 9% to 25% to account of uncertainty in Awaba sink holes) 15. Salt balance to reflect hydrogeology model uncertainity with relevant salt source concentrations 16. Sensitivity assessment on salt concentration assumptions

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	Caused by: mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.					
3. Groundwater level within the WBH (mine workings)	There is a risk to Operations from ::: Depressurisation or reduction in level that exceeds the acceptable impact ::: Caused by: impacts of geological structures or insufficient baseline data / monitoring less than adequate or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.	3.1.a. Geology experience from mandalong to be considered in hydrogeo model development	**C** (Pb)	3 (F)	**13 (S)**	3. Evaluate in detail, mine inflows from various parts of the WBH seam from historical information to determine likely inflow ranges to test in hydrogeo model. 4. Recover CN036 and CN038 piezometers 5. Use Winton Gale (2009) literature for understanding range of hydraulic conductivity
9. Water and Salt Balance	There is a risk to Operations from ::: Groundwater volumes results in change in the site water balance predicting in an increased discharge requirement beyond approved/acceptable limits ::: Caused by: mine design is less than adequate or Model conceptualisation does not	9.1.a. Rainfall uncertainty considered 9.1.b. Awaba model calibrated to Awaba seepage flow and rainfall response to groundwater level 9.1.c. Fassifern underground storage calibrated to rainfall response	**C** (Pb)	3 (E)	**13 (S)**	14. Re-evaluate model for varying rainfall interaction percentages (eg 9% to 25% to account of uncertainty in Awaba sink holes)

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.					
2. Groundwater levels within the GNS (Awaba)	There is a risk to Operations from ::: Groundwater level changes that result in an unacceptable impact ::: Caused by: impacts of geological structures or insufficient baseline data / monitoring less than adequate or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.	2.1.a. Sufficient baseline to understand longwall extraction effects on GNS 2.1.b. Methodology considers water balance approach to Awaba over hydrogeo model which may not fully represent the scenario	**D** (Pb)	3 (E)	**9 (M)**	2. Constant water level considered in hydrogeo model for Awaba, variance in water level to be considered in model to evaluate uncertainty in response mechanism (eg awaba dry, or 10th and 90th percentile water level, annual time frame)
6. Groundwater dependent ecosystems	There is a risk to Operations from ::: Depressurisation of groundwater level that could result on an impact to a GDE beyond the level of acceptance - GENERAL ::: Caused by: impacts of geological structures or insufficient baseline data / monitoring less than adequate or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or	6.1.a. Confirmation of plant communities undertaken	**D** (Pb)	3 (E)	**9 (M)**	6. Demarkate Awaba area from non-awaba areas in technical assessment 9. GWIA to include assessment to evaluate impact to high potential GDEs only

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.					
10. Cumulative impacts	There is a risk to Operations from ::: Project interactions with external factors result in an groundwater impact that is beyond acceptable limits ::: Caused by: insufficient baseline data / monitoring less than adequate or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.	10.1.a. Oceanic coal, west wallsend, Newstan Existing and proposed, Awaba Existing, Ash Dam, and Cooranbong all considered in model development	**D** (Pb)	3 (E)	**9** **(M)**	17. Boundary conditions varied to understand sensitivity to inflows and drawdown extent. (eg flooded surrounding pit compared with empty). 18. Eraring Ash Dam and interactions with the groundwater environment to be assessed
1. Groundwater levels within the alluvial layers	There is a risk to Operations from ::: Depressurisation or reduction in level that exceeds the acceptable impact ::: Caused by: impacts of geological structures or insufficient baseline data / monitoring less than adequate or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.	1.1.a. Sufficient baseline to understand longwall extraction effects on alluvium	**C** (IF)	2 (E)	**8** **(M)**	1. Desktop assessment for area of full extraction vs remaining pillars

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
4. Surface and groundwater connectivity	There is a risk to Operations from ::: Reduction in surface flow volumes into alluvial or further vertically ::: Caused by: impacts of geological structures or insufficient baseline data / monitoring less than adequate or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.	4.1.a. Suitable monitoring data for Alluvium across Project area	**C** (Pb)	2 (F)	**8 (M)**	6. Demarkate Awaba area from non-awaba areas in technical assessment 7. Identify groundwater monitoring evidence to support depressurisation from surface to Awaba. 3. Evaluate in detail, mine inflows from various parts of the WBH seam from historical information to determine likely inflow ranges to test in hydrogeo model. 8. baseflow sensitivity to be undertaken as partof model in absence of flow monitoring data
5. Groundwater bores - external users	There is a risk to Operations from ::: Depressurisation of private bores located within or potentially effected by the proposed mining operations - greater than 2m ::: Caused by: impacts of geological structures or mine design is less than adequate or over estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.	5.1.a. Public bores known as part mod 8 assessment	**D** (Pb)	2 (F)	**5 (L)**	
5. Groundwater bores - external users	There is a risk to Operations from ::: Inability to confirm compliance for impacts against all identified groundwater users. :::		**D** (Pb)	2 (F)	**5 (L)**	

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	Caused by: Existing monitoring system less than adequate or inability to gain access arrangements with property owners/bore owners Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.					
6. Groundwater dependent ecosystems	There is a risk to Operations from ::: Depressurisation of groundwater level that could result on an impact to a GDE beyond the level of acceptance - LISTED OR HIGH PRIORITY ::: Caused by: impacts of geological structures or insufficient baseline data / monitoring less than adequate or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.	6.2.a. No high priority receptors	**E** (Pb)	1 (F)	**1 (L)**	
8. Groundwater licensing	There is a risk to Operations from ::: Inadequate surface water license volumes ::: Caused by: impacts of geological structures or mine design is less than adequate or Model conceptualisation does not reflect natural system adequately or over estimation of model parameters or	8.2.a. Sufficient surface water licences	**E** (Pb)	1 (F)	**1 (L)**	

Newstan Colliery Groundwater Uncertainty Analysis 2019

Instructions

WRAC Analysis Sorted by RR (hover for instructions):

Step	Potential Incident	Current Controls	L	MRC	RR	Recommended Control
	under estimation of model parameters Resulting in: Business impact or Environmental impacts (eg GDEs) or Legal / non-compliance or Social impact.					

Newstan Colliery Groundwater Uncertainty Analysis 2019

Recommended Controls	Place(s) Used	Allocated To	Required By Date	Pulse User No.	PULSE Ref. No.
1. Desktop assessment for area of full extraction vs remaining pillars	Events: 1.1	Lachlan Hammersley			
2. Constant water level considered in hydrogeo model for Awaba, variance in water level to be considered in model to evaluate uncertainty in response mechanism (eg awaba dry, or 10th and 90th percentile water level, annual time frame)	Events: 2.1	Lachlan Hammersley			
3. Evaluate in detail, mine inflows from various parts of the WBH seam from historical information to determine likely inflow ranges to test in hydrogeo model.	Events: 3.1, 4.1	Lachlan Hammersley			
4. Recover CN036 and CN038 piezometers	Events: 3.1	Lachlan Hammersley			
5. Use Winton Gale (2009) literature for understanding range of hydraulic conductivity	Events: 3.1, 8.1	Lachlan Hammersley			
6. Demarkate Awaba area from non-awaba areas in technical assessment	Events: 4.1, 6.1	Lachlan Hammersley			
7. Identify groundwater monitoring evidence to support depressurisation from surface to Awaba.	Events: 4.1	Lachlan Hammersley			
8. baseflow sensitivity to be undertaken as partof model in absence of flow monitoring data	Events: 4.1	Lachlan Hammersley			
9. GWIA to include assessment to evaluate impact to high potential GDEs only	Events: 6.1	Lachlan Hammersley			
10. Additional monitoring required WBH seam (LW22 or similar)	Events: 7.1	Lachlan Hammersley			
11. Salt balance to incorporate hydrogeo flow and salt sources to identify risk associated with activity.	Events: 7.1	Lachlan Hammersley			
12. Hydrogeology model to consider conservative groundwater make predictions.	Events: 8.1	Lachlan Hammersley			
13. Uncertainity in rainfall volumes to be evaluated in supporting water balance	Events: 8.1	Lachlan Hammersley			
14. Re-evaluate model for varying rainfall interaction percentages (eg 9% to 25% to account of uncertainty in Awaba sink holes)	Events: 9.1, 9.2	Lachlan Hammersley			
15. Salt balance to reflect hydrogeology model uncertainity with relevant salt source concentrations	Events: 9.2	Lachlan Hammersley			
16. Sensitivity assessment on salt concentration assumptions	Events: 9.2	Lachlan Hammersley			
17. Boundary conditions varied to understand sensitivity to inflows and drawdown extent. (eg flooded surrounding pit compared with empty).	Events: 10.1	Lachlan Hammersley			
18. Eraring Ash Dam and interactions with the groundwater environment to be assessed	Events: 10.1	Lachlan Hammersley			

Newstan Colliery Groundwater Uncertainty Analysis 2019

Appendix G – Independent third party review

NEWSTAN EXTENSION

Groundwater Peer Review

Prepared for:

Centennial Coal Pty Ltd
Accounts Payable
PO Box 1000 FASSIFERN NSW
2283



SLR Ref: 665.10022-R01
Version No: -v1.0
March 2020

PREPARED BY

SLR Consulting Australia Pty Ltd
ABN 29 001 584 612
Level 1, The Central Building, UoW Innovation Campus
North Wollongong NSW 2500 Australia

T: +61 404 939 922
E: wollongong@slrconsulting.com www.slrconsulting.com

BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Centennial Coal Pty Ltd (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of the Client. No warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR.

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

DOCUMENT CONTROL

Reference	Date	Prepared	Checked	Authorised
665.10022-R01-v1.0	26 March 2020	Dr Arash Mohajeri	Claire Stephenson	Brian Rask

CONTENTS

1 INTRODUCTION 4
1.1 Background 4
2 REVIEW METHODOLOGY 6
2.1 Initial Review 6
2.2 Documentation 7
3 REPORTING 8
3.1 Data Matters 8
3.2 Summary of Conceptual Groundwater Model 10
3.3 Summary of Impact Predictions and Key Issues 11
4 NUMERICAL MODEL 15
4.1 Groundwater Model Design 15
4.2 Groundwater Model Calibration and Performance 16
4.3 Groundwater Model Predictions 17
5 CONCLUSIONS AND CONSIDERATIONS 20

DOCUMENT REFERENCES

TABLES

No table of figures entries found.

FIGURES

Figure 1 Project Layout (Source: GHD 2020, Figure 1-2) 5
Figure 2 Conceptual Groundwater Model – Alluvium 12
Figure 3 Conceptual Groundwater Model - Local 13
Figure 4 Conceptual Groundwater Model - Regional 14

APPENDICES

Appendix A Model Review

1 Introduction

SLR Consulting (SLR) were engaged by Centennial Coal to conduct a preliminary review of the groundwater assessment model for the Newstan Project by GHD. The review was conducted by Associate Groundwater Modeller Dr Arash Mohajeri and Principal Hydrogeologist Claire Stephenson.

1.1 Background

Newstan Colliery is an existing underground coal mine located approximately 25 kilometres south west of Newcastle. Mining operations at Newstan Colliery began in 1887 and has since included bord and pillar, and longwall mining methods. Mining at Newstan Colliery targeted the Newcastle Coal Measures, including the Northern and Fassifern seams, West Borehole, Borehole, Young Wallsend and Yard seams. Mining at Newstan Colliery was put in care and maintenance in 2014, but was approved in January 2019 under DA 73-11-98 to recommence as first workings within the West Borehole Seam in the southern portion of the mining lease.

The purpose of the Newstan Extension Project Groundwater Impact Assessment is to assess potential groundwater impacts associated with:

- Extraction of up to 25.0 Million tonnes (Mt) over 15 years with maximum extraction rate of 4 Mt per annum (Mtpa) of coal from West Borehole Seam.
- Mining to be undertaken using bord and pillar mining using continuous miner method, with first workings in areas with historical mining in overlying seams and sensitive surface features (i.e. Stockyard Creek, Main Northern Railway and Eraring Power Station), as well as partial extraction and total extraction in other areas (**Figure 1**).
- Extension of mining into southern portion of the mining lease, partially underlying the closed Awaba Colliery.
- In-seam gas drainage, with gas transferred to a new gas flaring facility to be located within the existing disturbance footprint of Awaba Colliery Surface Site.
- Use of existing site infrastructure and facilities, including extraction of underground water using the existing Fassifern Pump Station at Newstan Colliery Surface Site and ongoing groundwater management in accordance with Centennial's Northern Operations: Regional Water Management Plan.

Secretary's environmental assessment requirements (SEARs) have been issued for the project relevant to groundwater. In addition, the project was declared to be a controlled action (EPBC 2019/8528) and requires assessment and approval under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).



Figure 1 Project Layout (Source: GHD 2020, Figure 1-2)

2 Review Methodology

Appendix F of the 2001 Australian Groundwater Modelling Guidelines (Middlemis et al. 2001) includes a detailed checklist of nine items that should be considered for peer review of high complexity models. This work has reviewed items (1) the report, (2) data analysis (3) conceptualisation, (4) model design and (5) calibration, (7) prediction and (8) sensitivity analysis.

The review of items (6) verification was not applicable to this study. Item (9) uncertainty analysis was a part the scope for of this peer review; however, the uncertainty analysis was still ongoing at the time of preparation of this report.

It should also be recognised that the effort put into a modelling project is very dependent on possible timing and budgetary constraints that are generally not known to a reviewer.

A detailed assessment has been made in terms of the peer review checklists in **Attachment A**. **Attachment A** addresses reporting, data analysis, conceptualisation, model design, calibration, prediction, and sensitivity analysis. Supplementary comments are offered in the following sections.

2.1 Initial Review

A kickoff meeting was held on 12th November 2019, where initial discussion on the Project and model design was undertaken between Centennial Coal, GHD and SLR. A draft version of the groundwater impact assessment was provided for review, on 7th February 2020 and comments provided by SLR on 24th February and discussed in a meeting with Centennial Coal and GHD on 4th February.

The purpose of the initial review was to assess if the conceptual and the model design were consistent and that the groundwater model design meets the project objectives. The following summarizes some of the main comments made after the initial review:

- Reporting: Include more information on geology, hydrogeology, monitoring bores, faults, climate, underground water management;
- Conceptual Model: improve conceptual cross sections in the report with better illustration and labelling of geological structures, features, faults, mining in area;
- Conceptual Model: Provide more information on the goaf fractured height;
- Groundwater Model Design: Add creeks and rivers to the model using MODFLOW-USG RIV package;
- Groundwater Model Design: Add more information on recharge, EVT and Drain boundary conditions used in the model;
- Groundwater Model Calibration: Update the calibration data set with all the available data and use automatic calibration;
- Groundwater Model Calibration: Maintain the consistency of the calibrated model parameters;
- Groundwater Model Prediction: Add discussion on baseflow change and alluvium direct and indirect take (if applicable); and

- Groundwater Model Uncertainty Analysis: Consider Type 3 uncertainty analysis given the complexity of the model and lack of field measurements and observations.

2.2 Documentation

Reporting on the conceptualisation was updated by GHD to address some of the comments provided by SLR. Updates were also made to the groundwater model, including recalibration of the model and inclusion of model river cells. This review covers content provided within the following documents provided on 9th March 2020:

- Doc#1 - GHD, February 2020, Newstan Extension Project Groundwater Impact Assessment (GIA)
- Doc#2 - GHD, February 2020, Newstan Extension Project Groundwater Modelling Report,

Doc#1 has the following sections:

1. Introduction
2. Legislation and Policy
3. Site description
4. Groundwater management and monitoring
5. Impact assessment methodology
6. Impact assessment
7. Mitigation, management and monitoring
8. Summary
9. References

Doc#2 has the following sections:

1. Introduction
2. Hydrogeological conceptualisations
3. Groundwater modelling set-up
4. Predictive simulations
5. Model predictive results
6. Conclusions and recommendations
7. References

3 Reporting

As outlined within the *Australian Groundwater Modelling Guidelines* (2012) the level of detail within the conceptual model should be chosen, based on the modelling objectives, the availability of quality data, knowledge of the groundwater system of interest, and its complexity.

Previous assessments undertaken in the region were utilised for the assessment and referenced in the GHD report, including previous assessments undertaken by GHD for Newstan and Mandalong, assessment of Awaba Colliery by AGE (2008), Tasman Extension Project (RPS 2012) and annual reviews for Newstan and Oceanic Coal (West Wallsend). Other publicly available reports for surrounding operations such as West Wallsend and OCAL closure plan were not referenced that may provide additional input on the existing groundwater conditions in the area but are not integral to understanding site conditions.

The objectives of the modelling are stated by GHD in the groundwater impact assessment to assess potential impacts of the project on the groundwater environment by addressing the relevant Secretary's environmental assessment requirements (SEARs) for the project and relevant government agency requirements.

Previous review comments after conceptualisation have been in part addressed, but further improvements could be made to more clearly outline the conceptualisation relevant to the Project. Previous review comments after model design, calibration and prediction stages have been addressed.

The background conceptualisation is outlined in both Doc#1 and Doc#2. Doc#2 includes a summary and graphical representation of the conceptual groundwater model. The peer review included assessment of the data presented and publicly available data to more clearly identify the key groundwater aspects relevant to the Project. A summary of the availability of data is included in **Section 3.1** and a summary of the conceptualisation is included in **Section 3.1** and of the impact predictions in **Section 3.3**.

3.1 Data Matters

Doc#1 and Doc#2 include a summary of surface water features at site. No site-specific data is available for streamflow. The conceptualisation includes baseflow contributions from alluvium to rivers and surface water features. There is also discussion on seepage of water from mine workings in the coal measures (Awaba Seepage) to surface features (i.e. tributary of Muddy Lake). Therefore, collection of this data or use of surface water assessment predictions is recommended to better inform the model development and impact assessment.

Doc#1 includes a clear description of the geology within the Project area and surrounds and draws on mapped geology and studies in the area. This includes reference to a detailed investigation of alluvium along Stony Creek undertaken by AGE (2008). Doc#2 also includes a map (Figure 2-8) showing faults across the site and a paleochannel across the site. There is limited discussion on the characteristics of the paleochannel and how it may influence goaf effects. The paleochannel is also not represented in the groundwater model as a unique feature. Sinkholes are also referred to in Doc#1 and Doc#2 as being present and providing recharge to the Awaba underground void. Further discussion around the conceptualisation of these paleochannels and sinkholes is required to understand their influence on the impact predictions and whether they should be captured in the model.

A summary of horizontal hydraulic conductivity ranges from packer testing is included in Doc#2 for the Permian coal measures, with data presented in a table for each of the different seams and interburden sequences. No field data is presented for the hydraulic properties of other geological units (i.e. alluvium or Triassic sandstone) and no field data is presented for other parameters (i.e. vertical anisotropy or storage parameters).

Doc#1 includes a summary of most of the groundwater monitoring bores at site that are included in Doc#2. However, the coordinates or construction details are not provided, and some bores at site are not specified but results are presented in the calibration (i.e. MB01). Doc#2 includes a summary of bores at Mandalong Mine and the geology and data availability. The peer review identified that bore AE6 likely intersects regolith as opposed to alluvium based on the mapped extent of alluvium presented by GHD and the unsaturated groundwater conditions. Presentation of bore construction details would help enable greater interrogation of the quality and reliability of data used to develop the conceptualisation and numerical model.

Groundwater hydrographs presented in Doc#2 have clear signatures that document the groundwater system's response to stresses. A thorough cause-and-effect analysis underpins a valid hydrogeological conceptualisation. The cause-and-effect analysis reveals mining effects at depth but not in alluvium, with the exception of localised areas of groundwater seepage to surface (Awaba Seepage). Further interrogation of the data could be undertaken to understand vertical gradients and trends to better illustrate the interaction with active mining and water storage.

There is some discussion on water quality within Doc#1 and Doc#2, with graphs showing groundwater quality data recorded at site bores over time for a range of analytes in Doc#1. Piper diagrams comparing water quality between sources are also shown in Doc#1 Appendix C. This data is used to justify the conceptualisation of fracturing, therefore further detail on the source of these results is required as it is unclear if it relates to averages of historical data or one reading.

Doc#1 and Doc#2 include a thorough review and discussion on underground water management at Newstan Colliery and Awaba Colliery. This section includes useful graphical representation of timeseries water level and discharge data. Reference is included regarding site specific assessments of subsidence impacts by MSEC (2019) of goaf effects conducted by SCT (2019). The assessment by GHD has a contrary conceptualisation of fracture heights compared to the SCT (2019) assessment based on site observation data. The data presented includes inflow volumes and water quality; however, further data and discussion around this should be included to give the reader greater confidence in the conceptualisation used. This includes discussion around interaction with different geological features such as conglomerates and fault structures in the area.

Doc#1 includes a summary table of registered bores in the area that includes useful information on the logged stratigraphy and bore use. A map of the bores is also included that differentiates the bores based on their use. The text includes discussion on registered bores within different formations and identifies that most registered bores in the area used for stock and domestic purposes and are generally shallow (less than 50 m depth) and intersect the Triassic sandstone and Permian coal measures. Review of the locations indicates some may also intersect alluvium. It would be beneficial for informing the impact assessment to specify the formations for each bore in the table and/or on a map. Information on the bores is based on information in the groundwater database (Water NSW). There is no reference of a bore census conducted across the site to verify bore conditions. The location of potential groundwater dependent ecosystems (GDEs) is also presented in Doc#1 and Doc#2 based on the GDE Atlas. There is no reference to a site survey conducted on site.

3.2 Summary of Conceptual Groundwater Model

The conceptual groundwater model for the site includes three main groundwater bearing units:

- Alluvium
- Triassic sandstone; and
- Permian coal measures.

The alluvium is largely saturated within the Study area, with groundwater levels between 0.5 m and 5 m below surface and are reported to likely provide baseflow contributions to some creeks overlaying the Project area. As well as discussion on a general trend of downward seepage to underlying Triassic sandstone and Permian coal measures within the upland areas (i.e. upper reaches of Lords Creek). The alluvium is generally characterised as comprising clays, silty clays with a variable basal sand and gravel sequence. No impacts on alluvial groundwater levels associated with depressurisation of the underlying coal measures have been previously reported at Newstan (GHD 2010) or Mandalong (GHD 2013). This is potentially due to the presence of tuff bands within the coal measures that have the potential to seal mining induced cracks (AGE 2008). The alluvium is recharged by rainfall and potentially from lateral seepage from the surrounding shallow weathered Triassic sandstone and Permian coal measures, where saturated. There are also areas of known flow from the underground workings (Permian stratigraphy) to alluvium and surface via structural features (i.e. Awaba Seepage). The alluvial groundwater is generally fresh to brackish and slightly acidic. There are registered bores in the region that appear to intersect alluvium and are used for stock, domestic and poultry (i.e. GW027551, GW063752 and GW064067). Potential groundwater dependent ecosystems have been mapped in the region, however, there are no GDEs within the Project Application Area that are listed in Schedule 4 of the water sharing plans (WSP). The alluvial water sources within the Project Application Area are covered under the WSP for the Hunter Unregulated and Alluvial Water Sources. Conceptualisation of the alluvial groundwater system as presented by GHD is shown in **Figure 2**.

There is no detail on groundwater conditions associated with the Triassic sandstone. However, there are several groundwater users in the area with bores intersecting the Triassic sandstone.

Groundwater conditions within the Permian coal measures are influenced by historical mining, with depressurisation observed within the Great Northern Seam coal seam associated with active mining at Mandalong. The extent of depressurisation in the coal seam is buffered by groundwater storage within the historical workings at Awaba Colliery. Groundwater levels have recovered within the Awaba Workings to over 19 mAHD, which has resulted in seepage to surface in localised areas of approximately 0.5 ML/day to 3.5 ML/day where monitored. As a result, groundwater levels at the southern end of the workings near the Eraring Power Station are managed to minimise seepage. The source of recharge to the workings may relate to horizontal flow through the coal measures and workings from water storage up-gradient of Awaba (i.e. Newstan). There is also recharge from rainfall and surface water features such as Lake Macquarie; however, vertical movement of groundwater (including recharge) is limited by the confining interburden, which includes low permeability tuffs. Therefore, groundwater flow is primarily horizontal through the seams with recharge only occurring at sub-crop, or where faults or sinkholes are present. No discussion is included on the regional groundwater flow directions within the coal measures. The data presented indicates groundwater flow directions are currently influenced by recharge where the coal measures occur at outcrop to the west and north, and depressurisation from active mining at Newstan and Mandalong. Review of water quality data indicates water within the Permian coal measures is generally brackish and private water supply bores are present in the area that target the Permian coal measures and are used for stock and domestic water supply.

Conceptualisation of the groundwater system as presented by GHD is shown on a local scale in **Figure 2** and **Figure 3**, and regionally in **Figure 4**. The figures illustrate that potential groundwater impacts associated with the Project will be largely limited due to water storage and existing impacts associated with the Awaba Colliery. However, the conceptualisation does not capture potential impacts associated with structural features (i.e. faults) that are known to act as groundwater conduits in the region.

3.3 Summary of Impact Predictions and Key Issues

Numerical model predictions indicate groundwater inflows to the underground mine workings of up to 4.0 ML/day (1,460 ML/year) during mine operations. Groundwater drawdown within the mined West Borehole Seam was predicted to extend up to 2 km from the active mine area at the end of mining. Cumulative drawdown was predicted to extend up to 9.5 km from the active mine areas.

There was no predicted indirect take of groundwater from the alluvium and no predicted change in baseflow contributions.

No assessment of post closure groundwater conditions was undertaken.

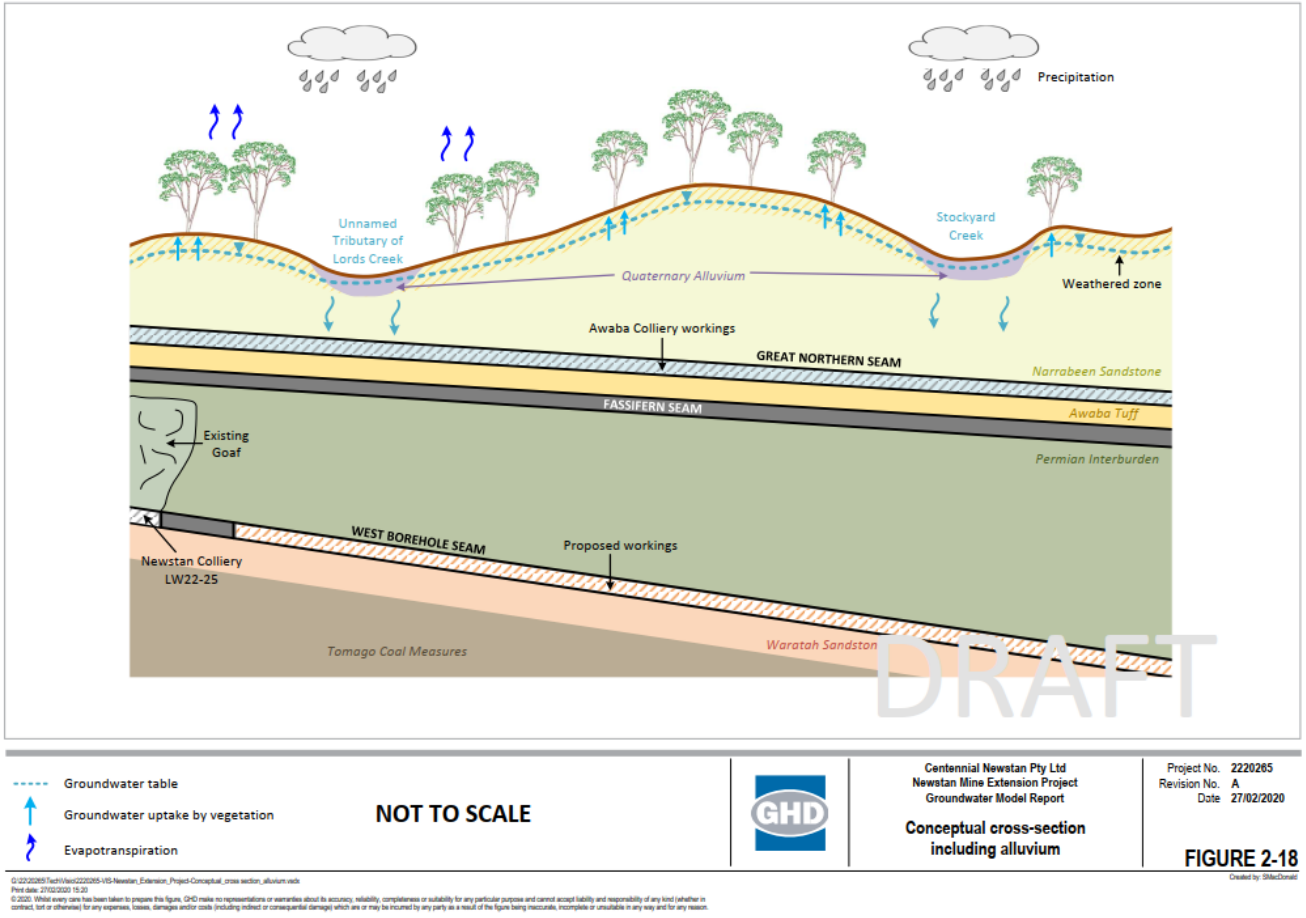


Figure 2 Conceptual Groundwater Model – Alluvium

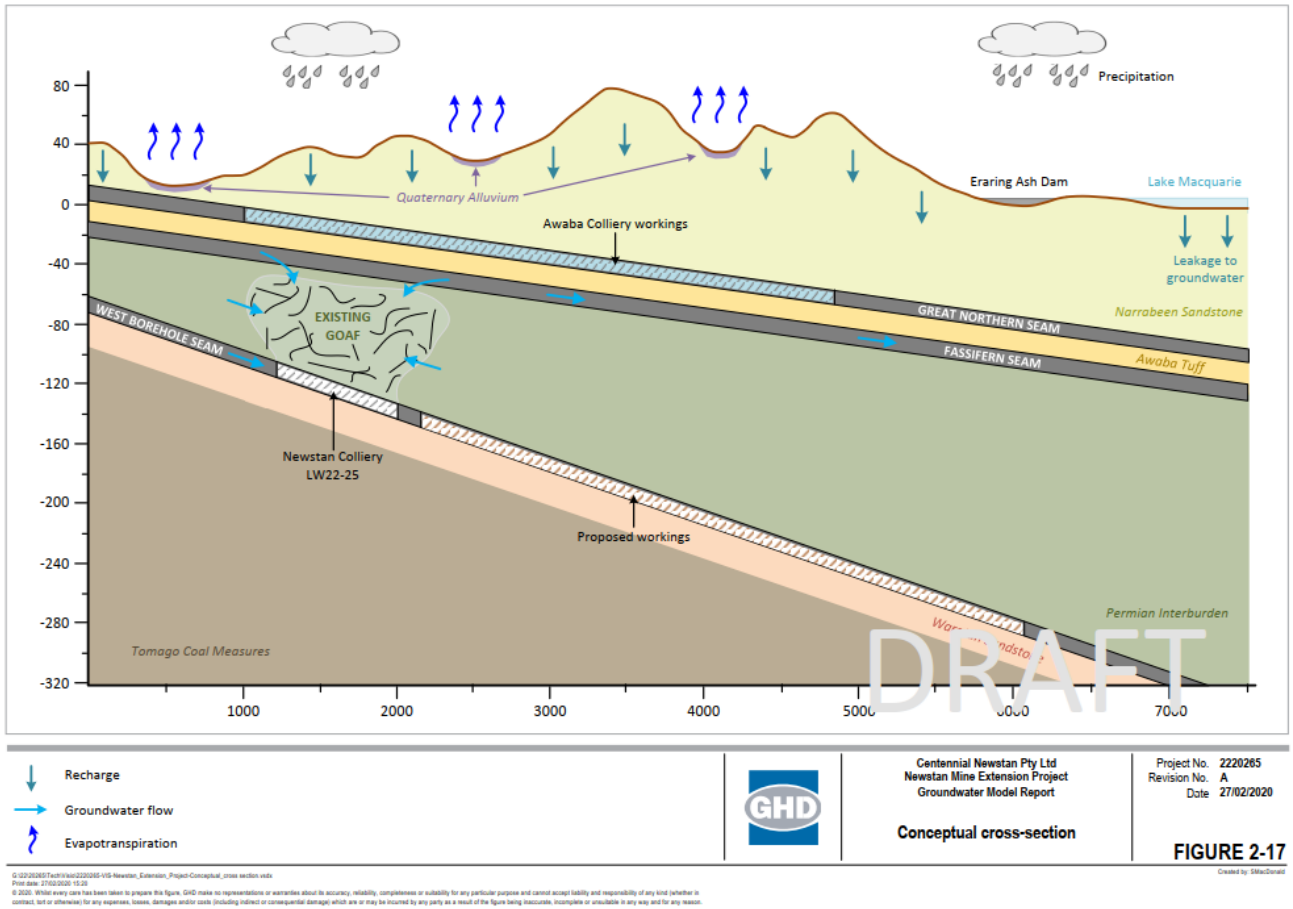


Figure 3 Conceptual Groundwater Model - Local

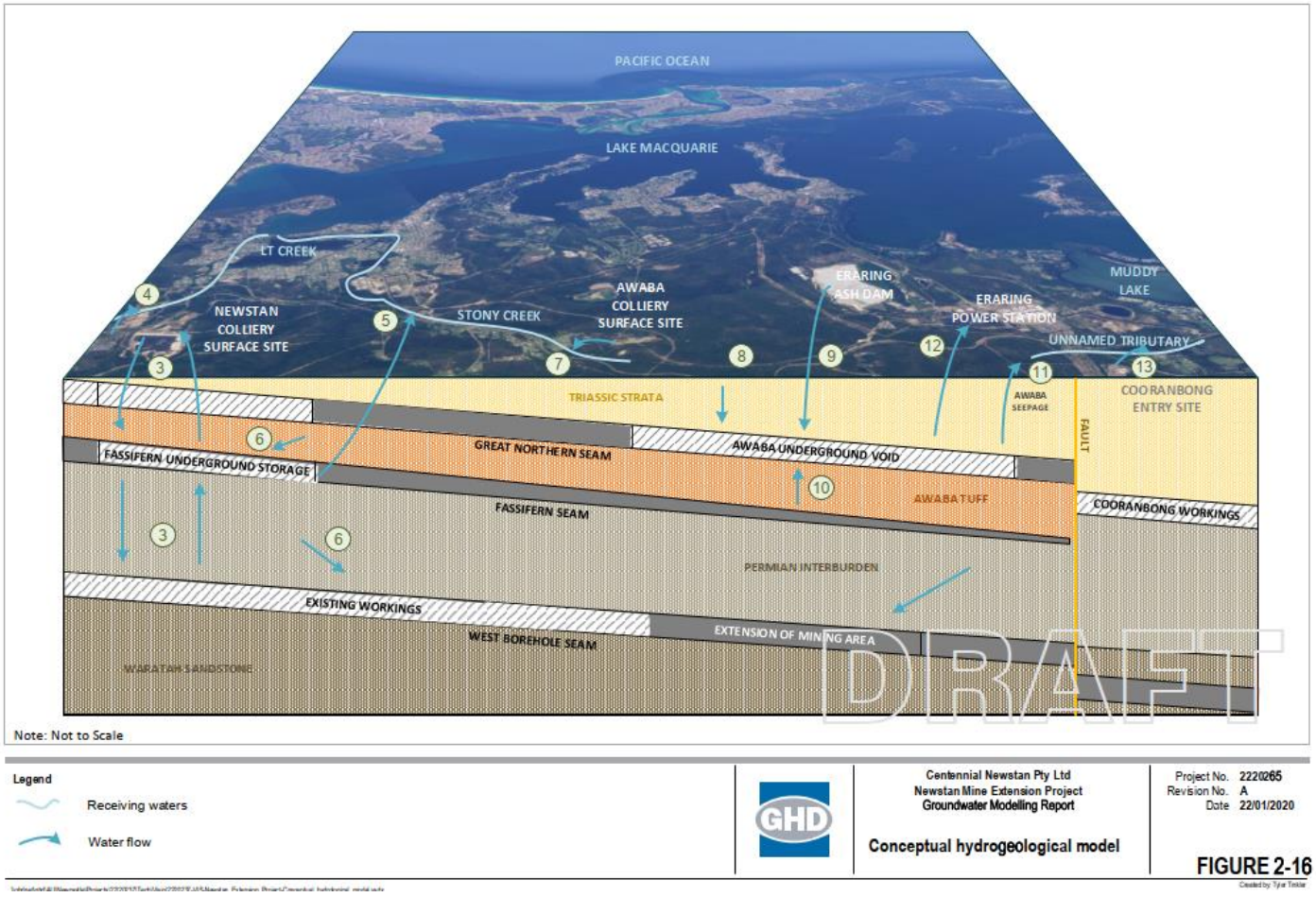


Figure 4 Conceptual Groundwater Model - Regional

4 Numerical Model

4.1 Groundwater Model Design

MODFLOW-USG software is used. A regional numerical groundwater model is constructed that covers an area of 921 km^2. The model extent is 25 km east to west and 45 km north to south. The model used quadtree mesh with the same level of cell refinement in all model layers. There are 12 layers representing stratigraphy. There is a total of 302,424 cells in the model. Grid refinement was undertaken around the mines and the alluvium with 50 m as the minimum cell size used in the grid. MODFLOW-USG pinch out option was not used.

Layers 1 represent alluvium and regolith while Layer 2 only represents regolith. Layer 3 of the model represents Narrabeen Sandstone. Layers 4, 6 and 10 represent Great Northern Seam, Fassifern Seam and West Borehole Seam, respectively. There are a few coal seams between the Fassifern Seam and the West Borehole Seam that are not included as separate layers in the model and are represented as combined Permian interburden units. As the pinch out option of MODFLOW-USG is not used, the coal seams are continuous throughout the model domain and have minimum thickness of 0.5 m where the coal seams are not present. Where the coal seams were present, a nominal thickness of 3 m was used.

The watercourses within the model domain were simulated using MODFLOW-USG River package. The model assumed no leakage from the water courses, and only baseflow to the rivers was enabled.

General Head Boundary (GHB) conditions were applied to the coal measures along the edges of the model domain. The GHB were assigned a head value of 0 m AHD along the eastern boundary of the model due to the proximity to the Pacific Ocean. GHBs were also used to represent Lake Macquarie in model layer 1. The GHBs that represent Lake Macquarie were assigned a conductance of 10,000 m^2/day and GHBs along the model boundary were assigned a conductance of 200 m^2/day. No reason is given why these conductance values were adopted.

Within the calibration and predictive runs, GHBs were also assigned to represent the flooding of the Fassifern Underground Storage, and Awaba Underground workings above the proposed mine workings. The report indicates the Awaba Underground has a constant head set at 15.768 m AHD and remained on for the duration of the predictive model. The Fassifern Underground Storage constant head set at 0 mAHD and was turned off at the end of 2034. The report indicates these constant levels were maintained in the predictive model, it is unclear if this also occurred in the calibration model. Doc#2 states that the predicted inflows are elevated due to the use of the GHB. However, there is no discussion in the report on the limitation this assumption has on the calibration parameters and ability of the model to predict impacts.

Recharge and evapotranspiration were represented using MODFLOW-USG RCH and EVT package. Two different recharge rates were applied to the regolith and alluvium in Layer 1. Recharge applied to Lake Macquarie was equal to the recharge applied to the alluvium. EVT of 0 m/day was applied to Lake Macquarie.

Historical mining at Newstan Colliery in the steady state and transient models are simulated using DRN boundary conditions which is an appropriate method. Drain cells were assigned to Layer 4 (Great Northern Seam), Layer 6 (Fassifern Seam) and Layer 10 (West Borehole seam). The drain cell elevation was assigned to 0.1 m above the floor of the model cell. The report suggests that Drain cells were assigned a conductance of 2,500 m^2/day, which was estimated by manually adjusting to match the observed inflows. The inference from this adopted method is that the drain cells do not fully desaturate the cells representing the mined coal layers. There is no justification of this in the modelling report. Typically, calibration is undertaken in which the drain cell conductance is set sufficiently high to fully desaturate the mined cells and then aquifer parameters, such as conductivities and\or storage properties, are adjusted to match both measured drawdown and inflow rates. The method adopted seems to be adjusting drawdown by increasing the relative influence (i.e. conductance) of the drain cells.

To represent the fracturing above the longwalls, a stacked drain approach was used. The stacked drain approach is common in simulating fracturing above the longwall panels. However, there is no information provided in the report on what Drain conductance values were used to represent the fractured zone.

Time-variant materials (TVM) package was not used. Therefore, the hydraulic properties of the mined seam remained unchanged upon the completion of the longwall mining.

The summary of the review of the model software, design (model extent, model cells and layers) are listed in **Table 2**.

4.2 Groundwater Model Calibration and Performance

A combined steady state and transient calibration model was built. The steady state model simulates the pre-1976 conditions and the transient mode simulates 1976 to 2019 conditions. The calibration has variable stress period lengths (monthly to annual).

An automatic calibration was undertaken using PEST (Doherty, 2016a, 2016b). 43 standpipe monitoring bores and 3 VWPs were used in the calibration, which included Mandalong Mine and Newstan mine monitoring bores. AE bores have been compared against the cumulative rainfall departure (CRD) and show match to climate seasonality. However, these bores were not included in the calibration. No reason is given for the exclusion of these bores from the calibration.

Parameters included in the calibration were horizontal conductivity, vertical to horizontal conductivity ratio, specific yield, specific storage, recharge and evapotranspiration rates.

Combined steady-state ad transient calibration statistics are presented together and show 8.3% scaled root mean squared (SRMS) for the calibration respectively, which is less than 10% recommend by the Australian Modelling Guidelines. The calibration scattergram (Doc#2 Figure 3-7) and the hydrographs shown in Doc#2 Appendix D indicate the model was able to capture the climate seasonality well. The model over predicted the groundwater levels in the alluvial bores but overall there is a reasonable match between observed and simulated in the alluvium bores. The calibration results show the model over predicts water levels in West Bores, and over and under predicts water levels in the Great Northern Seam.

The report would have benefited from inclusion of simulated water levels at the end of calibration in different layers of the model including alluvium and\or the simulated water table at the end of the calibration period. As it stands it is not possible for the reviewer to check the groundwater flow direction in the model to compare against the conceptual model. The report would also have benefitted from more detailed discussion on the residual maps and the calibration hydrographs to justify why the calibration was reasonable.

Table 3-6 of Doc #2 lists the calibration model parameters. The report states that "*Calibrated model parameters are generally similar (within an order of magnitude) to observed material parameters discussed in Section 2.1.11. The most notable discrepancy is for the West Borehole seam, where calibrated hydraulic conductivity is approximately one to two orders of magnitude lower than material properties discussed in Section 2.1.11*." The report would have been benefited from showing this comparison, such as using a box-and-whisker.

There is no discussion as to why West Borehole Seam calibrated conductivity does not match with field data and why it is two order of magnitude lower than the other coals seams in the model. The calibration specific storage for Layer 10 (West Borehole Seam) and Layer 5 (Awaba Tuff) are less than the minimum values shown in Table 3-4 of Doc#2. The horizontal conductivity of Permian interburden (Layers 7, 8 and 9) is calibrated to 6.5×10^{-6} m/day which is lower than the minimum field measurement conductivities discussed in Section 2.1.11 of Doc #2. The reviewer's opinion is that during the model calibration the horizonal conductivity values of Layers 7 to 9 were tied to each other. Therefore, the calibrated values for these three layers are the same. This means the depth dependence conductivity is not present in the Permian interburden units. Shallow and deeper parts of the interburden all have a conductivity of 6.5×10^{-6} m/day, which likely results in disconnection between the lower and upper layers of the model (i.e., no recharge to the Permian layers).

The water balance for the steady state and transient models are shown in Table 3-8 and Table 3-9 of Doc #2. Both models mass balance errors of less than 1% which indicates they are numerically stable.

As shown in the Table 3-8 and Table 3-9 of Doc #2, EVT OUT is the biggest component of the water balance for both steady state and transient model. The high EVT values are likely due to evapotranspiration acting as the main mechanism in removal of groundwater. RIV OUT which represents the groundwater contribution to the rivers shows significantly smaller values comparing the EVT. These results indicate that the rivers in the model are either assumed to be very shallow or the simulated groundwater levels always remain below base of the rivers which contradicts with the conceptual model presented in Doc #1 and the cross section in **Figure 2.**

The water balances presented for both steady-state and transient calibration indicate that the Lake Macquarie boundary conditions are adding water to the groundwater system.

The DRN OUT (i.e., mine inflows) for the transient calibration show an average simulated mine inflow of 5.1 ML/day for Newstan Colliery West Borehole Seam which does not match with the values shown in Figure 3-8 of Doc#2.

The water balance tables show that there is groundwater flow into Awaba Underground storage, while the model simulated groundwater flow out of the Fassifern Underground Storage. This may relate to the assumption of constant heads in the two underground areas, which does not match with observed changes in water levels as presented in Doc#1. This also indicates that the boundary conditions are controlling the modelled groundwater conditions in these layers. The GHB is adding and removing water from the system, rather than the model design (i.e. hydraulic parameters and recharge) capturing these observed conditions.

The summary of the review of the model calibration is listed **Table 3**.

4.3 Groundwater Model Predictions

Three model scenarios were included in the predictive modelling. These scenarios are listed in Table 4-1 of the Doc #2. The scenarios simulated were no mining, approved mining and, approved and proposed mining.

The predictive mine progression is not shown in the report.

The Drain package was used to simulate the long wall mining progression at Newstan. Horizontal and vertical hydraulic conductivities and storage values were not increased for the mined seam (the goaf) after mining. Therefore, the model parameters remained the same throughout the predictive model. For layers above the goaf, the height of continuous fracturing was assigned as 140 m based on model calibration. It is understood the stacked drain approach was used to simulate the fracturing above the goaf. However, no information is given in the report on the conductivity of the drain cells applied in the fractured area.

In areas where proposed workings are bord and pillar workings, mining was also simulated by progressively assigning drain cells to Layer 10 (West Borehole seam). There was no change in model parameter to represent the change in properties of the mined seam. The change in aquifer parameters as a result of mining is recommended as these parameters will be higher than the unaltered coal seams parameters. The change in parameters is particularly important in post-mining recovery. Using the aquifer parameters of unaltered coal seams for mined seams is not representing the proper water balance and can results in the model unrealistically predicting instant or very quick recovery

Table 5-1 and Table 5-2 of Doc #2 show the water balance for approved scenario and, approved and proposed scenario. As shown in the tables, EVT OUT is the biggest component of the water balance for both scenarios. The flow rates in the table show flow out of the GHB representing Awaba Underground to the groundwater system, which is opposite to what was reported in the calibration water table. The report states that the groundwater drawdown due to active mining in the vicinity of Awaba Underground is the reason for the change of flow in the Awaba Underground. It is also known that the water levels in Awaba Underground are controlled by pumping as discussed in Doc#1.

Table 5-3 of Doc #2 shows the change to the water balance due to the proposed mining. The table suggest the proposed mining does not have any impact on the river baseflow. Therefore, discussion on direct and indirect take from the alluvium and change in baseflow are not included in model prediction results.

The end of mining cumulative and incremental drawdowns are presented for different layers of the model in Appendix D of Doc#2. The colouring of the drawdown maps should be consistent to make it easier to compare the maps. Only drawdowns more than 1m should be shown in the figures. The report would have been benefited from showing maximum drawdown instead of end of mining drawdown. Some of the mined longwall panels are expected to be recovering by the completion of mining of the entire footprint. Therefore, drawdowns at the end of mining only shows drawdown where the panels have not recovered.

Figure D-5 of Doc #2 indicates there is no drawdown predicted in the alluvium due to the proposed mining. Figures D-6 and D-7 indicate the extents of incremental drawdown at the end of mining in Layer 4 (Great Northern Seam) and Layer 6 (Fassifern Seam) remain within the proposed mine footprint.

Figure D-4 of Doc#2 presents end of mining drawdown in Layer 10 (West Borehole seam). As shown in the figure the zone of impact has reached the model boundaries to the west and east and it is covering a large proportion of the model domain. Figure D-8 presents end of mining incremental drawdown in Layer 10. The figure only shows drawdowns above 5 m. However, the reviewer believes if drawdowns more than 1 m are plotted on the figure the extent drawdown will reach the south, west and east boundaries of the model. The zone of impact reaching the model boundaries indicates that either the model extent was not large enough to capture the impact or the parameters assigned to the layers were extreme and resulted in a very large zone of impact. The specific storage applied to Layer 10 and Layer 4 is 2.3×10^{-7} m^{-1}, which is a low value. This plus the low horizontal and vertical conductivity of the Permian interburden units means there is no recharge or leakage to West Borehole Seam. Therefore, it is possible that the combination of low recharge and low specific storage has resulted in large drawdown extents in West Borehole Seam.

The calibration showed that the model underpredicts water levels in West Borehole Seam, which means the model will under predict drawdown in Layer 10 in the prediction model. The report should provide a more detailed discussion of the predicted drawdowns. A discussion on why drawdown is so extensive in Layer 10 while there is hardly any drawdown in the layers above and what is the main driver for the drawdowns.

Section 7.1 of Doc #2 discusses a sensitivity run with a fracturing height of 220 m above the coal seam. Stacked drains are applied to Layer 7 to 9 as well Layer 4 and 5. Stacked drains were also activated in Layer 4 (Great Northern seam) and Layer 3 (Narrabeen Sandstone) in cells that were less than 220 m above the West Borehole seam. The inflow results in Figure 5-6 show the higher fractured height increased the simulated inflows by up to 50%. There are no drawdown maps presented for this sensitivity run. The reviewer believes the stacked drain in Layer 7 to Layer 9 should results in a larger zone of drawdown in Layer 6.

The unnumbered section of the report discusses the sensitivity of the Awaba underground void to fracture height. Figure 5-8 of Doc#2 shows approximately 2 ML/day change in flow out of the Awaba Underground Void as a result of high fracture height. The report states that "*The modelled volume of groundwater flow out of the Awaba underground void is likely influenced by the presence of a GHB to simulate the flooded Awaba workings. This provides a constant source of groundwater inflow into the model that likely overestimates the rate of seepage out of Awaba."* The reviewer believes sensitivity runs with higher and lower GHB conductance would have given a better understanding of the sensitivity of the model results to the GHB boundary conditions.

The recovery model set up and results are missing from the report. Therefore, it is not possible to review how the groundwater levels will recovery post-mining.

5 Conclusions and Considerations

Doc#1 and Doc#2 provides a basis for conceptualisation of the groundwater system and the numerical model. Reasonable amounts of data are considered in the conceptual model and the report provides an adequate summary of the data used for the conceptual model. However, further assessment of surface water and groundwater interactions, fault structures and post-closure groundwater conditions is recommended to fully understand potential impacts associated with the Project.

The model design and construction are appropriate. The modelling approach used in this study allows for the simulation of a multilayered and complex hydrogeological system. The model calibration is satisfactory. The transient calibration statistics show a good overall calibration performance. The overall match between observed and measured levels in the transient calibration is reasonable for most of the bores. However, the match between observed and simulated heads is poor in Layer 10 (West Borehole seam). The RIV package set up should be revised to provide consistency with the conceptual model. I

While the zone of depressurization due to the proposed mining is very extensive in Layer 10 (West Borehole seam) and reaches the boundaries of the model, there is no drawdown predicted in the alluvium. The model also predicts the proposed mine has no impact on the alluvium and baseflow. This is likely due to the current setup of rivers in the model, goaf height assumption (i.e., 140m) and the model parametrization such as low specific storage in West Borehole seam and Permian hydraulic conductivity not be depth dependence. The post-mining prediction model is missing from the report.

The overall conclusion is that while the conceptual model and model calibration are reasonable, the following improvements should be made to improve the predictive model:

- present starting groundwater conditions (groundwater heads) to understand how the current groundwater regime is captured in the model;
- the removal of boundary conditions within Awaba Colliery that buffer potential impacts;
- explore the presence and influence of structure features; and
- run a post-closure model and present results.

Based upon the information provided to date for the peer review, the reviewers are not able to draw a conclusion on model fitness to meet the objectives of the study. It is possible that the current model parameters and assumptions are a reasonable representation of the hydrogeologic environment, which result in the model predicting no impacts in the shallow aquifers. However, the reviewers have identified some assumptions and methods by which the model was setup and calibrated that would not be considered conservative on face value from the perspective of assessing impacts. However, this can only be determined by reviewing the uncertainty analysis on the model predictions that specifically test these assumptions and model setup.

It is also not possible to assess whether the predicted impacts extent would increase or decrease in post-mining. This can be assessed only when the post-mining recovery results are presented.

APPENDIX A

Model Review

Conceptualisation

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
3.1	Is the conceptual model consistent with prior knowledge?		Unknown	No	Maybe	Yes			
3.2	Is the conceptual model consistent with project budget?		Unknown	No	Maybe	Yes			
3.3	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes			
3.4	Is the conceptual model consistent with project deadline?		Unknown	No	Maybe	Yes			
3.5	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very Good			The conceptual model is presented in both Doc#1 and Doc#2 with different information provided in both. The information is presented, but improvements could be made to make it clearer and provide further discussion on matters raised such as faults (Awaba Seepage), sinkholes, paleochannels and justification of the fracture height conceptualisation.
3.6	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			Subsequent graphical representations were provided to illustrate interaction with alluvium. The figures do not include structural features such as the faults, sinkholes or paleoachannels.
3.7	Is the conceptual model unnecessarily simple?			Yes	No				Detail is provided on most matters. However further presentation of data to justify some points of the conceptualisation required.
3.8	Is the conceptual model unnecessarily complex?			Yes	No				

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
3.9	If any possibly key process is missing, is the justification adequate?		Missing	Deficient	Adequate	Very Good			Detail on regional processes are captured, including water level trends and water storage. Further justification is required on localised features such as faults (Awaba Seepage), sinkholes, paleochannels and fracture height conceptualisation.
3.10	Are limitations and uncertainties described?			No	Maybe	Yes			Text includes general discussion of uncertainty and assessment includes testing of parameter and scenario uncertainties. However, no explicit discussion on the uncertainty as outlined within IESC Explanatory Note for Uncertainty Analysis (IESC 2018), which covers four types of uncertainty, structural/conceptual, parameterisation, measurement error and scenario uncertainties. The review identified potential structural/conceptual uncertainties.
3.11	Has the conceptual model been reviewed independently?		Unknown	No	Maybe	Yes			
3.	TOTAL SCORE								

Model Design

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
4.1	Is the choice of mathematical model appropriate (analytical / numerical)?			No	Maybe	Yes			MODFLOW-USG is used
4.2	Is the spatial extent of the model appropriate?			No	Maybe	Yes			The predicted drawdowns in Layer 10 reached the model boundaries.
4.3	Is the spatial discretisation scale appropriate?		Missing	No	Maybe	Yes			Grid refinement within and around the mine footprint and along the creek lines.
4.4	Is the number of model layers justified?		Missing	No	Maybe	Yes			12 layers.
4.5	Is steady state simulated?		Missing	Deficient	Adequate	Very Good			Steady state model was built to simulate pre-1976 conditions
4.6	Is transient behaviour simulated?		Missing	Deficient	Adequate	Very Good			1976-2019
4.7	Is the stress period reasonable?		Missing	No	Maybe	Yes			Monthly and annual stress periods are used which allow climate seasonality to be captured in the transient calibration model.
4.8	Is the number of time steps per stress period justified?		Missing	Deficient	Adequate	Very Good			Automatically controlled
4.9	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very Good			GHB and no flow boundary conditions applied to edges of the model. RIR boundary condition should be checked. The water balance indicates the rivers could have been set up too shallow.
4.10	Are boundary condition locations consistent with the model grid configuration?		Missing	No	Maybe	Yes			
4.11	Are the initial conditions defensible?		Missing	Deficient	Adequate	Very Good			Initial conditions for the transient model are generated by the steady state model.
4.12	Is it clear what software has been selected?		Missing	No	Maybe	Yes			MODFLOW-USG with TVM capability
4.13	Is the software appropriate for the objectives of the study?			No	Maybe	Yes			
4.14	Is the software reputable?			No	Maybe	Yes			
4.15	Is the software in common use and accessible to reviewers?			No	Maybe	Yes			USGS open source software

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
4.16	How detailed is the rainfall recharge algorithm?		Missing	Deficient	Adequate	Very Good			Fraction of actual of historical rainfall is used in the model.

Calibration

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.1	Is sufficient data available for spatial calibration?			No	Maybe	Yes			The special distribution of the calibration points is limited to the site and Mandalong Mine.
5.2	Is sufficient data available for temporal calibration?			No	Maybe	Yes			Some data is available. Hydrographs are provided in Appendix D. Some bores are compared against the CRD but missing from the calibration.
5.3	Does the model claim to be adequately calibrated for the purpose of the study?		Missing	No	Maybe	Yes			
5.4	Are calibration difficulties acknowledged?		Missing	Deficient	Adequate	Very Good			A discussion on calibration should be added to the report.
5.5	Is it clear whether calibration is automated or trial-and-error?		Missing	No	Maybe	Yes			Automatic and manual combined approach using PEST HP
5.6	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			Transient scattergram, residuals map and statistics show %RMS of less than 10% which is considered adequate). Calibration statistics: Described in Section 6.3. Scattergrams: Figure 3-7 (Doc #2). Residuals maps: Figures D-1 and D-2 (Doc #2). Hydrographs: Appendix D (Doc #2). The model was manually calibrated to inflows by adjusting Drain conductance. Figure 3-8 shows the model over predicts comparing to the observed inflows. Head contours are not provided.

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.7	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			Poor to good match between observation and simulated water levels as shown by calibration hydrographs: in Appendix D (Doc #2).
5.8	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			Good match between observed and simulated heads in Layer 1 (unconsolidated sediments).
5.9	Are parts of the model well calibrated?		Unknown	No	Maybe	Yes			Yes.
5.10	Are parts of the model poorly calibrated?		Unknown	Yes	Maybe	No			The calibration is poor in West Borehole Seam (Layer 10)
5.11	Is the model calibrated to data from different hydrological regimes?		Unknown	No	Maybe	Yes			
5.12	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			Uniform parameter distribution in all the layers. Most calibrated hydraulic properties are consistent with field measurements listed Section 2.1.11 of Doc #2. Calibrated horizontal K values in Layer 10 is less than all the field measurements. No depth dependence for conductivity in Permian units. Permian interburden units all have calibrated Horizontal K of 6e-6.
5.13	Is a calibration statistic reported?		Missing	No	Maybe	Yes			Both steady state and trainset calibration are satisfactory.
5.14	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			8.3%SRMS, 6.4 mRMS.
5.15	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Mining complexity; homogeneous K per layer (same depth); some thick layers (assumed single head)
5.	**TOTAL SCORE**								

Prediction

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
7.1	Is prediction made for steady state conditions?		Missing	No	Maybe	Yes			Transient predictive model
7.2	Is prediction made for transient conditions?		Missing	No	Maybe	Yes			
7.3	Are the assumed stresses reasonable?		Missing	Deficient	Adequate	Very Good			More information is required on stacked drain used to simulate fracturing above the longwalls.
7.4	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			
7.5	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			Long-term average during prediction. No climate scenarios.
7.6	Have multiple scenarios been run for operational alternatives?		Missing	Deficient	Adequate	Very Good			Yes. One mine plan simulated. 3 scenarios, no mining, approved and, approved and proposed.
7.7	Are model predictions made at scales consistent with model space and time scales?		Missing	No	Maybe	Yes			
7.8	Are the model predictions plausible?			No	Maybe	Yes			-Recovery model set up and results are required. -The extent of drawdown in Layer 10 reached the boundaries of the model.

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
7.9	Are model predictions likely to be impacted by constraining boundary conditions?		Unknown	Yes	Maybe	No			The end of mining incremental and cumulative drawdown in Layer 10 reached the model boundaries. Therefore, there is a possibility the model boundaries are constraining the zone of impact. Using GHB boundary conditions within Awaba Colliery have impacted the model prediction and should be removed.
7.10	If boundary conditions affect the predictions, are the predictions defensible?		Unknown	No	Maybe	Yes			The predictions are likely to be defensible in Layer 1 to 6. However, layer 10 drawdown needs attention.
7.	**TOTAL SCORE**								

Sensitivity: Goaf fracture height

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
8.1	Is there discussion of qualitative sensitivities found during calibration?		Missing	Deficient	Adequate	Very Good			Only predictive sensitivity. Fracture height of 200 could have been tested in the calibration model too.
8.2	Has a post-calibration sensitivity analysis been performed?		Missing	Deficient	Adequate	Very Good			Only predictive sensitivity
8.3	Is the sensitivity analysis sufficiently intensive for key parameters?	NA	Missing	Deficient	Adequate	Very Good			
8.4	Is there a graphical presentation of sensitivity behaviour?		Missing	Deficient	Adequate	Very Good			Sensitivity of inflows is presented. Sensitivity of the drawdowns is missing. Uncertainty Analysis report has been undertaken to address this.
8.5	Are sensitivities classified as Type I to Type IV?	NA	Missing	No		Yes			See Guidelines Section 5.3

Q.	QUESTION	N/A or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
8.6	Has a Type IV sensitivity been recognised?		Missing	Yes	Maybe	No			See Guidelines Section 5.3
8.7	Is there a list of ranked sensitivity coefficients?	NA	Missing	Deficient	Adequate	Very Good			
8.8	Are sensitivity results used to qualify the reliability of model calibration?	NA	Missing	Deficient	Adequate	Very Good			
8.9	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			
8.	**TOTAL SCORE**								

ASIA PACIFIC OFFICES

BRISBANE
Level 2, 15 Astor Terrace
Spring Hill QLD 4000
Australia
T: +61 7 3858 4800
F: +61 7 3858 4801

CANBERRA
GPO 410
Canberra ACT 2600
Australia
T: +61 2 6287 0800
F: +61 2 9427 8200

DARWIN
Unit 5, 21 Parap Road
Parap NT 0820
Australia
T: +61 8 8998 0100
F: +61 8 9370 0101

GOLD COAST
Level 2, 194 Varsity Parade
Varsity Lakes QLD 4227
Australia
M: +61 438 763 516

MACKAY
21 River Street
Mackay QLD 4740
Australia
T: +61 7 3181 3300

MELBOURNE
Suite 2, 2 Domville Avenue
Hawthorn VIC 3122
Australia
T: +61 3 9249 9400
F: +61 3 9249 9499

NEWCASTLE
10 Kings Road
New Lambton NSW 2305
Australia
T: +61 2 4037 3200
F: +61 2 4037 3201

PERTH
Ground Floor, 503 Murray Street
Perth WA 6000
Australia
T: +61 8 9422 5900
F: +61 8 9422 5901

SYDNEY
2 Lincoln Street
Lane Cove NSW 2066
Australia
T: +61 2 9427 8100
F: +61 2 9427 8200

TOWNSVILLE
Level 1, 514 Sturt Street
Townsville QLD 4810
Australia
T: +61 7 4722 8000
F: +61 7 4722 8001

TOWNSVILLE SOUTH
12 Cannan Street
Townsville South QLD 4810
Australia
T: +61 7 4772 6500

WOLLONGONG
Level 1, The Central Building
UoW Innovation Campus
North Wollongong NSW 2500
Australia
T: +61 404 939 922

AUCKLAND
68 Beach Road
Auckland 1010
New Zealand
T: 0800 757 695

NELSON
6/A Cambridge Street
Richmond, Nelson 7020
New Zealand
T: +64 274 898 628

03 June 2020

Lachlan Hammersley
Manager Water Engineering
Centennial Newstan Pty Ltd
100 Miller Road
Fassifern NSW 2283

Our ref:22-SO-2111435880-23
Your ref:

Dear Lachlan

Newstan Extension Project
Response to Independent Model Review

GHD Pty Ltd (GHD) prepared the *Newstan Extension Project: Groundwater Impact Assessment* (GHD, 2020a) and the *Newstan Extension Project: Groundwater Model Report* (GHD, 2020b). These reports outline the development of the numerical groundwater flow model used to predict potential impacts of the project on groundwater resources. In addition, GHD prepared the *Newstan Extension Project: Surface Water Impact Assessment* (GHD, 2020c), which describes the water balance model developed for the project.

SLR Consulting Australia Pty Ltd (SLR) was engaged by Centennial Newstan as an Independent Model Reviewer. SLR prepared the *Newstan Extension Groundwater Peer Review* (SLR, 2020), based on their review of GHD (2020a) and GHD (2020b). SLR did not review GHD (2020c). This letter report has been prepared to respond to the findings of SLR (2020).

SLR (2020) concluded that while the conceptual model and model calibration are reasonable and the model is generally fit for purpose, the report claims that the following limitations exist within the model and report:

- Influence of structural features/faults on connected fracturing and post-closure flow pathways, particularly in relation to the Awaba Seep.
- Hydraulic parameters of paleochannels across the project area and potential influence on connected fracturing.
- General Head Boundary (GHB) used to control water levels in the Awaba Underground and its influence on the model calibration and predictions.

In addition, SLR raises other issues throughout the peer review report which have been addressed here. These issues include:

- Presenting starting groundwater conditions (groundwater heads) to understand how the current groundwater regime is captured in the model.
- Running a post closure model and presenting results.
- Calibration and prediction of groundwater levels within the West Borehole seam.
- Details regarding set up of the stacked drains and drain conductance.

Responses to the above points are discussed in the following sections.

1 Influence of structural features

Geological structural features are discussed in Section 3.4 and Section 3.4.1 of GHD (2020a). These geological structural features include:

- Seam split of the West Borehole seam to the east of the Extension of Mining Area into the Young Wallsend, Yard and Borehole seams.
- Faulting of the Great Northern seam to the south of Awaba Colliery.
- A number of faults in the vicinity of the proposed workings as mapped and interpreted by MSEC (2019).

There is a lack of groundwater monitoring data in the vicinity of the mapped faults to verify if these faults are a conduit or barrier to groundwater flow. Monitoring bores installed on either side of a fault may assist in verifying if groundwater flow is disconnected across the fault. Nevertheless, it is known that the faulting of the Great Northern seam provides a conduit for groundwater flow from the Awaba underground void to the surface in the area known as the Awaba Seep. This transfer is represented in the water balance model (GHD, 2020c). There is no information to suggest that this system of faults extends down to the West Borehole seam in this area and therefore has not been represented in the groundwater model.

Existing workings at Newstan Colliery have intersected a number of the mapped faults. There is limited monitoring data in the vicinity of these faults to determine if mining through these faults has caused significant drawdown in the overlying strata. The occurrence of significant drawdown may signify that the fault is a conduit of groundwater flow. Based on the available data from the monitoring network at Newstan Colliery, the only groundwater drawdown evident within strata above the West Borehole seam is attributable to historical workings within the Great Northern seam at Cooranbong Colliery, located to the south of the Extension of Mining Area. Trends in groundwater monitoring data are discussed in Section 4.1.1 of GHD (2020a).

Recorded groundwater inflows into existing West Borehole seam workings do not indicate that faults are acting as a conduit to groundwater flow. Existing longwall panels that undermine the Awaba underground void include Longwalls 22-25. The location of these existing panels is shown in Figure 2-8 of GHD (2020b). As discussed in Section 4.2.1 of GHD (2020a), approximately 0.25 ML/day of groundwater inflow to the West Borehole seam workings occurs in Longwalls 22-25. The source of this groundwater is most likely from the surrounding unmined West Borehole seam. This volume of groundwater inflow does not indicate a direct connection between the Awaba underground void and the West Borehole seam workings via a network of faults. By extension, the volume of groundwater inflow does not indicate the presence of a direct connection between the West Borehole seam and the shallow strata (such as alluvium) that overlies the Awaba underground void.

2 Influence of paleochannels

Paleochannels within the Extension of Mining Area have been mapped by MSEC (2019) and are shown in Figure 2-8 of GHD (2020b). No hydraulic parameters are available for these paleochannels.

Review of MSEC (2019) indicates the paleochannels were only taken into account in subsidence calculations in terms of their impact on geology. There is no information in terms of hydraulic properties of the paleochannel. There is limited information on the location of paleochannels with the exception of in the immediate vicinity of the workings. A paleochannel has been undermined by the existing Newstan Colliery West Borehole seam workings. This paleochannel was undermined by first workings only. The undermined paleochannel does not appear to influence inflows into the West Borehole seam workings. Therefore, with the exception of their influence on geology, paleochannels were excluded from the model.

3 Boundary conditions within Awaba Colliery

As discussed in Section 3.5.4 of GHD (2020b), GHBs have been used to simulate the water level within the flooded Awaba Colliery workings. Based on available monitoring data, flooding of the Awaba workings commenced in 2013 and therefore GHBs in the Awaba Colliery workings were activated at this time. GHB elevations were varied in accordance with water level observations in the Awaba underground void.

As outlined in GHD (2020c), the Awaba underground void is recharged by enhanced infiltration from the surface via sinkholes. Based on GHD's experience with modelling flooded shallow mine voids within the Newcastle Coalfield, a water balance model approach is more effective for predicting water levels within the void than a groundwater model which would not only require a more complex rainfall recharge model but also a more detailed representation of the mine void space. Therefore the Awaba underground void has been modelled in more detail by the water balance presented in GHD (2020c) and the groundwater model, which focuses on impacts due to mining within the West Borehole seam, has simplified the representation of the Awaba underground void by adopting a GHB. This is a conservative approach in terms of the prediction of groundwater inflows into the West Borehole seam should there be hydraulic connection between the proposed mine workings and the Awaba underground void (as demonstrated by the increased height of continuous fracturing scenario presented in Section 5.8.1 of GHD (2020b)). However, it is noted that SLR (2020) suggests that there is potential the GHB may be shielding the shallow layers from impacts of mining in the West Borehole seam. GHD considers that the alternative approach of enhancing recharge above the Awaba underground void to maintain the water level within the void would result in a similar effect. This alternative approach may be implemented in a future model update, although GHD believes that it will have minimal effect on model predictions.

As the Awaba Colliery workings are currently flooded, it would be necessary for the workings to depressurise, or partly depressurise, for impacts of proposed mining to extend to the shallow layers above the Awaba Colliery workings. As discussed in Section 1, existing longwall panels that undermine the Awaba underground void include Longwalls 22-25. The location of these existing panels is shown in Figure 2-8 of GHD (2020b). As discussed in Section 4.2.1 of GHD (2020a), approximately 0.25 ML/day of groundwater inflow to the West Borehole seam workings occurs in Longwalls 22-25. Therefore this volume of groundwater inflow does not indicate a direct connection between the Awaba underground void and the West Borehole seam workings. The thickness of interburden between the Awaba Colliery workings and the West Borehole seam is greater in the vicinity of the proposed workings than above Longwalls 22-25. Therefore it is considered unlikely that the proposed workings will result in significant depressurisation of the Awaba workings and subsequent impacts on shallow groundwater.

4 Starting groundwater conditions

It is assumed that the SLR (2020) comment regarding presenting starting groundwater conditions is referring to presenting groundwater levels for current conditions. Current conditions corresponds with the end of the calibration period. Figure 3-8 of GHD (2020b) represents the water table head for the end of the calibration period.

The modelled water table contours indicate that the groundwater flow direction generally reflects the topography. Water table head is elevated along catchment boundaries and decreases towards creek lines and Lake Macquarie. This is consistent with the conceptualisation of shallow groundwater levels discussed Section 2.1.6 of GHD (2020b).

Overall it should be noted that GHD utilised all available field data in the development and calibration of the model, including groundwater level data and aquifer property data. AE bore data were not used because the bores have not been surveyed and it was not possible to convert groundwater depths to elevations.

5 Post closure model

As discussed in Section 4.2 of GHD (2020b) a post closure model was developed and was run to January 2635; 600 years after the end of mining. Details regarding how drain cells were turned off and material properties were modified for the post closure model are provided in Section 4.2 of GHD (2020b). In particular, the horizontal hydraulic conductivity of layers within the zone of continuous fracturing above existing and proposed Newstan workings (i.e. up to a height of 140 m), as well as within the Newstan mine workings, were increased by 100 times for the post mining model.

The predictions for this period of time are presented in Section 5 of GHD (2020b) including flow budget and potential impacts on Eraring Ash Dam, Awaba workings and Fassifern Underground Storage. The post mining water table 600 years after the end of mining is shown in Figure E-10 of GHD (2020b). Figure E-10 shows that the post-mining water table is similar to the modelled water table at the end of calibration, shown in Figure 3-8 of GHD (2020b).

6 Groundwater levels within the West Borehole seam

As noted by SLR (2020), the zone of depressurisation within the West Borehole seam extends to the model boundaries. This is considered to be attributable to the fact that calibration of material properties of the West Borehole seam is based on limited groundwater monitoring data, primarily two vibrating wire piezometers (CN036 and CN038) within the West Borehole seam with data reported between 2005 and 2009. The quality of this data is unknown.

The calibration constrained uncertainty analysis utilised parameter sets with horizontal hydraulic conductivity values for the West Borehole seam and overlying Permian interburden up to one order of magnitude higher than the best fit calibrated values, however was not able to run even higher values for these parameters due to the calibration constraints. As more monitoring data becomes available for the West Borehole seam, the model will be updated and drawdown predictions for the West Borehole seam will be reassessed. As noted by SLR, it is unlikely that this is affecting predictions of drawdown in upper aquifers.

7 Stacked drains and drain conductance

SLR (2020) states that there is insufficient detail on how the stacked drains were set up in the model. Stacked drains were used to represent the height of depressurisation above secondary workings. It is an industry standard approach that does not require changing material properties of fractured strata during mining. Therefore it is not necessary to use the Time-Variant Materials (TVM) package. Once mining is complete and drains are turned off, material properties are then changed within the post-mining model to represent the enhanced permeability of strata within the fracture zone.

Details regarding the set up of the stacked drains are provided in Sections 2.2.5, 3.5 and 3.6.1 of GHD (2020b). Drain cell conductance of 2,500 m2/day is very high considering the relatively low hydraulic conductivity of the West Borehole seam and overlying Permian interburden and cell size adopted in the mining areas and results in full desaturation of drained cells.

8 References

GHD (2020a) *Newstan Extension Project: Groundwater Impact Assessment,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited.

GHD (2020b) *Newstan Extension Project: Groundwater Model Report,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited.

GHD (2020c) *Newstan Extension Project: Surface Water Impact Assessment,* prepared by GHD Pty Ltd for Centennial Newstan Pty Limited.

MSEC (2019) Newstan Colliery: Mine Extension Project – Subsidence Predictions and Impact Assessments for Natural and Built Features due to the proposed 201 to 218 Panels in Support *of the Environmental Impact Statement*, draft report, prepared by Mine Subsidence Engineering Consultants for Centennial Newstan Pty Limited, reference MSEC1042.

SLR (2020) *Newstan Extension: Groundwater Peer Review*, prepared by SLR Consulting Australia Pty Ltd for Centennial Coal Pty Ltd.

Sincerely
GHD



Stuart Gray
Technical Director - Hydrogeology
+61 2 49799017

Appendix H – Uncertainty analysis

Centennial Newstan Pty Ltd

Newstan Extension Project GIA
Uncertainty Analysis

April 2020

Table of contents

1. Overview 1
   1.1 Disclaimer 1
2. Set up 2
   2.1 Approach 2
   2.2 Model set up 2
3. Parameterisation 3
   3.1 Prior parameterisation 3
   3.2 Posterior parameter realisations 7
4. Predictive model runs 11
   4.1 Predictive outputs 11
5. References 32

Table index

Table 3-1 Parameters with log normal prior distributions applied 3

Table 3-2 Parameters with log-uniform and uniform prior distributions 4

Figure index

Figure 3-1 Input (prior) parameter histograms – horizontal hydraulic conductivity and vertical anisotropy 5

Figure 3-2 Input (prior) parameter histograms – specific storage and specific yield 6

Figure 3-3 Input (prior) parameter histograms – rainfall recharge and evapotranspiration rate 7

Figure 3-4 Posterior parameter histograms – horizontal hydraulic conductivity and vertical anisotropy 8

Figure 3-5 Posterior parameter histograms – specific storage and specific yield 9

Figure 3-6 Posterior parameter histograms – rainfall recharge and evapotranspiration rate 10

Figure 3-7 10th percentile maximum incremental groundwater drawdown Layer 10: West Borehole Seam 12

Figure 3-8 50th percentile maximum incremental groundwater drawdown Layer 10: West Borehole Seam 13

Figure 3-9 90th percentile maximum incremental groundwater drawdown Layer 10: West Borehole Seam 14

Figure 3-10 10th percentile maximum cumulative groundwater drawdown Layer 10: West Borehole Seam 15

Figure 3-11 50th percentile maximum cumulative groundwater drawdown Layer 10: West Borehole Seam 16
Figure 3-12 90th percentile maximum cumulative groundwater drawdown Layer 10: West Borehole Seam 17
Figure 3-13 10th percentile maximum incremental groundwater drawdown water table 18
Figure 3-14 50th percentile maximum incremental groundwater drawdown water table 19
Figure 3-15 90th percentile maximum incremental groundwater drawdown water table 20
Figure 3-16 10th percentile maximum cumulative groundwater drawdown water table 21
Figure 3-17 50th percentile maximum cumulative groundwater drawdown water table 22
Figure 3-18 90th percentile maximum cumulative groundwater drawdown water table 23
Figure 3-19 Cumulative and incremental drawdown at bore GW043431 24
Figure 3-20 Cumulative and incremental drawdown at bore GW052111 24
Figure 3-21 Cumulative and incremental drawdown at GW052381 25
Figure 3-22 Cumulative and incremental drawdown at GW053438 25
Figure 3-23 Cumulative and incremental drawdown at GW061202 26
Figure 3-24 Cumulative and incremental drawdown at GW063947 26
Figure 3-25 Cumulative and incremental drawdown at GW078354 27
Figure 3-26 Cumulative and incremental drawdown at GW078363 27
Figure 3-27 Cumulative and incremental drawdown at GW078591 28
Figure 3-28 Cumulative and incremental drawdown at GW203292 28
Figure 3-29 Modelled Newstan Colliery West Borehole seam groundwater inflows 29
Figure 3-30 Reduction in groundwater inflow into the Awaba void 29
Figure 3-31 Net groundwater flow into Fassifern Underground Storage 30
Figure 3-32 Net leakage from Eraring Ash Dam 30
Figure 4-27 Baseflow 90% probability of exceedance 31

1. Overview

The groundwater modelling process simplifies complex natural systems in both space and time based upon the available data and numerical considerations. Traditional groundwater modelling approaches have adopted the development of a single model to predict potential outcomes, however this approach does not incorporate the uncertainty inherent in model parameterization and conceptualization. Uncertainty analysis accepts that there is no single 'correct' prediction, and seeks to estimate a range of potential predictions.

An uncertainty analysis has been undertaken to support the groundwater modelling assessment at Newstan Colliery. The uncertainty analysis is based upon the numerical model documented with the *Newstan Colliery Extension of Mining Project Groundwater Model Report* (GHD, 2020a). Specifics related to the set-up and implementation of uncertainty analysis are outlined in this report.

Uncertainty analysis outlined in this report is stochastic modelling with Bayesian probability quantification. This is in accordance with level 3 uncertainty analysis outlined in the IESC Explanatory Note (Middlemis and Peeters, 2018).

A non-linear uncertainty analysis utilising a calibration-constrained Monte Carlo approach has been implemented. Guidance on the approach has been sourced from various resources including Middlemis and Peeters (2018), Doherty *et al* (2010), Doherty (2016) and Barnett *et al* (2012).

At the time of writing, the uncertainty analysis was in progress, with the predictive simulations yet to be completed. This memo has been prepared to document the approach implemented, and will be updated following completion of the predictive analysis.

1.1 Disclaimer

This Report has been prepared by GHD for Centennial Newstan Pty Ltd and may only be used and relied on by Centennial Newstan Pty Ltd for the purpose agreed between GHD and the Centennial Newstan Pty Ltd as set out in Section 1 of this Report.

GHD otherwise disclaims responsibility to any person other than Centennial Newstan Pty Ltd arising in connection with this Report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this Report were limited to those specifically detailed in the Report and are subject to the scope limitations set out in the Report.

The opinions, conclusions and any recommendations in this Report are based on conditions encountered and information reviewed at the date of preparation of the Report. GHD has no responsibility or obligation to update this Report to account for events or changes occurring subsequent to the date that the Report was prepared. Specifically, this Report does not take into account the effects, implications and consequences of or responses to COVID-19, which is a highly dynamic situation and rapidly changing. These effects, implications, consequences of and responses to COVID-19 may have a material effect on the opinions, conclusions, recommendations, assumptions, qualifications and limitations in this Report, and the entire Report must be re-examined and revisited in light of COVID-19. Where this Report is relied on or used without obtaining this further advice from GHD, to the maximum extent permitted by law, GHD disclaims all liability and responsibility to any person in connection with, arising from or in respect of this Report whether such liability arises in contract, tort (including negligence) or under statute.

The opinions, conclusions and any recommendations in this Report are based on assumptions made by GHD described in this Report. GHD disclaims liability arising from any of the assumptions being incorrect.

2. Set up

2.1 Approach

A calibration constrained Monte Carlo uncertainty analysis was completed. Monte Carlo analysis involves running the model with multiple parameter realisations to estimate the range of uncertainty associated with model prediction. The term ‘calibration-constrained’ means that only parameter combinations that provided a suitable match with the observation data were used for the predictive uncertainty analysis.

The groundwater model was initially run with 535 parameter realisations. Of these realisations, 200 provided an adequate match with historical observations.

Stochastic estimates of mine induced impacts will be estimated by calculating the 10th, 50th and 90th percentile values for key predictions.

2.2 Model set up

The set-up of the model was in accordance with Section 3 and Section 4 of GHD (2020a).

The uncertainty analysis comprised of several models.

1. Parameterisation model:
   - Steady state model to obtain starting heads.
   - Calibration model.
2. Following the calibration model runs, model outputs were compared to historical observations. Parameter realisations displaying an adequate match with historical observations were selected for the predictive phase runs.
3. Predictive model. Parameter realisations that provided a suitable match with historical observations were selected and run in the predictive model as described below:
   - Base case model: simulates existing workings and proposed workings at Newstan Colliery.
   - No proposed Newstan expansion model: simulates existing workings. Does not include proposed expansion of mining at Newstan Colliery.
   - No regional mining model: Does not simulate any existing or proposed mine workings. Note that a calibration phase model with no historical mining at Newstan or other mines within the model domain was initially run to obtain starting heads for the predictive model.

Comparison of results from these various predictive models allowed incremental impacts (due to the proposed mining at Newstan) to be identified and; cumulative impacts (due to existing regional mining and proposed mining at Newstan) to be identified.

3. Parameterisation

Parameterisation was completed by generating random parameter realisations based upon a prior statistical distribution. Each parameter realisation was run using the calibration model.

The parameters varied as part of uncertainty analysis included all parameters included as part of the PEST model calibration. A list of model parameters is presented in Table 3-3 of GHD (2020a).

3.1 Prior parameterisation

The input (prior) parameter distributions were based on the following:

1. Horizontal hydraulic conductivity (Kh), specific yield (Sy) and specific storage (Ss) were based on a lognormal distribution with standard deviation equal to half an order of magnitude and mean equal to the calibrated value. In the case of Sy, where there is less variability in parameter distributions, a standard deviation of a quarter of an order of magnitude was utilised. These distributions are summarised in Table 3-1.
2. Vertical anisotropy (Kv) and rainfall recharge were based on a log-uniform distribution between half an order of magnitude greater than and less than the calibrated value. These distributions are summarised in Table 3-2.
3. Evapotranspiration depth was based on a uniform distribution. The range of the distribution was between half the calibrated parameter value and one and a half times the calibrated value. These distributions are summarised in Table 3-2.

Table 3-1 Parameters with log normal prior distributions applied

Parameter	Description	Mean	Stdev Log10
kh_aluv	Kh alluvium	3.4820054	0.5
kh_rego	Kh regolith	0.14901151	0.5
kh_n_sst	Kh Narrabeen Sandstone	2.94E-05	0.5
kh_gn_seam	Kh Great Northern seam	0.01	0.5
kh_awaba	Kh Awaba Tuff	8.68E-04	0.5
kh_fas_seam	Kh Fassifern seam	9.94E-03	0.5
kh_iterb	Kh Permian Interburden	1.05E-05	0.5
kh_wb_seam	Kh West Borehole seam	1.00E-04	0.5
kh_w_sst	Kh Waratah Sandstone	0.01	0.5
kh_tcm	Kh Tomago Coal Measures	0.01	0.5
ss_aluv	Ss alluvium	1.21E-06	0.5
ss_rego	Ss regolith	1.30E-05	0.5
ss_n_sst	Ss Narrabeen Sandstone	1.08E-06	0.5
ss_gn_seam	Ss Great Northern seam	3.05E-07	0.5
ss_awaba	Ss Awaba Tuff	4.52E-07	0.5
ss_fas_seam	Ss Fassifern seam	8.77E-06	0.5
ss_iterb	Ss Permian Interburden	1.30E-05	0.5
ss_wb_seam	Ss West Borehole seam	9.35E-07	0.5
ss_w_sst	Ss Waratah Sandstone	1.91E-06	0.5
ss_tcm	Ss Tomago Coal Measures	3.01E-07	0.5
sy_aluv	Sy alluvium	5.00E-02	0.25
sy_rego	Sy regolith	7.51E-02	0.25

Notes to table:
Mean values presented are non-log transformed
Units: Kv (m/day), Sy (unitless), Ss (m^{-1})

Table 3-2 Parameters with log-uniform and uniform prior distributions

Parameter	Description	Type of distribution	Mean	Min	Max
kv_aluv	Vertical anisotropy alluvium	Log-uniform	11.70	3.70	36.99
kv_rego	Vertical anisotropy regolith	Log-uniform	5	1.58	15.81
kv_n_sst	Vertical anisotropy Narrabeen Sandstone	Log-uniform	5	1.58	15.81
kv_gn_seam	Vertical anisotropy Great Northern seam	Log-uniform	5	1.581	15.81
kv_awaba	Vertical anisotropy Awaba Tuff	Log-uniform	50	15.81	158.11
kv_fas_seam	Vertical anisotropy Fassifern seam	Log-uniform	20	6.32	63.25
kv_iterb	Vertical anisotropy Permian Interburden	Log-uniform	5.00	1.58	15.81
kv_wb_seam	Vertical anisotropy West Borehole seam	Log-uniform	12.90	4.08	40.81
kv_w_sst	Vertical anisotropy Waratah Sandstone	Log-uniform	5	1.58	15.81
kv_tcm	Vertical anisotropy Tomago Coal Measures	Log-uniform	5	1.58	15.81
r_fac_aluv	Recharge factor alluvium	Log-uniform	2.04E-02	6.46E-03	6.46E-02
r_fac_rego	Recharge factor regolith	Log-uniform	2.34E-03	7.39E-04	7.39E-03
etrate_veg	Evapotranspiration rate forest and woodland	Uniform	1.64E-03	8.22E-04	2.47E-03
etrate_ind	Evapotranspiration rate urban or developed areas	Uniform	3.56E-03	1.78E-03	5.34E-03
etrate_gras	Evapotranspiration rate grass	Uniform	2.43E-03	1.22E-03	3.65E-03

Notes to table:
All values presented are non-log transformed
Units: Vertical anisotropy (unitless Kh/Kv anisotropy factor), Evapotranspiration rate (m/day)

535 random parameter realisations were generated using a random number generator, according to the probability distributions listed in Table 3-1 and Table 3-2. The input (prior) parameter distributions are shown in Figure 3-1, Figure 3-2 and Figure 3-3.

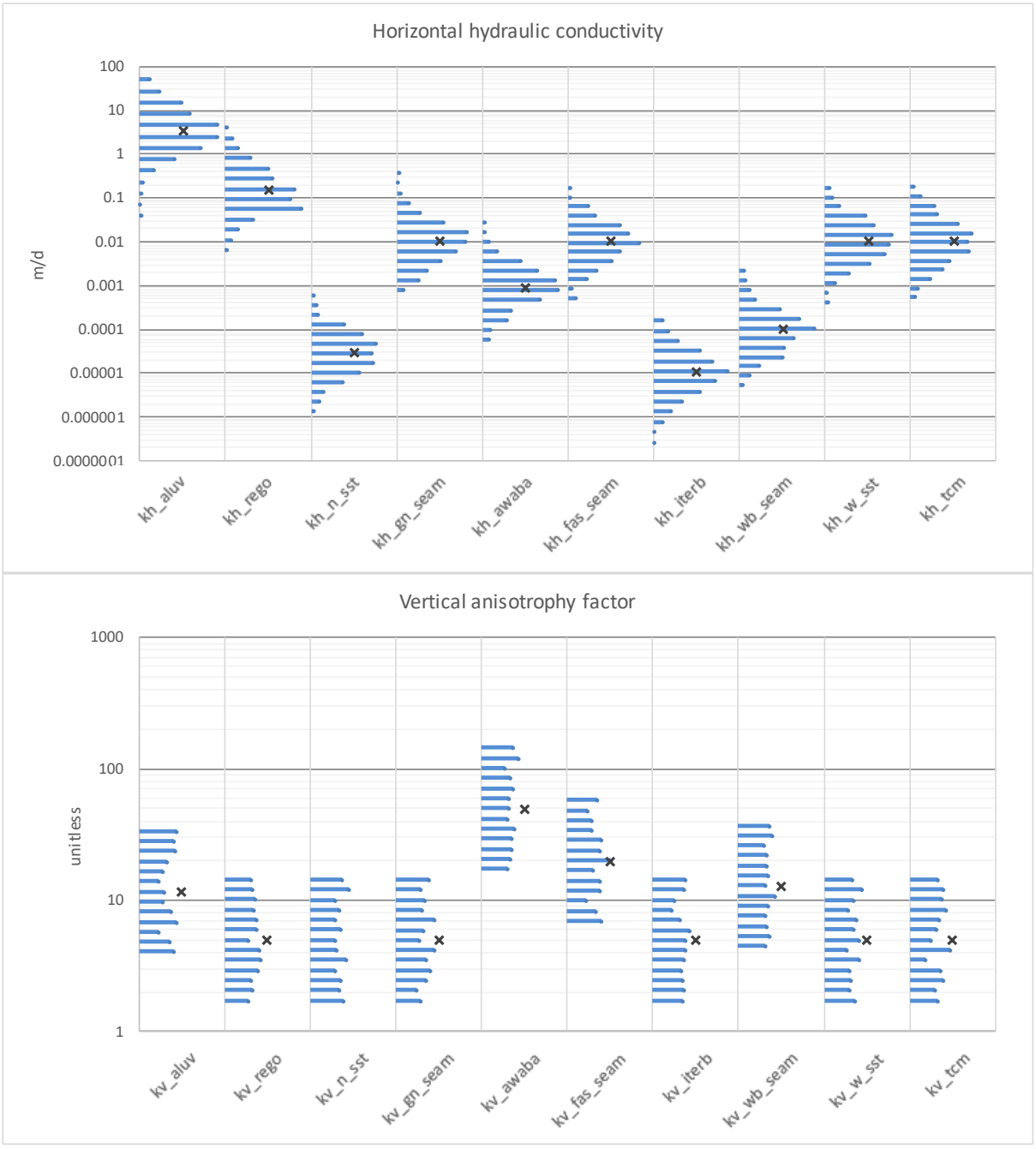


Figure 3-1 Input (prior) parameter histograms – horizontal hydraulic conductivity and vertical anisotropy

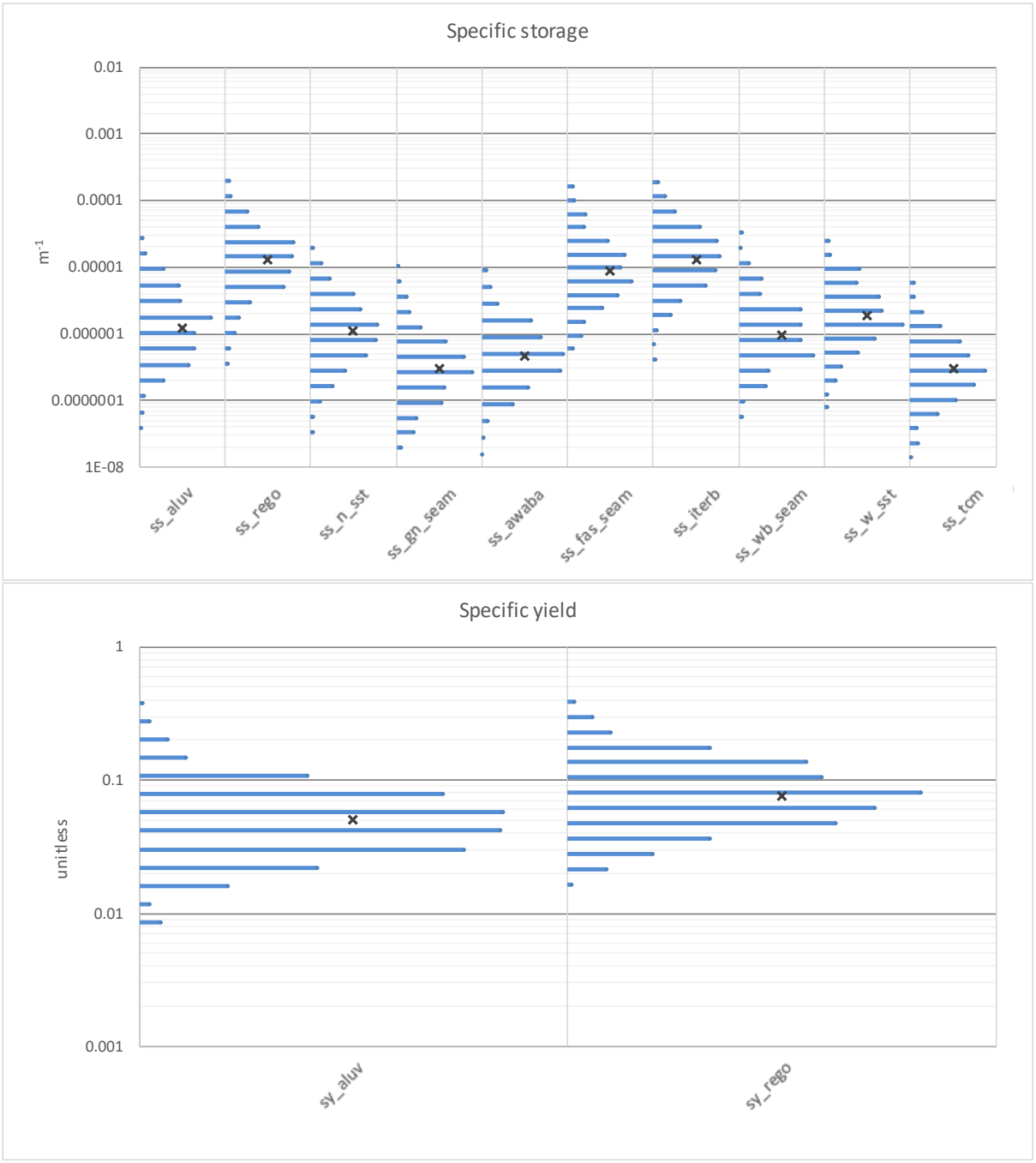


Figure 3-2 Input (prior) parameter histograms – specific storage and specific yield

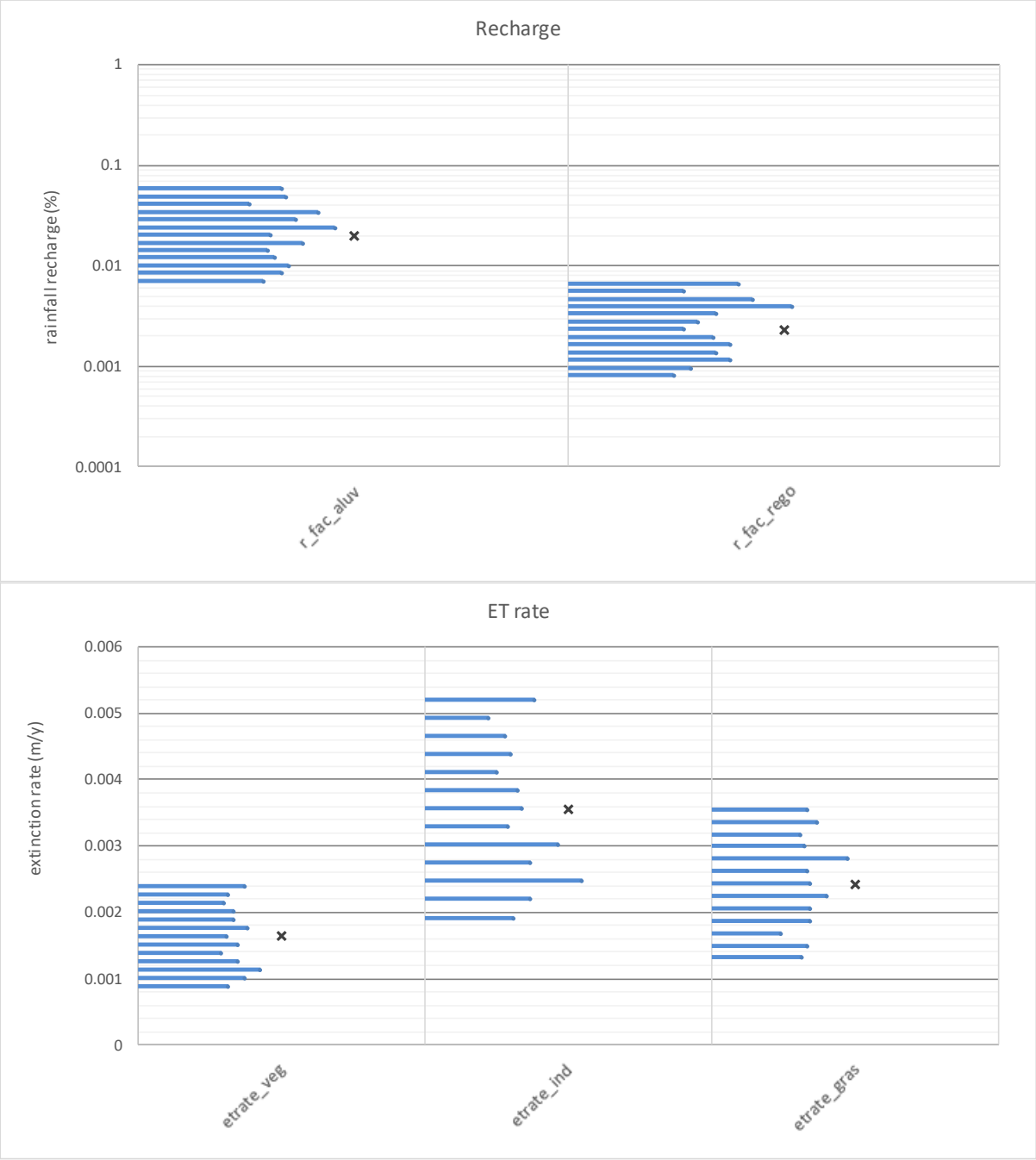


Figure 3-3 Input (prior) parameter histograms – rainfall recharge and evapotranspiration rate

3.2 Posterior parameter realisations

The prior parameter realisations were run through the calibration model to determine if they provided an adequate match with historical observation data. Parameter sets that failed to return suitable calibration statistics were rejected. An acceptance threshold of 1.25 times the objective function utilised in the PEST calibration of the calibrated model was adopted. This objective function comprised of a contribution from head matching, as well as trend matching.

535 prior parameter realisations were generated and run through the calibration model. A total of 200 of these realisations complied with the calibration threshold and will be utilised for the predictive uncertainty analysis runs. The posterior parameter realisation histograms are presented in Figure 3-4, Figure 3-5 and Figure 3-6.

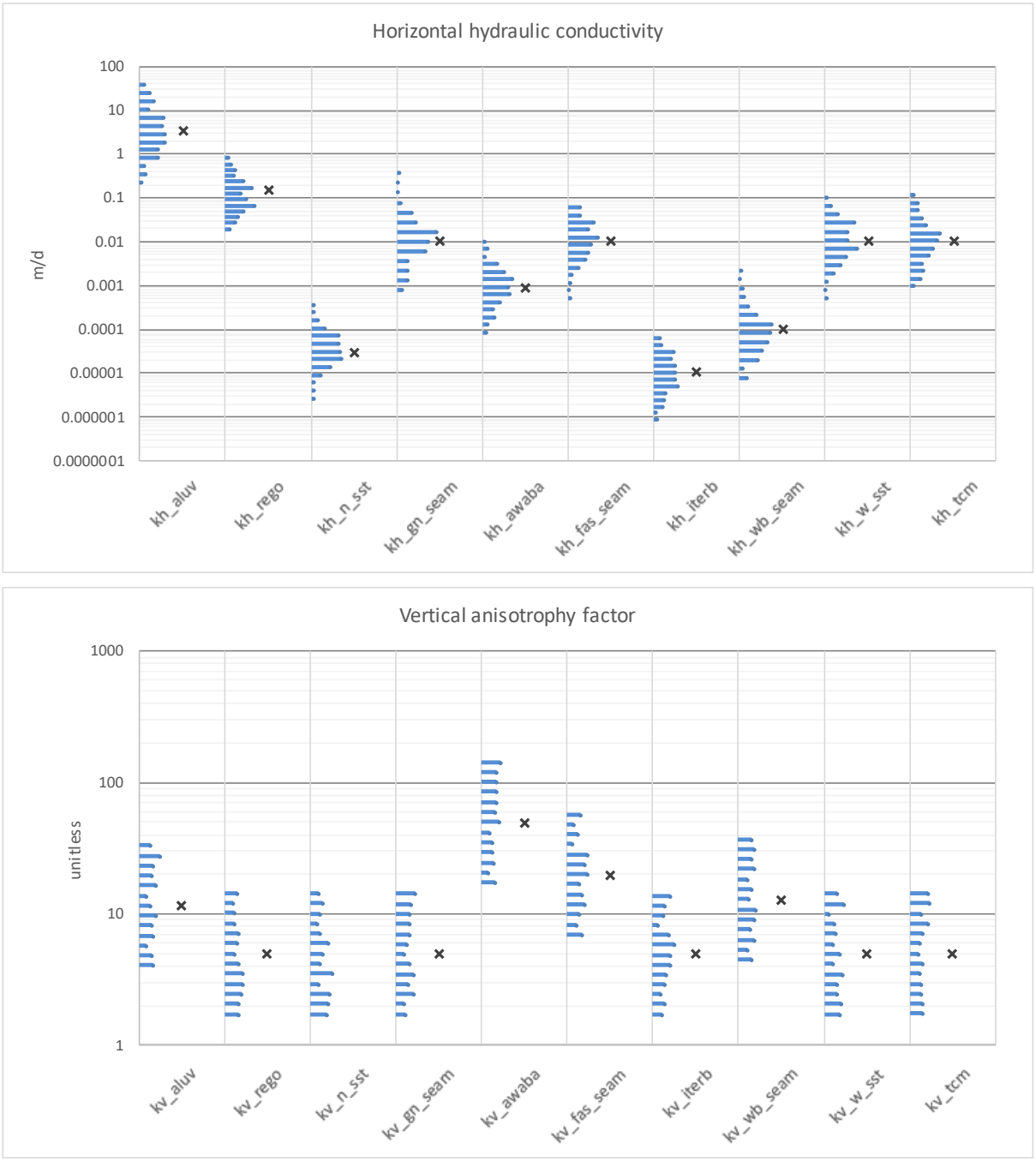


Figure 3-4 Posterior parameter histograms – horizontal hydraulic conductivity and vertical anisotropy

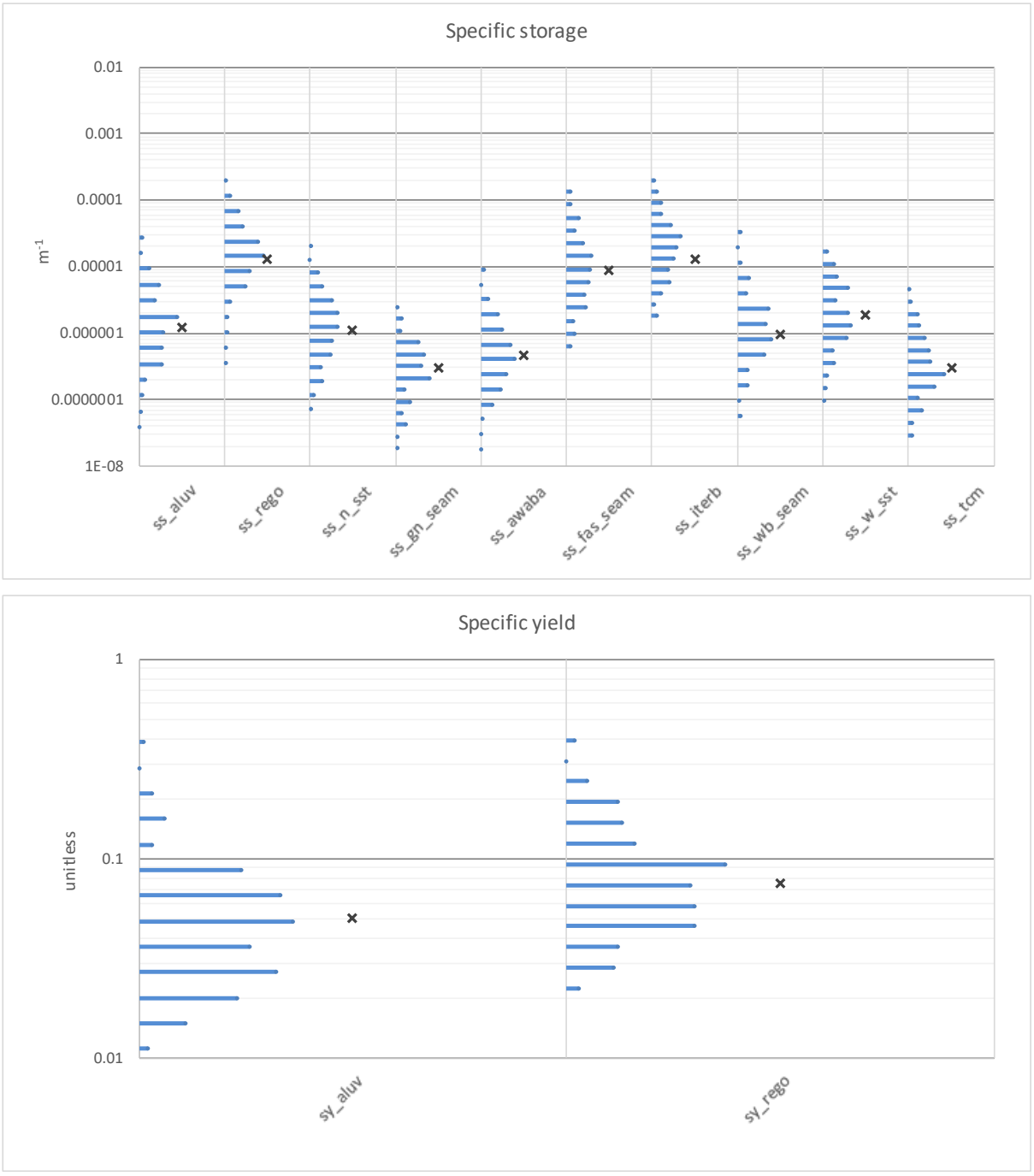
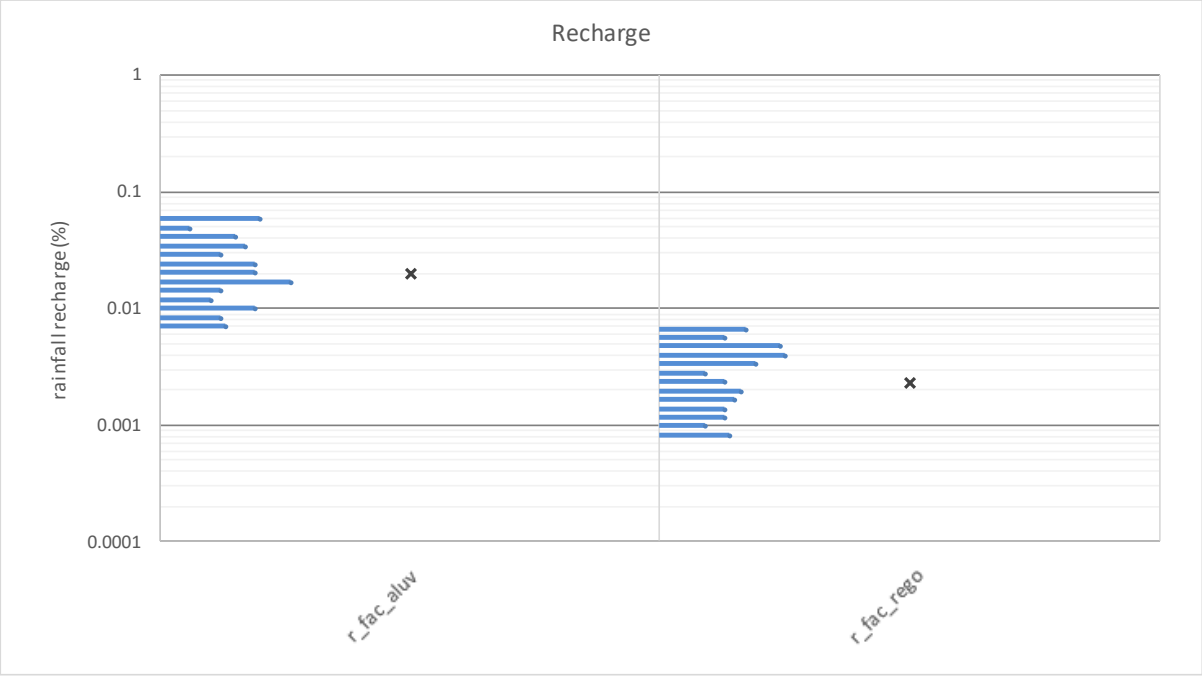


Figure 3-5 Posterior parameter histograms – specific storage and specific yield



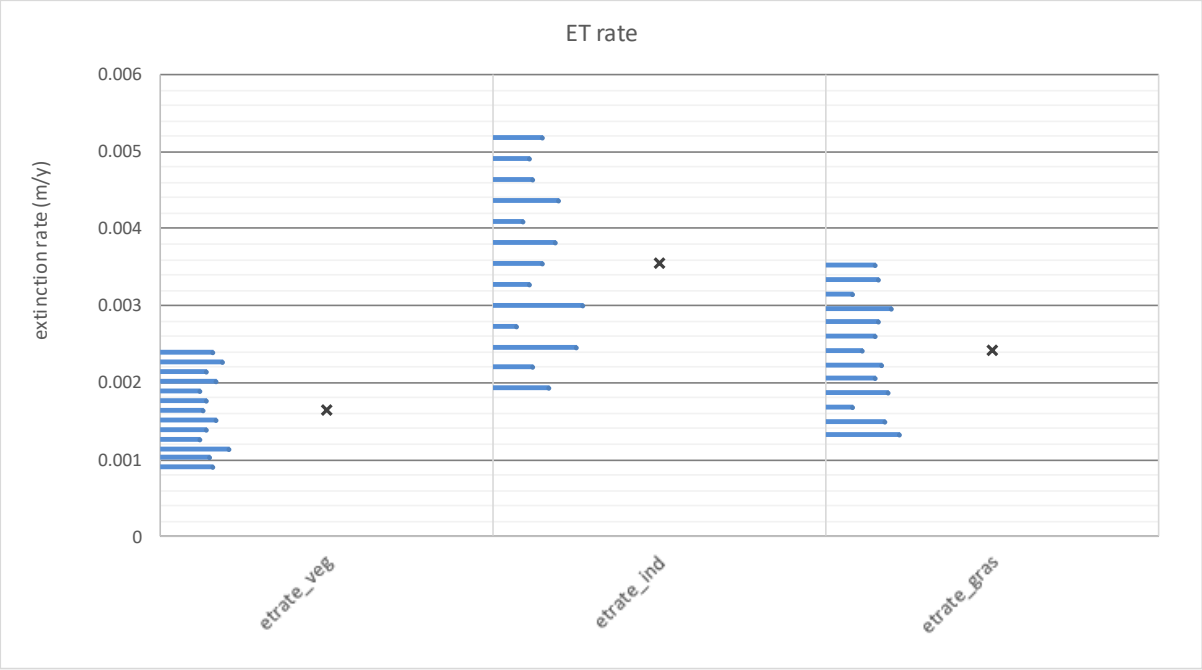


Figure 3-6 Posterior parameter histograms – rainfall recharge and evapotranspiration rate

4. Predictive model runs

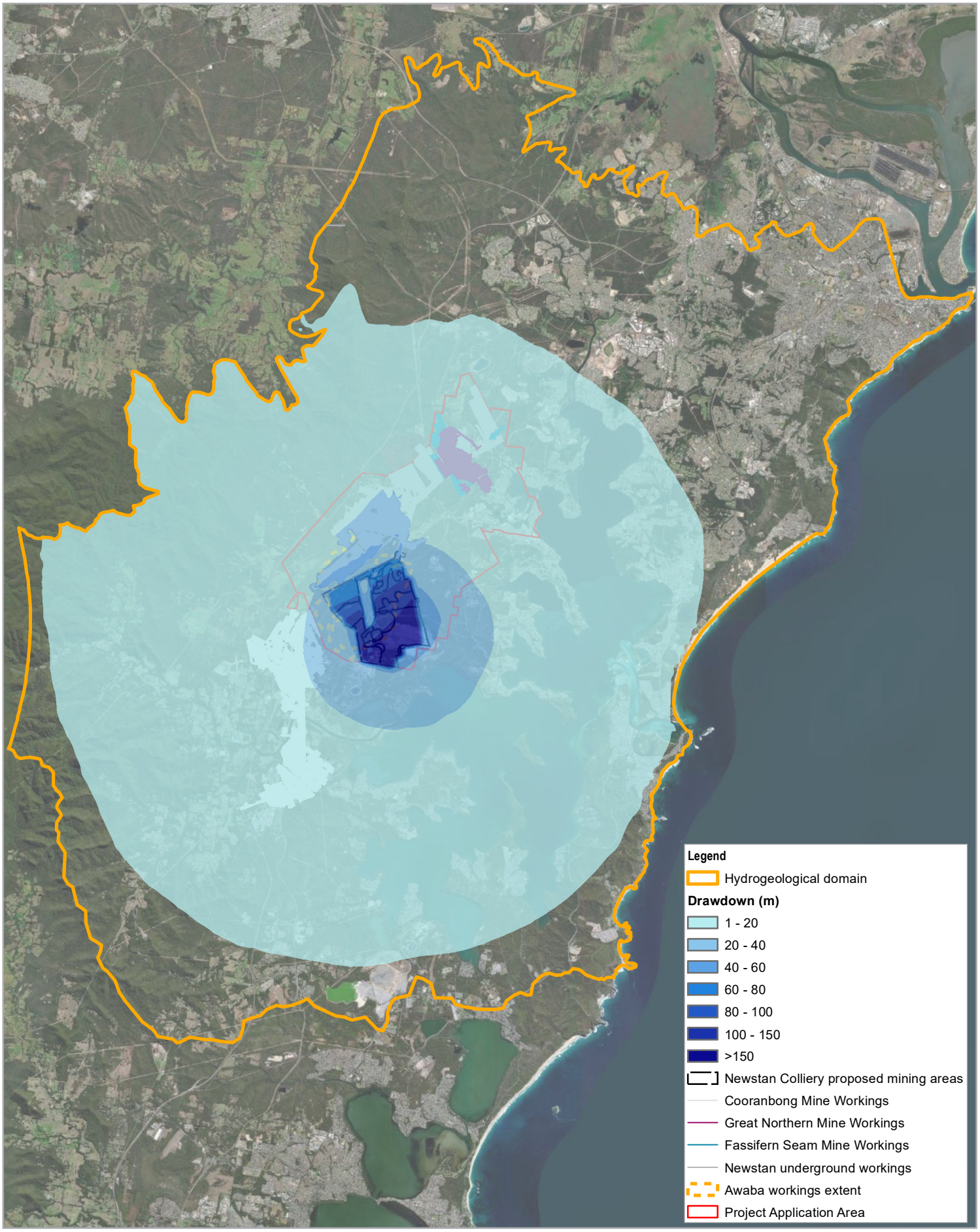
Of the 200 predictive model runs, 180 runs were successful. Percentile outputs has been calculated from the model outputs. Results have been presented for 90% probability of exceedance, 50% probability of exceedance and 10% probability of exceedance.

Similarly to GHD (2020a) incremental impacts refer to impacts attributable to the proposed workings at Newstan Colliery; and cumulative impacts refer to impacts attributable to the existing and proposed workings at Newstan Colliery, or existing workings at Cooranbong, Awaba Colliery, West Wallsend Colliery or Teralba Colliery.

4.1 Predictive outputs

4.1.1 Drawdown

Maximum cumulative and incremental drawdown (over all simulation time) for 10th, 50th and 90th percentiles for the water table and the West Borehole Seam (layer 10) is shown in Figure 4-1 to Figure 4-12.



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

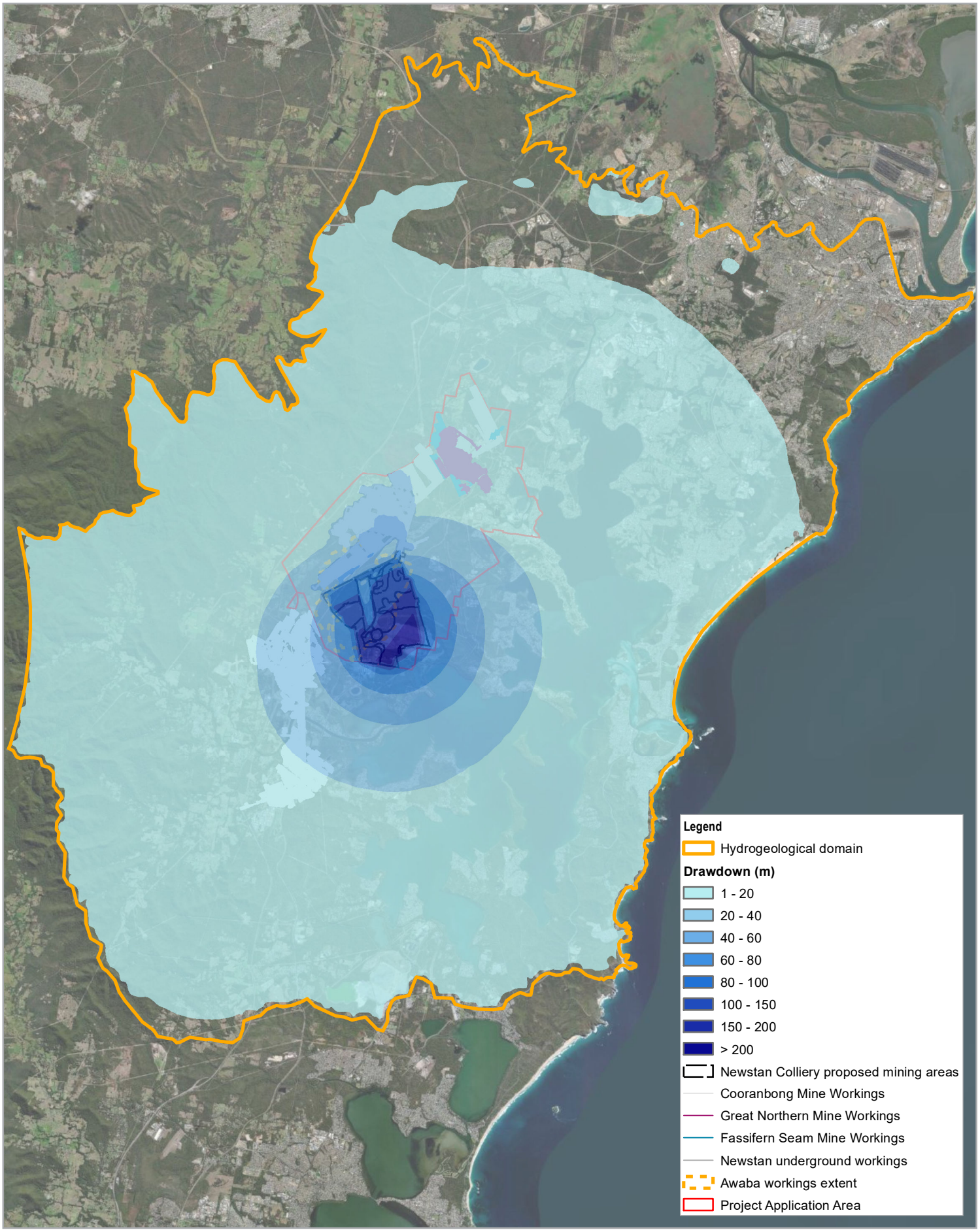
Incremental max groundwater drawdown
Layer 10: West Borehole Seam
10th percentile

Project No. **22-20265**
Revision No. **A**
Date **24/01/2020**

FIGURE 4-1

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-001_IncrementalDrawdown_Lyr10_10pc.mxd
Print date: 09 Apr 2020 - 13:56

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

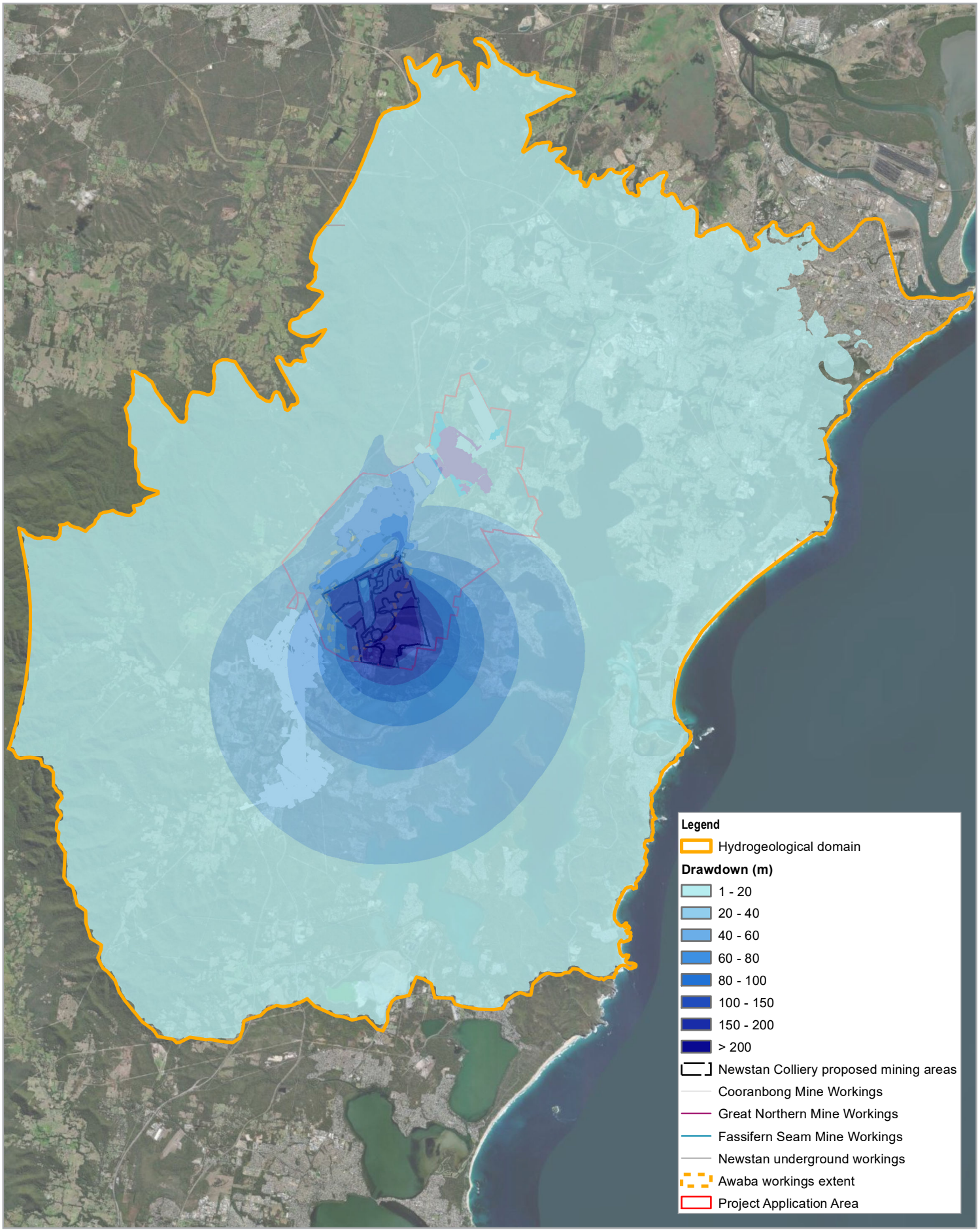
Incremental max groundwater drawdown
Layer 10: West Borehole Seam
50th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-2

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\IJA\22-20265-UA-002_IncrementalDrawdown_Lyr10_50pc.mxd
Print date: 09 Apr 2020 - 13:57

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

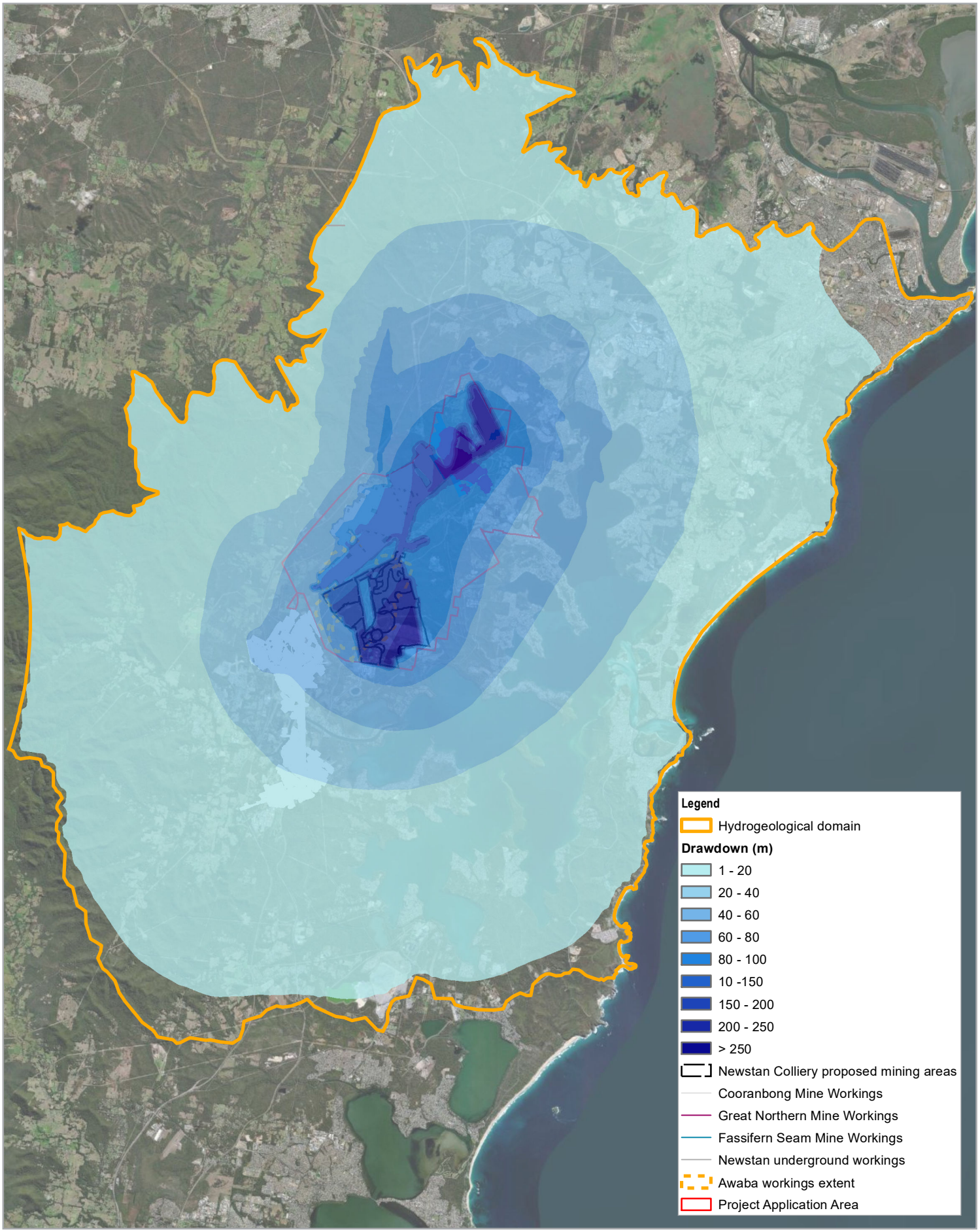
Incremental max groundwater drawdown
Layer 10: West Borehole Seam
90th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-3

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\IJA\22-20265-UA-003_IncrementalDrawdown_Lyr10_90pc.mxd
Print date: 09 Apr 2020 - 13:57

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

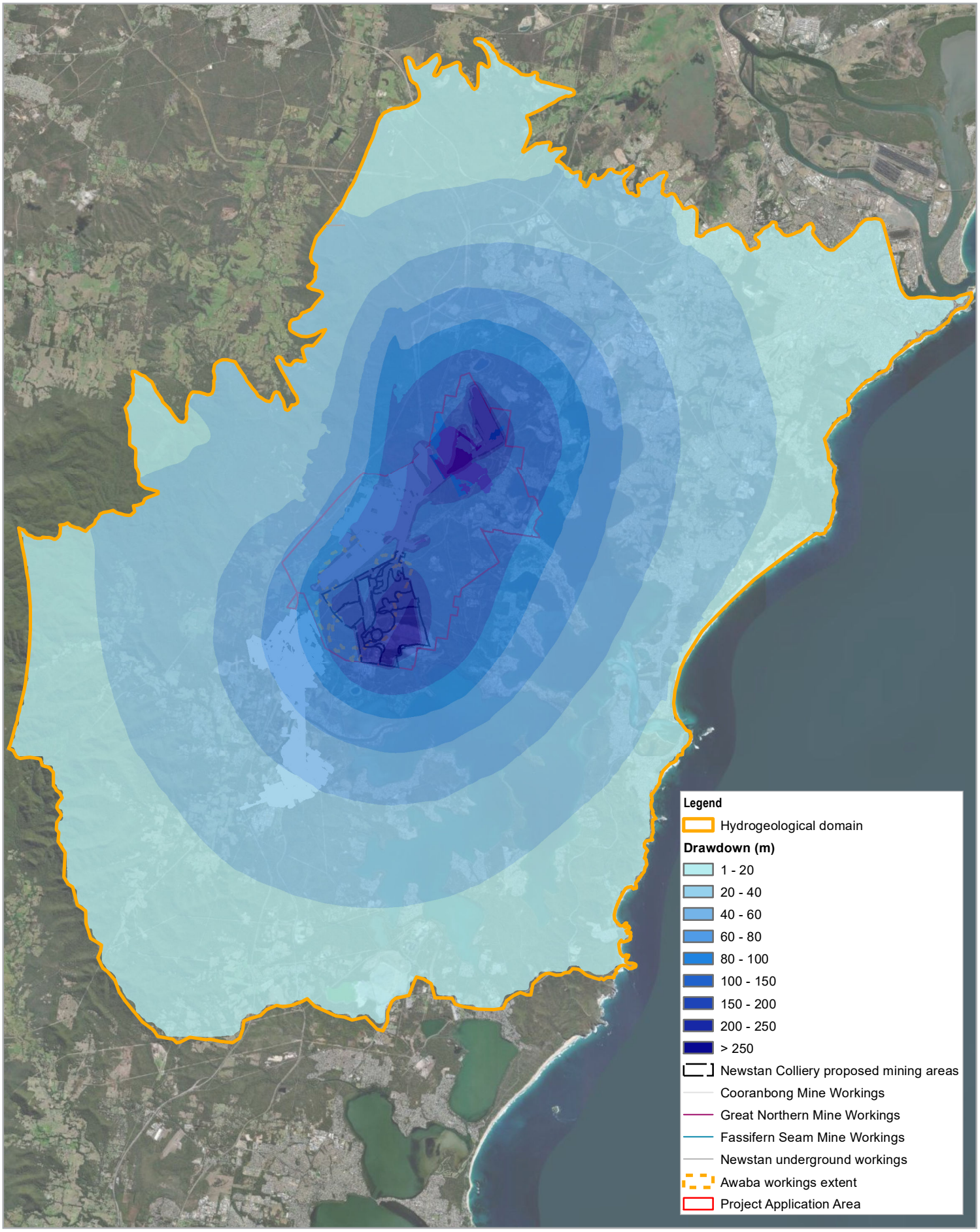
Cumulative max groundwater drawdown
Layer 10: West Borehole Seam
10th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-4

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-004_CumulativeDrawdown_Lyr10_10pc.mxd
Print date: 09 Apr 2020 - 13:58

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

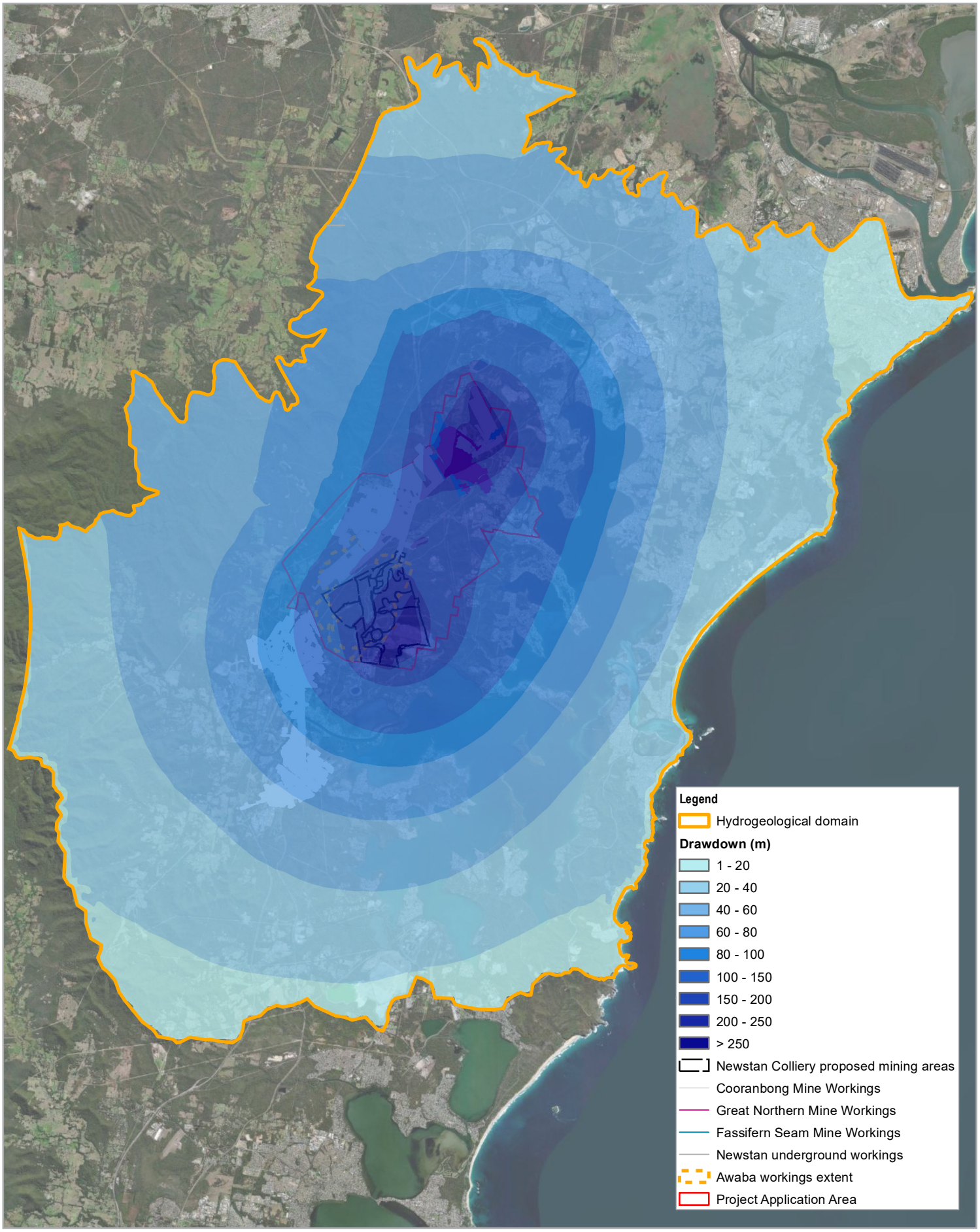
Cumulative max groundwater drawdown
Layer 10: West Borehole Seam
50th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-5

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-005_CumulativeDrawdown_Lyr10_50pc.mxd
Print date: 09 Apr 2020 - 14:02

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

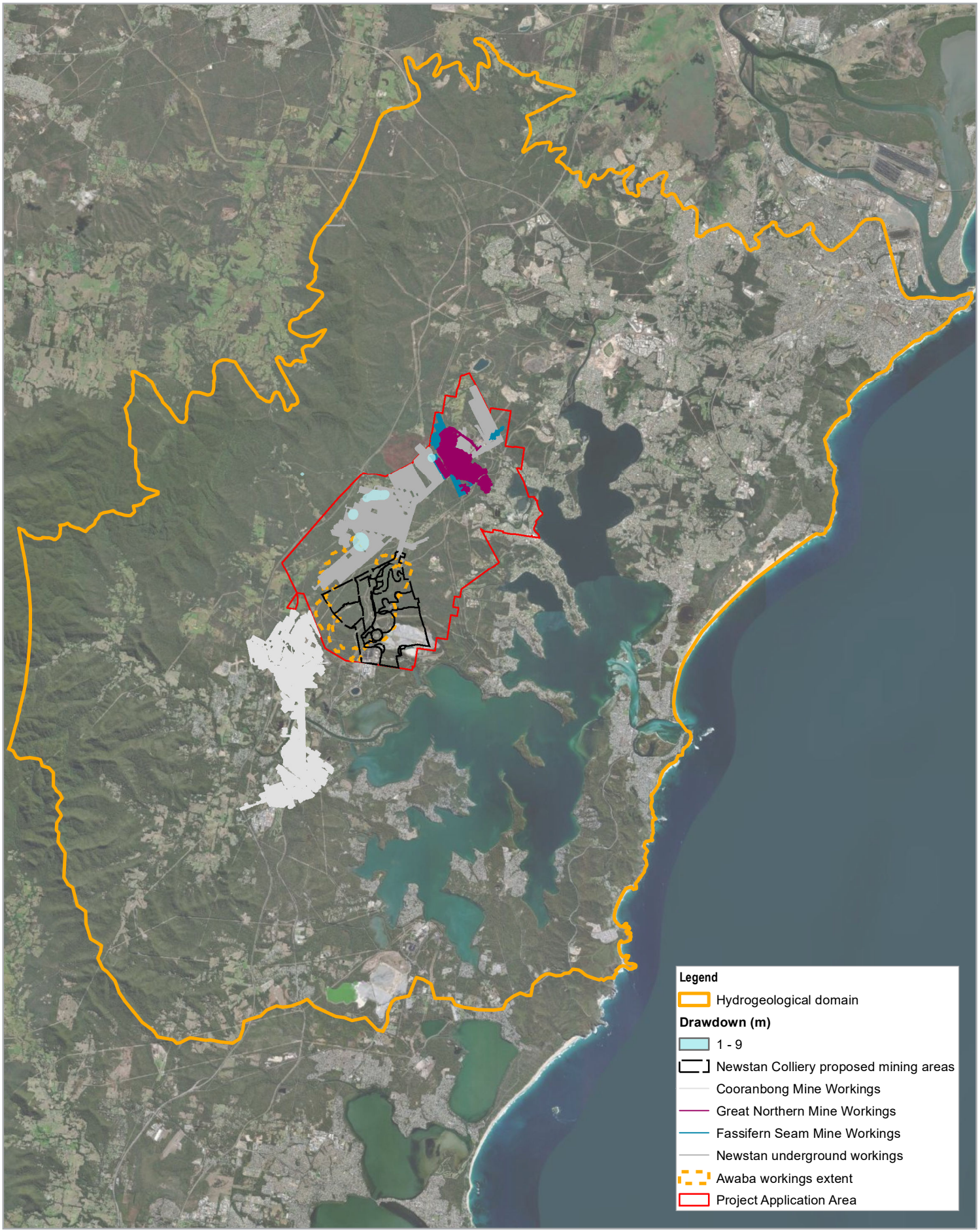
Cumulative max groundwater drawdown
Layer 10: West Borehole Seam
90th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-6

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-006_CumulativeDrawdown_Lyr10_90pc.mxd
Print date: 09 Apr 2020 - 14:00

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

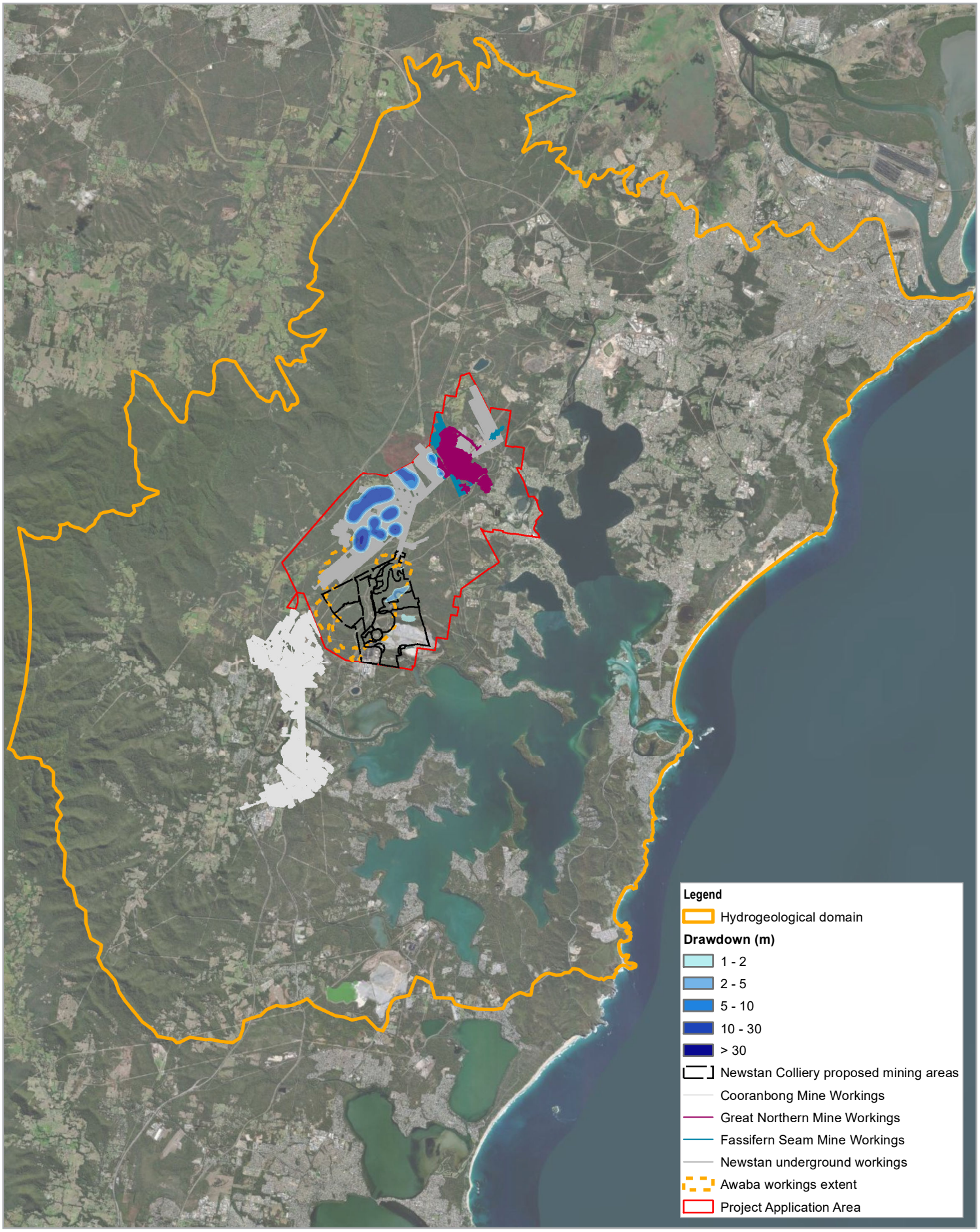
Incremental max groundwater drawdown
Water table
10th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-7

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-007_IncrementalDrawdown_WaterTable_10pc.mxd
Print date: 09 Apr 2020 - 14:03

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

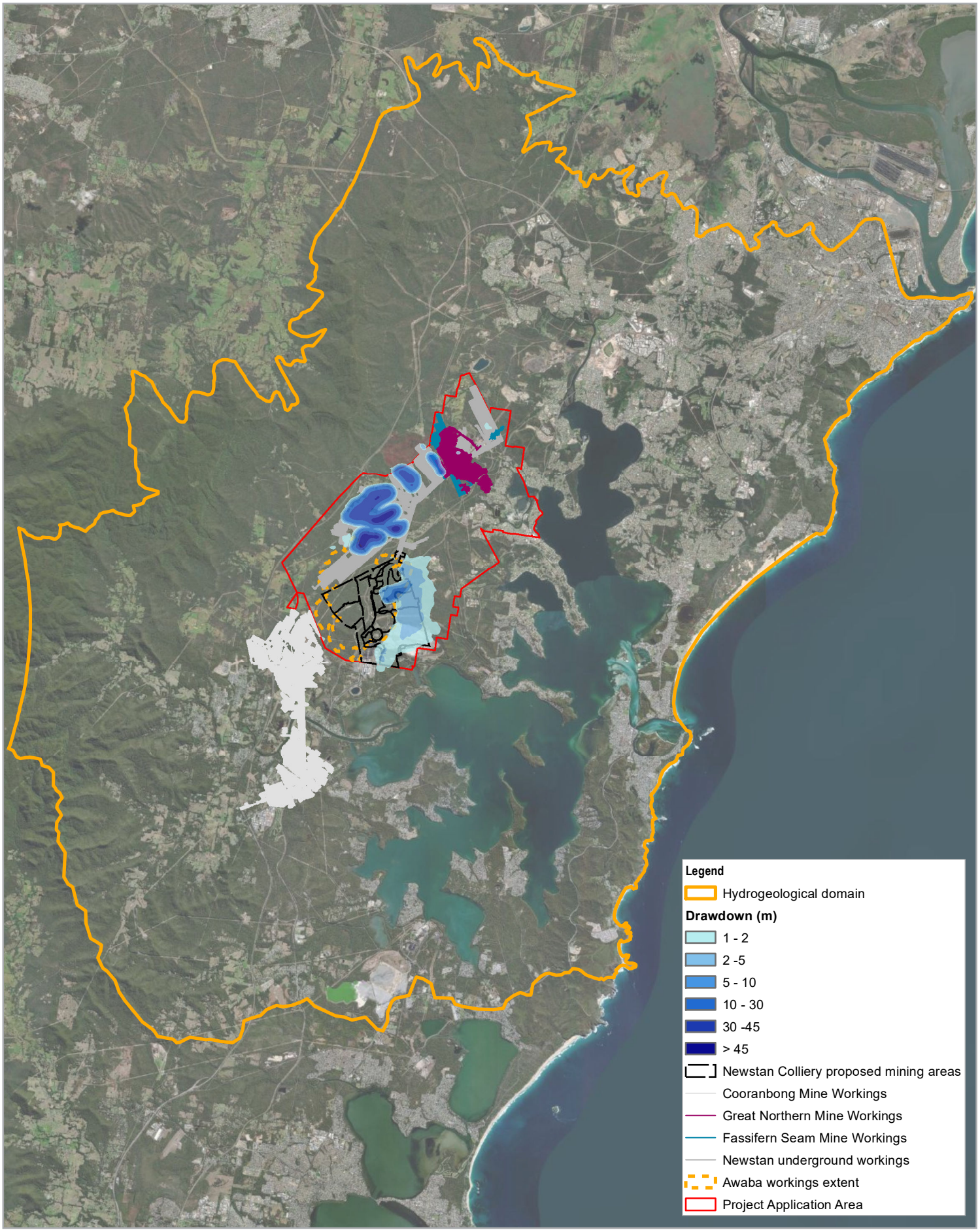
Incremental max groundwater drawdown
Water table
50th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-8

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-008_IncrementalDrawdown_WaterTable_50pc.mxd
Print date: 09 Apr 2020 - 14:00

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

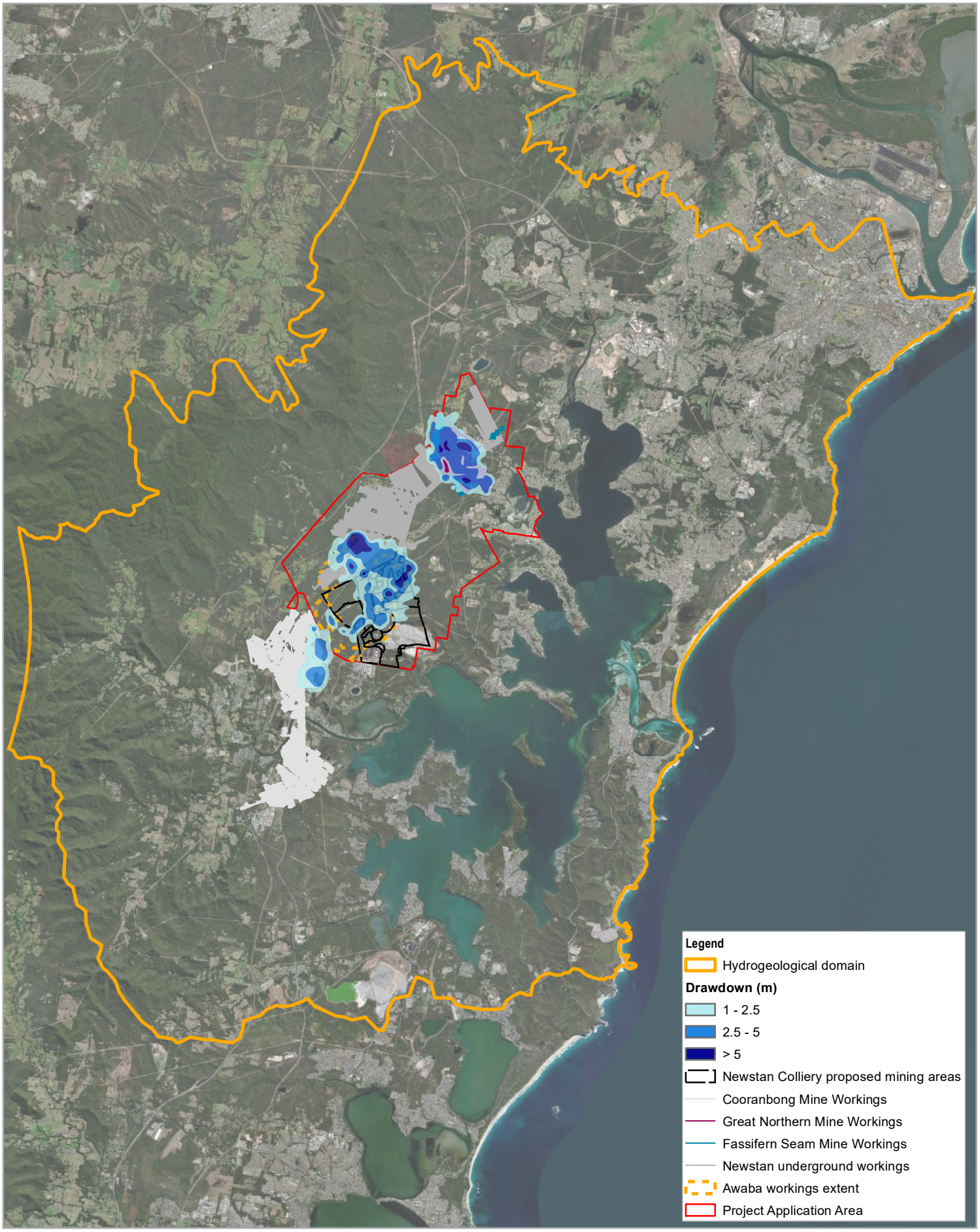
Incremental max groundwater drawdown
Water table
90th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-9

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-009_IncrementalDrawdown_WaterTable_90pc.mxd
Print date: 09 Apr 2020 - 14:05

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

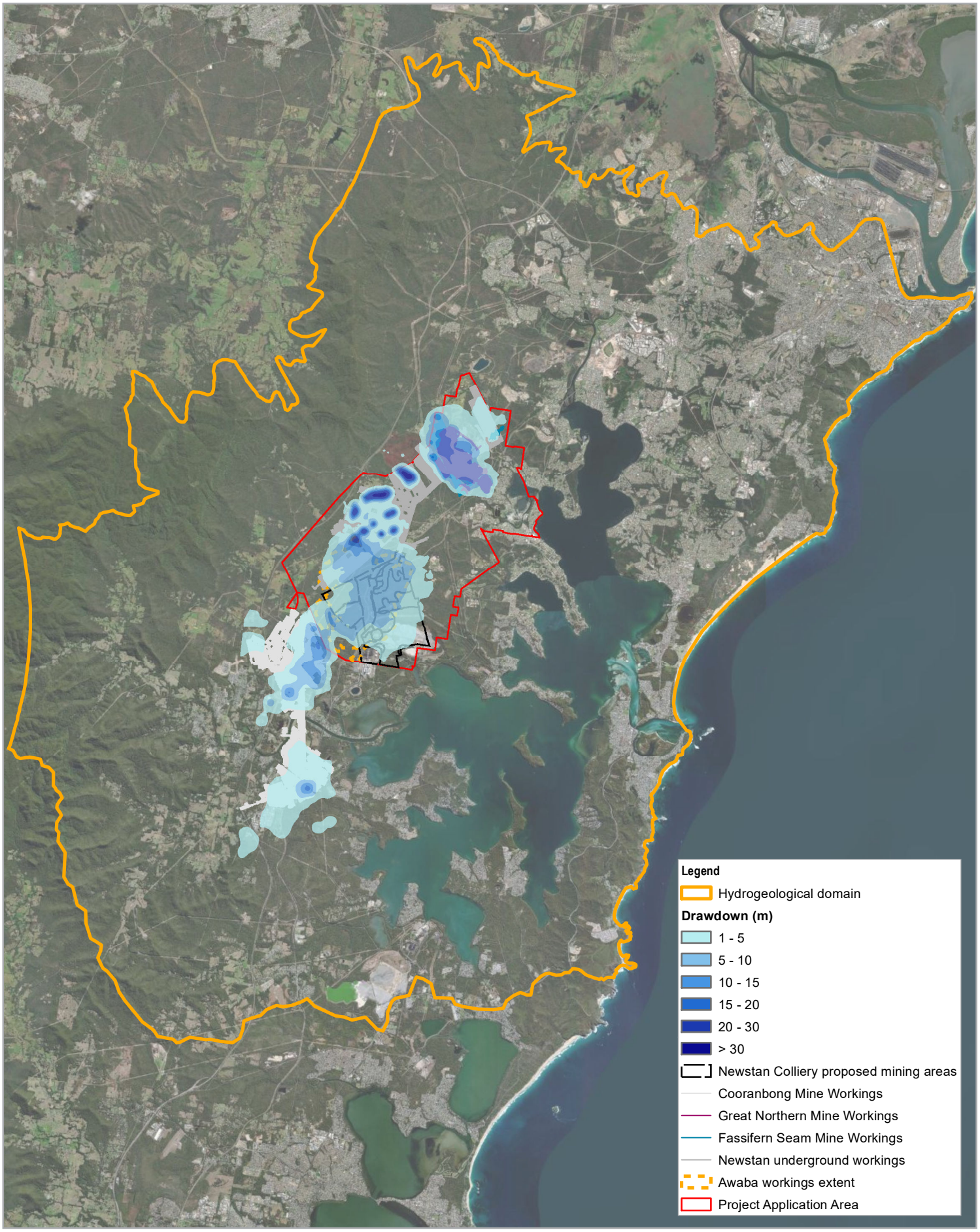
Cumulative max groundwater drawdown
Water table
10th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-10

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-010_CumulativeDrawdown_WaterTable_10pc.mxd
Print date: 09 Apr 2020 - 14:08

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

GHD

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

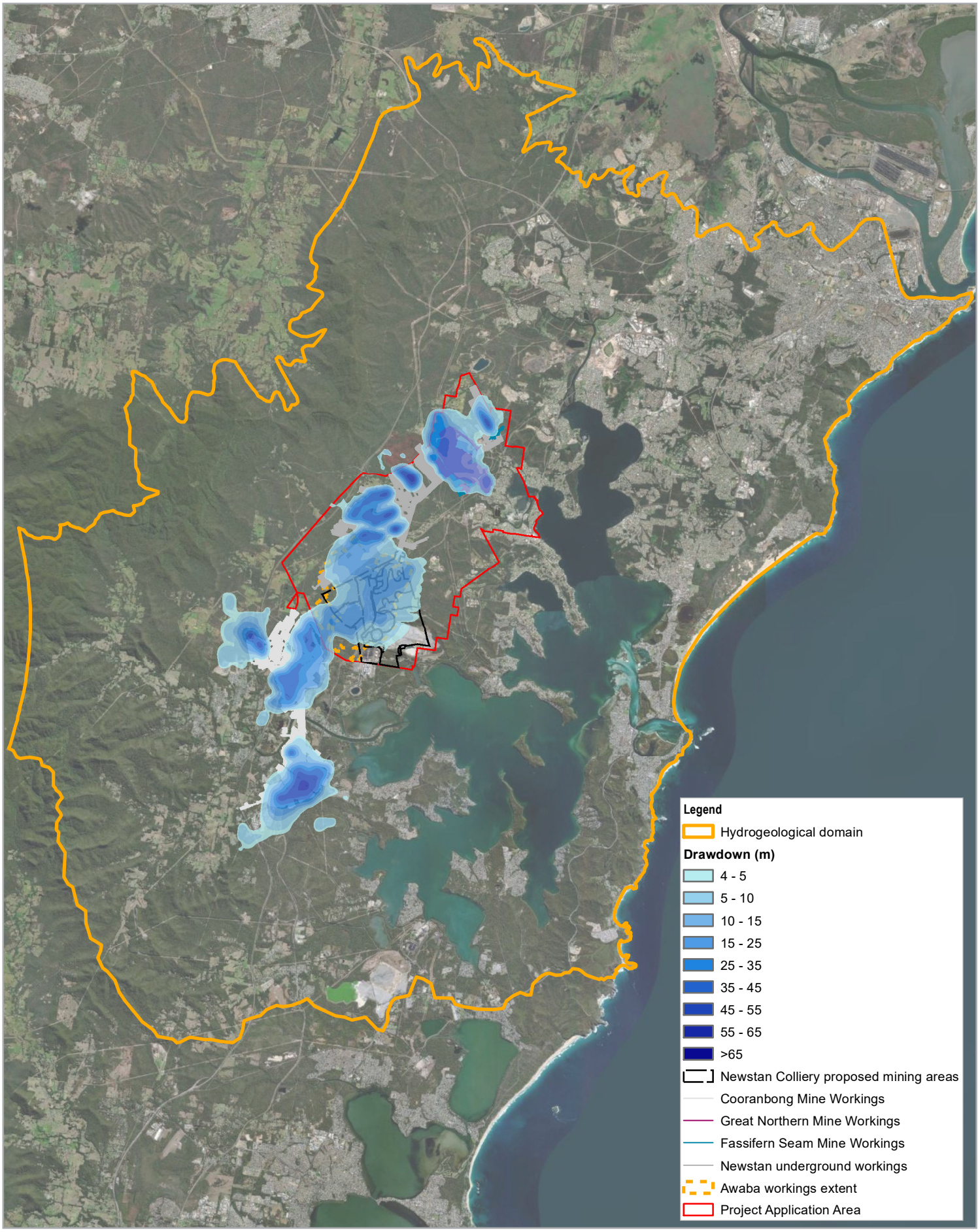
Cumulative max groundwater drawdown
Water table
50th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-11

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-011_CumulativeDrawdown_WaterTable_50pc.mxd
Print date: 09 Apr 2020 - 14:09

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald



Paper Size ISO A4

0 1.5 3 4.5 6

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 56

N

Centennial Newstan Pty Ltd
Extension of Mining Project
Uncertainty Analysis

Cumulative max groundwater drawdown
Water table
90th percentile

Project No. **22-20265**
Revision No. **A**
Date **07 Apr 2020**

FIGURE 4-12

G:\22\0105001\GIS\Maps\Deliverables\Hunter\Newstan\2220265\UA\22-20265-UA-012_CumulativeDrawdown_WaterTable_90pc.mxd
Print date: 09 Apr 2020 - 14:10

Data source: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community. Created by: smacdonald

4.1.2 Landholder bores

Groundwater drawdown has been assessed at landholder bores within the radius of drawdown of coal measures attributable to proposed workings from the best fit model run (GHD, 2020b). Details regarding these bores are in Table 6-1 of GHD (2020b).

Incremental and cumulative drawdown at each of the landholder bores has been plotted over time and is shown in Figure 4-13 to Figure 4-22.

Drawdown at landholder bores generally peaks within 2 years after the end of mining at Newstan.

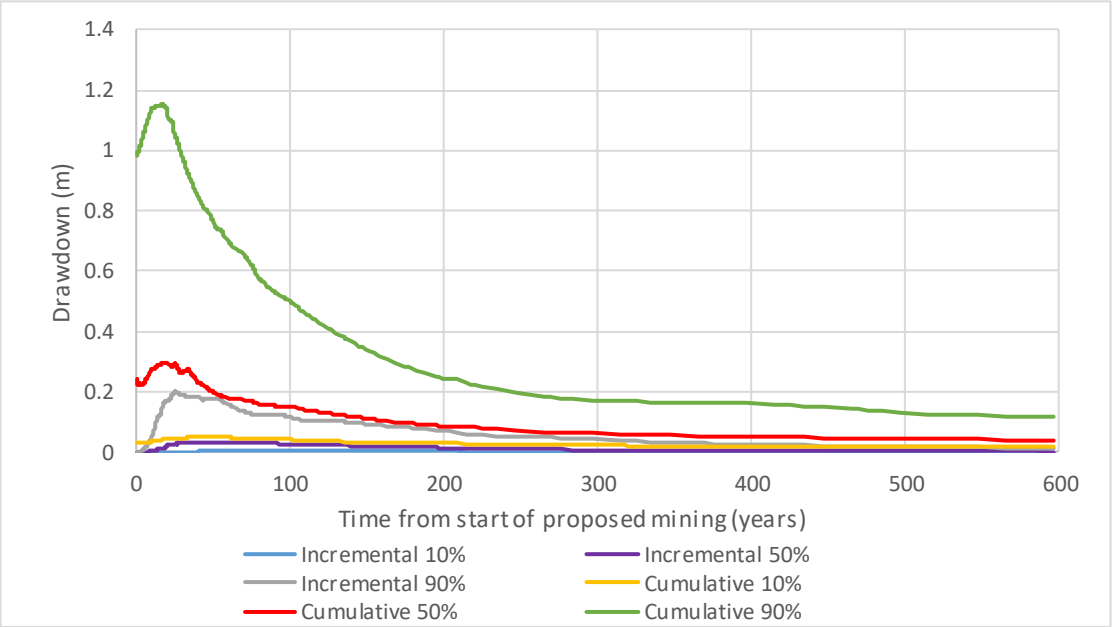


Figure 4-13 Cumulative and incremental drawdown at bore GW043431

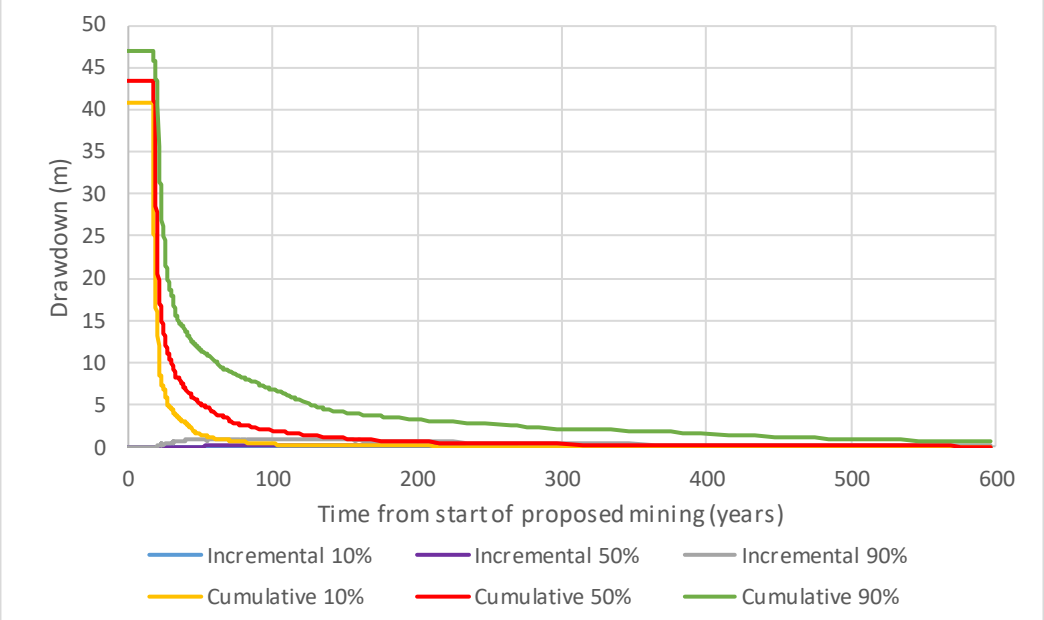


Figure 4-14 Cumulative and incremental drawdown at bore GW052111

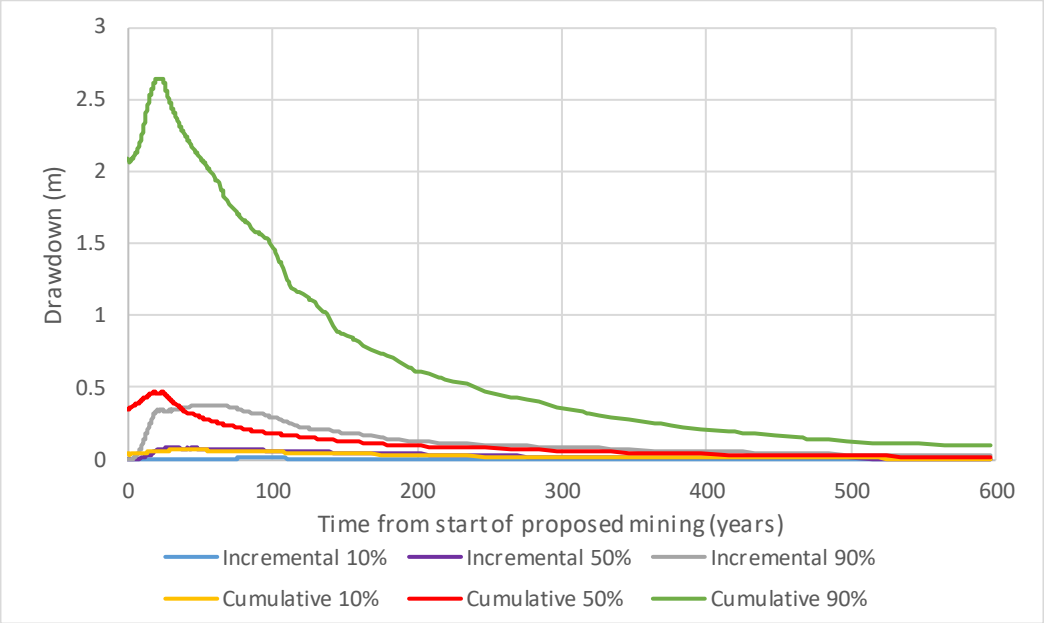


Figure 4-15 Cumulative and incremental drawdown at GW052381

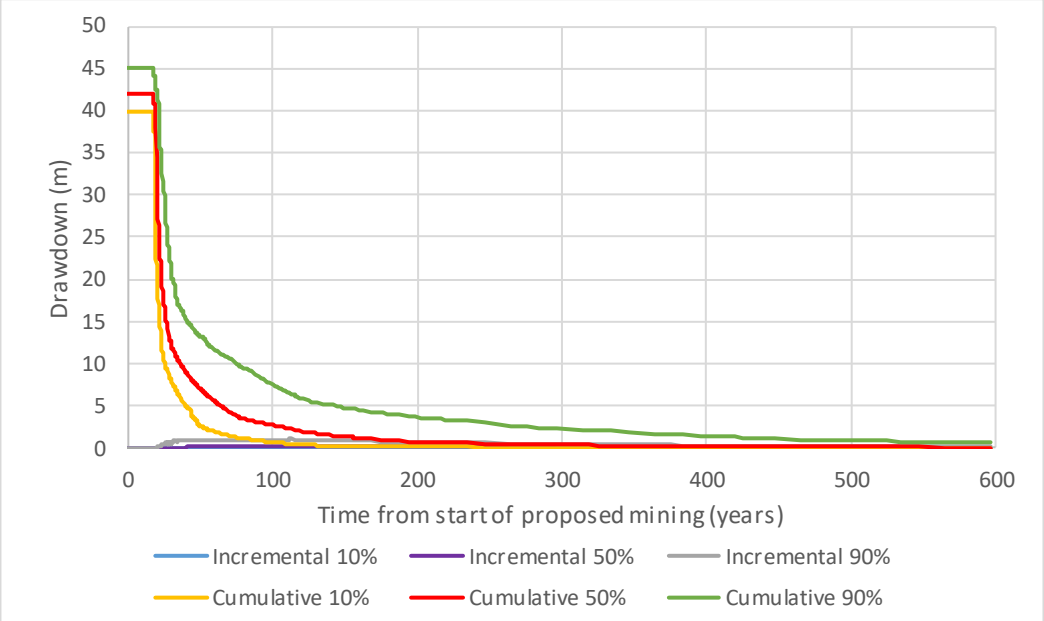


Figure 4-16 Cumulative and incremental drawdown at GW053438

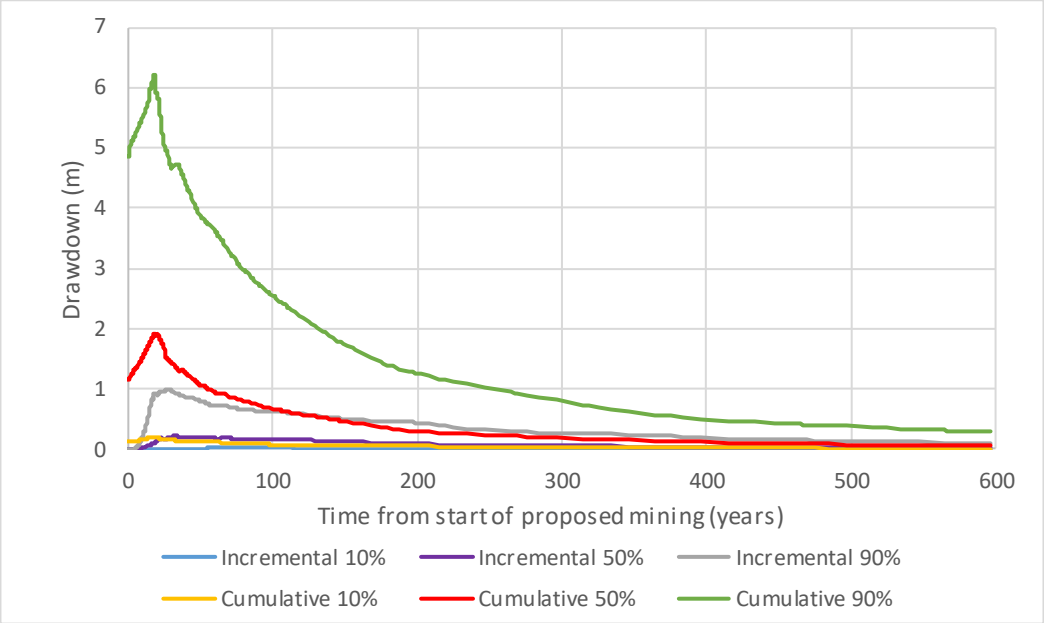


Figure 4-17 Cumulative and incremental drawdown at GW061202

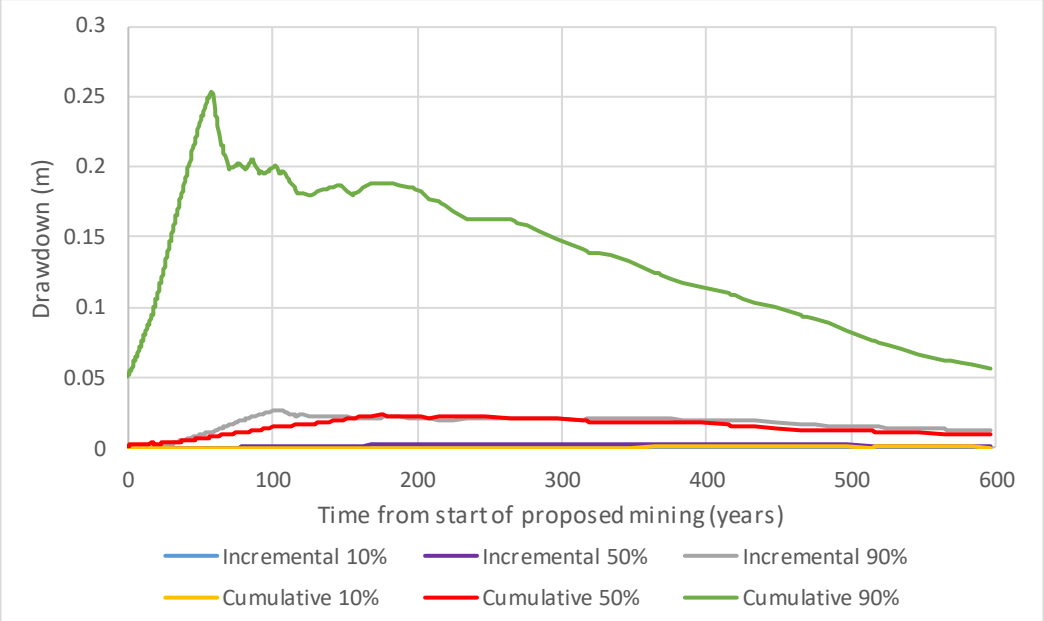


Figure 4-18 Cumulative and incremental drawdown at GW063947

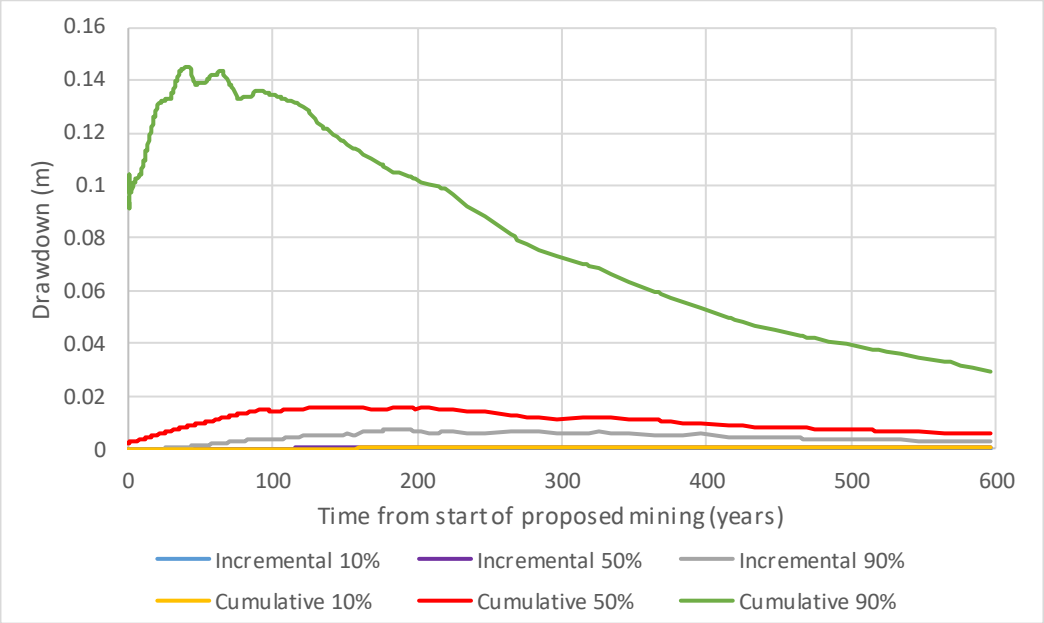


Figure 4-19 Cumulative and incremental drawdown at GW078354

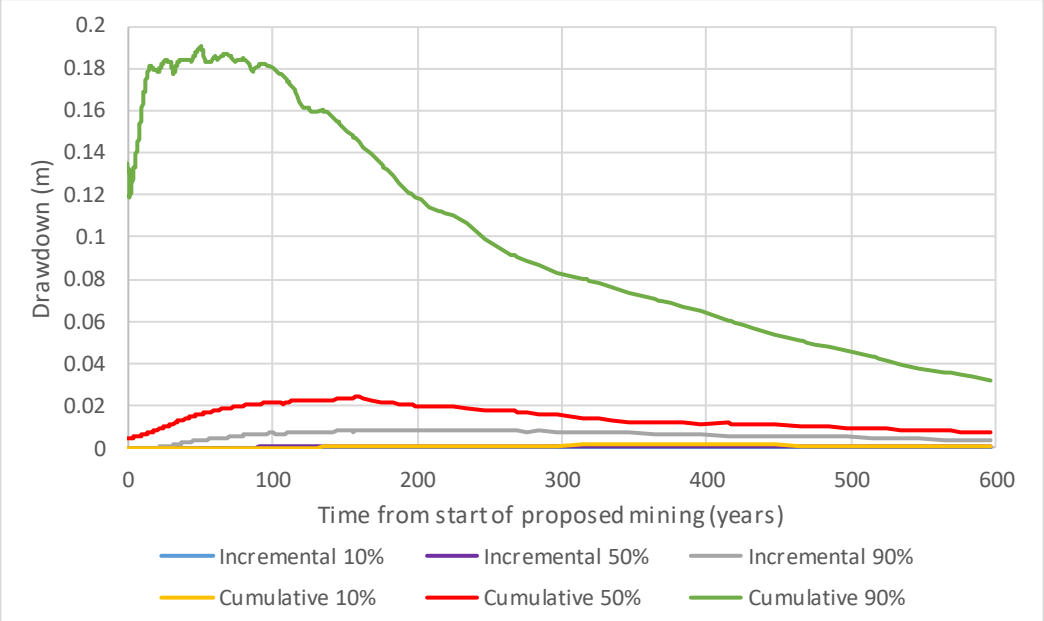


Figure 4-20 Cumulative and incremental drawdown at GW078363

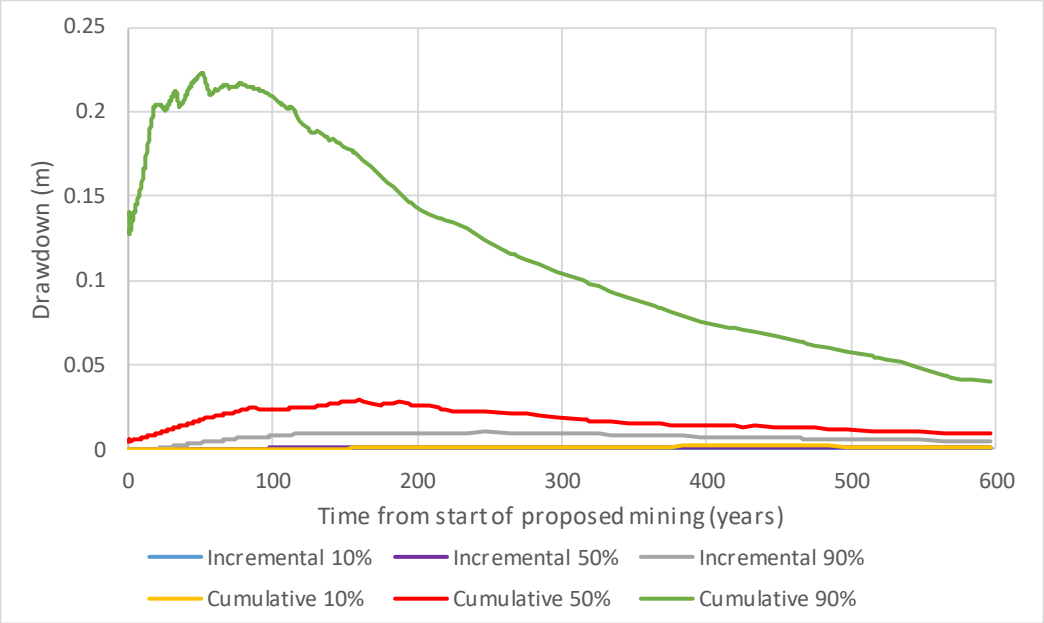


Figure 4-21 Cumulative and incremental drawdown at GW078591

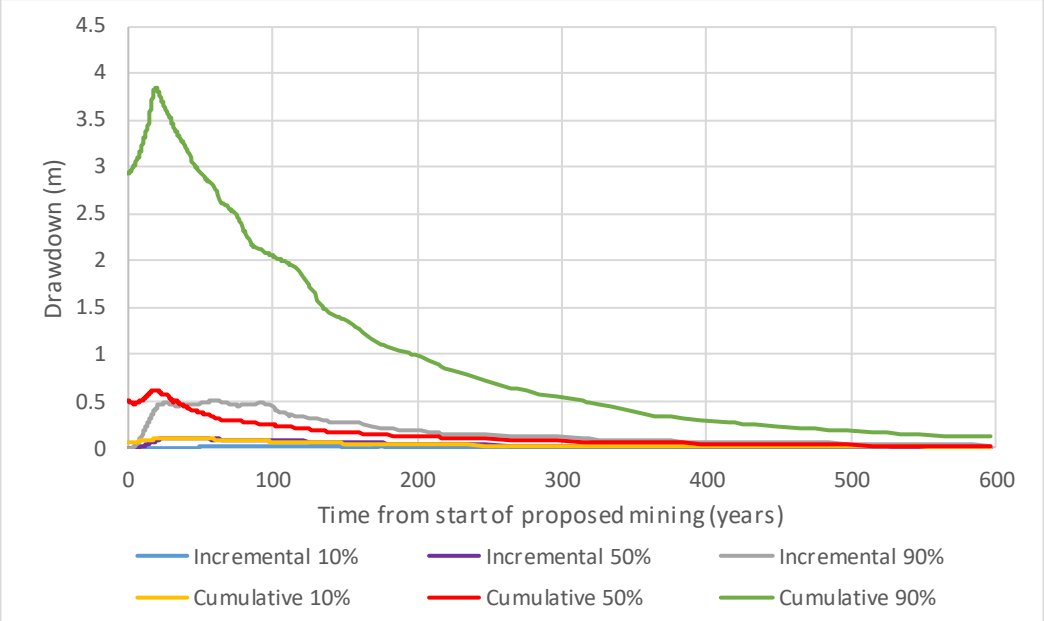


Figure 4-22 Cumulative and incremental drawdown at GW203292

4.1.3 Mine inflows

Mine inflows into the West Borehole Seam for proposed and existing workings at Newstan Colliery are shown in Figure 4-23.

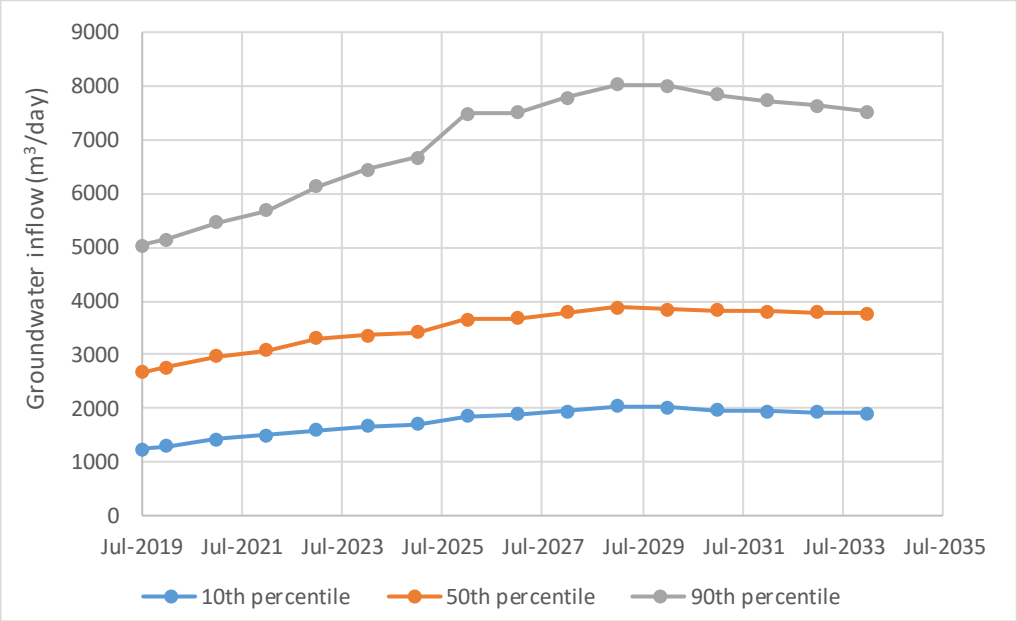


Figure 4-23 Modelled Newstan Colliery West Borehole seam groundwater inflows

4.1.4 Awaba workings

Net groundwater flow into Awaba has been extracted from the cell-by-cell flow output. As discussed in GHD (2020), proposed mining results in a reduction to groundwater inflow into the Awaba void. Therefore the reduction in groundwater inflow into the Awaba void due to the proposed mine workings is plotted in Figure 4-24.

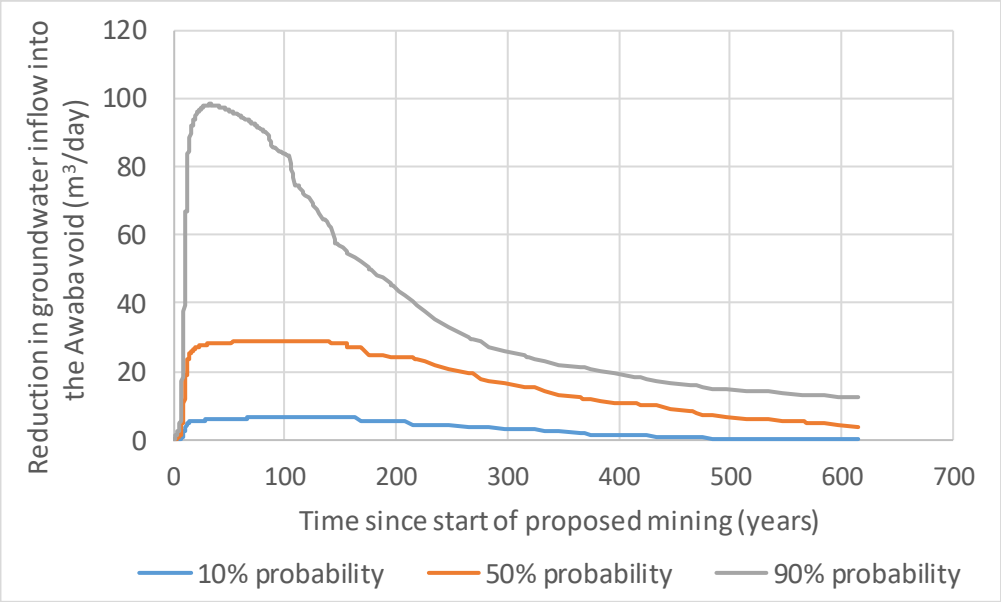


Figure 4-24 Reduction in groundwater inflow into the Awaba void

4.1.5 Fassifern underground storage

Net groundwater flow into the Fassifern Underground Storage has been extracted from the cell-by-cell flow output and is plotted in Figure 4-25.

Results have been presented for the base case model and the no proposed Newstan expansion model. The results show the proposed workings at Newstan have no impact on the Fassifern Underground Storage.

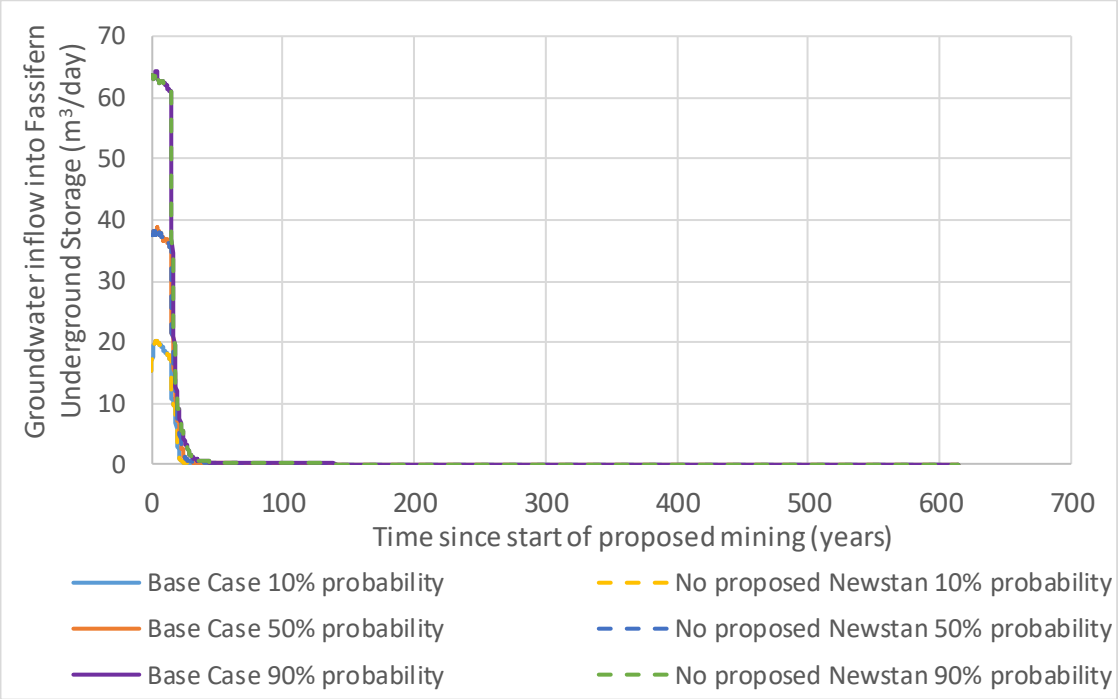


Figure 4-25 Net groundwater flow into Fassifern Underground Storage

4.1.6 Eraring Ash Dam

The net leakage from the Eraring Ash Dam has been extracted from the cell-by-cell flow output. The results are shown in Figure 4-26.

Results have been presented for the base case model and the no proposed Newstan expansion model. The results show the proposed workings at Newstan have no impact on leakage from the Eraring Ash Dam.

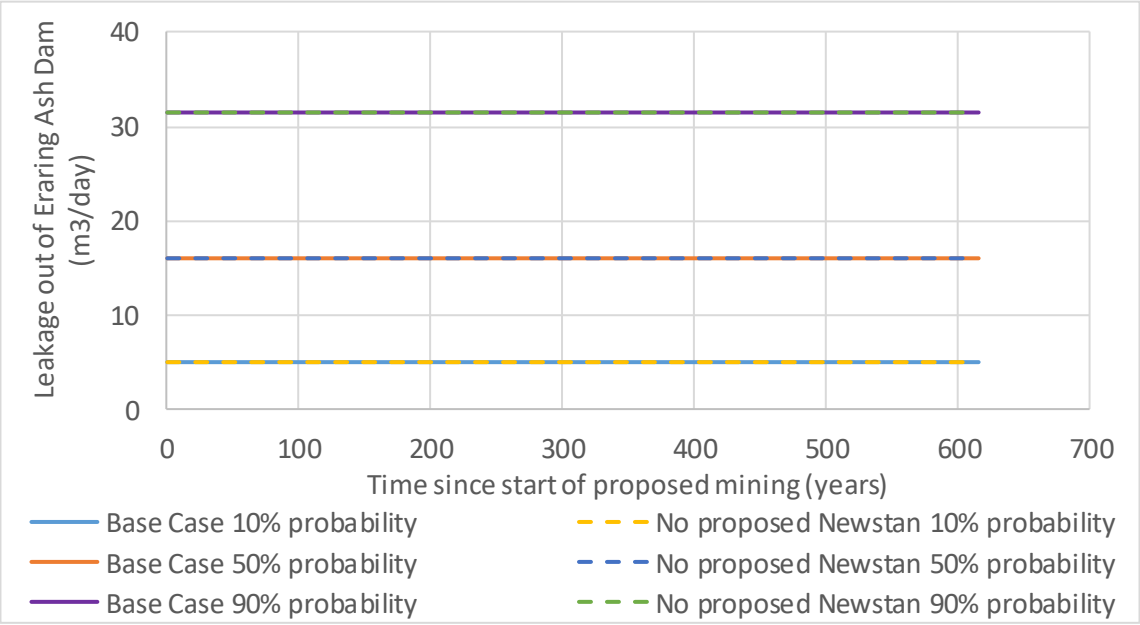


Figure 4-26 Net leakage from Eraring Ash Dam

4.1.7 Baseflow

Outflow to river cells (baseflow) has been extracted from the cell-by-cell flow output. Baseflow to rivers was zero for the calibrated model. Results have been presented for the base case model, the no proposed Newstan expansion model and the no regional mining model. Baseflow was zero for 10% and 90% probability of exceedance for all scenarios. Therefore baseflow has been plotted for 90% probability of exceedance only. Baseflow is plotted in Figure 4-27.

The results indicate that proposed mining has a negligible impact on baseflow, with proposed mining and existing mining modelled to result in a reduction of baseflow of less than 0.1 m^3/day.

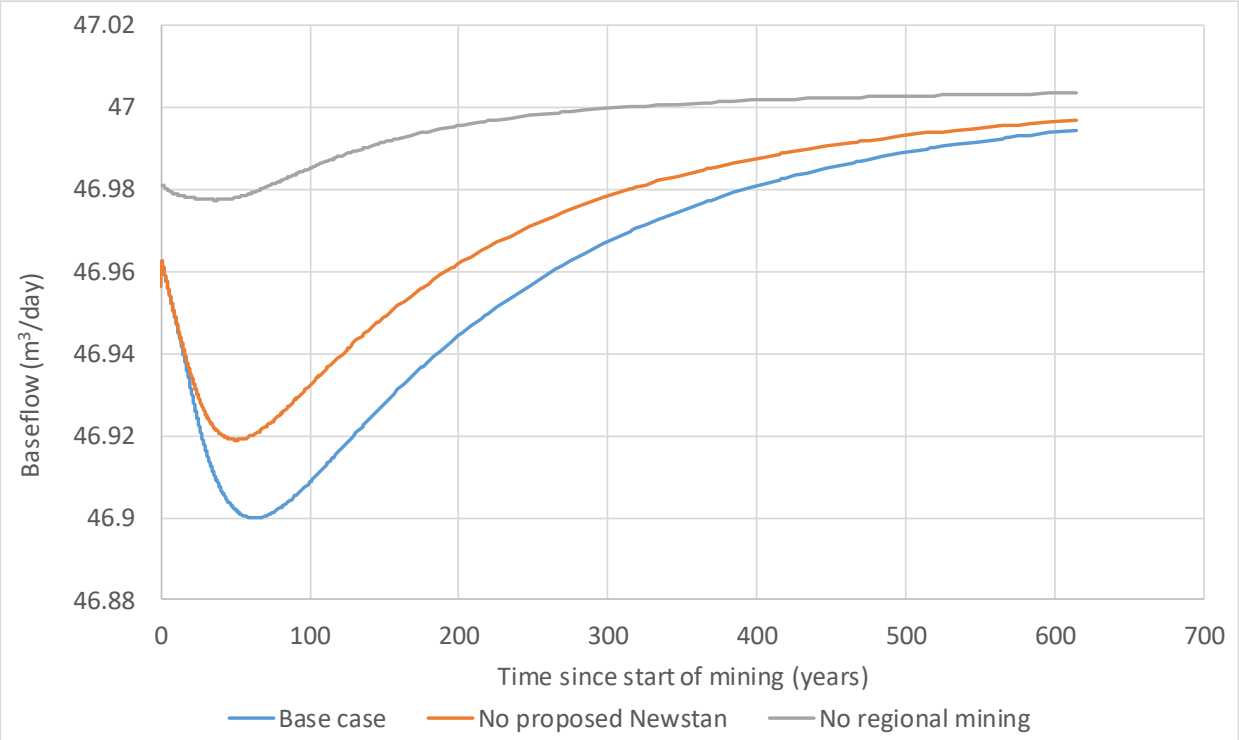


Figure 4-27 Baseflow 90% probability of exceedance

5. References

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 No. 82, National Water Commission, Canberra, 191 pp.

Doherty J, Hunt R and Tonkin M (2010) Approaches to Highly Parameterized Inversion: A Guide to Using PEST for Model-Parameter and Predictive-Uncertainty Analysis, Scientific Investigations Report 2010-5211, U.S. Department of the Interior and U.S. Geological Survey.

Doherty, J. (2016) PEST. Model-Independent Parameterisation. User Manual Part I: PEST, SENSAN and Global Optimisers. Brisbane : Watermark Numerical Computing.

GHD (2020a) Newstan Extension of Mining Project Groundwater Modelling Report.

GHD (2020b) Newstan Extension of Mining Project Groundwater Impact Assessment.

Middlemis H and Peeters LJM (2018) Explanatory Note, Uncertainty Analysis in Groundwater Modelling. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy.

GHD

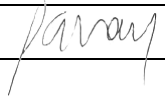
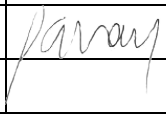
Suite 10 Zenith Building
6 Reliance Drive Tuggerah NSW 2259
T: 61 2 4350 4100 F: 61 2 4350 4101 E: centralcoastmail@ghd.com

© GHD 2020

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

GHDDocId/https://projects.ghd.com/oc/Newcastle3/newstanextensionproj/Delivery/Documents/2220265_LET_Uncertainty Analysis.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	I.Gilmore	S. Gray		S. Gray		27/03/2020
1	I. Gilmore	S. Gray		S. Gray		14/04/2020
						

www.ghd.com

GHD

Level 3 GHD Tower 24 Honeysuckle Drive Newcastle NSW 2300
PO BOX 5403 Hunter Region Mail Centre NSW 2310
T: 61 2 4979 9999 F: 61 2 4979 9988 E: ntlmail@ghd.com

© GHD 2020

This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.

22-SO-2111435880-5/https://projects.ghd.com/oc/Newcastle3/newstanextensionproj/Delivery/Documents/22-20265-REP_Newstan Extension_GMR.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	I Gilmore	S Gray	*S Gray*	S Gray	*S Gray*	14/04/2020
1	I Gilmore	S Gray	*S Gray*	S Gray	*S Gray*	20/05/2020
2	I Gilmore	S Gray		S Gray		05/06/2020

www.ghd.com

Appendix C – Groundwater quality

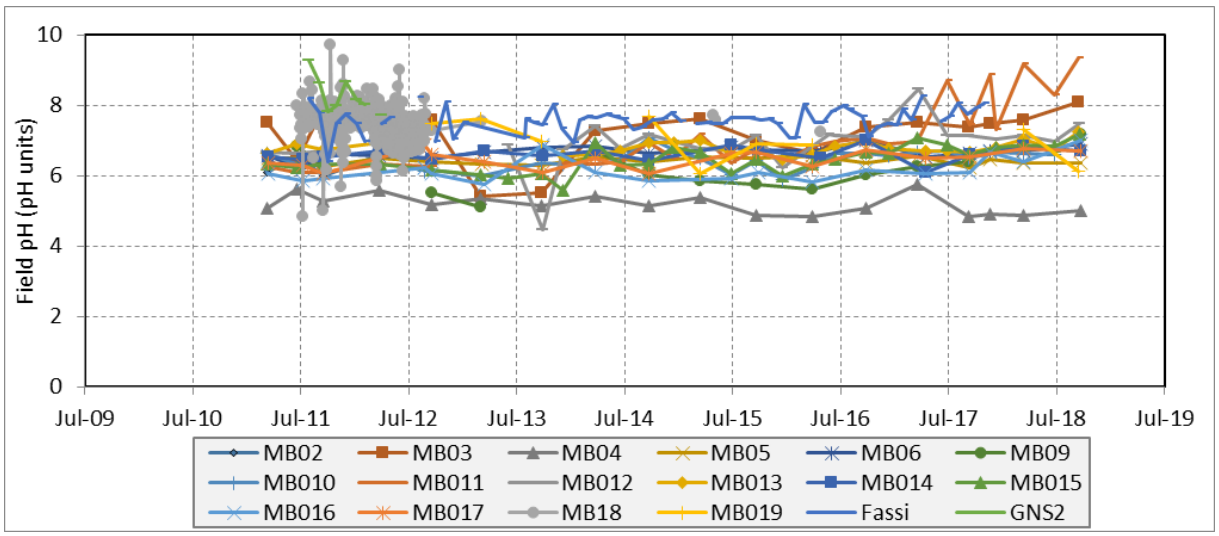


Figure C-1 Field pH monitored in groundwater

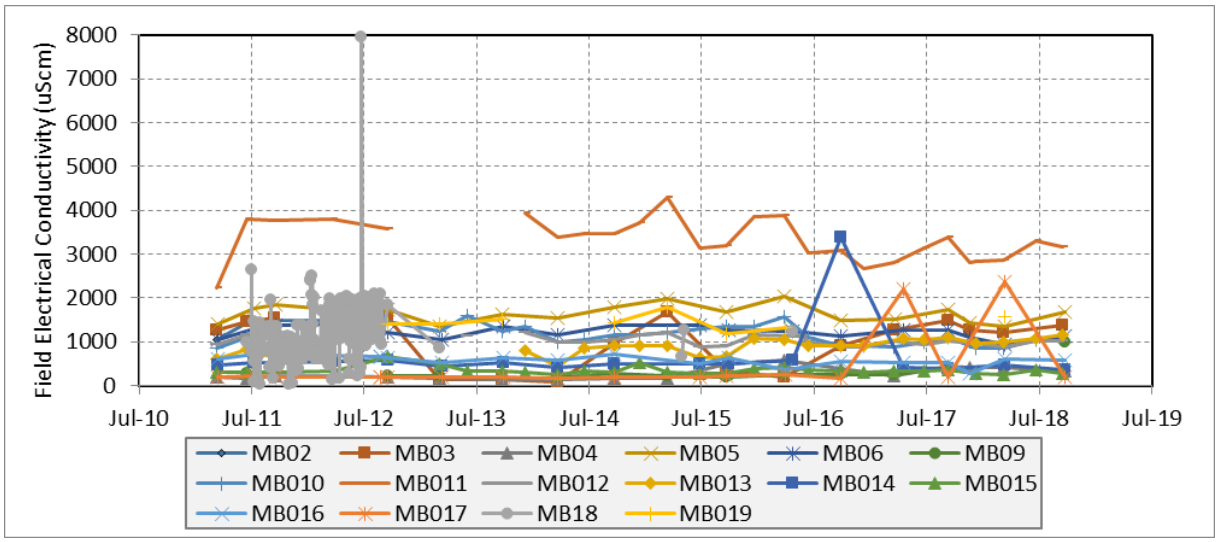


Figure C-2 Field electrical conductivity monitored in groundwater

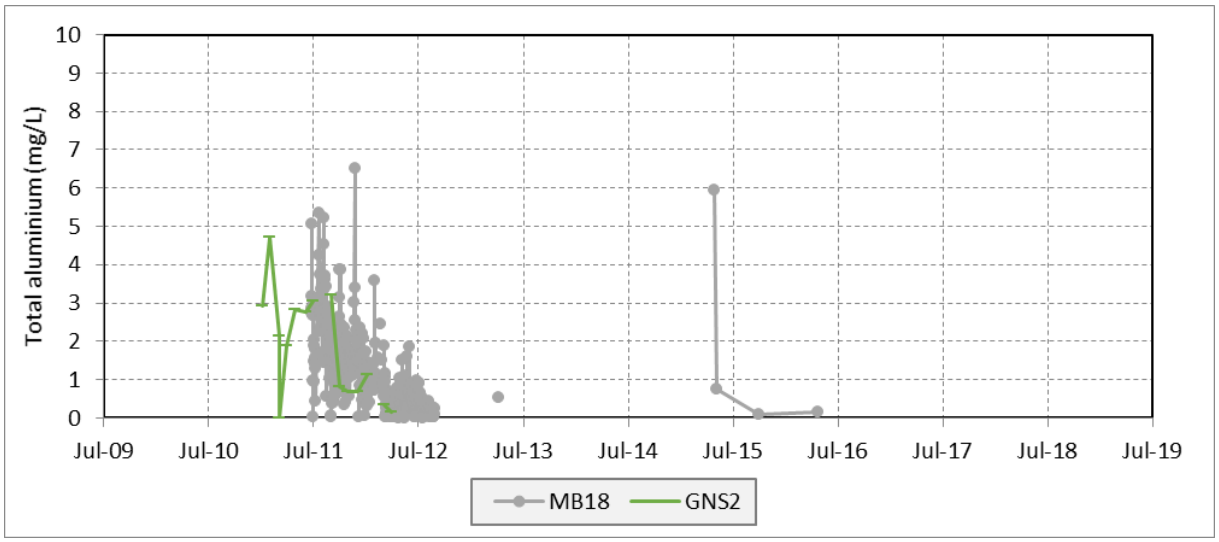


Figure C-3 Total aluminium monitored in groundwater

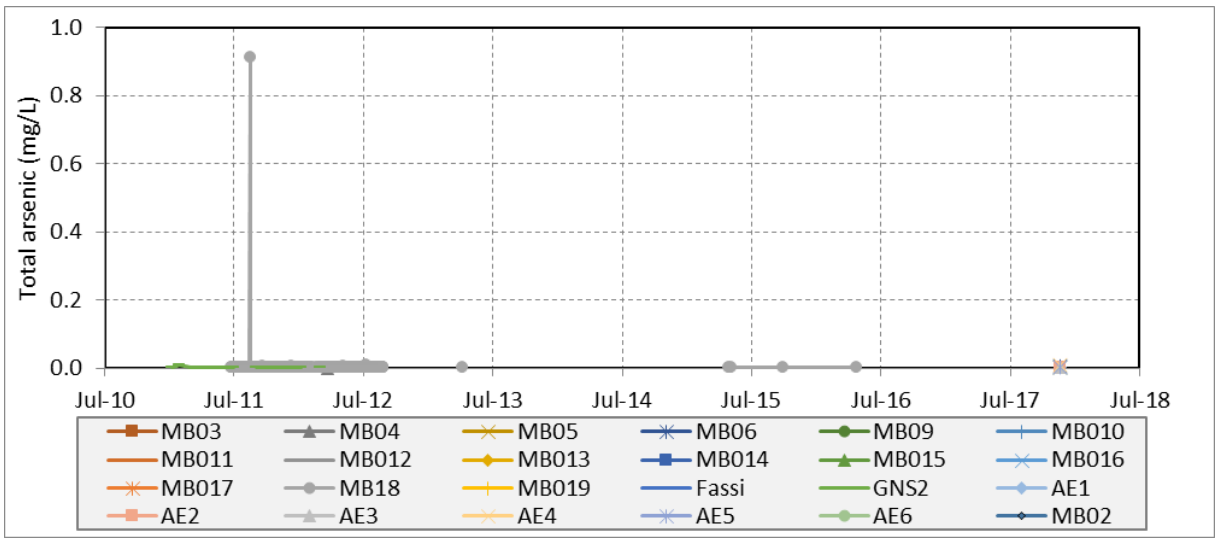


Figure C-4 Total arsenic monitored in groundwater

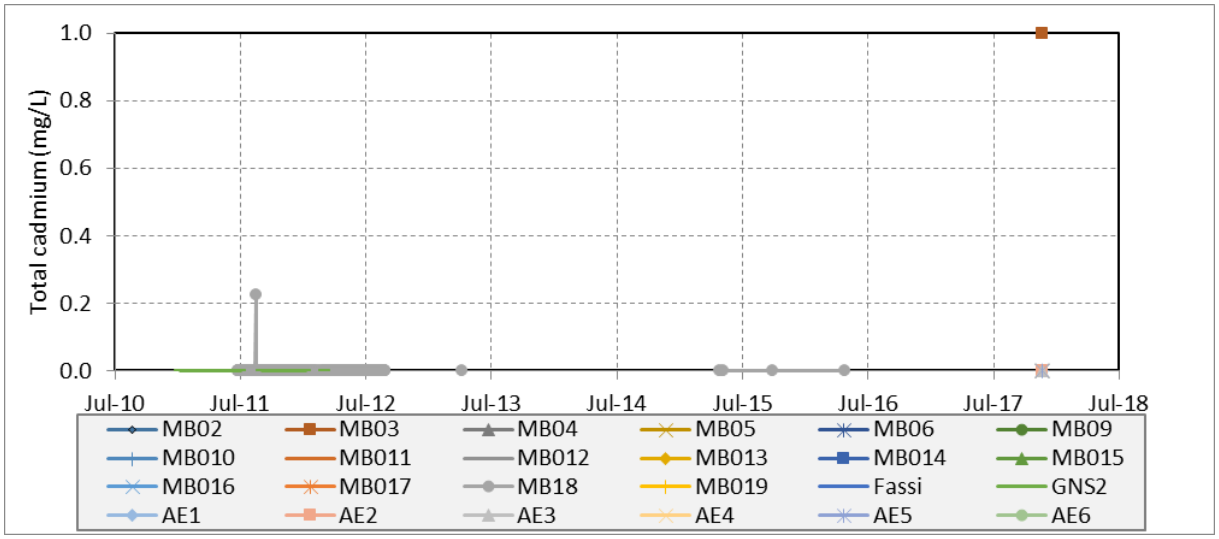


Figure C-5 Total cadmium monitored in groundwater

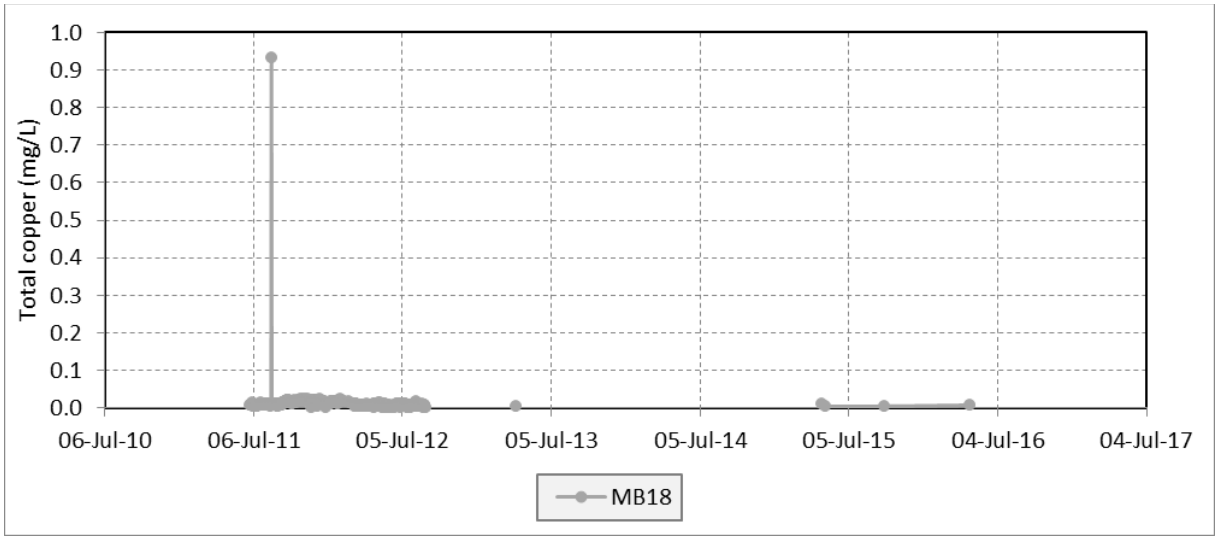


Figure C-6 Total copper monitored in groundwater

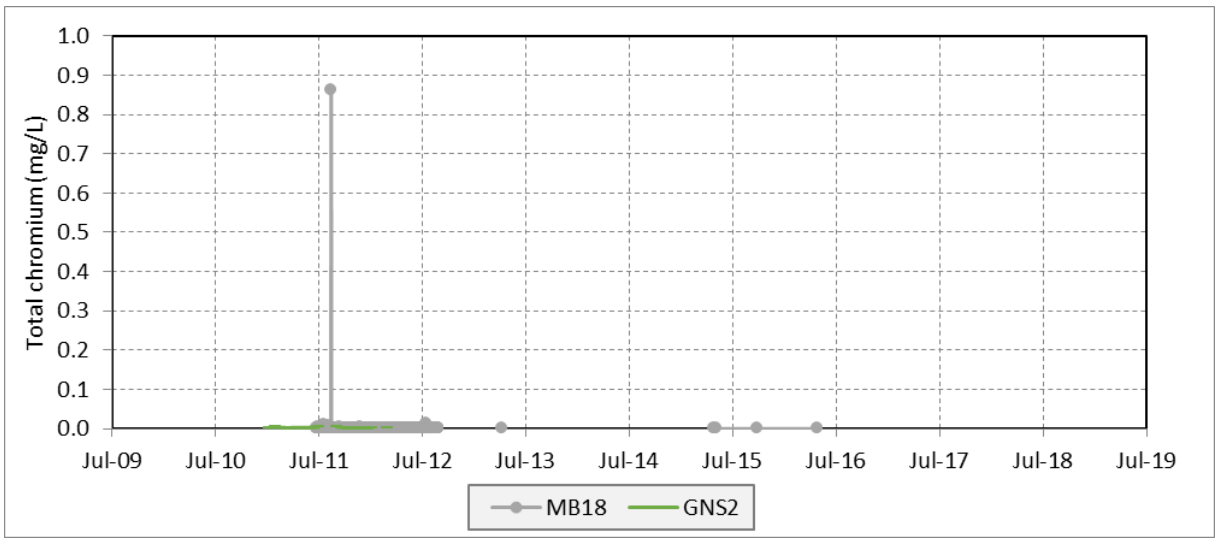


Figure C-7 Total chromium monitored in groundwater

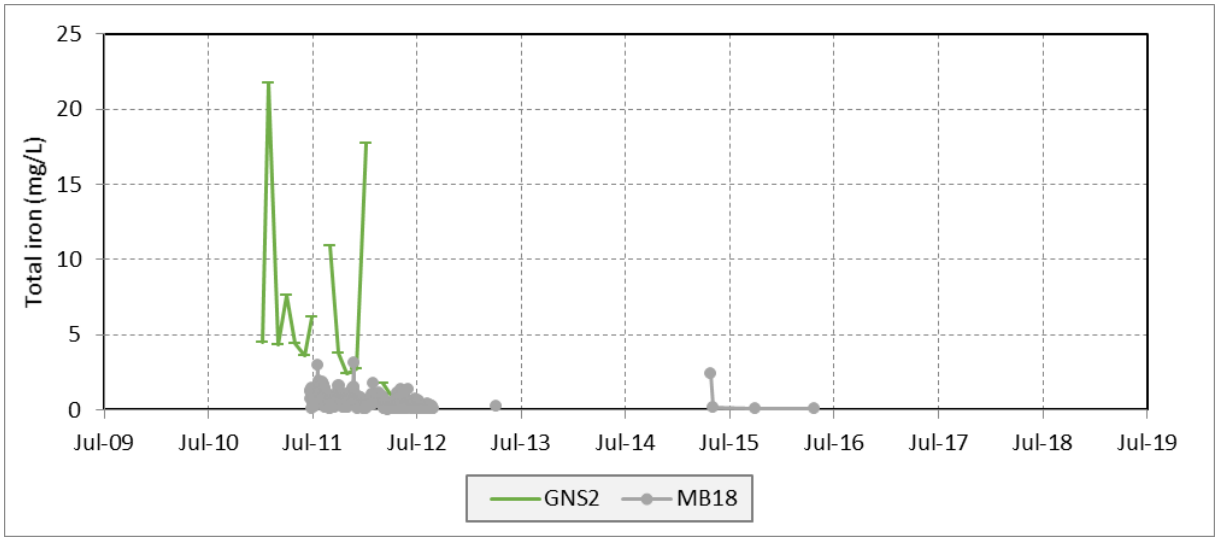


Figure C-8 Total iron monitored in groundwater

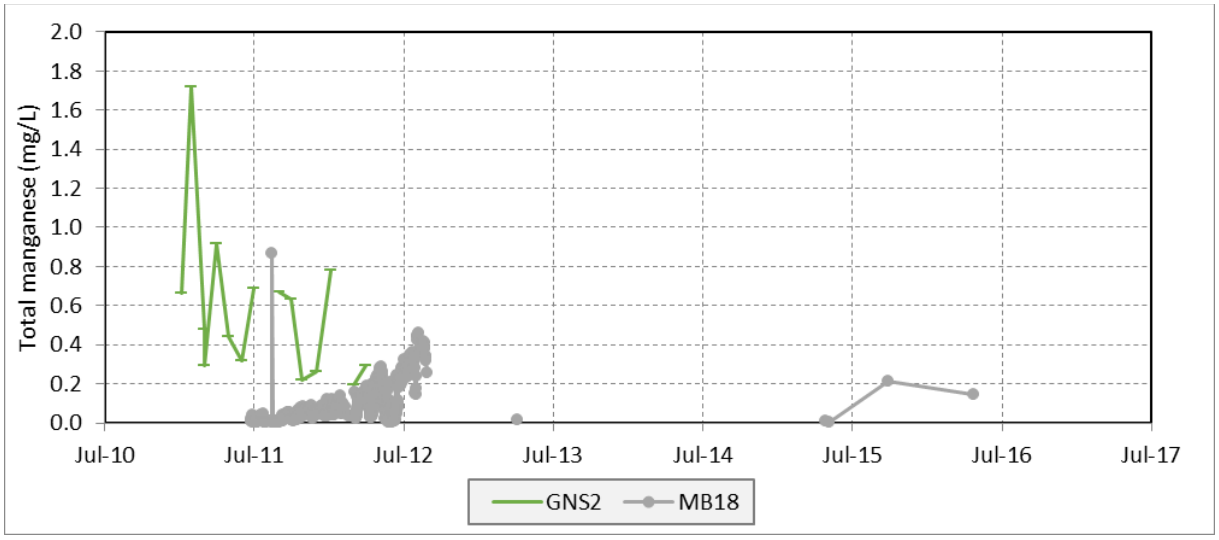


Figure C-9 Total manganese monitored in groundwater

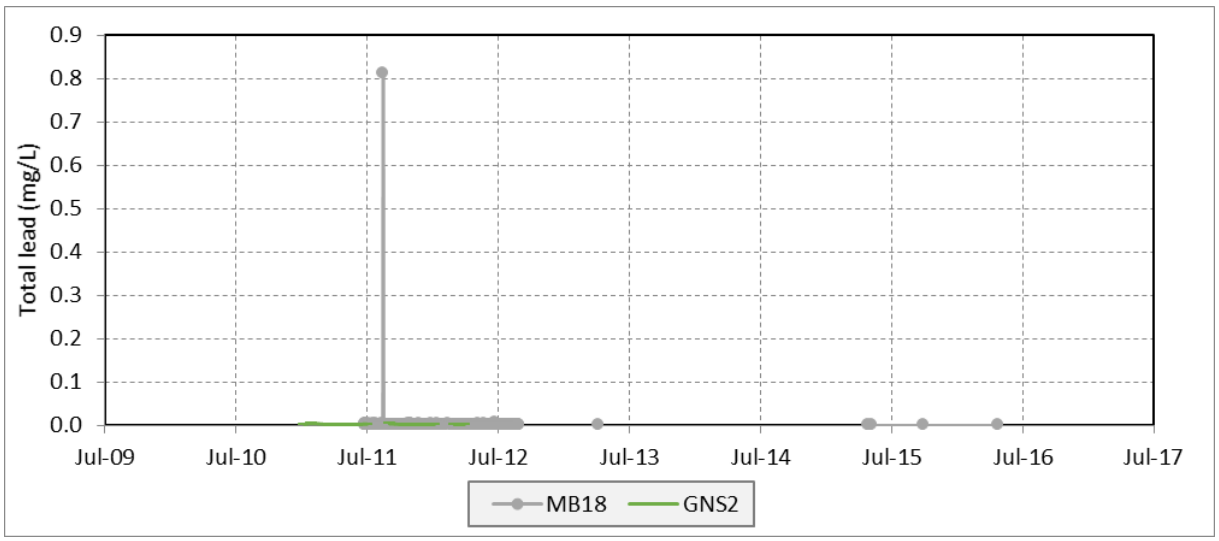


Figure C-10 Total lead monitored in groundwater

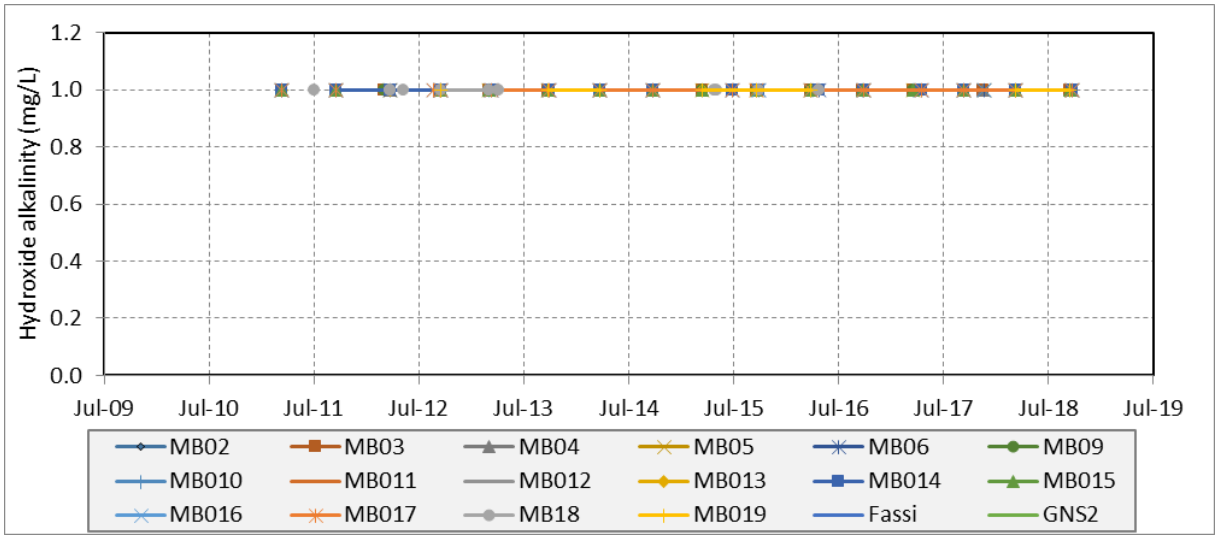


Figure C-11 Hydroxide alkalinity monitored in groundwater

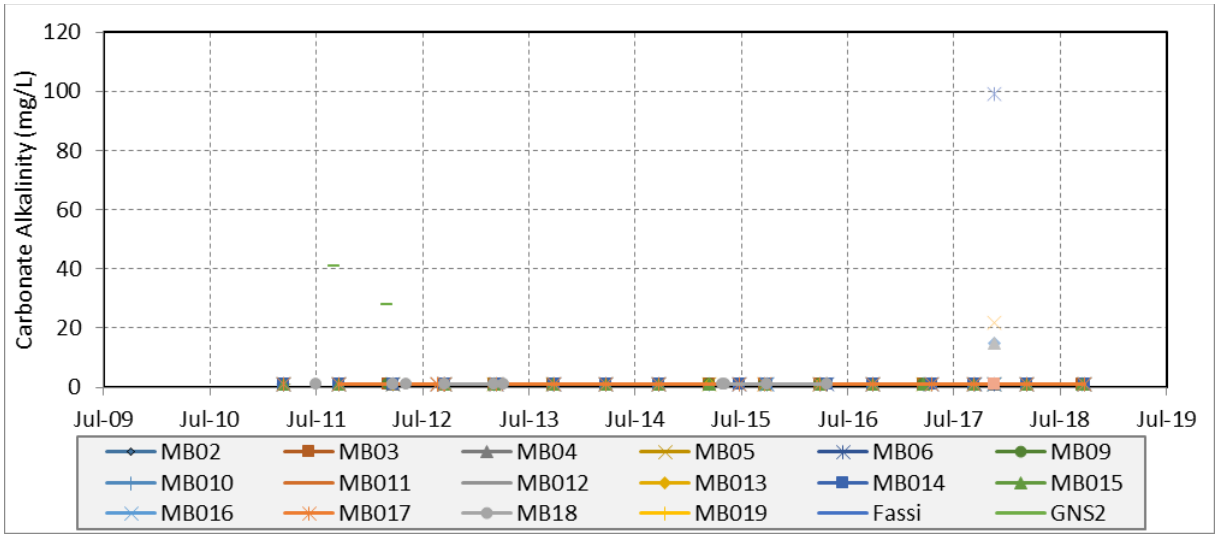


Figure C-12 Carbonate alkalinity monitored in groundwater

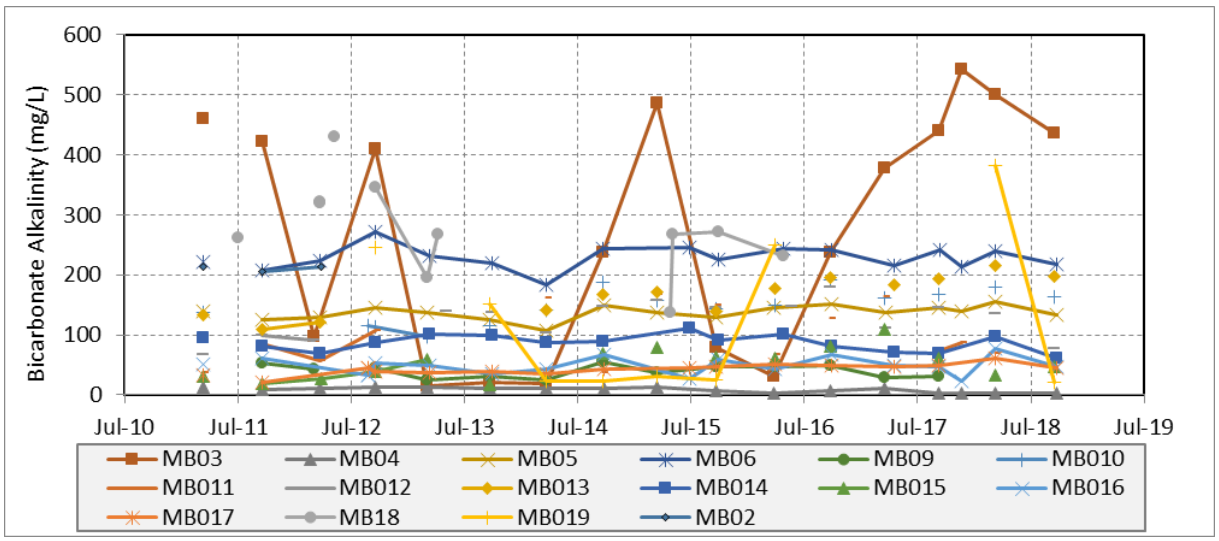


Figure C-13 Bicarbonate alkalinity monitored in groundwater

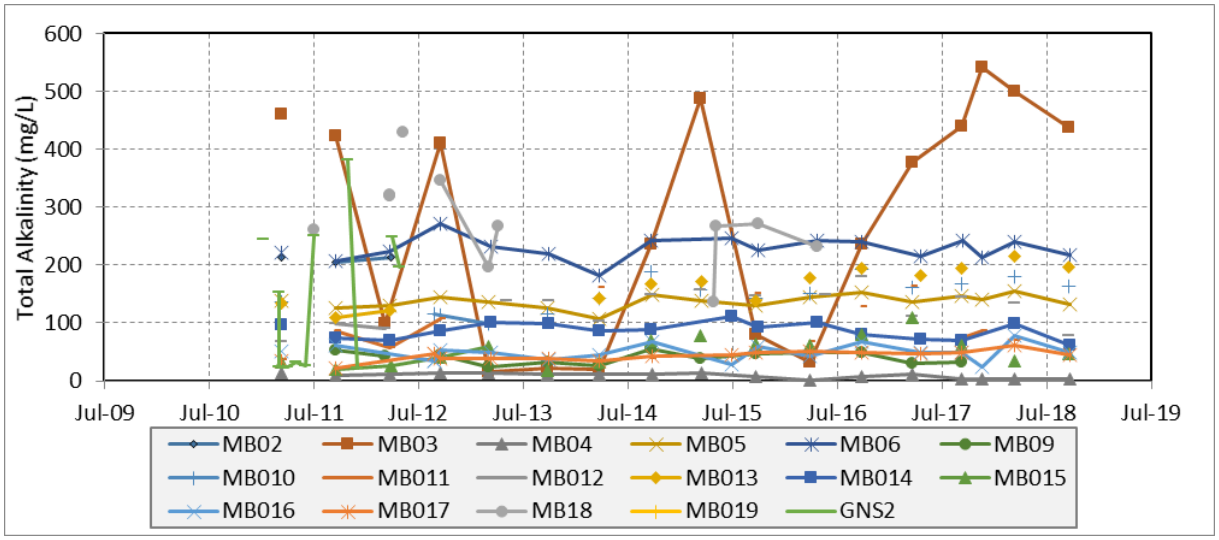


Figure C-14 Total alkalinity monitored in groundwater

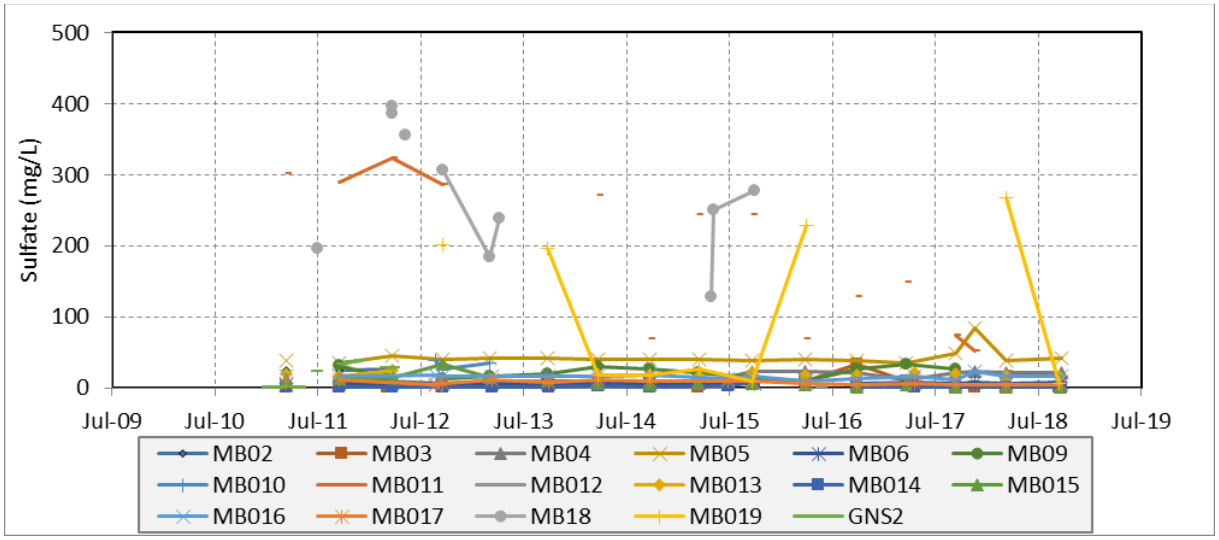


Figure C-15 Sulfate monitored in groundwater

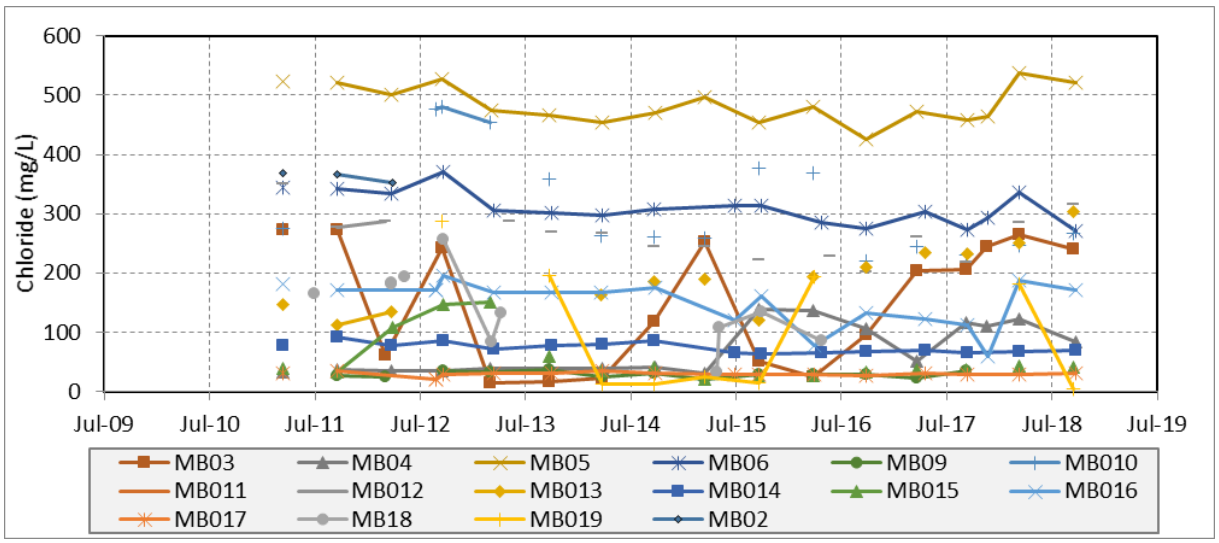


Figure C-16 Chloride monitored in groundwater

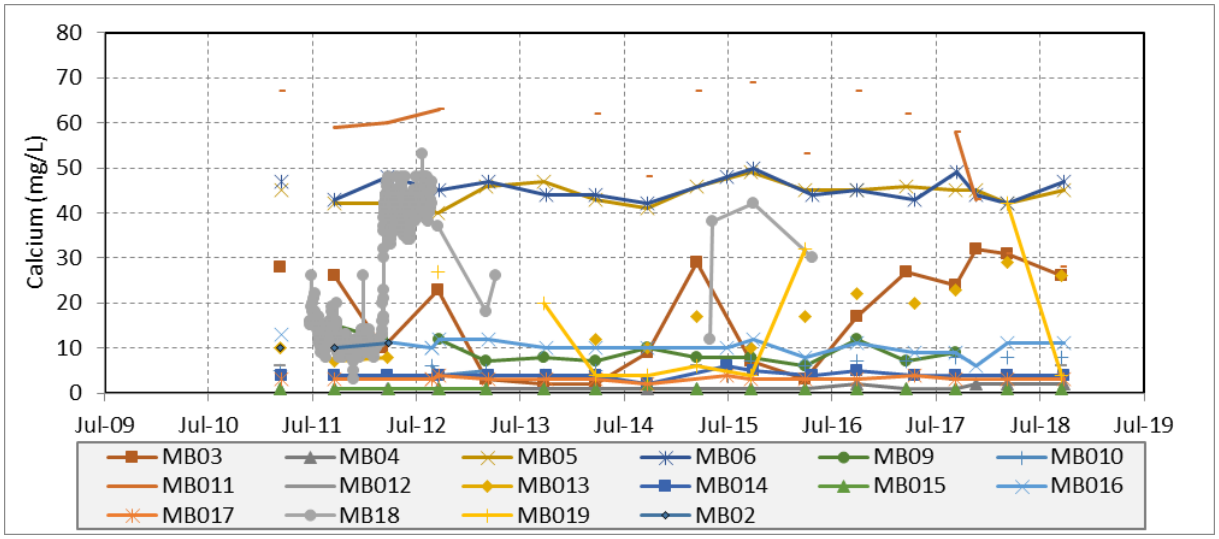


Figure C-17 Calcium monitored in groundwater

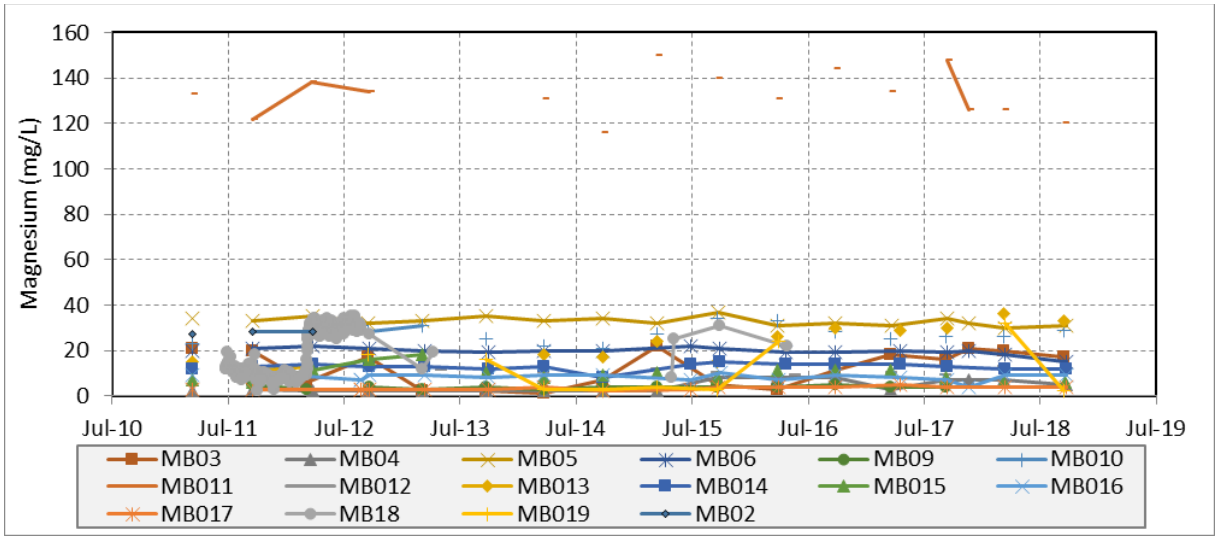


Figure C-18 Magnesium monitored in groundwater

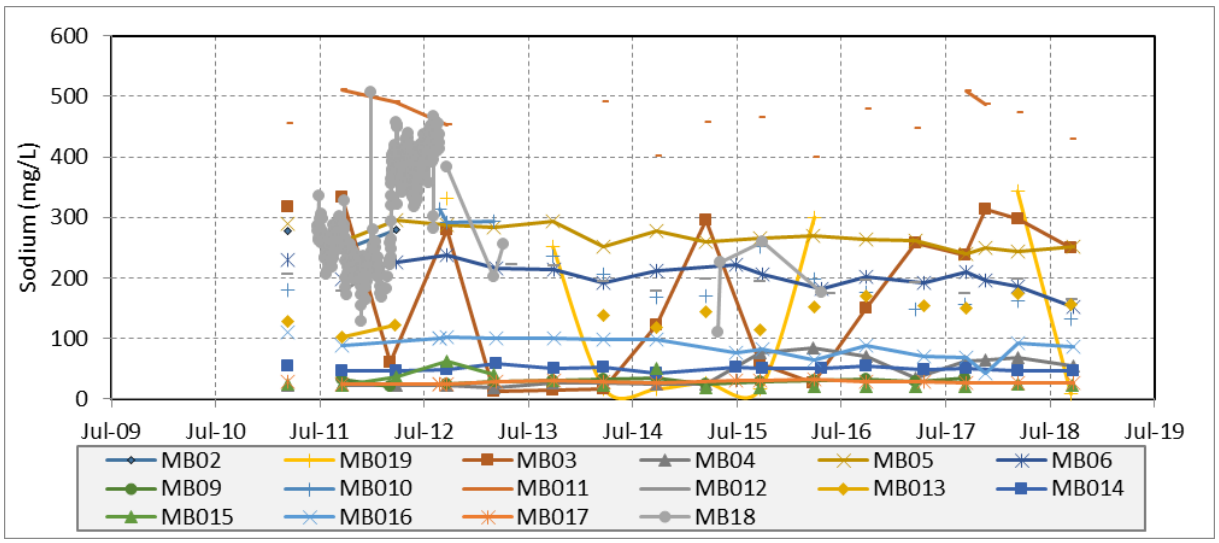


Figure C-19 Sodium monitored in groundwater

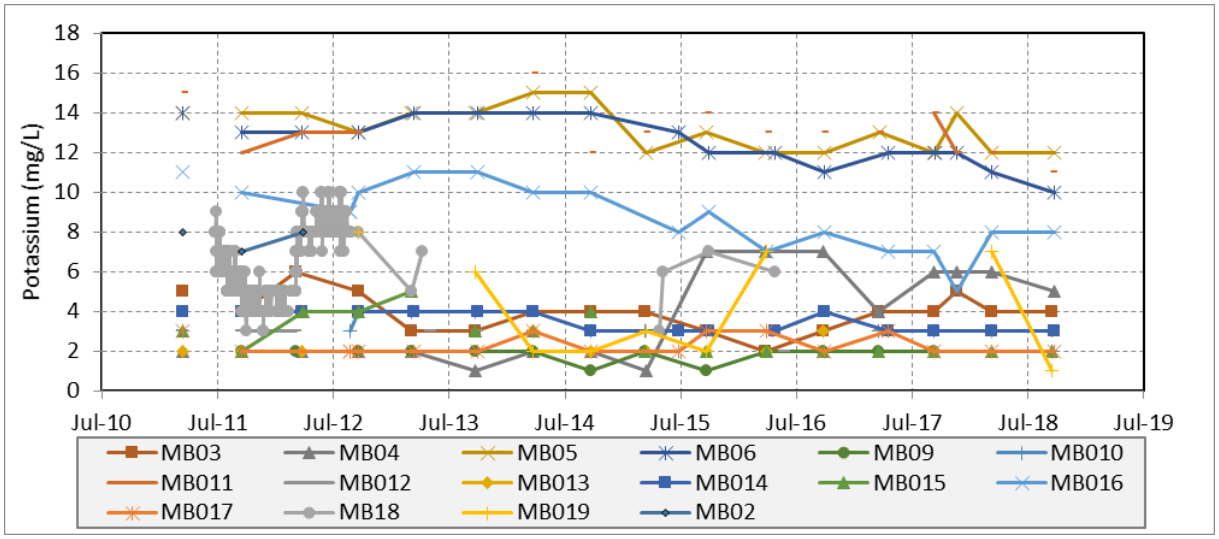


Figure C-20 Potassium monitored in groundwater

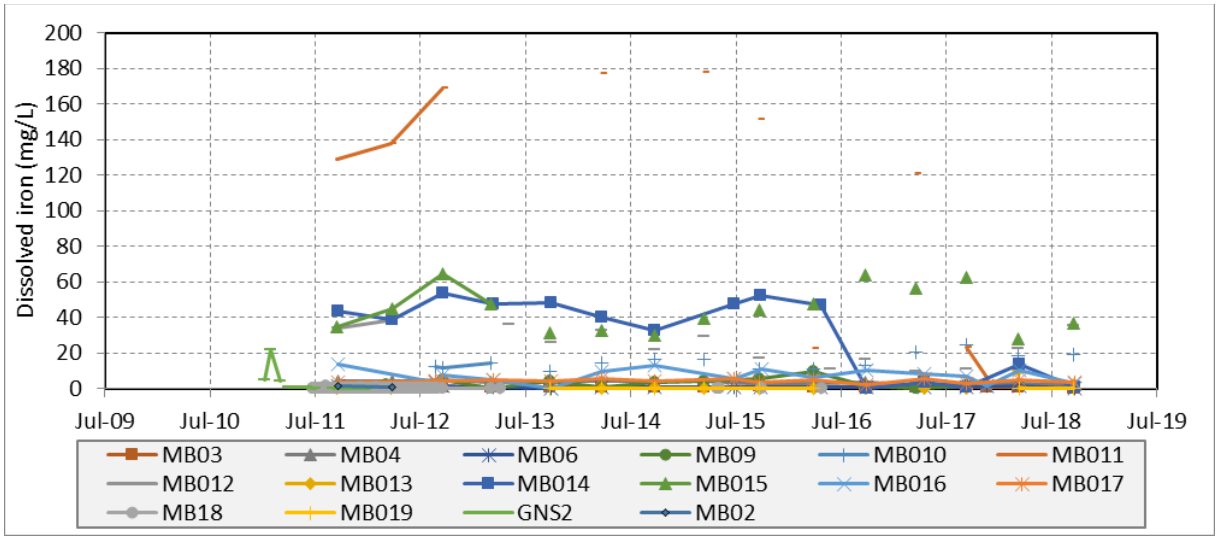


Figure C-21 Dissolved iron monitored in groundwater

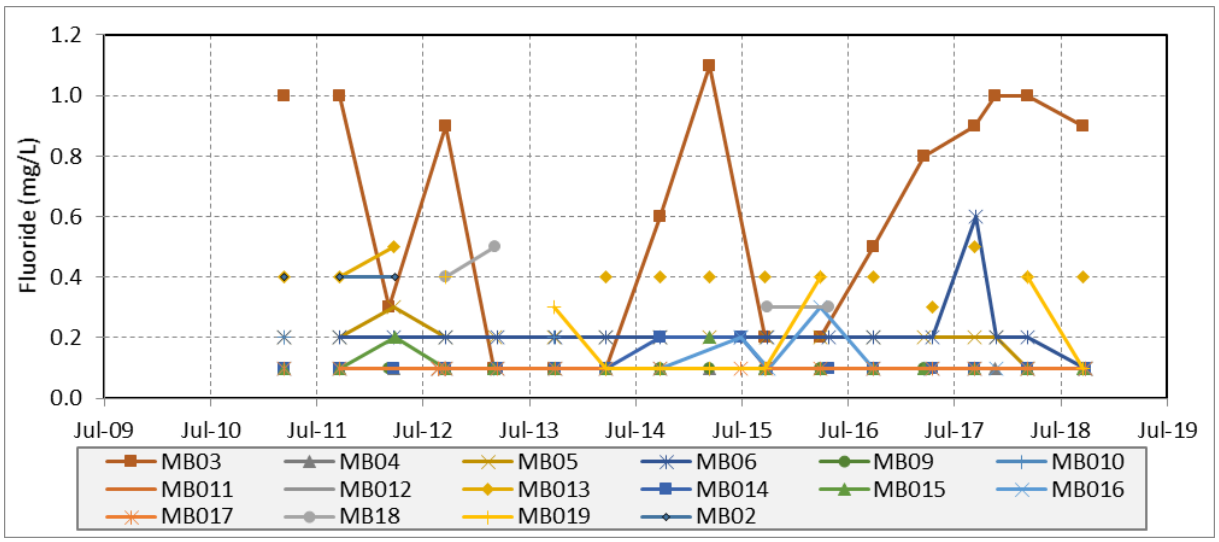


Figure C-22 Fluoride monitored in groundwater

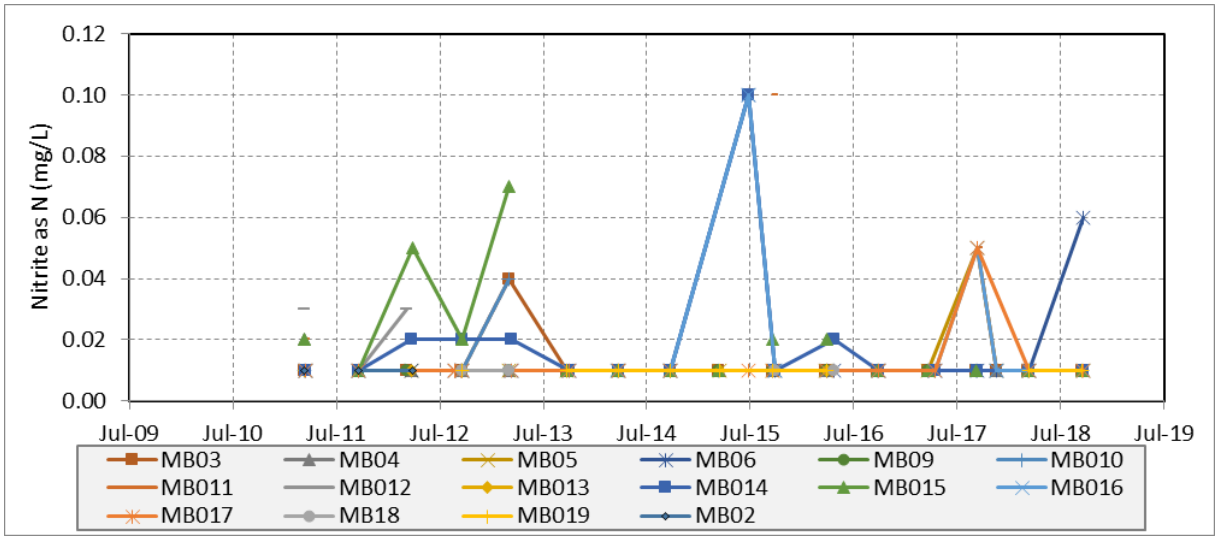


Figure C-23 Nitrite monitored in groundwater

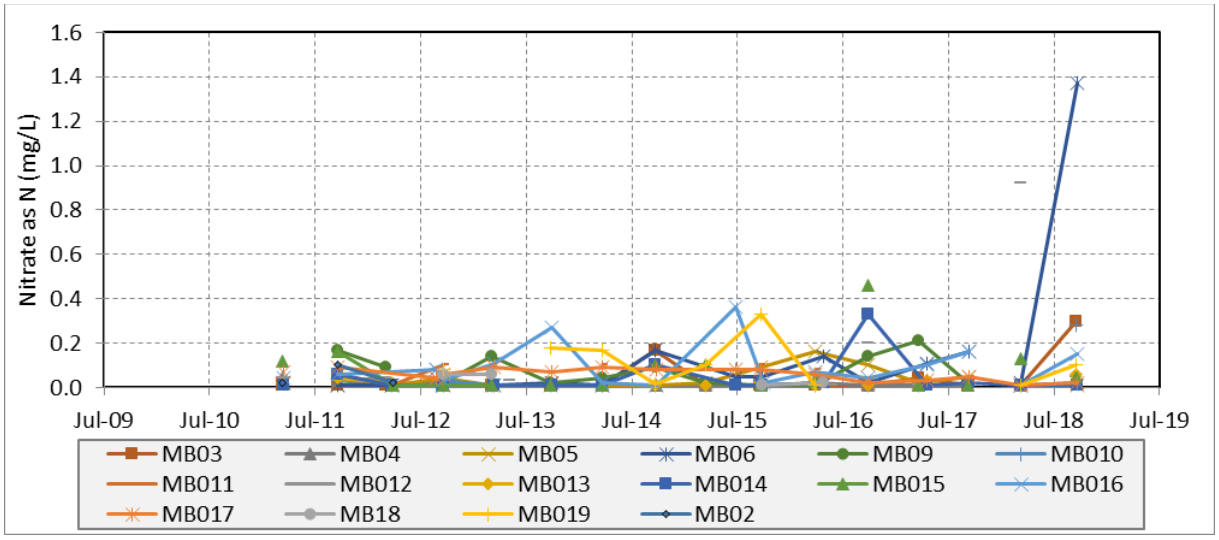


Figure C-24 Nitrate monitored in groundwater

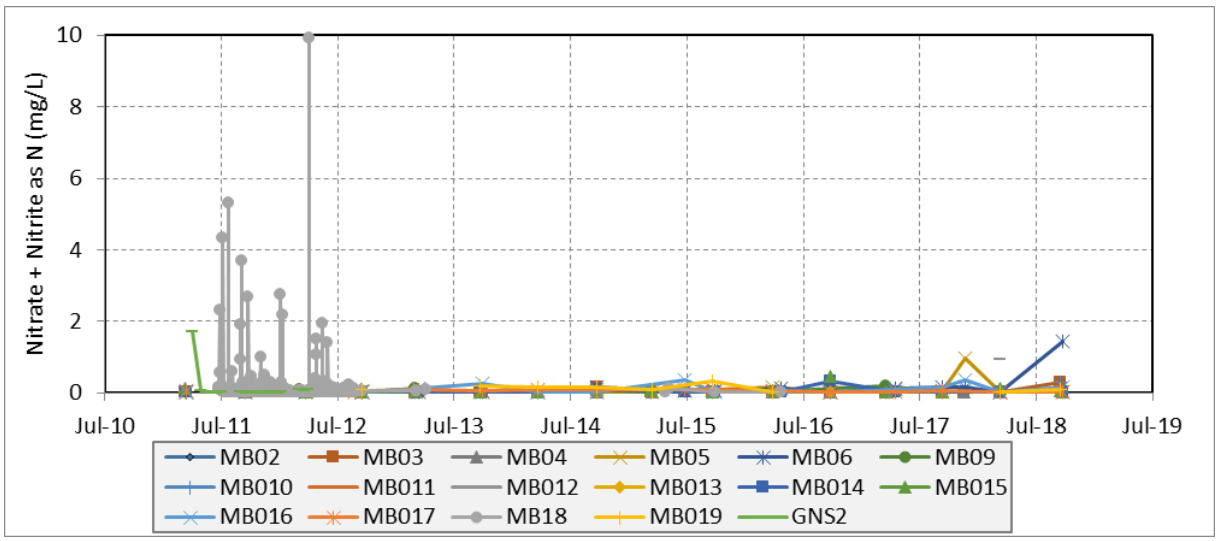


Figure C-25 Nitrate + nitrite monitored in groundwater

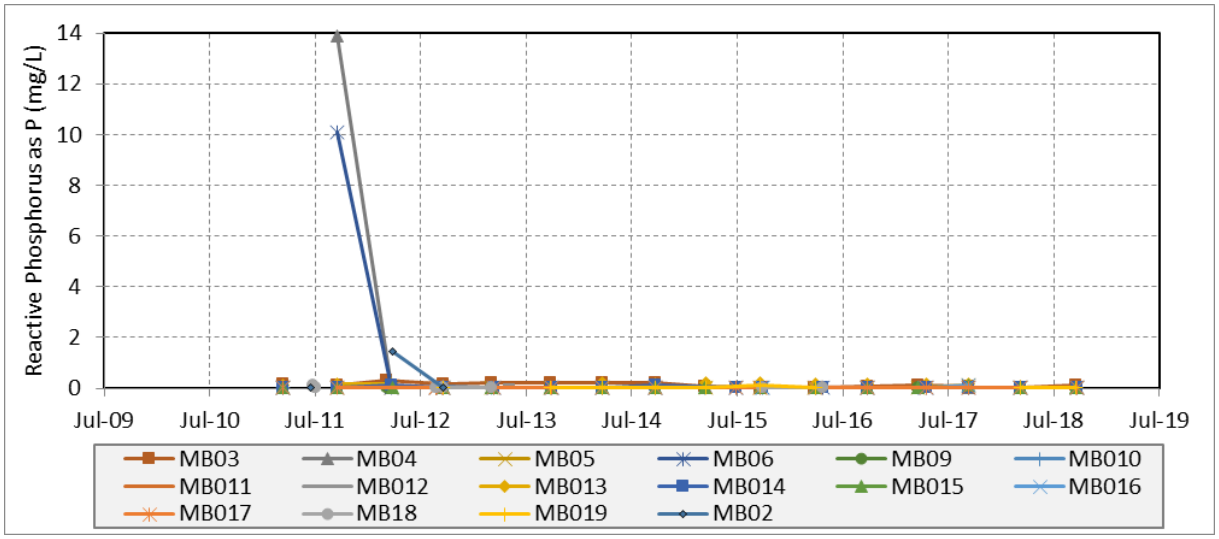


Figure C-26 Reactive phosphorus monitored in groundwater

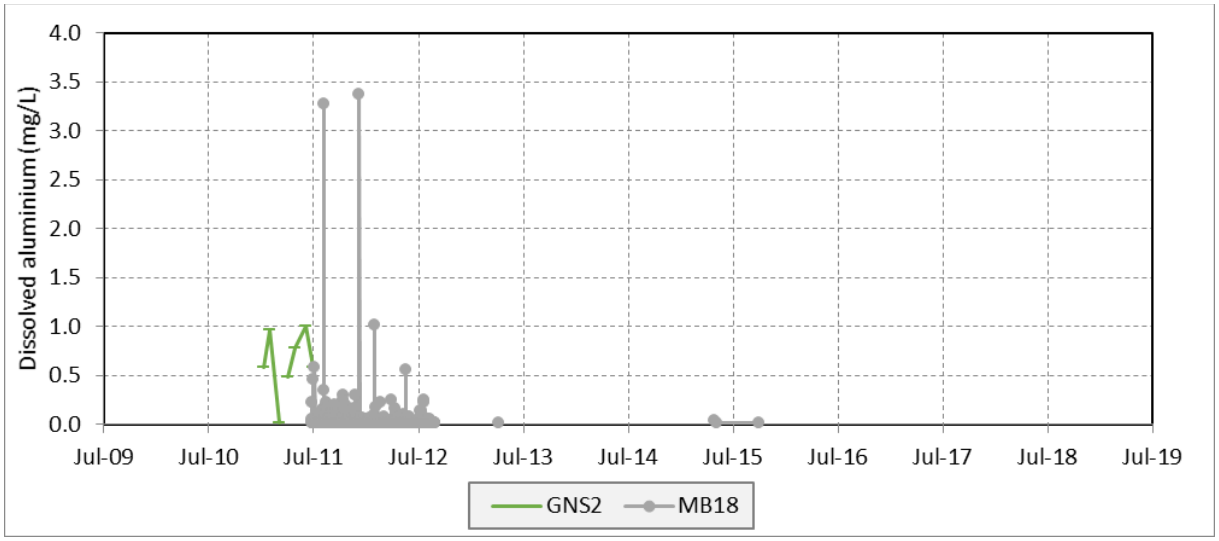


Figure C-27 Dissolved aluminium monitored in groundwater

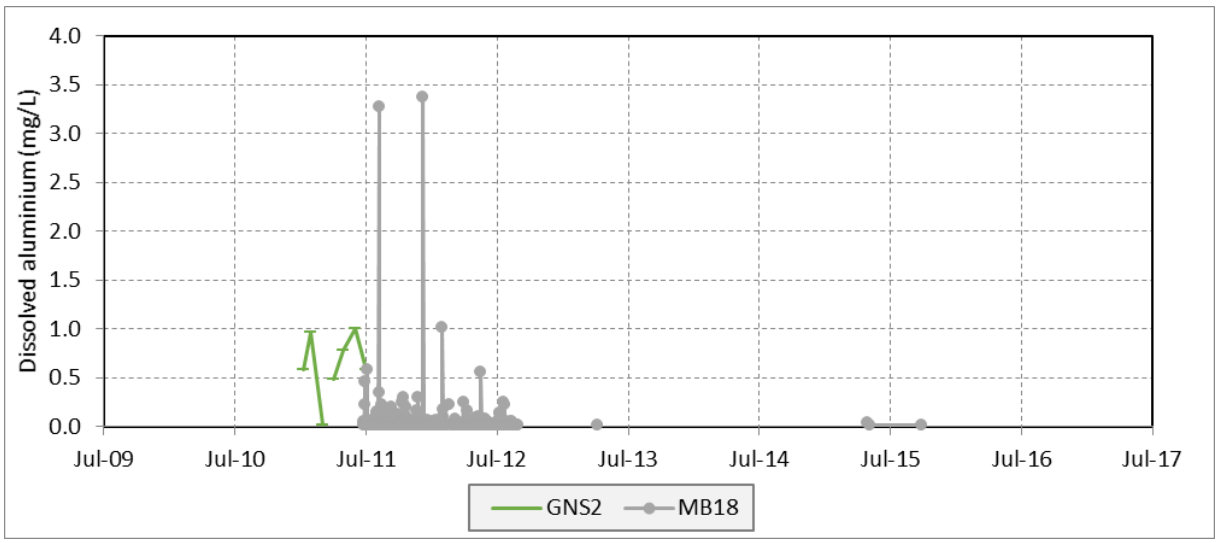


Figure C-28 Dissolved aluminium monitored in groundwater

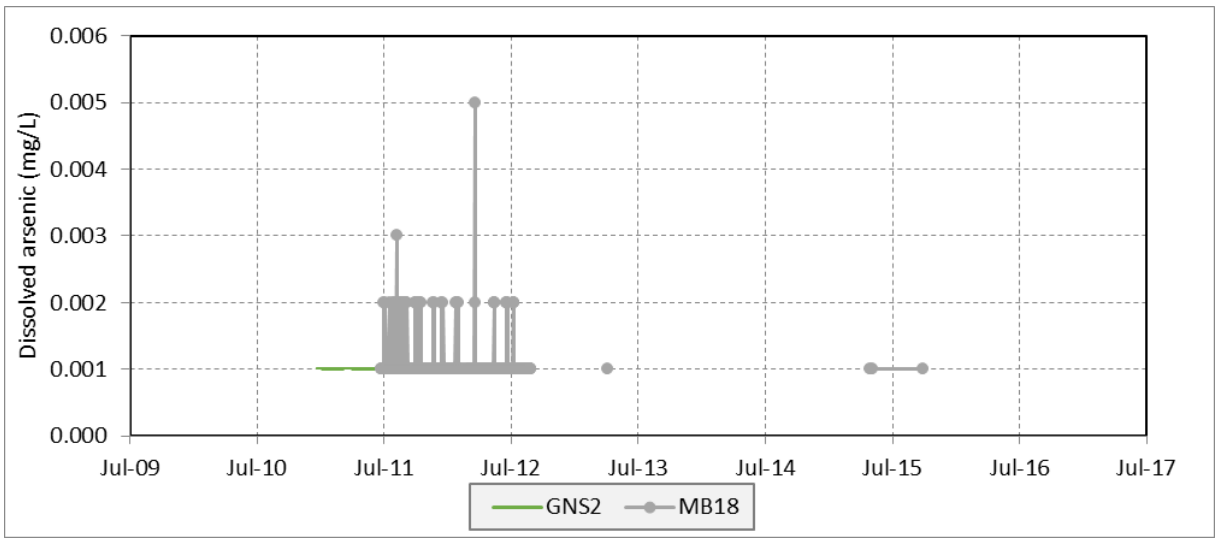


Figure C-29 Dissolved arsenic monitored in groundwater

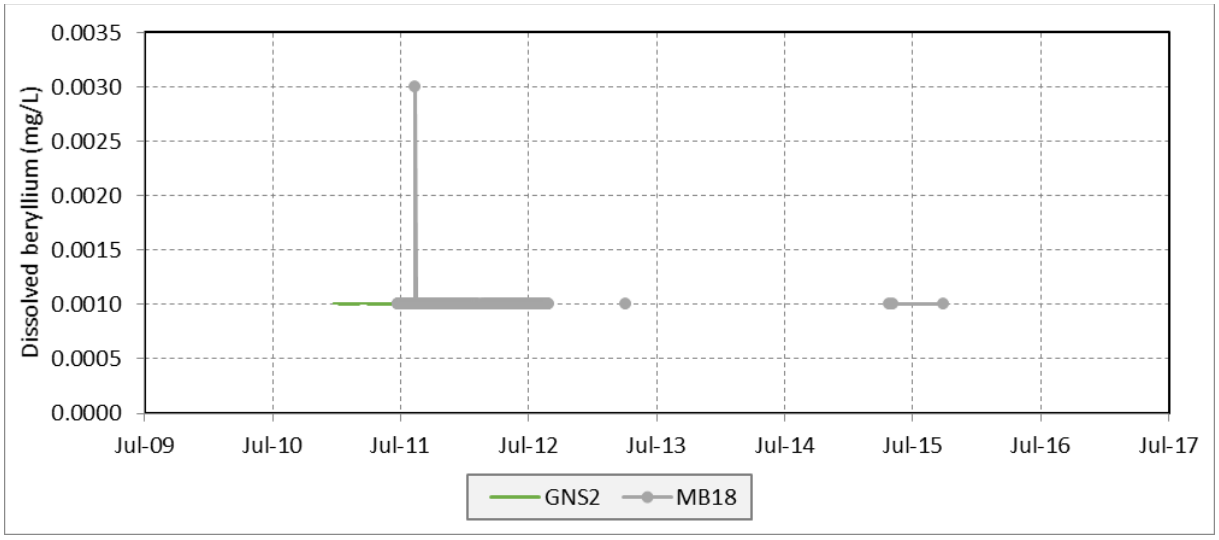


Figure C-30 Dissolved beryllium monitored in groundwater

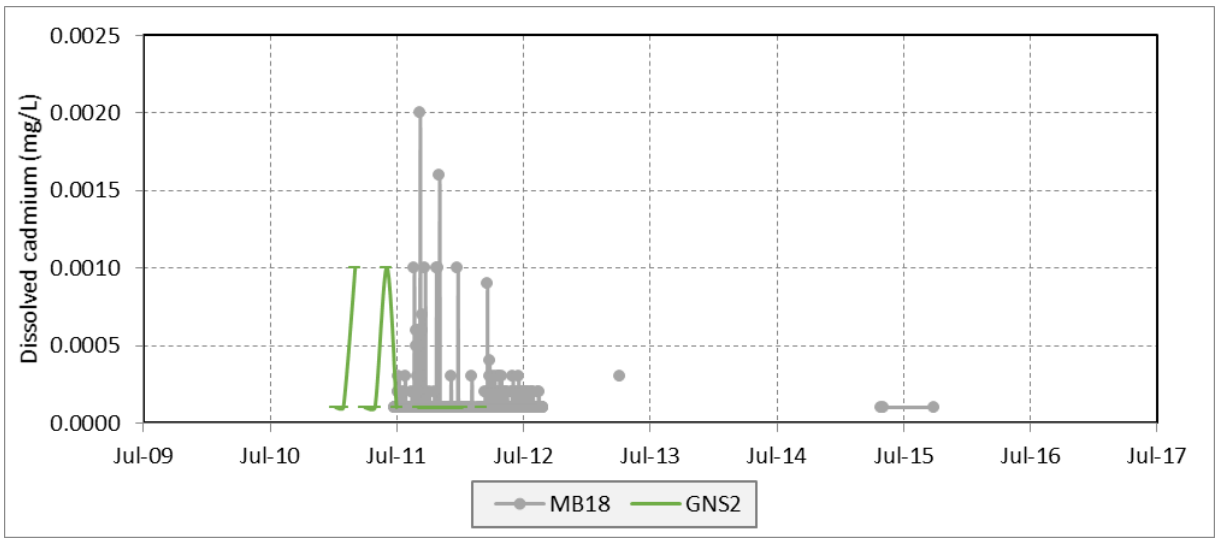


Figure C-31 Dissolved cadmium monitored in groundwater

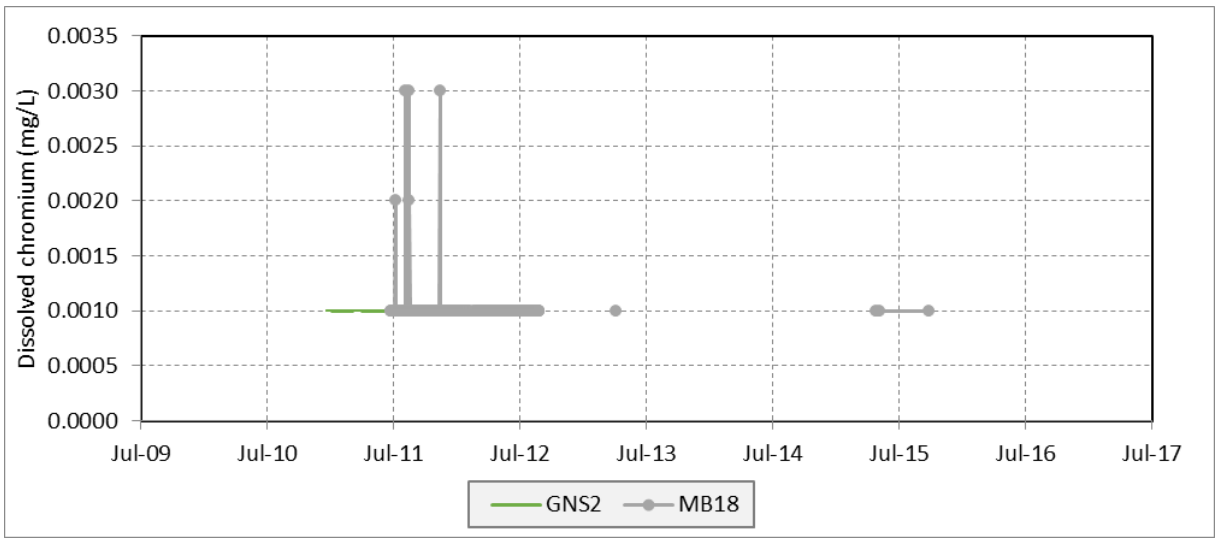


Figure C-32 Dissolved chromium monitored in groundwater

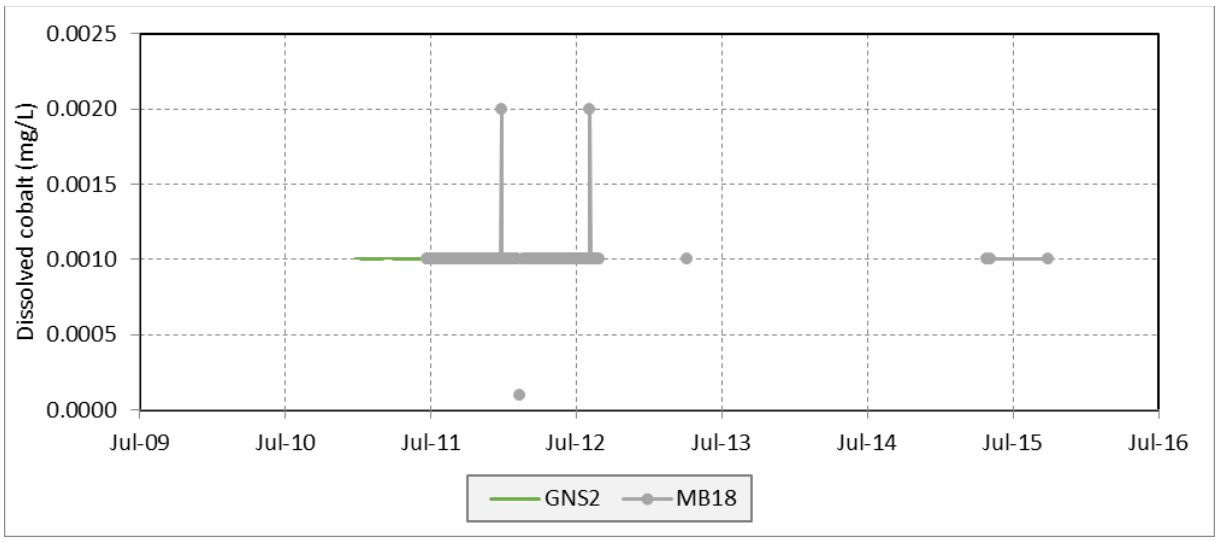


Figure C-33 Dissolved cobalt monitored in groundwater

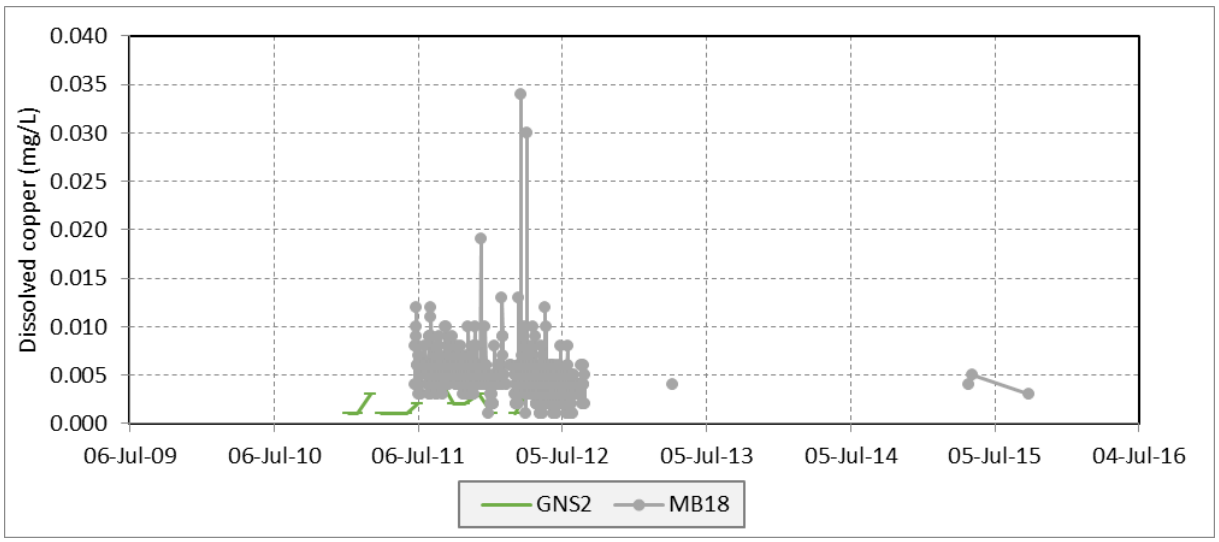


Figure C-34 Dissolved copper monitored in groundwater

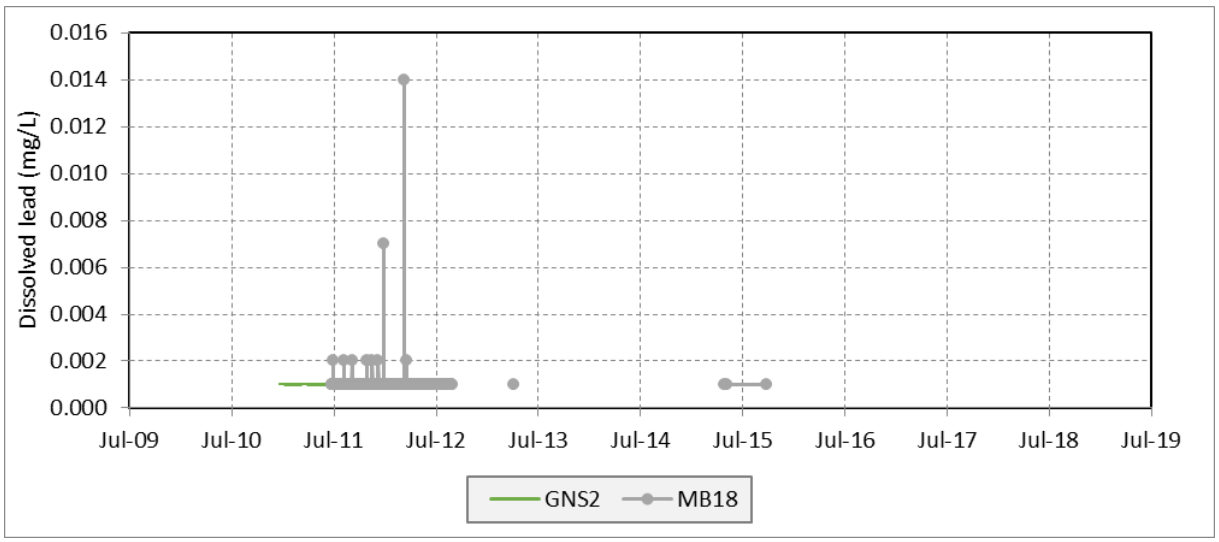


Figure C-35 Dissolved lead monitored in groundwater

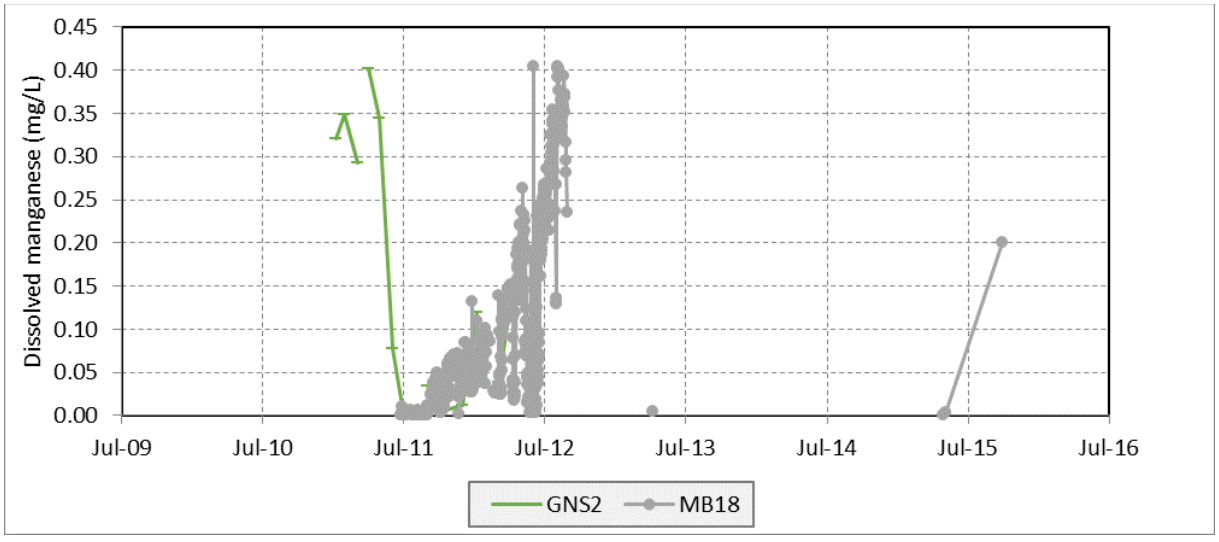


Figure C-36 Dissolved manganese monitored in groundwater

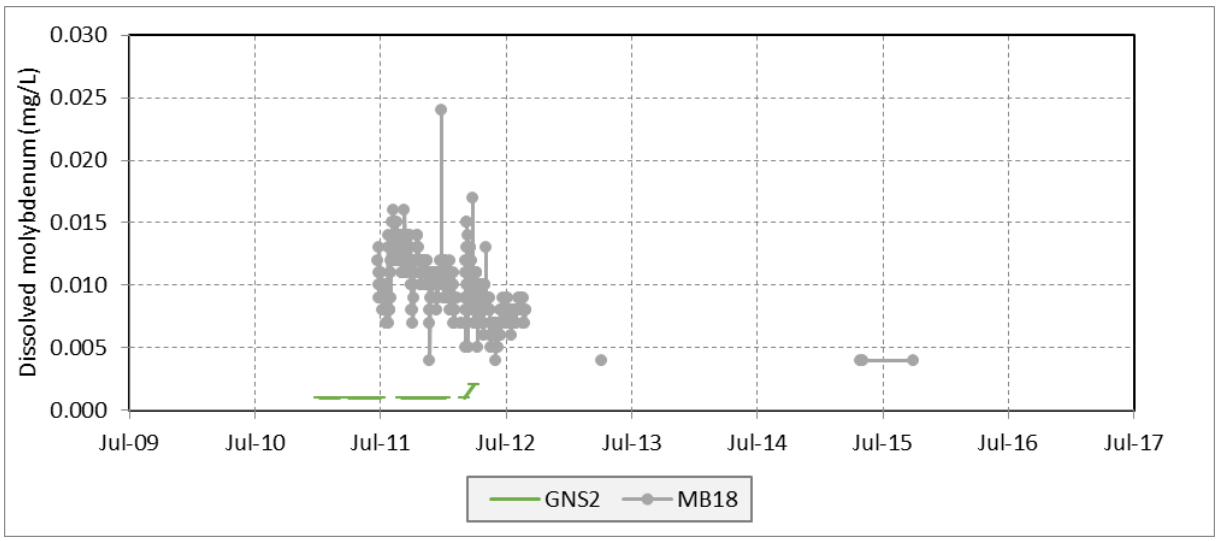


Figure C-37 Dissolved molybdenum monitored in groundwater

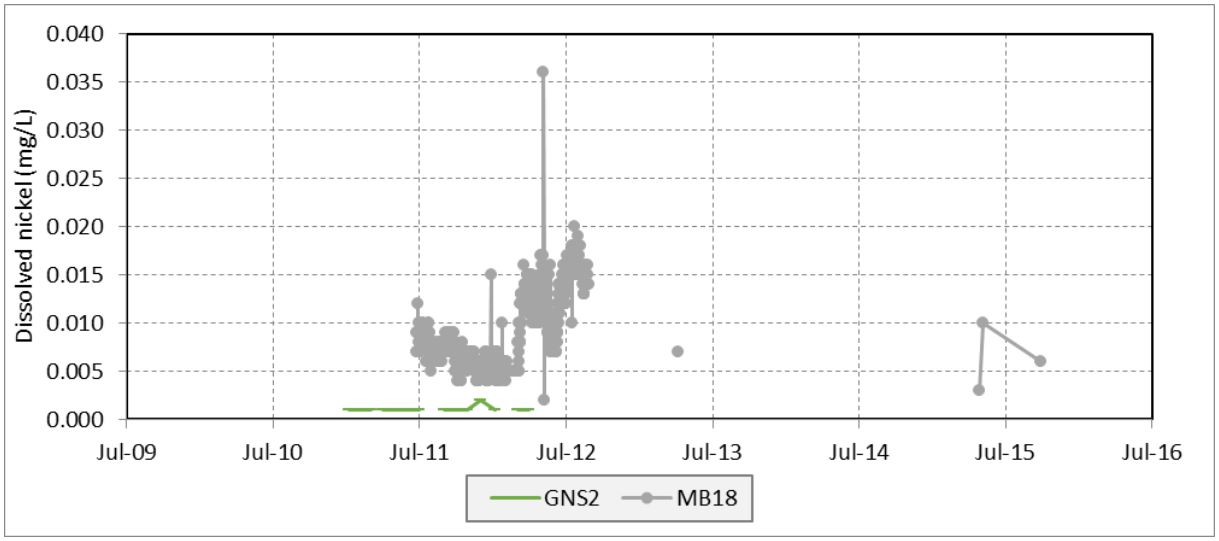


Figure C-38 Dissolved nickel monitored in groundwater

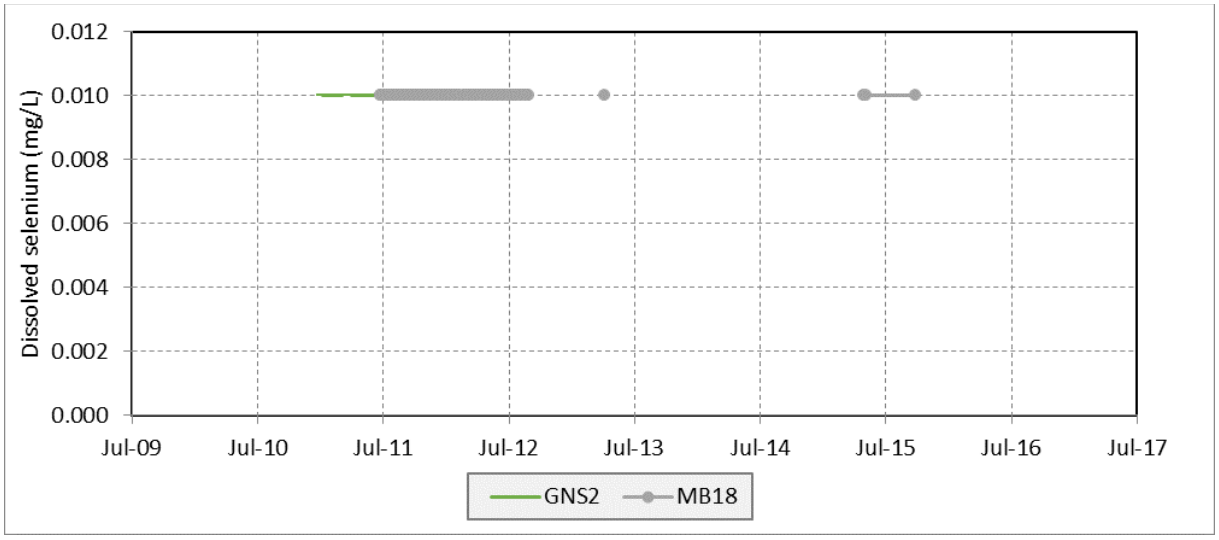


Figure C-39 Dissolved selenium monitored in groundwater

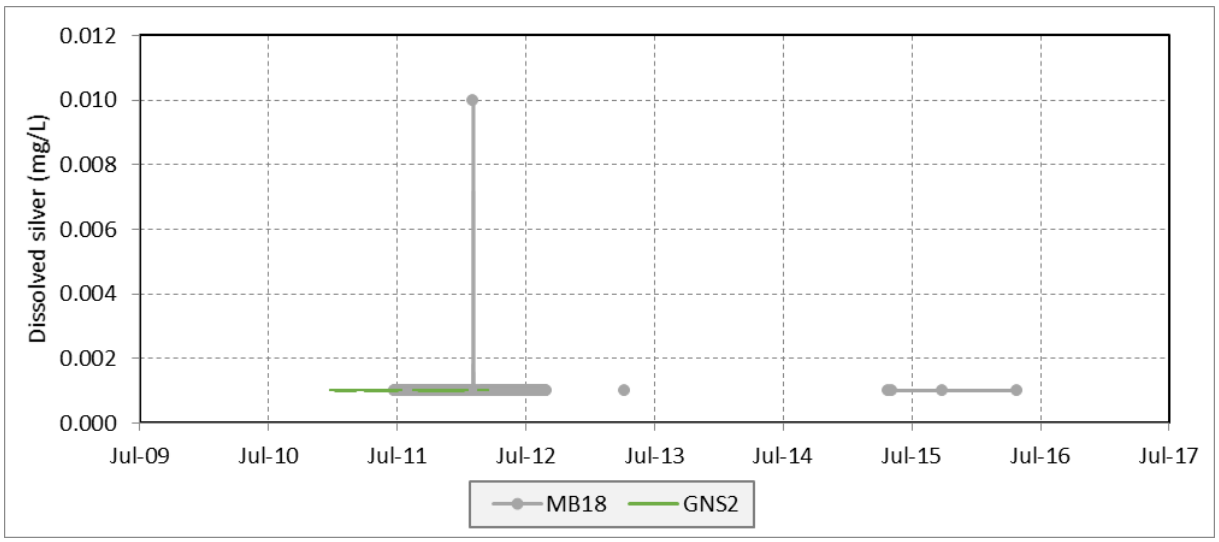


Figure C-40 Dissolved silver monitored in groundwater

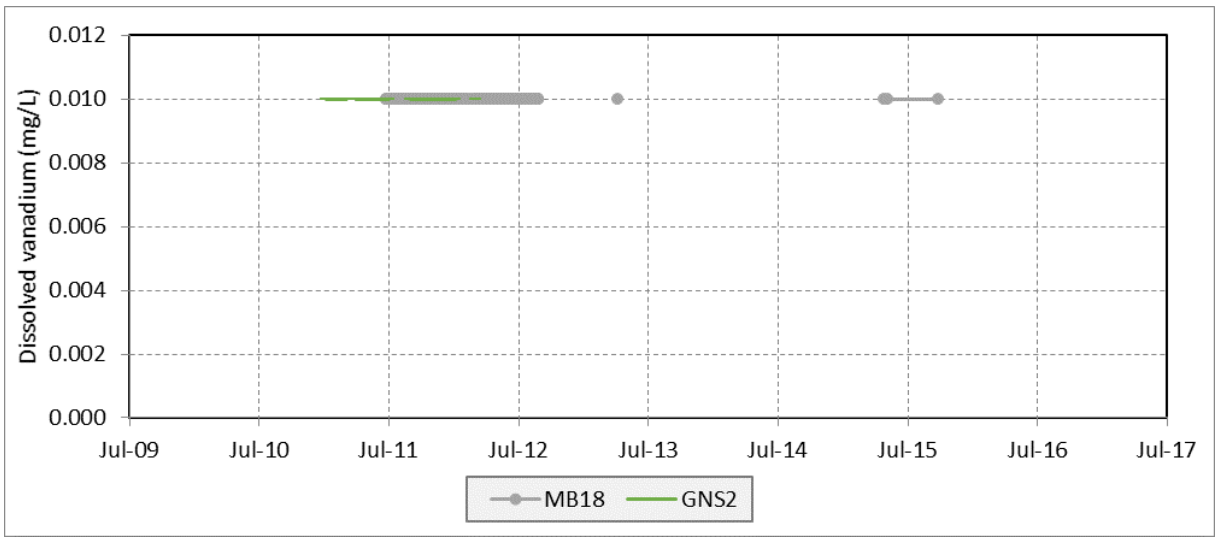


Figure C-41 Dissolved vanadium monitored in groundwater

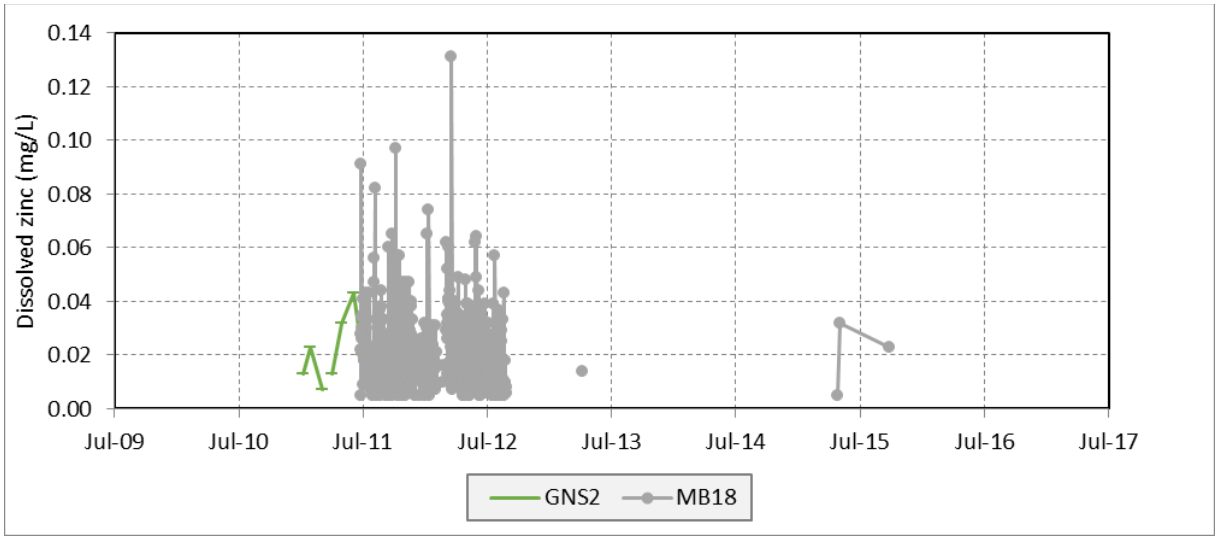


Figure C-42 Dissolved zinc monitored in groundwater

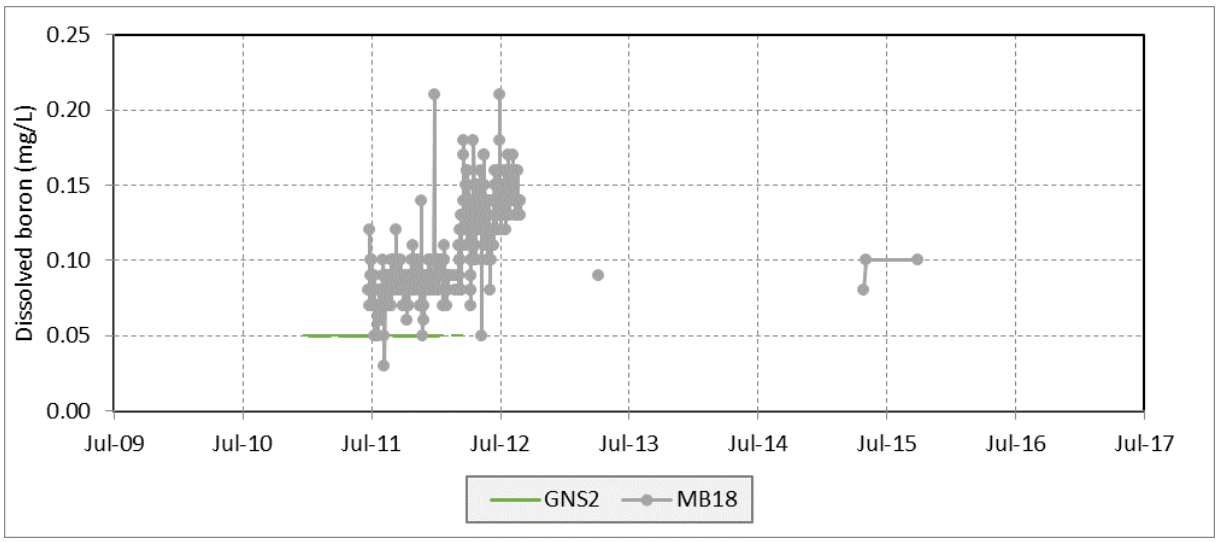


Figure C-43 Dissolved boron monitored in groundwater

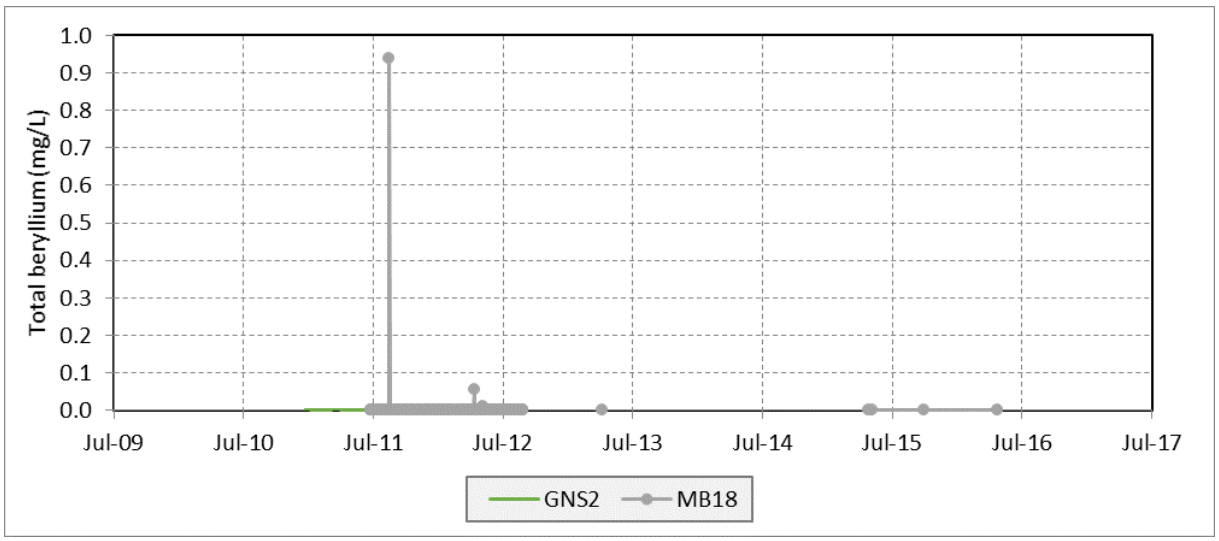


Figure C-44 Total beryllium monitored in groundwater

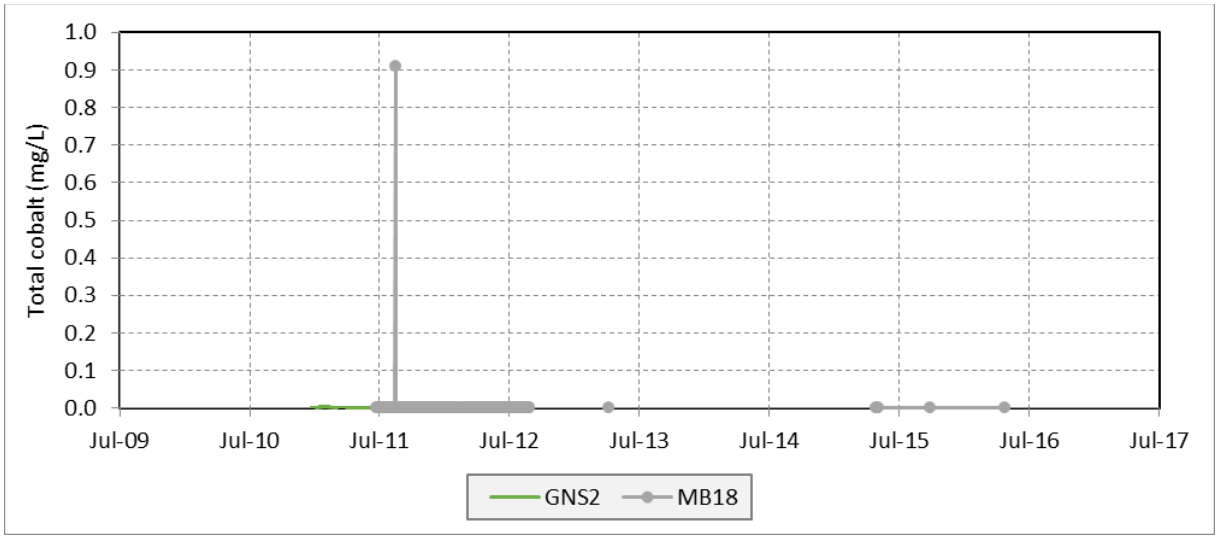


Figure C-45 Total cobalt monitored in groundwater

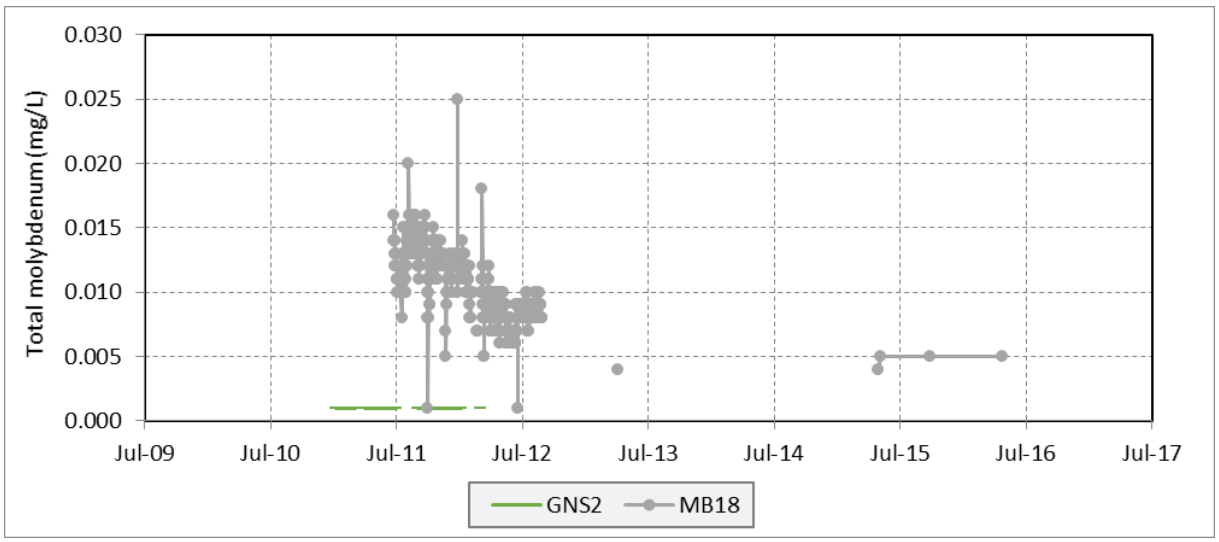


Figure C-46 Total molybdenum monitored in groundwater

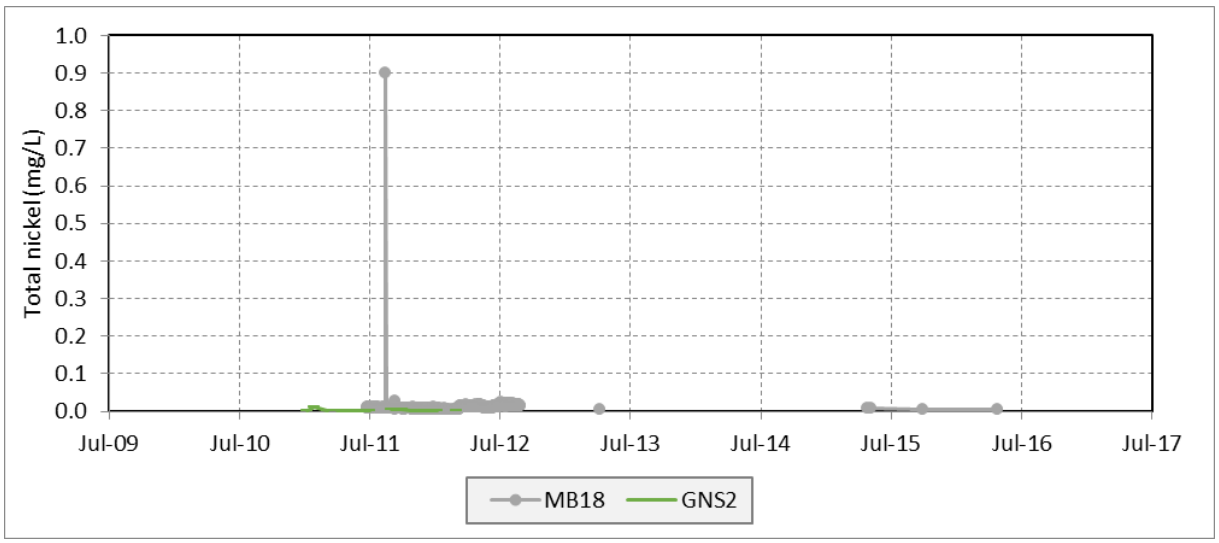


Figure C-47 Total nickel monitored in groundwater

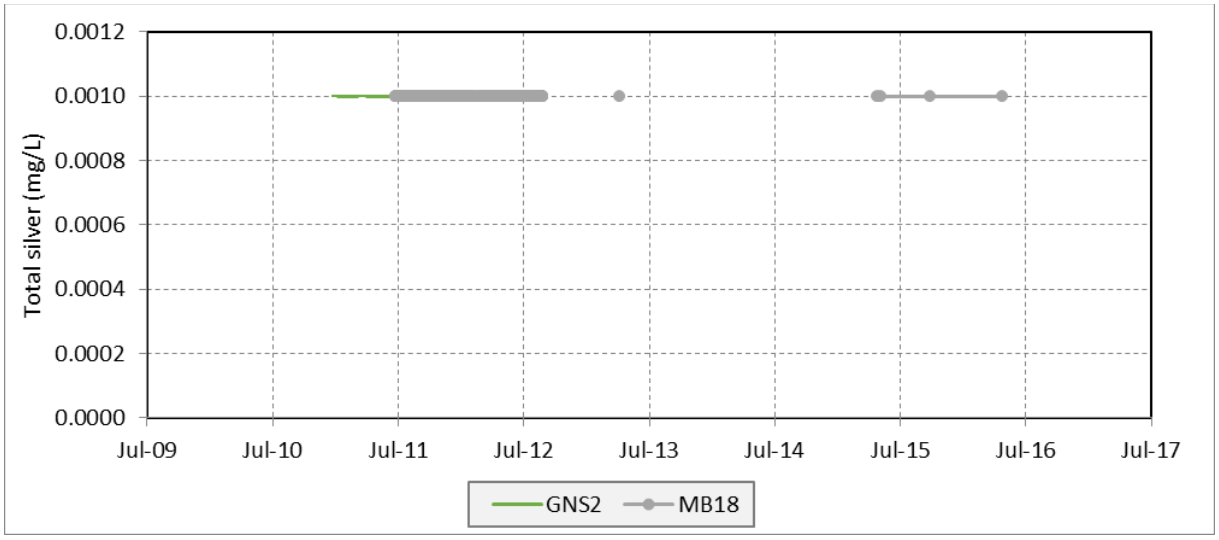


Figure C-48 Total silver monitored in groundwater

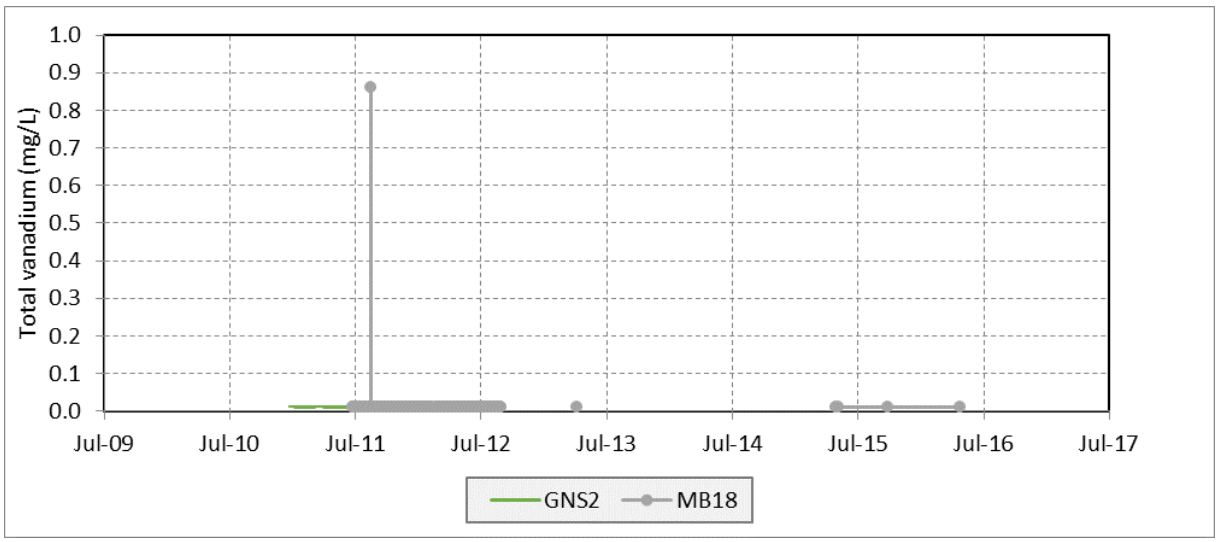


Figure C-49 Total vanadium monitored in groundwater

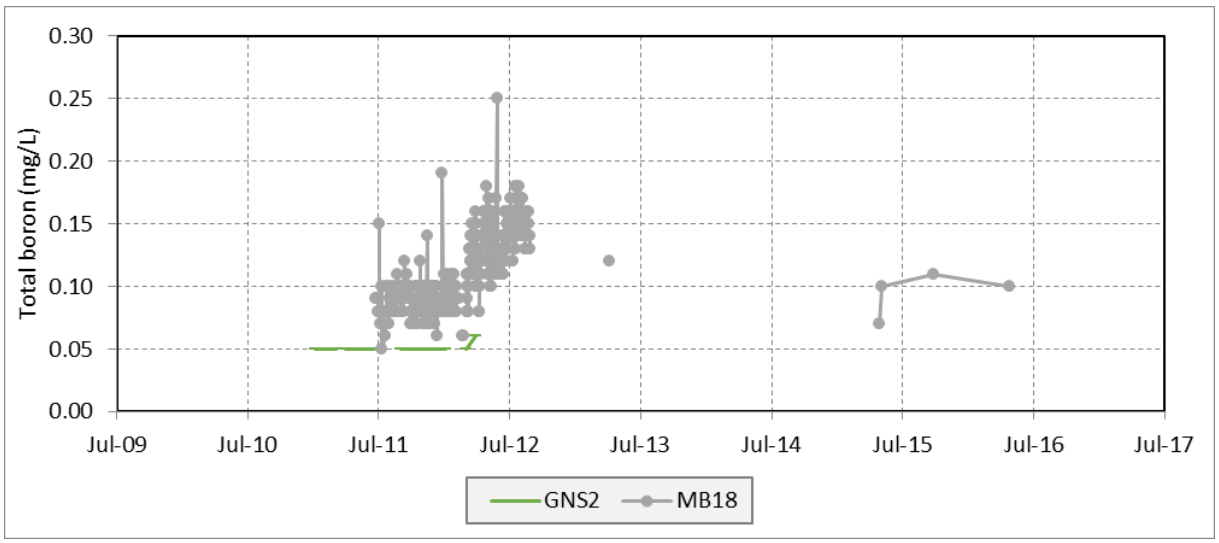


Figure C-50 Total boron monitored in groundwater

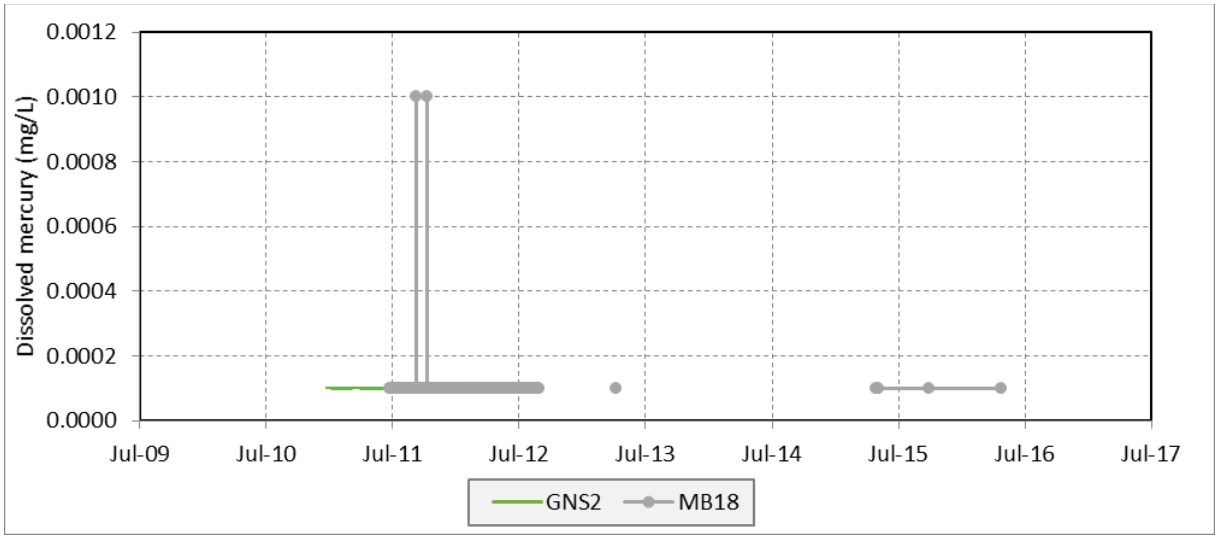


Figure C-51 Dissolved mercury monitored in groundwater

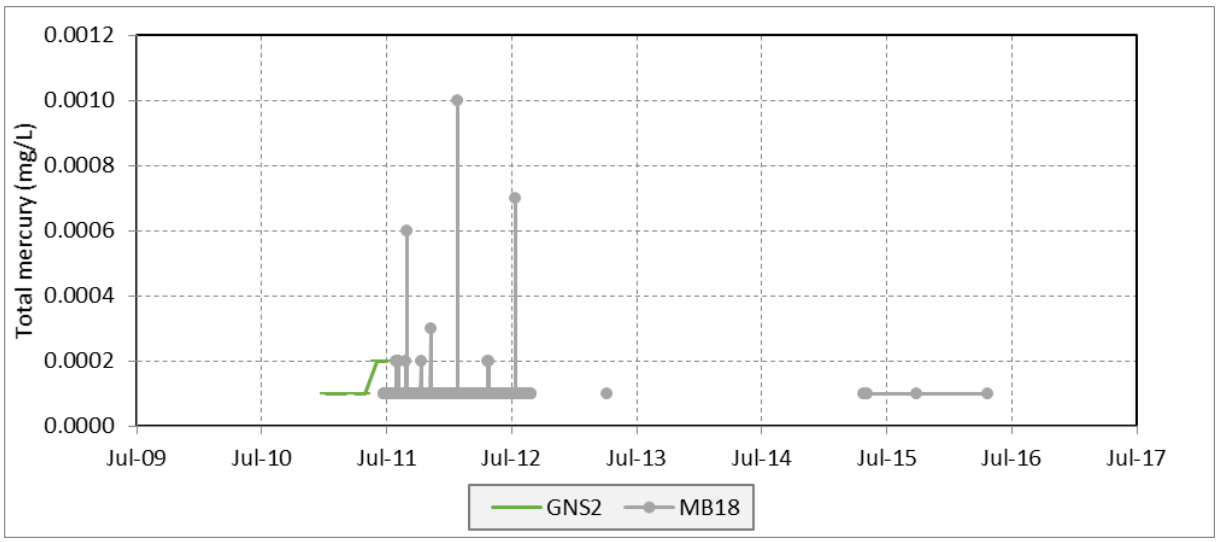


Figure C-52 Total mercury monitored in groundwater

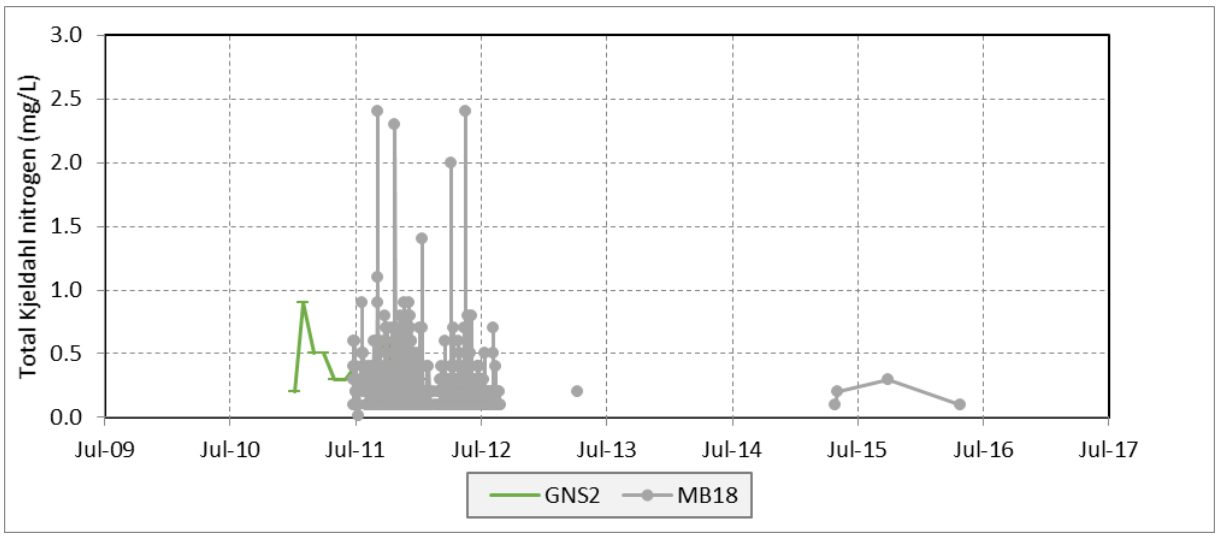


Figure C-53 Total Kjeldahl nitrogen monitored in groundwater

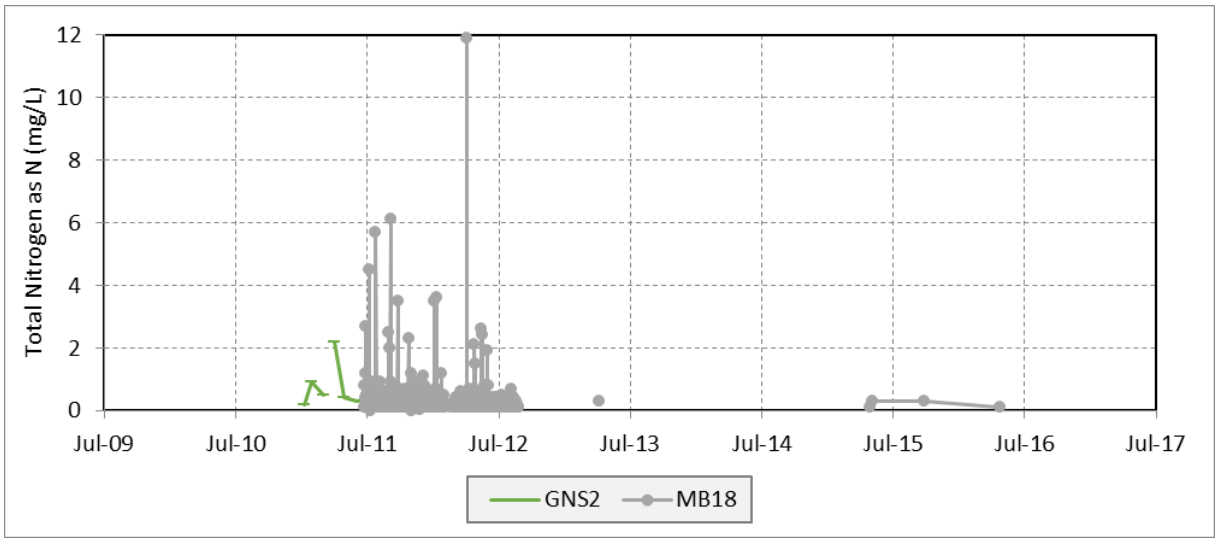


Figure C-54 Total nitrogen monitored in groundwater

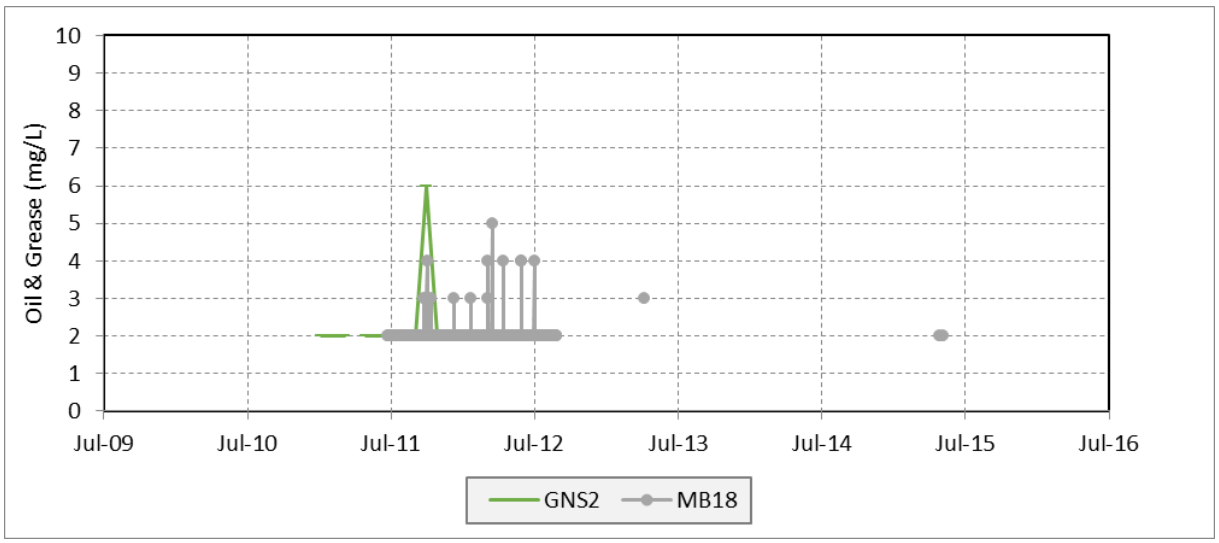


Figure C-55 Oil and grease monitored in groundwater

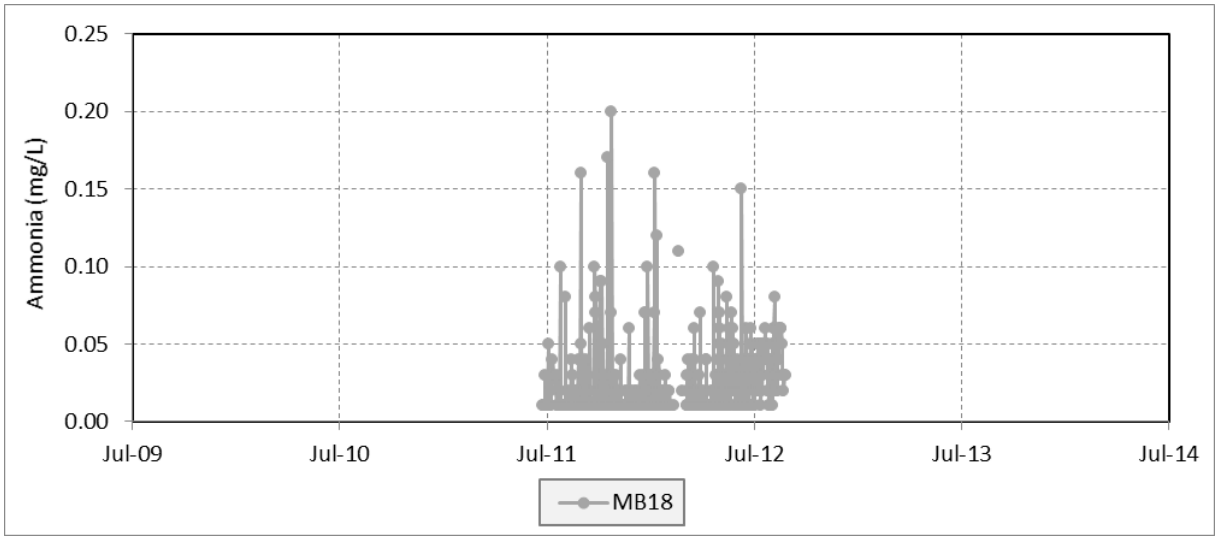


Figure C-56 Ammonia monitored in groundwater

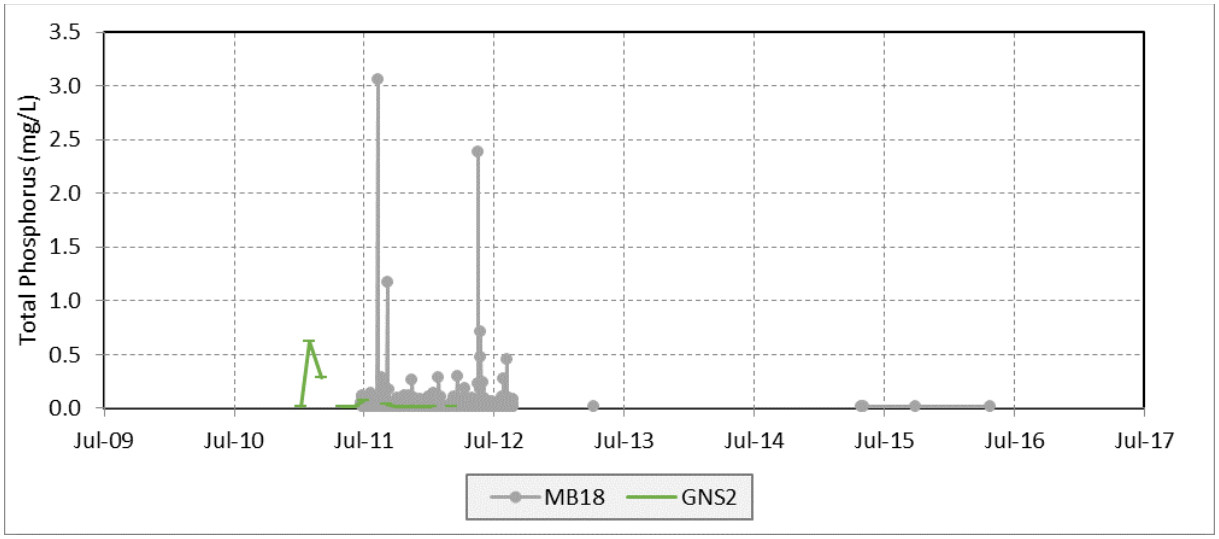


Figure C-57 Total phosphorus monitored in groundwater

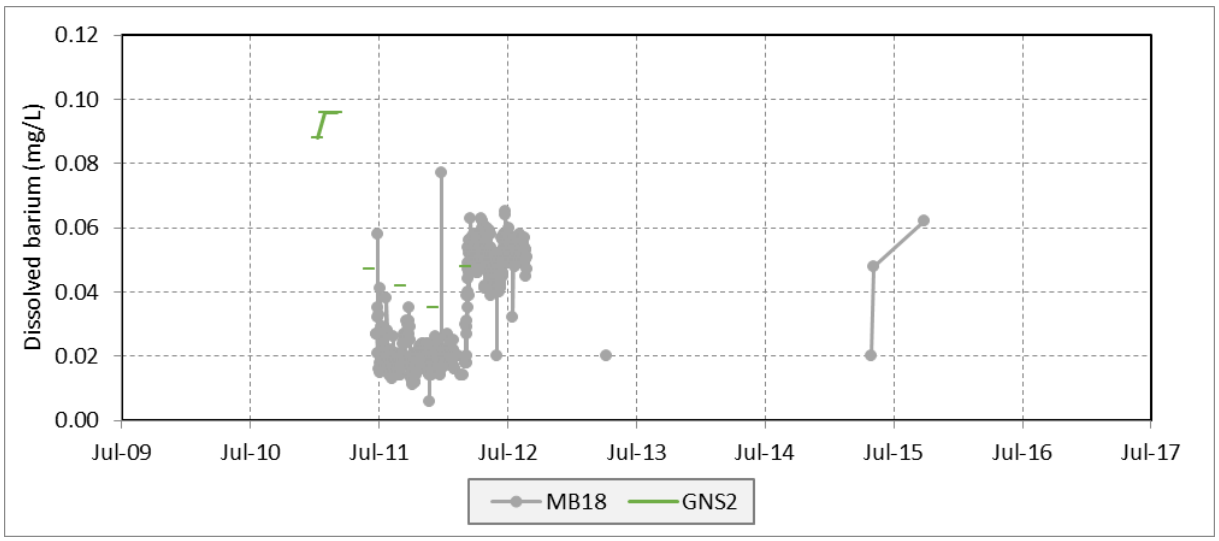


Figure C-58 Dissolved barium monitored in groundwater

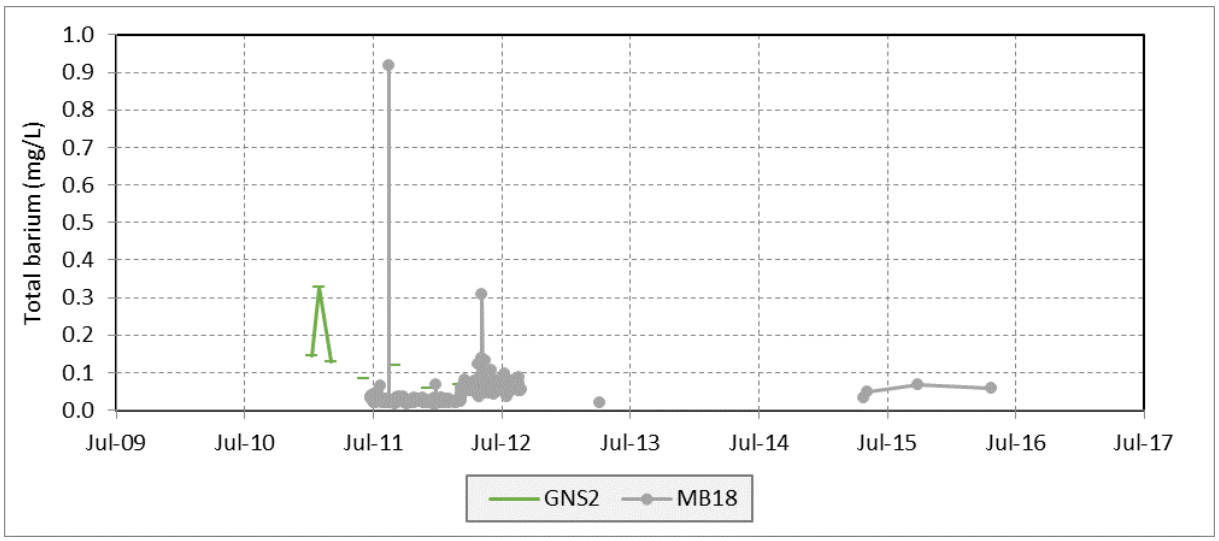


Figure C-59 Total barium monitored in groundwater

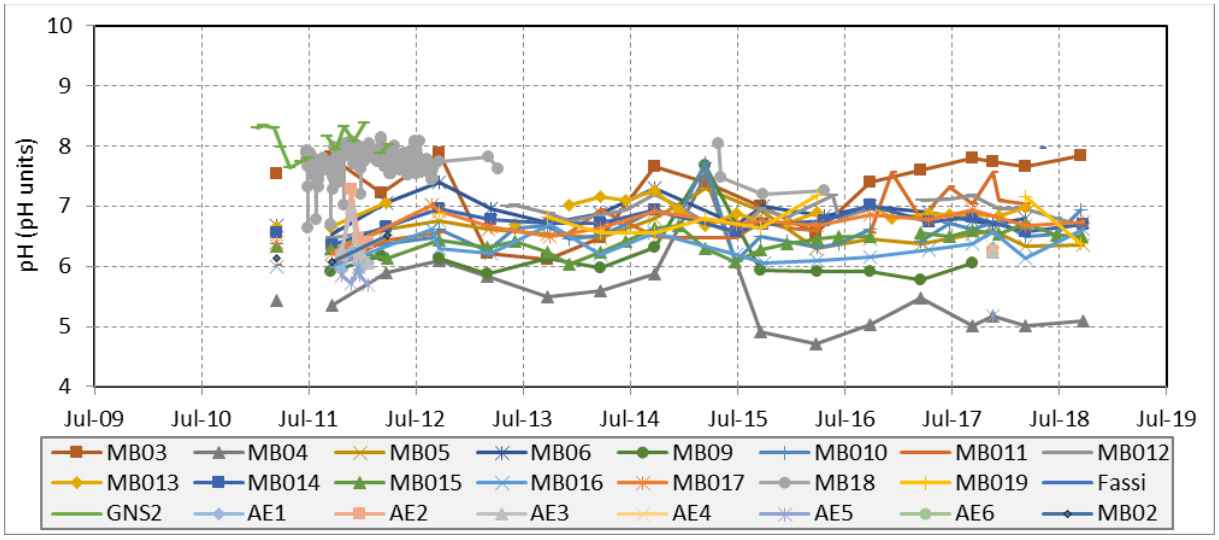


Figure C-60 Laboratory pH monitored in groundwater

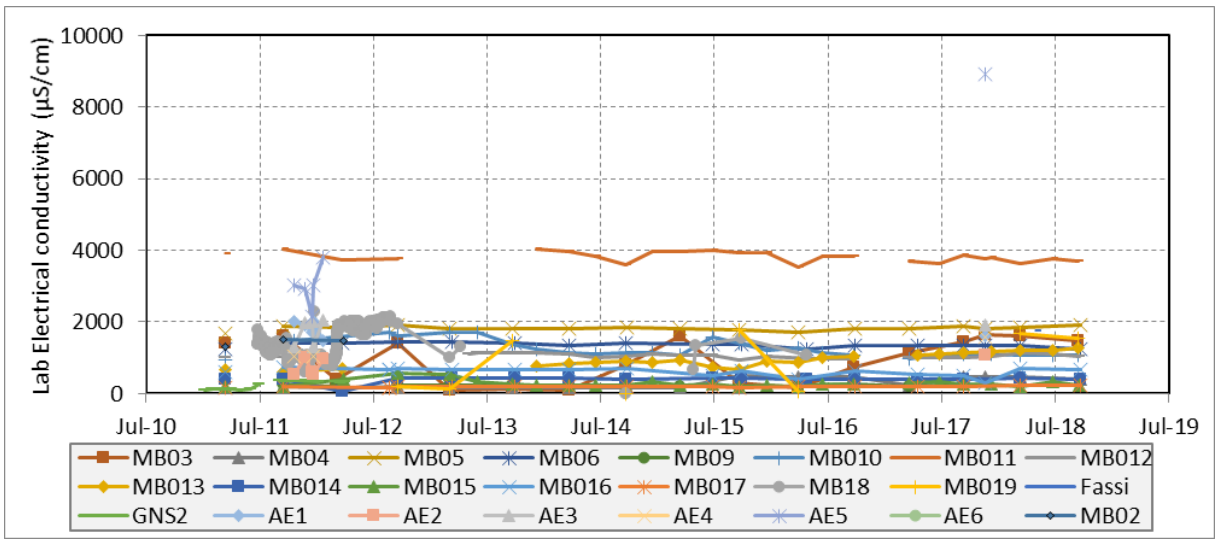


Figure C-61 Laboratory electrical conductivity monitored in groundwater

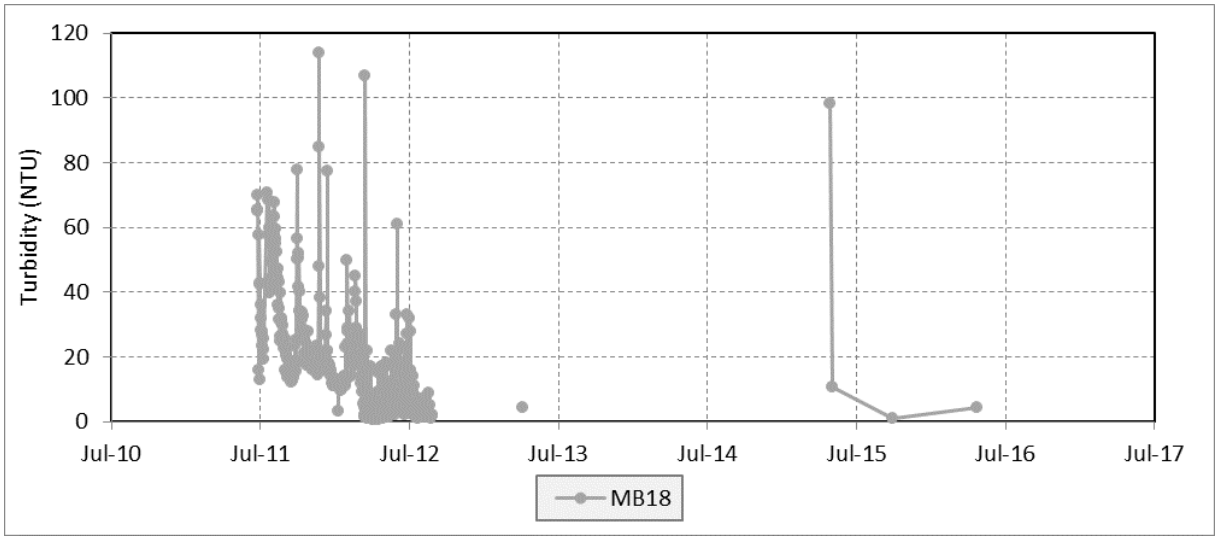


Figure C-62 Turbidity monitored in groundwater

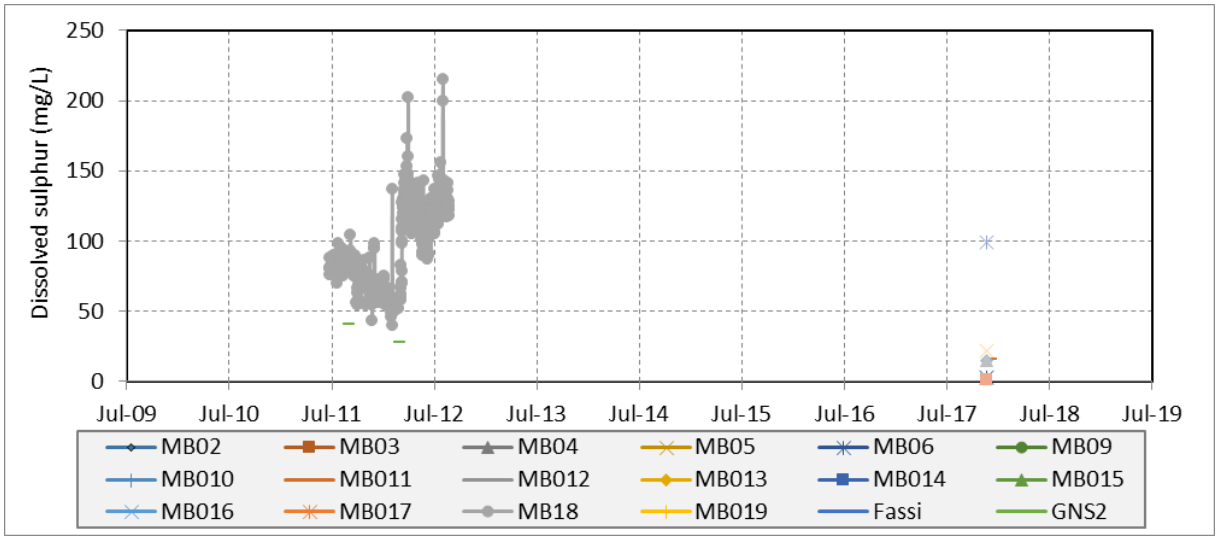


Figure C-63 Dissolved sulphur monitored in groundwater

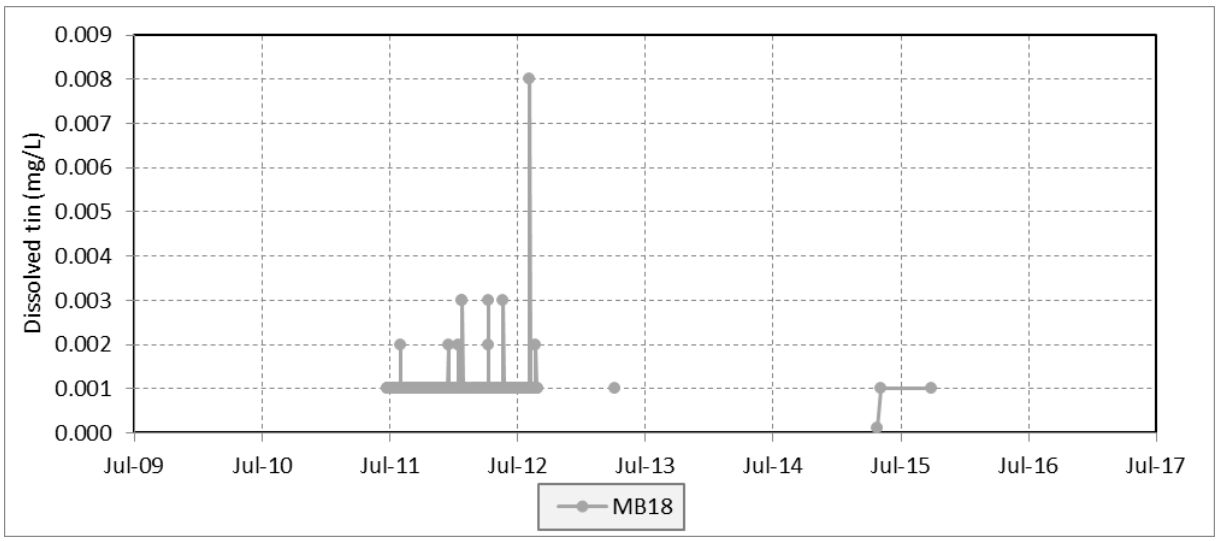


Figure C-64 Dissolved tin monitored in groundwater

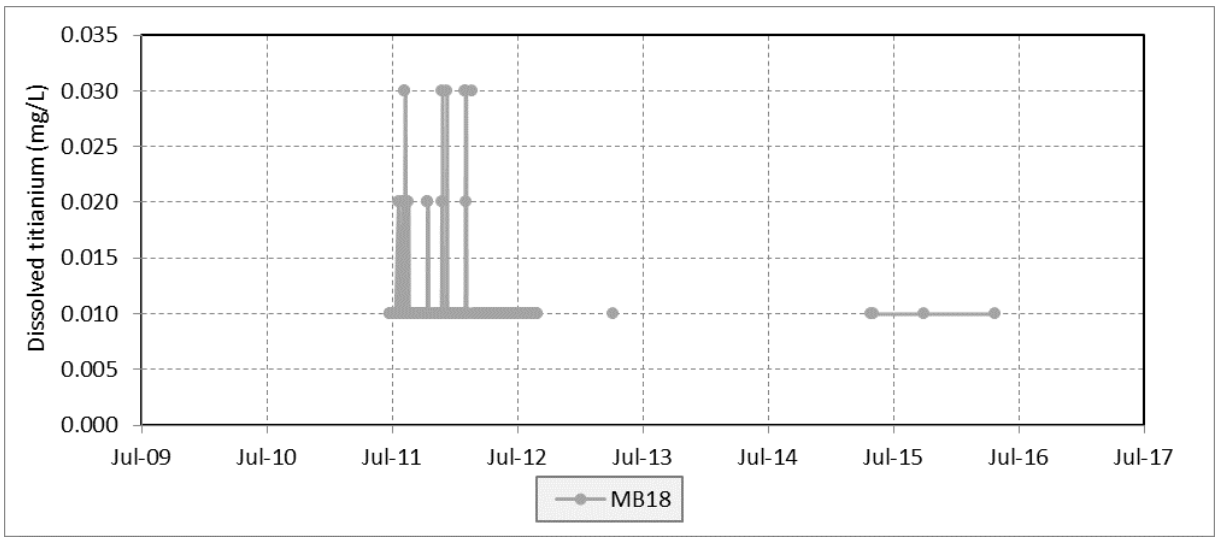


Figure C-65 Dissolved titanium monitored in groundwater

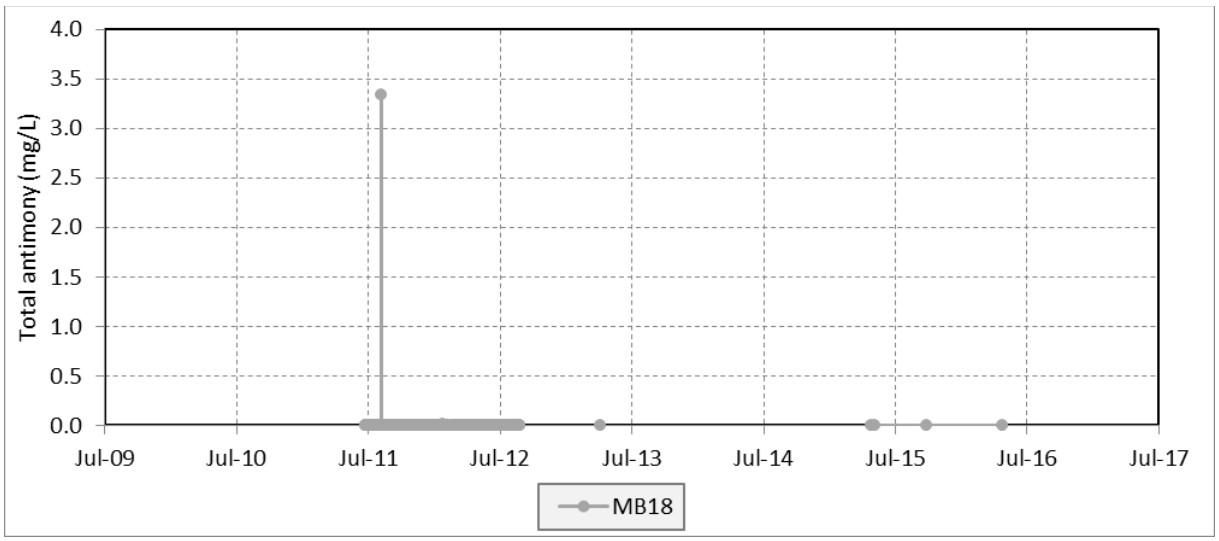


Figure C-66 Total antimony monitored in groundwater

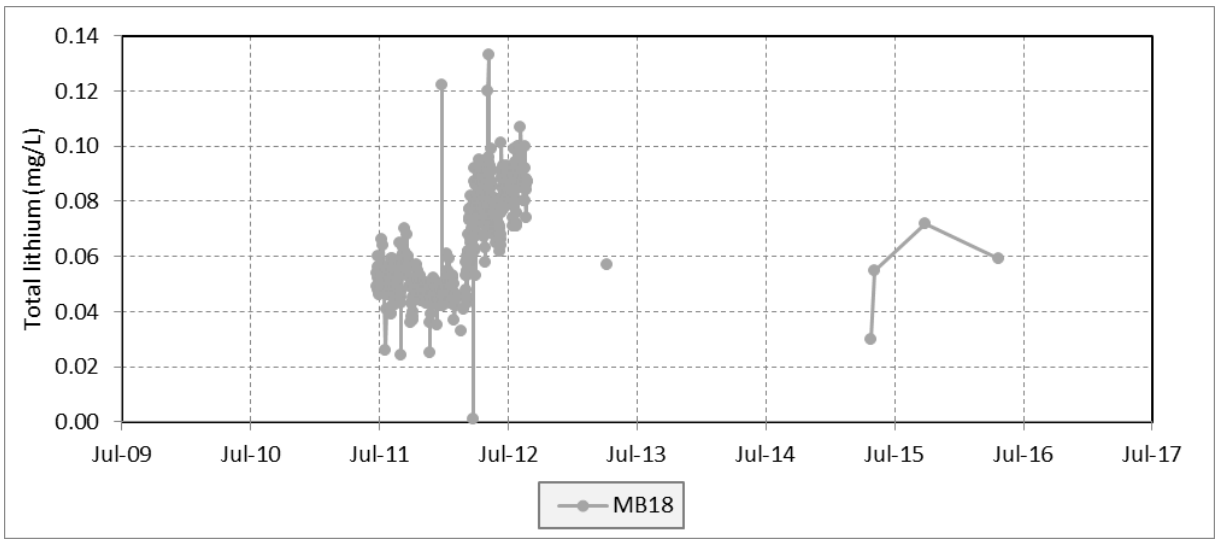


Figure C-67 Total lithium monitored in groundwater

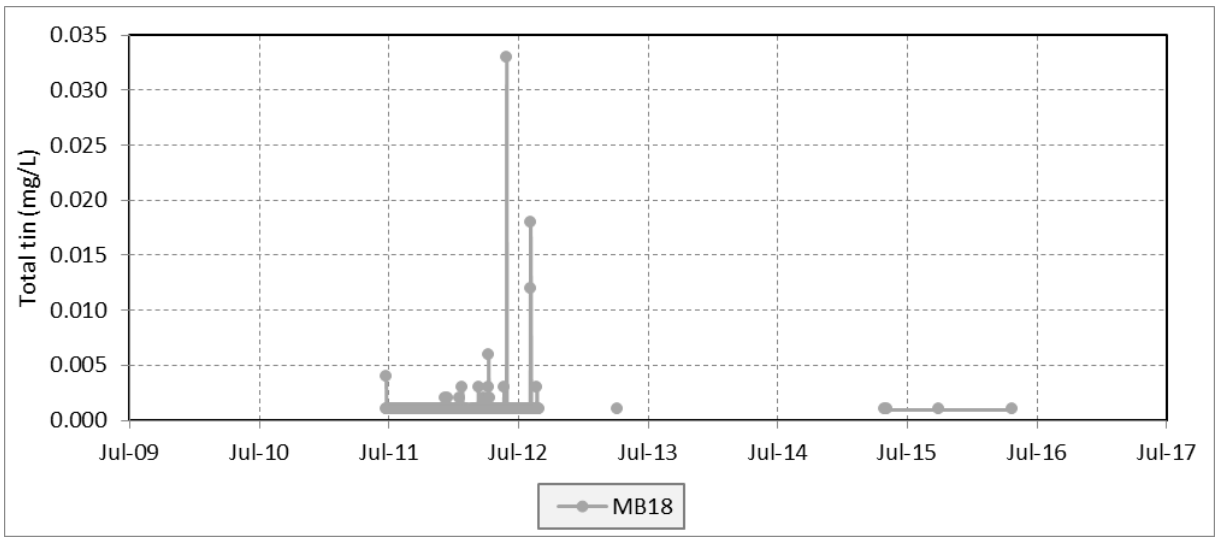


Figure C-68 Total tin monitored in groundwater

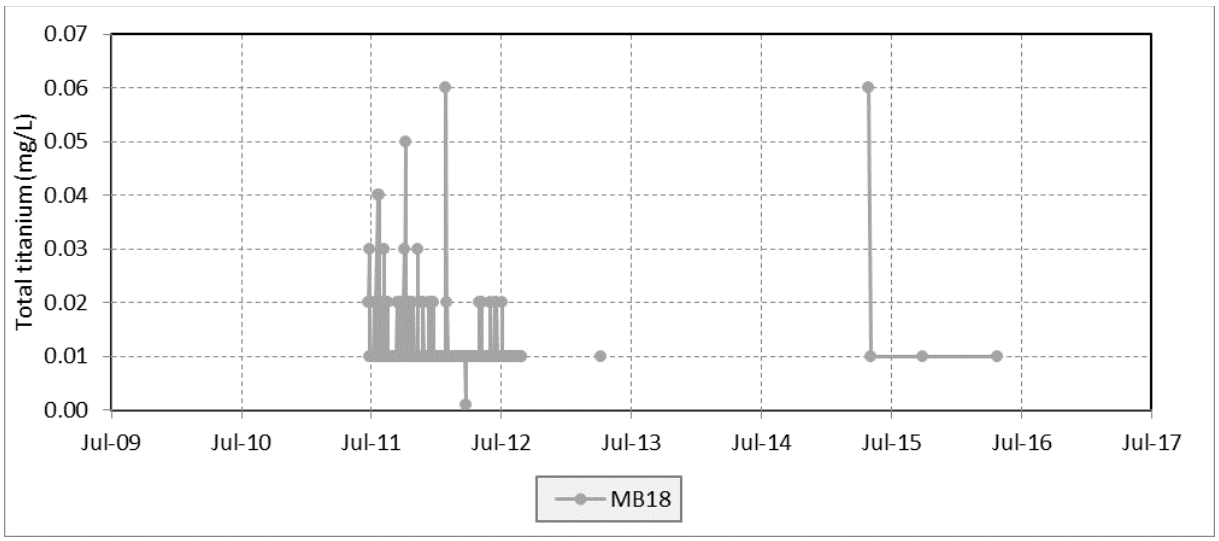


Figure C-69 Total titanium monitored in groundwater

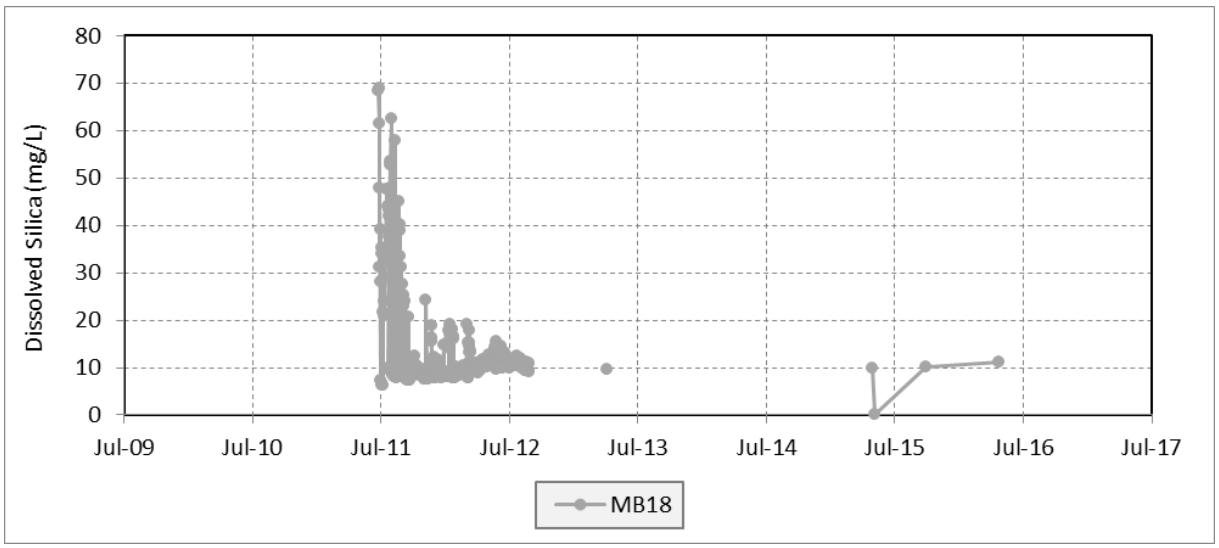


Figure C-70 Dissolved silica monitored in groundwater

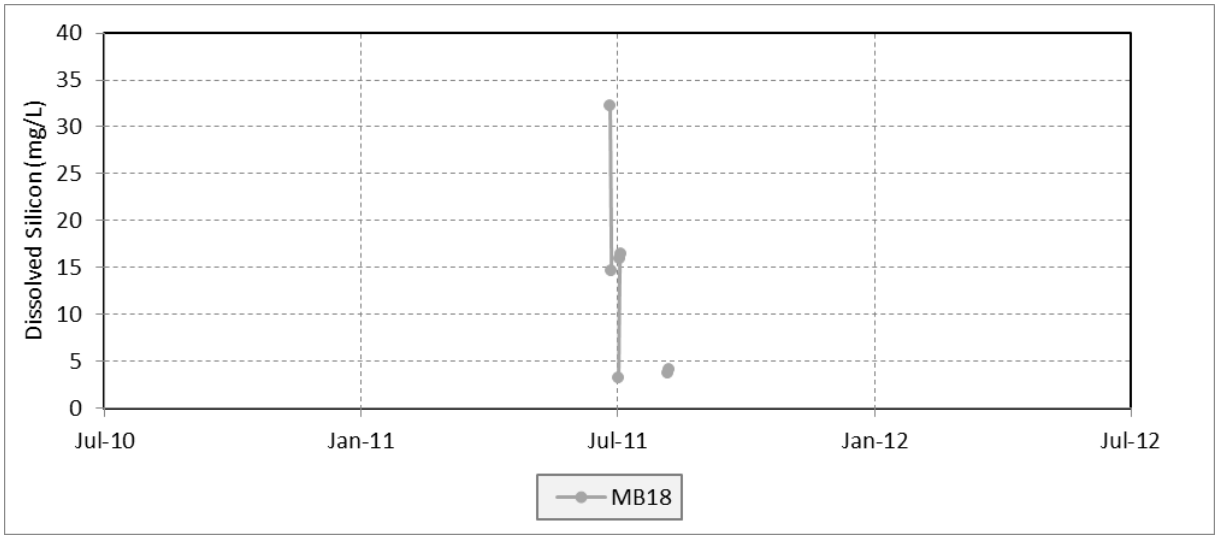


Figure C-71 Dissolved silicon monitored in groundwater

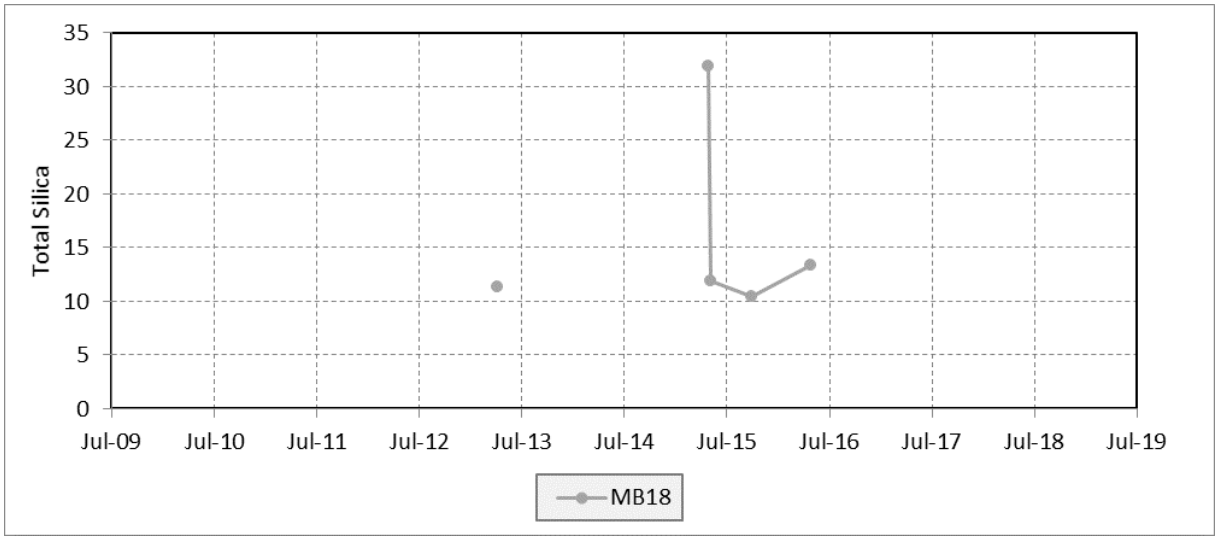


Figure C-72 Total silica monitored in groundwater

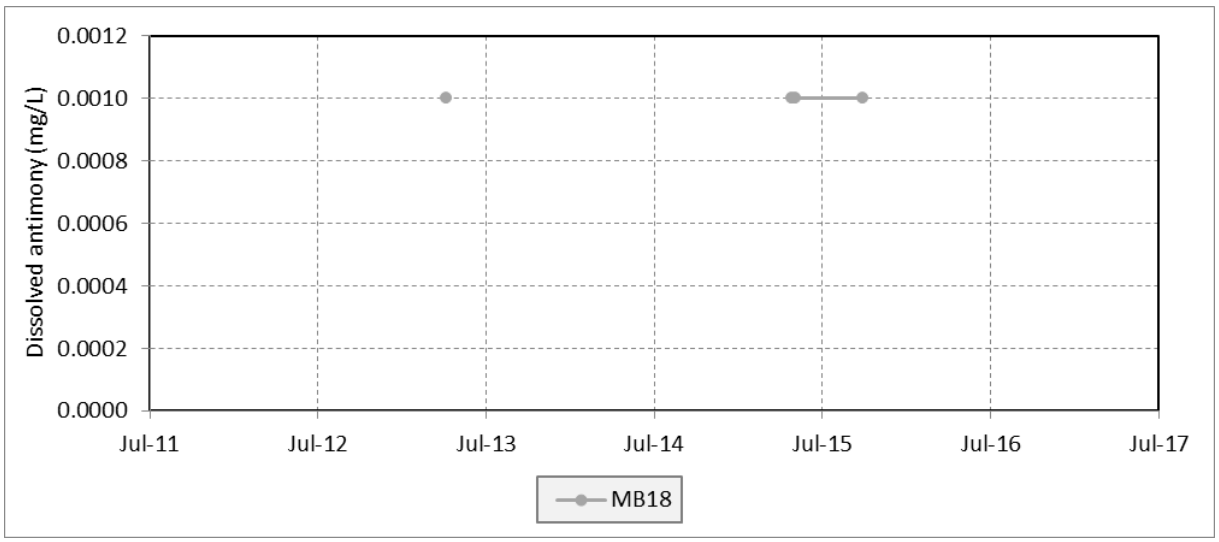


Figure C-73 Dissolved antimony monitored in groundwater

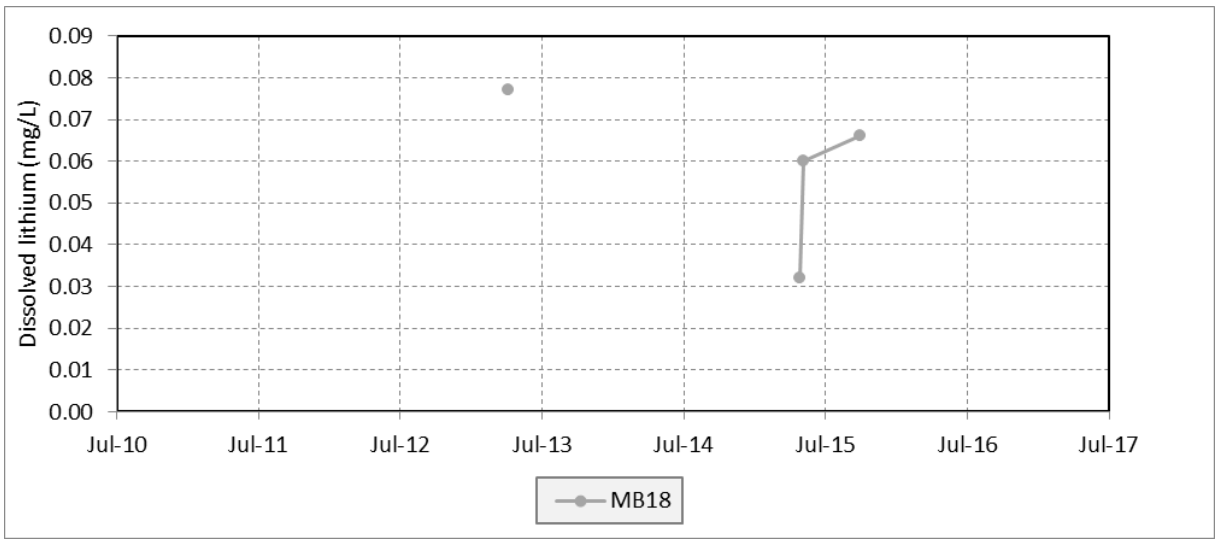


Figure C-74 Dissolved lithium monitored in groundwater

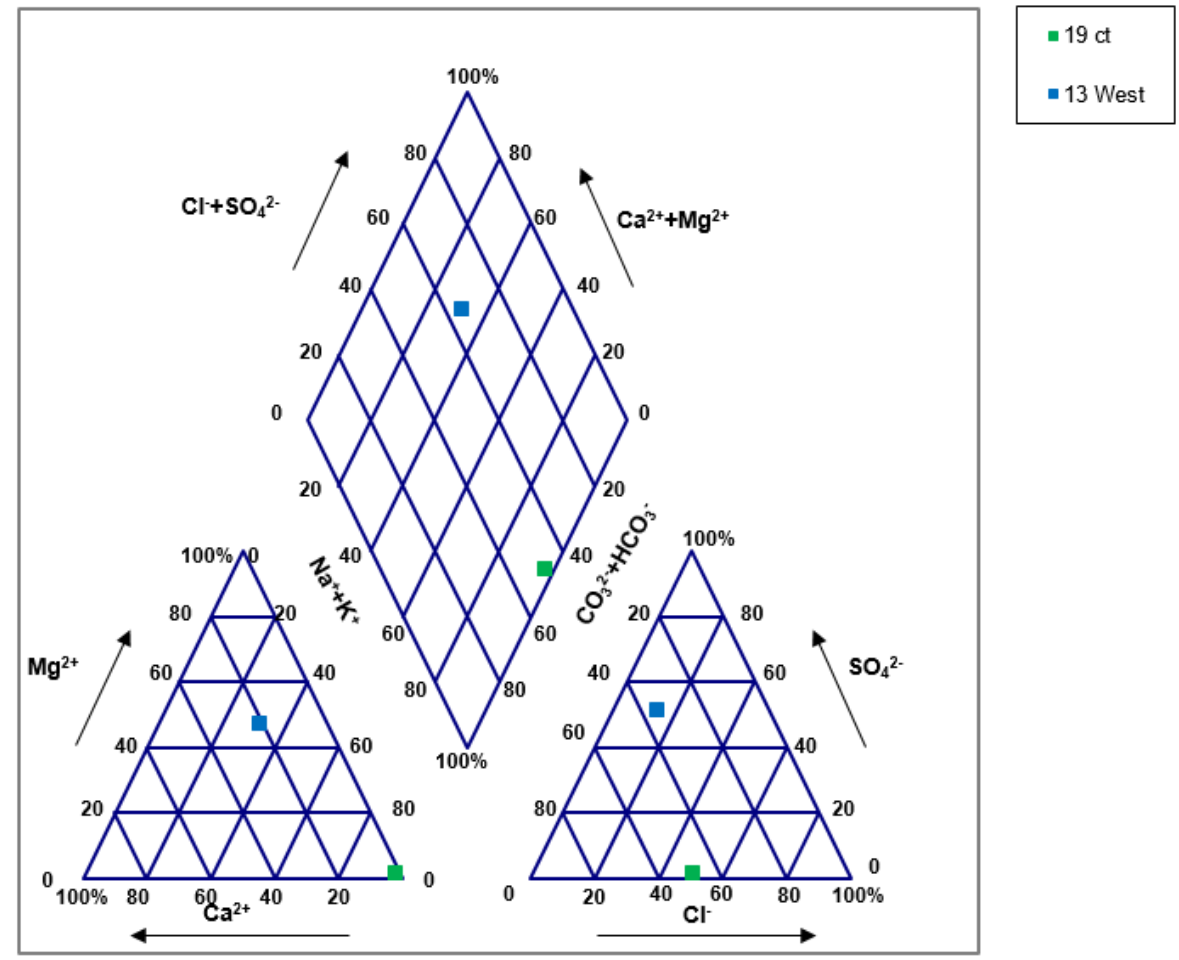


Figure C-75 Piper diagram comparing West Borehole seam (ct 19) and Awaba Colliery underground void (13 West 2)

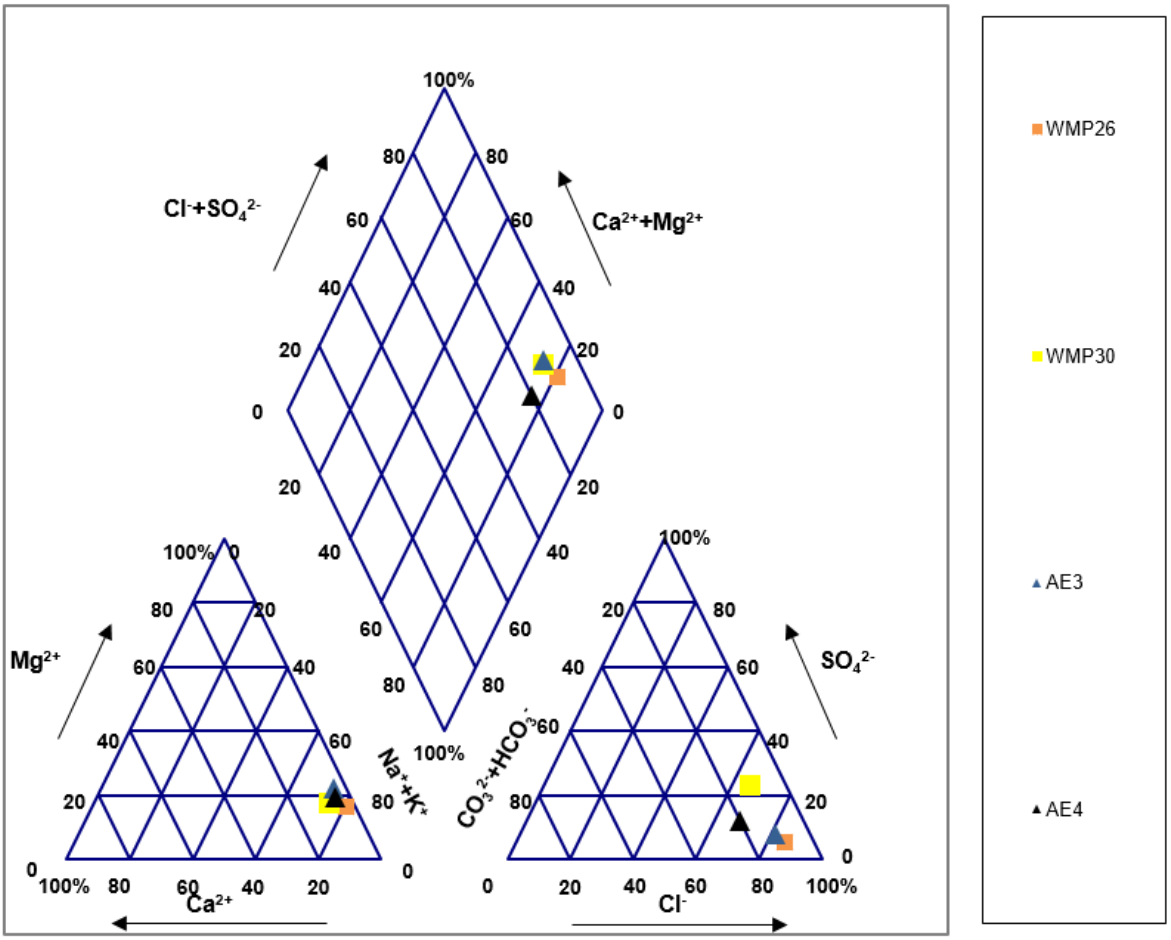
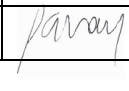


Figure C-76 Piper diagram comparing surface water (WMP26 and WMP30) and alluvial groundwater (AE3 and AE4)

GHD
Level 3 GHD Tower 24 Honeysuckle Drive Newcastle NSW 2300
PO BOX 5403 Hunter Region Mail Centre NSW 2310
T: 61 2 4979 9999 F: 61 2 4979 9988 E: ntlmail@ghd.com

© GHD 2020
This document is and shall remain the property of GHD. The document may only be used for the purpose for which it was commissioned and in accordance with the Terms of Engagement for the commission. Unauthorised use of this document in any form whatsoever is prohibited.
22-SO-2111435880-8/https://projects.ghd.com/oc/Newcastle3/newstanextensionproj/Delivery/Documents/22-20265-REP_Newstan Extension_GWIA_SG.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	I Gilmore	S Gray	*S Gray*	S Gray	*S Gray*	27/03/2020
1	I Gilmore	S Gray	*S Gray*	S Gray	*S Gray*	14/04/2020
2	I Gilmore	S Gray	*S Gray*	S Gray	*S Gray*	20/5/2020
3	I Gilmore	S Gray		S Gray		5/6/2020

www.ghd.com