

Draft report

Groundwater modelling report: Conceptualisation and Modelling approach

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1 Introduction

Pacific Environment is pleased to provide Cement Australia (Exploration) Pty Ltd (Cement Australia) with a numerical groundwater flow model for the East End Mine. The numerical model was based on the conceptual hydrogeological model, which is described in this report. The assumptions used in the numerical model are documented herein and justified where appropriate.

Current and previous mining activities have primarily been conducted on Mining Lease (ML) 3631, with less significant activities on ML 3659, ML 7629, ML 80002 and ML 80127. The model will be used to support Cement Australia's application for an extension into MLA 80156, which is located immediately southeast of the current mine. The numerical model will be used to: (1) identify the current impacts caused by the existing mine excavation; (2) predict future impacts created by continued mining of the current mining lease; and (3) predict future impacts created by continued mining of the current mining lease and the mine extension.

1.1 Background

Cement Australia have been monitoring groundwater in the vicinity of operations and to the west of this area (Bracewell area) since the late 1970s. The monitoring network has been expanded over the years to include over 96 bores, including a number of bores in the Bracewell area. One of the main drivers for the development of such an extensive bore network has been community concern over the impacts of mining on groundwater supplies in the Bracewell area (DERM, 2011).

In 2006, the Department of Environment and Resource Management (DERM) initiated a review of previous reports into groundwater resources and the potential impacts from mining. It concluded that there was "no evidence of impact from the mine occurring to the west of the mine area". The volcanoclastic rocks form a flow barrier to the west of the mine and prevent drawdowns in the upper Jacobs Creek and the Bracewell area (DERM, 2011).

1.2 Mining at East End Mine

Cement Australia mines limestone and clay at the East End Mine, approximately 30 km west of Gladstone. The limestone and clay are transported to Fisherman's Landing, just north of Gladstone, where it is manufactured into clinker (*Figure 1*). Mining started in 1980 and has mainly been conducted on ML 3631. The existing pit was excavated in a northwest/southeast direction, following the strike of the bedding plane. If the proposed extension into MLA 80156 is approved, the existing pit will be extended to the southeast, creating a single mine pit (*Figure 2*).

1.2.1 Dewatering

Water is pumped out of the mine sump into two settlement ponds, before it drains into Schultz Lagoon (*Figure 2*). The mine normally pumps around 4,000-5,500 kL/day from the mine, with volumes increasing to about 20,000 kL/day after heavy rainfalls. The drainage systems are discussed in more detail in Section 3.5.

1.3 Scope

The report outlines the conceptual hydrogeological model and the transient numerical model for the area surrounding Cement Australia's East End Mine. The numerical model is used to assess the potential drawdown that results from the East End Mine activities, including the proposed pit extension. This report includes a desktop review of previous reports, most notably:

- Department of Environment and Resource Management (DERM) 2011: Review of Groundwater in the Mount Larcom-Bracewell Area, February 2011.
- Groundwork Plus 2014: Cement Australia East End Mine, East End number 5 (MLA 80156), Groundwater Study, File ref: 214_712_002r1, 1 August 2014.
- Groundwork Plus 2016: Cement Australia East End Mine, Annual Water Monitoring Report 2015-2016, File ref: 214_630_019, 1 July 2016.
- Kalf and Associates 1997: Groundwater Model Determination of Current and Future East End Mine Pit Drawdowns, prepared on behalf of QCL, February 1997.

The conceptual hydrogeological model provides a basis for the assumptions used in the numerical modelling approach. The justification for these assumptions is documented in the report.

The model uses monitoring data provided by Groundwork Plus, who have been conducting monitoring at the site for over a decade. Pacific Environment has been provided with data from the 1980s through to March 2017. This data included water levels, water quality, monitoring bore information (i.e. aquifer intervals) and geological interpretations.

In this report, groundwater levels and groundwater drawdowns have been separated into three distinct scenarios:

1. unaffected by mining conditions (hypothetical model run with no mining);

2. affected by mining in the current mining lease (i.e. assuming the existing mine (ML 3631) operates in its current state until 2045); and
3. affected by the mine extension (ML 3631 and MLA 80156).

The extra drawdown created by the mine extension will be the difference between the current mining conditions (Scenario 2) and the mine extension (Scenario 3). For example, at bore 'example 1', if an unaffected water level of 20 m Australian Height Datum (AHD) is modelled (Scenario 1), and the water level is modelled at 15 m AHD assuming the current mining conditions (Scenario 2), and 14 m AHD assuming the mine is extended (scenario 3), then the total drawdown is 6 m. However, the drawdown created by the mine extension is 1 m.

A new provision of the Water Act (2000) was introduced on 6 December 2016. Chapter 3 of the Act now states that mining companies that take or interfere with groundwater will be subject to the obligations that currently apply to the petroleum and gas sector. Only MLA 80156 falls under this act. Therefore, this report will include figures showing the immediately affected area (IAA) and the long-term affected area (LAA). An affected area is defined as the area in which there has been drawdown of >5 m in less than 3 years (IAA) or any time after mining is initiated (LAA), because of the mine extension. As stated above, the drawdown created by the mine extension is the difference between the current mining conditions and the proposed mine extension.



Legend

Model Boundary Surface drainages



Cement Australia

The location of the East End Mine and Fishermans Landing

Groundwater Modelling Report

2 Physical setting

2.1 Topography and drainage systems

The topography map and the main drainage lines are shown in *Figure 3*, together with the numerical model boundary. There is a broad low-lying feature in the northern part of the model domain, encompassing Hut Creek, which drains to the north, and Machine Creek, which drains to the east and south. Machine Creek generally terminates to the north of Larcom Creek. Jacobs Creek drains the area to the west of the mine before flowing into Scrub Creek to the south of the mine. The confluence of Scrub Creek and Larcom Creek is located approximately 2 km southeast of the existing mine pit.

Produced water from the mine is pumped into two settlement ponds. The water flows out of the settlement ponds and over Weir 6 before it enters into East End Creek. The water eventually flows into Weir 1 where it is discharged from the mine site. The water flow continues along East End Creek before reaching Schultz Lagoon, a water feature created as a result of mine discharge waters. Ground surface elevation is generally around 30-80 m AHD around these main drainage lines, with elevations decreasing with distance downstream.

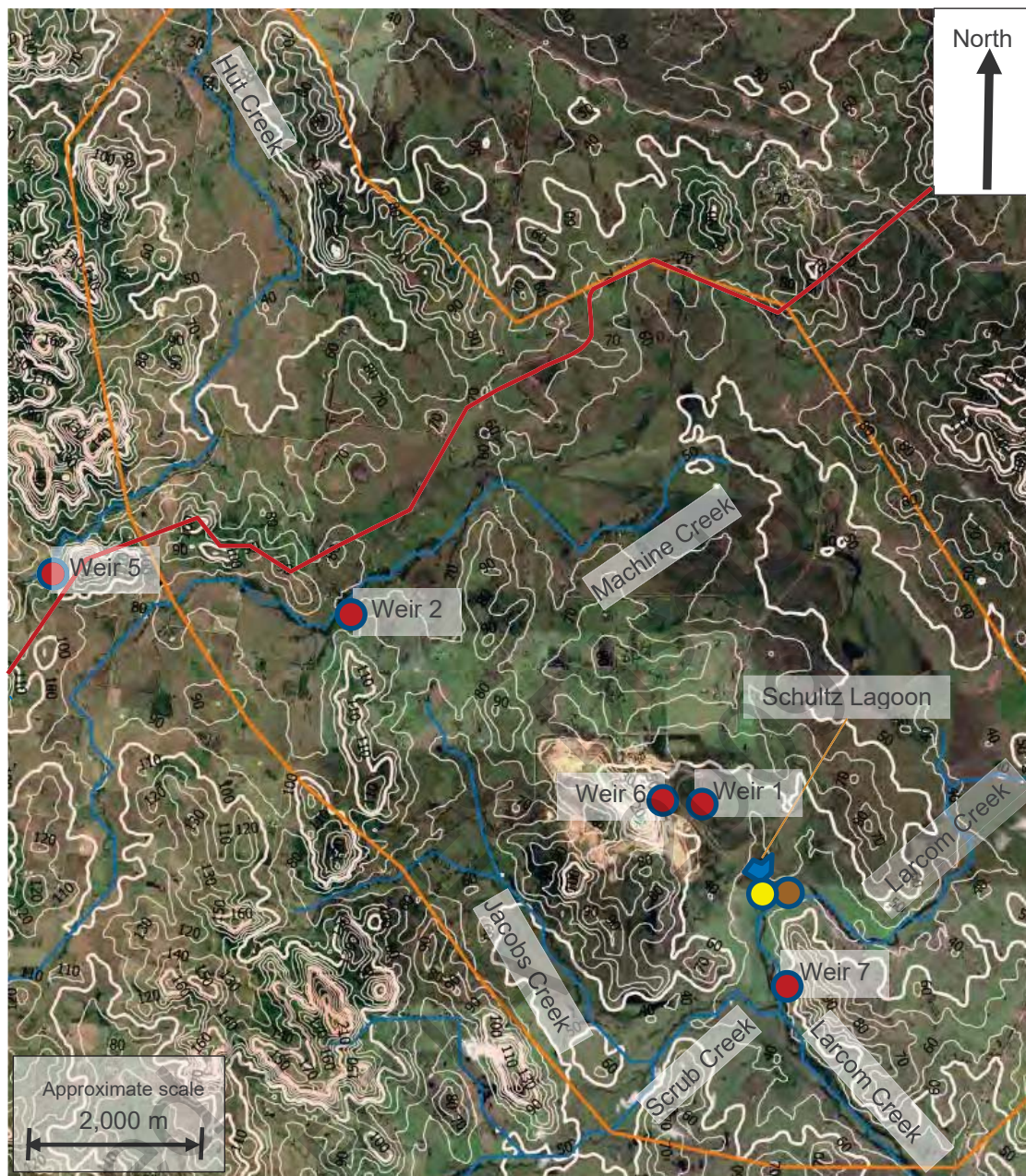


Figure 3 Topography map for the Cement Australia site and the immediate surrounds.

Surface water drainage lines (blue lines), surface water weirs (red dots), sampling 'Location 4' (yellow dot, at discharge of Schultz Lagoon), 'Monitoring Point C' (Brown dot, in Larcom Creek – up-gradient of Schultz Lagoon), the ground water model boundary (orange line), and the boundary between the Fitzroy River Basin (north of red line) and the Calliope River Basin (south of red line) are also displayed.

2.2 Climate

Figure 4 shows the monthly rainfall and evaporation data for the closest observation location, Mount Larcom Post Office (BoM station number 39068), which is located to the northeast of the model boundary (Figure 2). The average evaporation exceeds the average rainfall in every month of the year. Therefore, most of the time there won't be recharge to the groundwater, except for during and/or immediately after long wet periods or high intensity rainfalls.

Recharge to groundwater will occur either through direct recharge or through interaction with the surface water.

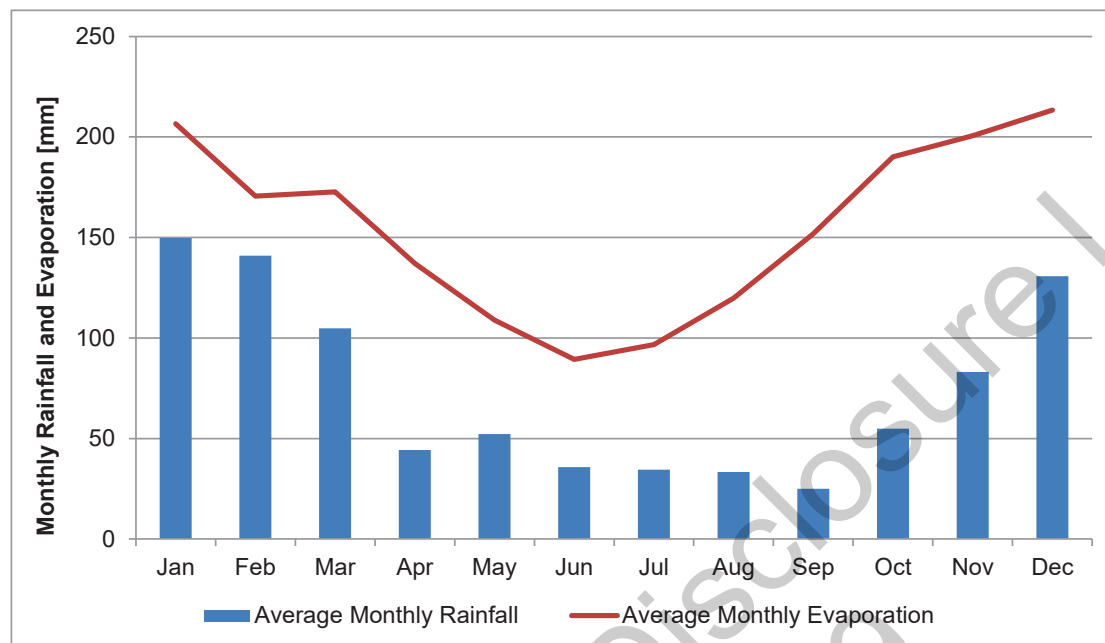


Figure 4 Average monthly rainfall and evaporation amounts (1960-2017) for Mount Larcom, located approximately 8 km north of the East End Mine (BoM, 2017a).

Figure 5 shows the total annual rainfall since 1960, highlighting wet and dry years. It is apparent that since mining at the East End mine started in 1980, a series of dry years occurred (1990s and 2000s). Pre-mining conditions might have been influenced by a higher than average climate (1970s were a wetter than average period).

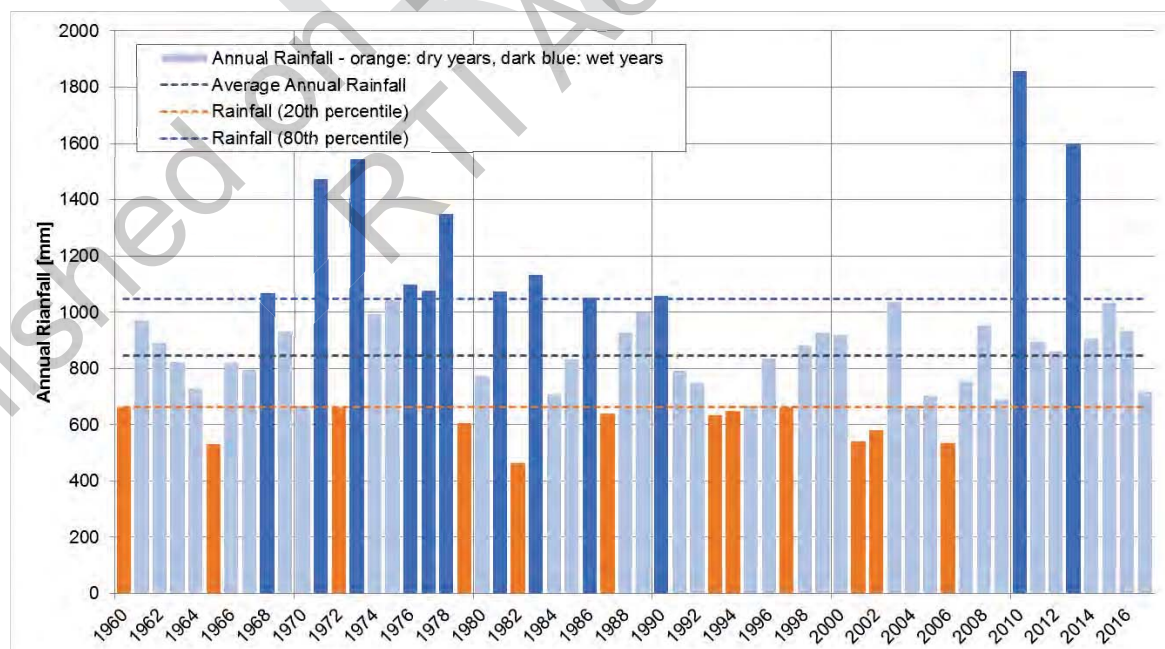


Figure 5 Climate statistics for Mount Larcom rainfall observations.

2.3 Landuse

The predominant land use in the region is agriculture, including grazing (sown pastures). Pasture production rates are generally classified as high (>3,500 kg/ha) in low-lying regions, with lower production rates in the more elevated regions (Figure 6).



Figure 6 Pasture production rates

High pasture production areas (>3,500 kg/ha) are shown in dark pink; medium production areas are shown in light purple (1,500-3,500 kg/ha); and low production areas (<1,500 kg/ha) are shown in light grey (Queensland Government, 2017). The model boundary is shown as a white outline.

2.4 Groundwater dependent ecosystems

Figure 7 shows groundwater dependent ecosystems (GDEs) for the site. There are no recognised subterranean GDEs in the vicinity of the site. There are two small terrestrial GDEs to the north of the pit near DHH96-2. Visual inspection indicates there are trees growing on a hill in this area. The *regulated vegetation map* shows the trees are listed as *Category B remnant vegetation* and the *vegetation management regional ecosystems and remnant map* shows that it is a *category A or B area that is a least concern regional ecosystem* (Queensland Globe, accessed on 16 November 2017).

DHH96-2 is screened in the weathered bedrock. Monitoring bore DHH96-1 is located approximately 600 m to the southeast of DHH96-2 and it is screened in the limestone. The electrical conductivity (EC) at DHH96-1 is significantly higher than at DHH96-2 and the water levels are lower (Table 1). The difference in water levels between the two bores is normally around 3 m, but can be as high as 5 m. Notably, the water level at DHH96-2 ranges from 44.87 m AHD to 51.05 m AHD over the 11 years of observation and it is heavily influenced by rainfalls. In contrast, the water levels in the in the bedrock bore are relatively stable, with water levels ranging from 44.60 m AHD to 46.21 at DHH96-1.

The stratigraphy and the differences in water levels and quality indicate that DHH96-2 is monitoring a perched aquifer system in the vicinity of the terrestrial GDE. It also indicates that this perched system is the likely source of this terrestrial GDE. Water from the perched aquifer may drain into the underlying bedrock aquifer; but water level gradient shows that it does not normally flow from the bedrock to the perched aquifer, as the perched groundwater level is usually around 3 m higher than the bedrock aquifer. In summary, the two systems are either: unconnected, or, groundwater flows from the perched system into the underlying bedrock aquifer. Assuming this assessment is correct, dewatering of the underlying bedrock would not impact on the terrestrial GDE.

Table 1 Summary statistics for monitoring bores DHH96-1 and DHH96-2, which are located near a terrestrial GDE.

EC (µS/cm)	Samples	Minimum	20 th percentile	50 th percentile	80 th percentile	Maximum
DHH96-1	22	2,650	23,160	25,050	26,900	40,500
DHH96-2	21	175	570	1,946	10,100	14,260
Water levels (m AHD / m BTOC)	Samples	Minimum	20 th percentile	50 th percentile	80 th percentile	Maximum
DHH96-1	42	44.60 / 7.05	44.84 / 6.81	45.35 / 6.30	46.27 / 5.38	46.21 / 5.24
DHH96-2	42	44.87 / 6.98	47.12 / 4.73	48.49 / 3.36	50.18 / 1.67	51.05 / 0.80
Note: m AHD means metres Australian Height Datum. m BTOC means metres below top of casing, which is 51.65 m AHD and 51.85 m AHD at DHH96-1 and DHH96-2 respectively.						

There is another terrestrial GDE on Scrub Creek, to the southwest of the mine, but this GDE is outside of the 'zone of influence' of the mine. Larcom Creek is an aquatic GDE in the area upgradient of the mine. Schultz Lagoon is located in-between this aquatic GDE and the existing and the proposed pits. As discussed in Section 2.1, water from Schultz Lagoon discharges into groundwater and Larcom Creek in this region. This discharging water will mitigate any impacts to the aquatic GDE on Larcom Creek. There are small aquatic GDEs to the northeast of the mine near Machine Creek, but these GDEs are outside of the 'zone of influence' of the mine.

Schultz Lagoon is also listed as an aquatic GDE; however, this water body is an artificial feature created by the discharge of mine-water. This surface water feature will continue to exist as long as the mine operates in its current form.



Figure 7 Groundwater dependent ecosystems (GDEs)

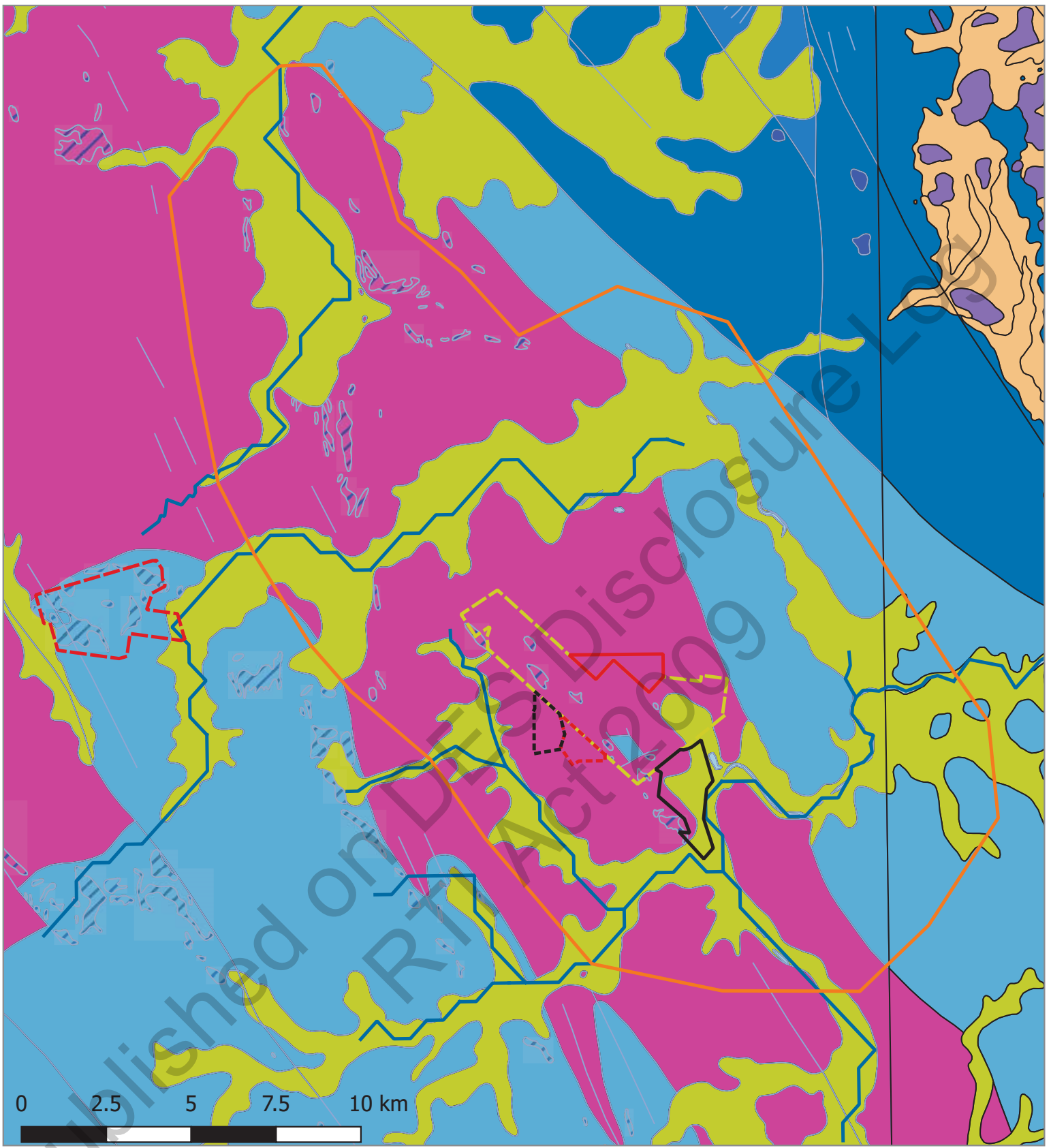
The above Groundwater dependent ecosystems (GDEs) are defined by the Bureau of Meteorology (<http://www.bom.gov.au/water/groundwater/gde/map.shtml>). The green polygons are terrestrial GDEs and the purple polygons are aquatic GDEs. There are no recognised subterranean GDEs in the vicinity of the site.

3 Geology and groundwater occurrence

3.1 Regional geology

The Bajool map sheet 9050 (DNRME, 2004) shows that the main geological units in the site area are the Erebus beds and the Mount Alma Formation (*Figure 8*). The Late Silurian to Middle Devonian Erebus beds are composed of dacitic to rhyolitic volcanoclastic sandstones and conglomerates, with minor siltstones, and, of note for the East End Mine, minor limestones and marble (Geoscience Australia, 2017). Whilst the limestone and marble are only a minor component of the Erebus beds, they form locally large lenses in the vicinity of the East End Mine (Groundwork Plus, 2014). The Erebus beds are a sub-unit of the Mount Holly Formation.

The Late Devonian to early Carboniferous Mount Alma Formation is mostly composed of thinly interbedded fine-grained sandstones and siltstones. There are also thick conglomerate beds with andesitic to dacitic clasts and siltstone rip-up-clasts (Geoscience Australia, 2017).



North

Legend

Model Boundary

— Surface water drainages

Mining leases

- ML 3631
- MLA 80156
- ML 3659
- ML 7629
- ML 80002
- ML 80127

Surface Geology

- Quaternary Sediments
- Erebus beds
- Erebus beds (limestone)
- Mount Alma Formation
- Mount Alma Formation (limestone)
- Rockhampton Group
- Rockhampton Group, Berserker Group
- Water body (unspecified)

Cement Australia

Regional surface geology.

Groundwater Modelling Report

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Figure

8

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DATUM GDA 1994, PROJECTION MGA ZONE

Base Data: Department of Natural Resources, Mines and Energy (DNRME) 2004; Bajool Surface Geology Map Sheet 9050; and Gladstone Surface Geology Map Sheet 9150

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3.2 Alluvium

The alluvial material surrounding Hut Creek, Machine Creek, Larcom Creek, Scrub Creek and Jacobs Creek is mapped as flood plain alluvium, comprising clay, silt, sand and gravel on Map Sheet 9050 (DNRME, 2004). No alluvium is mapped around East End Creek, which transports produced water (i.e. water pumped from the mine pit) from the mine. DNRM borehole logs have been assessed to determine the depth and composition of the alluvium in the study area. The hydrogeological properties of the alluvial deposits surrounding Hut Creek, Machine Creek, Larcom Creek, Scrub Creek and Jacobs Creek have been assessed separately using borehole logs from the DNRM (2017) groundwater database presented in the sections below.

3.2.1 Hut Creek alluvium

The base of the alluvium surrounding Hut Creek has been interpreted from the information compiled in *Table 2*. It is difficult to interpret the change from alluvium to bedrock, due to the lack of detail in the logs. The information in *Table 2* shows the alluvium near Larcom Creek is mostly composed of clay and it is likely to be less than 4 m deep.

Table 2 Geological summary of monitoring bores installed near Hut Creek (DNRM, 2017).

Bore ID / RN	Location	Depth (mBGL)	Description	Median SWL (mBTC) ⁽¹⁾
B111 / 88925	Edge of alluvium (upgradient)	0-4.0	Topsoil, sand and gravel (water)	0.00
		4.0-7.6	Weathering	
		7.6-21.0	Diorite (MHF)	
RC11-06 / 151449	Edge of alluvium	0.0-2.0	Topsoil	13.30
		2.0-22	Limestone-	
		22-42	Volcanics (Erebus beds)	
DHH97-4C / 97544	Edge of alluvium	0-1.0	Clay	3.50
		1.0-11.5	Clay with laterite & limestone	
		11.5-49.5	Limestone (some clay layers)	
DHH97-5 / 97545	Middle of alluvium	0-4.0	Silty clay	2.44
		4.0-20.0	Clay with limestone	
		20.0-28.0	Limestone with clay	
RC11-09 / 151434	Middle of alluvium	0-3.0	Brown clay	4.22
		3.0-8.0	Soft limestone	
		10.0-42.0	Limestone (Erebus beds)	

Note: ID is the Cement Australia identification number

RN is the bore's registered number

MHF is Mount Holly Formation

The blue text denotes the interpreted aquifer units

The red text denotes the interpreted alluvial material

Median standing water level (metres below top of casing) from data collected between September 2006 and March 2017

Monitoring bore locations are shown in Figure 2

3.2.2 Machine Creek alluvium

The base of the alluvium surrounding Machine Creek has been interpreted from the information compiled in Table 3. It is difficult to distinguish the alluvium from the unconsolidated weathered bedrock (normally clay), as the weathered bedrock can be up to 37 m thick (see DHH96-6, which was drilled into the bedrock; Table 3). Photographs 1 and 2 (Appendix A) were taken in Machine Creek at Weir 2 and near monitoring bore B21 respectively. The channel is less than 3-4 m deep and there is bedrock cropping out at the base of the stream. This indicates that the alluvium surrounding Machine Creek is less than 3-4 m thick in this region. Borehole logs from RC11-04 and DHH97-8B shows that there is unconsolidated material to 34 m and 24.5 m respectively. The deeper material is interpreted as weathered bedrock. The alluvium generally appears to be less than 4 m thick around Machine Creek.

Table 3 Geological summary of monitoring bores installed near Machine Creek (DNRM, 2017).

Bore ID / RN	Location	Depth (mBGL)	Description	Median SWL (mBTCOC) ⁽¹⁾
B102 / 91928	Erebus beds	0-8.5 8.5-24 24-24.6	Soil & clay Limestone Fractured limestone (MHF)	14.80
DHH96-6 / 97145	Erebus beds	0.0-11 11-37 37-59.3	Clay Weathered limestone-clay & creek gravel Limestone (MHF)	29.61
RC11-04 / 151480	Edge of alluvium	0-5 5-34 34-35 35-78	Brown clay (maybe alluvium to 3-4 m) Orange clay/silt Limestone Limestone (Erebus beds)	21.47
DHH97-8B / 97584	Middle of alluvium	0-4 4-24.5 24.5-28 28-51.4	Brown clay Clay – mostly orange Clay with limestone Limestone & volcanoclastic (MHF)	24.02

Note: ID is the Cement Australia identification number

RN is the bore's registered number

MHF is Mount Holly Formation

The blue text denotes the interpreted aquifer units

The red text denotes the interpreted alluvial material

Median standing water level (metres below top of casing) from data collected between September 2006 and March 2017

Monitoring bore locations are shown in Figure 2

3.2.3 Larcom Creek alluvium

The base of the alluvium surrounding Larcom Creek has been interpreted from the information compiled in Table 4. As with the alluvium at the other sites, it is difficult to interpret the change from alluvium to bedrock, due to the lack of detail in the logs. The information in Table 4 shows the alluvium near Larcom Creek is mostly composed of clay and it is likely to be less than 5 m deep. This is supported by Photograph 3 and 4 (Appendix A), which show that the bedrock is visible at the base of the stream at Weir 7 (see Figure 3 for location). The streambed is approximately 2 m below the ground surface of the alluvial plains.

Table 4 Geological summary of monitoring bores installed near Larcom Creek (DNRM, 2017).

Bore ID / RN	Location	Depth (mBGL)	Description	Median SWL (mBTC)(¹)
DHH96-41 / 97177	Edge of Alluvium	0-4.5 4.5-6 6-7 7-31	Clay Limestone (MHF) Clay Limestone	5.08
DHH97-6 / 97546	Erebus beds	0-2 2-8 8-11 11-13.5	Soil Clay Clay Silty Clay Silty Clay & Limestone	15.40
DHH96-9 / 97148	Edge of Alluvium	0-2 2-5 5-10 10-12 12-50	Clay Limestone & Clay Clay rock flour Limestone & Clay Limestone (MHF)	1.11
RC11-15 / 151459	Edge of Alluvium (upgradient of site)	0-3 3-6 6-100	Clay Weathered volcanics Volcanics (Erebus beds)	0.00
DHH96-10 / 97149	Erebus beds (upgradient of site)	0-7 7-11 11-18 18-30 30-50	Clay Rock flour no sample Volcanic rock Andesite (MHF)	3.98
RC11-12 / 151441	Edge of Alluvium	0-6 6-12 14-100	Clay (maybe alluvium to 2-5 m) Clay & rock Volcanics (Erebus beds)	5.84
RC11-13 / 151462	Erebus beds	0-6 6-24 24-33 33-100	Clay Volcanics Broken volcanics Volcanics	5.92

Note: ID is the Cement Australia identification number

RN is the bore's registered number

MHF is Mount Holly Formation

The blue text denotes the interpreted aquifer units

The red text denotes the interpreted alluvial material

Median standing water level (metres below top of casing) from data collected between September 2006 and March 2017

Monitoring bore locations are shown in Figure 2

3.2.4 Scrub Creek alluvium

The base of the alluvium surrounding Scrub Creek has been interpreted from the information compiled in *Table 5*. As with the alluvium at the other sites, it is difficult to interpret the change from alluvium to bedrock, due to the lack of detail in the logs. The information in *Table 5* shows the alluvium near Scrub Creek is mostly composed of clay and it is likely to be less than 7.5 m deep. Scrub Creek was visited on 5 June 2017; there was no bedrock cropping out at the base of the creek, which was incised approximately 4 m into the alluvial plain.

Table 5 Geological summary of monitoring bores installed near Scrub Creek (DNRM, 2017).

Bore ID / RN	Location	Depth (mBGL)	Description	Median SWL (mBTC)(¹)
B56 / 57128	Edge of Alluvium	0-3.05 3.05-6.1 6.1-20.73	Soil & Clay Sandy Clay Limestone (MHF) Aquifer from 8.5-9.9 m	2.72
DHH96-7 / 97146	Middle of Alluvium	0-7.5 7.5-50	Clay (possibly alluvium) Weathering & Clay (MHF)	3.45
B6 / 57076	Middle of Alluvium	0-1.52 1.52-4.57 4.57-10.36 10.36-15.54	Soil and clay Gritty clay Gritty clay & rock Rock Water (MAF)	2.02

Note: ID is the Cement Australia identification number

RN is the bore's registered number

MHF is Mount Holly Formation

MAF is Mount Alma Formation

The blue text denotes the interpreted aquifer units

The red text denotes the interpreted alluvial material

Median standing water level (metres below top of casing) from data collected between September 2006 and March 2017

Monitoring bore locations are shown in Figure 2

3.2.5 Jacobs Creek alluvium

The alluvium surrounding Jacobs Creek has also been assessed using the borehole logs from the DNRM (2017) groundwater database (*Table 6*). As with the alluvium at the other creeks, it is difficult to interpret the change from alluvium to bedrock, due to the lack of detail in the logs. The information in *Table 6* shows the alluvium near Jacobs Creek is mostly composed of clay and it is likely to be less than 6 m deep.

Table 6 Geological summary of monitoring bores installed near Jacobs Creek (DNRM, 2017).

Bore ID / RN	Location	Depth (mBGL)	Description	Aquifer (mBGL)	SWL (mBGL)
DHH96-15 / 97154	Edge of Alluvium	0-2	Clay	25-50	5.72
		2-12	Rock flour/rock		
		12-50	Metasediment & Volcaniclastic rock (MHF)		
DHH96-14 / 97153	Edge of Alluvium	0-6	Clay	25-	3.43
		6-50	Metasediment & Volcaniclastic rock (MHF)		
DHH96-13 / 97152	Edge of Alluvium	0-3	Clay	13-35	3.27
		7-13	Clay/rock & rock flour		
		13-50	Metasediment & Volcaniclastic rock (MHF)		
RC11-19 / 151437	Edge of Alluvium	0-3	Topsoil	73-100	5.56
		3-12	Weathered volcanics		
		12-100	Volcanics (Erebus beds)		
B61 / 57133	Edge of Alluvium		No details		2.53
DHH96-12 / 97151	Edge of Alluvium	0-5	Clay	22-32	3.92
		5-6	Gravel		
		6-14	Clay & rock		
		14-20	Rock flour		
		20-32	Clay & Limestone (MHF)		
DHH97-9 / 97547	Middle of Alluvium	0-2	Silty clay	-	1.11
		2-5	Clay with rock/limestone fragments		
		5-7	Clay		
		7-10	Clay with rock/limestone fragments		
		10-11	Clay limestone		

Note: ID is the Cement Australia identification number

RN is the bore's registered number

MHF is Mount Holly Formation

The blue text denotes the interpreted aquifer units

The red text denotes the interpreted alluvial material

Monitoring bore locations are shown in Figure 2

3.2.6 Alluvial groundwater

No alluvial groundwater was noted in the borehole logs in Table 2 to Table 6 and the logs show that the alluvium is generally clay. Therefore, the alluvium is unlikely to contain significant groundwater resources. There are no known monitoring bores specifically targeting the alluvium; this supports the conclusion that the alluvium is not productive.

3.3 Local geology

The geology has been mapped in more detail, and split into three geological assemblages: volcanoclastics, limestones and laterite, as shown in *Figure 9* (Groundwork Plus, 2014). The limestone has been recrystallised into marble where it contacted with granitic plutons and mafic dykes. *Figure 10* and *Figure 11* show three-dimensional representation of the dykes mapped in the pit. The dykes predominately strike to the northwest in-line with the main bedding strike, with lesser west-east trending dykes. The marble surrounding the dykes is generally dense and it has a low porosity. If the dykes remain unweathered and unfractured, the marble aureole is considered to be a barrier to groundwater flow.

The limestone includes marble (metamorphosed limestone) and the extent of the limestone generally coincides with the Erebus beds. The main exception is to the west of the modelled area near monitoring bores O11, B53, O10 and B35; this area is mapped as limestone (*Figure 9*) but the Mount Alma Formation is charted on the regional geology map (*Figure 8*). The volcanoclastic rocks generally include the sandstones and siltstones of the Erebus beds and the Mount Alma Formation.

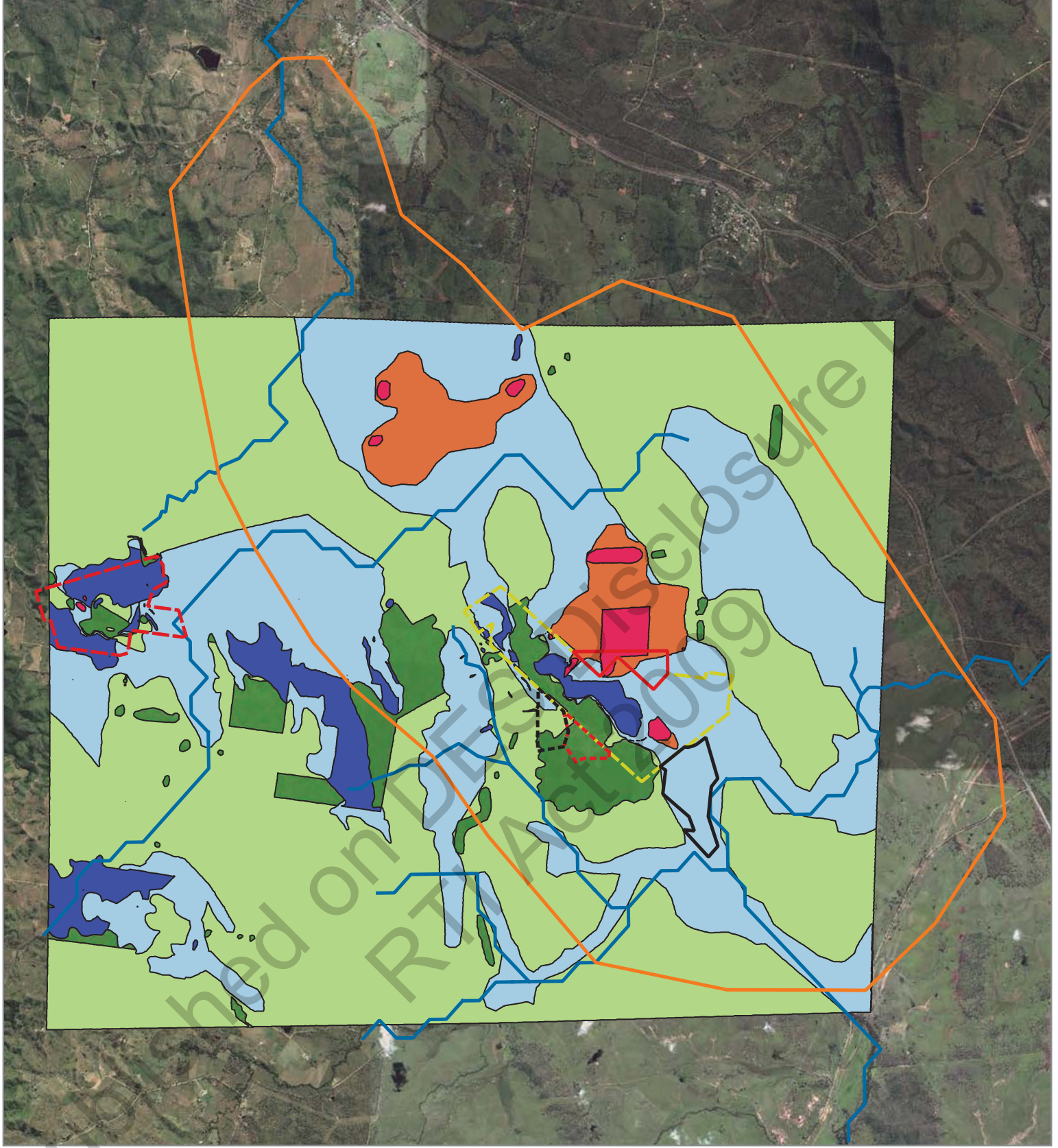
Near the East End Mine, the bedding strikes towards the northwest, with strata dipping steeply towards the southwest at around 70°-85° (Groundwork Plus, 2014). The Erebus beds and the Mount Alma Formation units share a faulted contact with each other according to Geoscience Australia (2017). However, Groundwork Plus (2014) reported the contact as an unconformity (i.e. no faulted – separated by a period of non-deposition). However, this distinction is not overly important in the context of this report.

The East End Mine is sited on a limestone belt running in a north-westerly direction (East End belt). There is another limestone belt to the west of MLA 80156 (the Bracewell belt), which is separated from the East End belt by a volcanoclastic rocks. Groundwater flow between the two limestone belts is restricted by the faulting and folding and the placement of the volcanoclastic rocks (DERM, 2011).

Groundwater flow will predominately occur along bedding planes within each structural block; i.e. between the individual limestone belts and within the volcanoclastic rocks. Any interflow between the volcanoclastics and the two limestone belts would generally be limited to areas with interconnected fractures (DERM, 2011).

3.3.1 Bedrock geology within the model area

The Erebus beds, crop-out in the central and western parts of the numerical model area. Therefore, the volcanoclastic sedimentary rocks in these regions are likely to be rhyolitic volcanoclastic sandstones and conglomerates, with minor siltstones (Geoscience Australia, 2017). The Mount Alma Formation crops out to the east of the model area. The volcanoclastic sedimentary rocks in this area are likely to be composed of thinly interbedded fine-grained sandstones and siltstones, with thick conglomerate interbeds.



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RTI 20-078

Legend

- | | |
|----------------------|-----------------------------|
| Model Boundary | Surface water drainages |
| Mining_leases | |
| ML 3631 | Volcaniclastics - confirmed |
| MLA 80156 | Volcaniclastics - suspected |
| ML 3659 | Limestone - confirmed |
| ML 7629 | Limestone - suspected |
| ML 80002 | Laterite - confirmed |
| ML 80127 | Laterite - suspected |

0 1 2 3 4 km



Base Data: Google Earth image

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Local surface geology (c/o Groundwork Plus).

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APPROVED BY: [Signature]
LAST MODIFIED: January 2018
VERSION: 2

Figure

9

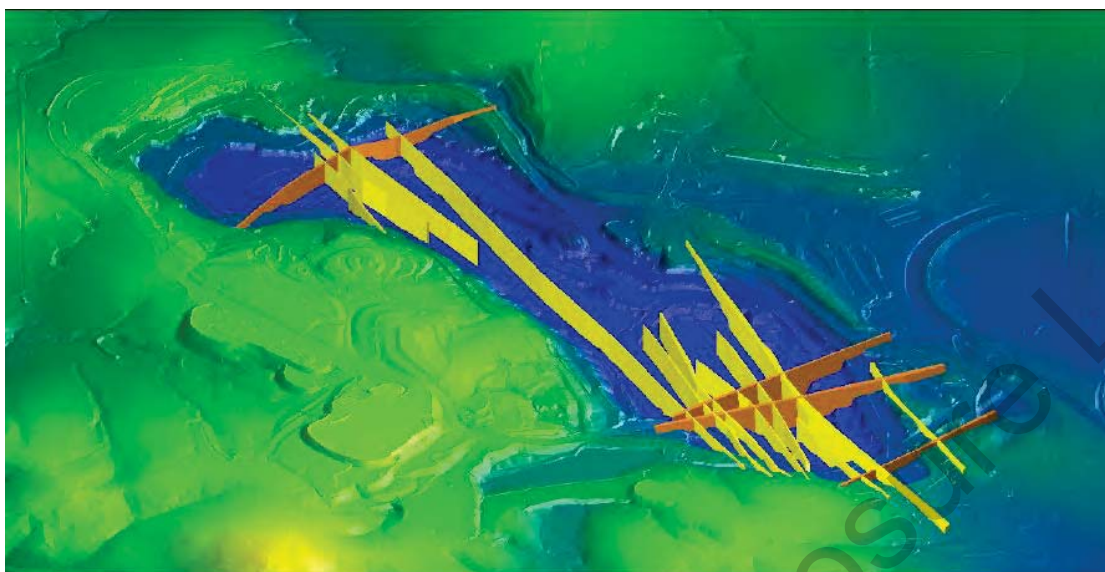


Figure 10 Three-dimensional representation of the dykes in the existing mine-pit (Groundwork plus, 2014)

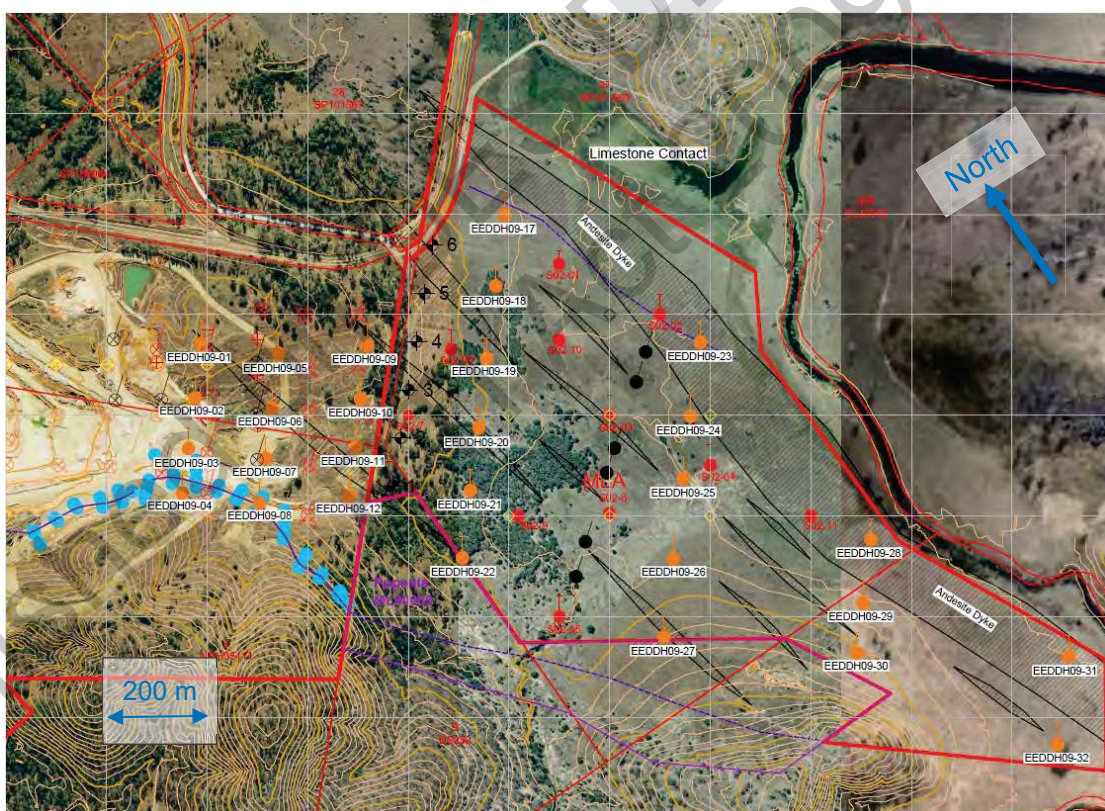


Figure 11 Geographical distribution of dykes, as mapped by Groundwork Plus geologists (care of Groundwork Plus).

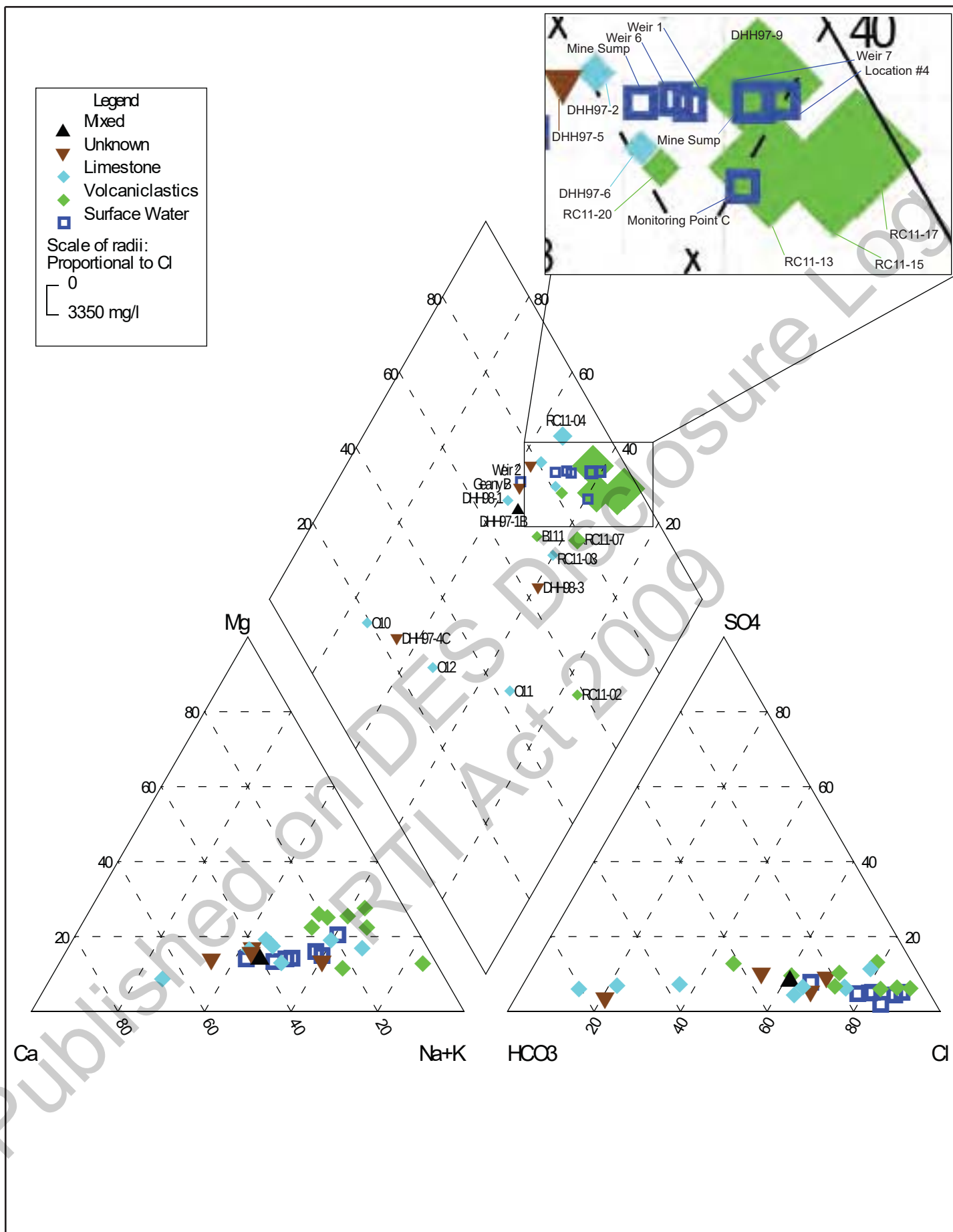
3.4 Water chemistry

The Piper diagram below (*Figure 12*) shows that groundwater at the site is mostly composed of calcium, sodium, bicarbonate and chloride, with lesser amounts of magnesium and sulphate. The proportion of sodium and chloride generally increases as the salinity increases. *Figure 13(a)* shows that groundwaters with total dissolved solids (TDS) less than 1,000 mg/L generally have very low chloride concentrations, showing that the ions are contributed by water-rock interactions. These less evolved samples are mostly composed of bicarbonate and a roughly equal mixture of major ions. There is a linear relationship between chloride and TDS, showing that the more saline waters have likely experienced evapotranspiration processes, as would be expected.

Figure 13(b) shows the hydrochemical evolution using bicarbonate and chloride. Water-rock interactions result in a higher proportion of bicarbonate in the dilute samples. The more saline samples have a higher proportion of chloride, as the bicarbonate drops out of solution (*Figure 14*), as these waters are super-saturated with respect to calcite. Samples collected from the volcanics generally have proportionally less calcium (compared to other major cations) than the other samples, and they are higher in sodium. The samples from the volcanics have probably experienced more evaporation than the other samples, indicating the rate of recharge is probably lower.

For the surface water samples, the calcium and bicarbonate concentrations decrease as the samples become more saline (*Figure 14*), indicating that calcite is precipitating (i.e. calcite is supersaturated).

Calcite dissolution is likely early in the groundwater evolution process; however, most samples are supersaturated with respect to calcite. The calcium concentration increases as the groundwater samples become more evolved (*Figure 14b*), but the bicarbonate concentration remains stable. The increase in TDS is a result of evaporation and water-rock interactions.



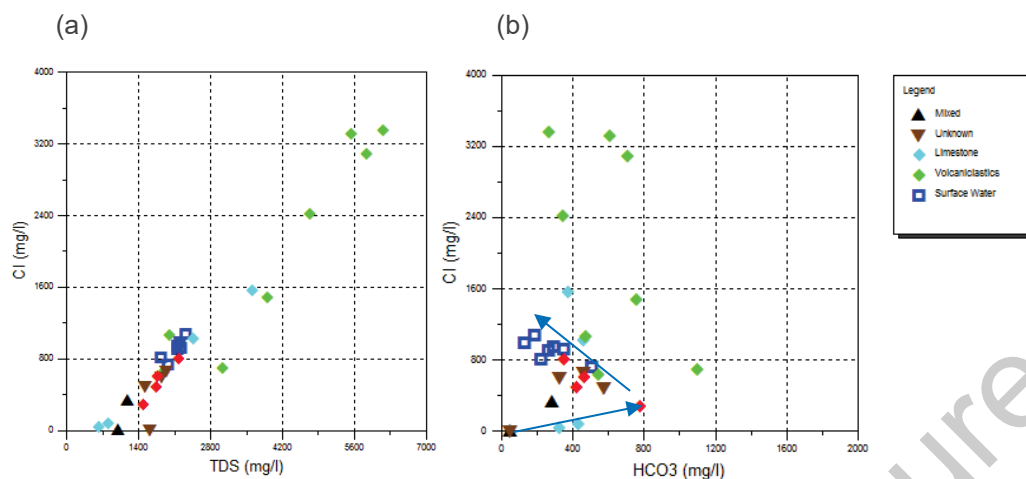


Figure 13 Scatter Plots: Relationship between dissolved solids & chloride and between bicarbonate versus chloride.
 (a) Scatter plot showing the linear relationship between total dissolved solids (TDS) and chloride.
 (b) Scatter plot showing bicarbonate versus chloride. The blue arrows show the hydrochemical evolution of most of the water samples, excluding the samples from the volcaniclastics.

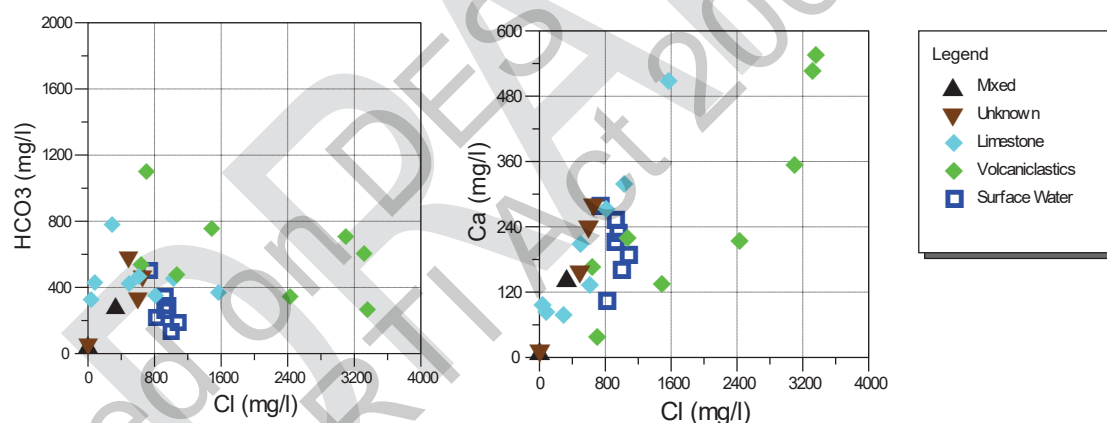


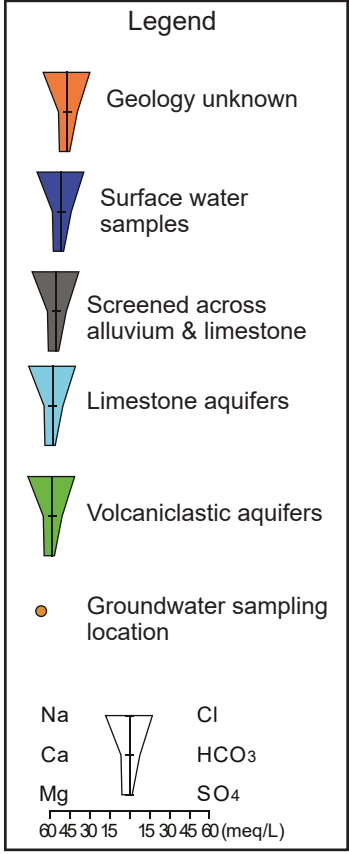
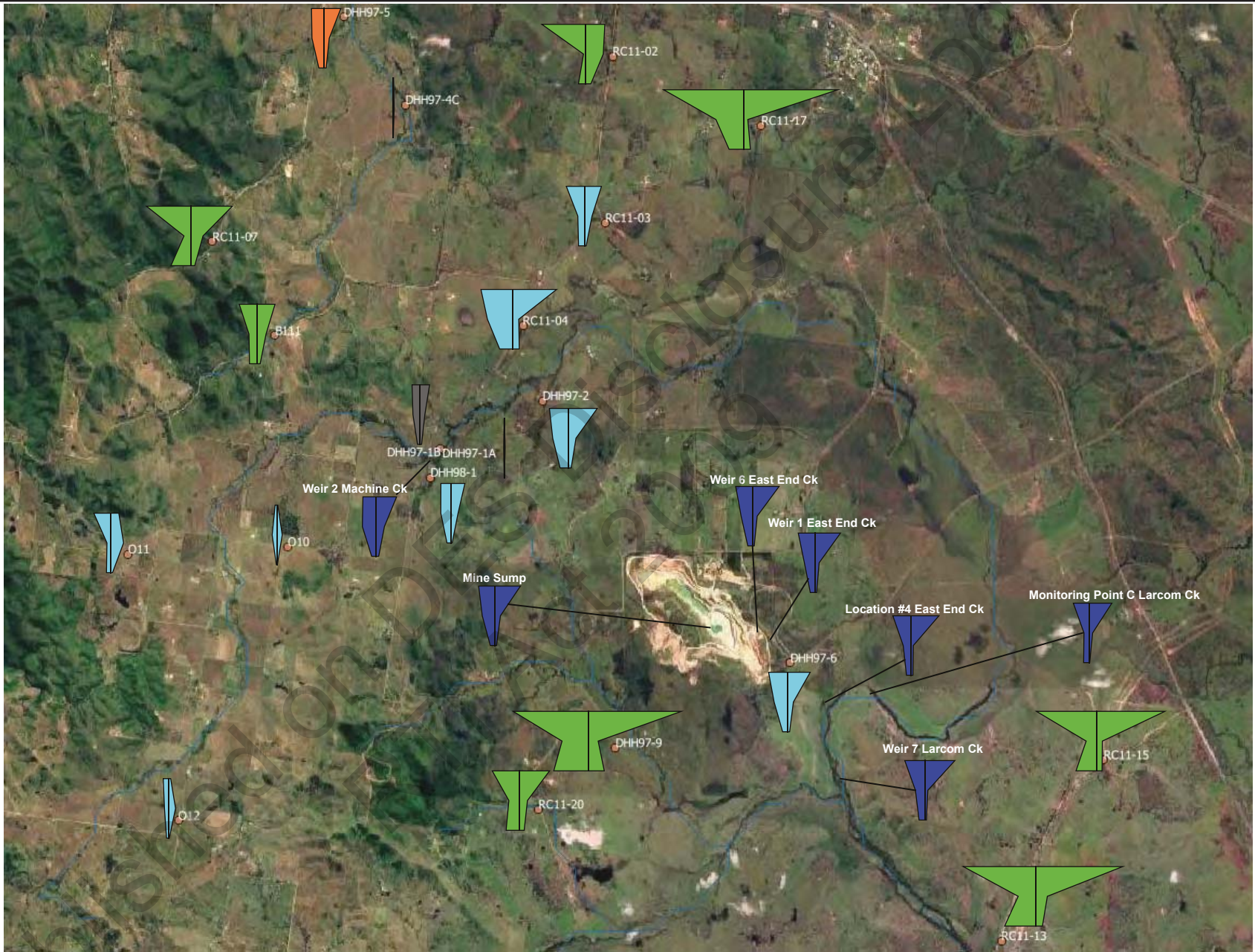
Figure 14 (a) Scatter plot showing chloride versus bicarbonate. (b) Scatter plot showing chloride versus calcium.

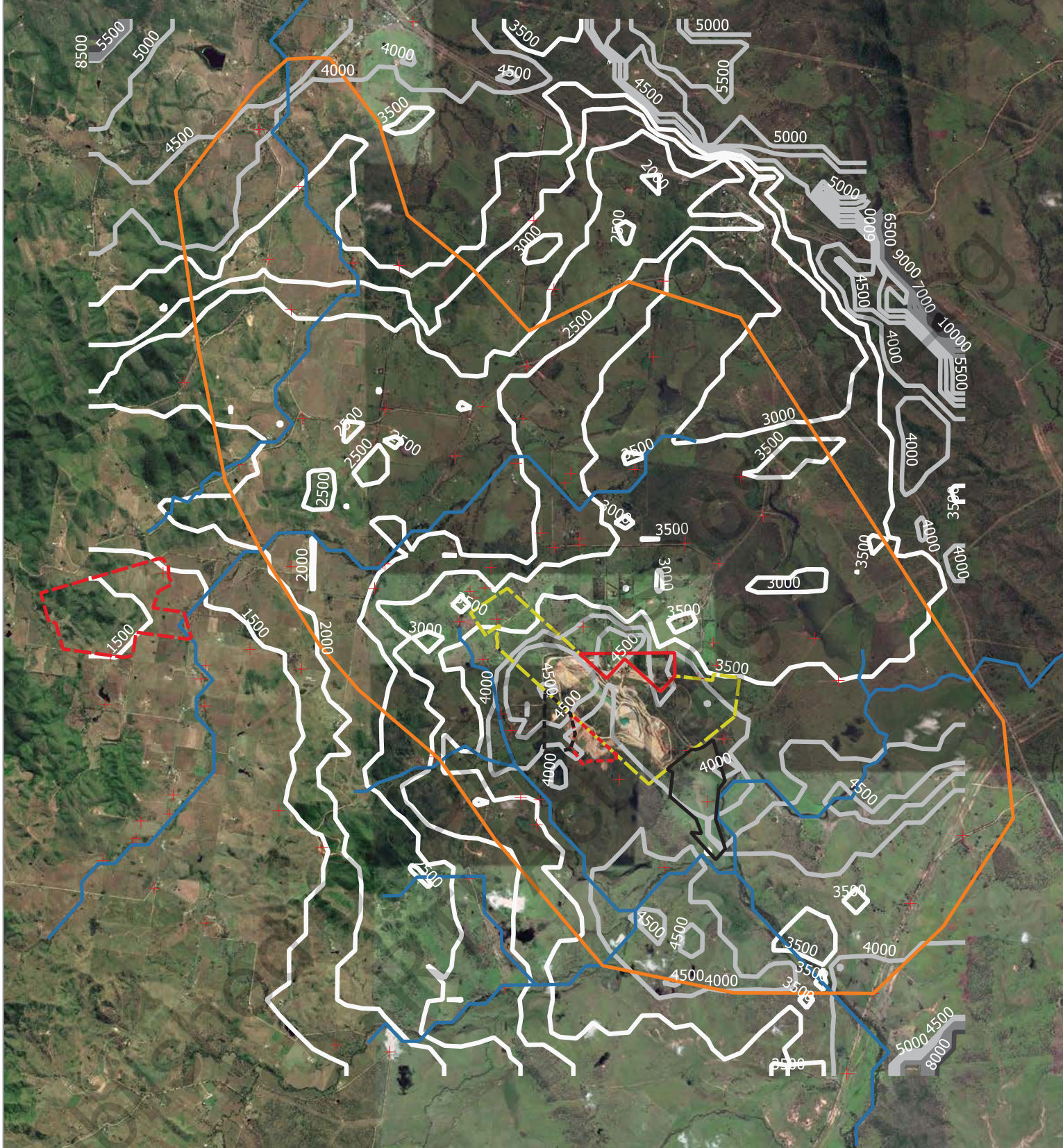
The groundwater and surface water chemistry is presented using Stiff diagrams in Figure 15. It shows that the samples from the volcaniclastics are generally dominated by sodium and chloride. The samples collected from the limestone generally have similar chemical signatures to the adjacent surface waters, indicating they are likely interconnected (see Section 4.3 for more details on the interconnection between groundwaters and surface waters).

Figure 16 shows the EC contours based on sampling conducted in September 2016. The EC is low in the Hut Creek subcatchment and the Machine Creek subcatchment, particularly in the area upgradient of the model boundary. The EC generally increases with distance

downstream in these subcatchments. The EC is more elevated around the mine and near Larcom Creek.

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Base Data: Google Earth image

Filename: B:\Engineering\Jobs 22000-22099\22050 Cement Australia Trigger Value Assessment\GIS\CA Geology and Bores3.ggs

Legend

+ Data points (bores) for EC contours

EC contours ($\mu\text{S}/\text{cm}$; kriging)

- 1500.0000 - 3500.0000
- 3500.0000 - 5500.0000
- 5500.0000 - 7500.0000
- 7500.0000 - 9500.0000
- 9500.0000 - 11500.0000
- Surface water drainages
- Model Boundary

Mining leases

- ML 3631
- MLA 80156
- ML 3659
- ML 7629
- ML 80002
- ML 80127

File B

Cement Australia

Electrical conductivities (EC) contours based on groundwater sampling conducted on September 2016 by Groundwork Plus.

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Figure

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3.5 Surface water flow

Daily average flow rate statistics from five monitored weirs are presented in *Table 7*. The data encompasses a relatively wet period between July 2011 and June 2016. Rainfall totals were significantly above the median in 2012/2013 and 2014/2015 and close to the median in 2011/2012, 2013/2014 and 2015/2016.

The flow rate at Hut Creek (Weir 5) was highly variable, depending on antecedent rainfalls. Flow rates in 2011/2012 were very low, during a period of 'normal' rainfalls. Flow rates increased in 2012/2013 during a very wet year (twice the average rainfall).

Produced water from the mine is pumped into two settlement ponds. The water flows out of the settlement ponds and over Weir 6 before it enters into East End Creek. The water eventually flows into Weir 1 where it is discharged from the mine site. The water flow continues along East End Creek before reaching Schultz Lagoon, a water feature created as a result of discharging mine waters. (Weir locations shown on *Figure 2*). *Figure 17* shows flow rates at the mine sump pumps, Weir 6, Weir 1 and Weir 7 (Larcom Creek, downgradient of Schultz Lagoon).

There is a period of low flow at all three weirs in late 2013, due to low rainfalls. During this period, the average flow rate at Weir 7 was around 200 m³/day, around 2,800 m³/day lower than they were at Weir 6. This indicates that there was water discharging into groundwater between Weir 6 (East End Creek) and Weir 7 (Larcom Creek). The discharge rate of 2,800 m³/day is considered a minimum discharge rate, as there is likely to be additional flow from further upgradient in Larcom Creek, which may also be recharging groundwater in this area. Furthermore, the pumping rate of the mine sump pumps is generally around 500-1,000 m³/day higher than at Weir 1, indicating that there is also water loss in the vicinity of the holding dam and upgradient of Weir 1.

During wet periods, the flow at Weir 7 is similar to that at Weir 1 and Weir 6. Surface water is still discharging into groundwater from East End Creek, Larcom Creek and Schultz Lagoon during these periods, but the rate of discharge is not evident, as Larcom Creek receives flow from upgradient of the site. The water discharging from surface water in this region is cycled back into groundwater, and ultimately, the mine. This surface water discharge is likely to reduce groundwater drawdowns to the south of Larcom Creek. Furthermore, the mine discharge into Schultz Lagoon also mitigates against impacts to surface water flows in Larcom Creek.

A sizeable proportion of this water is likely to be lost to evaporation. Assuming Schultz Lagoon is 330 m long by 100-320 m wide (normally 100 m wide, but it is around 320 m wide when the overflow area is used when the lagoon is full), using a pan evaporation rate of 2,000 mm per year (BoM, 2017b), the daily evaporation rate is approximately 180-580 m³/day.

In summary, the minimum groundwater recharge from East End Creek, Larcom Creek and Schultz Lagoon between the mine outflow and Weir 7 (down gradient of Schultz Lagoon on Larcom Creek; *Figure 2*) is likely to be around 3,000 m³/day. This groundwater recharge from the mine's production water mitigates groundwater drawdown in the area to the south of the existing pit.

Table 7 Daily average flow rate statistics from surface water monitoring locations.

	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016
Rainfall (mm)	876	1,636	865	1,019	853
Weir 5 - Hut Creek					
Minimum	0.004	1,125	115	2	0.002
10 th percentile	0.004	1,499	238	38	13
50 th percentile	0.005	2,270	772	277	156
90 th percentile	0.006	4,270	1,229	428	286
Maximum	0.006	73,110	3,812	44,482	7,116
Weir 2 - Machine Creek					
Minimum	98	104	0.00	147	326
10 th percentile	1,164	246	605	763	475
50 th percentile	1,462	8,478	1,226	1,097	935
90 th percentile	1,921	19,222	1,776	1,649	1,802
Maximum	12,571	332,030	217,312	8,161	13,278
Weir 1 - East End Creek					
Minimum	4	136	140	247	1,663
10 th percentile	221	2,688	670	1,309	1,848
50 th percentile	4,289	4,089	3,580	3,391	2,089
90 th percentile	8,275	11,575	6,050	5,155	2,280
Maximum	28,382	49,739	30,980	7,294	2,745
Weir 6 - East End Creek					
Minimum	27	2,212	128	451	12
10 th percentile	1,874	2,512	1,929	2,637	1,957
50 th percentile	3,282	2,684	2,857	4,443	3,222
90 th percentile	7,835	2,802	11,097	6,680	5,596
Maximum	14,298	2,814	11,998	10,331	11,630
Weir 7 - Larcom Creek					
Minimum	3,272	1,155	23	867	595
10 th percentile	3,703	1,305	157	2,714	1,101
50 th percentile	7,680	5,802	864	4,753	2,279
90 th percentile	19,659	17,708	11,605	13,140	17,828
Maximum	265,569	859,244	417,949	192,039	161,048
All flow rates are in m ³ /day (data care of Groundwork Plus 2017). The median annual rainfall for Mount Larcom Post Office was 846 mm and the mean rainfall was 895 mm (BoM, 2017a).					

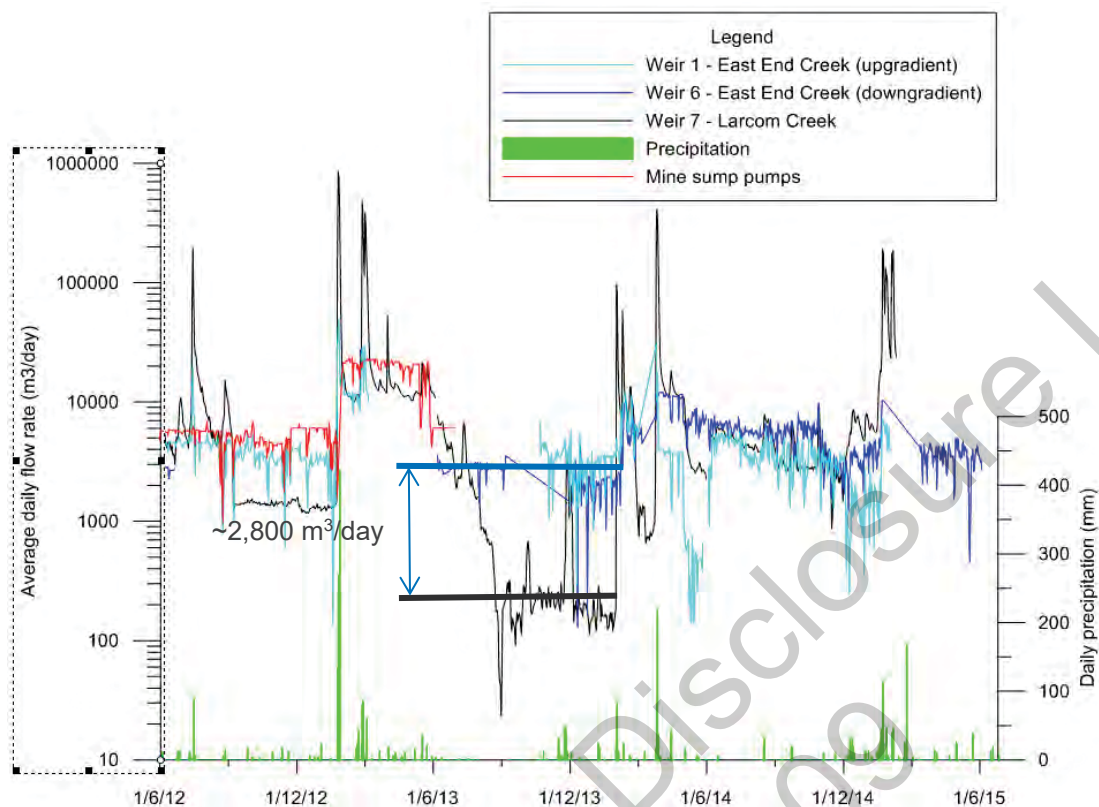


Figure 17 Surface water flow data from July 2012 through to the end of June 2015

4 Conceptual hydrogeological model

4.1 Groundwater flow

Figure 18 and Figure 19 show groundwater level contours from the pre-mining and from the mining period (2017) respectively. Prior to mining at East End, groundwater was mounded around some forested hills to the southwest of the mine. Groundwater flow generally followed topography with groundwater flowing from the hilltops towards the streams. The overall groundwater flow direction was generally towards the major drainage lines of Larcom Creek and Scrub Creek to the south and east, and towards Machine Creek in the area upgradient of the numerical model boundary.

The March 2017 groundwater level contours to the west of the mine, particularly west of the model boundary, are similar to those from 1977, showing there has been minimal impact in this area as a result of mining. However, there have been significant drawdowns near the mine, as expected.

Figure 20 shows drawdowns using the contour plots from 1977 and 2017 (Figure 18 and Figure 19 respectively). It should be noted that in some areas, the drawdowns may be an artefact of missing/additional data points. For example, in the volcanoclastics immediately to the southwest of the mine (outside of the model boundary), there is an area where the water levels appear to have decreased; however, there was a measurement recorded in 1977 (an elevated water level), but no measurement recorded in 2017. Figure 20 shows the drawdown has propagated preferentially along the strike of the bedding (i.e. northwest), with only minor drawdowns to the west and east.

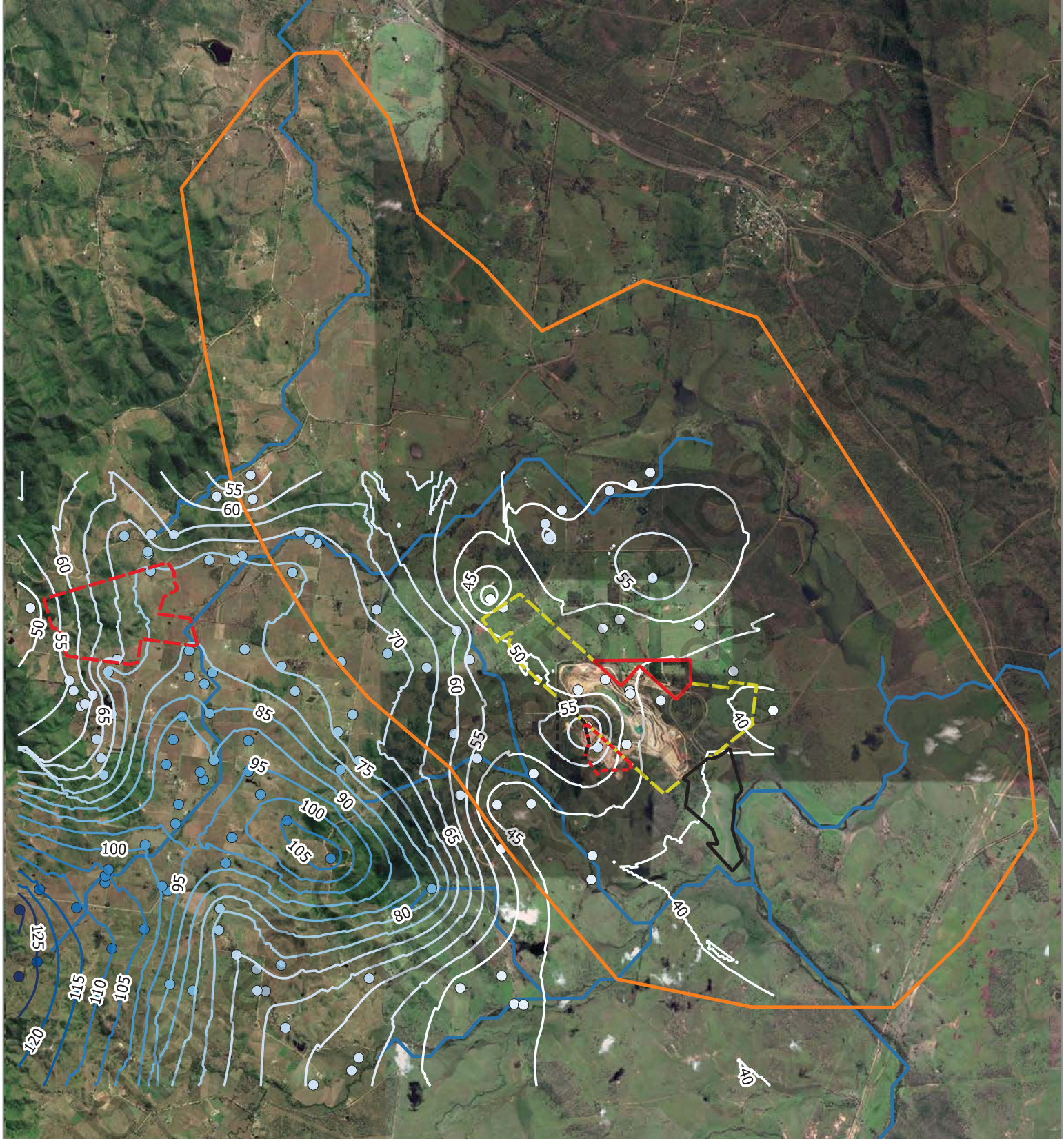
Near bores B78, B23 and B122, the gradient is very steep, indicating there is a barrier restricting the drawdown from extending to the west of B23. DNRM bore reports show that these bores are in the limestone, but the local geology map shows there are volcanoclastics to the west of B78. The exact nature of this flow barrier is unknown; possible flow barriers include:

- Figure 10 shows the dykes mapped in the existing mining pit. Assuming these dykes extend in line with the bedding plane (i.e. to the northwest), they would likely create a flow barrier that would restrict the drawdown from extending to the west; and/or
- Low permeability strata, such as a mudstones or clay layers to the east of B23 and the west of B122. The low permeability strata would likely extend to the northwest and the southeast, as it would likely be associated with bedding, which strikes to the northwest.

Regardless of the structure, it is evident that there is a low permeability, northwest striking feature in this region. The low permeability feature is likely propagated along the bedding plane to the northwest and the southeast. This feature has been incorporated into the numerical model by extending a lens of volcanoclastic rocks northward in this area (see Zone 11 in Section 5.2.4.2). The groundwater level contour plot (Figure 19) and the drawdown plot (Figure 20) do not show this steep gradient to the west and southwest of the existing mining

pit. There are relatively few monitoring bores to this region and the contouring methodology (QGIS) interprets a smooth contour between the data points. However, it is likely that the groundwater gradient is in-fact steep in this region, like it is near B78, B23 and B122.

As mentioned in Section 3.3, there is a significant dyke mapped between Schultz Lagoon and the pit (refer to *Figure 11*). The hydraulic conductivity of this feature is assumed to be low, and it would therefore act as a barrier to groundwater flow. This feature has therefore been included in the numerical model (refer to Section 5.2.4).



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DATUM GDA 1994, PROJECTION MGA ZONE



Base Data: Google Earth image

Legend

- Surface water drainages
- Model Boundary

Mining leases

- ML 3631
- MLA 80156
- ML 3659
- ML 7629
- ML 80002
- ML 80127

Groundwater levels - 1977 (m AHD)

- 40.0 - 50.0
- 50.0 - 60.0
- 60.0 - 70.0
- 70.0 - 80.0
- 80.0 - 90.0
- 90.0 - 100.0
- 100.0 - 110.0
- 110.0 - 120.0
- 120.0 - 130.0

Groundwater levels - 1977 (m AHD)

- 35.3 - 40.0
- 40.0 - 50.0
- 50.0 - 60.0
- 60.0 - 70.0
- 70.0 - 80.0
- 80.0 - 90.0
- 90.0 - 100.0
- 100.0 - 110.0
- 110.0 - 120.0
- 120.0 - 130.0
- 130.0 - 131.9

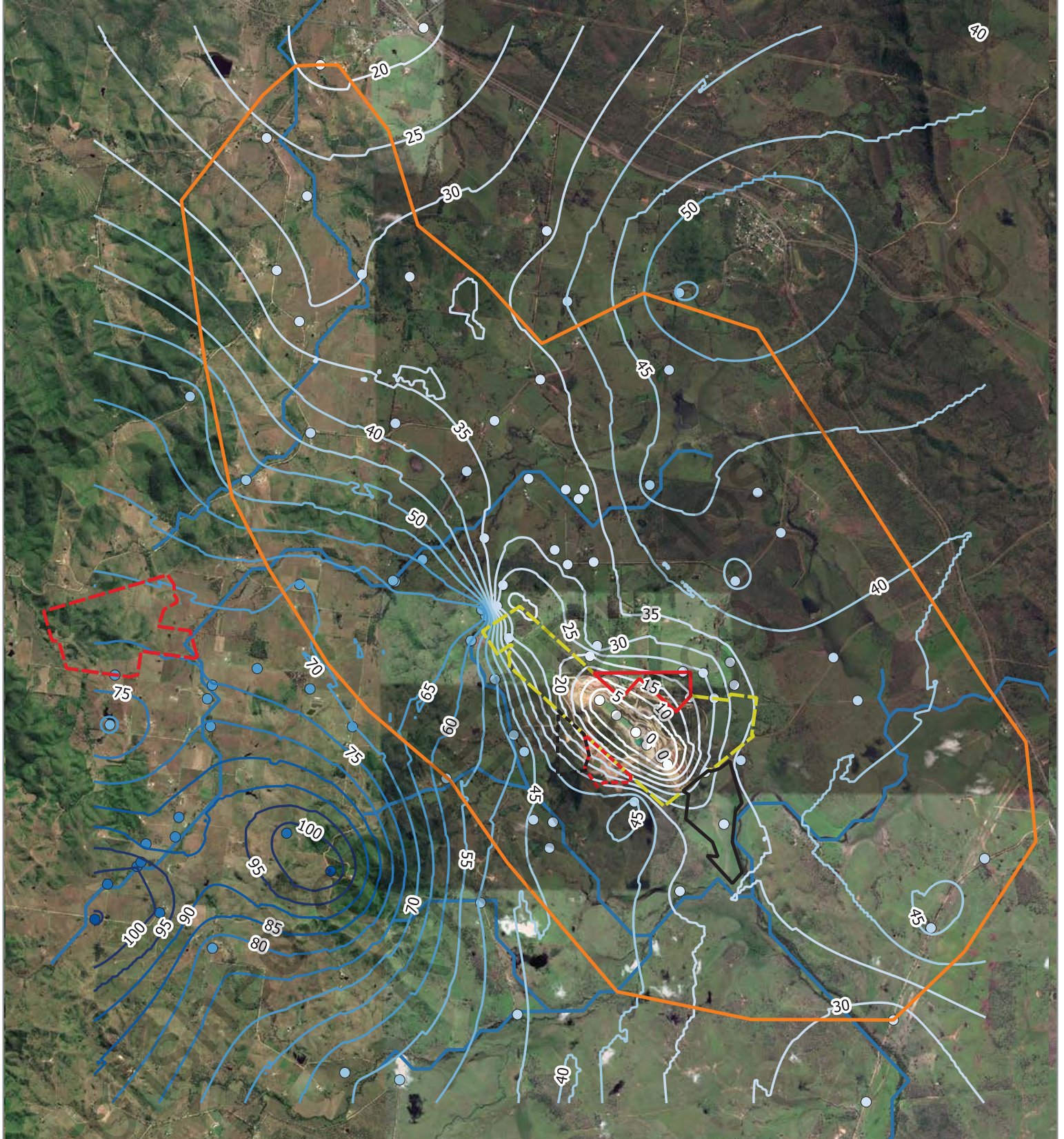
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Groundwater level contours from October 1977, before mining was initiated in 1980.

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Legend

- Surface water drainages
- Model Boundary

Mining Leases

- ML 3631
- MLA 80156
- ML 3659
- ML 7629
- ML 80002
- ML 80127

Groundwater levels - 2017 (m AHD)

- 0 - 12
- 12 - 23
- 23 - 35
- 35 - 47
- 47 - 58
- 58 - 70
- 70 - 82
- 82 - 93
- 93 - 105

Groundwater levels - 2017 (m AHD)

- 0.0 - 12.0
- 12.0 - 23.0
- 23.0 - 35.0
- 35.0 - 47.0
- 47.0 - 58.0
- 58.0 - 70.0
- 70.0 - 82.0
- 82.0 - 93.0
- 93.0 - 105.0
- 105.0 - 105.6

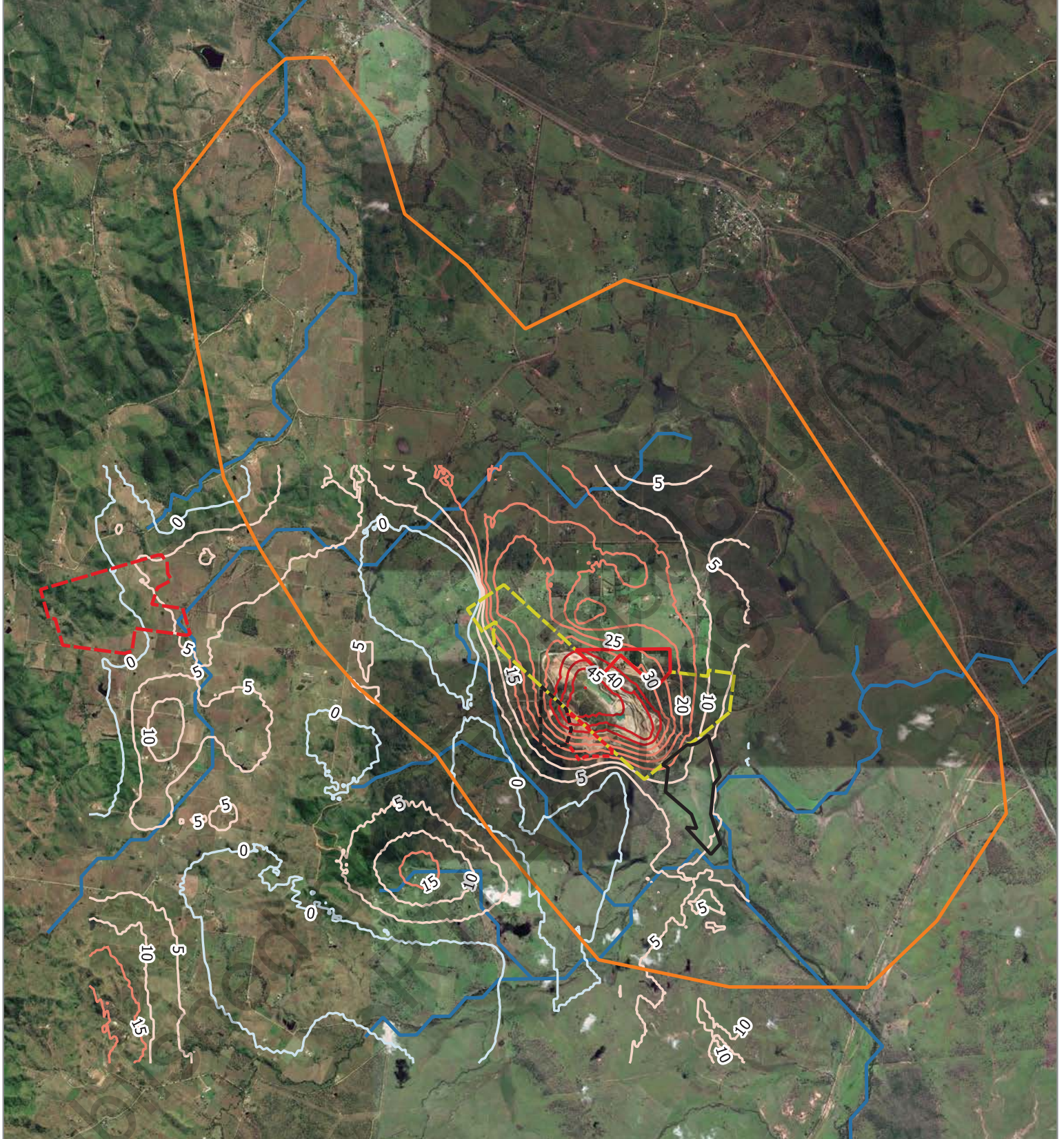
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Cement Australia

Groundwater level contours from March 2017.
The drawdown from the mine is predominately focussed in a north-westerly direction, in-line with the bedding planes

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North



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DATUM GDA 1994, PROJECTION MGA ZONE

0 1 2 3 4 km

RTI 21-078

Legend

- Surface water drainages
- Model Boundary

Mining_leases

- ML 3631
- MLA 80156
- ML 3659
- ML 7629
- ML 80002
- ML 80127

Drawdown (m) between 1977 and 2017

- 0
- 0 - 10
- 10 - 30
- 30 - 50

Cement Australia

Drawdown induced by the mine (i.e. difference between the water level contours in March 2017 and October 1977)

Groundwater Modelling Report

JOB ID: 21594
DRAWN BY:
APPROVED BY:
LAST MODIFIED: January 2018
2

Figure

20

File B

4.2 Aquifers

As detailed in Section 3, the main bedrock aquifers are the limestone and the volcanoclastic sedimentary rocks. The alluvial deposits are generally thin and they are composed mostly of clay; therefore, these systems are not considered to be significant aquifers in this region (refer to Section 3.2).

4.2.1 Limestone aquifers

The limestone is likely to have a low primary porosity and permeability, but dissolution along fractures and bedding planes is likely to increase the permeability in some areas. The limestone contains dykes that predominately strike towards the northwest, with less frequent east-west trending dykes. The limestone beds are sub-vertical and they strike in a north-westerly direction. The alignment of the bedding and the dykes will result in preferential flow to the northwest and southeast. This can be seen in *Figure 19*; the drawdown from the mine extends to the northwest, but there is little drawdown towards the west and east.

4.2.2 Volcanoclastic sedimentary rock aquifers

The volcanoclastics are predominately composed of sandstones, siltstones and conglomerate. The bedding strikes towards the northwest, as it does within the limestone. Sandstones and conglomerates generally have high primary porosities. However, calcium carbonate dissolved from the limestone may readily precipitate into open pores in the volcanoclastics, reducing the primary porosity of the volcanoclastic sedimentary rocks. Furthermore, weathering of silicate minerals may also result in the production of clay minerals, which will reduce the porosity and permeability of the host rock.

The interbedded fine-grained layers would generally restrict flow across the bedding (i.e. to the southwest and northeast), resulting in preferential flow to the northwest and southeast.

4.3 Surface water interactions with groundwater

The alluvium surrounding the surface water drainages is thin and mostly composed of clays. Therefore, the alluvium will generally not contain significant water storages and groundwater fluxes between surface water and the alluvium will be minimal. However, the creeks intersect the bedrock at some locations (see Photographs 1-4), and groundwater is likely to move directly between the bedrock and the streams.

4.3.1 Hut Creek

Groundwater level contours from 1977 (*Figure 18*) and 2017 (*Figure 19*) show that groundwater elevations are similar to the ground surface (*Figure 3*) near Hut Creek. Hut Creek may interact with groundwater in the numerical model area. Hut Creek is likely to be a gaining stream in the upper reaches and a losing stream in the mid to lower reaches.

4.3.2 Machine Creek

In the area upgradient of where the western-model boundary intersects Machine Creek, groundwater levels (see *Figure 18* and *Figure 19*) are similar to the ground surface (see *Figure 3*). This indicates groundwater is likely to recharge into the stream in this area. However, within the modelled area, groundwater levels are well below the ground surface. This suggests the alluvial groundwater is not recharged by water in the limestone within the model

boundary area and they are separated by an unsaturated zone upper layers of the bedrock. Based on this interpretation, alluvial groundwater and surface water in Machine Creek will not be impacted by further dewatering of the bedrock.

4.3.3 Larcom Creek and East End Creek

Borehole logs from the area surrounding Larcom Creek shows that the alluvium is generally composed of clays and other low permeability sediments and the alluvium is generally thin. Therefore, interactions between Larcom Creek and the alluvial groundwater would be minimal. However, Photographs 3 and 4 (Larcom Creek bed) show that the limestone crops out in the streambed, suggesting the stream is likely to interact with the limestone aquifer in this region.

Schultz Lagoon, a wetland created by the East End mining operations, is located immediately south of the mine, adjacent to Larcom Creek (*Figure 2*). The lagoon holds water that has been discharged from the mine via East End Creek. There is no surface water channel connecting Schultz Lagoon to Larcom Creek, although water does diffuse out of the dam. Discharge from East End Creek and Larcom Creek has been estimated at approximately 3,000 m³/day (refer to Section 3.5).

At Monitoring Point C, in Larcom Creek up-gradient of Schultz Lagoon, the electrical conductivity (EC) was 2,770 µS/cm, the EC at Location #4 (Schultz Lagoon discharge site) was 3,300 µS/cm and it was 3,490 µS/cm in Larcom Creek down gradient of Schultz Lagoon (Weir 7; monitoring locations shown on *Figure 3*). *Figure 12* shows that the major ion chemistry of Larcom Creek changes between Monitoring Point C and the downstream sample collected from Weir 7.

The EC, Na, Ca, Mg, Cl and SO₄ concentrations in Larcom Creek downstream of Schultz Lagoon (Weir 7) were higher than they were at upstream of the lagoon (Monitoring Point C). However, the bicarbonate concentration is distinctly lower (bicarbonate concentration was 216 mg/L and 186 mg/L at Monitoring Point C and Weir 7 respectively). This is noteworthy because the bicarbonate concentration at Schultz Lagoon was 129 mg/L, but the other major ions were elevated compared to the upstream sample from Larcom Creek. The downstream water sample from Larcom Creek appears to be a mixture of water from upstream and from Schultz Lagoon. Schultz Lagoon appears to recharge groundwater in the area, and it may also recharge Larcom Creek.

The conceptual model for groundwater surface water interactions in this area is summarised below:

- Upgradient of Schultz Lagoon in both East End Creek and Larcom Creek: surface water discharges into groundwater and some of this groundwater discharges into the existing mine pit;
- Downgradient of Schultz Lagoon in Larcom Creek: water from Schultz Lagoon discharges into groundwater. This surface water discharge reduces drawdown impacts to the south of Larcom Creek; and
- In Larcom Creek, the reach between Schultz Lagoon and the confluence with Scrub Creek is probably both losing and gaining, depending on antecedent rainfalls.

4.3.4 Scrub Creek

Groundwater levels in 1977 (*Figure 18*) were similar to topography near Scrub Creek near the confluence with Larcom Creek. This indicates that groundwater probably interacts with the stream. It is difficult to assess the losing/gaining condition of the stream. However, there is a terrestrial GDE near Scrub Creek to the west of the modelled area (*Figure 7*), which is representative of a region of shallow groundwater. This may be a gaining reach of Scrub Creek; however, the gaining/losing condition of the creek may vary depending on antecedent rainfalls.

4.3.5 Jacobs Creek

The groundwater level contours shown in *Figure 18* and *Figure 19* show that Jacobs Creek is generally a gaining stream.

4.4 Aquifer parameters

Table 8 shows a summary of groundwater information for bores within approximately 1 km of the existing mine pit (DNRM groundwater database). Two bores drilled to 72 m and 87 m were reported as dry and another had a yield of 0.01 L/s; however, yields (when recorded) were generally around 2 L/s. The yield results highlight the variable permeability of the limestone.

Multiple sources were interrogated to assess the aquifer parameters, as detailed below:

1. During the 1960s and 1970s, the Groundwater Advisory Service conducted pumping tests on new production bores in the Bracewell (west of site) and East End region; results are summarised below in *Table 9*.
2. The groundwater database (DNRM) was interrogated to find pumping tests conducted after the 1970s.
 - a. RN 84986 was tested in 1984
 - b. RN 97223, RN 97174 and RN 97585 were tested in 1998 and 1999. These bores are located within 10 m of each other. RN 97174 and RN 97585 have storativity results whilst RN 97223 does not; presumably, RN 97223 was the pumping bore and the other two were observation bores.
3. Kalf and Associates (1997) conducted seven rising head (slug) tests. Two pumping tests were also reported. The transmissivity was reported for testing conducted at two production bores (70 m²/day and 262 m²/day), but the aquifer thickness and hydraulic conductivity was not reported.

The results from these tests are presented in *Table 9*. From this data, it can be surmised that the hydraulic conductivity is generally between 3 m/day and 6 m/day, based on the pumping test data. However, most of these results are from production bores, which are generally installed when high yields are recorded. As such, the pumping test data is probably biased towards higher hydraulic conductivity values. The rising head (slug) test data may be more representative of the bulk conditions. These data show that the hydraulic conductivity ranges over several orders of magnitude, as would be expected in fractured rock and karst aquifers

One specific yield value of 0.00054 was reported for the East End Limestone in the DERM (2011) report. However, this is anonymously low and it is either a storativity / specific storage value for a confined aquifer or an erroneous test value. The groundwater database has two storativity entries; both are from the same pumping test, which was conducted on 16 April 1998. RN 97223 was pumped for 360 minutes at 4 L/s, with the response measured at RN 97174 and RN 97585. The storativity at RN 97174 was recorded as 0.2 and the storativity at RN 97585 was 0.02, an order of magnitude lower. Assuming the pumping test results are correct, these results highlight the variability of the limestone aquifer.

Kalf and Associates (1997) constructed a numerical model of the East End Mine area. The parameters used in the model were based on limited field data. Nonetheless, the parameters used here provide an indicative range for this assessment. They assigned a hydraulic conductivity of 1 to 15 m/day for the limestone and the storativity values (specific yield) ranged between 0.01 and 0.05. The volcanoclastic rocks were assigned a hydraulic conductivity of between 10^{-6} to 0.005 m/day and a storativity of 10^{-4} to 0.005.

There is a dyke mapped between Schultz Lagoon and the pit (refer to *Figure 11*). The hydraulic conductivity of this feature has not been tested, but it is assumed to be low, possibly in the range of 10^{-3} to 10^{-5} m/day. This feature is likely to have a significant impact on groundwater flow paths and it has therefore been incorporated into the model.

As a starting point for the numerical model, a likely range for the bulk hydraulic conductivity of the limestone is around 5 m/day. The hydraulic conductivity is likely vary significantly over small distances, as evident in the results of the slug tests conducted by Kalf and Associates (1997). Groundwater flow will be dominated by the highly permeable fractured zones. Furthermore, there may be dissolution along some of the fractures, resulting in localised regions of high permeability. This estimate is also consistent with hydraulic conductivities used in previous models (e.g. Kalf and Associates, 1997).

In the volcanoclastics, the hydraulic conductivity is likely to have been over-estimated in the pumping test data in *Table 9*, where it is estimated at 2.8 m/day, and under-estimated in the numerical model constructed by Kalf and Associates (1997), where it is estimated at between 10^{-6} to 0.005 m/day. The actual hydraulic conductivity is likely in-between these values. For the purposes of this report, a hydraulic conductivity of between 0.01 and 0.09 has been selected as a starting point for the numerical model calibration process.

Table 8 DNRM bore database summary.

RN	Depth	Top of limestone	Base of limestone	SWL	Aquifer interval	Screen / open	Yield (L/s)	Comments
57123	53	21	53	29.15	21-53	43-53	ND	
97165	70	36	70	46.90	56-70	50-70	3.50	
97158	45	ND	ND	30.00		33-45	ND	
136345	72	12	72	Dry	NA	ND	ND	
57111	37.5	ND	ND	16.98	ND	ND	ND	
136344	84	13	84	37.41	72-79	72-84	2.00	north of mine pit
136691	80	5	80	35.40	72-73	70-76	2.00	adjacent to 136344
97051	45	15	39 (no log	19.30	39-45	ND	2.20	
136768	87	10	87	Dry	NA	ND	ND	
97241	54.9	8.8	52.4	27.40	27.4-ND	ND	0.01	Andesite below 52.4 m
136487	131.67	3.05	131.67	ND	ND	ND	ND	
97164	65	33	65	38.50	38-65	45-65	2.10	
84432	100	20	100	14.00	ND	ND		"lots of water"
97163	41.3	24	41.3	20.50	24-41.3	28-41.3	2.10	
97167	36	12	36	13.50	15-25	15-27	9.50	
97157	30	16	50	ND	ND	ND	ND	
97175	57	NA	NA	15.10	52-57	ND	0.10	Andesite - Tuff
97546	41	13.5	41	10.42	ND	13-41	ND	
97177	31	7	31	2.00	26.5-	ND	5.00	Near Larcom Creek; DHH96-41
97147	21	2	21	5.80	3-21	12-21	ND	Near Larcom Creek; DHH96-8
97148	50	10	50	1.50	13-50	ND	ND	Near Schultz Lagoon; DHH96-6
97121	36	3	27	16.50	27-36	20-36	0.12	Basalt below 27 m
57104	5.99	ND	ND	3.35	ND	ND	1.00	1.5 m diameter well
97223	70	12.5	70	30.00	35-43	ND	2.50	Pumping test: T = 53 (16/4/1998); T =
97174	70	22	62	36.41	43-45	40-45	3.50	Andesite below 62 m. Pumping test: T =
97585	48	ND	ND	37.64	44-48	ND	2.92	Pumping test: T = 165 m2/day; S =
97262	63.5	0	63.5	32.99	ND	ND	ND	
97171	45	33	45	36.10	39-45	ND	ND	
57097	49.4	ND	ND	35.56	ND	44.8-49.4	1.30	

Note: all measurements in m below ground level unless otherwise stated; SWL means standing water level; bores without data were excluded from the summary.

Table 9 Summary of pumping test data

Bore location or data source	Geology	Number of tests	Minimum hydraulic conductivity	Maximum hydraulic conductivity	Median hydraulic conductivity	Average hydraulic conductivity
Bracewell ⁽¹⁾	Limestone	8	0.15	70	3.3	18
Bracewell ⁽¹⁾	Volcaniclastics	4	1.6	12	2.8	4.7
East End ⁽¹⁾	Limestone	4	2.6	82	6.4	24
Groundwater database ^(2a)	Limestone	1	0.1	50	5.2	15
Groundwater database ^(2b)	Limestone	2 (multiple wells; 5 results)	2.3	17	4.1	7.6
Kalf (1997) ⁽³⁾	Limestone	4	0.001	0.06* (or 10-100)*	0.02*	0.03*

Note: All hydraulic conductivity values are in m/day.

⁽¹⁾ Data from 16 production bores that were tested in the 1960s and 1970s by the Groundwater Advisory Service (DERM, 2011)

^(2a) Data from the groundwater database; testing conducted after the 1970s (DNRM)

^(2b) Pumping test information from tests conducted at RN 97223, RN 97174 and RN 97585 in 1998 and 1999 (Groundwater database; DNRM)

⁽³⁾ Falling head tests conducted at DHH96-1, DHH96-4, DHH96-5 and DHH96-6 conducted by Kalf and Associates (1997).

* An additional test was conducted on DHH96-43, producing "almost instantaneous recovery from fractured limestone" (say hydraulic conductivity between 10-100 m/day) ;

4.4.1 Effect of depth

Previous reports discuss how the permeability of the limestone decreases with depth (Groundwork Plus, 2014; Kalf and Associates, 1997), as per *Figure 21*. Pacific Environment assessed the relationship between bore depth and the hydraulic conductivity value using all available data (*Figure 22*). The R^2 value for the available data from bores screened in the limestone was 0.28. As most of the flow occurs through fractures and flow will be minimally impacted by areas with low hydraulic conductivities, we reassessed the data after removing the bores with hydraulic conductivity of less than 1 m/day. After these data were removed, the R^2 value reduced to 0.03.

While it is generally recognised that fractures will generally become less open with depth in some settings, there is no evidence to support this using the available data. In the context of numerical modelling, the addition of multiple layers would have created an extra level of complexity, without reducing the uncertainty. Furthermore, most of the monitoring bores have long screen lengths and it is rare to have nested bore sites (i.e. multiple bores screened at different depths but in the same geographical location). Therefore, it would be difficult to calibrate a multi-layer model. Hence, the numerical model was constructed in 2D, with the thickness of the model representing average characteristics over the entire depth.

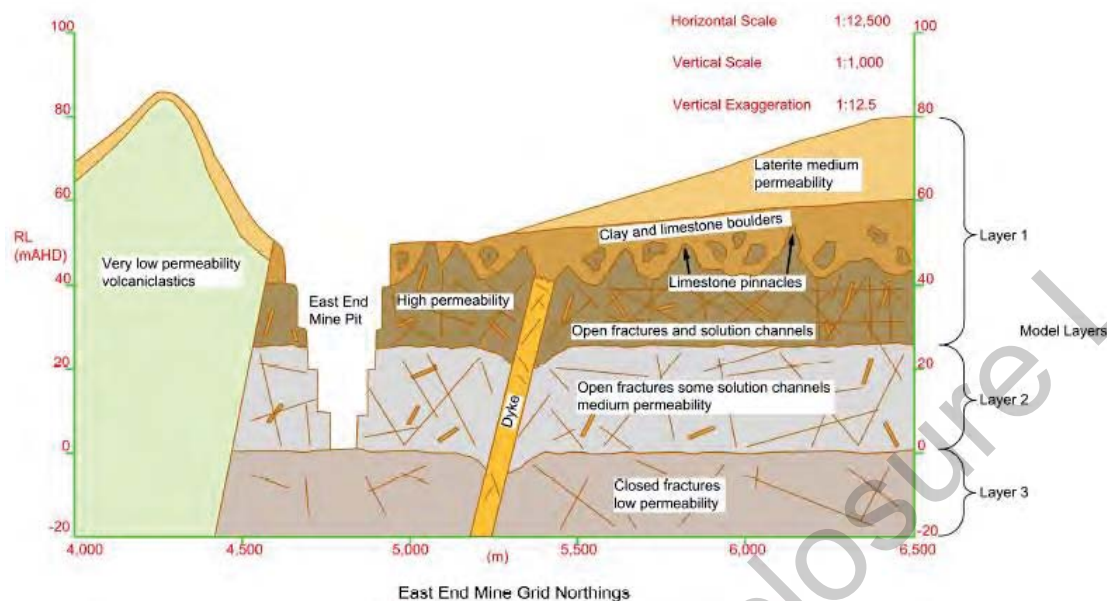


Figure 21 Schematic section through the East End aquifer (Groundwork Plus 2014, modified from Kalf and Associates, 1997)

Table 10 Summary of hydraulic conductivity data from Kalf and Associates (1997), DERM (2011) and the DNRM groundwater database.

Bore location	Geology	Hydraulic conductivity (m/day)	Bore depth (m)
Bracewell ⁽²⁾	Limestone	70	18.3
Bracewell ⁽²⁾	Limestone	53.6	18.3
Bracewell ⁽²⁾	Limestone	0.146	30.5
Bracewell ⁽²⁾	Limestone	3.3	24.69
Bracewell ⁽²⁾	Limestone	1.43	15.2
Bracewell ⁽²⁾	Limestone	3.35	24.69
Bracewell ⁽²⁾	Limestone	5.9	30.5
Bracewell ⁽²⁾	Limestone	2.29	25.3
Bracewell ⁽²⁾	Volcaniclastics	1.55	20.7
Bracewell ⁽²⁾	Volcaniclastics	11.6	17.6
Bracewell ⁽²⁾	Volcaniclastics	2.87	22.9
Bracewell ⁽²⁾	Volcaniclastics	2.66	24.4
East End ⁽²⁾	Limestone	8.37	???
East End ⁽²⁾	Limestone	2.59	39.01
East End ⁽²⁾	Limestone	4.35	51.4
East End ⁽²⁾	Limestone	82.1	36.6
88307 ⁽³⁾	Limestone	0.1	18.9
97542 ⁽³⁾	Limestone	1.7	48.5
97051 ⁽³⁾	Limestone	8.8	45
84986 ⁽³⁾	Limestone	49.5	9.9
88299 ⁽³⁾	No log	3.6	?
DHH96-1 ⁽¹⁾	Limestone	0.01	50
DHH96-2 ⁽¹⁾	Unconsolidated	0.001	20
DHH96-4 ⁽¹⁾	Limestone	0.06	60
DHH96-5 ⁽¹⁾	Limestone	0.03	50
DHH96-6 ⁽¹⁾	Limestone	0.001	59.3
DHH96-13 ⁽¹⁾	mixed	0.05	50
DHH96-43 ⁽¹⁾	Limestone	50*	47

⁽¹⁾ Information from Kalf and Associates (1997)

⁽²⁾ Information from DERM (2011)

⁽³⁾ Information from DNRM groundwater database – note; the hydraulic conductivity for the DNRM dataset is derived from the transmissivity divided by the screen length

* The test at DHH96-43 produced an “almost instantaneous recovery from fractured limestone”. This has been estimated at 50 m/day.

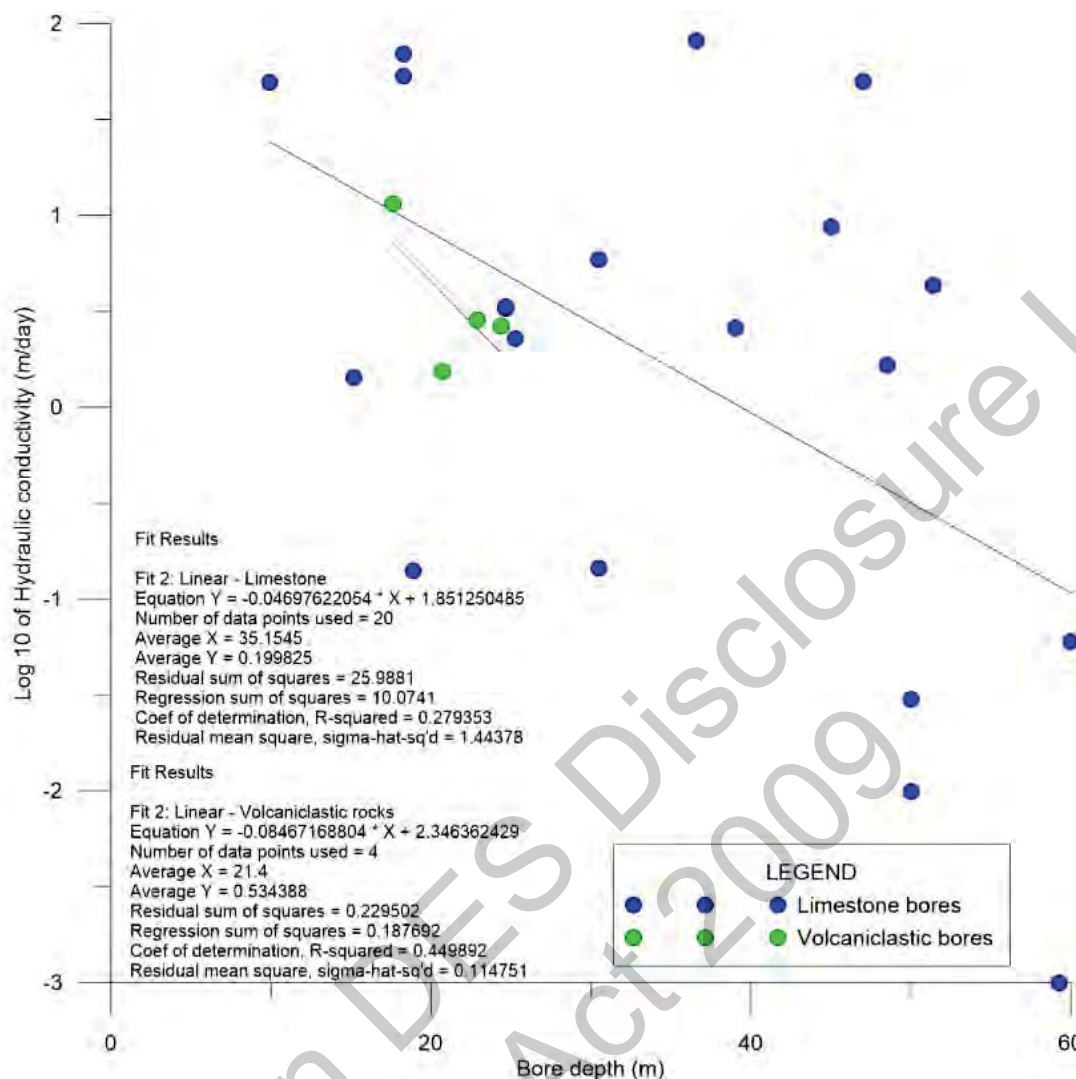


Figure 22 Hydraulic conductivity values for the limestone and volcaniclastic rock aquifers

4.4.2 Parameter anisotropy

Bedding planes and dykes are orientated in the north-westerly/south-easterly direction and the groundwater drawdown contours show that these features focus groundwater flows along these orientations. Initially, Pacific Environment planned on using an anisotropic modelling approach to simulate this effect. However, this methodology produced limitations that could not be resolved within the model and this approach was therefore abandoned and a traditional, isotropic modelling approach was utilised instead.

The anisotropy of the model was largely accounted for by assigning low hydraulic conductivities to the volcaniclastic rocks to the east and west of the existing pit. This allowed the model to replicate groundwater level observations at the site. More detail on parameterisation is provided in Section 5.2.4.

4.5 Recharge

For the purposes of this report, recharge will be defined as the quantity of water that reaches the water table, thereby adding to the total volume held in storage (de Vries and Simmers 2002). According to this definition, recharge is inclusive of water that is subsequently lost via groundwater discharge, pumping and plant use during the period of measurement.

Under natural conditions, groundwater pressure represents a balance between recharge and discharge in the groundwater system. An aquifer typically receives recharge in areas where the aquifer is exposed at the ground surface. In these areas, recharge mainly occurs during periods of high-intensity rainfall and associated high stream flow.

Bores closer to recharge areas typically show more immediate and clearer responses to variations in rainfall. Bores farther away from recharge areas typically show weaker responses, but water pressures can be seen to rise or fall in response to longer periods of above or below-average recharge.

There are two sub-sections presented:

- Groundwater response to rainfall (section 4.5.1): this section gives a qualitative overview of how the different bores respond to rainfall events.
- Chloride Mass Balance (section 4.5.2): quantitative assessment of the recharge amounts.

4.5.1 Groundwater response to rainfall

In order to assess the relationship between rainfall and recharge, it is necessary to compare rainfall data with time-series water level data. In this report, we have utilised the cumulative deviation from mean monthly rainfall (CDMMR) method to assess this relationship. When periods of higher than average rainfall are recorded, the CDMMR curve will rise, and during periods of lower than average rainfall, the CDMMR curve will decrease.

Appendix B shows hydrograph plots and the CDMMR plots for selected bores within the groundwater monitoring bore network. These bores were selected to encompass a geographical spread across the site to provide a snapshot of the groundwater level responses in the area.

There was an above average period of rainfall between 2010 and 2014 followed by a period of average rainfall between 2014 and 2017. Groundwater levels generally increased by around 4-10 m during the above average period of rainfall. Groundwater levels generally decreased by around 3-8 m during the period of average rainfall between 2014 and 2017. This rainfall response shows that groundwater is recharged locally, probably via diffuse infiltration through the unsaturated zone (diffuse recharge).

The creek beds provide another potential groundwater recharge pathway. Photographs 1, 3 and 4 (Appendix A) show that the bedrock commonly outcrops in the streambeds. This would provide a connection between the stream and the bedrock aquifers. Section 4.3 includes an assessment of the likely gaining and losing reaches of the streams in the area of interest.

Significant laterite soil layers are mapped to the east and northwest of MLA 80156 (refer to Figure 9). Laterites are rich in aluminium and iron and they are generally a rusty-red colour,

due to the high iron content. They are typically composed of cavities and pores and they generally form well-drained soils (Winterkorn et al., 1951). Therefore, they are not expected to impede groundwater recharge.

4.5.2 Chloride mass balance - recharge assessment

The chloride mass balance method has been widely applied in recharge (R) estimation studies in a variety of hydrogeological settings to estimate the long-term average recharge. The chloride mass balance method is applicable under the following circumstances: groundwater must be recharged exclusively by diffuse infiltration of rainfall, there is no surface runoff to or from the recharge area, Cl in groundwater is derived from precipitation and dry deposition (i.e. there are no other sources of Cl, such as halite, in the study area), and the groundwater system is in steady state. The method assumes that the Cl concentration of groundwater (GW_{Cl}) is related to the initial volume of precipitation (P) and the concentration (C_{P+D}) of Cl in precipitation and dry deposition, as is described by the following equation (Wood and Sanford 1995):

Equation 1
$$R = PC_{P+D}/GW_{Cl}$$

The monitoring bores selected for assessment of recharge were those located distal to the surface water drainage lines, in accordance with the assumptions of the method. The mean precipitation (P in Equation 1) was obtained from (BoM, 2017a), the chloride concentration of the rainfall (C_{P+D} in Equation 1) was estimated by dividing the mean precipitation by the mean Chloride deposition rate for the area (CSIRO, 2017). The results of this assessment are presented in *Table 11*. These estimates provide a guide only, as overland flow processes may have impacted on the results. These results show recharge rates are high in the Machine Creek sub-catchment to the west of the model area.

Table 11 Summary of recharge assessment using the chloride mass balance technique

Bores in Limestone	Chloride concentration (mg/L)	Recharge (mm)	Recharge (% rainfall)	Comments
O10	30	466.7	53%	west of model area - Machine Creek sub-catchment – probably an overestimate
O11	283	49.5	6%	west of model area - Machine Creek sub-catchment
O12	74	189.2	21%	west of model area - Machine Creek sub-catchment – probably an overestimate
RC11-03	604	23.2	3%	Machine Creek sub-catchment
RC11-04	1,560	9	1%	Machine Creek sub-catchment Near drainage line – may be impacted by overland flow
DHH98-1	488	28.7	3%	Machine Creek sub-catchment Close to – may be impacted by overland flow
Minimum	30	9.0	1% (3%)	Value in brackets – excludes results from bores that appear unsuitable for analysis (i.e. in red text above)
Median	389	39.1	4% (4%)	
Maximum	1,560	466.7	53% (6%)	
Bores in Volcaniclastic rocks	Chloride concentration (mg/L)	Recharge (mm)	Recharge (% rainfall)	Comments
RC11-07	1480	9.5	1%	Hut Creek sub-catchment
RC11-02	694	20.2	2%	Hut Creek sub-catchment
RC11-17	3350	4.2	0.5%	On boundary between the Hut Creek sub-catchment and the Machine Creek sub-catchment
RC11-15	2420	5.8	1%	Southeast of Larcom Creek
Minimum	694	4.2	0.5%	
Median	1950	7.6	1%	
Maximum	3350	20.2	2%	

5 Prediction of groundwater impacts

5.1 Methods and techniques for predicting groundwater impact

There are established mathematical relationships that can be used to predict water pressure changes in simple homogeneous formations in response to relatively uniform and localised water extraction. Techniques based on these relationships are referred to as analytical techniques. However, in situations where there are spatial variations in hydraulic properties, complex interactions with surrounding formations, and spatially distributed and variable groundwater extraction—as is the case in the East End Mine surroundings—analytical techniques are of limited use. In these instances, a numerical groundwater flow model is a more appropriate tool for predicting water pressure changes.

A groundwater flow model is a computer-based mathematical representation of a groundwater system using the laws of physics. A modelling code is used to construct a groundwater flow model. A model is generally developed for all or part of a groundwater system, with the modelled area referred to as the model domain. It is divided into a number of building blocks to represent the ground surface and the geologic formations present within the area.

There are three basic steps involved in constructing a groundwater flow model:

- **Conceptualisation.** This involves using available information to translate a complex three dimensional geological system, and knowledge of groundwater flow processes in that system, into a simple idealised representation. Numerous assumptions are involved in this process (refer to Section 4).
- **Model construction.** The simplified conceptual representation of the system is then converted into mathematical representation of the physical system and flow processes, which is the groundwater flow model. A model is a series of large computer files representing hydraulic parameters, boundary conditions, groundwater extraction, groundwater recharge, elevation of geologic layers, model grid, and other elements (Refer to Section 5.2).
- **Model calibration.** Once constructed, a model is then calibrated based on actual observed groundwater pressures, extraction rates and other available information including expert knowledge. This calibration process typically involves adjusting the hydraulic parameters of each model layer until the best possible match between predicted and observed data is achieved. Calibration of complex models is carried out using specialised computer programs (refer to Section 5.3).

Once constructed and calibrated, a model can then be used to predict changes in water pressure or flow in response to various development scenarios. Any prediction of the future will be subject to a degree of uncertainty and predictions made using a numerical model are no exception. Some uncertainties are associated with model construction; other uncertainties

can arise from the assumptions contained in the development scenario used to make predictions.

5.2 Regional groundwater flow model

5.2.1 Modelling Code

The modelling code used for groundwater modelling is Spring (v4.18, delta-h). Spring is a finite element groundwater modelling software. Spring's main modelling core SITRA is based on the USGS modelling code SUTRA, a well-known code for groundwater modelling. Spring is able to solve the groundwater equation for unsaturated and saturated conditions, and for steady state as well as transient conditions.

The finite elements method makes it possible to model features of interest (in this case the mine and the surface water bodies) at a higher resolution than the general grid, using a flexible combination of triangles and quadrangles.

5.2.2 Conceptual framework

The conceptual groundwater model was described in Section 4 in detail.

5.2.3 Model construction

5.2.3.1 Model boundaries

The model boundary extends 17 km from north to south and 7 km from west to east, as shown in *Figure 2*. The model boundary generally follows the high points in the topography (refer to *Figure 23*). As such, all boundaries along those high points are no-flow boundaries (water divides). To illustrate this concept, imagine a water divide that runs north-south. A raindrop that falls onto the eastern side of the divide will drain towards the east and a raindrop that falls onto the western side will drain towards the west. Hence, no flow is happening across that divide and the divide can be described as a no flow boundary.

An exception to this concept is the western boundary, which is a recharge boundary. Groundwater contour maps from pre-mining and post-mining (*Figure 18* and *Figure 19* respectively) show that groundwater mounds in the area surrounding the western boundary. This water is either flowing in from the Bracewell area limestone aquifer or is recharged by Machine Creek. Also, the groundwater recharge assessment showed that this area has the highest recharge rates (refer to Section 4.5.2). Therefore, this boundary has been assigned as a recharge/constant head boundary. The elevation of the groundwater head along the western boundary was set at 72 m AHD (steady state).

To the south (Larcom Creek, bore RC11-13,) a constant head boundary has been assigned to reflect the regional drainage towards the Calliope catchment and attributed aquifer. The same method has been applied to the north, where groundwater flows towards the Fitzroy River catchment (Hut Creek, bore RC11-10).

The topographic surface forms the "top boundary" and the lower boundary is a no-flow boundary.

5.2.3.2 Model grid

A numerical model represents a simplified representation of the reality. In an ideal case, the model would calculate the groundwater levels at each point in space and time. However, numerical modelling is limited by available computer resources. Hence, the resolution in space and time will be chosen depending on the size of the modelled site and the required detailing of certain features. The “real world” is broken up into elements and nodes. For example, a triangle element will be made up of three nodes. For each node, the groundwater level will be calculated considering the connecting nodes and the element properties between them.

The model grid was set up with increasing grid size from 40 m around the mine and Larcom Creek to 150 m in the greater region. The grid has been also refined around groundwater extraction wells to better simulate the cone of depression.

The overall grid contained ~8,200 nodes and ~9,400 elements.

The modelling has been undertaken in 2D (i.e. a single model layer). Even though some sources mention that the permeability of the rock formations is decreasing with depth (e.g. Kalf and Associates, 1997), this study could not find data that supported this concept (refer to Section 4.4.1). Another reason not to build a multi-layer (3D) model was the construction of the monitoring bores. Most of the bores are screened through a larger interval, making it impossible to assign each bore to a certain depth. The monitoring data is “2D” (covering the entire length), hence the model should reflect this.

Hence, this numerical model is constructed in 2D, which means that the permeability is constant over the entire model depth.

5.2.3.3 Timeframe

The model was initially run as a pre-mining steady state model to establish the water levels before mining started. Then the model was used to calculate the groundwater levels over time.

The modelled timeframe extends from 1980 to 2017 for history matching and further into the future (2045) for the predictive part of the model. The model is solving the groundwater equation with a daily resolution, however some of the transient input data has a quarterly (3-monthly) resolution (refer to Section 5.2.5.1).

5.2.4 Aquifer characteristics

5.2.4.1 Aquifer thickness

The vertical extent of the limestone and volcanoclastics has been confirmed to be 100 m deep. For example, 16 of the 21 RC11-series bores were drilled to a depth of 100 m. These bores were screened where the aquifer was intercepted and nine of the bores were screened at a depth of below 60 m, showing that it was common to encounter water-bearing units at these depths. It is suspected that the formations continue further down vertically. For the purpose of modelling, the aquifer base was derived by subtracting the thickness of 100 m from the topography. This results in an even thickness of 100 m.

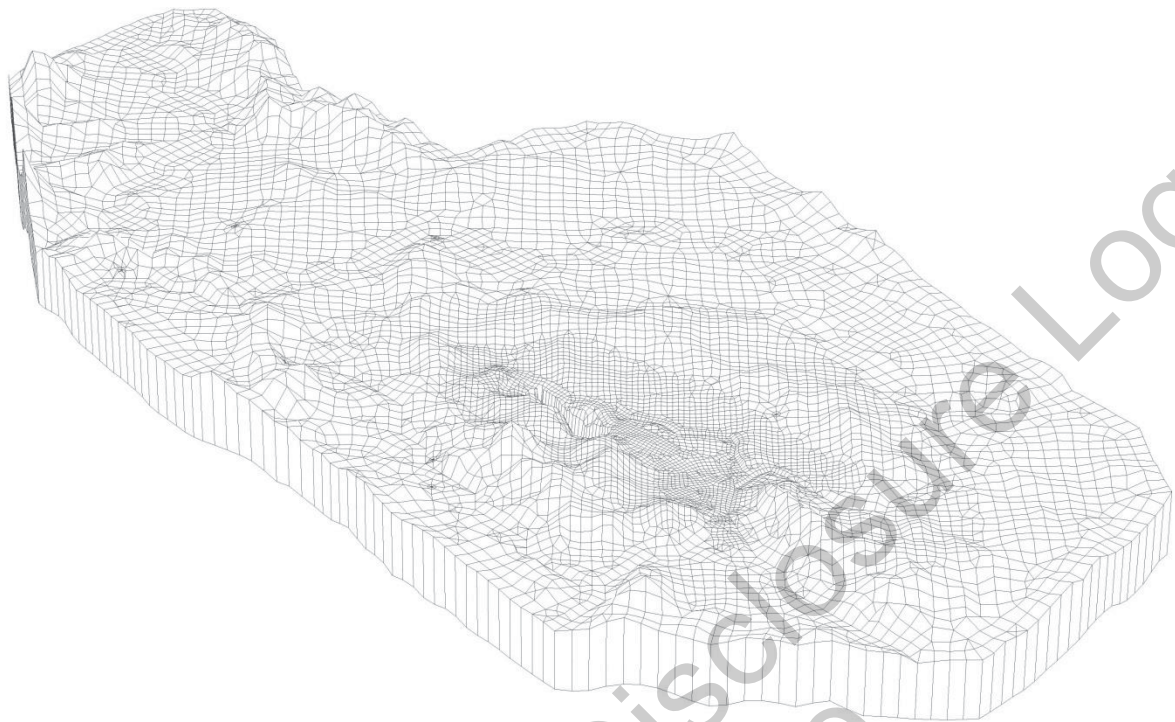


Figure 23 Topographic surface in the model

5.2.4.2 Hydraulic conductivity

The local and regional geology information was used to separate the limestone and the volcanics for modelling purposes. The local geology map was provided by Groundwork Plus, who work closely with Cement Australia to map the local geology. A mapped dyke was included as a succinct feature in the model. The limestones were further divided into six succinct zones and the volcanics were divided into seven sub-zones, as shown in Figure 24.

This enables the modelling software to assign different values hydraulic conductivity values to each zone during history matching process. Generally, the limestone hydraulic conductivities are higher than the ones in the volcanics.

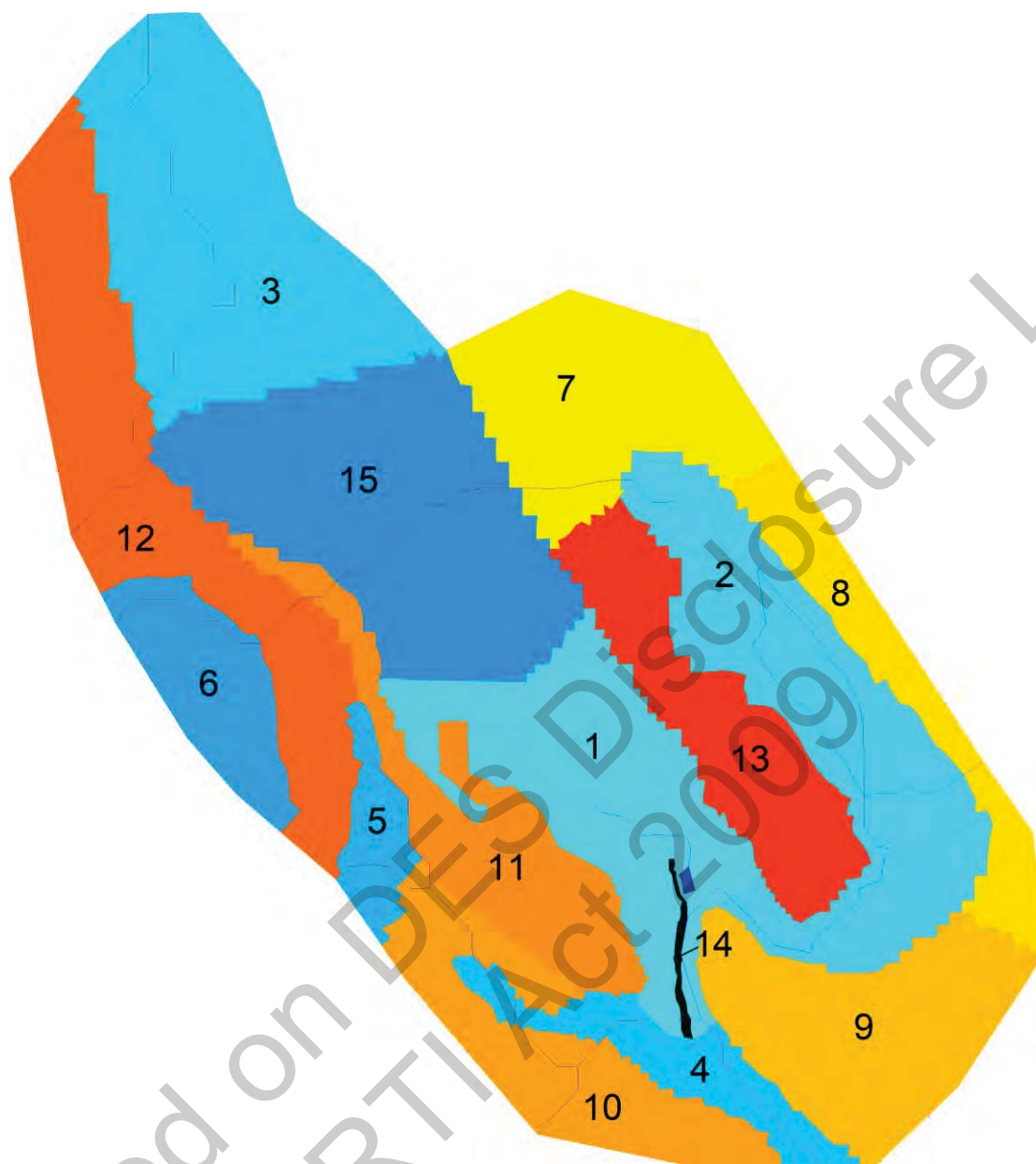


Figure 24 Zones of hydraulic conductivities (blues: limestone, orange/red: Volcaniclastics, dyke: black)

Table 12 Hydraulic conductivities used in the model

Zone	Formation	K pre-calibration m/day	K calibrated m/day
1	Limestone East End	5	4.0
2	Limestone East	5	3.5
3	Limestone North	5	4.7
4	Limestone South	5	3.2
5	Limestone West	5	3.1
6	Limestone Bracewell	5	4.2
15	Limestone Machine Ck	5	2.7
7	Volcaniclastics North East	0.09	0.07
8	Volcaniclastics East	0.09	0.07
9	Volcaniclastics South East	0.09	0.02
10	Volcaniclastics South West	0.09	0.06
11	Volcaniclastics East End	0.01	0.02
12	Volcaniclastics North West	0.09	0.14
13	Volcaniclastics Island	0.09	0.03
14	Mapped Dyke	0.0009	0.0007

5.2.4.3 Storage coefficient / porosity

The storage coefficient was estimated in previous studies to be around 1-2%. Larger fractures can have a porosity up to 20% (refer to Section 4.4). The storage coefficient was adjusted during history matching and an overall value of 1% performed best, i.e. no distinction between limestones and volcaniclastic rocks.

5.2.5 Groundwater sources and sinks

5.2.5.1 Recharge

Recharge estimates for the different rock types were calculated in Section 4.5 using the chloride mass balance method. The model used the median recharge values from Section 4.5 for the limestone (4% of rainfall) and the volcaniclastic rocks (1% of rainfall) as a basis for the recharge rates used in the predictive modelling run (2017 onwards, average conditions).

For the transient validation run, the observed rainfall was resampled into quarterly time steps (average of the three months) for the period from 1980 to 2017. Under the assumption that smaller rainfall events are not likely to contribute to the groundwater recharge, a cut-off value of 200 mm / quarter was introduced. Table 13 lists the recharge calculations for both limestone and volcaniclastic geologies in the model. If the quarterly rainfall was less than the cut-off value, the recharge was set to zero. This reflects the fact that for small rainfall events, no recharge is reaching the groundwater. If the rainfall exceeded the cut-off value, a factor slightly larger than established in Section 4.5 was applied. This reflects the fact that in wet conditions, the recharge is higher than average.

Table 13 Recharge input for transient calculations

	Rainfall < 200 mm/quarter	Rainfall > 200 mm/quarter
Limestone	GW recharge = 0	GW recharge = Rainfall * 0.058
Volcaliclastics	GW recharge = 0	GW recharge = Rainfall * 0.015

5.2.5.2 Surface water

The groundwater model considers the main surface water bodies in the model domain. Refer to Table 15 for a list of the creeks and their respective properties. Surface water can act as a groundwater source (losing streams) or sink (gaining streams).

The modelling program calculates the amount of water that either infiltrates into or exfiltrates out of the groundwater, depending on the gaining/losing condition of the stream reach, as follows:

- **Gaining stream:** the groundwater level is higher than the surface water level. In this case, the volume of water exfiltrating into the surface water is calculated with the leakage factor and the difference between groundwater and surface water level.
- **Losing stream, connected:** the groundwater level is lower than the surface water level, and groundwater and surface water are connected through a saturated porous medium. In this case, the volume of water infiltrating into the groundwater is calculated with the leakage factor and the difference between groundwater and surface water level.
- **Losing stream, disconnected:** the groundwater level is much lower than the surface water level, and groundwater and surface water are connected through an unsaturated porous medium. In this case, the volume of water infiltrating into the groundwater is calculated with the leakage factor and the difference between river bed elevation and surface water level (driving head is the depth of water in the river).

The surface water structures are implemented as line structures with a [leakage boundary](#). Each node along the creek line gets assigned a:

- Surface water level (steady state, estimated from topography).
- Leakage coefficient, based on creek width, creek bed conductance and creek bed thickness.

Unlike the creeks that are line structures, Schultz Lagoon has an area and is hence considered with a grouping of elements instead of a lines connecting nodes. Each element gets assigned a surface water level and a leakage coefficient, based on the lagoon's bed conductance and thickness.

Even though there is some surface water monitoring at the weir locations, the surface water levels are unknown. In this model, they were estimated from the topography (assumption that the creek bed surface is 2m below the natural surface in the digital elevation model). It was then assumed that all surface waters had a fix water level of 50 cm (i.e. the water level was 50 cm higher than the topographic surface). This steady state approach probably

underestimates the recharge during flood events, however it is suited to predictive modelling (average values).

All surface waters were assigned the same water level of 50 cm. The model calibration will adjust the leakage coefficient to ensure that the larger creeks will have increased volumes compared to smaller creeks.

5.2.5.3 Groundwater extractions

There are 92 registered extraction bores in the modelled area. Groundwater abstraction rates are unknown and have been estimated for the model using the following relationship:

- The farmland is mostly “blue gum / river red gum flats”, based on the Fitzroy grazing land management land type descriptions map (Queensland Government, 2017). The carrying capacity for blue gum land-type in the Gladstone/Bororen Coastal Lowlands is 1 adult beast equivalent (AE) per 2 hectares for breeding and growing and 1 AE per 1.6 hectares for fattening (CSCA, 1992). A value of 1 AE per 1.8 hectares was used in this study.
- Average daily consumption for cattle is 45 L/day;
- Average domestic water consumption is 340 L/person. We assumed two people per property;

The total groundwater take for each property was calculated using the above-mentioned assumptions. The groundwater take for each property was then divided equally between the existing registered bores on that property to obtain the daily groundwater abstraction rates at each registered bore. The resulting extractions estimates range from 1 to 51 m³/day.

5.2.5.4 Constant head boundaries

As discussed in Section 5.2.3.1, there are three constant head boundaries. These boundaries simulate the regional groundwater flow and were assigned at locations where observations were available. Although these observations have been collected over the years, a steady state value (at the 25th percentile of the observations) has been assigned. The 25th percentile leans towards drier times and this approach ensures that the model boundaries are a discharge point in the north and south.

The future variation of those bores is not known and hence a fixed value is better suited for the predictive modelling.

- RC11-10 north, 19 mAHD
- RC11-13 south, 27 mAHD
- Bracewell inflow, close to B21 72 mAHD

5.2.5.5 Mine dewatering

The mine is represented in the model as a [transient leakage boundary](#). The mine sump water level was implemented based on information provided by Groundworks Plus.

Similar to the [gaining stream](#), the groundwater level is higher than the mine sump level. In this case, the volume of water exfiltrating into the mine sump is calculated with the leakage factor and the difference between groundwater and mine sump water level. The mine sump level

was estimated based upon information provided by Groundwork Plus. The mine sump levels of the existing and proposed pits are presented in Figure 25.

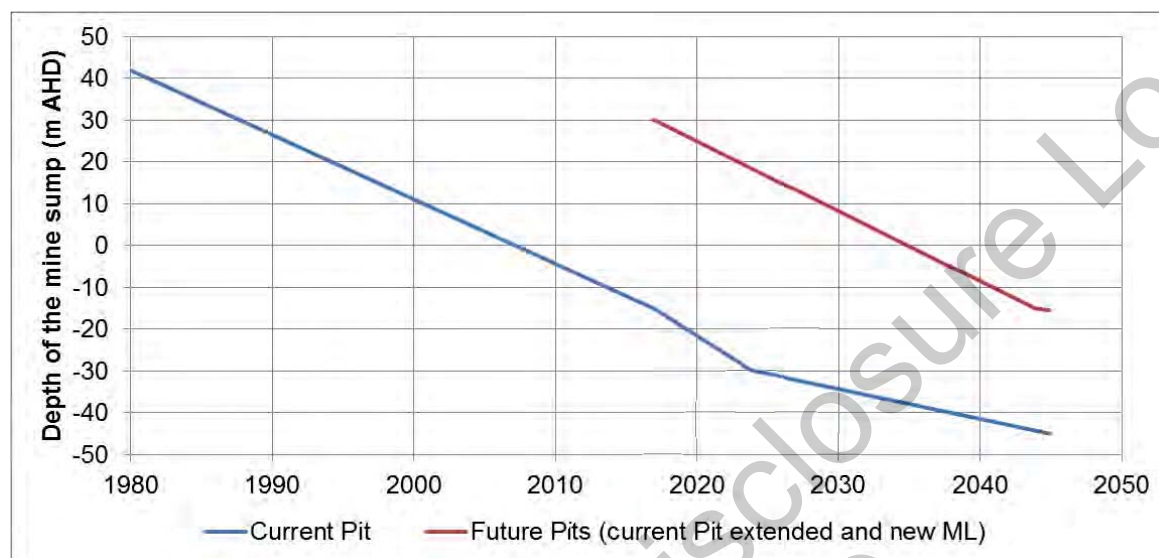


Figure 25 Observed and predicted pit water levels (provided by Groundworks Plus)

5.3 Model calibration and validation

5.3.1 Steady state

An initial attempt to calibrate the model with the pre-mining conditions (1979 data) failed due to the distribution of the available data. There were no data available to the north or east of the model, which made it impossible to calibrate the hydraulic conductivities in those areas. In areas with no observations, any model is insensitive to parameter changes. Therefore, when the model was calibrated using the data from 1979, several (and sometimes very different) hydraulic conductivities could yield the same results.

The model was hence calibrated with a quasi-steady state approach for the 2017 observed groundwater heads. The spatial distribution of the available water level data is better than in 1979. However, due to the mining impacts already occurring, this water level is not a real steady state, as the groundwater system was constantly changing due to the progression of the pit.

It was then assumed that the observed water levels in 2017 reflect a “quasi-steady state” with the mining conditions of the year 2000 (the mining sump was at 0 mAHD in 2000). This quasi-steady state assumes that the mining conditions of the year 2000 were prevalent for 17 years (i.e. the pit remained at 0 mAHD for 17 years), by when a quasi-steady state could be expected. This contrasts with the actual conditions, as the pit progressed to -15 mAHD. This pit-progression would significantly impact on groundwater levels near the pit, but the impacts to water levels near the perimeter of the model would be negligible.

The hydraulic conductivity values for the 15 zones and the 11 creek leakage factors were automatically calibrated using the automated calibration tool in the modelling software

(inverse method). The results for the hydraulic conductivities best estimates are presented in *Table 12*.

The differences between observed and calculated groundwater levels are plotted in *Figure 26*. Of the 59 bores, 45 fit with ± 5 m, 10 are underestimated (5 m and more below the 45 degree line) and 5 are overestimated (5 m and more above the 45 degree line). The outliers can be explained with local features and model simplifications. They were given less weight in the calibration process to reflect those uncertainties around the observations.

The resulting weighted root mean square error is 4.31 m and the scaled RMS is 8%. For the level of sophistication (zonal approach, steady state calibration), this SRMS was deemed acceptable.

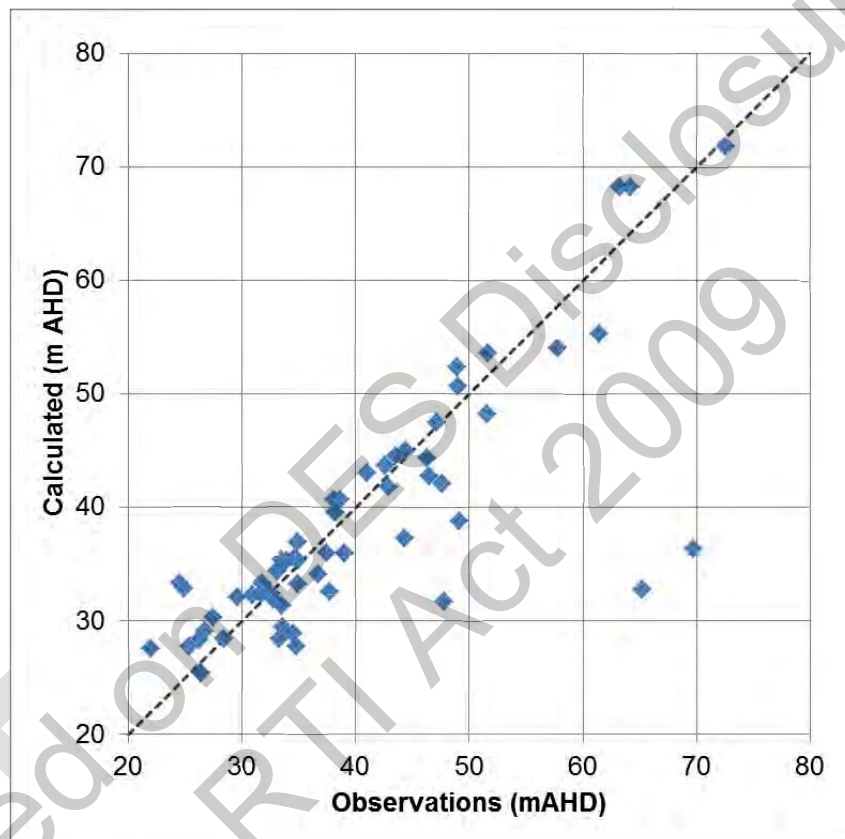


Figure 26 steady state calibration results

5.3.2 Validation (1980-2017)

Appendix D shows the full transient validation results for all available monitoring bores. These are discussed in detail in Appendix E. General observations include:

- There are many monitoring bores within the model area, which have been used to calibrate parameters.
- The steady state boundary condition for constant heads and creek water levels are dampening some of the climatic effects
- The averaging of the recharge into quarterly inputs also dampens large events (distribution from a two day event to a 90 day period).

- The zonal approach is not always able to match bores that are located close to each other and have different observed levels. This variation is caused by local effects, such as geological features, the underlying geology (which is represented of interpreted maps). It is not the aim of this study to reflect these local effects.
- There are a few bores with large groundwater extraction rates, which may or may not be accurate estimates. Generally, the bores with extractions are not well suited for calibration / validation purposes. However, as the real extraction is unknown, these bores still have been included.

5.4 Predictive model runs

Table 14 lists the three main scenarios calculated.

Table 14 Modelling scenarios

Scenario 1 No Mining	Scenario 2 Mine continues operations as currently approved (ML 3631)	Scenario 3 Mine extension approved (ML 3631 and MLA 80156)
<p>This scenario is run to show how the groundwater system would change over time with no mining present.</p> <p>This is a hypothetical scenario and will be used to calculate the impacts (i.e. drawdowns).</p> <p>Refer to Figure 29 (teal line)</p>	<p>This model run assumes that the current mine as approved operates until 2045 under the development scenario provided (Figure 25). The pit outline as per 2017 was advanced as the blue line depicts. The available space to the north and south was advanced as the red line depicts.</p> <p>This scenario represents the future impacts (i.e. zone of influence) that are estimated to occur based on the already approved mining activities.</p> <p>Refer to Figure 29 (orange line)</p>	<p>This model run then adds on the impact of mining on the proposed extension. The pit advances further to the south into MLA 80156 and the vertical progression follows the red line in Figure 25.</p> <p>This scenario represents the future impacts (i.e. zone of influence) that are estimated to occur based on pending approval of the mining activities on MLA 80156. It is the main scenario for future impact assessment. It will be used to discuss all the results, run the sensitivity analysis and climate scenarios.</p> <p>Refer to Figure 29 (black line)</p>

The predictive runs were performed with an average groundwater recharge and average river water levels. In Section 5.4.6, a sequence of dry and wet years respectively has been calculated to assess the climatic impacts.

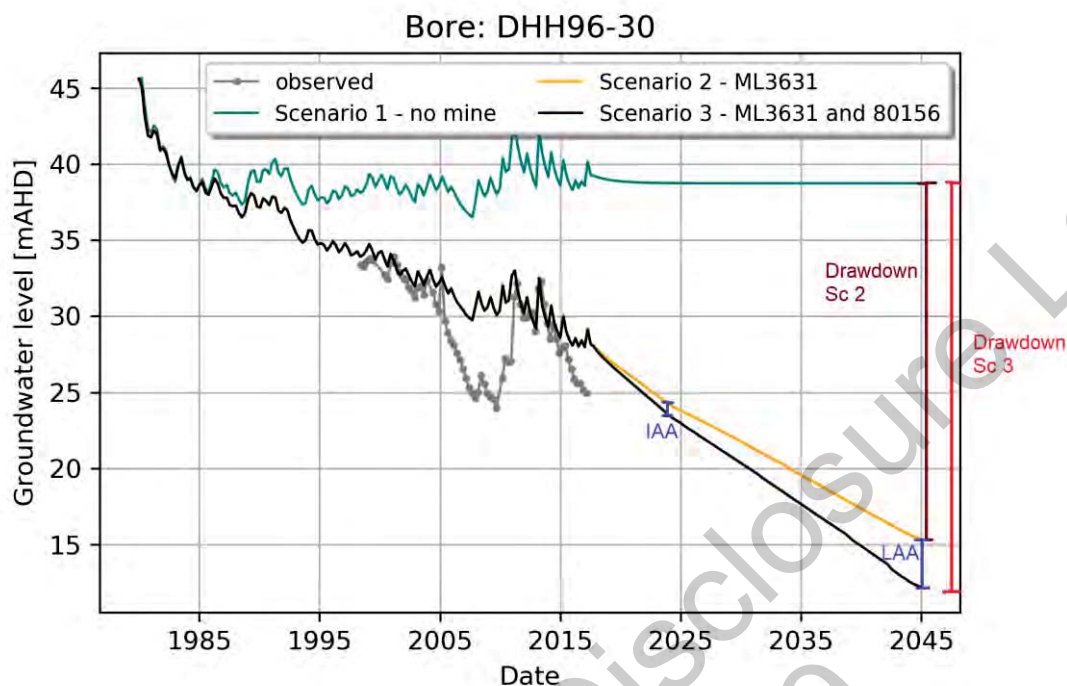


Figure 27 Visualisation of total drawdown and the IAA/LAA

5.4.1 Total drawdowns

To assess the impact of the mine (both as currently approved ML 3631 and the combination of ML 3631 and MLA 80156), the total maximum drawdowns were calculated. Figure 27 shows the calculated hydrographs for a selected bore for the three scenarios. This figure visualises how the resulting total drawdowns were derived (in red and dark red). This was done for the entire model and the resulting 5 m drawdown contours are presented in Figure 28. These contours were used to define the zone of impact for the trigger value assessment.

5.4.2 Areas affected by the mining extension

A new provision of the Water Act (2000) was introduced on 6 December 2016. Chapter 3 of the Act now states that mining companies that take or interfere with groundwater will be subject to the obligations that currently apply to the petroleum and gas sector. Only MLA 80156 falls under this act. Therefore, this report will include figures showing the immediately affected area (IAA) and the long-term affected area (LAA) for this mining lease only.

5.4.2.1 Immediately affected areas

The Immediately affected areas (IAA) of an aquifer is the area within which water levels are predicted to decrease, due to water extraction by petroleum tenure holders, by more than the trigger threshold within **three years**. The trigger thresholds are specified in the Water Act; the trigger for consolidated aquifers (such as sandstone) is five metres. As the UWIR will be only required for the new mining lease, we show the IAA for the new mining lease only, i.e. the difference between Scenario 2 and 3. This is visualised in Figure 27. Because the calculated difference between those two scenarios after three years is 1.26 m maximum, the 1 m

drawdown is presented in *Figure 29*. Based on the modelling results, the IAA trigger threshold will not be exceeded in the next three years.

5.4.2.2 Long-term affected areas

The Long-term Affected Area (LAA) of an aquifer is the area within which water levels are predicted to decrease, due to water extraction by petroleum tenure holders, by more than the trigger threshold at **any time in the future**. The trigger thresholds are specified in the Water Act; the trigger for consolidated aquifers is five metres.

Because the mining impacts are reversible (refer to Section 5.5 for the recovery calculations), the LAA in this instance is the maximum impact experienced by 2045. As the UWIR will be only required for the new mining lease, we show the LAA for the new mining lease only, i.e. the difference between Scenario 2 and 3 (refer to *Figure 27*). The resulting 5 m drawdown curve is presented in *Figure 29*.

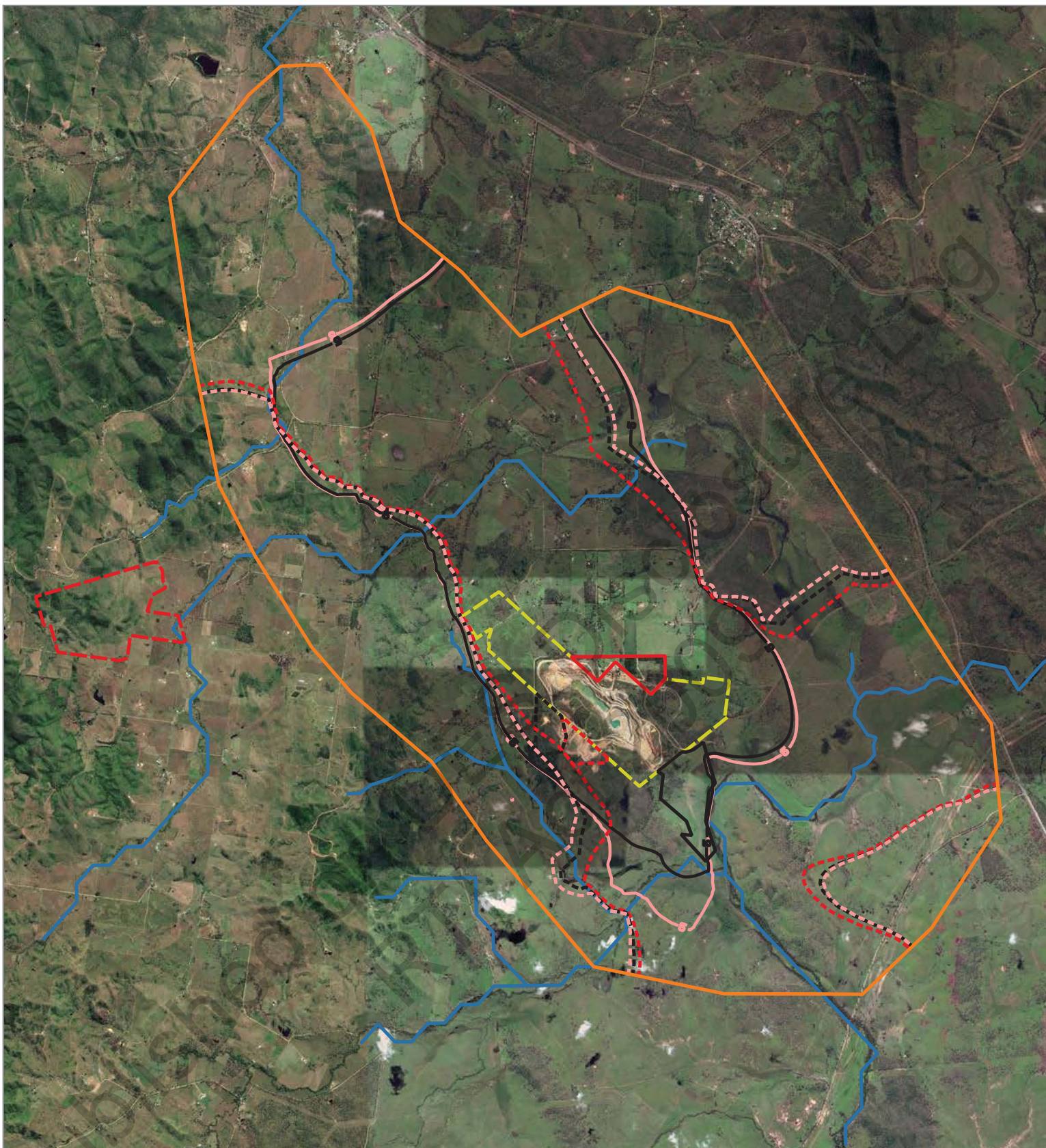
5.4.3 Flow fields

In Appendix H, flow fields for four points in time are presented. They show the flow direction based on the groundwater levels at this point in time.

- 1985 Early Mining
- 2017 Current
- 2045 Maximum Impact
- 2100 Post mining recovery

A detailed discussion of the figures is presented in Appendix H and a summary of the findings is presented below:

- The surface water divide north of Machine Creek was also represented in the groundwater model as a groundwater divide (500 m further north). This groundwater divide was not changing in the model over the mining timeframe and was moving to the south in the post-mining recovery run. According to the model, this would mean that the impact is not moving into the Hut Creek area.
- Schultz Lagoon was created by mining operations, as water collected in the mine sump is diverted into this area. As displayed in the figures (2017 and 2045 in particular; Appendix H), the modelling results show that the lagoon is losing water, which flows back towards the mine. The dyke (in black) is a flow barrier and the water is flowing around it.



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DATUM GDA 1994, PROJECTION MGA ZONE

0 1 2 3 km

RTI 2017/078

Legend

- Modelled 'zone of influence' (5 m Drawdown Curve - 2045) - Existing Pit Scenario 2 - ML 3631
- Modelled 'zone of influence' (5 m Drawdown Curve 2045) - - Pit Extension - Scenario 3 - MLA 80156
- - - 40 m AHD Groundwater contour 2017
- - - 40 m AHD Groundwater contour - 2045
- - - 40 m AHD Groundwater contour - 2045
- Surface water drainages
- Model Boundary

Mining Leases

- ML 3631
- MLA 80156
- ML 3659
- ML 7629
- ML 80002
- ML 80127

Cement Australia

Mining leases at the East End Mine, the model boundary, the 40 m AHD groundwater contour lines and the zone of influence (2045)

Groundwater Modelling Report

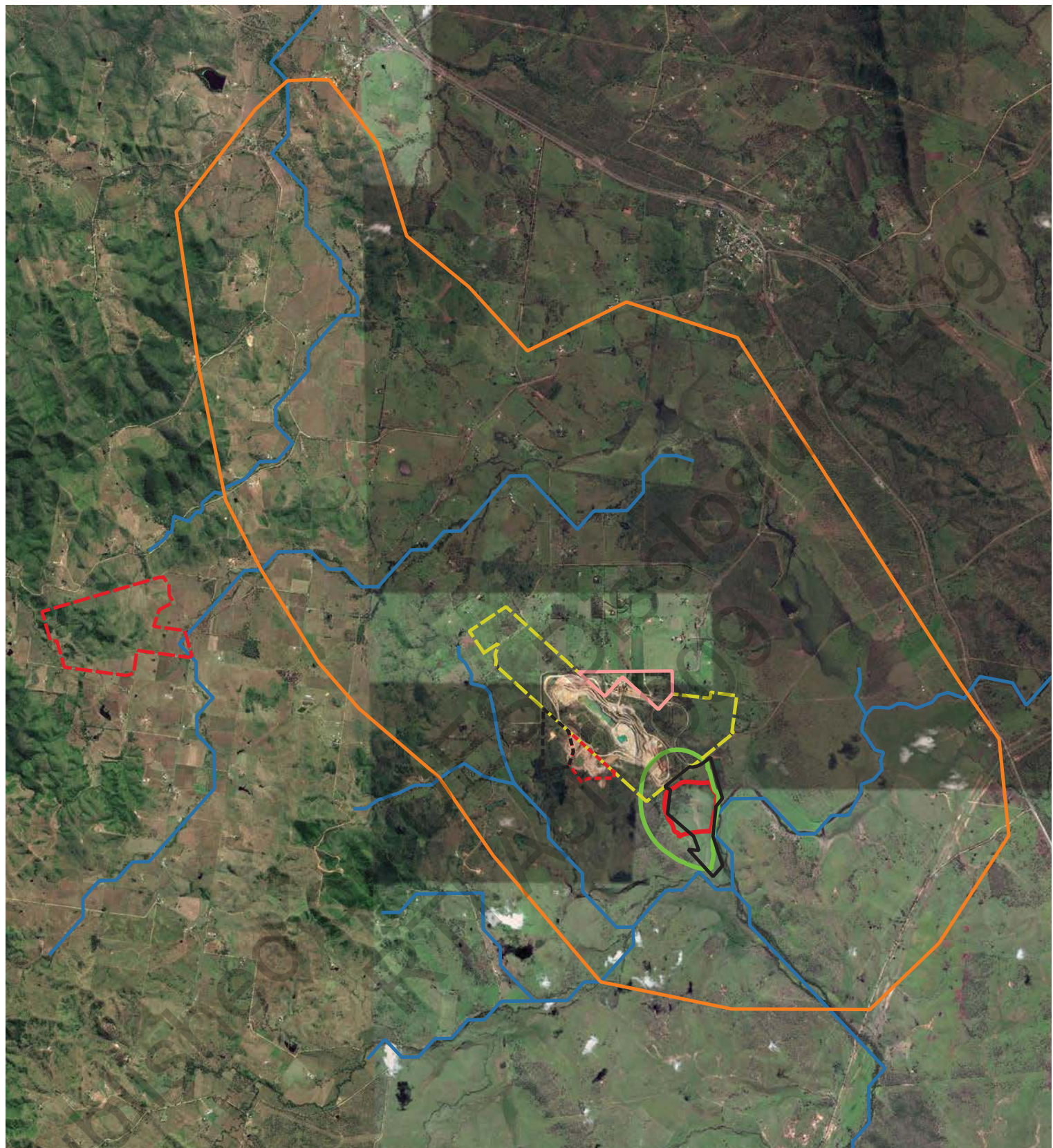
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Figure

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Base Data: Google Earth image



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DATUM GDA 1994, PROJECTION MGA ZONE

0 1 2 3 km

RTI 20-078

Base Data: Google Earth image

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Legend

- Surface water drainages
- Model Boundary
- Immediately affected Area: 1m drawdown contour
- Long-term affected area: 5 m drawdown contour

Mining leases

- ML 3631
- MLA 80156
- ML 3659
- ML 7629
- ML 80002
- ML 80127

Cement Australia

Long-term affected area and immediately affected area contours - as a result of the mine extension (Scenario 3)

Groundwater Modelling Report

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5.4.4 Surface water interaction

The groundwater model is able to calculate the surface water / groundwater interaction in a very rudimentary way. The surface water level was considered steady state only and was estimated from the topographic surface. Hence, these results are indicative only. If there are regions of interest that should be analysed in more detail, a survey of the river beds and levels is required. This would allow for a more sophisticated model of the surface water / groundwater interactions.

In Table 15, the results for the surface water / groundwater interactions are listed per creek (or section of the creek). With the groundwater levels decreasing over time, some of the creeks change from gaining to losing.

Table 15 Surface water bodies in the groundwater model

Name	Description	Net balance in the groundwater model	Rates 2000-2017 (m ³ /day)	Rates average 2035-2045 (m ³ /day)	Rates dry climate 2035-2045 (m ³ /day)	Rates wet climate 2035-2045 (m ³ /day)Wet
Hut Creek		Losing	2,040	2,380	2150	2160
Machine Creek (upper)	From model boundary to Weir 2	Gaining	-106	-89	-83	-113
Machine Creek (lower)	From Weir 2 to end of creek	Losing	800	830	780	800
Jacobs Creek		Gaining/losing	-140	340	360	188
Scrub Creek		Losing	390	610	610	580
Larcom Creek (upper)	From model boundary to Schultz Lagoon	Gaining	-1,655	-415	-290	-870
Larcom Creek (middle)	From Schultz Lagoon to confluence with Scrub Ck	Gaining/Losing	-83	84	84	67
Larcom Creek (lower)	From confluence with Scrub Ck to model boundary	Losing	430	1,113	1,110	1,050
East End Creek		Losing	350	390	390	390
Schultz Lagoon		Losing	1,700	4,100	4,100	4,100

Note: blue shades indicate overall gaining conditions (minus means exfiltration from groundwater into surface water) and orange cells indicate over all losing conditions over the length of the considered creek or part of the creek

Figure 30 shows the inflow into the mining pit over the validation period. In the first 10 years of mining, around 1 ML/day was estimated by the model to have discharged into the mining sump. This value increased with the pit advancing further down vertically. It was estimated at 5 ML/day for the most recent years. This is in-line with the estimates provided in Section 1.2.1. The pit in the model was simplified, it is considered to be vertical where in reality it is sloped and the base is smaller than the outline. Hence it is likely that the groundwater model is overestimating the inflows.

Figure 30 also shows the amount of water lost by Schultz Lagoon over time. The inflows from the Lagoon into the groundwater were calculated into the range of 1-2 ML/day. This is less

than estimated in Section 3.5, where the sum of inflows from East End Creek and Schultz Lagoon was estimated to be 3 ML/day. Again, the surface water / groundwater interactions were implemented in steady state and this could lead to the difference.

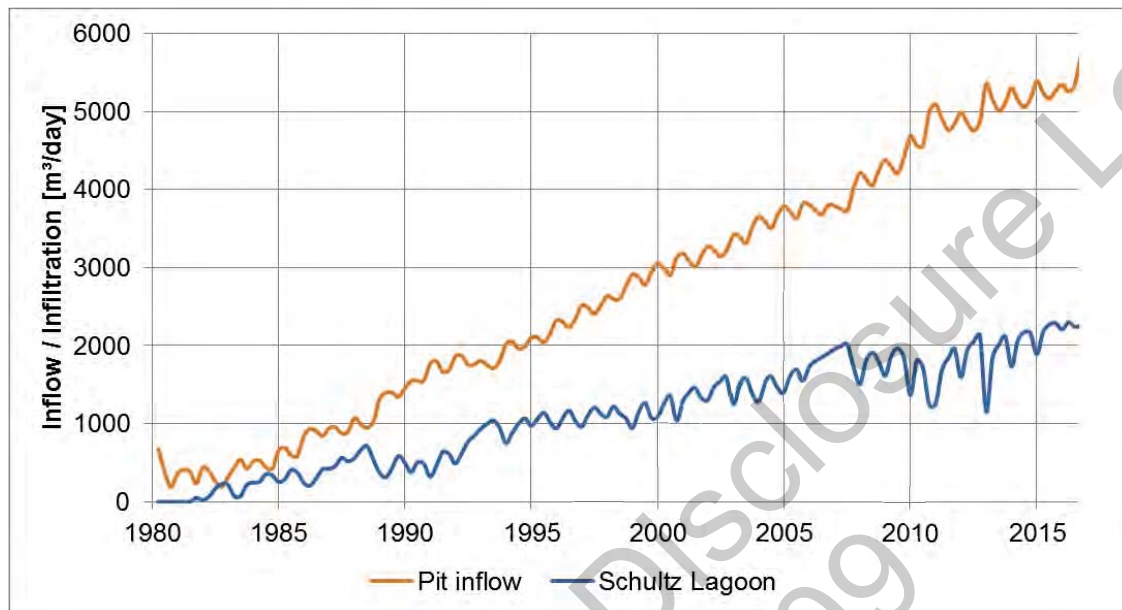


Figure 30 Modelled inflows to the mining sump and infiltration from Schultz Lagoon into the groundwater

5.4.5 Sensitivity analysis

5.4.5.1 Parameters

For the sensitivity analysis, the parameters listed in Table 16 have been changed to assess the impact on the results.

The hydraulic conductivity was varied by a factor 5 (increased and decreased). The resulting sensitivity will show how well the model is able to replicate the groundwater conditions if the model parameter is not representing the actual conditions.

There was some sensitivity analysis undertaken around the groundwater / surface water interaction, namely by varying the river bed conductances (how well the surface water and groundwaters are connected) as well as the creek connection (the thickness of the saturated zone before the connection is lost when the conditions turn to unsaturated flow).

The last parameter tested for sensitivity was the storage. Because the value used in the model was already at the lower range of the values documented in literature, the value was only increased for the analysis.

Table 16 Sensitivity analysis parameters

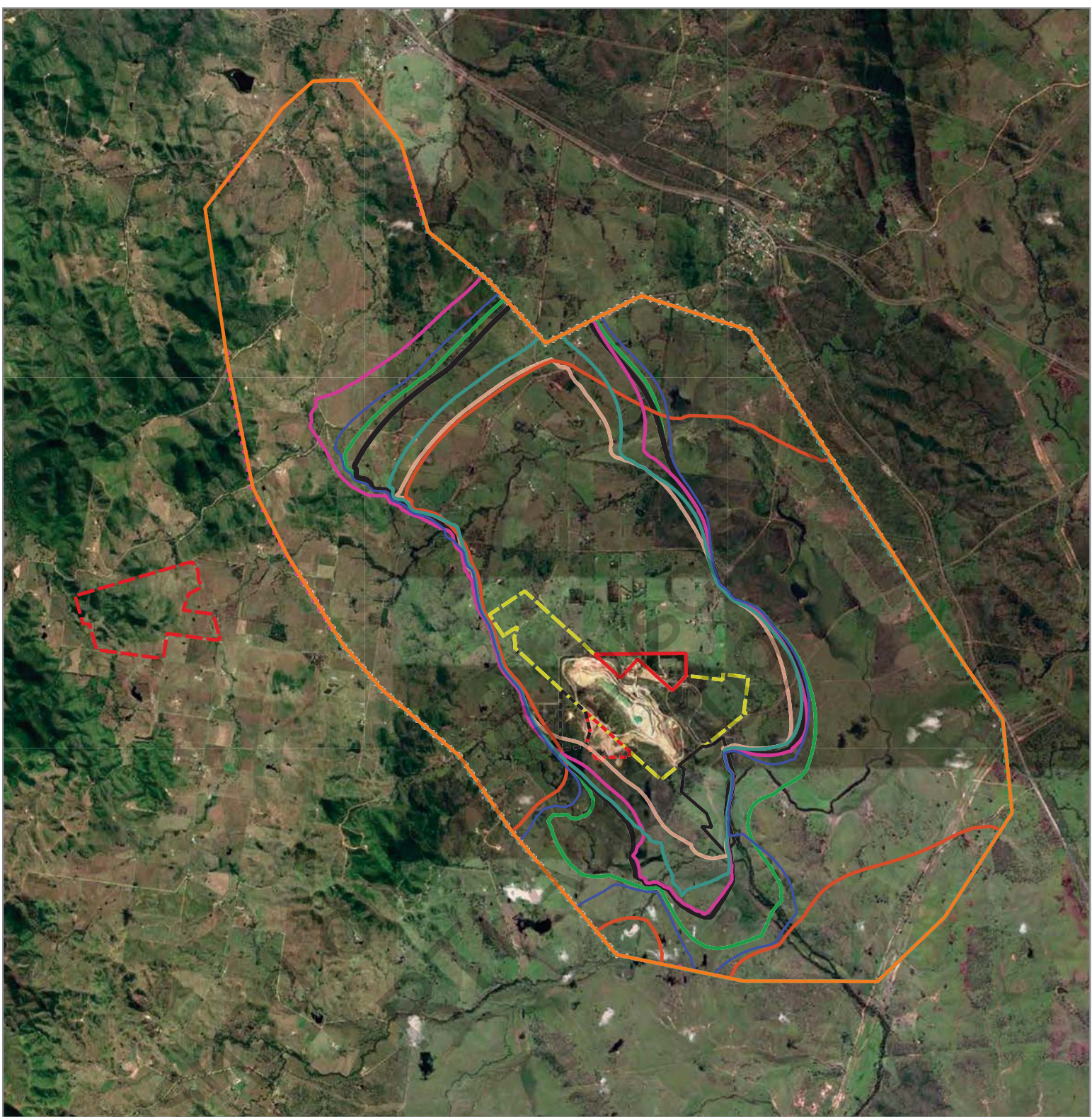
Parameter	Factor	Comment	Result
Hydraulic conductivity	5	Unlikely for the limestone, the model value is on the upper range (for an average representation)	Impact zone significantly larger to the east and south. The extent to the north slightly reduced.
Hydraulic conductivity	1/5		Impact zone smaller
Leakage Coefficients	2	Creek bed conductance increased	Impact zone smaller
Leakage Coefficients	1/2	Creek bed conductance decreased	Impact zone similar, larger in the Scrub creek area
Storage	5	Storage coefficient 5 times higher. A lower values was not considered, as the model parameter is already at the lower end of the range.	Impact zone similar, larger in to the north.
Creek connection		Saturated zone thickness decreased (saturated connection lost faster and unsaturated conditions limit infiltration)	Impact zone similar, larger in the Scrub creek area

5.4.5.2 Discussion

Figure 31 shows the resulting 5 m drawdown lines (zone of influence in the year 2045) for all sensitivity runs. All zones are of a similar extent, which means that the estimate of the zone of impact is robust.

Exceptions are:

- The model run with the higher hydraulic conductivity values produces a more widespread zone of influence. It is unlikely that the limestones have a hydraulic conductivity of 25 m/day across the entire model area. Local preferential flow paths can have that level of permeability. However, this will only produce local impacts along that preferential pathway and not a wide spread drawdown pattern.
- When reducing the connection to the rivers (either by reducing the leakage coefficients or reducing the saturated zone), the general zone of impact remains similar compared to the calibrated model. However, in the south western corner (Scrub Creek alluvium), the drawdown extents further. This can be explained by the limestone extending up in this direction (Zone 4, refer to Figure 22)
- When increasing the storage coefficient, the general shape of the zone of influence remains similar to the calibrated model, however it extends approximately 500 m further to the north.



Legend

Sensitivity Analysis

- 5m_Drawdown - Basecase
- 5m_Drawdown - Leakage x 2
- 5m_Drawdown - Leakage /2
- 5m_Drawdown - Storage x 5
- 5m_Drawdown - Hydraulic Conductivity x 5
- 5m_Drawdown - Hydraulic Conductivity /5
- 5m_Drawdown - Creek Connection Changed

Mining leases

- ML 3631
- MLA 80156
- ML 3659
- ML 7629
- ML 80002
- ML 80127

0 1 2 3 4 km



Cement Australia

Sensitivity Analysis

Groundwater Modelling Report

Pacific Environment
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Base Data: Google Earth

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Figure

M

5.4.6 Climate Scenarios

The impact of dryer or wetter than average years was assessed by setting up two synthetic recharge time series based on past climate; refer to *Figure 5* for a plot with the observed rainfall statistics. Out of the entire data set, two time series have been selected:

- Dry years: 1992-2006 (15 years), two consecutive cycles
- Wet years: 1971 -1986 (16 years), two consecutive cycles

These time series were “attached” to the observed data used in the model (1980 to 2017) to inform the model for the predictive part (2017-2045).

Appendix F shows the hydrographs with the average climatic future conditions in green, for wet conditions in blue and for dry conditions in red.

The plots show that the climate has an impact on the water levels that can be up to 5 m between the wet and the dry scenario. However, generally they also show that if there is a mine impact, this effect is mostly larger than the climatic variability and is captured well with the average conditions used in the original model run. Furthermore, water levels from the three scenarios converge towards the end of the modelling period, showing that climatic impacts to groundwater levels are generally temporary. In other words, when modelled groundwater levels decreased during the drought, they quickly recovered when average rainfalls were recorded.

5.5 Post-Mining Recovery

In order to assess the longevity of the mining impacts, a model run for the post-mining recovery was performed. The main scope of the transient groundwater model was for the mining impact during operations, and the model was not specifically built to calculate the recovery. However, it was possible to use the current model to calculate an **estimate** of the recovery period.

5.5.1 Assumptions

To calculate the post-mining recovery curve, some of the boundary conditions were required to be changed to reflect the post-mining conditions.

The pit was originally modelled with a leakage boundary condition to reflect the water levels in the mine sump as the target water levels. For the recovery, the water levels in the final void are unknown and the concept of the leakage boundary is no longer applicable.

Instead, the final void is represented as a “lake”, with a very high hydraulic conductivity (1000 m/d) and a storage coefficient of 1 (which means that 100% of the volume is filled with water). Note that this is only an approximation of the actual seepage interface. The lake in the void will be exposed to rainfall and evaporation. As the average annual evaporation exceeds the rainfall, a “negative recharge” of 1m/yr was applied (this simulates the rainfall minus the evaporation).

The model was run until 2100, which is an additional 55 years after the theoretical mining cessation date of 2045.

5.5.2 Results

The results are attached in Appendix G (per bore). In general, the water levels recover in 20 to 30 years to pre-mining water levels.

Some of the bores show an initial decline after mining ceases. This can be explained with the assumptions in the model - the current pit, which will be deeper in 2045 than the ones to the north and south, will initially draw in water from the north and south due to calculations being 2d and over the entire depth. In reality, this won't happen. The deepest pit will fill first and the others will follow.

Another important point is that the modelled surface water/ groundwater interactions return to pre-mining conditions as well, i.e. a gaining stream that might have had reduced contributions from the groundwater during mining, will get the same amount of water as in pre-mining conditions. Refer to *Table 17* for details.

Table 17 Surface water bodies in the groundwater model

Name	Description	Net balance in the groundwater model	Rates 2000-2017 (m ³ /day)	Rates average 2035-2045 (m ³ /day)	Rates Post Mining recovery (m ³ /day)
Hut Creek		Losing	2,040	2,380	2,035
Machine Creek (upper)	From model boundary to Weir 2	Gaining	-106	-89	-106
Machine Creek (lower)	From Weir 2 to end of creek	Losing	800	830	776
Jacobs Creek		Gaining/ losing	-140	340	-170
Scrub Creek		Gaining/ losing	390	610	242
Larcom Creek (upper)	From model boundary to Schultz Lagoon	Gaining	-1,655	-415	-1432
Larcom Creek (middle)	From Schultz Lagoon to confluence with Scrub Ck	Gaining/Losing	-83	87	-44
Larcom Creek (lower)	From confluence with Scrub Ck to model boundary	Losing	430	1,113	413
East End Creek		Losing	350	390	NA
Schultz Lagoon		Losing	1,700	4,100	NA

Note: blue shades indicate overall gaining conditions (minus means exfiltration from groundwater into surface water) and orange cells indicate over all losing conditions over the length of the considered creek or part of the creek

6 Summary

6.1 Conceptual hydrogeological model

The conceptual model presented here is in general agreeance with previous investigations (e.g. Kalf and Associates, 1997; DERM, 2011). However, this investigation did expand on past reports; notably, with the assessment of the prominence of alluvial aquifers, the recharge investigation and the assessment of the relationship between bore depth and hydraulic conductivity.

The East End Mine is sited on a limestone belt running in a north-westerly direction (East End belt). There is another limestone belt to the west of MLA 80156 (the Bracewell belt), which is separated from the East End belt by a volcanoclastic rocks. Groundwater flow between the two limestone belts is restricted by the faulting and folding and the placement of the volcanoclastic rocks (DERM, 2011).

Near the East End Mine, the bedding strikes towards the northwest, with strata dipping steeply towards the southwest at around 70°-85° (Groundwork Plus, 2014). Groundwater flow predominately occurs along bedding planes within each structural block; i.e. between the individual limestone belts and within the volcanoclastic rocks. Any interflow between the volcanoclastics and the two limestone belts would generally be limited to areas with interconnected fractures (DERM, 2011).

Groundwater flow generally follows topography with groundwater flowing from the hilltops towards the streams. The overall groundwater flow direction was generally towards the major drainage lines of Larcom Creek and Scrub Creek to the south and east, and towards Machine Creek in the area upgradient of the numerical model boundary.

The alluvium is generally composed of clays and they do not contain significant water storages. Drawdown in the north of the site is unlikely to affect water flows in Machine Creek, as the creek is hydraulically disconnected from the underlying limestone aquifer. Groundwater is most-likely connected to groundwater near Larcom Creek; however, impacts to stream flows are mitigated by the emplacement of Schultz Lagoon, an artificial wetland created by the mine. Schultz Lagoon stores production water from the mine and most of this water is recycled back into the limestone aquifer. This prevents significant groundwater drawdown from occurring in the area surrounding Larcom Creek.

There appears to be a low permeability, northwest-southeast trending feature located to the northwest of the existing pit, as evidenced by the steep groundwater level gradient near B78, B23 and B122. The low permeability feature is likely propagated along the bedding plane to the northwest and the southeast. This feature has been incorporated into the numerical model by extending a lens of volcanoclastic rocks northward in this area (refer to Zone 11 in *Figure 24*).

There is a significant dyke mapped between Schultz Lagoon and the pit (refer to *Figure 11*). The hydraulic conductivity of this feature has not been tested, but it is assumed to be low. This feature is likely to have a significant impact on groundwater flow paths and it was therefore incorporated into the model.

Recharge was estimated at several monitoring bores using the chloride mass balance approach (refer to Section 4.5.2). The median value for the limestone bores was 4% of total rainfall, and 1% for the volcanoclastic rocks.

While it is generally recognised that fractures will generally become less open with depth in some settings, there is no evidence to support this using the available data. For implication for the context of numerical modelling, refer to Section 5.2.3.2.

6.2 Numerical model

The major change from previous groundwater models (Kalf and Associates, 1997 and Groundworks Plus, 2014) was the consideration of the groundwater level changes over time. The model was calibrated in steady state and then validated with transient data. Generally, the model is able to replicate the observed groundwater levels well on a regional scale. There are areas where local structures and/or unknown geology resulted in poor fit in the history matching, however this was expected given the regional approach.

The **groundwater recharge** estimates for the limestones from this study agree with the values from previous studies (4% of rainfall). This study also quantified the recharge to the volcanoclastics (1% of rainfall). The transient recharge was calculated quarterly with a threshold (under which no recharge occurred). The modelling showed that this approach could replicate the observed water levels in most of the bores.

Another area of improvement was the **groundwater/surface water interaction**, which has been included in more detail than in the previous models. However, due to limited data the representation is only very rudimentary. If more clarity is required for future models, surface water bodies of special interest (e.g. groundwater dependent ecosystems) could be surveyed and then incorporated into the model with the improved topographic information as well as transient water levels.

Previous studies have not included **non-mining extractions** from the regional aquifers. This study has attempted to estimate the extractions based on landuse. Currently, those are in steady state.

When starting the modelling process, Pacific Environment identified two more areas of improvement, which however have then not be included into the final model:

- **Anisotropy:** The conceptual hydrogeological model identified an anisotropy factor along the bedding plane (higher hydraulic conductivities parallel to the bedding plane, lower hydraulic conductivities perpendicular to the bedding plane). It was attempted to include this concept into the numerical model, however, better history matching was achieved when not including it. This may indicate that the process is less important than anticipated. For future modelling, it could be attempted to re-calibrate the hydraulic conductivities with the anisotropy factor.
- **2D vs 3D:** The hydraulic conductivity was deemed to decrease with depth and hence a 3D model was proposed. The analysis of bore data however could not identify a clear trend. Given that there is uncertainty in the model (from conceptualisation, data, and assumptions), the addition of multiple layers would have created an extra level of complexity, without reducing the uncertainty. Furthermore, most of the monitoring bores have long screen lengths and it is rare to have nested bore sites (i.e. multiple

bores screened at different depths but in the same geographical location). Therefore, it would be difficult to calibrate a multi-layer model. Hence, the numerical model was constructed in 2D, with the thickness of the model representing average characteristics over the entire depth.

The presented groundwater model showed an improved understanding of the system in some areas. Some future areas of improvement are:

- Improvement of understanding around the surface water / groundwater interactions around Larcom Creek and Schultz Lagoon and the role of the dyke feature in this area. Pacific Environment (2017) recommended additional groundwater monitoring around those areas. Once enough data is collected (2-3 years), the model could be re-assessed with the newly available data.
- Surface water/groundwater interaction: A more accurate representation of the surface water / groundwater interactions would be desirable, however, not enough data was available at the time of this study. If creeks of interest are identified, field work (surveying creek beds and estimation of water levels during base flow and flood events) would improve the input parameter for the model and reduce some uncertainty.

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Appendix A

Photographic log



Photograph 1: Weir 2 in Machine Creek (refer to Figure 2 for the location of Weir 2; Photograph taken on 5 June 2017).



Photograph 2: Machine Creek near monitoring bore B21 (refer to Figure 2 for the location of B21; Photograph taken on 5 June 2017).



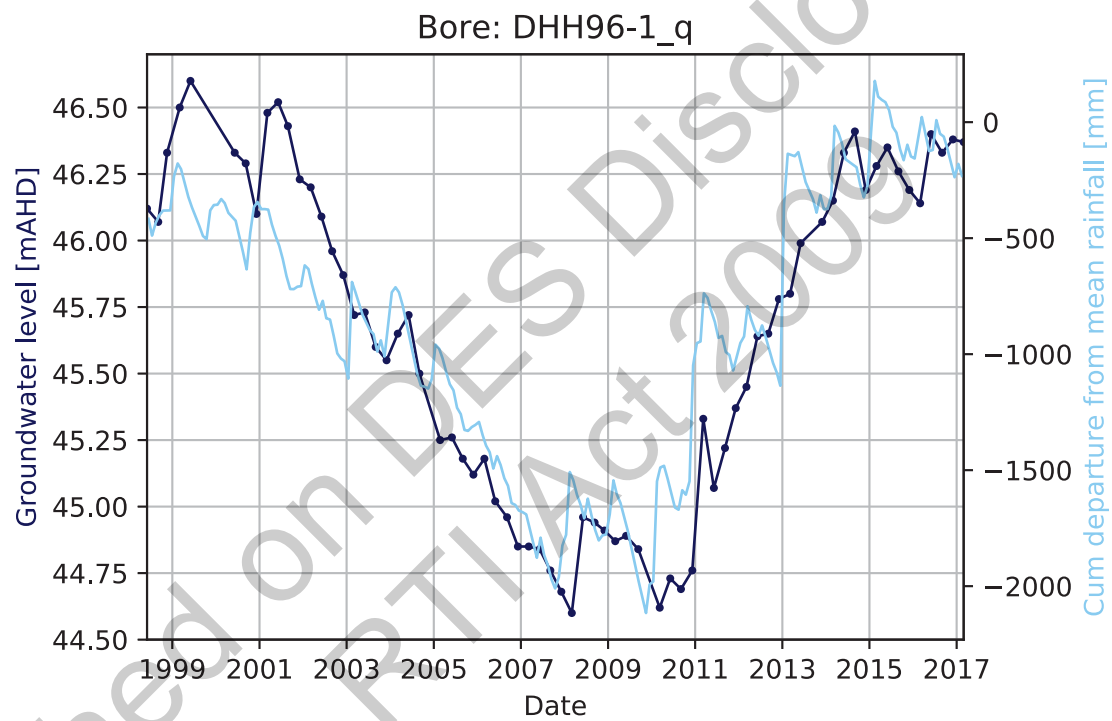
Photograph 3: Weir 7 on Larcom Creek – looking northward (refer to Figure 2 for the location of B21; Photograph taken on 5 June 2017).

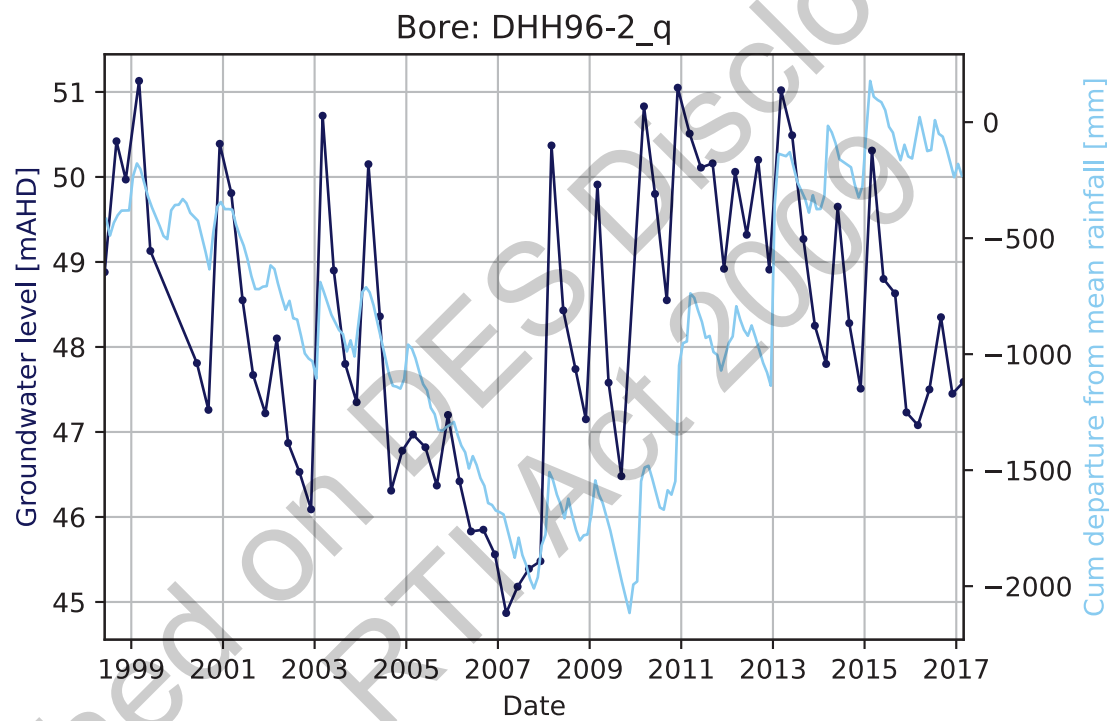


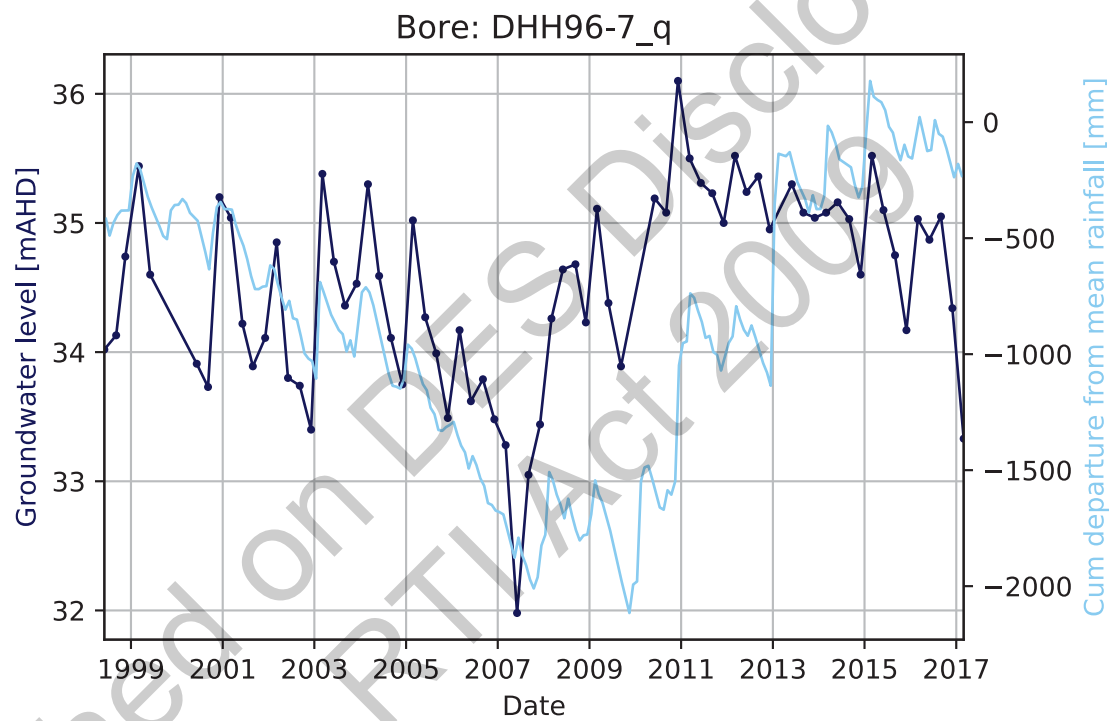
Photograph 4: Weir 7 on Larcom Creek – looking southward (refer to Figure 2 for the location of B21; Photograph taken on 5 June 2017).

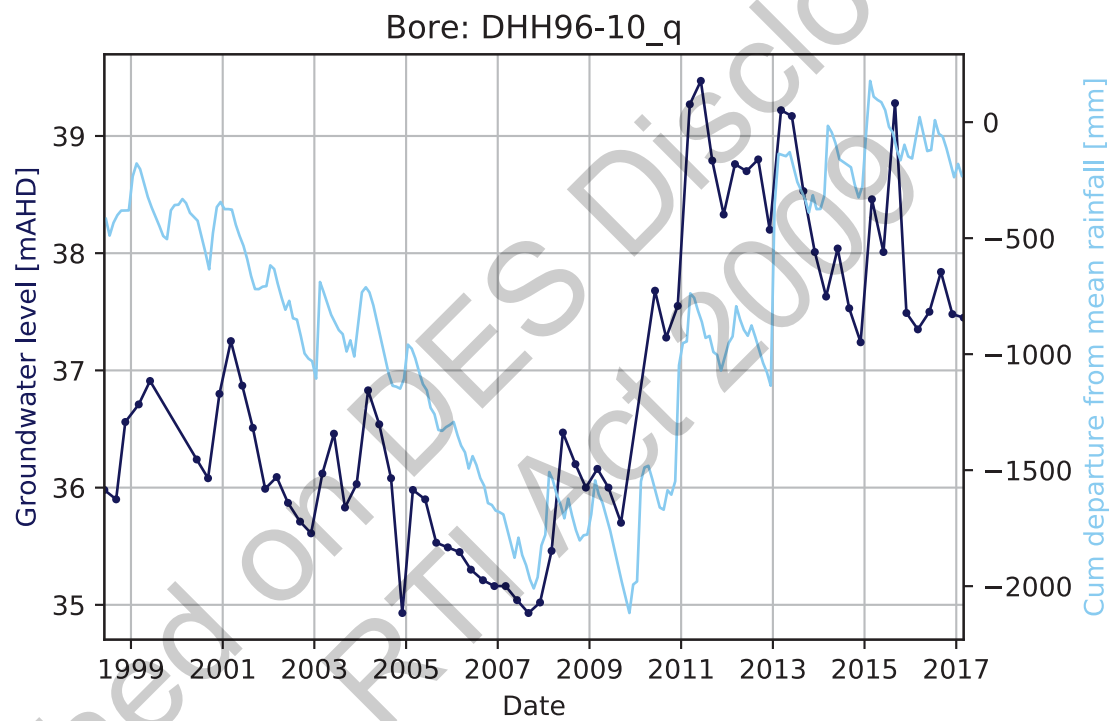
Appendix B

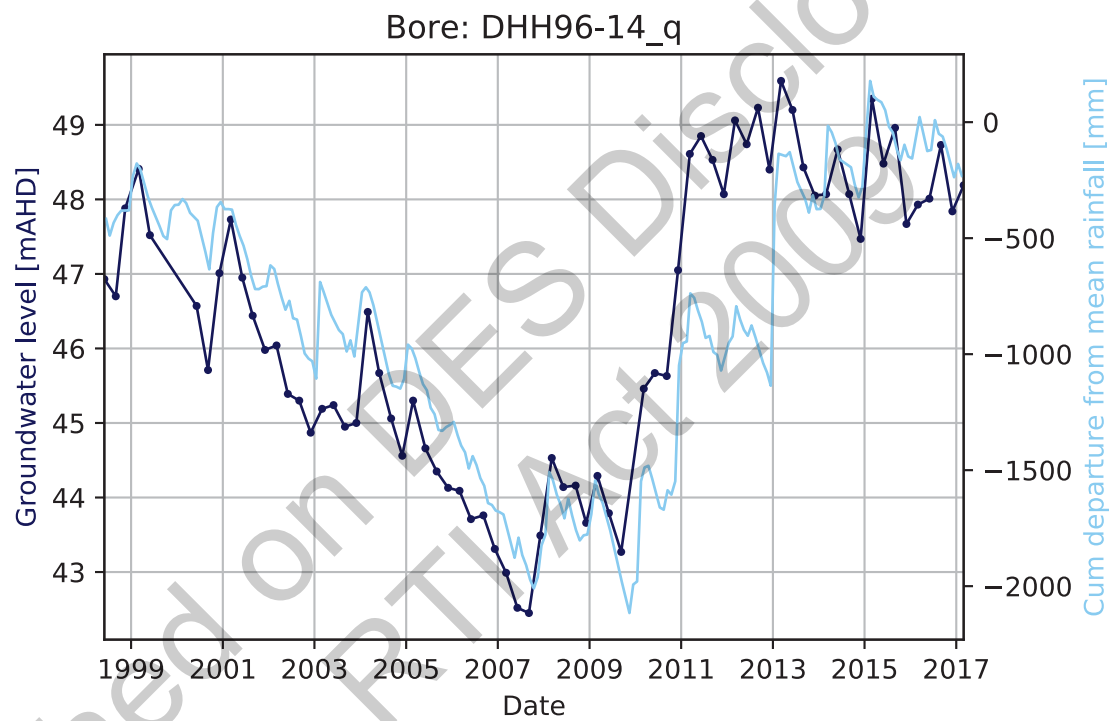
Selected Hydrographs and CDMMR



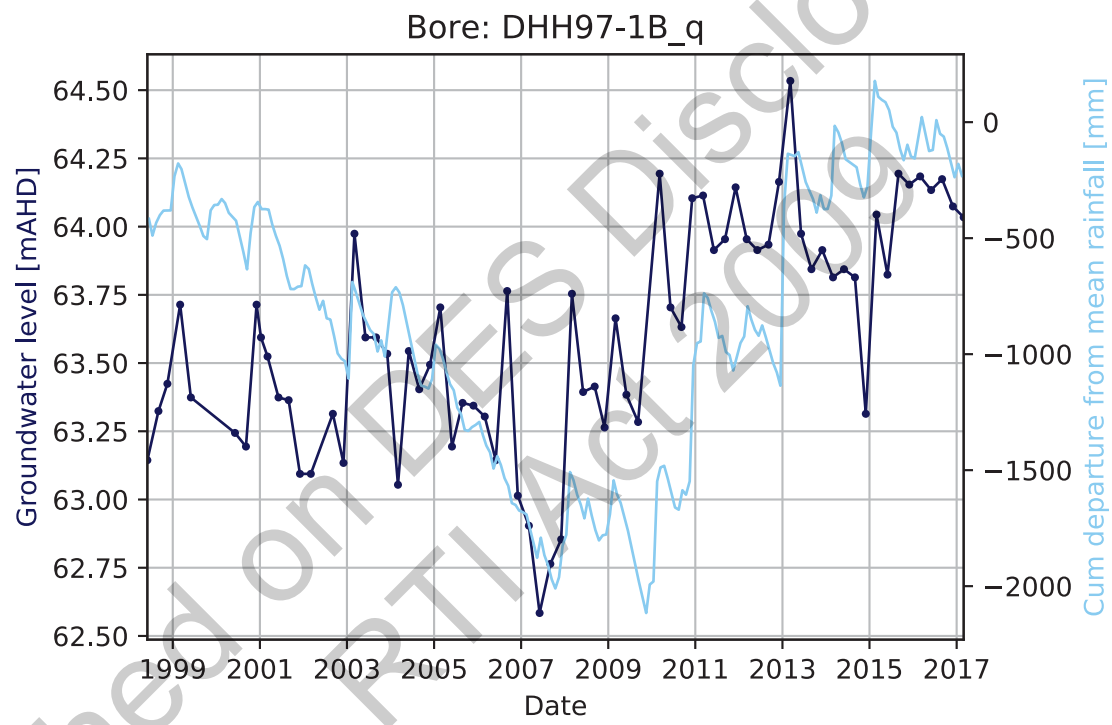


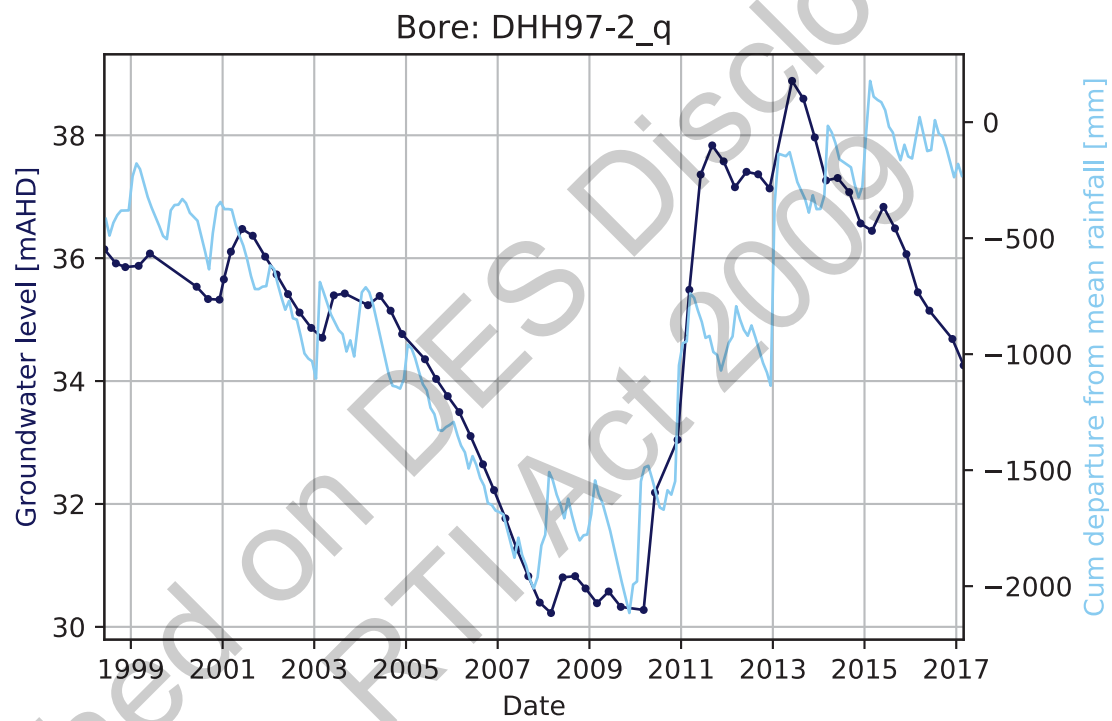


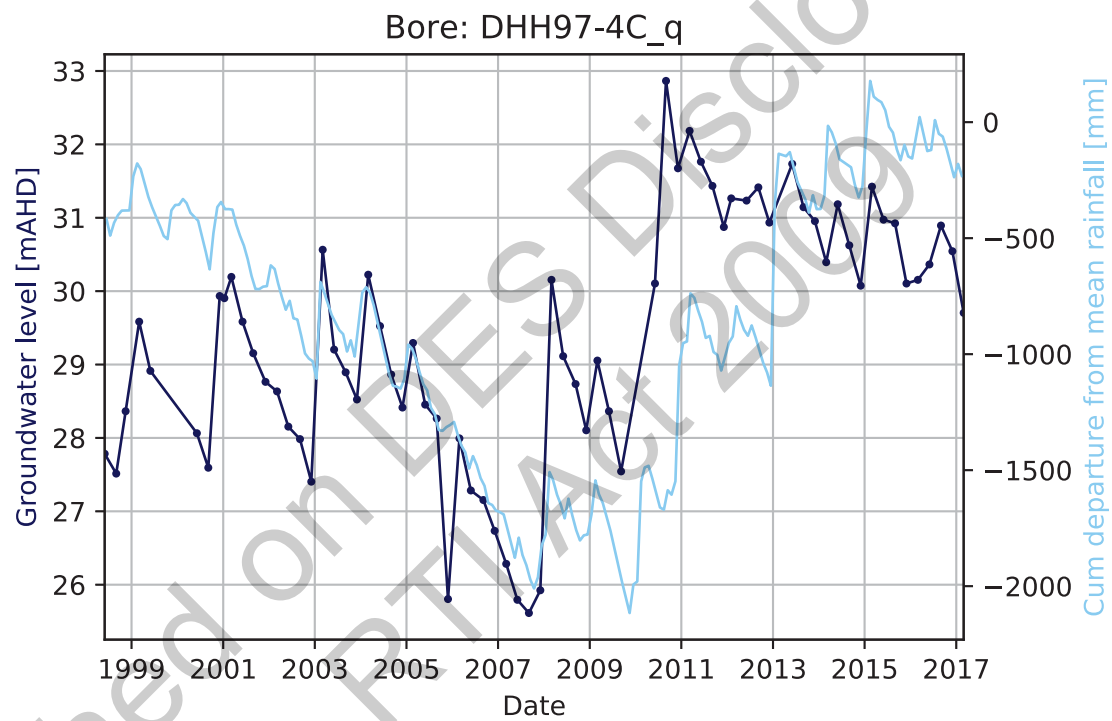


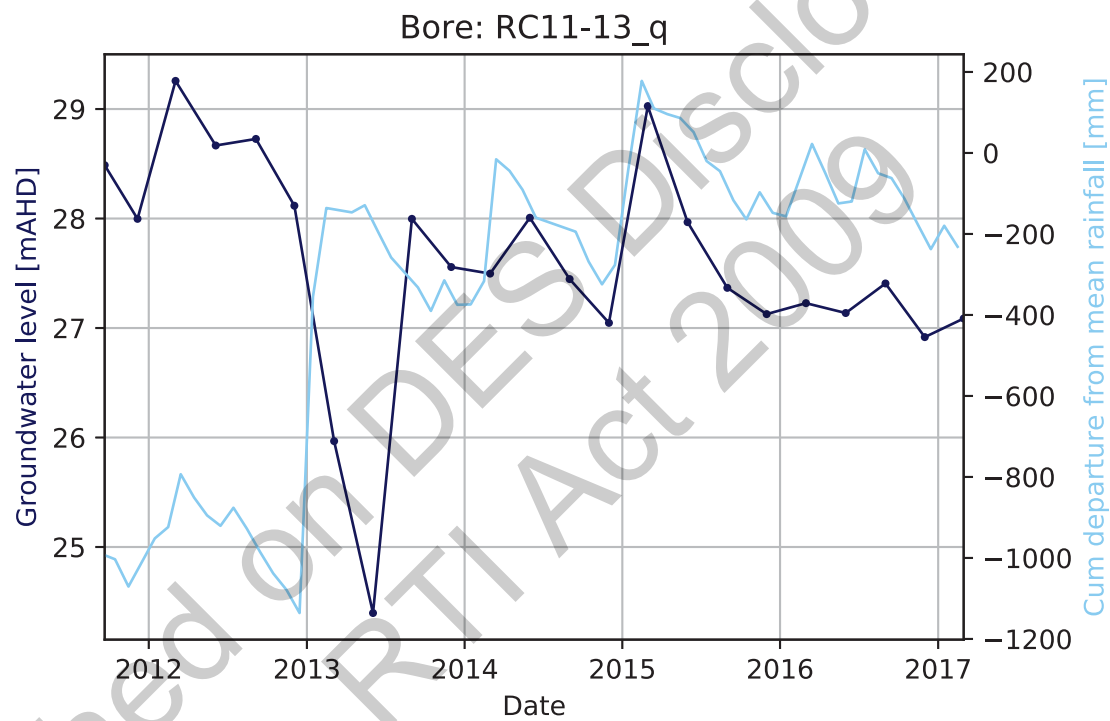


Published on RTI Act 2009 Disclosure Log









Appendix C

Summary of monitoring bore details

Summary of monitoring bore details

Bore	ZOI (Y/N)	DNRM Ref	Easting	Northing	Bench Mark (mAHD)	Geology
B2	N	57073	285383	7356121	99.02	Volcaniclastics
B3	N	57074	287041	7356176	112.03	Unsure
B4	N	57075	287699	7355611	109.48	Volcaniclastics
B6	N	57076	287908	7352611	58.32	Unsure
B19	N	57088	284375	7355417	106.68	Limestone
B21	N	57090	287235	7359879	79.56	Limestone
B23	N	57092	290006	7359408	75.00	Limestone
B29	N	57098	285935	7358379	86.66	Limestone
B33	N	57103	285908	7357765	88.29	Limestone
B35	N	57105	288020	7357761	83.67	Limestone
B38	N	57108	292448	7361357	51.50	Volcaniclastics
B44	N	57114	284409	7357789	69.24	Limestone
B53	N	57125	284924	7360073	73.11	Limestone
B56	N	57128	290478	7353477	49.24	Limestone
B61	N	57133	290715	7356376	46.60	Volcaniclastics
B66	N	57138	285436	7356413	100.51	Volcaniclastics
B71	N	57143	284814	7355680	105.52	Volcaniclastics
B72	N	57145	284872	7355745	102.12	Volcaniclastics
B78	N	88082	289947	7359503	76.80	Volcaniclastics
B79	N	57146	284947	7356016	102.07	Volcaniclastics
B100 (HOL S)	Y	97253	291387	7361153	54.80	Limestone
B101 (HOL N)	Y	97252	291474	7361292	54.70	Limestone
B102	Y	91928	288660	7362277	52.91	Unsure
B104	N	88320	291220	7364092	44.49	Unsure
B110	N	97526	285861	7358176	86.12	Limestone
B111	N	88925	286437	7361431	51.69	Volcaniclastics
B122	Y	97242	290173	7359558	69.22	Limestone
B123	N	88624	290750	7362129	57.61	Limestone
O3	Y	84433	290347	7359083	69.87	Unsure
O4	N	84434	287389	7358324	85.64	Limestone
O6	N	84436	285283	7359781	90.88	Limestone
O8	N	84438	284185	7354894	114.18	Limestone
O10	N		286603	7358626	87.18	Limestone
O11	N		284483	7358529	90.07	Limestone
O12	N		285149	7354992	107.42	Limestone
DHH96-1	N	97140	293721	7359928	51.65	Limestone
DHH96-2	N	97141	293215	7360238	51.85	Unconsolidated
DHH96-4	N	97143	291225	7360175	59.15	Limestone
DHH96-5	N	97144	294399	7360648	44.77	Limestone
DHH96-6	Y	97145	290136	7362315	63.84	Limestone
DHH96-7	N	97146	292897	7355313	38.46	Limestone
DHH96-9	Y	97148	293804	7357261	37.78	Limestone
DHH96-10	N	97149	295543	7358150	41.51	Volcanics
DHH96-11	N	97150	295182	7358790	40.04	Mixed
DHH96-12	N	97151	291007	7356340	47.10	Mixed
DHH96-13	N	97152	290579	7357389	51.51	Mixed
DHH96-14	N	97153	290423	7357638	51.40	Volcanics
DHH96-15	N	97154	290143	7358468	56.85	Volcanics
DHH96-16	N	97155	289786	7359044	63.25	Limestone
DHH96-19	Y	97158	291666	7358966	64.68	Unknown
DHH96-20	Y	97051	291557	7358810	54.17	Limestone
DHH96-21	Y	97159	291033	7360392	66.26	Limestone
DHH96-24	Y	97162	290262	7359868	69.72	Limestone
DHH96-25	N	97163	293243	7358560	54.67	Limestone
DHH96-29	Y	97121	293707	7358382	51.90	Mixed
DHH96-30	Y	97167	293408	7358184	47.70	Limestone
DHH96-31	Y	97120	293644	7358722	67.00	Limestone
DHH96-37	N	97173	291610	7360306	70.72	Limestone
DHH96-39	N	97175	292218	7356643	61.14	Volcanics
DHH96-40	N	97176	294054	7361248	45.86	Limestone
DHH96-41	Y	97177	293552	7356310	36.67	Limestone
DHH96-42	N	97178	291197	7361291	56.24	Limestone
DHH96-43	Y	97179	291613	7360213	61.56	Unknown
DHH97-1A	N	97540	288654	7359921	67.66	Volcanics
DHH97-1B	N	97541	288624	7359936	68.19	Mixed

ZOI = zone of influence (Kalf and Associates 1997).

DNRM = the Department of Natural Resources and Mines.

Bore coordinates: GDA94 / MGA zone 56.

m AHD = metres Australian Height Datum.

Summary of monitoring bore details

Bore	ZOI (Y/N)	DNRM Ref	Easting	Northing	Bench Mark (mAHD)	Geology
DHH97-2	Y	97542	289985	7360567	61.27	Limestone
DHH97-4C	N	97544	288164	7364497	33.96	Unsure
DHH97-5	N	97545	287345	7365660	30.49	Unsure
DHH97-6	Y	97546	293276	7357085	43.08	Limestone
DHH97-8B	Y	97584	290643	7361454	58.04	Limestone
DHH97-9	N	97547	290955	7355957	45.16	Volcaniclastics
DHH98-1	N	97931	288496	7359549	71.21	Limestone
DHH99-1	N	111133	289062	7360248	65.21	Volcaniclastics
RC11-01	N	151464	289081	7368164	26.33	Volcanics
RC11-02	N	151439	290915	7365141	36.21	Volcanics
RC11-03	Y	151479	290817	7362928	70.51	Limestone
RC11-04	Y	151480	289722	7361564	60.46	Limestone (multiple screens)
RC11-05	N	151450	287396	7362134	54.91	Mixed
RC11-06	N	151449	287230	7363793	44.88	Mixed
RC11-07	N	151433	285603	7362677	71.18	Volcanics
RC11-08	N	151481	286893	7364554	38.78	Mixed
RC11-09	N	151434	286744	7366525	30.49	Limestone
RC11-10	N	151448	287542	7367615	27.17	Limestone
RC11-11	N	151460	288873	7364459	69.89	Limestone
RC11-12	N	151441	295670	7352176	32.20	Volcanics
RC11-13	N	151462	296075	7353395	33.42	Volcanics
RC11-14	N	151463	296635	7354765	46.31	Volcanics
RC11-15	N	151459	297434	7355797	44.98	Volcanics
RC11-16	N	151435	285936	7354464	84.19	Limestone
RC11-17	N	151436	292890	7364220	70.27	Volcanics
RC11-18	N	151461	292735	7363071	49.62	Volcanics
RC11-19	N	151437	289418	7356990	63.13	Volcanics
RC11-20	N	151438	289930	7355141	62.89	Volcanics
RC11-21	N	151440	288723	7352504	62.60	Volcanics
EE Mine Forest Bore SE	Y	111505	293043	7358197	47.87	Limestone
East End Mine Forest Bore NE	Y	111504	292941	7358579	56.83	Unsure

ZOI = zone of influence (Kalf and Associates 1997).

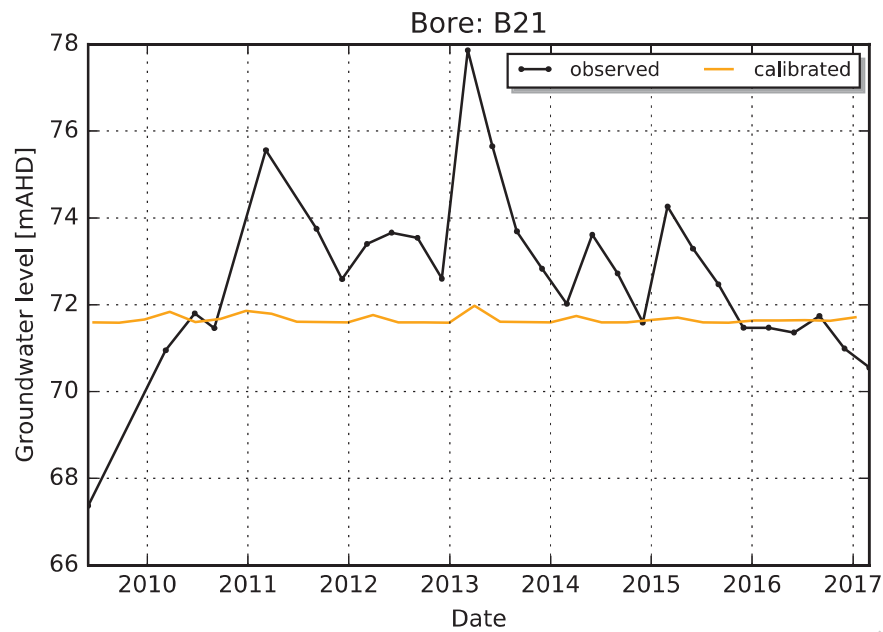
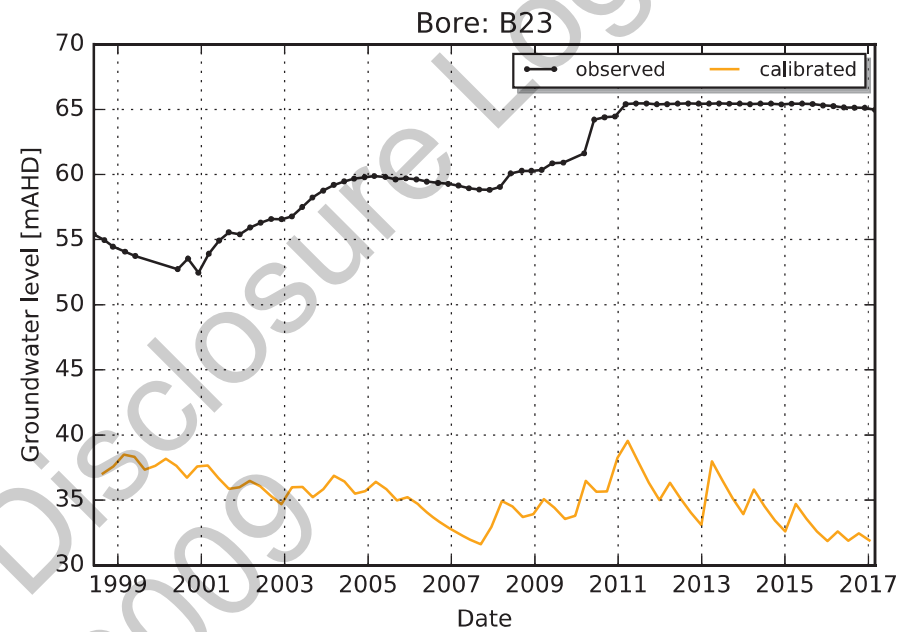
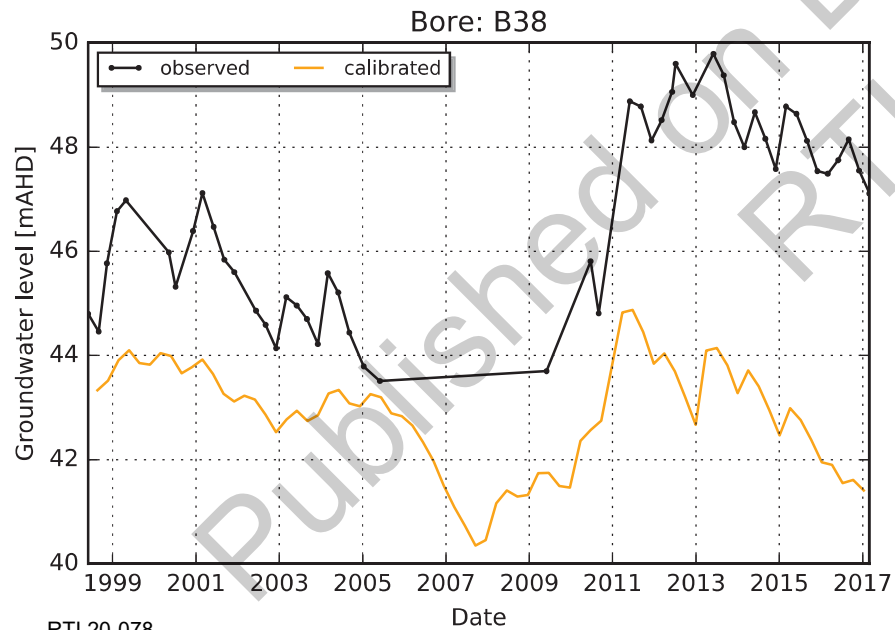
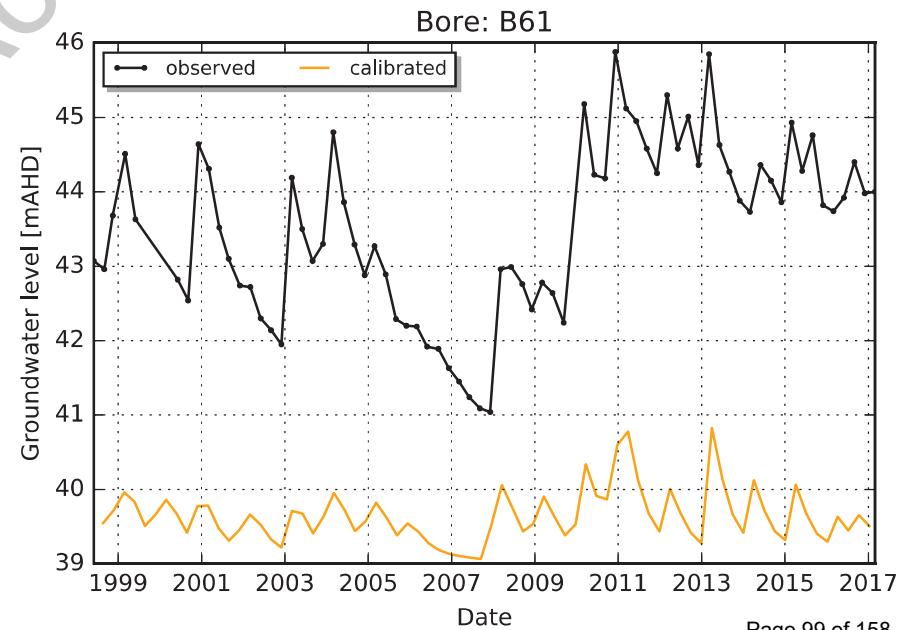
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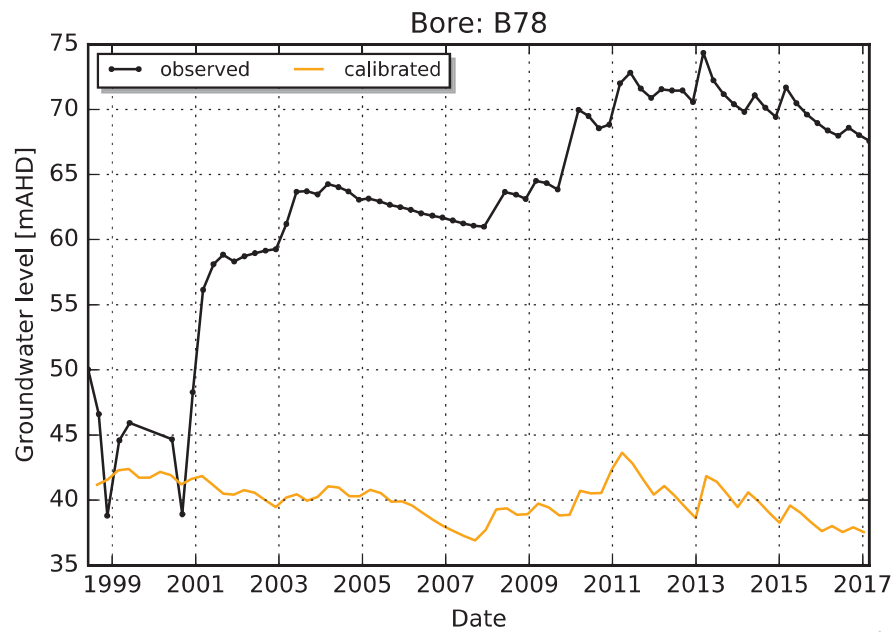
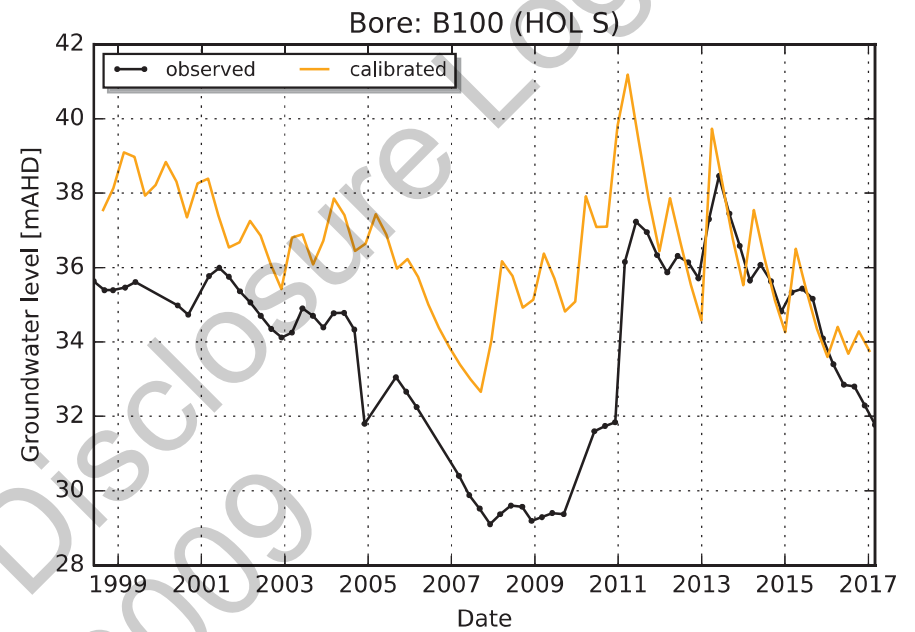
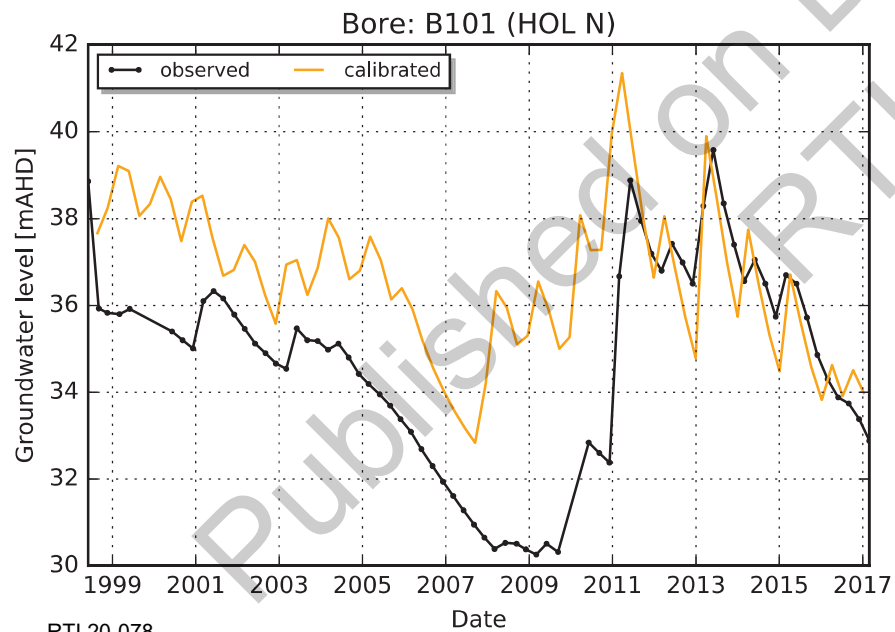
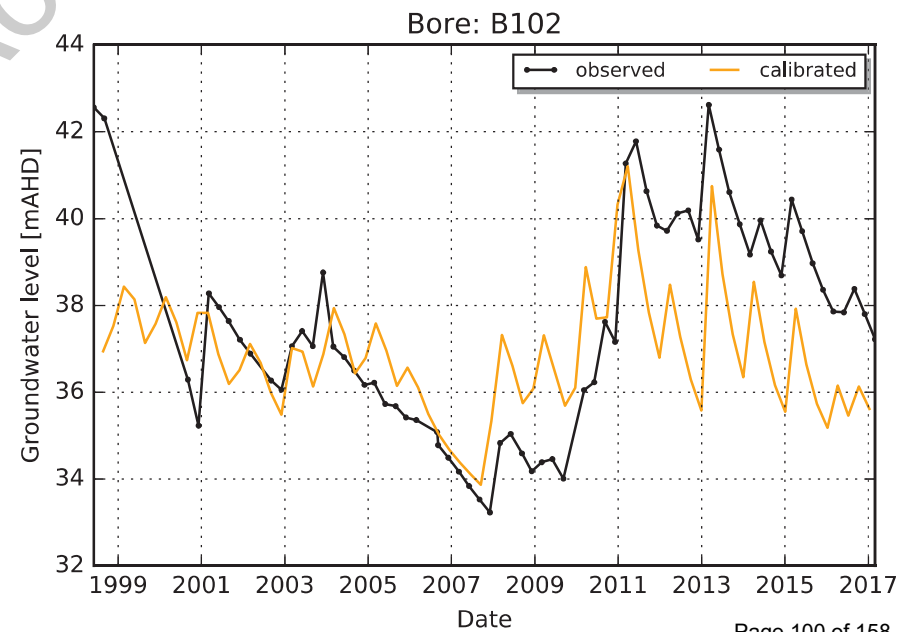
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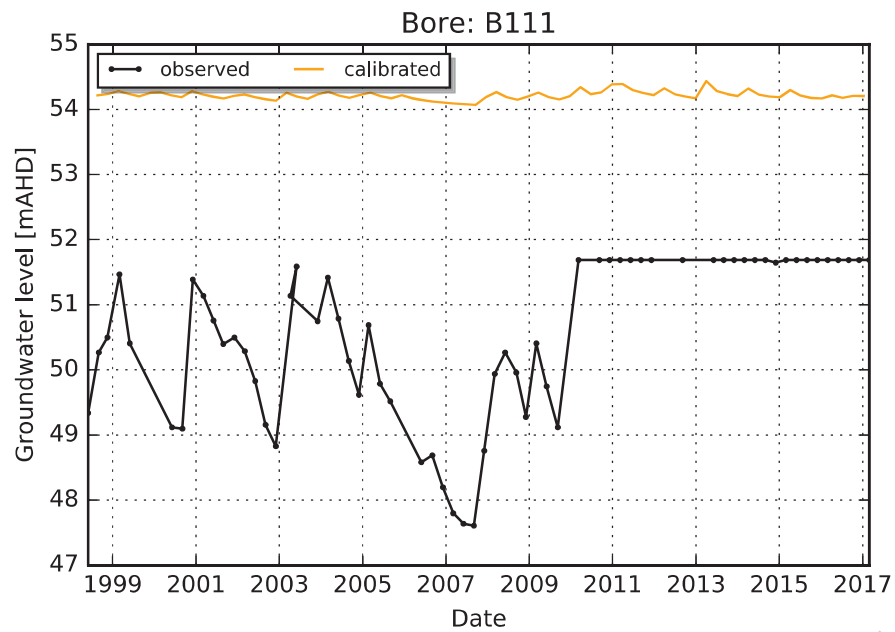
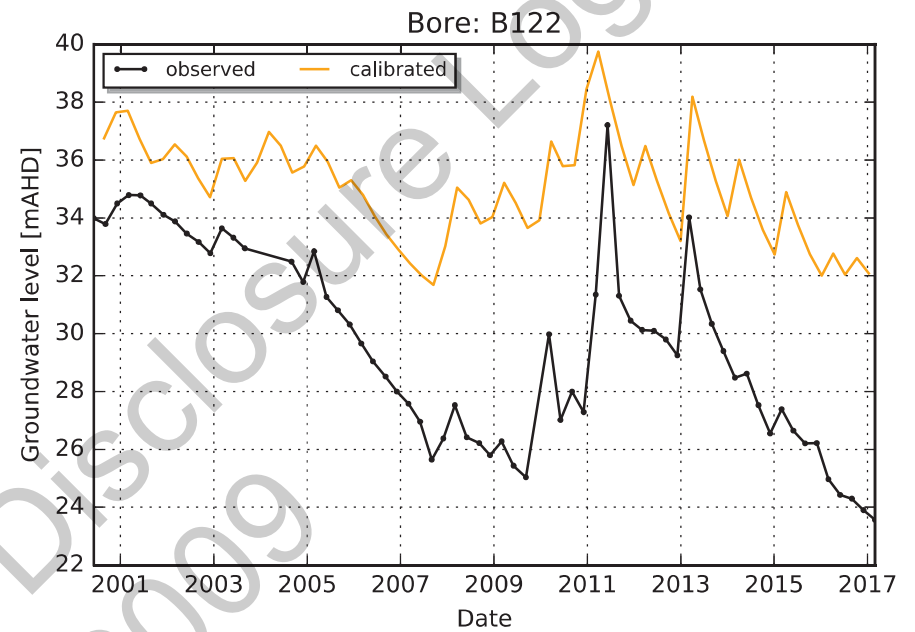
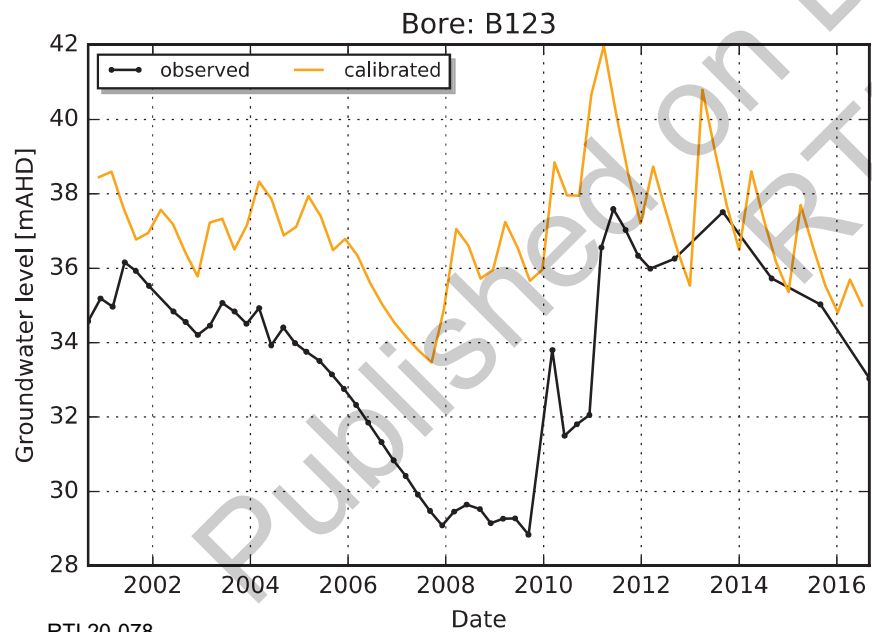
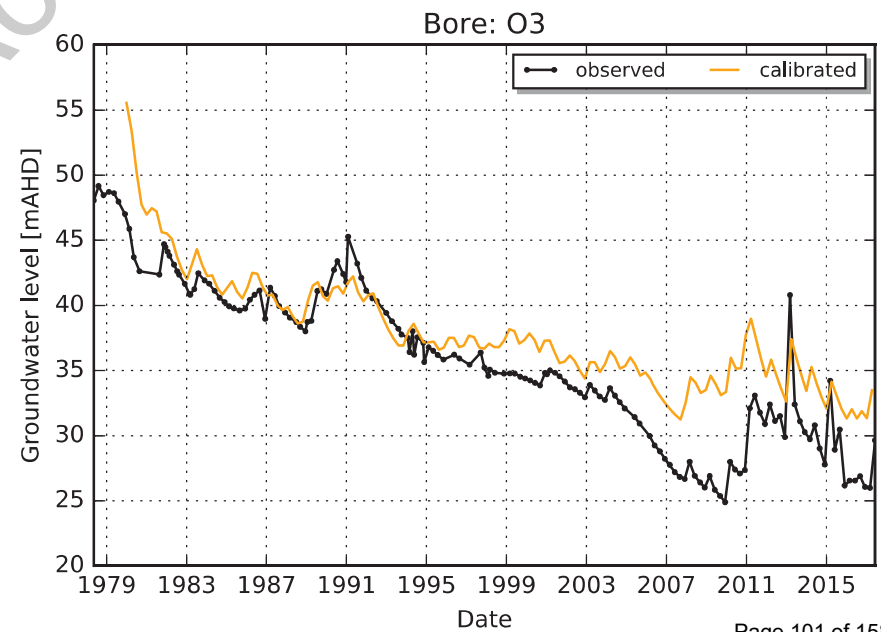
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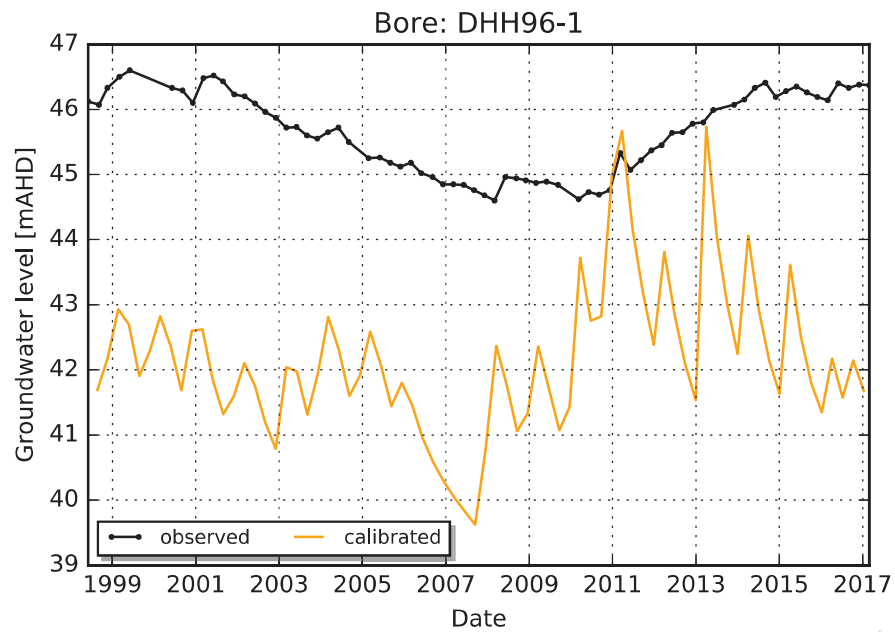
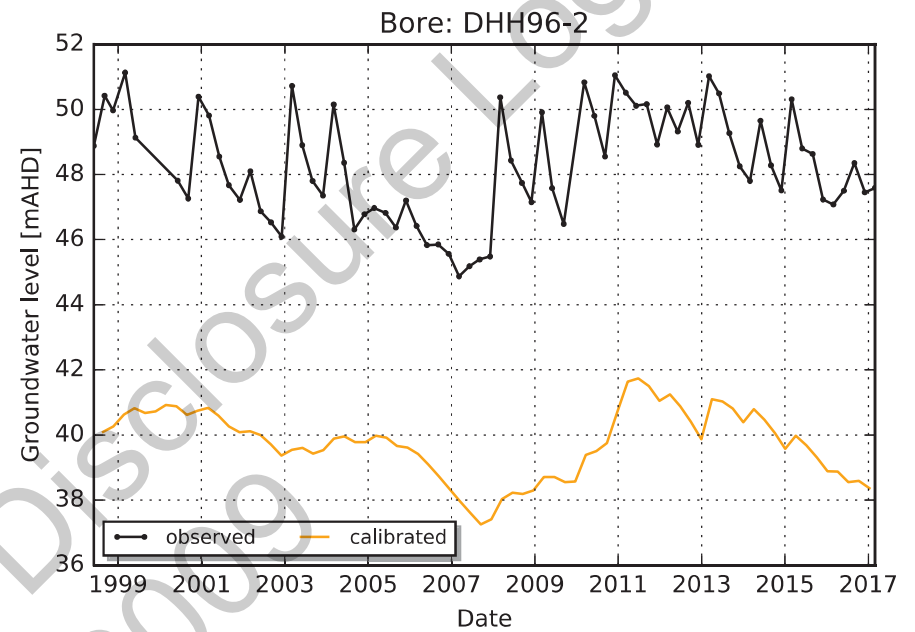
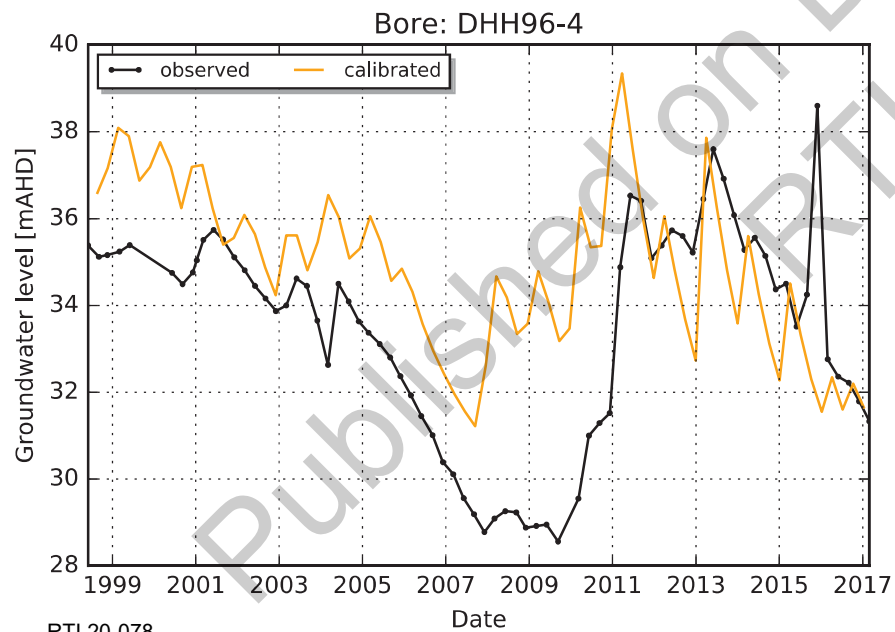
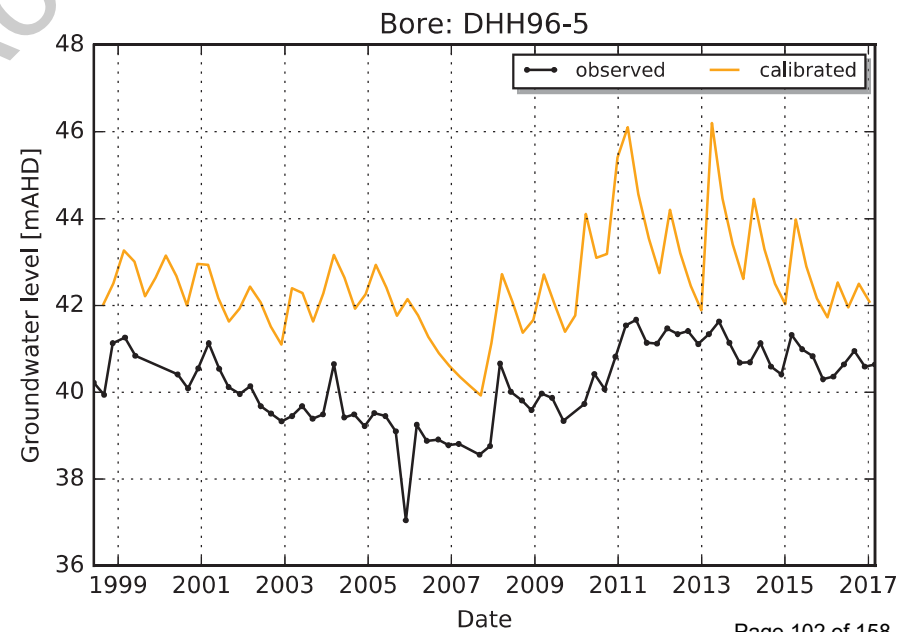
Appendix D

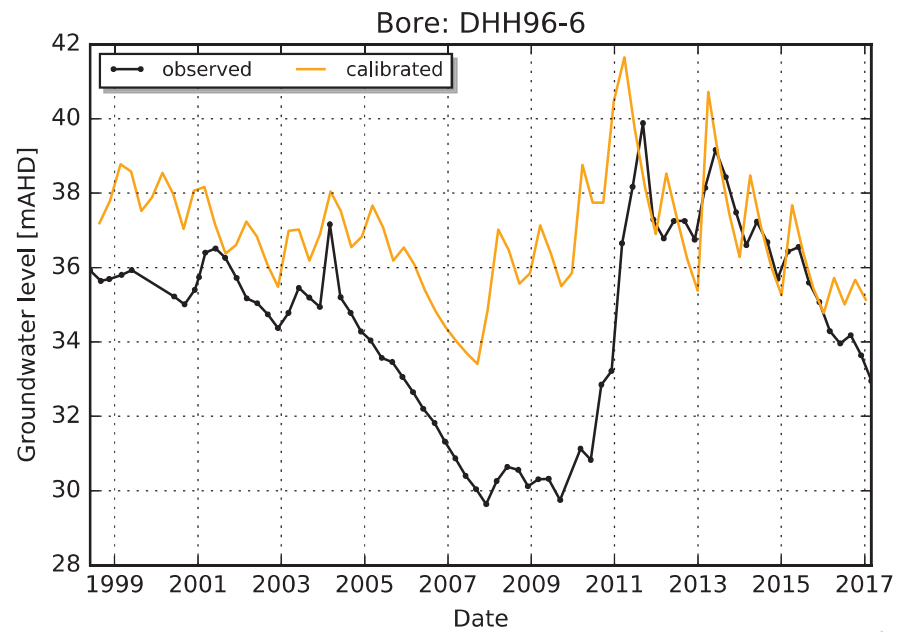
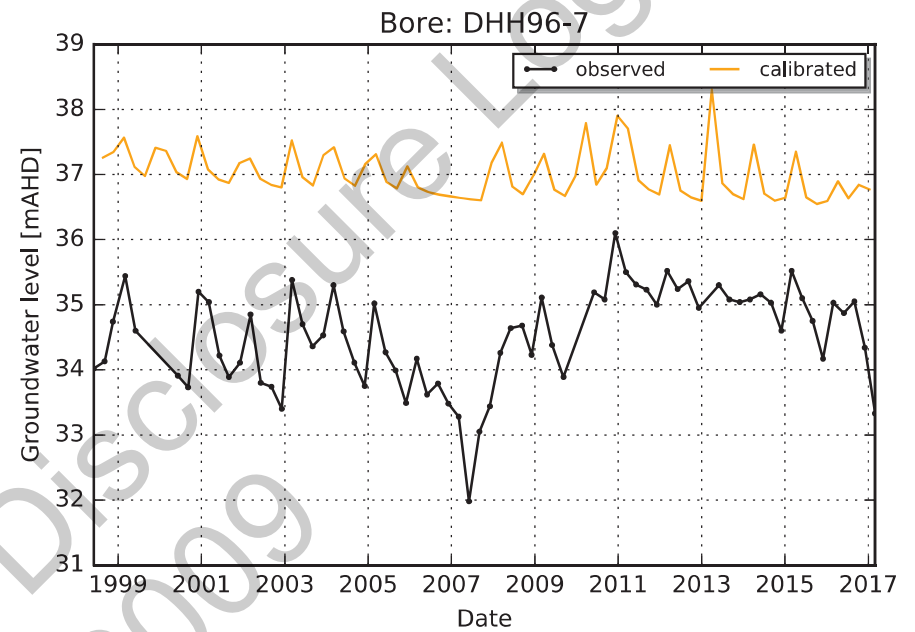
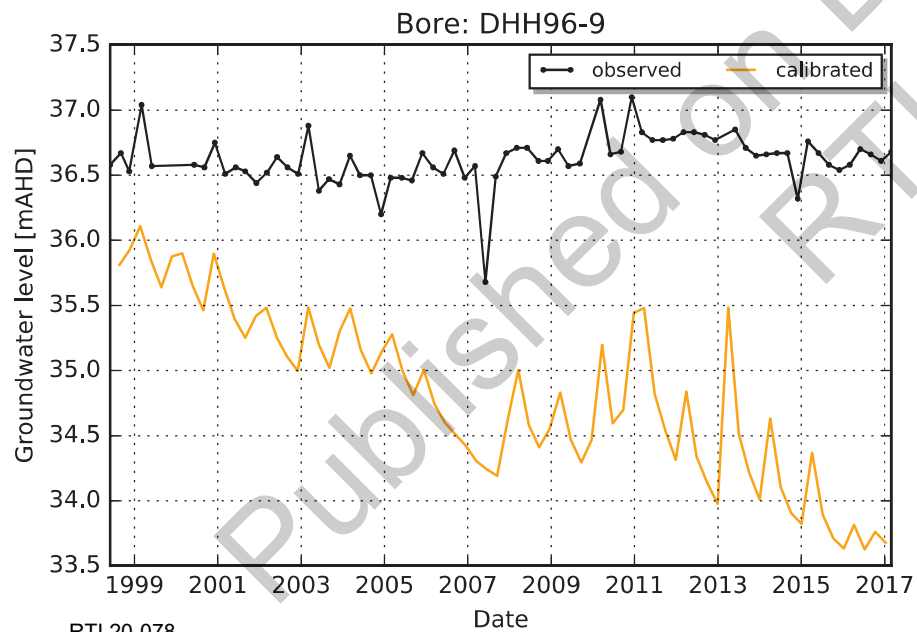
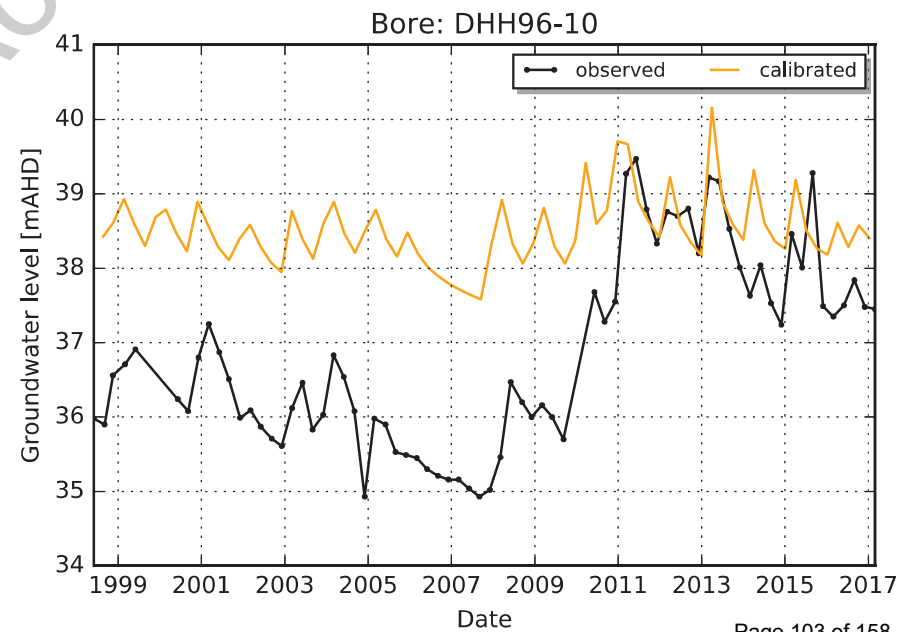
Validation plots

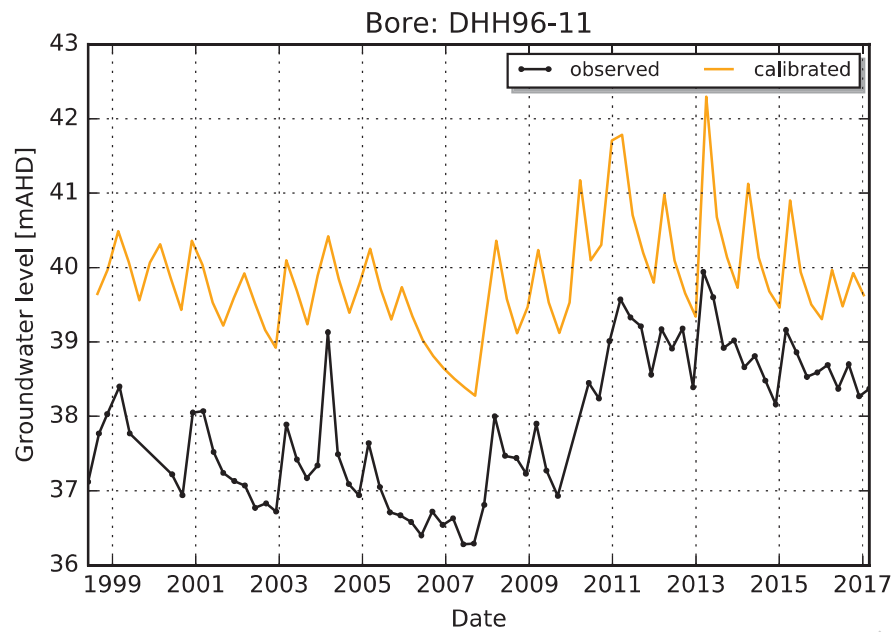
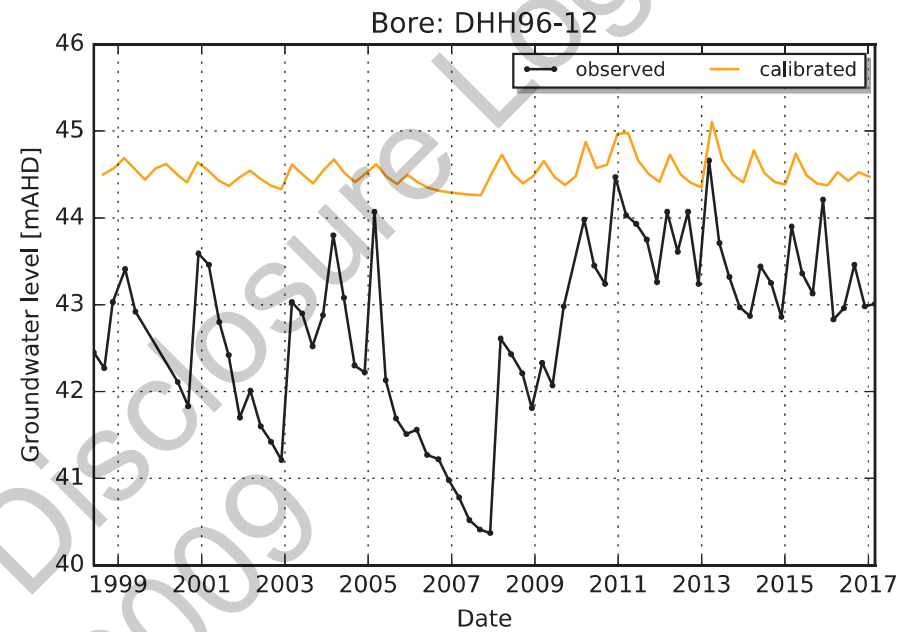
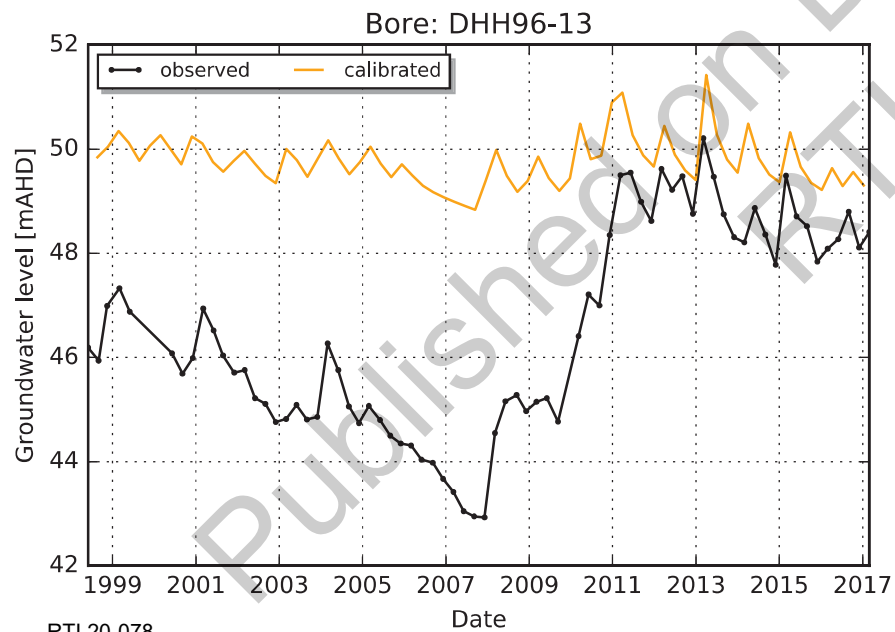
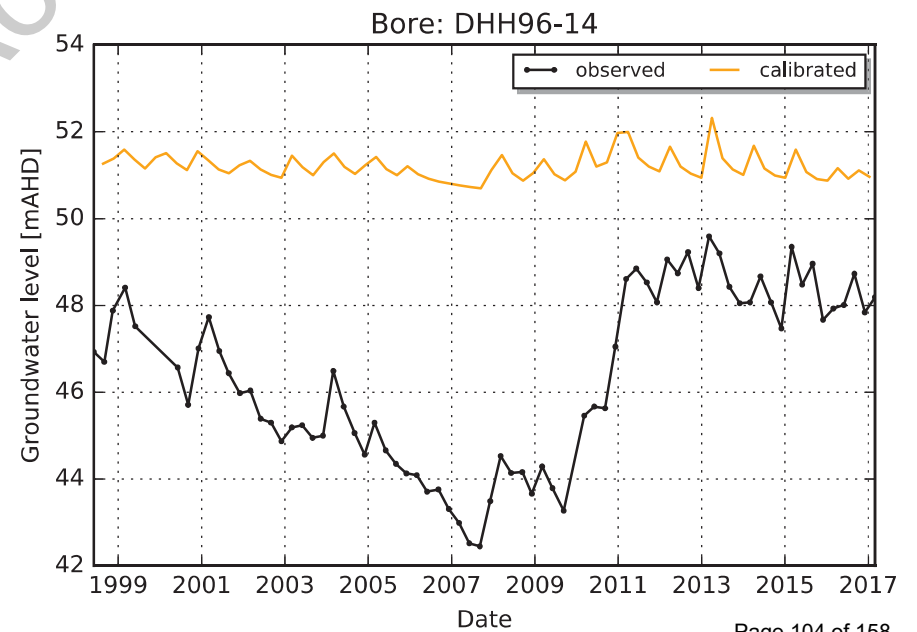


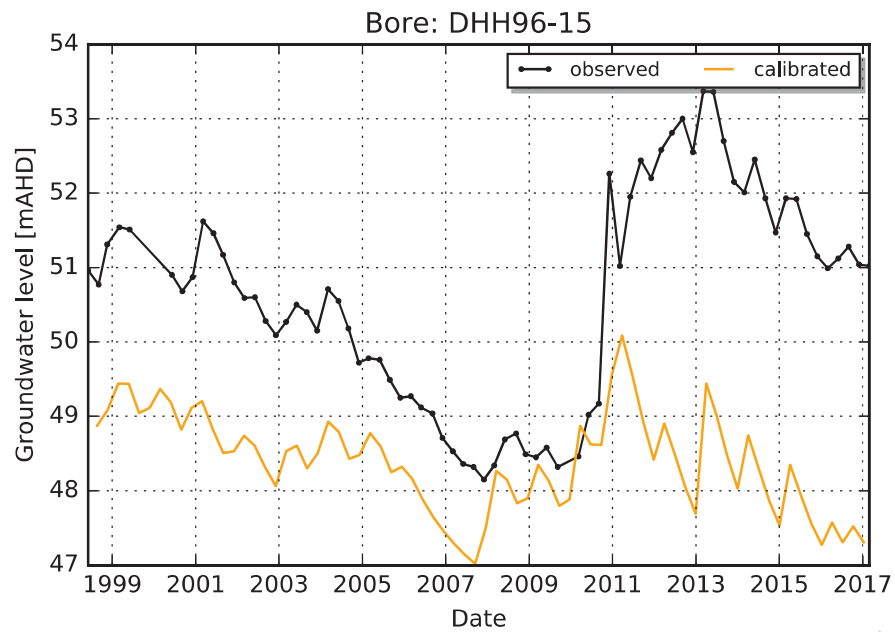
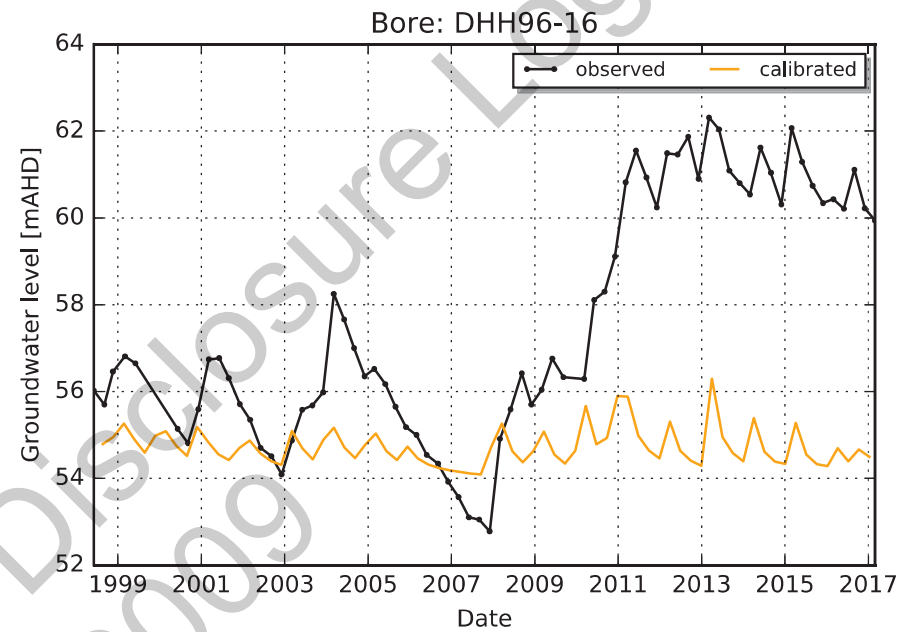
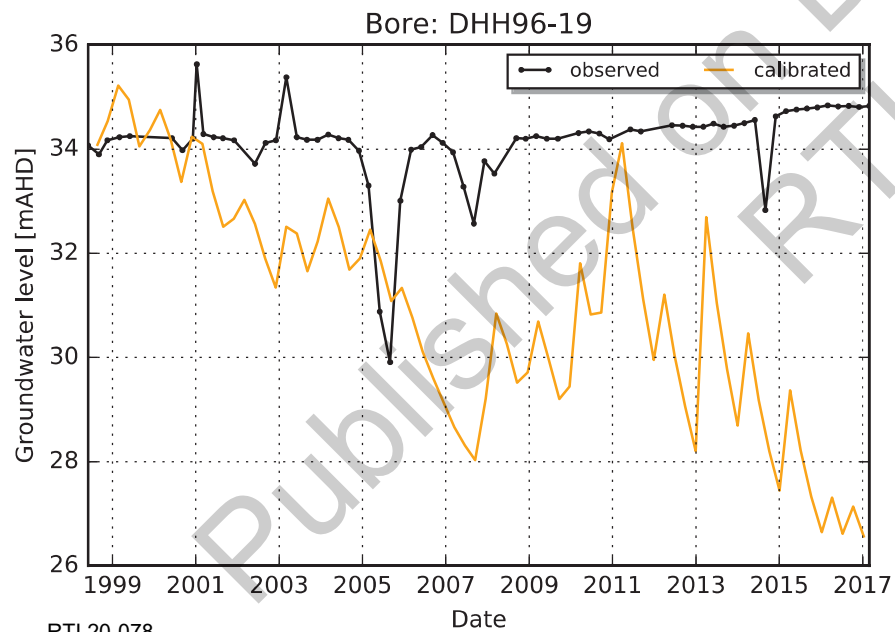
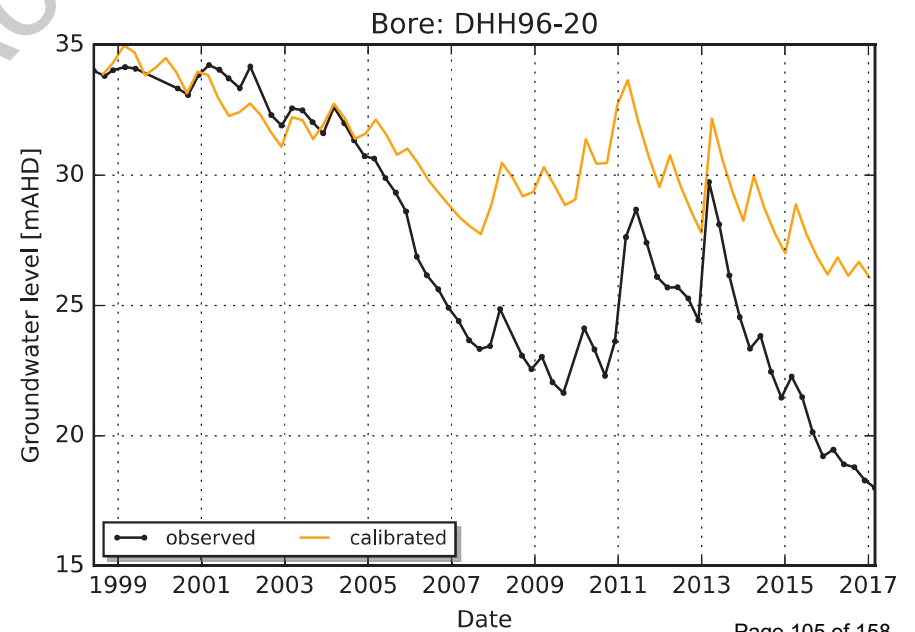


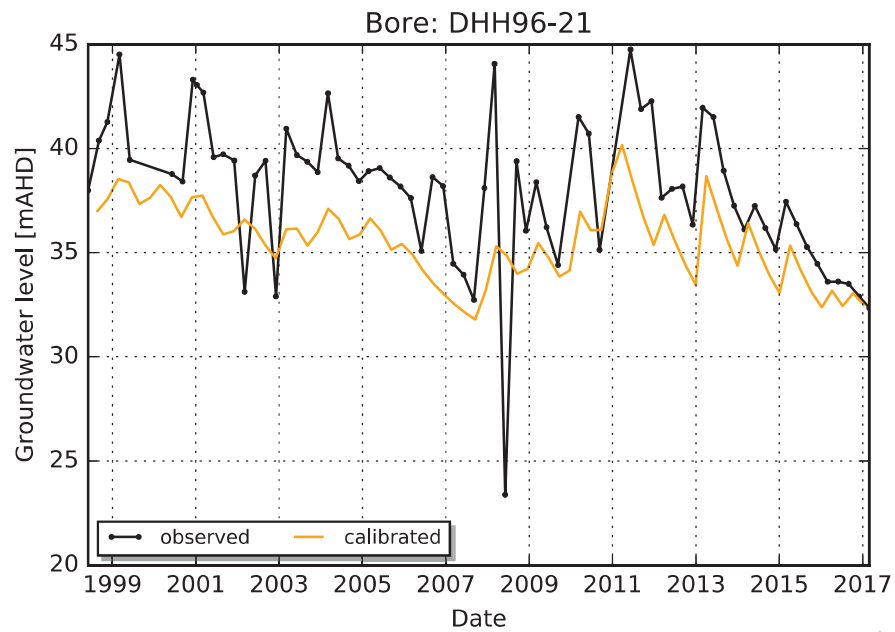
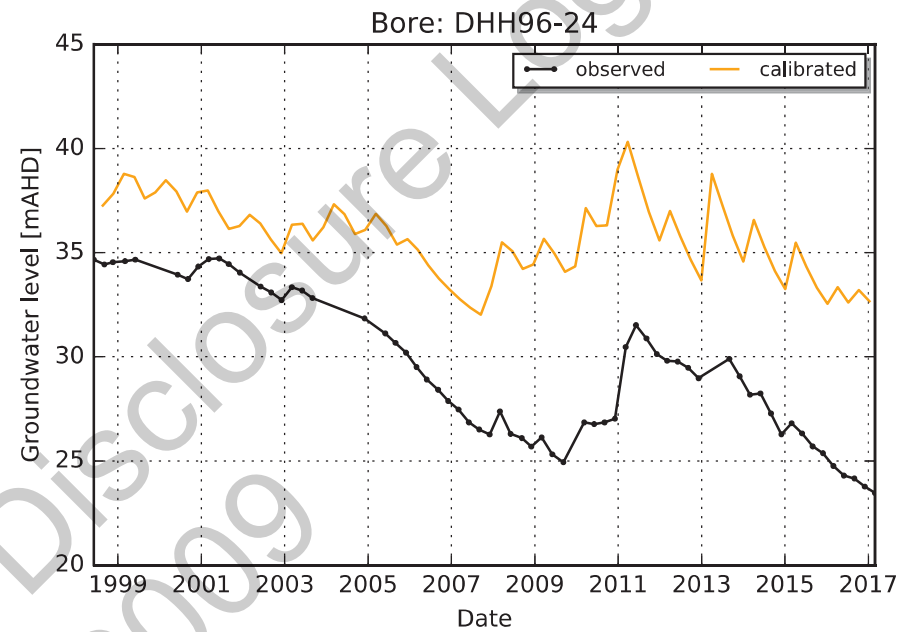
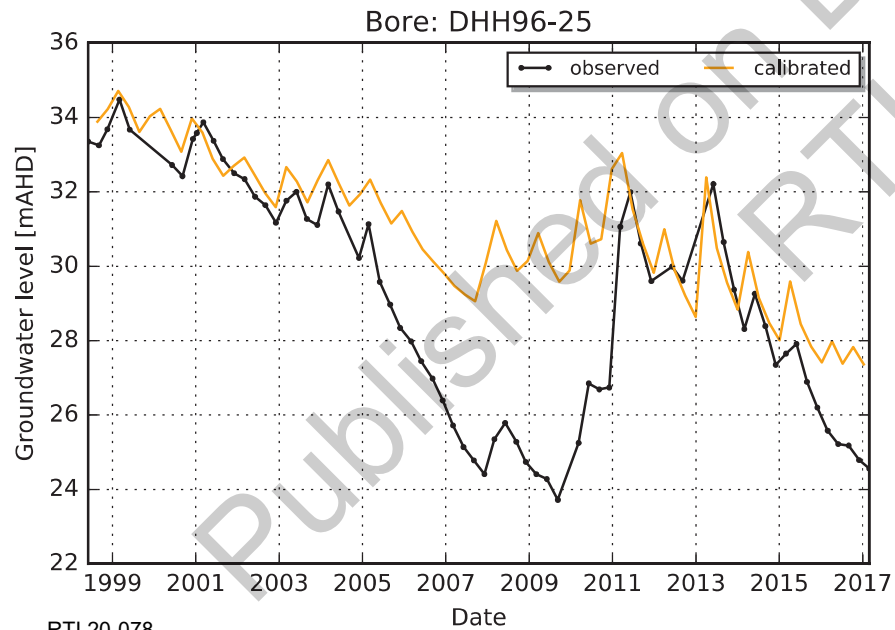
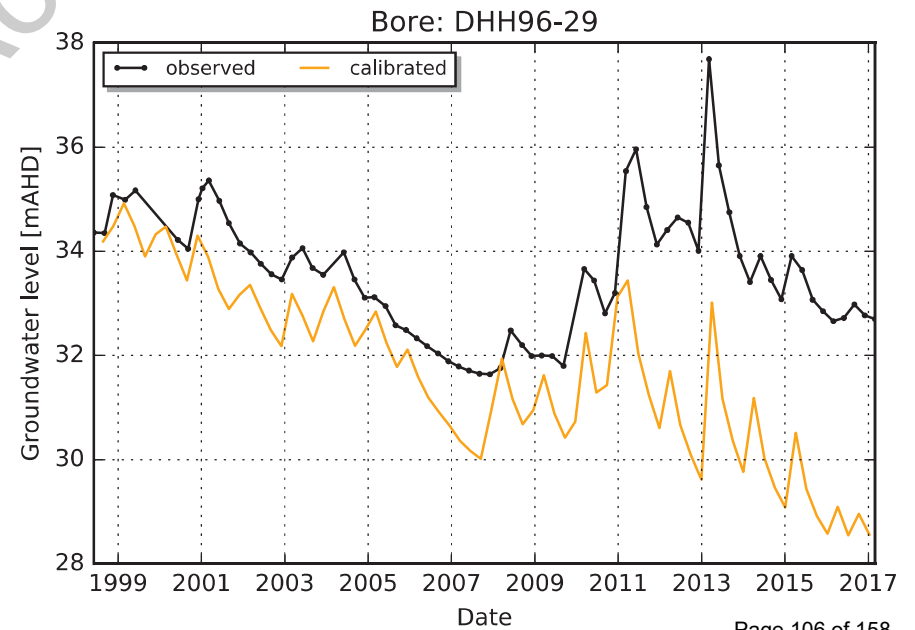


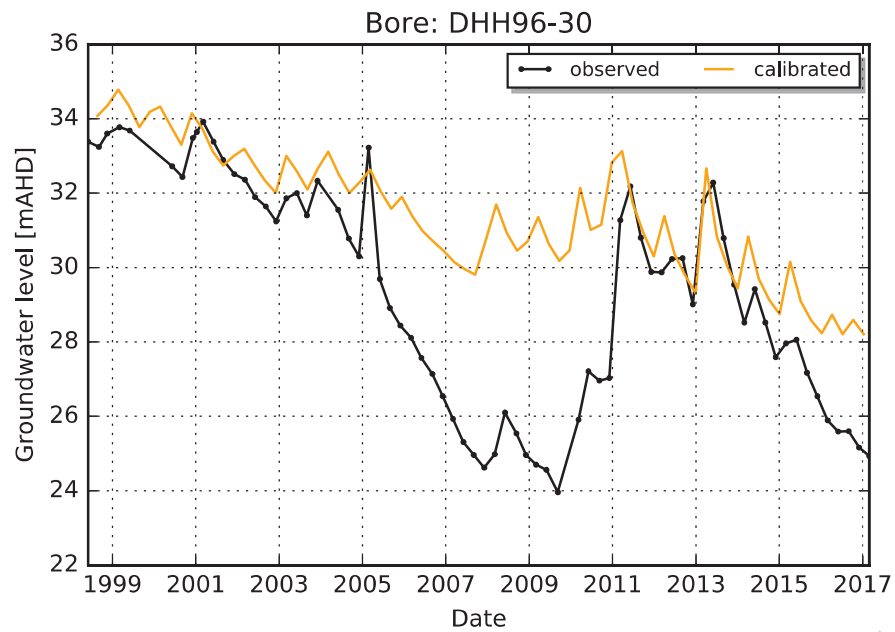
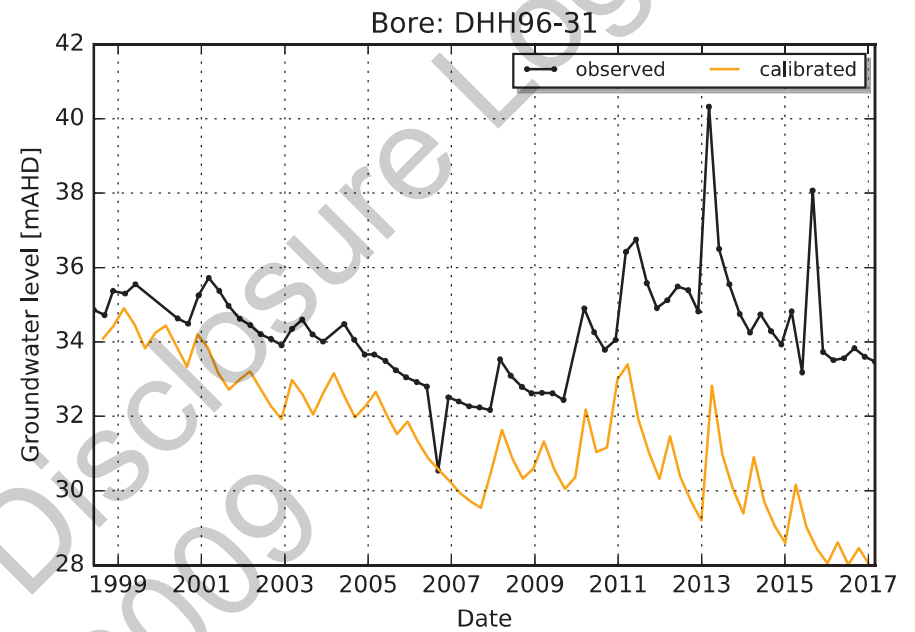
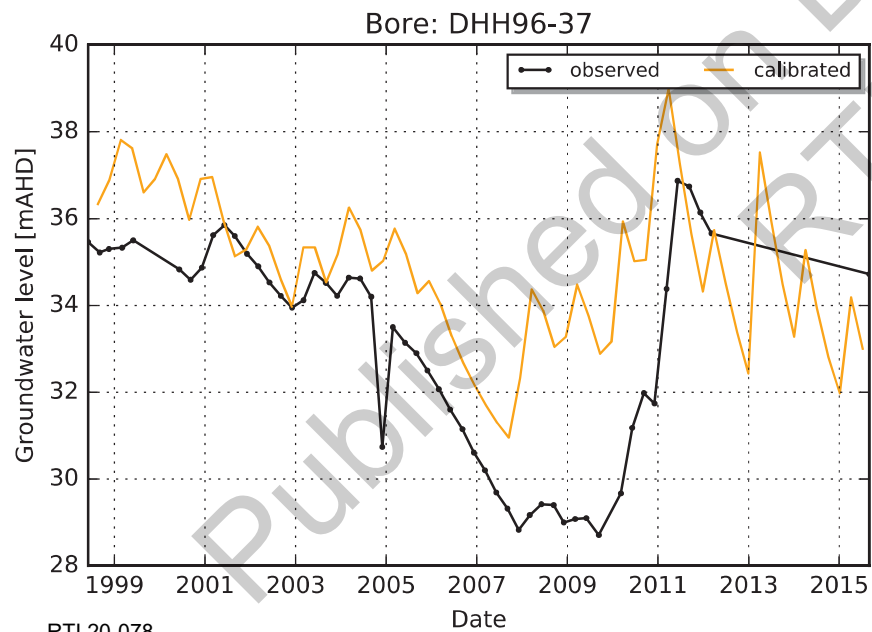
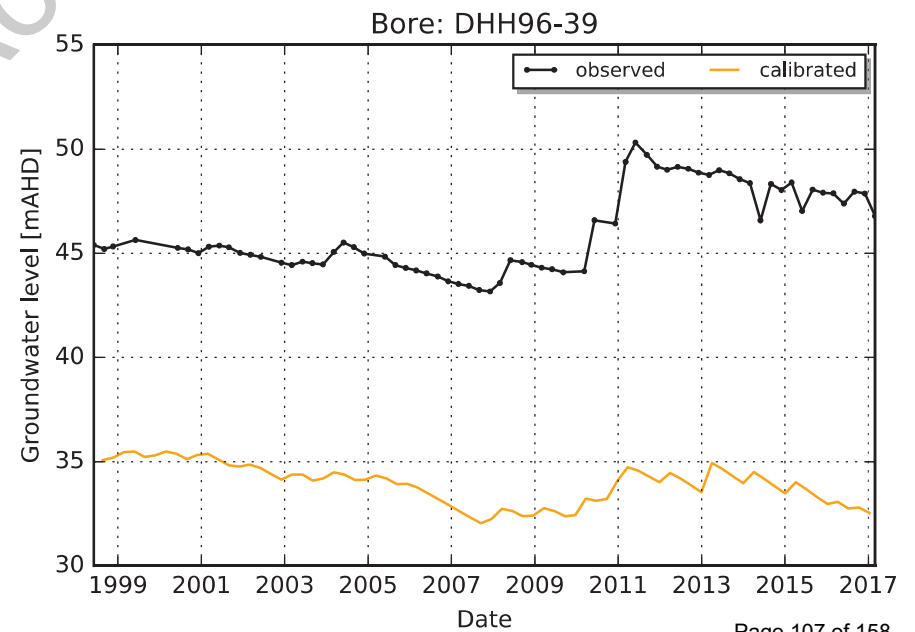


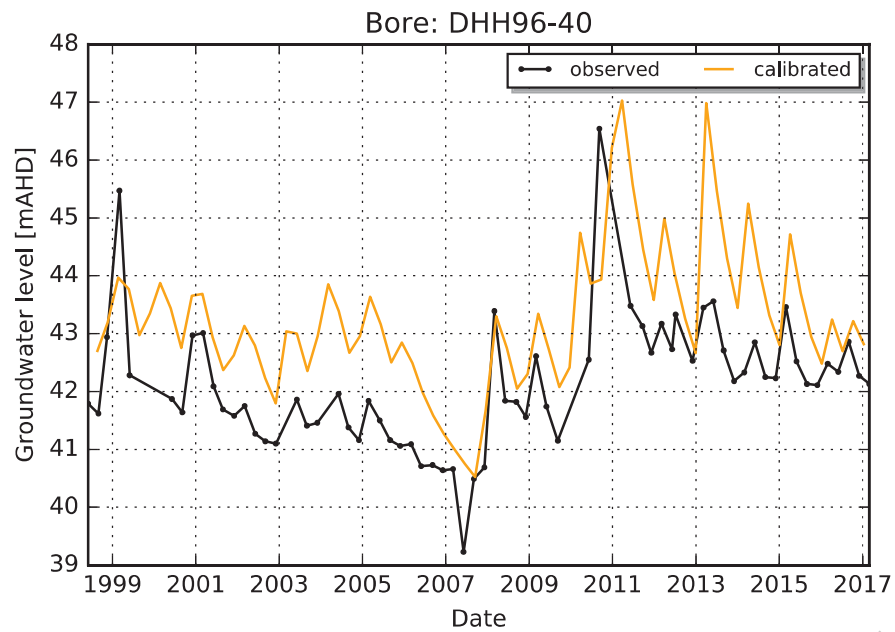
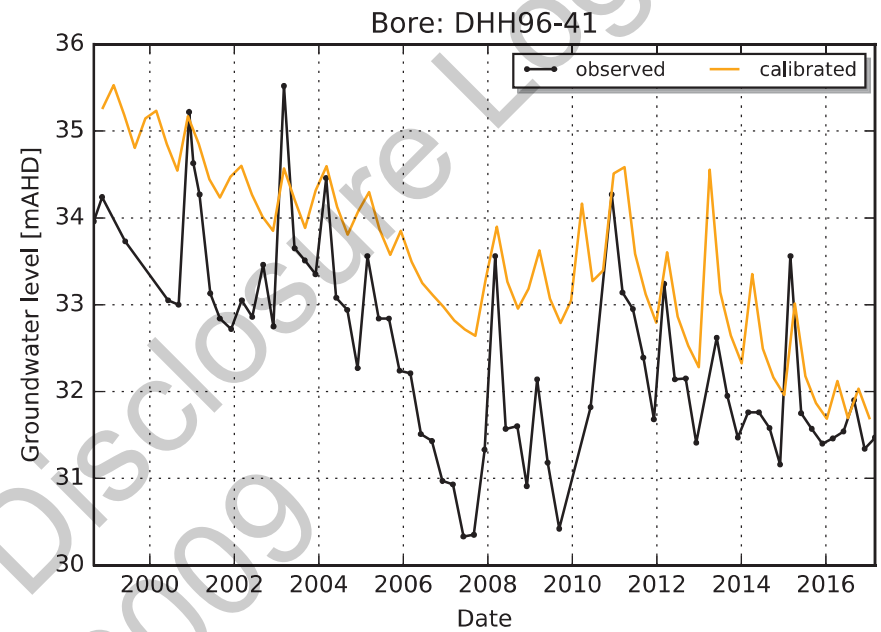
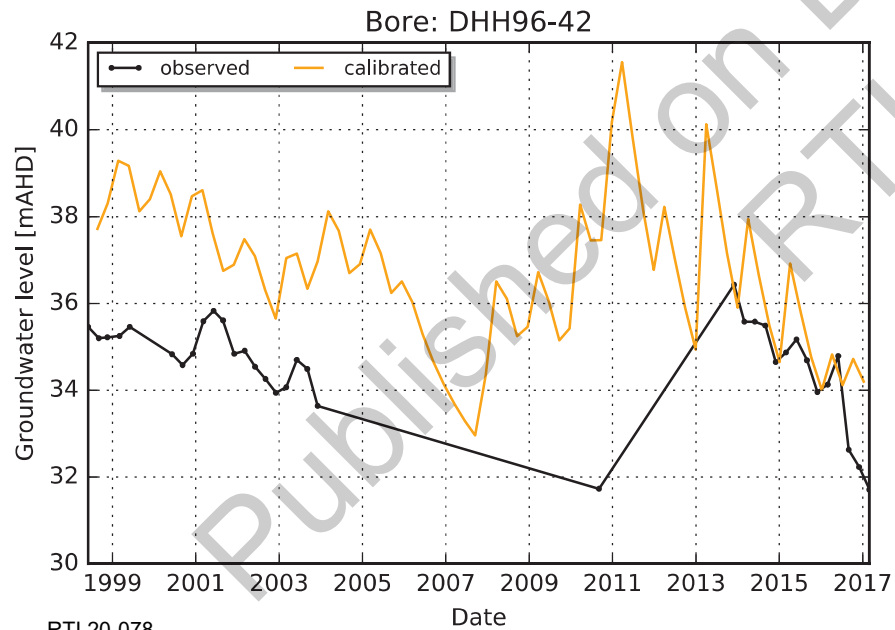
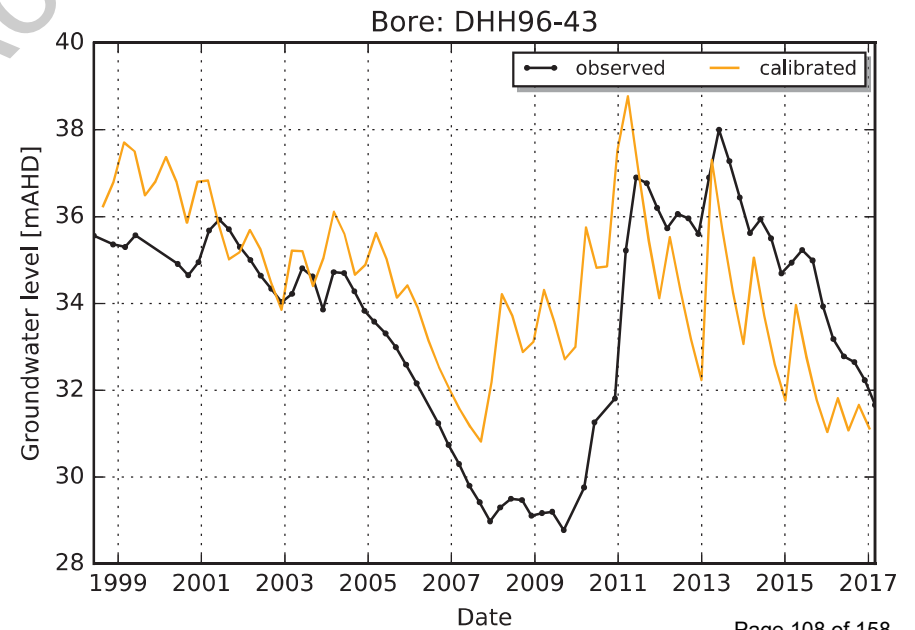


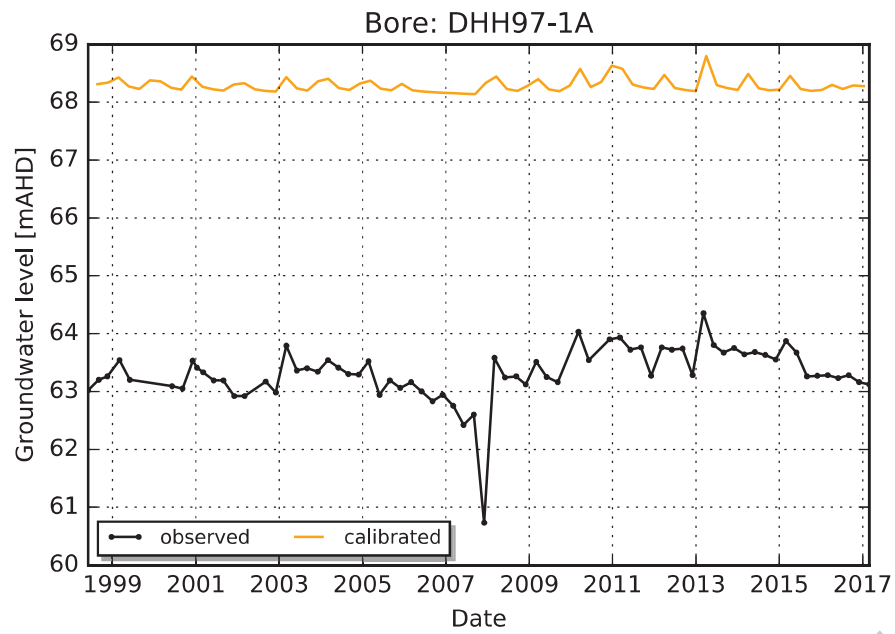
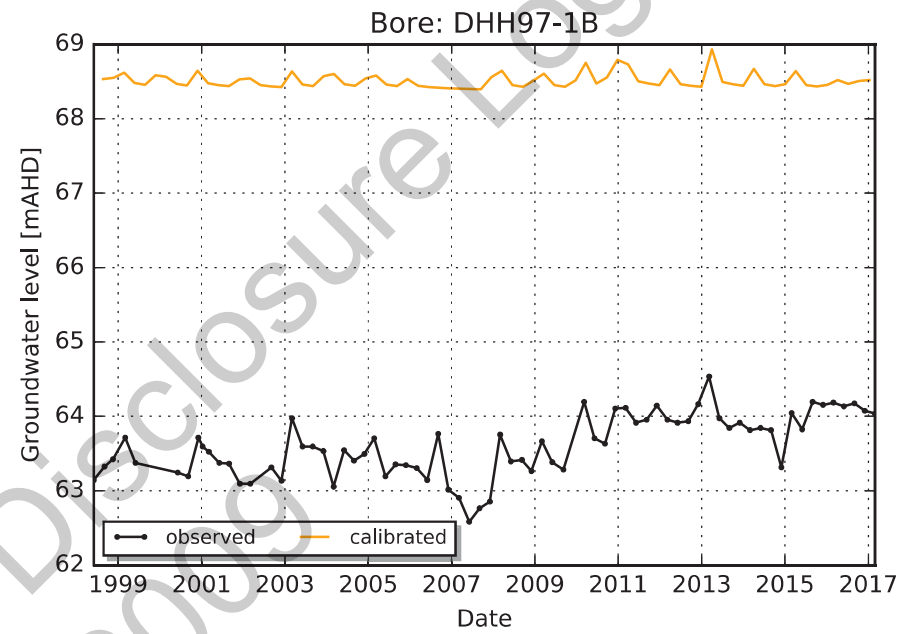
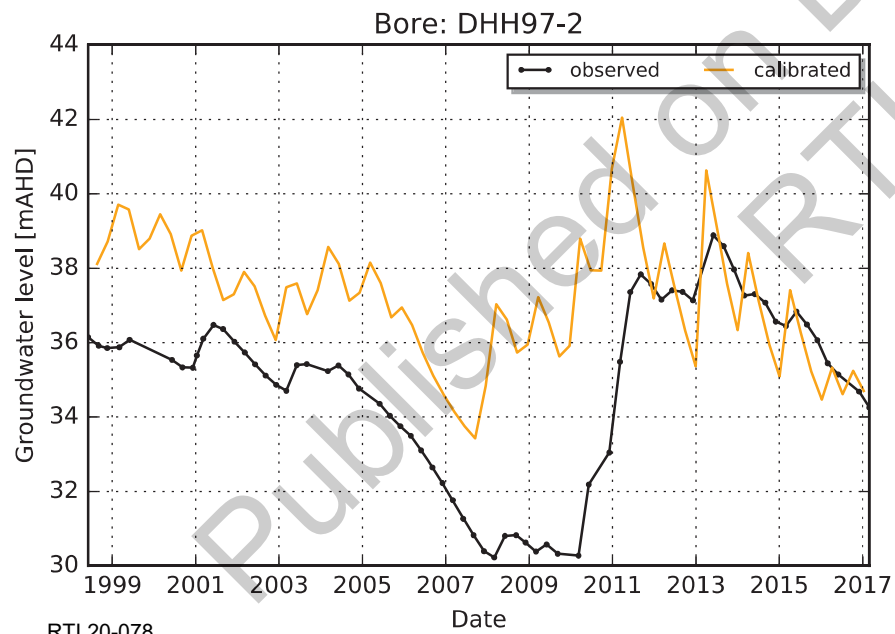
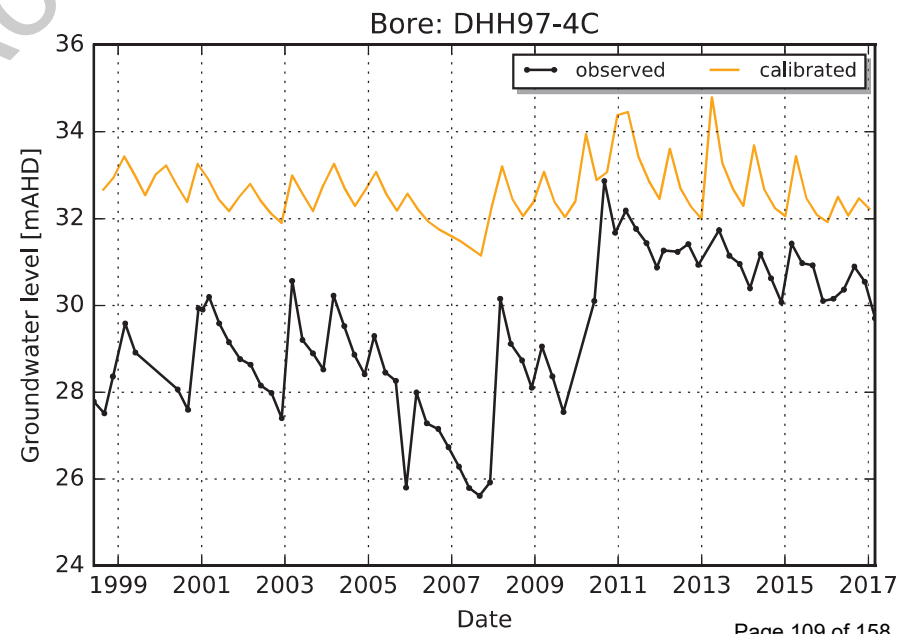


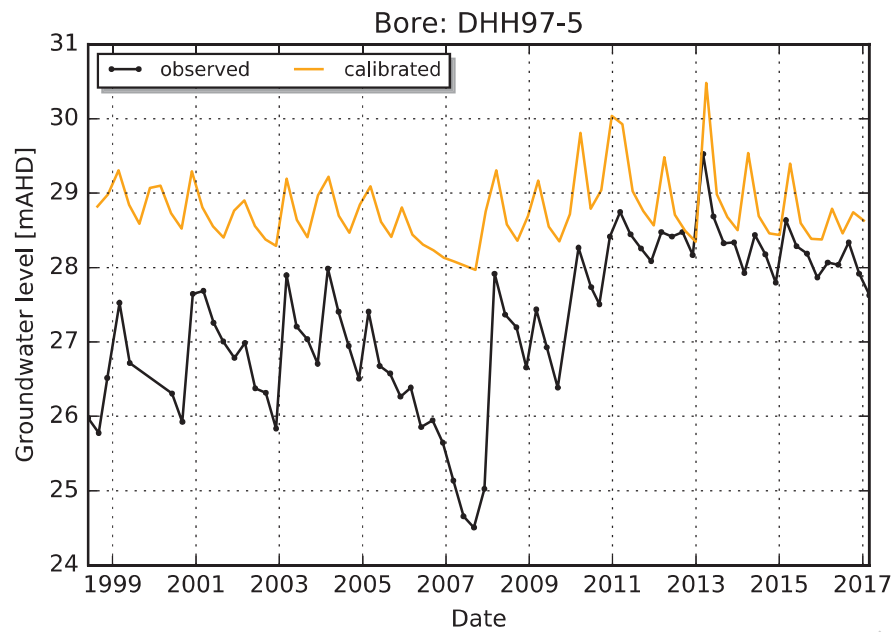
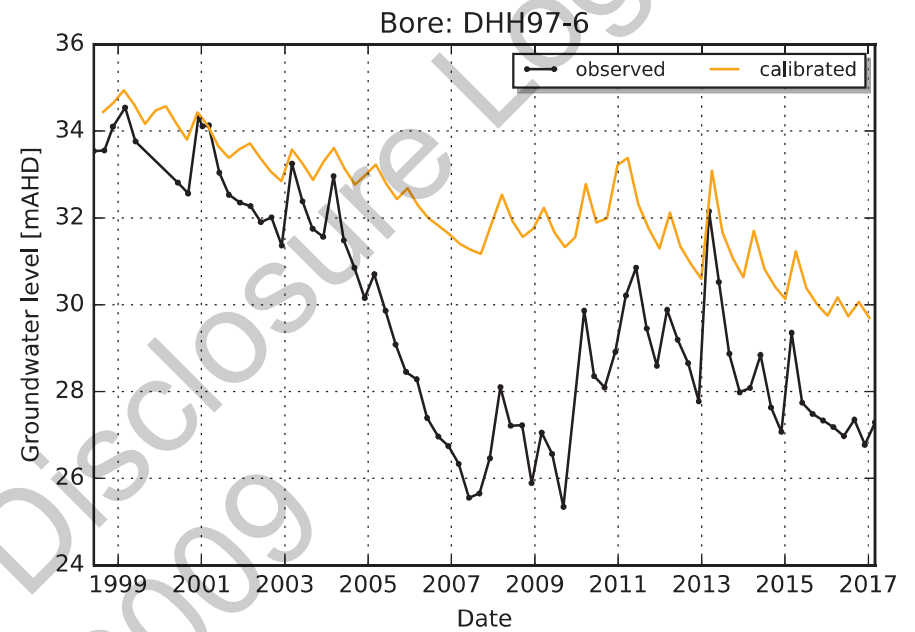
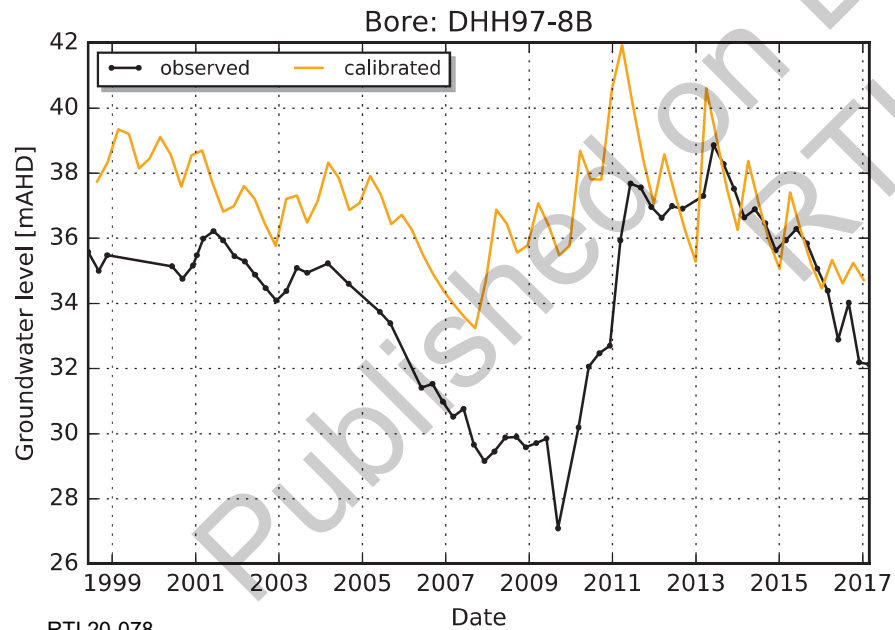
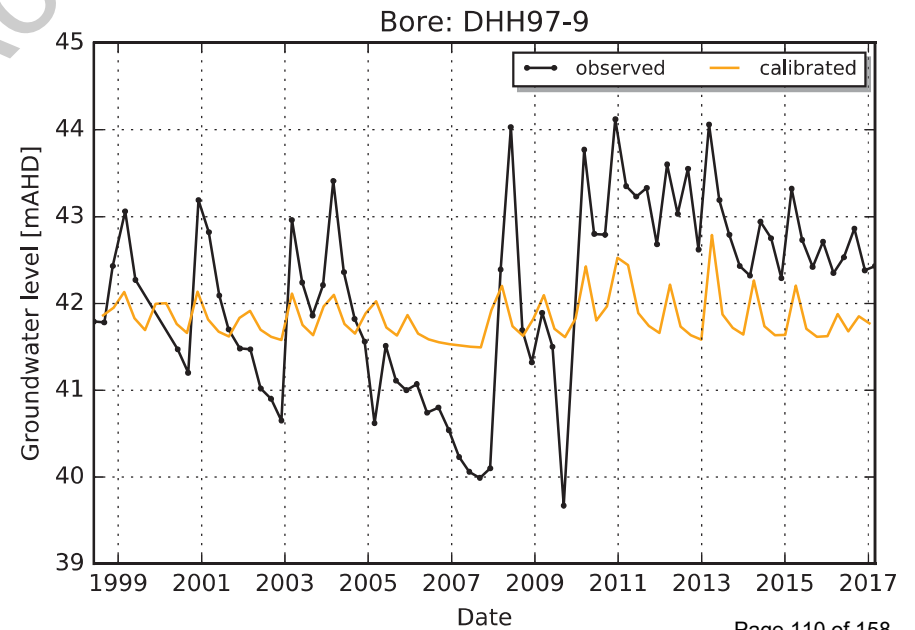


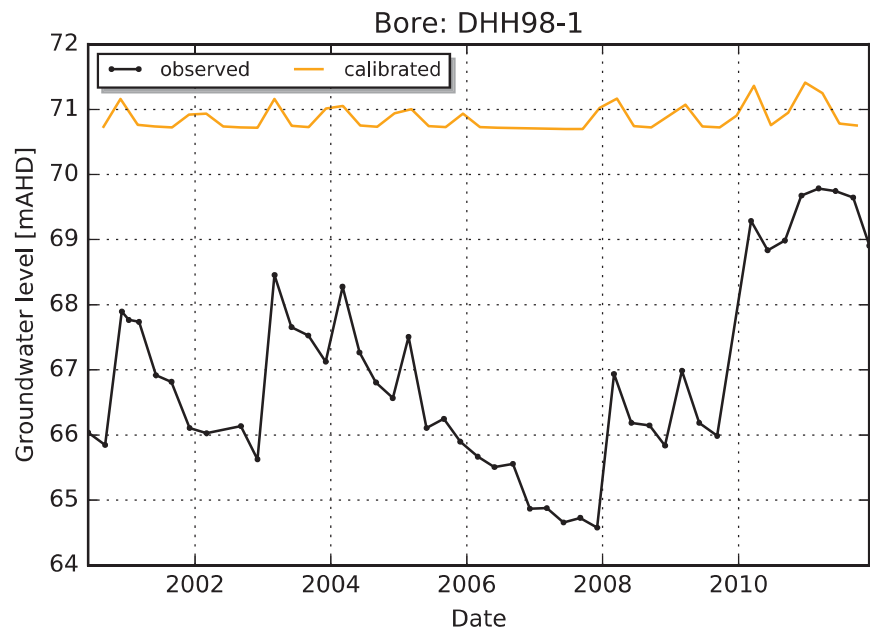
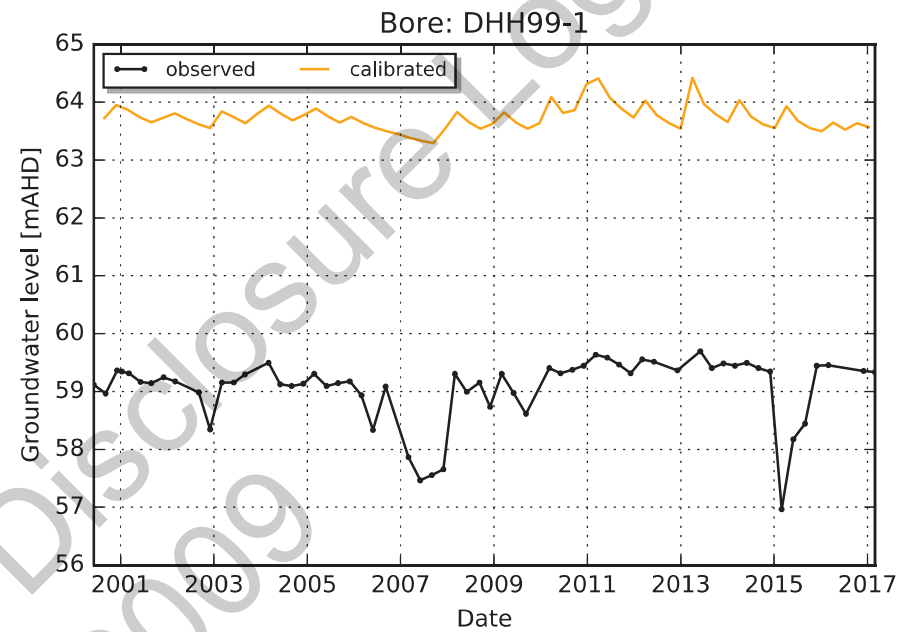
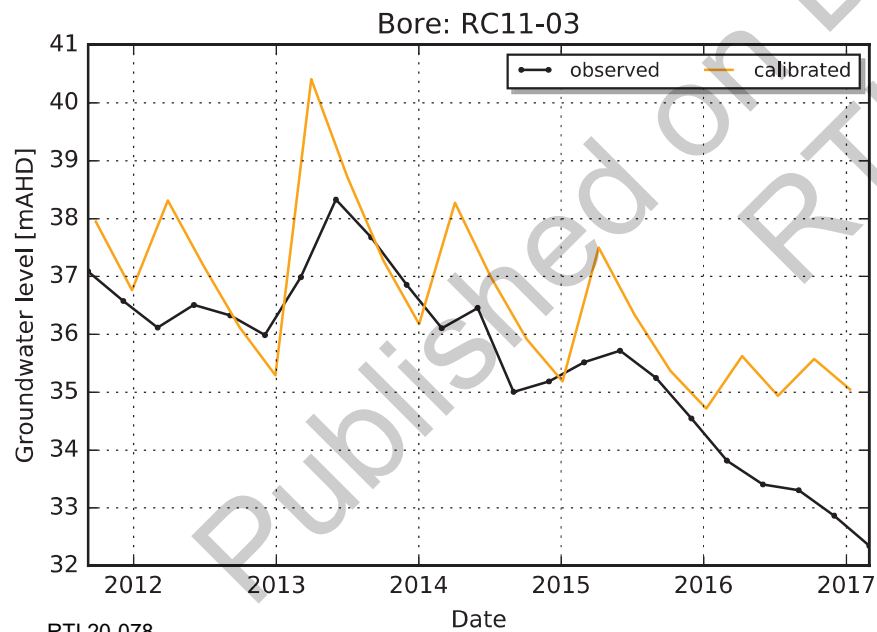
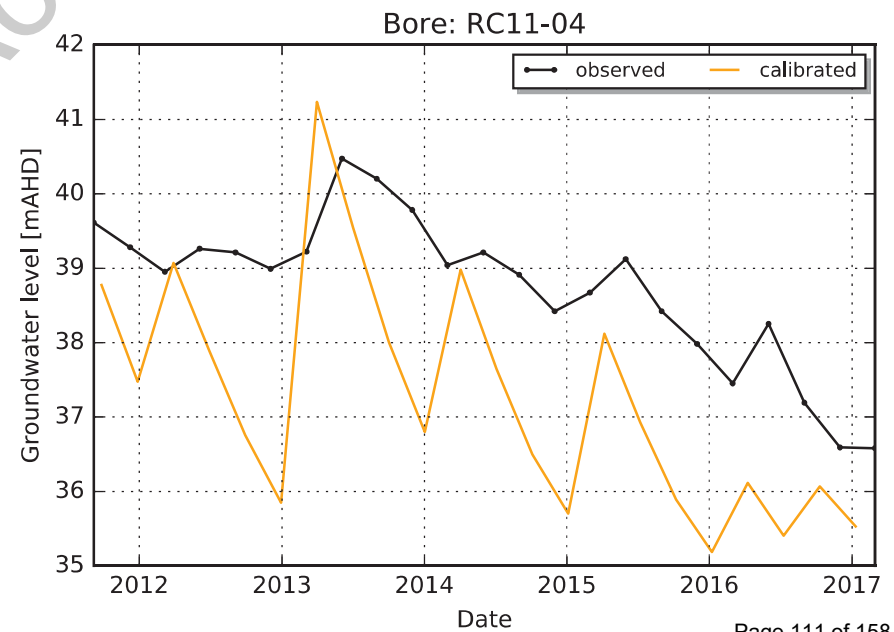


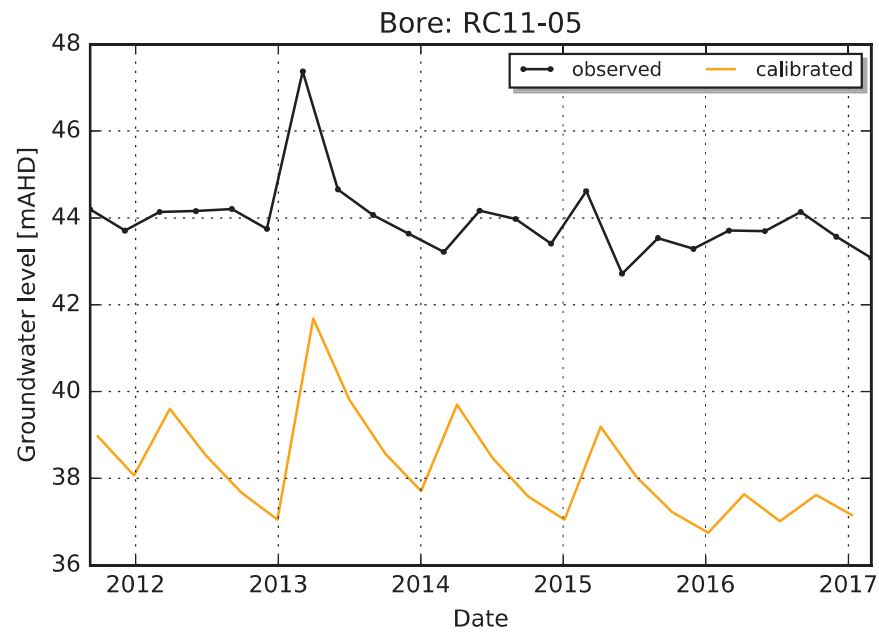
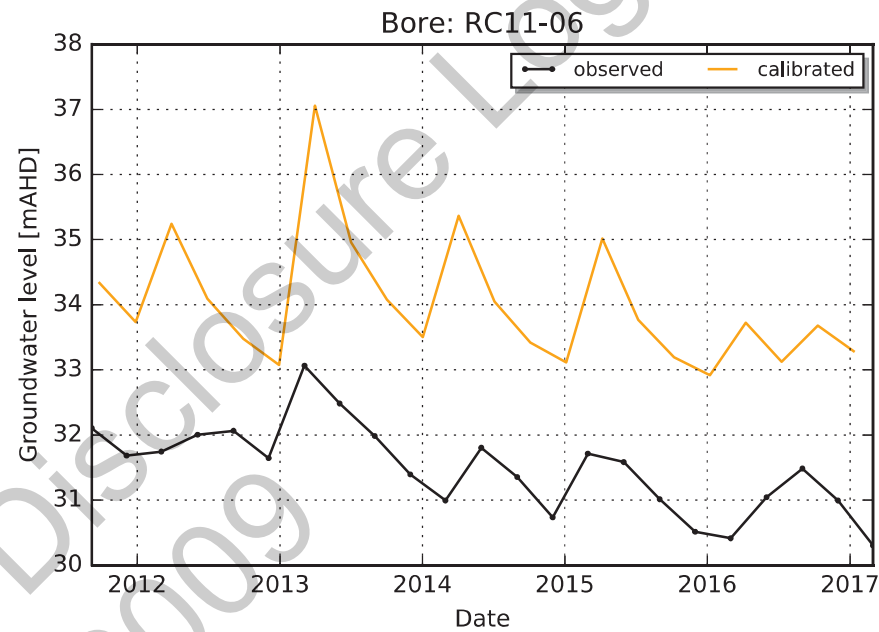
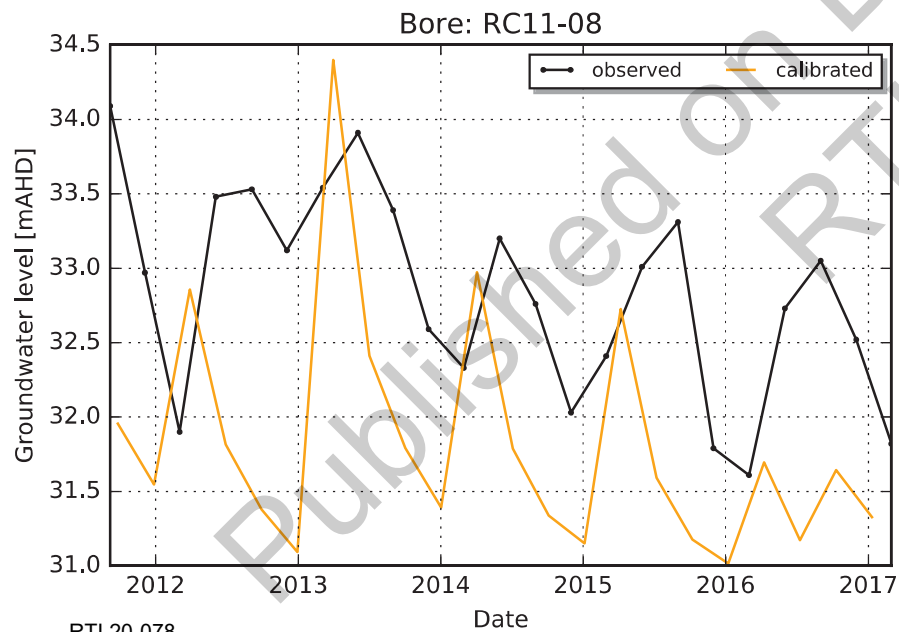
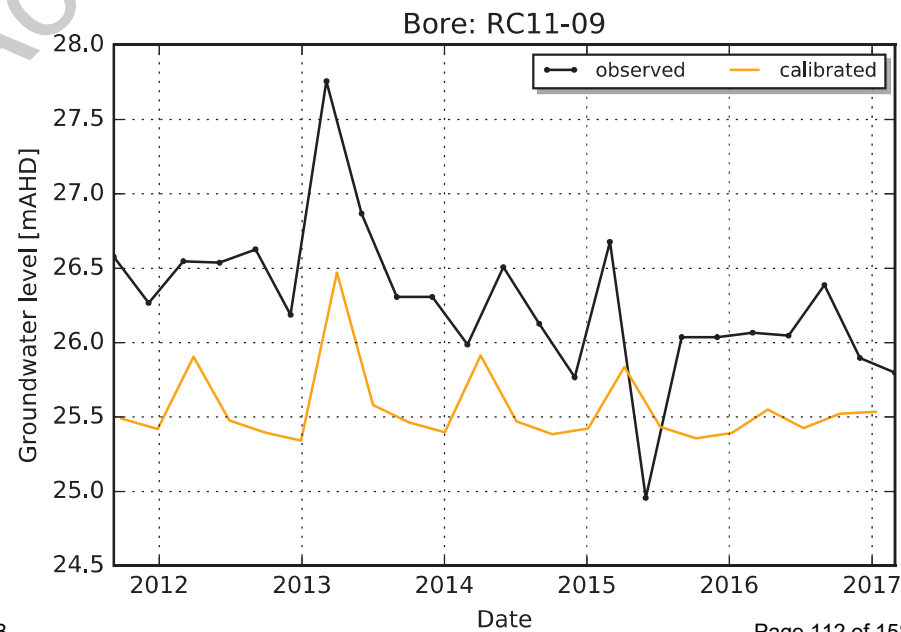


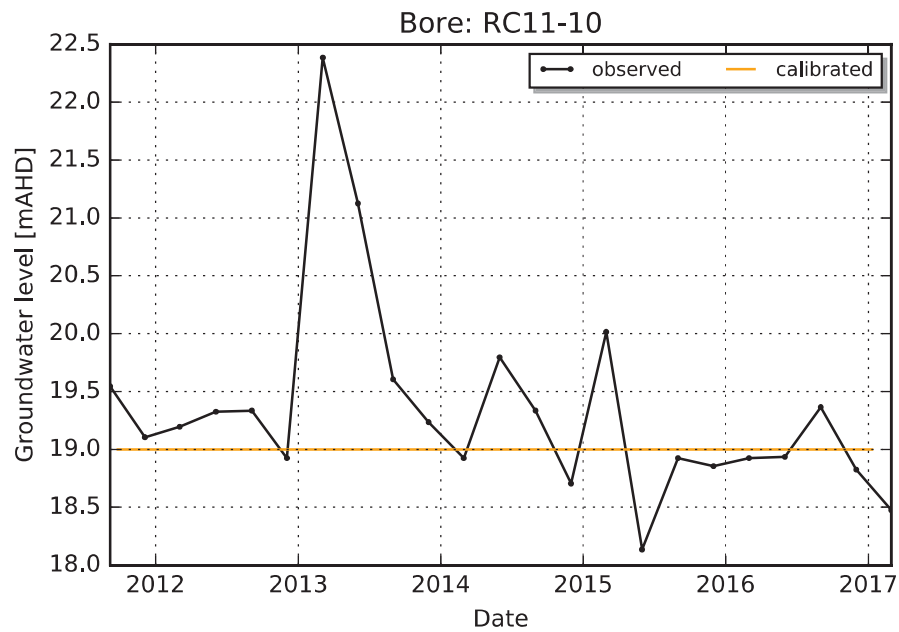
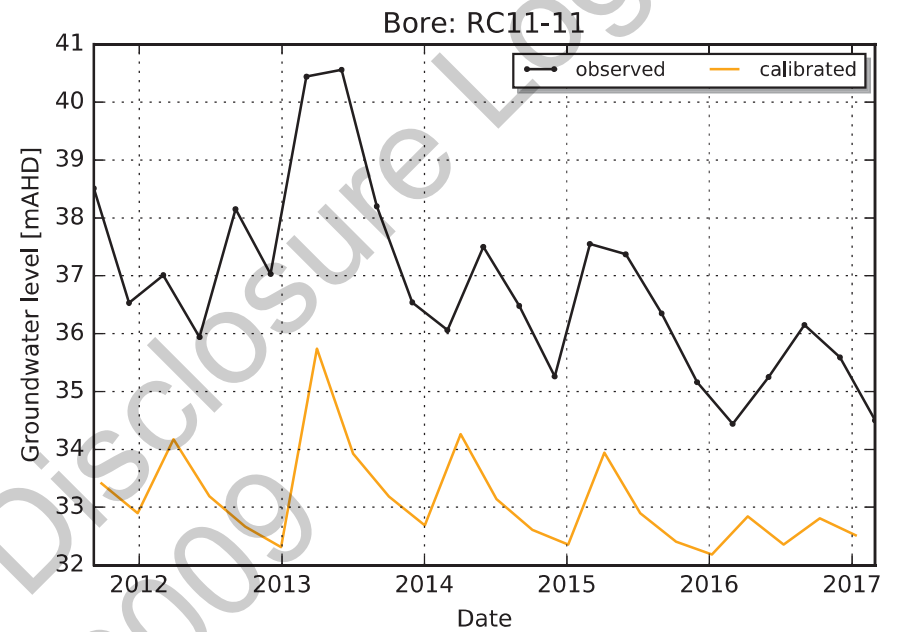
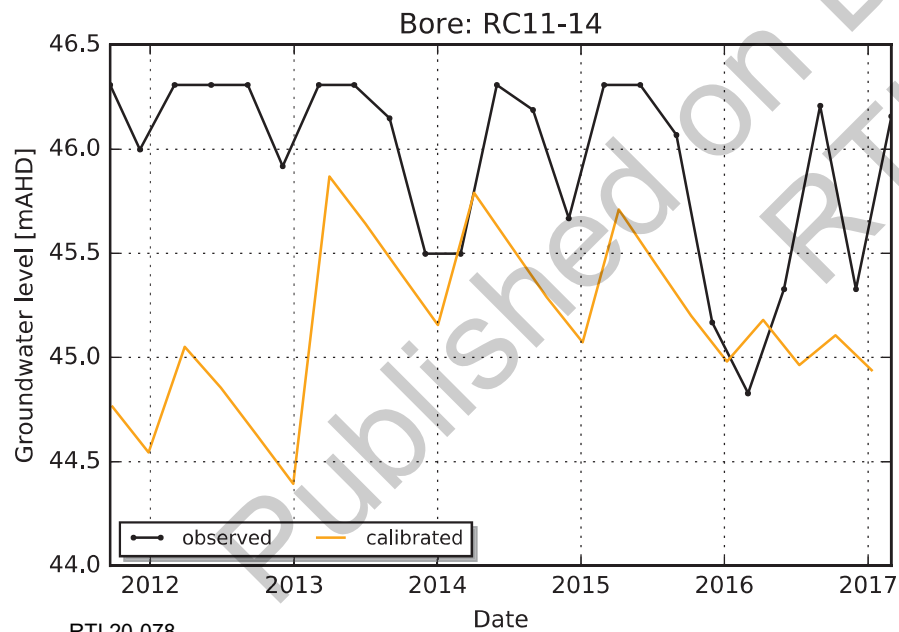
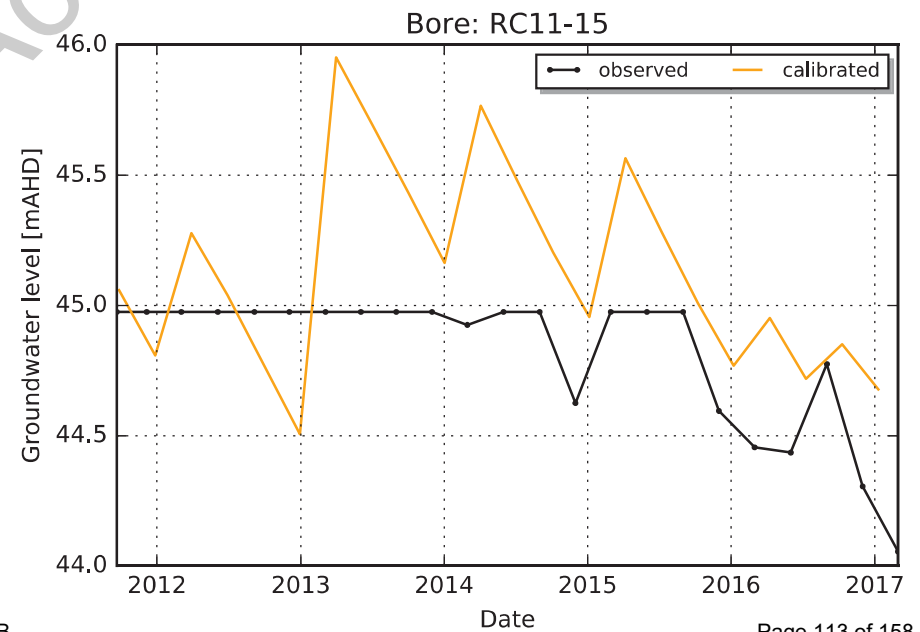


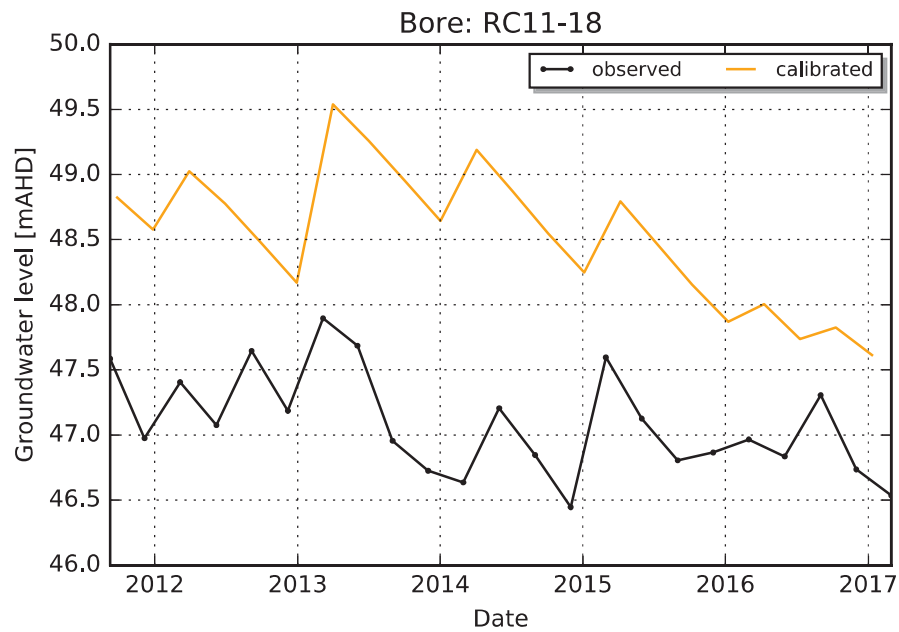
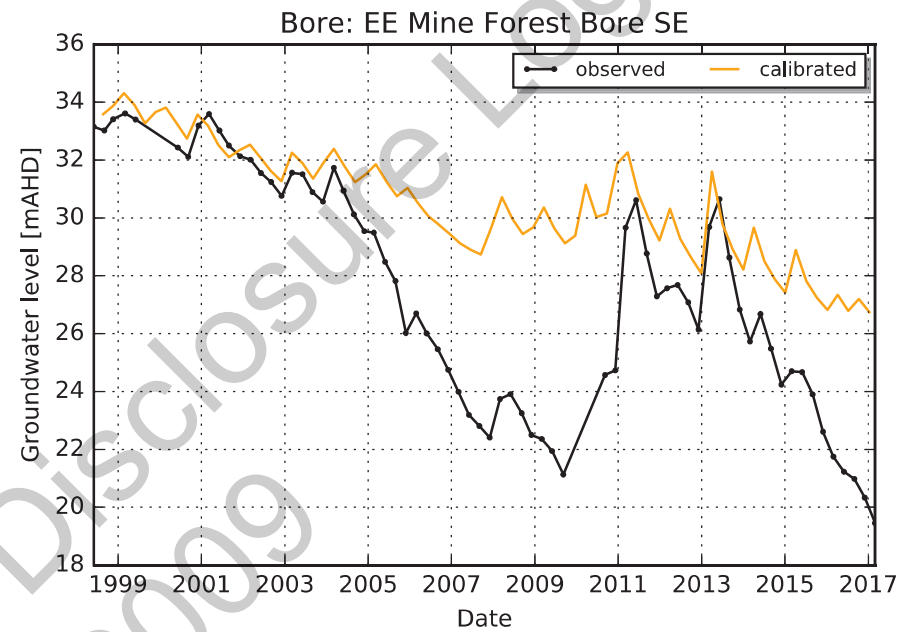
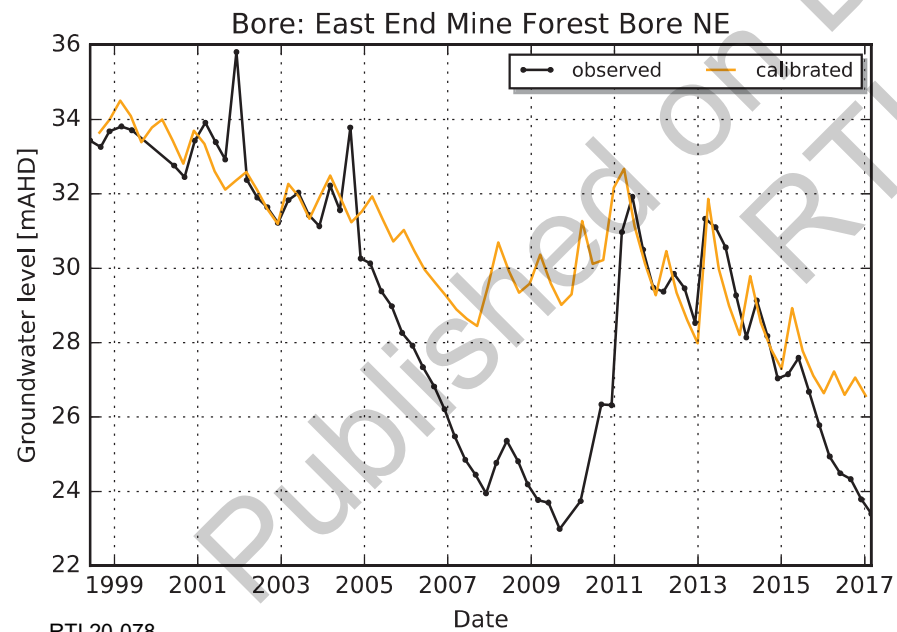












Appendix E

Time series for model validation – assessment and comments

Bore name	Pumped	Comments	Possible cause
B21	Major	Variability underestimated	Close to a steady state constant head boundary. Variability cannot be reflected
B23	Minor	Observed head between 55-65 mAHD, modelled:30-40 mAHD	Bore located at a boundary between zones. If the bore fell into the volcanics, the results would likely improve.
B38		Variability well reflected, calculated absolute levels too low	
B61	Major	Variability and calculated absolute levels too low	Bore located in the volcanics, but high pump rate, likely local higher hydraulic conductivity that cannot be calibrated separately within the zone
B78	Minor	Hydrograph not well matched. Level right in 1999-2001, then 20-30m too low	Bore located at a boundary between zones. If the bore fell into the volcanics, the results would likely improve.
B100 (HOLS)		Well matched in variability and level	
B101 (HOL N)		Well matched in variability and level	
B102		Well matched in variability and level	
B111	Minor	Variability and calculated absolute levels too high	Bore close to boundary, it might be a boundary effect
B122	Minor	Variability well reflected, calculated absolute levels too high	B122, B78 and B23 are located within 200m of each other and show very different levels. The zonal approach cannot match each of those bores to the same degree.
B123		Well matched in variability and level	
O3		Longest record Well matched in variability and level	
DHH96-1		Variability overestimated, levels underestimated	This bore is adjacent to a perched aquifer, which may be draining into groundwater. This may appear to be moderating water level fluctuations.
DHH96-2		Variability underestimated, levels underestimated	This bore is screened in a perched aquifer and the water levels are not indicative of the bedrock aquifer.
DHH96-4		Well matched in variability and level	
DHH96-5		Variability underestimated, absolute calculated levels matching well	
DHH96-6		Good match, dry period in 2004-2009 underestimated.	
DHH96-7	Minor	Calculated levels overestimated by 3m	Steady state pump in the model (no variation) and close to Scrub Ck (also steady state in the model)
DHH96-9	Minor	Observed hydrograph varies between 36.5 and 37 m AHD, whereas the calculations show a 2m decline over 20 years.	Potentially the anisotropic nature or a local feature would block this flow in reality.
DHH96-10	Minor	Good match, follows climate nicely	
DHH96-11	Minor	Good match for after 2011, overestimates levels before that	
DHH96-12		Too little variation in the calculated timeseries. Overall level well matched.	
DHH96-13		Too little variation in the calculated timeseries. Overall level after 2011 well matched.	Bore located at zone boundary between volcanics and limestone.
DHH96-14		Too little variation in the calculated timeseries. Overall level overestimated.	Bore located at zone boundary between volcanics and limestone.
DHH96-15		Variability too low, levels too low.	Bores located in a thin transition zone of volcanics and Limestone. Might be local effect
DHH96-16		Variability too low, levels too low.	Bores located in a thin transition zone of volcanics and Limestone. Might be local effect

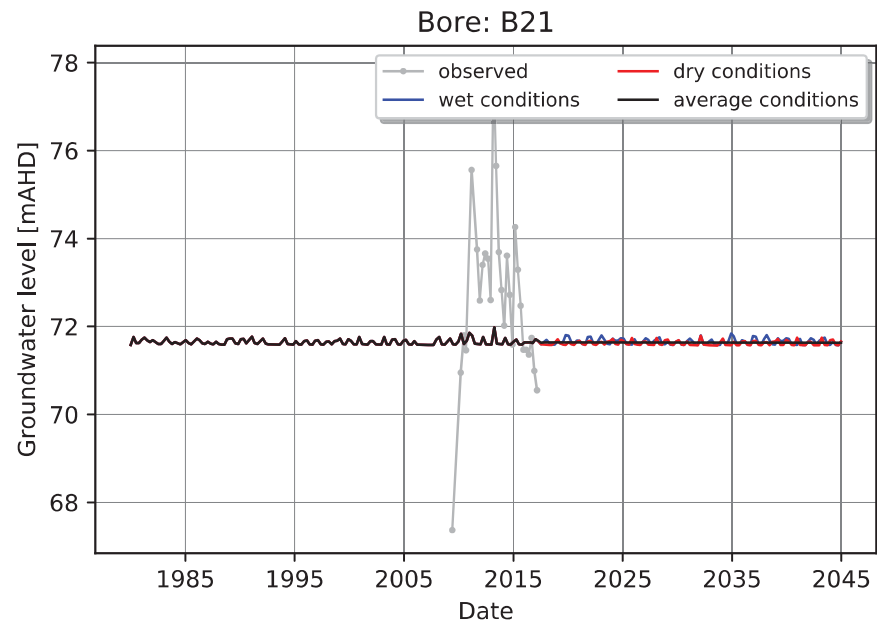
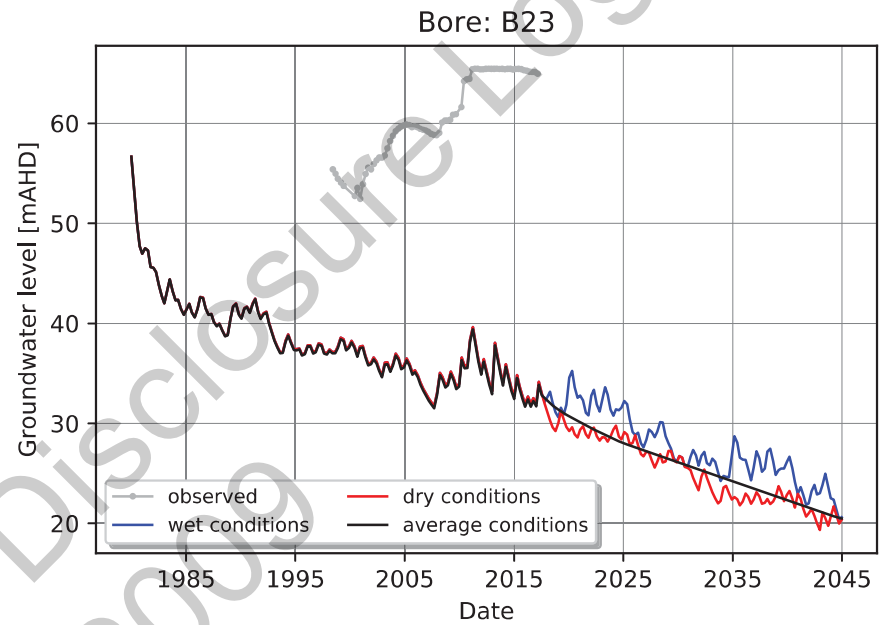
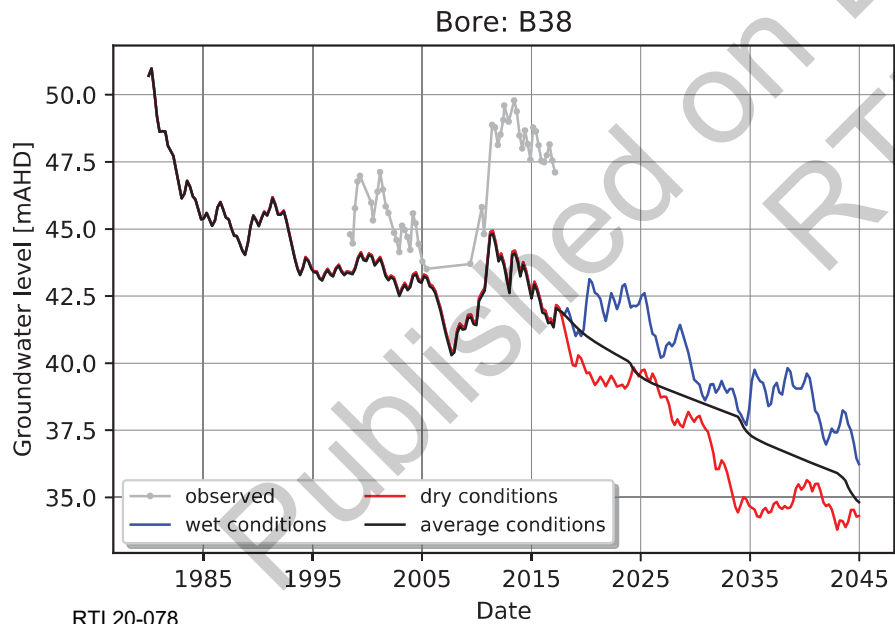
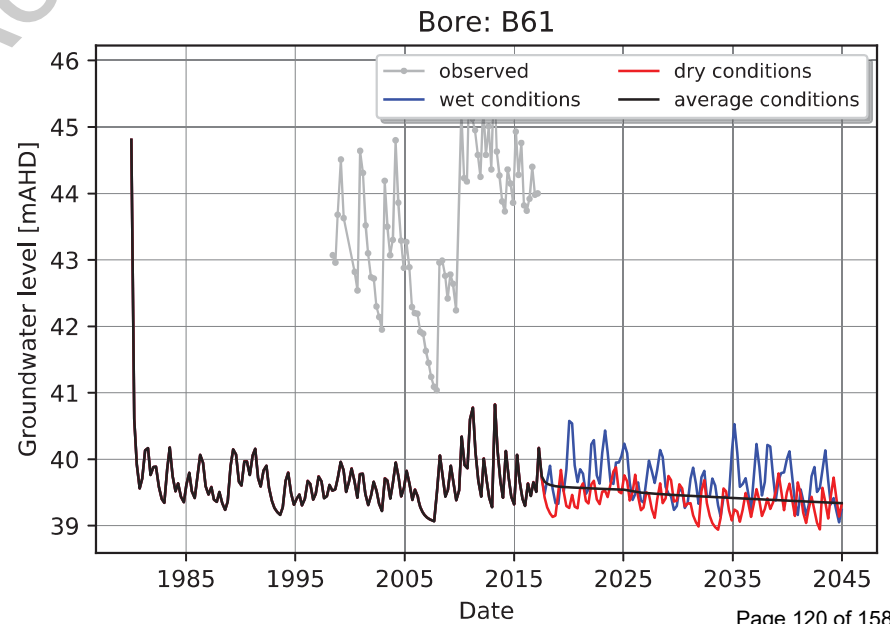
Bore name	Pumped	Comments	Possible cause
DHH96-19	Minor	Variability overestimated, levels underestimated	DHH96-19 and DHH96-20 are located 200m away from each other. DHH96-19 shows constant levels at 34-35 mAHD, whereas levels in DHH96-20 decrease to 20m AHD. With the zonal approach, these local differences cannot be matched
DHH96-20		Variability well matched, levels 199-2005 well matched, then mining influence overestimated	See above
DHH96-21	Minor	Variability and levels well matched	
DHH96-24	Medium	Variability well matched, levels overestimated	Unknown
DHH96-25		Variability and levels well matched, with exception of the dry period	
DHH96-29	Major	Variability and levels well matched until 2011, then level underestimated	Pump might have been deactivated in 2011 (in reality, still going in the model) Mining impact after 2011 in the model, which is not observed in reality.
DHH96-30		Variability and levels well matched, with exception of the dry period	
DHH96-31	Minor	Variability and levels well matched until 2011, then level underestimated	(same as DHH96-26, also close to that bore) Pump might have been deactivated in 2011 (in reality, still going in the model) Mining impact after 2011 in the model, which is not observed in reality.
DHH96-37	Medium	Variability and levels well matched	
DHH96-39	Minor	Variability well matched, levels 10 m to low.	This bore is in the volcanics (low hydraulic conductivity) and is pumped. This is a local drawdown.
DHH96-40	Medium		
DHH96-41	Minor	Variability and levels well matched	
DHH96-42		Gap in observations. Otherwise well matched	
DHH96-43		Variability and levels well matched	
DHH97-1A		Variability too low, levels too high.	Volcanic zone estimate might be too low in this region. Also dependent on steady state river conditions.
DHH97-1B		Variability too low, levels too high.	Volcanic zone estimate might be too low in this region. Also dependent on steady state river conditions.
DHH97-2	Minor	Variability and levels well matched	
DHH97-4C	Minor	Variability too low and levels slightly too high in the first part of the timeseries	Close to Hut Cr, which explains the low variability.
DHH97-5		Variability too low and levels well matched	
DHH97-6		Variability too low (dry season decline underestimated), levels adequate	Close to the mine
DHH97-8B	Major	Variability and levels well matched	
DHH97-9		Variability too low, levels well matched	Bore located at a boundary between volcanics and limestones (in the model)
DHH98-1		Variability too low, levels too high.	Close to constant head boundary
DHH99-1	Medium	Variability well matched (except two drawdowns), absolute calculated levels too high	The drawdown may stem from pumping, which is steady state in the model
RC11-03		Well matched	
RC11-04		Well matched	
RC11-05		Variability reflected, levels fairly well matched (2m under)	

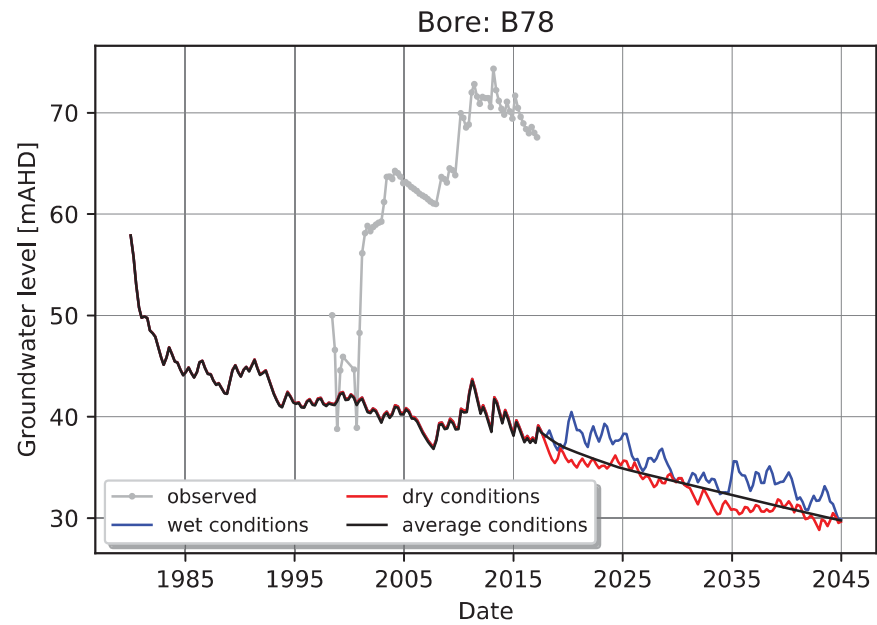
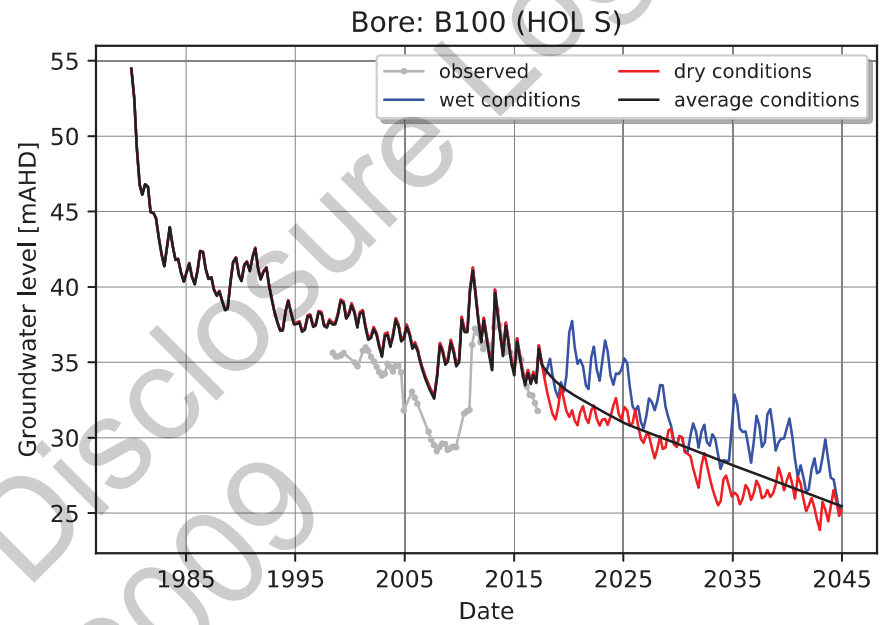
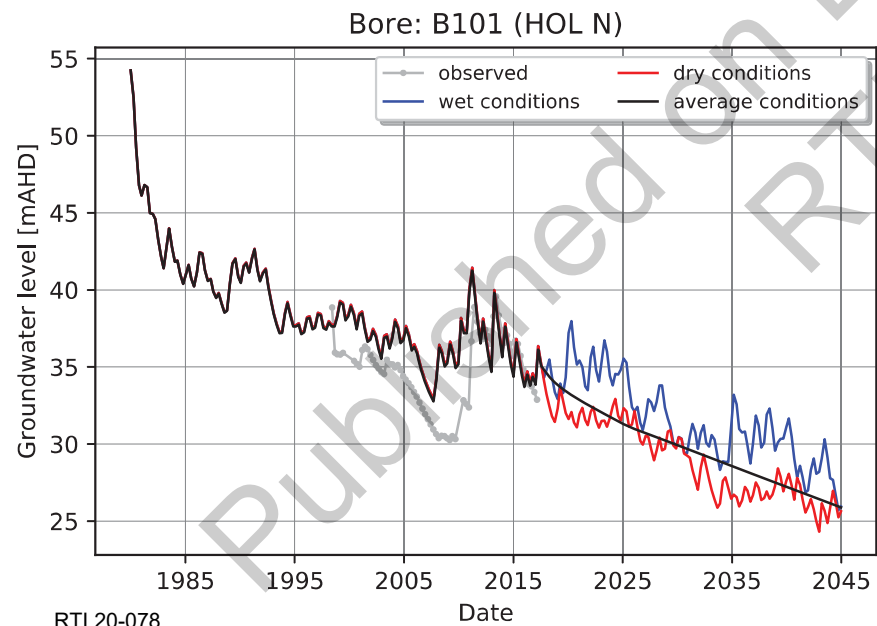
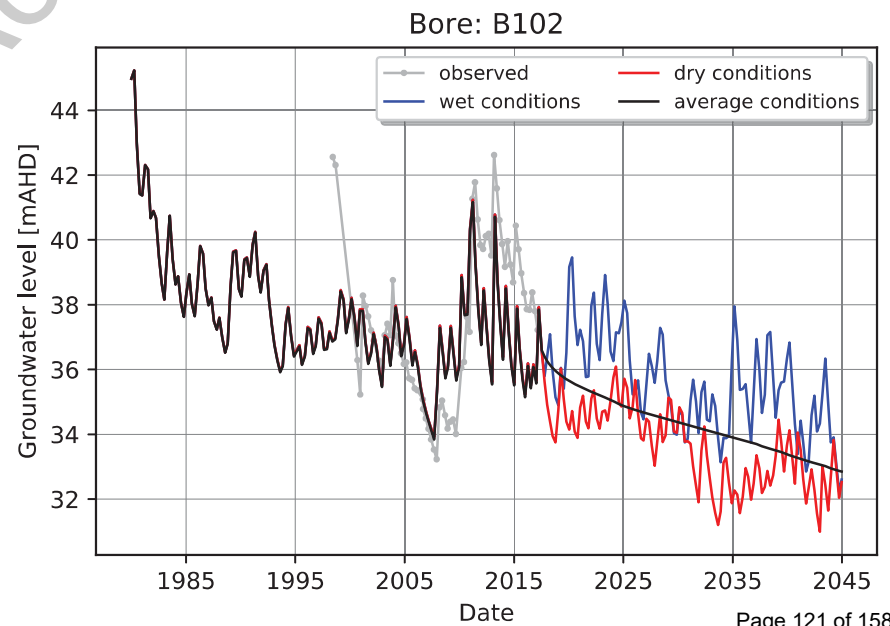
Bore name	Pumped	Comments	Possible cause
RC11-06		Variability reflected, levels fairly well matched (2m over)	
RC11-08		Well matched	
RC11-09		Well matched	
RC11-10		Variability underestimated	Bore used for Steady state constant head boundary.
RC11-11		Variability well reflected, levels underestimated	Unknown
RC11-14		Well matched	
RC11-15		Well matched	
RC11-18		Good match	
EE Mine Fore: - Bore NE		Reflection of dry period in the 1990ies is underestimated, otherwise well matched	
EE Mine Fore: - Bore SE		Reflection of dry period in the 1990ies is underestimated, otherwise well matched	

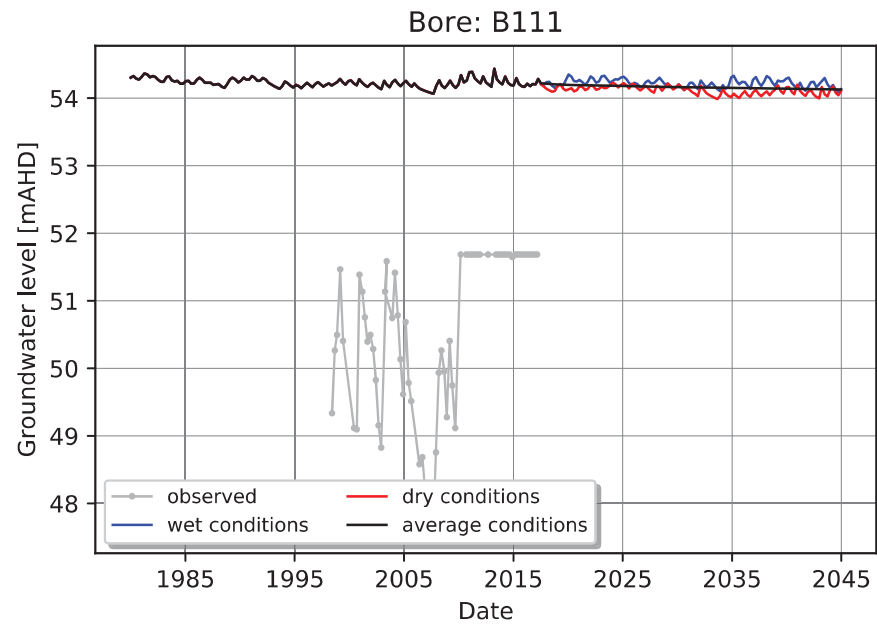
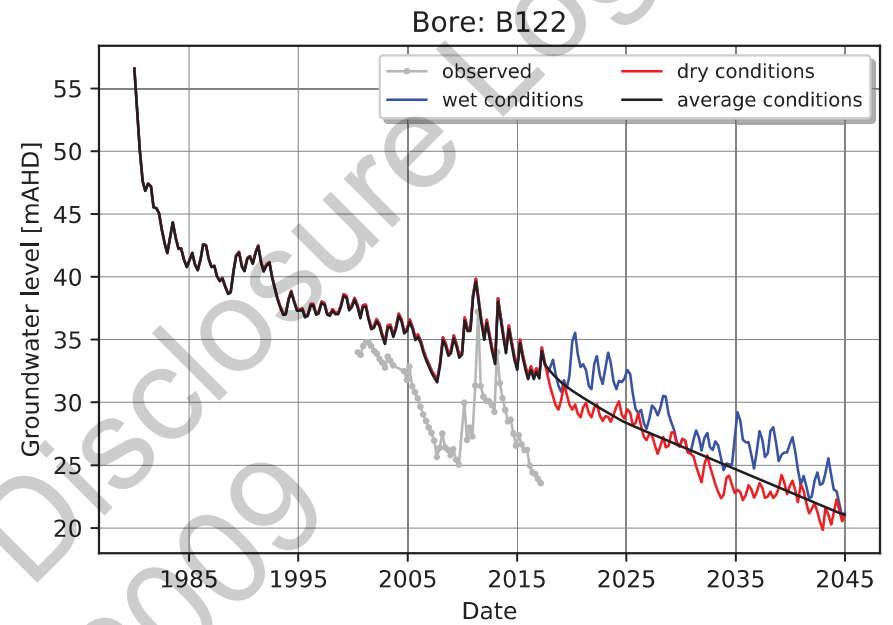
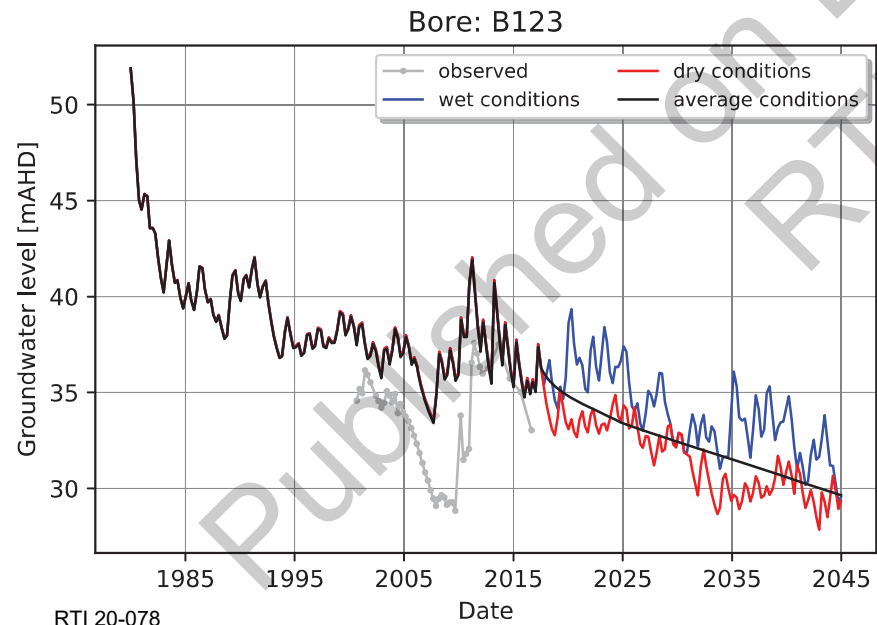
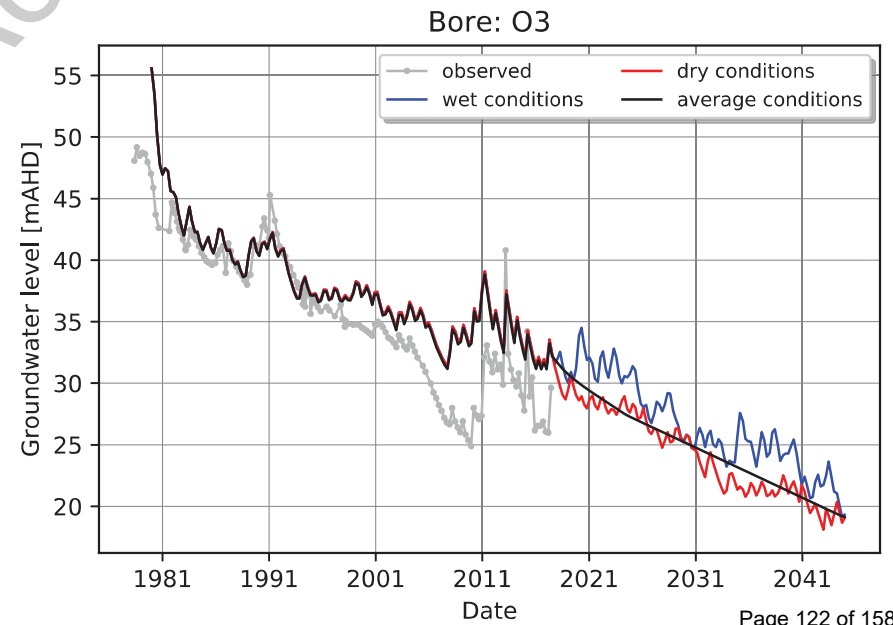
Pumping: minor 0-10 m³/day. Medium 10-30 m³/day, major 30-60 m³/day

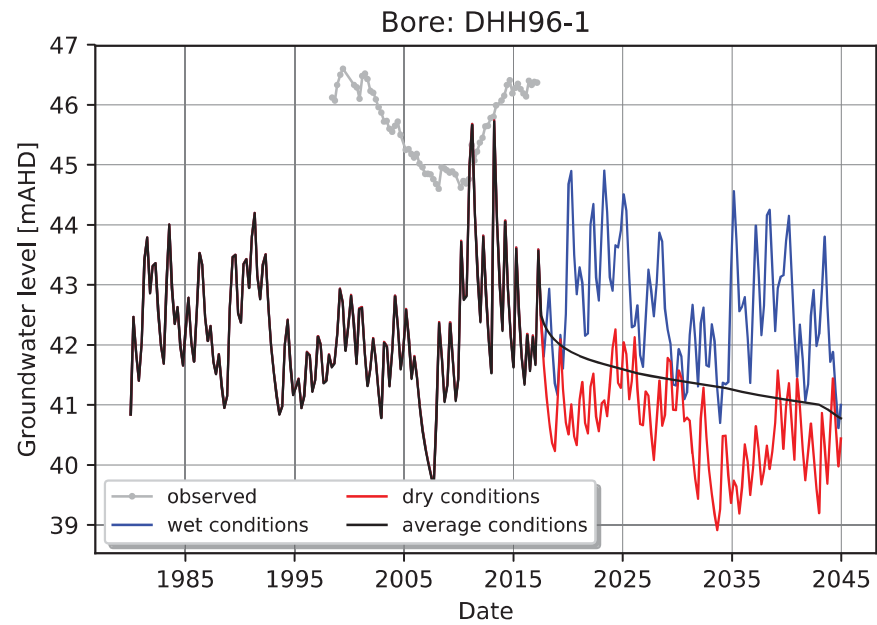
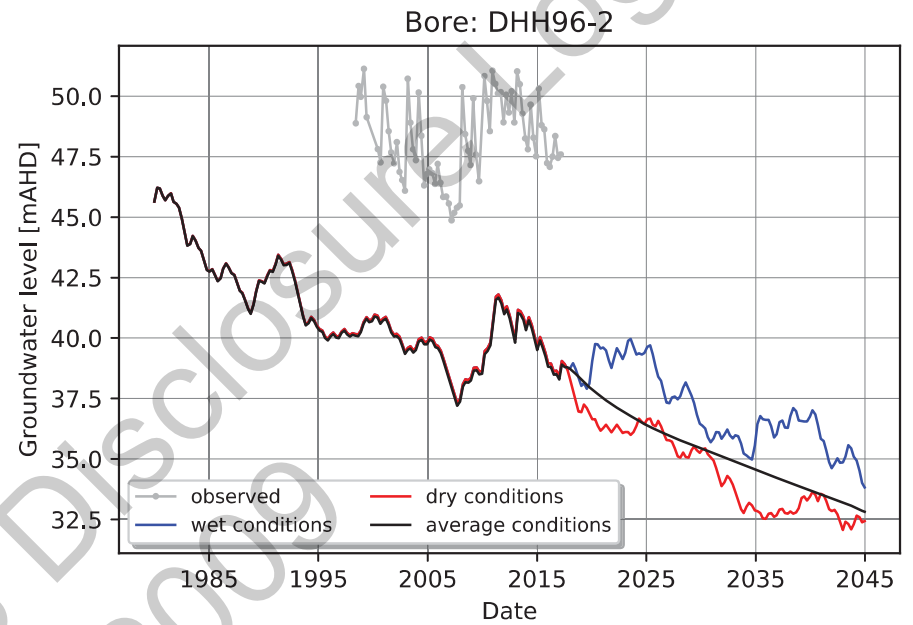
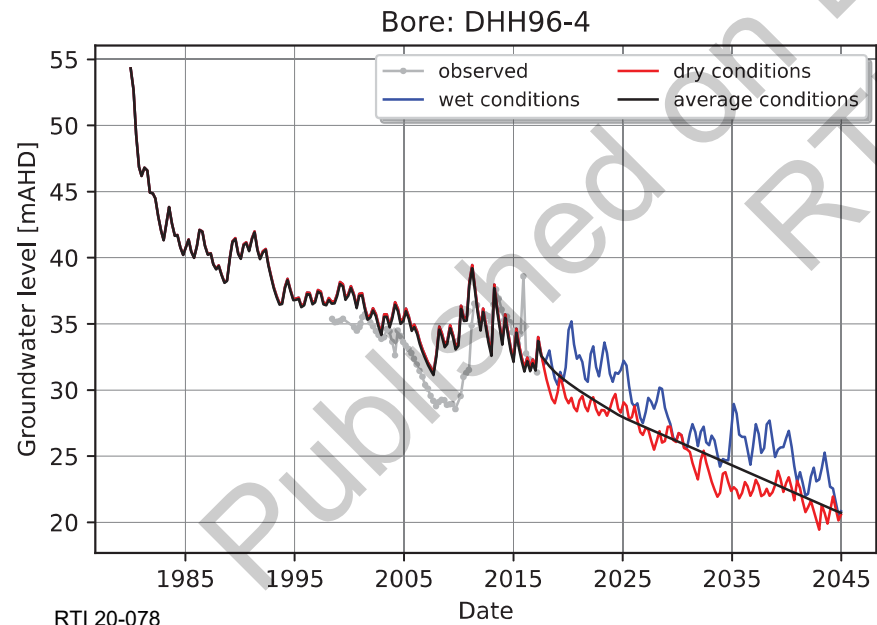
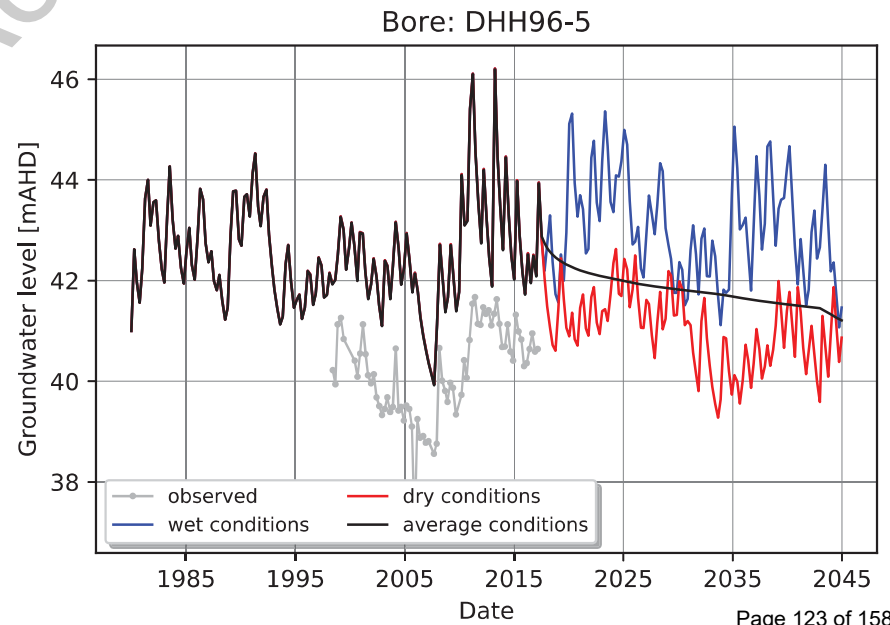
Appendix F

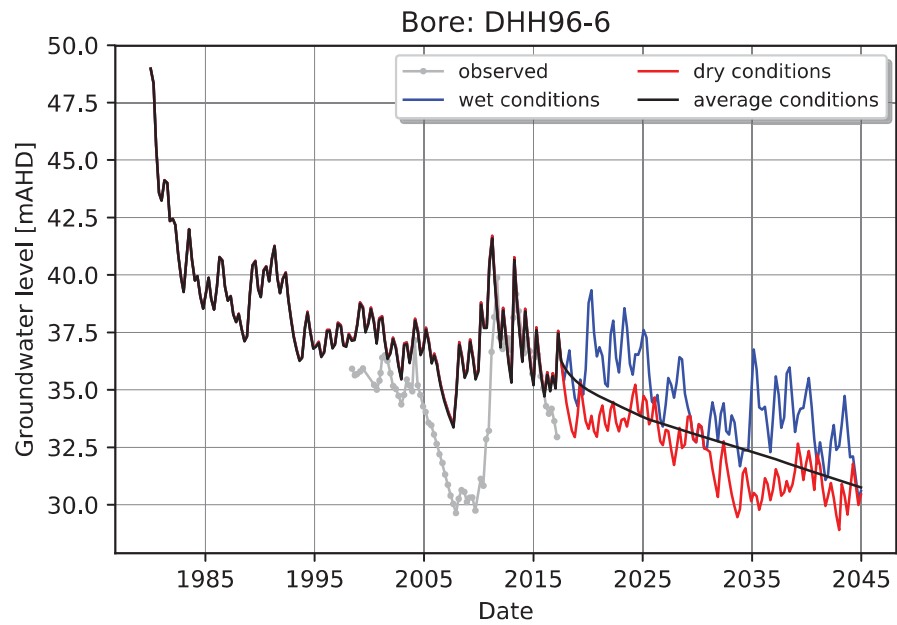
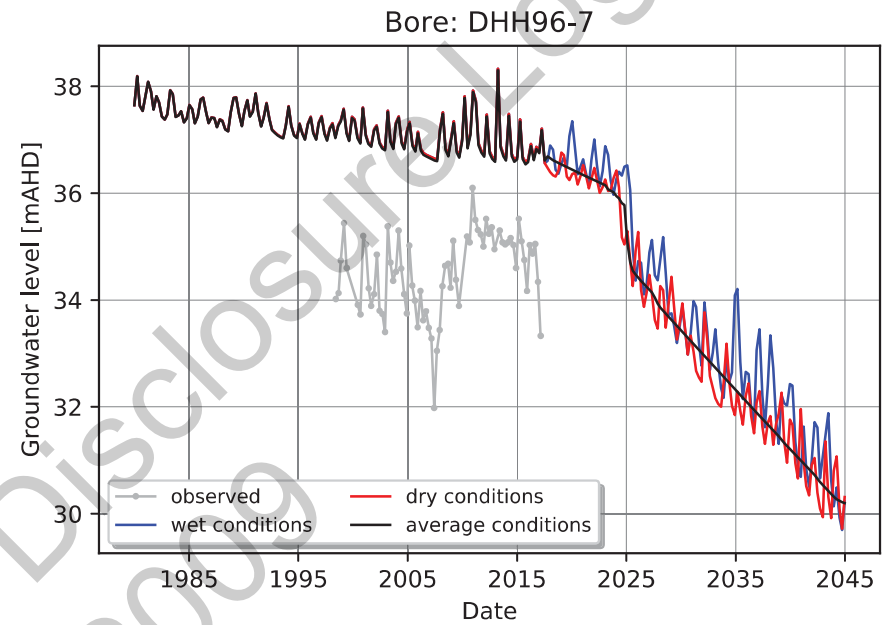
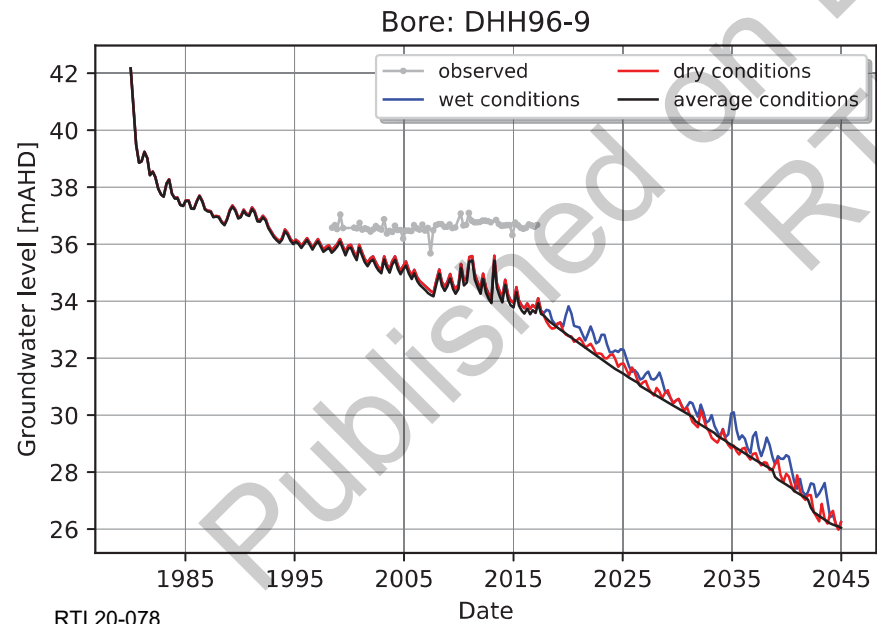
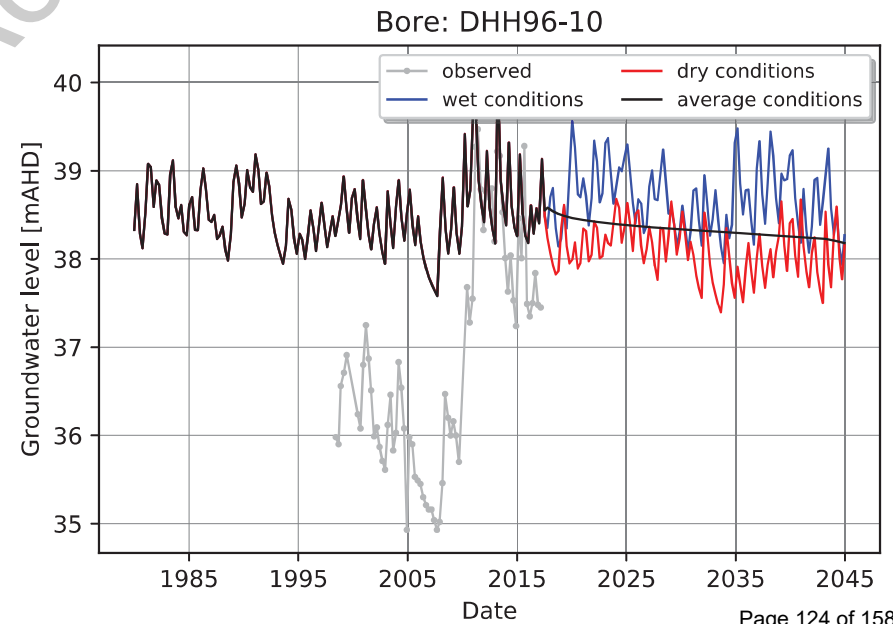
Climate scenarios

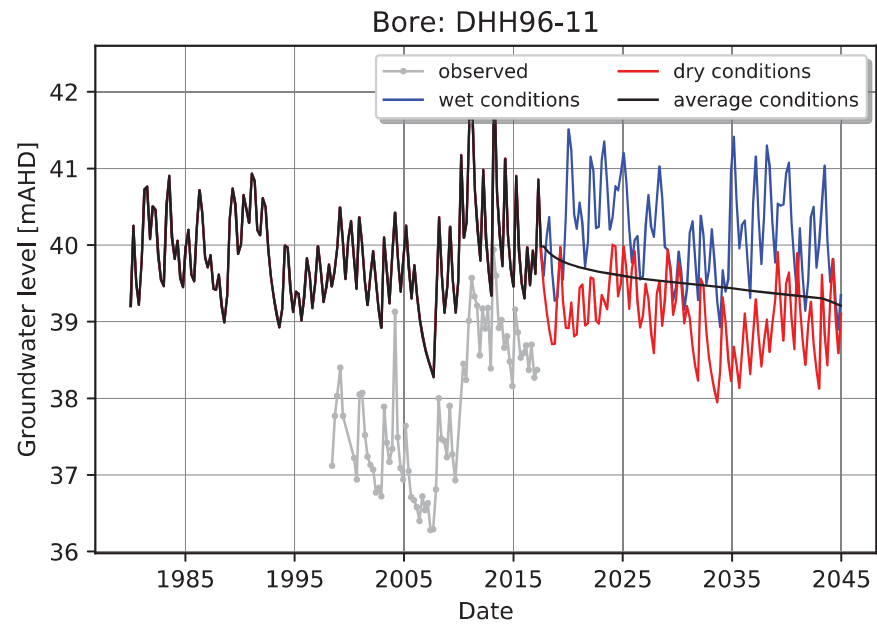
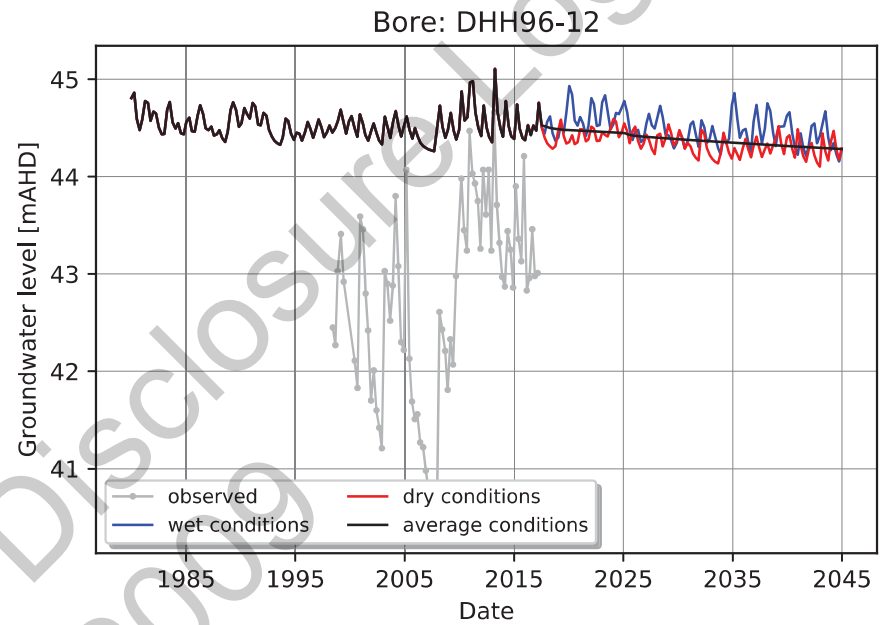
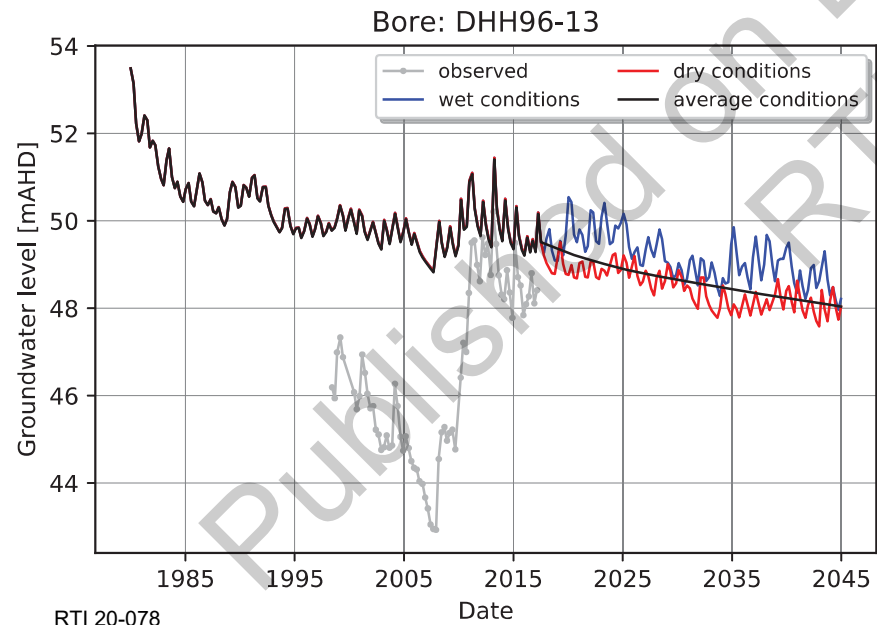
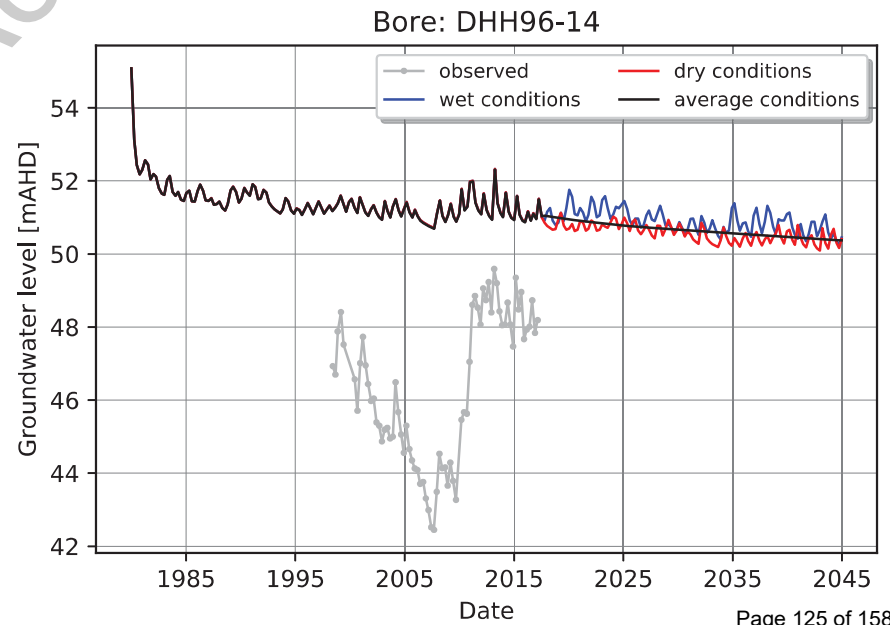


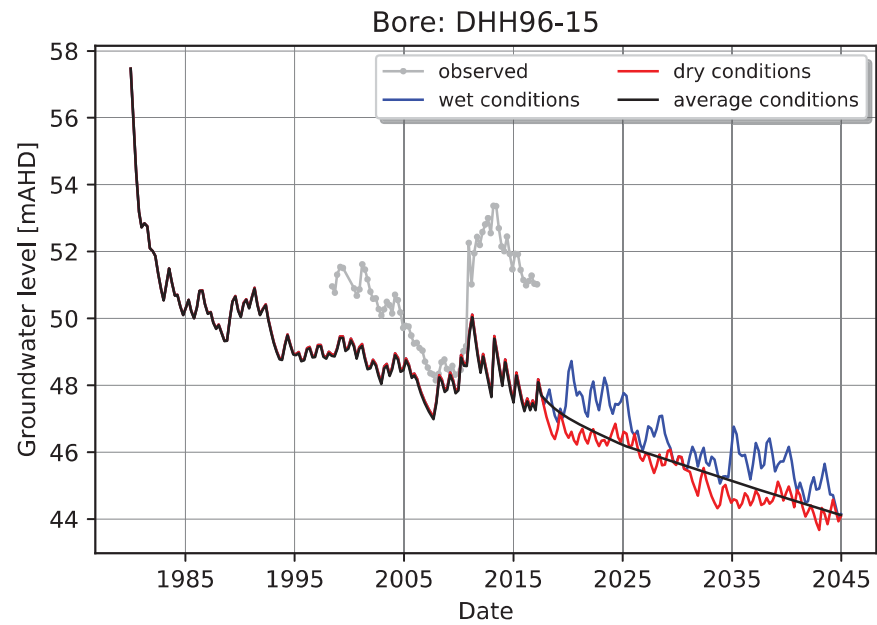
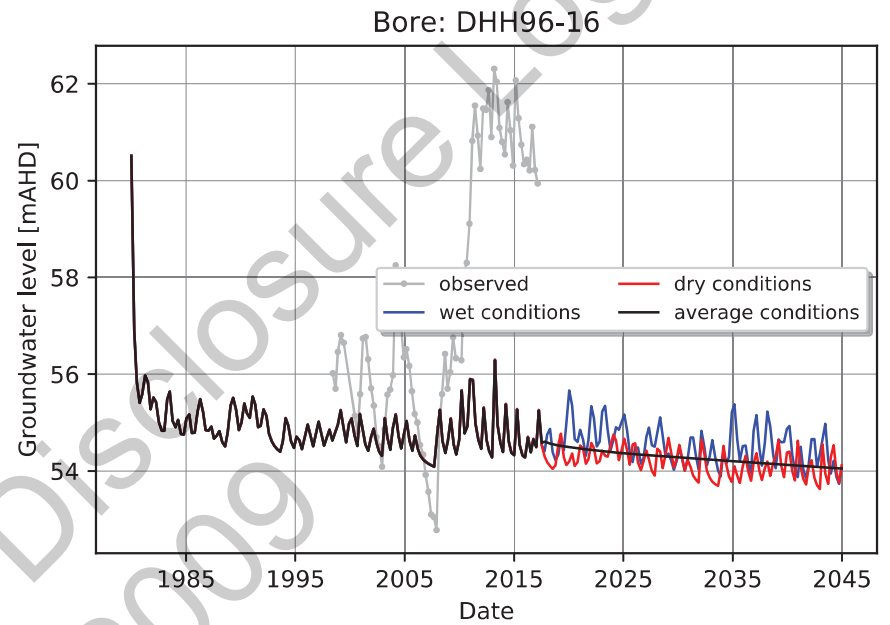
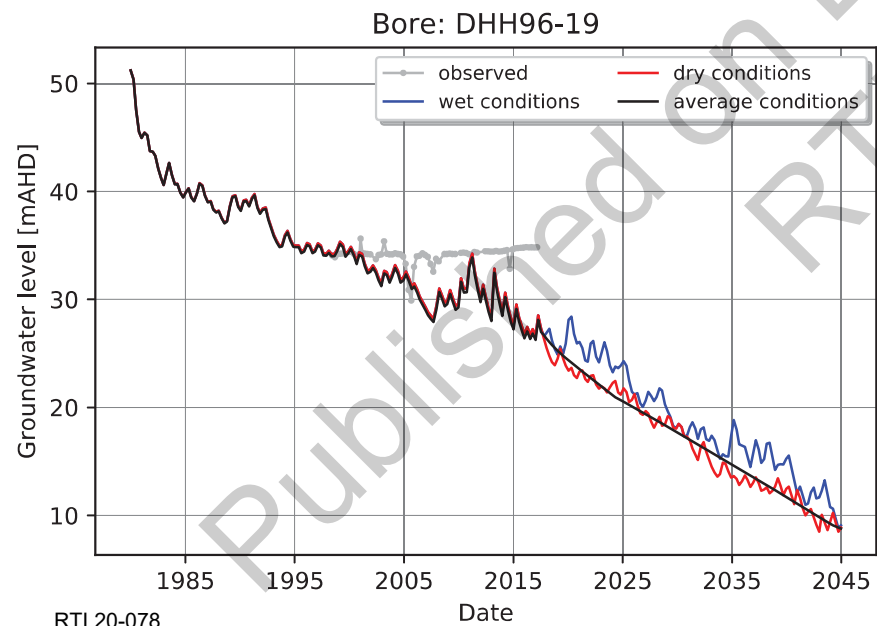
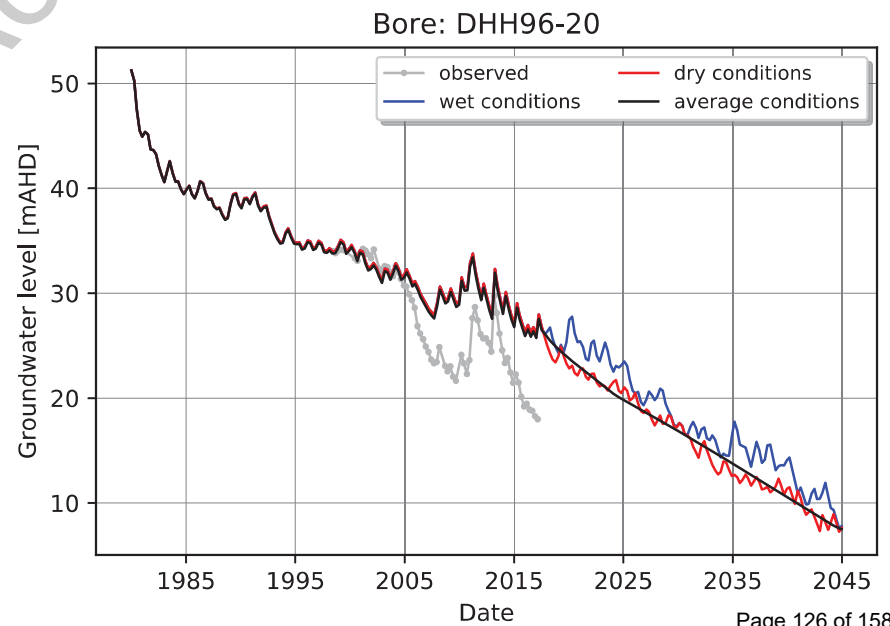


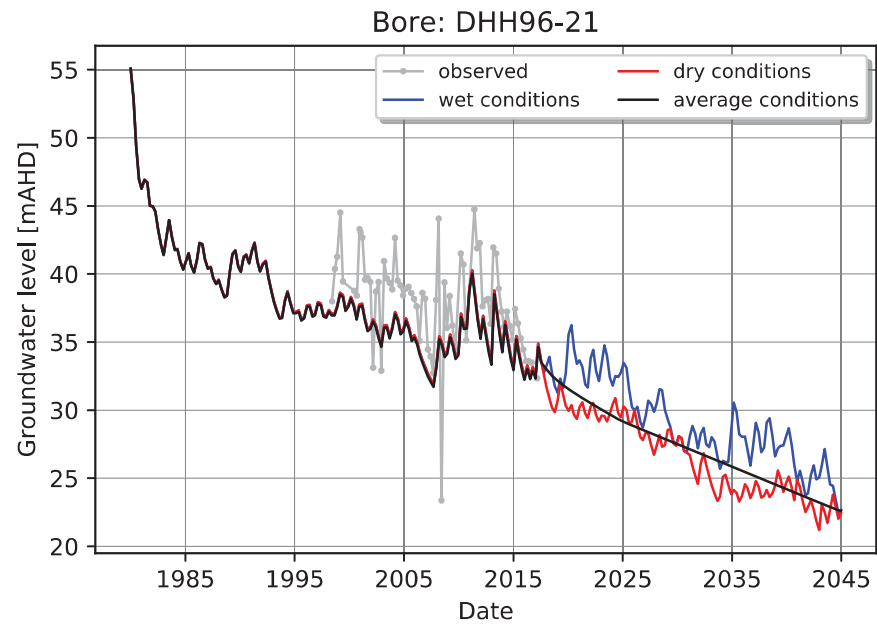
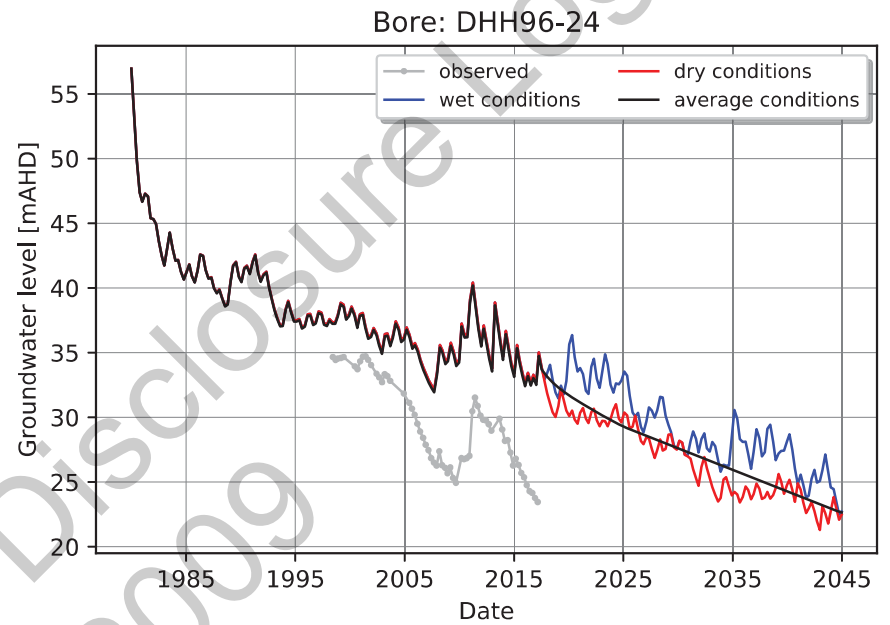
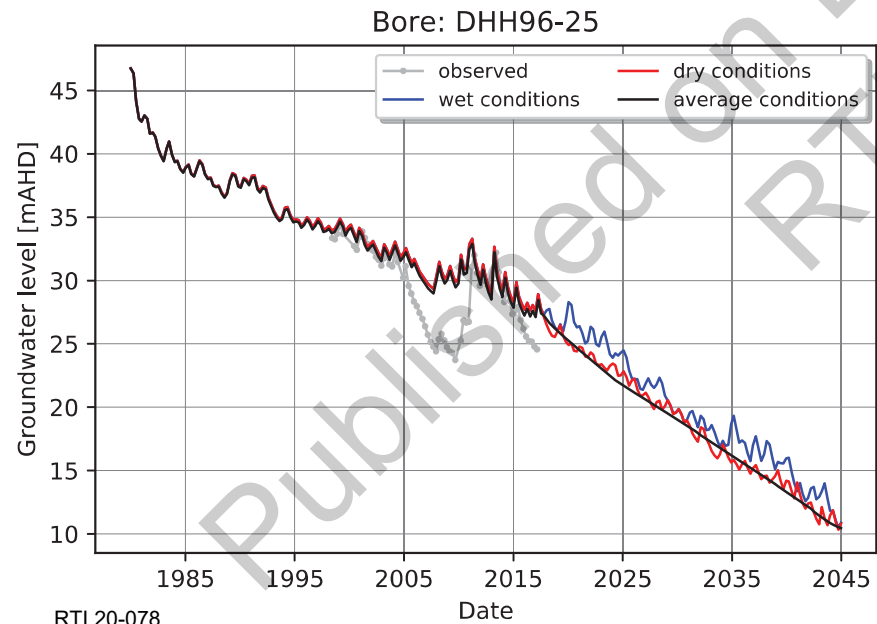
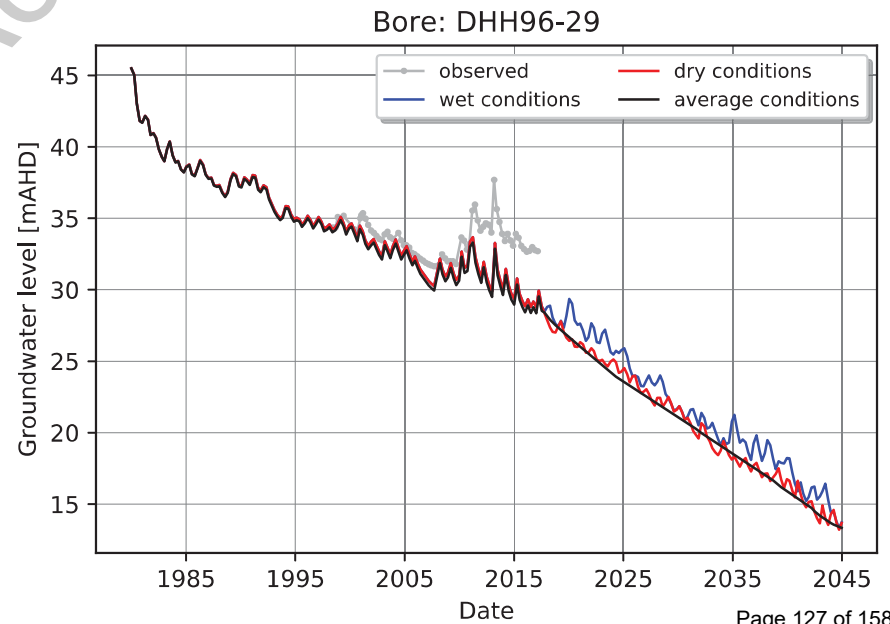


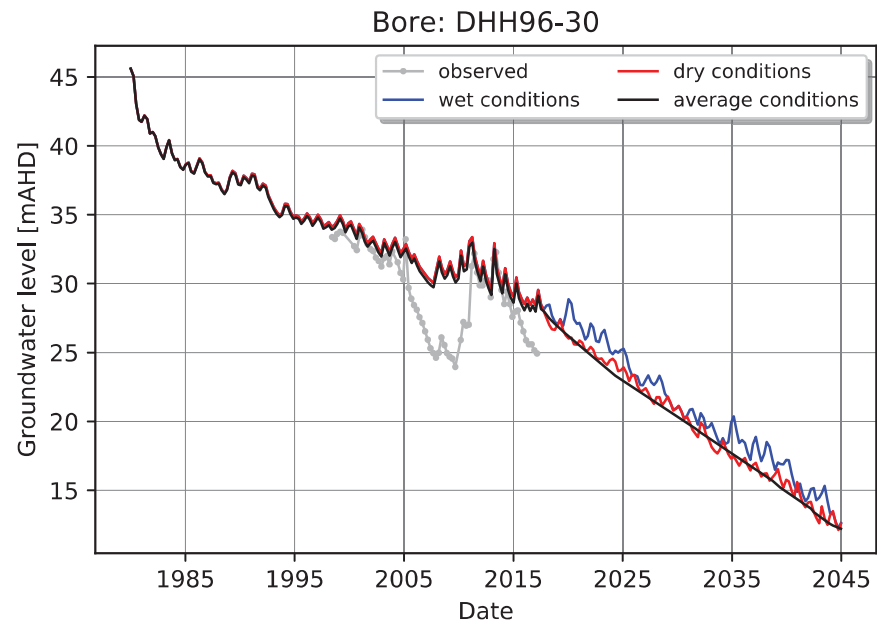
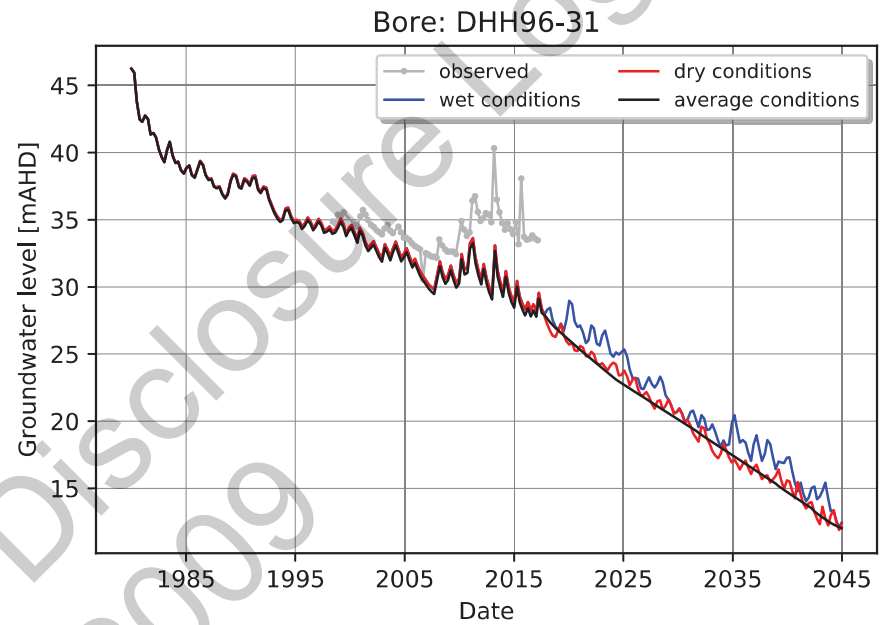
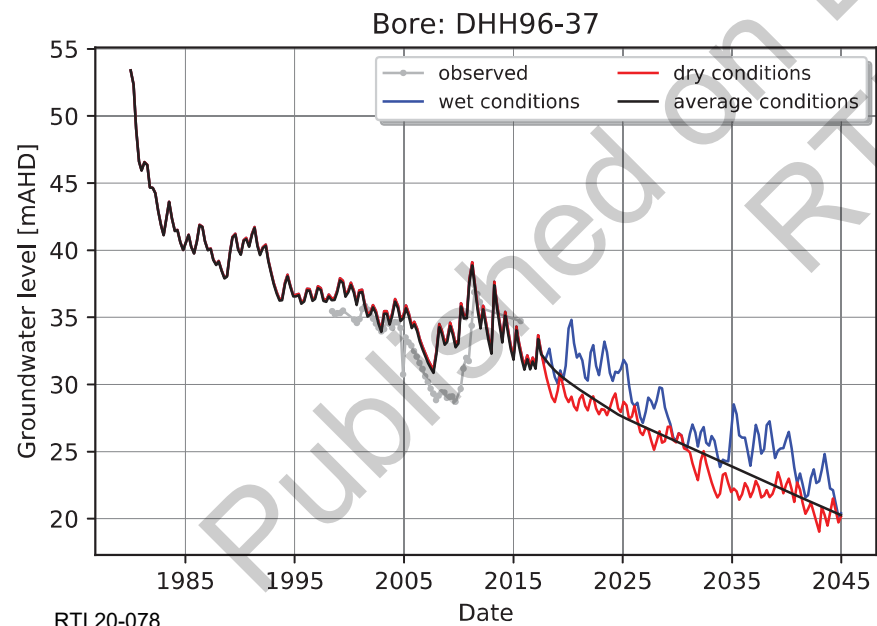
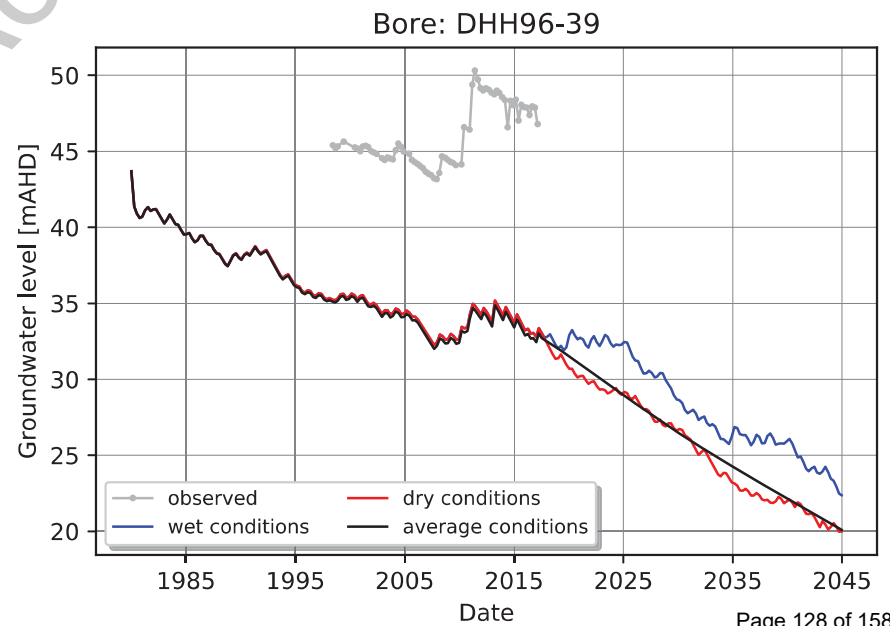


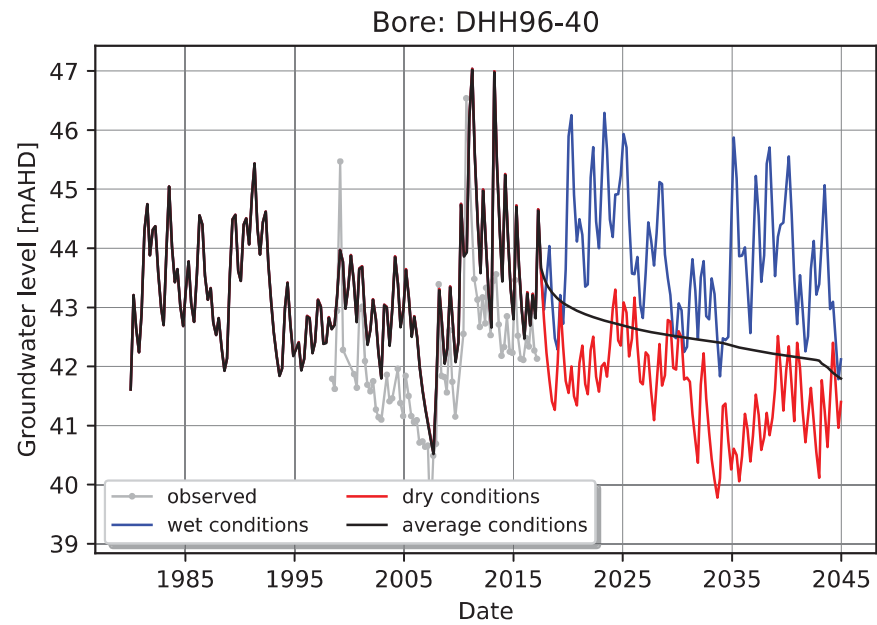
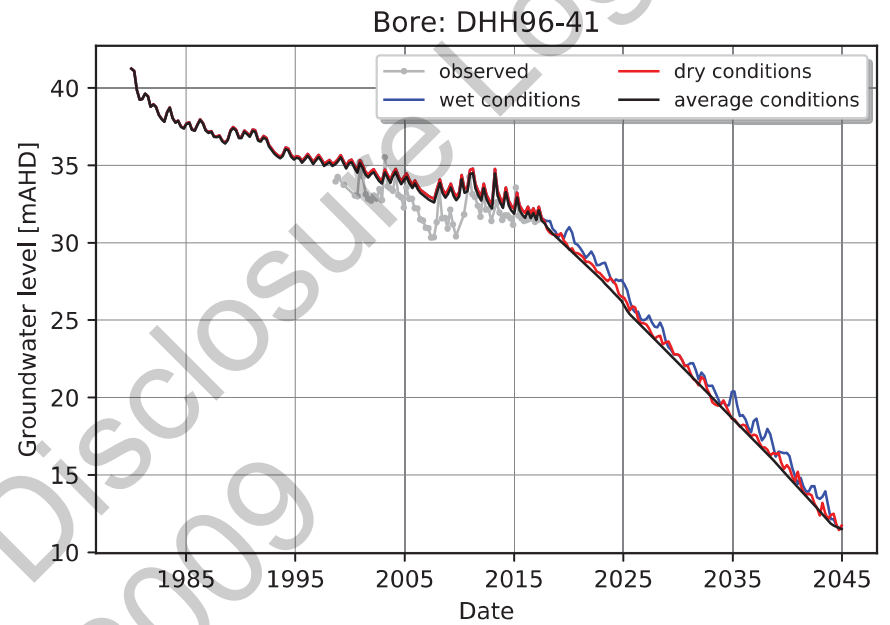
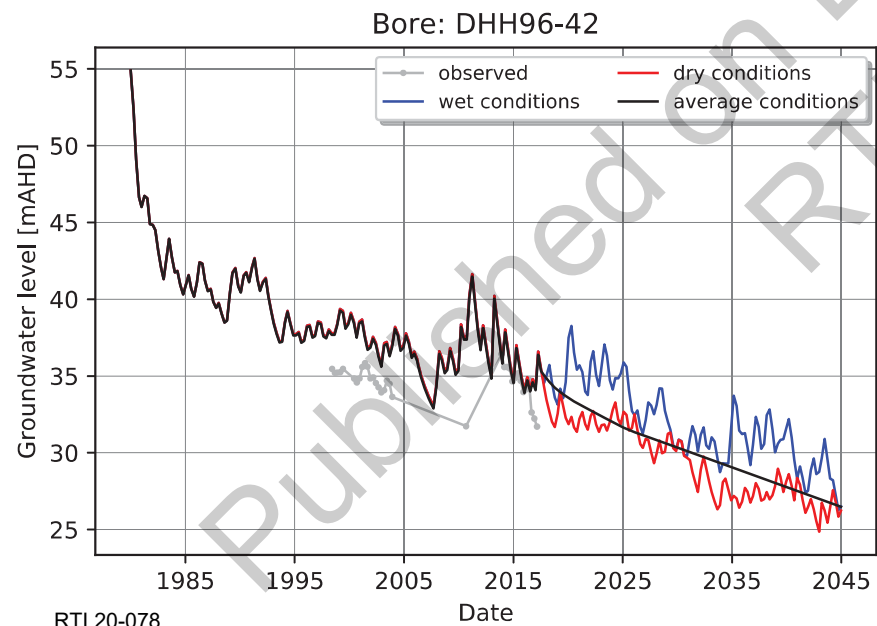
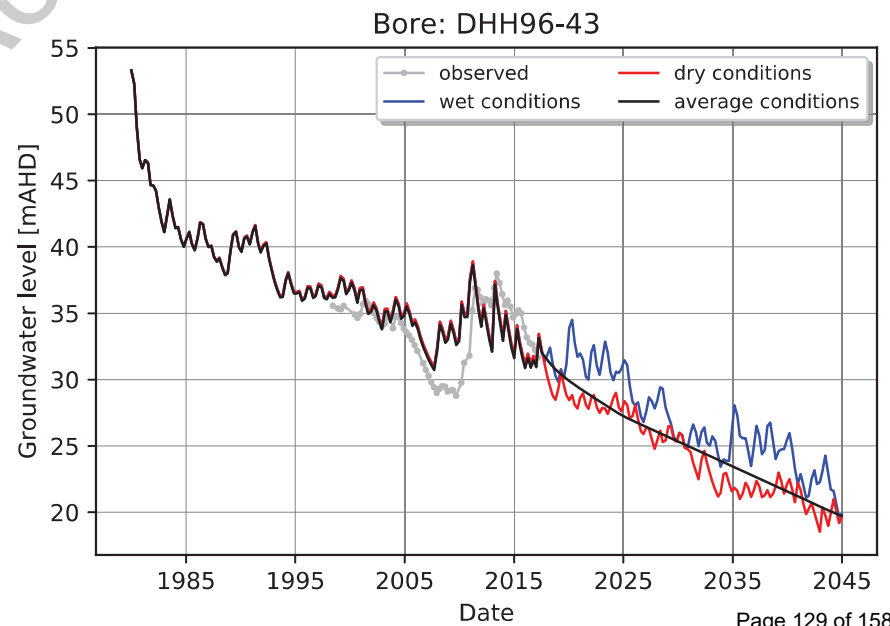


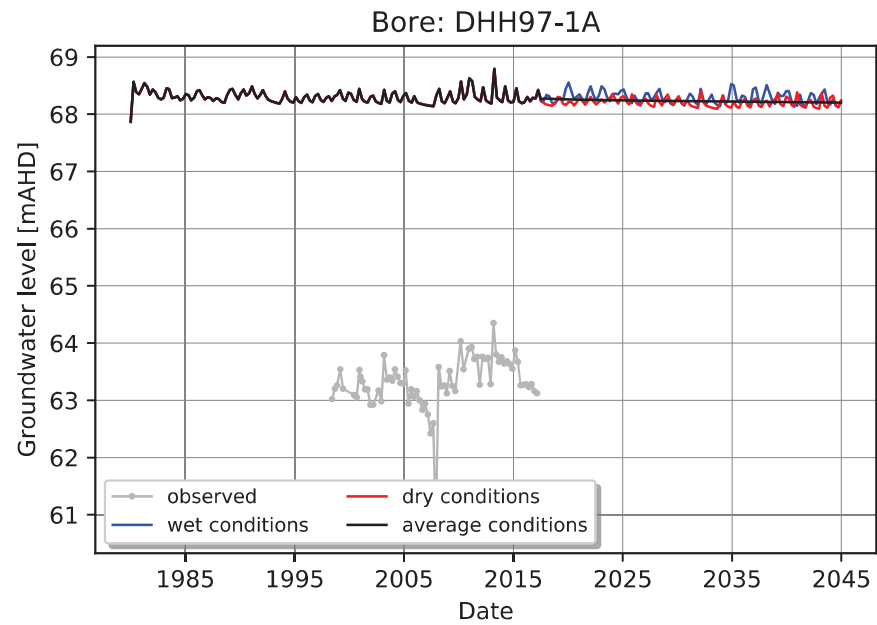
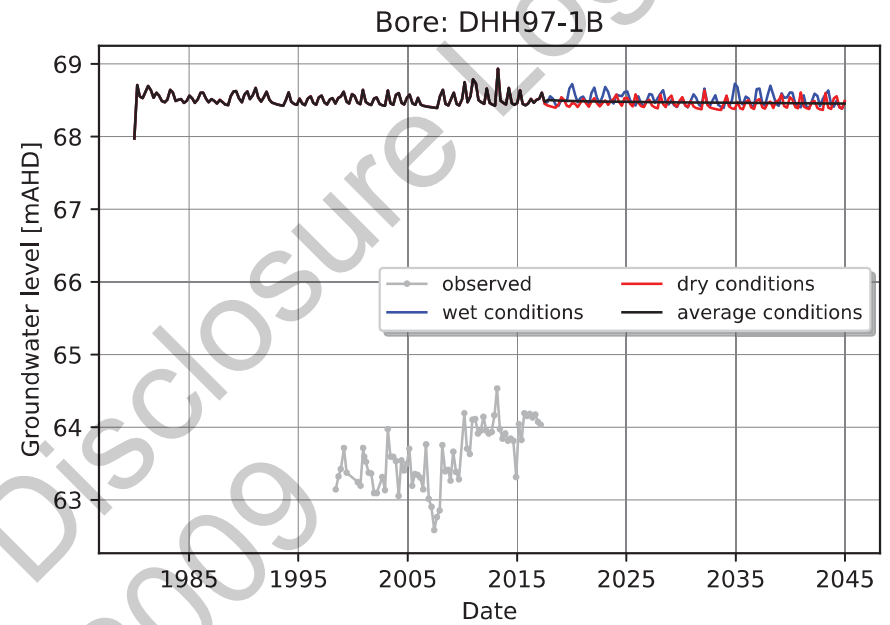
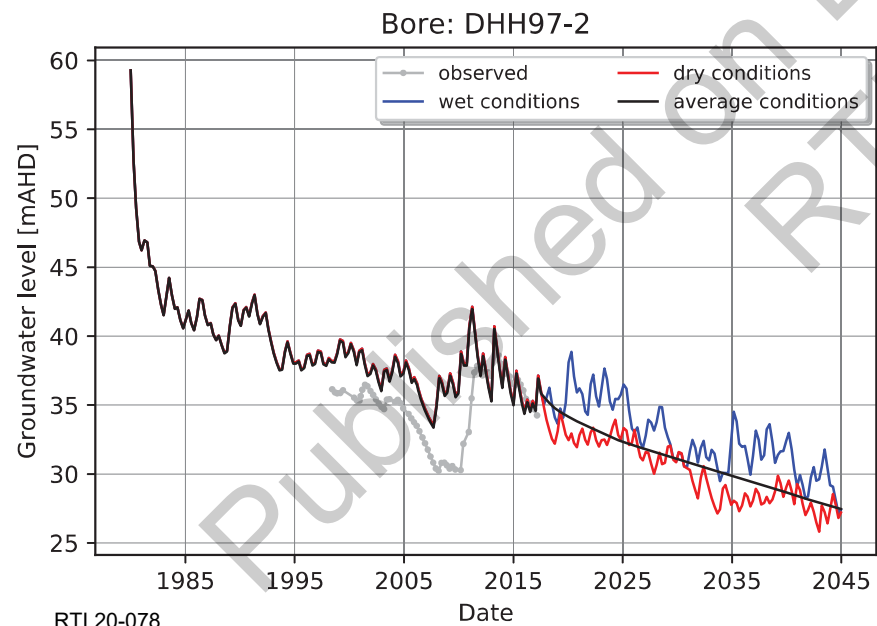
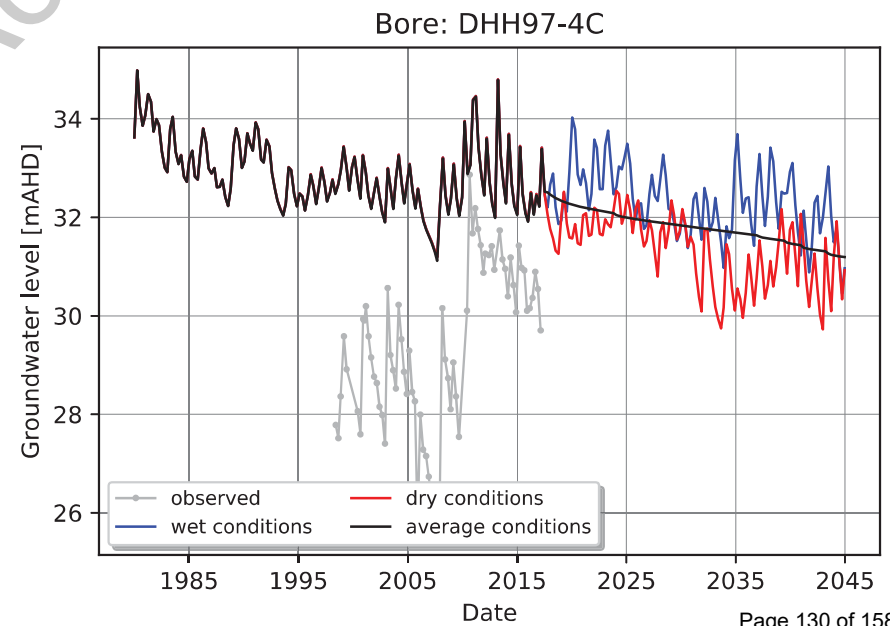


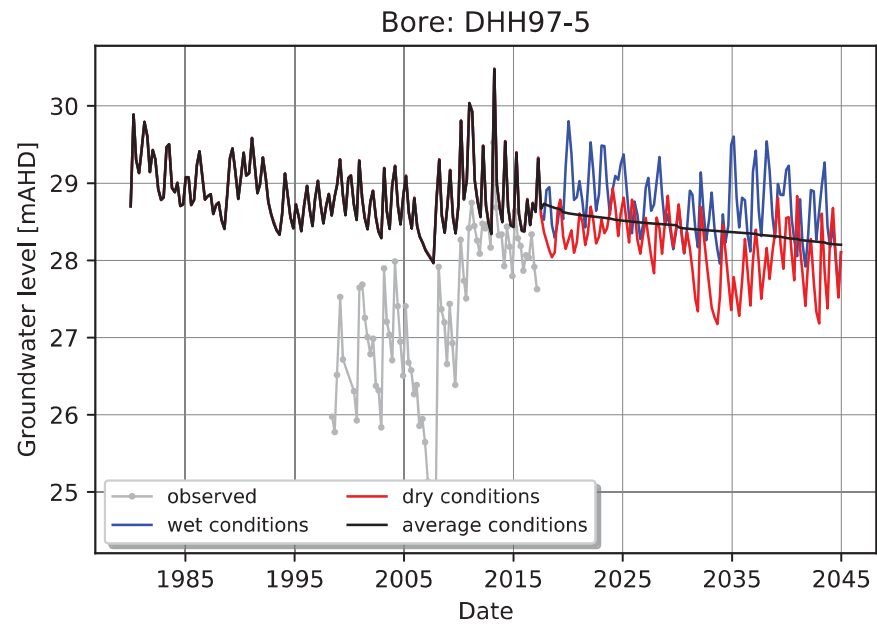
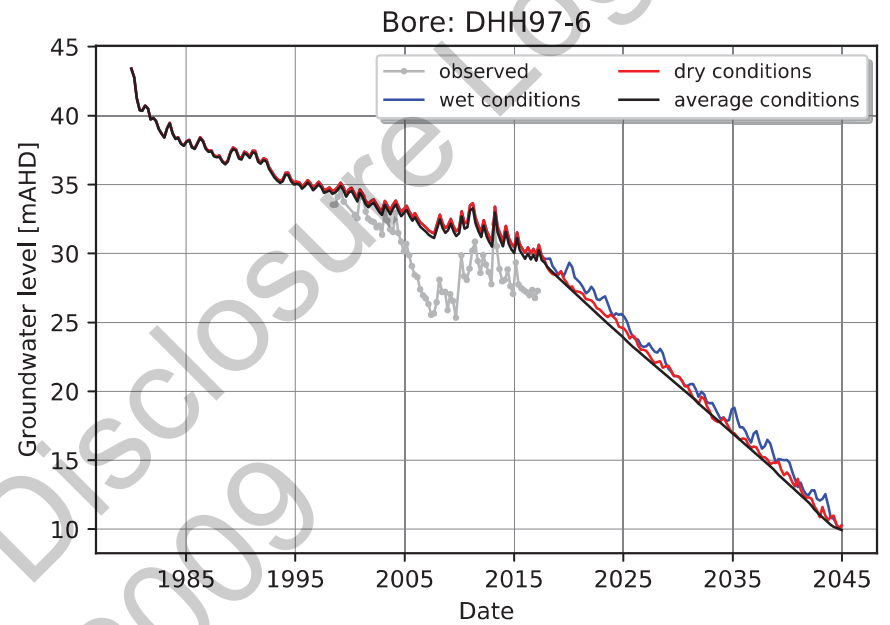
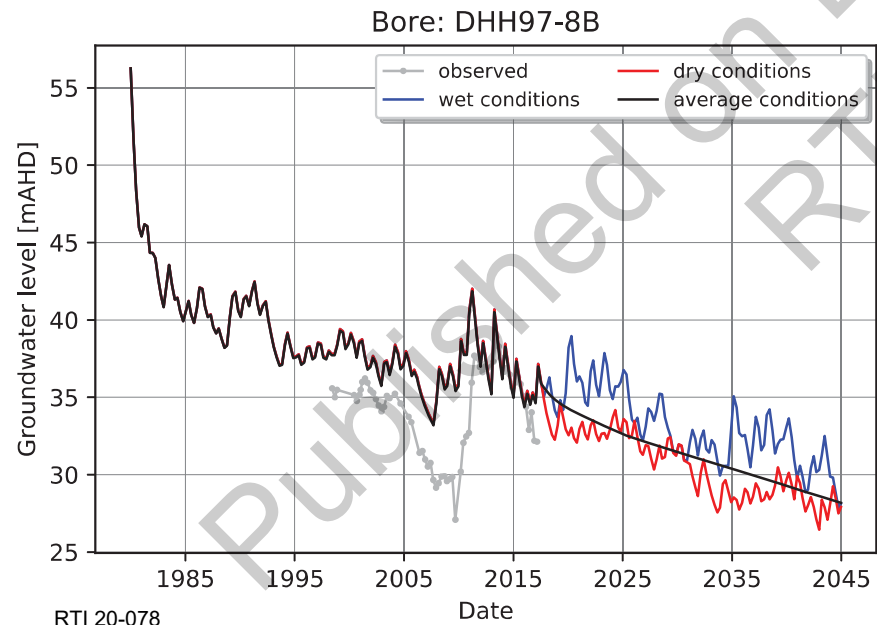
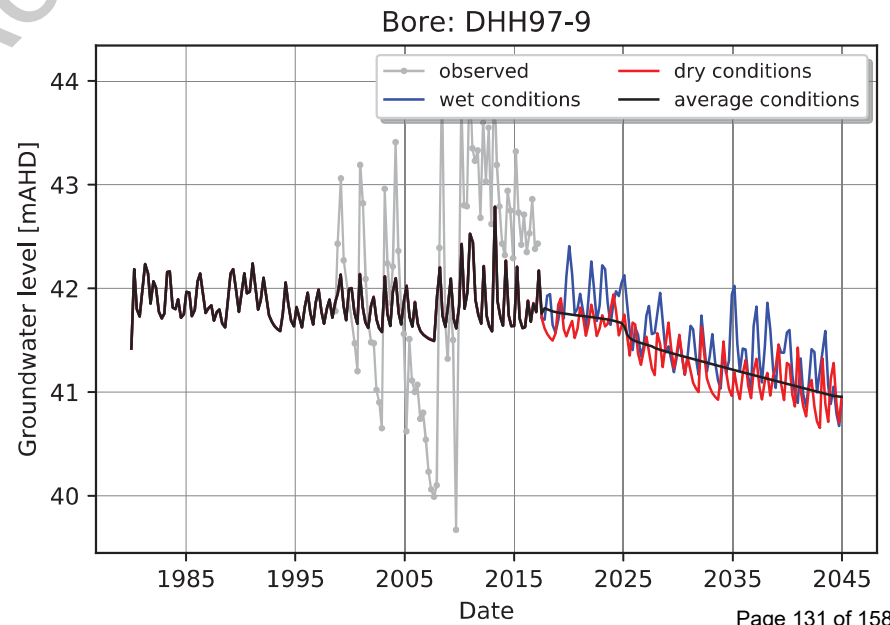


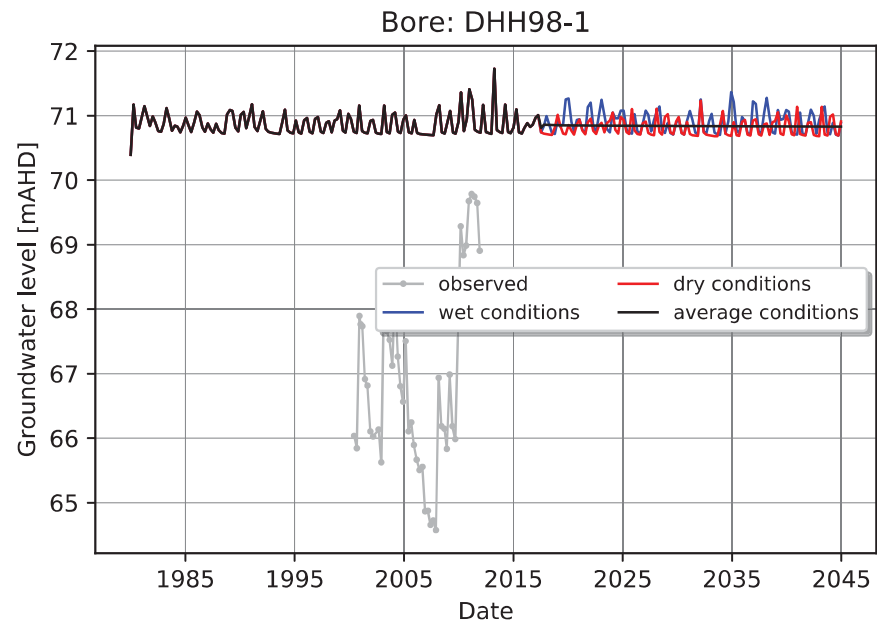
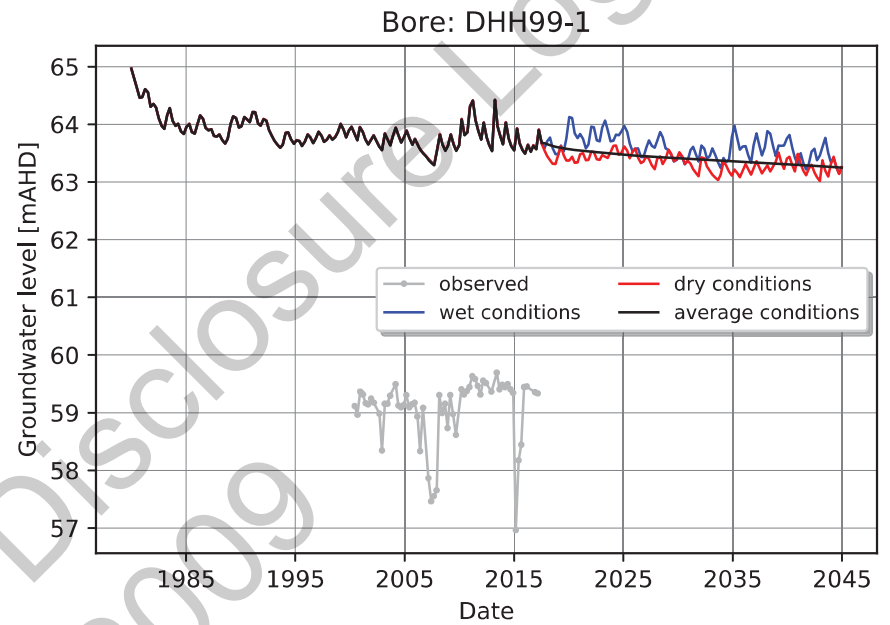
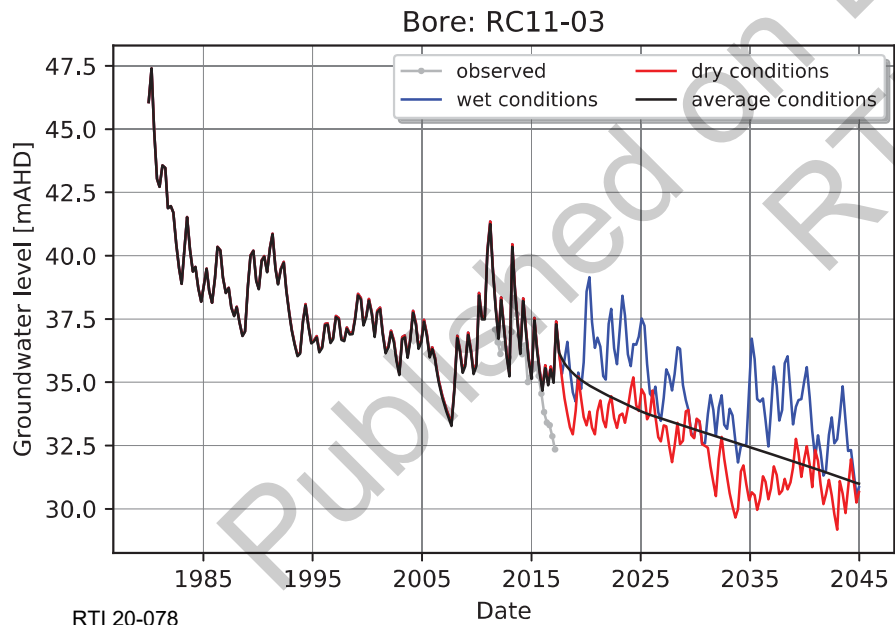
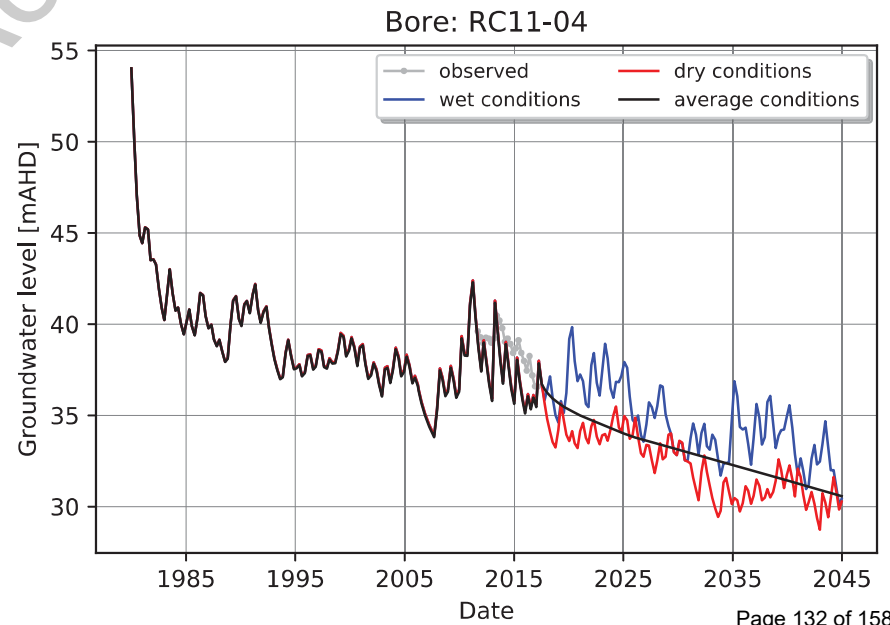


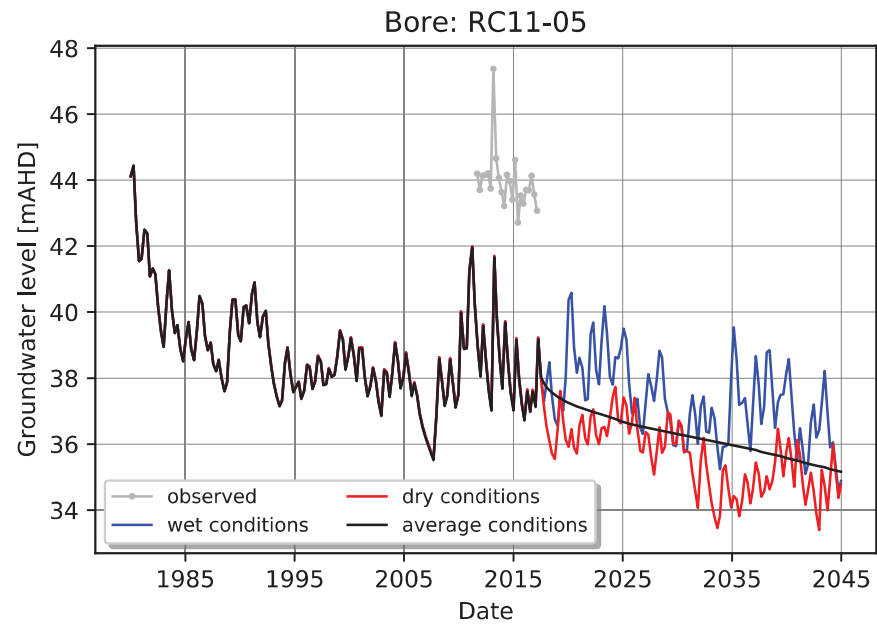
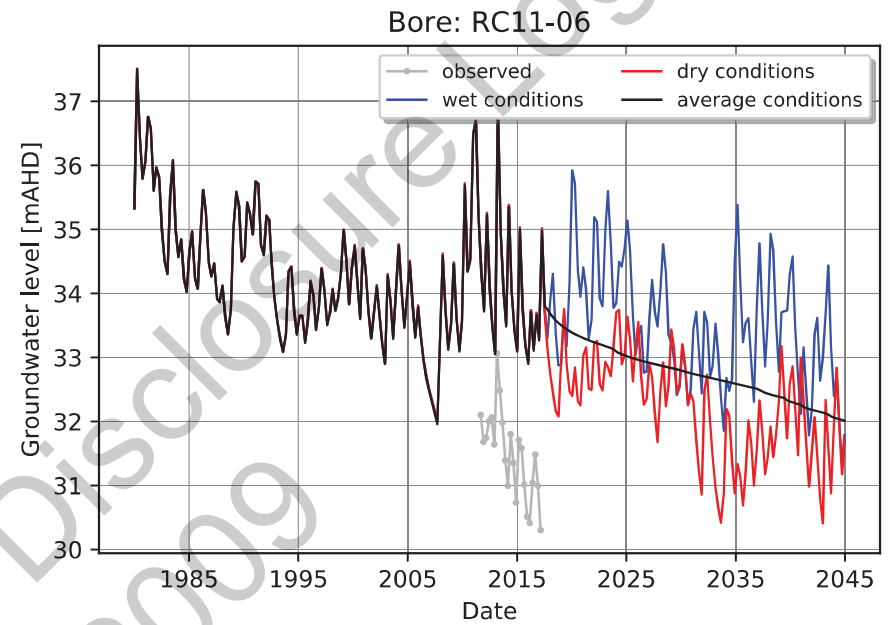
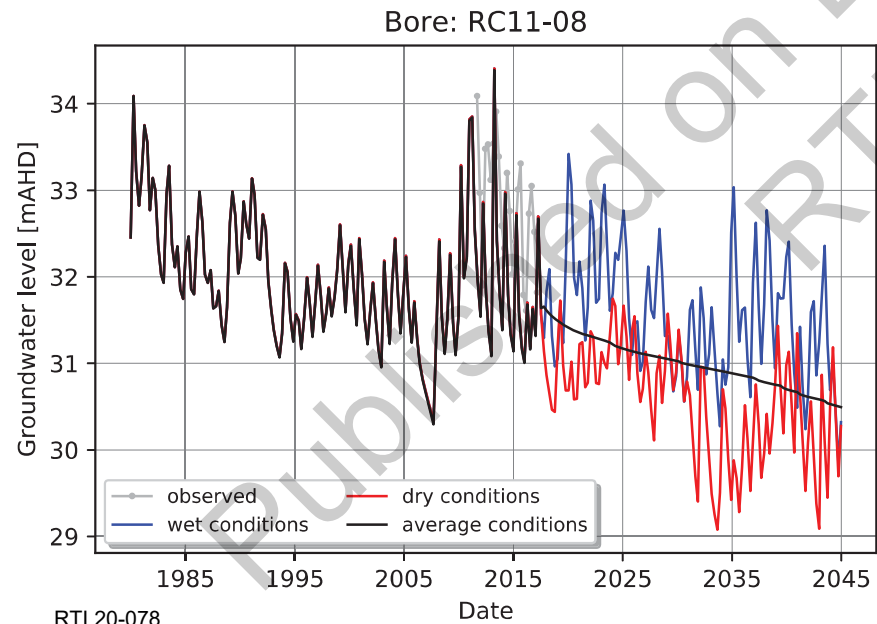
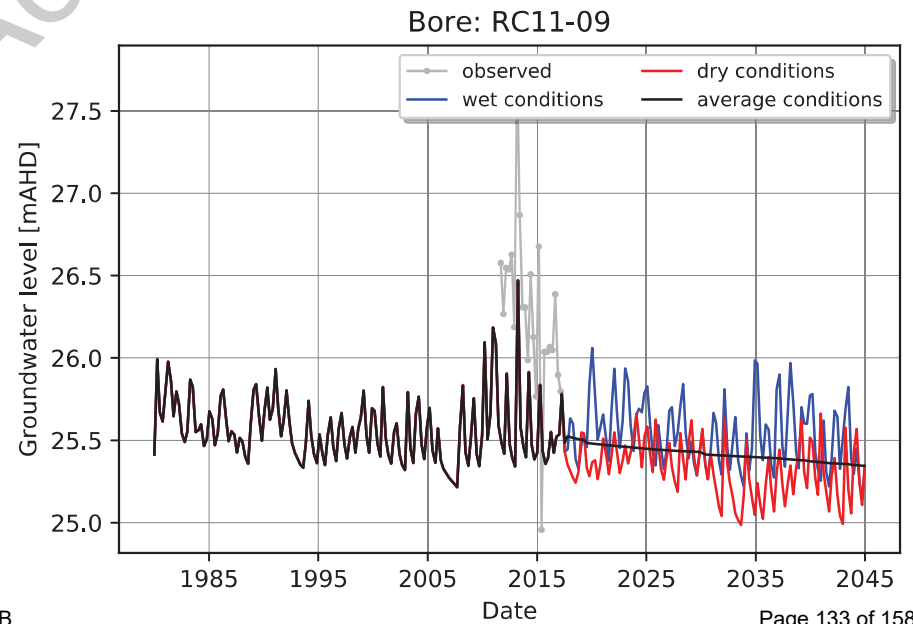


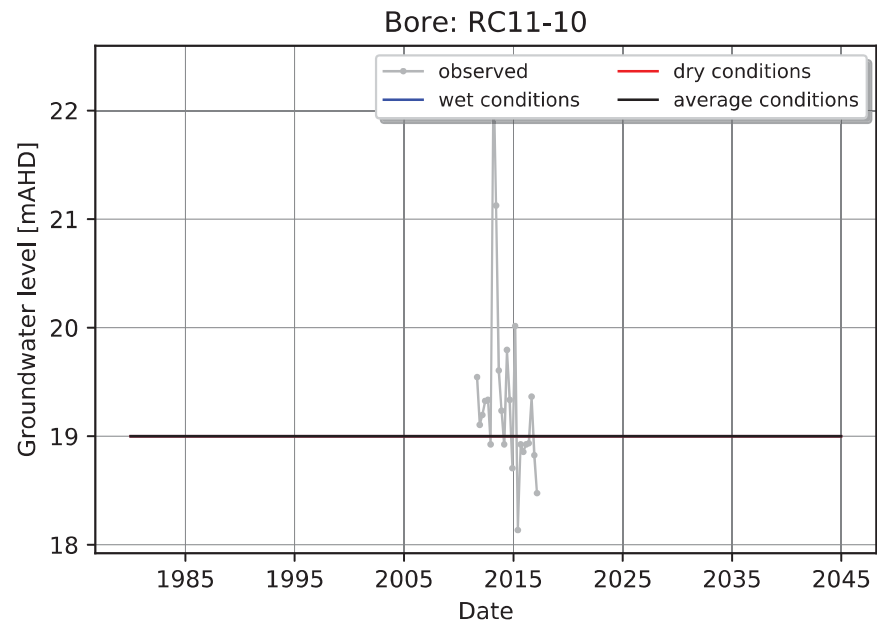
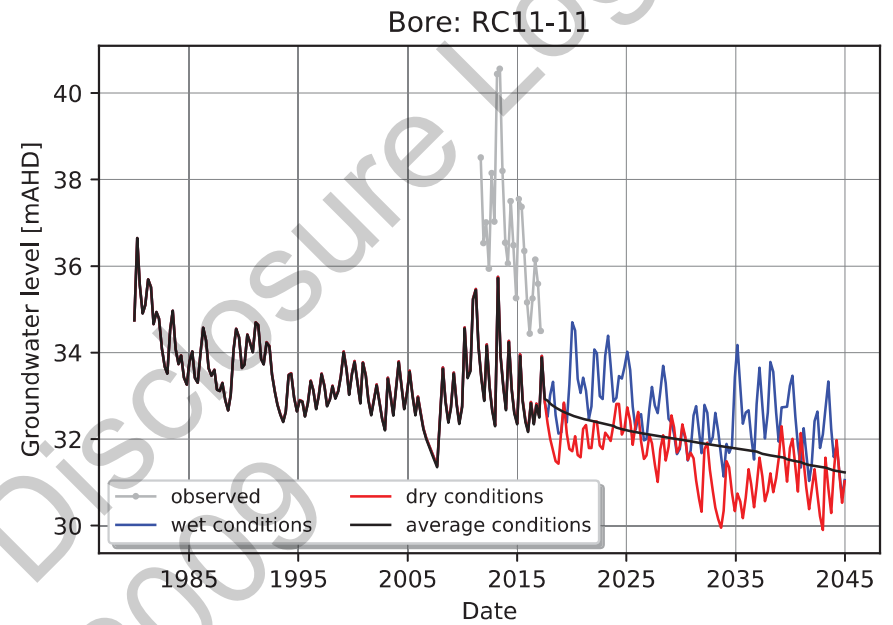
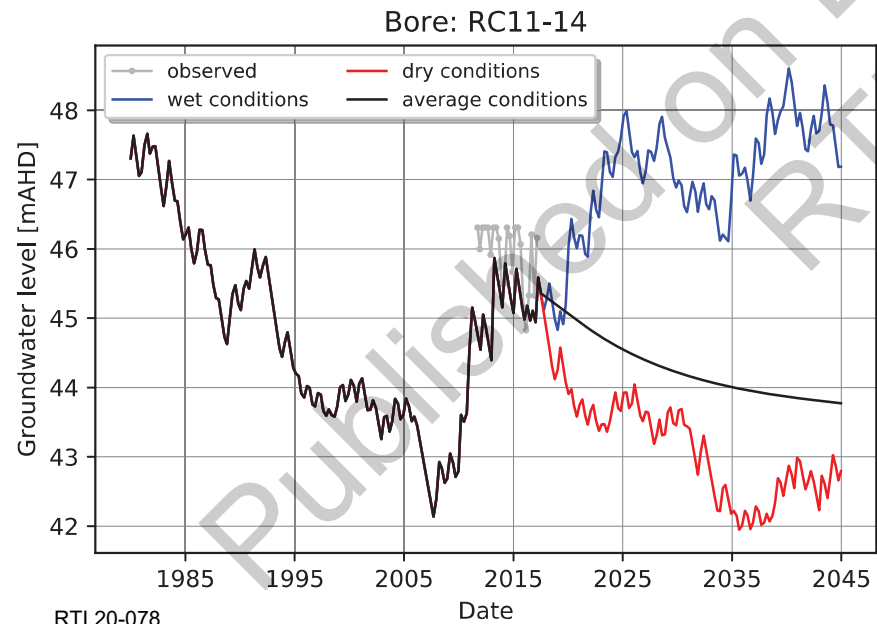
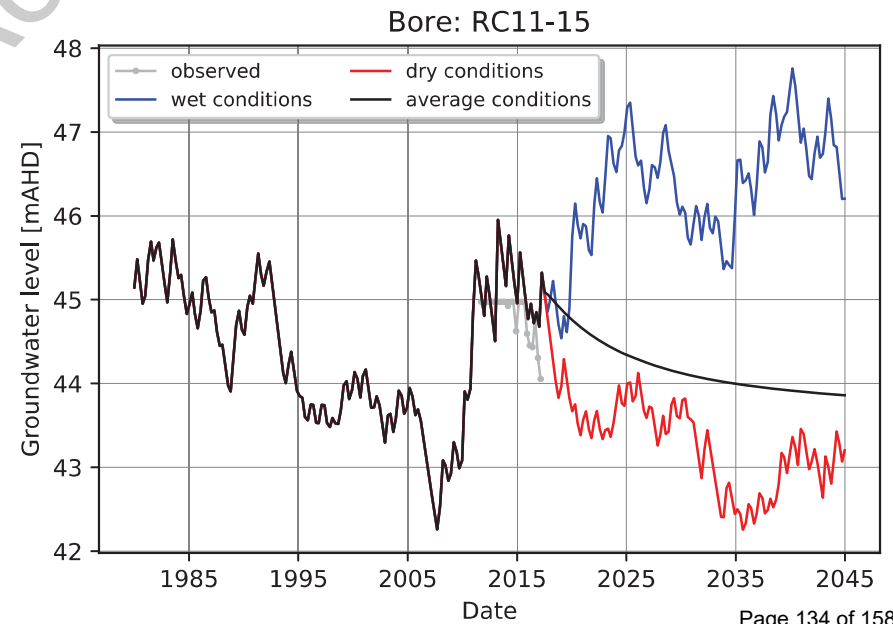


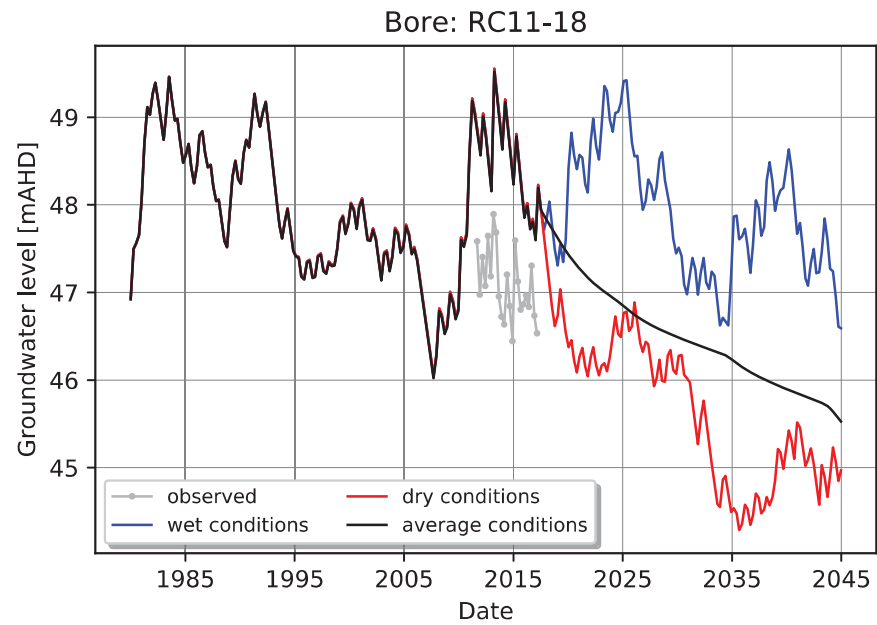
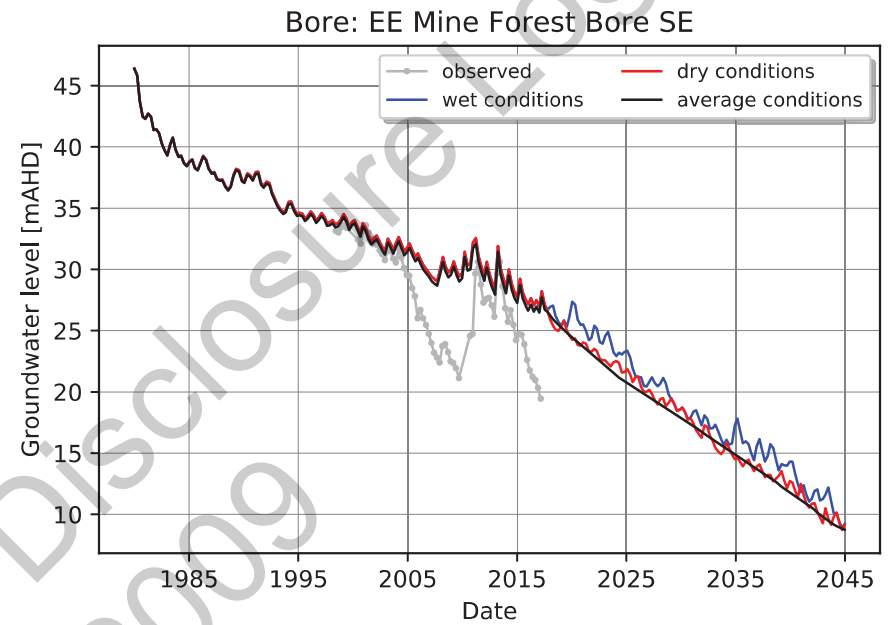
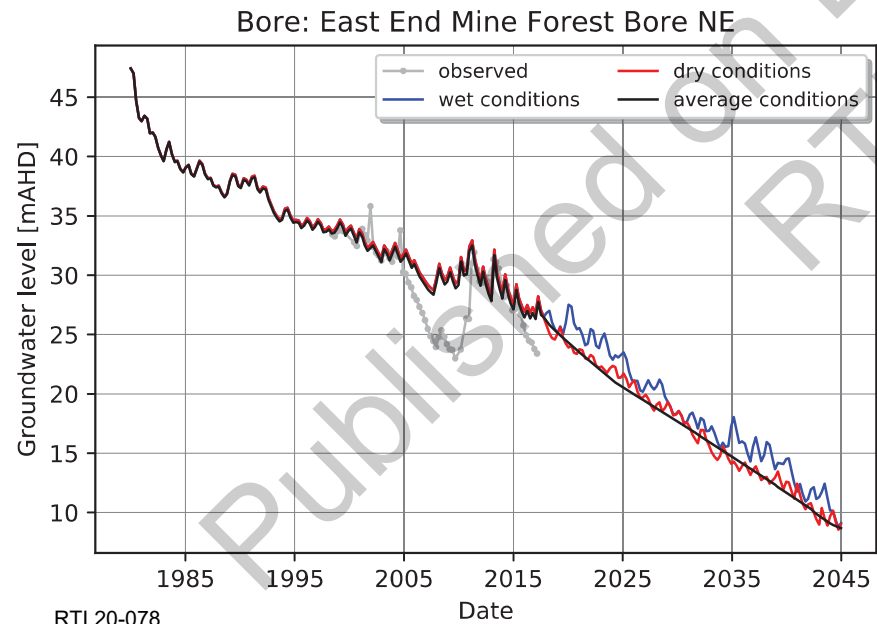






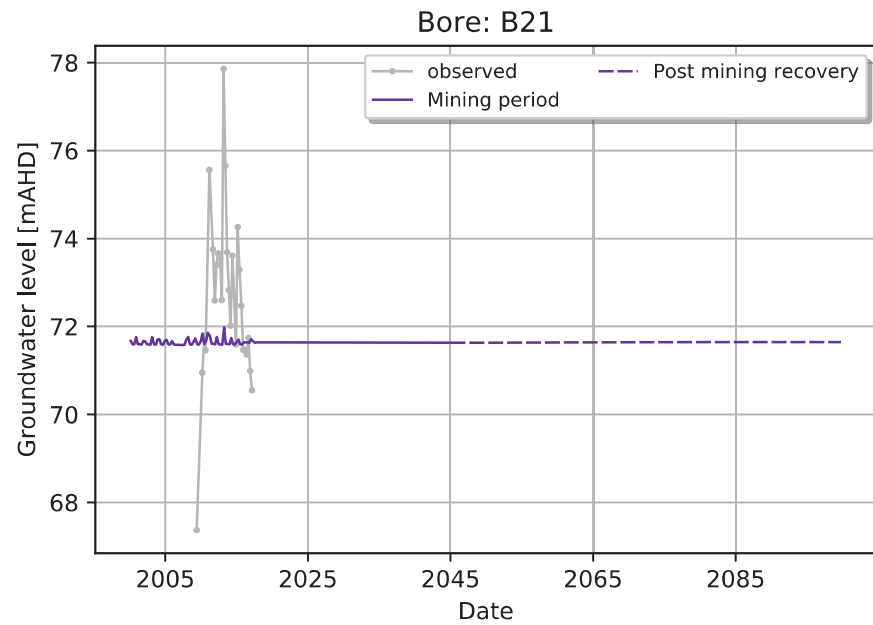
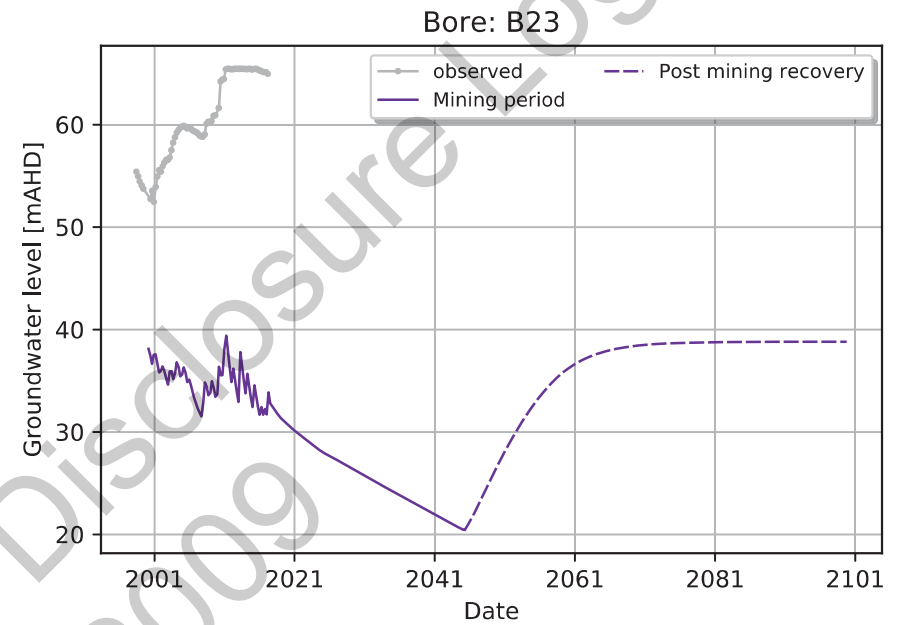
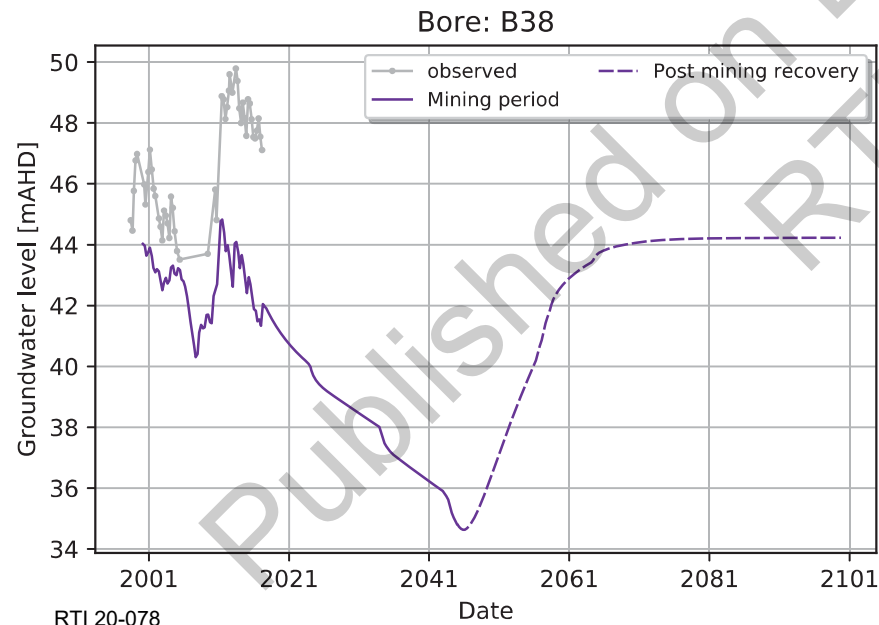
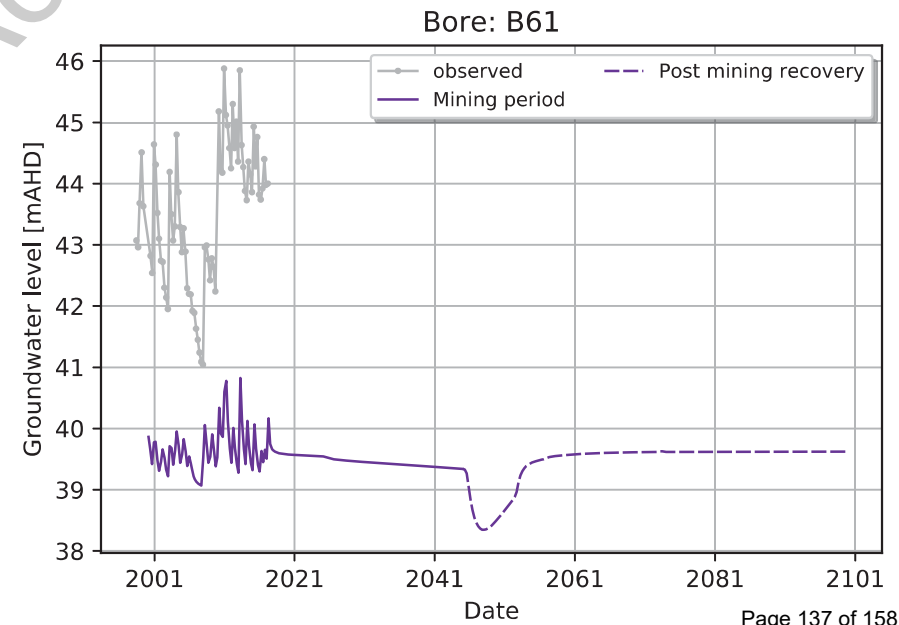


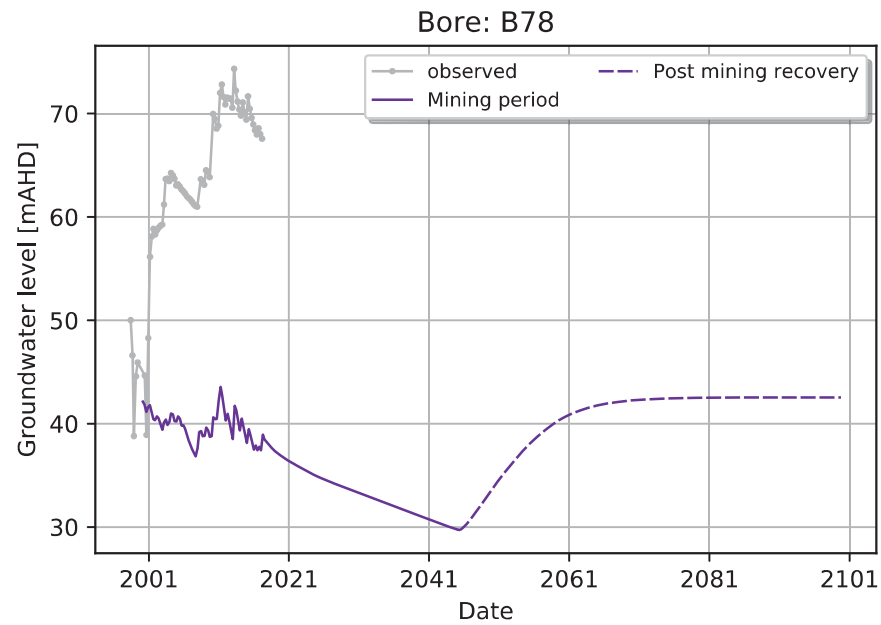
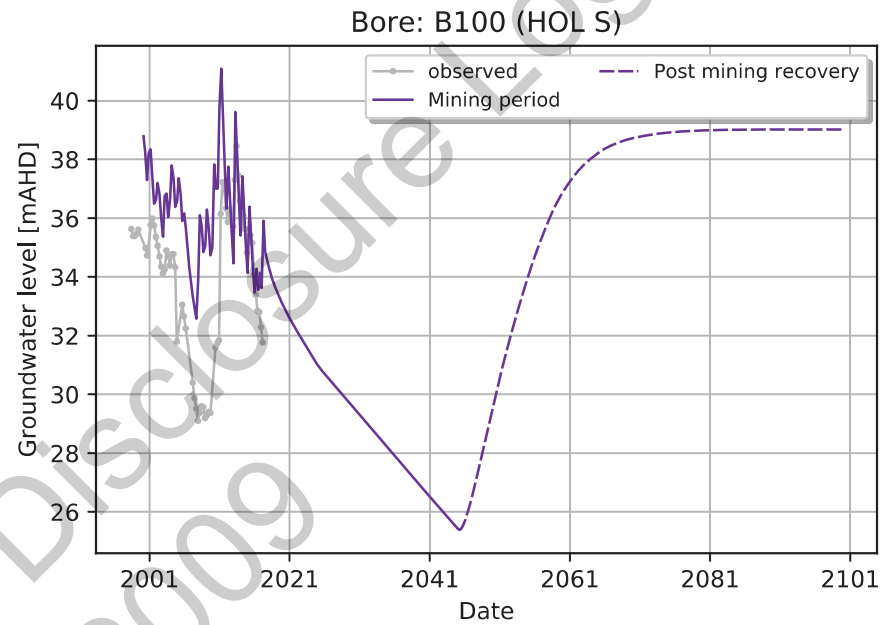
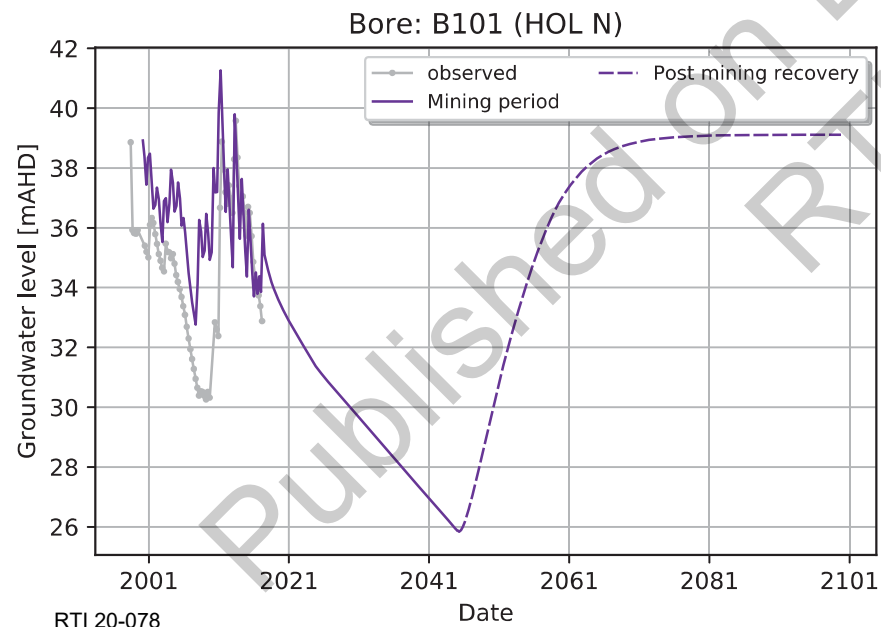
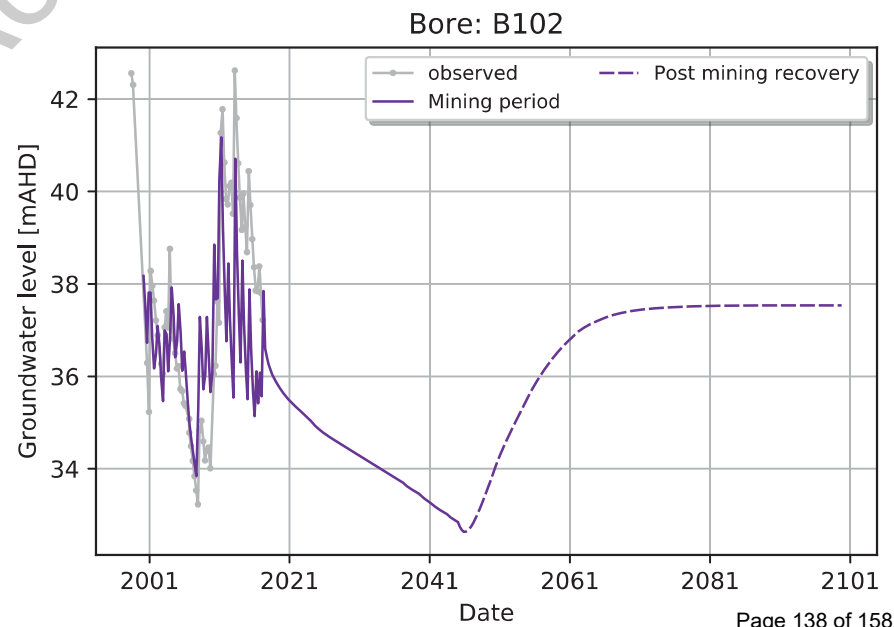


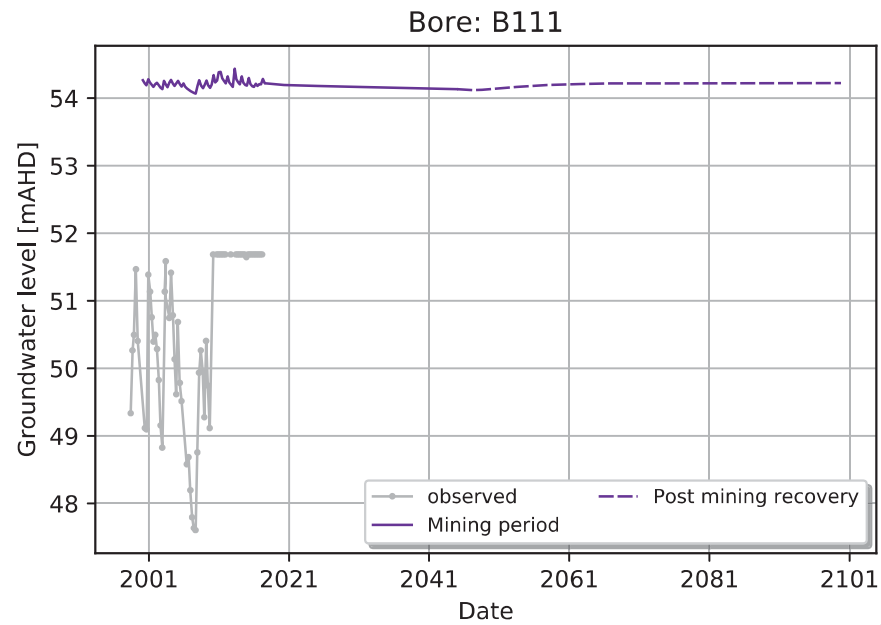
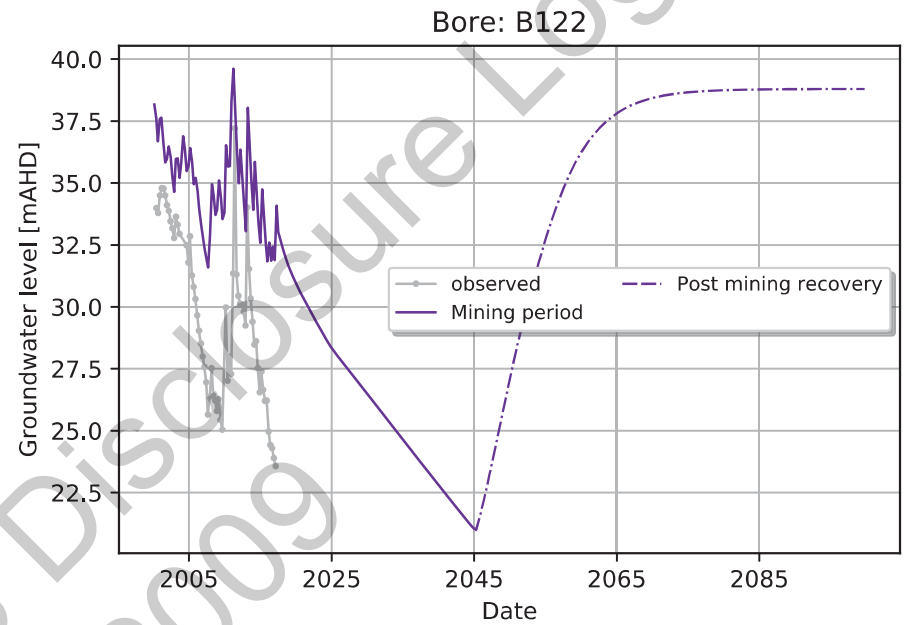
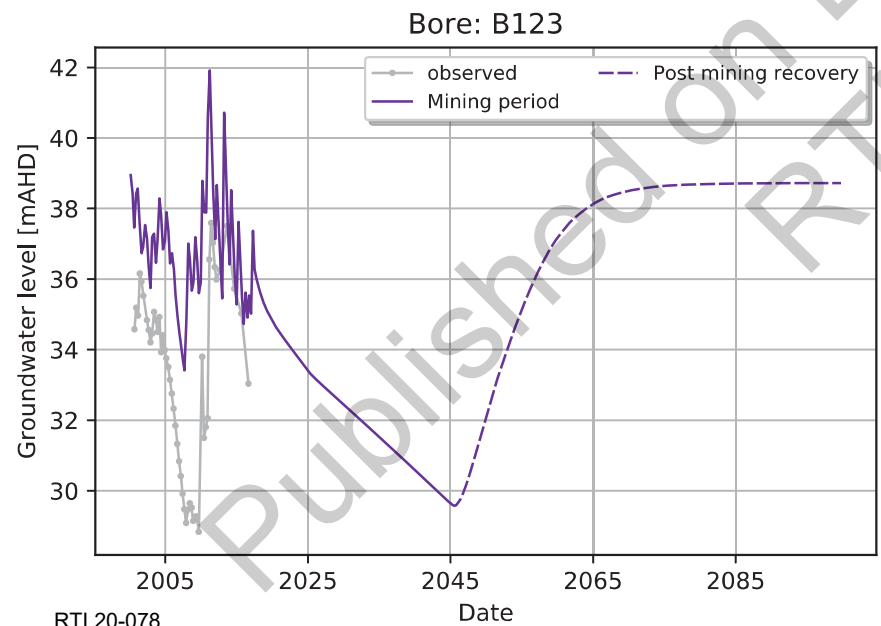
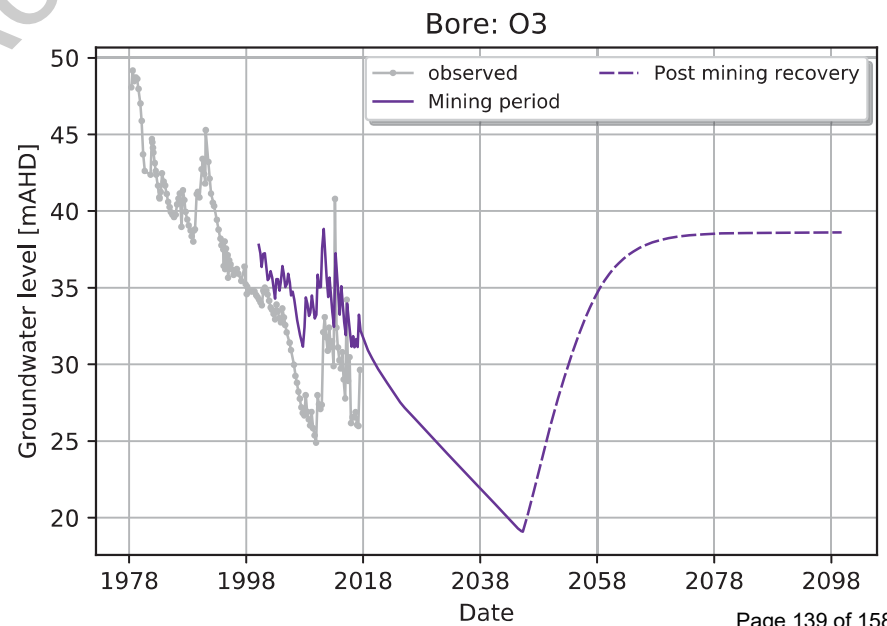


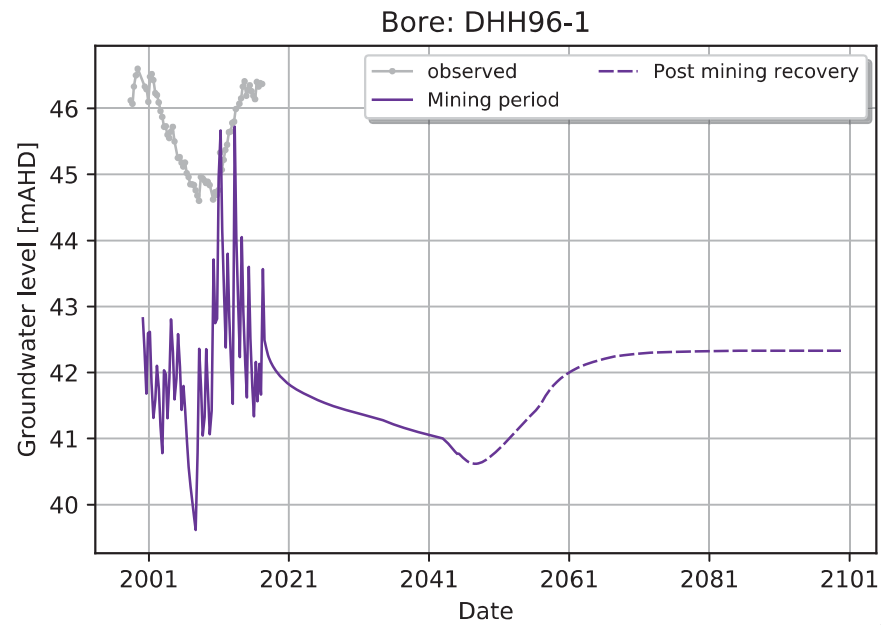
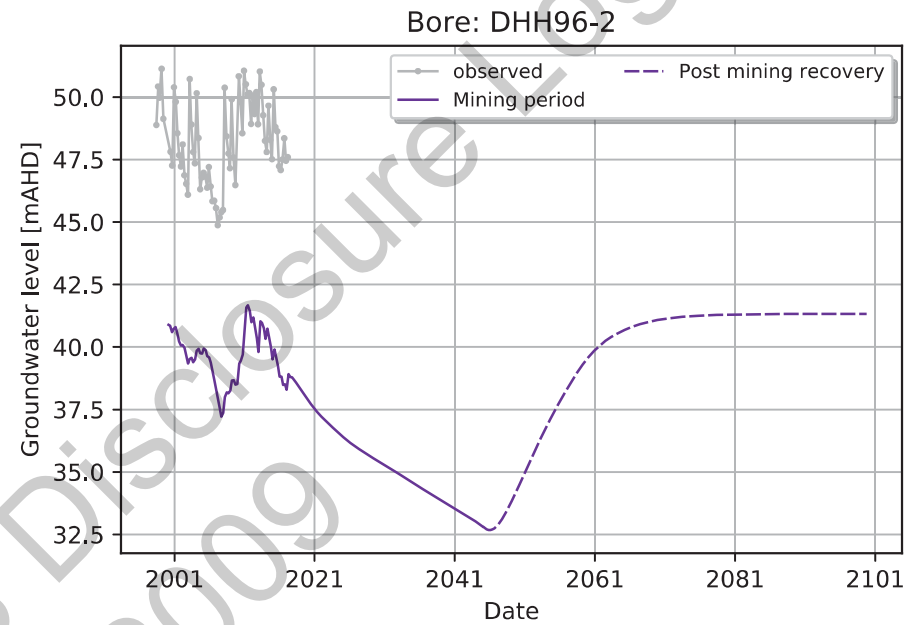
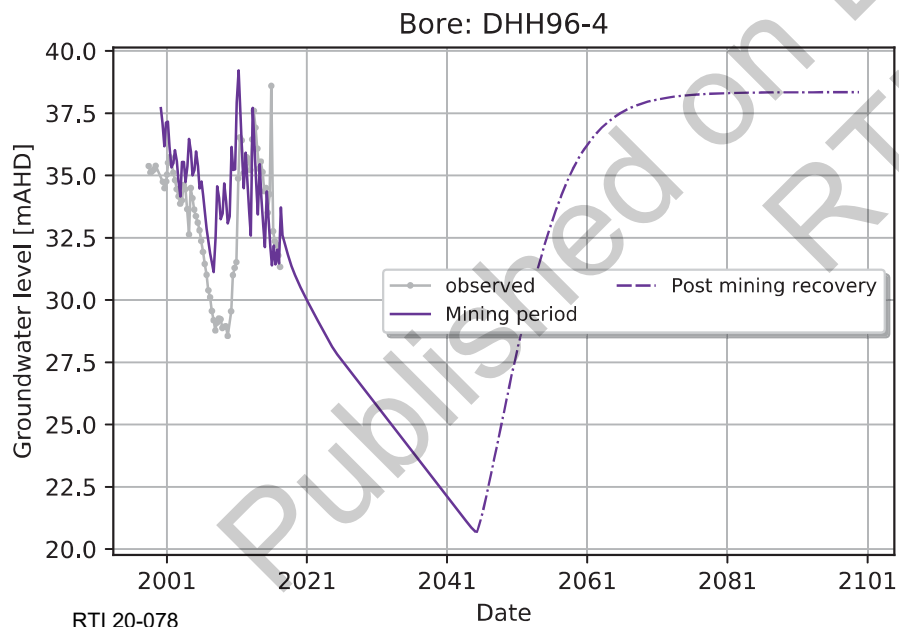
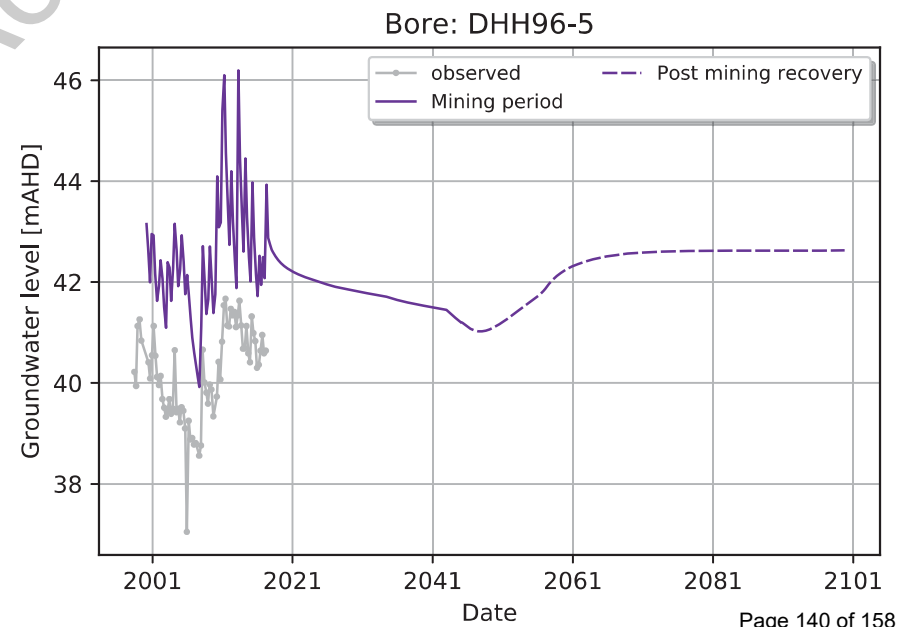
Appendix G

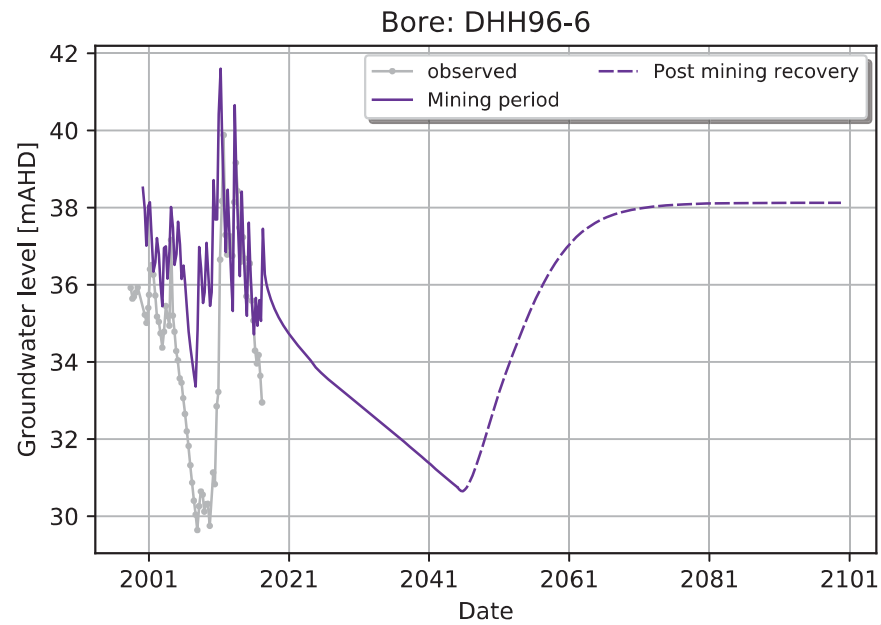
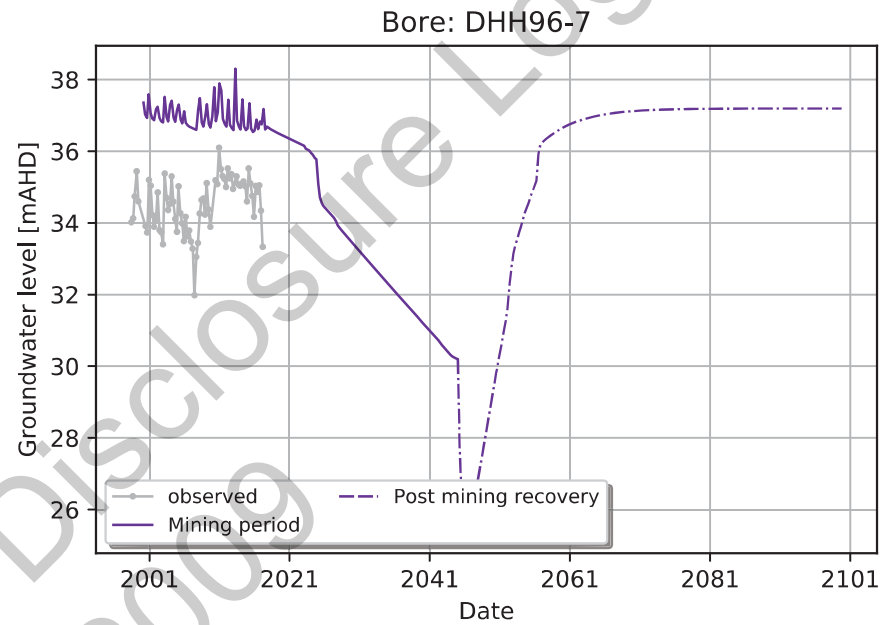
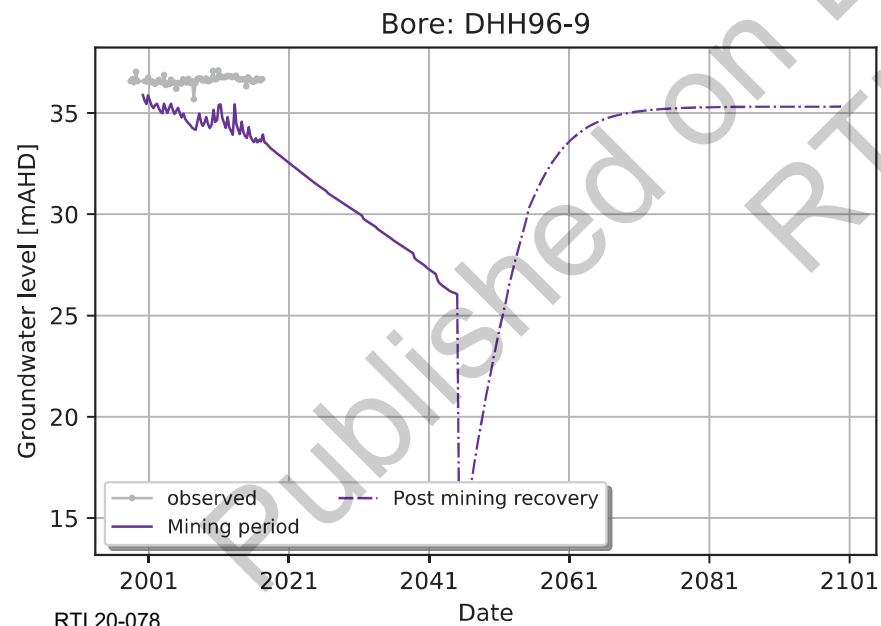
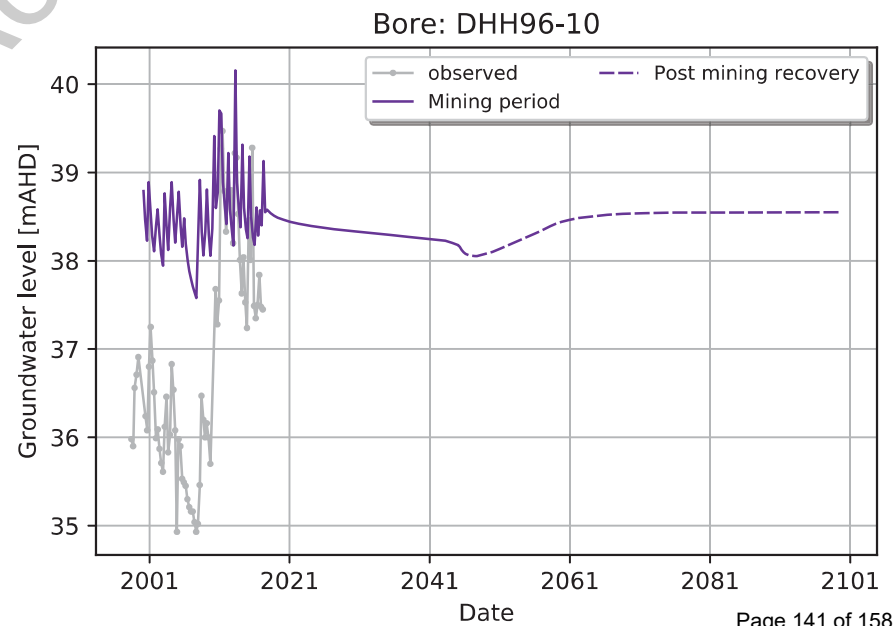
Post-mining recovery plots

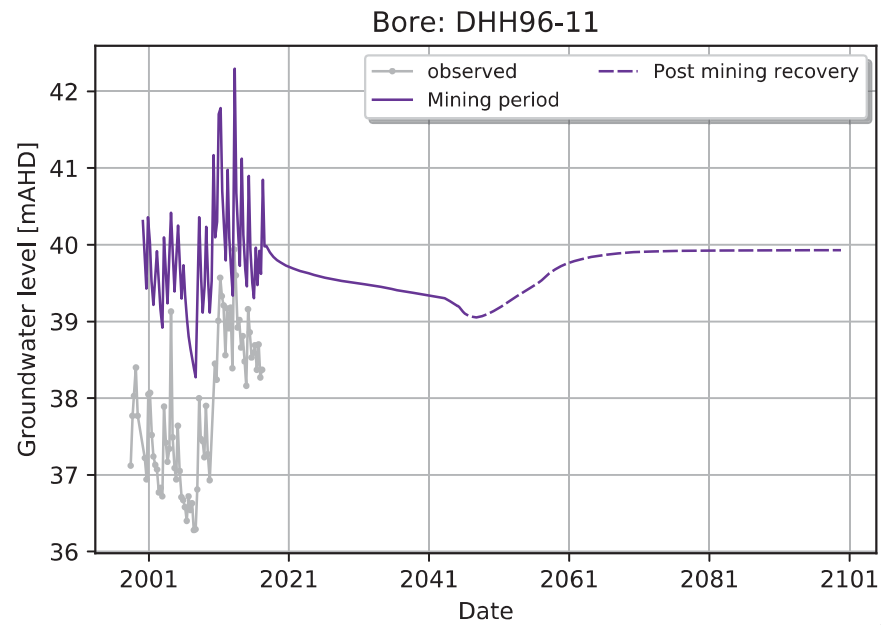
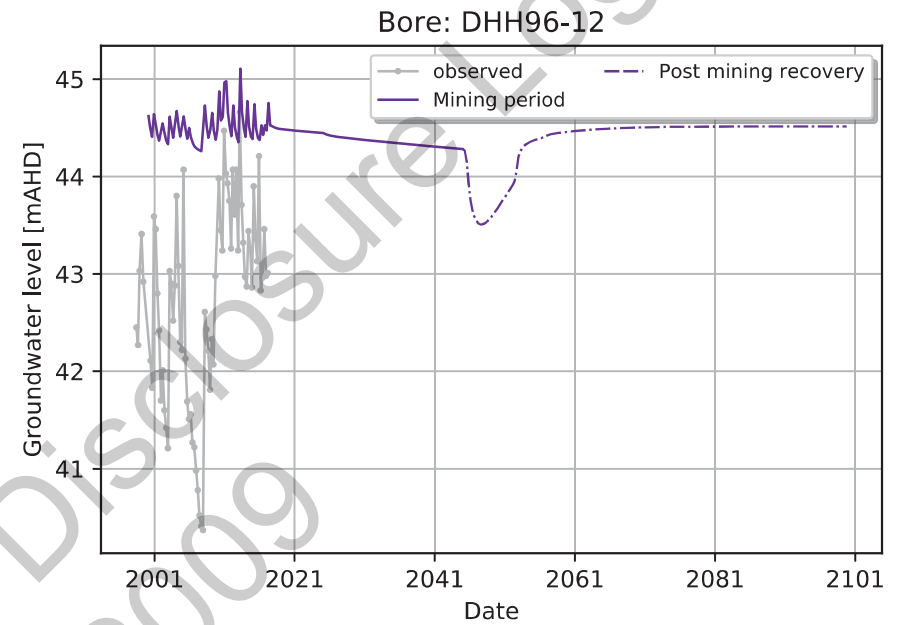
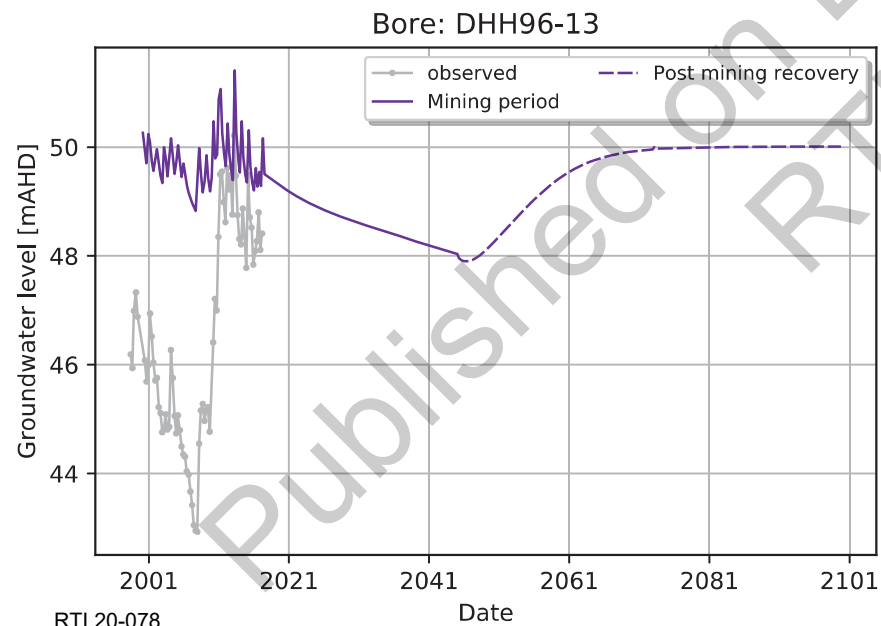
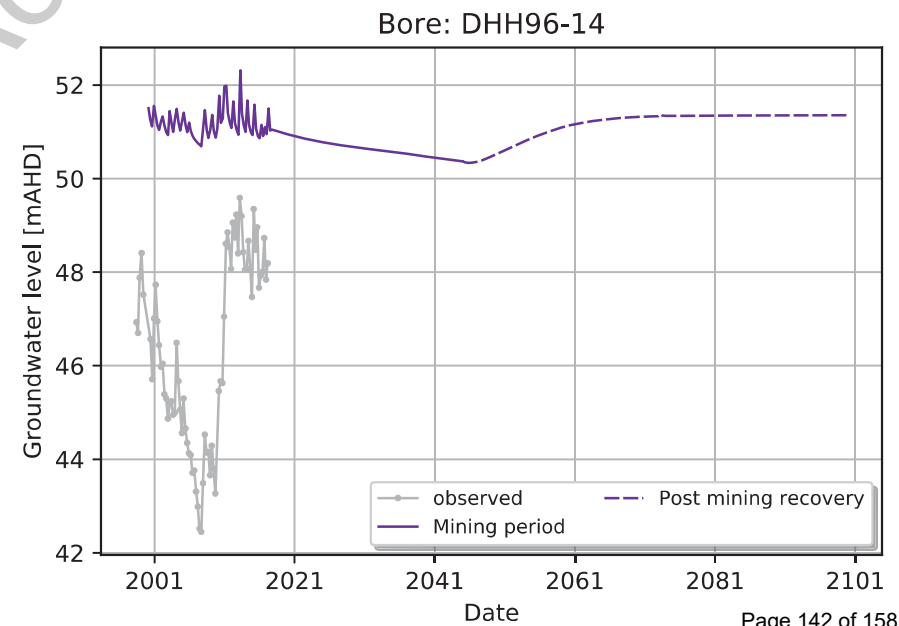


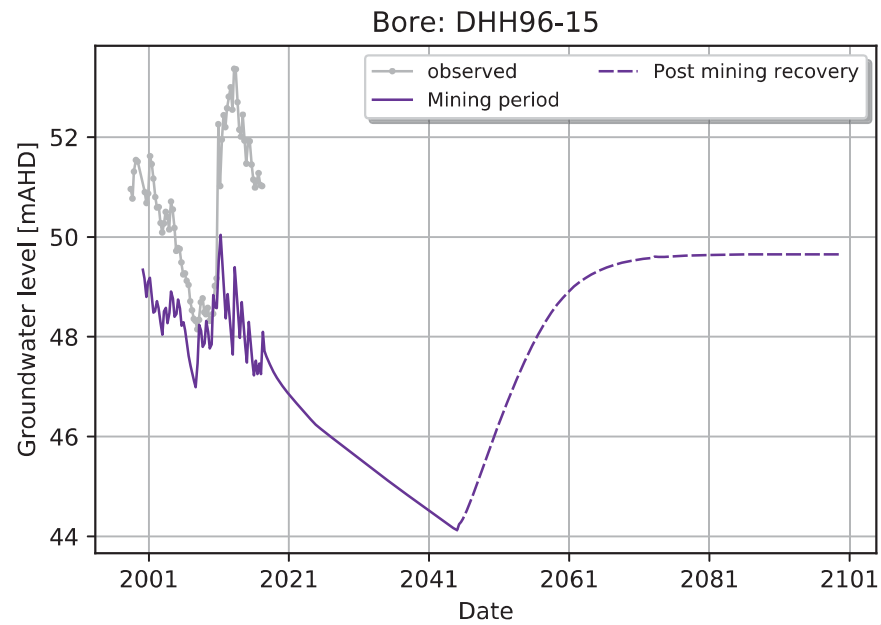
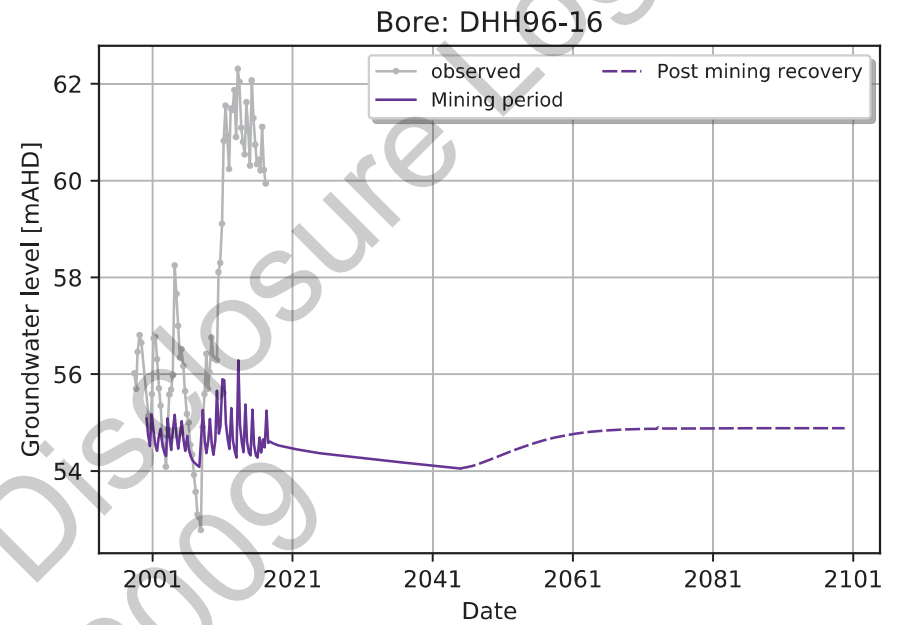
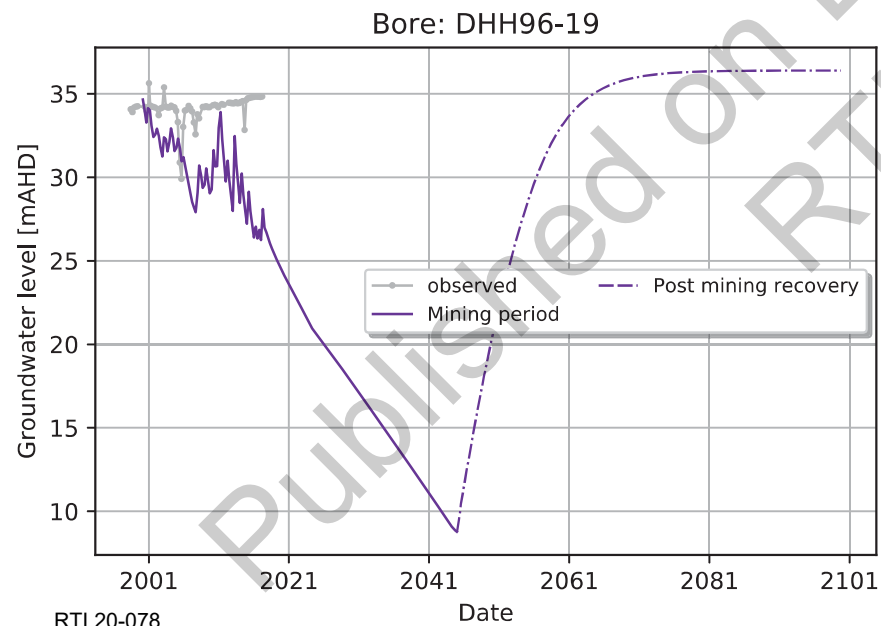
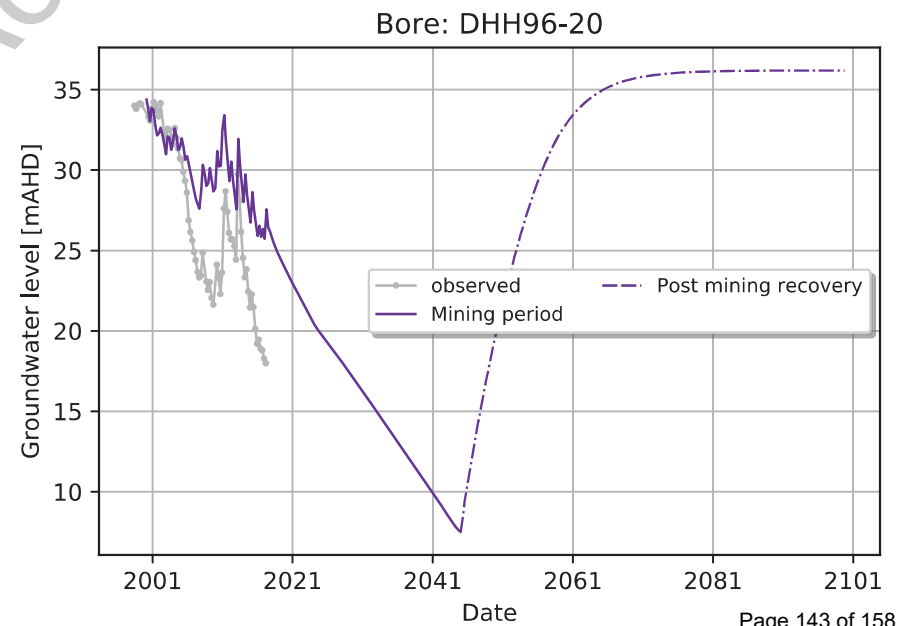


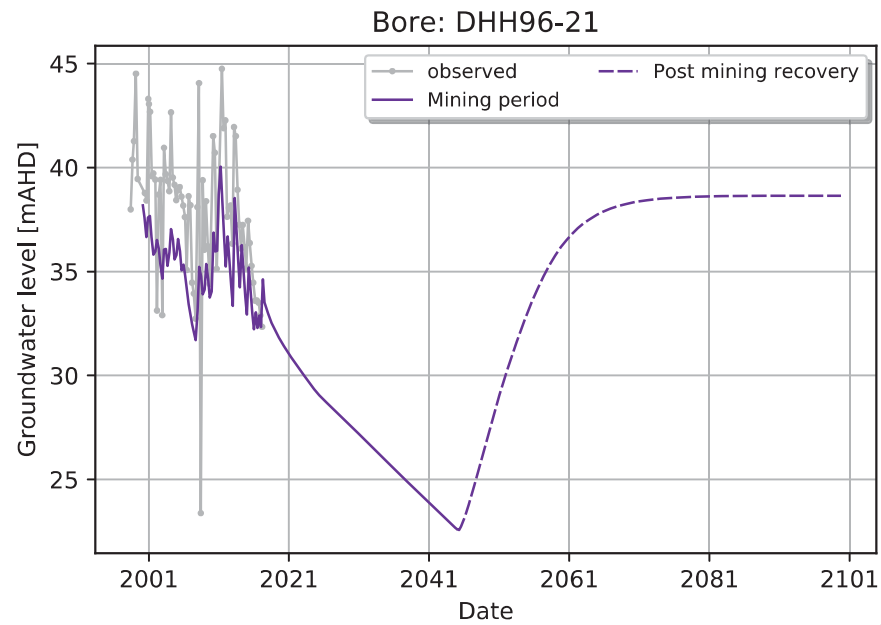
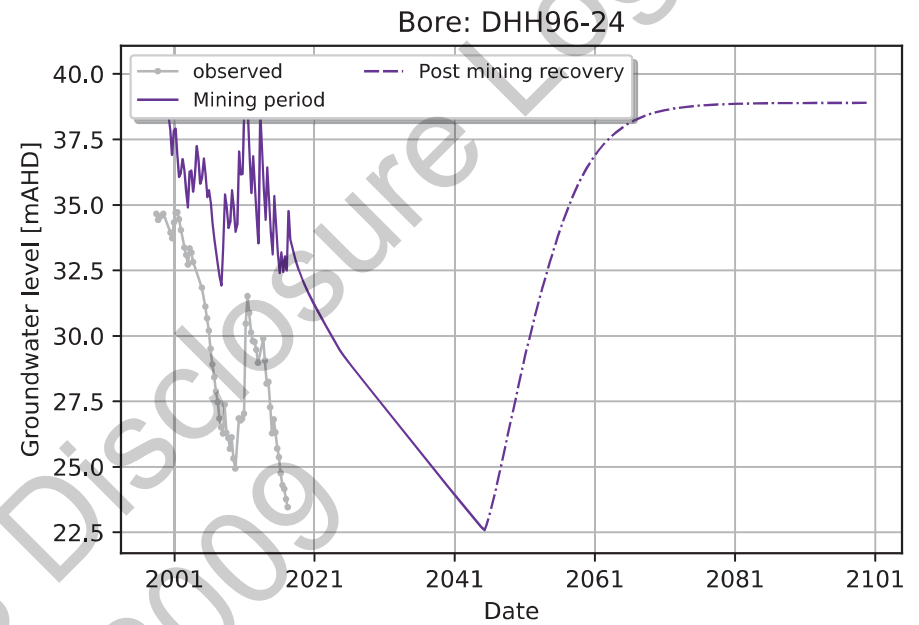
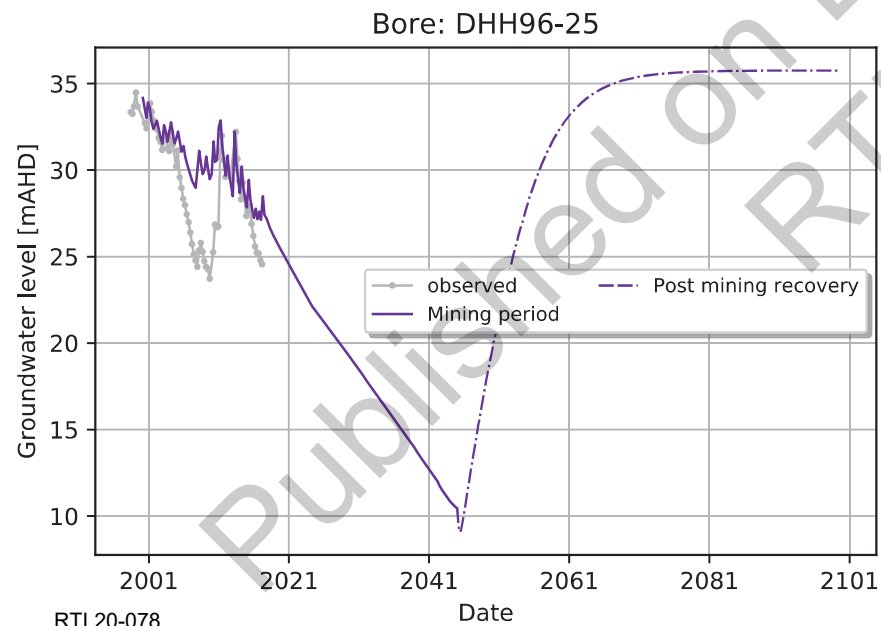
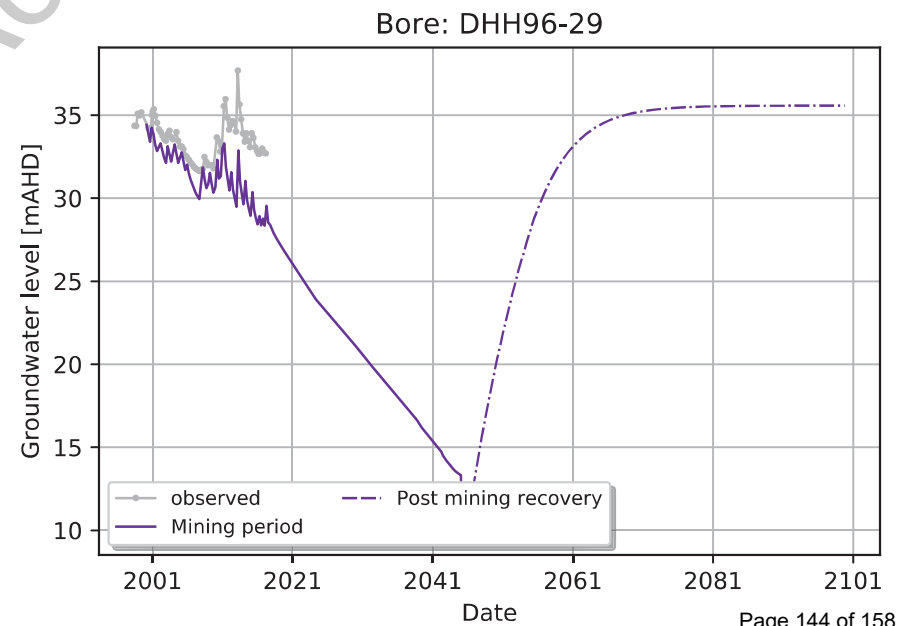


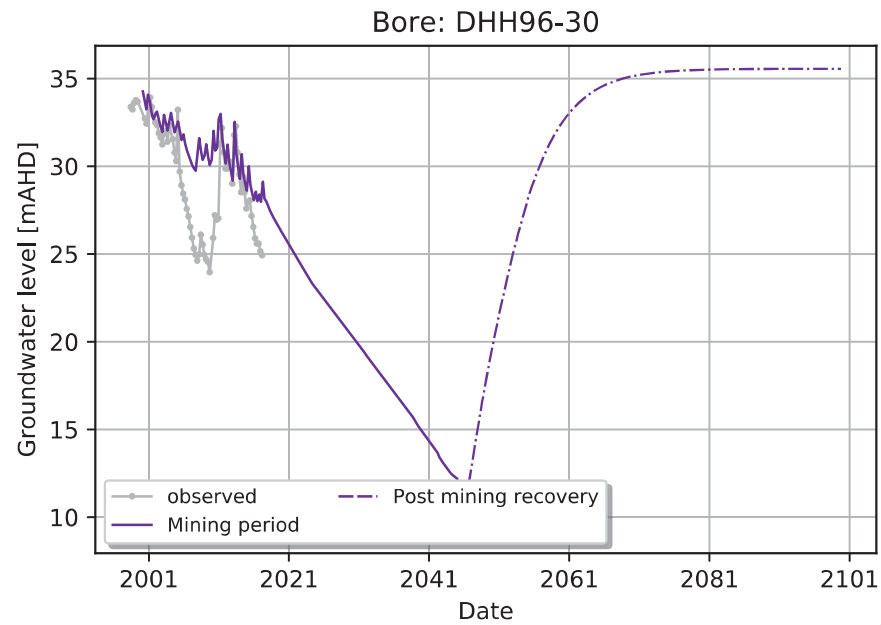
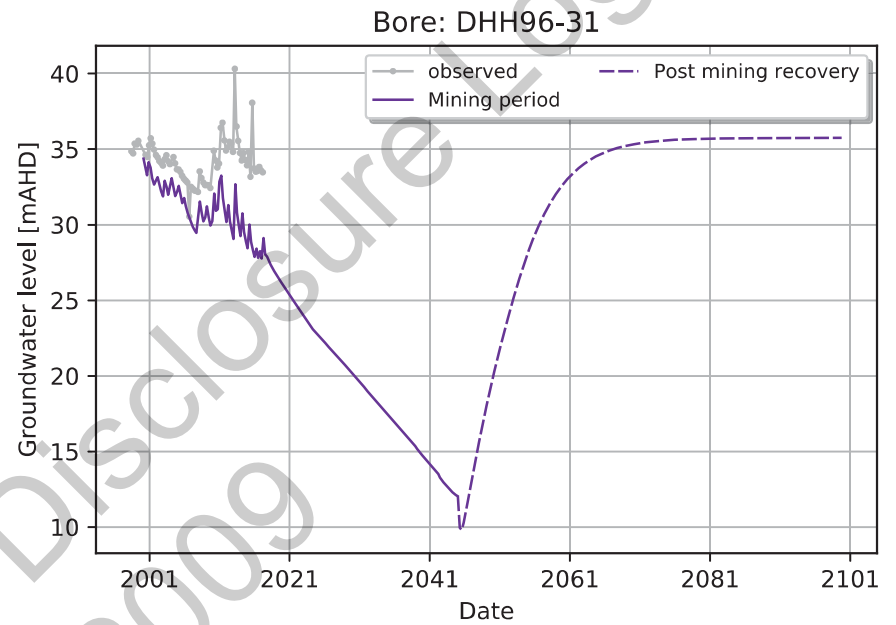
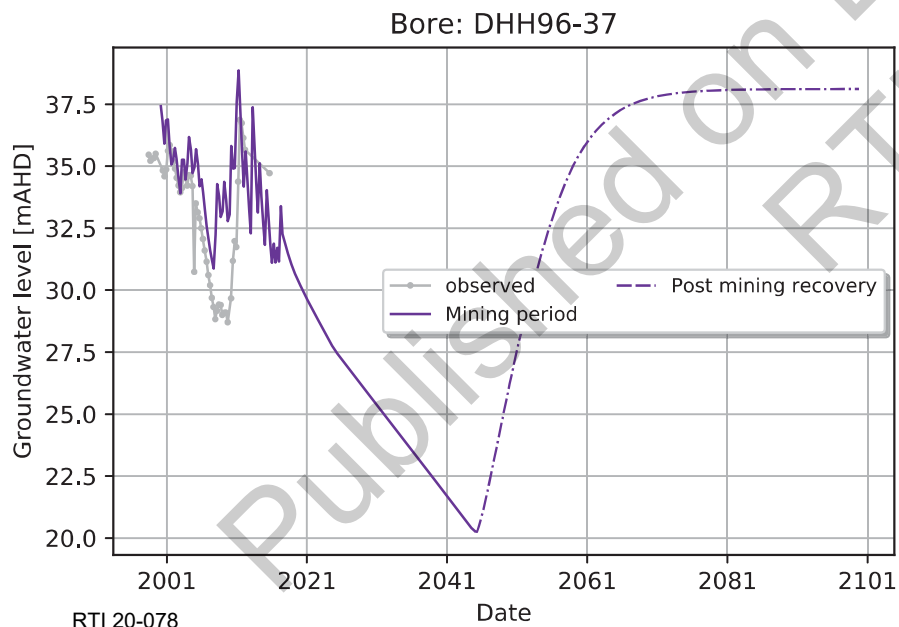
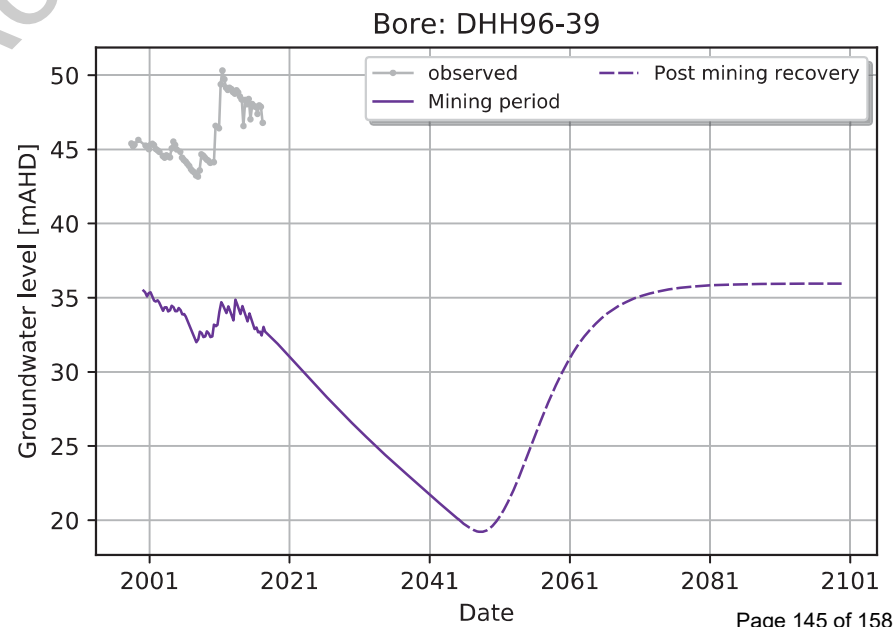


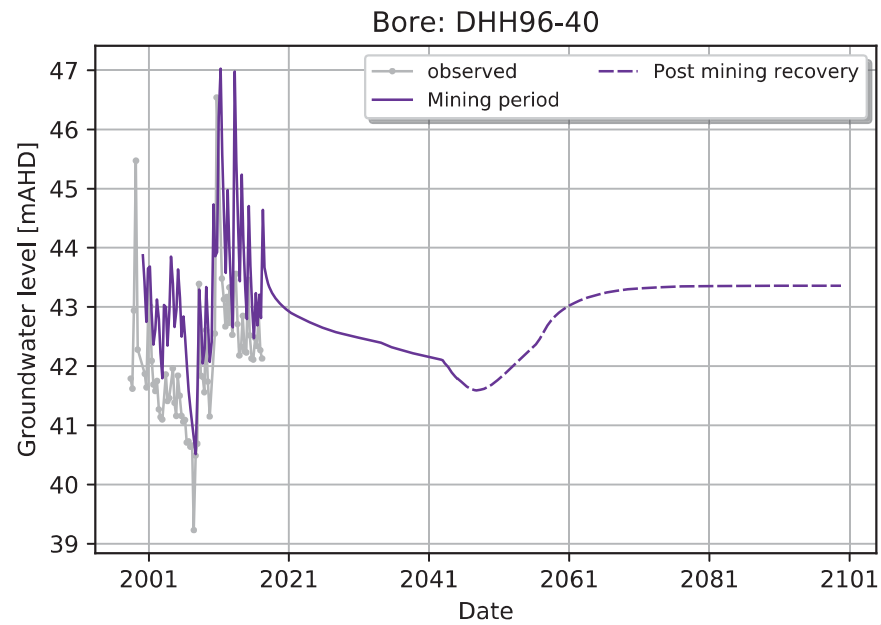
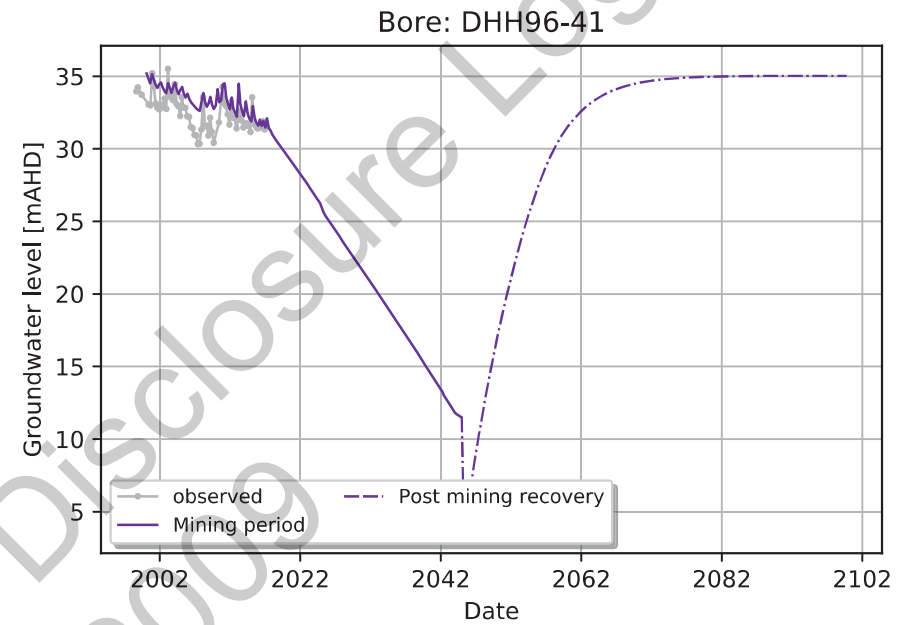
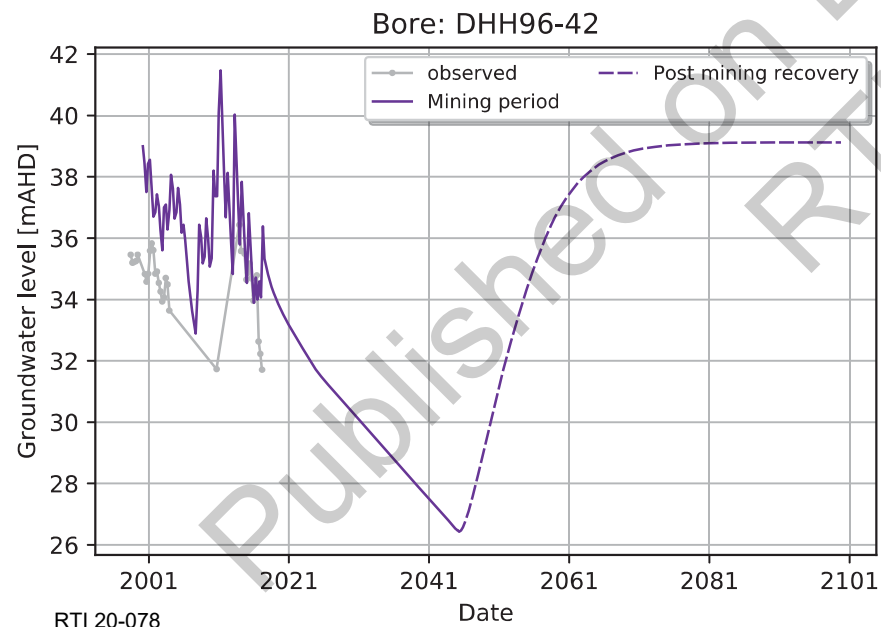
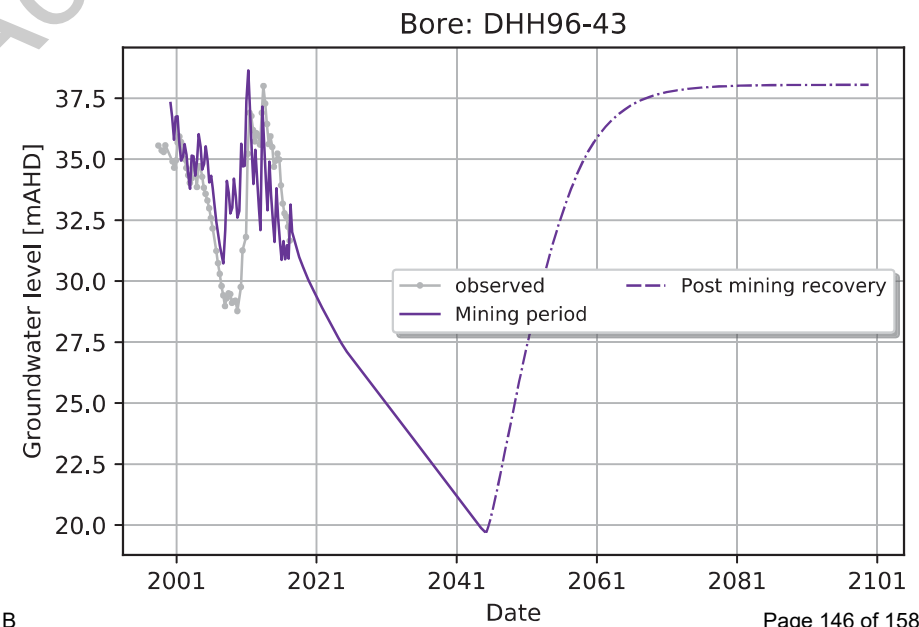


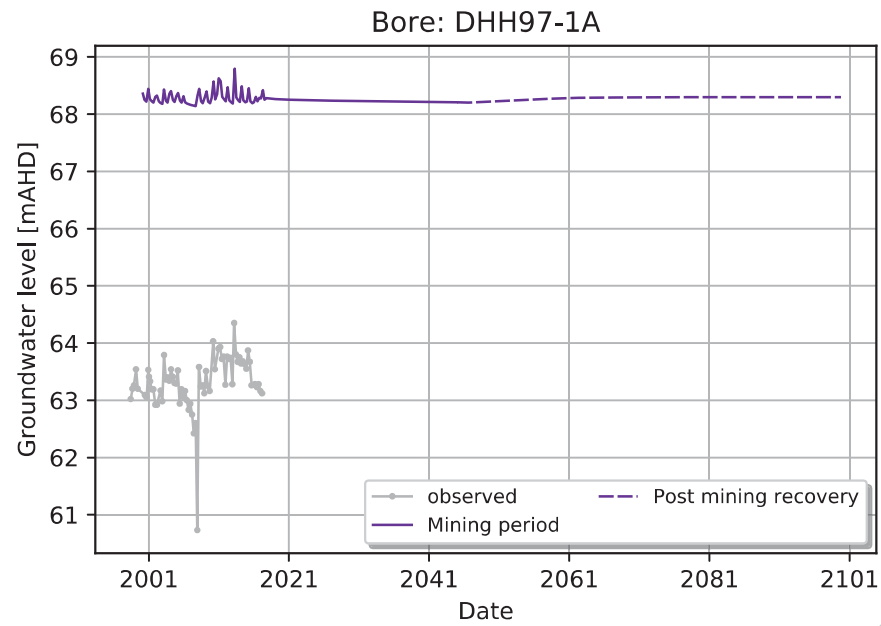
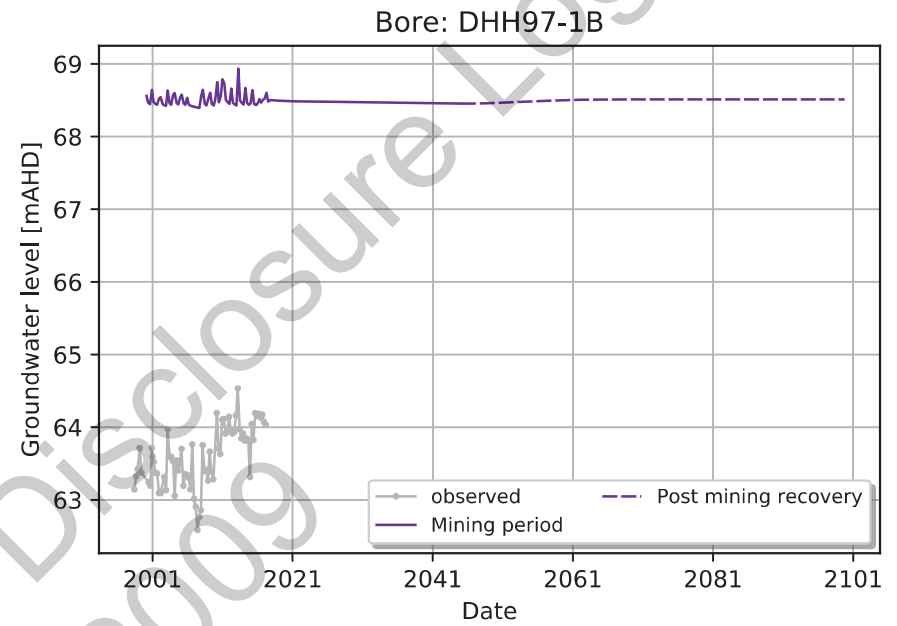
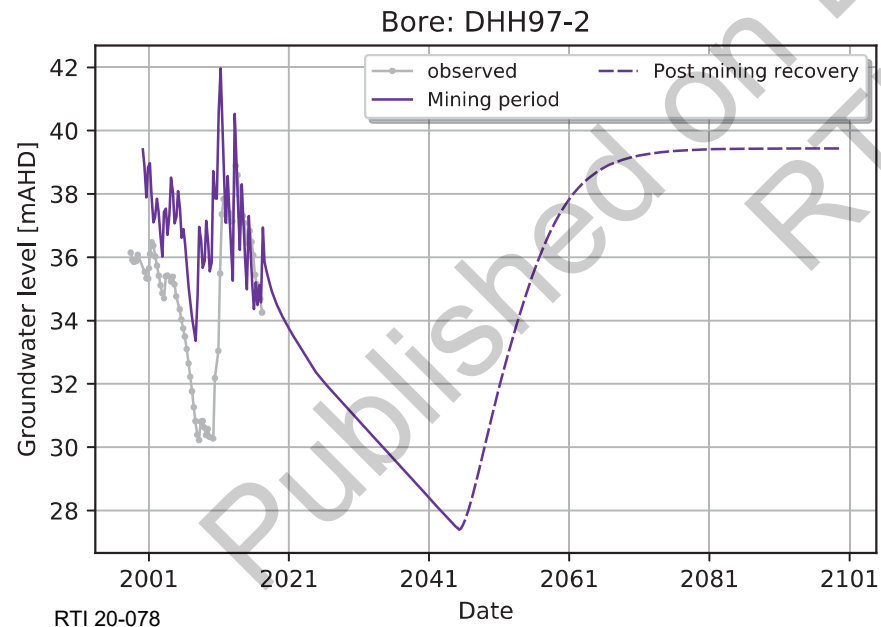
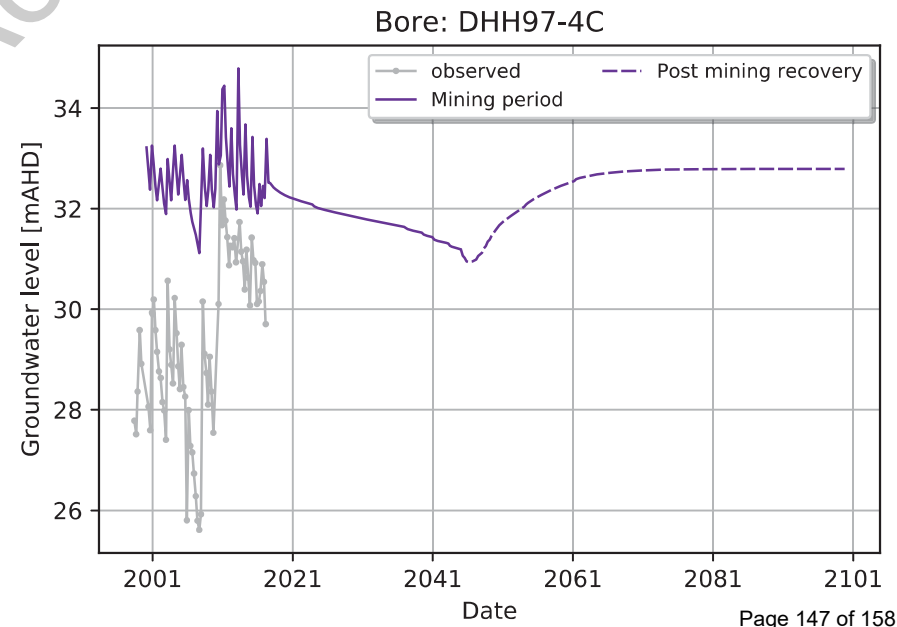


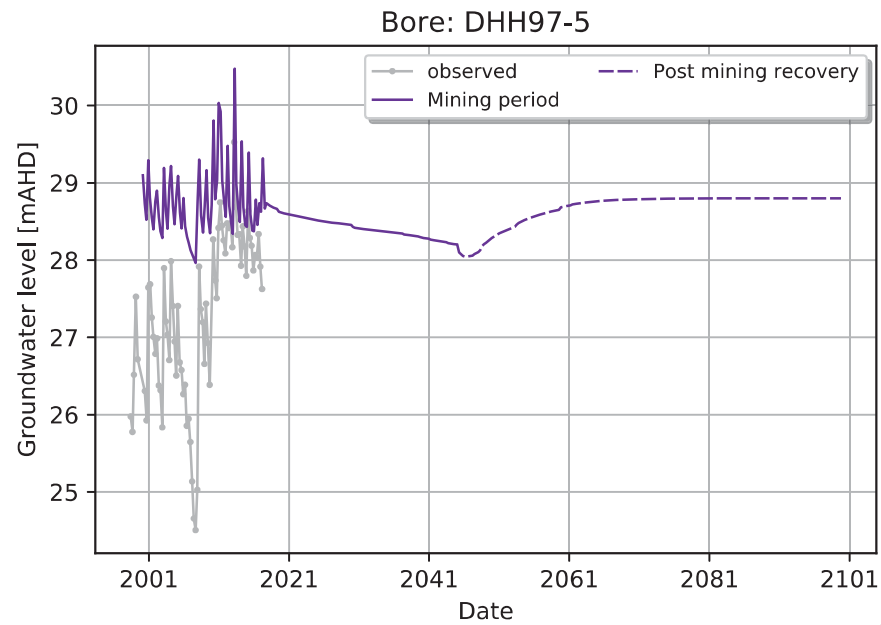
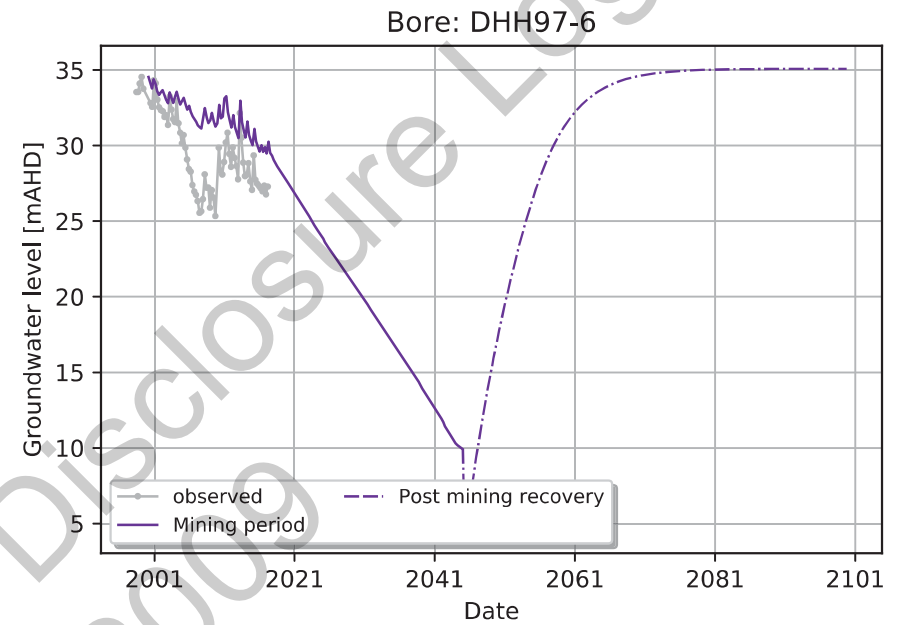
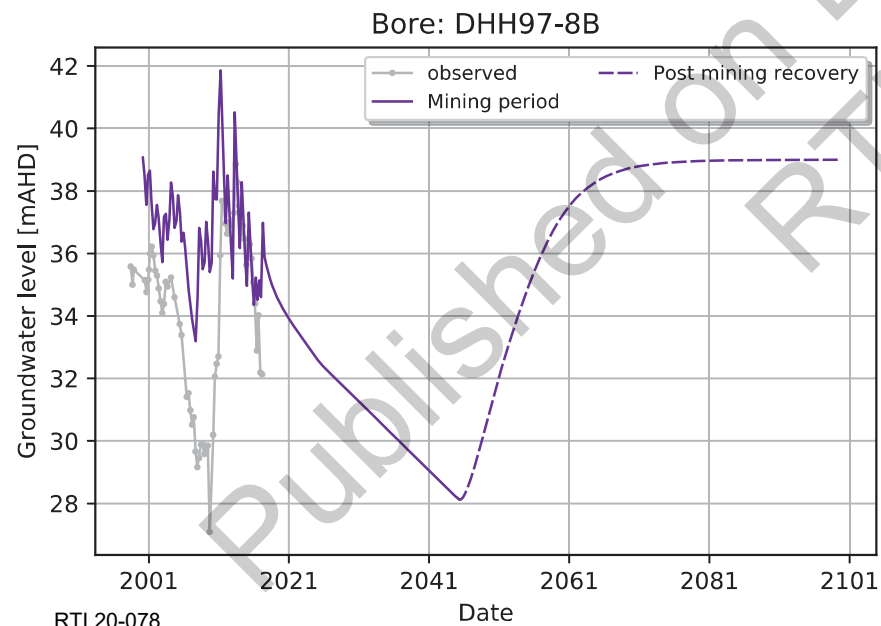
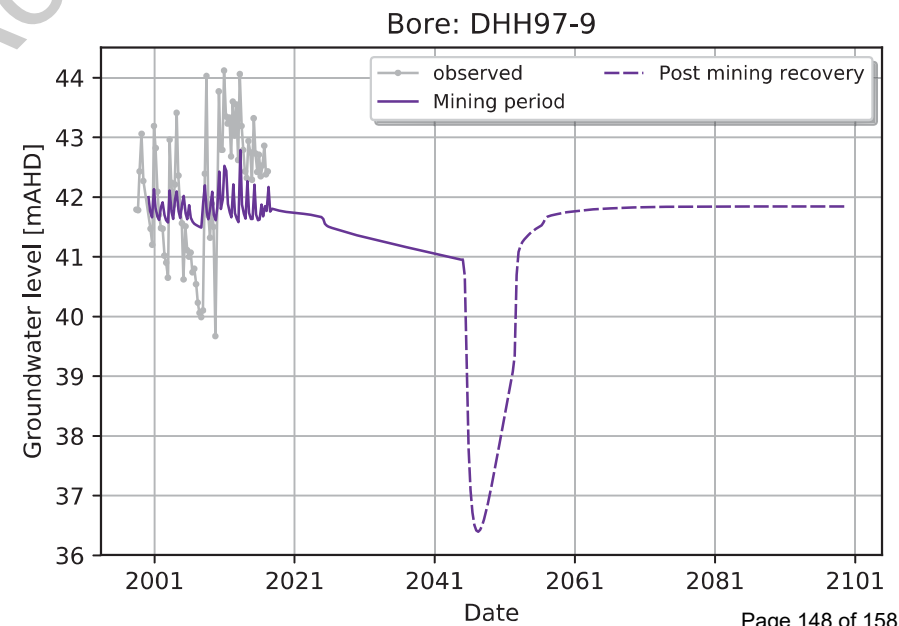


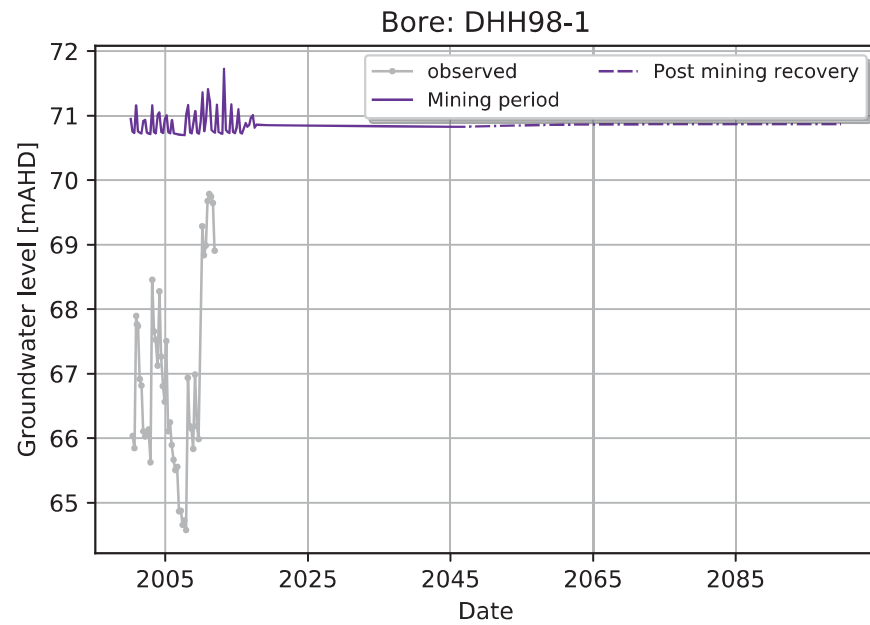
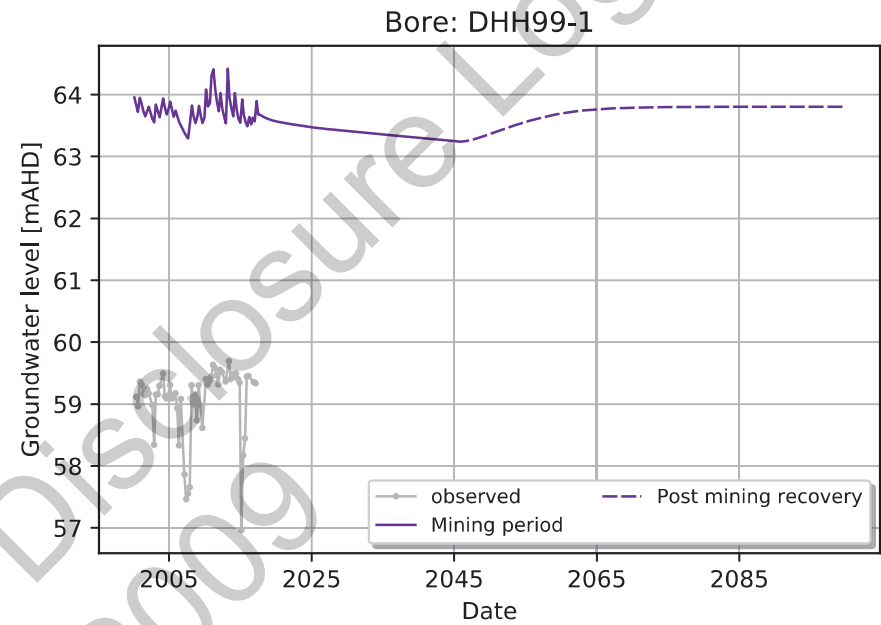
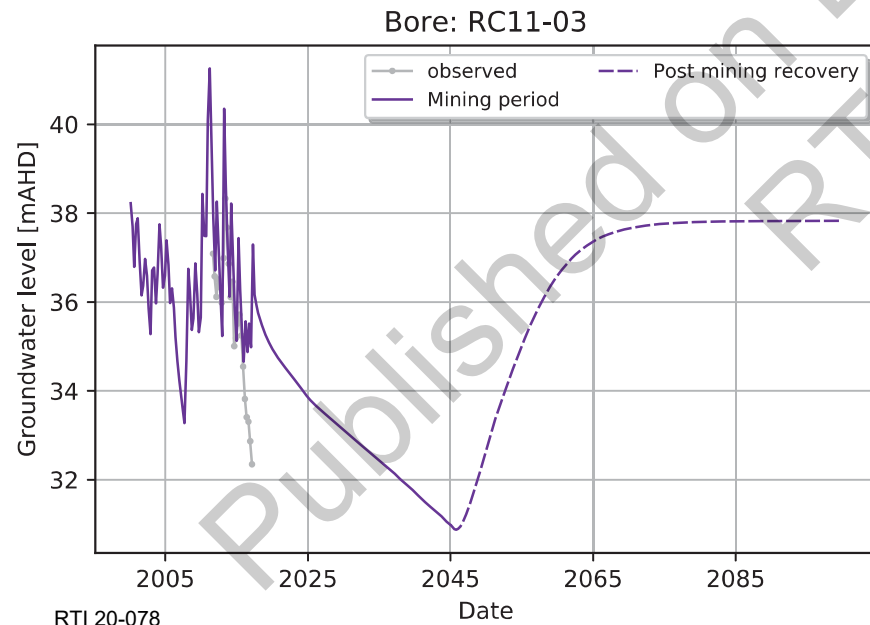
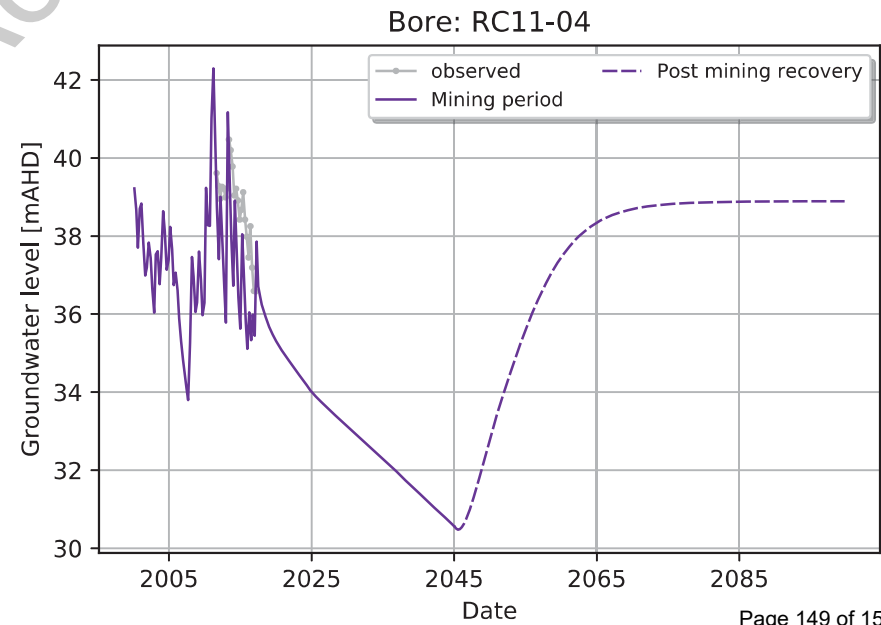


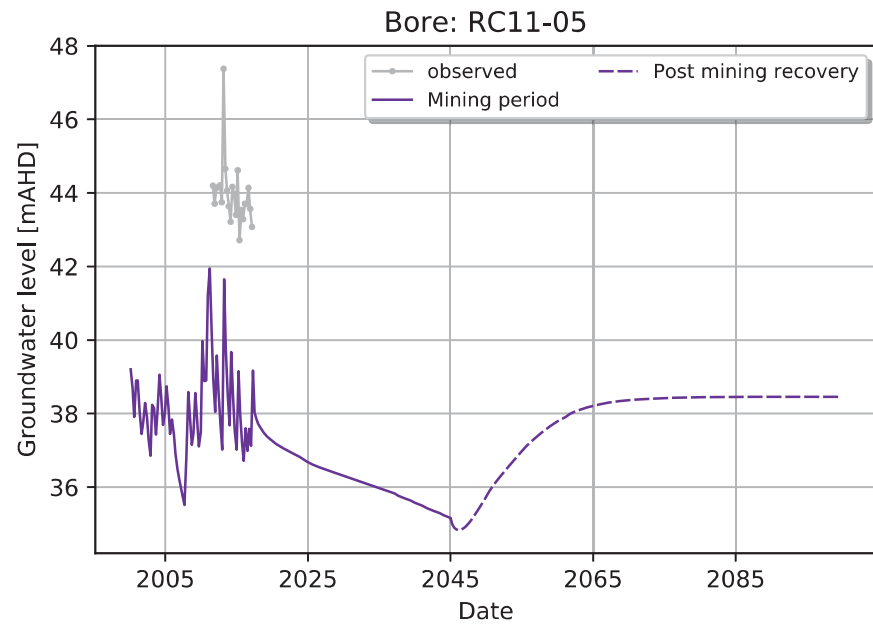
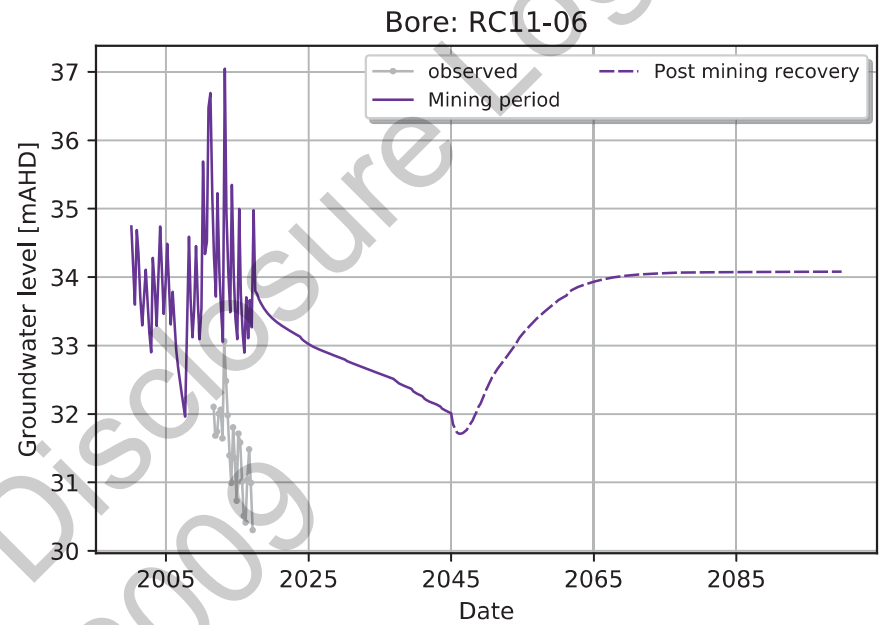
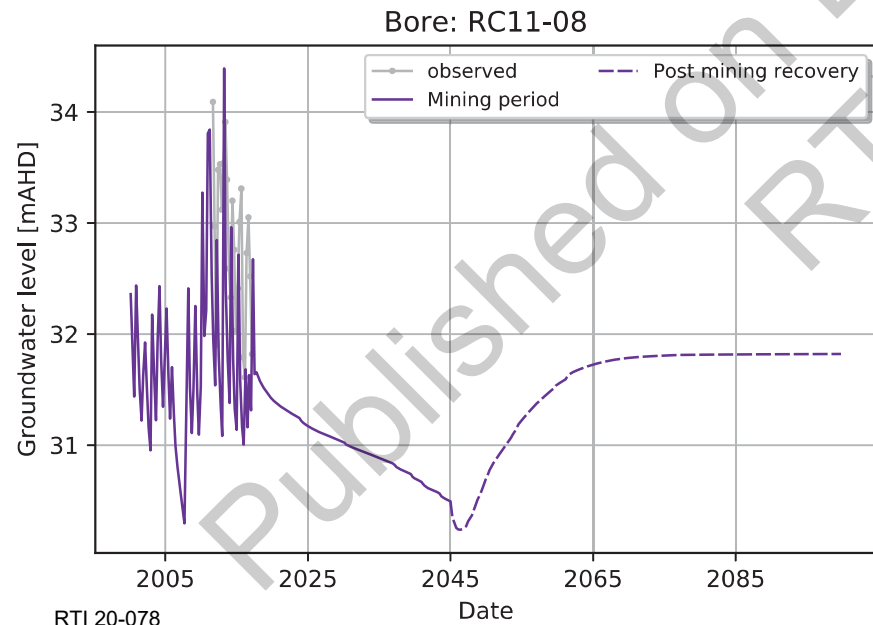
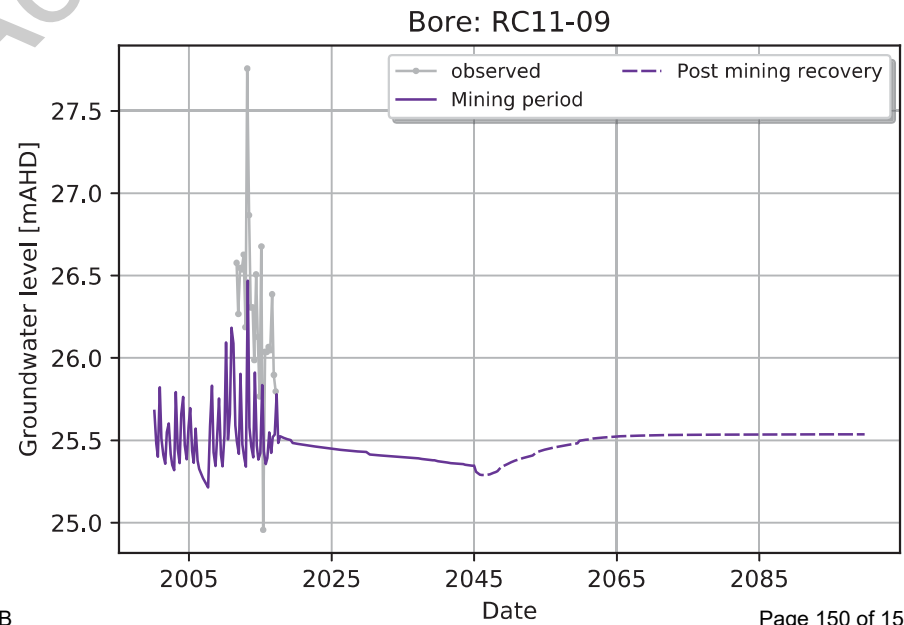


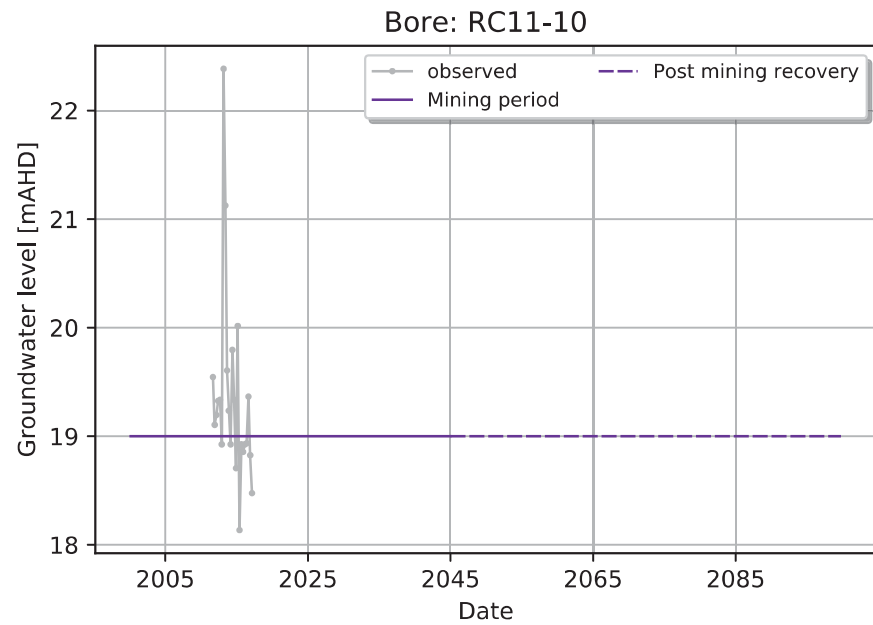
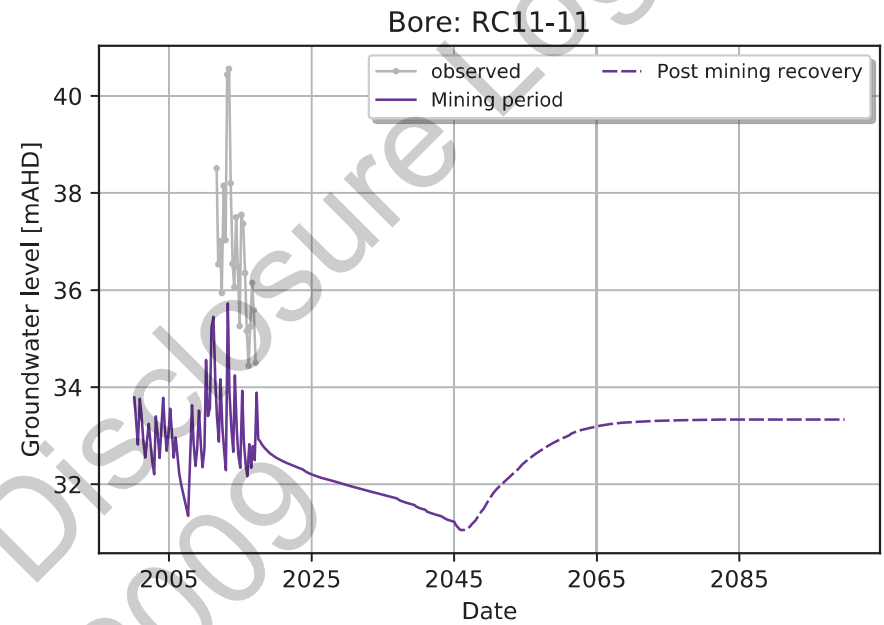
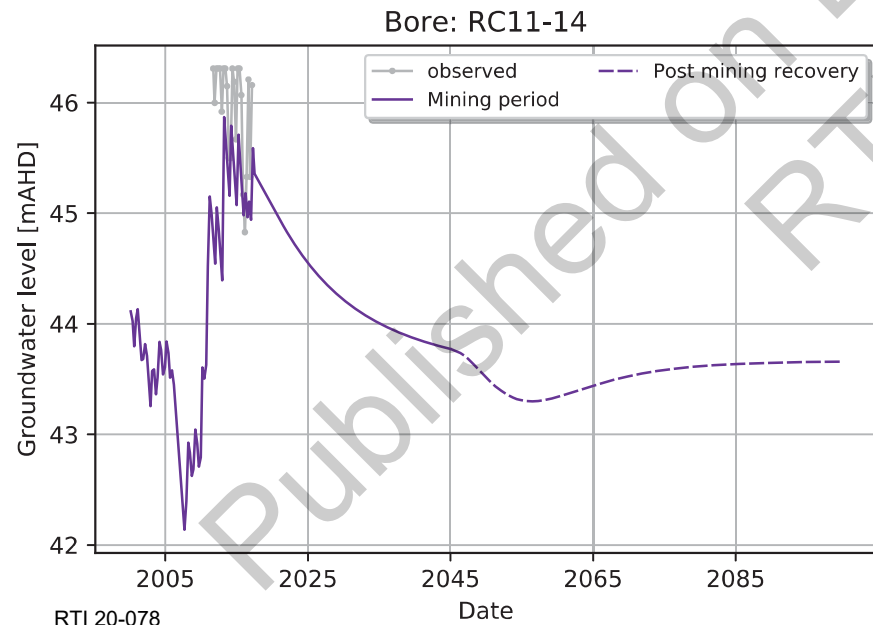
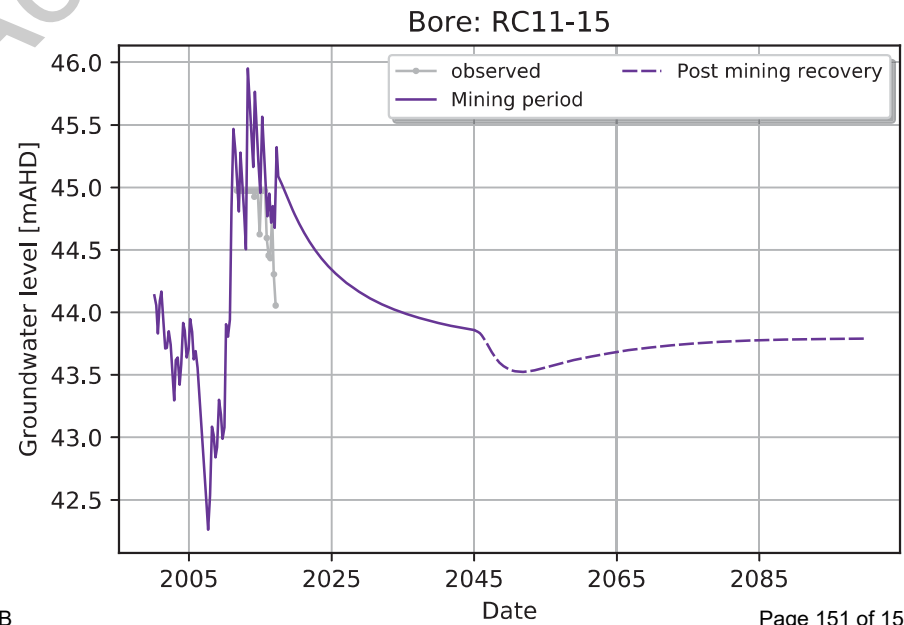


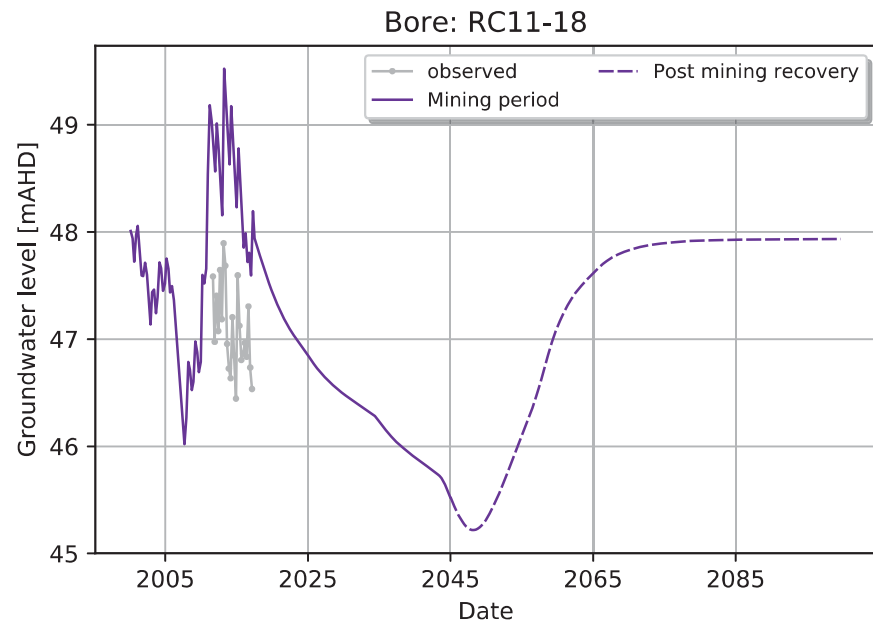
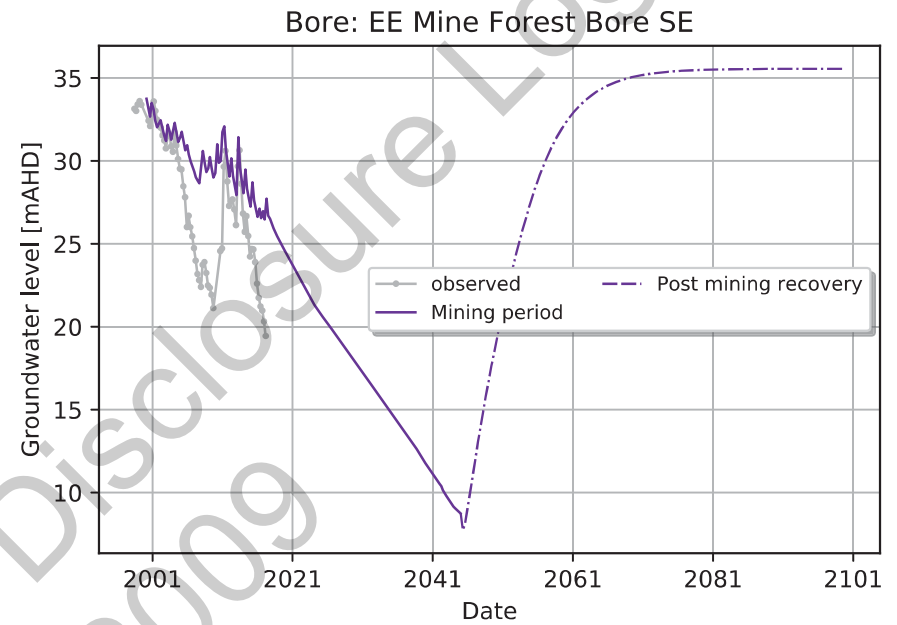
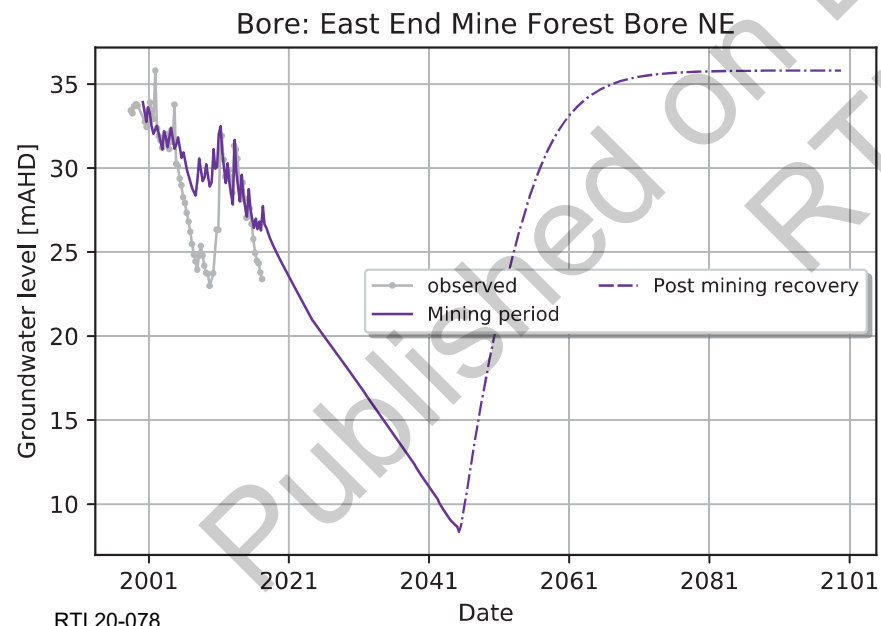












Appendix H

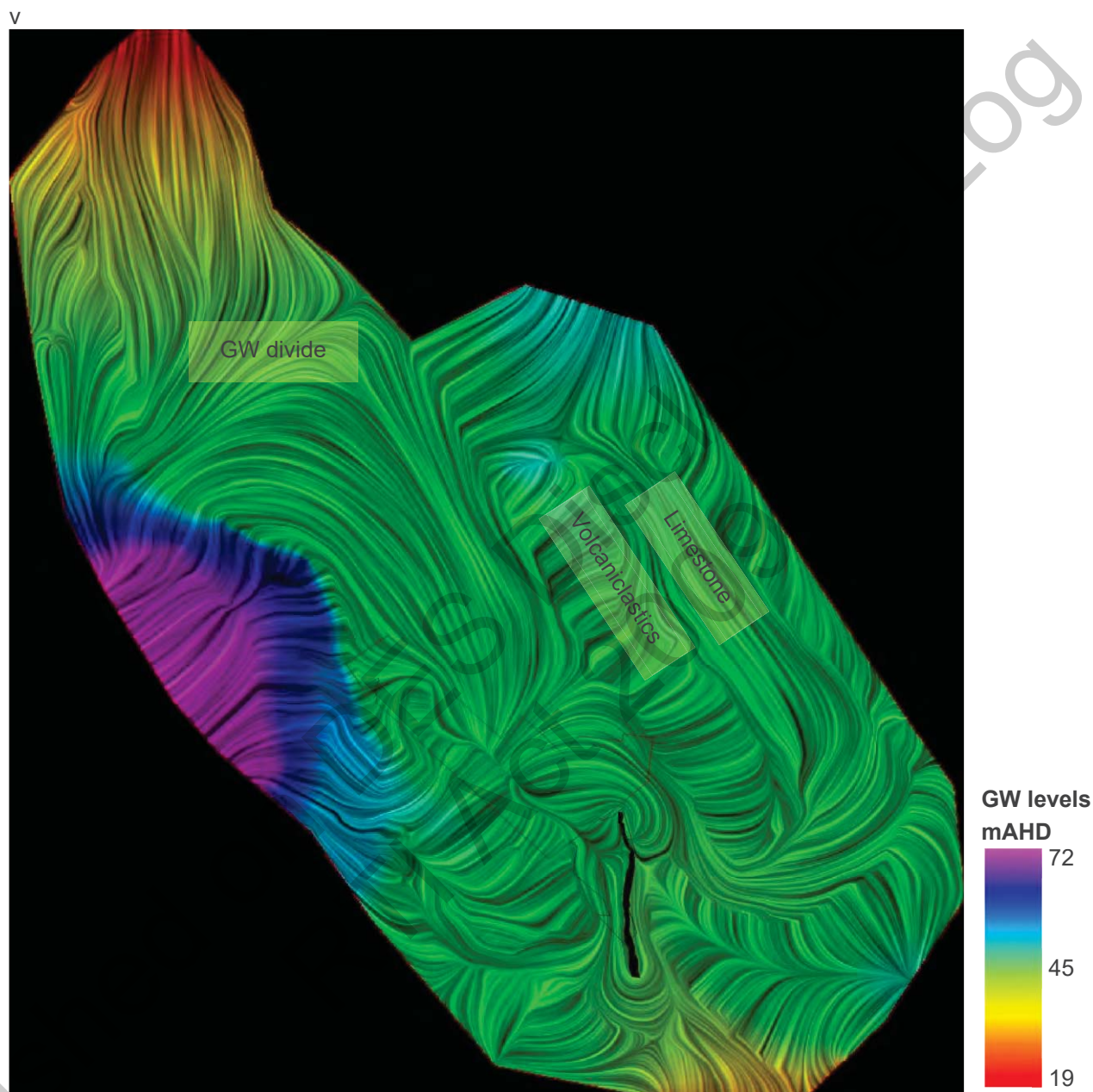
Flow fields

Background

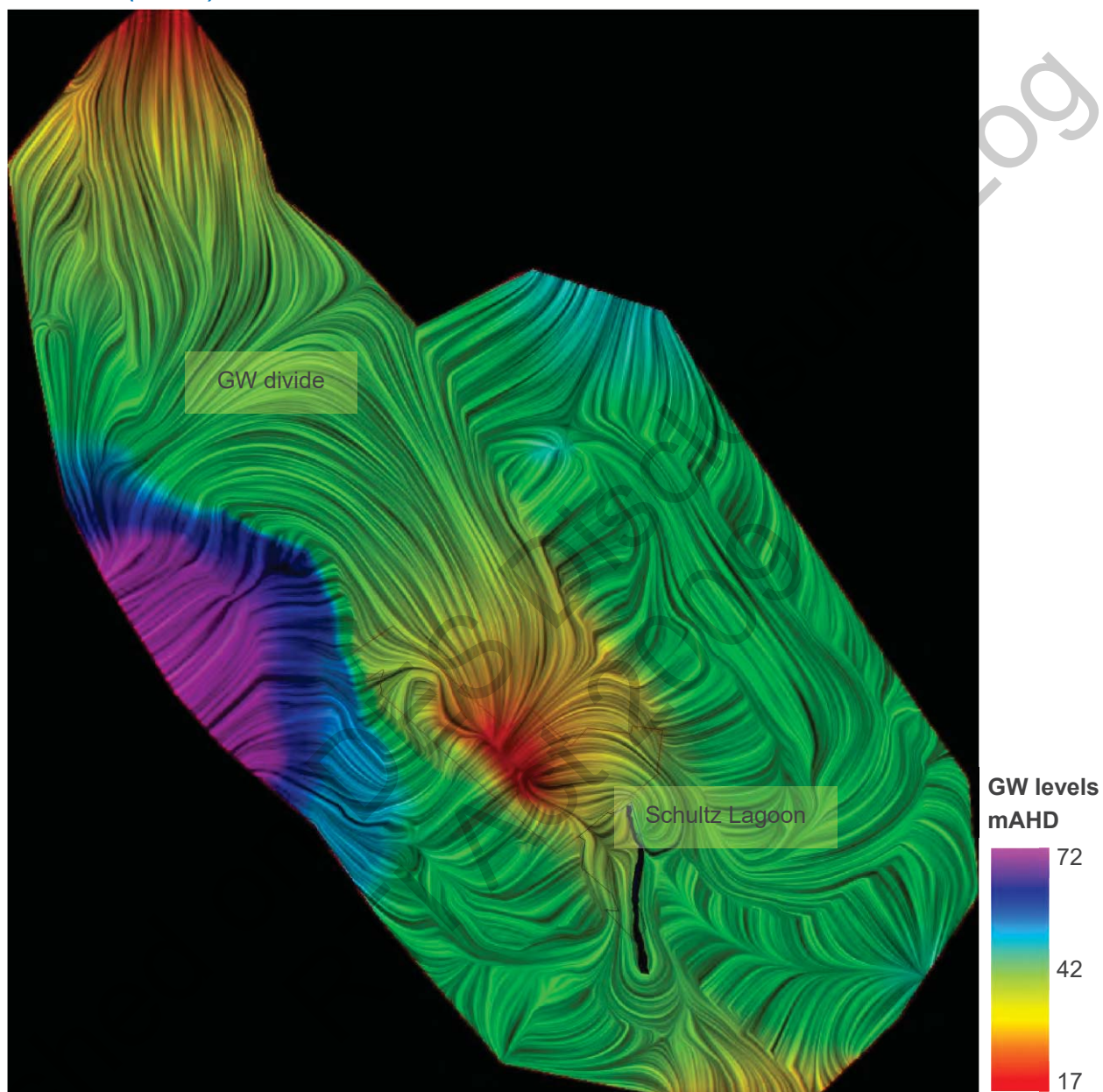
The flow fields show the groundwater flow fields at certain points in time. The flow fields from the each timestep will be calculated based on the groundwater levels in the respective time step. Note that the colour scale is different for each time step, as it the program colours the groundwater levels taking into account the minimum and maximum water levels at the respective time step. With mining progressing, the minimum water level changes over time.

The plots also show the mining lease (current and potential extension) as well as the location of the dyke.

Early mining (1985)

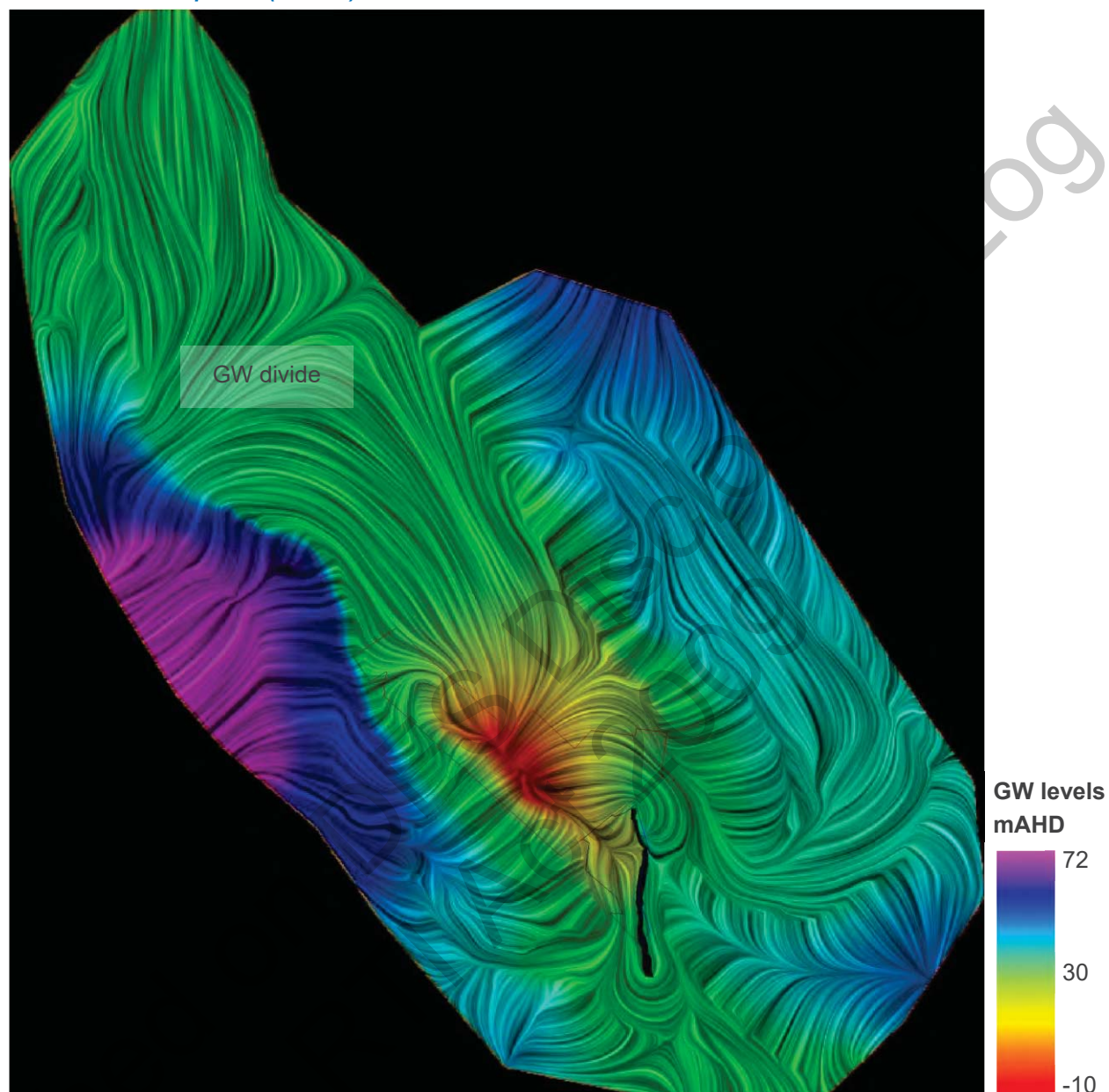


The figure shows the elevated groundwater levels in the Bracewell limestones (purple) with a steep decline into the East End Limestones. To the north, the groundwater divide between Fitzroy basin and Calliope basin is marked (slightly north of the surface water divide). The water will flow through the limestones with less resistance, which is shown by long parallel flow lines. Some water will flow slowly through the volcaniclastics, which is marked in the figure.

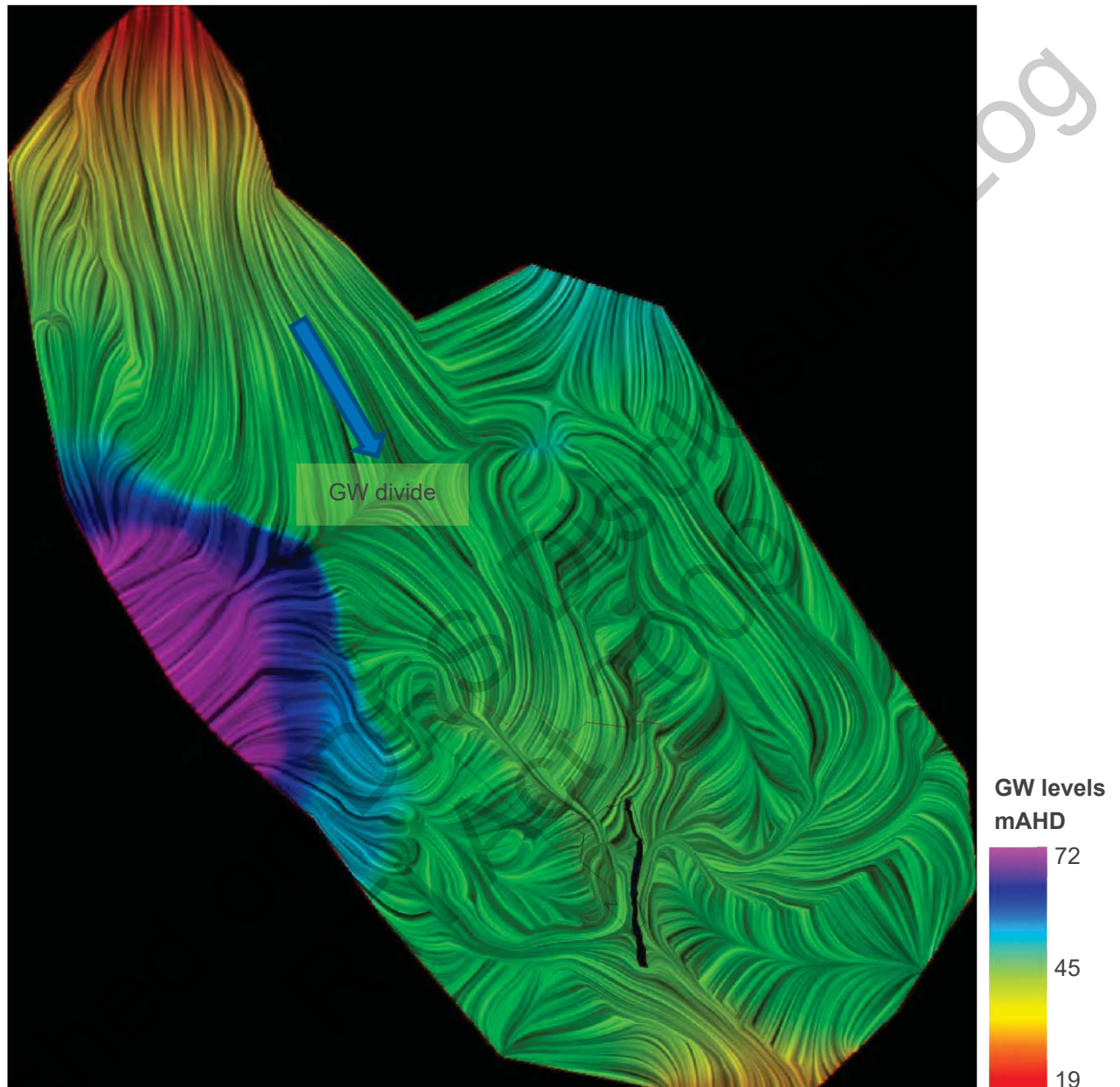
Current (2017)

This figure presents the flow field for the current conditions. The colours represent the groundwater levels at this point in time. The calculated groundwater divide has not moved, which is an indication that the calculated impact does not move into the Hut Creek area. The mining impact is now clearly visible, with the flow lines draining into the mining pit. Water is flowing from Schultz Lagoon into the mining pit.

Maximum impact (2045)



This looks similar to the current (2017) flow pattern, however note that the scale showing the water levels has changed (due to further drawdown). The groundwater divide is calculated to be at the same location as in previous years, meaning that the impact is not moving further north.

Post mining (2100)

The post recovery figure shows recovered water levels (same scale as 1985). The groundwater divide was calculated further to the south (around Machine Creek). This means that the model predicts the groundwater levels to recover in this area in the long-term (based on average climate). According to the modelling, groundwater is flowing towards the final void. Schultz Lagoon is not present anymore (created by mine water) and groundwater is flowing towards Larcom Creek in the model.