Australasian Groundwater & Environmental Consultants

Report on

Boggabri, Tarrawonga, Maules Creek Complex Groundwater Model Update

Prepared for
Boggabri Tarrawonga, Maules Creek (BTM)

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Boggabri, Tarrawonga, Maules Creek Complex Groundwater Model Update

1 Introduction

The Boggabri, Tarrawonga, Maules Creek (BTM) mining complex (BTM Complex) comprises three adjacent open cut coal mines located in the Gunnedah Basin, approximately 15 kilometres (km) northeast of the township of Boggabri in north-western NSW (Figure 1.1). The mines are owned and operated as follows:

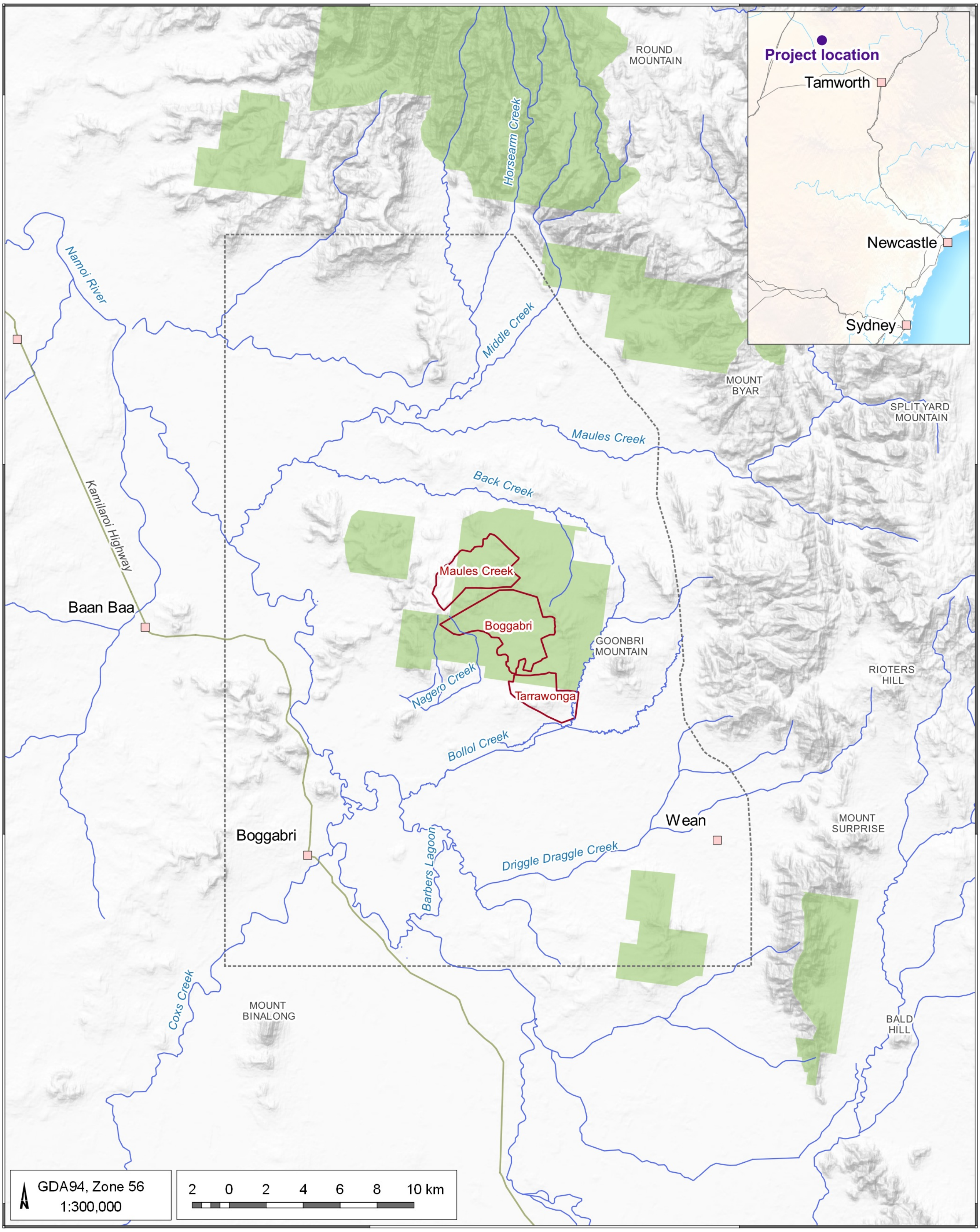
- Boggabri Mine – operated by Boggabri Coal Operations Pty Ltd (BCOPL), a joint venture between Idemitsu Australia Resources through its subsidiary company Boggabri Coal Pty Ltd (80%), Chugoku Electric Power Australia Resources Pty Ltd (10%), and NS Boggabri Pty Ltd (10%);
- Tarrawonga Mine – operated by Tarrawonga Coal Pty Ltd (TCPL), a subsidiary of Whitehaven Coal Mining Ltd (100%); and
- Maules Creek Coal Mine (MCCM) – operated by Maules Creek Coal Pty (MCC), a joint venture between Whitehaven Coal Mining Ltd (75%), ITOCHU Corporation (15%), and J-Power Corporation Pty Ltd (10%).

The study area (Figure 1.1), with the model domain centred on the BTM complex, remains the same as in the previous version of the model (AGE 2018). The model domain encompasses the alluvial management zones to the north, west and south of the complex, with the eastern boundary defined by the Mooki Thrust System.

Conditions of approval for the mining operations require that the impacts to groundwater predicted by numerical models are verified against observed datasets every three years. The most recent update (AGE2018) was completed following an independent peer review. A copy of the report was provided to the NSW Department of Planning and Environment (DP&E), Natural Resource Access Regulator (NRAR) and the Department of Planning, Industry and Environment - Water (DPIE-Water), with a final version also published on the website of Maules Creek Coal and Tarrawonga Coal.

Recommendations were received from government agencies to incorporate into the next revision of the model and the associated report. BTM Complex representatives engaged Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) to review and undertake an update to the model in response to the recommendations. A stakeholder meeting including AGE, BTM Complex representatives and attendees from the DPIE, NRAR and DPIE-Water was facilitated to discuss the numerical model (March 2019). Further consultation and review occurred with stakeholders following the initial meeting and is described in Section 2.

This report describes the further work undertaken to address these items including further review of available datasets, conceptualisation and updates to the numerical model.



LEGEND

- Populated place
- Road
- Drainage
- Maximum open cut footprint
- Study area
- State forest

BTM model update (G1850P)

Project location

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FIGURE No: **1.1**

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2 Objectives and scope of work

Each of the mines within the BTM Complex is approved under Section 75J of the NSW *Environmental Planning & Assessment Act 1979*. The respective approvals include conditions to:

- prevent, minimise and offset adverse environmental impacts;
- set standards and performance measures for acceptable environmental performance;
- require regular monitoring and reporting; and
- provide for the ongoing environmental management of the project.

The Project Approval documents set out conditions for all aspects of the project, i.e. noise, blasting, air quality, biodiversity, heritage, water. Schedule 3 within the Project Approval outlines Environmental Performance Conditions that relate to groundwater. Each of the BTM Complex mines are required to prepare *"a Groundwater Management Plan, which includes …a program to validate the groundwater model for the project, including an independent review of the model every 3 years, and comparison of monitoring results with modelled predictions."*

The most recent validation and update to the groundwater model was undertaken by AGE (2018), following review by BTM Complex representatives and independent peer review. The report described the:

- verification process;
- updates to numerical model;
- calibration; and
- predictions and uncertainty.

The report prepared by AGE (2018) provided a series of recommendations to improve the model. As noted previously, review by NSW Government departments recommended inclusions to the conceptual and numerical model. There were a number of 'themes' evident in the comments and subsequent discussions. These were:

- operational conditions:
  - non-technical comments that related to compliance and approval conditions.
- observed datasets:
  - vertical gradients;
  - groundwater extraction data;
  - areas with data gaps; and
  - vibrating wire piezometer (VWP) accuracy.
- verification/review of previous models;
- model build:
  - grid refinement;
  - recharge and evapotranspiration; and
  - hydraulic properties.
- calibration of observed and modelled datasets:
  - trends;
  - vertical gradients;
  - spatial and vertical variability of parameters;
  - calibrated values compared to field tests; and
  - calibration target errors.

- uncertainty analysis – relating to the sensitivity of:
  - heads used to represent rivers;
  - faults; and
  - predicted takes.
- predictions – model output and implications for licensing and impact assessment:
  - apportioning of impacts to each mine; and
  - accuracy of estimated takes and impacts.
- reporting:
  - expansion of report text to make it 'stand-alone' and suitable for a reader with no prior knowledge of the BTM complex;
  - improved visualisation of model outputs; and
  - additional text on nearby water dependent assets.

The project to address the comments from NSW Government was broken down into a series of sequential stages following the guidance by Barnett et al, (2012) in the Australian Groundwater Modelling Guidelines. The project stages were:

- stage 1 – planning, conceptualisation and model design;
- stage 2 – construction and calibration;
- stage 3 – predictions and uncertainty analysis; and
- stage 4 – reporting.

Meetings were held with representatives of the NSW Government and representatives of the BTM complex mines at the completion of each of these stages. The meetings provided a process of iterative peer review during the project and were held in:

- March 2019: Project planning meeting;
- June 2019: Conceptualisation meeting;
- December 2019: Calibration meeting; and
- September 2020: Calibration and predictions meeting.

The adequacy of the work prepared for each stage was discussed in the meetings and it was agreed if either the project should progress to the next stage, or if additional work in the existing stage was required.

This report describes the updates to the conceptual and numerical models to address comments from the NSW Government. This report is structured as follows:

- Section 1: Introduction – provides an overview of the mining areas and operators;
- Section 2: Objectives and scope of work – describes the assessment scope and report structure;
- Section 3: Regional setting – describes the environmental setting of the project including land use, topography, drainage and climate;
- Section 4: History of mining activities – summarises aspects of mining relevant to impacts on groundwater;
- Section 5: Geology – contains a detailed description of the local and regional formations and geological structures;
- Section 6: Hydrogeology – describes the existing groundwater regime of the BTM area and its surrounds;
- Section 7: Conceptual model – presents a conceptual model for the groundwater regime based on the available hydrogeological datasets;
- Section 8: Review of numerical models – provides a summary of groundwater models prepared for the BTM area or for the surrounding region;
- Section 9: Model objectives and requirements – outlines the objectives and intended use of the model;
- Section10: Model construction and development – describes the approach to representing the conceptual model in the numerical model to evaluate impacts on the groundwater regime;

- Section 11: Model calibration – describes the ability of the model to replicate historical water level measurements and estimates of mine pit inflow;
- Section 12: Model predictions and impact assessment – summarises the operational impacts predicted by the numerical model until mine closure; and
- Section 13: provides a summary of the work undertaken, key conclusions and recommendations for future models.
- Appendix A contains tabulated details for each of the monitoring locations.
- Appendix B presents hydraulic conductivity test results from various sources.
- Appendix C contains hydrographs for each of the monitoring sites in the BTM Complex and from the surrounding area.
- Appendix D contains cross sections through the numerical model.
- Appendix E contains hydrographs showing the observed and model simulated groundwater levels for each monitoring point; and
- Appendix F contains maps showing the hydraulic properties adopted in all model layers.

3 Regional setting

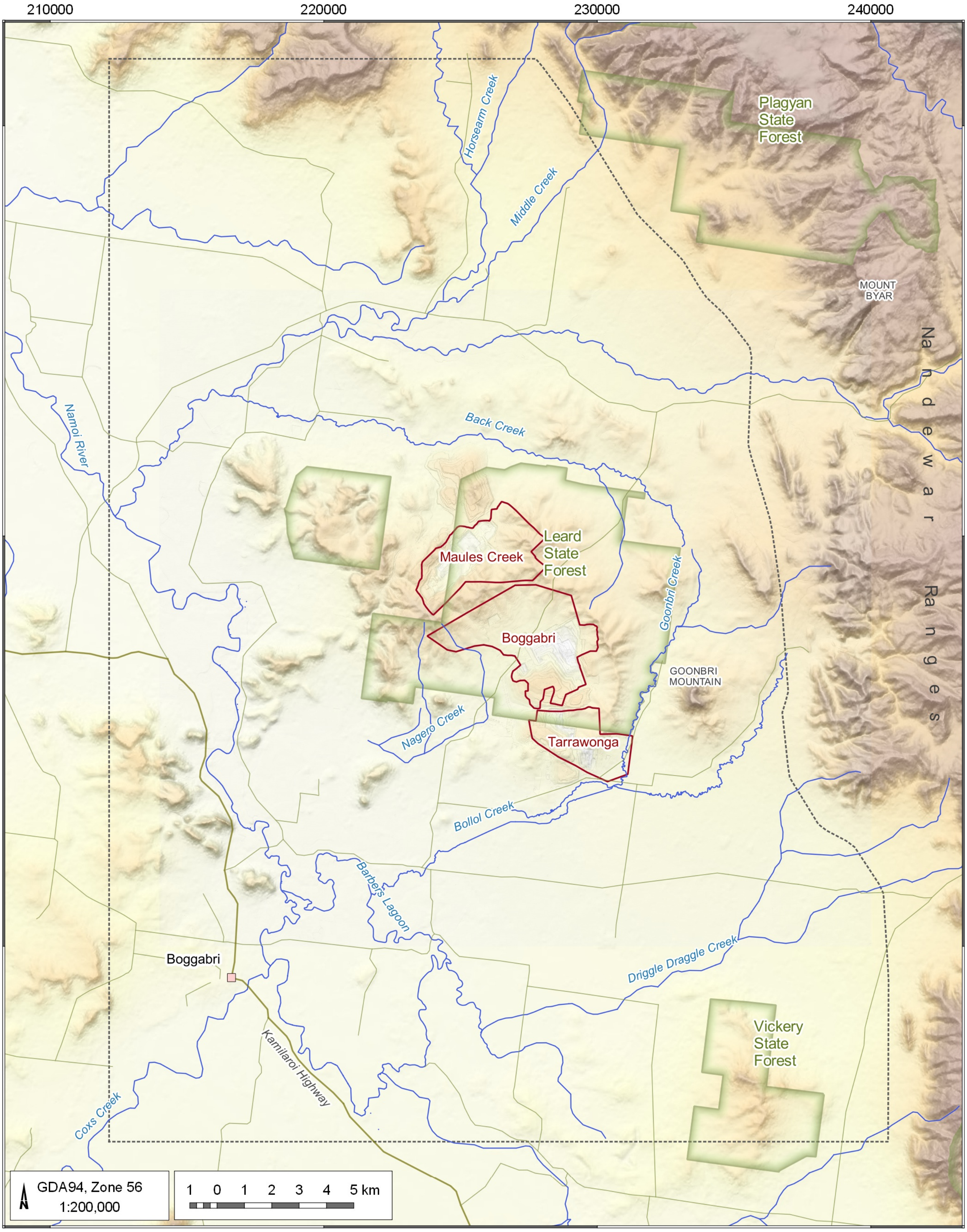
3.1 Terrain, drainage and land use

The terrain of the region is characterised by wide and flat alluvial plains, bounded by wooded hills and ridgelines. Surface elevation is controlled by the underlying geology, with areas of higher elevation comprised of outcropping volcanic and sedimentary sequences, overlain by alluvial sediments in low lying areas. The BTM Complex is located within an area of hills that rise to approximately 400 metres Australian Height Datum (mAHD), about 150 metres (m) above the surrounding flood plains (Figure 3.1). Approximately 8 km to the east of the BTM Complex the terrain changes to the notably more mountainous Nandewar Ranges, which form part of the Great Dividing Range. Elevations within the ranges can rise to over 1,000 mAHD.

The hills and slopes of the BTM Complex are drained by a series of generally westerly flowing ephemeral creeks that meander across floodplains and discharge to the Namoi River. The Namoi River is about 8 km to 10 km west of the BTM mines and is the most significant surface drainage feature in the area. Tributaries of the Namoi River include Maules Creek to the north of the BTM Complex and Bollol Creek to the south. These tributaries flow in a westerly direction and also have large, broad, gently sloping flood plains connecting to the Namoi River flood plain. The headwaters for the Maules Creek and Bollol Creek are both located within the Nandewar Ranges, and the upper catchments can provide large volumes of runoff to the creeks that persist for short durations. The Namoi River surface flows are regulated through storage and release of water from upstream dams, which include Keepit Dam and Split Rock Dam.

A more detailed discussion of the creeks and rivers, and their connectivity with the groundwater regime is provided with Section 6.5.5.

The BTM Complex is situated within the Leard State Forest. Predominant land uses in the study area are forestry and mining in the hills, and agriculture in the alluvial plains and lower ridge country. The Namoi River alluvial floodplain (Figure 3.1) supports an array of agricultural enterprises. Parts of the study area are irrigated, using water sourced from the regulated Namoi River, or alluvial groundwater.



LEGEND

- Road
- Drainage
- Maximum open cut footprint
- Study area
- State forest

Elevation (mAHD)

- 200
- 300
- 400
- 500
- 800
- 1000

BTM model update (G1850P)

Topography

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FIGURE No: **3.1**

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3.2 Climate

The climate of the study area is characterised by hot summers, with thunderstorms and comparatively mild dry winters. Climate data was sourced from the Scientific Dataset for Land Owners (SILO), for the coordinates 30.60° S, 150.15° E. The SILO dataset is used to obtain location specific climate data, which is calculated from surrounding weather stations and interpolated through splining and kriging techniques. Climate data for the 2006 to 2019 period was analysed within this section, where the start date coincides with initial mining approvals for the BTM Complex.

The mean annual rainfall recorded over 2006 to 2019 was 627 millimetres (mm)/year, most of which falls in the warmer months of the year (November to March). Potential evaporation rates (pan evaporation) exceed rainfall throughout the year, with the highest moisture deficits occurring in summer (Table 3.1 and Figure 3.2). Pan evaporation rates are consistently higher than evapotranspiration rates (Figure 3.2), reflecting the higher energy required to remove water from the soil profile.

Table 3.1 Summary of climate averages (January 2006 to April 2019)

Month	Mean monthly rainfall (mm)	Mean monthly pan evaporation (mm)	Evapotranspiration [a] (mm)
January	73	254	196
February	69	211	162
March	54	182	144
April	30	130	103
May	34	86	74
June	54	55	49
July	35	62	55
August	43	92	78
September	44	132	109
October	45	185	150
November	79	217	170
December	69	236	184
Annual	**627**	**1,841**	**1,475**

Note: [a] Potential/synthetic evapotranspiration, calculates as per FAO56 (short crop).

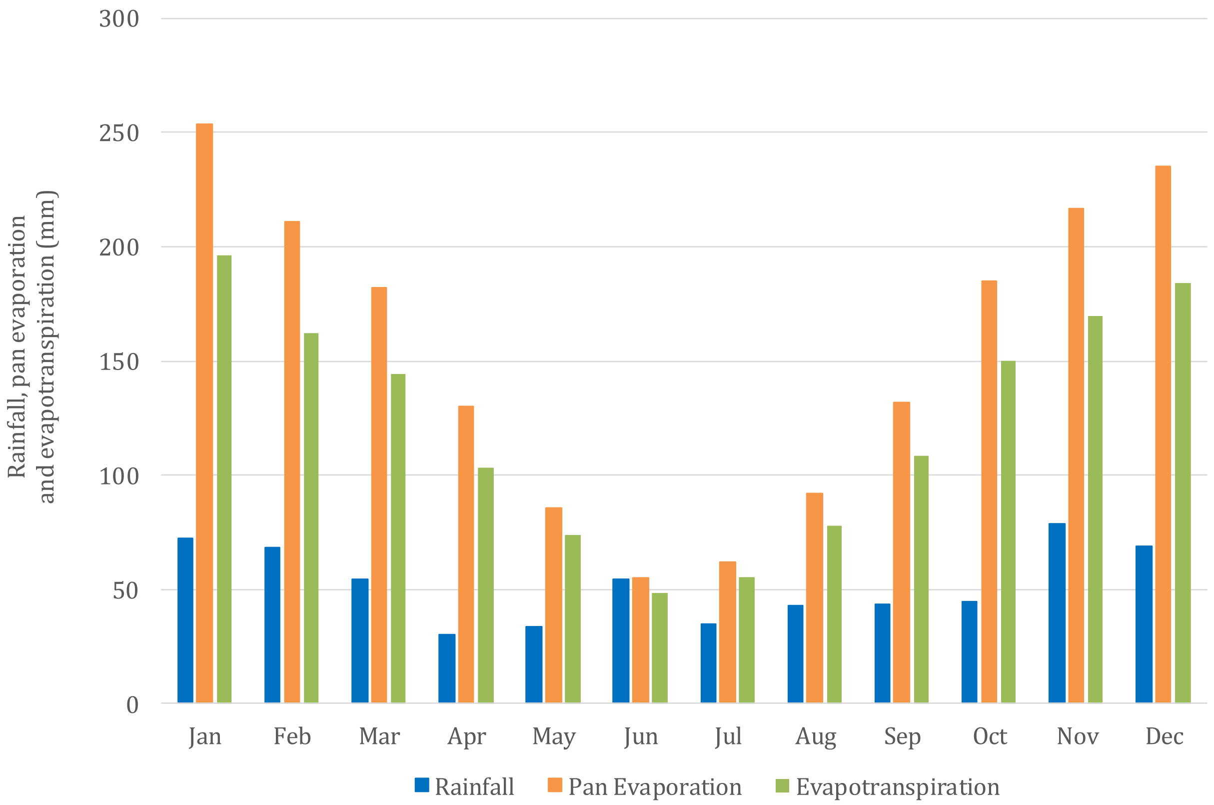


Figure 3.2 Average monthly rainfall and pan evaporation (January 2006 to April 2019)

To confirm that rainfall data sourced from SILO is accurate, results were compared to records from local weather stations. Each of the mines have their own weather station, and where available, comparisons between each site's recorded rainfall and the SILO dataset are provided in Figure 3.3. SILO rainfall data generally agrees with site specific data and is therefore deemed appropriate for use. Differences between the trends of each mine highlight the local variability of rainfall.

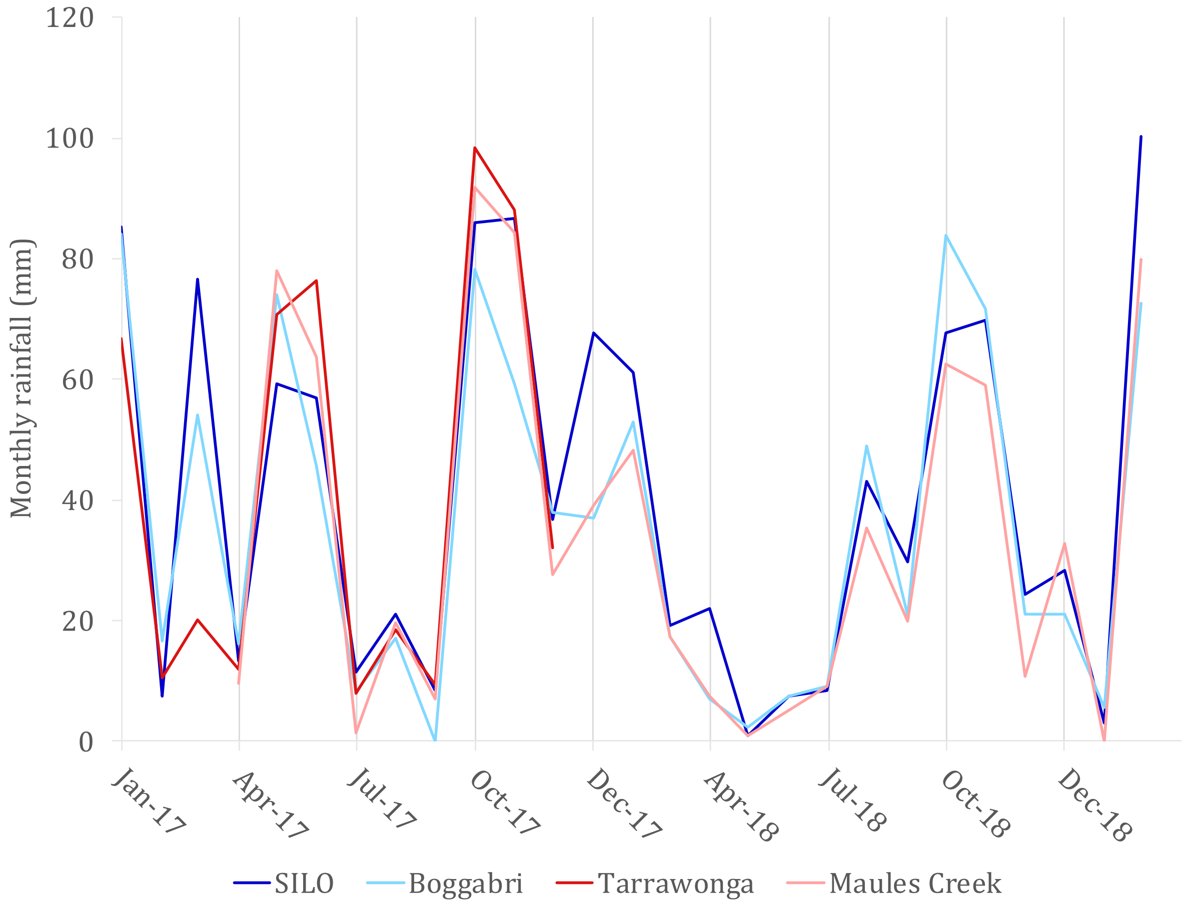


Figure 3.3 Rainfall – Site weather stations vs SILO

In order to place recent rainfall years into a historical context, the cumulative rainfall departure (CRD) (also referred to as the residual rainfall mass) was calculated. The CRD is calculated by subtracting the long-term average monthly rainfall from the actual monthly rainfall, providing a monthly departure from average conditions. A rising slope in the CRD plot indicates periods of above average rainfall, while a falling slope indicates below average rainfall. A standard technique for assessing groundwater level trends is to compare the water level hydrographs with the CRD. The CRD can be used to assess if changes in groundwater levels are correlated with climatic conditions or other factors such as resource extraction, mining, irrigation etc.

Variations in CRD for the 2006 to 2019 period are provided in Figure 3.4, with longer term variations (post 1950) also provided for context. Notable trends, which occurred after the onset of mining, include a running seven-year period of below average rainfall, occurring between 2012 and the present. Long term variations demonstrate the cyclic nature of drought, with the drought from 2017 to 2019 being a significant recent event.

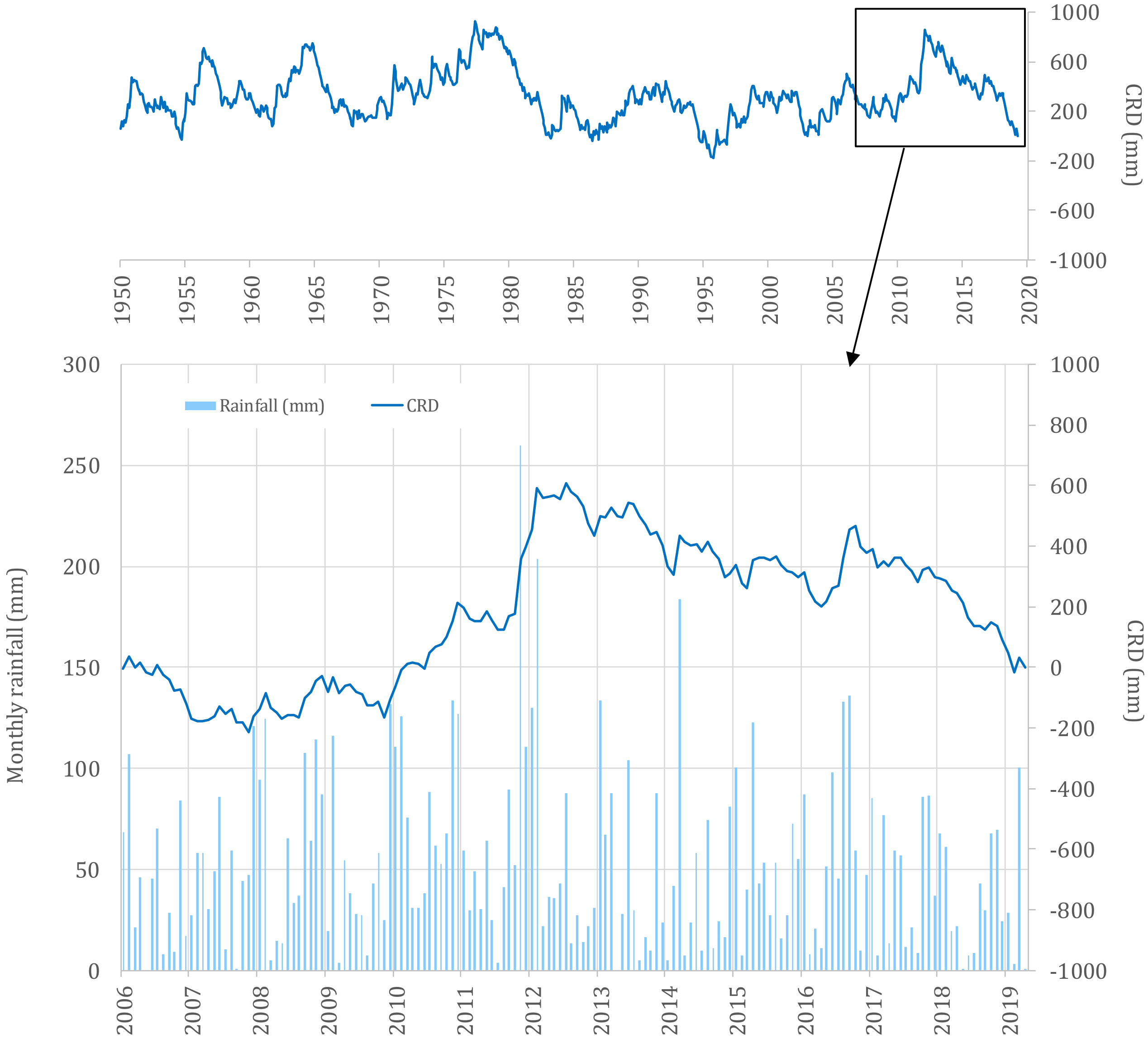


Figure 3.4 Cumulative rainfall deficit

4 History of mining activities

4.1 Boggabri

Construction of the Boggabri Coal Mine commenced in 2005 with the first coal delivered to the run-of-mine (ROM) coal pad in October 2006. The current method of open cut mining allows coal extraction to occur in the uppermost seams in the Maules Creek sequence including the Braymont, Bollol Creek, Jeralong and Merriown. The Project is currently approved to extract up to 8.6 million tons per annum (Mtpa) ROM coal until 31 December 2033. The approved mining area for the Boggabri Mine is shown on Figure 4.1 and the coal volumes produced to date are provided in Table 4.1. The mined out areas of the Boggabri Mine are being progressively backfilled with waste rock as the working face advances. Rehabilitation has started over areas of the waste rock that have reached their final post-mining landform. At the time of writing Boggabri Mine has submitted a Modification to their Project Approval seeking an increase to the approved maximum depth of mining down to the Templemore Coal Seam to recover an additional 61.6 Mt of ROM coal within the currently approved Mine Disturbance Boundary. This will result in the extension of the mine life by six years.

Table 4.1 Product coal produced to date (source Boggabri Mine Operations Plan, December 2018)

Calendar year	Product coal produced (Mt)
2006	0.24
2007	1.49
2008	1.47
2009	1.56
2010	2.11
2011	2.65
2012	3.34
2013	4.66
2014	5.49
2015	6.63
2016	6.93
2017	6.90
2018	6.6
2019	6.1

4.2 Tarrawonga

The Tarrawonga Mine is located immediately to the south of the Boggabri Mine. Tarrawonga commenced coal production within mining lease (ML) 1579 during 2006. Extraction occurs from the Braymont to Nagero seams in the Maules Creek sequence using truck and excavator methods. An expansion to the original mining area was approved in 2013. At the time of this model update, the Project was approved to extract up to 3 Mtpa ROM coal until the end of December 2030. The approved mining area at the time of this model update for the Tarrawonga Mine is shown on Figure 4.1 and the ROM coal volumes produced to date are provided in Table 4.2. Similar to Boggabri Coal Mine, the mined out areas of the Tarrawonga Mine are being progressively backfilled with waste rock as the working face advances. Rehabilitation has started over areas of the waste rock that have reached their final post-mining landform.

The approval at the time of this model update allowed the mining area to remove coal under part of the Goonbri Creek flood plain. This was conditional on Tarrawonga installing a low permeability cut off wall to reduce the seepage of groundwater into the mining area, and the diversion of Goonbri Creek in a new channel on the outside of the low permeability barrier.

A modification for Tarrawonga Mine (Modification 7) has recently been approved (February 2021) to increase the extraction rate to up to 3.5 Mtpa and modify the final landform design. As a result, operations will no longer be mining through the Goonbri Creek alluvium, and the low permeability cut off wall will no longer be installed, nor will Goonbri Creek require diversion.

Table 4.2 ROM coal produced 2010-2018 (source Tarrawonga Coal Annual Reviews, Whitehaven 2019a)

Calendar year	ROM coal produced (Mt)
2010/11	1.58
2011/12	1.74
2012/13	1.95
2013/14	1.85
2014/15	2.38
2015/16	2.24
2016	1.76
2017	1.87
2018	2.75
2019	2.25

4.3 Maules Creek

The Maules Creek Mine is located to the north of the Boggabri Mine. Commercial production started from Maules Creek in mid-2015. The Project is currently approved to extract up to 13 Mtpa ROM coal until the end of December 2034. Maules Creek is approved to extract from the Maules Creek sequence down to the Templemore seam. The approved mining area for the Maules Creek Mine is shown on Figure 4.1 and the coal volumes produced to date are provided in Table 4.3. There has been no emplacement of waste rock in the pit to date. Waste rock is being transported to the out of pit waste rock dump to the north of the active mining area.

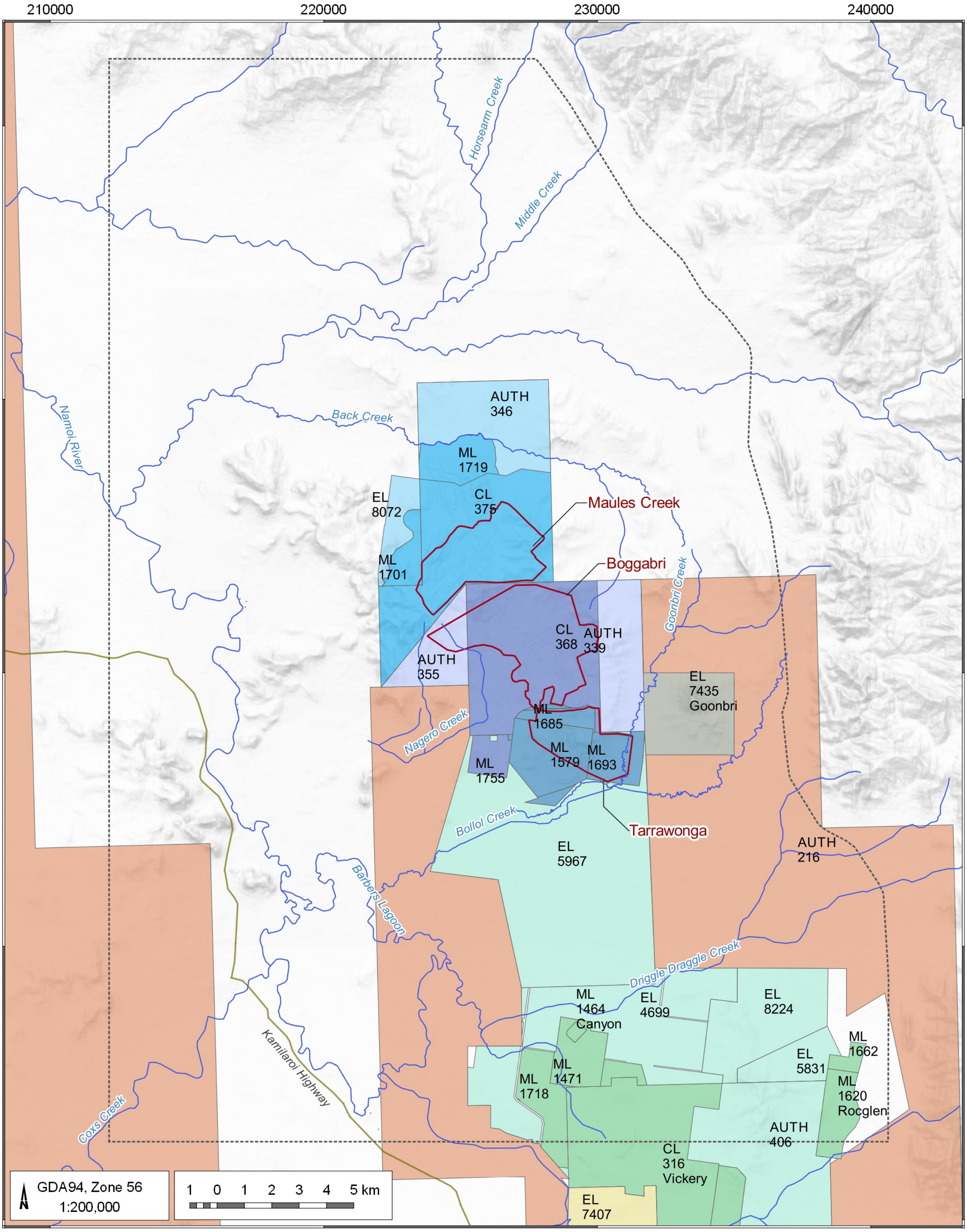
Table 4.3 Coal produced to date (source Maules Creek Annual Reviews, Whitehaven 2019b)

Calendar year	ROM coal produced (Mt)
2014	0.1
2015	5.8
2016	8.9
2017	10.5
2018	10.1
2019	9.7

4.4 Other nearby mining areas

The Goonbri exploration lease (EL 7435) lies to the east of the Tarrawonga Mine (see Figure 4.1). A review of environmental factors was submitted for the project in 2012 but no further submissions have been received for the project since that time.

The Vickery, Canyon (within the Vickery Extension Project footprint) and Rocglen (in rehabilitation and closure) mines are located some 12 km to 14 km to the south of the BTM complex. While historical modelling has not indicated the potential for significant connectivity of the groundwater systems with the BTM complex area, some of the permeability testing data available from these sites is useful and has been considered in this report. The Narrabri Mine is located approximately 27 km west-northwest of the BTM complex, within a separate sub-basin (Mullaley Sub-basin) relative to the BTM complex operations.



LEGEND

- Road
- Drainage
- Maximum open cut footprint
- Study area

Mining areas

- Boggabri
- Tarrawonga
- Maules Creek
- Whitehaven

Exploration areas

- Boggabri
- Maules Creek
- Whitehaven
- Goonbri
- Coalworks
- Government

BTM model update (G1850P)

Mining leases and approved BTM mining areas

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FIGURE No: **4.1**

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5 Geology

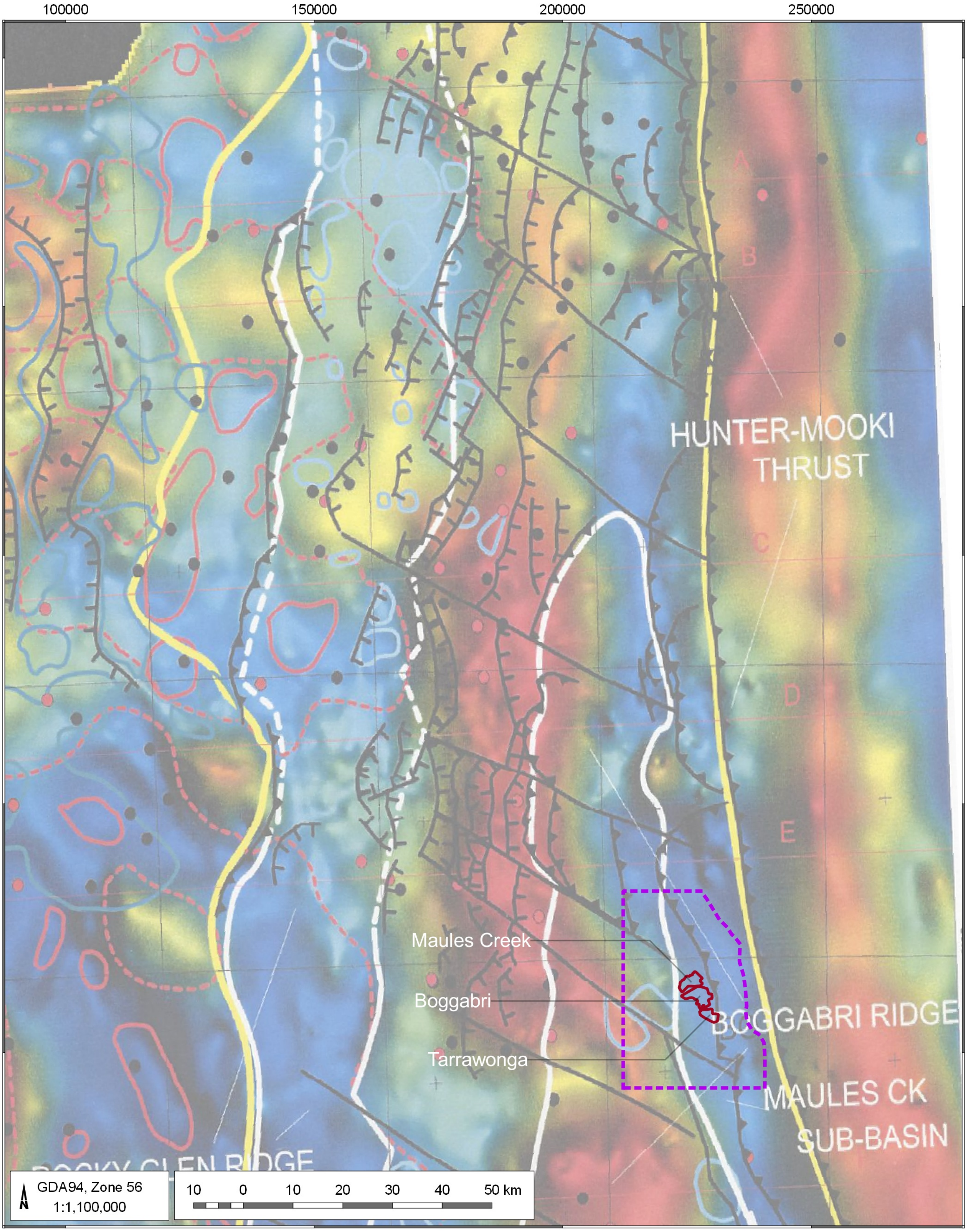
5.1 Regional setting and stratigraphy

The BTM Complex and surrounds are located within the Maules Creek Sub-basin, which forms part of the larger Gunnedah Basin. The Maules Creek Sub-basin is separated from the Mullaley Sub-basin to the west by a north-south trending volcanic ridge (termed the Boggabri Ridge), with the Mooki Thrust Fault System forming the eastern boundary. Gunn (2002) interpreted the location of the Boggabri Ridge and Maules Creek Sub-basin using magnetic surveys, with the extent shown in Figure 5.1. The BTM Complex is situated to the east of the Boggabri Ridge at the western edge of the Maules Creek Sub-basin where coal seams occur relatively close to the surface and are therefore suitable to open cut mining methods.

The main stratigraphic units occurring within the study area and the dominant lithology within each are:

- Quaternary alluvium – unconsolidated clays, silts, sands and gravels;
- Tertiary volcanics – basalt, dolerite, teschenite, nephelinite and trachyte;
- Permian Maules Creek Formation – comprising multiple coal seams, interbedded with conglomerate, sandstone and siltstone (Figure 5.3);
- Permian Leard Formation – claystone, conglomerate, sandstone and siltstone; and
- Permian Boggabri Volcanics – Rhyolitic to dacitic lavas, tuff and interbedded shale.

A map of the surface geology is provided in Figure 5.2. Mining activities target coal seams within the Maules Creek Formation, where the coal measures subcrop to the west against the basal Boggabri Volcanics (Figure 5.2). Alluvial plains formed around Maules Creek, Bollol/Driggle Draggle Creeks and the Namoi River occur to the north, south, and west of the BTM Complex respectively (Figure 5.2). Tertiary Volcanics and the Leard Formation are not widespread within the region.



LEGEND

Approved mining area

Study area

BTM model update (G1850P)

Maules Creek Sub-basin (Gunn 2002)

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FIGURE No: **5.1**

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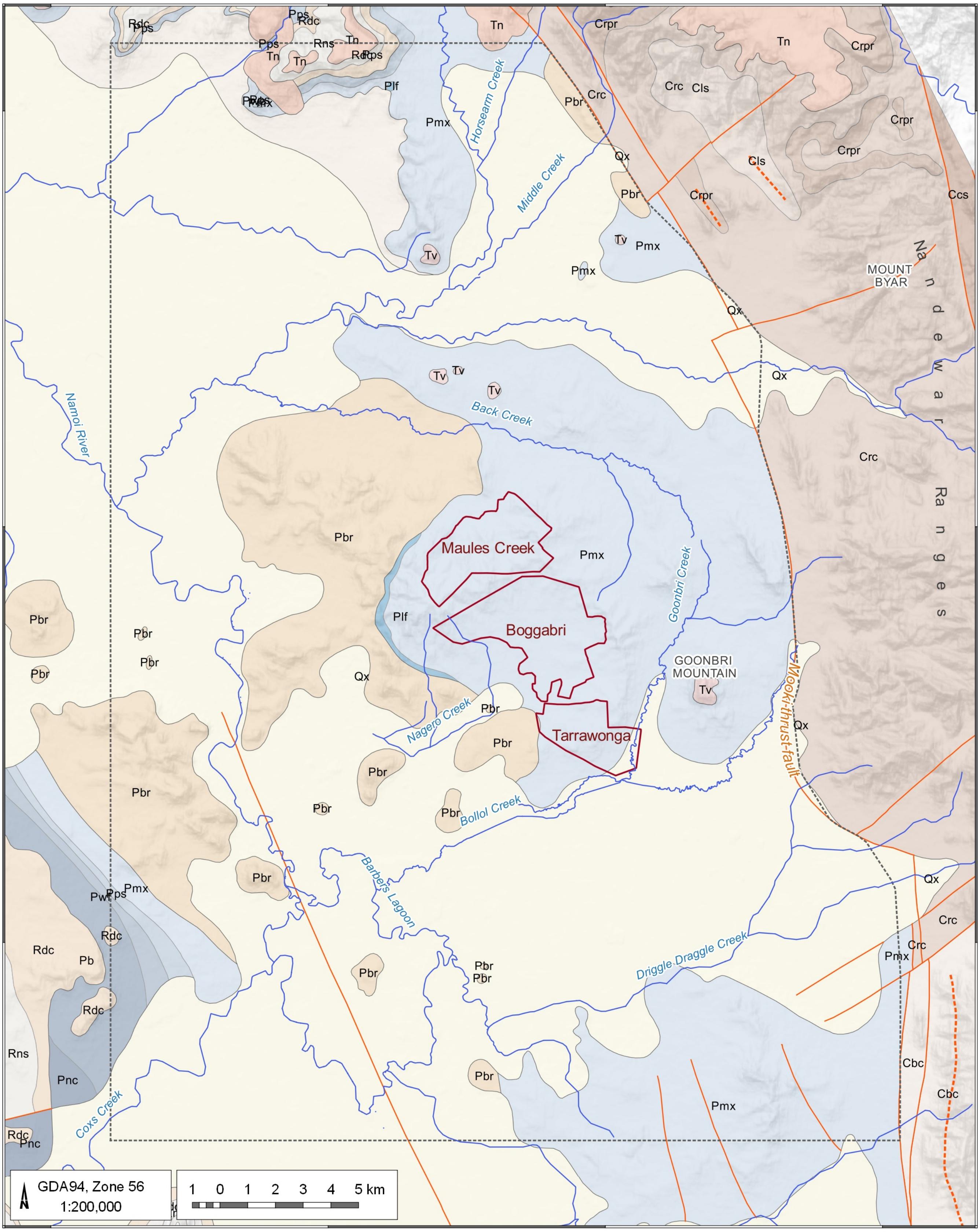

LEGEND

- Drainage
- Maximum open cut footprint
- Study area

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tn - Tertiary Nandewar Volcanics
- Tv - Tertiary Volcanics
- Rns - Napperby Formation
- Rdc - Digby Formation
- Pnc - Black Jack Group
- Pb - Pamboola Formation
- Pwf - Watermark Formation
- Pps - Porcupine Formation
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pwb - Werrie Basalt
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Cls - Lark Hill Formation
- Crc - Rocky Creek Conglomerate
- Crpr - Plagyan Rhyodacite Tuff Member
- Ccs - Clifden Formation
- Fault
- Fold

BTM model update (G1850P)

Regional geology (Pratt 1998a)

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FIGURE No: **5.2**

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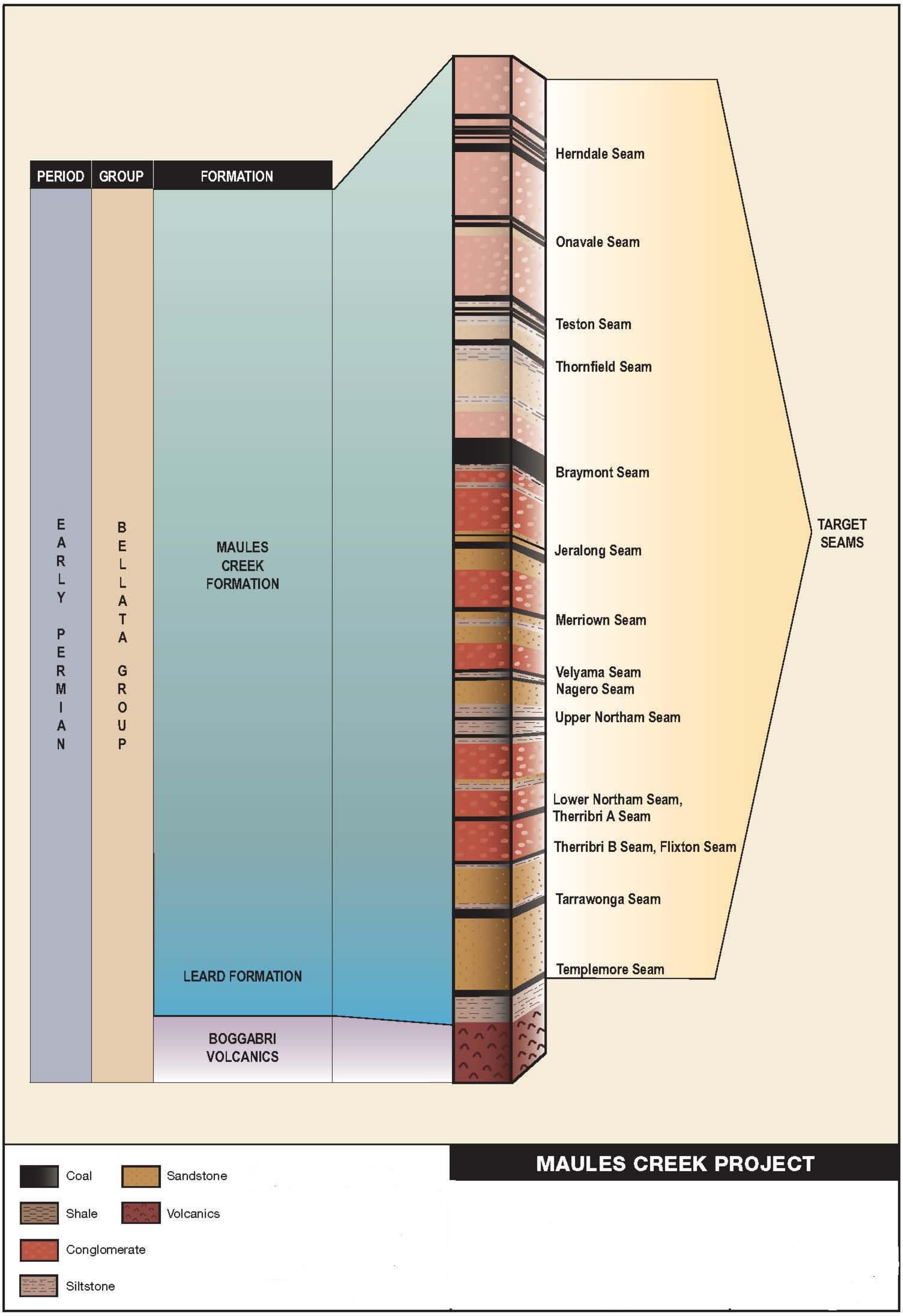


Figure 5.3 Local stratigraphic column (source Hansen Bailey 2010)

5.2 Previous vs current geological data sources

The BTM complex mines each maintain a geological model of their operating area. These geological models do not extend outside the lease boundaries for each of the operations. To develop a conceptual and numerical groundwater flow model of mining projects requires geological information on a more regional scale beyond the mining footprint, and the limited extent the geological models is a common issue for groundwater studies. This issue was addressed during the approval process for the Maules Creek Mine by developing a regional geological model that extended well beyond the footprint for each mine. The regional geological model was prepared by JB Mining (2010) and used as the basis for layers in the groundwater flow model developed by AGE (2011) and in subsequent models including AGE (2018).

During the current project the BTM complex operations provided updated geological information from within their lease areas to allow the conceptual and numerical groundwater flow models to be updated. New data was specific to each mine's immediate footprint, including updated layers for the Permian coal measures, depth of weathering, and the underlying Boggabri Volcanics. This information provided additional detail in the geological surfaces that was not available previously. No new geological information was available outside the extent of each operations geological model, so in regional areas where no new information was available the study used the geological model prepared by JB Mining (2010).

Personal communication with site geologists from each mine in the BTM complex also provided additional information about local geological structures that was not previously available.

5.3 Alluvium

Alluvial plains surround the Permian outcrop, which contains the BTM Mining Complex (Figure 5.2). These include:

- Maules Creek alluvium (north);
- Bollol, Driggle Draggle and Barneys Spring Creek alluvium (south); and
- Namoi River alluvium (west).

To the north of the BTM Complex, the Maules Creek alluvium is divided into two distinct zones by a constriction in the flood plain, created by the outcropping Maules Creek Formation (Figure 5.2). Upstream of the constriction, the Maules Creek alluvium is approximately 90 km^2 in area and is predominately formed along three ephemeral creeks and their tributaries (Maules Creek, Horsearm Creek and Middle Creek). Downstream of the constriction the alluvial plain widens significantly and also covers an area of approximately 90 km^2 before transitioning to the Namoi River alluvium.

The alluvial plains to the south of the BTM Complex cover an area of approximately 200 km^2, with the ephemeral Bollol Creek acting as the main drainage channel through the northern section, and Driggle Draggle/Barneys Spring Creeks in the southern section. As the creeks move onto the flatter lying plains, the creek channels often become poorly defined, with little incision into the landscape. When they are flowing, the creeks discharge into Barbers Lagoon, which is interpreted to signify the beginning of the Namoi River alluvium.

To the west of the BTM Complex, the Namoi River meanders in a general southeast to northwest direction through wide flood plains. The flood plains constrict at the area known as Gins Leap, where the presence of outcropping Boggabri Volcanics limits the expanse of alluvium. Further to the north, beyond Gins Leap, the flood plain again widens and merges with the Maules Creek alluvial plain.

The extent of alluvium shown in Figure 5.2 was sourced from the 1:100,000 scale geological map (Pratt 1998a). Notes accompanying this map (Pratt 1998b) state that the boundaries of the alluvium were defined using topographic relief. Alluvial plains are relatively flat lying with very gentle slopes, and no significant topographic relief across their width. As they reach the surrounding bedrock, which is more resistant to weathering, the relief typically increases, causing a distinct break of slope. This distinction was used by the government to define the alluvial boundaries. While useful for defining the limit of alluvium across large areas, validation can be required at a local scale where the transition requires more accurate definition.

Alluvium associated with the Namoi River is often vertically divided into two different geological units, namely the Narrabri Formation at surface and the underlying Gunnedah Formation. This distinction is adopted in order to characterise differences in alluvial sediments, which are generally upward-fining (Herr et al. 2018). Gates & Ross (1980) were the first to differentiate between the two alluvial units, noting that:

- the Narrabri Formation forms the surficial cover and comprises extensive overbank clays, with lesser channel sands/gravels, likely deposited by leveed meandering streams; and
- the underlying Gunnedah Formation fills the main palaeovalley floors and consists of moderately well sorted sands/gravel, with interbedded clays, likely deposited by braided streams.

Recent studies of Namoi alluvium suggest that this differentiation may be an oversimplification, where:

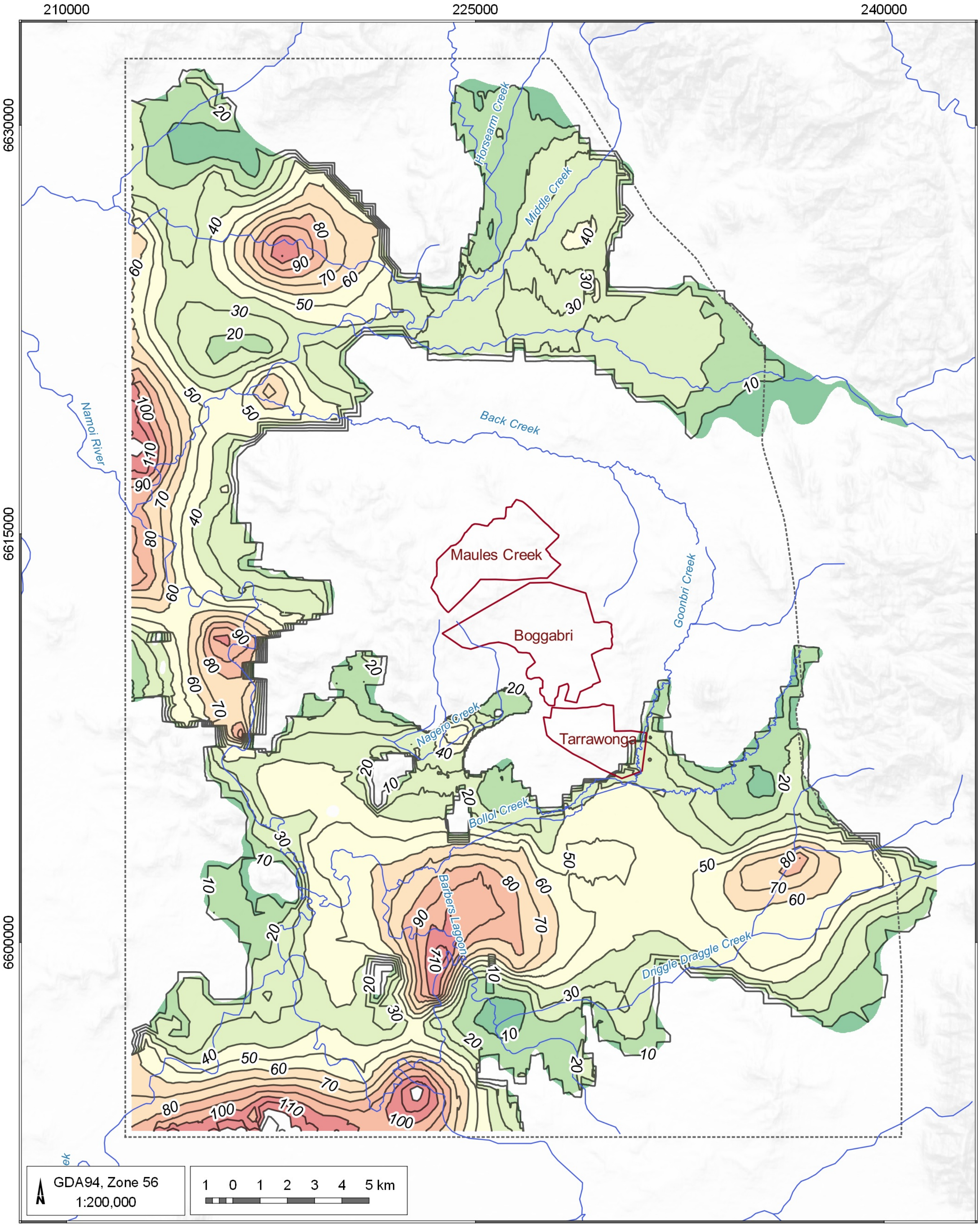
'Detailed examination has failed to detect any evidence of a boundary between Narrabri and Gunnedah formations revealing rather a gradual change in dominance of clays and silts over sands and gravels embedded in a clay-rich matrix' (Acworth et al. 2015).

Alluvial thickness is variable throughout the study area. Total alluvial thickness, thickness of the Narrabri Formation and thickness of the Gunnedah Formation were derived from interpretations of geological data within the Upper Namoi Alluvium Groundwater Model (McNeilage 2006). The resulting thicknesses are presented in Figure 5.4 and Figure 5.5.

At a regional scale the alluvium is generally thickest within the main Namoi River alluvial plain, thinning towards the edges of the plain and along the tributaries (McNeilage 2006). Within the study area, total alluvial thicknesses exceeding 90 m generally occur within the Namoi River alluvial plains. Thicker sequences are also notably present below the constriction along Maules Creek, and off the eastern edge of Barbers Lagoon.

Within the Namoi River alluvial plain, thick sequences of alluvium (>90 m) coincide with thick sequences of both the Narrabri Formation and the Gunnedah Formation (>40 m and >60 m, respectively). Conversely, relatively thick sequences of alluvium within the Maules Creek and Bollol Creek/Driggle Draggle alluvial plains are predominately attributed to the Gunnedah Formation, with comparatively thin sequences of the overlying Narrabri Formation.

Conceptually, a review of Narrabri Formation/Gunnedah Formation thicknesses suggests that alluvium is thickest where the Gunnedah Formation is present, indicating palaeochannels. Additionally, varying thicknesses of the younger Narrabri Formation suggests that deposition of this alluvial material is largely constrained to the Namoi River alluvial plain.



LEGEND

- Drainage
- Maximum open cut footprint
- Study area

Alluvium thickness (m)

- 0 - 10
- 10 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- Contour line

BTM model update (G1850P)

Total alluvium thickness

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FIGURE No: **5.4**

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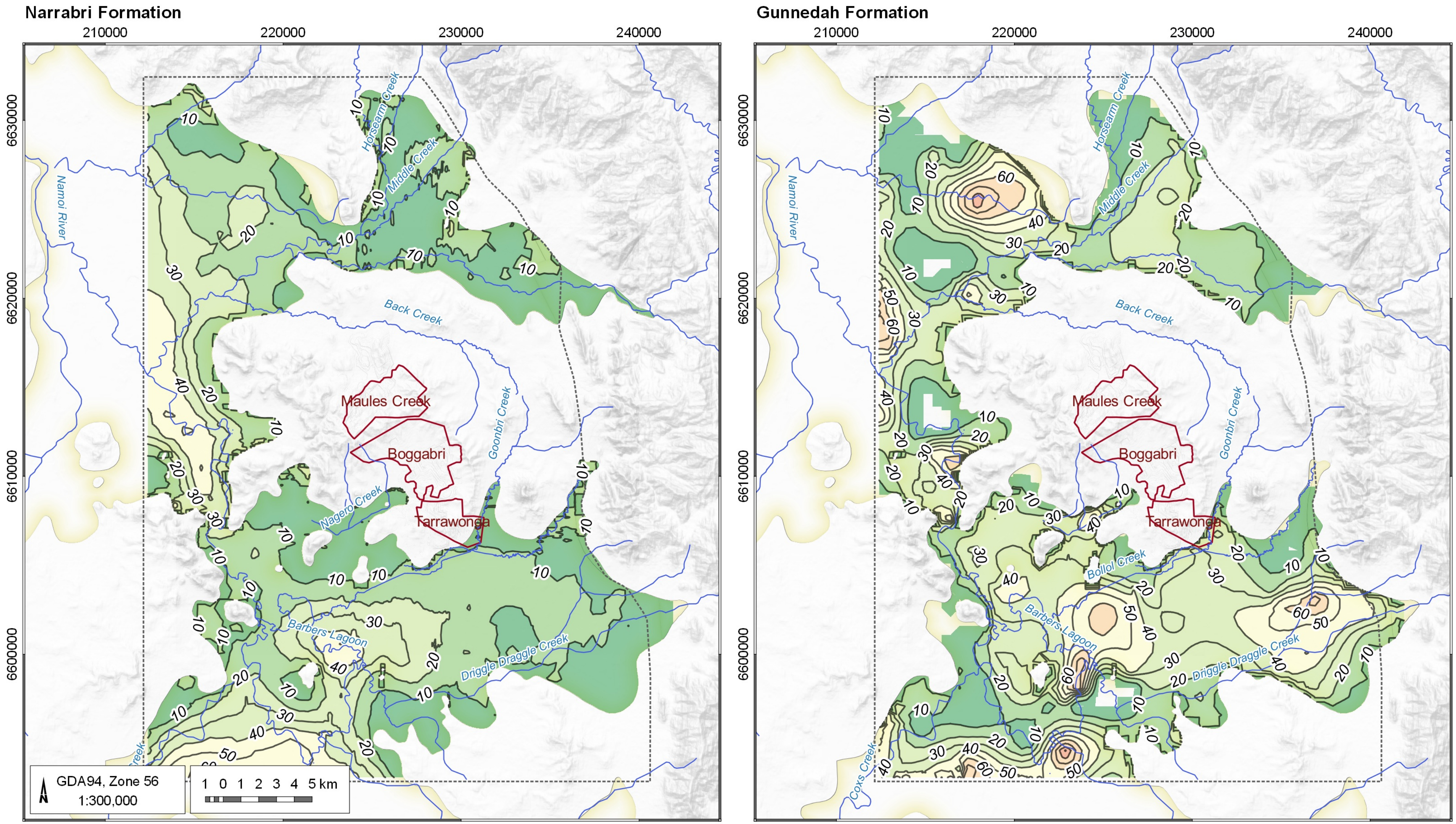

LEGEND

- Drainage
- Maximum open cut footprint
- Study area
- Alluvium extent

Thickness (m)

- 0 - 10
- 10 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120
- Contour lines

BTM model update (G1850P)

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Thickness of Narrabri Formation and Gunnedah Formation

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FIGURE No:
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5.4 Regolith

Regolith is comprised of surficial soils and weathered bedrock and is of variable thickness. Depth of regolith is dependent on factors such as the depth of weathering and extent/frequency of fracturing. In the immediate vicinity of the BTM Complex, mine geological models show that the weathered thickness of the Maules Creek Formation and the Boggabri Volcanics generally ranges between 1 m and 30 m. Sandstones and conglomerates are most affected by the weathering process, while finer grained sediments can form an effective barrier to weathering. Deeper weathering profiles may occur along fractures and potential fault zones.

5.5 Tertiary volcanics

While Tertiary volcanic intrusions are not extensive in the area, local outcrops have been mapped, including Goonbri Mountain to the east of Tarrawonga (see Figure 5.2). Pratt (1998b) suggests that the undifferentiated volcanics may be outliers of the Nandewar Volcanic Complex, which is located approximately 20 km north of the BTM Complex. Dykes are known to be present within all three mines and were observed during the May 2019 AGE site inspection. Although present, dykes within the BTM Complex are a relatively small component of the overarching geology, and were only observed in the Tarrawonga Mine.

5.6 Permian coal measures

Stratigraphically, the Maules Creek Sub-basin is comprised of the Maules Creek Formation, which is underlain in part by the Leard Formation. Mining activities are limited to extraction of high quality coal seams from the Maules Creek Formation, with the underlying Leard Formation only containing a few minor coal seams of poor quality (Whitehouse 1993). Relatively thick sequences of interburden separate coal seams and are predominately comprised of cemented conglomerate, with less frequent layers of sandstone and siltstone (Figure 5.3).

Sediments of the Maules Creek Formation generally dip between 2° and 5° to the east, thickening in this direction to a maximum depth between 745 m and 1,135 m near the Mooki Thrust System. (Cowan 1995). Coal seams are interpreted to have developed on a weathered palaeo-surface of varying topography, with seams in the eastern half of the basin highly split relative to mining areas of the BTM Complex.

Mining within the BTM Complex occurs along the western edge of the Maules Creek Sub-basin, with the coal measures either subcropping onto volcanics of the Boggabri Ridge, or weathering out at this boundary if shallow (JB Mining 2010). A review of each mine's geological model suggests that in areas where the Maules Creek Formation directly underlies the alluvium there is the potential for several of the coal seams to subcrop onto the alluvium.

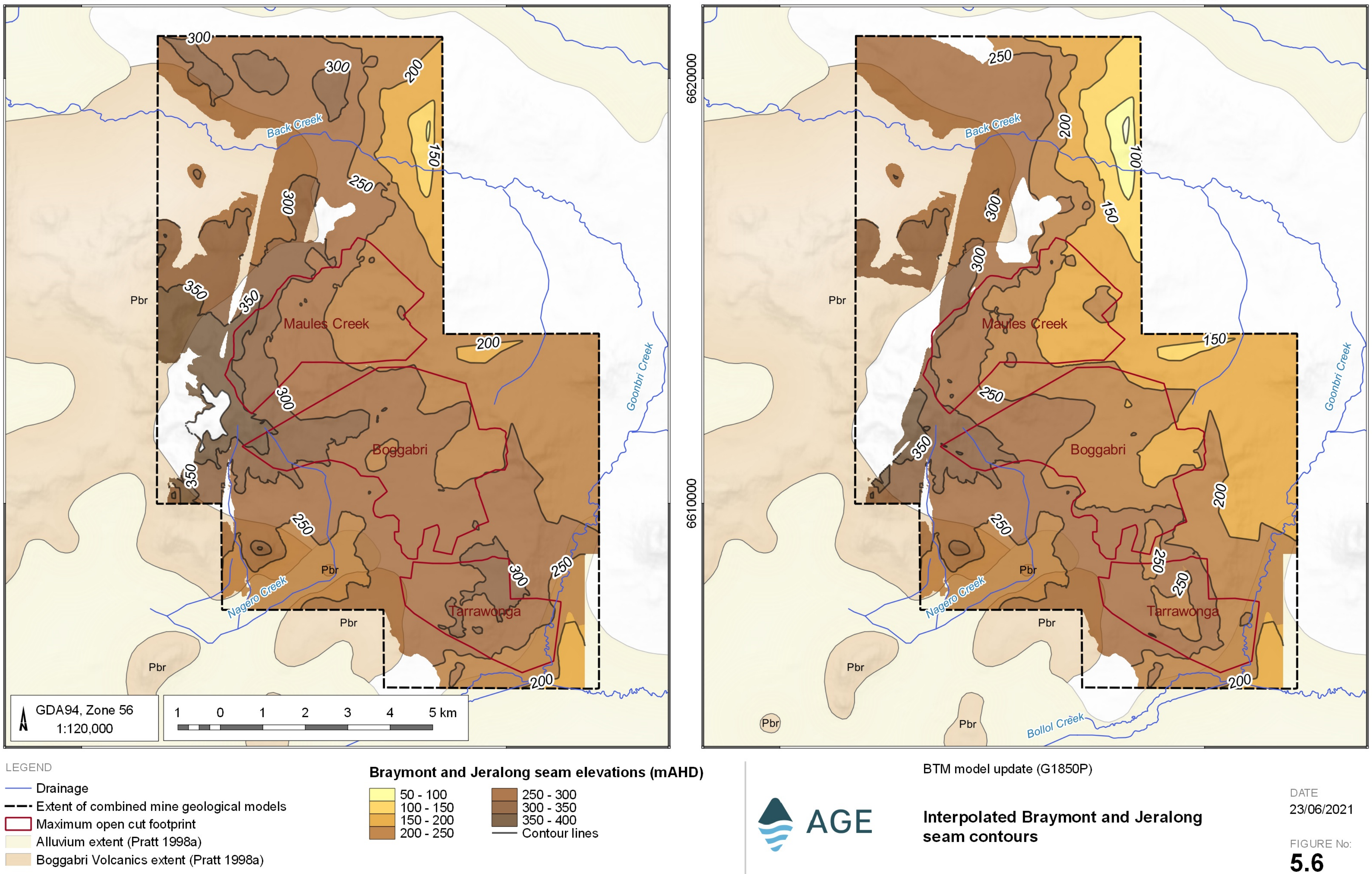
To the southwest of Boggabri, all coal seams above the Nagero Seam potentially sub-crop underneath the alluvial 'gulf' or 'tongue' of the Namoi River alluvium, while to the south of Tarrawonga, coal seams above the Nagero Seam sub-crop onto the alluvial plain of the Bollol Creek alluvium. The Tarrawonga geological model suggests that the Jeralong Seam is the deepest seam to sub-crop onto alluvium of Goonbri Creek. To the north of Maules Creek Mine all coal seams above the Braymont Seam are weathered out near the surface. As such, the Braymont Seam is the shallowest coal seam with any potential to form a direct connection between mining activities and Maules Creek alluvium. Seams below the Braymont are seen to subcrop onto the Boggabri Volcanism immediately to the north of Maules Creek Mine. However, it is not possible to determine the presence/absence of these seams below Maules Creek due to the extent of the geological model.

Structurally all coal seams are relatively consistent with one another and dip direction/slope remains equal for seams of various depths. While the locally observed eastern component of dip is consistent with regional trends (JB Mining 2010), there are some variances apparent at a local scale evident from each mine's geological model (Figure 5.6). These include:

- a northeast component of dip;
- relatively steep coal seam dips at the edges of the basin; and
- oscillations of seam highs and lows, striking in a north-northwest direction through Tarrawonga (relatively high), Boggabri (relatively low in eastern section and relatively high along northern boundary) and Maules Creek (relatively low in eastern section).

Braymont seam contours

Jeralong seam contours



BTM model update (G1850P)

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Interpolated Braymont and Jeralong seam contours

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FIGURE No: **5.6**

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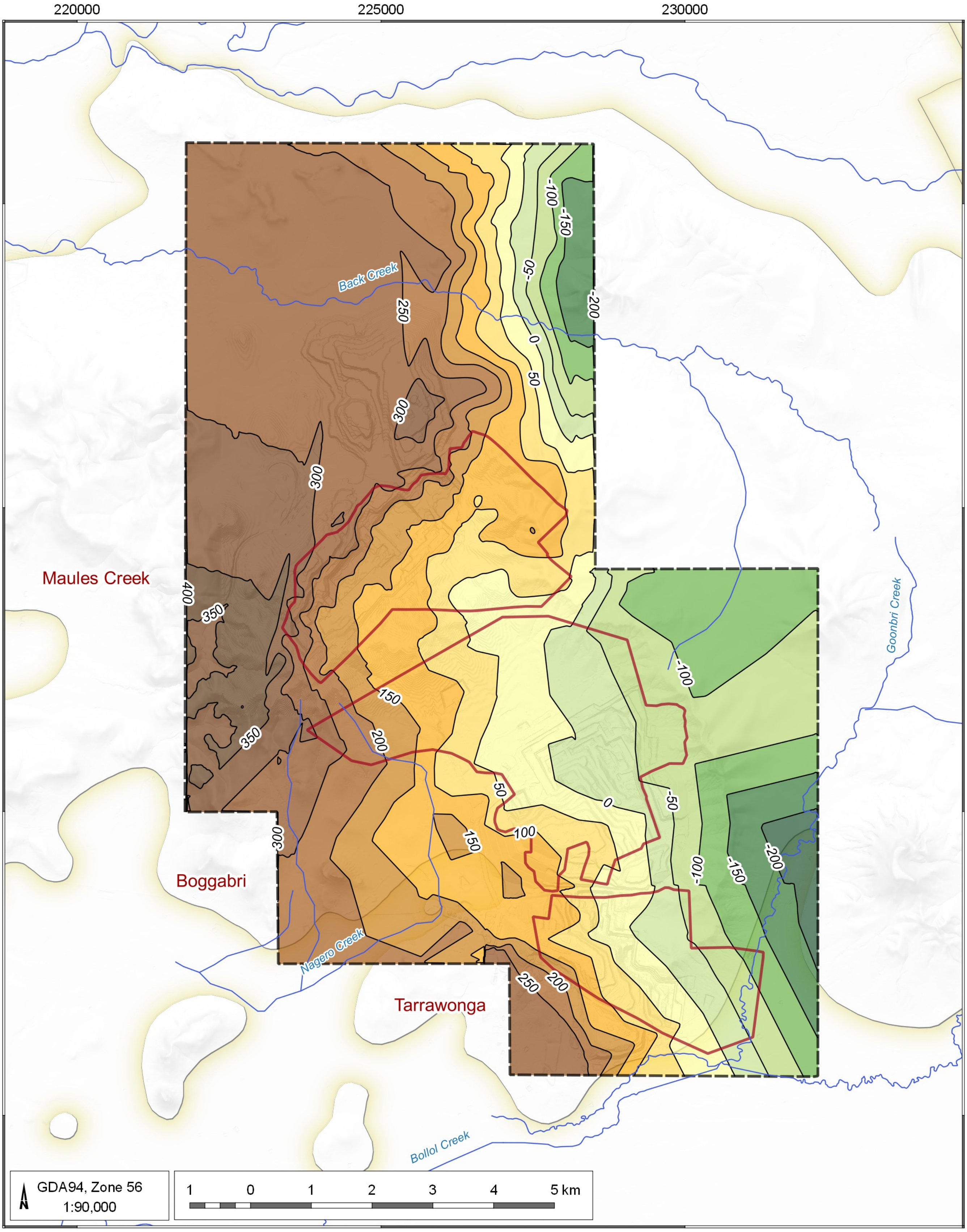
5.7 Boggabri Volcanics

As discussed in Section 5.1, the Boggabri Ridge, which forms the western boundary of the Maules Creek Sub-basin, is comprised of silicic volcanics of the Boggabri Volcanics. The Boggabri Volcanics were formed in a small-scale rifting environment, during the late Carboniferous/early Permian (Tadros 1995). These unconformable volcanics were then subject to extensive erosion and weathering during the very early Permian, resulting in the formation of an irregular palaeo-topography, onto which the sediments of the Maules Creek Formation were deposited.

Mapped outcrops of the Boggabri Volcanics (Figure 5.2) generally match basement highs (derived from a combination of each mine's geological model, Figure 5.7), with the BTM Complex located on the steep eastern flank of the Boggabri Ridge. Regional geological modelling completed by JB Mining (2010) shows the Boggabri Ridge sharply falling to the east in the vicinity of the BTM Complex and then flattening out, or gradually rising at an approximate longitude of 150.22°.



LEGEND

- Drainage
- Extent of combined mine geological models
- Maximum open cut footprint
- Alluvium extent

Elevation of Boggabri Volcanics (mAHD)

- -200 - -150
- -150 - -100
- -100 - -50
- -50 - 0
- 0 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- 200 - 250
- 250 - 300
- 300 - 350
- 350 - 400
- Contour lines

BTM model update (G1850P)

Elevation of Boggabri Volcanics

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FIGURE No: **5.7**

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5.8 Geological structures

A number of structural features have been identified within the study area and include:

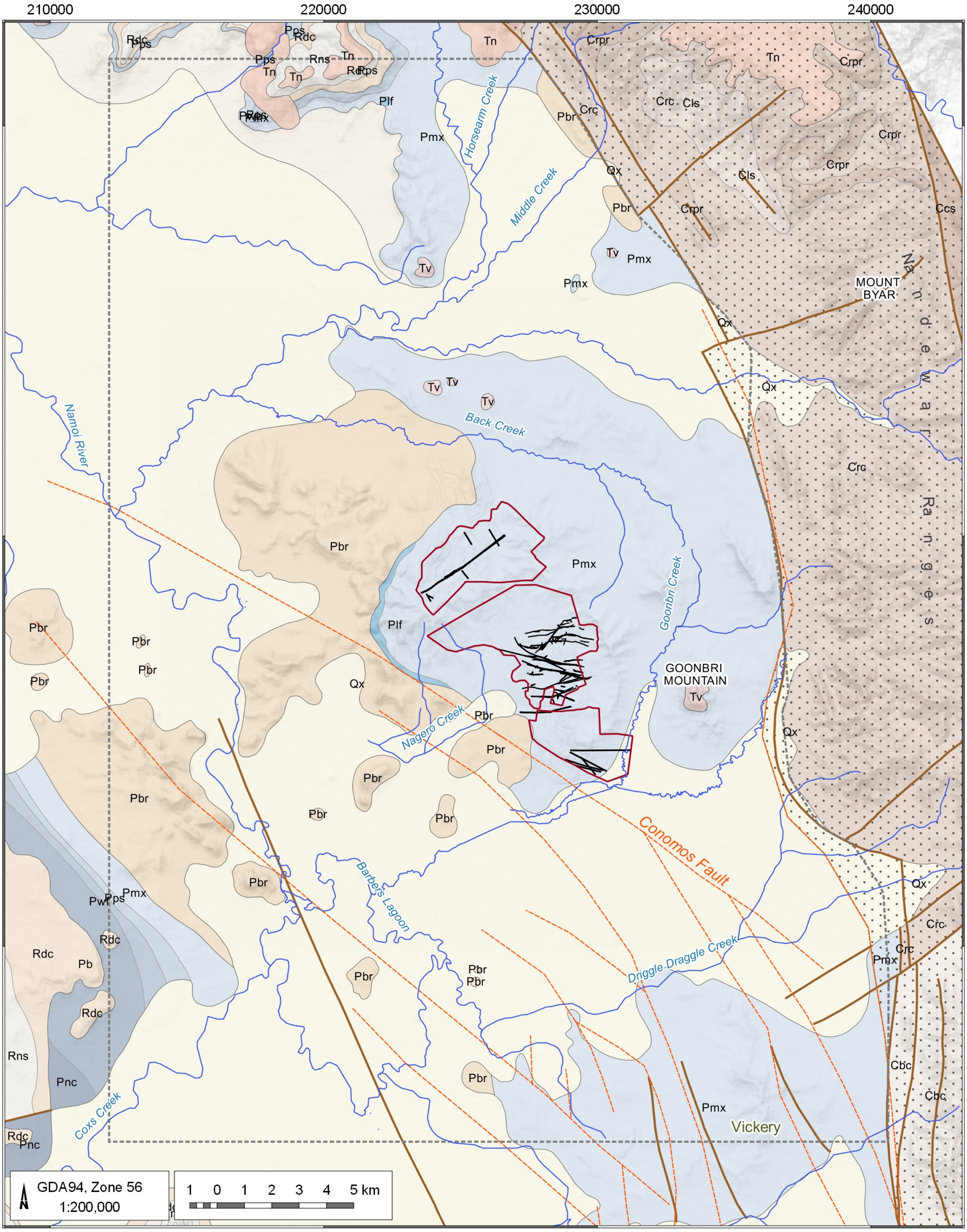
- mine specific faults – sourced from each mine's geological model – coloured black in Figure 5.8;
- regional faults and folds – after Pratt (1998a) – coloured red in Figure 5.8; and
- regional faults – source unknown, locations provided by Whitehaven geologists – coloured orange in Figure 5.8.

Normal faults are relatively common within the BTM Complex and are of variable orientation. These minor faults all have throws of less than 5 m.

Regional faults, which are shown in the mapping of Pratt (1998a), either strike at approximately 330° or 225°, and largely occur in the Vickery area. The Mooki Fault System is also shown, forming the eastern edge of the Maules Creek Sub-basin. Geological logs for monitoring site REG2, which is located approximately 1.7 km west of the mapped Mooki Fault System are almost entirely void of coal, suggesting that the fault system may be located further to the west than mapped by Pratt (1998a).

Additional, unverified mapped faults are extensive to the south of the BTM Complex, striking at approximately 300º. The source of this data provided by Whitehaven is unknown. A fault immediately south of the BTM Complex (Figure 5.8) is termed the Conomos Fault and has a displacement of 60 m to 90 m, north block up. Older iterations of the Tarrawonga geological model, which extend past the inferred location of the Conomos Fault, confirm its presence. These faults were not included in the JB Mining (2010) geological interpretation that was utilised in the previous groundwater models (AGE 2014, AGE 2018).

Additional faults are consistent with 1980s exploration work, which identified sub-parallel and perpendicular faulting to the Hunter-Mooki Thrust. These faults were tentatively identified within the exploration permit, with vertical throws ranging from 20 m to 50 m (AGE 2014). This finding is again repeated in Whitehouse (1993) who noted that, *"faulting, both subparallel and perpendicular to the Hunter-Mooki Fault system, has displaced a block in the southeast, with respect to the remainder of the area. Several of the other blocks have been displaced some 40 m to 50 m, by prominent faults"*.



LEGEND

- Drainage
- Regional faults (source unknown)
- Regional faults and folds (Pratt 1998a)
- Mine faults
- Study area
- Mooki Thrust Fault System
- Maximum open cut footprint

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tn - Tertiary Nandewar Volcanics
- Tv - Tertiary Volcanics
- Rns - Napperby Formation
- Rdc - Digby Formation
- Pnc - Black Jack Group
- Pb - Pamboola Formation
- Pwf - Watermark Formation
- Pps - Porcupine Formation
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pwb - Werrie Basalt
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Cls - Lark Hill Formation
- Crc - Rocky Creek Conglomerate
- Crpr - Plagyan Rhyodacite Tuff Member
- Ccs - Clifden Formation
- Cas - Caroda Formation

BTM model update (G1850P)

Local and regional faulting (various sources)

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FIGURE No:
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6 Hydrogeology

6.1 Groundwater monitoring network

Monitoring bores and vibrating wire piezometers (VWP) have been installed in a series of separate campaigns within the BTM Complex, with bores from each series named differently. Each of the BTM mines have a network of monitoring bores around the mining area to detect local impacts on groundwater levels. Additionally, there is a network installed further from the mining areas, designed to detect any cumulative impacts from the BTM Complex within and under the surrounding alluvial aquifers.

Appendix A contains a summary table describing the details of all the monitoring bores at the BTM Complex. Figure 6.1 shows the location of each of the bores. Where an array of multiple VWP sensors are installed within a single borehole then only the primary bore ID is shown, with Appendix A containing the installation details for each sensor. The sections below describe the various campaigns undertaken to install the monitoring bores.

6.1.1 'IBC' series

Prior to the commencement of the Boggabri Coal Mine, Parsons Brinkerhoff (2005) undertook a baseline groundwater assessment that included installing monitoring bores, permeability testing and groundwater modelling for the first 6 years of the mine life. This project included the installation of the 'IBC' series of bores around the mining area that comprised seven bores targeting coal seams and volcanic basement. Many of these bores were within the approved footprint and have been removed as mining has progressed.

6.1.2 'MW' series

The 'MW' series of bores was installed at Tarrawonga Mine in 2006 as part of baseline investigations prior to mining. A reference describing the installation of these bores has not been located to date. Most bores remain active, although bores MW6/MW8 are damaged and bore MW7 will eventually be destroyed by the progression of mining.

6.1.3 'BCS' series

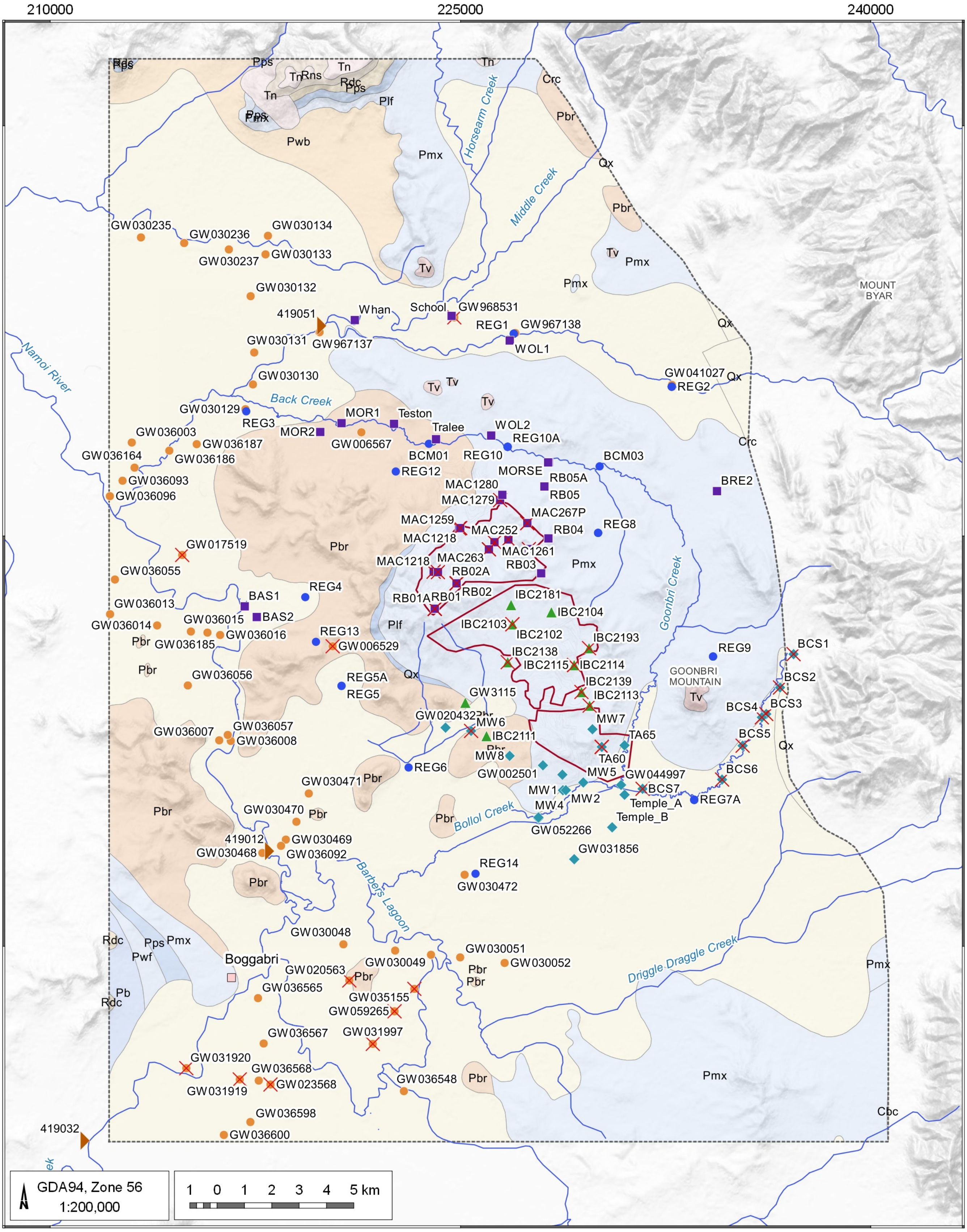
The 'BCS' series of bores along Bollol Creek to the east of the mining area was installed by Tarrawonga Mine for a short term investigation at the request of a local landholder. Whilst the installation date is not known, water level records are available intermittently for these bores from 2007. These bores are less than 50 m deep, targeting shallow alluvium or shallow rock.

6.1.4 'MAC' series

The 'MAC' series was established around the Maules Creek Mine in 2010 to gather information on the groundwater regime for the environmental assessment of the mine. This baseline data was used to develop and calibrate a numerical model in order to predict the impacts of mining on the groundwater regime. The bores were installed within former exploration holes, with a total of eight groundwater monitoring bores and four VWPs constructed. Most of the 'MAC' series monitoring bores and all the VWPs were damaged or destroyed by the progress of mining or by protestors. Only standpipe bore MAC1280 remains active. The MAC1280 bore is now located immediately to the east of the waste rock dump.

6.1.5 'TA' series

Two multi-level vibrating wire piezometers ('TA' series) were installed at Tarrawonga Mine in 2011. Four sensors at variable depths were installed at TA60, while eight sensors were installed at TA65. TA60 was removed by pre-stripping for mining in 2019.



LEGEND

- Drainage
- Maximum open cut footprint
- Study area

Monitoring bore

Group

- Boggabri-Active
- Boggabri-Destroyed
- Cumulative-Active
- Maules Creek-Active
- Maules Creek-Destroyed
- Tarrawonga-Active
- Tarrawonga-Destroyed
- Tarrawonga-Unknown
- WaterNSW-Active
- WaterNSW-Inactive
- WaterNSW SW gauging station

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tn - Tertiary Nandewar Volcanics
- Tv - Tertiary Volcanics
- Rns - Napperby Formation
- Rdc - Digby Formation
- Pb - Pamboola Formation
- Pwf - Watermark Formation
- Pps - Porcupine Formation
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pwb - Werrie Basalt
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Crc - Rocky Creek Conglomerate

BTM model update (G1850P)

Regional groundwater monitoring network

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FIGURE No: 6.1

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6.1.6 'RB' series

The 'RB' series of bores was designed to replace the 'MAC' series and installed between October 2013 and February 2014. The 'RB' series comprises three groundwater monitoring bores and five multi-level VWPs. Two of the locations (RB01 and RB02) were constructed in the Maules Creek mining footprint and were removed by the progress of mining in early 2017.

6.1.7 'REG' and 'BCM' series

The 'REG' series comprises twelve groundwater monitoring bores and six multi-level VWPs designed to detect cumulative impacts from the BTM Complex. These were endorsed by the department as part of approval for the relevant Water Management Plan. These are sampled by an independent contractor engaged by Maules Creek Mine. Of these bores, BCM1, BCM3 and REG10A were installed along Back Creek to assess the potential for shallow groundwater and the presence of Groundwater Dependent Ecosystems (GDE).

6.1.8 'GW' bores

The NSW Department of Industry - Water (DI Water) maintain a network of monitoring bores within the Namoi Valley alluvium that surrounds the BTM Complex. The purpose of these bores is to monitor groundwater levels and quality within the Narrabri and Gunnedah Formations. These bores all have the prefix 'GW' and are shown in Figure 6.1. Some of the 'GW' bores have been monitored routinely since the mid-1970s providing a long record of groundwater fluctuations. Some of the bores have electronic water level loggers and are equipped with telemetry with real time datasets available online[1].

6.1.9 Maules Creek Mine private monitoring bores

Maules Creek Mine collect water samples from up to 12 landholder bores biannually for water level and/or water quality analyses. While all 12 bores were originally privately owned, a number our now owned by Maules Creek Mine. Many of the bores are old and the bore construction details are often unclear or unknown. Data from the bores is used to generate a baseline dataset for each site. However, the data may be given a lower confidence level than that collected from the dedicated monitoring bores installed by the mine, due to the lack of detail on the exact geological strata being monitored. It has not been possible to collect data from all private bores in each sampling round due to bore access or equipment restrictions.

6.2 Hydrostratigraphic units

6.2.1 Summary

Local stratigraphy can be broadly classified into three distinct hydrostratigraphic units, which include:

- a Quaternary alluvial groundwater system;
- a Permian groundwater system of the Maules Creek Formation; and
- a late Carboniferous/early Permian groundwater system of the Boggabri Volcanics.

Table 6.1 provides a summary of the hydrogeological characteristics of each hydrostratigraphic unit.

[1] Accessed: https://realtimedata.waternsw.com.au/water.

Table 6.1 Overview of hydrogeological regime

Hydrostratigraphic unit	Groundwater bearing lithology	Hydrogeological characteristics
Narrabri Formation	Alluvium	Surface alluvial cover, comprising extensive overbank clays, with lesser channel sands/gravels. Relative to the underlying Gunnedah Formation, a greater presence of clay results in higher salinity and lower yields.
Gunnedah Formation	Alluvium	Basal paleochannel alluvium, comprising sands/gravel with interbedded clay. Can be extremely high yielding and fresh. Groundwater abstraction from aquifer is significant.
Maules Creek Formation	Coal seams	Prime water bearing lithology of the Maules Creek Formation. Sixteen coal seams of variable thickness, with a cumulative thickness greater than 35 m. Low to moderately permeable and generally fresh to brackish close to the outcrop area.
	Interburden	Hydrogeologically 'tight' and therefore very low yielding to essentially dry conglomerate/sandstone that comprises the majority of the Maules Creek Formation.
	Regolith	Variable in thickness, with deeper weathering profiles found along fractures and potential fault zones. Interpreted to be more permeable than fresh rock, although still hydrogeologically 'tight'. Limited information on water quality as it is commonly above the water table.
Boggabri Volcanics	Silicic volcanics	Small amount of outcrop in study area, generally forms basement of Maules Creek Sub-basin. Considered to be of very low permeability/impermeable, particularly at depth. Where present, groundwater likely stored in fractures and/or weathered material. Brackish to moderately saline in quality.

Details on the composition, extent and thickness of these hydrostratigraphic units are discussed in Section 5, with specific hydrogeological details provided in the following sections. Although Tertiary Volcanics and the Leard Formation are present within the study area, they are not anticipated to have any significant impact on the hydrogeological regime in the BTM areas.

6.2.2 Groundwater management

Within the study area, groundwater is managed by DPIE-Water under two Water Sharing Plans (WSPs), namely the:

- Water Sharing Plan for the *Upper and Lower Namoi Groundwater Sources 2003*; and
- Water Sharing Plan for the *NSW Murray Darling Basin Porous Rock Groundwater Sources 2011*.

The WSP for the *Upper and Lower Namoi Groundwater Sources* includes all water contained in unconsolidated alluvial sediment aquifers, which are associated with the Namoi River and its tributaries. Alluvial aquifers are divided into a number of management zones, with Upper Zone 11, Upper Zone 5, Upper Zone 4 and Upper Zone 2 occurring within the study area (Figure 6.2).

Within the study area, groundwater is managed under the Gunnedah-Oxley Basin sub-division of the *NSW Murray Darling Basin Porous Rock Groundwater Sources* WSP (Figure 6.2). This sub-division includes all rocks that are Permian, Triassic, Jurassic, Cretaceous and Tertiary in age, as well as any alluvial sediments within outcropped areas.

Each groundwater management zone has a specific number of water access licences (WAL), which pertain to a total annual entitlement (not including basic access rights). A comparison between the total entitlements for each management zone and the entitlements held by the combined BTM Mining Complex are provided below in Table 6.2.

Table 6.2 Water access licence entitlements

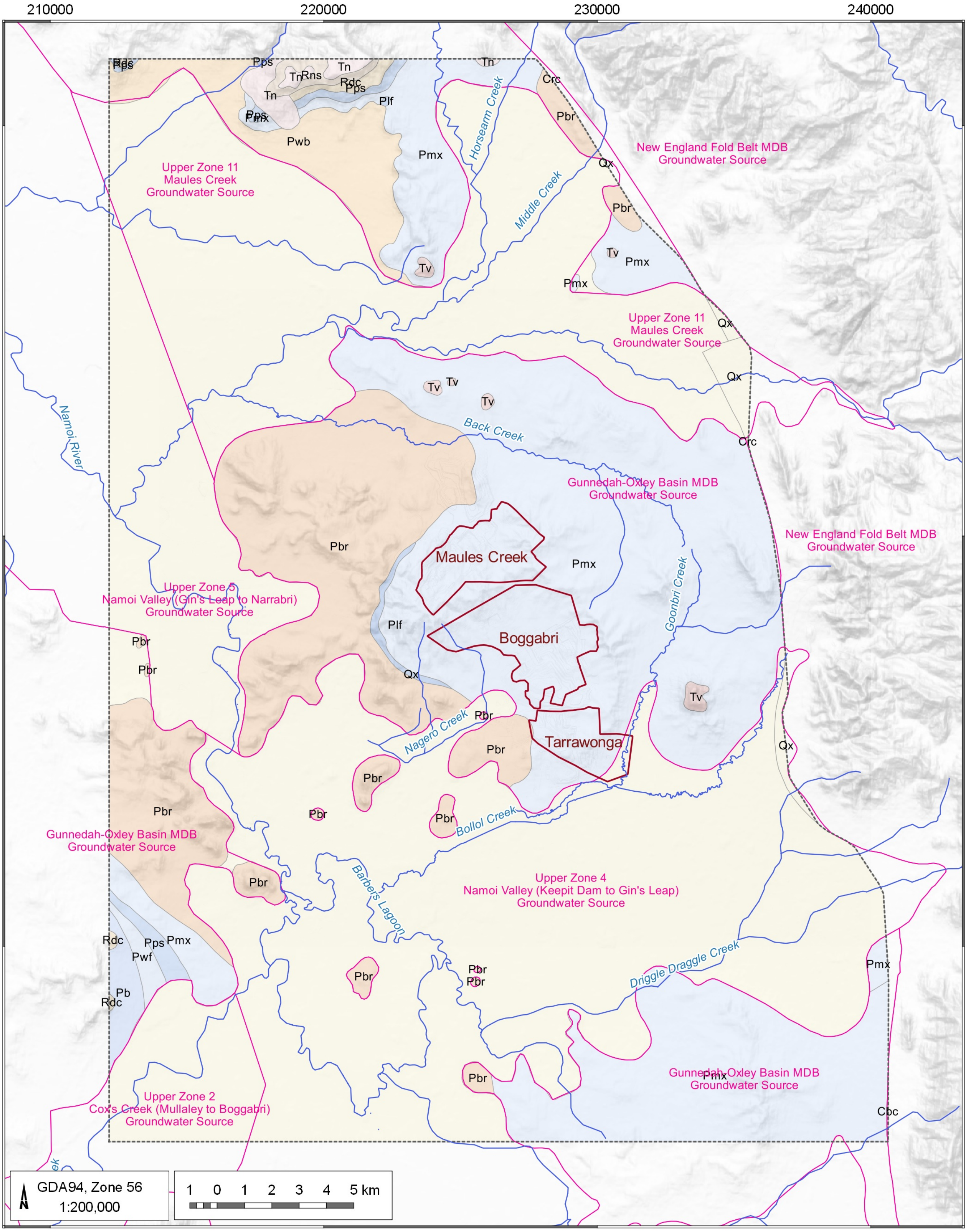
Management zone	Total of WALs #	Total entitlement (ML*/year)	Combined BTM Complex entitlement (ML/year)
Upper Zone 11	29	2,223	78
Upper Zone 5	74	15,992	135
Upper Zone 4	166	21,032	1,444
Upper Zone 2	30	7,141	-
Gunnedah-Oxley Basin	144	23,109	2,283.5

Notes: Data taken from the WaterNSW Water Register for the 2019/2020 financial year accessed: https://waterregister.waternsw.com.au/water-register-frame.

* ML = megalitres.

Total entitlement may vary dependent on carryover, purchase, or transfer within respective companies.

The flow in the Namoi River in the study area is regulated by releases from Keepit Dam. Water in the regulated river occurs in the Upper Namoi Regulated Water Source, and is managed under the *Upper Namoi and Lower Namoi Regulated River Water Sources* (2016) WSP.



LEGEND

- Drainage
- Maximum open cut footprint
- Study area
- Namoi Groundwater Management areas

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tn - Tertiary Nandewar Volcanics
- Tv - Tertiary Volcanics
- Rns - Napperby Formation
- Rdc - Digby Formation
- Pb - Pamboola Formation
- Pwf - Watermark Formation
- Pps - Porcupine Formation
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pwb - Werrie Basalt
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Crc - Rocky Creek Conglomerate

BTM model update (G1850P)

Groundwater management areas of the study area

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FIGURE No: **6.2**

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G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\06.02_G1850_Groundwater management areas of the study area.qgs

6.3 Hydraulic parameters

6.3.1 Alluvium

Within the study area, measurements of alluvial hydraulic conductivity are available from 19 pumping tests, with calculated values ranging from 1.2×10^{-3} m/day to 3.6×10^{2} m/day (AGC 1981, Coffey & Partners 1983, Heritage Computing 2012, PB 2015 and Aryal et al. 2018). Although targeted lithologies are difficult to determine from some reports, the significant variability of hydraulic conductivity suggests tests were undertaken in a wide range of alluvial sediments.

At a larger scale, hydraulic testing of alluvium within the Gunnedah Basin has been collated as part of the Namoi bioregional assessment (Aryal et al. 2018). General statistics for alluvial hydraulic conductivity for the entire Namoi region are presented below in Table 6.3. Use of the entire dataset is considered appropriate for conceptualisation as the hydraulic properties of the alluvium are likely to be relatively consistent, given the regionally consistent depositional environment. Statistics highlight the impact of alluvial heterogeneity, with median hydraulic conductivity of the finer grained Narrabri Formation sediments two order of magnitude less than sands and gravel of the Gunnedah Formation.

Local bore yields are consistent with the lithology driven variability of hydraulic conductivity. Within the study area, yields taken from 18 bores range from less than 1 L/s up to a maximum of 175 L/s (AGE 2014).

Table 6.3 Hydraulic conductivity of alluvium (after Aryal et al. 2018)

Hydrostratigraphic unit	Hydraulic conductivity (m/day)		
	Median	Min	Max
All alluvium*	0.003	0.0001	259
Narrabri Formation	0.09	0.002	3.14
Gunnedah Formation	6.18	1.79	28.5

Note: * Stratigraphy is not known for all locations.

6.3.2 Permian coal measures

Measurements of hydraulic conductivity for the Maules Creek Formation are available from a range of studies conducted for mining projects within the BTM Complex. An overview of these testing programs and their methodology is provided below:

- Herring (1979) – performed tests on a selection of exploration holes that encountered sufficient groundwater flow to enable pumping at the proposed site of the Boggabri Mine;
- Coffey and Partners (1983) – performed lugeon tests in the coal seams and interburden at site of the proposed Maules Creek Mine;
- Parsons Brinkerhoff (2005a) – tested discrete profiles with inflatable packers in the coal seams and interburden at the site of Boggabri Mine;
- AGE (2011) – tested discrete profiles with inflatable packers in the coal seams and interburden at Maules Creek Mine;
- RPS Aquaterra (2011) – conducted permeability tests on interburden core samples, pumping tests and slug tests at Tarrawonga Mine; and
- AGE (2017) – conducted core permeability tests on samples of interburden from the Maules Creek Mine.

A visual summary of hydraulic conductivity measured at multiple depths within the Maules Creek Formation is presented in Figure 6.3 and Figure 6.4, for the coal seams and interburden respectively. The graphs show data from the BTM complex and data also from the Vickery and Rocglen mines contained within the Namoi bioregional assessment (Aryal et al. 2018).

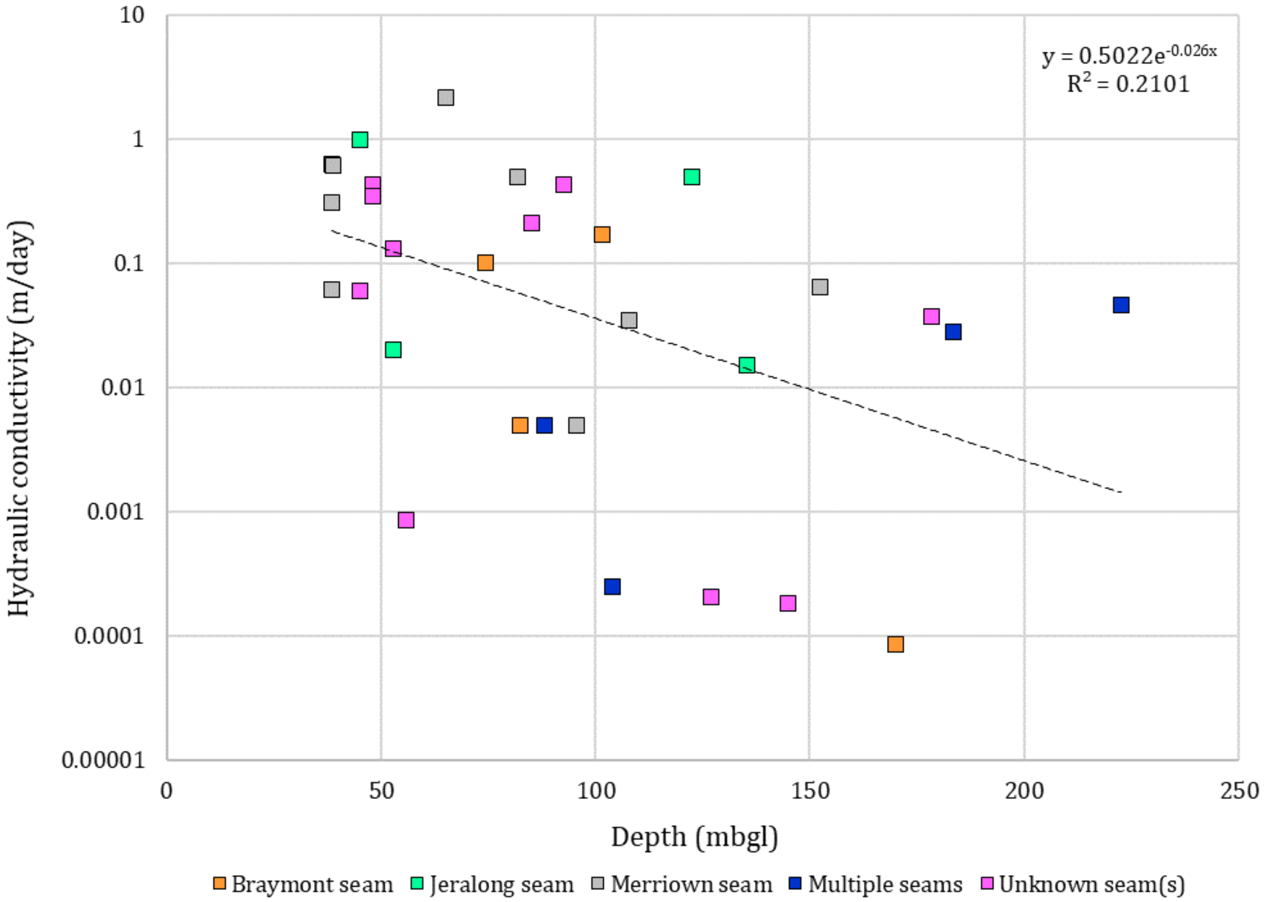


Figure 6.3 Hydraulic conductivity vs depth – coal seams

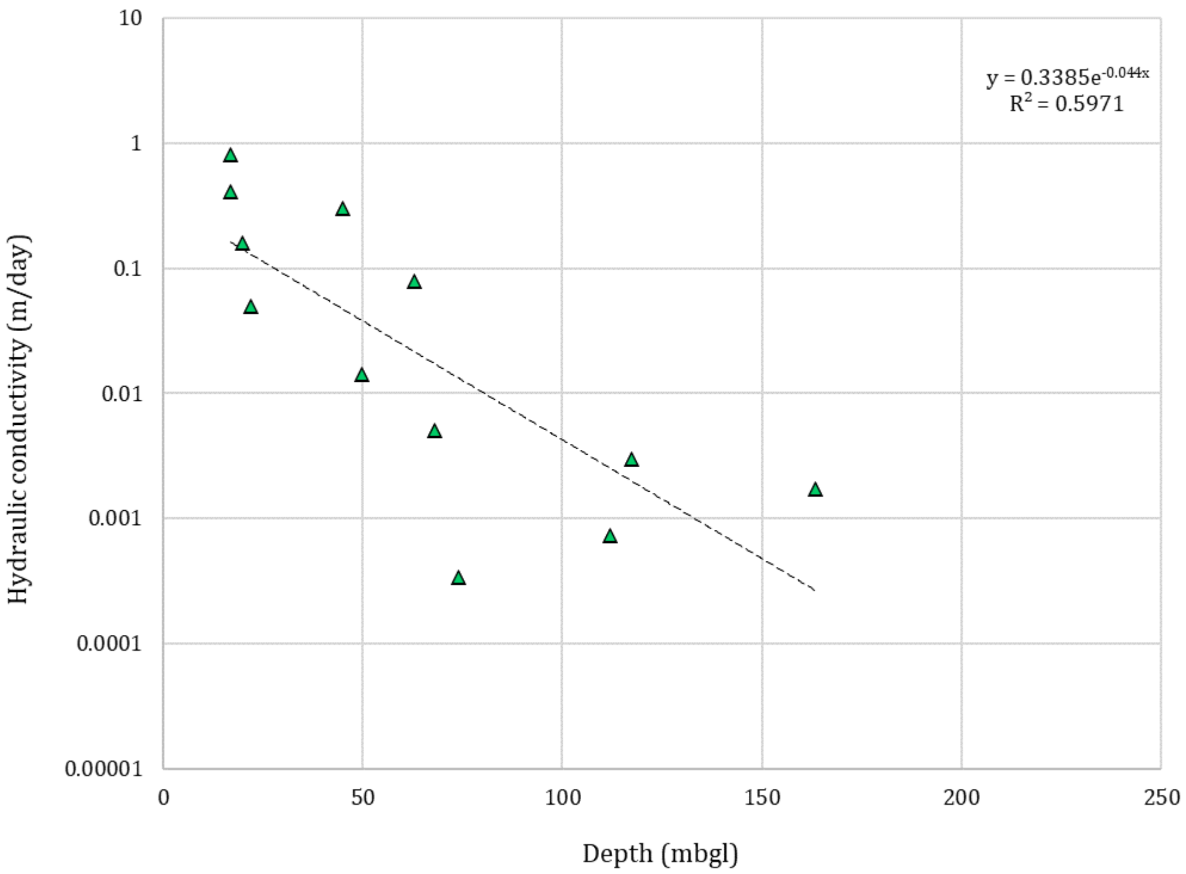


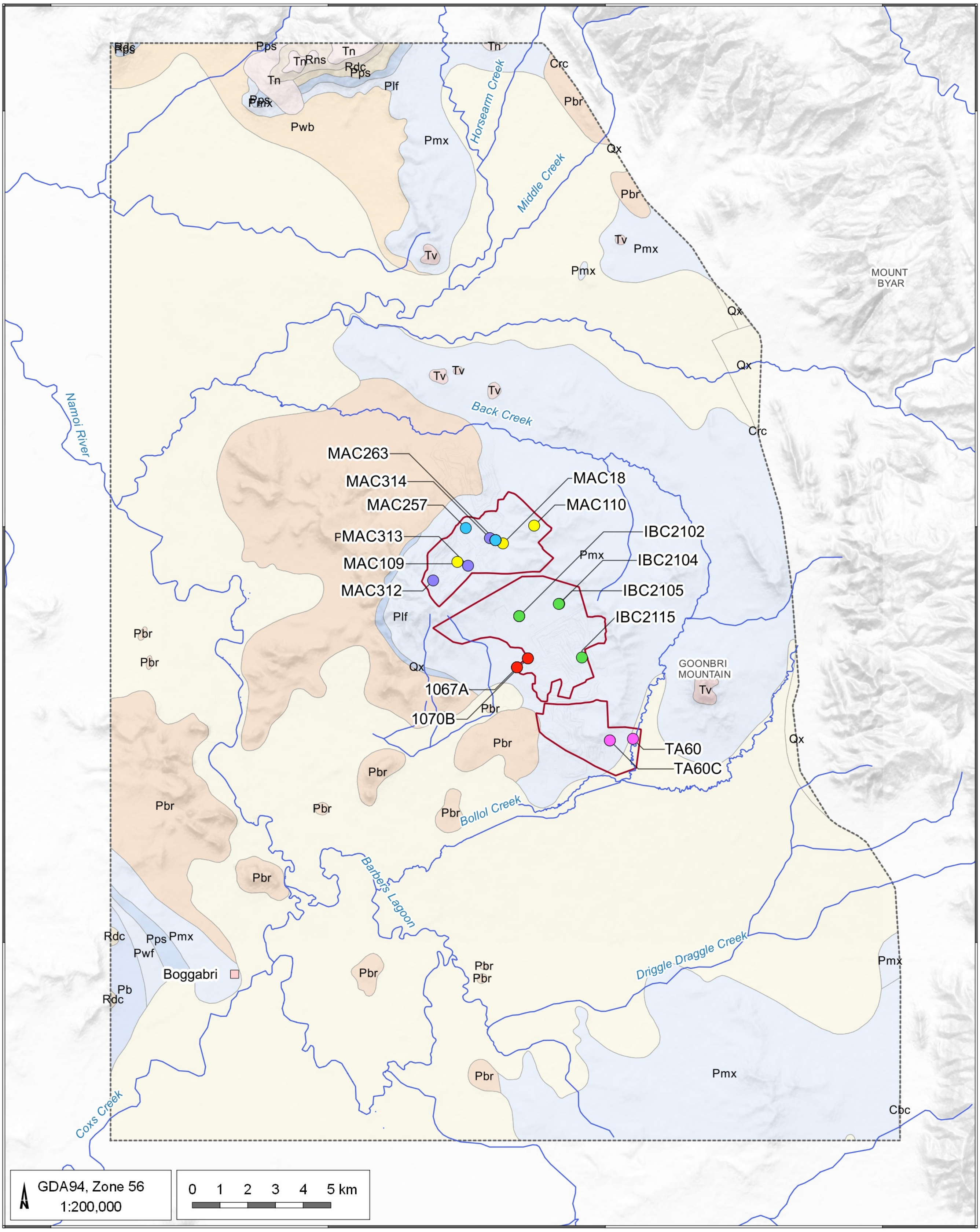
Figure 6.4 Hydraulic conductivity vs depth – interburden

Coal seam hydraulic conductivity is highly variable, with approximately five orders of magnitude separating the highest and lowest estimates. Data shows a poorly defined trend, where increases in depth may correlate to a decrease in hydraulic conductivity. There is insufficient data to provide confidence in this relationship; and it should be noted that the maximum depth of investigation (~ 220 m) is roughly only a quarter of what is estimated to be the Maules Creek Formation's maximum thickness (see Section 5.6).

The hydraulic conductivity of the interburden is variable with approximately three orders of magnitude separating the maximum and minimum. There is a reasonably strong relationship between hydraulic conductivity and depth, with lower values found in deeper tests. However, it should be noted that only twelve tests were included in the analysis, eight of which were completed in Vickery and Rocglen mines.

Results of core permeability tests in core samples of interburden (RPS Aquaterra 2011 and AGE 2017) are not included in Figure 6.4. Estimates of permeability in these tests are solely attributed to the texture of the rock and do not consider secondary permeability, which is associated with rock fractures, joints and foliation. As such, core permeability tests are usually an underestimate of total permeability. Hydraulic conductivity values determined during core permeability tests are a consistent with other testing methods, in that interburden is of low to very low permeability. Vertical permeability was also tested during core analysis and vertical values were generally found to be lower than horizontal values, with vertical permeability values routinely falling below 1 x 10^{-6} m/day, particularly within finer grained sediments (AGE 2017).

Coal seams are generally more permeable than interburden, with an average hydraulic conductivity of 0.6 m/day (39 tests) compared to 0.03 m/day (11 tests, not including core permeability test results). Horizontal hydraulic conductivity test results are provided in Appendix B for analyses within the BTM Complex and where available, the local test locations are shown in Figure 6.5.



LEGEND

- Drainage
- Maximum open cut footprint
- Study area

Test bore

- Herring 1970
- PB 2005
- RPS Aquaterra 2011
- AGE 2011
- AGE 2017
- Coffey and Partners 1983

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tn - Tertiary Nandewar Volcanics
- Tv - Tertiary Volcanics
- Rns - Napperby Formation
- Rdc - Digby Formation
- Pb - Pamboola Formation
- Pwf - Watermark Formation
- Pps - Porcupine Formation
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pwb - Werrie Basalt
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Crc - Rocky Creek Conglomerate

BTM model update (G1850P)

Map of hydraulic testing locations for Permian coal measures

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FIGURE No: **6.5**

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G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\06.05_G1850_Map of hydraulic testing locations for Permian coal measures.qgs

6.3.3 Boggabri Volcanics

To date, hydraulic testing of the Boggabri Volcanics is limited, with two core permeability tests completed as part of the Vickery EIS (GES 2012) and two rising head tests with inflatable packers attempted as part of the Maules Creek EIS (AGE 2011).

Core permeability testing indicated a mean horizontal hydraulic conductivity of 2.4×10^{-6} m/day and a mean vertical hydraulic conductivity of 4.0×10^{-6} m/day. These findings are consistent with attempted rising head tests, where analysis was not possible due to a lack of flow. AGE (2011), concluded that these failed tests were indicative of a very low hydraulic conductivity of less than 10^{-4} m/day.

Hydraulic testing of the Boggabri Volcanics is indicative of relatively impermeable rock. To the west of the BTM Complex, regular groundwater monitoring demonstrates that groundwater is present in the system. Although still low, appreciable inflows at these locations are likely attributed to their relatively shallow depth, where the Boggabri Volcanics are likely weathered.

6.3.4 Spoil

Measurements of hydraulic characteristics for spoil material are rarely available in mining projects, and no test data is available for BTM. Spoils have typically been represented in conceptual and numerical models as permeable and porous. Observations during mining indicate this is an appropriate assumption whilst mines are operating. However, the effects of ongoing consolidation contributing to reduced permeability and porosity are not commonly measured. It is expected that both the permeability and porosity of spoils reduces over time due to overburden pressure, as well as in-situ weathering releasing clay minerals into the spoil matrix.

6.4 Horizontal hydraulic gradients and flow directions

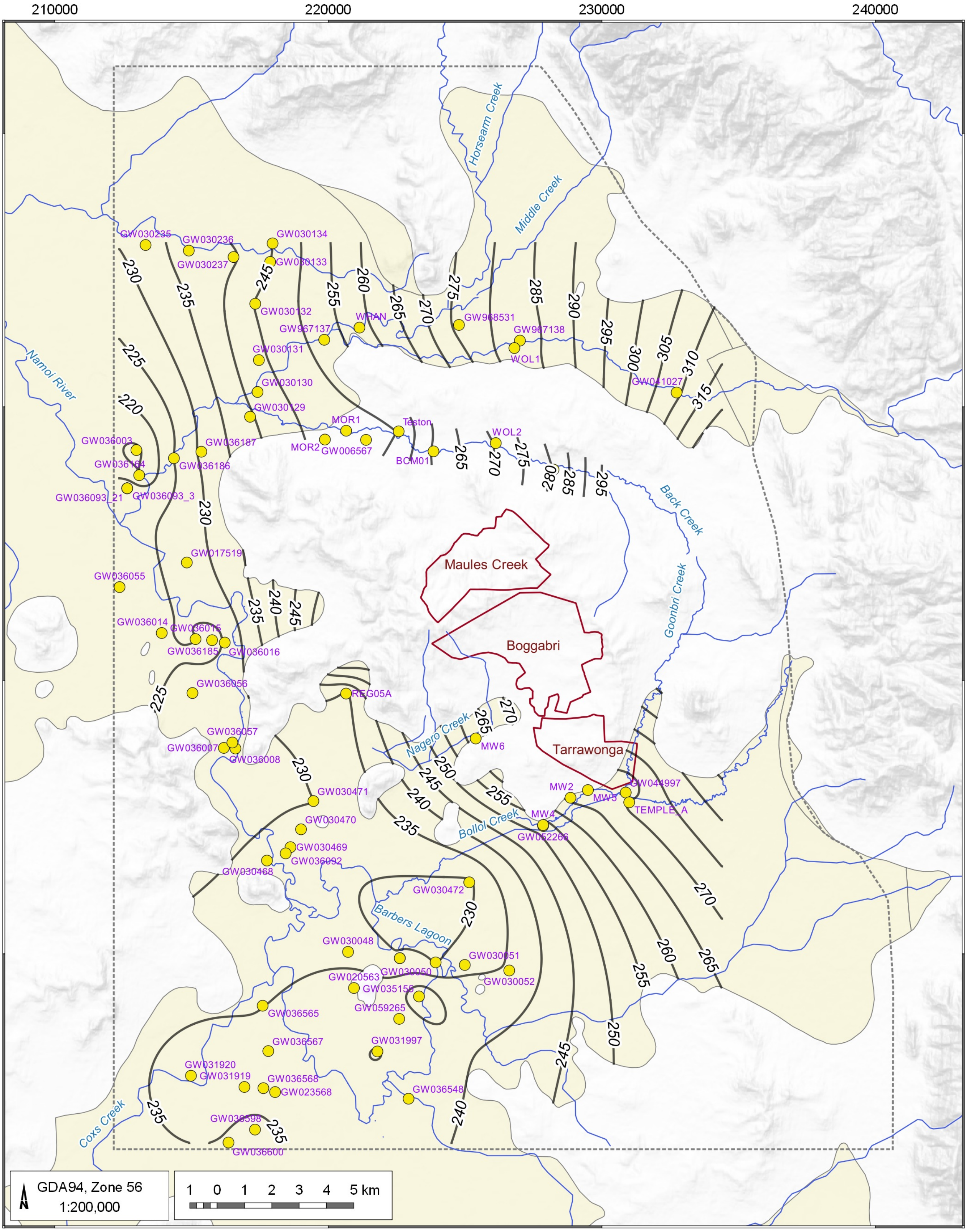
Recent groundwater levels within alluvium, coal seams of the Maules Creek Formation and the Boggabri Volcanics were sourced from each mine's monitoring network and from registered groundwater bore data, which is available from the WaterNSW online database[2].

Within the study area, groundwater levels within the alluvial aquifers range from approximately 309 mAHD in the east, to 214 mAHD along the Namoi River in the northwest. Groundwater generally flows from east to west within the Maules Creek/Back Creek alluvial plain, and generally towards the southwest within the Bollol Creek/Driggle Draggle Creek alluvial plain (Figure 6.6). Groundwater flow within alluvium of the Namoi River alluvium generally follows the direction of the river, with flow either to the northwest or north (McNeilage 2006).

Groundwater levels within coal seams of the Maules Creek Formation are presented in Figure 6.7, noting that at multi-level monitoring locations, only the shallowest water level was analysed. It is difficult to accurately determine natural flow direction in this formation, as many of the coal seam monitoring bores have been drawn down by mining activities. At monitoring locations away from mining areas (REG1, REG2, REG7, REG9 and REG10), differences in shallow groundwater levels suggest groundwater flow from the east to the west, although data is limited.

Groundwater contours of the Boggabri Volcanics (Figure 6.8) show groundwater generally flowing to the west from the edge of the BTM Complex. Relatively high groundwater levels observed in REG13 form a local maximum, where to the north groundwater flow is due west, and to the south groundwater flow is largely to the southwest.

[2] Accessed: https://realtimedata.waternsw.com.au/water.



LEGEND

Drainage
Maximum open cut footprint
Study area
Alluvium extent

Alluvium bores
GW036548 : Bore ID
Alluvium water table contours (mAHD)

BTM model update (G1850P)

Quaternary alluvium water table

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FIGURE No:
6.6

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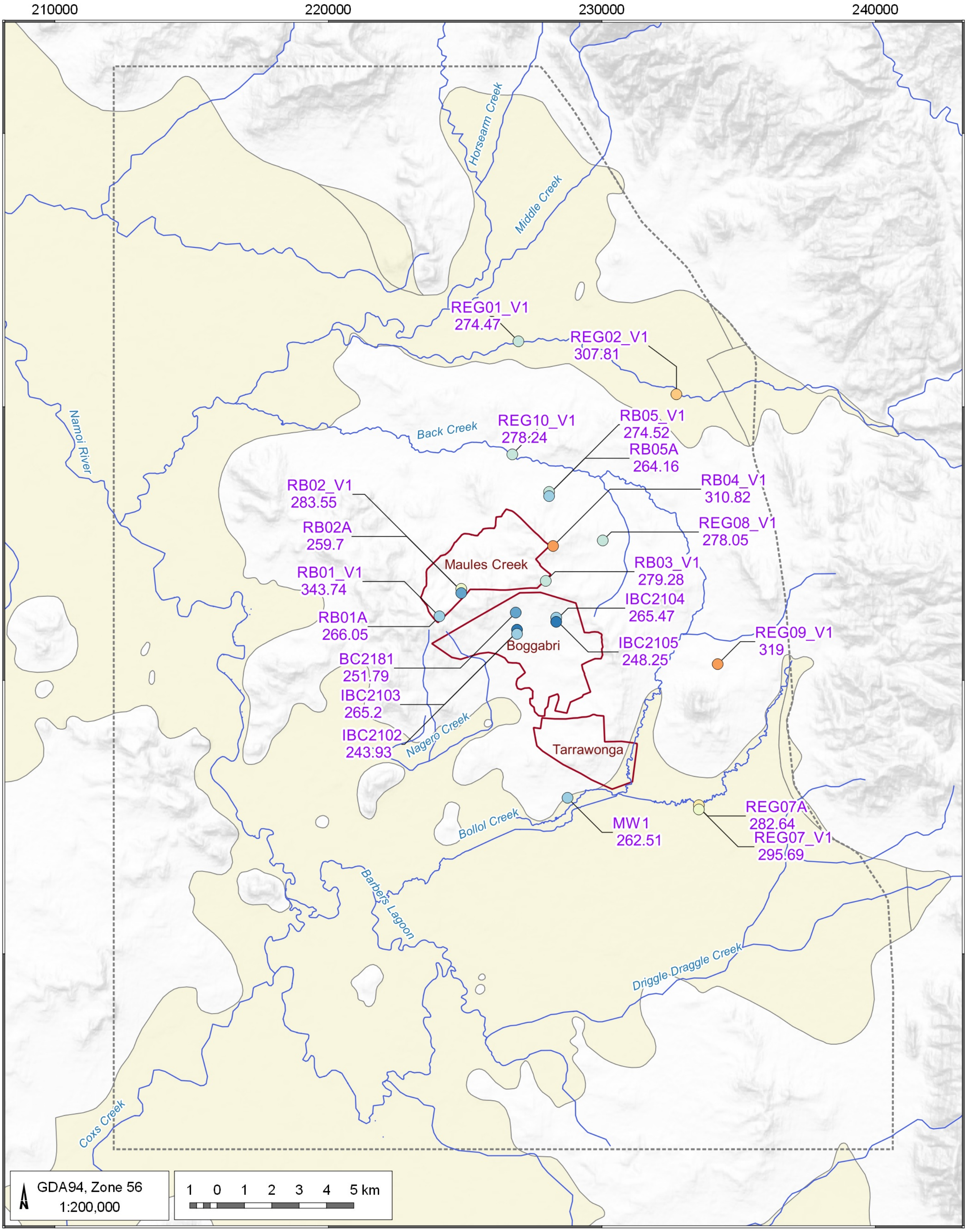

LEGEND

- Drainage
- Maximum open cut footprint
- Study area
- Alluvium extent

Upper groundwater levels in Maules Creek Formation coal seam

- 240 - 250
- 255 - 264
- 260 - 270
- 270 - 280
- 280 - 290
- 290 - 300
- 300 - 310
- 310 - 320
- 320 - 330
- 330 - 340

REG07A : Bore ID
282.64: Water table (mAHD)

BTM model update (G1850P)

Upper Maules Creek Formation water table

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FIGURE No:
6.7

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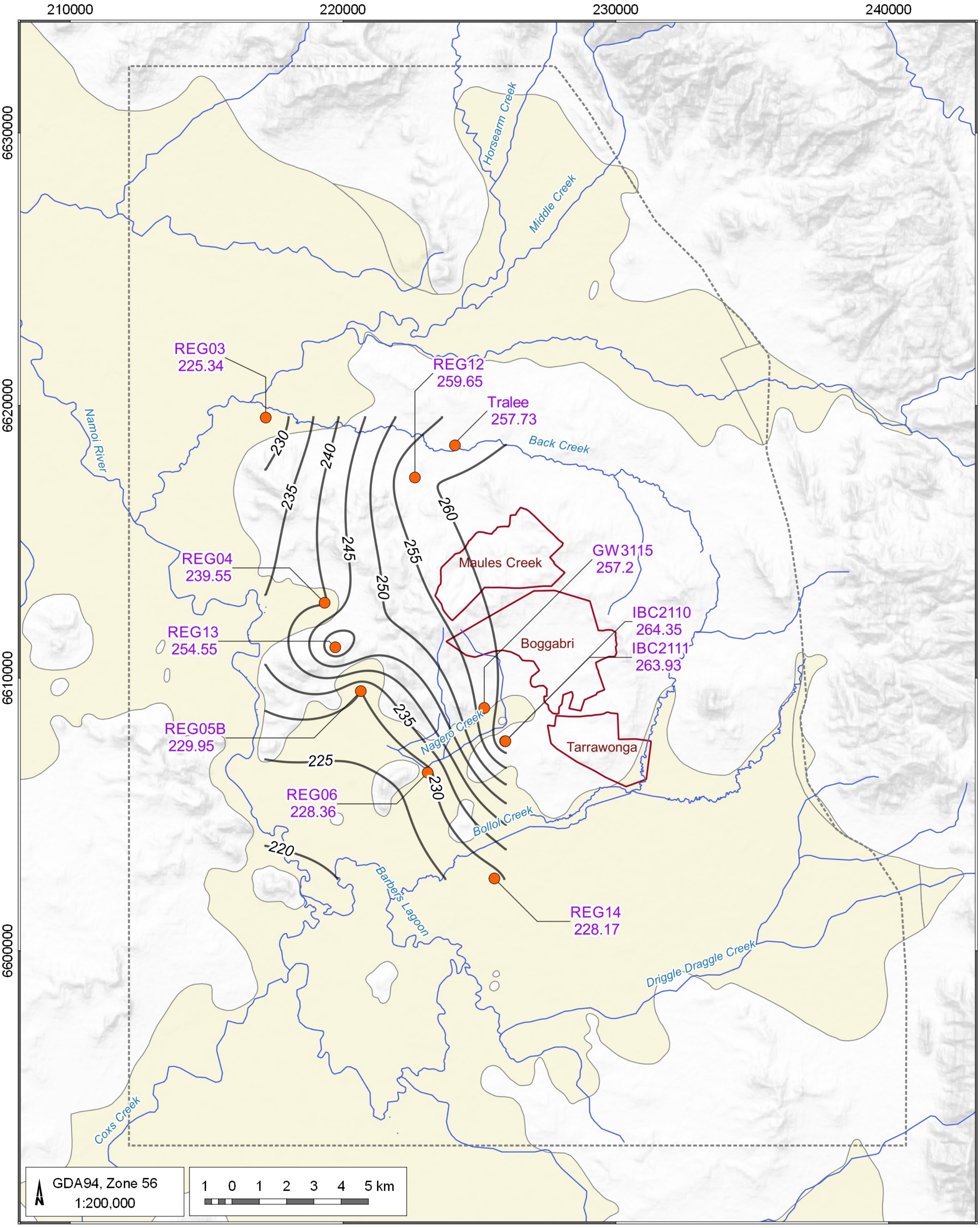

LEGEND

- Drainage
- Maximum open cut footprint
- Study area
- Alluvium extent
- Boggabri Volcanic bores
  - REG14 : Bore ID
  - 228.17: Water table (mAHD)
- Water table contours (mAHD)

BTM model update (G1850P)

Boggabri Volcanics water table

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FIGURE No: **6.8**

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6.5 Water level fluctuations and interaction

The magnitude and nature of water level fluctuations measured in monitoring bores and VWPs depends on a range of factors including aquifer properties, recharge rates, and proximity to stressors such as pumping and mining. The water levels observed in the monitoring bore network were reviewed and are discussed in the following sections, with hydrographs for all bores provided in Appendix C.

6.5.1 Alluvial water level trends and vertical gradients

Many groundwater monitoring bores were installed into the Upper Namoi alluvium by the NSW government during the 1970's. The length of recorded data for these sites can be over 40 years. The bores are often nested or clustered, with two or three piezometers measuring water levels at different depths within the alluvial aquifer.

An example hydrograph for a nested alluvial bore (GW036016), located immediately north of Gin's Leap, is presented in Figure 6.9. The cumulative rainfall deficit (CRD) is also shown for context. All three of the piezometers have a clear response to the changing rainfall deficit, with water levels rising after significant rainfall, and falling during periods of lower than average rainfall. Prior to ~1993 the water levels at all three depths were very similar, with a slight downwards gradient observed and only small (<1 m) changes in water level. Water levels were also relatively stable, varying around a level of ~ 228 mAHD. Since ~1993 the water levels in the two deeper piezometers have shown a much greater short term variation. Also of note is the overall falling trend in water levels between 1995 and 2010 despite there being a relatively stable CRD. Given the location of the bore, and the type of response seen, it is likely that the water levels in the deeper piezometers are reflecting nearby irrigation abstraction. The lack of fluctuations seen in the shallowest piezometer suggests that there is a retarded hydraulic connection between the upper and lower alluvial units. The overall falling trend suggests that the groundwater from this aquifer was being over-abstracted during this period in this area.

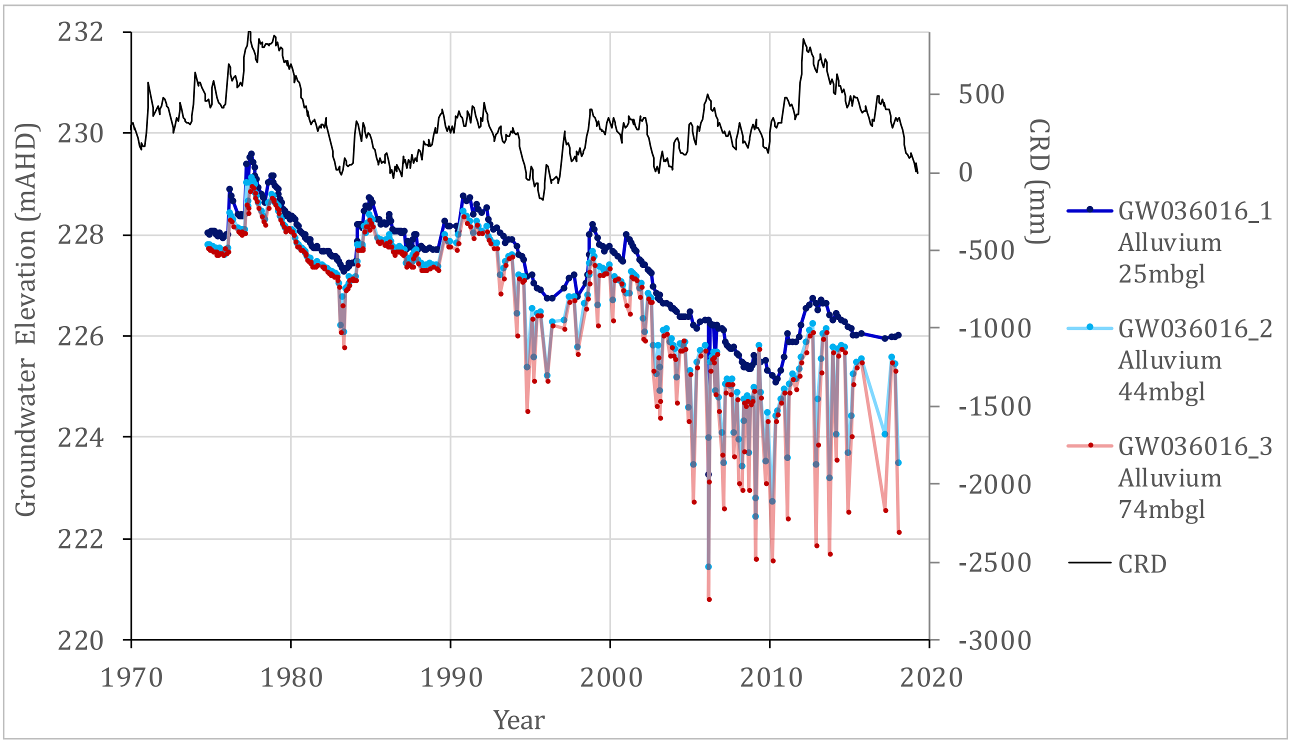


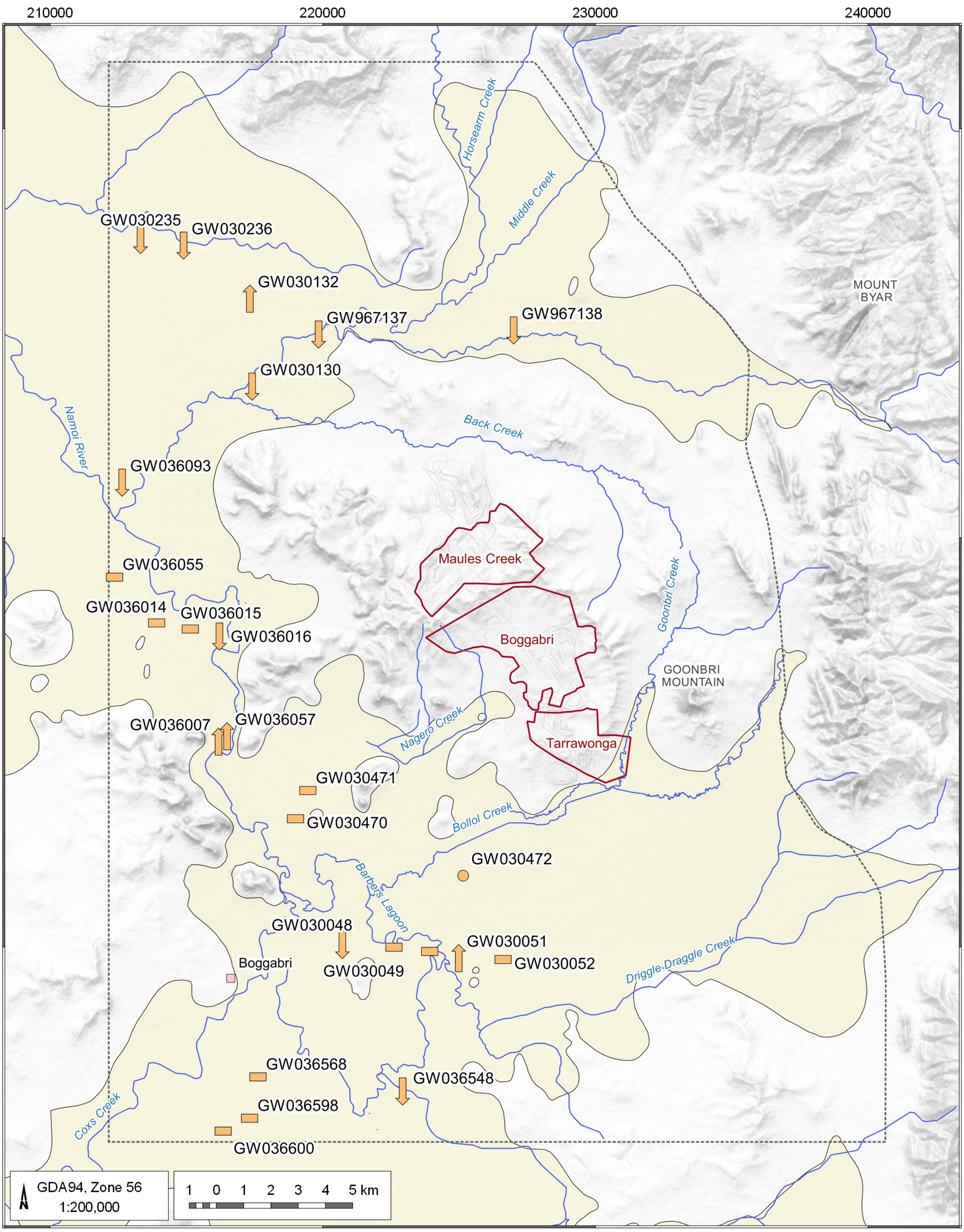
Figure 6.9 Example hydrograph for alluvium (bore GW036016)

The vertical gradients observed within the alluvial units are not always downwards. Within the study area there are several sites where the hydraulic conductivity in the upper and lower units appears to be sufficiently similar to prevent a vertical gradient forming. Vertically upwards gradients are also observed at a small number of sites. The gradients can also change over time as the stresses local to the site vary. A qualitative assessment of the alluvial bores resulted in the following gradients being observed:

- Downward 9
- Neutral 11
- Upward 4
- Anomalous response 1

The spatial distribution of the classified responses is shown in Figure 6.10. There is no obvious spatial pattern to the vertical gradients, although there may be a better hydraulic connection through the alluvial sequence along the main Namoi River paleochannel.

There is an atypical response observed at GW030472, where the shallowest piezometer has rising water levels, and the deeper sites have falling levels that appear to be influenced by abstraction. The shallow piezometer also has a lower water level than observed in the deeper piezometers.



LEGEND

- Drainage
- Maximum open cut footprint
- Study area
- Alluvium extent

Qualitative vertical gradient

- Upwards gradient
- Downwards gradient
- No obvious gradient
- Atypical response

BTM model update (G1850P)

Vertical gradients observed within the alluvial units

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FIGURE No: **6.10**

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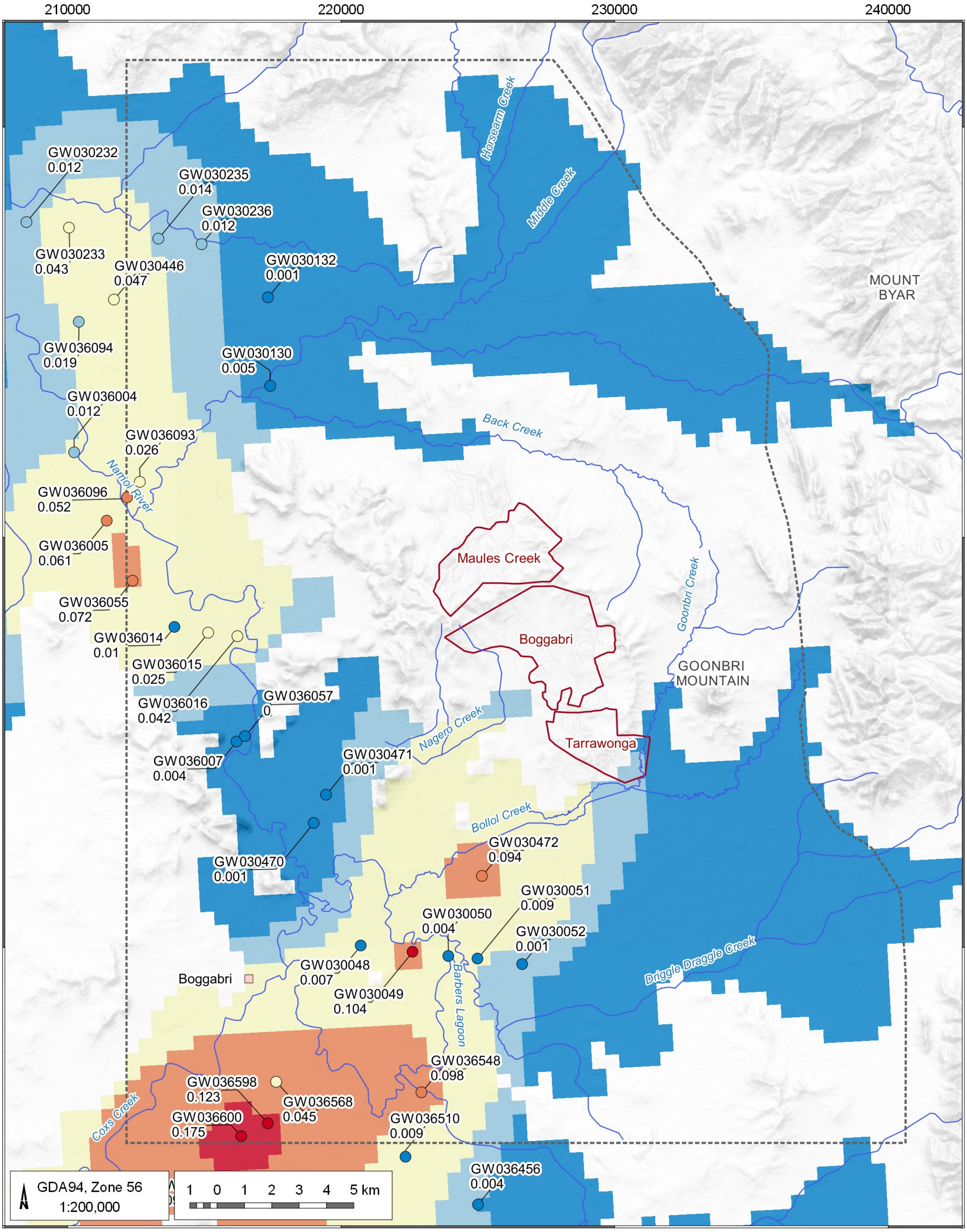
An overall decline in water levels have been observed in almost all of the nested government water level monitoring bores (Appendix C). The exceptions are GW030051 and GW030052 (and the shallow piezometer at GW030472), located in the centre of Zone 4 between Bollol Creek and Driggle Draggle Creek. Water levels in the bores has risen by 1.5 m and 3.5 m respectively since the early 1970's and may be related to increased irrigation leakage in the vicinity of the monitoring bores; or a very long term response to increased recharge induced by land clearing and levelling.

The temporal differences in alluvial aquifer vertical gradients were assessed as part of the Namoi bioregional assessment and are shown in Figure 6.11 (Aryal et al. 2018). The linear level trend was calculated for each nested piezometer, and for each nested group the maximum difference in the slope between 1983 and 2012 was plotted. Bores and areas with no data, or no significant difference in water level trends between nested sites, are shown in dark blue; while bores and areas with the greatest difference in water level are shown as yellow and then red. There are a number of potential reasons for increasing divergence. As previously discussed for site GW036016, the main differences observed along the Namoi River corridor are likely to be strongly correlated to irrigation abstractions occurring from the deeper alluvium. Further analysis on the impact of irrigation abstraction is difficult, as abstraction records are not publicly available.



LEGEND

- Drainage
- Maximum open cut footprint
- Study area

Difference in GW level trend (m/year)

Points	Grid
0.00 - 0.01	<0.01
0.01 - 0.02	0.01 - 0.02
0.02 - 0.05	0.02 - 0.05
0.05 - 0.10	0.05 - 0.10
0.10 - 1.05	>0.1

BTM model update (G1850P)

Difference in GW level trend (m/year)

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FIGURE No: **6.11**

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6.5.2 Permian coal measures water level trends

In contrast to the alluvial areas, there are no long-term government monitoring bores recording water levels within the Permian strata. Instead, the Permian coal measures are monitored through a combination of mine-owned monitoring bores and VWPs, and a small number of private bores that are also monitored by the mines. As many of the private bores are relatively old, their construction details can be unknown, and the exact strata being monitored is often unclear. The private bores are useful to examine spatial differences and ongoing trends but should not be analysed in isolation. Bores installed within the mining footprint often have a shorter lifespan than the private bores as they are removed over time as mining progresses through the approved footprint. Water levels in these bores typically decline rapidly in response to depressurisation propagating through the coal seam as the mine approaches. Monitoring at these bores typically ceases when land clearing ahead of mining is necessary. Some bores have only monitored during specific investigations for short periods. The bores that have been removed or are no longer actively monitored are identified on Figure 6.1.

Figure 6.12 to Figure 6.16 display water level hydrographs for selected Permian monitoring locations, with all other Permian hydrographs provided in Appendix C.

Water levels in the Permian strata within or close to the active mining areas have been falling as the pits have expanded and progressed below the water table. A zone of depressurised water levels around the mining areas was predicted for the various approvals for the three mines and is therefore not unexpected. Multi-level sites typically show downwards vertical gradients in the upper units, with water levels in the shallow strata remaining higher than levels in the deeper units. More significant depressurisation of the deeper seams is expected to occur because a steeper hydraulic gradient is created by the open pits in the deeper seams exposed in the mining area.

At sites peripheral to the mines (REG1, REG2, REG7 and REG9) the gradients remain downwards throughout the profile. Closer to the mines (most RB series, REG10, REG8 and TA65) the deeper gradients can be more variable. As the deeper sensors can be recording pressures below the deepest coal seams being mined, this likely reflects pressure reduction to the base of the mined seams and then a return to higher pressures below this depth. Vertical pressure changes over time are shown for RB05 and TA65 in Figure 6.17. The pressure changes observed at RB05 show a relatively steady downwards gradient that reduces in all sensors over time. In contrast, at TA65 the vertical gradient between the seams has become steeper over time as the mine depressurises to the base of the Nagero seam (sensor at ~ 177 mAHD).

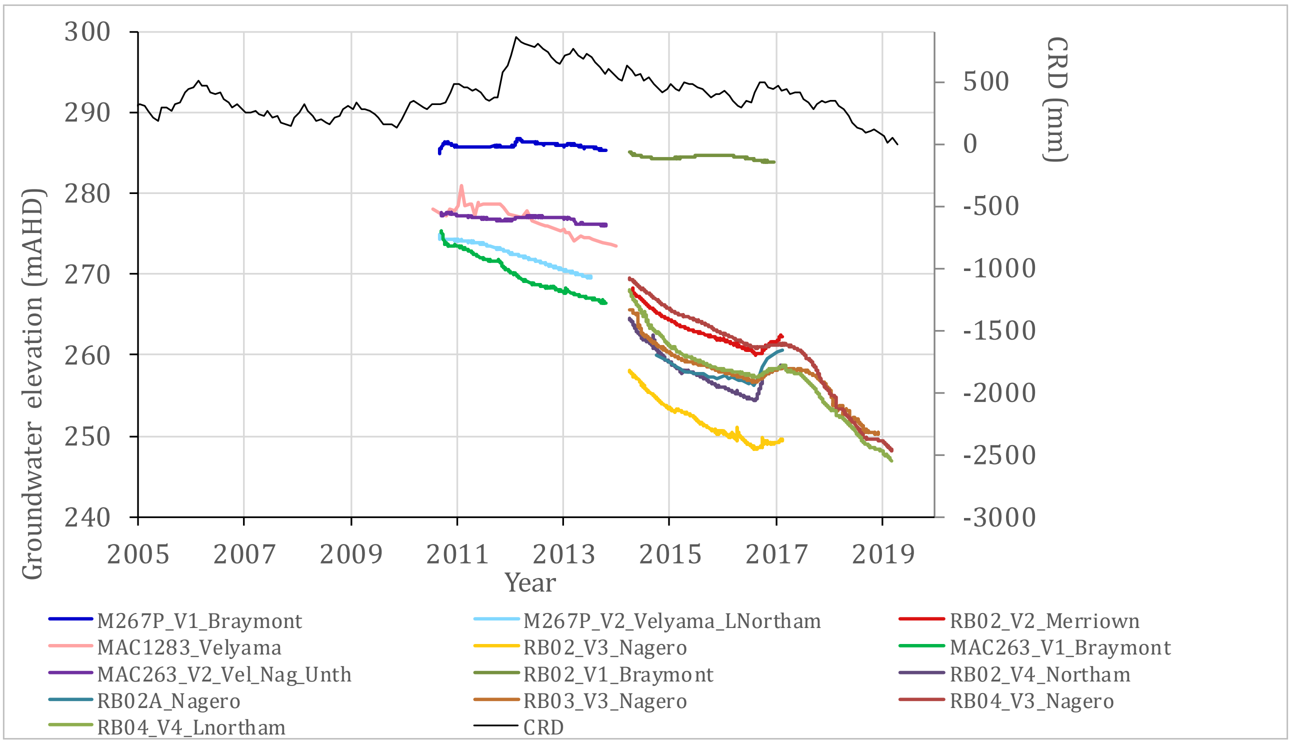


Figure 6.12 Selected Permian hydrographs – Maules Creek Mine

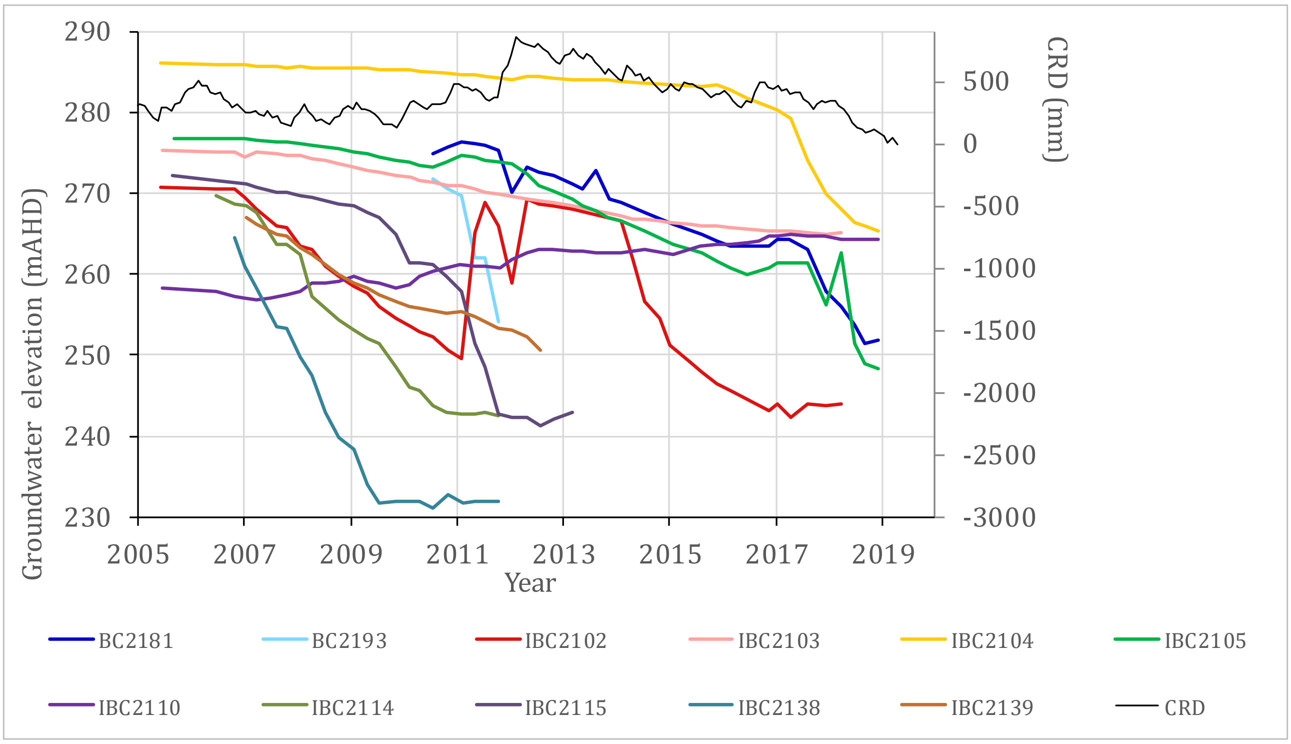


Figure 6.13 Selected Permian hydrographs – Boggabri Mine

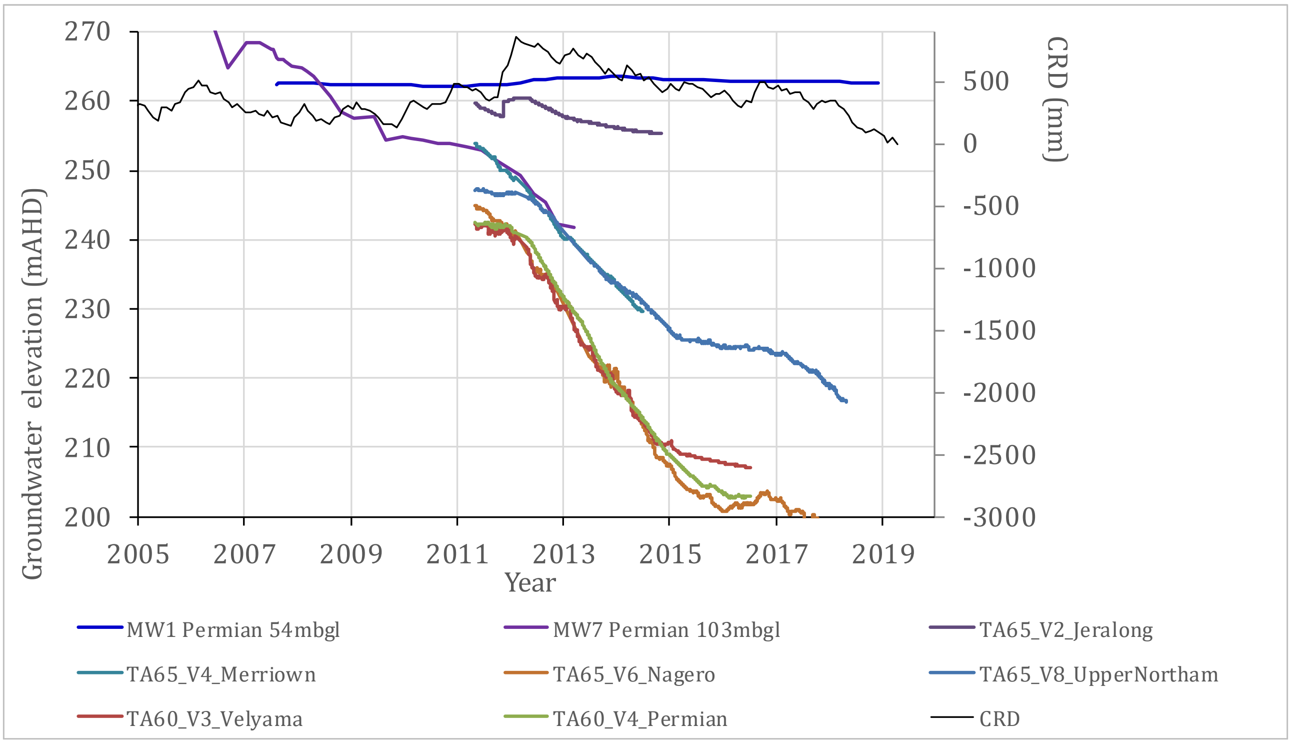


Figure 6.14 Selected Permian hydrographs – Tarrawonga Mine

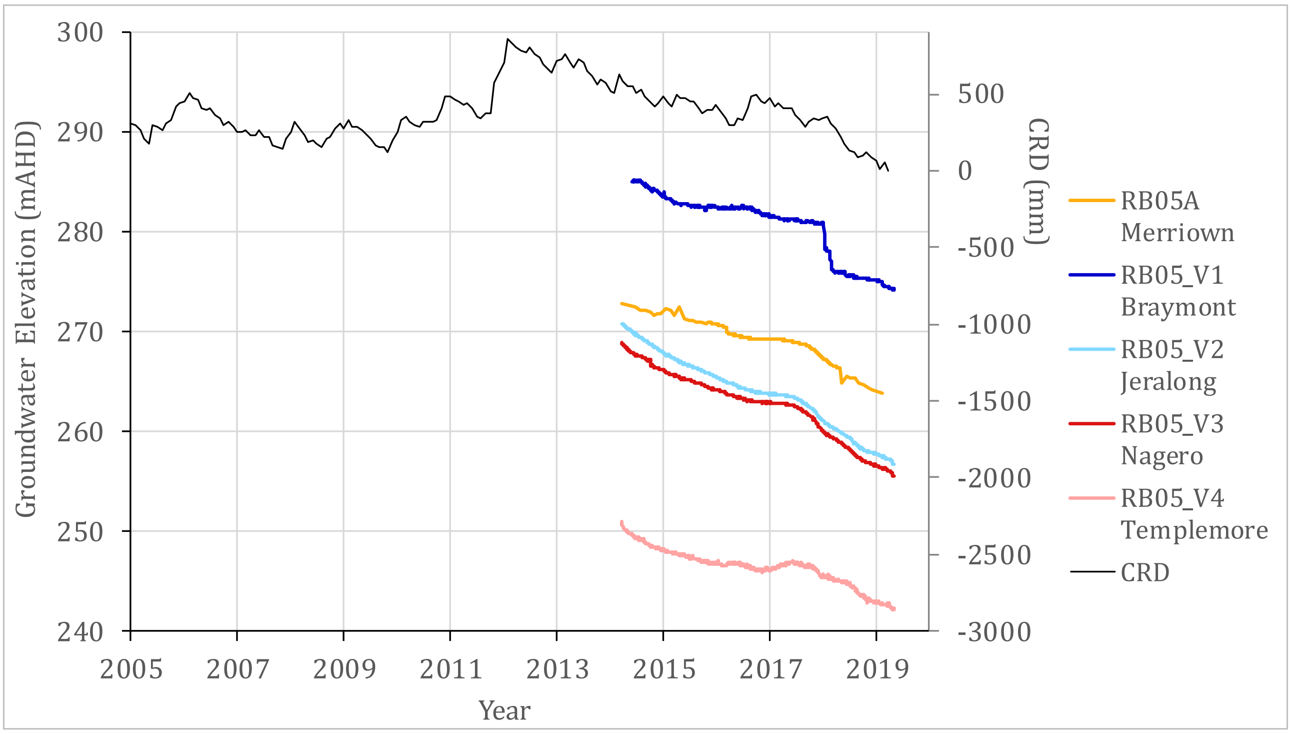


Figure 6.15 Multilevel VWP RB05 hydrographs

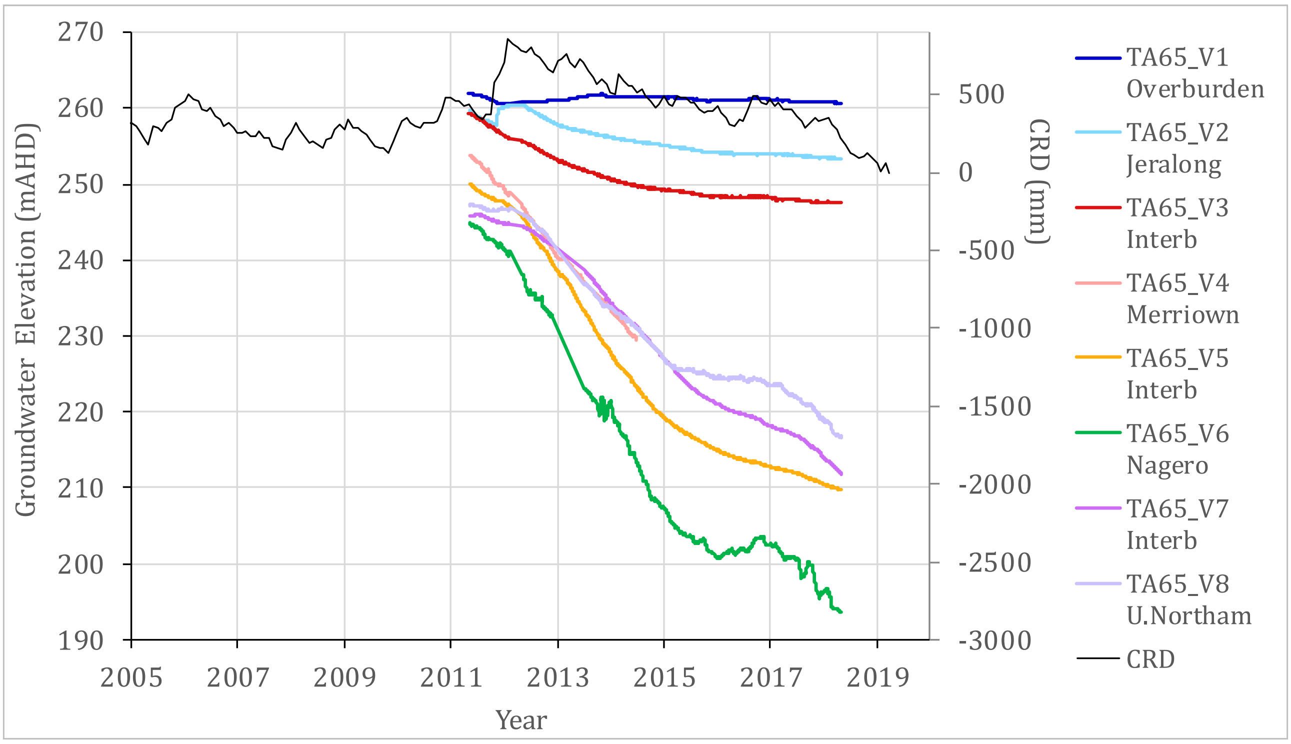
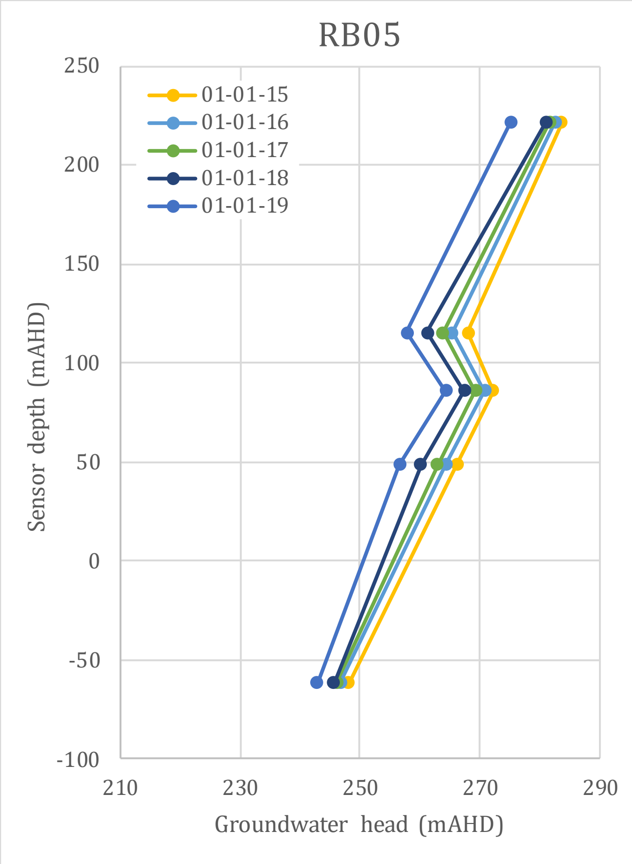


Figure 6.16 Multilevel VWP TA65 hydrographs



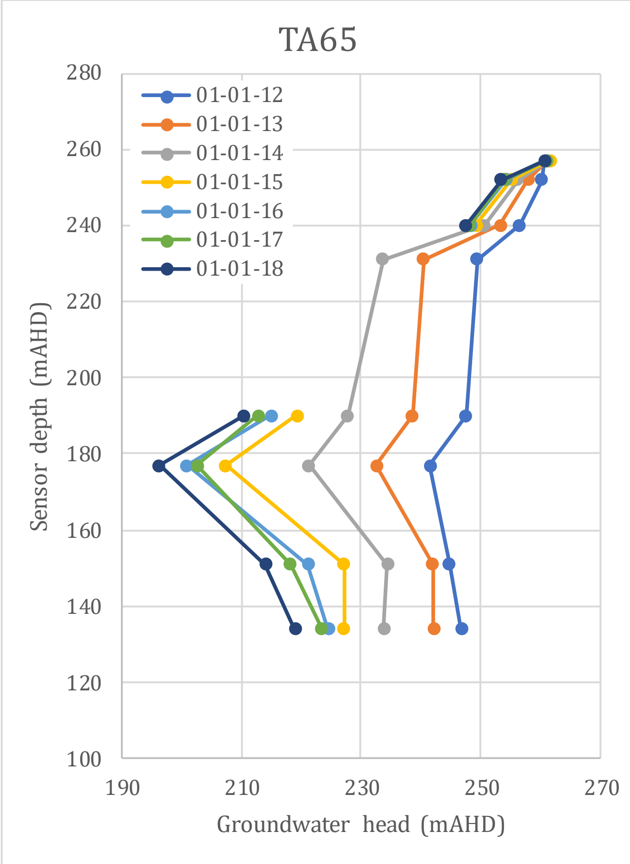


Figure 6.17 Annual groundwater head pressures at two multi-level sites

6.5.3 Boggabri Volcanics water level trends

Groundwater levels in the monitoring bores located in the higher areas of the Boggabri Ridge (REG3, REG4, REG5A and REG13) have shown only small water level fluctuations of ~0.5 m to date. As the bores were installed in 2015 there is only a short dataset to analyse, with late 2016 onwards being a period of below average rainfall. There are possibly small increases in water level observed after the high rainfall event in mid-2016, but more data from average rainfall years will be needed to confirm whether the bores exhibit seasonal responses. Despite the ongoing drought, the observed water levels have not fallen significantly. Coupled with the small response to the rainfall event in 2016, this suggests that the Boggabri Volcanics typically have a low recharge rate and are of low permeability along the ridgeline.

Greater fluctuations are observed at the sites of lower elevations. From north to south these are:

- REG3 – located close to the end of Back Creek. The bore is close to a shallow alluvial bore and is likely responding to nearby abstractions.
- REG6 – located to the west of Boggabri Mine at the end of the alluvial 'gulf' or 'tongue'. Water levels had been stable until early 2018, after which levels have fallen by ~ 2 m. This is possibly related to the drought and could either reflect a natural fall in level or an increase in nearby groundwater abstraction. Bores closer to the mines have not responded as strongly as REG6.
- REG14 – located south of Bollol Creek and adjacent to a WaterNSW nested alluvial bore. The REG14 bore exhibits a similar abstraction response to the deeper piezometers at the alluvial site.

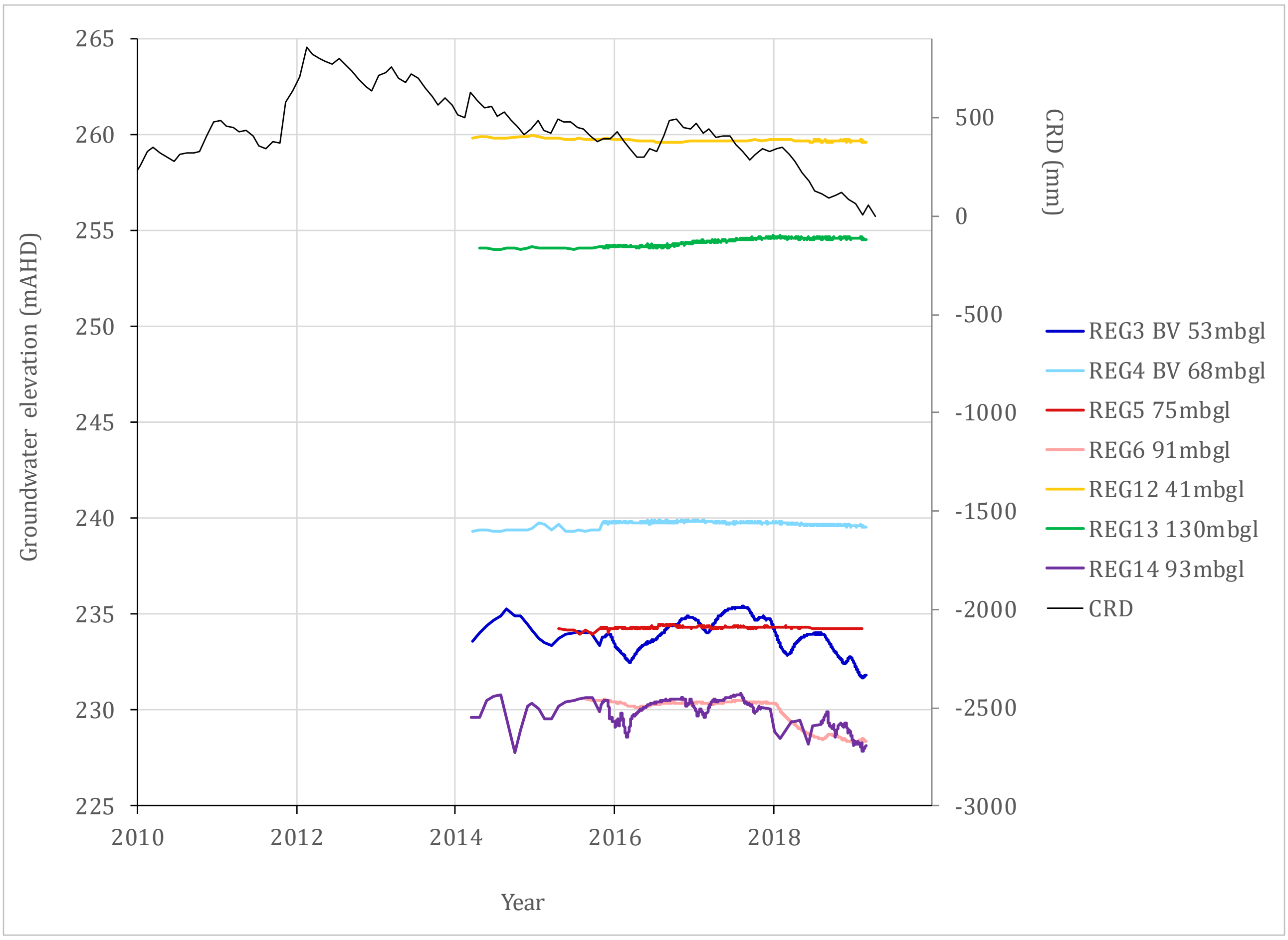


Figure 6.18 Boggabri Volcanics hydrographs

6.5.4 Alluvial connectivity to coal measures

Multi-level monitoring that extends through both the alluvium and the coal measures is limited to three sites within the study area (Figure 6.1), namely:

- REG1/GW967138, to the north of the BTM Complex, adjacent to Maules Creek;
- REG2/GW041027, to the north of the BTM Complex, adjacent to Maules Creek, possibly within fault zone material; and
- REG7/REG7A, approximately 3.5 km south of Goonbri Mountain.

Vertical differences in groundwater levels at REG1/GW967138 (Figure 6.19) strongly indicate a downwards hydraulic gradient from alluvium to the underlying coal seams. Monitoring indicates this hydraulic gradient was established prior to the Maules Creek Mine commencing operations. Responses to rainfall are visible in the alluvium and upper coal seams, with the magnitude of this response reducing at depth. Water levels in REG2/GW041027 (Figure 6.20) also show a downwards hydraulic gradient, although the coal measures at this location may potentially be influenced by faulting.

Groundwater level data recorded in REG7/REG7A (Figure 6.21) is not consistent with trends observed in the other two sites. At this location the groundwater level within the alluvium is lower than the upper coal seams and there is an upward hydraulic gradient in two coal seams. The groundwater level measured within the upper coal seam appears to indicate the potential for artesian groundwater conditions. There is some uncertainty in the validity of the hydraulic gradients at this site.

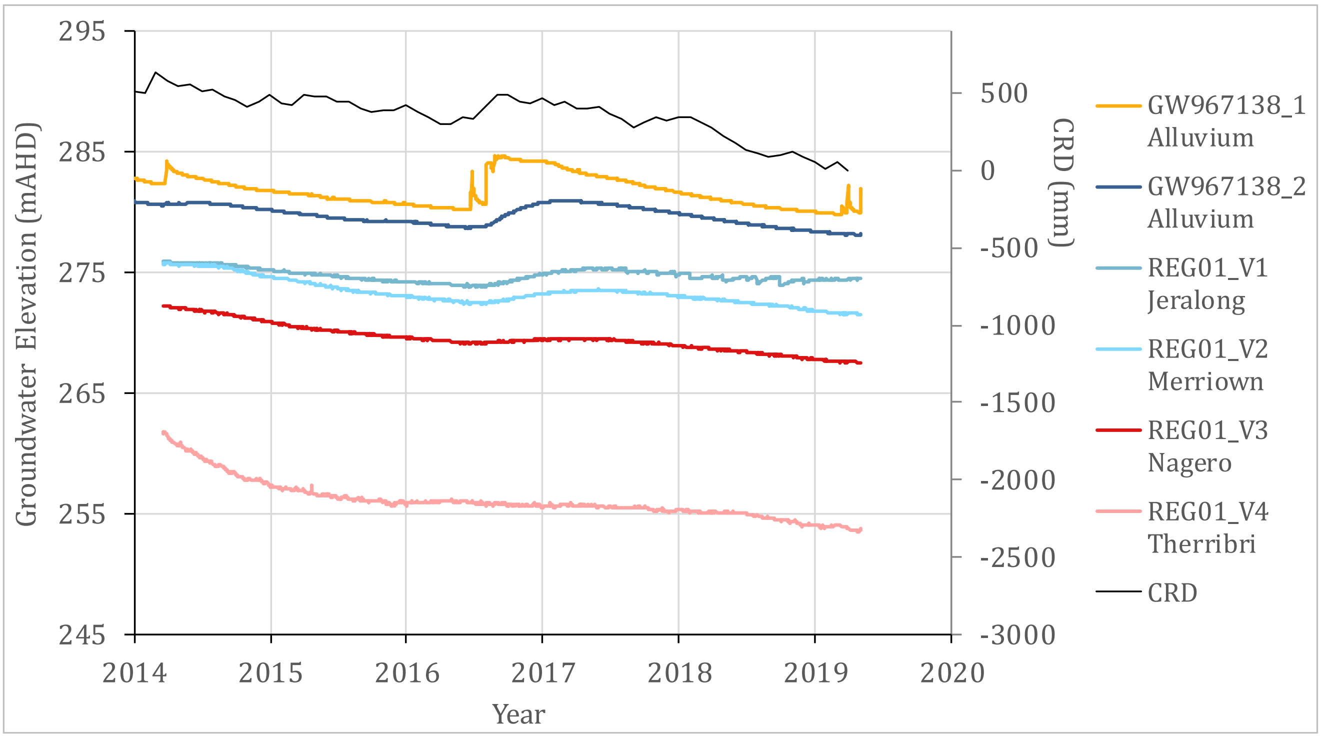


Figure 6.19 REG1/GW967138 hydrograph

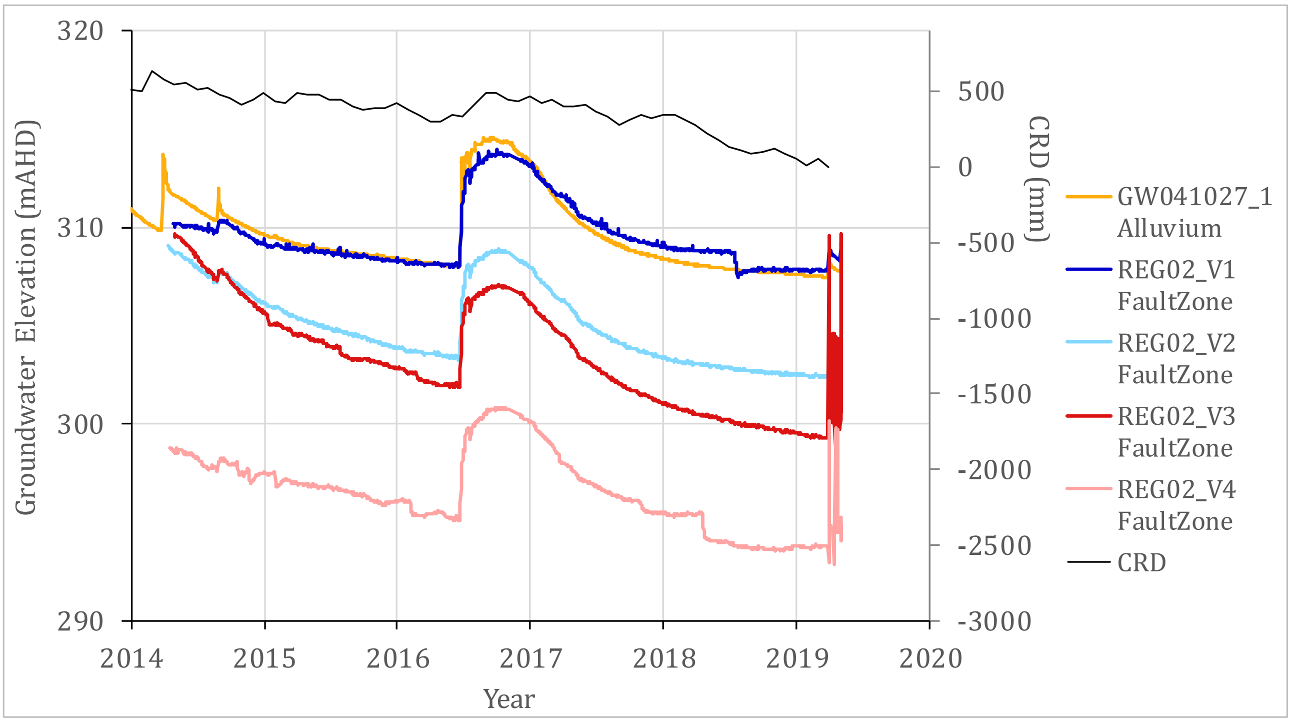


Figure 6.20 REG2/GW041027 hydrograph

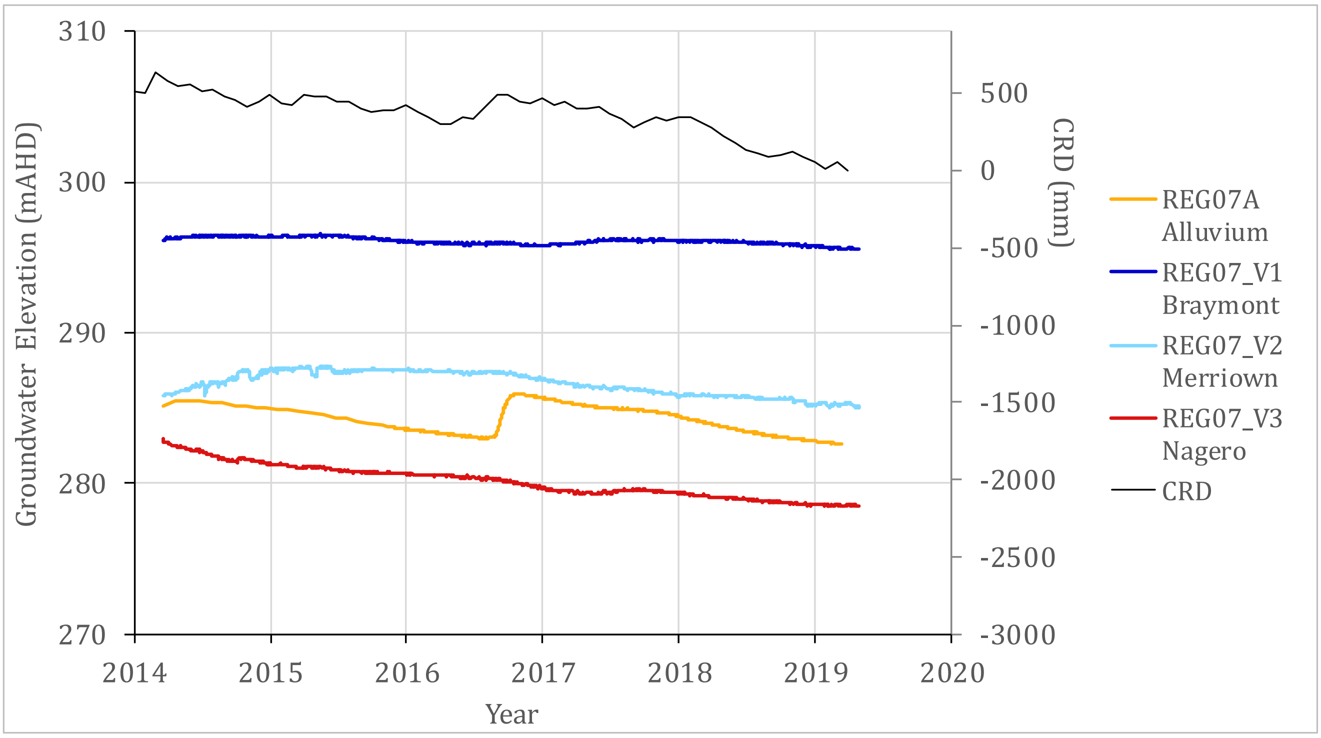


Figure 6.21 REG7/REG7A hydrograph

6.5.5 Surface water connectivity to groundwater

There are three groups of nested bores and/or VWPs along Maules Creek. From east to west these are:

- Thornfield Crossing - GW041027 (single)/REG2;
- Green Gully - GW967138 (paired)/REG1; and
- Elfin Crossing - GW967138 (paired).

There is also a surface water gauging station at the Elfin Crossing site, known as Avoca East (WaterNSW site ID 419051).

Reviewing the groundwater levels and hydraulic gradients at these three locations in relation to ground surface and the streamflow (where available) allows an understanding of connectivity between the creek and groundwater to be developed. Where groundwater levels are below the creek bed, or there is a vertical downwards gradient, the creek will be losing water into the water table. Where groundwater levels are above the creek bed, and there is a vertically upward hydraulic gradient, then the creek will gain water from groundwater. Plots of the levels are provided as Figure 6.22 to Figure 6.24. DEM derived estimates of creek bed elevations have been added for Thornfield Crossing and Green Gully. For the Avoca East site, the cease to flow level is as provided by WaterNSW. Groundwater levels for the 'GW' bores were also taken from the WaterNSW website.

Plots indicate that Maules Creek is only gaining from groundwater during level peaks, which are generally short-term (creek bed elevations sourced from 5 m NSW Government DEM). Most of the time, data shows that surface water is lost to underlying sediments. The shallowest groundwater monitoring sites at each location are typically the most responsive to water level changes, presumably as a result of rainfall runoff entering the creek channels, with the deeper responses being dampened in both magnitude and time. The magnitude of water level changes after significant rainfall are greatest at Thornfield Crossing and reduce downstream. The rapid responses seen in the shallowest groundwater monitoring bores indicates that the shallow alluvium is highly connected to surface water flows in the creek.

There are strong downward gradients present from shallow depths at both the Green Gully and Elfin Crossing sites. The shallow vertical gradient is not as strong at Thornfield Crossing, although the VWP responses at this site are atypical for the area, possibly due to the bore being located in fractured fault zone material.

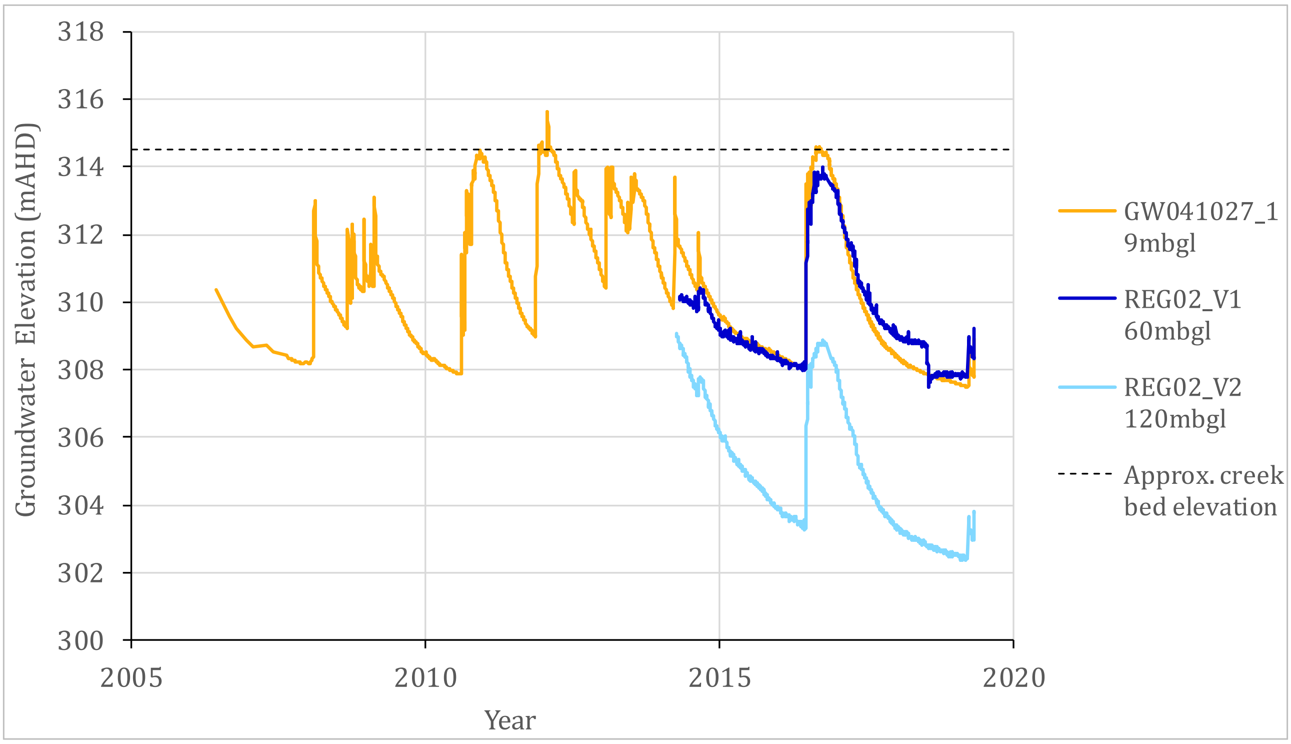


Figure 6.22 Observed water levels at Thornfield Crossing

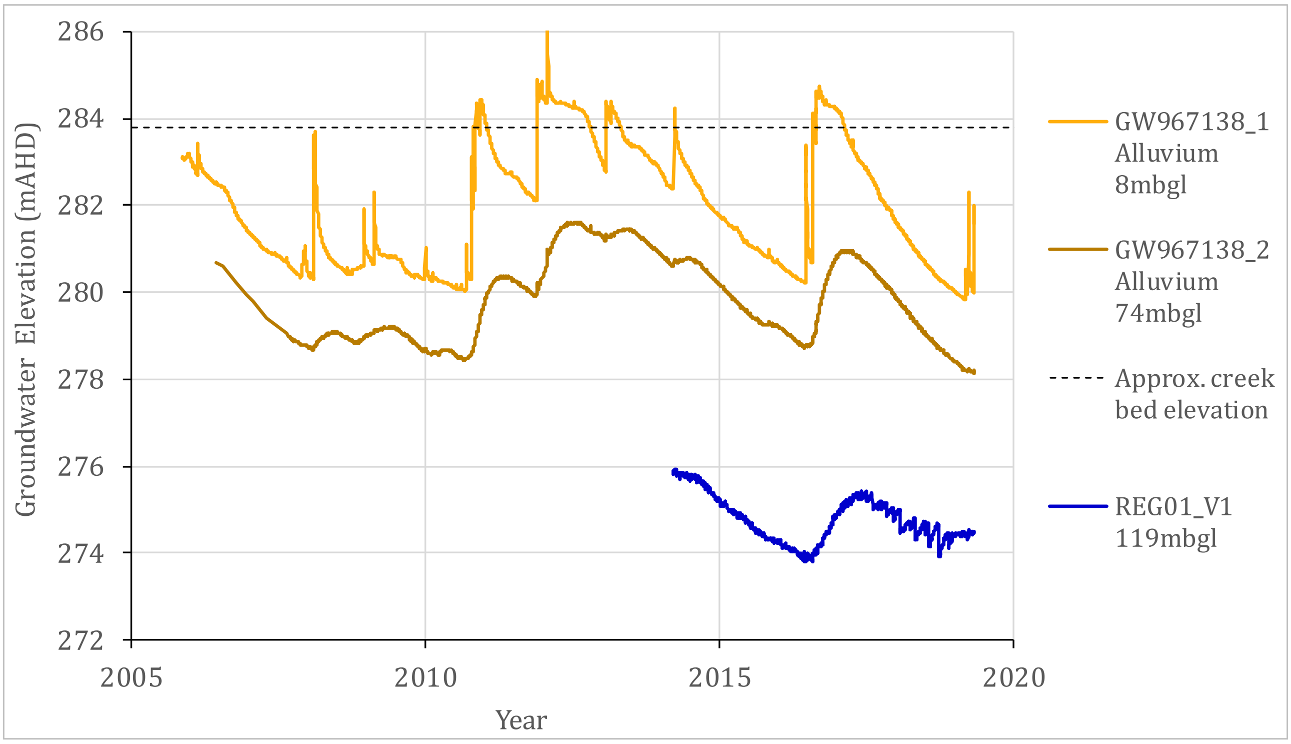


Figure 6.23 Observed water levels at Green Gully

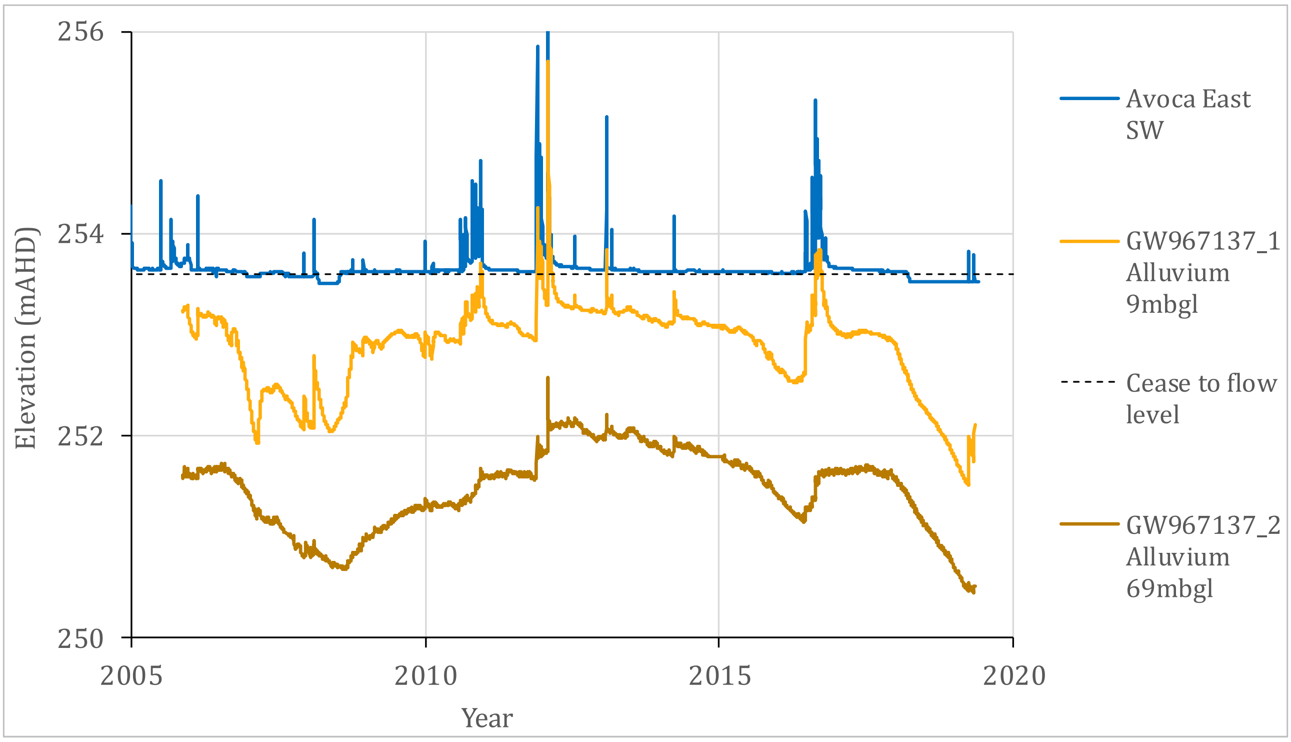


Figure 6.24 Observed water levels at Elfin Crossing

Preliminary results of field sampling completed along Maules Creek in 2006, from the lower reaches of Horsearm Creek to the Namoi River, interpreted a horizontal flow at Elfin Crossing and a downwards gradient further downstream (Anderson & Acworth 2006). The flowing section of the creek also reduced by 4 km between field visits in August and October 2006. Temperature variations in the creek during August 2006 suggested that around the confluence of Horsearm Creek and Maules Creek there was groundwater inflow to the creek. Conversely, in the lower reaches of Maules Creek, there was no evidence of groundwater. Electrical conductivity sampling of the surface water suggested that in August 2006 the majority of surface flow came from the Horsearm Creek (92%), with only 8% from Upper Maules Creek.

A further study at Elfin Crossing by UNSW in 2008 (Rau et al. 2008) concluded that at the time of data collection, the stream was losing water to the streambed at Elfin Crossing. UNSW has recently initiated further research into stream bed recharge occurring within the Maules Creek catchment. The project has included installation of additional surface water and groundwater instrumentation, that will provide datasets for future research and analysis.

A review of the WaterNSW data for Avoca East suggests that there has been less flow observed in the creek since around the year 2000 (Figure 6.25) which precedes mining activities in the catchment. When the flow duration curves are compared for the early and later years there is a clear difference in the percentage of time that the creek has been dry (Figure 6.26). The average flows have also been lower, although has been little change to the highest flows recorded. It appears that falling groundwater levels, which are likely attributed to increased irrigation abstraction in the area, have reduced baseflow at Elfin Crossing.

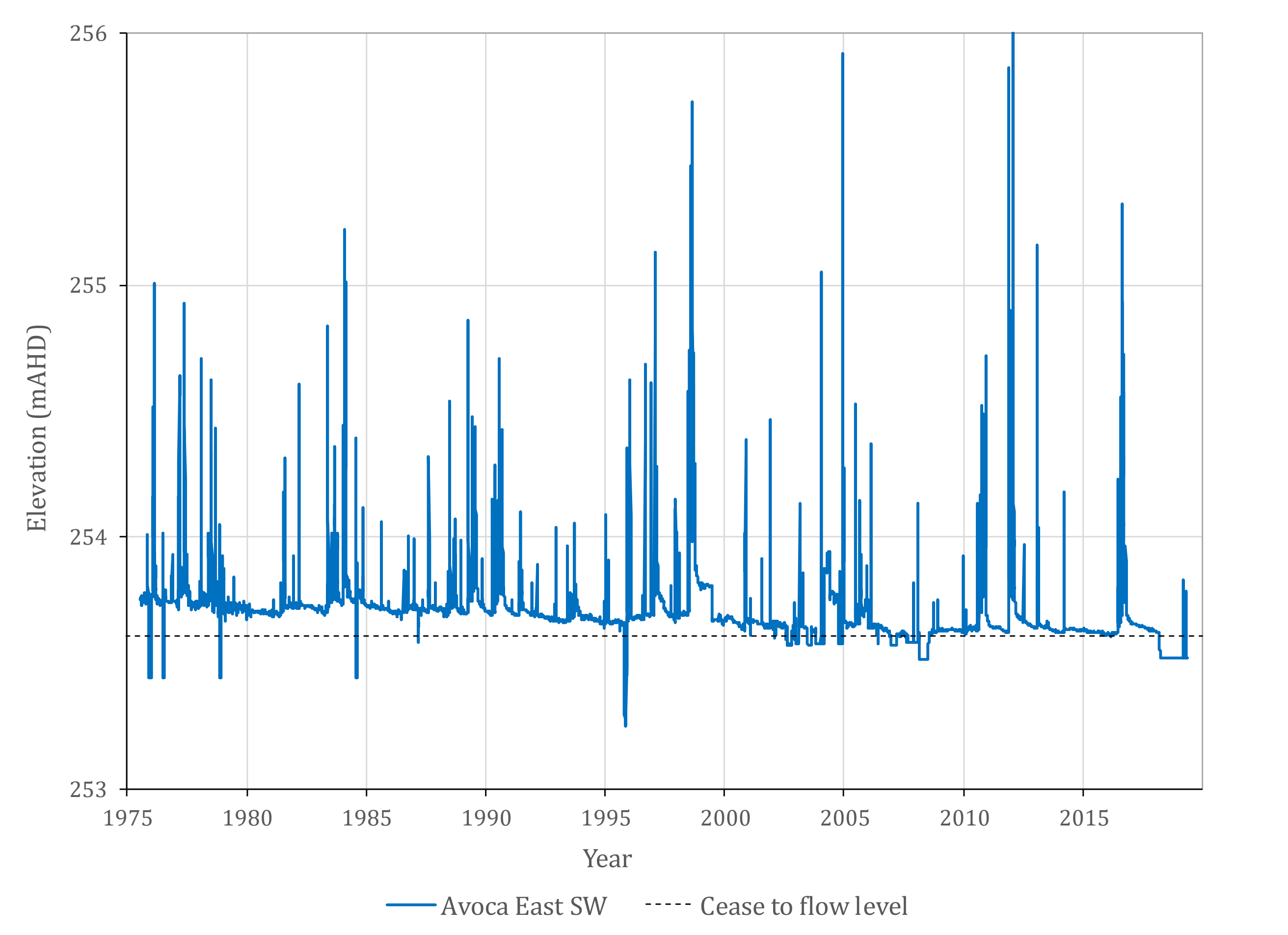


Figure 6.25 Maules Creek surface water flow at Avoca East

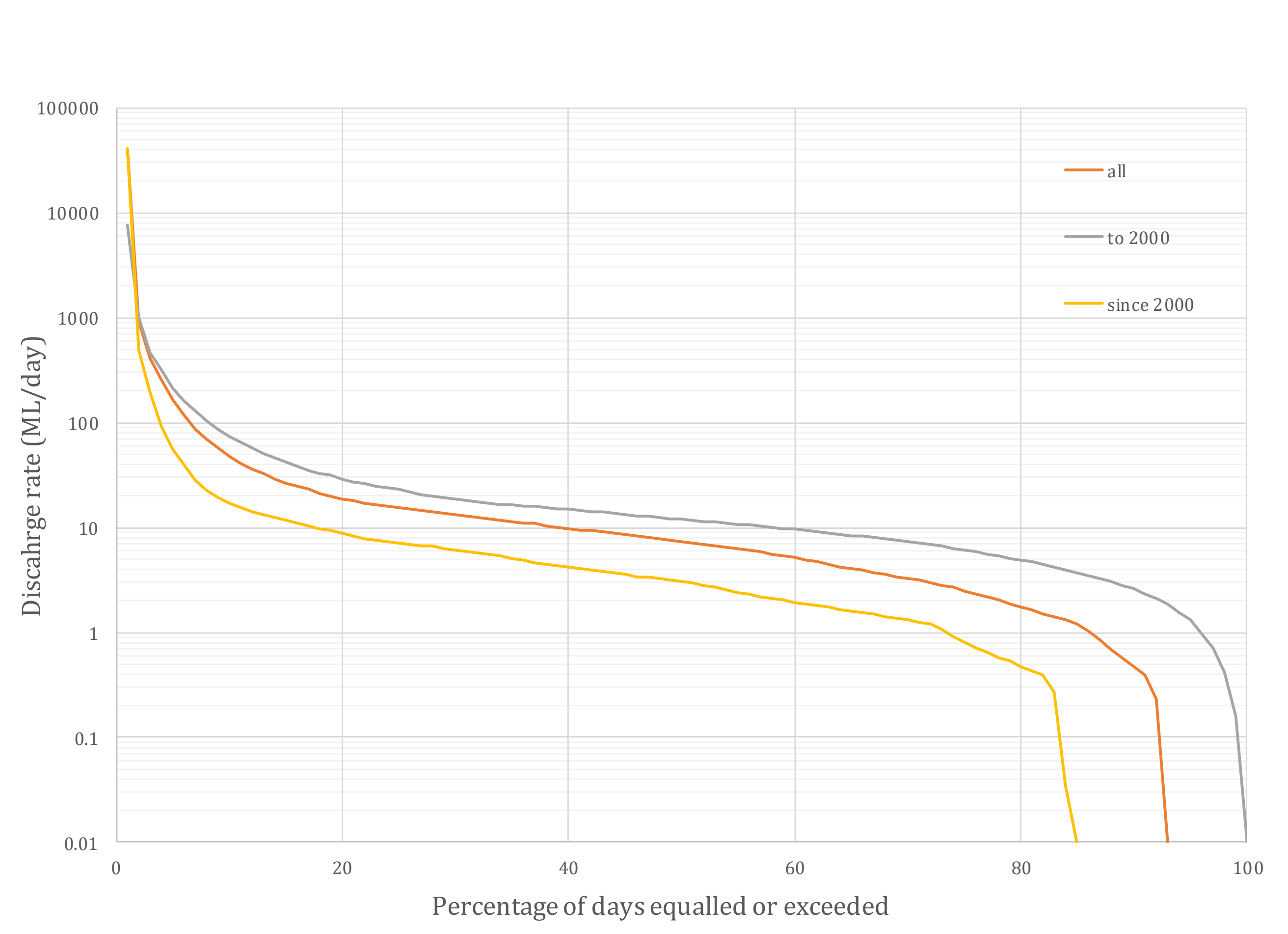


Figure 6.26 Flow duration curve for Avoca East (shows less flow since 2000)

WaterNSW have a river gauging station on the Namoi River at Boggabri (Station ID 418012). The river stage is compared to nearby shallow alluvial groundwater levels in Figure 6.27. Water levels in the river are highly variable and have a larger range than the groundwater bores. Water levels in the shallow bores were typically over 1 m higher than the river stage between the start of the record and approximately 2005. Since that time the groundwater and river stage have been very similar. It should be noted that the Namoi River has been regulated since the 1960's, when Keepit Dam was commissioned for irrigation storage and flood mitigation. However, the basal river stage appears to have remained relatively stable over the record while groundwater levels that have fallen. The reduced hydraulic gradient between the groundwater and the river will result in a smaller groundwater discharge into the river than is likely to have been seen historically. On occasions where the river stage is higher than the groundwater elevation, there is the potential for the river to lose water into the alluvial aquifer. This can be observed as rising alluvial water levels that coincide with a spike in the river stage. Depending on the time of year, the alluvial rise could also be related to direct rainfall-recharge onto the aquifer, and/or a reduction in irrigation abstraction demand following heavy rainfall events.

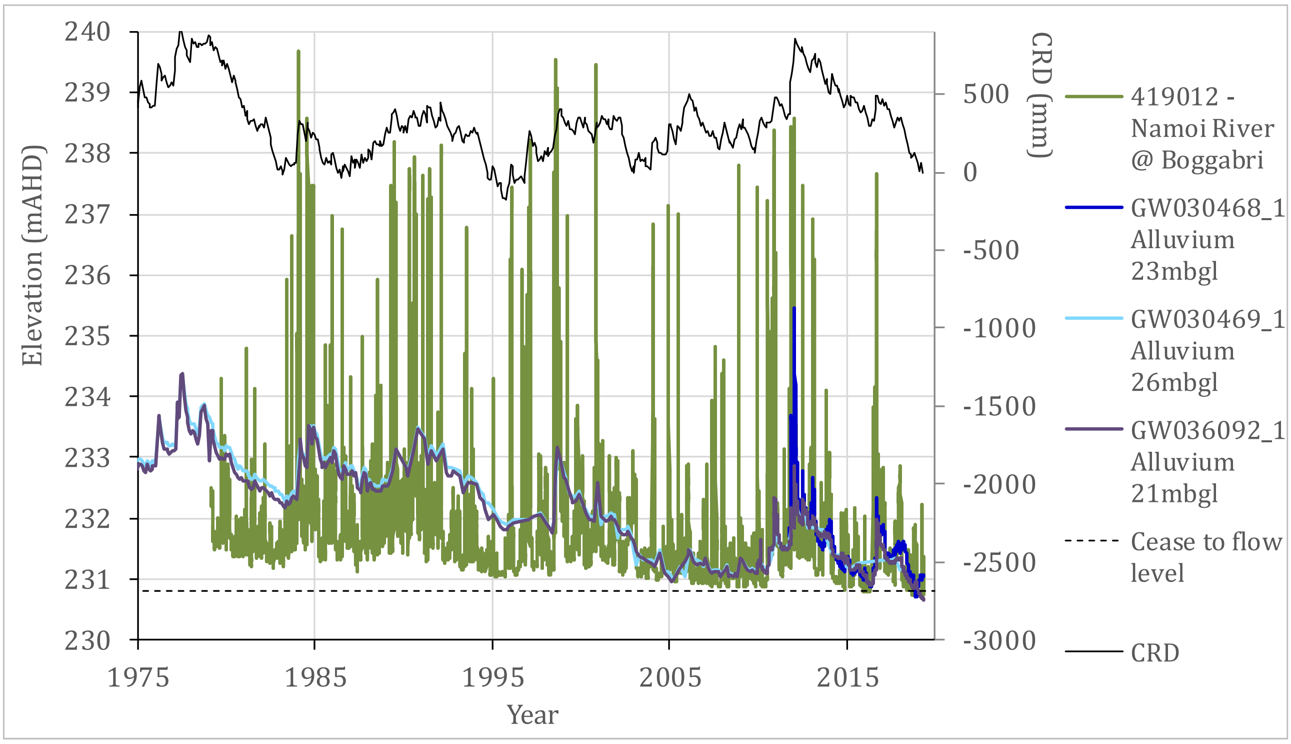


Figure 6.27 Namoi River and groundwater levels at Boggabri

6.6 Groundwater quality

Collectively, operators of the BTM mining complex have undertaken groundwater quality monitoring at 58 locations, with the earliest data collected in June 2005. The historical monitoring network is comprised of groundwater bores that were installed into a variety of lithologies, which include alluvium, coal seams of the Maules Creek Formation, interburden of the Maules Creek Formation and basement volcanics. Summary statistics for electrical conductivity (EC) and pH are presented below in Table 6.4. The spatial distribution of EC and pH is also shown in Figure 6.28 and Figure 6.29 (respectively), where each monitoring location's most recent data is presented.

Table 6.4 Summary statistics – pH and EC

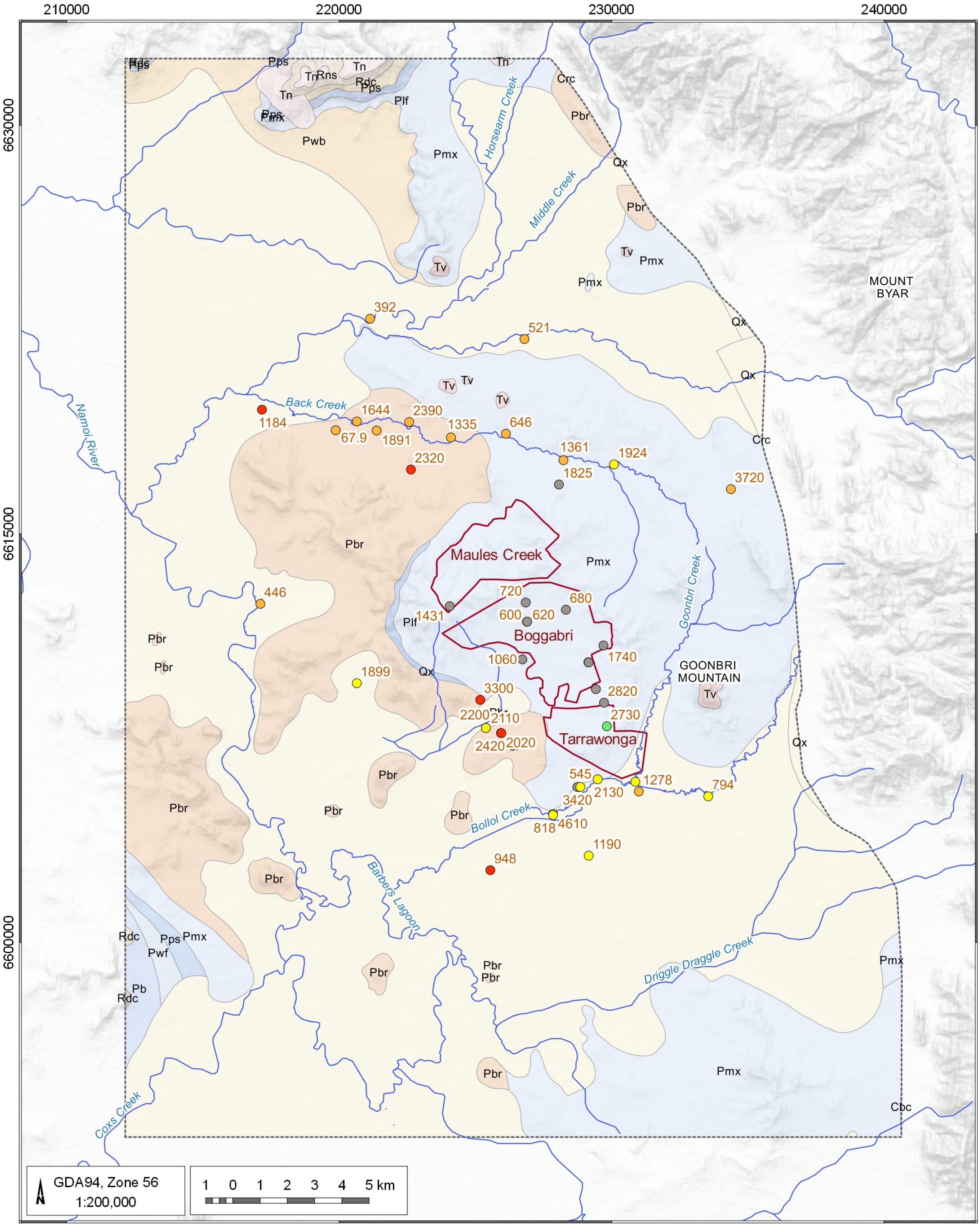
Screened lithology	Coal seams	Alluvium	Volcanics	Interburden
pH				
Min	6.20	6.36	5.72	7.20
Max	9.96	9.10	9.63	8.32
Median	7.20	7.30	7.49	7.40
Mean	7.30	7.34	7.45	7.47
Standard deviation	0.64	0.35	0.55	0.26
Count	285	317	216	17
EC				
Min	1*	215	786	2,010
Max	5,470	6,900	3,970	2,950
Median	1,009	1,290	2,050	2,310
Mean	1,552	1,765	2,142	2,381
Standard deviation	1,006	1,302	788	284
Count	275	302	220	15

Notes: Analysis was completed omitting data from grout impacted bores IBC2104, MAC1279, MAC1280, RB02A, REG4, REG6 and REG13; and

* Data considered erroneous.

Salinity has the main influence on beneficial use of groundwater. Salinity generally correlates to EC (which is simple to measure), so salinity was categorised based on the following EC ranges for groundwater (FAO 2013):

- Fresh water <700 µS/cm
- Brackish (slightly saline) 700 to 2,000 µS/cm
- Moderately saline 2,000 to 10,000 µS/cm
- Saline 10,000 to 25,000 µS/cm
- Highly saline 25,000 to 45,000 µS/cm
- Brine >45,000 µS/cm



LEGEND

Drainage
Maximum open cut footprint
Study area

Mine monitoring bores

- Alluvium
- Coal seam
- Interburden
- Volcanics
- Unknown

1190 : EC (µS/cm)

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tn - Tertiary Nandewar Volcanics
- Tv - Tertiary Volcanics
- Rns - Napperby Formation
- Rdc - Digby Formation
- Pb - Pamboola Formation
- Pwf - Watermark Formation
- Pps - Porcupine Formation
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pwb - Werrie Basalt
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Crc - Rocky Creek Conglomerate

BTM model update (G1850P)

Spatial distribution of EC (mine monitoring)

AGE

DATE 23/06/2021

FIGURE No: **6.28**

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Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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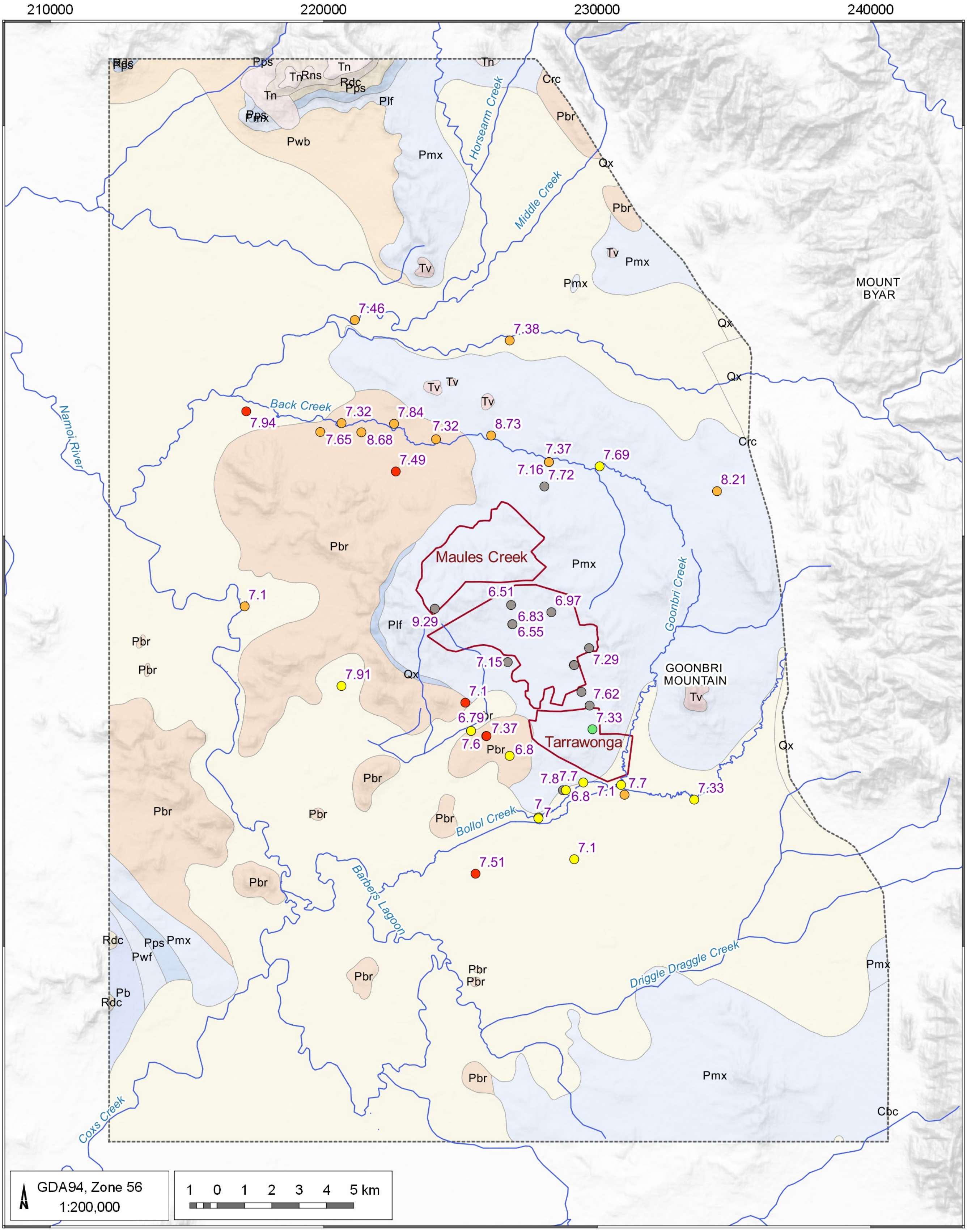

LEGEND

- Drainage
- Maximum open cut footprint
- Study area

Mine monitoring bores

- Alluvium
- Coal seam
- Interburden
- Volcanics
- Unknown

7.1 : pH

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tn - Tertiary Nandewar Volcanics
- Tv - Tertiary Volcanics
- Rns - Napperby Formation
- Rdc - Digby Formation
- Pb - Pamboola Formation
- Pwf - Watermark Formation
- Pps - Porcupine Formation
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- Plf - Leard Formation
- Pwb - Werrie Basalt
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Crc - Rocky Creek Conglomerate

BTM model update (G1850P)

Spatial distribution of pH (mine monitoring)

AGE

DATE 23/06/2021

FIGURE No: **6.29**

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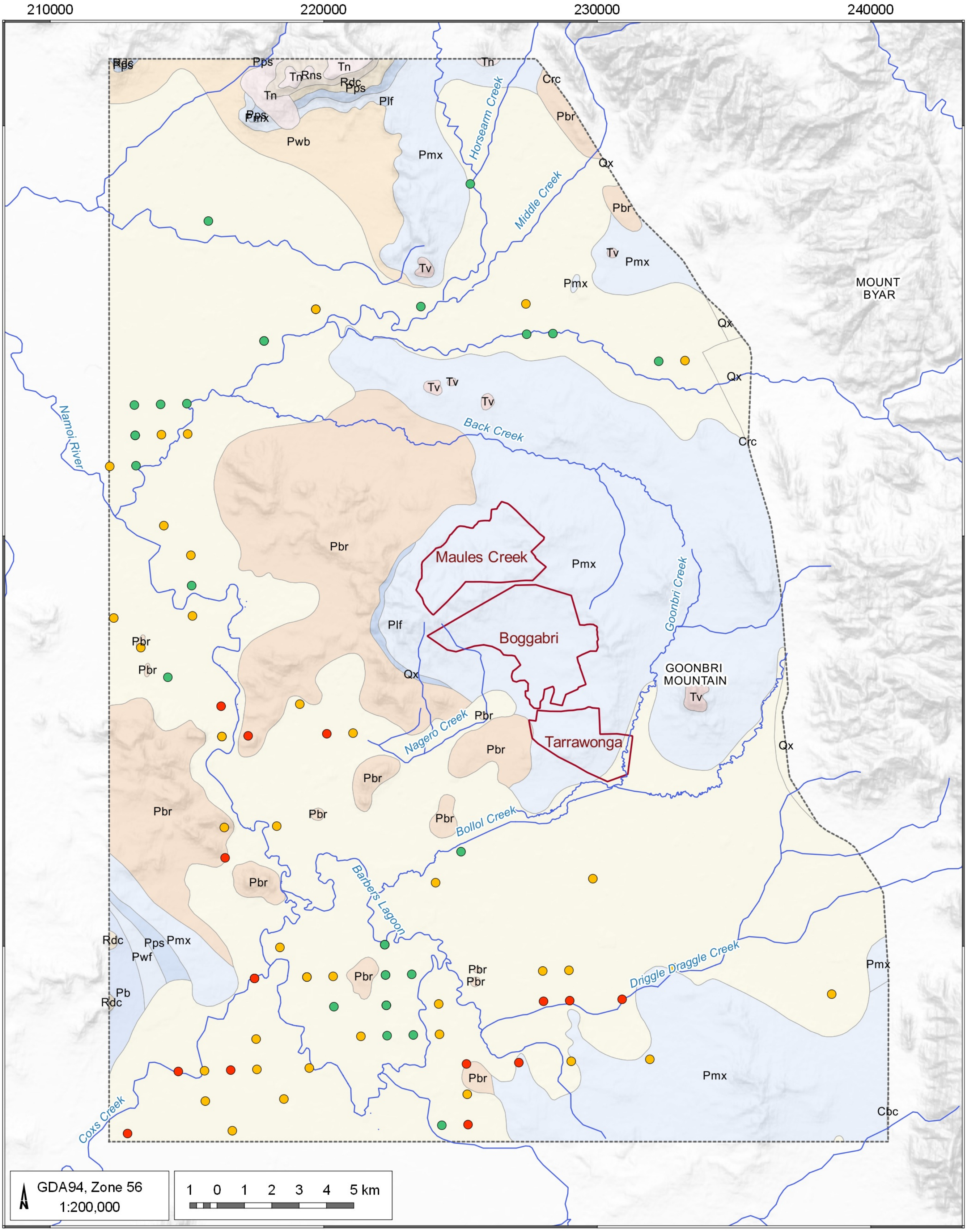
6.6.1 Alluvium

Data sourced from each mine's groundwater monitoring network (Table 6.4) indicates that alluvial groundwater is generally brackish (median EC of 1,290 µS/cm), with a neutral pH (median of 7.30). The high variability of EC is likely attributed to changes in recharge rates and lithology (discussed in Section 5.3), where salt storage in finer grained lithologies is relatively high (CSIRO 2007).

These findings are generally consistent with bioregional assessment data, where regional groundwater quality of the Namoi sub-region is typified by a median EC value of 1,013 µS/cm over the entire region. (Pena-Arancibia et al. 2016). Within the study area, government alluvial bores range from fresh to moderately saline (Figure 6.30), noting that:

- the freshest groundwater is generally found in bores adjacent to the Namoi River, Barbers Lagoon and Maules Creek; and
- away from these drainage features and adjacent to the Namoi River constriction, salinity is generally higher.



LEGEND

- Drainage
- Maximum open cut footprint
- Study area

Government alluvial bores

- Fresh (0 - 700 µS/cm)
- Brackish (700 – 2,000 µS/cm)
- Moderately saline (2,000 – 10,000 µS/cm)

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tn - Tertiary Nandewar Volcanics
- Tv - Tertiary Volcanics
- Rns - Napperby Formation
- Rdc - Digby Formation
- Pb - Pamboola Formation
- Pwf - Watermark Formation
- Pps - Porcupine Formation
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pwb - Werrie Basalt
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Crc - Rocky Creek Conglomerate

BTM model update (G1850P)

Salinity of alluvium in study area (Namoi bioregional assessment)

AGE

DATE 23/06/2021

FIGURE No: **6.30**

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6.6.2 Permian coal measures

Monitoring data demonstrates that salinity within the Maules Creek Formation is variable, with brackish coal seam groundwater (median EC of 1,009 µS/cm) and moderately saline interburden groundwater (median EC of 2,310 µS/cm). Groundwater pH is generally consistent between the coal seams and the interburden, with a median value of 7.30 and 7.40 respectively.

Locally, groundwater within the Permian coal seams is generally fresher than that of the alluvium. As discussed in Section 6.6.1, the higher median EC of the alluvium is likely attributed to variances in lithology. However, the salinity of coal seam groundwater is still relatively low and suggests that the outcropping coal seams readily receive recharge in the ridge area.

6.6.3 Boggabri Volcanics

Data sourced from each mine's groundwater monitoring network (Table 6.4) indicates that groundwater of the Boggabri Volcanics is moderately saline, with a median EC of 2,050 µS/cm. Groundwater pH generally typifies neutral conditions, with a median pH of 7.49. However, the wide-spread of pH data demonstrates that in part, this groundwater may be acidic or alkaline.

6.7 Mining groundwater use

6.7.1 Passive take

The mines within the BTM Complex do not directly intersect any productive aquifers, and therefore the volume of groundwater entering the mining area is not large compared to mining operations that operate in more permeable and porous environments. Within the BTM Complex, groundwater is not problematic for mining activities and advanced dewatering with bores prior to mining is not required. The groundwater intersected in the mining areas is commonly evident only as damp evaporating seeps in active mine faces. The volume of water taken from groundwater ingress is impossible to directly measure because it is not collected at a single point, and is subject to a range of processes including evaporation, mixing with surface runoff/rainfall and adhering to mined materials. There are two main methods which can be used to estimate the volume of groundwater intercepted during mining: firstly, groundwater flow models (numerical and analytical) that attempt to represent the groundwater flow processes directly; and secondly, water balance models that indirectly estimate the volume of groundwater entering mining areas.

The mines within the BTM Complex have utilised both numerical groundwater models and water balance models to estimate the volume of groundwater intercepted by mining. These estimates are documented in the annual reviews prepared for each mine and are summarised in the sections below.

6.7.1.1 Boggabri

The annual reviews for the Boggabri Mine provide estimates of groundwater inflow to the mining areas for the calendar years from 2014 to 2019 as follows:

- 2014: 0.69 ML/day to 0.75 ML/day (224 – 274 ML/year);
- 2015: 0.51 ML/day to 0.57 ML/day (186 – 208 ML/year);
- 2016: 0.20 ML/day to 0.26 ML/day (73.2 - 95.2 ML/year);
- 2017: 0.82 ML/day to 0.88 ML/day (299.3 – 321.2 ML/year);
- 2018: 0.96 ML/day to 1.02 ML/day (350.4 – 372.3 ML/year); and
- 2019: 0.55 ML/day (199.1ML/year).

The Annual Reviews indicate the average volume of water pumped from the mining area over the reporting period, which is comprised of groundwater and rainfall/runoff, ranged from 4.46 ML/day (1,628 ML/year) to 3.47 ML/day (1,267 ML/year). This indicates the groundwater inflows were generally a small portion of the site water balance.

6.7.1.2 Tarrawonga

The Tarrawonga Mine also reports water takes in its annual reviews. The total volumes pumped from the pit have not always been separated into the groundwater and surface water components. A summary of the estimates provided in annual reviews from 2014/2015 to 2018 are as follows:

- 2014/15: No inflow estimates were provided other than commenting that the majority of water inflows to the open pit were from surface water;
- 2015/16: <0.5 ML/day (~224.5 ML/year from groundwater and in-pit surface water runoff);
- 2016: <0.5 ML/day (~137.6 ML/year from groundwater and in-pit surface water runoff);
- 2017: 0.5 ML/day (183 ML/year) groundwater for the period Mar 2017 to Mar 2018;
- 2018: 0.5 ML/day (183 ML/year) groundwater for the period Jan 2018 to Dec 2018; and
- 2019: 0.2 ML/day (58 ML/year) from groundwater.

6.7.1.3 Maules Creek

The Maules Creek Mine only intercepted the regional groundwater table in 2018. Prior to then there had only been small seepages observed from 2016 when the mine reached the Braymont coal seam. These seepages were removed from the pit through in-pit evaporation, or entrainment within interburden material with no active pumping required. The volumes of groundwater estimated to have been removed from the pit from 2015 to 2018 are as follows:

- 2015: negligible (<5 ML/year);
- 2016: negligible (<10 ML/year);
- 2017: negligible (<10 ML/year);
- 2018: 1.58 ML/day (576 ML/year); and
- 2019: 0.64 ML/day (233 ML/year).

6.7.1.4 Predicted inflows

The predicted inflows from the 2014 and 2018 groundwater models for the current period are compared to the estimates from the water balance models in Table 6.5 below. When comparing these models it is important to understand the differences. The water balance model is a back calculation of groundwater inflow, whereas the numerical model is a forward prediction without the benefit of inflow measurements.

The groundwater models both predict that Boggabri will have the highest inflow, and Tarrawonga the least inflow. There is a good agreement between the groundwater and water balance modelled inflows for Tarrawonga. For Boggabri the predicted groundwater model inflows are slightly higher than those calculated by the water balance, and for Maules Creek the predicted groundwater model inflows are lower than those estimated from the water balance model. However, total inflows across all three mines are similar.

Table 6.5 Comparison of observed and predicted groundwater inflows

Site	Numerical model forward predicted inflow (ML/day)		Water balance model back calculation (ML/day)
	2014 model	2018 model	
Boggabri	1 – 1.5	1.6	0.2 – 1.0
Tarrawonga	0 – 0.05	0.4	<0.5 – 0.5
Maules Creek	0.1 - 0.7	0.8	<0.01 – 1.6

When interpreting the results in Table 6.5 it is important to note that the groundwater model represents groundwater removed by pumping, water that evaporates from the highwall, and water bound with coal and spoil. In contrast the water balance method only estimates the volume of water that flows into the mine water circuit. Both methods are therefore not directly comparable due to differing underlying assumptions. Whilst estimates are different, the agreement is considered relatively good given the differences in the methodologies.

6.7.2 Borefield abstraction

In addition to passive water take as a result of mining below the water table, Boggabri is also licensed to take water from supply bores located to the west of the mine, in Zone 4 of the Upper Namoi Groundwater Source.

The Boggabri borefield comprises two primary abstraction bores and backups and began operation in the 2017/2018 water year. The bores are licensed to abstract up to 2,544 ML/year from the alluvial groundwater system. The totals abstracted from the two bores during the two most recent water years they have been licensed are:

- 2017/2018 – 464 ML; and
- 2018/2019 – ~1,880 ML to late April 2019, with two months yet to abstract in the water year. At current average monthly rates, the total abstraction will remain within the licensed volume.

6.8 Groundwater dependent assets

Information on potential groundwater dependent assets is summarised below.

6.8.1 Bioregional assessment – Namoi subregion water dependent assets

In the context of bioregional assessments, water-dependent assets are defined as *'an asset potentially impacted by changes in groundwater and/or surface water due to coal or coal seam gas development. Some ecological assets solely depend on rainfall and will not be considered as water dependent if evidence does not support a linkage to groundwater or surface water'* (O'Grady et al 2015). Assets can be classified for economic, ecological, or sociocultural.

In the Namoi sub-region ecological water dependent assets are classified into three subgroups (O'Grady et al. 2015):

- 'Surface water feature' – 1,142 assets;
- 'Groundwater feature (subsurface)' – 33 assets; and
- 'Vegetation' – 509 assets, of which:
  - Groundwater-dependent ecosystems (GDE) – 442 assets; and
  - Habitat (potential species distribution) – 67 assets.

Each of the groundwater management zones within the Namoi sub-catchment (including the Upper Namoi alluvium groundwater management zones, and the bedrock Gunnedah Basin groundwater management zone) are considered water dependent within the 'Groundwater feature (subsurface)' subgroup. There are 21 groundwater springs identified within the Namoi sub-catchment. The closest to the BTM Complex is approximately 20 km to the east of the Namoi River and will be in a different hydrogeological area.

Although assets within the 'Vegetation' subgroup are discussed in the bioregional assessment, there are no maps identifying their exact locations. The report notes that a large number of assets were assumed to be water dependent if they were classified in the Bureau of Meteorology National Atlas of Groundwater Dependent Ecosystems (GDE) (BoM 2012).

Economic water dependent assets represent water access licenses, basic water rights, water source areas, water supply infrastructure, and regulated rivers. Within the Namoi subregion there are 88 surface water economic assets and 80 groundwater economic assets. The assets identified represent groups of smaller elements, e.g. in the Namoi region the 80 groundwater assets account for 8,891 groundwater access entitlements. The private water users within the BTM study area are discussed further in Section 6.8.2.

The bioregional assessment identified 30 sociocultural water dependent assets within the Namoi subregion. These were judged to be water dependent based on the presence of floodplain and wetland areas within their spatial extent. The report notes that meetings were held with the indigenous knowledge holders in the Namoi subregion to gain further understanding of indigenous cultural water dependent assets. There are no maps within the bioregional assessment showing the locations of the sociocultural water dependent assets within the Namoi subregion (O'Grady. 2015).

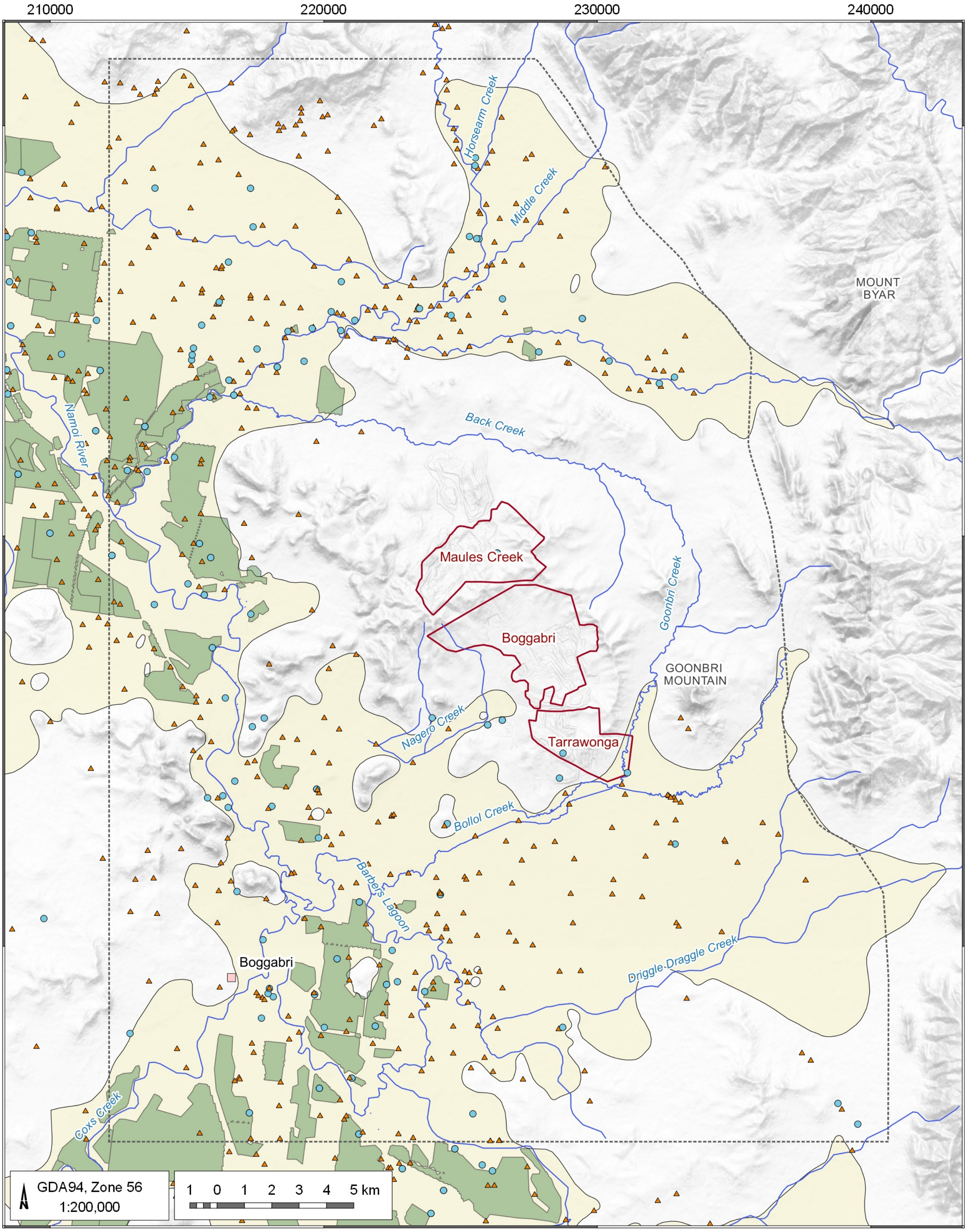
6.8.2 Private groundwater bore users

There are a large number of bores located close to the BTM Complex. These are licensed for a number of purposes. The bioregional assessment for the Namoi catchment identified 540 bores within the study area that had a groundwater abstraction license (O'Grady et al. 2015) (Figure 6.31). The licenses were allocated as:

- Basic access right (stock and/or domestic) only – 417 sites; and
- Water access right (may also include stock or domestic use) – 123 sites.

Within the study area, the licensed bores are located primarily across the alluvial aquifers, with a much lower number located within bedrock. There are fewer bores mapped along the eastern margin of the alluvium, where it thins as the basin approaches the Hunter-Mooki Fault System.

The bores with the greatest volumes of water access rights are concentrated along the main Namoi River corridor. The locations typically coincide with the areas identified as being irrigated (Janardhanan et al. 2018), although there may also be surface water abstractions supporting the irrigation. A comparison of the bioregional assessment water access rights bores against the abstraction bores in the 2018 groundwater model showed a similar pattern, although the exact locations were not a direct match, especially along the southern boundary of the model (Figure 6.32).



LEGEND

- Drainage
- Maximum open cut footprint
- Study area
- Irrigated land area*
- Alluvium extent

Groundwater licence type

- Basic access rights only
- Water access right

* Data sources: Janardhanan et al, 2018

BTM model update (G1850P)

Groundwater licences and irrigation areas

AGE

DATE 23/06/2021

FIGURE No: **6.31**

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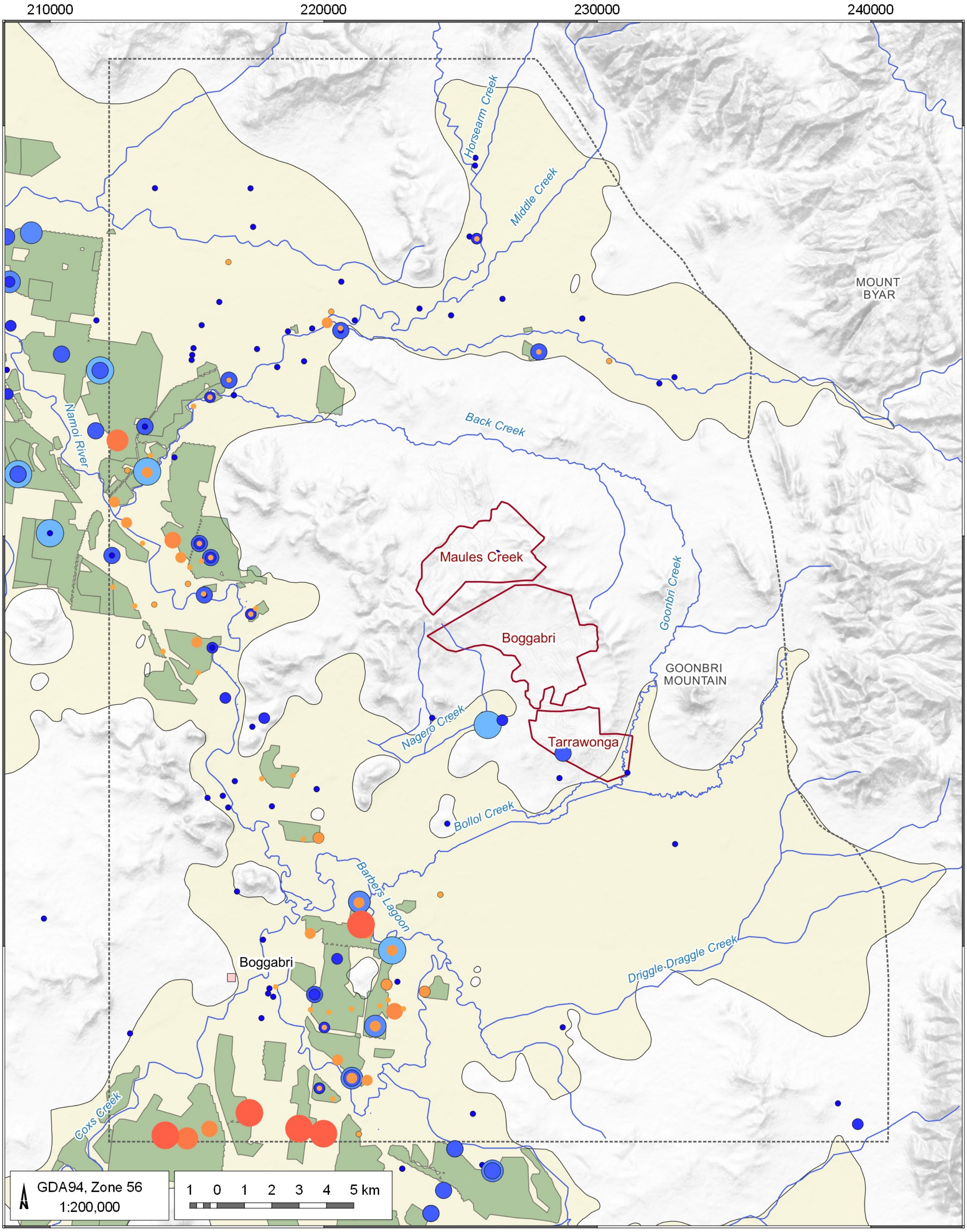
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\06.32_G1850_Groundwater licences and irrigation areas.qgs



LEGEND

- Drainage
- Maximum open cut footprint
- Study area
- Irrigated land area*
- Alluvium extent

AGE(2018) modelled irrigation use (ML/year)

- 1 - 500
- 500 - 1000
- 1000 - 1500
- 1500 - 2000
- 2000 - 2607

Water Sharing Plan allocations (ML/year)*

- 0 - 100
- 100 - 200
- 200 - 400
- 400 - 600
- 600 - 1000

* Data sources: Janardhanan et al, 2018

BTM model update (G1850P)

Modelled irrigation use vs Water Sharing Plan allocations*

AGE

DATE 23/06/2021

FIGURE No: **6.32**

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7 Conceptual groundwater model

Conceptual models are abstractions or simplifications of reality. During development of conceptual models, the essence of how the key system components operate and interact is studied. A conceptual model describes how water enters, moves, and exits a hydrogeological system; and how groundwater interacts with surface water systems or other water dependent assets. A conceptual model forms the basis for developing a numerical groundwater model. Section 3 of the Australian Groundwater Modelling Guidelines (Barnett et al. 2012) provides guidance on conceptualisation, and specifies that development of the conceptual model should consider:

- hydrogeological domain, including:
  - hydrostratigraphy (Section 6.2 and Section 7.2);
  - aquifer properties (Section 6.3 and Section 7.2);
  - conceptual boundaries (Section 5 and 6); and
  - stresses (Section 7.7).
- physical processes, such as (but not limited to):
  - aquifer conditions (steady-state/transient state) (Section 6.5);
  - flow directions (Section 6.4);
  - recharge/discharge processes (Section 7.1); and
  - groundwater/surface water interactions (Section 7.5).

The guidelines also suggest keeping alternative conceptualisations in mind and undertaking on-going checking/updating of the conceptualisation throughout the current and future phases of the works. This conceptual model was developed to inform an update to the numerical model and therefore aligns well with the methodology recommended in the modelling guidelines.

7.1 Groundwater recharge

Rainfall is the principal means for recharge to groundwater in the study area. The amount of water that will eventually reach underlying groundwater systems depends on the rate and duration of rainfall, soil/vegetation properties, depth of the water-table and residual soil moisture. Rainfall recharge cannot be directly measured, but can be indirectly estimated using a range of methods including:

- soil moisture balances;
- numerical modelling;
- chloride mass balance; and
- water table fluctuations.

These methods were used to provide estimates of rainfall recharge in the BTM complex region and discussed in the sections below.

7.1.1 Soil moisture balance

The soil moisture balance method uses recorded rainfall, evapotranspiration and groundwater level datasets to estimate when the soil profile becomes sufficiently saturated to promote deep drainage and recharge to the underlying water table. The method estimates effective recharge and the timing of recharge via the following steps:

- daily rainfall and evapotranspiration data for the required period is obtained from public domain sources;
- a soil water deficit [SWD] value is defined, which is the total amount of rainfall required to saturate the soil profile;
- when rainfall takes place the volume stored in the soil profile is calculated by adding rainfall and removing evapotranspiration to determine the daily net amount of rainfall in storage;

- to simulate remnant soil saturation that remains after a rainfall event, an exponential decay function is applied to the SWD;
- when sufficient water accumulates in the soil to exceed the SWD, effective recharge [ER] is assumed to have taken place;
- the calculated ER is capped at a maximum value to prevent extreme events generating unrealistic rates of recharge; and
- the initial SWD and the ER cap of the soil is then adjusted until a match between recharge events and groundwater level rises in monitoring bores is achieved.

Groundwater levels recorded in government-owned alluvial groundwater bores were used as part of this process because they respond clearly to recharge events and because daily water level measurements are available via telemetry. Rainfall and evapotranspiration data were sourced from the SILO database. Correlated recharge events and groundwater level increases between January 2006 and May 2019 are presented in Figure 7.1, which was calculated assuming an initial SWD of 50 mm and an ER cap of 25 mm/day. The temporal relationship between rainfall, SWD and ER over the same period is shown in Figure 7.2.

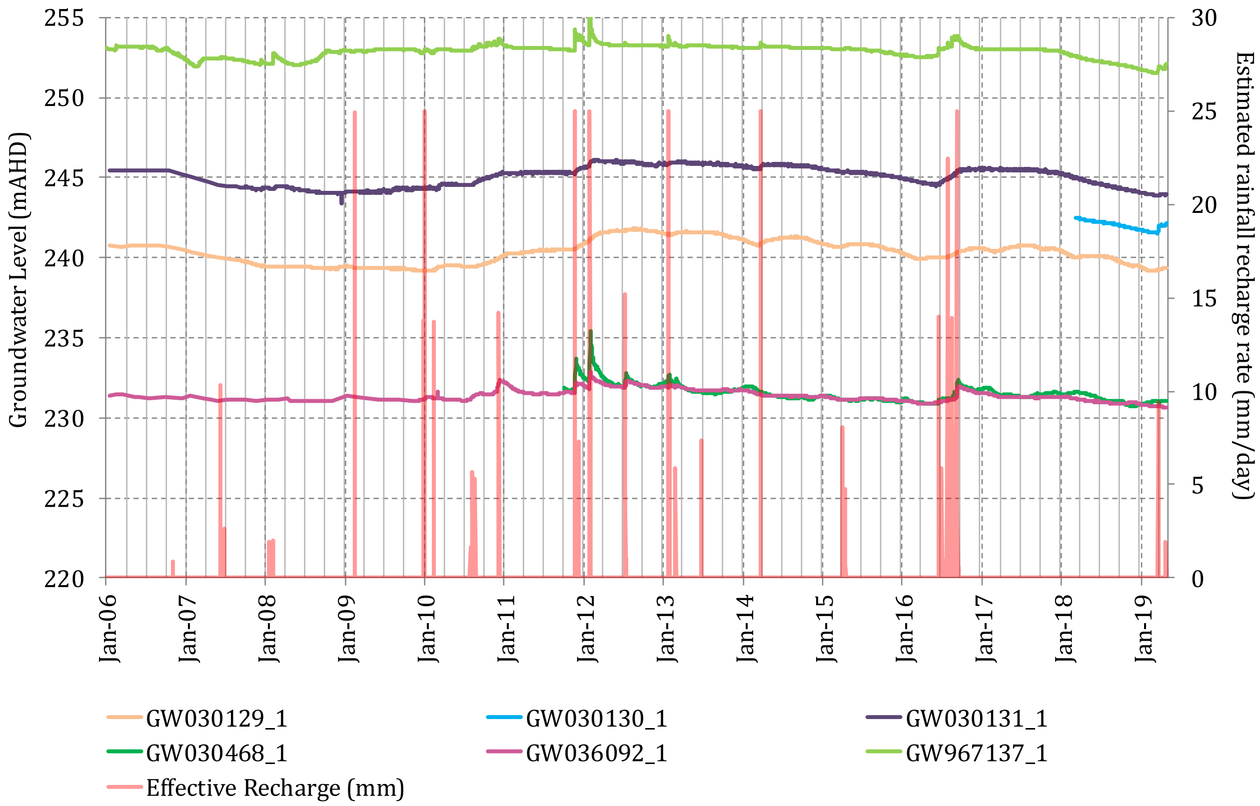


Figure 7.1 Estimated rainfall-recharge events and alluvial groundwater levels

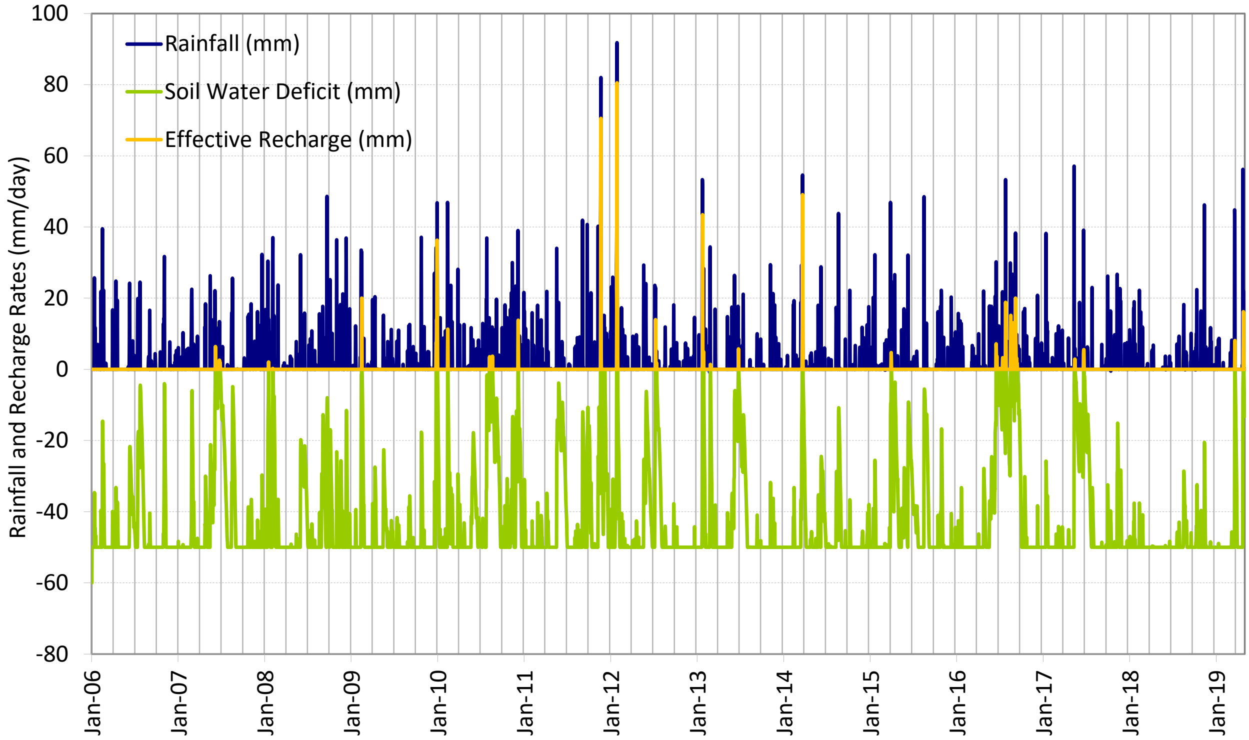


Figure 7.2 Soil moisture balance – rainfall, soil water deficit and effective recharge relationship

Table 7.1 Annual alluvial recharge estimated via soil moisture balance – 2006 to 2019

Year	Rainfall (mm/year)	Capped Recharge (mm/year)	% of rainfall
2006	504	1	0.2
2007	590	17	2.9
2008	760	5	0.6
2009	552	61	11.1
2010	942	99	10.5
2011	814	78	9.6
2012	665	101	15.2
2013	592	61	10.4
2014	536	57	10.7
2015	616	14	2.4
2016	715	149	20.8
2017	549	0	0
2018	421	0	0
2019*	192	13	6.7
Average	**603**	**47**	**7.2**

Note: * Data to 12/05/2019.

The soil moisture balance method highlights how the annual recharge to the alluvial groundwater systems varies widely depending not only on rainfall totals, but also soil moisture preceding rainfall events. The drought conditions observed since 2016 are reflected in the estimated groundwater recharge rates with only 13 mm recharge estimated since this time, and no recharge in 2017 and 2018.

Estimates of recharge to bedrock were not determined using the soil moisture balance method. Groundwater responses to recharge within these units are dampened in both magnitude and time, which makes correlations difficult to detect and the method unsuitable.

7.1.2 Modelled recharge

Previous modelling (AGE, 2018) used the initial estimates from the soil moisture balance and allowed these to vary across zones representing the alluvial plain, Permian coal measures, Boggabri Volcanics, break of slope and the Boggabri mine coal handling and processing plant (CHPP) to calibrate with water level measurements from monitoring bores (Figure 7.3). Calibrated recharge rates for each zone are presented in Table 7.2.

Table 7.2 Modelled recharge by zone – 2006 to 2019

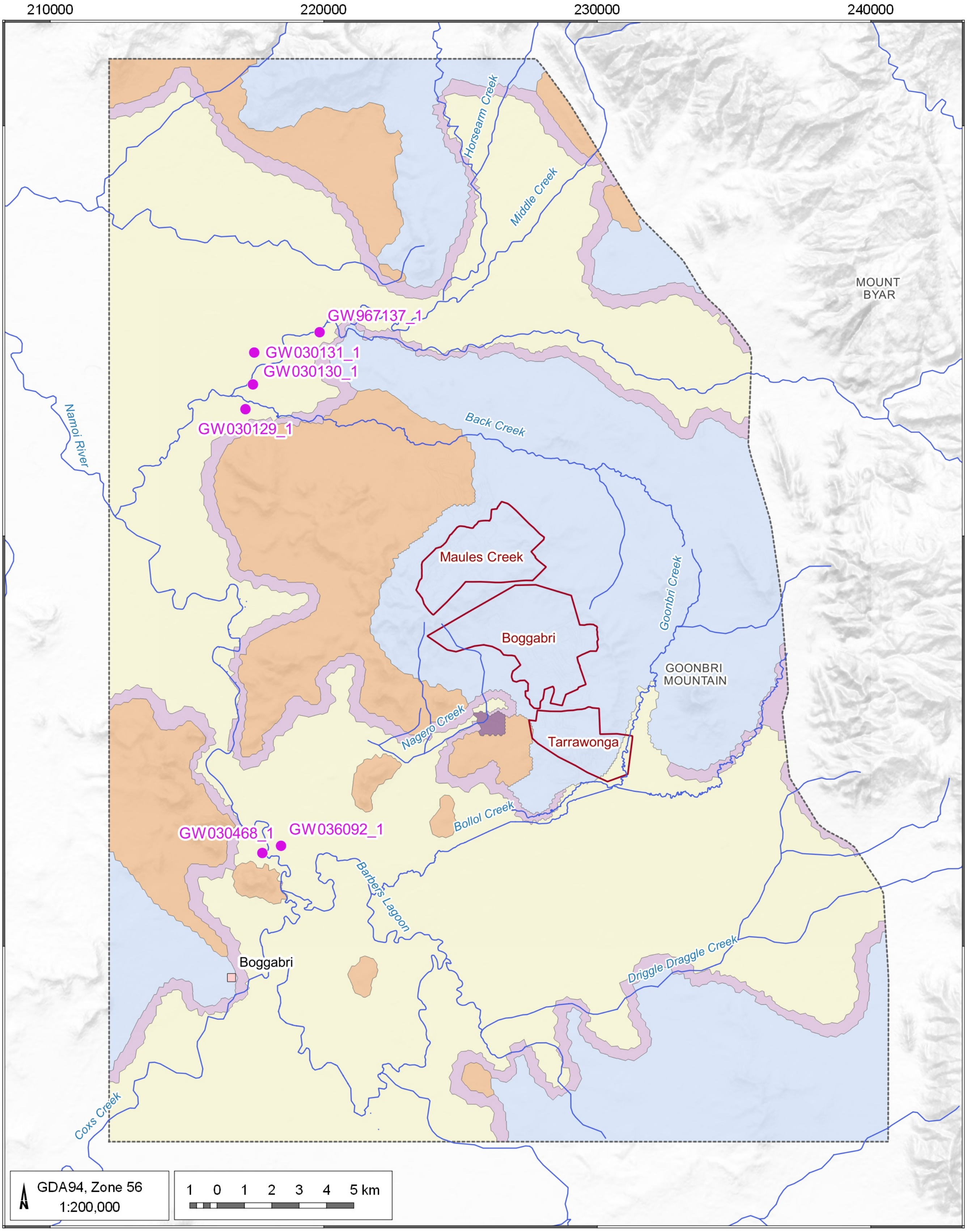
Year	Rainfall (mm/year)	Recharge (mm/year)				
		Alluvium	Permian	Boggabri Volcanics	Break of slope	CHPP
2006	504	0.2	0.0009	0.0001	0.4	0.0001
2007	590	3.4	0.02	0.002	8.5	0.002
2008	760	0.9	0.005	0.0005	2.4	0.0006
2009	552	12	0.06	0.007	31	0.008
2010	942	20	0.10	0.011	49	0.013
2011	814	15	0.08	0.009	39	0.010
2012	665	20	0.10	0.011	50	0.013
2013	592	12	0.06	0.007	31	0.008
2014	536	11	0.06	0.006	29	0.007
2015	616	2.9	0.01	0.002	7.2	0.002
2016	715	29	0.15	0.017	74	0.020
2017	549	0	0	0	0	0
2018	421	0	0	0	0	0
2019*	192	2.5	0.01	0.001	6.4	0.002

Note: * Data to 12/05/2019.

Table 7.2 highlights the relatively low recharge rates required to achieve model calibration, except at the break of slope, where significant volumes of recharge occur in the model. Whilst high recharge rates occur in this area, the weighted average recharge rate over the entire study area was approximately 6 mm/year which is about 1% of average annual rainfall. This recharge rate is less than the range determined by McNeilage (2006) for the Upper Namoi Alluvium Groundwater Model of between 3% and 9% of rainfall.

The wide differences between estimates of recharge from the numerical model and the soil moisture balance model warrant further investigation. Figure 7.3 shows the recharge zones utilised in the numerical model as well as the monitoring bores used to calibrate the soil moisture balance model. It shows that the monitoring bores used to calibrate the soil moisture balance model are all in proximity to drainage features that have the potential to enhance recharge when they are flowing. Figure 7.3 also highlights a lack of monitoring bores at the break of slope, where water level records could be used to justify the enhanced recharge adopted by the model.

Therefore, comparisons of the two recharge estimation methods suggest that values estimated from the soil moisture balance may be an over-estimate for the alluvium, and enhanced recharge along drainage features needs to be considered. The influence on the break of slope on recharge rates also remains uncertain due to the limited amount of monitoring bores in this area.



LEGEND

- Bores used for soil moisture balance
- GW030468_1: Bore ID
- Drainage
- Maximum open cut footprint
- Study area

Recharge zones

- Zone 1 - Alluvium
- Zone 2 - Permian
- Zone 3 - Boggabri volcanics
- Zone 4 - Break of slope
- Zone 5 - Boggabri-Tarrawonga CHPP

BTM model update (G1850P)

Recharge zones after AGE (2018)

AGE

DATE 30/08/2021

FIGURE No: **7.3**

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7.1.3 Chloride mass balance (CMB)

Groundwater quality datasets can also be used to indirectly estimate recharge using the chloride mass-balance method (CMB). Chloride concentrations of rainfall-runoff water generally increase as the water infiltrates through the root zone due to evapotranspiration, with concentrations remaining constant below the root zone (Scanlon et al. 2002). As such, differences between the chloride deposition rate (D, kg/ha/yr) and the chloride concentration of groundwater (C_{gw}, mg/L) can be used to estimate groundwater recharge (R, cm/yr) as per Equation 1 (Leaney et al. 2011).

Equation 1 $$R = D / C_{gw}$$

The assumptions behind application of the CMB are that (Wood 1999):

- chloride in groundwater is sourced from rainfall (not from rock weathering or interactions with streams or deeper aquifers);
- chloride is conservative in the system (no sources or sinks);
- chloride flux does not change over time (steady state conditions);
- there is no recycling of chloride in the system (e.g. due to irrigation drainage); and
- the chloride imported/exported via runoff or runon can be accounted for (Leaney et al. 2011).

Recharge was estimated for the BTM complex area using this method, with results presented in Table 7.3. The average chloride deposition rate was extracted from the national dataset (Leaney et al. 2011), while chloride concentrations of groundwater were sourced from the collective BTM groundwater monitoring network sampling dataset.

Table 7.3 Recharge – chloride mass balance vs modelled

Groundwater system	Recharge –CMB [a] (mm/year)	Recharge – modelled (AGE 2018) [b] (mm/year)
Alluvium	2.58	9.3
Maules Creek Formation	7.92	0.05
Boggabri Volcanics	1.90	0.005

Notes: [a] Calculated using median chloride concentrations.
[b] Average modelled recharge from 2006 to 2016.

Table 7.3 indicates that the CMB estimates of recharge to the alluvium are generally consistent with values estimated during previous numerical modelling. Conversely the CMB method provides a significantly higher estimate of recharge to the Maules Creek Formation and the Boggabri Volcanics than the numerical modelling.

Variations between the two estimation methods may be attributed to the relatively high relief of the Maules Creek Formation and the Boggabri Volcanics in the mining areas. When the steady-state CMB method is used in upland areas, runoff can be significant and changes the chloride deposition rate (Leaney et al. 2011). Appreciable levels of runoff, which are not accounted for in the adopted chloride deposition rate, would result in an overestimate of recharge to the Maules Creek Formation and the Boggabri Volcanics. Additionally, observations in the ridge area indicates relatively thin root zones within the outcrops of the Maules Creek Formation/Boggabri Volcanics, which may also result in an overestimate of recharge.

The Namoi bioregional assessment (Aryal et al. 2018) also used the CMB approach to estimate rainfall recharge. Estimates of groundwater recharge were generally consistent to estimation in this report, with:

- an approximate recharge of 5 mm/year to the Maules Creek Formation/Boggabri Volcanics; and
- variable rates of recharge to the alluvium ranging from <1 mm/year to 40 mm/year.

7.1.4 Water table fluctuation

The water table fluctuation method relies on rises in groundwater level being related to recharge events and is best applied to a shallow water table that displays a sharp rise in water level (Leaney et al. 2011). Recharge (R) is calculated as per Equation 2, where S_y is the specific yield of the aquifer, and Δh is the change in water level over a period of time (Δt).

Equation 2 $$R = S_y \times \Delta h / \Delta t$$

This method was implemented for the following two recharge events (shown in Figure 7.1):

- 31/01/2012 to 04/02/2012 – Bores GW967137_1 and GW30468_1; and
- 30/03/2019 to 31/03/2019 – Bores GW967137_1 and GW30130_1.

Calculated results are provided in Table 7.4 and include comparisons to recharge rates determined using the soil moisture bucket balance.

Table 7.4 Recharge – water table fluctuation vs soil moisture bucket

Bore ID	Event from	Event to	Recharge – water table fluctuation (mm/day)		Recharge – soil moisture balance (mm/day)
			Sy = 0.052	Sy = 0.22	
GW967137_1	31/01/2012	02/02/2012	4	18	15
GW030468_1	01/02/2012	05/02/2012	3	11	13
GW967137_1	29/03/2019	01/04/2019	0.2	0.9	0.9
GW030130_1	30/03/2019	31/03/2019	1	3	3

When adopting a specific yield value of 0.052, which is consistent with previous groundwater modelling (AGE 2018 and McNeilage 2006), the calculated recharge is much less than recharge determined using the soil moisture balance method (approximately 20% to 30%). However, when adopting a higher specific yield value of 0.22 (value for sand, after Heath 1983) results are similar. Similarities between the two methods of estimation supports the hypothesis of enhanced recharge around drainage features, which is introduced in Section 7.1.2.

7.2 Hydrogeological units

As discussed in Section 6.2.1, the local hydrogeological regime is conceptualised to comprise the following lithologies:

- alluvium of the Narrabri Formation;
- alluvium of the Gunnedah Formation;
- coal seams of the Maules Creek Formation;
- interburden of the Maules Creek Formation; and
- silicic volcanics of the Boggabri Volcanics.

Bore yields and field estimations of hydraulic parameters (Section 6.3) indicate that the most productive groundwater system in the area is the deeper alluvium of the Gunnedah Formation. Appreciably productive groundwater systems are also found within the overlying alluvium of the Narrabri Formation and the Permian coal seams. Permian interburden, which is largely comprised of cemented conglomerate and sandstone, is relatively impermeable and serves as a confining layer, partially restricting groundwater flow between individual coal seams and the overlying alluvium. Basal volcanics also act as a relatively impermeable unit and are found underlying both the alluvium and the Maules Creek Formation.

7.3 Role of geological structures

"Folding and faulting of sedimentary rocks can give rise to complex hydrogeological systems. Fault zones can act as either barriers to groundwater flow or as groundwater conduits, or have negligible influence, depending on the nature of the fault zone and the material within it" (Fetter 2001). Geological structures such as faults are known to occur in the BTM area. Geological mapping and data from adjacent projects have highlighted several major structures and some smaller scale faults.

The hydraulic nature of individual faults can be variable and is typically unknown in great detail. In addition to displacing the geological units and 'breaking' the hydraulic pathway, the fault materials themselves can act as conduits where they are present as one or more open fractures. However, where the faulted rock consists of fine grained material, clayey material, or cementing material, these faults may have a lower permeability than the host rock.

Within the study area the REG2 bore was interpreted as intercepting fault zone materials rather than the coal measures strata predicted on the regional geology map. The fault may be related to the nearby Hunter-Mooki Fault System. The multi-level VWP sensors installed at REG2 all show similar rapid responses to rainfall-recharge. After the 2016 flood event the water levels rose by ~ 5 m at all sensors, with no dampening of the responses in the deeper strata as observed at other multi-level sites. This suggests that either the fault zone around REG2 is more permeable than the coal measures but probably of low storage given the large magnitude of the response, or that the REG2 borehole is not well sealed and can allow recharge to flow downwards through the borehole.

The spatial extent of the REG2 fault is unknown, and it is also unknown whether the permeability of the fault zone is constant or variable along its length. There is little data available for other faults within the study area. Site personnel reported that one of the minor faults intercepted within the Boggabri pit has a small seepage, as does one of the minor faults at Tarrawonga. Site personnel at Tarrawonga also commented that weathered volcanic dykes and sills were often wetter than the coal measures strata.

The nature of the Conomos fault, and any other structures in the area are unknown. Modelled interpretations of the Conomos fault were provided by site personnel and show that all seams are upthrown on the northern, mining side of the fault.

Conceptually, the presence and potential impacts of faults are difficult to generalise across the study area. It is possible that faults reduce geological interconnectivity, with coal seams abutting the less permeable interburden, limiting groundwater flow. Alternatively, it is possible for faults to act as conduits either through increases in permeability (as observed in REG2), or through upthrow resulting in a greater propensity of coal seems in connection with more transmissive alluvial aquifers. A level of uncertainty around the behaviour of faults and their influence on the conceptual model therefore remains.

7.4 Groundwater levels and flows

Monitoring data indicates the water table elevation and flow direction within the Upper Namoi alluvium is generally a reflection of topography, with groundwater in the higher elevation areas flowing towards the Namoi River.

Groundwater discharge (or outflow) occurs via a series of different mechanisms. Under natural conditions prior to mining and agricultural development, groundwater would have discharged to low lying water bodies and drainage lines that intersect the water table, being predominantly the Namoi River and downstream areas of Maules Creek. Groundwater discharge would also have occurred via evapotranspiration from deep rooted vegetation. With mining and agricultural development of the catchment, discharge now also occurs via seepage and evaporation at a mine face and via bores abstracting groundwater for agricultural and water supply purposes.

Under natural conditions, the main regional drainage feature around the BTM Complex is the Namoi River, making it the main natural discharge location for the regional groundwater system. Decreases in groundwater levels adjacent to the Namoi River have been observed and occur alongside a relatively stable river stage. The likely result of this reduction in hydraulic gradient is less groundwater discharge to the river, when compared to historical observations.

Smaller drainage features, such as Maules Creek, may also receive groundwater discharge (baseflow) at times, although data suggests this is limited to periods of above average rainfall when the water table is high.

The natural groundwater system has been modified as a result of agricultural and mining activities. Historically, the clearing of land for agriculture, and abstraction of groundwater for stock and domestic or irrigation use, have modified and interrupted the natural groundwater flow and discharge pathways. This impact on the alluvial system is prominent in alluvial monitoring bores, where an overall decline in water levels have been observed in almost all bores. More recently, mining activities at the BTM Complex have modified the groundwater system of the Permian coal measures, with a significant reduction in water level observed in bores close to mined areas, as predicted during the approvals process for each mine. The magnitude of the drawdown diminishes with distance from the mining areas and up hydraulic gradient (east of the BTM Complex).

Water levels in most of the alluvial bores show a strong correlation to rainfall patterns, with rising water levels following above average rainfall periods, and falling water levels following below average rainfall periods. Seasonal abstraction of groundwater from the alluvium is frequently observed through large water levels fluctuations in the deeper alluvial monitoring bores. A longer term fall in water levels, overprinting the seasonal cycle is also observable within the alluvium. The long term fall appears to be related to historical over abstraction of groundwater from the alluvial areas. This will also have caused interruptions to the natural flow and discharge pathways within the alluvium; e.g. lower groundwater discharge to the Namoi River as groundwater moving towards the river is intercepted by abstraction bores. In contrast there are some areas where shallow groundwater levels have been observed to be rising within the alluvium, potentially related to irrigation, and/or a long term increase in recharge due to clearing and land levelling.

The majority of groundwater licences in the study area permit abstraction from the Namoi River alluvium, which is all classified as a highly productive aquifer. Registered bores do target the Permian bedrock units; however, there is no recorded large-scale groundwater abstraction from the Permian strata for agricultural or domestic uses. This is likely due to the low permeability of the bedrock units limiting the volumes of water that can be removed. The Permian groundwater system is not classified as highly productive according to the NSW AIP (2012). The volume of water abstracted for stock and domestic use is not considered to be significant compared to the other groundwater discharge mechanisms.

Natural groundwater levels within the Permian coal measures are influenced by topography and the permeability of the different geological units. Groundwater recharged into areas at the highest topographical elevations typically flows towards areas with a lower topographical elevation. Flows are expected to be greatest within the more permeable and transmissive geological units, and lower in the less permeable units. Multi-level bores installed in the eastern areas of the Maules Creek/Bollol Creek catchments typically show a vertically downward gradient through the entire profile monitored. This indicates that the eastern catchment is principally a recharge area. Natural discharge of the Permian coal measures is inferred further west at the interface with the Boggabri volcanics ridge where the contrast in permeability and influence of the Namoi River discharge zone if expected to promote an upward gradient from the bedrock to the alluvial aquifer. Groundwater also discharges into mined areas of the BTM Complex where the depth of mining exposes the seam face.

Mining activities have altered the recharge pathways and groundwater flowpaths close to the active mining areas. Pre-mining hydraulic gradients within the Permian coal measures would be expected to be similar to those still observed at the more peripheral monitoring sites. However, close to the mines the lowest pressures are now observed in sensors located within the target coal seams rather than the deeper sensors installed below the mining floors. Inflows to the mines are inevitable once the mining floor falls below the water table. Groundwater flows into the mining voids along open fractures in the interburden and along the higher permeability coal seams. Maules Creek Mine only intercepted the regional water table in 2018, whereas the older mines had been experiencing small groundwater inflows for several years. Inflows are typically removed through pumping from in-pit sumps as required to keep the pits dry enough for safe working. Groundwater is also removed from the mining areas tied up into the damp spoil or ROM coal, and via evaporation from pit wall seepages or in-pit storages and sumps.

Bores located along the outcropping Boggabri Ridge have typically shown minimal water level fluctuations over the period of monitoring. The monitored levels suggest that the unweathered Boggabri Volcanics are low permeability and will limit the propagation of any pressure changes generated in the coal measures during mining.

7.5 Alluvial connectivity to coal measures

In the Maules Creek area to the east of mining, vertical hydraulic gradients measured in multilevel monitoring sites that extend through both the alluvium and the coal measures indicate downwards movement from the alluvium into the underlying bedrock. This gradient was established prior to mining at Maules Creek Mine and is considered to be a function of the rising surface topography and the permeability of the underlying coal measures.

Potential connections between the mining areas and the alluvial groundwater systems could occur via the following geological features:

- direct subcrop of coal seams onto alluvium;
- enhanced interconnectivity driven by weathered interburden;
- enhanced interconnectivity driven by weathered volcanics (where coal seams subcrop); and
- enhanced fault driven interconnectivity.

The geological models provided by each of the BTM mines were reviewed to determine where the coal seams could subcrop and connect under the alluvial plains. The review indicated that:

- to the southwest of Boggabri, all coal seams above the Nagero Seam subcrop underneath the alluvial 'tongue';
- to the south of Tarrawonga, coal seams above the Nagero Seam subcrop onto the alluvial plain of the Bollol Creek alluvium; and
- the Jeralong Seam is the deepest seam to subcrop onto alluvium of Goonbri Creek.

Subcrop is shown graphically on the geological sections included within Appendix D.

Subcrop below Maules Creek is difficult to confidently infer due to the geological model extent. At the model's northern boundary all seams above the Braymont Seam are weathered out, and all seams below the Braymont Seam subcrop onto the Boggabri Volcanics directly north of current mining.

Regolith thickness is variable, although can approach 30 m in some areas of the BTM Complex (Section 5.4). The specific hydraulic nature of individual faults is unknown (as discussed in Section 7.3).

7.6 Groundwater-surface water interactions and GDEs

Conceptually, there are limited ephemeral surface water features in the study that have the potential to be groundwater gaining. Observations indicate that most surface water features recharge the underlying groundwater systems during periods of flow. The exception to this is the Namoi River, where observations indicate that sections are groundwater gaining. However, as water levels in the alluvial aquifer have fallen the connection has reduced. The elevation of the Namoi River stage at Boggabri is now similar to that in the surrounding groundwater bores, which will have reduced the volume of groundwater discharging into the river.

Back Creek has very limited incision and groundwater levels are deep enough to mean there is no significant connectivity with the water table. Groundwater levels are closer to surface along Maules Creek but appear to have only been able to discharge directly into the creek during extremely wet periods in areas downstream of Elfin Crossing.

No high priority GDEs are noted in the WSPs that lie within the study area; however, the BoM GDE Atlas does identify areas of known aquatic GDEs (Maules Creek), or areas with high potential to support aquatic or terrestrial GDEs. These potential areas are subject to ground truthing using local surveys to prove that GDEs are present. No significant decline in groundwater levels within the riparian zone along Maules Creek that could be attributed to mining activities is evident in the monitoring datasets.

7.7 Potential impact causal pathways

For the purposes of bioregional assessments causal pathways are defined as, *“the logical chains of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water dependent assets”* (Henderson et al. 2016). Water dependent assets can be impacted by changes to quality; and changes to timing, duration, pressure and flow conditions of groundwater/surface water systems. Water dependent assets in the vicinity of the BTM Complex were identified in Section 6.8.

The identification of causal pathways between the proposed development and the water-dependent assets is an important part of the impact assessment process. Causal pathways are initiated by an activity associated with the coal resource development. In the case of the BTM Complex, this is the mining of coal from within the approved mining areas. It is also important to note surrounding areas and water-dependent assets that are unlikely to be impacted as a result of mining activities.

There are four main causal pathway groups associated with coal mining, although there is commonly overlap or linkage between them:

- ‘subsurface depressurisation and dewatering’;
- ‘subsurface physical flow paths’;
- ‘surface water drainage’; and
- ‘operational water management’.

This report focusses on those causal groups primarily related to groundwater, that is ‘subsurface depressurisation and dewatering’, and ‘subsurface physical flow paths’. ‘Surface water drainage’ is also briefly discussed in relation to groundwater-surface water interactions.

The ‘subsurface depressurisation and dewatering’ group of causal pathways occurs when coal mines intentionally dewater the subsurface so that open-cut mining operations can occur safely. The pre-existing hydraulic gradients are disrupted, usually causing changes to groundwater levels and pressures; and occasionally altering groundwater quality. Pumping from conventional bores extracting groundwater to support mining activities is also part of this causal group. However, the scale of these effects is typically less than those associated with open cut mine dewatering. Groundwater extraction for open cut mine development can unintentionally affect non-target strata in situations where direct hydraulic connections exist. The connections could be diffuse, such as connections between adjacent geological layers, or more focussed via structures such as faults.

The ‘subsurface physical flow paths’ causal pathway group involves activities that physically modify the rock mass, creating new pathways that water may flow along. During open cut mining the enhanced pathways may occur via flow along unsealed exploration bores or incorrectly installed monitoring bores. Long term the replacement of pre-mining bedrock by spoil or a final void lake would alter the physical properties of the subsurface compared to pre-mining conditions.

Example causal pathway diagrams for open cut coal mining developments are presented in Henderson et al. (2016). The groundwater components that are potentially relevant to mining at the BTM Complex are summarised in Table 7.5. The table outlines the most likely pathways, impact causes, impact modes and activities to generate the impacts. The potential hydrogeological effects on the groundwater system are noted in the final column. Those components that are most likely to produce the greatest changes to the groundwater system, or which have been identified as occurring within the BTM area, are highlighted bold.

Many of the smaller scale issues can be managed by following current best practices to reduce the likelihood of them occurring, e.g. those activities caused by equipment failure or poor component design.

The potential activities that are most likely to produce impacts over a large area relate to the inevitable effects of open cut mining below the groundwater table, and backfilling of the resulting mining void with spoil.

Risks and causal pathways have been included in the modelling considerations and conceptualisation.
The most likely potential causal pathways identified should be considered when designing the numerical groundwater model to ensure that they are suitably represented.

Table 7.5 Causal pathways with a groundwater component

Pathway	Cause	Mode and activity	Hydrological effect
Aquifer outcrop areas – deep soil drainage	Coal characteristics	Fire in stockpiles, fire in the pit from excavation or blasting, fire in stockpiles	Quality
	Incomplete rehabilitation	Negligence during post-closure mine decontamination	Quality
	Consolidation of loose backfill	Compaction or settlement of backfill over time	Direction
	Diverting site drain line	Changes to natural surface drainage through diverting creeks or for rainfall and runoff diversion Disruption of natural surface drainage via dam construction, site preparation, topsoil and spoil preparation Disruption of natural surface drainage by excavation of the pit	Quality, Direction, Volume/quantity
	Inevitable, deliberate	Deliberate pit wall dewatering Leaching of spoil dumps or coal stockpiles Runoff changes via topsoil excavation and storage	Quality, Flow (reduction), Pressure, Volume/ quantity
	Poor handling/management	Excessive runoff during closure from water management structures	Quality
Aquifer outcrop areas – SW-GW interactions	Human error, accident	Equipment (pipe) failure leading to containment failure for dewatering water, waste streams, mine dewatering, treatment, re-use, disposal Substantial spillage from on-site mine equipment or on-site coal transport Treatment plant failure during mine water treatment, re-use, disposal	Quality
	Containment failure, leaching, flooding	Groundwater or surface water contamination from drill cutting disposal Increased inflow from natural events during dewatering, treatment, reuse and disposal processes Overflow and/or loss of containment of surface water Treatment plant failure during mine water treatment, re-use, disposal Leaching of tailings water decant dam	Quality
	Physical disruption of river boundary or channel	Linking aquifers via preferential drainage if mine expansion too close to river/lake	Flow (reduction), Pressure, Volume/ quantity

Pathway	Cause	Mode and activity	Hydrological effect
Aquifers – Groundwater conditions	Drilling control issues	Pressure imbalance and localised water table changes	Quality, Level
	Incomplete grouting	Incomplete/compromised cementing leading to linking of aquifers within groundwater bores	Quality, Composition
	Poor design, construction	Bore leakage between aquifers following abandonment Linking aquifers in groundwater supply bores with long screens	Quality, Composition
Aquifers – Groundwater conditions post mining	Inevitable, deliberate	Artificial point of recharge, enhanced aquifer interconnectivity, groundwater source/sink – post closure water filling the pit	Direction, Pressure, Volume/quantity
		Leaching from in-pit backfill/spoil dump Groundwater extraction from groundwater supply bores	Quality Pressure

Note: Bold highlighting indicates those causes and activities that are likely to cause the greatest changes at the BTM mining complex.

8 Review of existing numerical models

This section provides a summary of the numerical groundwater flow models completed within BTM study area.

8.1 History of numerical models

8.1.1 BTM mining complex models

Parsons Brinkerhoff (2005) developed the first groundwater model for the Boggabri Coal Mine as part of the project approval process using MODFLOW. The model was later recalibrated by Parsons Brinkerhoff (2008) and used to evaluate the groundwater impacts of changes in mine plans. This model was converted to MODFLOW SURFACT by AGE (2010) as part of the 'Continuation of Boggabri Mine Project'. The early models were relatively simplistic with limited detail on the coal seam surfaces in the Maules Creek sub-basin. This was because at that time there was little information available on the geometry of the coal seams outside the Boggabri Coal Mine area, particularly under the alluvial flood plain surrounding the site. For that reason, the early numerical models did not represent the coal seams individually but lumped the coal seams and interburden into layers with a transmissivity equivalent to that estimated for the coal seams.

During the planning stages for the Maules Creek project in 2010, it was recognised that because of the close proximity of the Maules Creek Project, Boggabri Coal Mine and the Tarrawonga Project, the quantification of cumulative impacts would be required. This led to a data sharing agreement in 2010 between the mining companies to facilitate cumulative impact assessment. Combined geological models allowed the coal seams to be better defined across the mining areas and under the alluvial plains. The groundwater model developed for the Boggabri Coal Mine was then updated with this data and used as the basis for a new model to simulate the entire mining complex for the Maules Creek Project approval process (AGE 2011).

An outcome of the approvals process for Boggabri and Maules Creek Mine was the installation of a network of bores to monitor cumulative impacts on the flood plain surrounding the ridge area where mining occurs. The cumulative monitoring bore network, known as the BTM network, representing Boggabri, Tarrawonga and Maules Creek Mines was installed between November 2013 and January 2014 under the supervision of Maules Creek Mine geologists. At this time, the Maules Creek groundwater numerical model was also updated by AGE (2014).

Heritage Computing (2012) developed a model for the Tarrawonga Coal Project that utilised the geological layers developed during the data sharing process. Boggabri Mine also commissioned Parsons Brinckerhoff (2015) to develop a numerical groundwater model of the alluvial aquifer. The purpose of the model was to assess the impact of installing a borefield within the Namoi River alluvium to the west of the Boggabri Ridge to supply 'make up' water to the mine. The model represented the alluvium and basement volcanics but not the Permian coal measures. The model was also smaller (12.1 km x 17.3 km [209.33 km^2]) than the regional scale models developed for approval of the mining areas.

In 2017 Boggabri Coal requested AGE to update the Boggabri groundwater model for their three-yearly numerical groundwater model review (a condition of the mine approval). The latest groundwater model completed for the BTM Complex at the time was for Maules Creek Mine (AGE 2014). Following discussions with Maules Creek Mine and Tarrawonga Mine it was agreed that all three mines would collaborate and provide data for the update, to ensure that the model and its subsequent impact predictions were accurate for all three sites. The model was updated during 2017, with the report being issued in 2018 (AGE 2018). The key updates made to the model were:

- conversion to MODFLOW-USG to improve run times;
- a revised mesh (model grid);
- little change to the model layering, with the exception of splitting out the Nagero seam to better represent the base of Tarrawonga Mine;
- updates to the historical and future mining areas for Boggabri and Tarrawonga;
- calibration to a longer observed water level dataset;
- use of PEST calibration to determine hydraulic property values;

- revised predictive impacts; and
- uncertainty analysis on the cumulative model outcomes.

NRAR provided comments on the report in December 2018, and it was later agreed that there were areas of improvement that could be made to the model that would require a more substantial rebuild than the 2018 update.

8.1.2 Regional/non BTM mining models

Several other groundwater models have been completed that include the BTM mining area or surrounds, but whose primary purpose was not solely assessing impacts from BTM.

McNeilage (2006) developed a water resource model for Zones 2, 3, 4, 5, 11, 12 of the Upper Namoi Alluvium Groundwater Sources. The model represented the alluvium as two layers and assumed that the underlying bedrock was impermeable. The model has a uniform 1 km grid. The model report contains details around the definition of the alluvial thickness and identification of the split between the Narrabri and Gunnedah alluvial formations. The geological information from this report was used in the BTM numerical groundwater models to develop the alluvial layering for alluvial zones.

The Namoi Catchment Water Study (NCWS) (SWS 2012) was conducted to assess the cumulative impacts of coal mining and CSG developments on water resources of the Gunnedah Basin. The model was extremely large (30,400 km^2) and utilised a 1 km model grid to represent the hydrogeological regime. The entire Maules Creek formation was simulated using three model layers, with no differentiation between coal seams and interburden. Although the model was a useful tool for assessing regional impacts, the large grid size and low vertical resolution of the Maules Creek formation made the NCWS model unsuitable for assessing the local scale impacts on water resources around the BTM mining complex.

The approved Vickery Coal Mine is located on a separate outcrop of Permian rock to the south of alluvial Zone 4, approximately 10 km south of Tarrawonga Coal Mine. The Vickery groundwater models (Heritage Computing 2013 & HydroSimulations 2018) extend northwards to include the Zone 4 alluvium and the Tarrawonga Coal Mine but do not cover the Boggabri or Maules Creek mining areas. The Vickery models were based on the 2012 Tarrawonga model, with the coal seams at Vickery also being represented as layers of lumped seams. Although the Vickery models can be reviewed to check consistency of layering and hydraulic properties, they are unsuitable for assessing impacts from the BTM Complex without being extended to cover the BTM mining areas.

Although the numerical model developed for the Narrabri Gas Project includes the Maules Creek sub-basin, the large cell sizes and simplified representation of the coal seams would reduce the accuracy of any impact assessment related to the BTM complex mines. Assessing impacts from coal mines was not the objective of the Narrabri model at the time it was built. The calibration of this model did not attempt to estimate the hydrogeological properties of the different geological units as there were few historical groundwater head measurements in the deeper geological units; instead, the available head data were simulated as head boundary conditions, and the boundary conditions (including recharge) replaced by fluxes needed to replicate the heads (CDM Smith 2016).

A regional model was also developed as part of the bioregional assessment for the Namoi Catchment (Janardhanan et al. 2018). The model was built using MODFLOW-USG and incorporated a Voronoi mesh with cell sizes across the BTM mines of approximately 500 m. Although the model includes the BTM Mining Complex, the Maules Creek Formation was represented as a single layer and would have to be refined to better represent impacts from the mining if these were a required output.

8.2 Model summaries

Table 8.1 below summarises key features of the historical models that lie within the BTM study area. The models were built at different times, using different model codes, and for different purposes. The larger scale models represent the Maules Creek formation with not enough detail to accurately predict localised impacts from mining at the BTM complex. The models with a primary purpose of predicting mining related impacts typically represent the coal seams as four or five groups of lumped seams rather than individual seams. This was a necessary simplification in order to have a model that would run in a computer in a reasonable time and therefore allow a thorough calibration phase of modelling.

Table 8.1 Historical model comparisons

Model	Author/date	Purpose	Model code	Model area (km^2)	Grid cell size (m)	Layers	Calibration (SS/TR)	Alluvials modelled?	Coal seams modelled?	Lowest seam modelled	Sensitivity/ Uncertainty ?	Comments
Upper Namoi Alluvium	McNeilage 2006	Alluvial water resources	Modflow 96	2,365	1,000 x 1,000	2	TR	Y	N	N/A	S	Alluvial water resources model for Zones 2, 3, 4, 5, 11, 12. Two layer model of alluvium only, assumes impermeable bedrock underlying the alluvium Calibration - 1985 – 2001 (16 years), monthly stress periods Predictions not included in this report – Development and calibration only
Boggabri Coal mine	PB 2005	Coal mine impact assessment	Modflow	650	100 x 100	3	SS	Y	N	Base of L1 set to base of Merriown seam	S	Calibration – SS only Prediction – 2006 – 2011. 6 years, 12 x 6 monthly SPs Alluvials modelled as two layers Maules Creek Formation modelled as 2 layers - lumped coal measures rather than coal seams and interburden. Layer 3 Boggabri Volcanics is 'non active' (no flow?)
Boggabri Coal mine	PB 2008	Coal mine impact assessment	Modflow	650	100 x 100	3	SS	Y	N	Base of L1 set to base of Merriown seam	N	Calibration – SS only Prediction – 2008 – 2011, 4 years, 8 x 6 monthly SPs Model build not specified but assumed to be the same as 2005 model
Boggabri Coal mine	AGE 2010	Coal mine impact assessment	Modflow Surfact	892	50 x 50 – 100 x 100	5	SS	Y	N	Base of L3 set to base of Merriown seam	S	Calibration – SS only Prediction – 2006 – 2032, 107 quarterly SPs Maules Creek Formation modelled as 2 layers - lumped coal measures rather than coal seams and interburden
Maules Creek mine	AGE 2011	Coal mine impact assessment	Modflow Surfact	1,190	50 x 50 – 500 x 500	12	SS	Y	Y – 4 groups	Templemore group (L10)	S	Calibration – SS only Prediction – 2006 – 2032, 107 quarterly SPs
Maules Creek mine	AGE 2014	Coal mine impact assessment	Modflow Surfact	1,190	50 x 50 – 500 x 500	12	SS & TR	Y	Y – 4 groups	Templemore group (L10)	N	Calibration – 2006 – 2013, 31 quarterly SPs Prediction – 2014 – 2043, 119 quarterly SPs PEST used to assist with calibration
Tarrawonga Coal mine	RCA 2005	Coal mine impact assessment	--	--	--	--	--	--	--	--	--	Aka East Boggabri Mine. Limited spatial extent. Considered unsuitable for updating in 2012 as it did not accommodate cumulative effects from neighbouring mines (Heritage Computing, 2012)
Tarrawonga Coal mine	Heritage Computing 2012	Coal mine impact assessment	Modflow Surfact	1,518	50 - 500	12	TR	Y	Y – 4 groups	Nagero. Different grouping to AGE models	S	Calibration - 2006 – 2010, monthly SPs Prediction - annual from 2011 to 2032 Only TV stress in predictive model is mining
BTM Complex	AGE 2018	Coal mine impact assessment	Modflow USG – Voroni and rectangular grid	961	100 x 50. 200 x 200, 115 – 650 diameter polygons	19	SS & TR	Y	Y – 5 groups	Templemore group (L17)	U	Calibration – 2006 – 2014, quarterly SPs Prediction – 2006 – 2032, 107 quarterly SPs One of the grouped coal seams from the AGE 2014 model was split to better represent the base of Tarrawonga Mine (Nagero seam) PEST used to assist with calibration

Model	Author/date	Purpose	Model code	Model area (km^2)	Grid cell size (m)	Layers	Calibration (SS/TR)	Alluvials modelled?	Coal seams modelled?	Lowest seam modelled	Sensitivity/ Uncertainty ?	Comments
Boggabri alluvials	PB 2015	Water resources	Modflow 2005	209	50 x 50	3	SS & TR	Y	N	N/A	S	Calibration - 2004 – 2014, 44 quarterly SPs Prediction – 27 years, 17 pumping and 10 recovery Two alluvial layers and an underlying aquitard (Boggabri volcanics) Used PEST and pilot points to calibrate Layer 2 Reducing the anisotropy ratio between horizontal and vertical conductivity from 0.1 to 0.01 improved calibration
Namoi Catchment Water Study	SWS 2012	Coal mining and coal seam gas impact assessment	Modflow 2000	30,381	1,000	20	TR	Y	N (in Maules Creek sub-basin)	N/A. Maules Creek Formation split into 3 layers	S	Calibration - 1985 – mid 2010, 306 monthly SPs Prediction – mid 2010 to 2099 – 19.5 years monthly, then annual
Narrabri CSG - Gunnedah Basin Regional Model	CDM Smith 2016	Coal Seam Gas impact assessment	Modflow Surfact	53,219	1,000 x 1,000 – 5,000 x 5,000	24	SS*	Y	N (in Maules Creek sub-basin)	N/A. Maules Creek Formation split into 5 layers	S*	Calibration – SS – flux matching Prediction – 1997 – 2041, annual SPs, plus 1475 year recovery period Alluvials modelled as one layer only *Calibration completed via flow boundary flux matching to produce observed heads rather than varying parameters. Traditional calibration and sensitivity not appropriate
Bioregional assessment – Namoi catchment	Janardhanan et al 2018	Impact assessment	Modflow USG – Voroni grid	59,000	300 – 3000 Voroni grid	9	SS & TR	Y	N	Maules Creek Formation = 1 layer only	S & U	Calibration – 1983 – 2012 Prediction - from 2012 to 2102
Vickery Coal	Heritage Computing 2013	Coal mine impact assessment	Modflow Surfact	957	50 - 500	14	SS & TR	Y	Y – 5 groups	Whitehaven seam (Different naming of deeper seams to those in BTM area)	S	Calibration – 2006 – 2011, 72 monthly SPs Prediction - 2012 to 2042, annual SPs, plus 200 year recovery model Model extends northwards from Vickery and includes Tarrawonga Mine but not Boggabri or Maules Creek mines
Vickery Coal	HydroSimulations 2018	Coal mine impact assessment	Modflow USG – rectangular grid	957	100 x 100	14	Pseudo SS (10,000 year) &TR	Y	Y – 5 groups	Whitehaven seam (Different naming of deeper seams to those in BTM area)	S	Calibration – 2006 – 2011, 72 monthly SPs Verification – 2012 – 2017, 6 month or annual SPs Prediction - 2018 to 2044, annual SPs, plus recovery model Long model run time precluded PEST based sensitivity analysis Model extends northwards from Vickery and includes Tarrawonga Mine but not Boggabri or Maules Creek mines

Notes: Y: Yes; S: sensitivity; TR: transient; N: No; SP: stress period(s); U: uncertainty; L: model layer; SS: steady state

9 Model objectives and requirements

9.1 Objectives and intended model use

The conditions of the project approval for each of the mines in the BTM complex require *"a program to validate the groundwater model for the project, including an independent review of the model every three years and comparison of the monitoring results with modelled predictions.", as well as "a Leard Forest Mining Precinct Water Management Strategy that has been prepared in consultation with other mines in the precinct to …..coordinate modelling programs for validation, recalibration and re-running of the groundwater and surface water models using approved mine operations plans.*

The objective of the groundwater modelling is to satisfy the above project approval conditions relating to modelling. The project approval conditions provide no guidance on the methodology for the three-yearly update, but simply state it should be undertaken. The work described by AGE (2018) represented the first coordinated effort between the BTM mines to validate, update, recalibrate and re-run impacts predicted for the BTM complex.

The review conducted by DPIE-Water and NRAR of AGE (2018) provided feedback on the interpretation of data, and the methodology/outcomes of numerical modelling. The objective of the current update is address comments from DPIE-Water/NRAR and improve how the numerical model represents the groundwater regime of the BTM complex.

The purpose of continuing validation and re-running of the model is to determine if environmental impacts are significantly different to those determined during the approvals process. It is important to note that model predictions will change over time as new data becomes available and the models are improved. Whilst the model predictions will unavoidably change, this does not mean that the environmental impact of those predictions necessarily differs.

The updated numerical model is used to assess the nature of environmental impacts over the life of BTM Complex projects including:

- drawdown in the surrounding alluvial aquifer impacting on the yield of private water supply bores and groundwater dependent ecosystems;
- drawdown in the alluvial aquifer impacting on the baseflow in creeks/rivers and surface water expression; and
- water take from each water source exceeding volumes allocated from water licenses held by the BTM complex.

9.2 Key measures of modelling success

A successful model for the BTM complex provides predictions of future environmental impacts that are useful for all stakeholders. This does not mean that the model can perfectly represent past and future changes within the groundwater regime in the BTM study area, but simply that it is useful tool to guide environmental monitoring and management of the groundwater systems. Accurately matching historical water levels and water flows does not necessarily mean a model can predict future behaviour of a groundwater system. Therefore, a successful model is considered one where predictions are provided with acknowledgement that continuous improvement over time is warranted.

No groundwater models prepared for the BTM complex have predicted the mining will create widespread drawdown within the surrounding alluvial aquifer, and monitoring to date has validated these predictions. Groundwater monitoring data is always overprinted with the influence of climatic conditions and the challenge when interpreting this data is to separate the influence of mining from other stressors such as irrigation and climatic conditions including drought. Therefore, a successful numerical model is considered one that assists in interpreting environmental monitoring data by separating mining influences from other stressors. This can only be done looking backwards as future climatic conditions including rainfall are not known.

Another common measure of success is for the model to match measured water levels with less than 5% error (scaled root mean squared error). Groundwater professionals are moving away from this being a primary indicator of calibration, and for the BTM complex it is not considered the most important measure of success. It is considered a successful model for the BTM complex will be able to replicate the main environmental processes occurring within the complex and immediate surrounds including magnitude, timing and extent of depressurisation detected through the monitoring data.

10 Model construction and development

10.1 Model code

The model was developed using the MODFLOW-USG (MFUSG) modelling package, which is consistent with the approach adopted in the AGE (2018) model. MFUSG is considered superior to previous versions of MODFLOW as it allows the use of an unstructured model mesh (from triangles to n-sided polygons), meaning that the model grid can be designed to fit environmental features such as rivers, water bodies and excavations etc. MFUSG is numerically stable and does not require continuous layers; meaning it can simulate geological units that pinch out or subcrop, such as coal seams. Flow transfer processes between layers that are not directly connected such as bedrock and alluvium can therefore be more accurately represented and simulated.

The amount of water level data available for the BTM complex now means that trial and error selection of model properties is not an efficient method to calibrate the model. The typically faster run times associated with MFUSG mean that the code is well-suited to automated calibration. In addition, MFUSG is not restricted by licence agreements, allowing numerous iterations of the model to be run simultaneously. This can reduce the total time taken for model calibration, and uncertainty analysis where required.

The model was created using Fortran code and a MODFLOW-USG edition of the Groundwater Data Utilities by Watermark Numerical Computing. The model mesh was updated using Algomesh (HydroAlgorithmics, 2014).

10.2 Model design

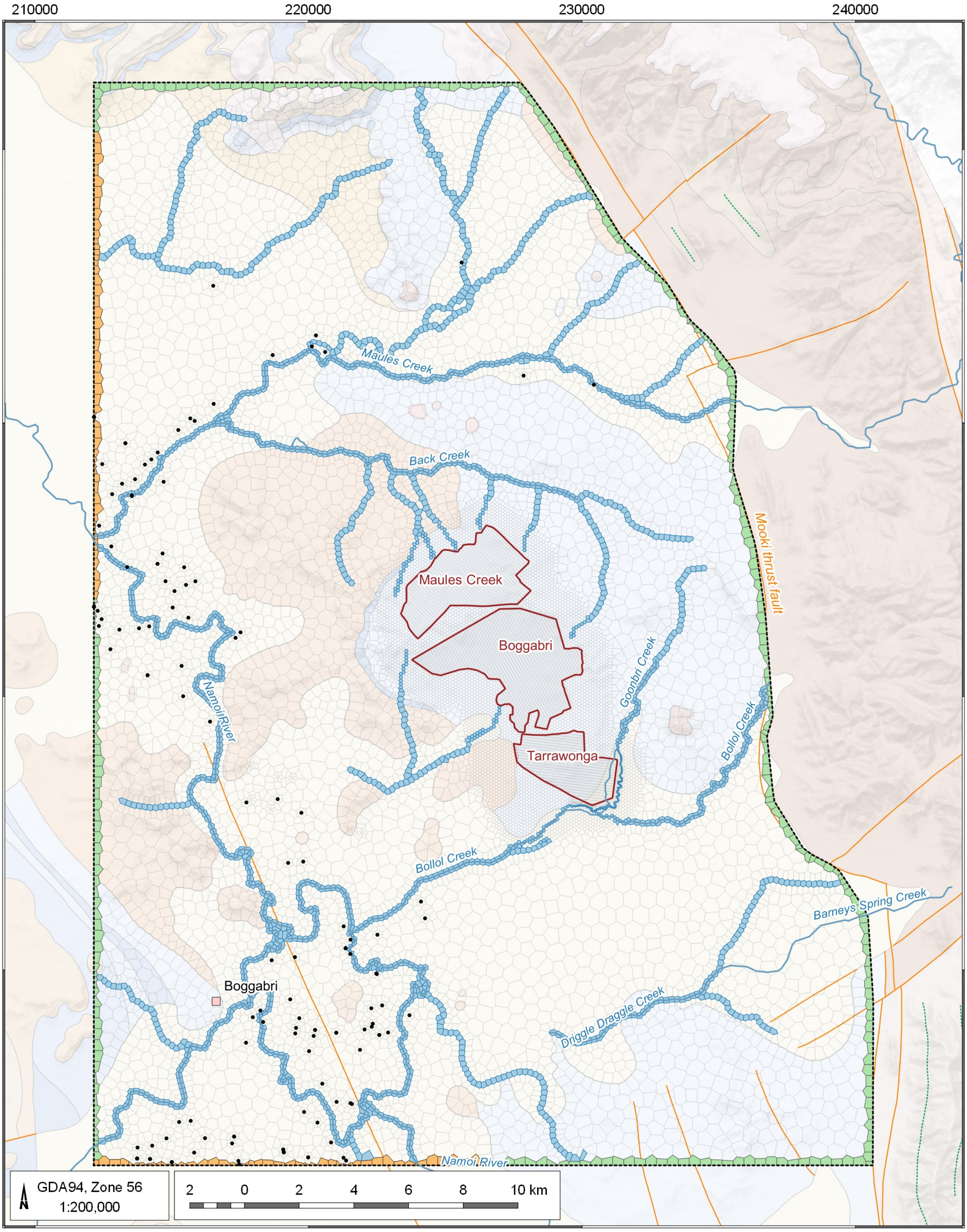
10.2.1 Extent and boundaries

The model domain was centred on the approved mining activities in the BTM complex. The model covers the main sensitive receptors, being alluvial management zones to the north, west and south of the complex. The eastern extent of the model is constrained by the Mooki Thrust System, which represents the extent of the Maules Creek sub-basin, and a change in hydrogeological regime to an area less sensitive to environmental impact from the BTM complex. The model domain is approximately 30 km wide and 40 km long, with the Mooki Thrust System defining the eastern edge of the model, as shown in Figure 10.1. The adopted model extent remains the same as the previous version of the model, which is documented in AGE (2018).

Boundary conditions are consistent with conceptual hydrogeological understandings of the area, with groundwater flow in/out of the model largely occurring through the alluvium, and the Mooki Thrust system representing a change in hydrogeological regime. Adopted boundary conditions are:

- a ‘no flow’ boundary along the Mooki Thrust System (eastern model extent) (all layers);
- General Head Boundaries (GHB) in alluvial layers along sections of the southern and western boundaries of the model (Figure 10.1), where alluvial groundwater enters and leaves the model, respectively (layers 1 and 2); and
- ‘no flow’ boundaries along the remainder of the northern, western and southern boundaries (all layers).

The adoption of no flow boundaries is considered suitable given that the major sources of groundwater are conceptualised to be through local rainfall recharge, as well as flow through the Namoi River alluvium, from the south-southeast to the north-northwest. Rainfall recharge is modelled using the recharge package (see Section 10.3.1), while the southern and western GHBs are used to simulate flow through the Namoi River alluvium. The adoption of no flow boundaries along the Mooki Thrust System is appropriate given that this feature is conceptualised to represent a groundwater divide, and the implementation of no flow boundaries at this location is consistent with contemporary modelling completed as part of the bioregional assessment (Janardhanan et al. 2018). No flow boundaries that are adopted along the northern, western and southern boundaries almost entirely correspond to areas of bedrock, where groundwater fluxes are expected to be minor. Additionally, the implementation of no flow boundaries is a conservative approach when modelling the impacts of mining. A widespread implementation of GHBs would have the potential to provide excess water to the model, which could erroneously dampen impacts, particularly when considering that observations along these boundaries are sparse.



LEGEND

- Populated place
- Abstraction bore
- Major drainage
- Mine maximum open cut outlines
- Model extent
- General head boundary (layers 1-2)/no flow boundary (layers 3-34)
- No flow boundary (layers 1-34)
- River cell
- Mesh

Gunnedah Coalfield rock unit (1:100k)

- Qx - Quaternary Sediments
- Tv - Tertiary Volcanics
- Pmx - Maules Creek and Goonbri formations
- Plf - Leard Formation
- Pbr - Boggabri Volcanics
- Cbc - Currabubula Formation
- Crc - Rocky Creek Conglomerate
- Fault

BTM Complex Groundwater Model Update (G1850P)

Model domain

AGE

DATE 30/08/2021

FIGURE No: **10.1**

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Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\10.01_G1850_Model domain.qgs

10.2.1.1 Consideration of other mining activities

Mining operations that were not incorporated into this numerical model and the rationale for not including these operations are detailed below.

- Modification 7 for the Tarrawonga Mine – The approval for this modification was granted in February 2021, which postdates the numerical modelling completed for this project (calibration and predictions finalised by September 2020). The groundwater assessment for the Tarrawonga modification (HydroSimulations, 2019) indicates that a reduction in the extent of the open cut reduces the impact of the operation to surrounding groundwater systems. As such, the modelling completed as part of this assessment can be considered a conservative prediction of cumulative impacts.
- The Vickery Mine (~ 14 km south of BTM complex centre) – Groundwater modelling that was completed as part of the EIS for Vickery Mine Extension SSD (HydroSimulations, 2018) predicts that the maximum water table drawdown will largely be limited to the area of Permian outcrop adjacent to the operation. As such, when considered in addition to the BTM Complex mines, any significant cumulative impacts to alluvial aquifers are unlikely.
- The Narrabri Mine (27 km west-northwest of BTM complex centre) – Mining as part of this operation takes place in Mullaley Sub-basin, which is separated by the Boggabri Ridge from Maules Creek Sub-basin that is mined by the BTM complex. The Boggabri Ridge is comprised of the Boggabri Volcanics, which are known to be of very low permeability/impermeable, and cumulative impacts within each of the respective coal measures is therefore unlikely. Additionally the high groundwater storage within the Namoi River alluvium also acts as an effective boundary condition between the mining areas. Finally, neither the BTM Complex or the Narrabri mine are modelled to generate any significant or extensive drawdown in the Namoi alluvium that would generate a cumulative impact (AGE 2018; AGE, 2020).

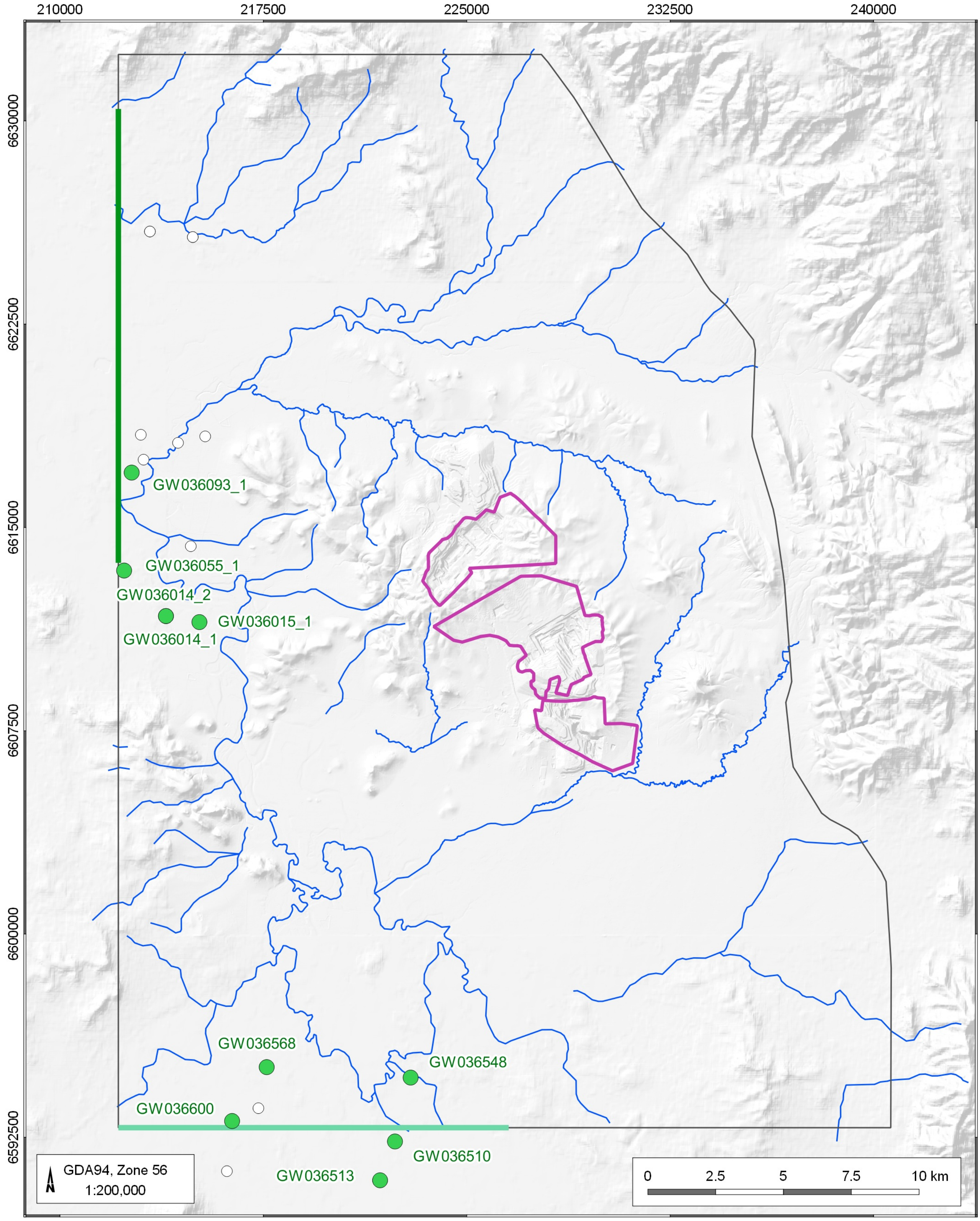
10.2.2 General head boundaries

Groundwater levels at the general head boundaries were determined based on the average groundwater levels measured in monitoring bores in proximity to the model boundary. The GHBs were setup in the numerical groundwater model to represent alluvial groundwater entering and leaving the model. The GHB zones are displayed in Figure 10.2. The GHB cells were only represented in model layers 1 and 2 to represent flow in the Quaternary alluvium.

An analysis of observed groundwater levels in the vicinity of each GHB zone was performed with the objective of establishing the input levels for the numerical simulation. The existing government bores are displayed in Figure 10.2, and their levels are presented in Figure 10.3 to Figure 10.6.

Figure 10.3 includes all the levels available in the vicinity of the Western GHB since 2005 (the numerical simulation starts in 2006). High variability across the levels from different monitoring bores can be observed, with some relatively high levels caused possibly by locally perched groundwater, and some lower levels where pumping abstraction is evident. Both of those effects have a masking effect over the less disturbed groundwater level of the general alluvial system; and were therefore filtered out in Figure 10.4. Figure 10.4 displays the levels that better represent the less disturbed alluvial groundwater system. The levels displayed in Figure 10.4 are relatively well grouped and oscillate together, suggesting they do not represent localised perched systems; they also display less pumping effects compared to the previous figure. The groundwater level in the bores displayed in Figure 10.4 oscillates around 225 mAHD, and therefore this value was used in the setup of the Western GHB in the numerical groundwater model.

Figure 10.5 includes all the levels available in its vicinity since 2005. High variability across the levels from different monitoring bores can be observed, with a few relatively high levels again possibly caused by locally perched groundwater, and some lower levels where pumping abstraction is again evident. Again, these effects were filtered out in Figure 10.6 to determine the level to adopt in the numerical model. The groundwater level in the bores displayed in Figure 10.6 oscillates around 235 mAHD, and therefore this value was used in the setup of the Southern GHB in the numerical groundwater model.



LEGEND

Monitoring bores used in model

- no
- yes

GHB zones

- south
- west

- Drainage
- Mine outline
- Model extent

BTM Complex Groundwater Model Update (G1850P)

GHB boundaries and monitoring locations in their vicinity

AGE

DATE 23/06/2021

FIGURE No: **10.2**

©2021 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\10.02_G1850_GHB boundaries and monitoring locations in their vicinity.qgs

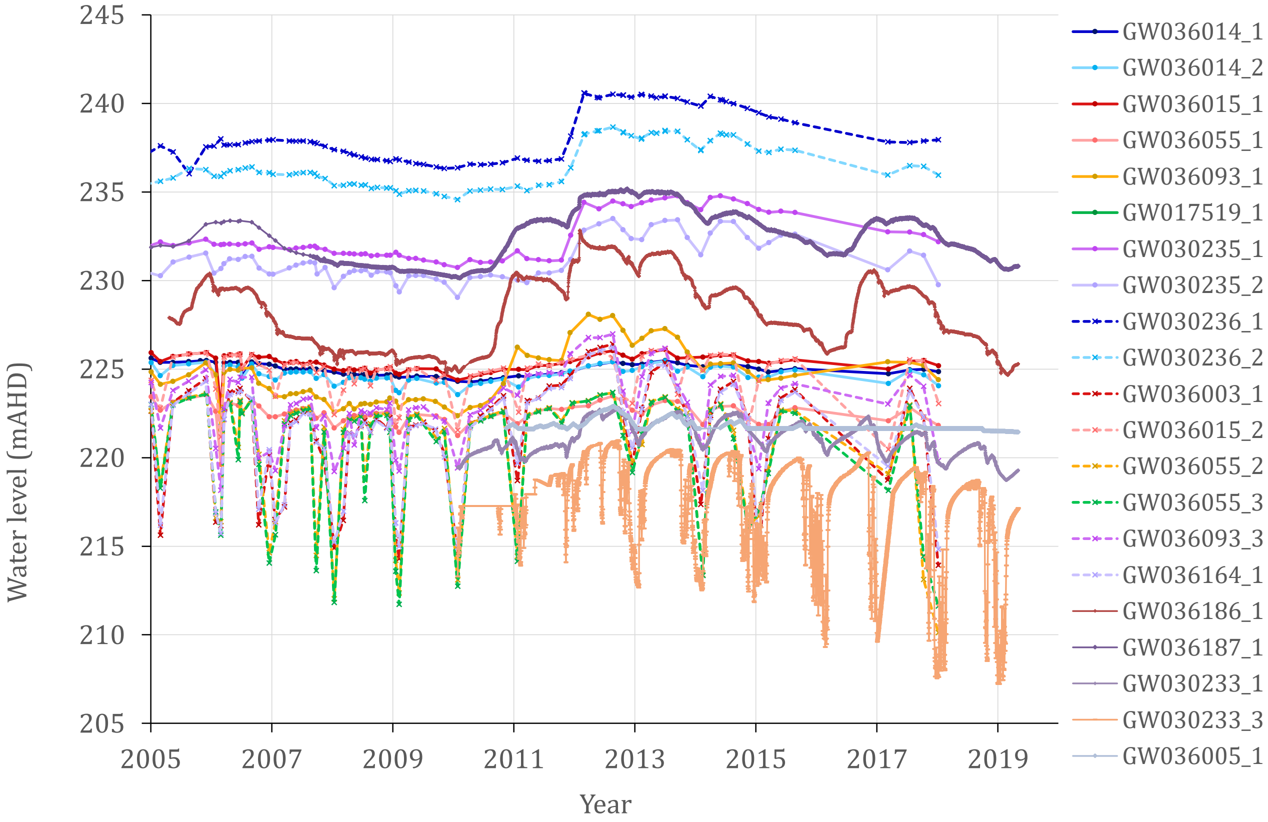


Figure 10.3 Observed groundwater levels in the vicinity of the Western GHB

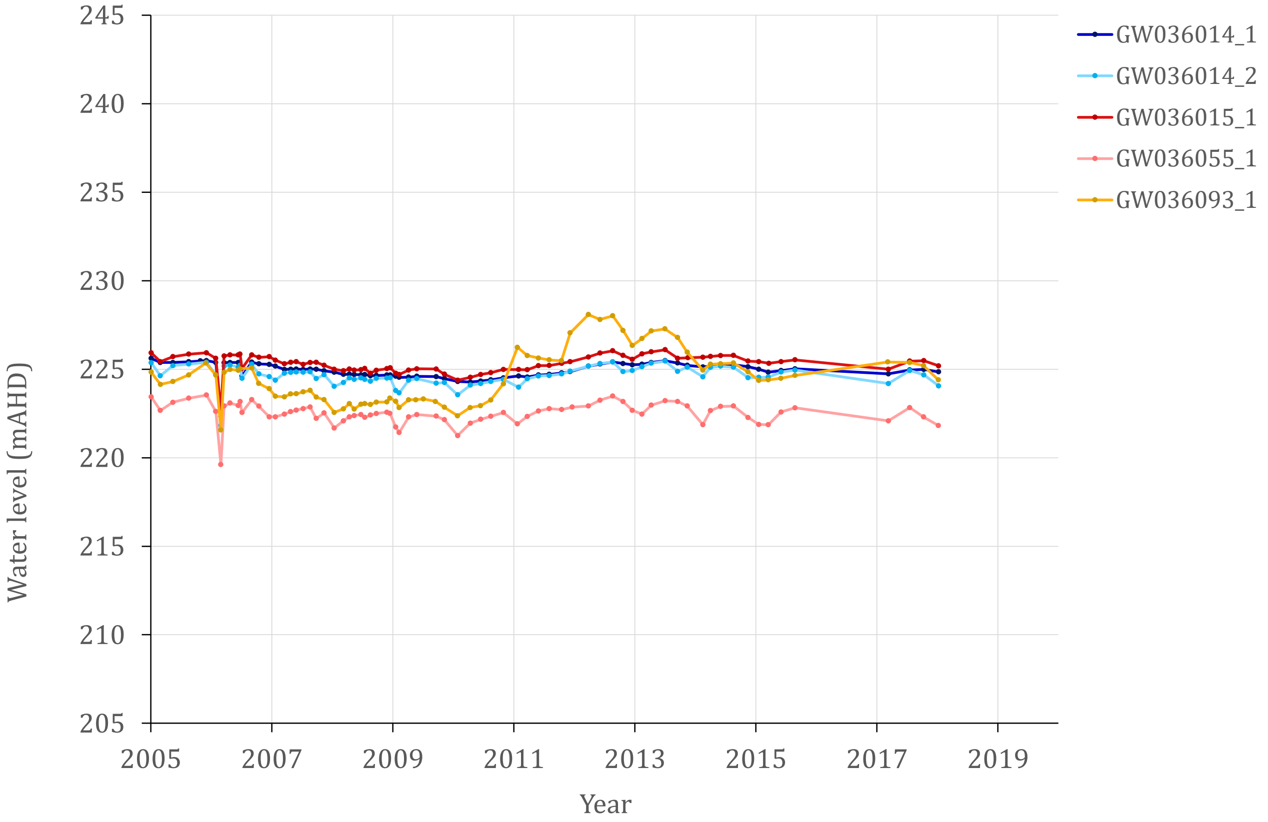


Figure 10.4 Subset of the observed groundwater levels in the vicinity of the Western GHB

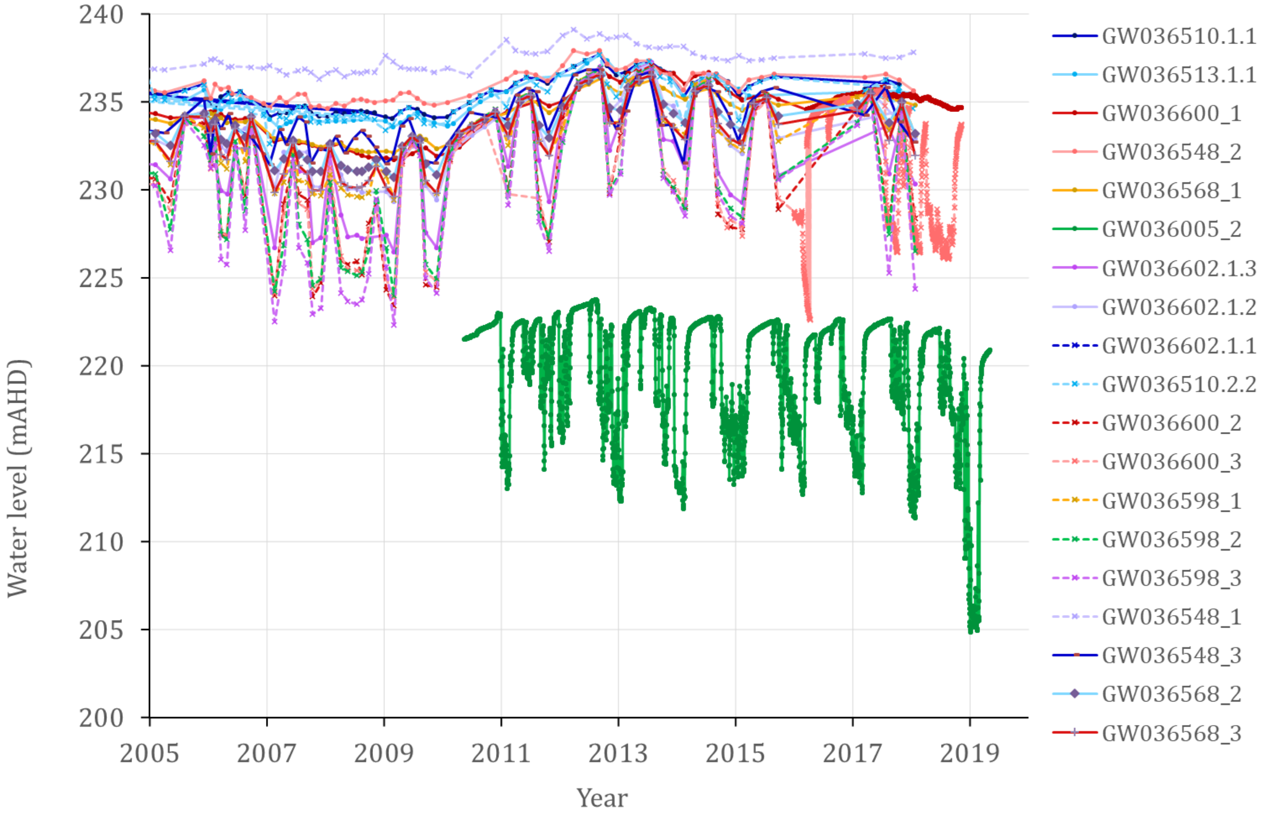


Figure 10.5 Observed groundwater levels in the vicinity of the Southern GHB

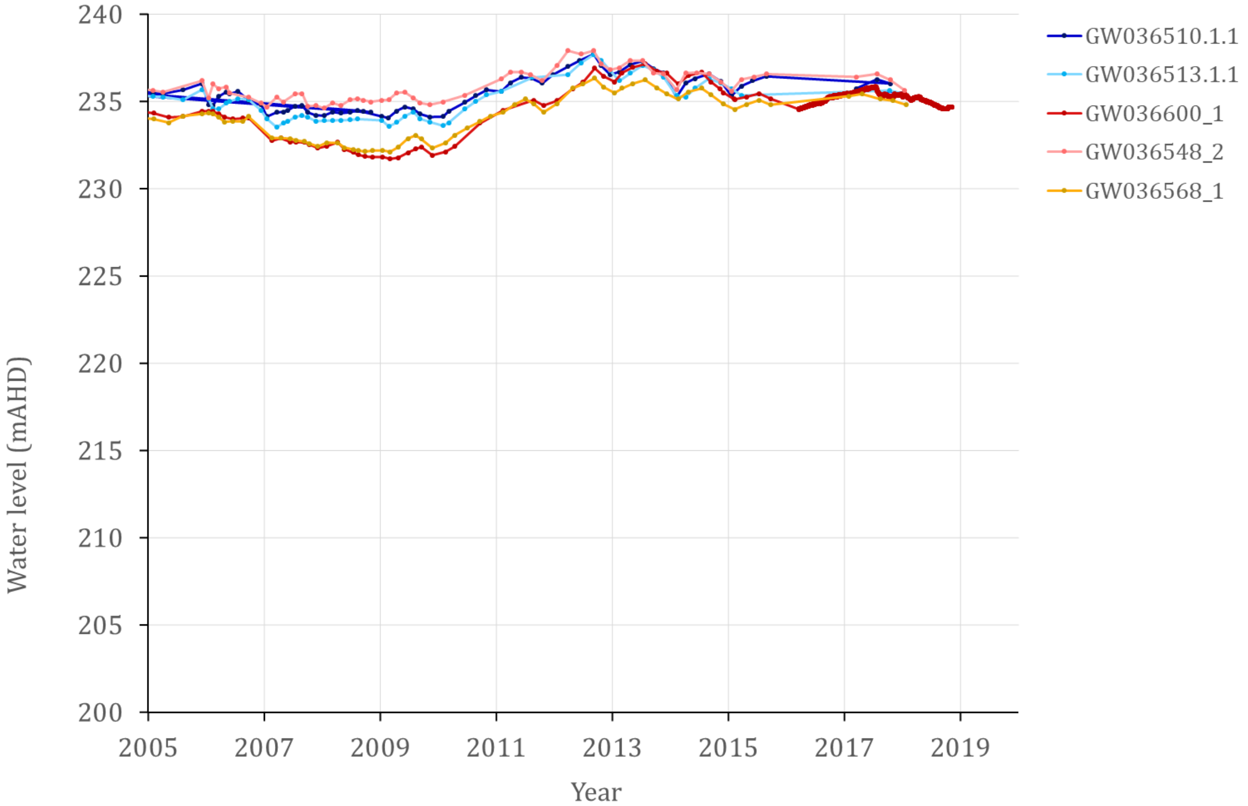


Figure 10.6 Subset of the observed groundwater levels in the vicinity of the Southern GHB

10.2.3 Grid

The model domain was discretised into 339,855 total model cells with a maximum of 18,920 cells in any one layer. The model cells varied in size and geometry to best represent different environmental and mining features throughout the model domain, as shown in Figure 10.1. The model grid was comprised of two types of cells, namely rectangular cells aligned with the primary direction of mining for each of BTM mines, and voronoi polygons for the remainder of the model area. Cell sizes were selected to ensure the following important features could be represented with adequate detail, while still ensuring the cell count was not prohibitive for model stability/run time:

- open cut mines – 50 m x 100 m orthogonal grid;
- areas surrounding open cut mines - Voronoi grid with up to 120 m between cell centres;
- streams and alluvial flood plains - Voronoi grid with up to 220 m between cell centres;
- adjacent to active extraction bores - Voronoi grid with approximately 175 m diameter;
- adjacent to inferred Conomos Fault - Voronoi grid with approximately 450 m x 350 m cells; and

Within the remainder of the model domain, larger Voronoi grids were adopted, with up to 800 m between cell centres.

10.2.4 Model layers

The key hydrostratigraphic units identified in the conceptual model are represented in the numerical model by 34 separate model layers (Table 10.1). Previous versions of the BTM complex numerical model have lumped the 16 known coal seams into 'super seams' that represent multiple coal seams in single layers in the numerical model. This approach has been taken in the past to ensure the run time of the numerical model remained manageable.

The updated version of the model resulted in an increase in the number of model layers from 19 model layers AGE (2018) model to 34 in the current version representing a gradual improvement in the representation of the hydrostratigraphic units (Table 10.1). The purpose of introducing the additional model layers was to improve the ability of the model to represent observed pressure heads in coal seam bores and VWPs.

Table 10.1 Model layer changes

Model layer		Geological unit
2018 model	2019 model	
1	1	Narrabri Formation (alluvium)
2	2	Gunnedah Formation (alluvium)
3	3	Interburden
4	4	Interburden
5	5	Herndale seam
5	5	Onavale Seam
5	5	Teston Seam
5	5	Thornfield Seam
6	6	Interburden
7	7	Interburden
8	8	Braymont Seam
8	9	Interburden
8	10	Interburden

Model layer		Geological unit
2018 model	2019 model	
8	11	Bollol Creek Seam
8	12	Interburden
8	13	Interburden
8	14	Jeralong Seam
8	15	Interburden
8	16	Interburden
8	17	Merriown Seam
9	18	Interburden
10	19	Interburden
11	20	Velyama Seam
11	20	Nagero Seam
12	21	Interburden
13	22	Interburden
14	23	Upper Northam Seam
14	23	Lower Northam Seam
14	24	Interburden
14	25	Interburden
14	26	Therribri A Seam
14	26	Therribri B Seam
14	27	Interburden
14	28	Interburden
14	29	Flixton Seam
15	-	Interburden
16	-	Interburden
17	29	Tarrawonga Seam
17	30	Interburden
17	31	Interburden
17	32	Templemore Seam
18	33	Interburden
19	34	Volcanics

Updates were also made to the elevation of the selected layers in the numerical model based on new information collected from a range of sources. Table 10.2 details the geological datasets used to update the elevation of selected model layers.

Table 10.2 Geological model data sources

Data source	Area of application in numerical model	Changed from AGE (2018)	Note
Geological models from BTM mines [a]	Within each mines footprint	Yes	Surfaces updated including topography, base of weathering, coal seams, interburden and basement volcanics
JB Mining (2010) regional geological model	Entire model extent outside of each mine's disturbance footprint	No unchanged	Only includes coal measures and basement volcanics
CSIRO depth of regolith dataset [b]	Entire model extent outside of each mine's disturbance footprint	Yes	No regolith/weathering applied under areas of alluvium
NSW Government Upper Namoi alluvial groundwater flow model [c]	Used to update base of alluvium	Yes	Alluvial groundwater information provided by NSW Government.
NSW Government 5 m DEM [c]	Entire model extent outside of each mine's disturbance footprint	Yes	2016 acquisition date

Notes: [a] Model surfaces for Boggabri, Tarrawonga and Maules Creek Mines received in May 2019.
[b] https://aclep.csiro.au/aclep/soillandlandscapegrid/.
[c] https://elevation.fsdf.org.au.

The model layers for the coal seams in previous iterations of the BTM complex numerical model were based on a regional geological model prepared by JB Mining (2010) as part of the Maules Creek Mine approval process. The coal seam surfaces in the numerical model were updated in the mining areas using geological models provided by each of the BTM complex mines. The geological surfaces provided by each mine were combined into a single geological model created using Seequent's Leapfrog Geo software package before being imported into the numerical model.

The NSW government also provided surfaces from an updated numerical groundwater flow model of the Namoi alluvium. The layers from this model were used to update the elevation of the alluvium in the BTM complex model. The land surface in the model and the depth of regolith was also updated using publicly available datasets as detailed in Table 10.2.

The updates to the numerical model layers resulted in improved representation of geological layers as well as terrain features including regional drainage lines.

10.2.5 Geological structures

Smaller localised faults, which have been observed in each mine's open cut pit, are conceptualised to have no significant impact on regional flow. These faults are not represented in the numerical model.

The Conomos Fault was identified during the model update through consultation with geologists working at the BTM complex. As discussed in Section 5.8, the Conomos Fault appears to be a significant geological feature and has an interpreted displacement of 60 m to 90 m immediately to the south of Tarrawonga operations. Given the potential for this fault to cut and offset the continuity of the coal seams to the south of the BTM complex it was represented as a barrier to groundwater flow in the updated numerical model in layers 3 and below. The conductance was allowed to vary between 0% and 100% during calibration (see Section 11.3.3).

The Mooki Thrust System is represented as a no flow barrier as it represents the boundary between the edge of the Maules Creek sub-basin and the non-coal New England fold belt.

10.2.6 Timing

To guide the model calibration, an initial steady state calibration to obtain pre-mining conditions was undertaken. This was followed by a transient simulation for the purposes of calibration, where groundwater levels and flows were matched to available measurements. Stress periods remained consistent with AGE (2018), i.e. quarterly stress periods (91.25 days), with the updated transient model consisting of 55 quarterly stress periods running from January 2006 to June 2019. Predictive modelling ran to December 2036, which was selected as this date is when the last of the BTM mines is approved to operate based on current approvals.

10.2.7 Mining progression

Time dependant mining progressions were used to represent approved mining in the model and were established using pit shell surfaces for historical progressions, with 3D staged mine plan surfaces/polygons used for future progressions. Datasets were provided independently by Boggabri, Tarrawonga and Maules Creek mines. The mine plans adopted in Boggabri and Tarrawonga remained the same as those adopted in the AGE (2018) model. A summary of the adopted data is provided below in Table 10.3.

Table 10.3 Mining progression dataset details

Mine	Year historical pit shells available to	Year mine plans extend to	Deepest seam intersected by mining	Equivalent layer in groundwater model
Boggabri	2018	2033	Merriown	17
Tarrawonga	2019	2029	Nagero	20
Maules Creek	2019	2035	Templemore	32

The timing and location of mining represented within the numerical model contains an unavoidable element of uncertainty. Middlemis and Peeters (2018) categorise this as ‘scenario uncertainty’. This is because records of historical mining can be difficult to obtain, or are necessarily simplified and assumptions on the progress of mining operations, particularly older operations are therefore required. The exact advancement of future mining operations is also uncertain as all mining operations are subject to market conditions that can alter the economics of projects. The historical and future mining represented within the numerical model should therefore be considered a guide rather than highly accurate. Despite these unavoidable limitations, the model is considered to largely have mining represented where it has occurred historically and is approved to occur in the future; it is only the timing and elevation of the mining that has a level of uncertainty.

The uncertainty in the location and progression of mining has potential to influence the calibration of the model in areas where water level calibration points are situated in close proximity to mining activities. In areas more distant from mining activities the uncertainties in the historical progression of mining obviously become less influential on the model predictions.

The requirement to update the BTM complex model every three years addresses this uncertainty by allowing changes in schedules to be represented in the updated models, and also for validation of predictions or further calibration utilising new monitoring and parameter datasets.

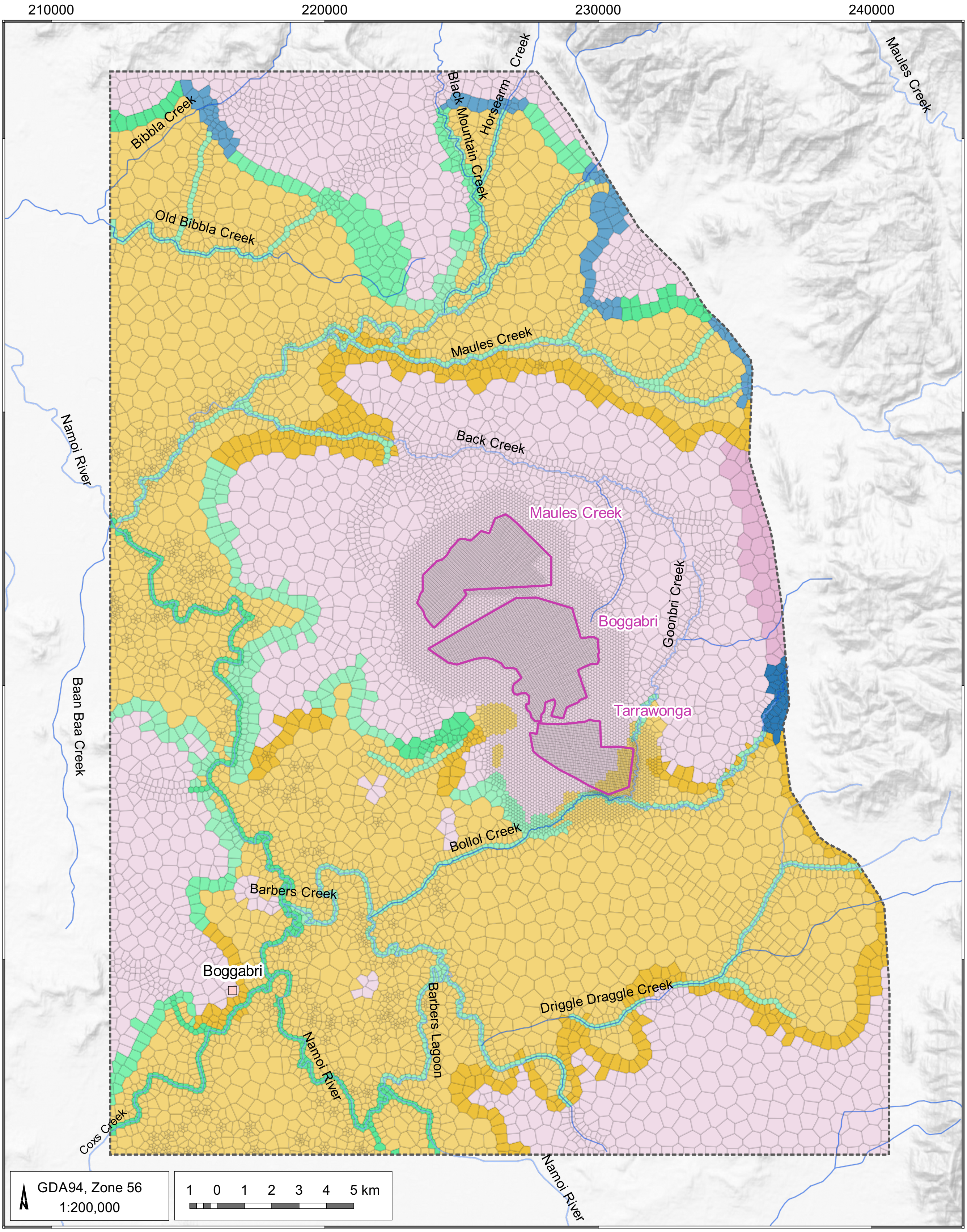
10.3 System stresses

10.3.1 Recharge

Groundwater recharge occurs via diffuse infiltration of rainfall through the soil profile and subsequent deep drainage to underlying groundwater systems. The MODFLOW USG recharge package (RCH) was used to represent diffuse rainfall recharge to model layer 1. The upstream weighting function with the CONSTANTCV option was selected and therefore flow through the vadose zone was not simulated in the model. Several different recharge zones were assigned and include the Permian coal measures, the Boggabri Volcanics, the alluvial flood plain, creek bed/drainage features within the alluvium, and break of slope areas (Figure 10.7).

A spreadsheet based soil moisture balance (see Section 7.1.1) was used to guide the groundwater recharge rates that were used as part of the model calibration process. The timing and magnitude of these recharge events were used to calibrate recharge to the alluvial flood plains, while only the timing was used to estimate when the soil profile was fully saturated following rainfall, and subsequently when deep drainage to the water table occurred. Based on this timing, the 'base' alluvial recharge rates were factored down within the Permian coal measures/volcanics recharge zones and factored up within the break of slope/waterway zones.

Recharge rates within each zone are presented in Figure 10.7. Recharge to the Permian coal measures and Boggabri Volcanics was negligible at 0 mm/year to 0.8 mm/year, although recharge was enhanced at the break of slope along the Permian Ridge. Recharge to the alluvium ranged from 20 mm/year to 30 mm/year and was enhanced along waterways within the alluvial zones (40 mm/year to 100 mm/year), representing losses from losing streams during flow events.



LEGEND

- Populated place
- Drainage
- Model mesh
- Model extent
- Mine outline

Recharge (mm/year)

- 0.0 - 0.8
- 0.8 - 2
- 2 - 20
- 20 - 30
- 30 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 200
- 200 - 400

BTM Complex Groundwater Model Update (G1850P)

Rainfall recharge zones

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DATE 23/06/2021

FIGURE No: **10.7**

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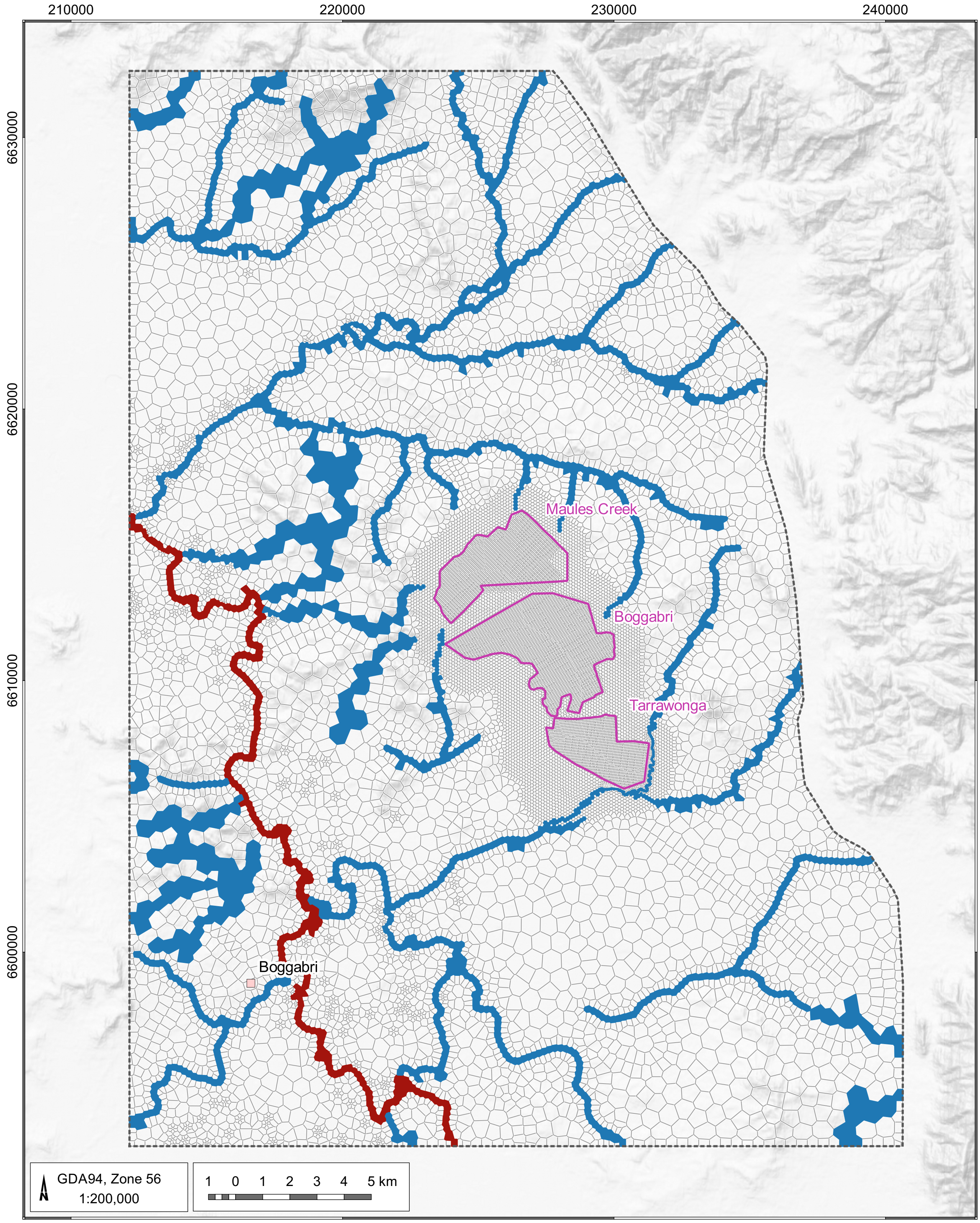
10.3.2 Surface drainage

As previously discussed, surface water features in the area are largely ephemeral (excluding the Namoi River) and are conceptualised to recharge the underlying groundwater systems during periods of flow. This surface water to groundwater flux is modelled through the use of the recharge package, where recharge to these features is 1.3 to 3.3 times higher than that of the alluvial areas that are located away from these creeks (see Section 10.3.1). To model situations where this flux could be reversed, i.e. groundwater gaining streams, the major ephemeral creeks were represented using the MODFLOW river package (RIV) (Figure 10.8 and Figure 10.9). Generally, groundwater gaining streams are only conceptualised to be present during significant recharge events where the alluvium is saturated to an extent that results in the water table rising to a higher elevation than the creek beds. The river cells in the model were assigned a water level equal to the bed elevation of the creek, hence they can only simulate the "drainage" of water out of the aquifer where and when the groundwater levels are high enough. The bed levels for the creeks represented by RIV were based on previous observations over the area and were set by subtracting the average river depth from the topography. All creek beds were less than or equal to 1.9 m deep based on observations in the region. Modelled RIV parameters are detailed below in Table 10.4.

Perennial groundwater gaining surface water features are limited to sections of the Namoi River, which was represented using the MODFLOW stream (STR) package (Figure 10.8 and Figure 10.9), with a 30 m wide, 2 m thick sloping stream bed incised 1.9 m into the landscape (Table 10.4). Flow in the river from outside of the model domain was simulated using quarterly flow observations at the upstream model boundary.

The river cells in the model were assigned a water level equal to the base elevation, hence they can only simulate the "drainage" of water out of the aquifer where and when the groundwater levels are high enough. The proposed alignment of the Goonbri Creek diversion was represented in the model from the commencement of the calibration period in 2006. The water table within the model was below the base of Goonbri Creek and therefore the calibration was not considered sensitive to the creek location as it does not interact with shallow groundwater.



LEGEND

Populated place
Drainage
Model extent
Model mesh
Mine outline
River package
Stream package

BTM Complex Groundwater Model Update (G1850P)

River and surface drainage cells

AGE

DATE 23/06/2021

FIGURE No: **10.8**

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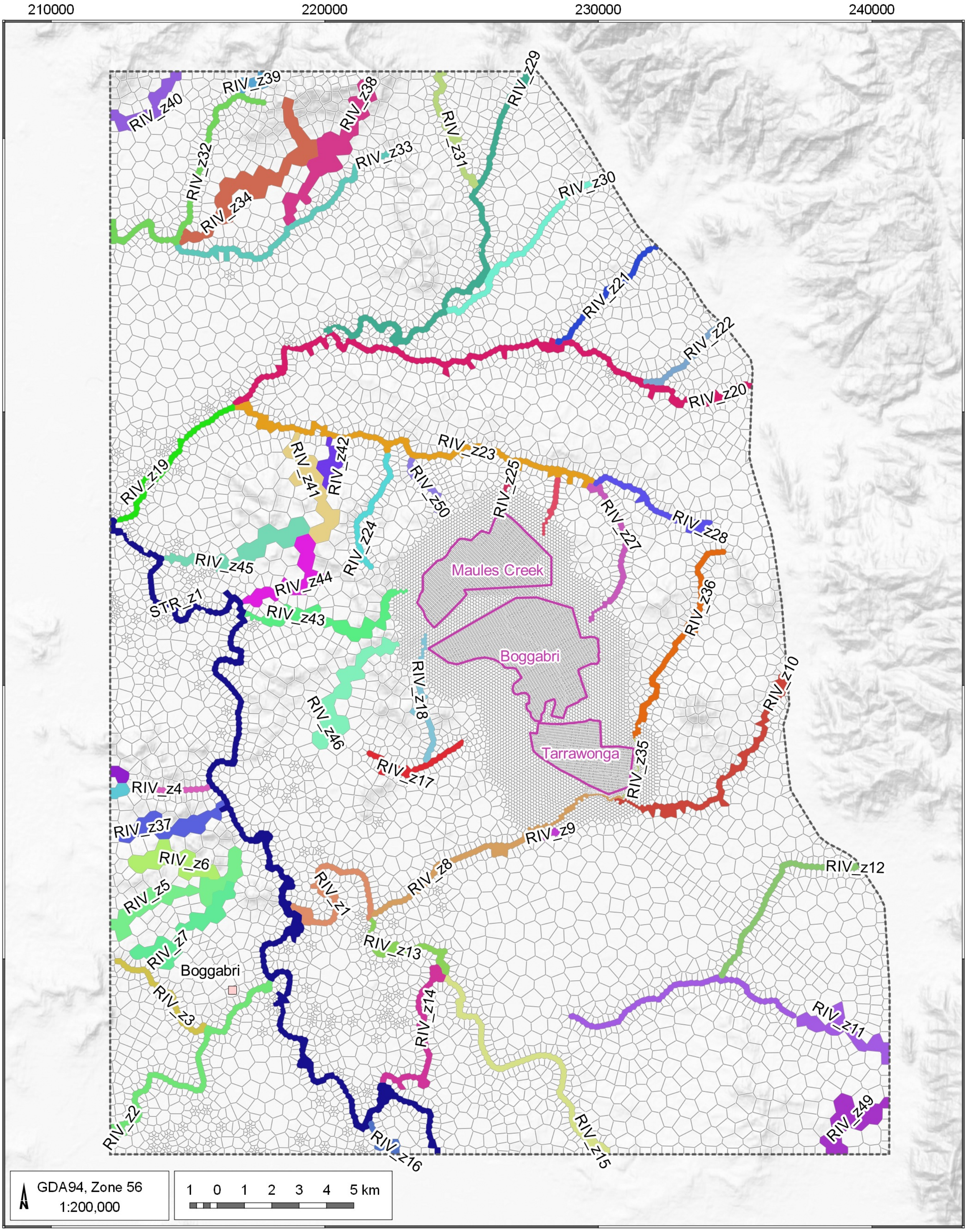

LEGEND

- Populated place
- Drainage
- Model extent
- Model mesh
- Mine outline

Stream zone (STR_z1)

- 1

River zones (RIV_z13)

1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50

BTM Complex Groundwater Model Update (G1850P)

Rivers and surface drainage cells – zones

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FIGURE No: **10.9**

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Table 10.4 Modelled RIV/STR parameters

ID	Kv (m/day)	Width (m)	Bed thickness (m)	Incision depth (m)	Slope	Manning's coefficient
STR_z1	0.09	30	2	1.9	0.004	0.03
RIV_z1	1	10	2	1.9	-	-
RIV_z2	1	15	1	3	-	-
RIV_z3	1	15	1	3	-	-
RIV_z4	1	5	1	0.4	-	-
RIV_z5	1	5	1	0.5	-	-
RIV_z6	1	5	1	0.5	-	-
RIV_z7	1	5	1	0.5	-	-
RIV_z8	1	5	1	0.2	-	-
RIV_z9	1	5	1	0.2	-	-
RIV_z10	1	5	1	0.2	-	-
RIV_z11	1	5	1	0.5	-	-
RIV_z12	1	5	1	0.5	-	-
RIV_z13	1	10	2	1.9	-	-
RIV_z14	1	10	2	1.9	-	-
RIV_z15	1	5	1	1	-	-
RIV_z16	1	5	1	1	-	-
RIV_z17	1	5	1	0.5	-	-
RIV_z18	1	5	1	0.5	-	-
RIV_z19	1	10	1	0	-	-
RIV_z20	1	10	1	0	-	-
RIV_z21	1	5	1	0.8	-	-
RIV_z22	1	5	1	0.8	-	-
RIV_z23	1	4	1	0	-	-
RIV_z24	1	2	1	0.5	-	-
RIV_z25	1	2	1	0.5	-	-
RIV_z26	1	2	1	0.5	-	-
RIV_z27	1	2	1	0	-	-
RIV_z28	1	2	1	0.5	-	-
RIV_z29	1	30	1	1	-	-
RIV_z30	1	15	1	1	-	-
RIV_z31	1	15	1	1	-	-
RIV_z32	1	10	1	0.5	-	-
RIV_z33	1	10	1	0.5	-	-

ID	Kv (m/day)	Width (m)	Bed thickness (m)	Incision depth (m)	Slope	Manning's coefficient
RIV_z34	1	10	1	0.5	-	-
RIV_z35	1	3	1	0.5	-	-
RIV_z36	1	3	1	0	-	-
RIV_z37	1	5	1	0.5	-	-

Note: - not applicable

10.3.3 Evapotranspiration

A review of the depth to water table was undertaken to determine if evapotranspiration was a significant discharge mechanism for groundwater in the region. The steady state numerical model indicated the depth to the water table is a function of topography, being very deep in the ridge areas and closer to the land surface in the lower lying alluvial plains. In the area where the BTM complex mines are situated the water table is commonly over 50 m to 100 m below the surface and evapotranspiration therefore does not occur. The alluvial plains also have simulated groundwater levels exceeding 2 m below the land surface and again were considered to have limited evapotranspiration, particularly considering the plains are largely cleared of deep rooted trees and vegetation. For these reasons' evapotranspiration was not represented in the numerical model.

10.3.4 Abstraction

Private abstraction from irrigation bores was represented in the model using the MODFLOW well package. Actual abstraction rates for the 2006 to 2019 period were provided by DPIE-Water following stakeholder meetings. This is a significant improvement on the 2018 iteration of the model, which only had access to abstractions recorded in the 2006 to 2010 period. Locations of private abstraction bores, which are active in the model over the period 2006 to 2019 period are shown in Figure 10.10.

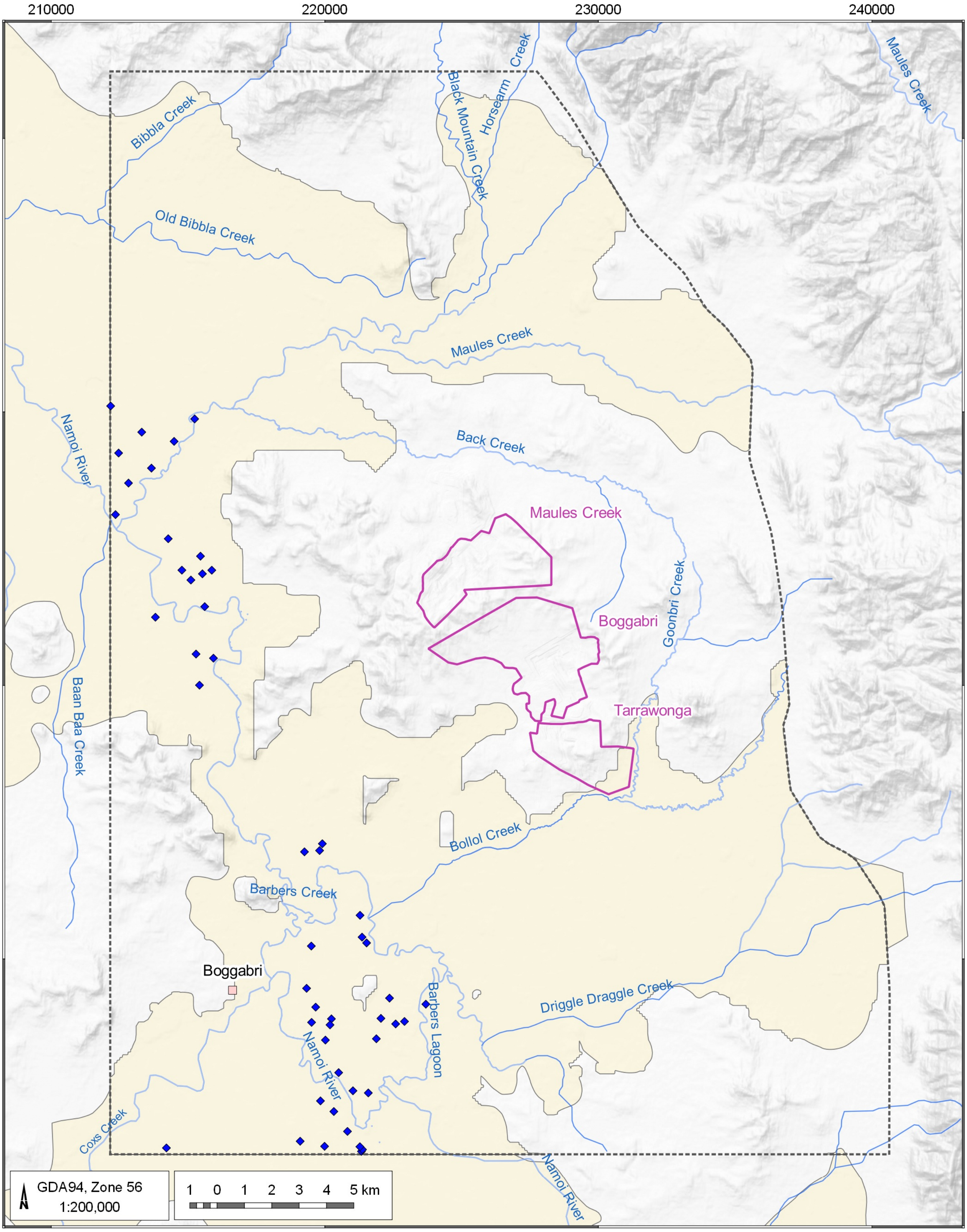
Abstraction data was incorporated into the model at quarterly stress periods. Where meter readings of the provided dataset were less frequent than quarterly, the data was normalised linearly to represent quarterly periods (e.g. an abstraction of 60 ML over three quarters was converted to 20 ML over each quarter). Alternatively, where more than a single reading was taken during the quarter, abstraction data was averaged for that period.

Some differences between new abstraction dataset and the old dataset were noted during processing. In each dataset, total abstraction for the 2006 to 2010 period is approximately equal, although the timing of the extractions does vary. A reason for this could not be determined, but is not considered to have significantly influenced the model predictions.

10.3.5 Mining

The model represents mining activities using the MODFLOW drain (DRN) package, with the progression of mining over time based on the schedules provided by BTM mines (as discussed in Section 10.2.7). Drain cells were applied to all intersected model cells, with reference elevations set to the floor of each cell, down to the coal seam targeted for extraction by mining. A nominally high drain conductance of 100 m^2/day was applied to the drain cells to ensure unhindered flow of groundwater into the cell.

Accumulation of spoils was not represented within the model, with the pit shells represented as fully drained for the entire period of approved mining.



LEGEND

- Populated place
- Pumping bores
- Drainage
- Model extent
- Mine outline
- Modelled alluvium extent

BTM Complex Groundwater Model Update (G1850P)

Pumping bore locations

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DATE 30/08/2021

FIGURE No: **10.10**

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11 Model calibration

11.1 Approach and method

The objective of the calibration process was to ensure the model could replicate key aspects of the groundwater regime identified through the review of the conceptual model, and also address comments received from the NSW government review team during the calibration process. These key aspects of the calibration to be achieved were termed the 'success criteria' and used to guide the calibration process. The success criteria included achieving an improved match with vertical gradients between the Permian and alluvial, valid hydraulic property ranges, measured water level trends due to mining and climate and observed groundwater inflows to mining areas.

The model was calibrated in two stages. Firstly, a steady state model was manually calibrated to reproduce groundwater levels prior to mining occurring at the BTM complex. The water levels from the steady state model were then used as starting conditions for a transient calibration. The transient model used for calibration was set up with 125 quarterly (91.3 days) stress periods, representing the period from January 2006 to December 2036.

The calibration process involved manual model runs testing the influence of single parameters, as well as automated parameter testing using parameterisation software (PEST_HP, Doherty 2018). The calibration focussed on adjusting the following properties in the model:

- horizontal and vertical hydraulic conductivity;
- percentage of recharge to each recharge zone; and
- storage properties - specific yield and specific storage.

At the completion of the model simulation the final combination of model parameters was manually checked to ensure that they remained consistent with the conceptual understanding of the area. As with all models the resulting calibration is non-unique, that is an alternative set of parameters could produce an equally valid calibration, especially where simulations are sensitive to parameter combinations that lie within the calibration null space. The calibration null space refers to the model parameters and parameter combinations that are not informed by the available observed measurements. A model calibrated in this way is classified as conditionally calibrated (verified) in that it has not yet been falsified by tests against observational data (Middlemis & Peeters, 2018).

11.2 Calibration targets

A total of 204 monitoring points were used to calibrate the model, comprising:

- 108 monitoring points from the BTM Complex Monitoring Network, which included bores and VWPs that screen the alluvium and Permian coal measures; and
- 96 NSW Government monitoring bores installed primarily within the Quaternary alluvium;

Middlemis & Peeters (2018) suggest groundwater assessments consider the uncertainty around measurements used during the modelling process. The groundwater levels within the monitoring network are measured manually with electronic water level dippers and the water level converted to an elevation based on surveyed levels at measurement point which is usually the top of bore casing. Modern electronic water level dippers are expected to be accurate to within ±1 cm, and with the measurement point elevation also ±1 m to 10 cm depending on the method of surveying. The measurement of water levels within the monitoring network is therefore considered unlikely to have introduced any significant uncertainty to the model predictions. Vibrating wire piezometers in contrast measure pore pressure which is converted to a potentiometric surface based on the elevation of the VWP sensor. The VWPs are sealed with cement grout within the boreholes and therefore cannot be validated, or the data loggers checked for instrument drift.

Therefore, the measurement error for the VWPs is considered higher than monitoring bores and possibly in the range of ±5 m to 10 m. Despite the potential for a larger measurement error in the VWP data, when used with caution it is still considered a useful additional dataset to understand the groundwater regime and guide the calibration of the numerical model where the observed pressure changes are considered conceptually sound.

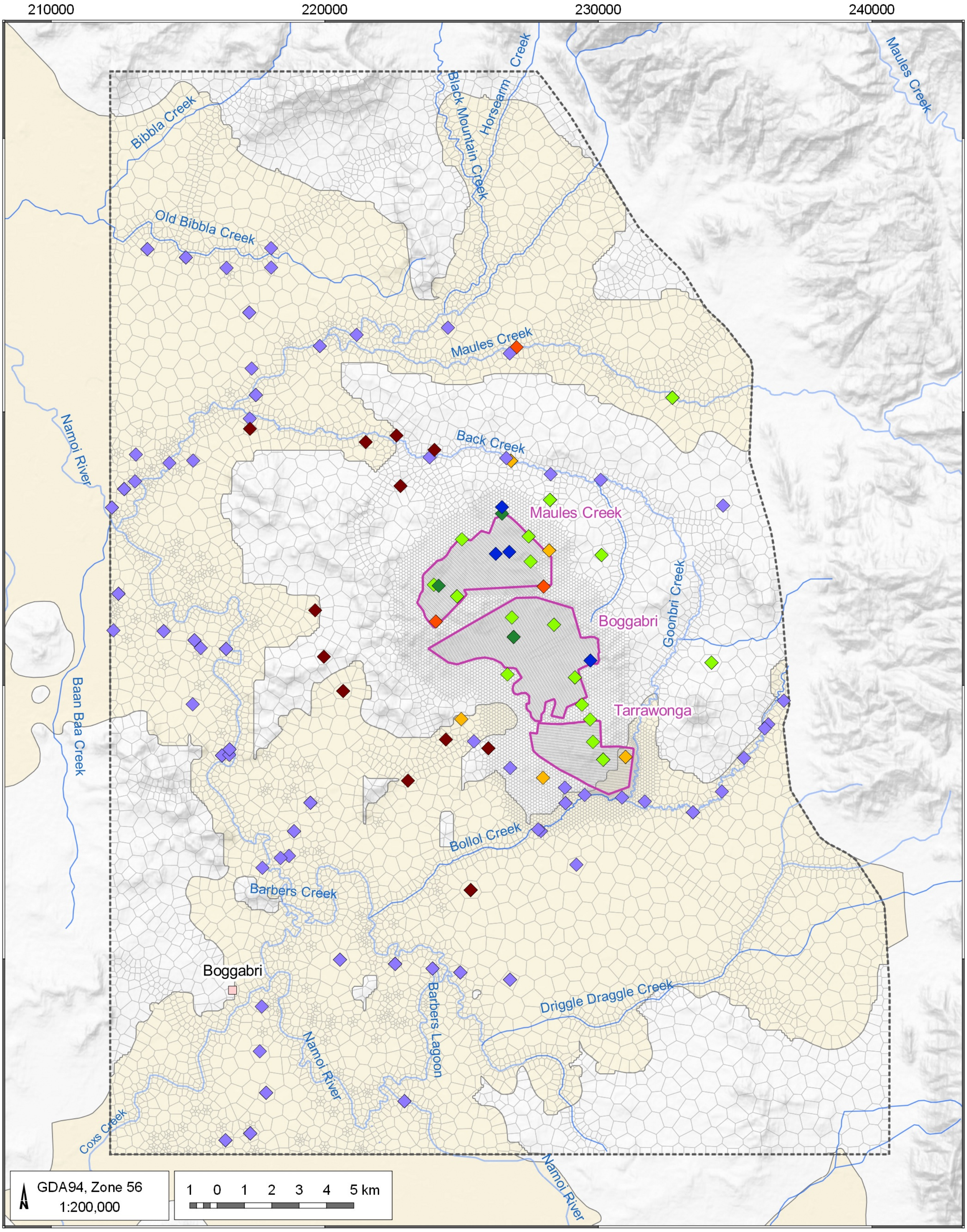
Figure 11.1 shows the locations of the observation bores and VWPs that were used in the calibration process. For model calibration purposes the observation bore water level records were weighted as follows:

- obviously anomalous results were removed;
- datalogger data was reduced to an appropriate frequency; and
- datapoints for each location were weighted according to the formula:

weight of datapoint = 1/ √ (number of points for that site).

Using this method bores with longer records have a lower weighting per datapoint, but a higher overall weighting in the combined dataset. The model was calibrated to the observed water level datasets, with the 'best calibrated' model returning the lowest objective function (phi) value i.e., the lowest statistical difference between the observed and modelled values across the chosen dataset.

Previous modelling has had difficulty replicating the large vertical head differences that are observed between VWP sensors of different depths. To better replicate these vertical differences in head through the Permian strata, the vertical gradients were used as an additional calibration target at the site of all VWPs. The weighting of these vertical gradients was carefully adjusted throughout the calibration process, and in select cases was weighted more heavily than the absolute head observation.



LEGEND

- Populated place
- Drainage
- Model extent
- Model mesh
- Mine outline
- Modelled alluvium extent

Model layer

- 1 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 34

BTM Complex Groundwater Model Update (G1850P)

Observation points used for calibration

AGE

DATE 23/06/2021

FIGURE No: **11.1**

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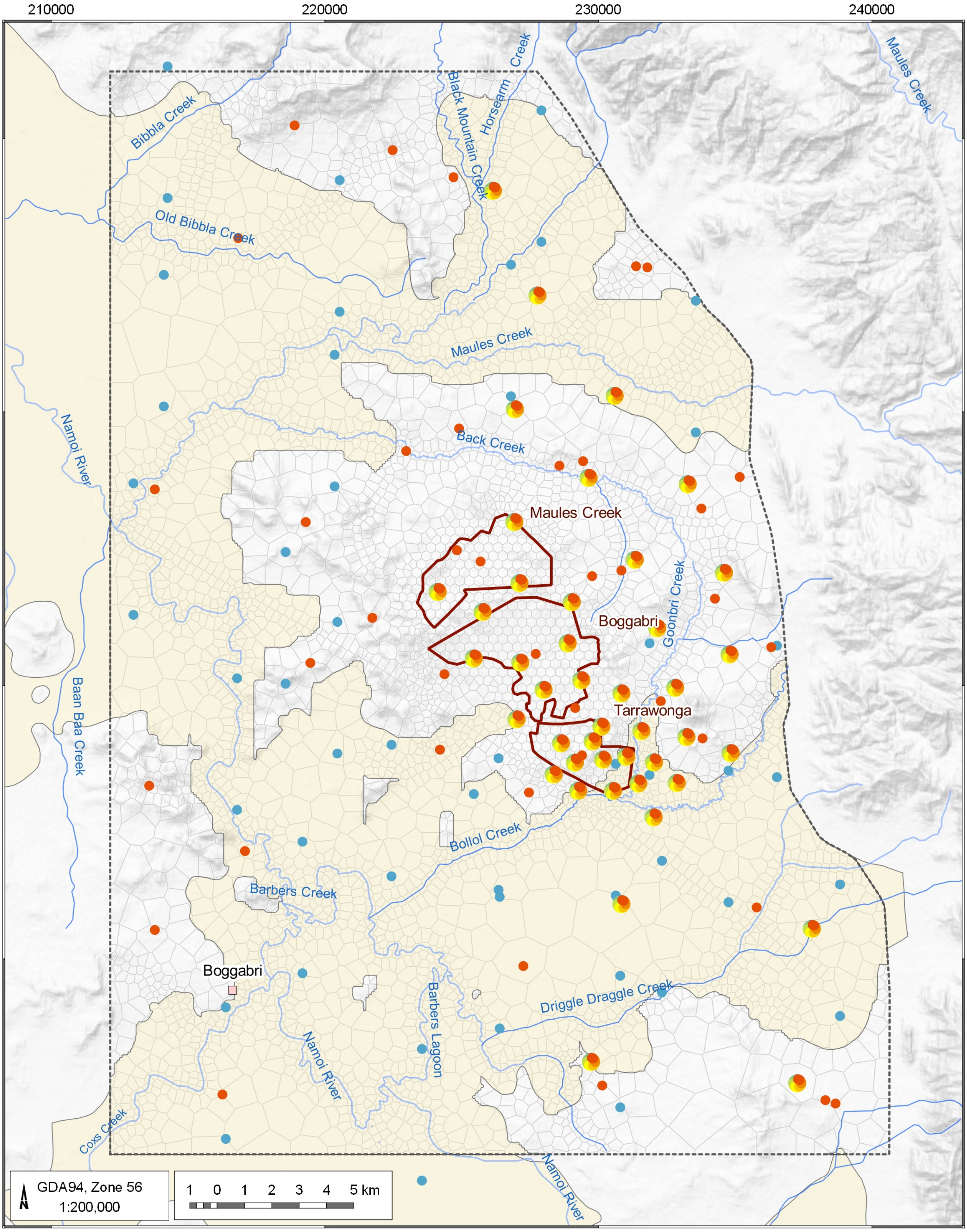
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\11.01_G1850_Observation points used for calibration.qgs

The model domain contains a significant network of monitoring bores and water level datasets. The water level responses recorded in the monitoring bores vary depending on a range of factors including geology, location, climatic conditions and mining activities. Water levels recorded in the monitoring bores indicate heterogeneous hydraulic properties and recharge rates. To represent heterogeneity within the model domain and provide a degree of flexibility during the calibration, a series of pilot points were added to each model layer.

The locations of the pilot points in each model layer are shown in Figure 11.2. The pilot points were situated where it was clear from water level monitoring data or model predictions that heterogeneity in hydraulic properties and/or recharge may be influencing the observations and would be required in the model to provide similar predictions. The pilot points were therefore clustered around the mining areas where the bulk of the available data is located and where the most variability in water levels occurs. For example, pilot points were located in the vicinity of monitoring sites TA60 and TA65, where enhanced permeability was required to match observations, with additional points away from these sites to allow the model the ability to reduce permeability where observations were not suggesting it was enhanced at for example REG07 and REG09.

The pilot points were interpolated across the model domain in each layer of the model using ordinary automatic Kriging through PLPROC (Watermark Numerical Computing, 2015). Horizontal and vertical conductivity were then adjusted, and the absolute values were capped to ensure maximum and minimum values did not exceed appropriate ranges for each units outlined in Section 6.3. Specific storage values are constrained by literature ranges.



LEGEND

- Populated place
- Drainage
- Model extent
- Model mesh
- Mine outline
- Modelled alluvium extent

Model layer of pilot point

- 1 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- 30 - 35

NOTE:
For visual clarity, point dispalcement factor is used for pilot point locations

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Pilot point locations

AGE

DATE 30/08/2021

FIGURE No: **11.2**

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G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\11.02_G1850_Pilot point locations.qgs

11.3 Calibration results

11.3.1 Water level history matching

Figure 11.3 presents the observed and simulated groundwater levels determined from the calibration in a scattergram.

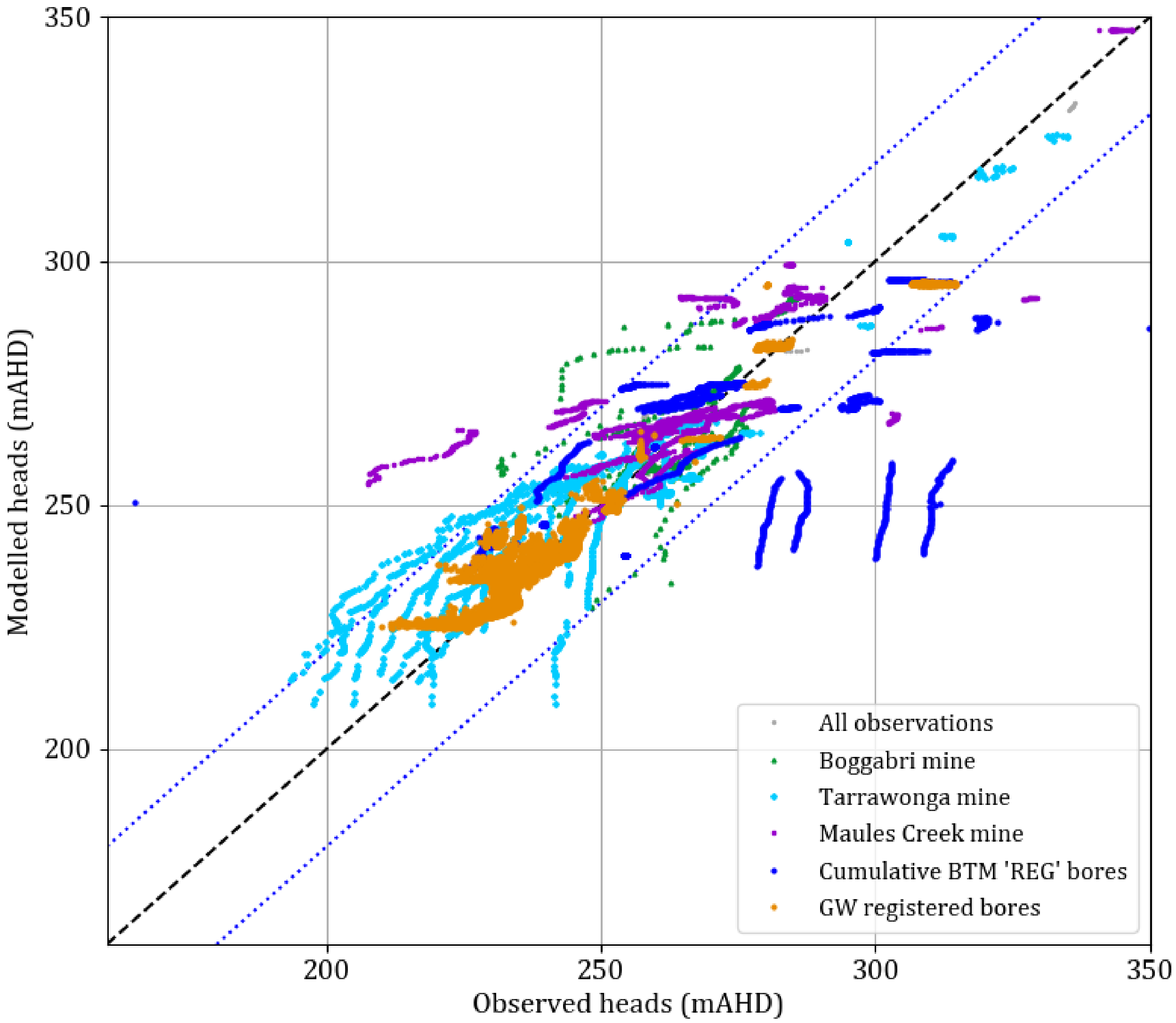


Figure 11.3 Transient calibration – modelled vs observed groundwater levels

The root mean square (RMS) error calculated for the calibrated model was 16.19 m. The total measured head change across the model domain was 367.06 m, with a scaled root mean square (SRMS) of 4.41%, indicating a good match for the type of system being modelled.

Appendix E presents the calibration hydrographs for each monitoring point, showing the fit between modelled and observed groundwater levels from 2006 to 2019.

Where monitoring bores are installed with a nested design adjacent to multilevel VWPs the observed and predicted levels are shown as grouped so the ability of the model to match the absolute levels and vertical gradients within and between layers can be examined. Charts showing the observed and predicted water levels in each monitoring bore or VWP sensor are also shown separately.

The hydrographs contained within Appendix E indicate the model can generally replicate declining pressure trends where these have been observed via VWPs, and some of the head separation that occurs through the Permian strata, particularly in areas adjacent to the BTM mines where the depressurisation enhances the vertical gradients through the Permian strata (e.g. RB05, RB05).

A notable recharge event in mid/late 2016 that is evident in the monitoring data is generally not reproduced at the same scale in many of the monitoring bores installed within the Permian strata around the mines, and this remains an area for future improvement of the model.

REG01 is a multilevel VWP site located adjacent to Maules Creek and NSW government monitoring bores GW967138. The model simulates the higher groundwater level observed within the alluvial aquifer and a lower pressure within the underlying Permian bedrock that indicates a downgradient from the alluvium to the underlying bedrock. An improved replication of the vertical gradient between the alluvium and bedrock was a request from the NSW government reviewers with the purpose of improving the validity of the water take estimates made by the model. This request has been achieved by the updated model in the location of REG01. The model indicates a gradient from the alluvium to the bedrock occurs through much of Maules Creek and is discussed further in Section 11.3.2.

It can be seen at the site of REG01 the different pressures observed within the VWPs through the Permian sequence is not well replicated by the model. Conceptually this may relate to the location of the subcrop for each coal seam which has not been well defined in the area underlying the Maules Creek alluvium. This is a residual uncertainty in the geology that cannot be addressed further with modelling.

The IBC series of monitoring bores installed within the footprint of the Boggabri mine provide a good record of water level responses induced by mining. The model generally simulates the overall water level trends measured in these bores well. The exception is IBC 2102 which rises when the model is predicting a declining trend. This is potentially due to temporary storage of water within the pit, that is not represented within the model.

The model provides an improved match to the VWPs within TA60 and TA65 east of the Tarrawonga Mine, which have recorded declining water levels that could not be matched well by the previous version of the model (AGE, 2018). Pilot points installed within this area of the model allowed a localised higher permeability to occur in this area of the model which enhanced the drainage of groundwater to the mining areas and better matches the magnitude of the predicted drawdown.

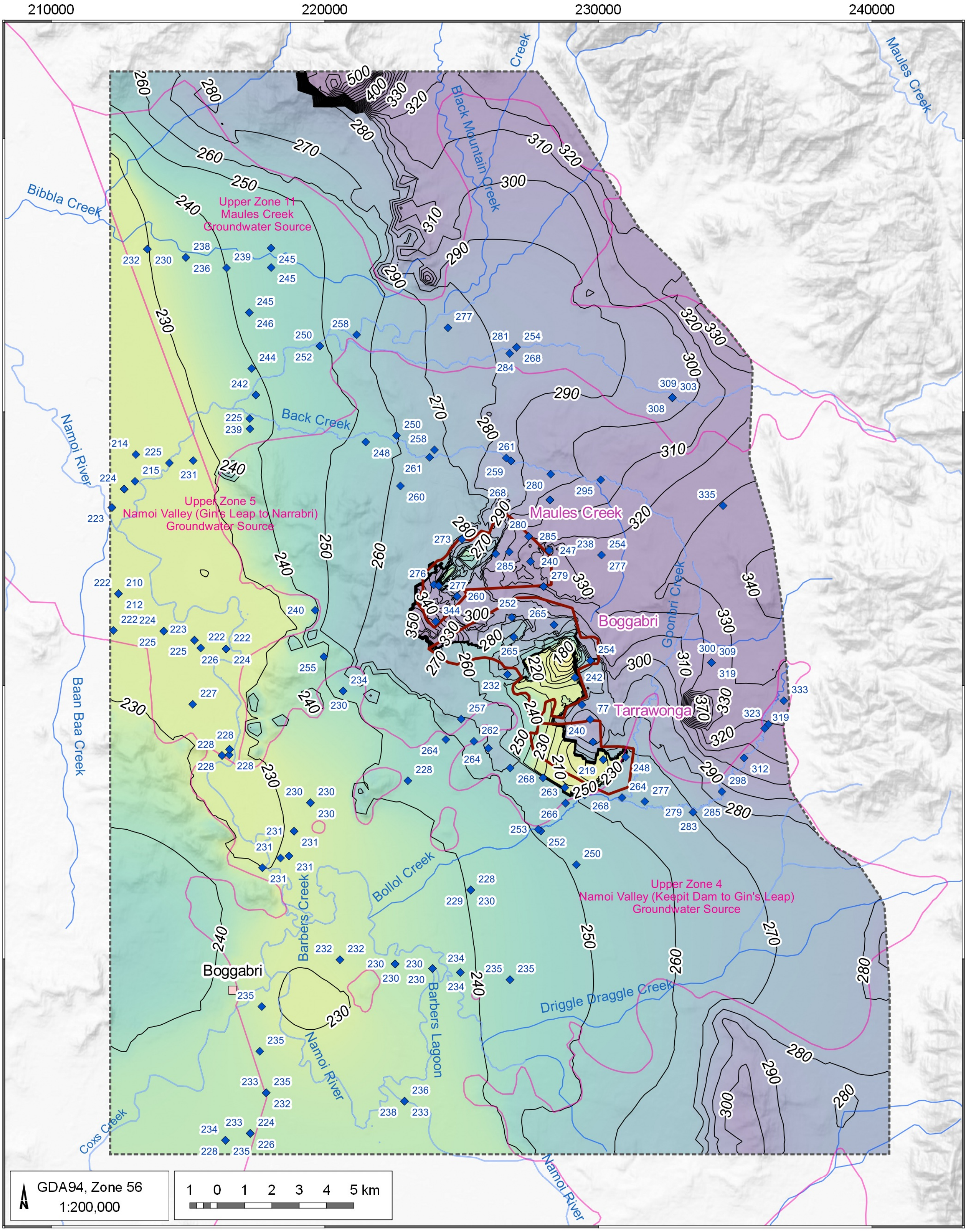
The GW series are largely government monitoring bores installed within the alluvial aquifer to the west of the BTM complex. The model replicates the absolute levels well within the alluvial aquifer, probably due to the high permeability and storage that promote relatively flat hydraulic gradients and predictable levels. Trends in the GW series of monitoring bores are generally not influenced by mining but driven by climatic conditions and groundwater abstraction from private irrigation bores. Climatic trends are clearly influencing groundwater levels within the model, sometimes more significantly than is observed within the monitoring data.

Overall, the ability of the model to predict groundwater levels is considered to have improved due the updates made to the model. Despite this reproducing all the major trends observed within the monitoring network remains challenging, as all the complexity within the hydrogeological regime cannot be contained within a necessarily simplified model. Despite these challenges the model is considered an improvement on the previous version and to meet the identified success criteria.

11.3.2 Water table and potentiometric surface

The simulated water table along with measured groundwater levels in monitoring bores during 2019 is shown in Figure 11.4. The water table shows the dominant west to east flow direction within the model domain which is influenced by the topography and alignment the Maules Creek and Bollol Creek alluvial aquifers. The dominant flow direction turns towards the north at the western boundary of the model, flowing in the same direction as the Namoi River. The active mining areas within the BTM complex area are evident in the water table as areas of locally lowered water levels with inward hydraulic gradients.

Figure 11.5 shows the simulated potentiometric surface within the Merriown Seam in 2019. The figures show a flatter hydraulic gradient than occurs within the water table and flow directions more strongly influence by the active mining areas. The Merriown seam potentiometric surface is generally at a lower elevation than the water table indicating a vertical gradient from the alluvium downwards into the underlying coal measures sequence occurs in the eastern area of the model where topography rises. This is supported by available monitoring data. Depressurised zones within the potentiometric surface caused by the mining within the BTM complex footprint is also evident on the figure.



LEGEND

- Populated place
- Observation locations
- Drainage
- Model extent
- Mine outline
- Alluvial boundary zones

2019 simulated water table (mAHD)

- 150
- 200
- 250
- 300
- 600

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Simulated water table 2019

AGE

DATE 23/06/2021

FIGURE No: **11.4**

©2021 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au
Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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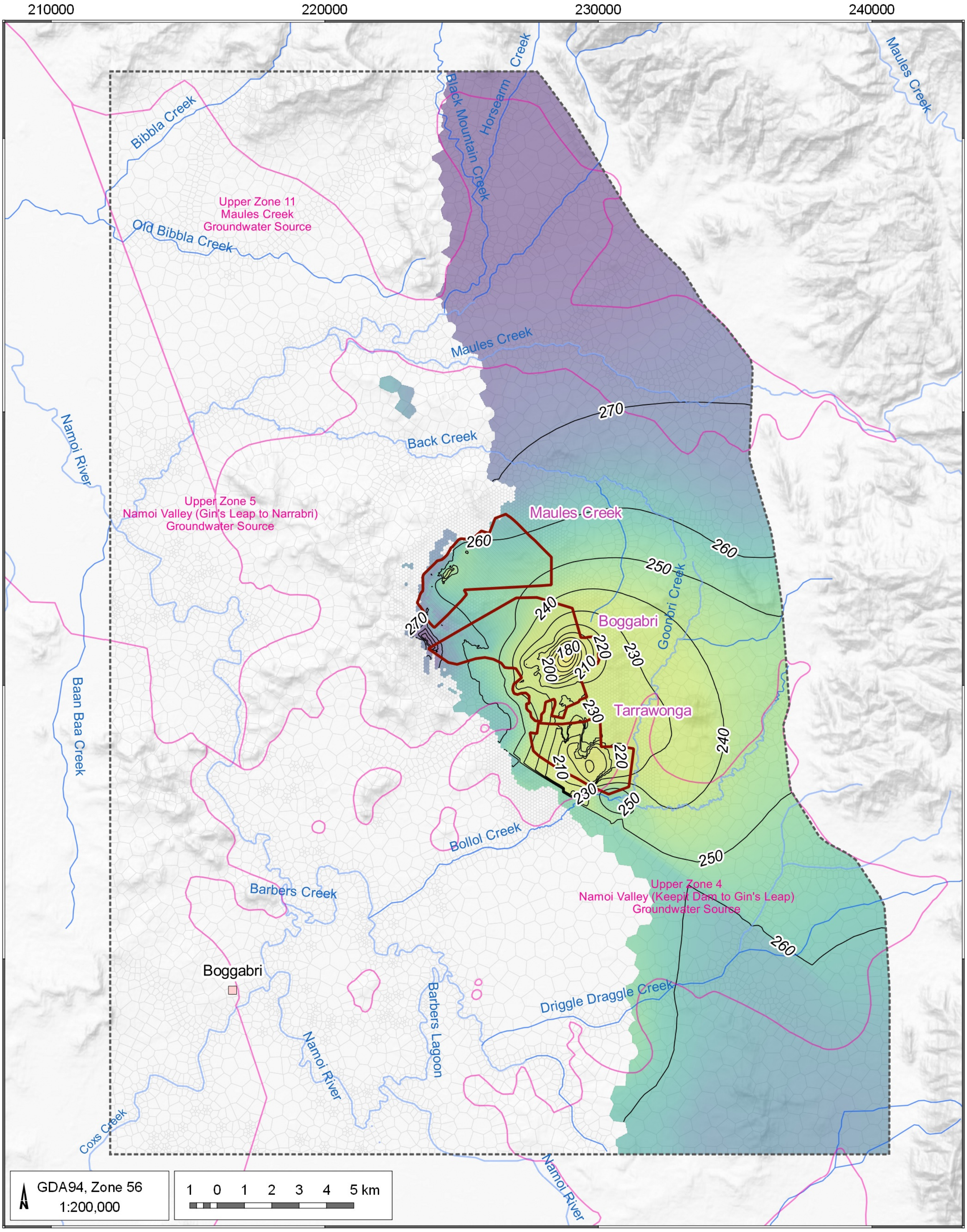

LEGEND

- Populated place
- Drainage
- Model extent
- Model mesh
- Mine outline
- Alluvial boundary zones

Contour line

Head (mAHD)

- 150
- 200
- 250
- 300

BTM Complex Groundwater Model Update (G1850P)

Simulated potentiometric surface – Merriown Seam 2019

AGE

DATE 23/06/2021

FIGURE No: **11.5**

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Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\11.05_G1850_Simulated potentiometric surface – Merriown Seam 2019.qgs

11.3.3 Hydraulic parameters

The hydraulic parameter ranges adopted for each model layer were guided by the field measurements described in Section 6.3 and where data was not present, experience with similar hydrogeological settings was taken into consideration. The calibration was commenced using uniform values of hydraulic conductivity for the model layers representing the alluvium, regolith and coal seams, which are relatively the most permeable layers within the hydrogeological regime. A function representing hydraulic conductivity reducing with depth below the surface was used to obtain the starting values for the model layers representing the lower permeability interburden as this was suggested in the available field data and known to occur in the Sydney and Bowen Basins.

The 'base' hydraulic properties are summarised in Table 11.1 below. These base hydraulic properties were the initial values used to setup the model and were then adjusted using pilot points across the model. The individual pilot point values determined from the calibration process are presented on the maps shown in Appendix F. These maps show the spatial variability in calibrated hydraulic properties (horizontal and vertical hydraulic conductivity, specific storage, specific yield). Appendix F also includes charts that show the adopted hydraulic conductivity values from the calibration versus depth for each cell in each model layer (blue dots), and the starting values (red line) prior to commencing the PEST calibration process.

A summary of the process implemented to generate the horizontal hydraulic conductivity values that are presented in Table 11.1 and Appendix F was as follows:

Interburden layers

- initial depth dependent function (Table 11.1) obtained as part of calibration process;
- further adjustment via pilot point multipliers allowing the value in each cell to vary up or down by an order of magnitude from the initial depth dependent function (Appendix F); and
- values constrained by minimum (1 x 10^{-5} m/day) and maximum (1 x 10^{-2} m/day) caps (Table 11.1) to remain consistent with field measurements.

Alluvial, coal seam and volcanic layers

- base value (Table 11.1) obtained as part of calibration process; and
- further adjustment via pilot point multipliers allows the value in each cell to vary up or down by an order of magnitude (Appendix F).

The final calibrated values (Appendix F) for the vertical conductivity multiplier, specific yield and specific storage are all calibrated in a manner that is consistent with the process outlined above for non-interburden layers, noting that specific storage values are constrained by the range defined by Rau et al (2018). Direct testing data is not available for specific storage (Ss) of the coal seams or interburden. Rau et al (2018) provides limits based on poroelastic theory, which indicates that specific storage is restricted to the range of 2.3 x 10^{-7} m^{-1} and 1.3 x 10^{-5} m^{-1}. The calibrated parameters were restricted to remain within these bounds.

Throughout the calibration process care was taken to ensure that parameter values remained plausible based on the available field testing data that is discussed in Section 6.3. Comparisons between the modelled base values and field testing results for horizontal hydraulic conductivity are provided for the coal seam layers and interburden layers in Figure 11.6 and Figure 11.7, respectively. These figures show that base values are generally consistent with field measurements. Some of the coal seam test results are lower than the calibrated base values. However, modelled values are still consistent with majority of the dataset, and the adoption of higher hydraulic conductivity values rather than lower values is a more conservative approach to impact modelling. Comparisons between calibrated base values and test data for the interburden layers clearly shows the impact of constraining the range of possible values. Previous versions of the model incorporated a greater range and the tighter bounds seen here is deliberate. Through consultation with DPIE-Water technical specialists, limiting the variability to three orders of magnitude was considered a more appropriate approach.

Table 11.1 Calibrated base hydraulic properties used in the numerical groundwater model

Model layer	Lithology	Kh (m/day)			Kv (m/day)	Sy (dec %)	Ss (m^{-1})
		Base value	cap max	cap min			
1	Alluvium -Narrabri Fm	10			Kh x 0.49	0.008	2.3×10^{-7}
1	Regolith	0.03			Kh x 0.12	0.004	2.2×10^{-7}
2	Alluvium -Gunnedah Fm	4.74			Kh x 0.54	0.25	2.3×10^{-7}
3	Interburden	2500 x (depth ^ -2.7)	0.01	1×10^{-5}	Kh x 0.037	0.00007	1.0×10^{-6}
4	Interburden	1500 x (depth ^ -3.7)	0.01	1×10^{-5}	Kh x 0.02	0.00009	1.0×10^{-6}
5	Seam Herndale, Onavale, Teston, Thornfield	0.005			Kh x 0.01	0.05	9.1×10^{-6}
6	Interburden	2500 x (depth ^ -3.7)	0.01	1×10^{-5}	Kh x 0.01	0.0007	1.0×10^{-6}
7	Interburden	1500 x (depth ^ -2.7)	0.01	1×10^{-5}	Kh x 0.03	0.0007	1.0×10^{-6}
8	Seam Braymont	0.63			Kh x 0.3	0.05	1.3×10^{-5}
9	Interburden	2500 x (depth ^ -3.7)	0.01	1×10^{-5}	Kh x 0.0009	0.0007	1.0×10^{-6}
10	Interburden	2500 x (depth ^ -2.3)	0.01	1×10^{-5}	Kh x 0.08	0.00007	1.0×10^{-6}
11	Seam Bollol_Ck	0.13			Kh x 0.08	0.05	9.2×10^{-6}
12	Interburden	1500 x (depth ^ -3.7)	0.01	1×10^{-5}	Kh x 0.1	0.00009	1.0×10^{-6}
13	Interburden	1500 x (depth ^ -3.7)	0.01	1×10^{-5}	Kh x 0.001	0.00009	2.3×10^{-7}
14	Seam Jeralong	0.14			Kh x 0.08	0.05	1.0×10^{-5}
15	Interburden	1500 x (depth ^ -3.0)	0.01	1×10^{-5}	Kh x 0.001	0.00007	1.0×10^{-6}
16	Interburden	2500 x (depth ^ -2.3)	0.01	1×10^{-5}	Kh x 0.0004	0.00007	1.0×10^{-6}
17	Seam Merriown	0.03			Kh x 0.55	0.01	3.0×10^{-6}
18	Interburden	2500 x (depth ^ -2.3)	0.01	1×10^{-5}	Kh x 0.0002	0.00009	2.3×10^{-7}
19	Interburden	2500 x (depth ^ -2.3)	0.01	1×10^{-5}	Kh x 0.1	0.00009	3.1×10^{-7}

Model layer	Lithology	Kh (m/day)			Kv (m/day)	Sy (dec %)	Ss (m^{-1})
		Base value	cap max	cap min			
20	Seams Velyama, Nagero	0.31			Kh x 0.12	0.01	1.3×10^{-5}
21	Interburden	2500 x (depth ^ -2.3)	0.01	1×10^{-5}	Kh x 0.05	0.00007	2.3×10^{-7}
22	Interburden	2500 x (depth ^ -2.3)	0.01	1×10^{-5}	Kh x 0.1	0.00007	2.3×10^{-7}
23	Seams Upper_Northam, Lower_Northam	0.03			Kh x 0.3	0.01	1.1×10^{-5}
24	Interburden	2500 x (depth ^ -2.3)	0.01	1×10^{-5}	Kh x 0.001	0.00009	2.3×10^{-7}
25	Interburden	1500 x (depth ^ -2.3)	0.01	1×10^{-5}	Kh x 0.05	0.00009	2.3×10^{-7}
26	Seams Therribri_A, Therribri_B	0.09			Kh x 0.02	0.01	8.0×10^{-6}
27	Interburden	1502 x (depth ^ -2.3)	0.01	1×10^{-5}	Kh x 0.01	0.00007	2.3×10^{-7}
28	Interburden	2500 x (depth ^ -3.7)	0.01	1×10^{-5}	Kh x 0.003	0.00009	2.3×10^{-7}
29	Seams Flixton, Tarrawonga	0.04			Kh x 0.04	0.01	8.3×10^{-6}
30	Interburden	2119 x (depth ^ -3.7)	0.01	1×10^{-5}	Kh x 0.03	0.00007	2.3×10^{-7}
31	Interburden	2016 x (depth ^ -3.7)	0.01	1×10^{-5}	Kh x 0.003	0.00009	2.3×10^{-7}
32	Seam Templemore	0.05			Kh x 0.03	0.01	1.3×10^{-5}
33	Interburden	1500 x (depth ^ -3.7)	0.01	1×10^{-5}	Kh x 0.007	0.00009	5.7×10^{-7}
34	Volcanics	0.001			Kh x 0.55	0.00009	2.2×10^{-7}

Note: * depth: For the Kh calculation, depth of the cell in metres from the ground level. For the numerical groundwater model, the depth of a given cell is measured between the cell centre and the top of layer 01 in the vertical column of cells.

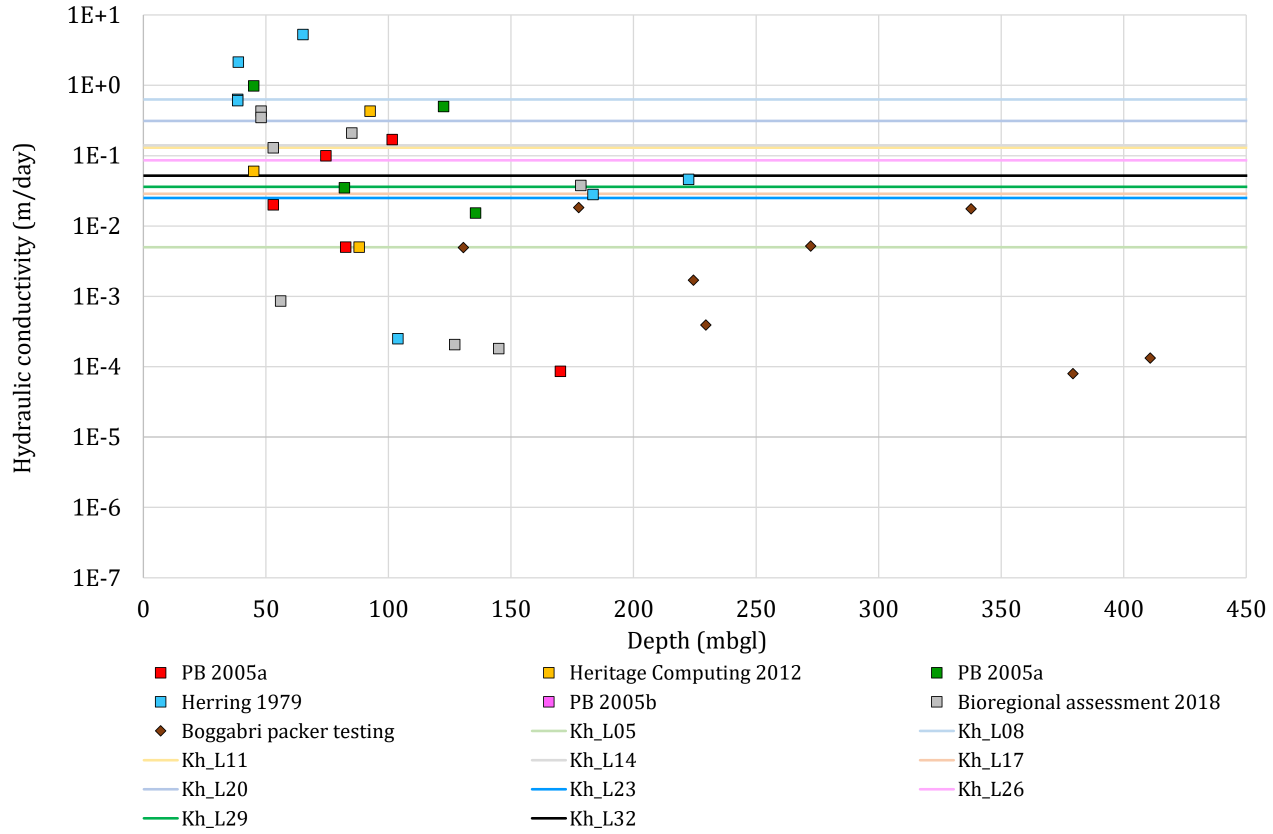


Figure 11.6 Coal seams – modelled values (lines) vs field testing (points)

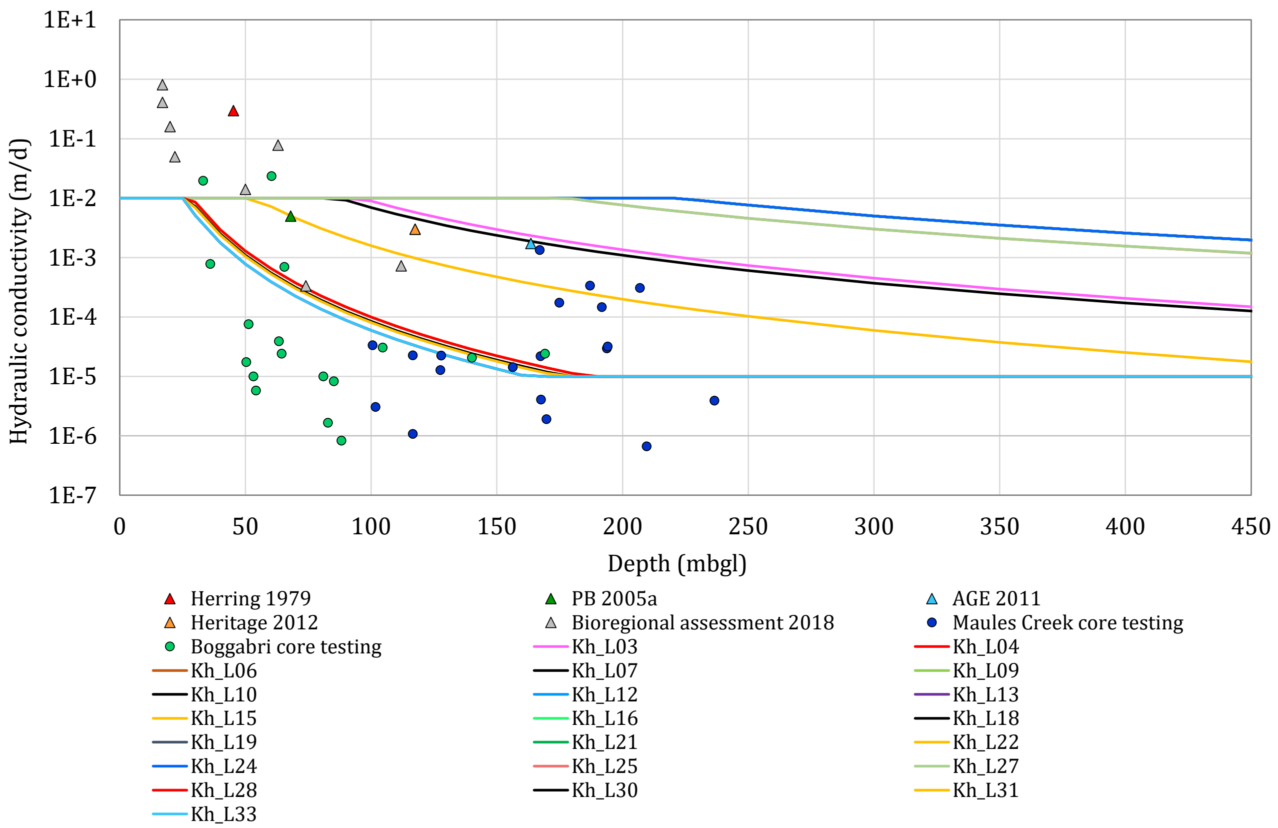


Figure 11.7 Interburden – modelled values (lines) vs field testing (points)

11.3.4 Water budget

The mass balance error, that is, the difference between calculated model inflows and outflows at the completion of the steady state calibration was 0.03%. The maximum percent discrepancy at any time step in the simulation was also 1.98%. This value indicates that the model is stable and achieves an accurate numerical solution. This maximum error is within acceptable limits for adequate numerical convergence (<2%: Australian Modelling Guidelines – Barnett [2012]).

Table 11.2 shows the water budget for the steady state (pre-mining) model and the averages from the transient model for the period 2006 to 2019.

Table 11.2 Calibration stage water budget (ML/day)

Parameter	Steady state model			Transient model average		
	in	out	in - out	in	out	in - out
Storage	0.00	0.00	0.00	36.27	27.22	9.05
Recharge	55.82	0.00	55.82	41.74	0.00	41.74
River	0.00	19.41	-19.41	0.00	16.07	-16.07
Stream	16.87	15.42	1.45	12.33	14.09	-1.76
General head boundary	0.07	31.13	-31.06	0.27	25.18	-24.91
Wells	0.00	6.78	-6.78	0.00	5.81	-5.81
Drains	0.00	0.00	0.00	0.00	2.25	-2.25
Total	**72.76**	**72.74**	**0.02**	**90.61**	**90.62**	**-0.01**

The steady state water budget indicates that recharge to the groundwater system within the model averages 55.82 ML/day, with approximately 17.96 ML/day being discharged via surface drainage. Regional through flow from the general head boundary contributes 0.09% of the total input to the groundwater model.

The transient model water budget departs from steady state conditions because of mining in the model domain. Mining dewatering represented by drain cells indicates regional dewatering intercepts 2.25 ML/day on average, which indirectly reduces stream baseflow, and increases inflows from the general head boundaries. Recharge from rainfall and river leakage decreases slightly within the transient model due to the use of actual climatic data during the transient calibration period from 2006 to 2019.

The calibrated model water budget represents the optimal balance PEST arrived at using the groundwater levels and mine inflows as a target. There is inherent significant uncertainty in these volumes as the majority of the budget components are not directly measurable in the field across the model domain.

11.3.5 Parameter sensitivity and identifiability

Identifiability is a term used to describe the capability of a model calibration to constrain parameters used by a model. An identifiability value of one means that the range in the model parameter can be constrained through the calibration process and hence the parameter is highly estimable. In contrast, an identifiability value of zero indicates that the parameter range cannot be constrained by the calibration and hence its uncertainty is not reduced through the calibration process.

To further investigate this issue the PEST utility GENLINPRED was used to provide an estimate of parameter identifiability. GENLINPRED provides an identifiability value for each model parameter, with these values for select parameters (recharge, HFB hydraulic conductivity, horizontal hydraulic conductivity) shown in Figure 11.8. As discussed previously, horizontal hydraulic conductivity values were adjusted via pilot points, and as such identifiability values are more likely to be elevated when the pilot point is located near a suitable observation point. This needs to be taken into consideration while analysing these pilot point adjusted parameters, with relative difference being of more importance than the absolute identifiability value, which is an average.

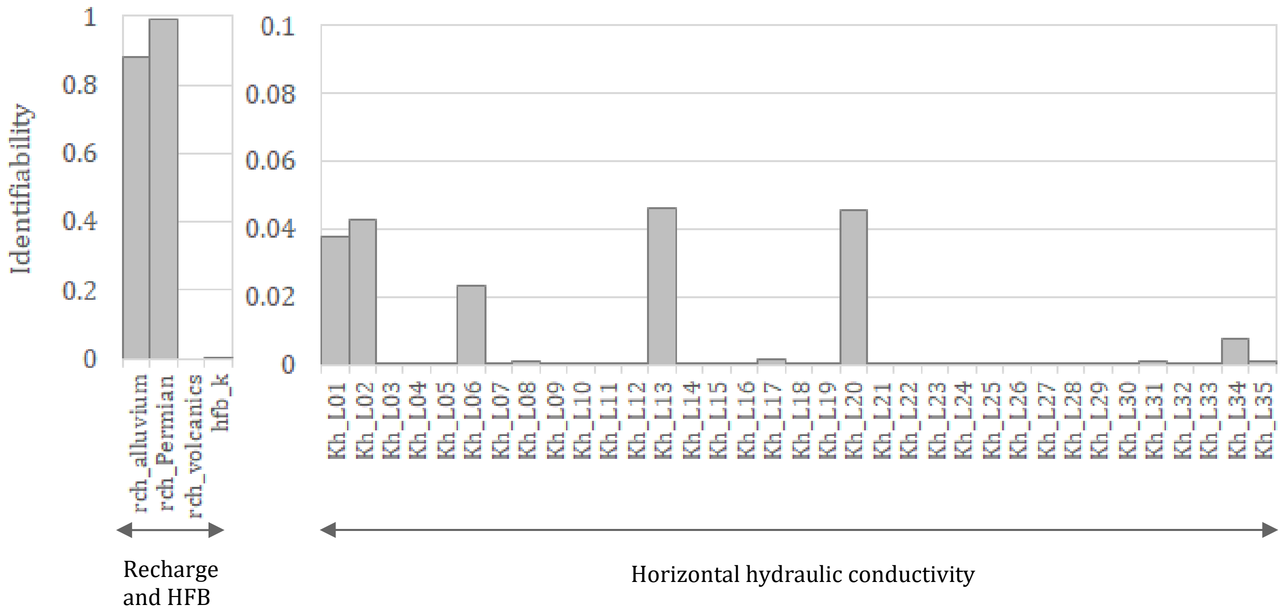


Figure 11.8 Parameter identifiability

Some parameters were determined to be more identifiable than others, with differences often driven by the amount of data available, which influences the parameter in question. For example, the identifiability of horizontal hydraulic conductivity in the alluvium is relatively elevated, due to the large number of locations where alluvial head observations are available. Horizontal hydraulic conductivity identifiability values are also relatively elevated in interburden layers 6 and 13, coal seam layer 20, and basal volcanic layer 34. The identifiably of recharge varied for the main geological units, with recharge to the alluvium and Permian units being highly identifiable (> 0.8), while recharge to the volcanics was of low identifiability. Note that these identifiability values relate to the modelled recharge prior to adjustment via factoring. The identifiability of the horizontal flow barrier hydraulic conductivity that is used to represent the Conomos Fault is low, which is expected given that data and observations relating to this feature are very limited.

Identifiability is only a qualitative indicator and should not be over-interpreted. However, it can provide some insight into calibrated model behaviour. Parameters with high identifiability can be interpreted as important controls on model performance. Identifiable parameters indicate where the groundwater and conceptual models are suitably constructed to replicate measured processes.

The results from the identifiability analysis can be used to derive the posterior distributions for uncertainty analysis. If not managed properly, parameters that are highly identifiable can have a narrow posterior distribution when conducting uncertainty analysis. Parameters with low identifiability could imply the parameter is insensitive to the measurement data, or there are no observation data to inform the parameter. In these instances, the range of parameters explored in the uncertainty analysis should be broadened.

11.3.6 Mine inflow verification

Figure 11.9 shows the simulated groundwater inflow to the drain cells representing the BTM complex open cut mining areas.

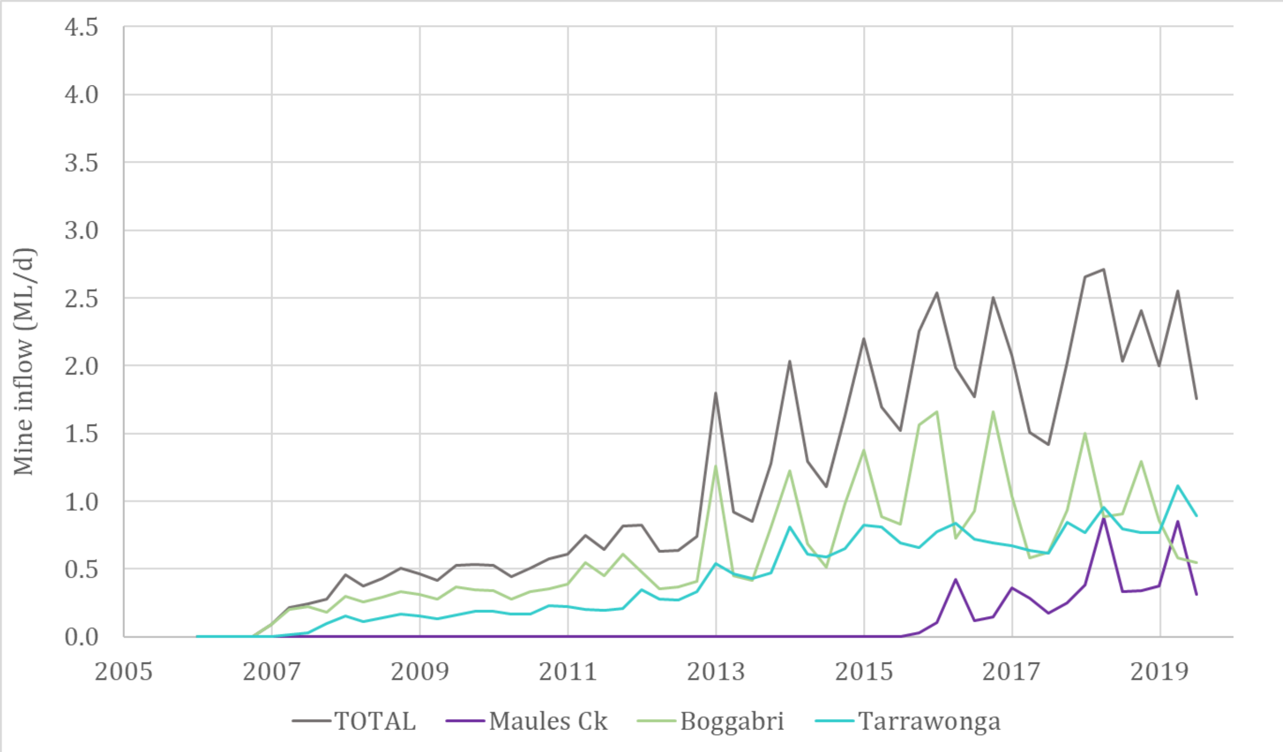


Figure 11.9 Simulated inflow to mining areas (2006 to 2020)

Groundwater inflows to the open cut mining areas are not large compared to the scale of the BTM mine excavations. The groundwater intercepted by the excavations is difficult to measure accurately as it can evaporate when exposed in the mine face/floor, adhere to excavated spoil and coal, or be mixed with rainfall runoff and pumped to water storage areas. The most common method to estimate the groundwater inflow is to use a mine site water balance model to compare inputs and outputs and determine if any additional water can be attributed to groundwater inflow. Estimates of groundwater inflow from water balance models were used to guide the calibration process.

Comparisons between predicted inflows and estimates (Table 11.3) indicate that on average, modelled estimate of inflow are 164 ML/year greater than water balance estimates (Section 6.7.1). This is not unexpected, given that numerical groundwater models predict total groundwater inflows into the mining void, whereas water balance models estimate pumpable inflows once the water has migrated to a sump. Therefore, comparisons of inflows estimated via these different methods will not provide the same results. Numerical models typically predict a higher groundwater inflow than a water balance estimate, which is generally seen here.

Table 11.3 Comparison of predicted groundwater inflows and water balance estimates

Site	Year	Predicted inflow (ML/day)		
		Modelled	Maximum water balance estimate	Difference
Boggabri	2014	325	274	+ 51
	2015	452	208	+ 244
	2016	397	95	+ 301
	2017	727	321	+ 405
	2018	580	372	+ 208
	2019	376	199	+ 177
Tarrawonga	2015	267	183	+ 84
	2016	265	183	+ 82
	2017	501	183	+ 319
	2018	327	183	+ 144
	2019	266	73	+ 193
Maules Creek	2015	182	5	+ 177
	2016	309	10	+ 299
	2017	183	10	+ 173
	2018	238	576	- 338
	2019	332	233	+ 99

12 Model predictions and impact assessment

12.1.1 Model setup

The predictive modelling was completed by extending the calibrated model. The predictive model was set up with quarterly stress periods (91.3 days) from January 2020 to December 2036. December 2036 was adopted as the end of predictions as this is when the last of the BTM mines are currently approved to operate to.

The time variant model packages were extended to the end of the simulation. The general head packages were extended using the same uniform values adopted in the calibration model. The well and recharge packages were extended by repeating the average quarterly rates assigned within the calibration model.

The future mining schedules were provided by each of the mines within the BTM complex and processed into quarterly stress periods. Similar to the historical model the drain cells used to simulate mining remained active for the entire simulation. The drain cells were set to the base of the lowest coal seam being mined. For Boggabri Mine this was layer 17 (Merriown seam), layer 20 (Nagero seam) for Tarrawonga Mine and from layer 32 (Templemore seam) for Maules Creek depending on the area being mined.

The planned low permeability barrier adjacent to the Tarrawonga Mine was represented from 2024 using the time-variant materials package. The barrier was installed through model layers 1 and 2 (alluvium) and assigned a hydraulic conductivity of 1 x 10^{-10} m/day.

12.1.2 Mining phase water budget summary

Figure 12.1 shows the budget for the components of the predictive model. Positive values indicate water entering the model and negative numbers represent water leaving. Table 12.1 summarises the average values for the model water budget over the predictive period.

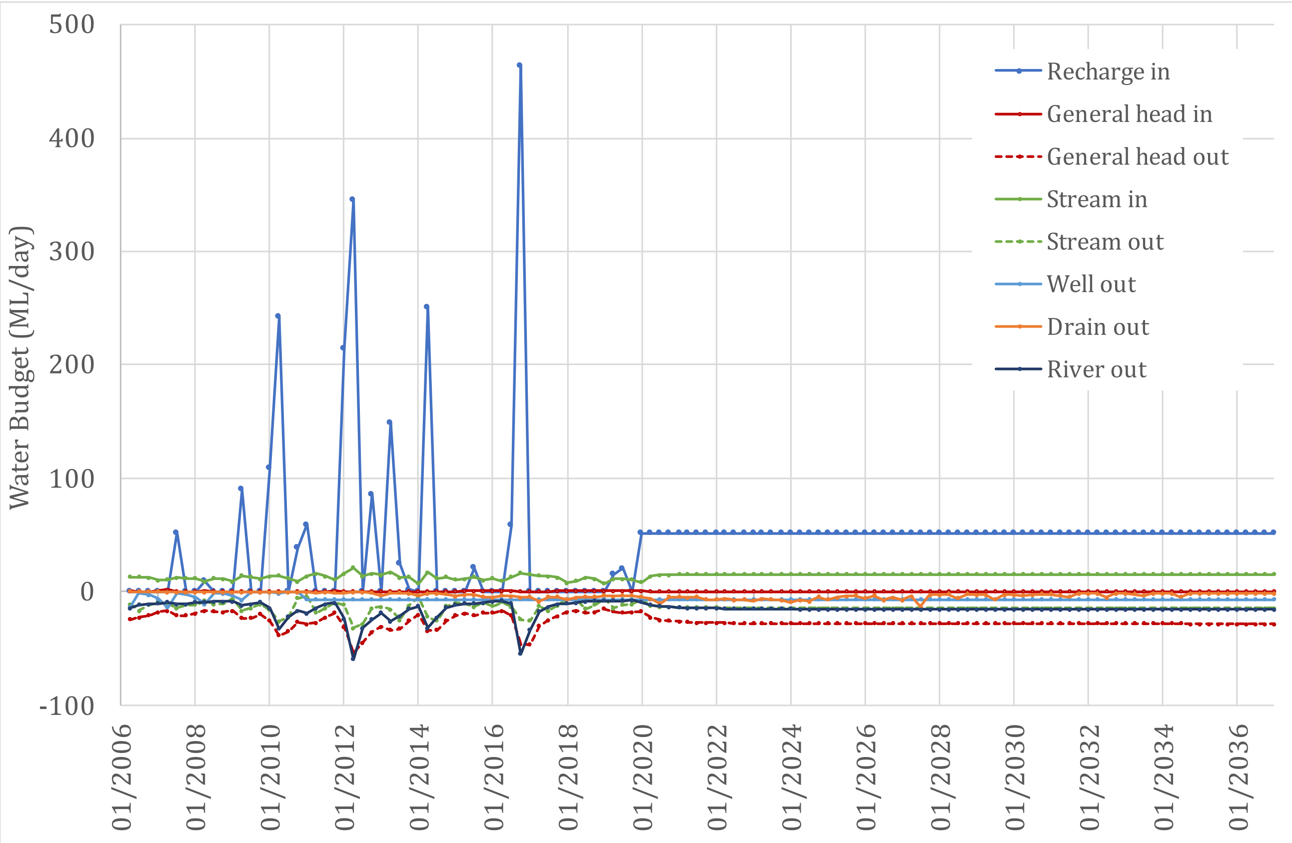


Figure 12.1 Predictive model cumulative water budget

Table 12.1 Transient predictive model water budget

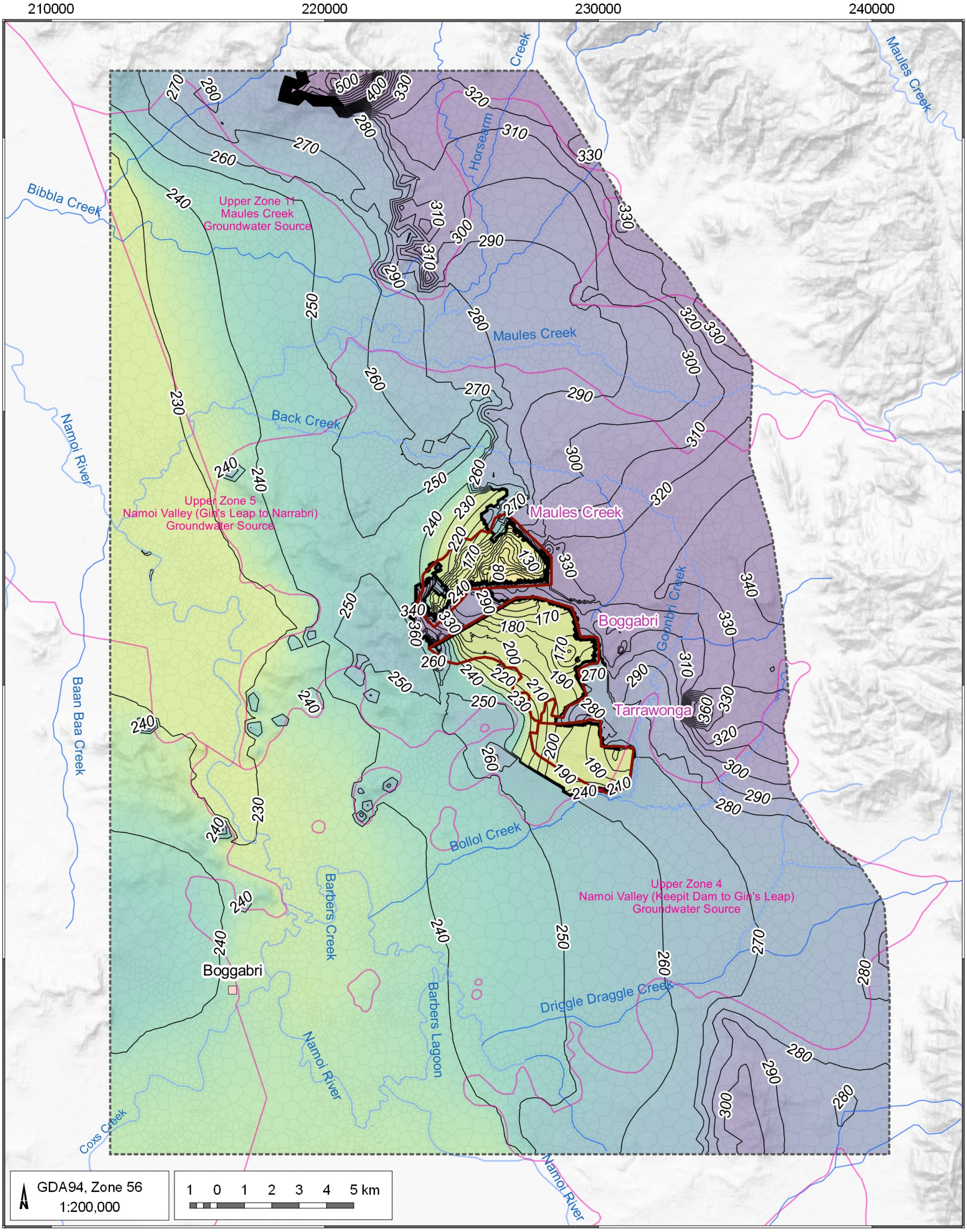
Parameter	Input (ML/day)			Output (ML/day)		
	minimum	average	maximum	minimum	average	maximum
Storage	0.93	5.05	88.56	0.00	2.44	37.01
Recharge	0.00	50.53	51.27	0.00	0.00	0.00
River	0.00	0.00	0.00	7.21	15.27	15.82
Stream	3.64	15.26	15.52	2.41	14.42	14.80
General Head boundary	0.12	0.15	0.80	16.54	27.71	28.40
Wells	0.00	0.00	0.00	6.78	6.78	6.78
Drains	0.00	0.00	0.00	1.45	4.36	88.80
TOTAL IN/OUT	**43.30**	**70.98**	**155.43**	**43.30**	**70.98**	**155.43**

Figure 12.1 shows that the influence of mining, as represented by flows to the drain cells, is a relatively small component of the water balance at the scale of the regional model. The cumulative mass balance error at the completion of the predictive run was 0.0%. The maximum percent discrepancy for individual time steps within the transient model run is 0.01%. This maximum error is within acceptable limits for adequate numerical convergence (<2%: Australian Modelling Guidelines – Barnett [2012]).

12.1.3 Water table and potentiometric surface

The simulated water table at 2036 is shown in Figure 12.2. Outside the footprint of mining the water table remains similar to the 2019 simulation with a dominant west to east flow direction aligned with Maules Creek and Bollol Creek alluvial aquifers, and northwards flow following the alignment of the Namoi River. The active mining areas within the BTM complex area are evident in the water table as areas of locally lowered water levels with inward hydraulic gradients.

Figure 12.3 shows the simulated potentiometric surface within the Merriown Seam in 2036. Similar to the 2019 predictions, the figures show a flatter hydraulic gradient and lower water levels than is predicted for the water table, indicating a downward vertical gradient. The flow directions remain strongly influenced by the active mining areas with flow predicted from the north and south along strike of the coal seams towards the mining areas. Extensive drawdown within the Merriown coal seam is evident, as all mining projects are approved to target this coal seam.



LEGEND

- Populated place
- Drainage
- Model extent
- Model mesh
- Mine outline
- Alluvial boundary zones

Contour line

potentiometric surface (mAHD)

- 50
- 100
- 200
- 300
- 400
- 550

BTM Complex Groundwater Model Update (G1850P)

Simulated water table – 2036

AGE

DATE 23/06/2021

FIGURE No: **12.2**

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Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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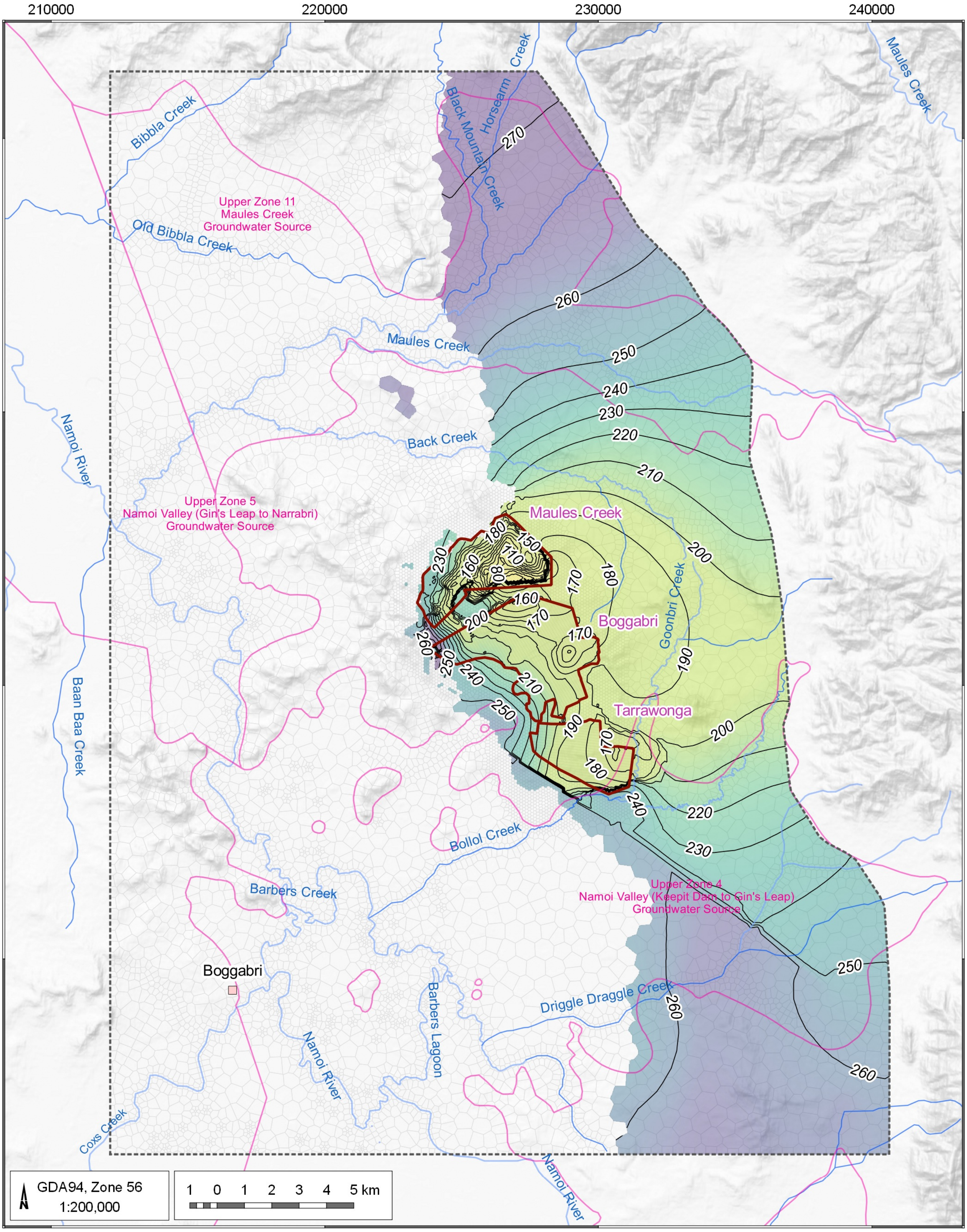

LEGEND

- Populated place
- Drainage
- Model extent
- Model mesh
- Mine outline
- Alluvial boundary zones

Contour line

potentiometric surface (mAHD)

- 50
- 100
- 200
- 300
- 400
- 550

BTM Complex Groundwater Model Update (G1850P)

Simulated potentiometric surface – Merriown seam – 2036

AGE

DATE 23/06/2021

FIGURE No: **12.3**

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Source: LiDAR DEM © Department Finance, Services and Innovation, 2016; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\12.03_G1850_Simulated potentiometric surface – Merriown seam – 2036.qgs

12.1.4 Drawdown

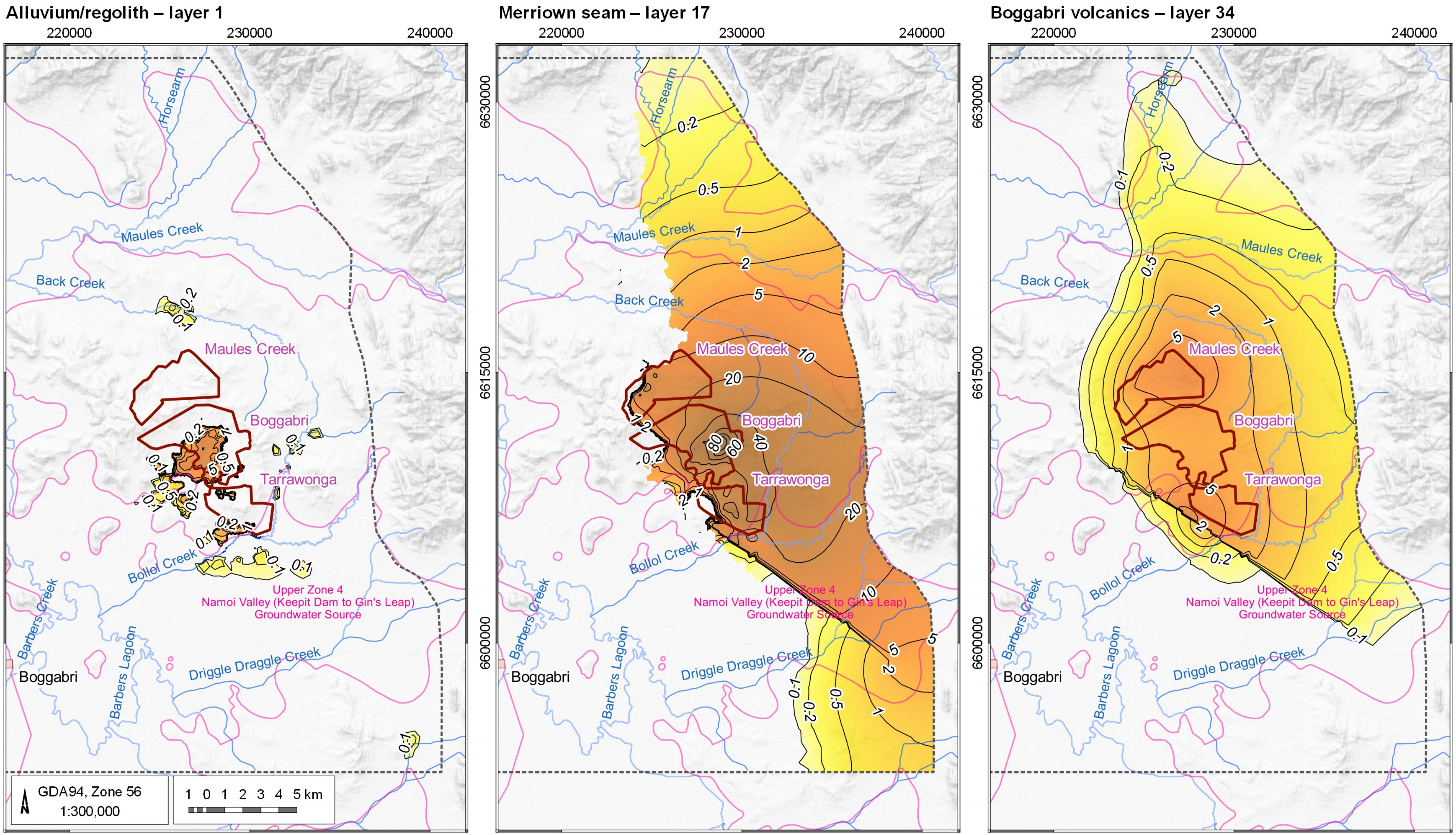
The updated model was used to simulate drawdown at 2036 which is the last year when the BTM mines are approved to be operating. Figure 12.4 and Figure 12.5 show the cumulative drawdown for the following model layers at 2019 and 2036.

- layer 1: Alluvium/regolith;
- layer 17: Merriown seam; and
- layer 34: Boggabri volcanics.

The figures show the zone of drawdown within the Merriown seam is predicted to expand over time and reach the model boundaries by 2036. This is considered a conservative over estimate of the drawdown, as the recalibrated model still over predicts drawdown propagation to the east through the coal seams; an impact that has not been observed in the monitoring points that are more distant from the mining areas (e.g. REG07, REG09).

The influence of the Conomos Fault in the model is also evident in the shape of the predicted drawdown within the coal seams and Boggabri volcanics basement. The model indicates the Conomos Fault retards the magnitude of the drawdown to the south of the fault. When interpreting the predicted drawdown, it is important to note that other faults are known to exist to the north and south of the BTM complex, but are not represented within the numerical model. It is expected that depressurisation and drawdown within the coal seams will not propagate beyond the faults which offset and terminate the coal seams against lower permeability interburden. This is potentially already evident in the lack of drawdown observed to the east in the observation network (e.g. REG07, REG09).

Whilst the drawdown is predicted to be extensive within the coal seams, it does not result in a large and widespread drawdown propagating upwards and into the Namoi Valley alluvium. The drawdown is largely confined to the alluvial areas immediately adjacent to the active mining at Boggabri and Tarrawonga Mines. The model predicts drawdown within the alluvial groundwater systems is largely less than 0.2 m in the Bollol Creek alluvium south of the BTM complex and less than 0.1 m within the Maules Creek alluvium to the north. This small amount of drawdown would not likely be discernible from climatically induced fluctuations in groundwater levels observed in monitoring bores. There are two small areas immediately adjacent to the Boggabri and Tarrawonga mines where drawdown is predicted to in the order of 1 m to 2 m by 2036.



LEGEND

- Populated place
- Drainage
- Contour line
- Model extent
- Mine outline
- Alluvial boundary zones

Drawdown (m)

0	1	50
0.1	2	100
0.2	5	200
0.5	10	500
	20	

AGE

BTM Complex Groundwater Model Update (G1850P)

Simulated drawdown at end 2020

DATE
23/06/2021

FIGURE No:
12.4

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Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
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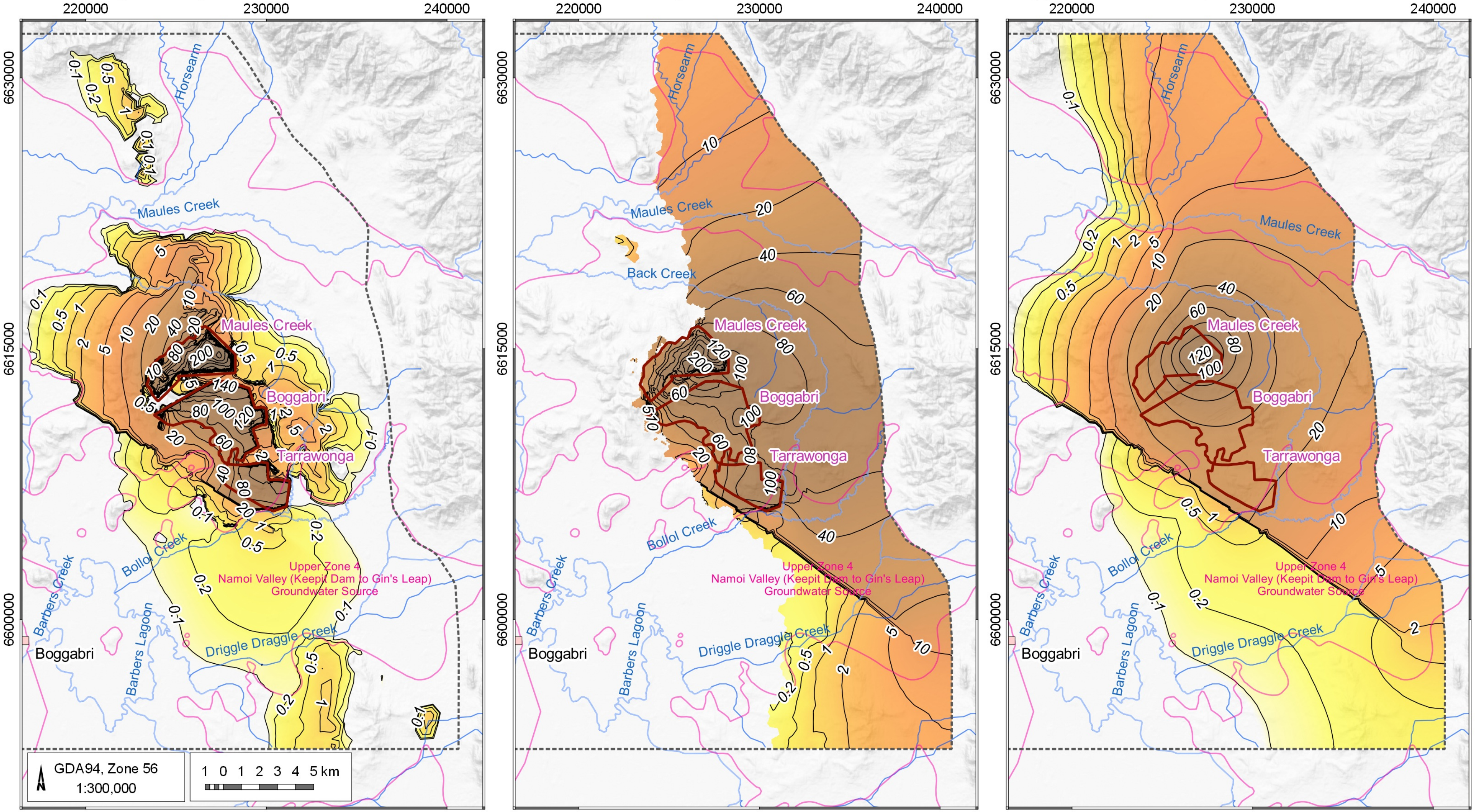
Alluvium/regolith – layer 1 | Merriown seam – layer 17 | Boggabri volcanics – layer 34



LEGEND

- Populated place
- Drainage
- Contour line
- Model extent
- Mine outline
- Alluvial boundary zones

Drawdown (m)

0, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200, 500

AGE

BTM Complex Groundwater Model Update (G1850P)

Simulated drawdown at end 2036

DATE
23/06/2021

FIGURE No:
12.5

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12.1.5 Impact on groundwater users

A large buffer of land surrounding the open cut mines is owned by the operators of the BTM complex. The model indicates that drawdown will not exceed the 2 m threshold for alluvial aquifers on any private land nominated in the Aquifer Interference Policy. Therefore, no private landholders' bores are predicted to be impacted by the approved mining. This is a prediction consistent with all previous numerical models developed to simulate the impacts of mining at the BTM complex on the groundwater regime.

12.1.6 Mine inflow

The AIP requires the accounting for all groundwater taken, either directly or indirectly from groundwater systems. Groundwater intercepted from the BTM mining area is considered a direct take from the Permian groundwater system. The discussion below refers to the volume of groundwater intercepted by mining from the Permian groundwater systems. This includes groundwater that cannot be pumped because it evaporates, groundwater that is bound to coal/spoils as well as groundwater that flows into sumps for pumping.

Figure 12.6 shows the volume of groundwater predicted to be directly intercepted by mining at the BTM complex within each of the mining areas. Table 12.2 summarises the annual volumes of groundwater directly intercepted within each of the BTM complex mines.

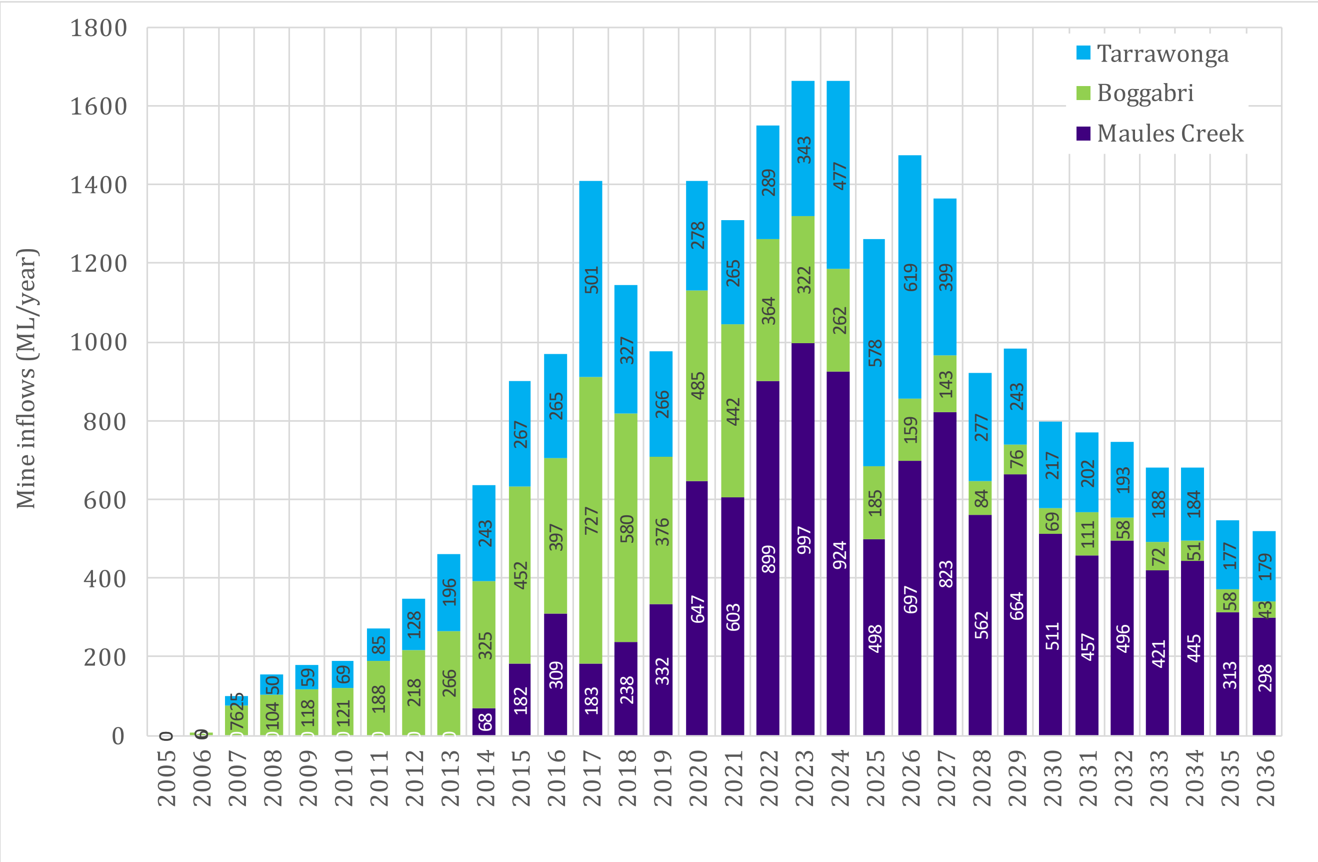

Figure 12.6 Predicted groundwater directly intercepted in BTM complex mines

Table 12.2 Predicted total volume of groundwater intercepted within each mining area

Year	Predicted volume of groundwater intercepted from mining areas (ML/year)		
	Boggabri	Tarrawonga	Maules Creek
2021	441.51	264.82	603.37
2022	363.63	288.56	899.37
2023	322.15	343.10	996.65
2024	262.10	477.47	923.55
2025	185.40	577.74	497.79
2026	159.46	619.42	696.63
2027	142.93	399.49	823.10
2028	83.69	276.77	561.61
2029	76.14	243.41	663.78
2030	68.62	216.97	510.57
2031	110.75	201.76	457.33
2032	57.86	192.63	495.87
2033	71.89	188.35	420.55
2034	50.86	183.60	444.90
2035	57.76	176.51	313.07
2036	42.80	178.89	298.11

Figure 12.6 shows the volume of groundwater intercepted by the BTM complex gradually rises as the footprint of mining grows, peaking around 1700 ML/year by 2023/2024. After this time the model predicts the volume of groundwater directly intercepted by the open cut mines gradually falls as the coal seams become dewatered and depressurised by the cumulative impacts of the three mines resulting in gentler hydraulic gradients and less mine inflow.

12.1.7 Water licensing

Within the region, groundwater is managed under the *Water Sharing Plan for the Murray Darling Basin Porous Rock Groundwater Sources* (porous rock WSP) and the *Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources* (alluvial WSP). The AIP requires mines account for water taken directly from the excavated groundwater systems, as well as flows of water indirectly influenced by pressure changes in adjacent water sources not directly mined. The BTM complex mines hold Water Access Licenses (WALs) to account for the groundwater directly and indirectly intercepted by mining.

Table 12.3 and Table 12.4 summarise the WALs held by the BTM complex mines from each of the water management units.

Table 12.3 Water access licenses and total entitlement within each mining area (porous rock WSP)

Mine	Water access licenses [1] (ML/year)	Total entitlement (units)
Boggabri	WAL 29473 – 177.5 units WAL 29562 – 700 units	877.5
Tarrawonga	WAL 31084 - 250 units WAL 29548 – 50 units	300
Maules Creek	WAL 29467 – 6 units WAL 29588 – 300 units WAL 36641 – 800 units	1106

Note: [1] Gunnedah - Oxley Basin NSW Murray Darling Basin Porous Rock Groundwater Sources.

Table 12.4 Water access licenses and total entitlement within each mining area (alluvial WSP)

Mine	Water access licenses (ML/year)	Zone	Total entitlement (units)
Boggabri	WAL 15037 WAL 24103 WAL 12767 WAL 12691 WAL 36547 WAL 37519	4 4 4 4 4 4	1028
Boggabri	WAL 42234	11	20
Tarrawonga	-	4	453
Tarrawonga	no entitlement	11	-
Maules Creek	WAL 27385	4	38
Maules Creek	WAL 12811	5	135
Maules Creek	WAL 12479	11	78

Table 12.5 presents the predicted volume of groundwater removed by each mine from each management zone under the alluvial WSP.

Indirect alluvial take was estimated using zone budgets from five model scenarios, which included a no mining scenario, a scenario with mining at all three of the sites, and three more scenarios representing mining at each of the BTM sites individually. The model with all mining was then run to calculate the change in groundwater flow to the alluvial zones compared to the model with no mining. The change in groundwater flow to the alluvial zones for each of the models with only one mine operating was also calculated. The calculated change in flow from each of the three models with only one mine were then combined to determine the proportion of impact attributable to each operation. The time varying factor for each mine was then applied to the change in flow calculated by the model with all three mines operating to estimate the proportion of the cumulative impact attributable to each operation.

Zones were defined as per the groundwater management zones detailed in the WSPs for the Upper and Lower Namoi Groundwater Sources, as well as the NSW Murray Darling Basin Porous Rock Groundwater Sources. To prevent double accounting, porous rock take was corrected by subtracting indirect alluvial take from the total inflow reporting to each of the mining areas.

Table 12.5 Predicted groundwater volume indirectly intercepted from alluvial aquifer zones

Year	Volume requiring licensing under alluvial WSP (ML/year)					
	Boggabri		Tarrawonga		Maules Creek	
	Zone 4	Zone 11	Zone 4	Zone 11	Zone 4	Zone 11
Entitlement[1#]	1028	20	453	0	38	78
2021	60	1	36	**1**	**79**	2
2022	42	1	33	**1**	**104**	3
2023	37	1	39	**1**	**115**	4
2024	32	1	57	**2**	**107**	4
2025	29	1	91	**4**	**79**	4
2026	21	1	86	**4**	**96**	5
2027	22	1	73	**4**	**112**	6
2028	20	1	66	**4**	**123**	8
2029	17	1	55	**4**	**139**	10
2030	18	1	59	**5**	**137**	11
2031	31	3	59	**5**	**126**	11
2032	18	2	61	**6**	**138**	13
2033	24	2	62	**6**	**132**	13
2034	17	2	63	**7**	**139**	15
2035	23	3	71	**8**	**126**	14
2036	18	2	76	**9**	**127**	15

Notes: [1] Total number of units for water access licenses held from each alluvial WSP management zone.
[#] Entitlements held by each organisation may vary over time due to purchase, sale or transfer of licenses.
Bold text indicates when predicted 'water take' exceeds available entitlements.

Table 12.5 shows the total volume of entitlements held by the BTM mines (1,444 ML) in zone 4 of the alluvial WSP exceeds the combined 'water take' from this zone predicted by the numerical model.. Transfer of water entitlements between the BTM mines would ensure each operation remains within its entitlement for zone 4.

The combined volume of water entitlements held within zone 11 (98 ML) is less than zone 4, with Maules Creek mine and Boggabri mine holding entitlements for this zone. The model predicts take from zone 11 for all three mines despite Boggabri and Tarrawonga being geographically further from zone 11 than Maules Creek. Hydrogeologically the three pits are essentially acting as a single large pit. The geographic location of each individual pit is therefore of lesser importance to the propagation of cumulative impacts.

This total volume of entitlements in zone 11 of the alluvial WSP also exceeds the combined 'water take' predicted for this zone by the numerical model. If individual entitlements are compared with predictions from the numerical model, there has been a potential shortage at Tarrawonga Mine from 2019 as the mine does not hold any water entitlements for this zone. However, transfer of water entitlements from Maules Creek (if required) would ensure each operation remains within its entitlement for this zone.

Maules Creek Mine also holds a WAL with an entitlement of 135 ML within zone 5. The alluvial WSP zones 2 and 5 occur in the model area, but are not predicted to be impacted by the mining at any of the operations so are not included within the above tables.

The volumes of water required to be accounted for under the porous rock WSP were estimated as follows:

a) the groundwater directly intercepted by each mining area by drain cells (representing dewatering of the mining voids) was extracted from the model (refer Table 12.2);

b) the indirect change in groundwater flux from the porous rock WSP into the alluvial WSP area due to mining activities was extracted from the model – this volume of water was assigned as 'water take' from the alluvial WSP; and

c) the alluvial 'water take' was subtracted from the drain cell flux directly into the mining areas to calculate the 'water take' from the porous rock WSP (a minus b).

This method prevents double accounting of 'water take' from the porous rock with the 'water take' from the alluvial WSPs. Table 12.6 below presents the total volume of groundwater removed from the porous rock WSP, and the corrected volume to prevent double accounting of alluvial groundwater in the porous rock 'water take'.

Table 12.6 Predicted volume of groundwater intercepted within each mining area within porous rock WSP

Year	Total volume of groundwater intercepted from mining areas (ML/year)			Volume requiring licensing under porous rock WSP (ML/year)		
	Boggabri	Tarrawonga	Maules Creek	Boggabri	Tarrawonga	Maules Creek
Entitlement[1,2]	-	-	-	877.5	300	1106
2021	442	265	603	381	228	522
2022	34	289	899	321	255	792
2023	322	343	997	284	**303**	878
2024	262	477	924	229	**418**	813
2025	185	578	498	155	**483**	415
2026	159	619	697	137	**529**	596
2027	143	399	823	120	**322**	705
2028	84	277	562	63	207	431
2029	76	243	664	58	184	515
2030	69	217	511	50	153	363
2031	111	202	457	77	138	320
2032	58	193	496	38	126	345
2033	72	188	421	46	120	276
2034	51	184	445	32	114	291
2035	58	177	313	32	98	173
2036	43	179	298	23	94	156

Notes: [1] Total number of units for water access licenses held from porous rock WSP.

[2] Entitlements held by each organisation may vary over time due to purchase, sale or transfer of licenses.

Bold text indicates when predicted 'water take' exceeds available entitlements.

Table 12.6 shows that Boggabri and Maules Creek mines hold sufficient licences to account for their predicted take from the porous rock WSP until 2036. If individual entitlements are compared with predictions from the numerical model, there is a potential shortage at Tarrawonga Mine, with the predicted take above 300 ML/year from 2023-2027. However, transfer of water entitlements from the other two mines would ensure Tarrawonga remains within their entitlement for this zone.

Together, the BTM complex holds sufficient WALs to account for the peak volume of groundwater predicted to be intercepted by mining from the porous rock WSP. Cumulatively the BTM complex holds 2,283.5 ML of WALs, with the predicted annual volume of groundwater intercepted by the complex from the porous rock to be at or below 1465 ML for the period 2019 to 2036.

13 Summary, conclusions and recommendations

This report describes an update to the conceptual and numerical groundwater flow models for the BTM mine complex in NSW. The updates were initiated by the BTM mines in response to comments on the previous update to the numerical model submitted to the NSW government in 2018.

The updates to the conceptual and numerical models were undertaken in a staged manner over the 2019 and 2020 calendar years in accordance with the process recommended in the Australian Groundwater Modelling Guidelines (Barnett, 2012).)

Structural changes to the numerical model included updating the elevation of model layers based on geological models provided by the BTM mines. A single fault known as the Conomos Fault that occurs to the south-west of the mining complex was also added to the model, and represented as a low permeability barrier to groundwater flow. Mine plans representing the progress of mining over time were also provided by each of the mines in the BTM complex and were used to update in the numerical model.

The update to the conceptual model occurred during a period of drought that resulted in no surface water flow in the major creek systems to the north and south of the mining complex. A site inspection and review of monitoring data indicated much of the Maules Creek and Bollol creek beds were dry and do not intersect the water table and behave as zones of enhanced recharge to the underlying water table. The representation of recharge was changed in the numerical model to allow recharge to be enhanced along the creek beds based on this change to the conceptual model.

The break of slope zone at the contact between the ridge areas and the alluvial flood plains was also represented in previous versions of the model as a zone of enhanced recharge. These zones were further subdivided in the updated numerical model based on catchment size and area, to allow differing recharge values to be determined for each zone through the calibration process. Whilst this area of enhanced recharge remains an un-proven aspect of the conceptual model as there is no significant monitoring within this zone, this update allowed further information from modelling to act as a guide to potential recharge rates in these areas. .

The model was recalibrated using a history matching process to replicate trends in measured groundwater levels and estimated mine inflows. Pilot points were introduced to the model to allow for more spatial variability in the adopted hydraulic properties. This resulted in an improved simulation of water level trends in areas of the model. The vertical gradient between the alluvial and bedrock groundwater systems was also adopted as a calibration parameter, with an improved match. This resulted in an improved replication in the model of the downward vertical gradient observed between water levels within the Maules Creek alluvium and the underlying alluvium. Overall, the ability of the model to predict groundwater levels is considered to have improved due the updates made to the model.

Whilst it was considered an overall improvement in the ability of the model to replicate historical water level trends was achieved, it was also clear that the model could not replicate all aspects observed in the monitoring datasets. For example there was an inability of the model to replicate the elevation of groundwater levels in the eastern area of the model, despite the introduction of recharge zones at the edge of the model along the break of slope to assist in this regard. It was concluded that groundwater flow entering the model across the eastern boundary which aligns with the limit of the coal measures, was more significant than previously assumed.

The different pressures observed via the VWPs installed through the Permian sequence were not replicated well by the model under the Maules Creek alluvium. Conceptually this may relate the location of the subcrop for each coal seam which has not been well defined in the area underlying the Maules Creek alluvium. This is a residual uncertainty in the geology that cannot be addressed further with modelling.

The updated model was used to simulate long term drawdown and the volume of water take that each of the BTM complex mines should account for with water access licences. The model predictions indicate that the BTM complex as a group holds sufficient licences to account for their take of water. Some transfer of water between the mines, or within respective companies is required to cover the indirect water take from the alluvial water sources.

It is recommended that the next update to the model due in three years should:

- extend the eastern model boundary to the Maules Creek and Bollol Creek catchment boundaries to represent groundwater flow from the New England Fold belt geological units entering the model; and
- review the data and work being undertaken by UNSW to estimate stream bed recharge in the Maules Creek catchment and determine if updates to the numerical model are warranted.

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Appendix A

Groundwater monitoring locations (BTM Complex and surrounding area)

Bore ID	Alternative_ID	Type	Status	Network	Easting (GDA94Z56)	Northing (GDA94Z56)	GL (mAHD)	GL Alt (mAHD)	Top of Casing (mAHD)	Stickup (m)	Bore depth (m)	Screen/sensor depth (mbgl)	Target geology
BCM01		SP	Active	Maules Creek	223841	6618371	273.39				10	6.75 - 9.75	Alluvium
BCM03		SP	Active	Maules Creek	230085	6617546	305.02				10	6.75 - 9.75	Alluvium
BCS1		Private	Unknown	Tarrawonga	237177	6610679	343						Alluvium
BCS2		Private	Unknown	Tarrawonga	236682	6609459	331				16.2		Alluvium
BCS3		Private	Unknown	Tarrawonga	236179	6608490	323				45.7		Alluvium
BCS4		Private	Unknown	Tarrawonga	236016	6608368	323				39		Alluvium
BCS5		Private	Unknown	Tarrawonga	235314	6607331	314						Alluvium
BCS6		Private	Unknown	Tarrawonga	234563	6606093	302						Alluvium
BCS7		Private	Unknown	Tarrawonga	231656	6605754	281.3						Alluvium
GW002129		Private	Active	Tarrawonga	228724	6606271					297.2		Coal Aquifer in Mine Lease
GW002501		Private	Active	Tarrawonga	228013	6606613	291.1				77.1		Interburden. Model has weathered and volcanics only
GW020432		Private	Active	Tarrawonga	224451	6607991	265				48.8		Volcanics
GW031856		Private	Active	Tarrawonga	229157	6603179				0.6	50.3		Alluvial
GW044997		Private	Active	Tarrawonga	230870	6605895		276.56		0.2	45.7		Alluvial
GW052266		Private	Active	Tarrawonga	227848	6604674		260.36		0.1	91.4		Alluvial
GW3115		Private	Active	Boggabri	225174	6608903			280				Boggabri Volcanics
IBC2102		SP	Destroyed	Boggabri	226892	6611771	322	321			85	78-82	Merriown Coal Seam
IBC2103		SP	Destroyed	Boggabri	226898	6611773	321.8	321			59	50-56	Jeralong Coal Seam
IBC2104		SP	Active	Boggabri	228336	6612215	331.1	330			87	80-84	Braymont Coal Seam
IBC2105		SP	Active	Boggabri	228321	6612212	331.4	330			160	151-157	Merriown Coal Seam
IBC2110	MW3 / GW967860	SP	Active	Boggabri	225939	6607684	272.8	273 or 268.7			100	91-97	Boggabri Volcanics
IBC2111		SP	Active	Boggabri	225950	6607683	272.7	272.5			45	36-42	Boggabri Volcanics
IBC2113		SP	Destroyed	Boggabri	229720	6608797	343.4	343			96.8		Merriown Coal Seam
IBC2114		SP	Destroyed	Boggabri	229146	6610283	324.8	325			86	77-83	Bollol Creek Coal Seam
IBC2115		SP	Destroyed	Boggabri	229155	6610279	325	325			111.5	103-107	Merriown Coal Seam
IBC2138		SP	Destroyed	Boggabri	226725	6610387	294.5		294.46		66	57-63	Merriown Coal Seam
IBC2139		SP	Destroyed	Boggabri	229421	6609296	319.4		319.35		92.79	83-89	Merriown Coal Seam
BC2181		SP	Active	Boggabri	226848	6612477	335.2		335.2		114	105-111	Merriown Coal Seam
BC2193		SP	Destroyed	Boggabri	229699	6610899	340		340		96.3	87-93	Braymont Coal Seam
M267P_V1		VWP	Destroyed	Maules Creek	227440	6615472	404.76	405.56			299	151.5	Braymont
M267P_V2		VWP	Destroyed	Maules Creek	227440	6615472	404.76	405.56			299	256.5	Velyama, Upper Northam
MAC1218		SP	Destroyed	Maules Creek	224015	6613693	360.4	361.4	362.32	0.9	110	107 – 110	Nagero Upper
MAC1219		SP	Destroyed	Maules Creek	224172	6613678	369.61	370.41	341.23	0.8	163	107 – 110	Jeralong/Merriown
MAC1259	MAC1259B?	SP	Destroyed	Maules Creek	224948	6615277	316.15	316.95	317.1	0.15	98	94 – 97	
MAC1261		SP	Destroyed	Maules Creek	226750	6614872	381.48	382.28	383.07	0.9	180	161 – 164	Braymont
MAC1279		SP	Destroyed	Maules Creek	226446	6616312	326.05	326.85	327.76	0.9	144	70 – 73	Jeralong
MAC1280		SP	Active	Maules Creek	226525	6616503	322.5	323.5	324.55	0.9	146	56 – 59	Interburden between Braymont seams
MAC1283		SP	Destroyed	Maules Creek	224989	6615291	317.42	318.22	318.98	0.8	91	61 – 64	Velyama
MAC252		SP	Destroyed	Maules Creek	226240	6614772	340.98	340.98	341.54	0.75	101	92.5 – 98.5	Braymont
MAC263_V1		VWP	Destroyed	Maules Creek	226037	6614513	347.46	348.26			-	105	Braymont
MAC263_V2		VWP	Destroyed	Maules Creek	226037	6614513	347.46	348.26			-	183	Velyama Nagero Seam, Upper Northam
MAC268P		VWP	Destroyed	Maules Creek	227498	6614521	415.97	416.77	416.92		-	280	Velyama Nagero Seam, Upper Northam
MW1	GW967848	SP	Active	Tarrawonga	228743	6605702	269.51			0.7	56	52-56	Permian Coal Measures
MW2	GW967849	SP	Active	Tarrawonga	228851	6605704	269.72			0.8	7	4-7	Alluvial
MW4	GW967850	SP	Active	Tarrawonga	227848	6604708	262.67			0.7	20	17-20	Alluvial
MW5	GW967851	SP	Active	Tarrawonga	229488	6605985	271.32			0.8	8.3	5.3-8.3	Alluvial
MW6	GW967881	SP	Destroyed	Tarrawonga	225385	6607871	264.41		268	0.8	32	29-32	Alluvial
MW7	GW967883	SP	Active	Tarrawonga	229823	6607932	344.32			1	105	102-105	Permian Sediments
MW8	GW967882	SP	Active	Tarrawonga	226795	6606958	280.93			0.8	26	23-26	Alluvial
RB01_V1		VWP	Destroyed	Maules Creek	224058	6612333	433.05				-	97	Braymont
RB01_V2		VWP	Destroyed	Maules Creek	224058	6612333	433.05				-	140	Merriown
RB01_V3		VWP	Destroyed	Maules Creek	224058	6612333	433.05				-	194.5	Flixton
RB01A		SP	Destroyed	Maules Creek	224058	6612341	432.41				220.5	213.5 - 219.5	Templemore
RB02_V1		VWP	Destroyed	Maules Creek	224860	6613267	398.17				-	110.5	Braymont
RB02_V2		VWP	Destroyed	Maules Creek	224860	6613267	398.17				-	162	Merriown
RB02_V3		VWP	Destroyed	Maules Creek	224860	6613267	398.17				-	226	Nagero
RB02_V4		VWP	Destroyed	Maules Creek	224860	6613267	398.17				-	229.5	Northam
RB02A		SP	Destroyed	Maules Creek	224853	6613266	398.08				234	227 - 233	Nagero
RB03_V1		VWP	Active	Maules Creek	227947	6613635	407.89				-	164	Braymont

Bore ID	Alternative_ID	Type	Status	Network	Easting (GDA94Z56)	Northing (GDA94Z56)	GL (mAHD)	GL Alt (mAHD)	Top of Casing (mAHD)	Stickup (m)	Bore depth (m)	Screen/sensor depth (mbgl)	Target geology
RB03_V2		VWP	Active	Maules Creek	227947	6613635	407.89				-	242	Merriown
RB03_V3		VWP	Active	Maules Creek	227947	6613635	407.89				-	289	Nagero
RB03_V4		VWP	Active	Maules Creek	227947	6613635	407.89				-	317	Templemore
RB04_V1		VWP	Active	Maules Creek	228213	6614910	437.53				-	209	Braymont
RB04_V2		VWP	Active	Maules Creek	228213	6614910	437.53				-	272.5	Merriown
RB04_V3		VWP	Active	Maules Creek	228213	6614910	437.53				-	309	Nagero
RB04_V4		VWP	Active	Maules Creek	228213	6614910	437.53				-	339	Lower Northam
RB05_V1		VWP	Active	Maules Creek	228071	6616813	328.4				-	107	Braymont
RB05_V2		VWP	Active	Maules Creek	228071	6616813	328.4				-	213	Jeralong
RB05_V3		VWP	Active	Maules Creek	228071	6616813	328.4				-	280	Nagero
RB05_V4		VWP	Active	Maules Creek	228071	6616813	328.4				-	390	Templemore
RB05A		SP	Active	Maules Creek	228065	6616810	328.1	328.4			246.5	239 - 245	Merriown
REG1_V1		VWP	Active	Cumulative	226946	6622396	286.17				-	118.7	Jeralong
REG1_V2		VWP	Active	Cumulative	226946	6622396	286.17				-	134.5	Merriown
REG1_V3		VWP	Active	Cumulative	226946	6622396	286.17				-	193.5	Nagero
REG1_V4		VWP	Active	Cumulative	226946	6622396	286.17				-	281.5	Therribri
REG10_V1		VWP	Active	Cumulative	226723	6618261	287.12				-	55	Braymont
REG10_V2		VWP	Active	Cumulative	226723	6618261	287.12				-	144.2	Merriown
REG10_V3		VWP	Active	Cumulative	226723	6618261	287.12				-	178	Nagero
REG10_V4		VWP	Active	Cumulative	226723	6618261	287.12				-	185.5	Upper Northam
REG10A		SP	Active	Cumulative	226717	6618260	287.12				10	6.75 - 9.75	Alluvium
REG12		SP	Active	Cumulative	222632	6617358	285.61				48.3	38.4 - 44.4	Boggabri Volcanics
REG13		SP	Active	Cumulative	219713	6611129	277.08				133	128 - 132	Boggabri Volcanics
REG14		SP	Active	Cumulative	225547	6602649	250.18				102	90 - 96	Basement
REG2_V1		VWP	Active	Cumulative	232722	6620459	317.01				-	60	Fault zone
REG2_V2		VWP	Active	Cumulative	232722	6620459	317.01				-	120	Fault zone
REG2_V3		VWP	Active	Cumulative	232722	6620459	317.01				-	200	Fault zone
REG2_V4		VWP	Active	Cumulative	232722	6620459	317.01				-	260	Fault zone
REG3		SP	Active	Cumulative	217164	6619558	241.6	247.6*			57	50.50 - 56.50	Boggabri Volcanics
REG4		SP	Active	Cumulative	219323	6612763	259.95				72.5	65.5 - 71.5	Boggabri Volcanics
REG5		SP	Active	Cumulative	220649	6609521	252.17				78.7	72.2 - 78.2	Boggabri Volcanics
REG5A		SP	Active	Cumulative	220646	6609514	252.03				22	18 – 21	Alluvium
REG6		SP	Active	Cumulative	223100	6606534	250.65				96	88.0 – 94.0	Boggabri Volcanics
REG7_V1		VWP	Active	Cumulative	233543	6605348	291.62				-	67.5	Braymont
REG7_V2		VWP	Active	Cumulative	233543	6605348	291.62				-	148.2	Merriown
REG7_V3		VWP	Active	Cumulative	233543	6605348	291.62				-	242.5	Nagero
REG7A		SP	Active	Cumulative	233545	6605359	291.71				36	24 - 30	Alluvium
REG8_V1		VWP	Active	Cumulative	230030	6615113	341.6				-	91.5	Braymont
REG8_V2		VWP	Active	Cumulative	230030	6615113	341.6				-	221	Merriown
REG8_V3		VWP	Active	Cumulative	230030	6615113	341.6				-	274	Nagero
REG9_V1		VWP	Active	Cumulative	234233	6610591	346.81				-	115.8	Braymont
REG9_V2		VWP	Active	Cumulative	234233	6610591	346.81				-	175.2	Merriown
REG9_V3		VWP	Active	Cumulative	234233	6610591	346.81				-	268	Nagero
TEMPLE_A		Private	Active	Tarrawonga	230997	6605537		277.84		0.5			
TEMPLE_B		Private	Active	Tarrawonga	230544	6604345							
TA60_V1		VWP	Destroyed	Tarrawonga	230164	6607286	317.46	317.68			-	69	Velyama interburden
TA60_V2		VWP	Destroyed	Tarrawonga	230164	6607286	317.46	317.68			-	89	Velyama interburden
TA60_V3		VWP	Destroyed	Tarrawonga	230164	6607286	317.46	317.68			-	109	Velyama seam
TA60_V4		VWP	Destroyed	Tarrawonga	230164	6607286	317.46	317.68			-	118	Velyama-Nagero interburden
TA65_V1		VWP	Active	Tarrawonga	230997	6607344	287.08	287.03			-	30	Jeralong overburden
TA65_V2		VWP	Active	Tarrawonga	230997	6607344	287.08	287.03			-	35	Jeralong seam
TA65_V3		VWP	Active	Tarrawonga	230997	6607344	287.08	287.03			-	47	Jeralong-Merriown Interburden
TA65_V4		VWP	Active	Tarrawonga	230997	6607344	287.08	287.03			-	56	Merriown Seam
TA65_V5		VWP	Active	Tarrawonga	230997	6607344	287.08	287.03			-	97	Velyama-Nagero Interburden
TA65_V6		VWP	Active	Tarrawonga	230997	6607344	287.08	287.03			-	110	Nagero Seam
TA65_V7		VWP	Active	Tarrawonga	230997	6607344	287.08	287.03			-	136	Nagero-Upper Northam Interburden
TA65_V8		VWP	Active	Tarrawonga	230997	6607344	287.08	287.03			-	153	Upper Northam Seam
WHAN	GW060214	Private	Active	Maules Creek	221134	6622897	264*				10		
School	GW027653	Private	Active	Maules Creek	224673	6623048	282*				8.4		Gravel
WOL1	GW062778	Private	Active	Maules Creek	226799	6622149	290*				7.2		

Bore ID	Alternative_ID	Type	Status	Network	Easting (GDA94Z56)	Northing (GDA94Z56)	GL (mAHD)	GL Alt (mAHD)	Top of Casing (mAHD)	Stickup (m)	Bore depth (m)	Screen/sensor depth (mbgl)	Target geology
WOL2		Private	Active	Maules Creek	226119	6618673	285*				TBC		
MOR1		Private	Active	Maules Creek	220649	6619125	260*				TBC		
MOR2		Private	Active	Maules Creek	219871	6618803	2560*	260*			TBC		
TESTON	GW003489	Private	Active	Maules Creek	222568	6619102	270*				45.4		Hard rock
TRALEE	GW003478	Private	Active	Maules Creek	224102	6618538	278*				33.8		Basalt
MORSE	GW001869	Private	Active	Maules Creek	228203	6617691	302*				63.1		Sandstone
BRE2	GW000583	Private	Active	Maules Creek	234377	6616639	354*				96.3		Hard rock
BAS1		Private	Active	Maules Creek	217107	6612427	239*				TBC		
BAS2		Private	Active	Maules Creek	217548	6612037	238*				TBC		

Bore ID	Alternative_ID	Type	Status	Network	Easting (GDA94Z56)	Northing (GDA94Z56)	GL (mAHD)	GL Alt (mAHD)	Top of Casing (mAHD)	Stickup (m)	Bore depth (m)	Screen/sensor depth (mbgl)	Target geology
GW030048_1		SP - Nested (2)	Active	DPI Water	220717	6600067	241.9	241.9	242.36	0.46	53.6	11.6-17.7	Alluvium
GW030048_2		SP - Nested (2)	Active	DPI Water	220717	6600067	241.9	241.9	242.36	0.46	53.6	34.4-35.9	Alluvium
GW030049_1		SP - Nested (3)	Active	DPI Water	222611	6599839	243	243	243.56	0.56	74.7	19.2-20.4	Alluvium
GW030049_2		SP - Nested (3)	Active	DPI Water	222611	6599839	243	243	243.56	0.56	74.7	25.9-28.9	Alluvium
GW030049_3		SP - Nested (3)	Active	DPI Water	222611	6599839	243	243	243.56	0.56	74.7	57.6-61.9	Alluvium
GW030050_1		SP - Nested (3)	Active	DPI Water	223919	6599684	242.7	242.7	243.2	0.5	143.9	29.9-34.5	Alluvium
GW030050_2		SP - Nested (3)	Active	DPI Water	223919	6599684	242.7	242.7	243.2	0.5	143.9	49.4-50.9	Alluvium
GW030050_3		SP - Nested (3)	Active	DPI Water	223919	6599684	242.7	242.7	243.2	0.5	143.9	97.5-105.7	Alluvium
GW030051_1		SP - Nested (2)	Active	DPI Water	224986	6599589	244.2	244.2	244.72	0.52	67.1	17.7-18.6	Alluvium
GW030051_2		SP - Nested (2)	Active	DPI Water	224986	6599589	244.2	244.2	244.72	0.52	67.1	55.2-56.7	Weathered bedrock
GW030052_1		SP - Nested (2)	Active	DPI Water	226612	6599387	248.4	248.8	248.81	0.41	97.5	19.8-21.3	Alluvium
GW030052_2		SP - Nested (2)	Active	DPI Water	226612	6599387	248.4	248.4	248.81	0.41	97.5	25.9-27.4	Alluvium
GW030129_1	Mardi Gras Rd	SP	Active	DPI Water	217135	6619637	247.97		247.97		62.5	23.2-24.4	Alluvium
GW030130_1	Mardi Gras	SP - Nested (2)	Active	DPI Water	217409	6620543	248.45		248.45		103	15.2-16.2	Alluvium
GW030130_2	Mardi Gras	SP - Nested (2)	Active	DPI Water	217409	6620543	248.45		248.45		103	54.9-56.7	Alluvium
GW030131_1	Harparary Rd	SP	Active	DPI Water	217455	6621709	250.73		250.73		22	16.8-18.3	Clay & weathered bedrock
GW030132_1		SP - Nested (2)	Active	DPI Water	217325	6623769	251	251	251.53	0.53	64.3	8.2-9.4	Alluvium
GW030132_2		SP - Nested (2)	Active	DPI Water	217325	6623769	251	251	251.53	0.53	64.3	32.6-34.1	Alluvium
GW030133_1		SP	Active	DPI Water	217869	6625298	254.2	254.2	254.83	0.63	107.3	46.6-47.5	Alluvium
GW030134_1		SP	Active	DPI Water	217958	6625978	254.8	254.8	255.35	0.55	106.7	14.6-17.4	Alluvium
GW030235_1		SP - Nested (2)	Active	DPI Water	213314	6625918	241.4	241.4	242.17	0.77	87.2	25-26.5	Alluvium
GW030235_2		SP - Nested (2)	Active	DPI Water	213314	6625918	241.4	241.4	242.17	0.77	87.2	50.9-52.7	Alluvium
GW030236_1		SP - Nested (2)	Active	DPI Water	214894	6625713	245.31	244.8	245.31	0.51	57.3	12.8-15.2	Alluvium
GW030236_2		SP - Nested (2)	Active	DPI Water	214894	6625713	245.31	244.8	245.31	0.51	57.3	54.3-55.8	Alluvium
GW030237_1		SP	Active	DPI Water	216529	6625478	249.9	249.9	250.51	0.61	70.1	64-65.5	Alluvium
GW030468_1	Namoi River Bore	SP	Active	DPI Water	217752	6603407	240.39		240.39		45.7	21.3-24.4	Alluvium
GW030469_1		SP	Active	DPI Water	218612	6603896	239.8	239.8	240.69	0.89	38.8	24.3-27.4	Alluvium
GW030470_1		SP - Nested (2)	Active	DPI Water	218998	6604550	240.2	240.2	241.17	0.97	30.8	10.4-16.2	Alluvium
GW030470_2		SP - Nested (2)	Active	DPI Water	218998	6604550	240.2	240.2	241.13	0.93	30.8	19.8-22.8	Alluvium
GW030471_1		SP - Nested (3)	Active	DPI Water	219451	6605582	239.6	239.6	240.5	0.9	49.7	16.4-18.9	Alluvium
GW030471_2		SP - Nested (3)	Active	DPI Water	219451	6605582	239.6	239.6	240.5	0.9	49.7	24.4-30.5	Alluvium
GW030471_3		SP - Nested (3)	Active	DPI Water	219451	6605582	239.6	239.6	240.55	0.95	49.7	41.5-44.5	Alluvium
GW030472_1		SP - Nested (3)	Active	DPI Water	225148	6602611	248	248	248.91	0.91	106.7	23.8-25	Alluvium
GW030472_2		SP - Nested (3)	Active	DPI Water	225148	6602611	248	248	248.9	0.9	106.7	57.3-59.7	Alluvium
GW030472_3		SP - Nested (3)	Active	DPI Water	225148	6602611	248	248	248.9	0.9	106.7	94.5-101.5	Conglomerate
GW030535_1		SP	Active	DPI Water	222609	6599838	241	241	242.06	1.06	75	54.9-60.6	Alluvium
GW036003_1		SP	Active	DPI Water	212979	6618417	233.8	233.8	234.76	0.96	121.4	97.5-101	Alluvium
GW036007_1		SP - Nested (3)	Active	DPI Water	216176	6607527	235.8	235.8	236.66	0.86	51.5	16.5-22.6	Alluvium
GW036007_2		SP - Nested (3)	Active	DPI Water	216176	6607527	235.8	235.8	236.72	0.92	51.5	29.6-32.6	Alluvium
GW036007_3		SP - Nested (3)	Active	DPI Water	216176	6607527	235.8	235.8	236.74	0.94	51.5	37.8-39.8	Alluvium
GW036008_1		SP	Active	DPI Water	216599	6607505	235.1	235.1	235.88	0.78	61	18.3-21.3	Alluvium
GW036013_1		SP	Active	DPI Water	212185	6612140	233.9	233.9	234.78	0.88	49.7	18.9-21.9	Alluvium
GW036014_1		SP - Nested (2)	Active	DPI Water	213905	6611728	235.3	235.3	236.13	0.83	65.5	18.3-21.3	Alluvium
GW036014_2		SP - Nested (2)	Active	DPI Water	213905	6611728	235.3	235.3	236.13	0.83	65.5	39.6-45.7	Alluvium
GW036015_1		SP - Nested (2)	Active	DPI Water	215140	6611506	236	236	236.91	0.91	74.1	19.8-22.8	Alluvium
GW036015_2		SP - Nested (2)	Active	DPI Water	215140	6611506	236	236	236.91	0.92	74.1	50.3-53.4	Alluvium
GW036016_1		SP - Nested (3)	Active	DPI Water	216209	6611379	237.1	237.1	237.92	0.82	89.3	22.9-27.4	Alluvium
GW036016_2		SP - Nested (3)	Active	DPI Water	216209	6611379	237.1	237.1	237.92	0.82	89.3	42.7-45.7	Alluvium
GW036016_3		SP - Nested (3)	Active	DPI Water	216209	6611379	237.1	237.1	237.95	0.85	89.3	73.1-76.2	Alluvium
GW036055_1		SP - Nested (3)	Active	DPI Water	212363	6613407	233.6	233.6	234.51	0.91	93.6	27.4-30.5	Alluvium
GW036055_2		SP - Nested (3)	Active	DPI Water	212363	6613407	233.6	233.6	234.54	0.94	93.6	45.7-48.8	Alluvium
GW036055_3		SP - Nested (3)	Active	DPI Water	212363	6613407	233.6	233.6	234.53	0.93	93.6	60.9-64	Alluvium
GW036056_1		SP	Active	DPI Water	215028	6609534	237.2	237.2	238.21	1.01	49.7	18.9-21.9	Alluvium
GW036057_1		SP - Nested (2)	Active	DPI Water	216487	6607724	236.3	236.3	237.26	0.96	98.5	39.6-42.7	Alluvium
GW036057_2		SP - Nested (2)	Active	DPI Water	216487	6607724	236.3	236.3	237.27	0.97	98.5	73.2-76.2	Alluvium
GW036092_1	Robertsons Hill	SP	Active	DPI Water	218436	6603669	238.69	237.5	238.69	1.19	30.8	19.8-22.8	Alluvium
GW036093_1		SP - Nested (3)	Active	DPI Water	212641	6617021	232	232	233.22	1.22	89.3	21.3-24.3	Alluvium
GW036093_2		SP - Nested (3)	Active	DPI Water	212641	6617021	232	232	233.18	1.18	89.3	51.8-54.8	Alluvium
GW036093_3		SP - Nested (3)	Active	DPI Water	212641	6617021	232	232	233.17	1.17	89.3	66.8-70.1	Alluvium
GW036096_1		SP - Nested (2)	Active	DPI Water	212177	6616456	233.3	233.3	234.4	1.1	74.7	21.3-24.3	Alluvium

Bore ID	Alternative_ID	Type	Status	Network	Easting (GDA94Z56)	Northing (GDA94Z56)	GL (mAHD)	GL Alt (mAHD)	Top of Casing (mAHD)	Stickup (m)	Bore depth (m)	Screen/sensor depth (mbgl)	Target geology
GW036096_2		SP - Nested (2)	Active	DPI Water	212177	6616456	233.3	233.3	234.45	1.15	74.7	39.6-42.6	Alluvium
GW036164_1		SP	Active	DPI Water	213080	6617499	233.4	233.4	234.37	0.97	111.3	103.6-106.6	Alluvium
GW036185_1		SP	Active	DPI Water	215746	6611466	234.6	234.56	235.63	1.07	115.8	91.4-94.5	Alluvium
GW036186_1	Merriendi Crossing	SP	Active	DPI Water	214351	6618121	239.07		239.07		67.1	22.8-25.9	Alluvium
GW036187_1	Merriendi Rd	SP	Active	DPI Water	215353	6618358	261.32		241.38		42.7	25.6-28.3	Alluvium
GW036548_1		SP - Nested (3)	Active	DPI Water	222929	6594698	245.6	245.6	246.74	1.14	124	19-23	Alluvium
GW036548_2		SP - Nested (3)	Active	DPI Water	222929	6594698	245.6	245.6	246.74	1.14	124	57-61	Alluvium
GW036548_3		SP - Nested (3)	Active	DPI Water	222929	6594698	245.6	245.6	246.74	1.14	124	87.5-93.5	Alluvium
GW036565_1		SP	Active	DPI Water	217594	6598099	242.7	242.7	243.8	1.1	34	15-17	Alluvium
GW036567_1		SP	Active	DPI Water	217801	6596440	243.5	243.5	244.58	1.08	38	25-29	Alluvium
GW036568_1		SP - Nested (3)	Active	DPI Water	217621	6595084	244.1	244.1	245.25	1.15	89	26.5-30.5	Alluvium
GW036568_2		SP - Nested (3)	Active	DPI Water	217621	6595084	244.1	244.1	245.25	1.15	89	42-46	Alluvium
GW036568_3		SP - Nested (3)	Active	DPI Water	217621	6595084	244.1	244.1	245.25	1.15	89	60-64	Alluvium
GW036598_1		SP - Nested (3)	Active	DPI Water	217315	6593569	245.3	245.3	246.46	1.16	134	25-31	Alluvium
GW036598_2		SP - Nested (3)	Active	DPI Water	217315	6593569	245.3	245.3	246.46	1.16	134	74-79	Alluvium
GW036598_3		SP - Nested (3)	Active	DPI Water	217315	6593569	245.3	245.3	246.46	1.16	134	123-129	Alluvium
GW036600_1	Binnalong Rd	SP - Nested (3)	Active	DPI Water	216345	6593096	246.97		246.97		141.5	13-15	Alluvium
GW036600_2	Binnalong Rd	SP - Nested (3)	Active	DPI Water	216345	6593096	246.97				141.5	100-105	Alluvium
GW036600_3	Binnalong Rd	SP - Nested (3)	Active	DPI Water	216345	6593096	246.97		246.97		141.5	122-127	Alluvium
GW041027_1	Thornfield Xing	SP	Active	DPI Water	232730	6620523	318.45		318.45		83.5	8.3-14.3	Alluvium
GW967137_1	Elfin Crossing	SP - Nested (2)	Active	DPI Water	219846	6622452	258.79		258.8		84	8-11	Alluvium
GW967137_2	Elfin Crossing	SP - Nested (2)	Active	DPI Water	219846	6622452	288.55		258.79		84	64-75	Alluvium
GW967138_1	Green Gully	SP - Nested (2)	Active	DPI Water	227001	6622603	288.13		288.55		89.6	7-10	Alluvium
GW967138_2	Green Gully	SP - Nested (2)	Active	DPI Water	227001	6622603	288.13		288.13		89.6	71-77	

Appendix B

Horizontal hydraulic conductivity test results

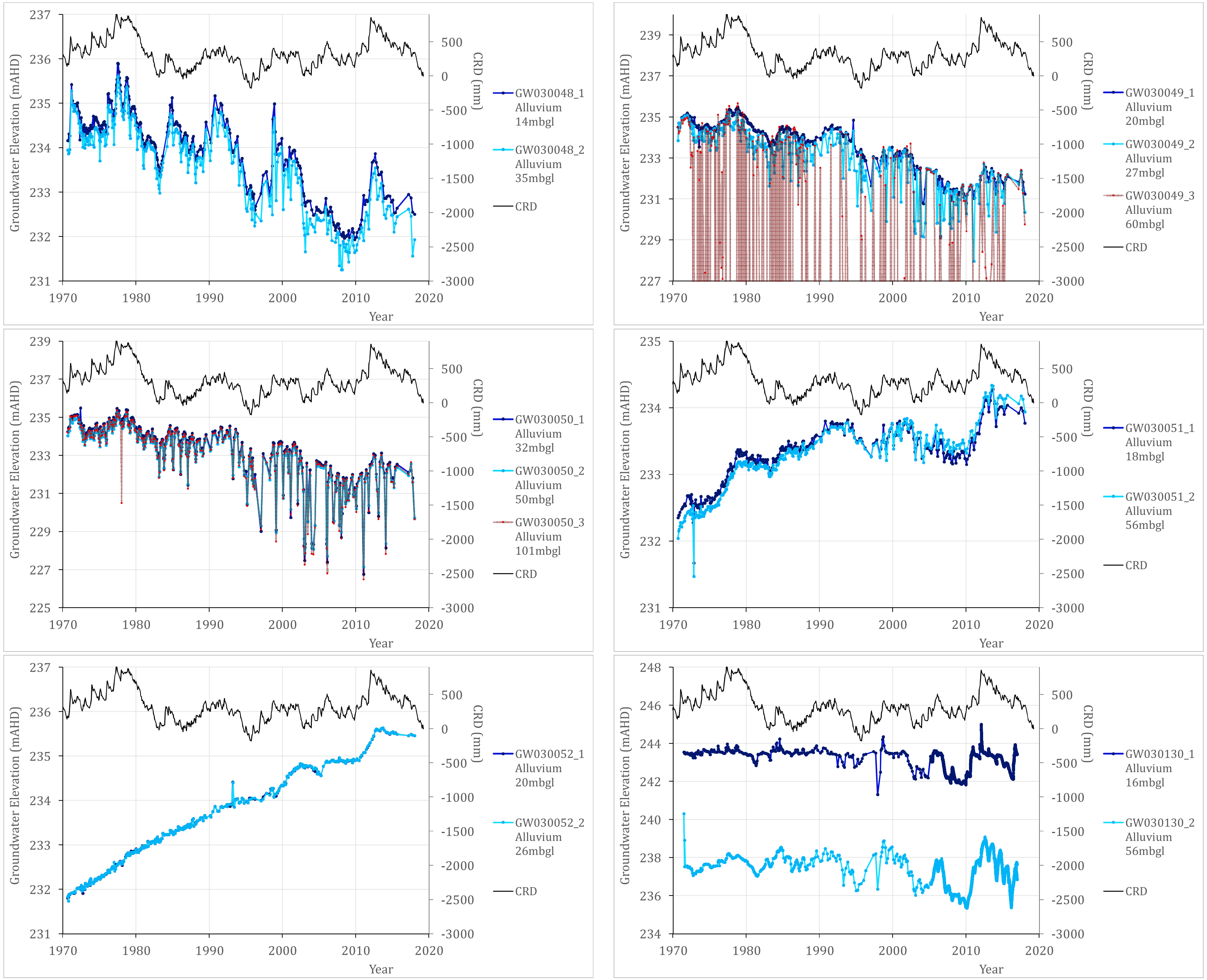
Report	Bore ID	Easting	Northing	Type of test	Tested interval (mbgl)	Tested unit	Hydraulic conductivity (m/d)
Herring 1979	1070A	227206	6610248	pumping	221 to 223	Jeralong Seam	0.98
	1067A	226813	6609924	pumping	248 to 250	Merriown	0.31
	1067A	226813	6609924	pumping	248 to 250	Merriown	0.63
	1067A	226813	6609924	pumping	248 to 250	Merriown	0.61
	1067B	226813	6609924	pumping	248 to 250	Merriown	2.14
	1070C	227206	6610248	pumping	221 to 223	Merriown	5.28
Coffey and Partners 1983a	MAC109	224662	6613728	packer	69 to 79	Braymont	0.1
	MAC110	227432	6615038	packer	168 to 172	Braymont	8.6 E-5
	MAC18	226306	6614396	packer	n/a	Braymont	0.001
PB 2005a	IBC2102	226892.1	6611771	packer	50 to 56	Jeralong	0.01 to 0.03
	IBC2102	226892.1	6611771	packer	79 to 85	Merriown	0.01 to 0.06
	IBC2104	228336	6612215	packer	79 to 86	Braymont	<0.005 to 0.01
	IBC2105	228321.4	6612212	packer	119 to 126	Jeralong	<0.5 to 1
	IBC2115	229155	6610279	packer	104 to 111	Merriown	<0.005
AGE 2011	MAC257	224965.9	6614950	packer	93 to 98	Merriown	0.065
	MAC263	226036.9	6614513	packer	99 to 104	Braymont	0.17
	MAC263	226036.9	6614513	packer	133 to 138	Jeralong	0.0153
	MAC263	226036.9	6614513	packer	150 to 155	Merriown	0.0615
	MAC263	226036.9	6614513	packer	176 to 181	Velyama	0.0377
	MAC263	226036.9	6614513	packer	181 to 186	Nagero, Upper Northam	0.028
	MAC263	226036.9	6614513	packer	220 to 225	Lower Northam, Therribri	0.0461
AGE 2011	MAC265	n/a	n/a	packer	55 to 153	Entire Hole	2.50E-04
Heritage Computing 2012	TAWB14	n/a	n/a	pumping or slug	49 to 56	Coal	0.13
	TA60C	230164	6607286	pumping or slug	86 to 89	Merriown - Nagero	0.005
Herring 1979	1070B	227206	6610248	pumping	241 to 243	Interburden (above Jeralong)	0.30

Report	Bore ID	Easting	Northing	Type of test	Tested interval (mbgl)	Tested unit	Hydraulic conductivity (m/d)
PB 2005a	IBC2102	226892.1	6611771	packer	65 to 71	Interburden (conglomerate)	<0.005
AGE 2011	MAC263	226036.9	6614513	packer	161 to 166	Interburden (conglomerate)	0.00173
RPS Aquaterra 2011	Above Je (1 test)	n/a	n/a	core	55 to 56*	Interburden	6.49E-05
	Je – Mn (6 tests)	n/a	n/a	core	49 to 71*	Interburden	3.37E-06
	Mn – Vy (5 tests)	n/a	n/a	core	61 to 114*	Interburden	2.38E-06
	Vy – Ng (4 tests)	n/a	n/a	core	105 to 123*	Interburden	3.58E-06
	Ng – Un (9 tests)	n/a	n/a	core	118 to 165*	Interburden	2.49E-05
	Un – Ln (3 tests)	n/a	n/a	core	156 to 164*	Interburden	6.49E-05
Heritage Computing 2012	TA60C	230164	6607286	pumping or slug	116 to 119	Interburden	0.003
AGE 2017	MAC312	223788	6613059	core	100.6	Interburden (conglomerate)	3.35E-05
	MAC312	223788	6613059	core	116.6	Interburden (conglomerate)	2.26E-05
	MAC313	225047	6613591	core	101.8	Interburden (conglomerate)	3.07E-06
	MAC313	225047	6613591	core	127.6	Interburden (sandstone)	1.28E-05
	MAC313	225047	6613591	core	127.9	Interburden (sandstone)	2.25E-05
	MAC313	225047	6613591	core	167.1	Interburden (conglomerate)	1.34E-03
	MAC313	225047	6613591	core	167.4	Interburden (conglomerate)	2.19E-05
	MAC313	225047	6613591	core	174.9	Interburden (conglomerate)	1.74E-04
	MAC313	225047	6613591	core	187.1	Interburden (conglomerate)	3.39E-04
	MAC313	225047	6613591	core	191.8	Interburden (conglomerate)	1.47E-04
	MAC313	225047	6613591	core	206.9	Interburden (conglomerate)	3.09E-04

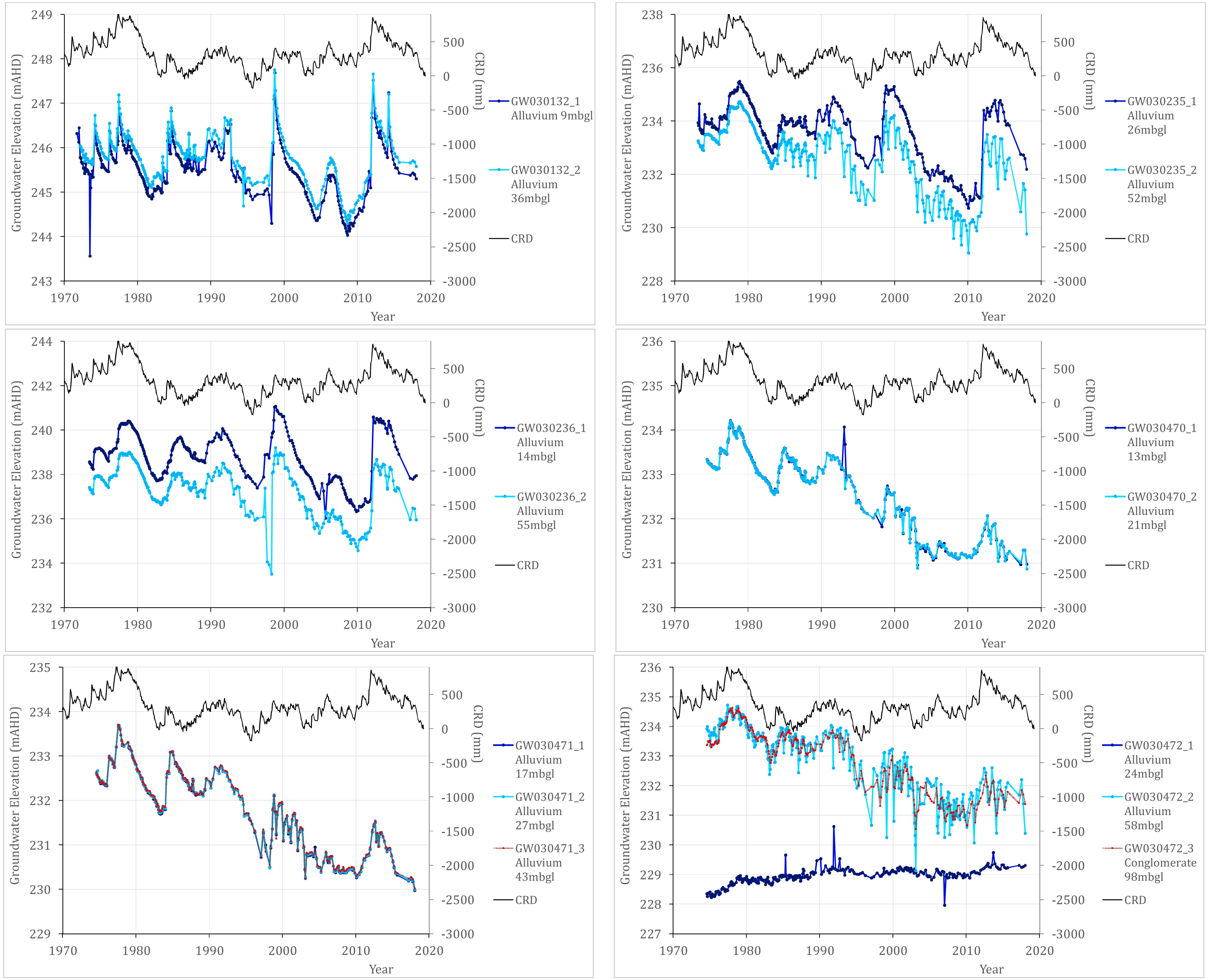
Report	Bore ID	Easting	Northing	Type of test	Tested interval (mbgl)	Tested unit	Hydraulic conductivity (m/d)
	MAC314	225835	6614586	core	116.6	Interburden (conglomerate)	1.08E-06
	MAC314	225835	6614586	core	156.4	Interburden (conglomerate)	1.43E-05
	MAC314	225835	6614586	core	167.6	Interburden (conglomerate)	4.07E-06
	MAC314	225835	6614586	core	169.8	Interburden (conglomerate)	1.91E-06
	MAC314	225835	6614586	core	193.8	Interburden (sandstone)	2.97E-05
	MAC314	225835	6614586	core	194.1	Interburden (sandstone)	3.19E-05
	MAC314	225835	6614586	core	209.6	Interburden (sandstone)	6.65E-07
	MAC314	225835	6614586	core	236.6	Interburden (conglomerate)	3.91E-06

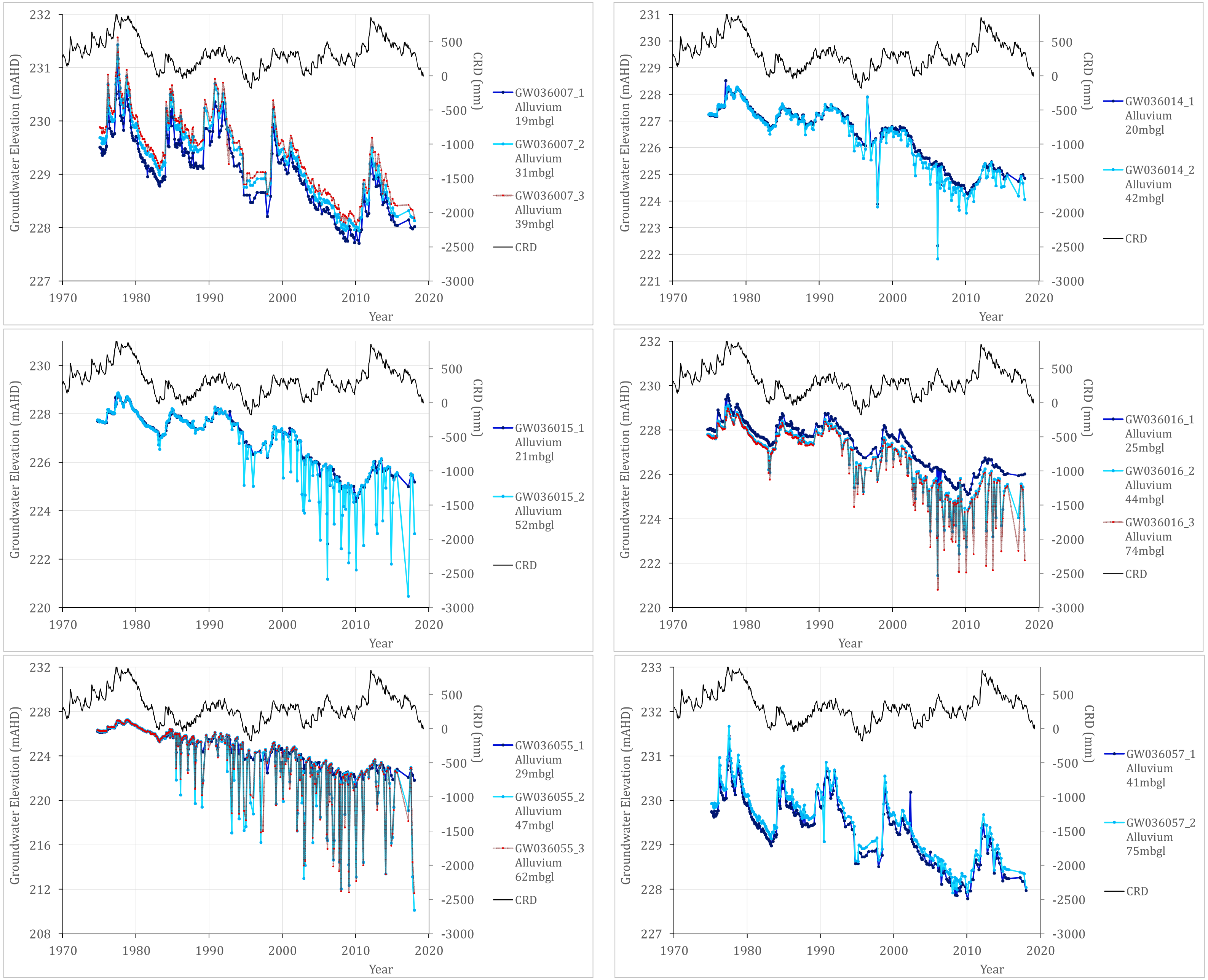
Appendix C

Groundwater hydrographs
(BTM Complex and surrounding area)

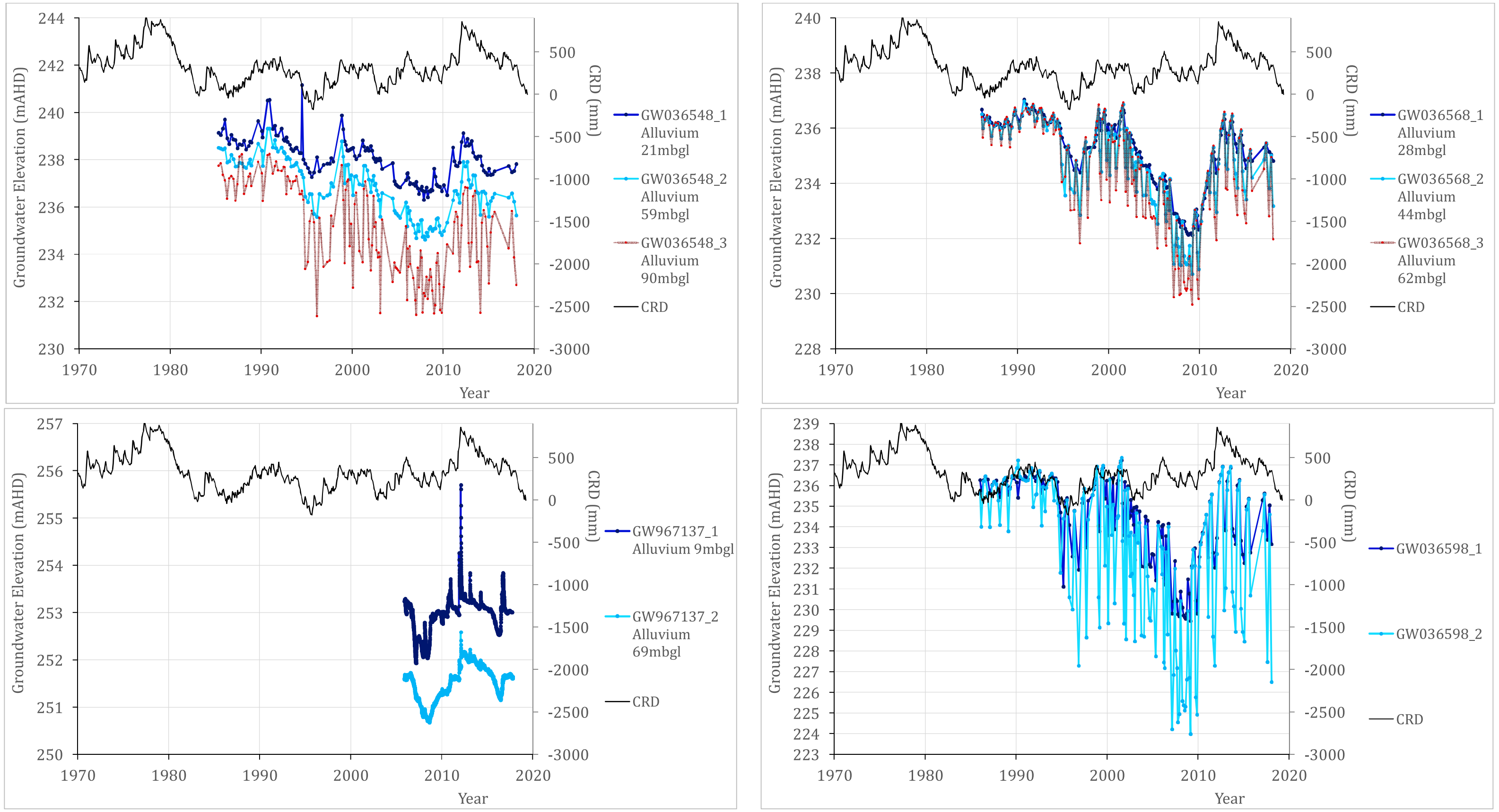


Groundwater Elevation (mAHD)
CRD (mm)
Year
GW030048_1 Alluvium 14mbgl
GW030048_2 Alluvium 35mbgl
CRD
GW030049_1 Alluvium 20mbgl
GW030049_2 Alluvium 27mbgl
GW030049_3 Alluvium 60mbgl
CRD
GW030050_1 Alluvium 32mbgl
GW030050_2 Alluvium 50mbgl
GW030050_3 Alluvium 101mbgl
CRD
GW030051_1 Alluvium 18mbgl
GW030051_2 Alluvium 56mbgl
CRD
GW030052_1 Alluvium 20mbgl
GW030052_2 Alluvium 26mbgl
CRD
GW030130_1 Alluvium 16mbgl
GW030130_2 Alluvium 56mbgl
CRD

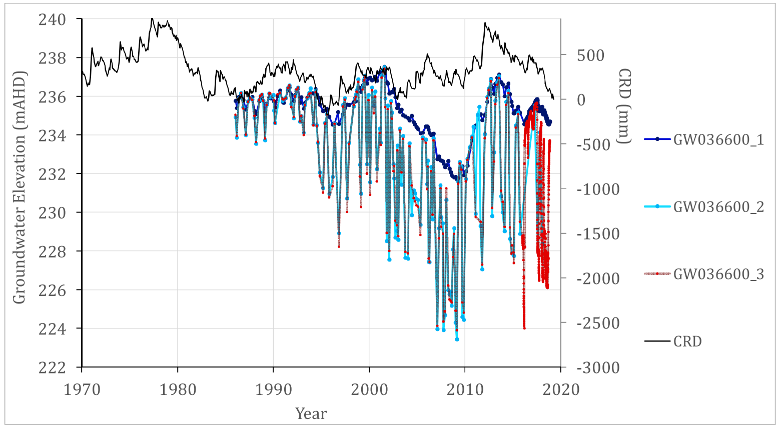

Groundwater Elevation (mAHD)
CRD (mm)
Year
GW030132_1 Alluvium 9mbgl
GW030132_2 Alluvium 36mbgl
CRD
GW030235_1 Alluvium 26mbgl
GW030235_2 Alluvium 52mbgl
CRD
GW030236_1 Alluvium 14mbgl
GW030236_2 Alluvium 55mbgl
CRD
GW030470_1 Alluvium 13mbgl
GW030470_2 Alluvium 21mbgl
CRD
GW030471_1 Alluvium 17mbgl
GW030471_2 Alluvium 27mbgl
GW030471_3 Alluvium 43mbgl
CRD
GW030472_1 Alluvium 24mbgl
GW030472_2 Alluvium 58mbgl
GW030472_3 Conglomerate 98mbgl
CRD

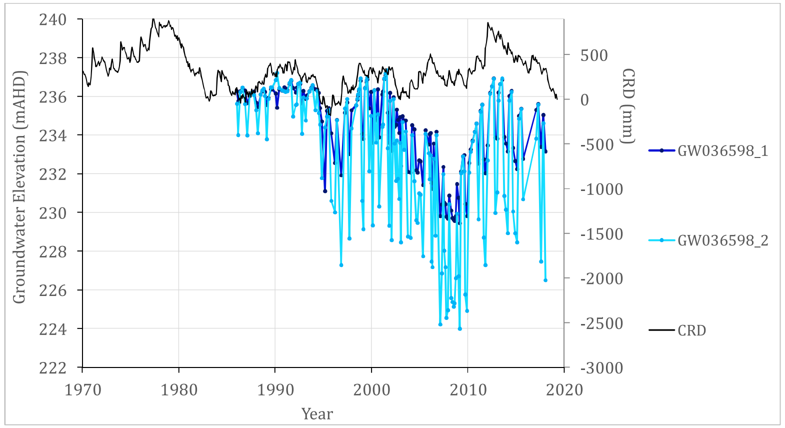


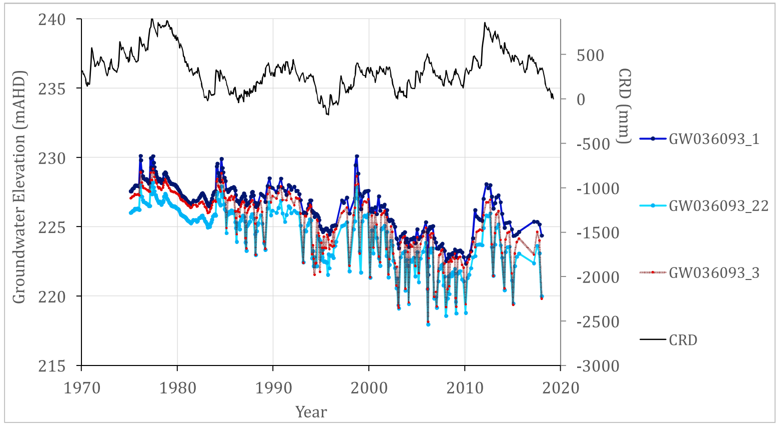
Groundwater Elevation (mAHD)
CRD (mm)
Year
GW036007_1 Alluvium 19mbgl
GW036007_2 Alluvium 31mbgl
GW036007_3 Alluvium 39mbgl
CRD
GW036014_1 Alluvium 20mbgl
GW036014_2 Alluvium 42mbgl
CRD
GW036015_1 Alluvium 21mbgl
GW036015_2 Alluvium 52mbgl
CRD
GW036016_1 Alluvium 25mbgl
GW036016_2 Alluvium 44mbgl
GW036016_3 Alluvium 74mbgl
CRD
GW036055_1 Alluvium 29mbgl
GW036055_2 Alluvium 47mbgl
GW036055_3 Alluvium 62mbgl
CRD
GW036057_1 Alluvium 41mbgl
GW036057_2 Alluvium 75mbgl
CRD
1970
1980
1990
2000
2010
2020

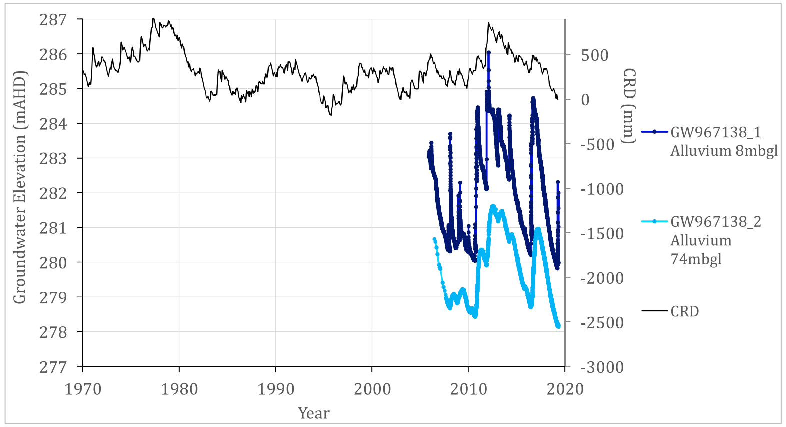


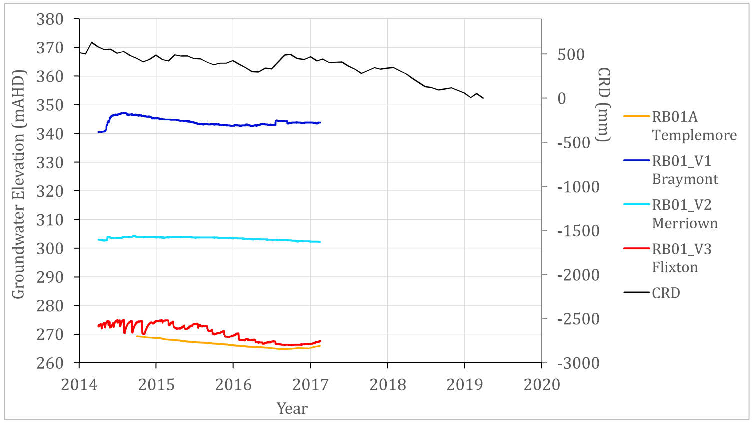
Groundwater Elevation (mAHD)
CRD (mm)
Year
GW036548_1 Alluvium 21mbgl
GW036548_2 Alluvium 59mbgl
GW036548_3 Alluvium 90mbgl
CRD
GW036568_1 Alluvium 28mbgl
GW036568_2 Alluvium 44mbgl
GW036568_3 Alluvium 62mbgl
CRD
GW967137_1 Alluvium 9mbgl
GW967137_2 Alluvium 69mbgl
CRD
GW036598_1
GW036598_2
CRD

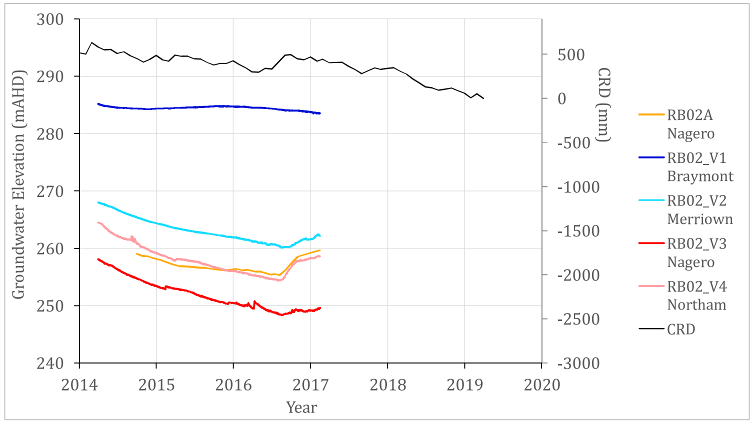

Groundwater Elevation (mAHD)
CRD (mm)
Year
GW036600_1
GW036600_2
GW036600_3
CRD

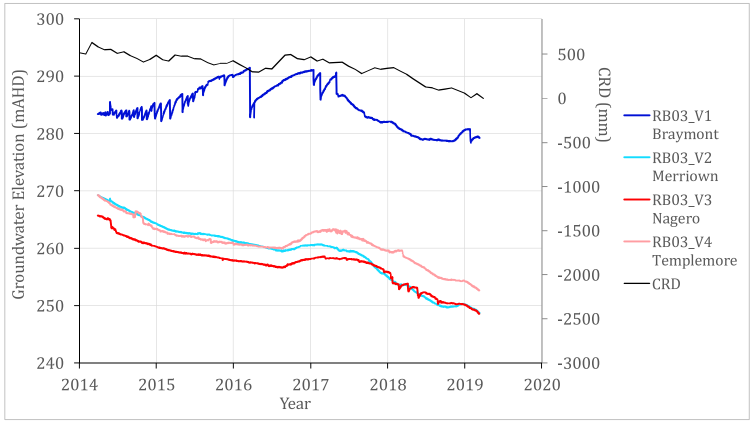

Groundwater Elevation (mAHD)
CRD (mm)
Year
GW036598_1
GW036598_2
CRD

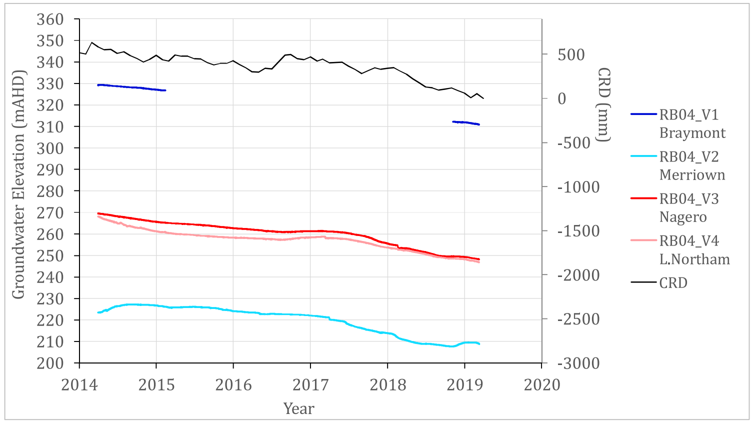

Groundwater Elevation (mAHD)
CRD (mm)
Year
GW036093_1
GW036093_22
GW036093_3
CRD

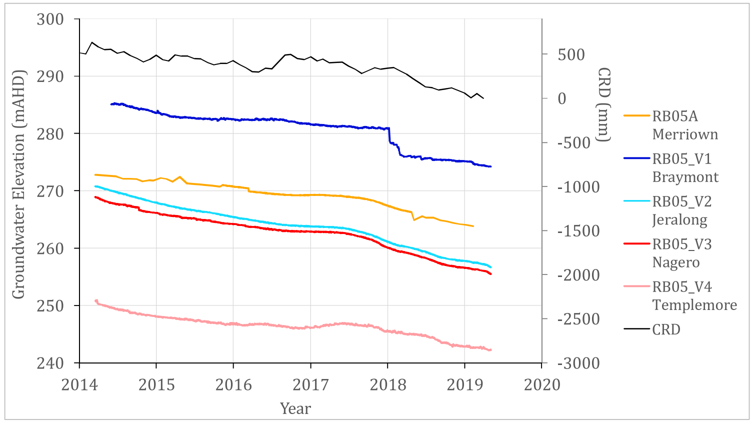

Groundwater Elevation (mAHD)
CRD (mm)
Year
GW967138_1 Alluvium 8mbgl
GW967138_2 Alluvium 74mbgl
CRD

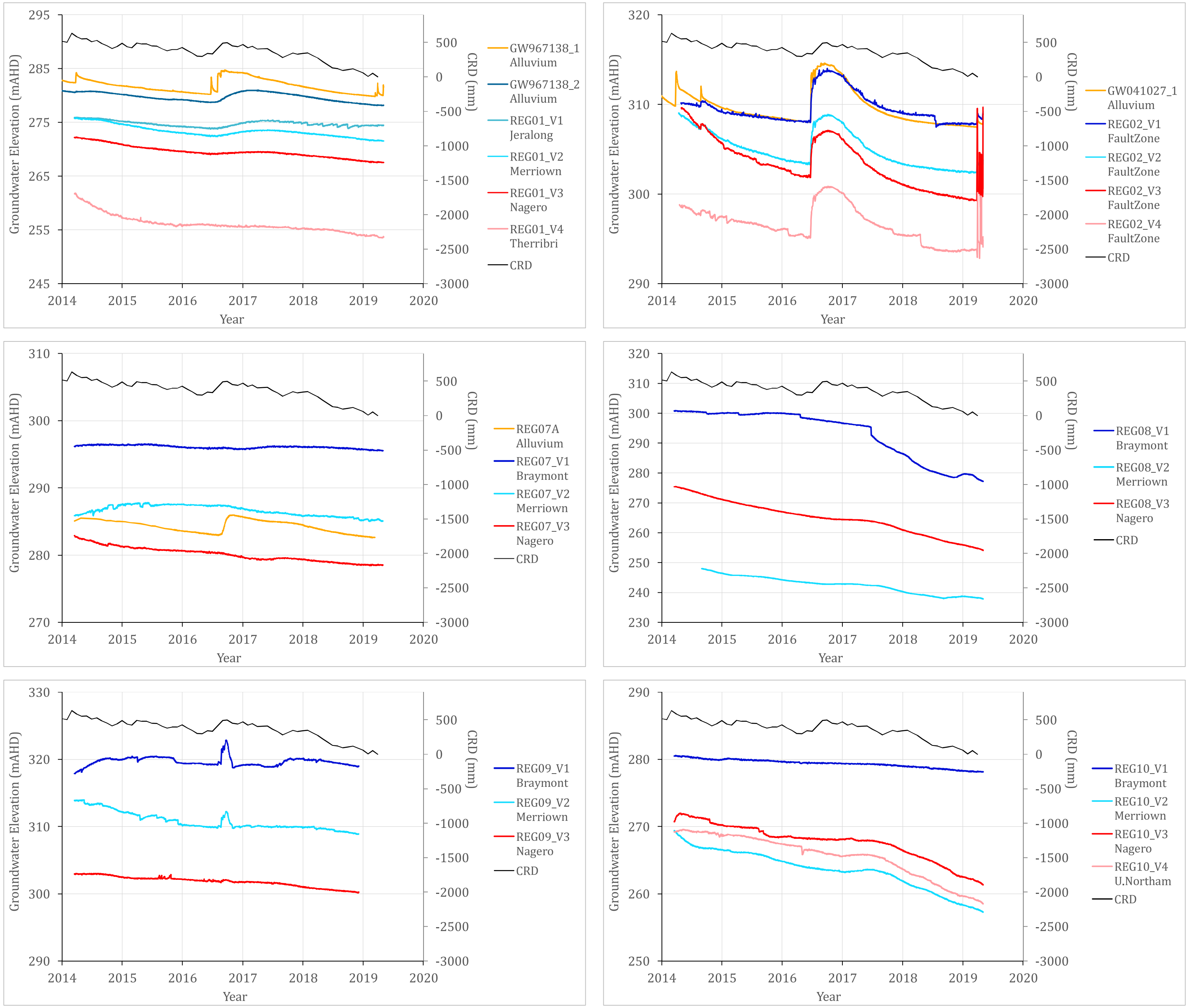

Groundwater Elevation (mAHD)
CRD (mm)
Year
RB01A Templemore
RB01_V1 Braymont
RB01_V2 Merriown
RB01_V3 Flixton
CRD


Groundwater Elevation (mAHD)
CRD (mm)
Year
RB02A Nagero
RB02_V1 Braymont
RB02_V2 Merriown
RB02_V3 Nagero
RB02_V4 Northam
CRD


Groundwater Elevation (mAHD)
CRD (mm)
Year
RB03_V1 Braymont
RB03_V2 Merriown
RB03_V3 Nagero
RB03_V4 Templemore
CRD

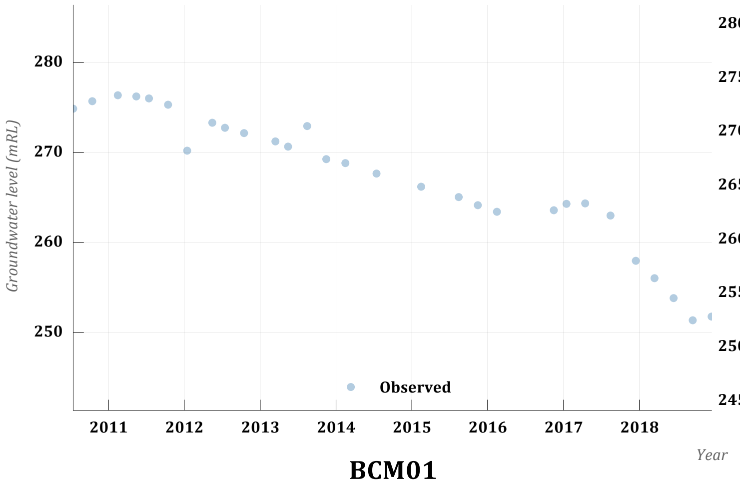

Groundwater Elevation (mAHD)
CRD (mm)
Year
RB04_V1 Braymont
RB04_V2 Merriown
RB04_V3 Nagero
RB04_V4 L.Northam
CRD


Groundwater Elevation (mAHD)
CRD (mm)
Year
RB05A Merriown
RB05_V1 Braymont
RB05_V2 Jeralong
RB05_V3 Nagero
RB05_V4 Templemore
CRD

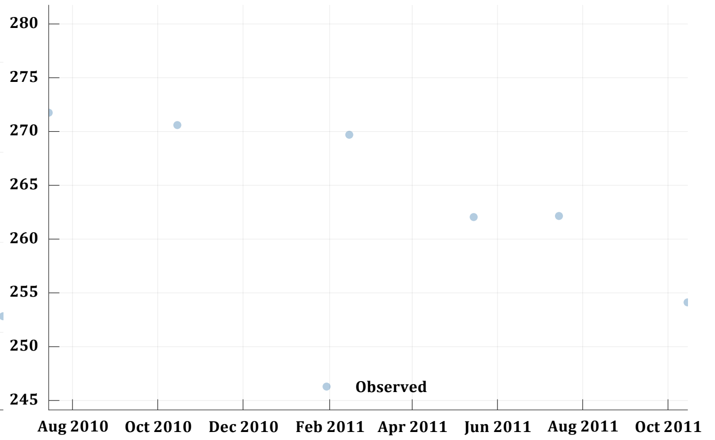


Groundwater Elevation (mAHD)
CRD (mm)
Year
2014
2015
2016
2017
2018
2019
2020
GW967138_1 Alluvium
GW967138_2 Alluvium
REG01_V1 Jeralong
REG01_V2 Merriown
REG01_V3 Nagero
REG01_V4 Therribri
CRD
GW041027_1 Alluvium
REG02_V1 FaultZone
REG02_V2 FaultZone
REG02_V3 FaultZone
REG02_V4 FaultZone
CRD
REG07A Alluvium
REG07_V1 Braymont
REG07_V2 Merriown
REG07_V3 Nagero
CRD
REG08_V1 Braymont
REG08_V2 Merriown
REG08_V3 Nagero
CRD
REG09_V1 Braymont
REG09_V2 Merriown
REG09_V3 Nagero
CRD
REG10_V1 Braymont
REG10_V2 Merriown
REG10_V3 Nagero
REG10_V4 U.Northam
CRD

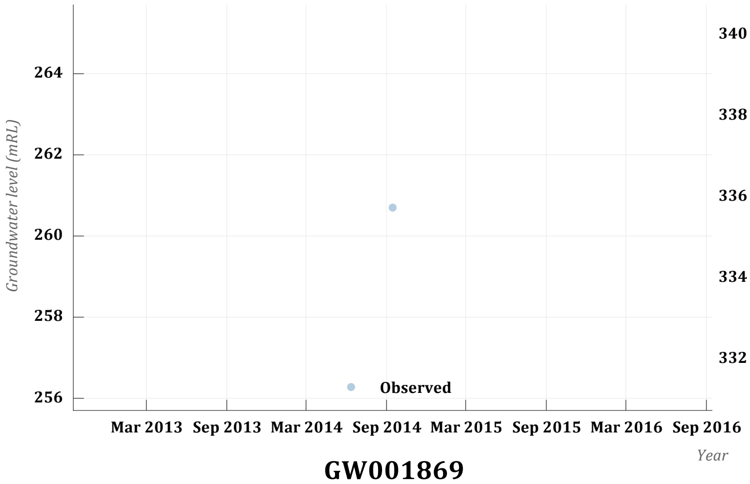
BC2181



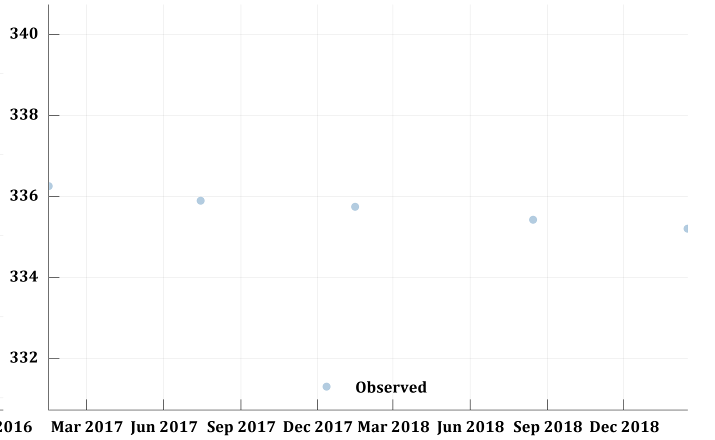
BC2193



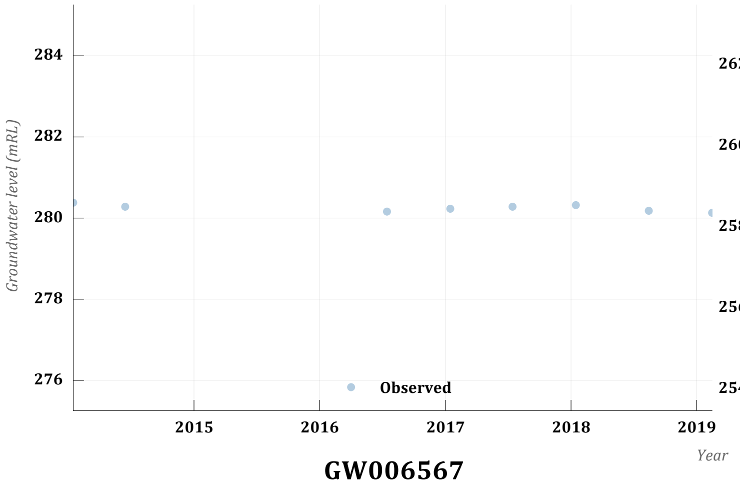
BCM01



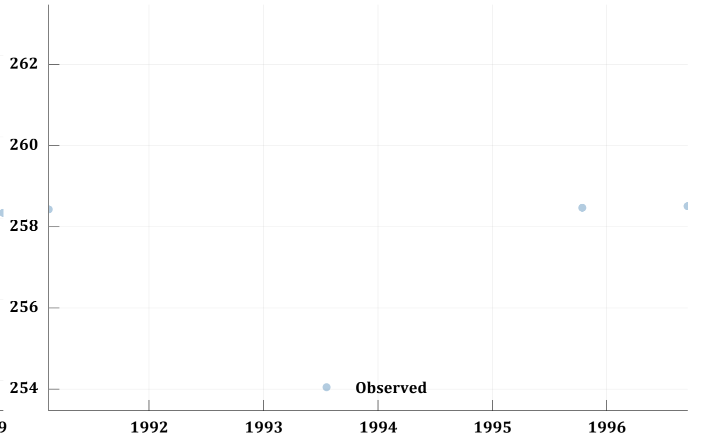
BRE2



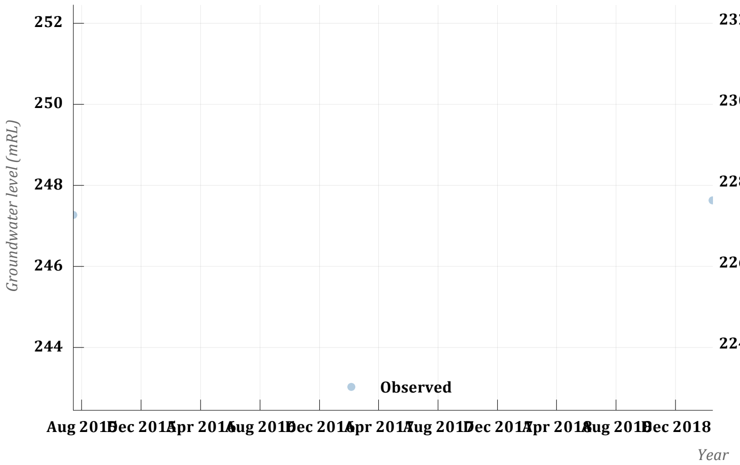
GW001869



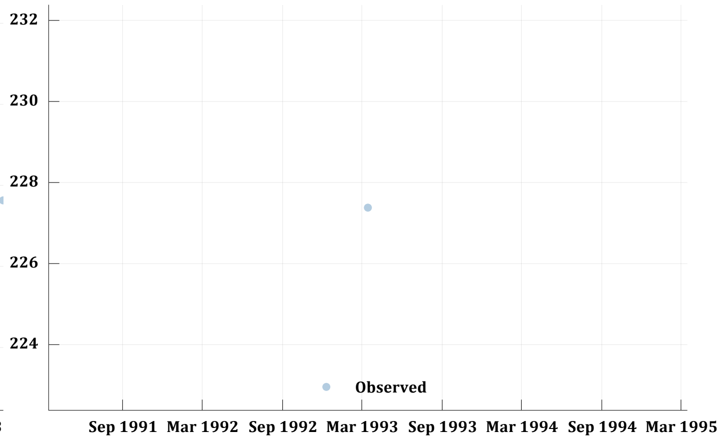
GW006529_1



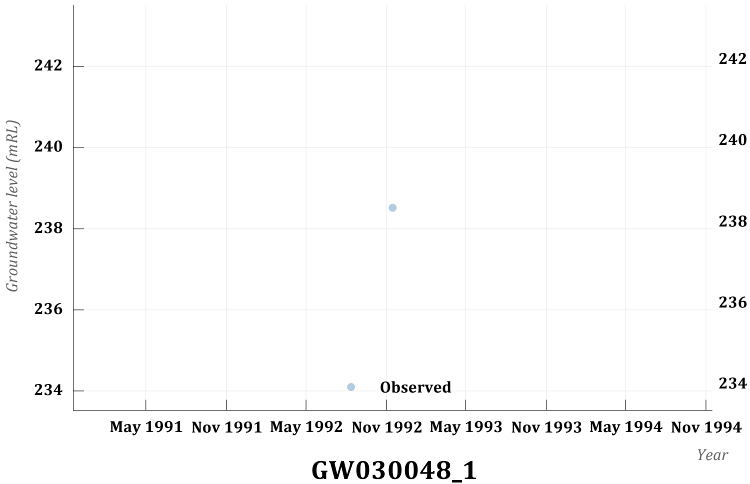
GW006567



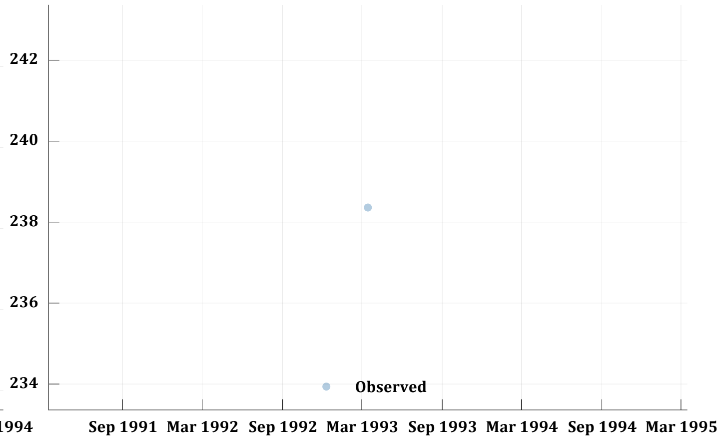
GW017519_1



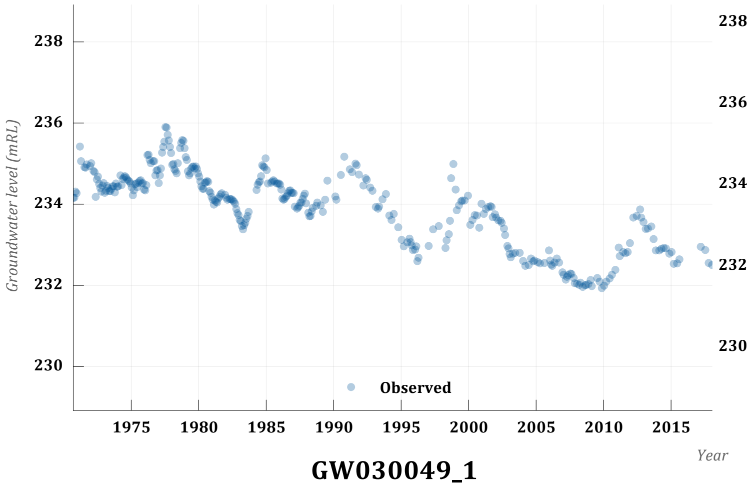
GW020563_1



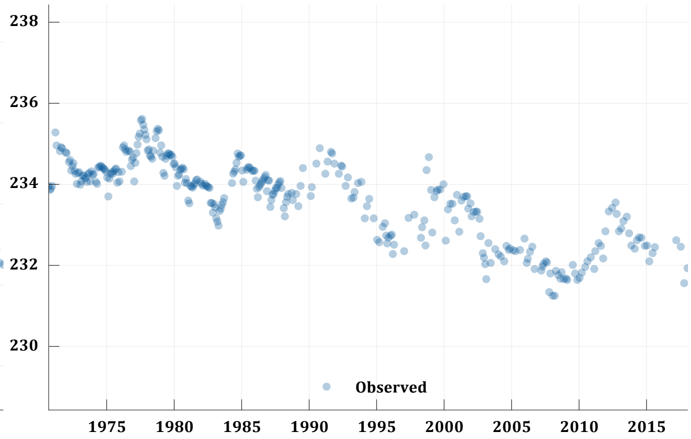
GW023568_1



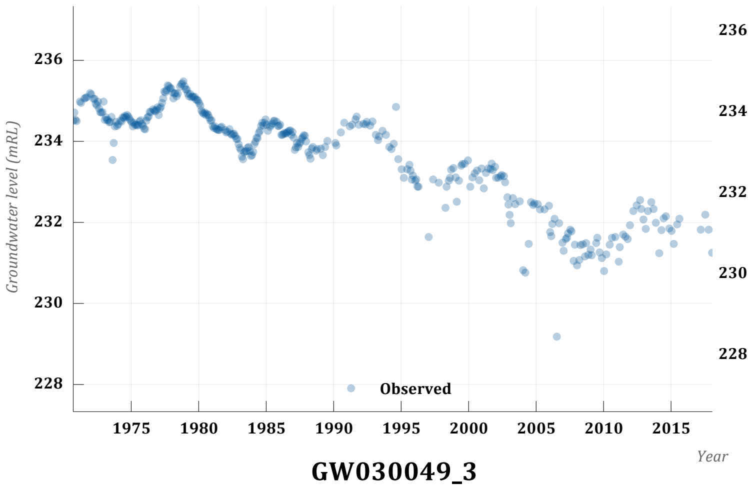
GW030048_1



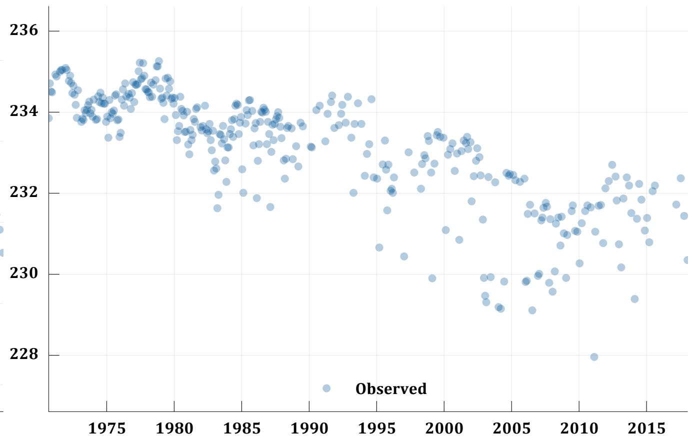
GW030048_2



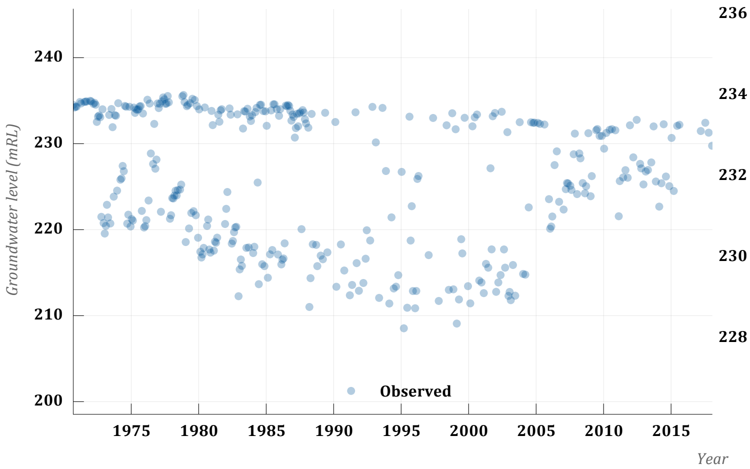
GW030049_1



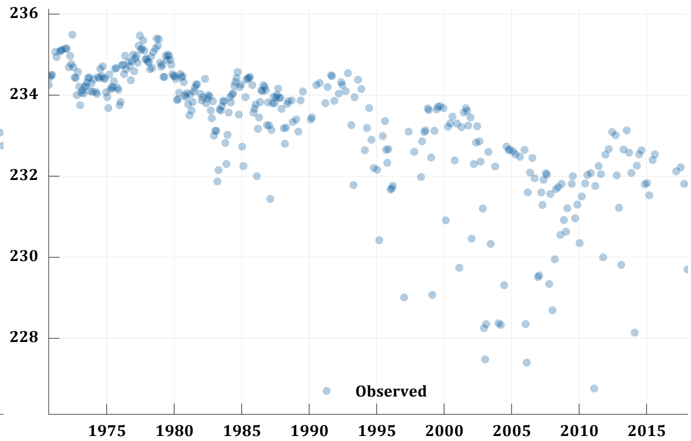
GW030049_2

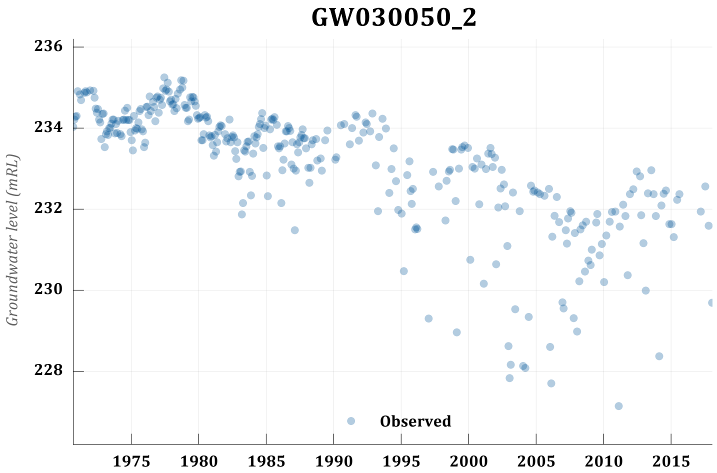


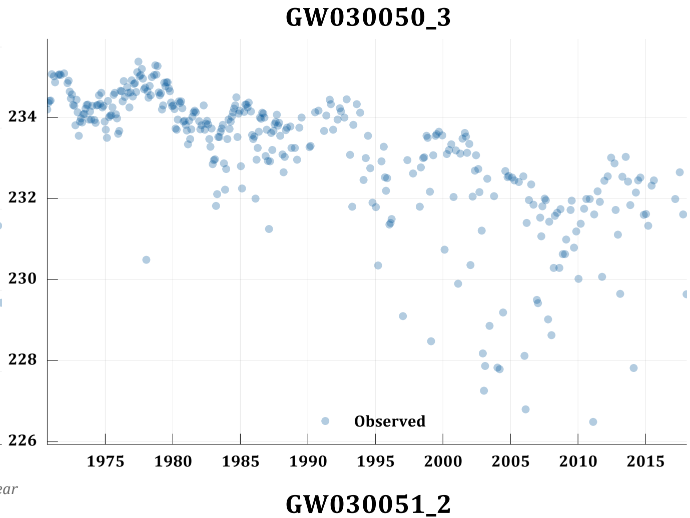
GW030049_3

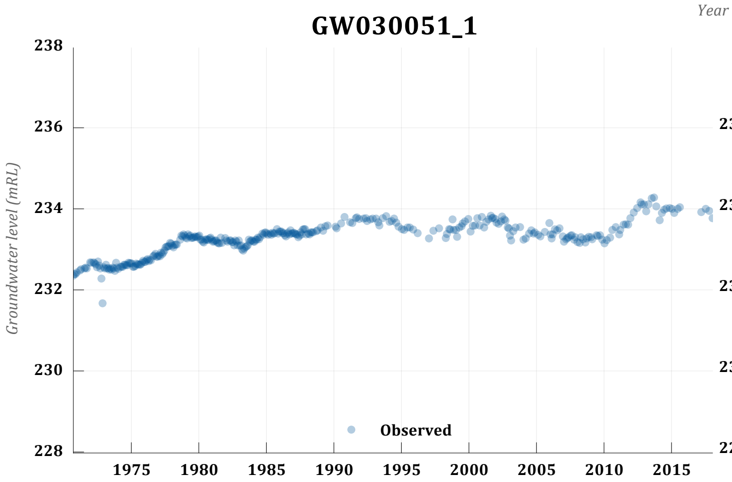


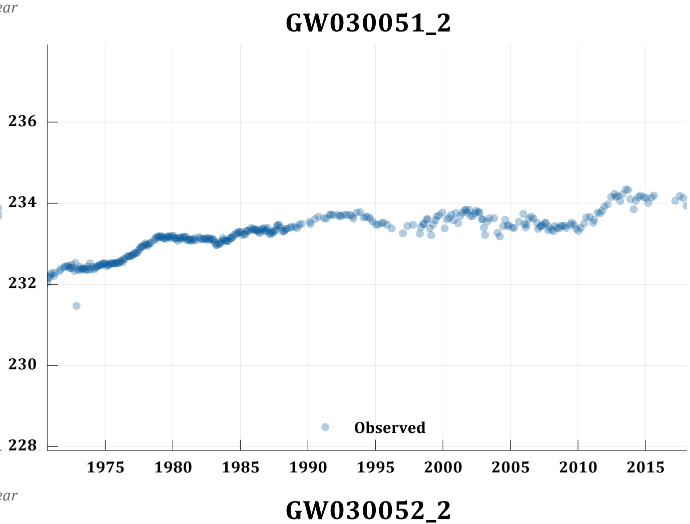
GW030050_1

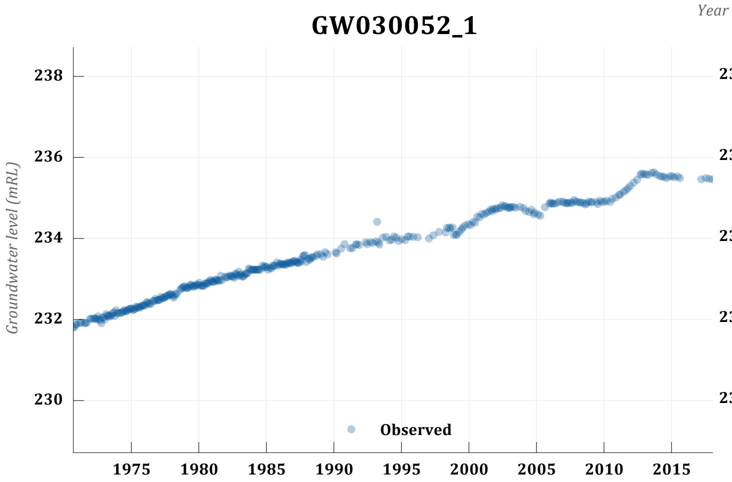


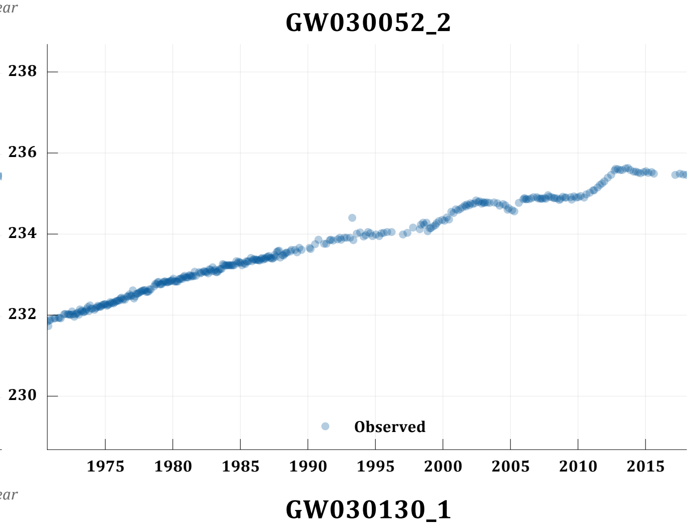

GW030050_2
Groundwater level (mRL)
Observed

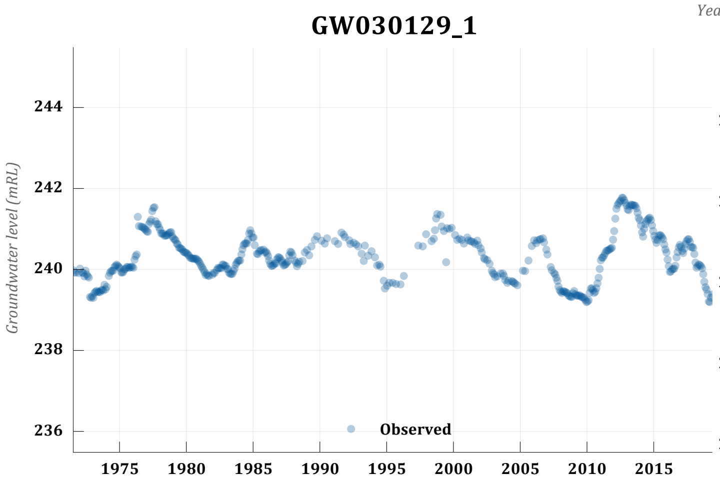

GW030050_3
Observed
Year

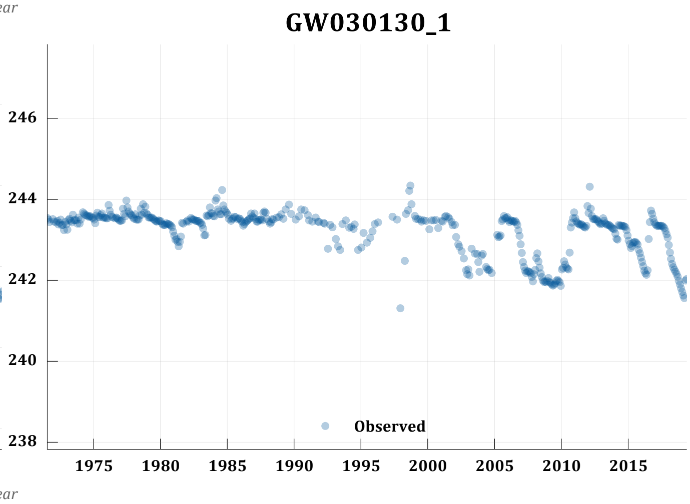

GW030051_1
Groundwater level (mRL)
Observed


GW030051_2
Observed
Year

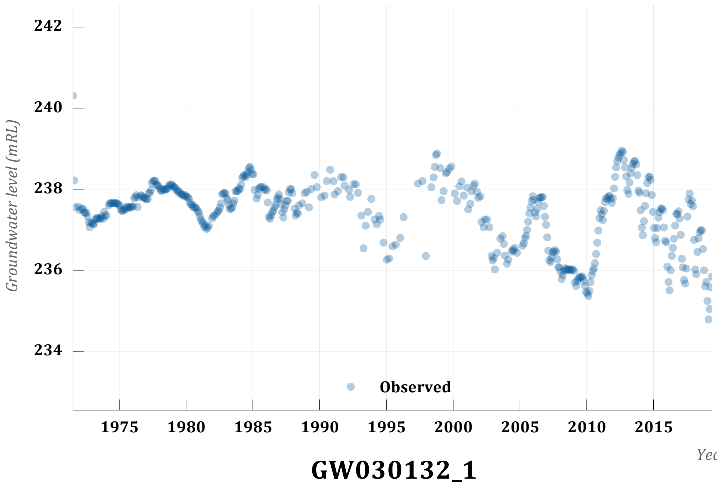

GW030052_1
Groundwater level (mRL)
Observed


GW030052_2
Observed
Year

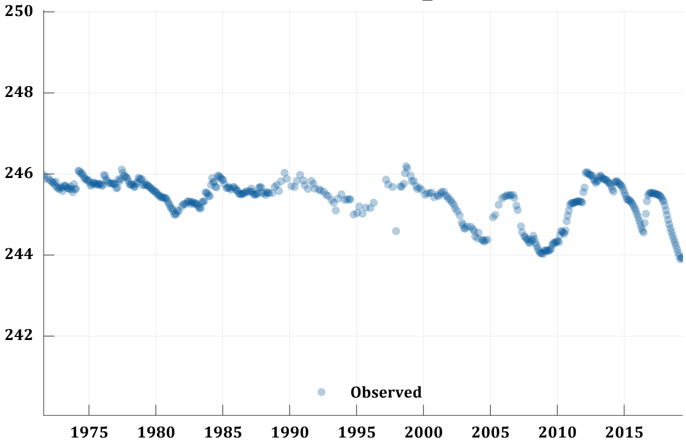

GW030129_1
Groundwater level (mRL)
Observed


GW030130_1
Observed
Year

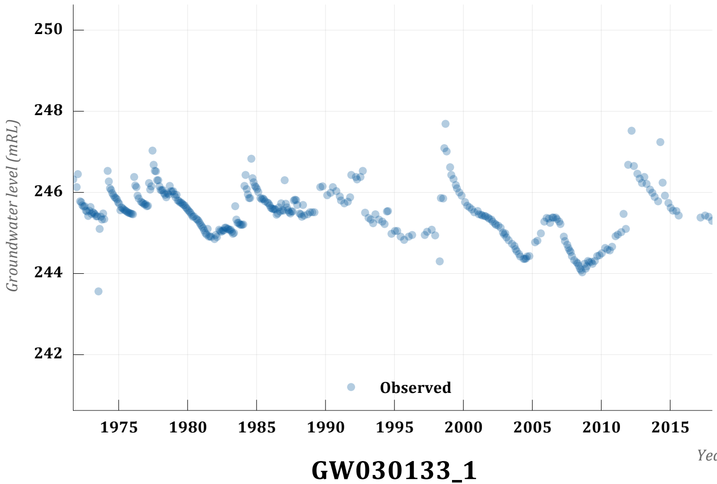
GW030130_2



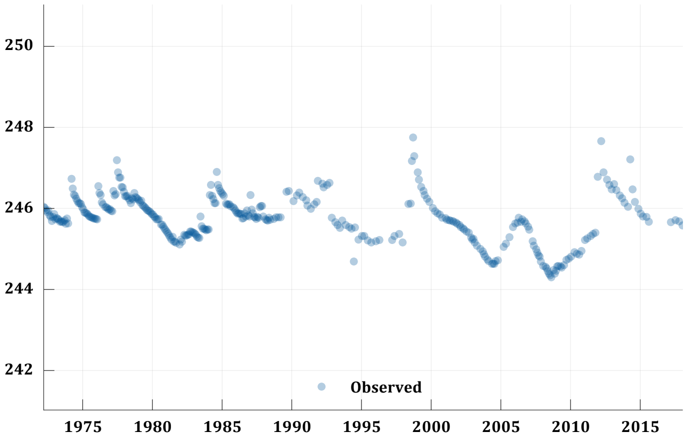
GW030131_1



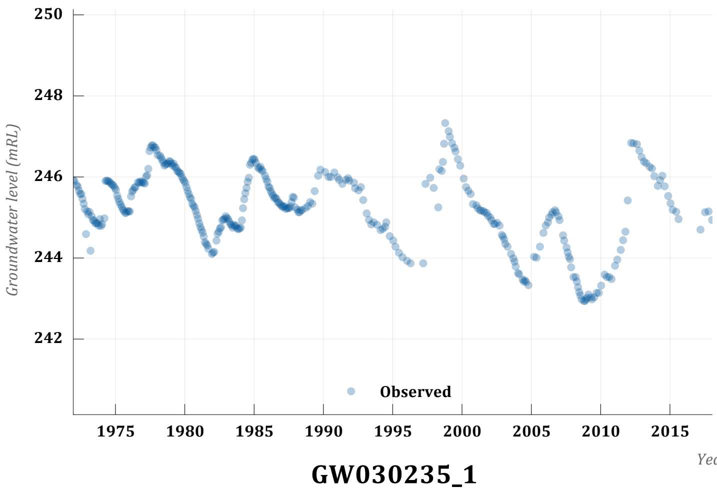
GW030132_1



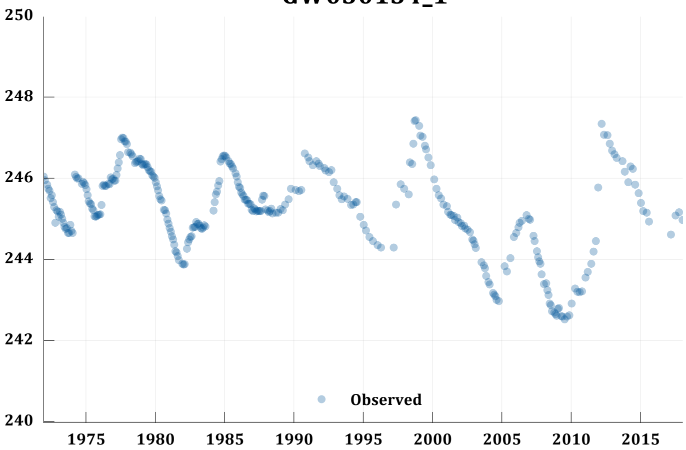
GW030132_2



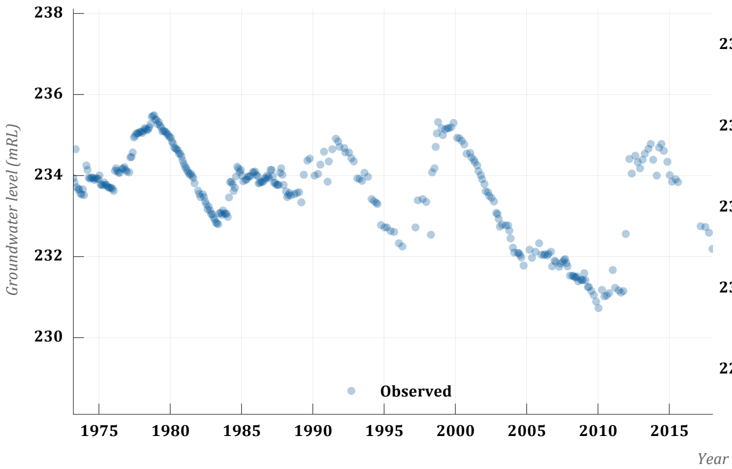
GW030133_1



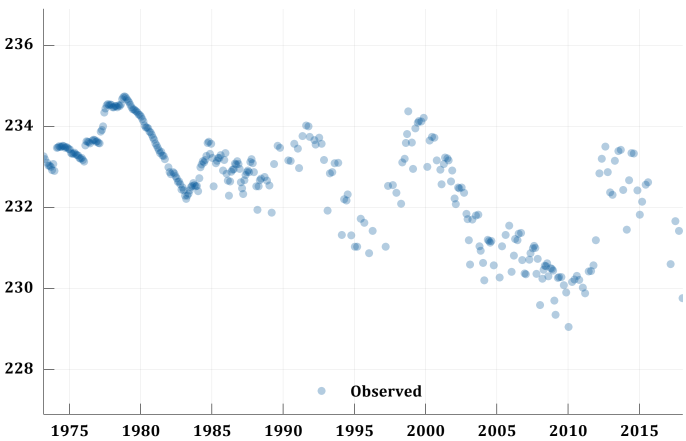
GW030134_1



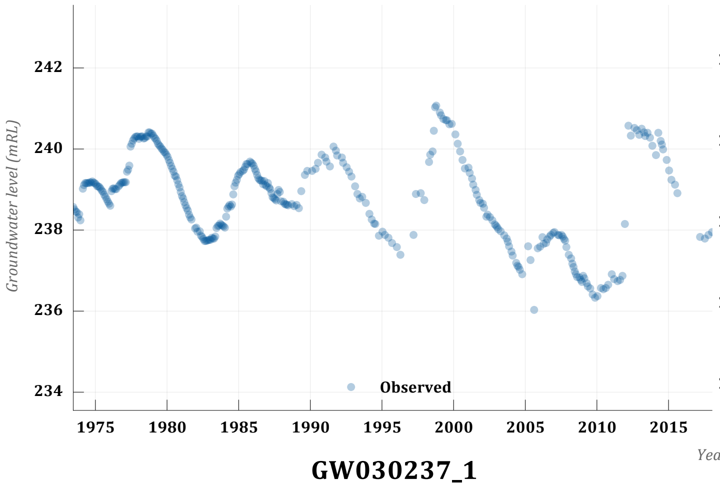
GW030235_1



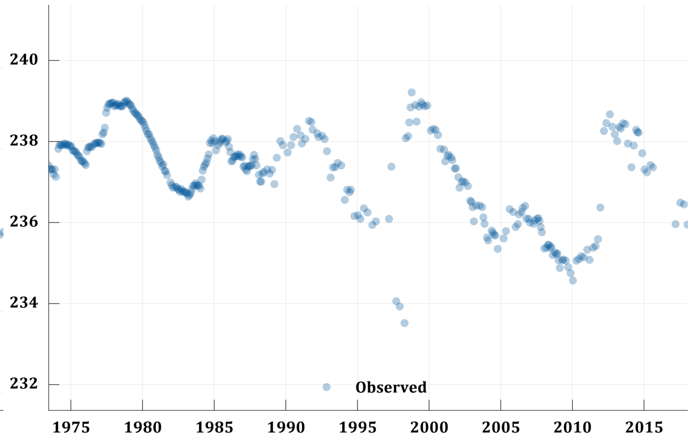
GW030235_2



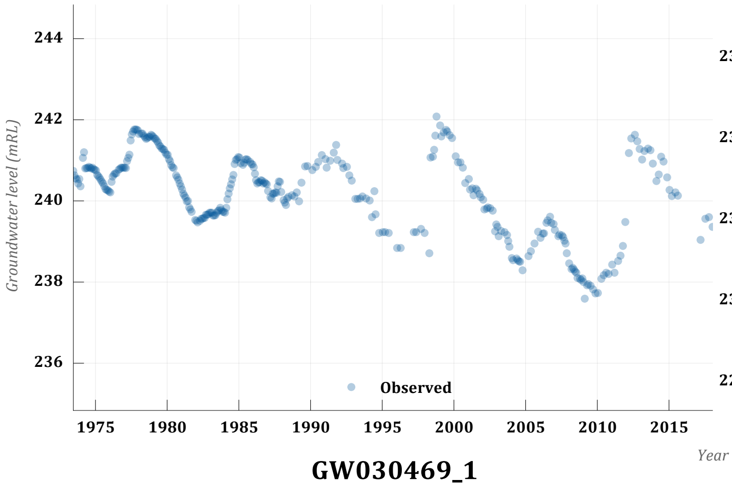
GW030236_1



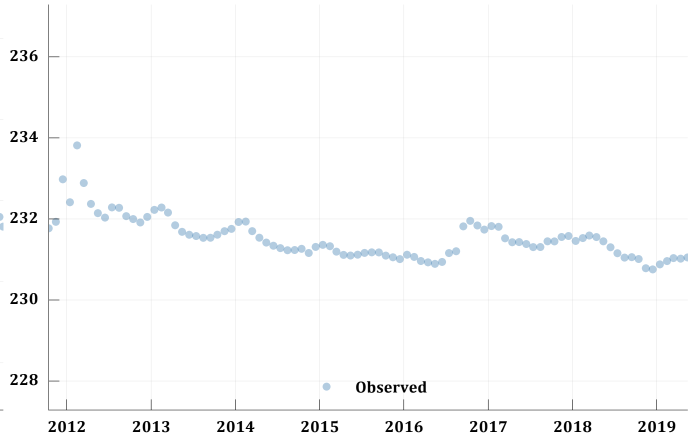
GW030236_2



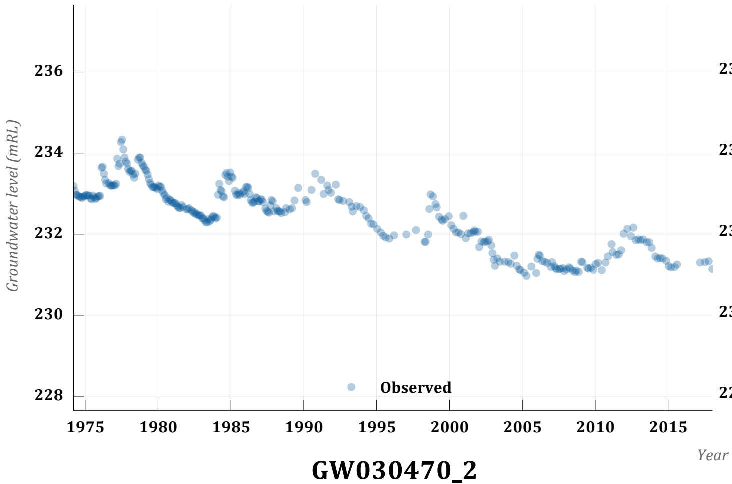
GW030237_1



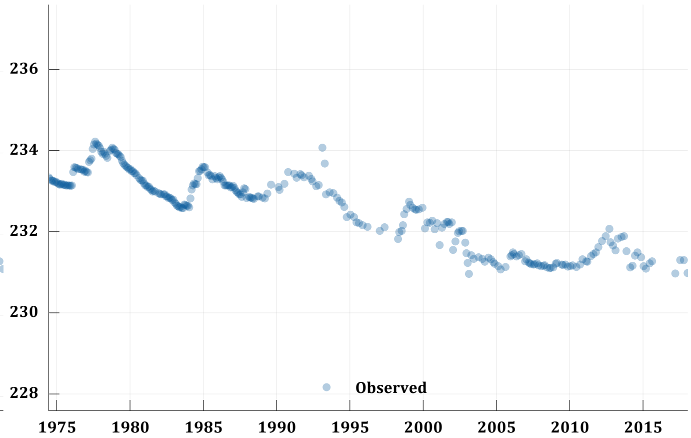
GW030468_1



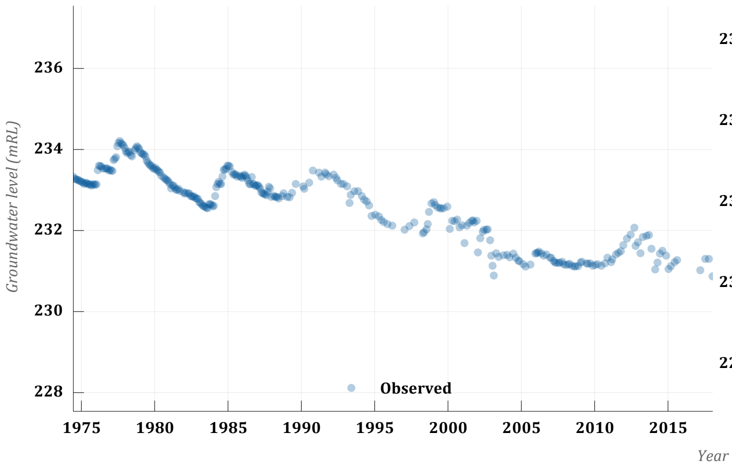
GW030469_1



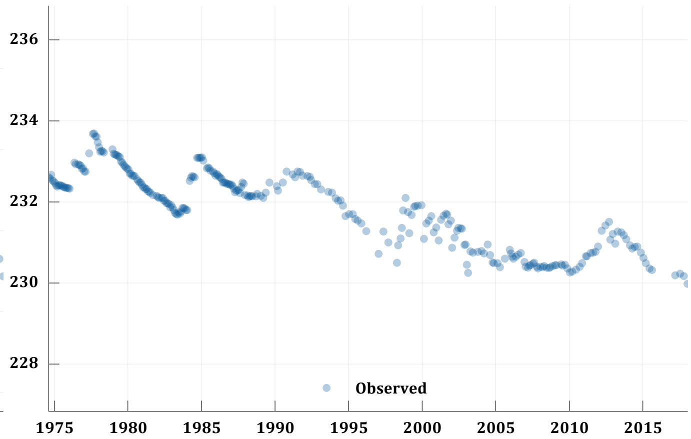
GW030470_1



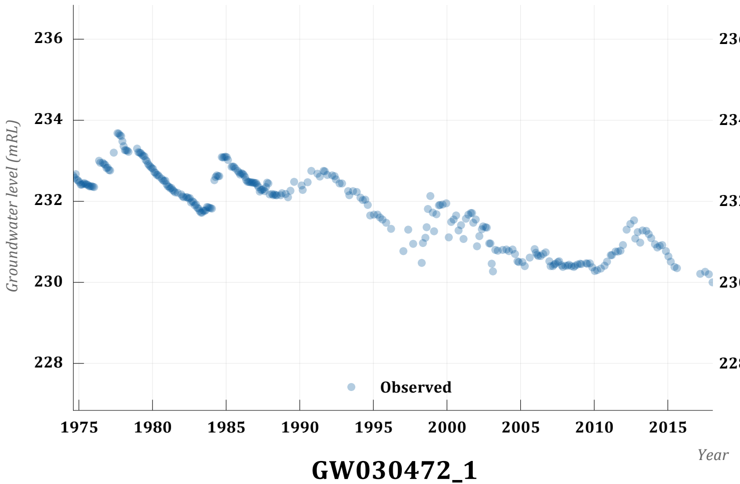
GW030470_2



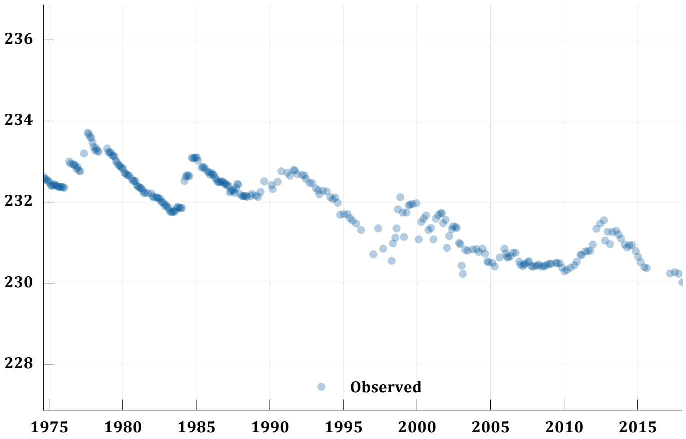
GW030471_1



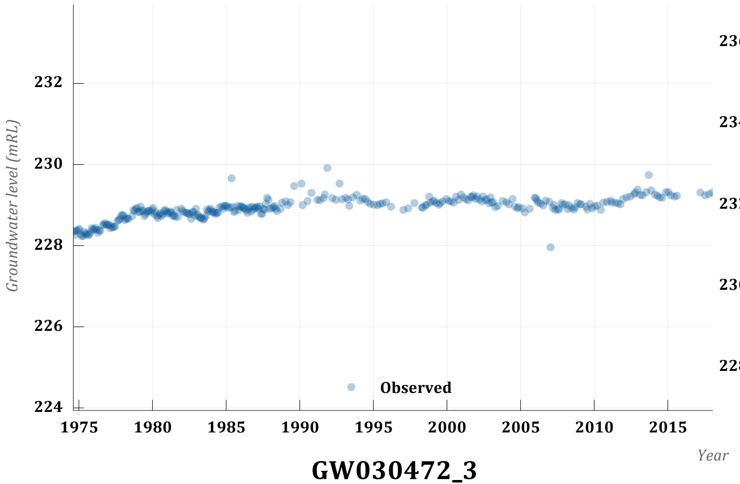
GW030471_2



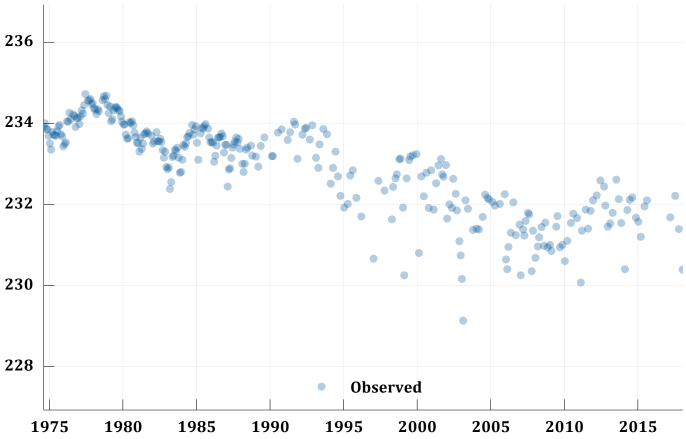
GW030471_3



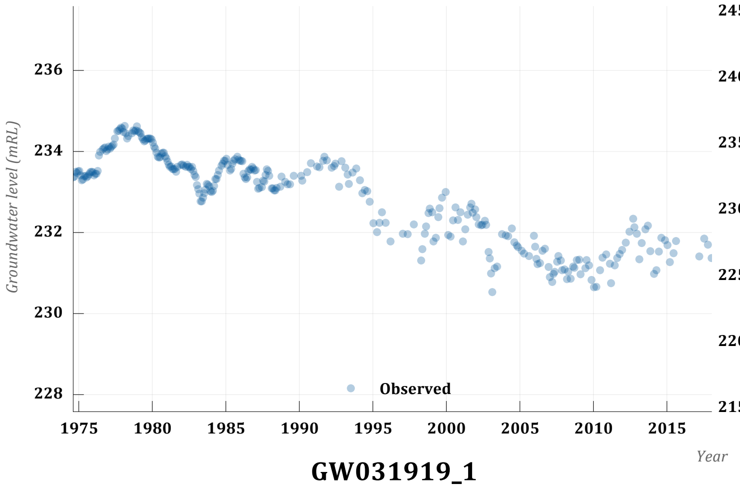
GW030472_1



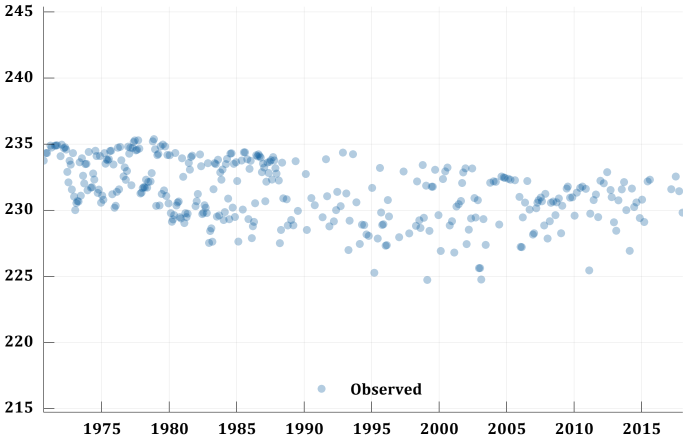
GW030472_2



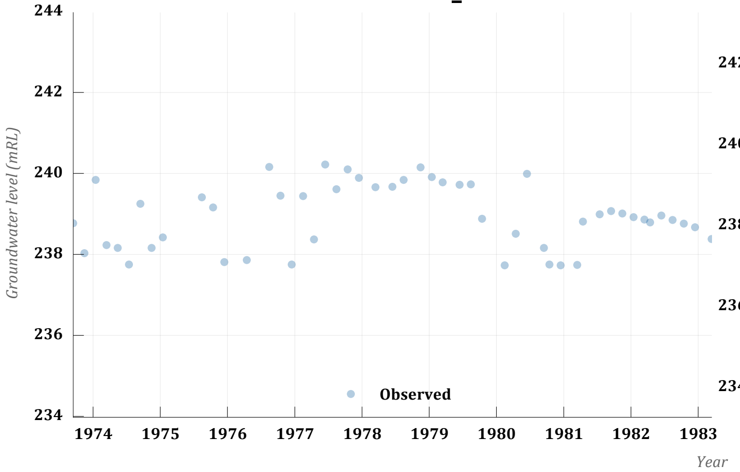
GW030472_3



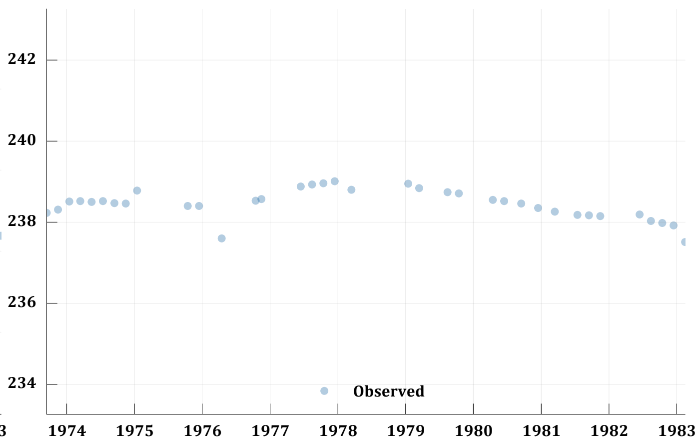
GW030535_1



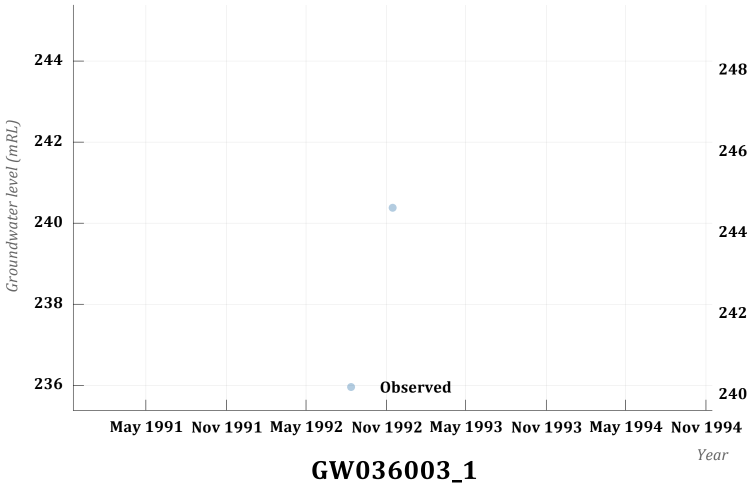
GW031919_1



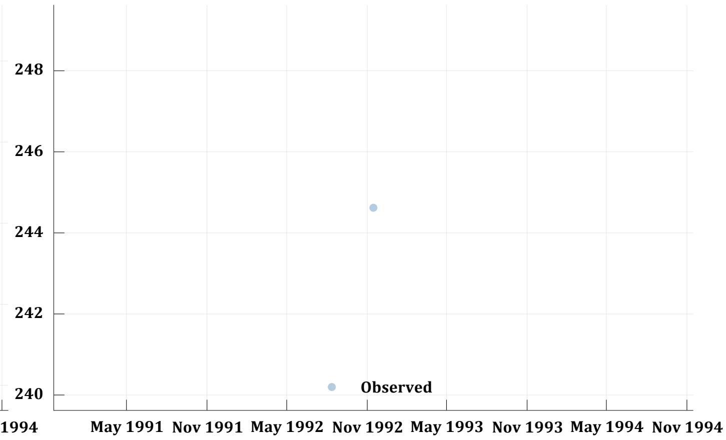
GW031920_1



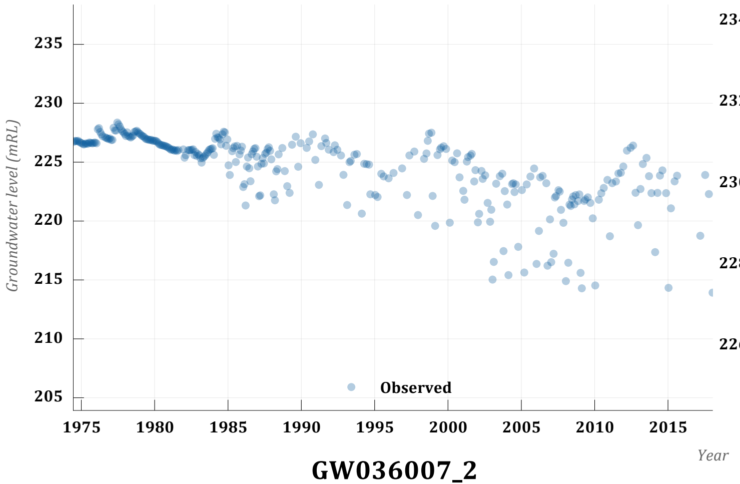
GW031997_1



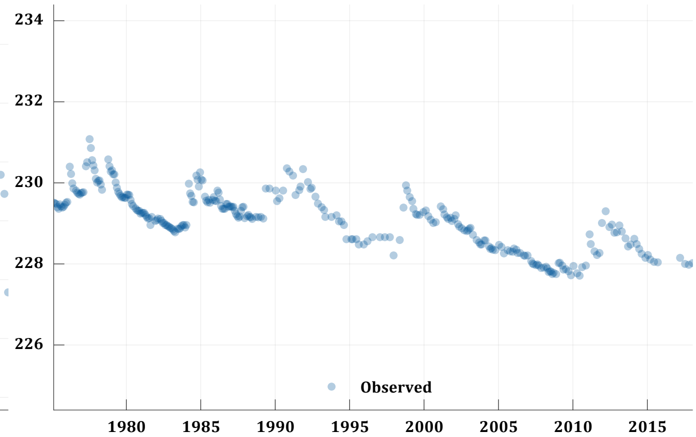
GW035155_1



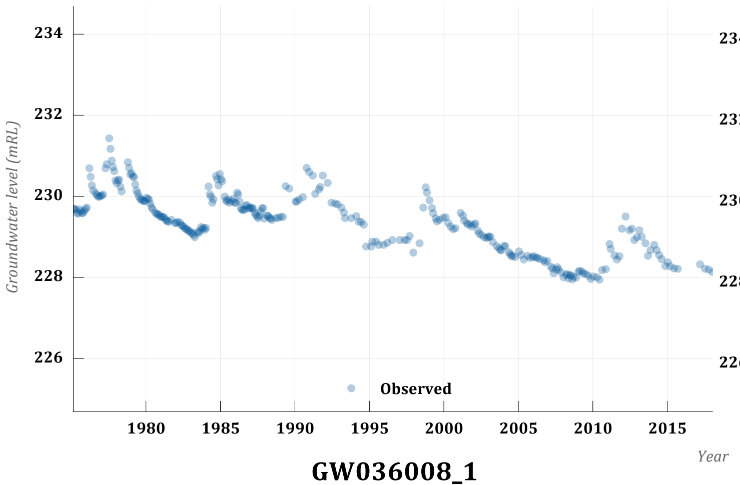
GW036003_1



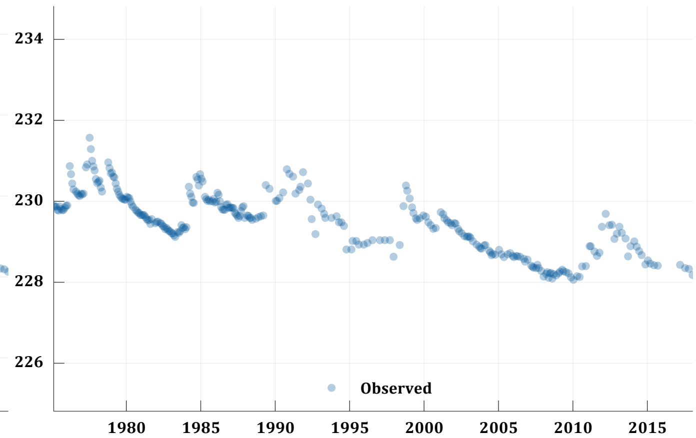
GW036007_1



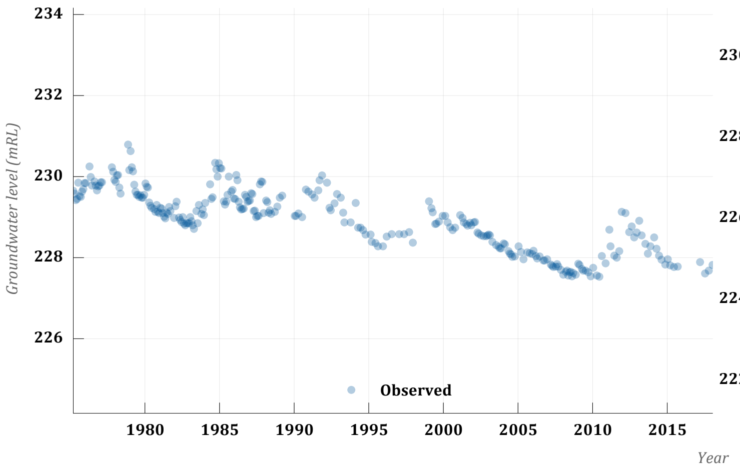
GW036007_2



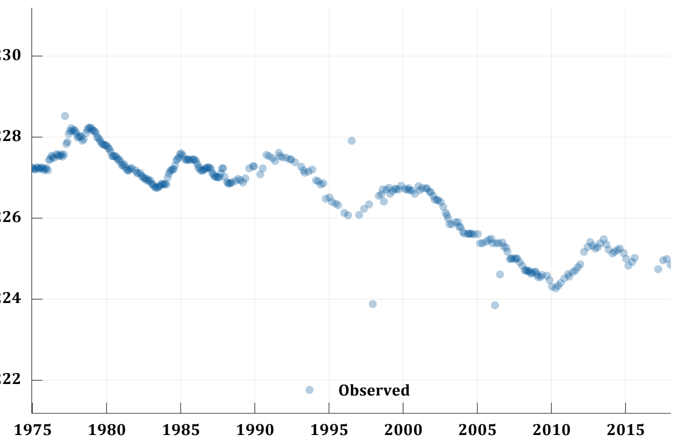
GW036007_3

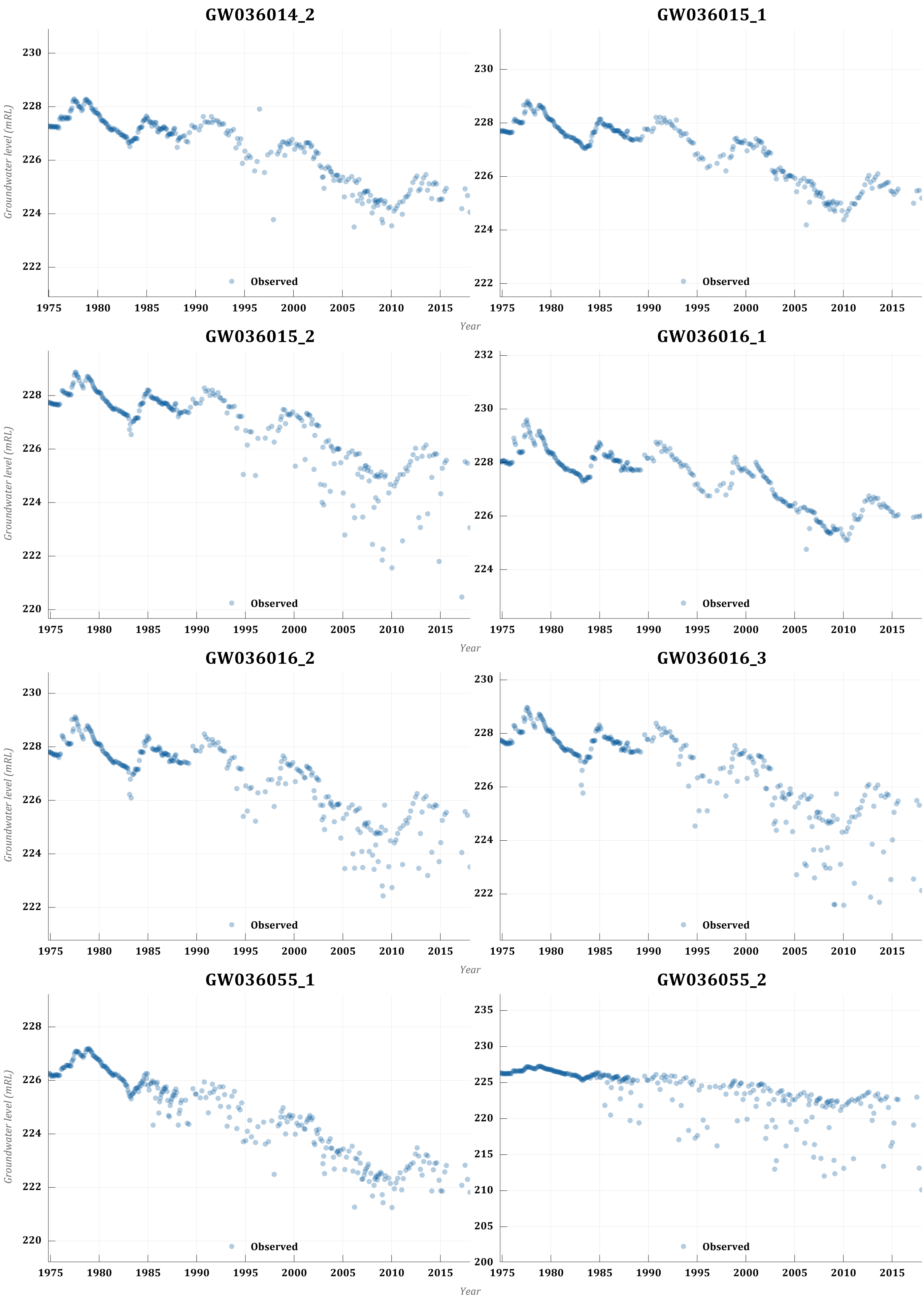


GW036008_1

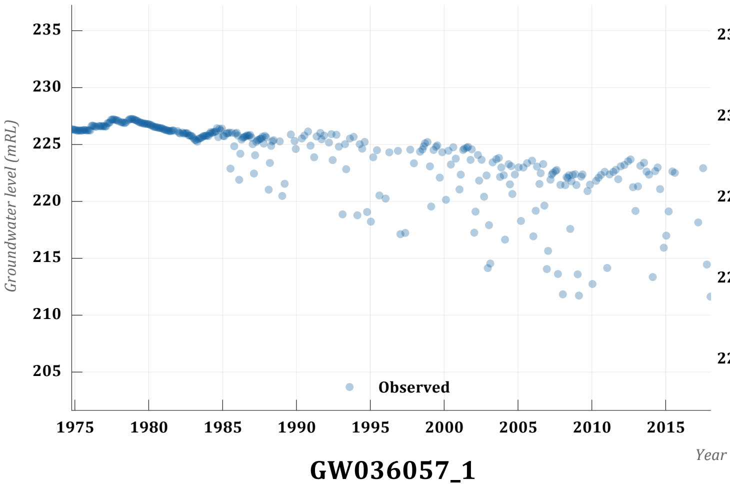


GW036014_1

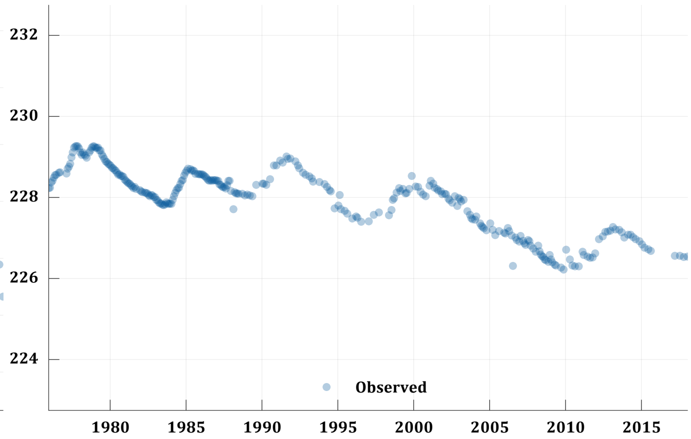



GW036014_2
GW036015_1
GW036015_2
GW036016_1
GW036016_2
GW036016_3
GW036055_1
GW036055_2
Groundwater level (mRL)
Year
Observed

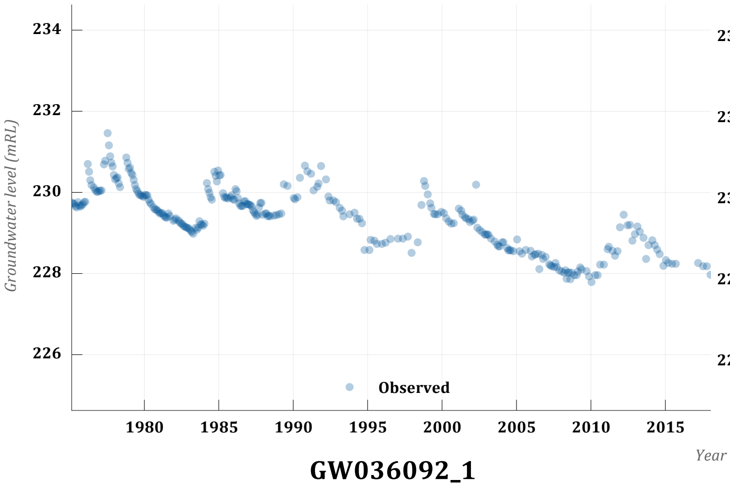
GW036055_3



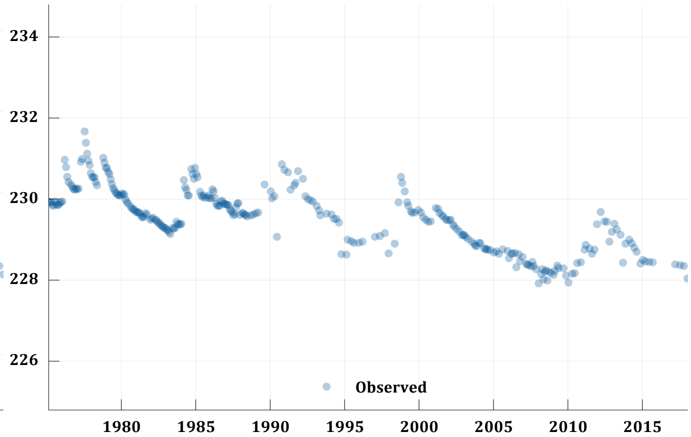
GW036056_1



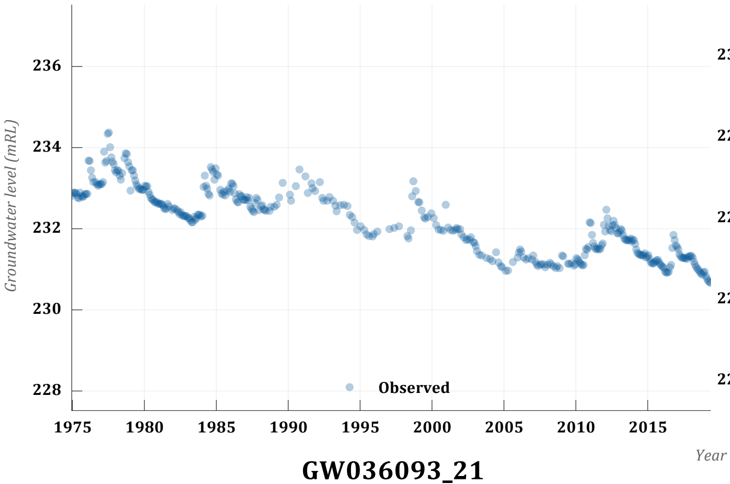
GW036057_1



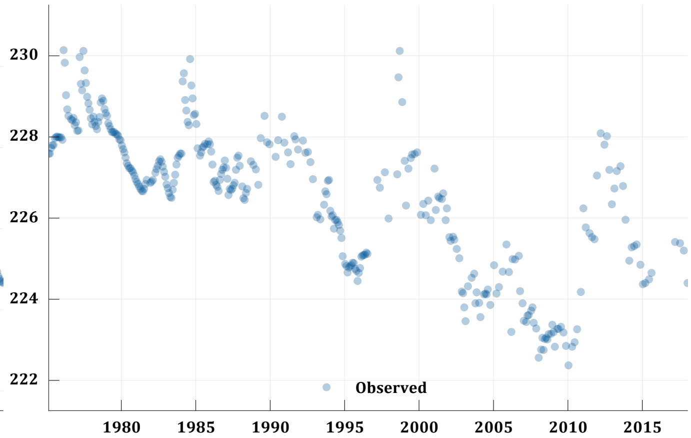
GW036057_2



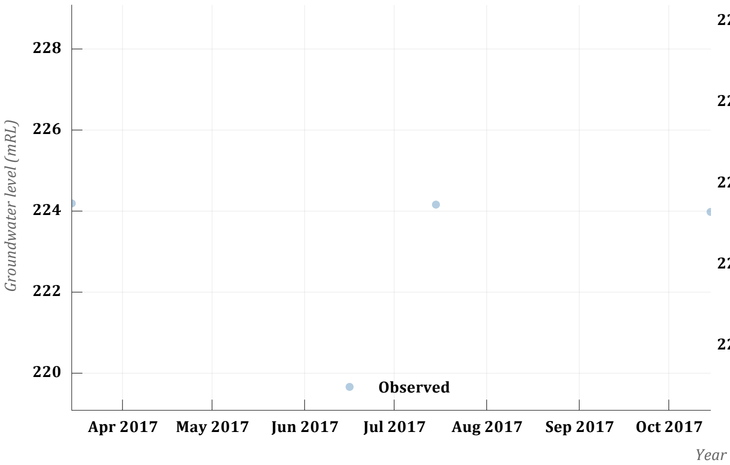
GW036092_1



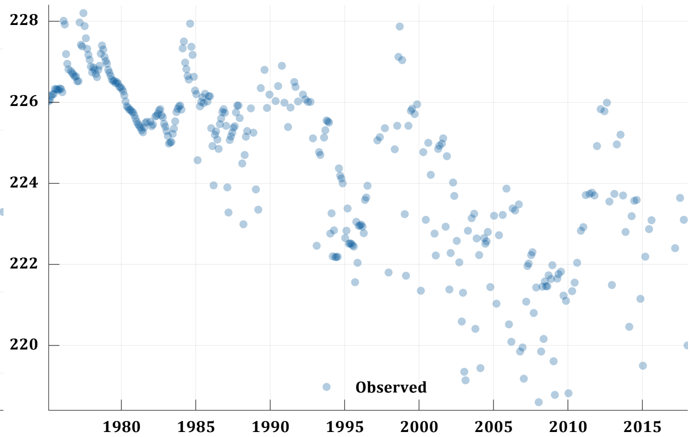
GW036093_1



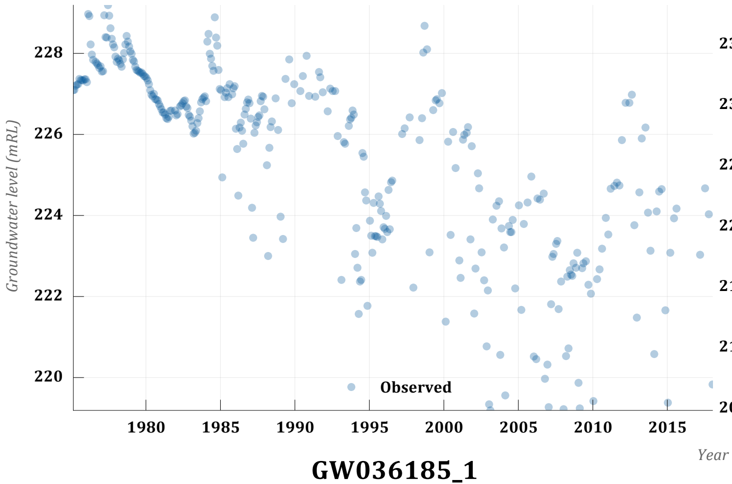
GW036093_21



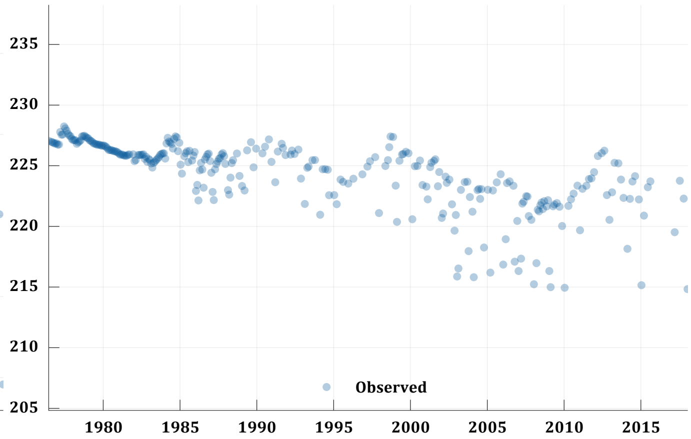
GW036093_22



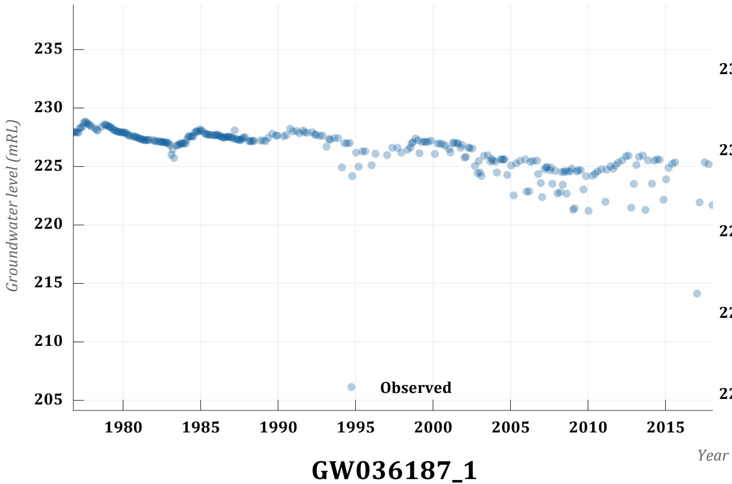
GW036093_3



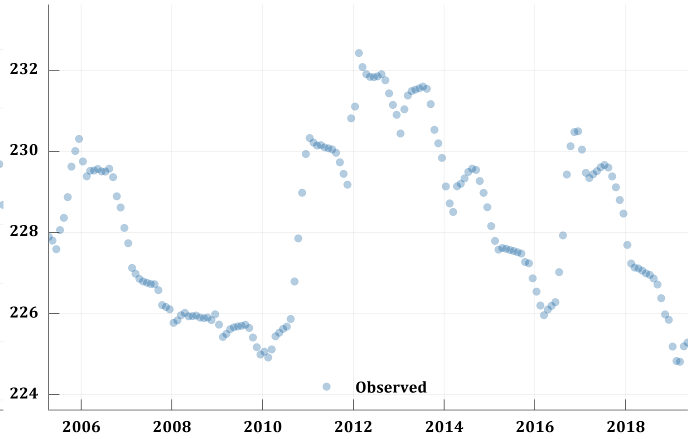
GW036164_1



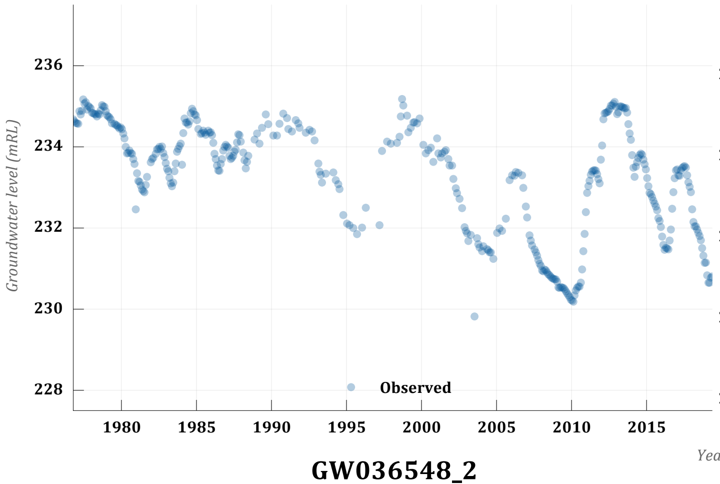
GW036185_1



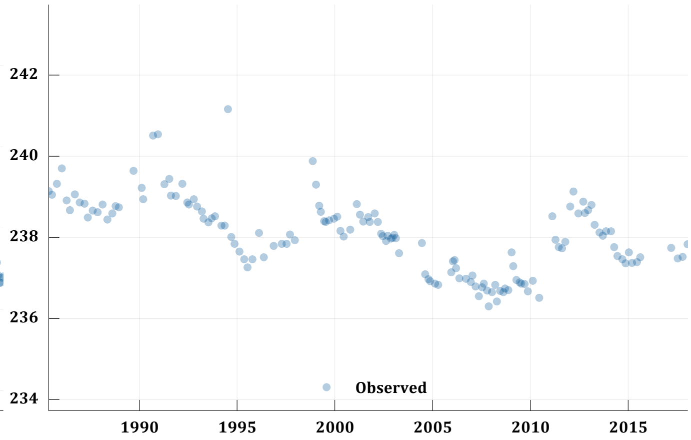
GW036186_1



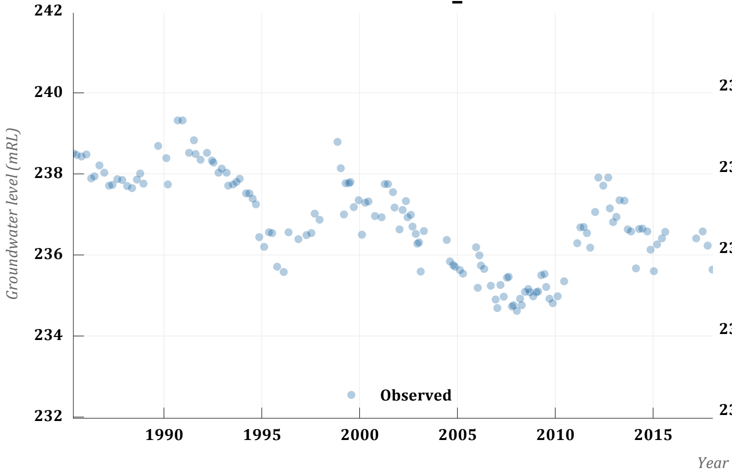
GW036187_1



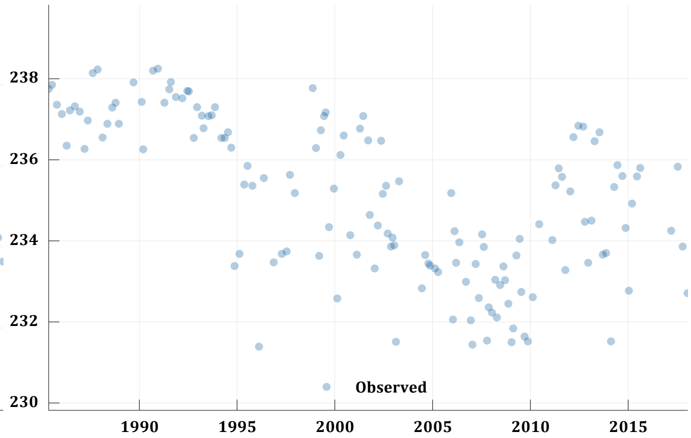
GW036548_1

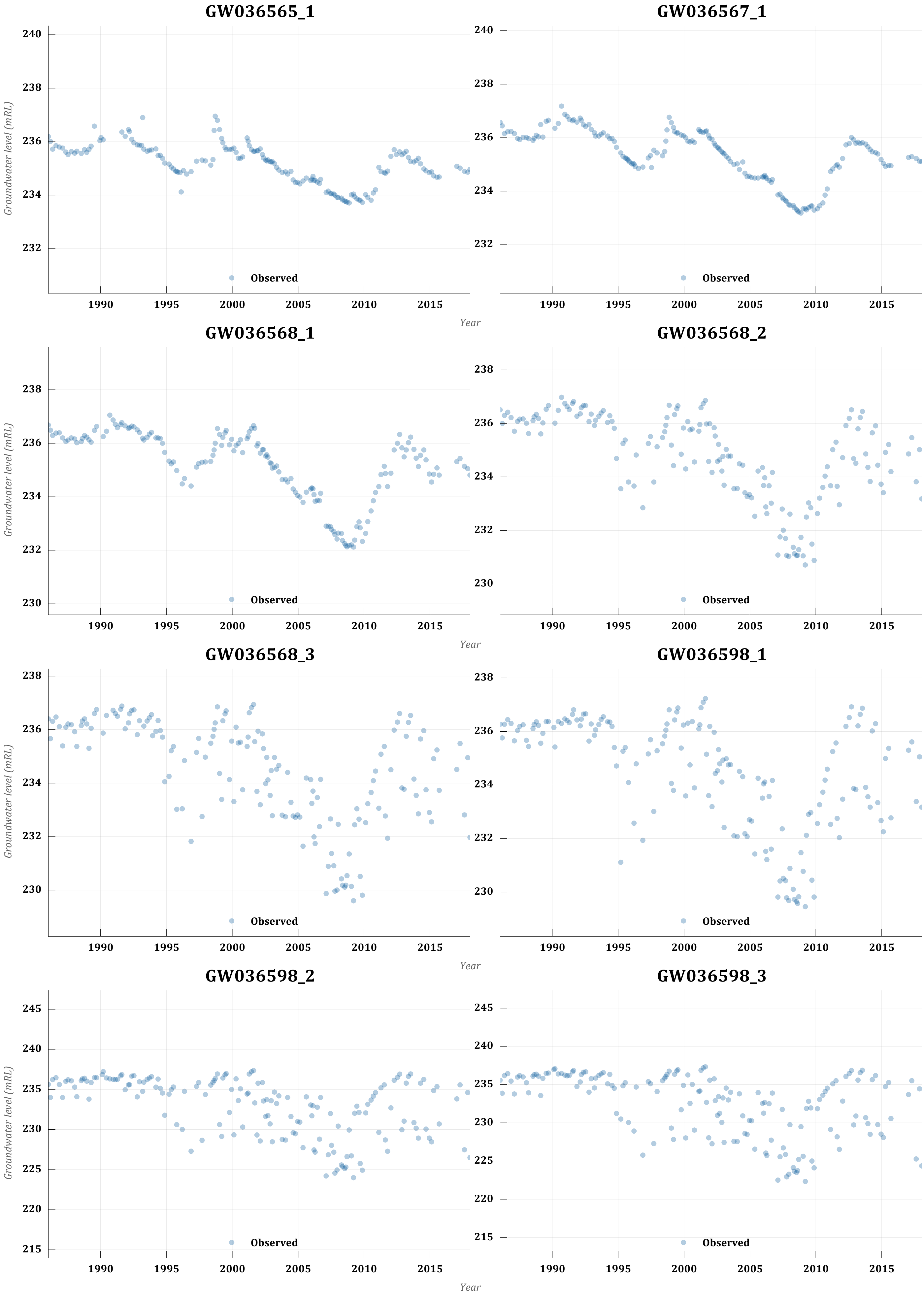


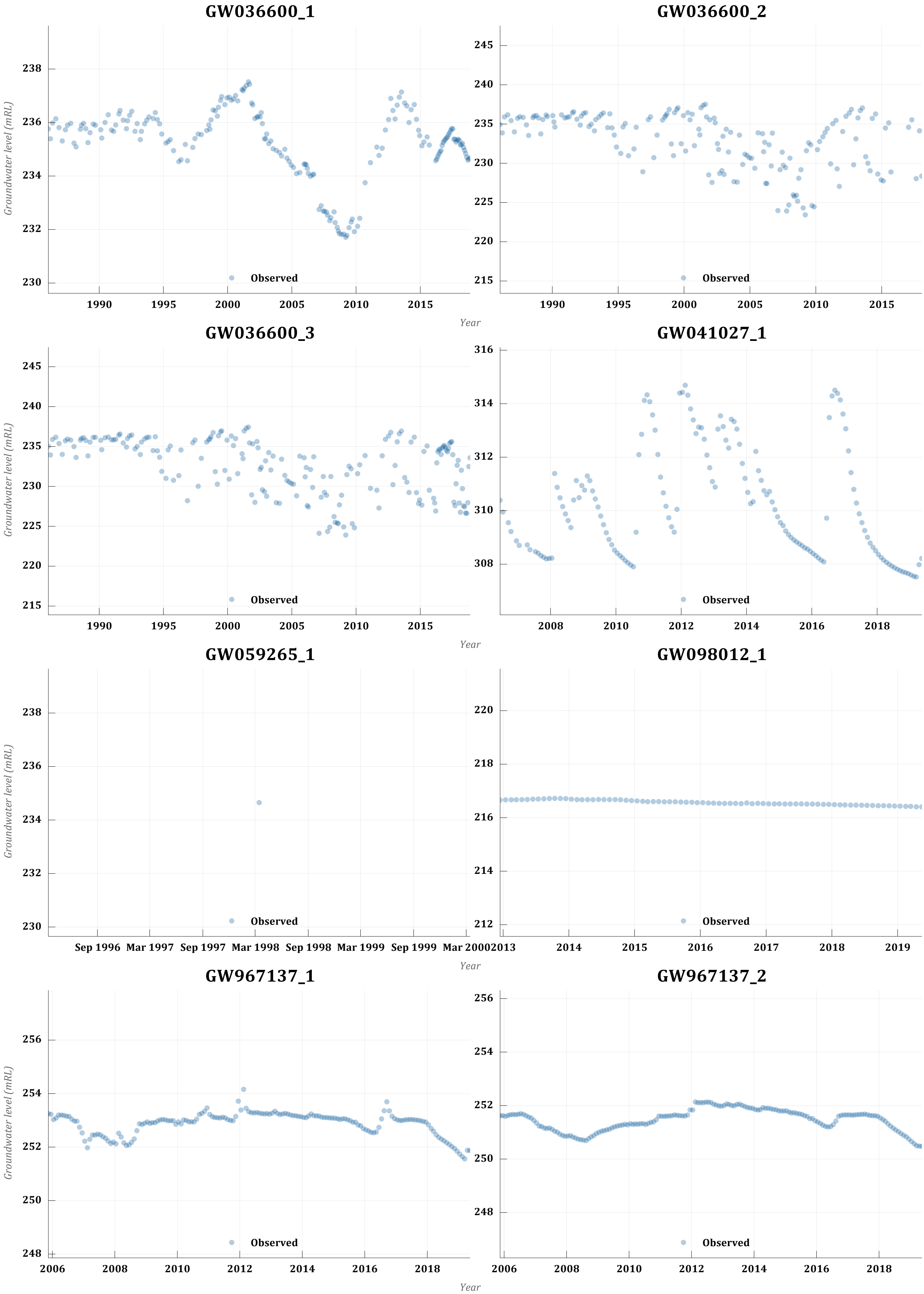
GW036548_2



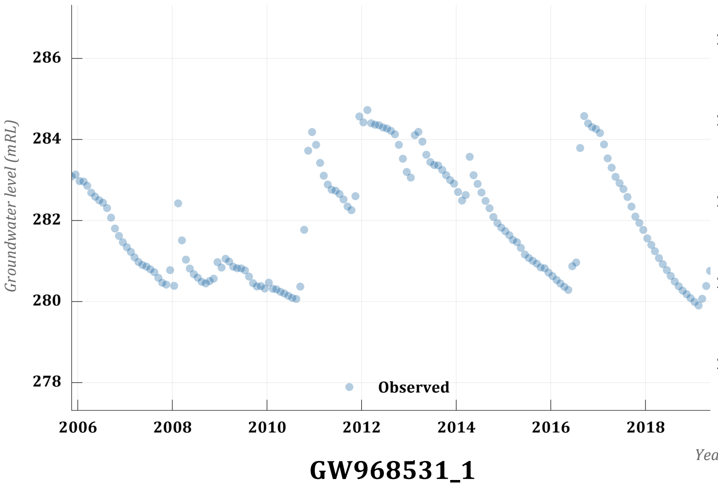
GW036548_3



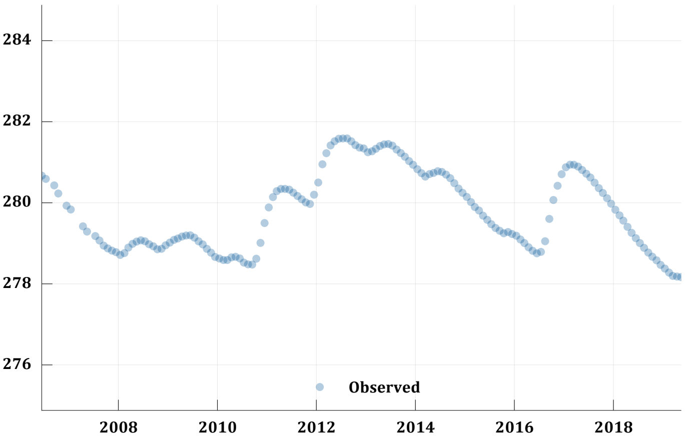

GW036565_1
GW036567_1
GW036568_1
GW036568_2
GW036568_3
GW036598_1
GW036598_2
GW036598_3
Groundwater level (mRL)
Year
Observed


GW036600_1
GW036600_2
GW036600_3
GW041027_1
GW059265_1
GW098012_1
GW967137_1
GW967137_2
Groundwater level (mRL)
Year
Observed
Sep 1996 Mar 1997 Sep 1997 Mar 1998 Sep 1998 Mar 1999 Sep 1999 Mar 2000

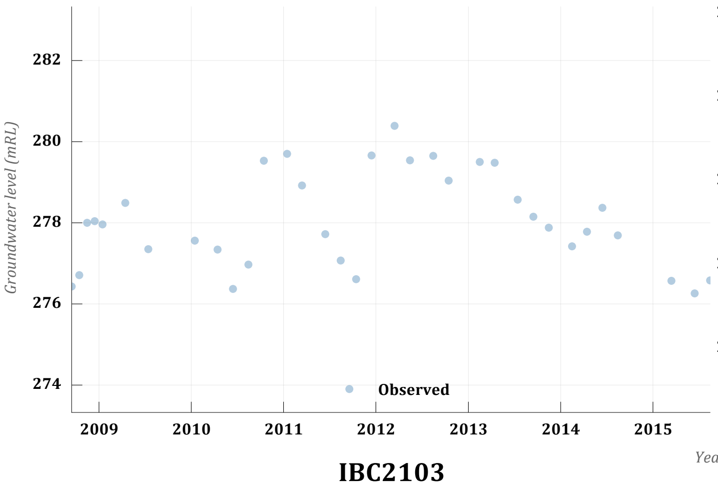
GW967138_1



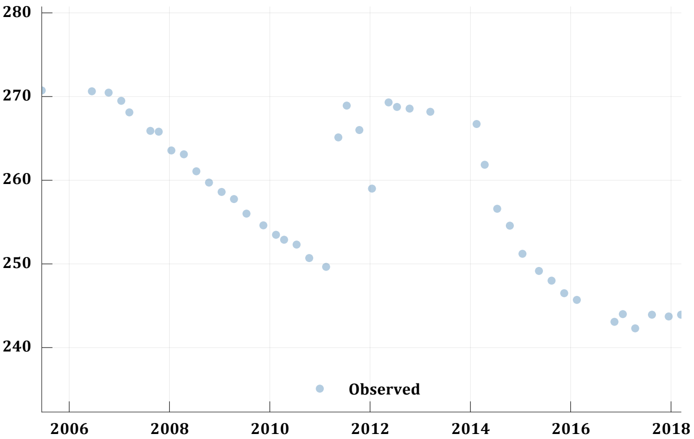
GW967138_2



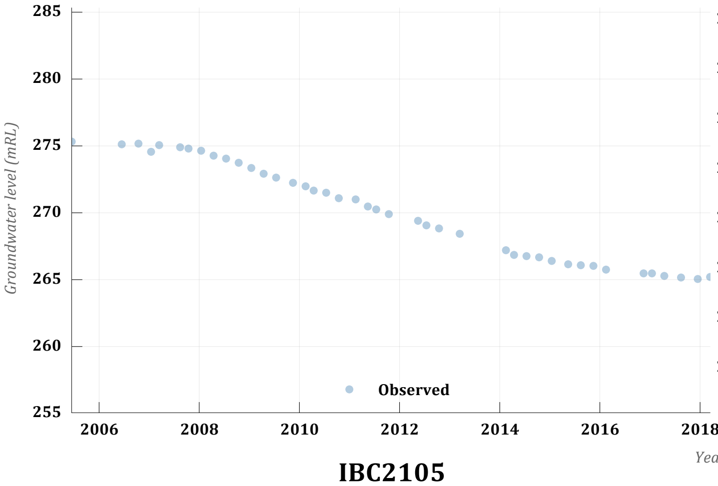
GW968531_1



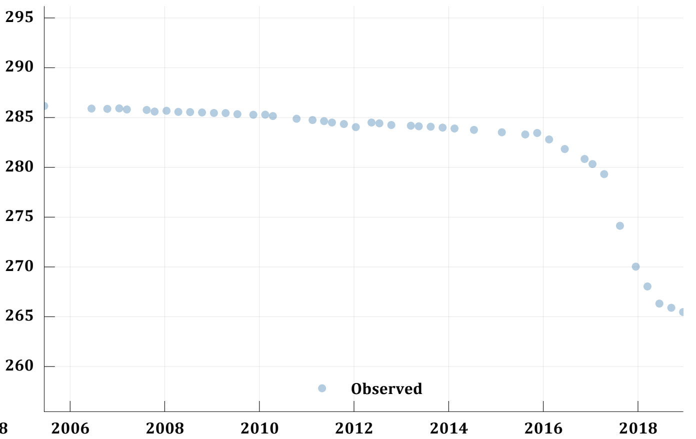
IBC2102



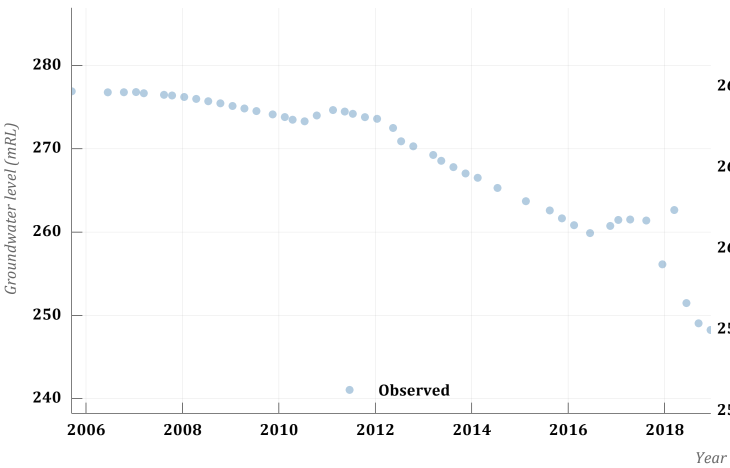
IBC2103



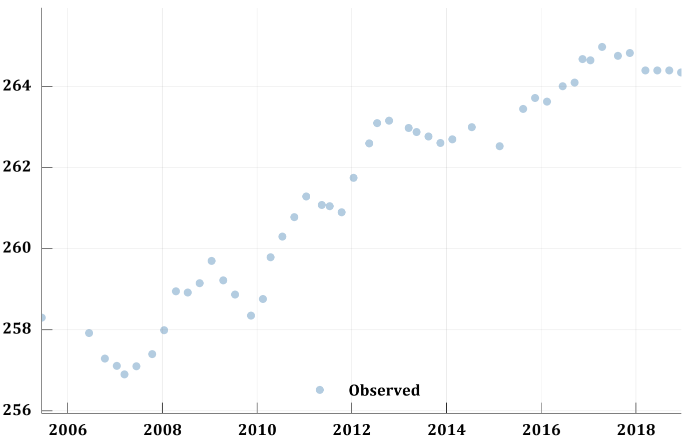
IBC2104



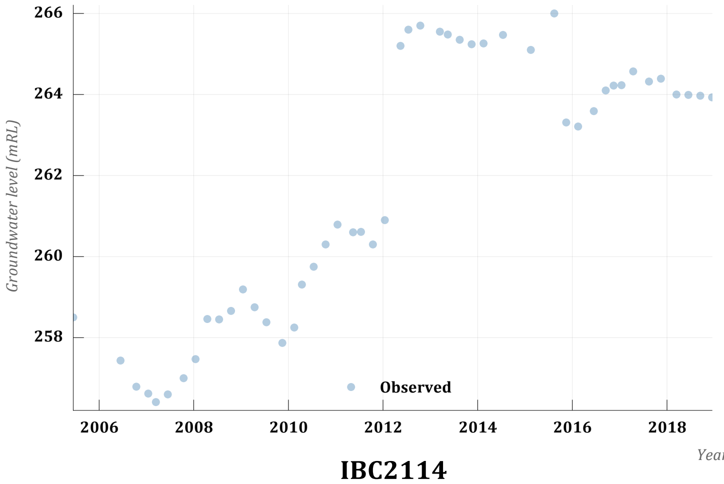
IBC2105



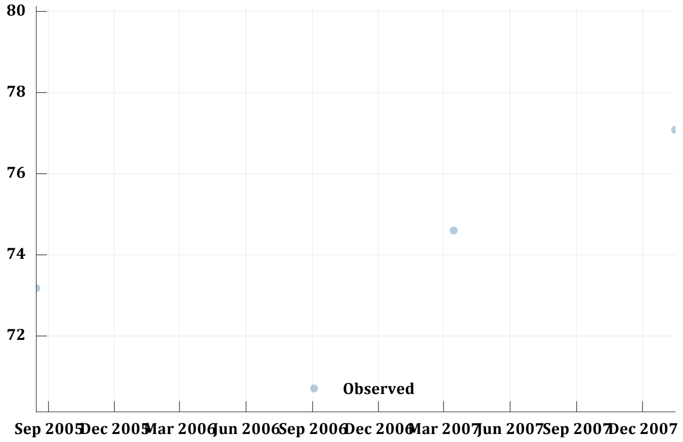
IBC2110



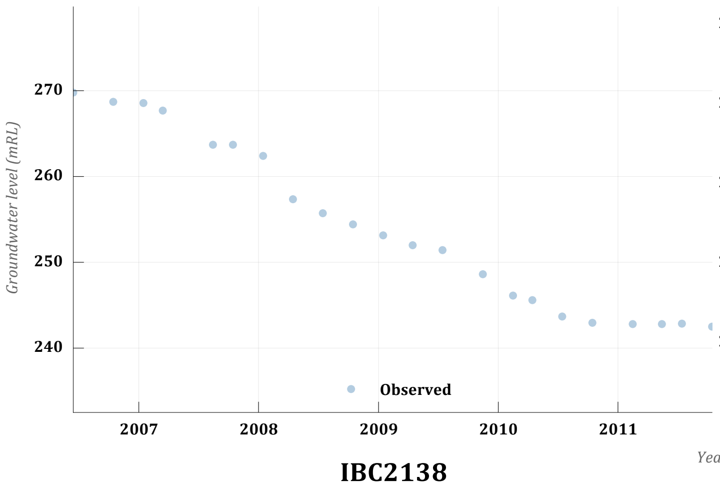
IBC2111



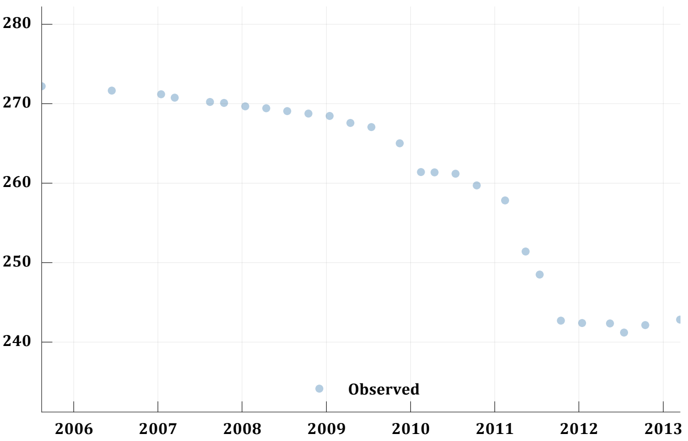
IBC2113



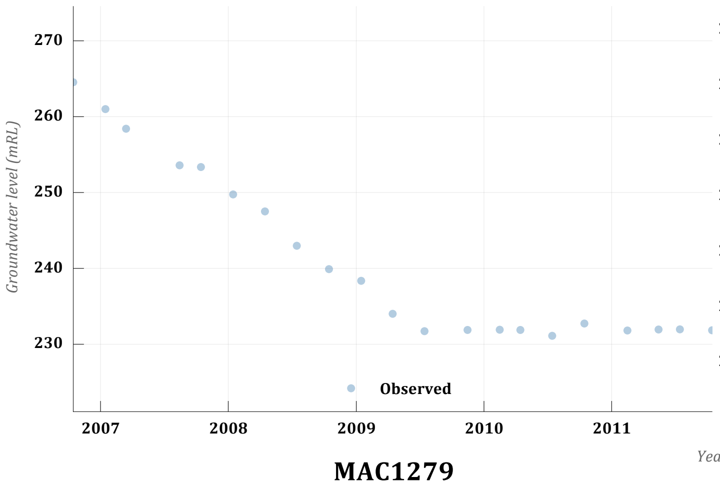
IBC2114



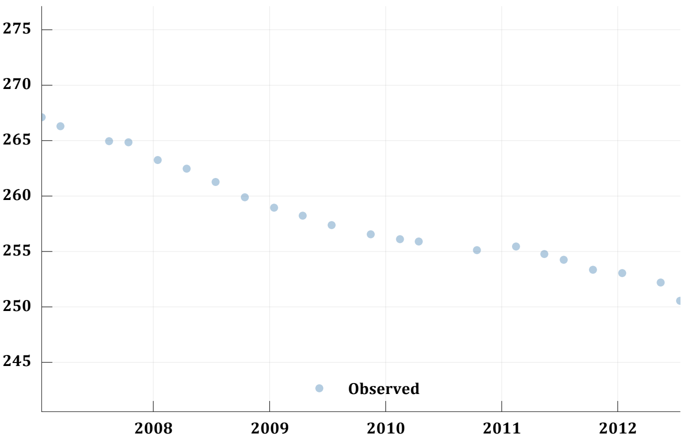
IBC2115



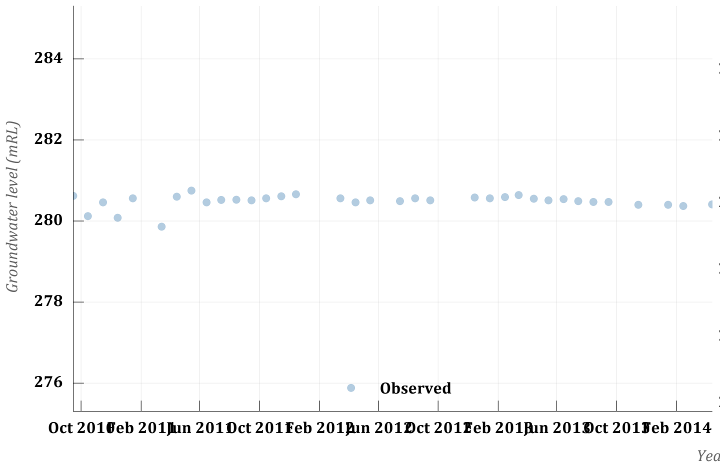
IBC2138



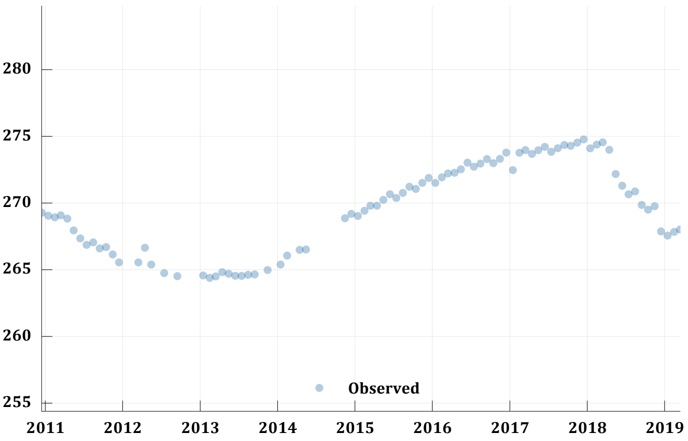
IBC2139

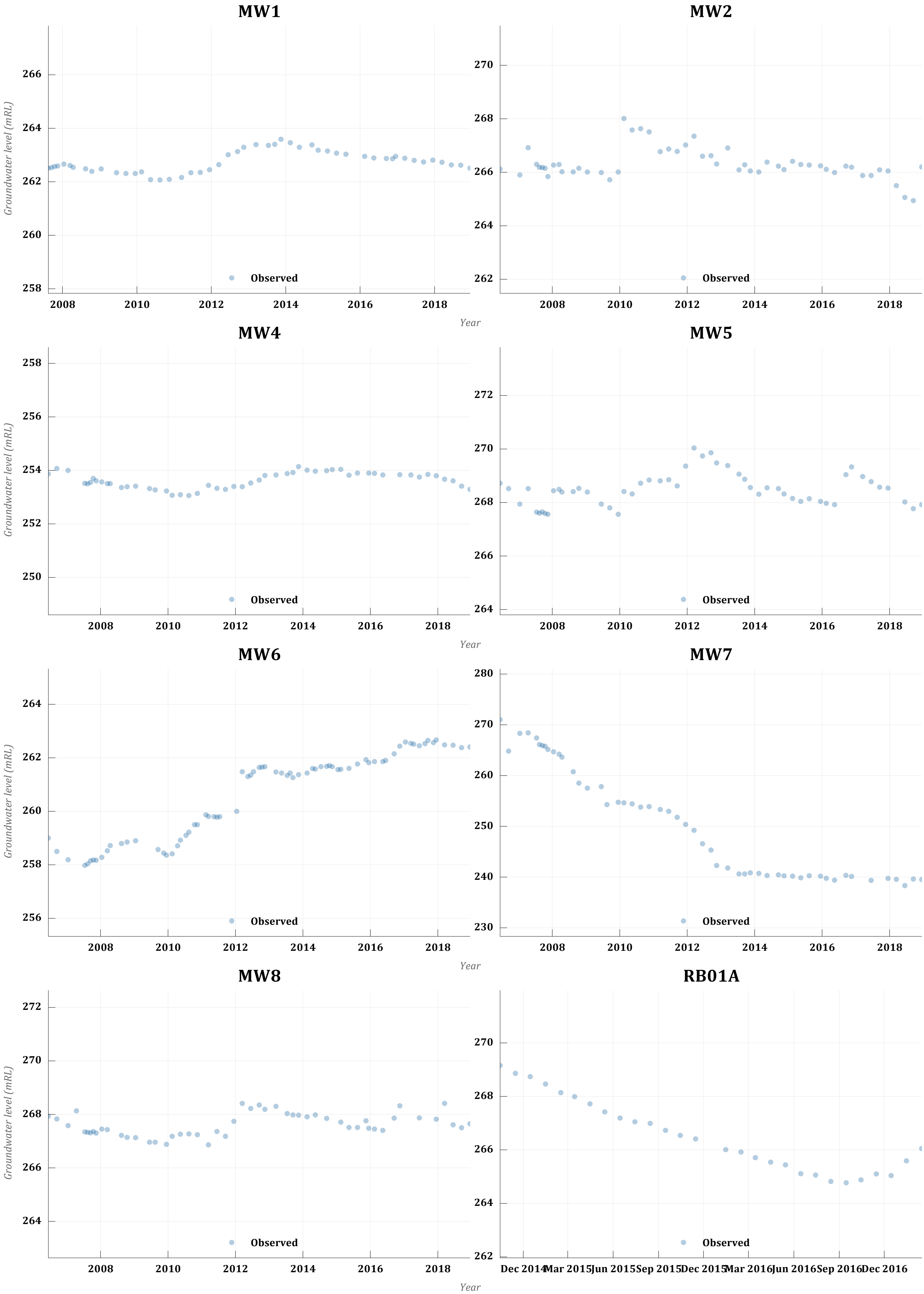


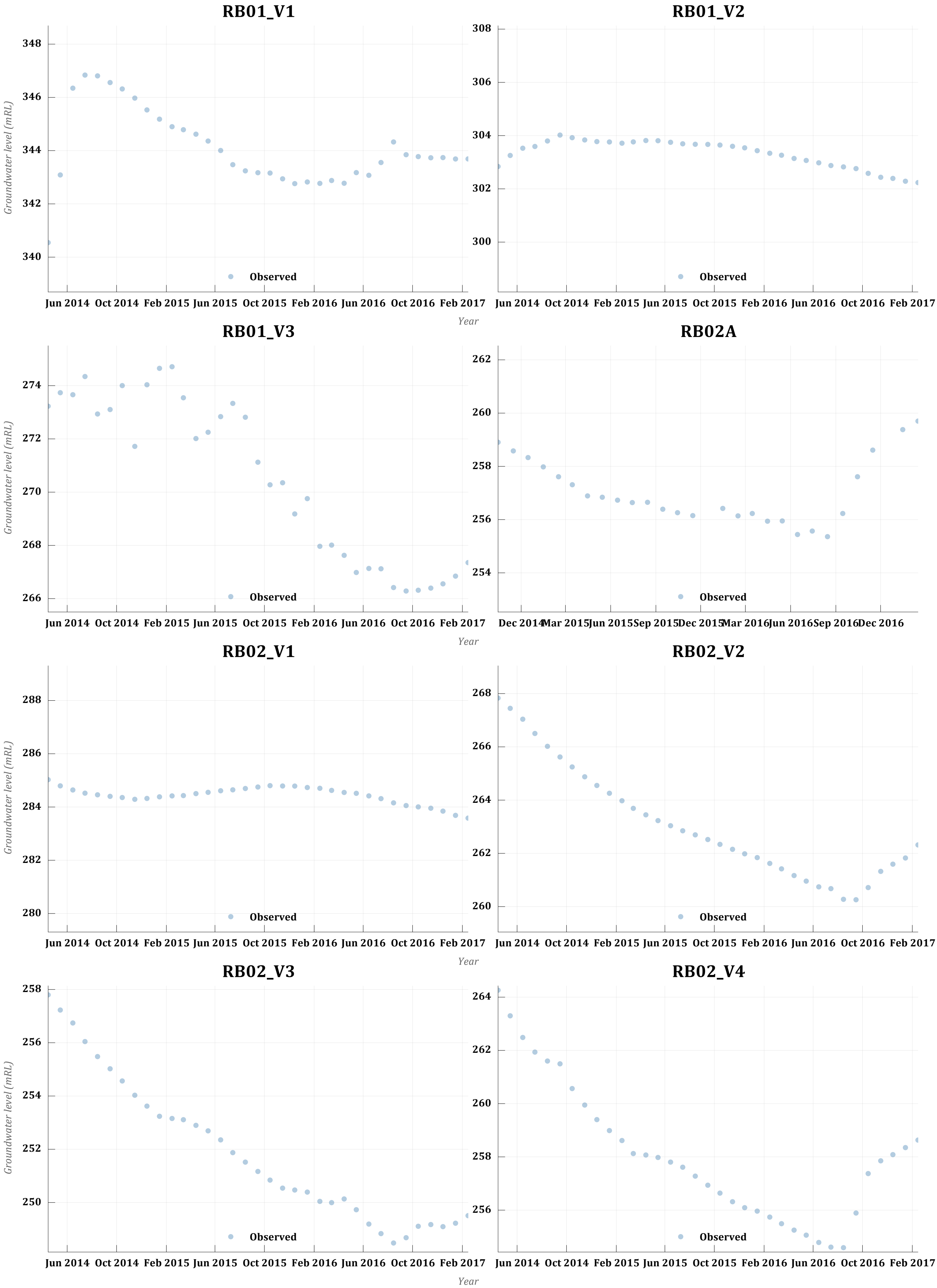
MAC1279

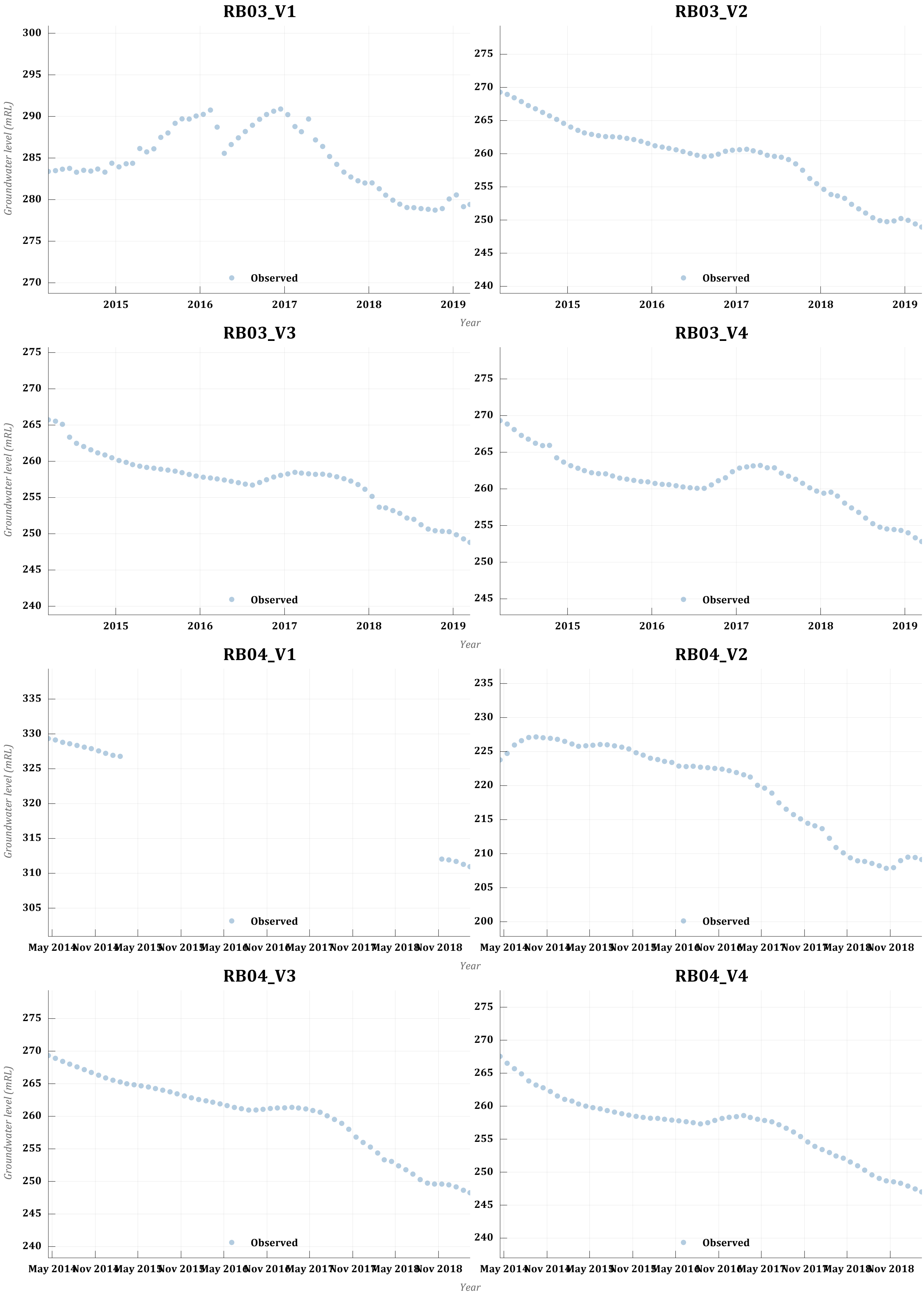


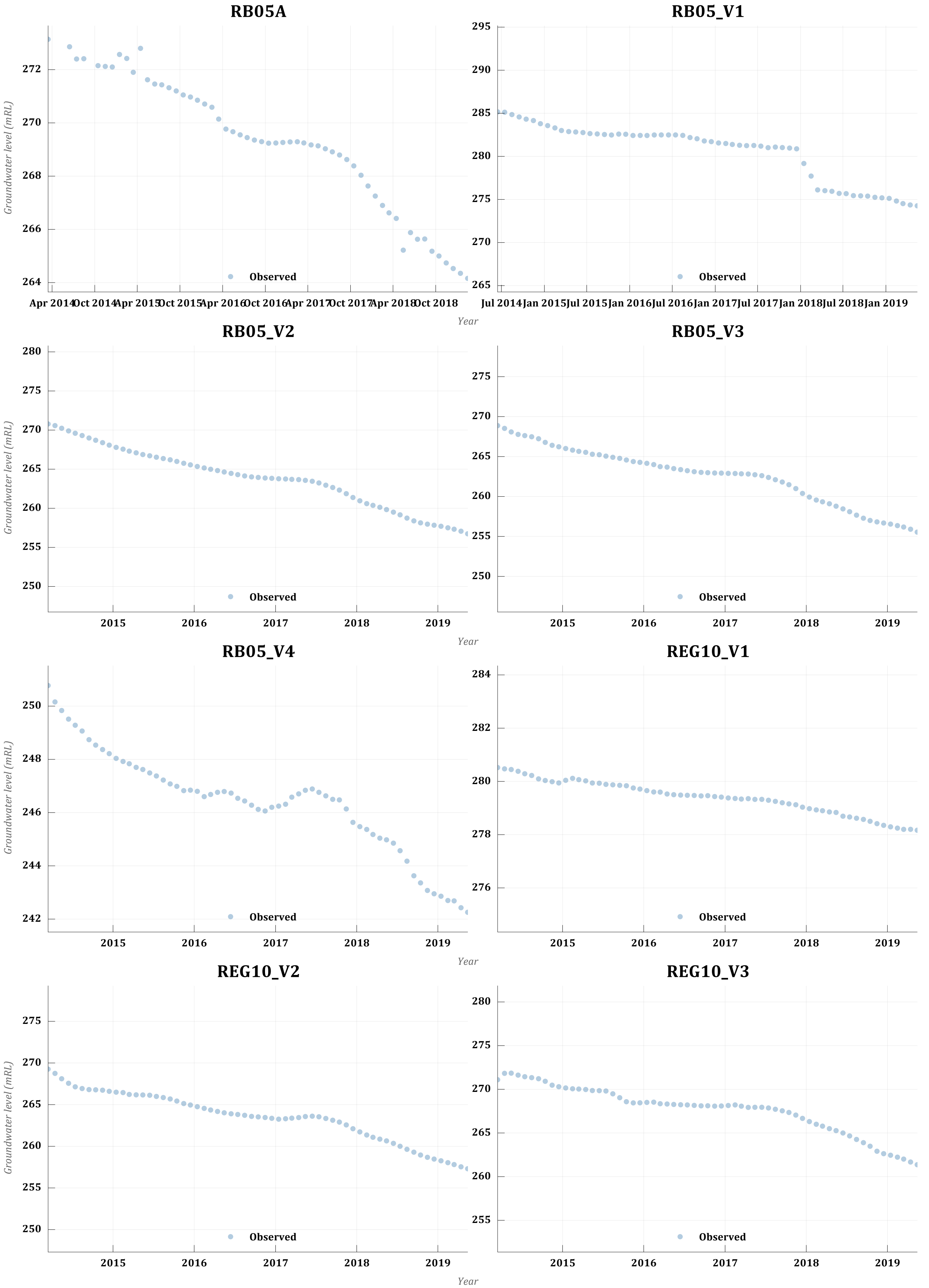
MAC1280



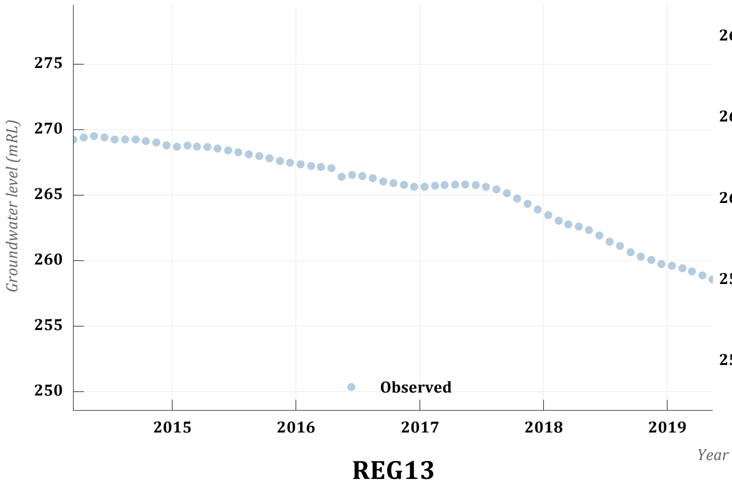

MW1
MW2
MW4
MW5
MW6
MW7
MW8
RB01A
Groundwater level (mRL)
Year
Observed
2008
2010
2012
2014
2016
2018
Dec 2014
Mar 2015
Jun 2015
Sep 2015
Dec 2015
Mar 2016
Jun 2016
Sep 2016
Dec 2016


RB01_V1
Groundwater level (mRL)
340
342
344
346
348
Observed
Jun 2014 Oct 2014 Feb 2015 Jun 2015 Oct 2015 Feb 2016 Jun 2016 Oct 2016 Feb 2017
Year
RB01_V2
300
302
304
306
308
Observed
Jun 2014 Oct 2014 Feb 2015 Jun 2015 Oct 2015 Feb 2016 Jun 2016 Oct 2016 Feb 2017
RB01_V3
Groundwater level (mRL)
266
268
270
272
274
Observed
Jun 2014 Oct 2014 Feb 2015 Jun 2015 Oct 2015 Feb 2016 Jun 2016 Oct 2016 Feb 2017
Year
RB02A
254
256
258
260
262
Observed
Dec 2014 Mar 2015 Jun 2015 Sep 2015 Dec 2015 Mar 2016 Jun 2016 Sep 2016 Dec 2016
RB02_V1
Groundwater level (mRL)
280
282
284
286
288
Observed
Jun 2014 Oct 2014 Feb 2015 Jun 2015 Oct 2015 Feb 2016 Jun 2016 Oct 2016 Feb 2017
Year
RB02_V2
260
262
264
266
268
Observed
Jun 2014 Oct 2014 Feb 2015 Jun 2015 Oct 2015 Feb 2016 Jun 2016 Oct 2016 Feb 2017
RB02_V3
Groundwater level (mRL)
250
252
254
256
258
Observed
Jun 2014 Oct 2014 Feb 2015 Jun 2015 Oct 2015 Feb 2016 Jun 2016 Oct 2016 Feb 2017
Year
RB02_V4
256
258
260
262
264
Observed
Jun 2014 Oct 2014 Feb 2015 Jun 2015 Oct 2015 Feb 2016 Jun 2016 Oct 2016 Feb 2017

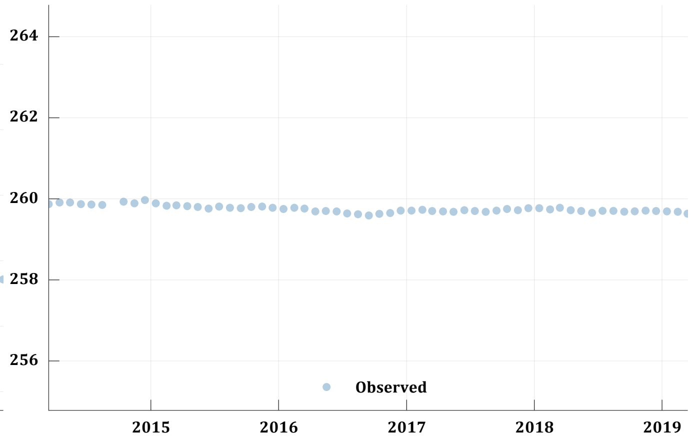

RB03_V1
300
295
290
285
280
275
270
Groundwater level (mRL)
Observed
2015
2016
2017
2018
2019
RB03_V2
275
270
265
260
255
250
245
240
Observed
2015
2016
2017
2018
2019
Year
RB03_V3
275
270
265
260
255
250
245
240
Groundwater level (mRL)
Observed
2015
2016
2017
2018
2019
RB03_V4
275
270
265
260
255
250
245
Observed
2015
2016
2017
2018
2019
Year
RB04_V1
335
330
325
320
315
310
305
Groundwater level (mRL)
Observed
May 2014
Nov 2014
May 2015
Nov 2015
May 2016
Nov 2016
May 2017
Nov 2017
May 2018
Nov 2018
RB04_V2
235
230
225
220
215
210
205
200
Observed
May 2014
Nov 2014
May 2015
Nov 2015
May 2016
Nov 2016
May 2017
Nov 2017
May 2018
Nov 2018
Year
RB04_V3
275
270
265
260
255
250
245
240
Groundwater level (mRL)
Observed
May 2014
Nov 2014
May 2015
Nov 2015
May 2016
Nov 2016
May 2017
Nov 2017
May 2018
Nov 2018
RB04_V4
275
270
265
260
255
250
245
240
Observed
May 2014
Nov 2014
May 2015
Nov 2015
May 2016
Nov 2016
May 2017
Nov 2017
May 2018
Nov 2018
Year


RB05A
Groundwater level (mRL)
264
266
268
270
272
Observed
Apr 2014
Oct 2014
Apr 2015
Oct 2015
Apr 2016
Oct 2016
Apr 2017
Oct 2017
Apr 2018
Oct 2018
RB05_V1
265
270
275
280
285
290
295
Observed
Jul 2014
Jan 2015
Jul 2015
Jan 2016
Jul 2016
Jan 2017
Jul 2017
Jan 2018
Jul 2018
Jan 2019
Year
RB05_V2
Groundwater level (mRL)
250
255
260
265
270
275
280
Observed
2015
2016
2017
2018
2019
RB05_V3
250
255
260
265
270
275
Observed
2015
2016
2017
2018
2019
Year
RB05_V4
Groundwater level (mRL)
242
244
246
248
250
Observed
2015
2016
2017
2018
2019
REG10_V1
276
278
280
282
284
Observed
2015
2016
2017
2018
2019
Year
REG10_V2
Groundwater level (mRL)
250
255
260
265
270
275
Observed
2015
2016
2017
2018
2019
REG10_V3
255
260
265
270
275
280
Observed
2015
2016
2017
2018
2019
Year

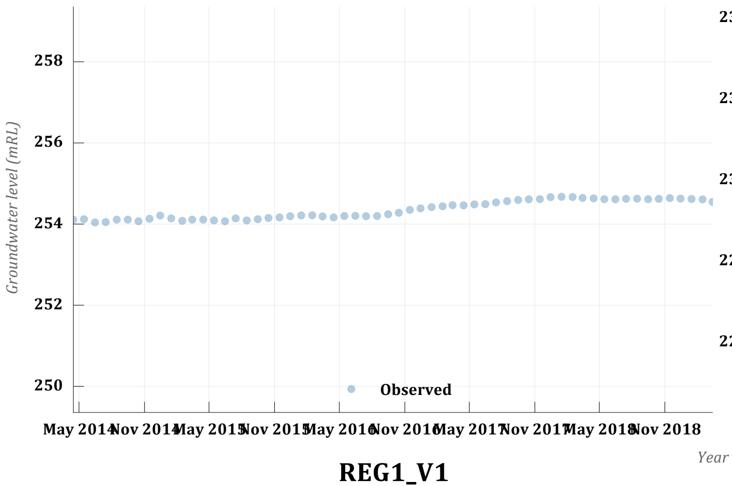
REG10_V4



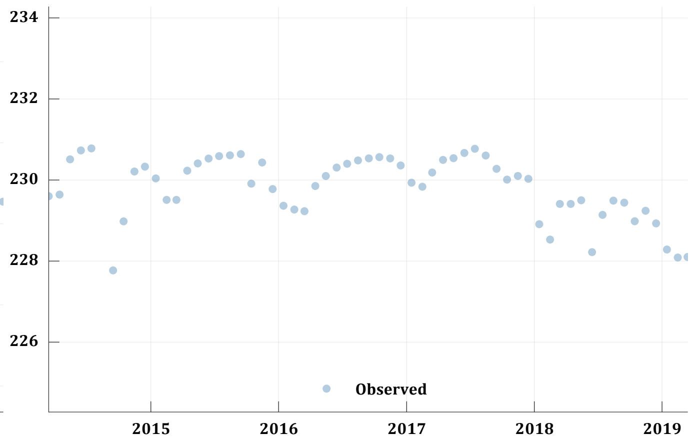
REG12



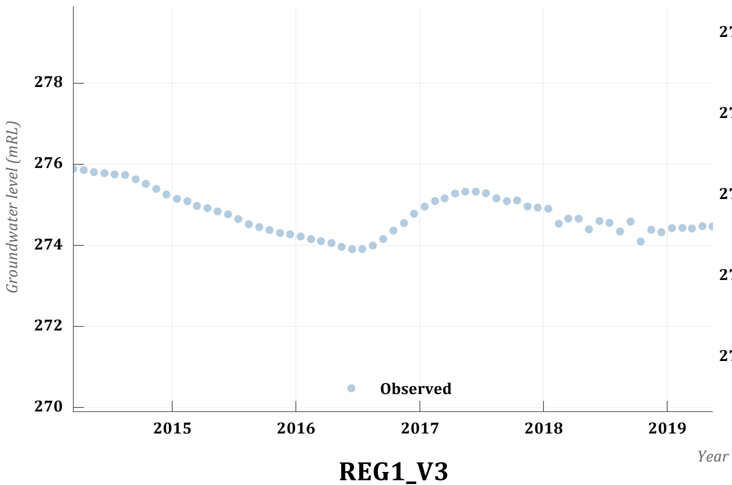
REG13



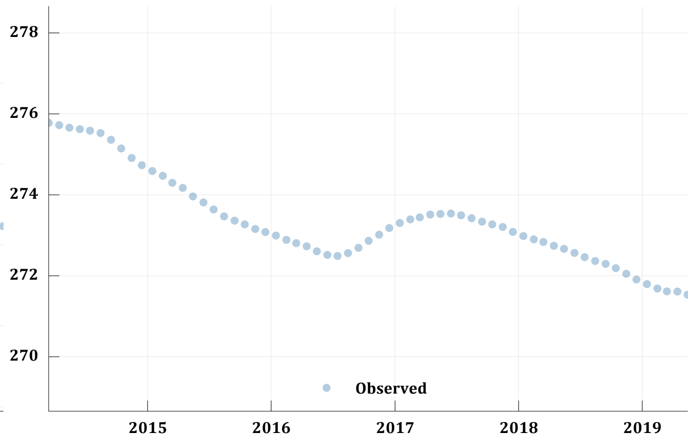
REG14



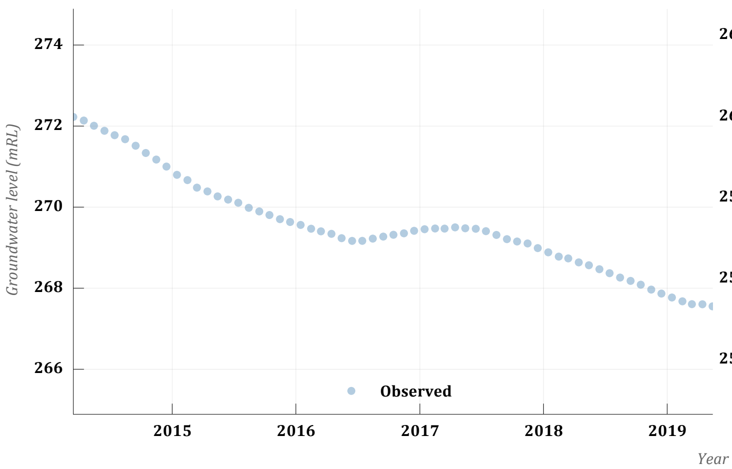
REG1_V1



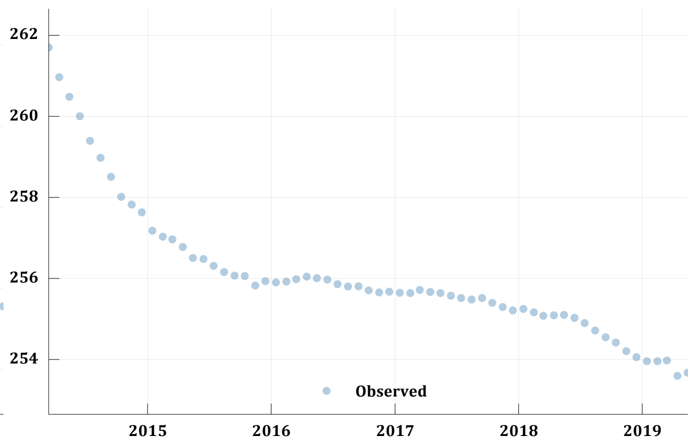
REG1_V2

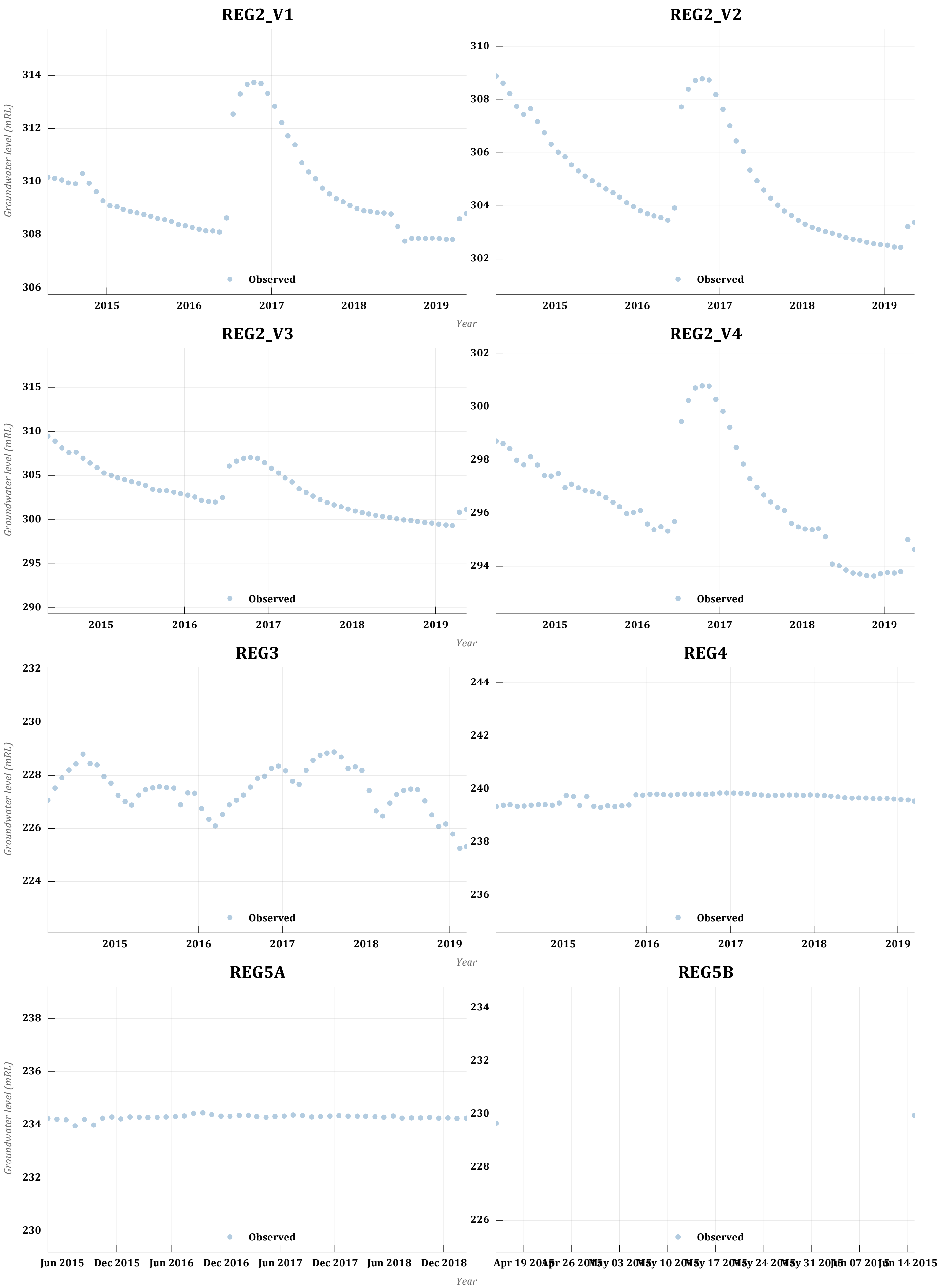


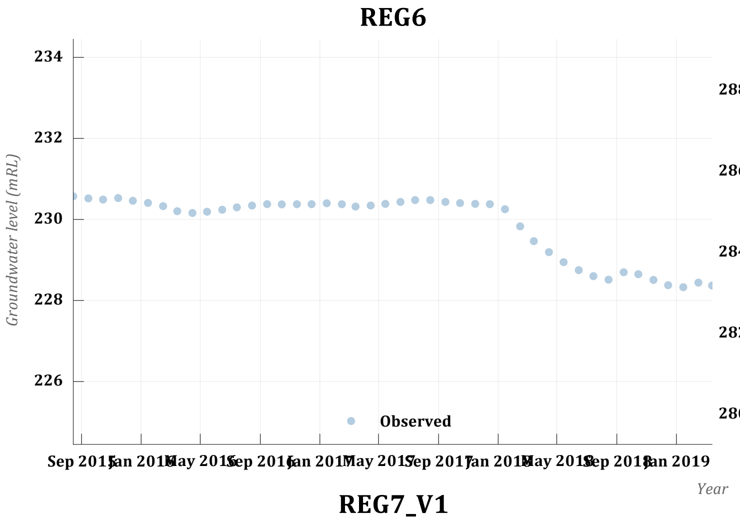
REG1_V3

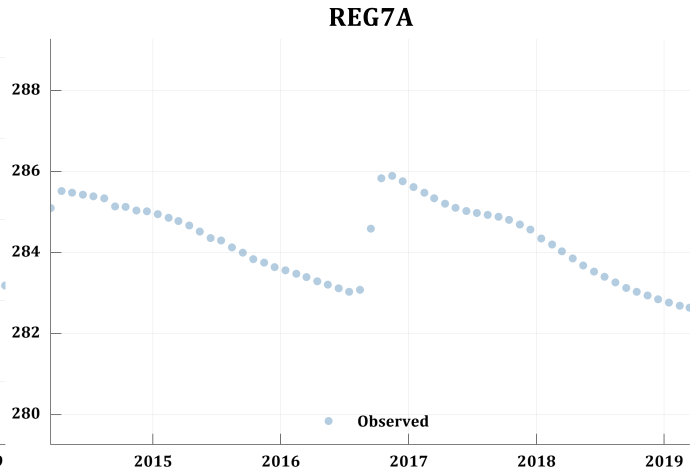


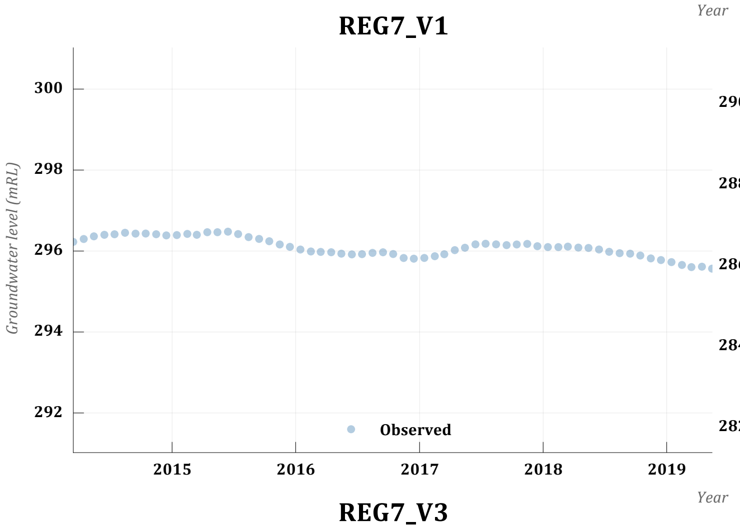
REG1_V4

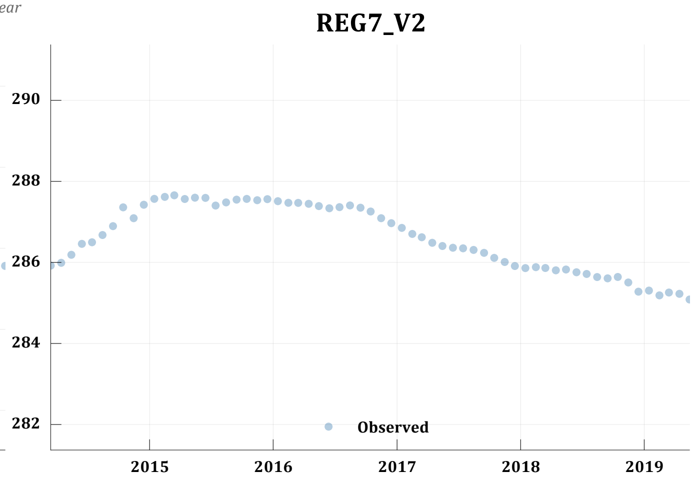


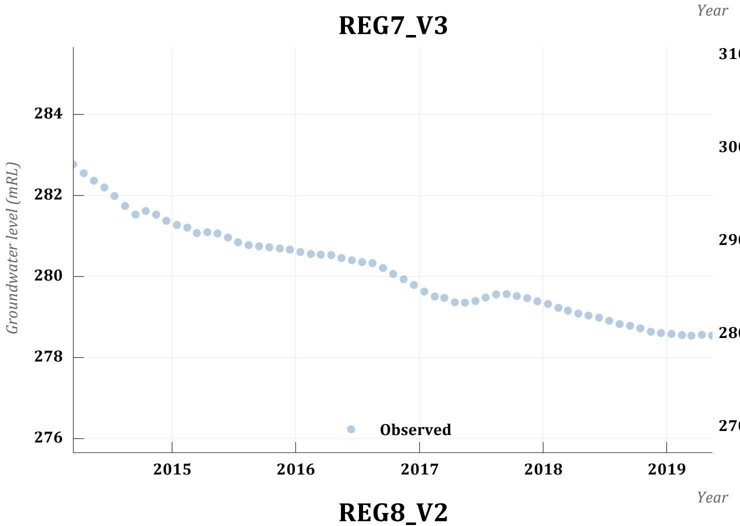

REG2_V1
REG2_V2
REG2_V3
REG2_V4
REG3
REG4
REG5A
REG5B
Groundwater level (mRL)
Year
Observed
2015
2016
2017
2018
2019
Jun 2015
Dec 2015
Jun 2016
Dec 2016
Jun 2017
Dec 2017
Jun 2018
Dec 2018
Apr 19 2015
Jun 14 2015

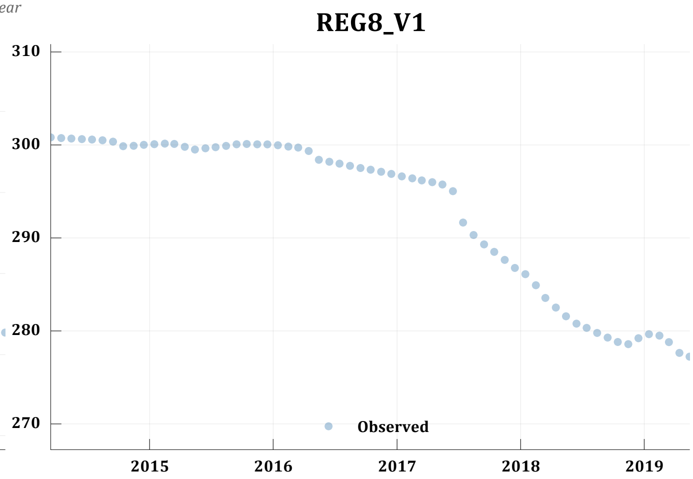

REG6
Groundwater level (mRL)
234
232
230
228
226
Observed
Sep 2015 Jan 2016 May 2016 Sep 2016 Jan 2017 May 2017 Sep 2017 Jan 2018 May 2018 Sep 2018 Jan 2019
Year

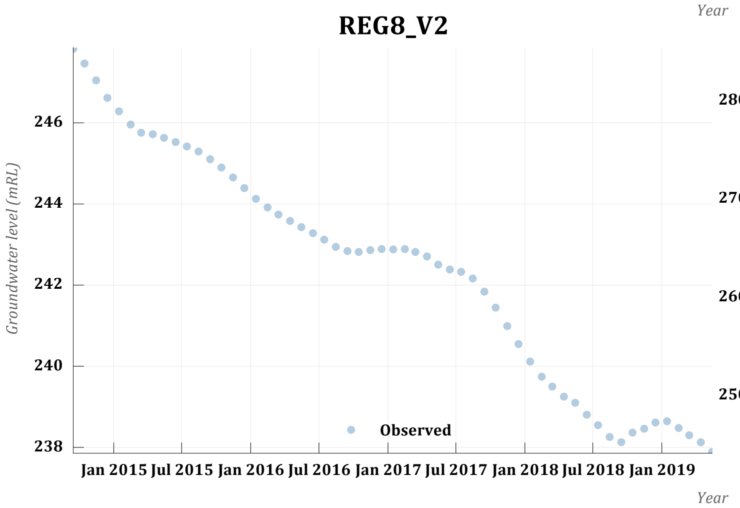

REG7A
288
286
284
282
280
Observed
2015
2016
2017
2018
2019

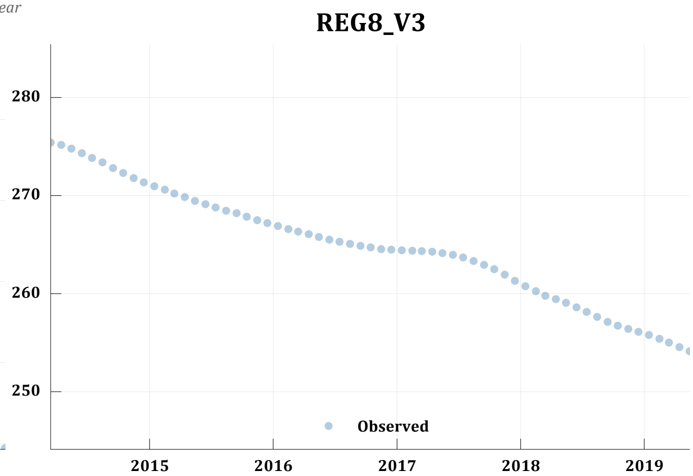

REG7_V1
Groundwater level (mRL)
300
298
296
294
292
Observed
2015
2016
2017
2018
2019
Year


REG7_V2
290
288
286
284
282
Observed
2015
2016
2017
2018
2019

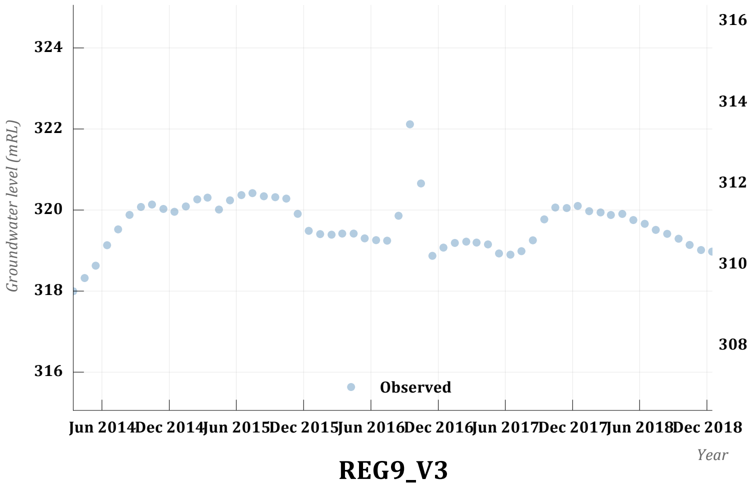

REG7_V3
Groundwater level (mRL)
284
282
280
278
276
Observed
2015
2016
2017
2018
2019
Year


REG8_V1
310
300
290
280
270
Observed
2015
2016
2017
2018
2019

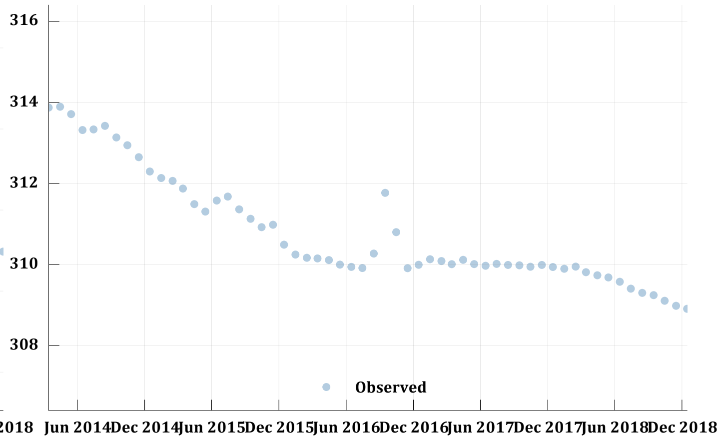

REG8_V2
Groundwater level (mRL)
246
244
242
240
238
Observed
Jan 2015 Jul 2015 Jan 2016 Jul 2016 Jan 2017 Jul 2017 Jan 2018 Jul 2018 Jan 2019
Year


REG8_V3
280
270
260
250
Observed
2015
2016
2017
2018
2019

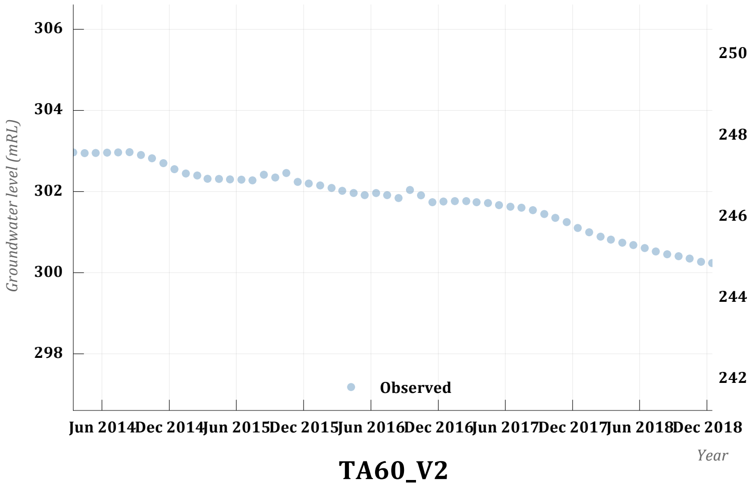
REG9_V1



REG9_V2



REG9_V3



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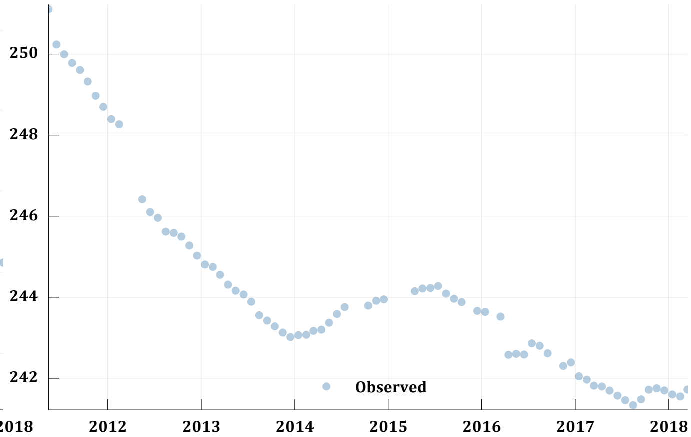

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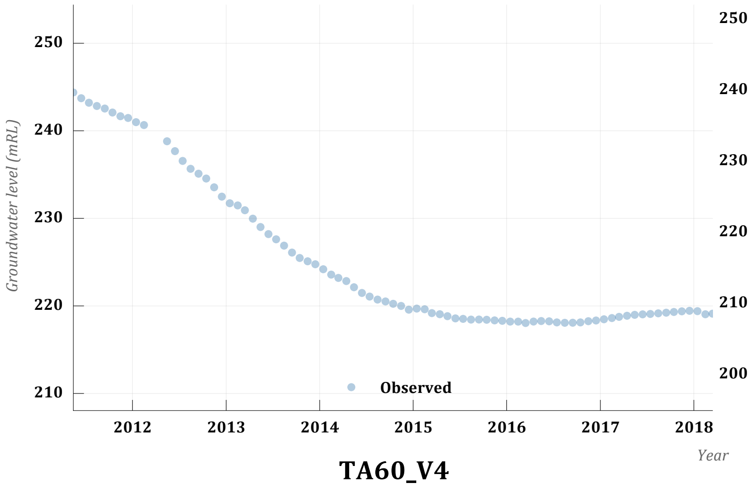

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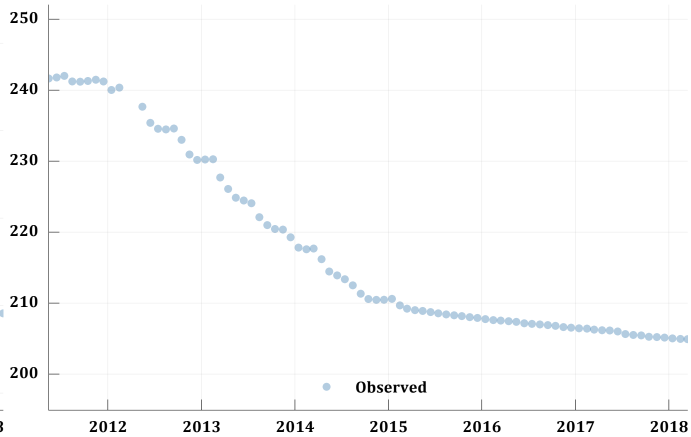

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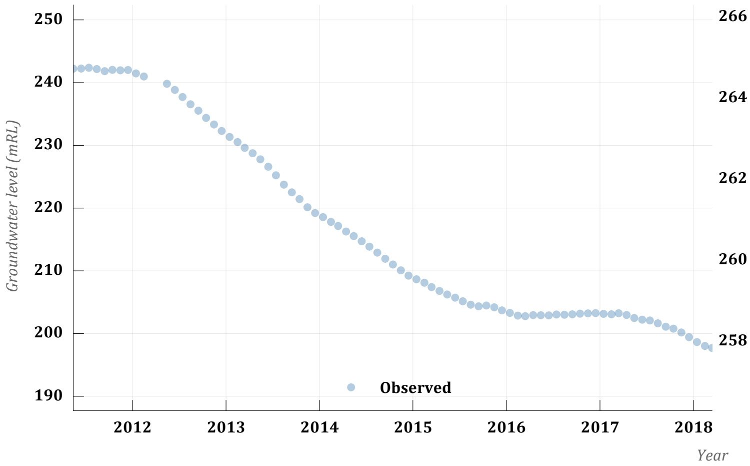

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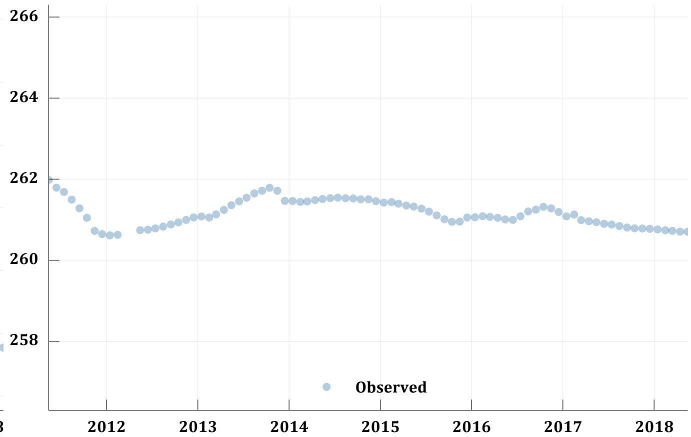

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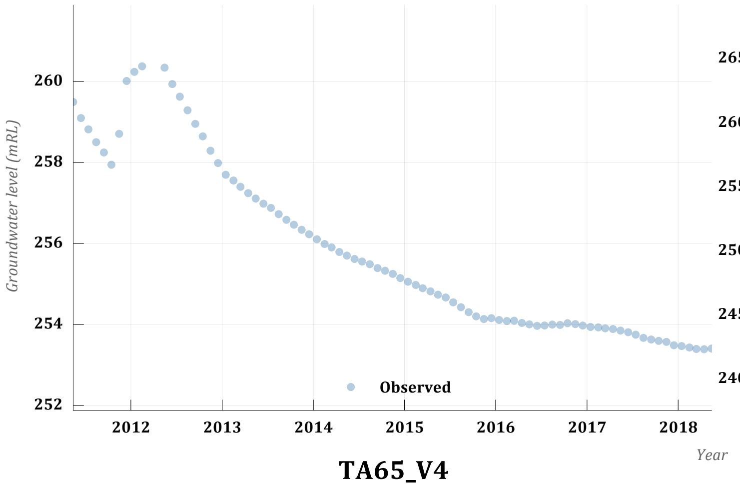

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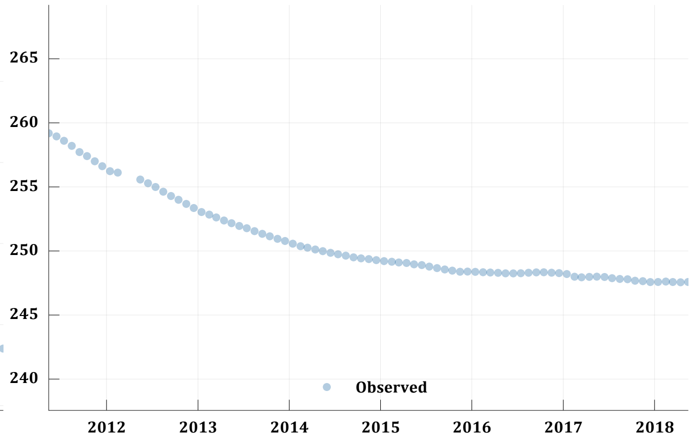

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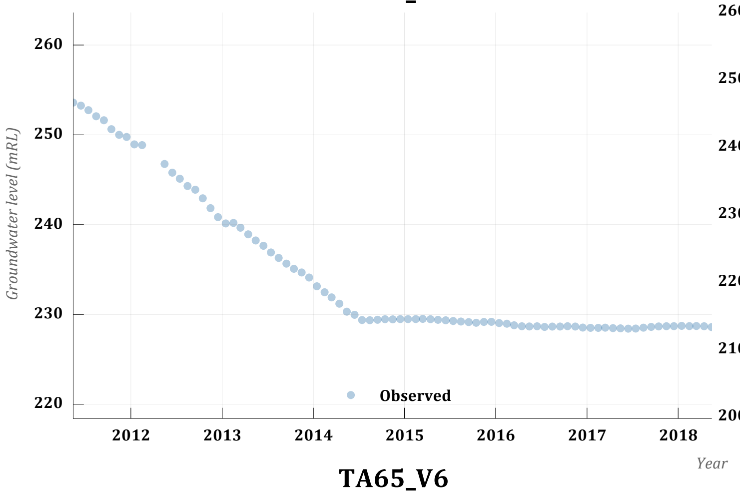

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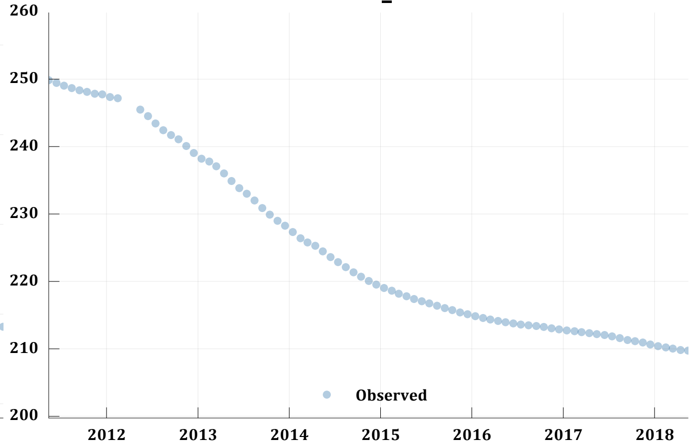

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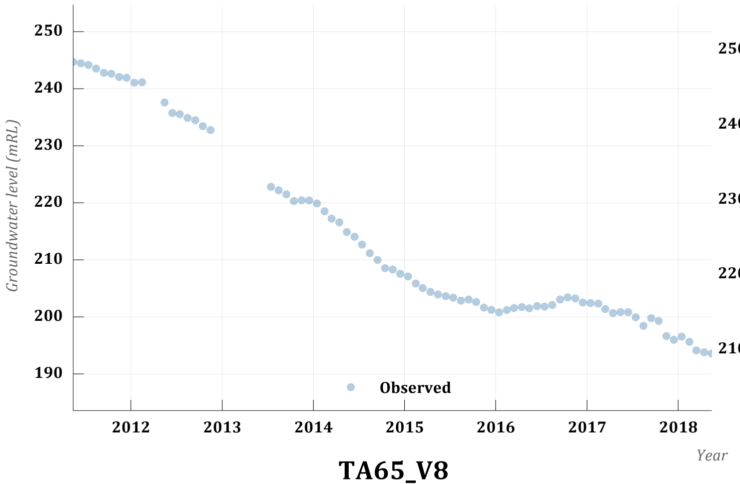

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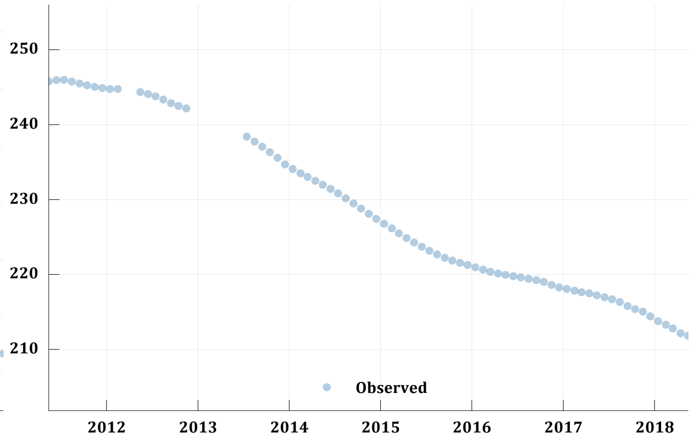

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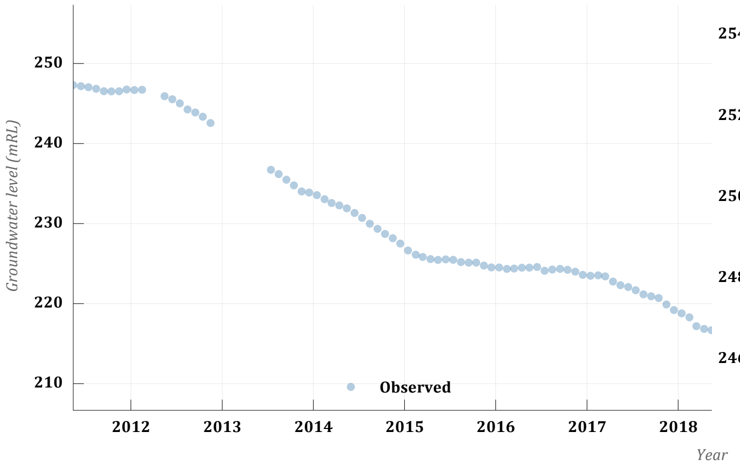

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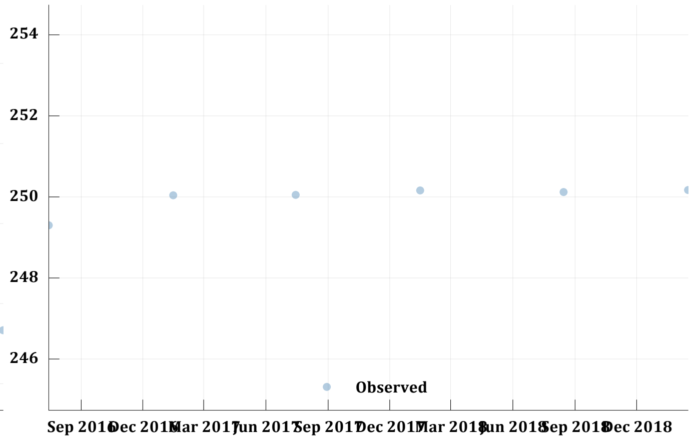
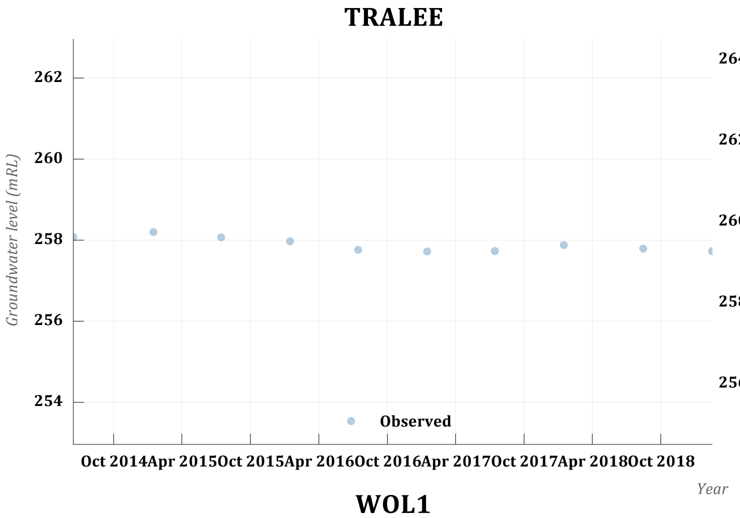
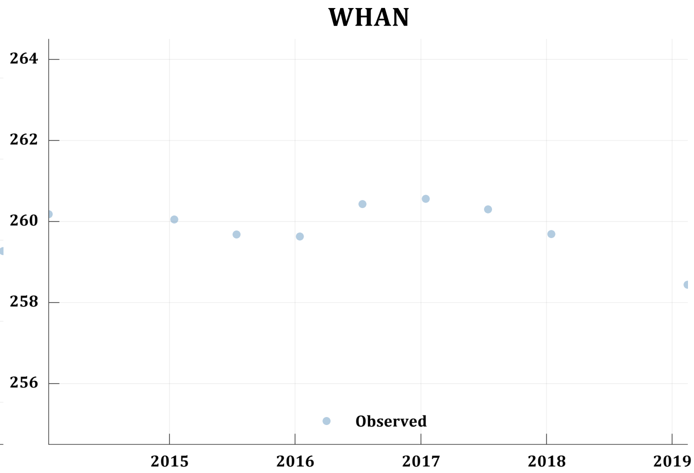
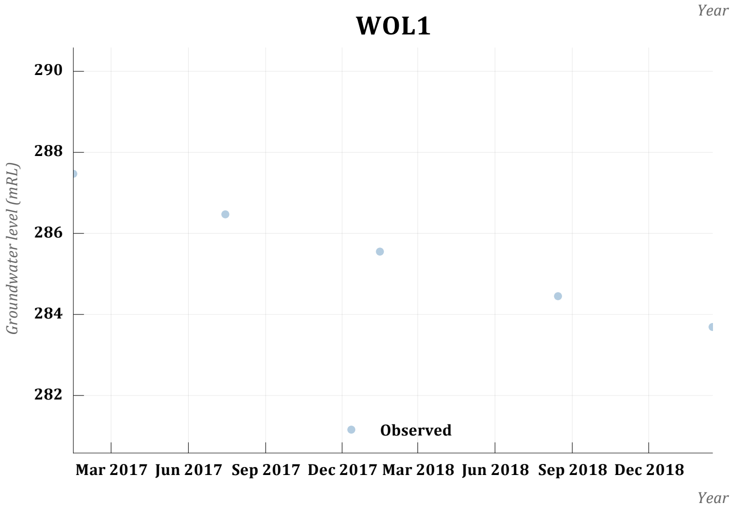


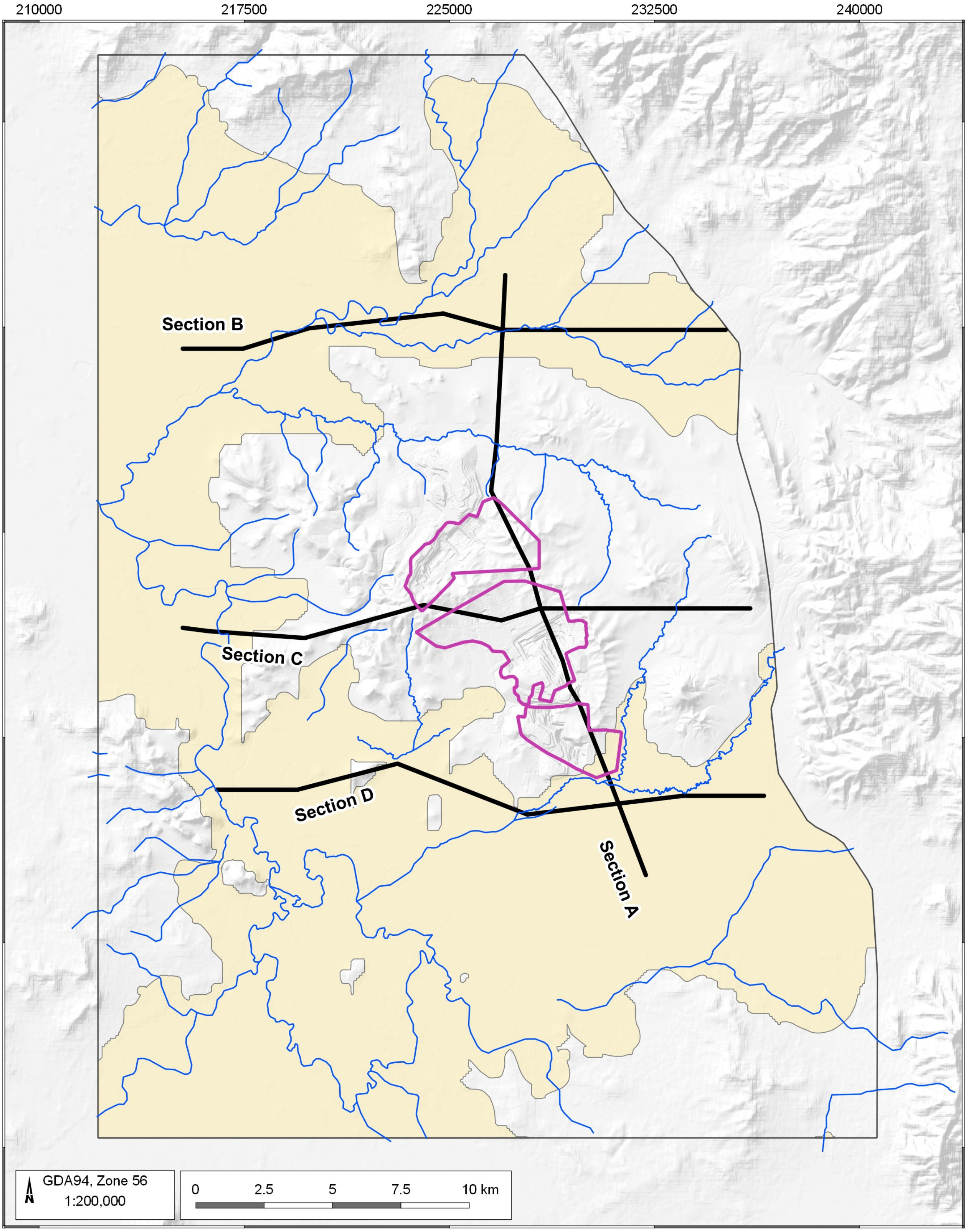

TRALEE
Groundwater level (mRL)
262
260
258
256
254
Observed
Oct 2014
Apr 2015
Oct 2015
Apr 2016
Oct 2016
Apr 2017
Oct 2017
Apr 2018
Oct 2018
Year


WHAN
264
262
260
258
256
Observed
2015
2016
2017
2018
2019


WOL1
Groundwater level (mRL)
290
288
286
284
282
Observed
Mar 2017
Jun 2017
Sep 2017
Dec 2017
Mar 2018
Jun 2018
Sep 2018
Dec 2018
Year

Appendix D

Cross sections



LEGEND

- Drainage
- Cross section
- Mine outline
- Model extent
- Alluvium extent

BTM Complex Groundwater Model Update (G1850P)

Location of cross-sections

AGE

DATE 30/08/2021

FIGURE No: **D 1**

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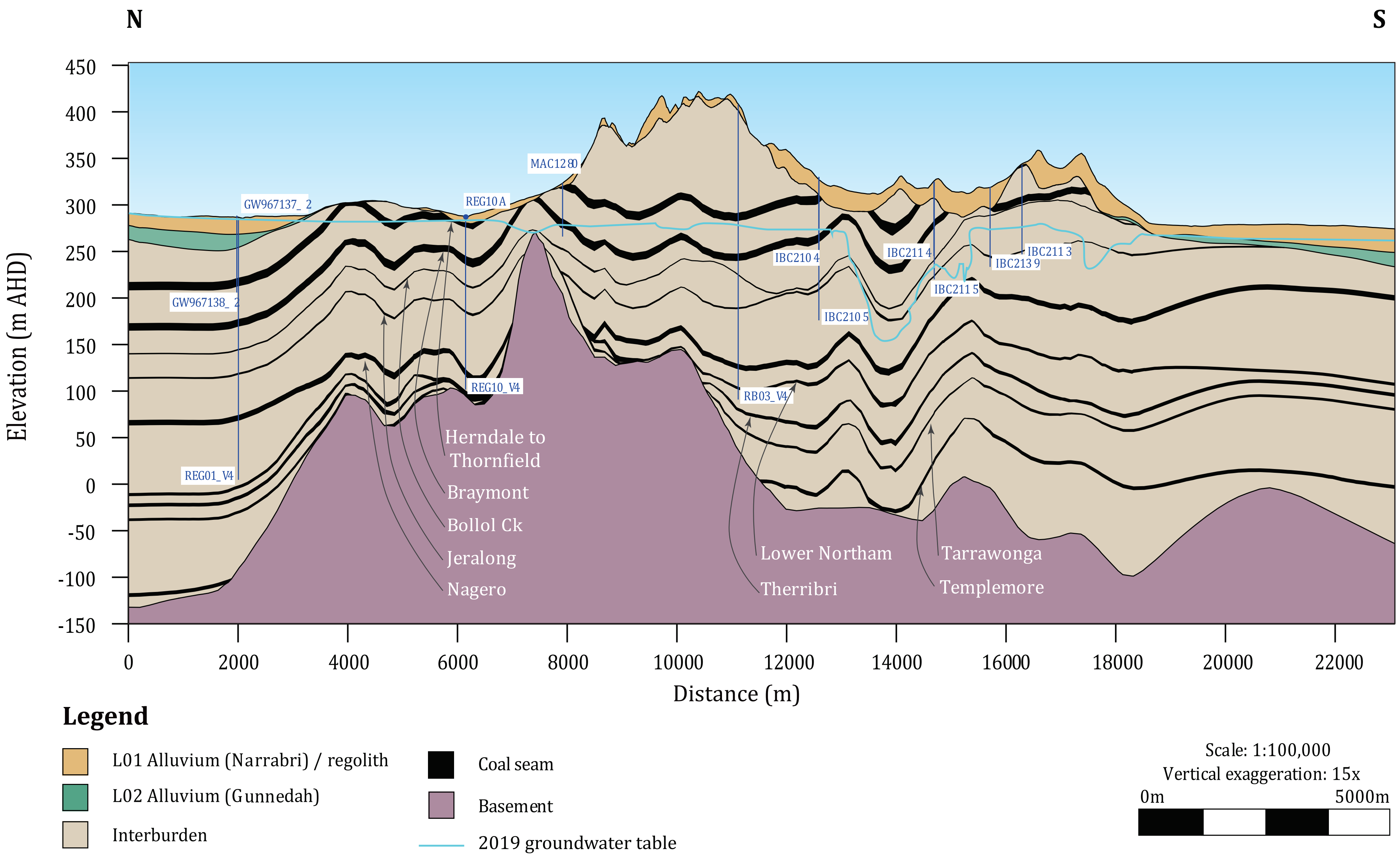
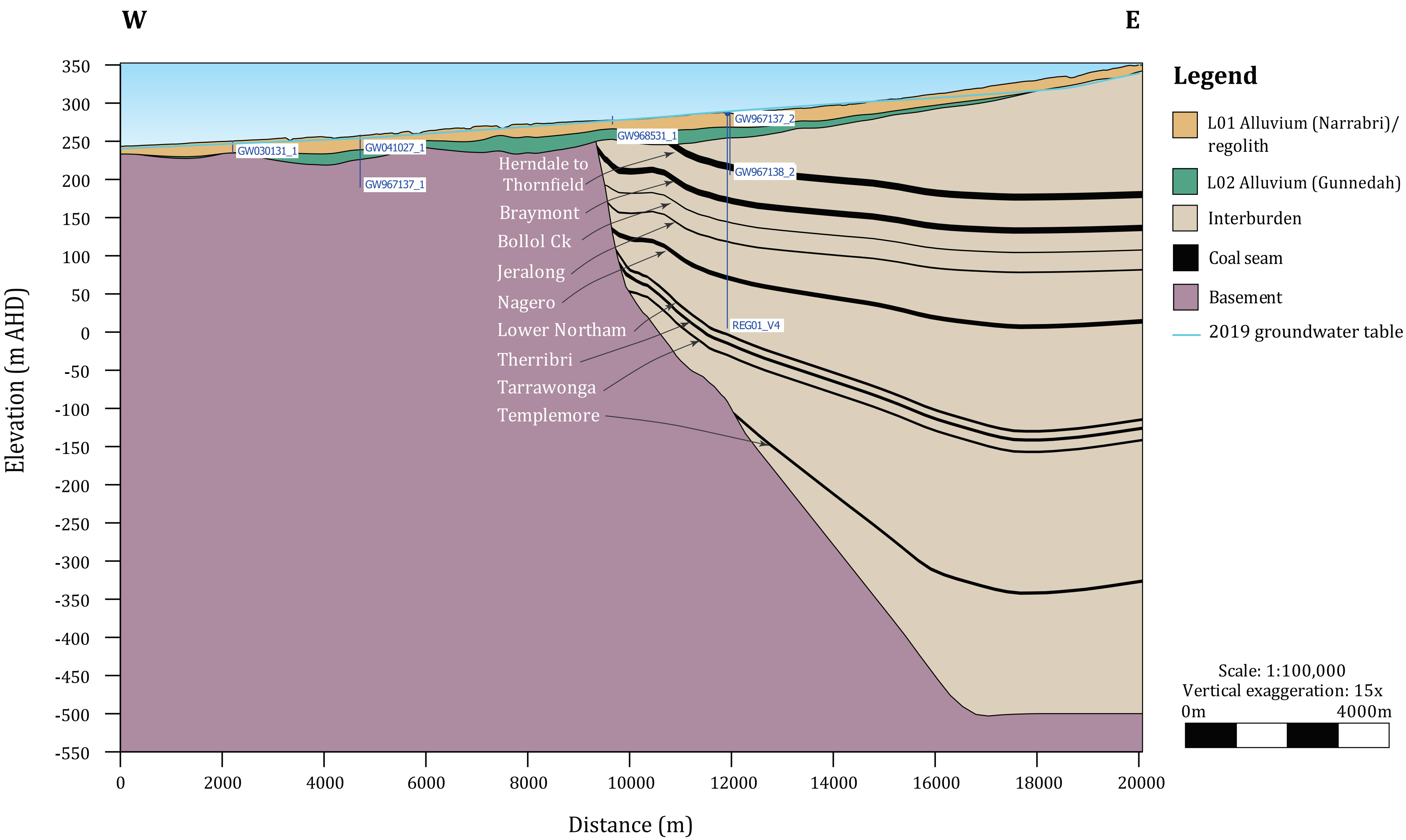
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\001_model_update_report\D 01_G1850_Location of cross sections.qgs



Cross-section A (North to South) with 2019 groundwater table

Figure D 2

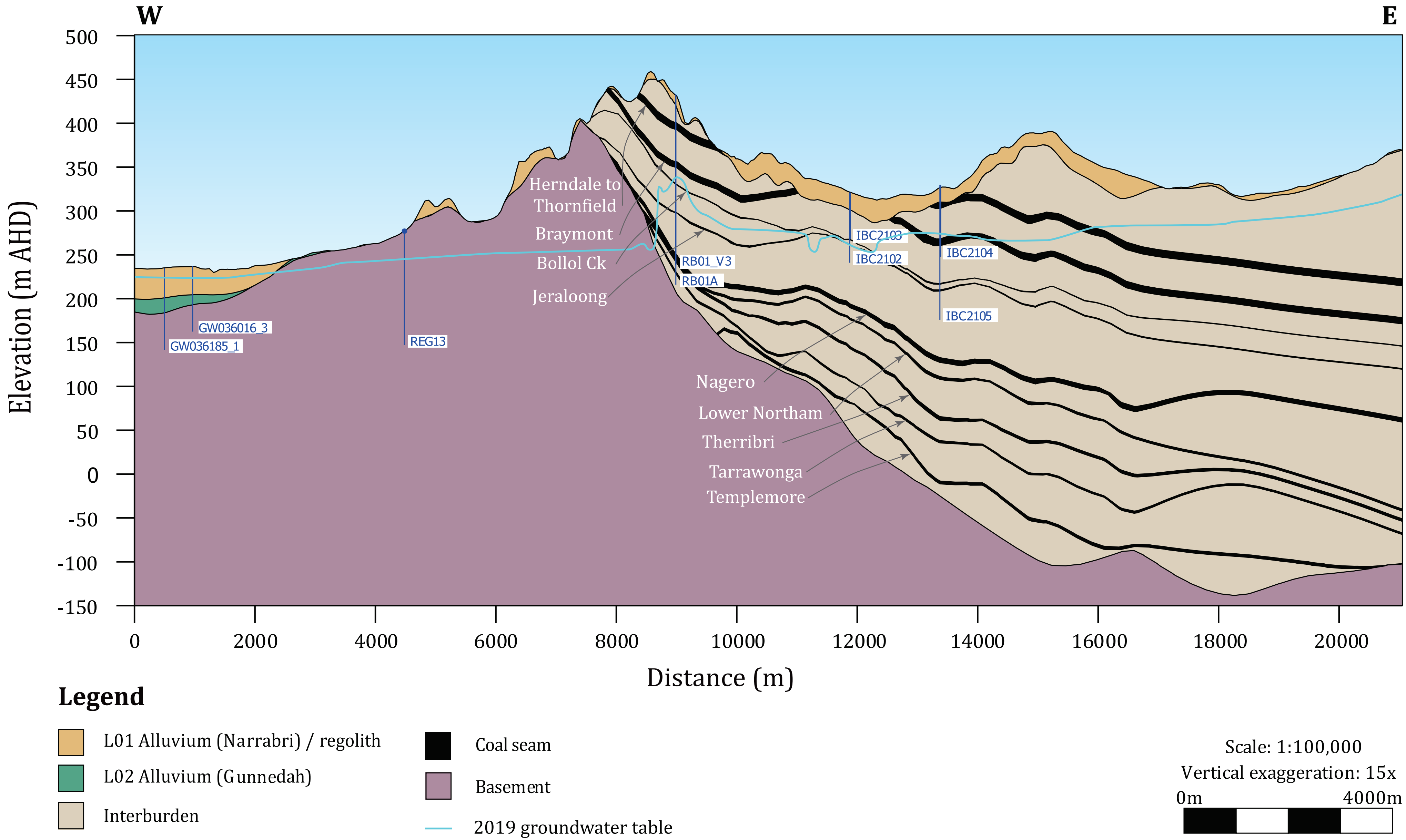
BTM model update (G1850P)



Cross-section B (West to East) with 2019 groundwater table

Figure D 3

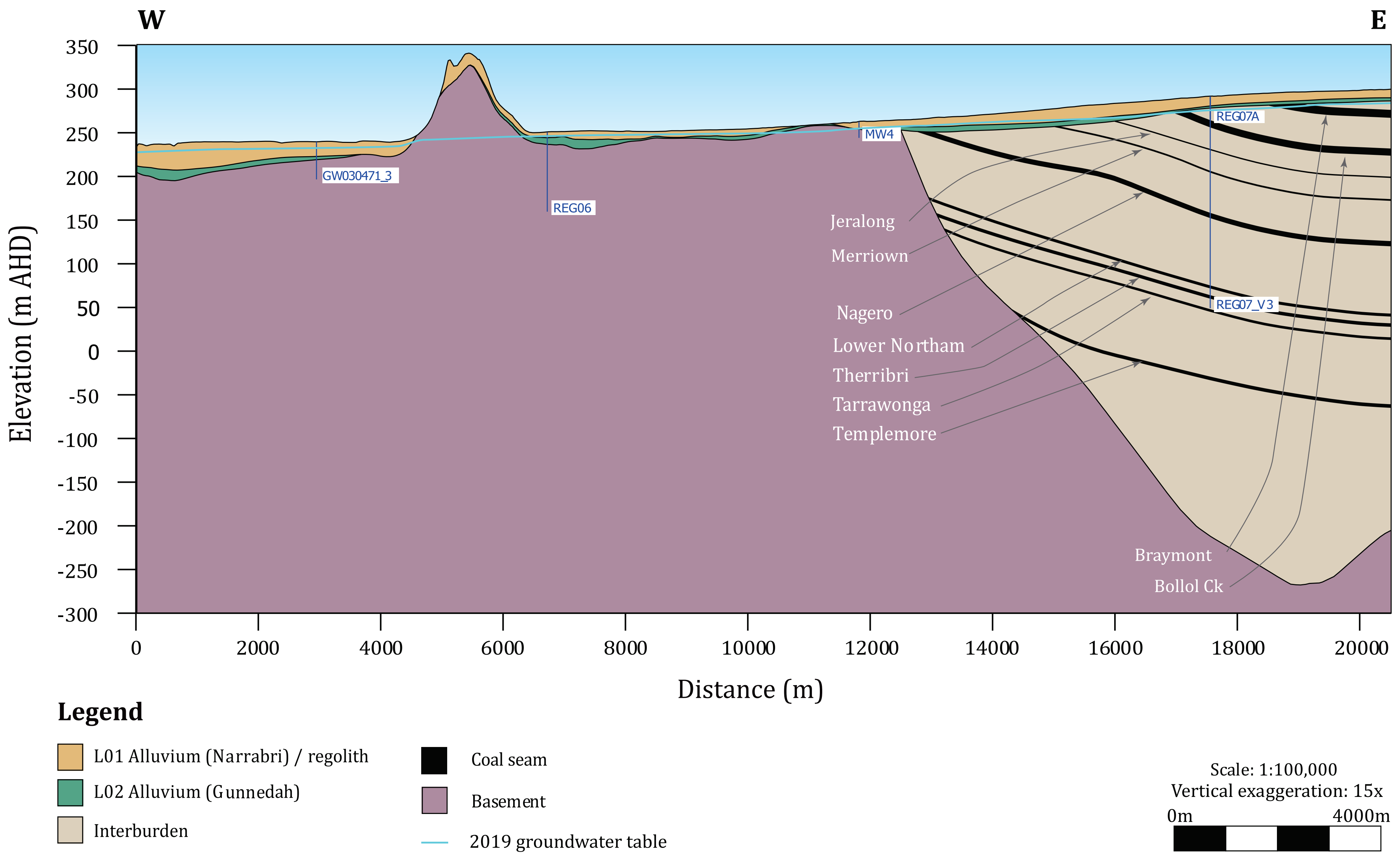
BTM model update (G1850P)



Cross-section C (West to East) with 2019 groundwater table

Figure D 4

BTM model update (G1850P)



Cross-section D (West to East) with 2019 groundwater table

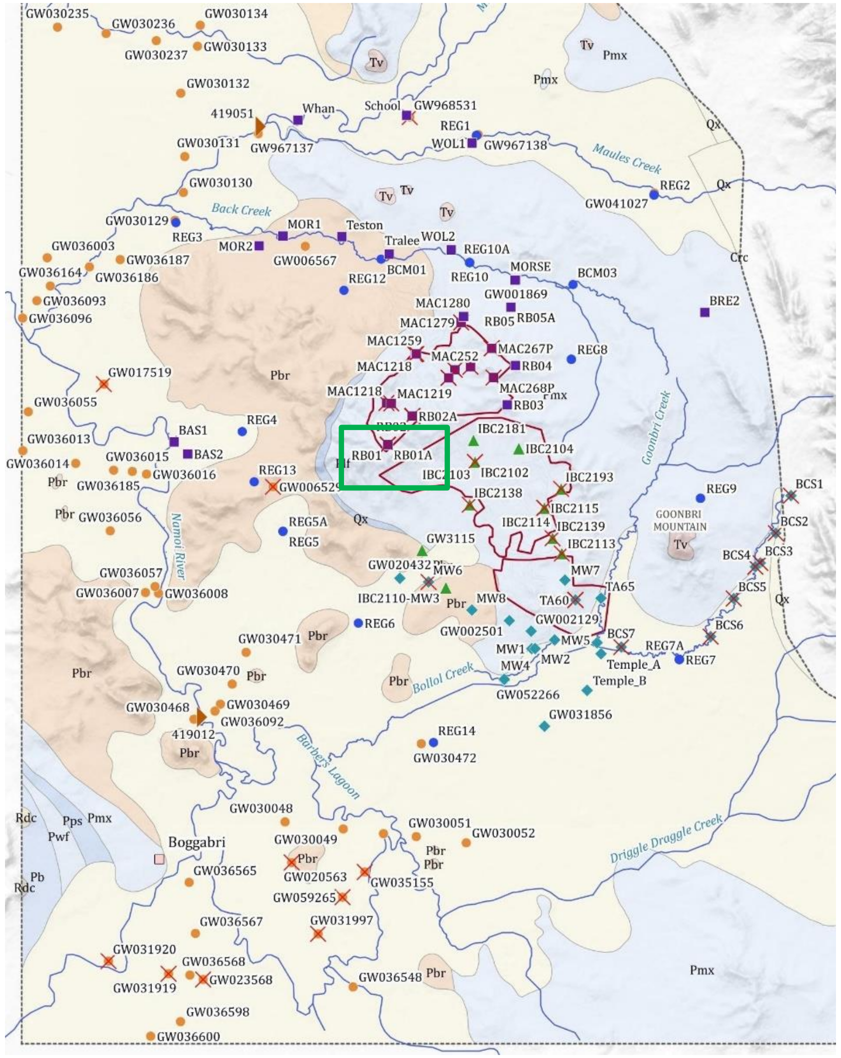
Figure D 5

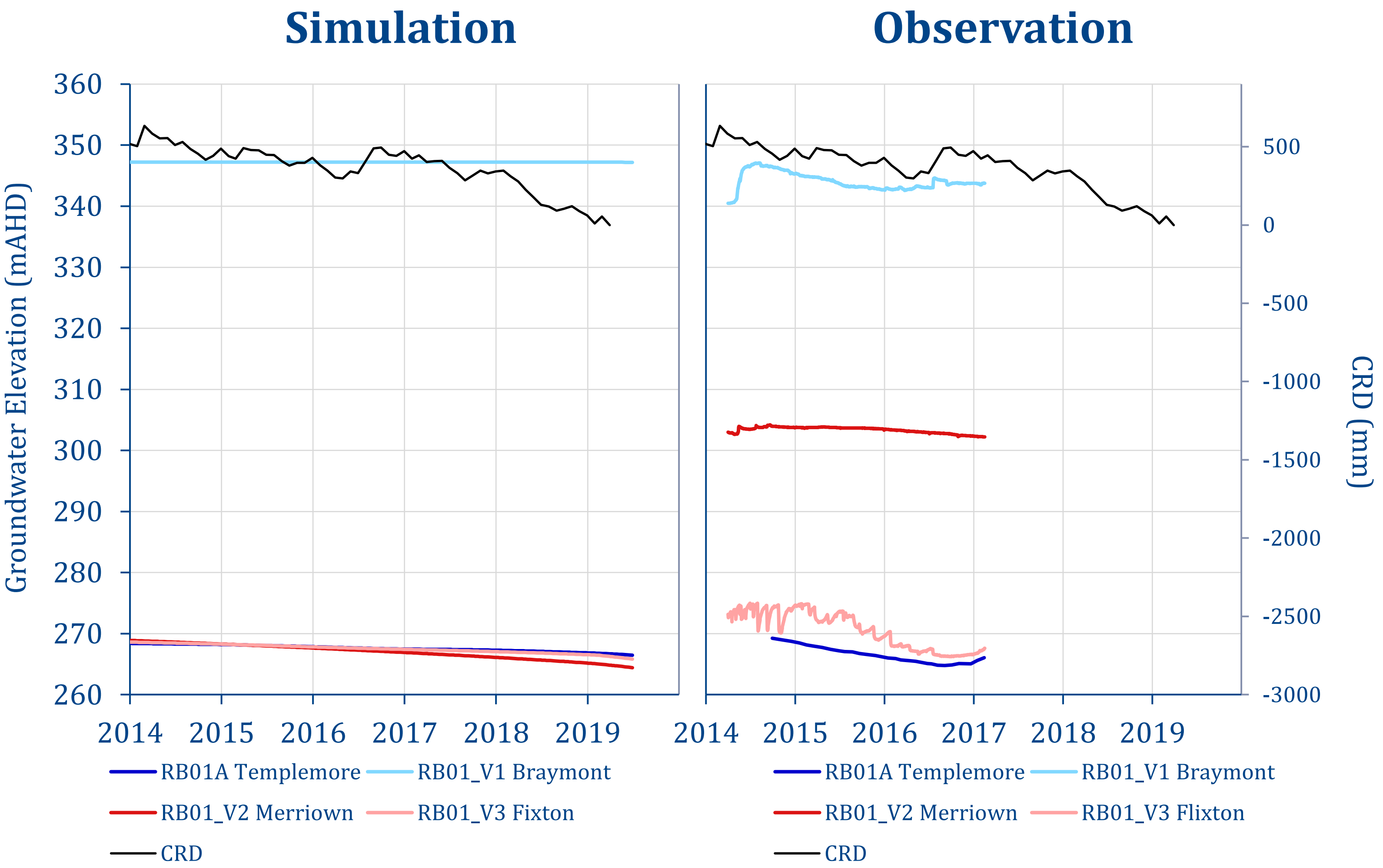
BTM model update (G1850P)

Appendix E

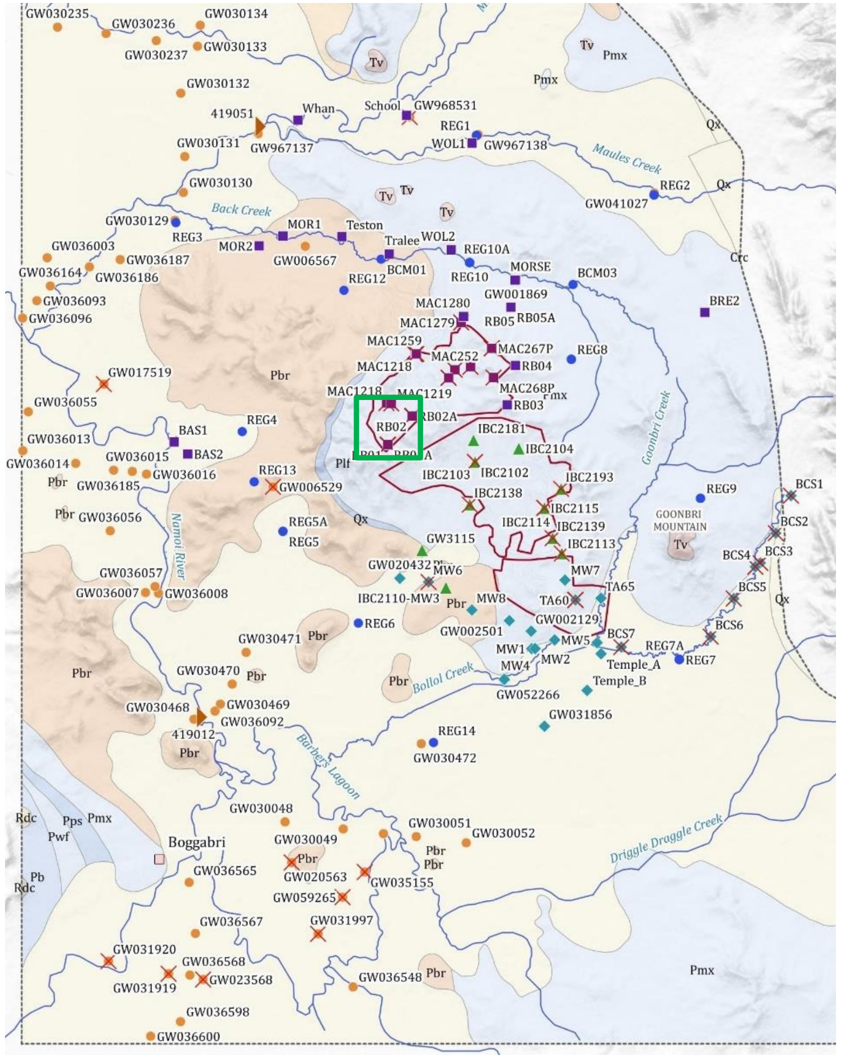
Observed and simulated groundwater levels

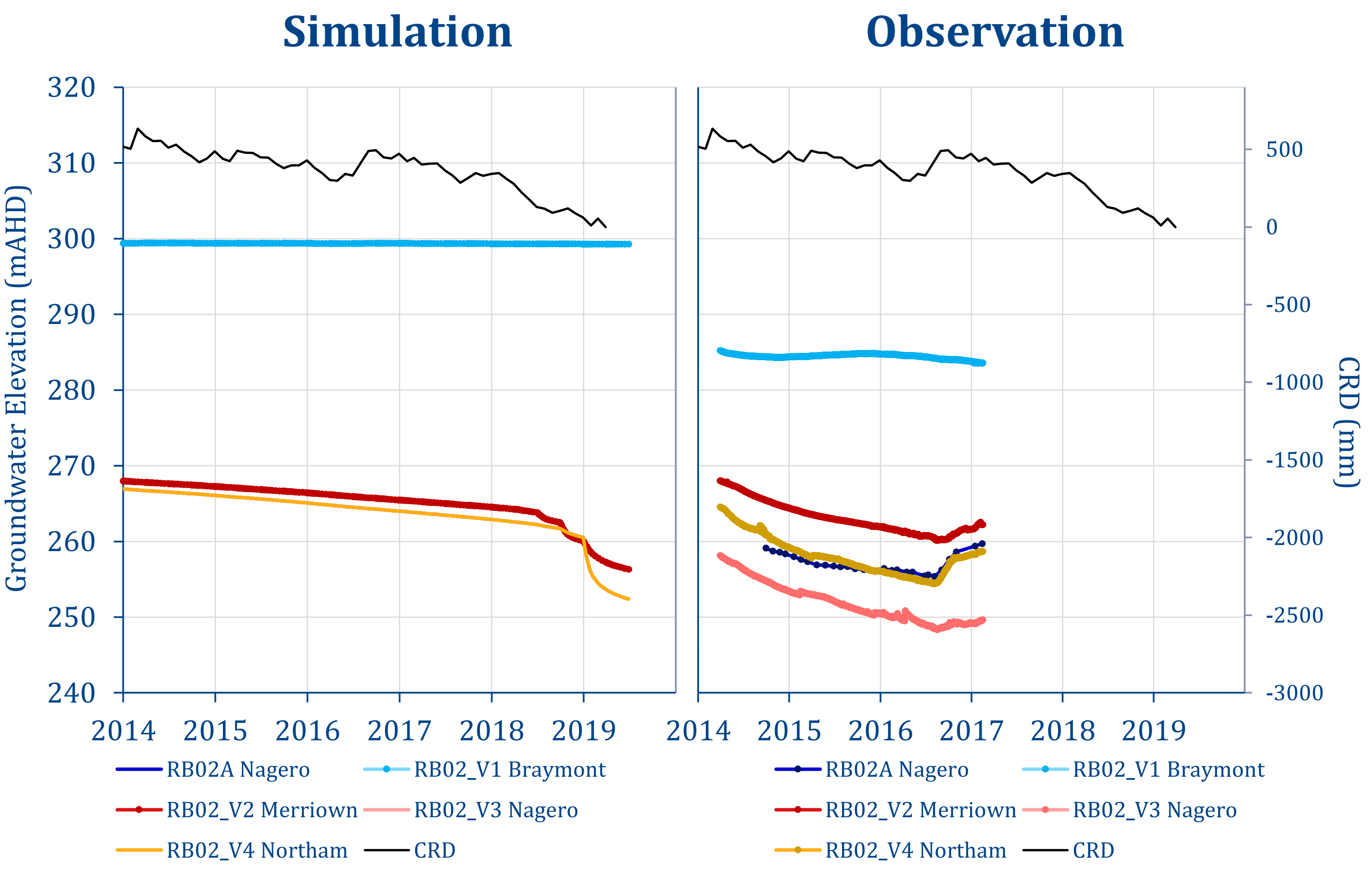
RB01 - Permian



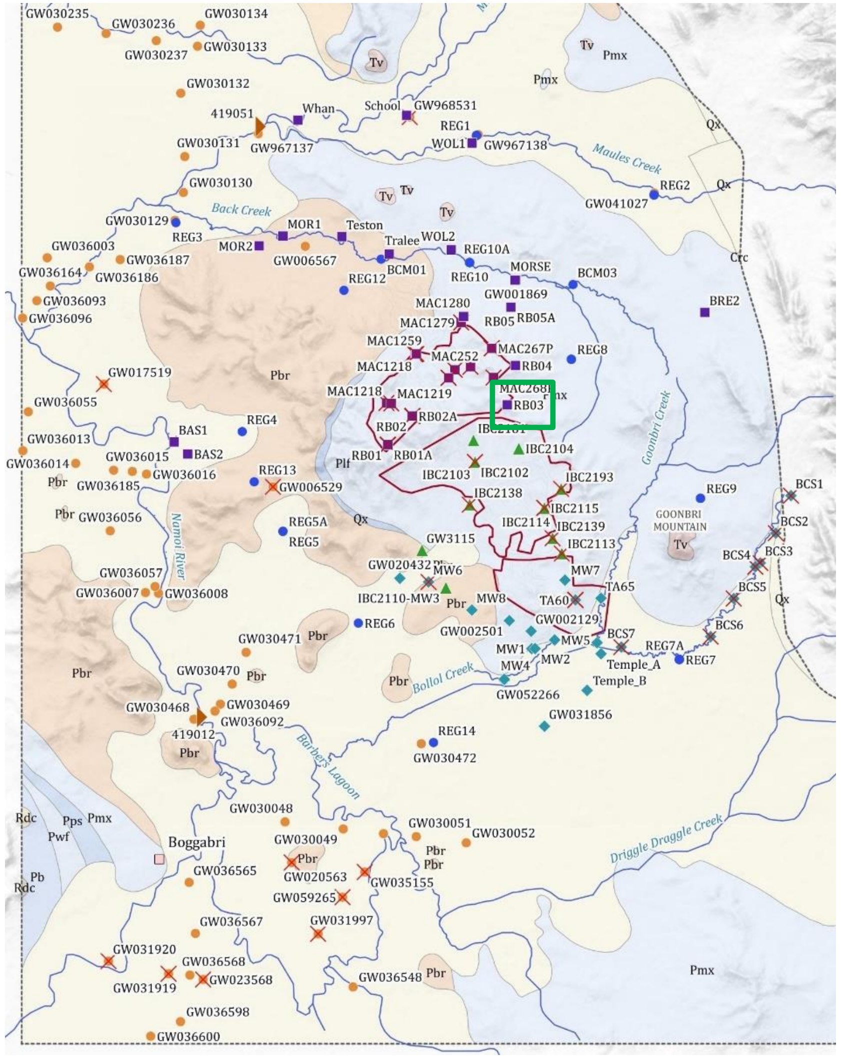


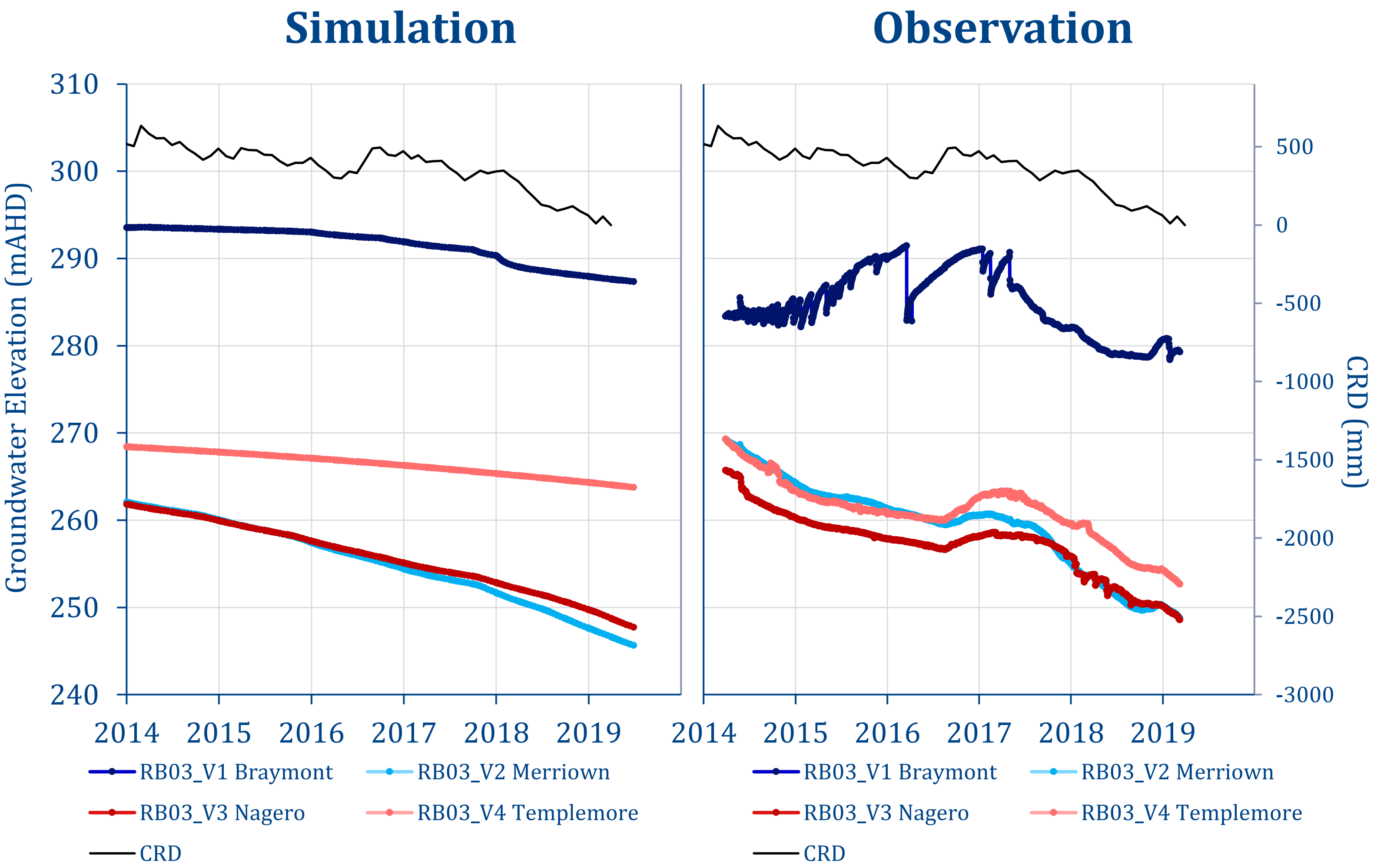
RB02 - Permian



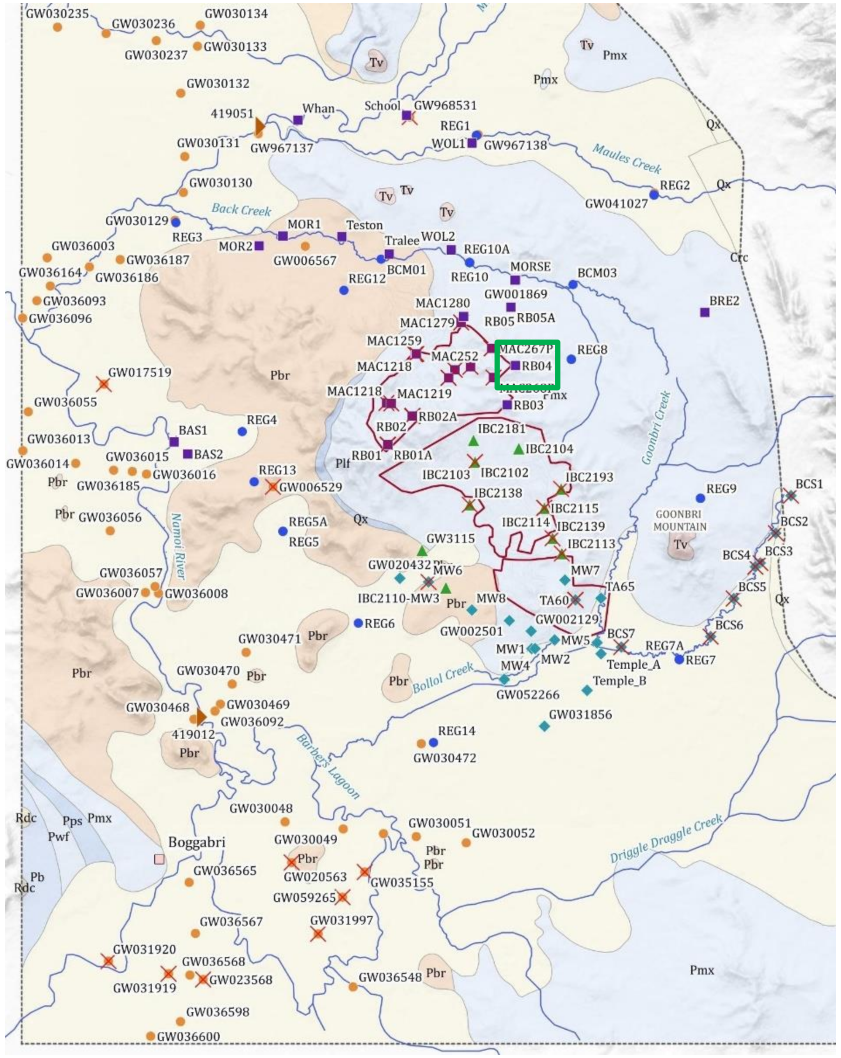


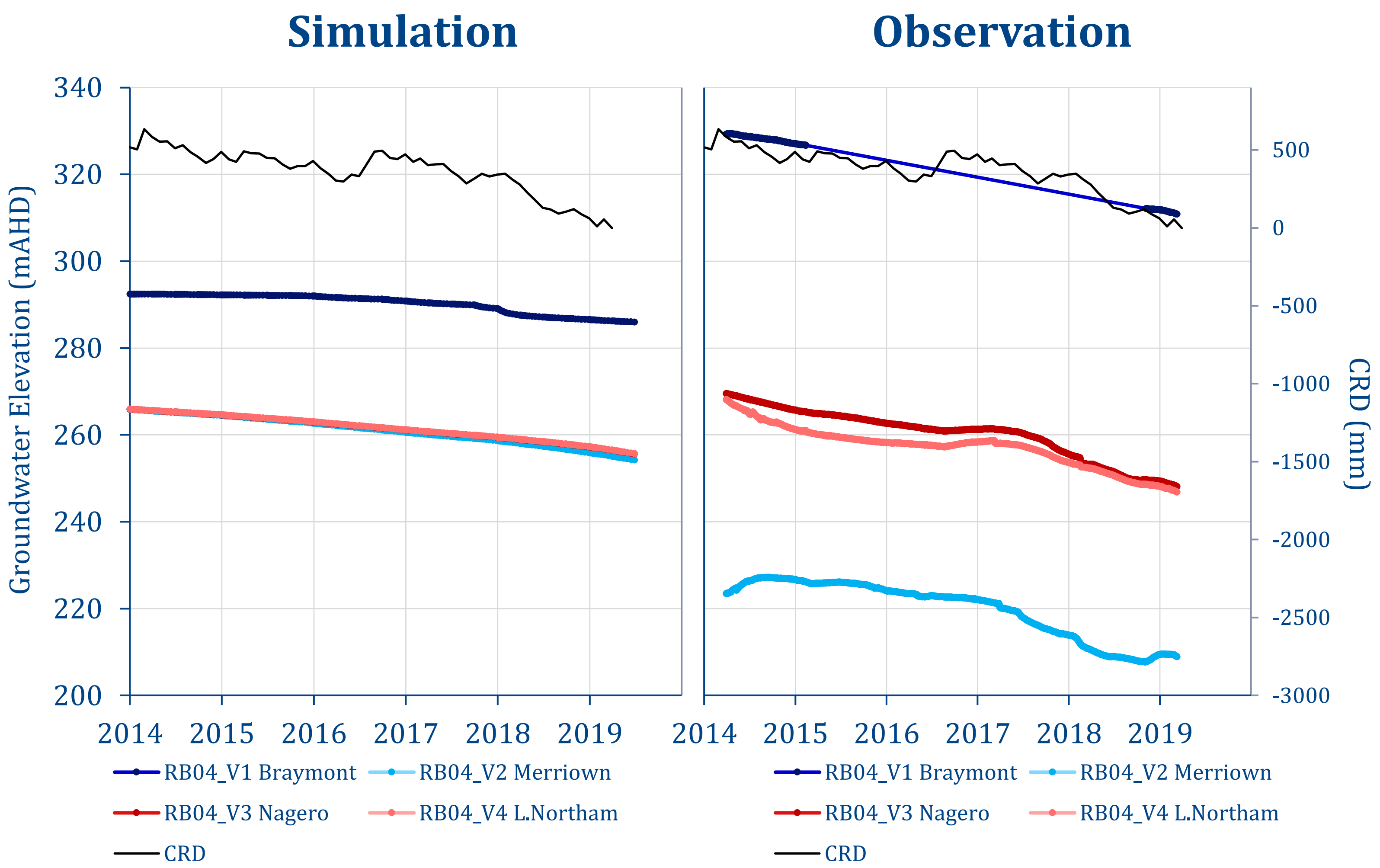
RB03 - Permian





RB04 - Permian





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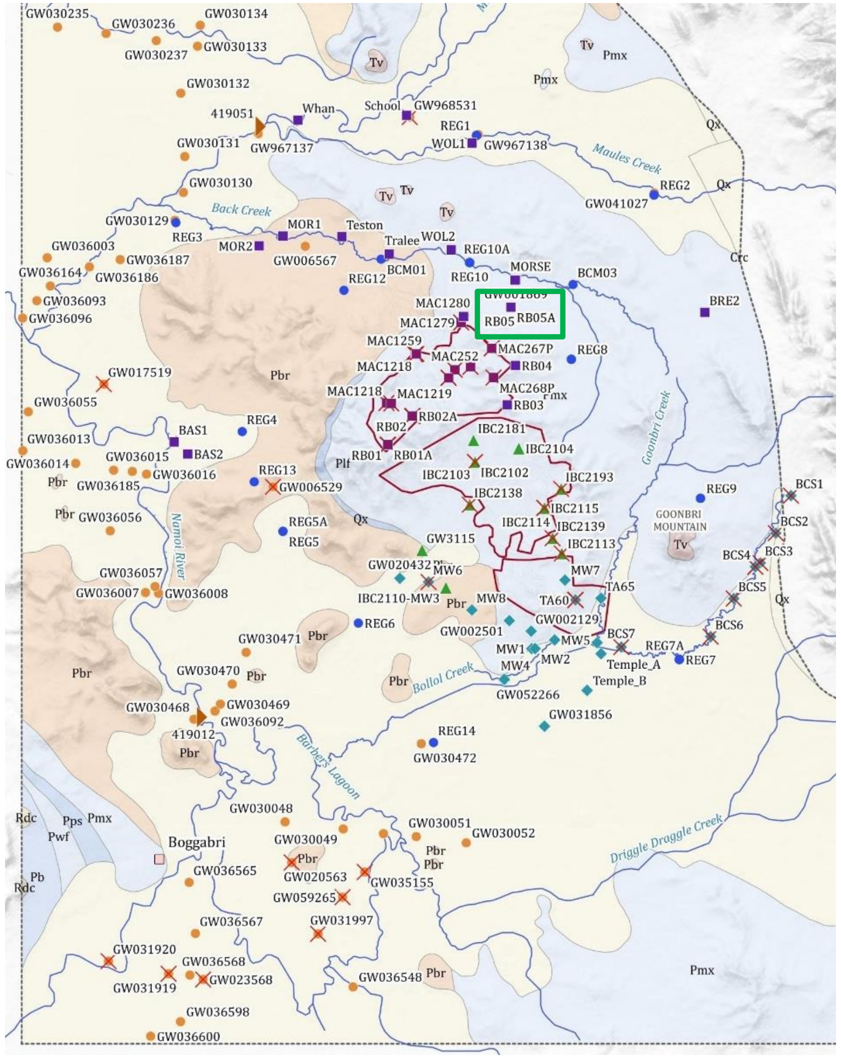
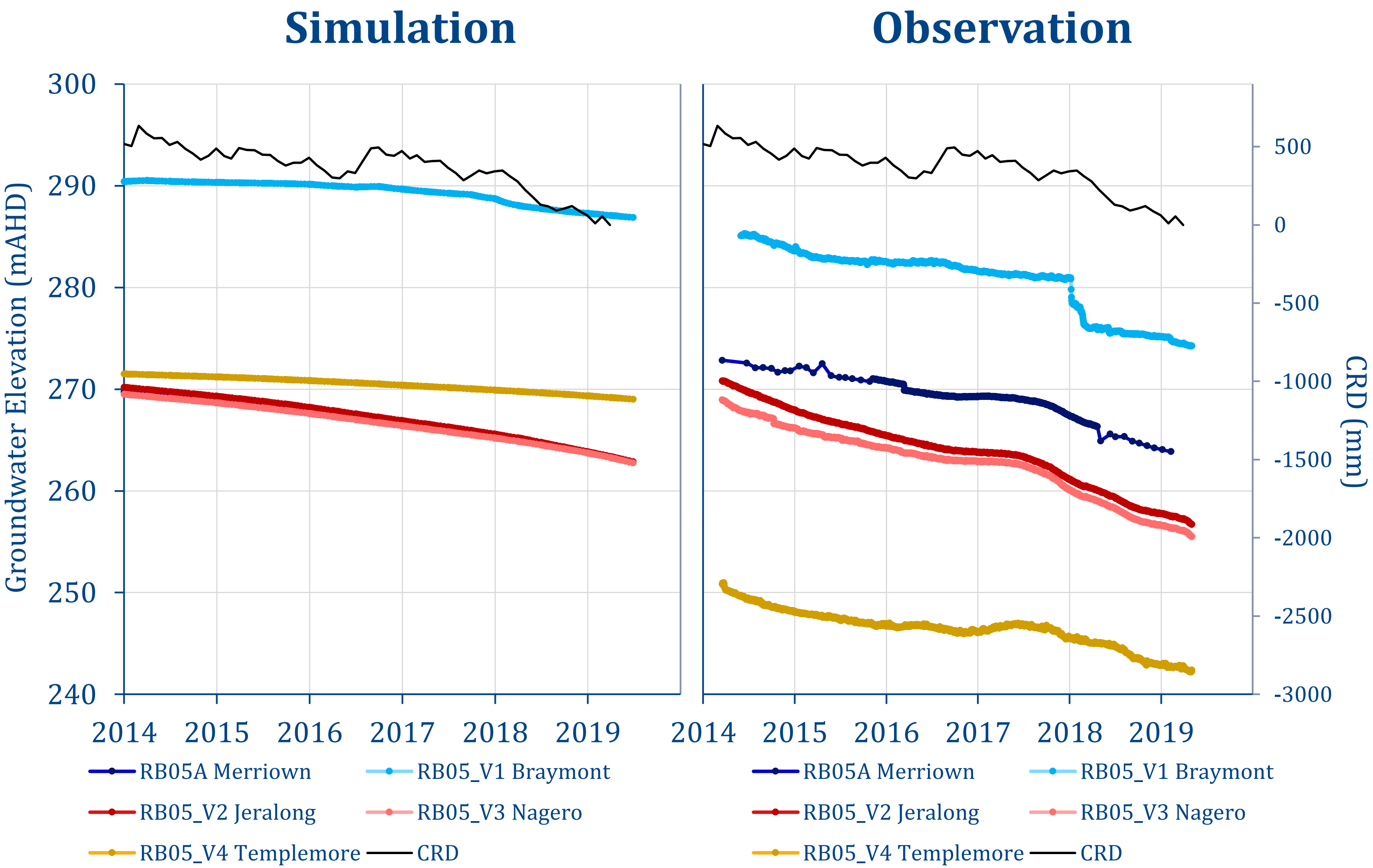
RB05 - Permian





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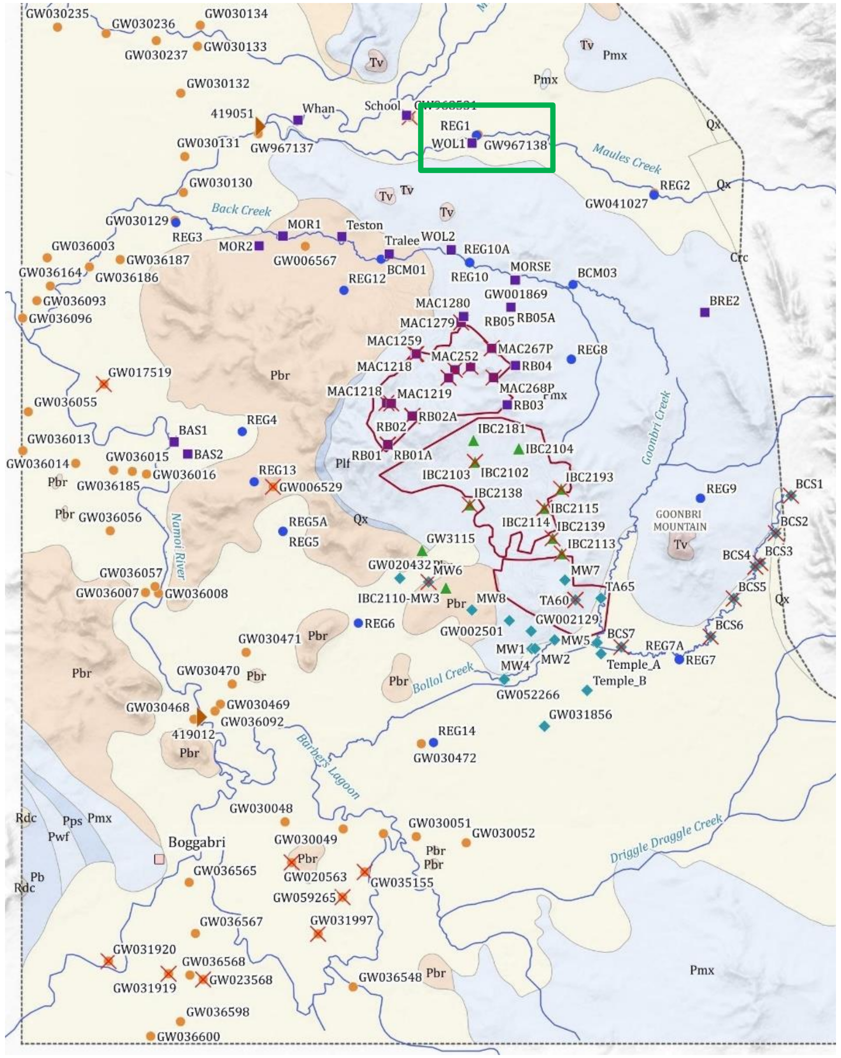
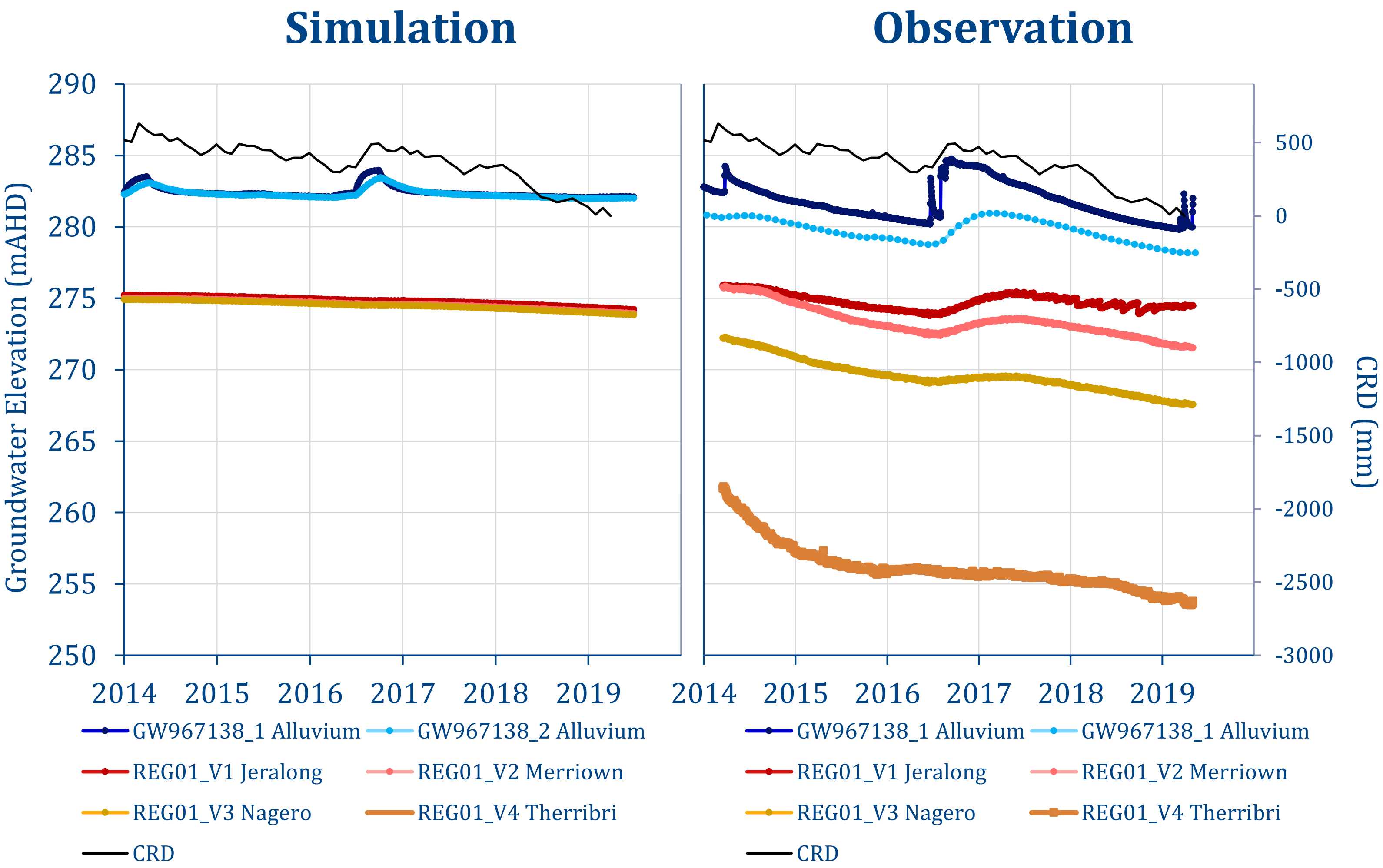
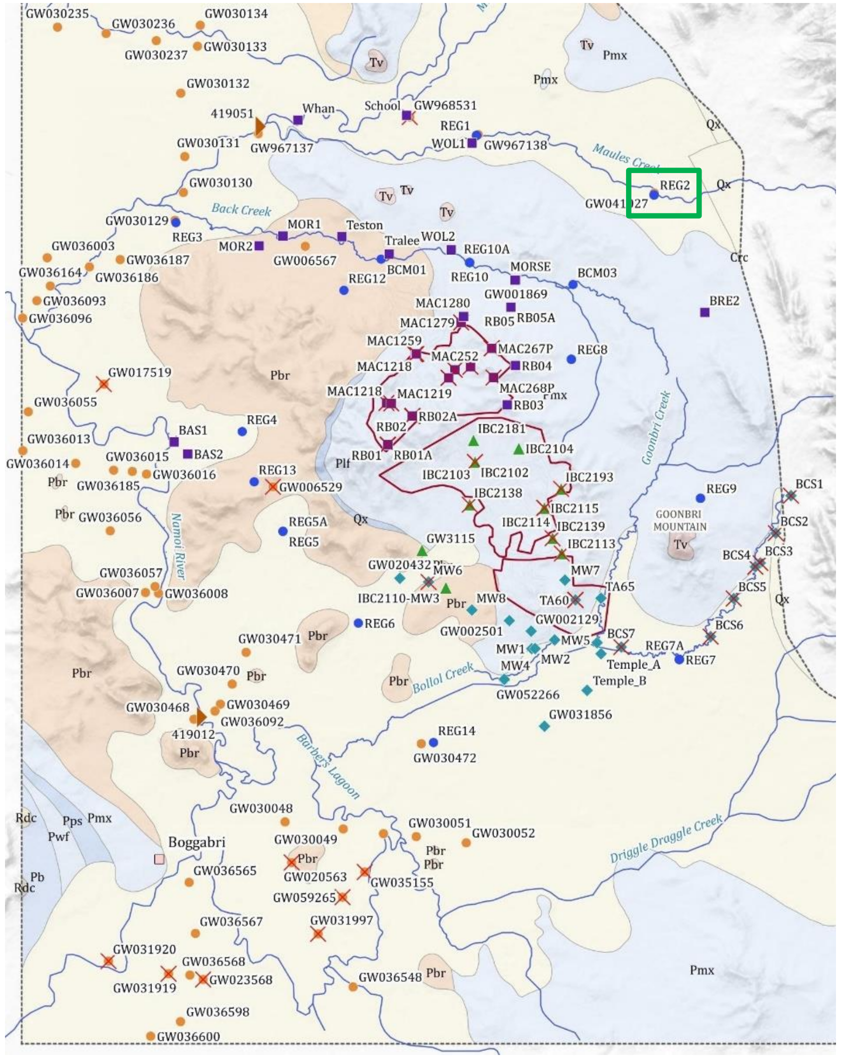
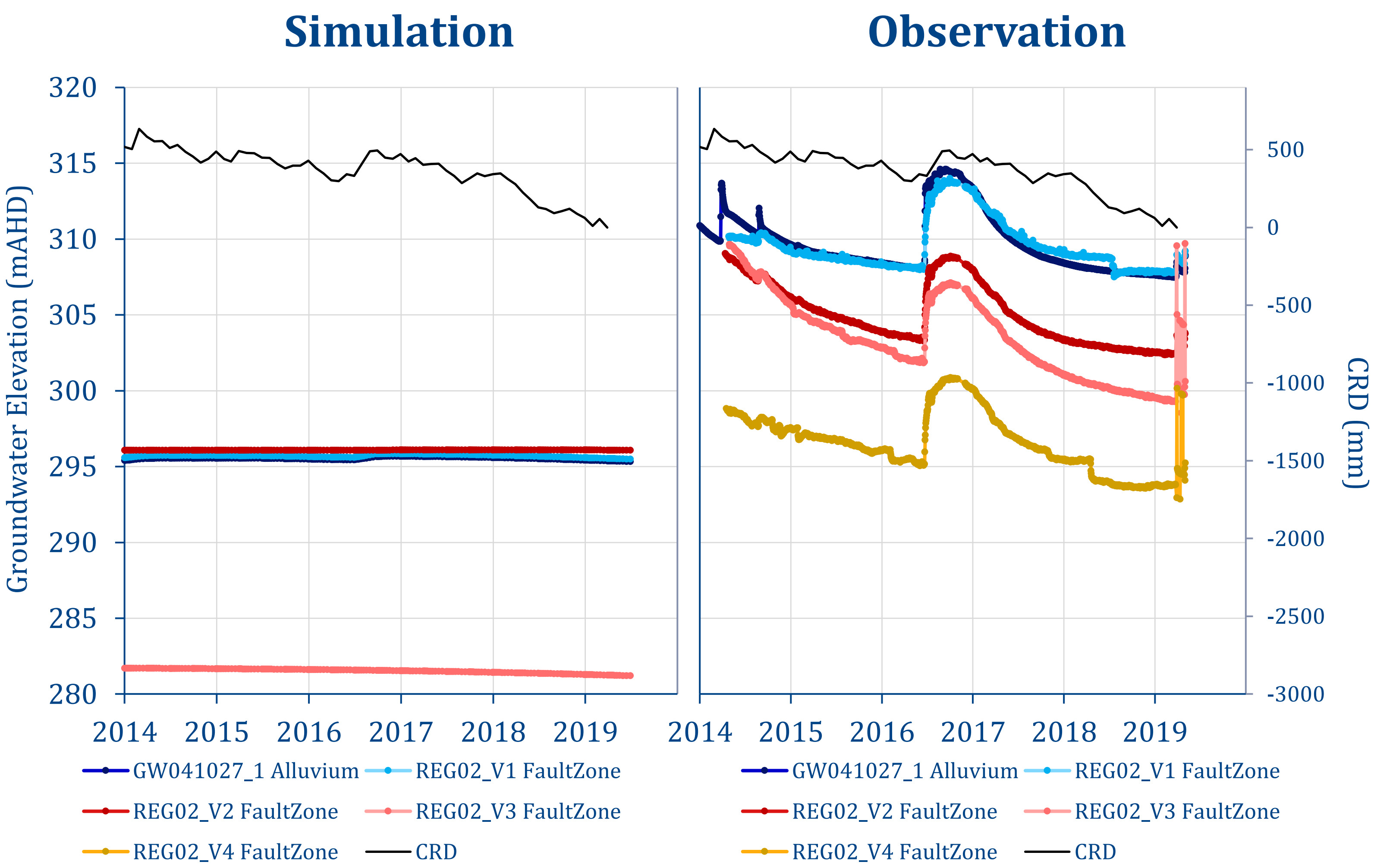
REG01 - Permian



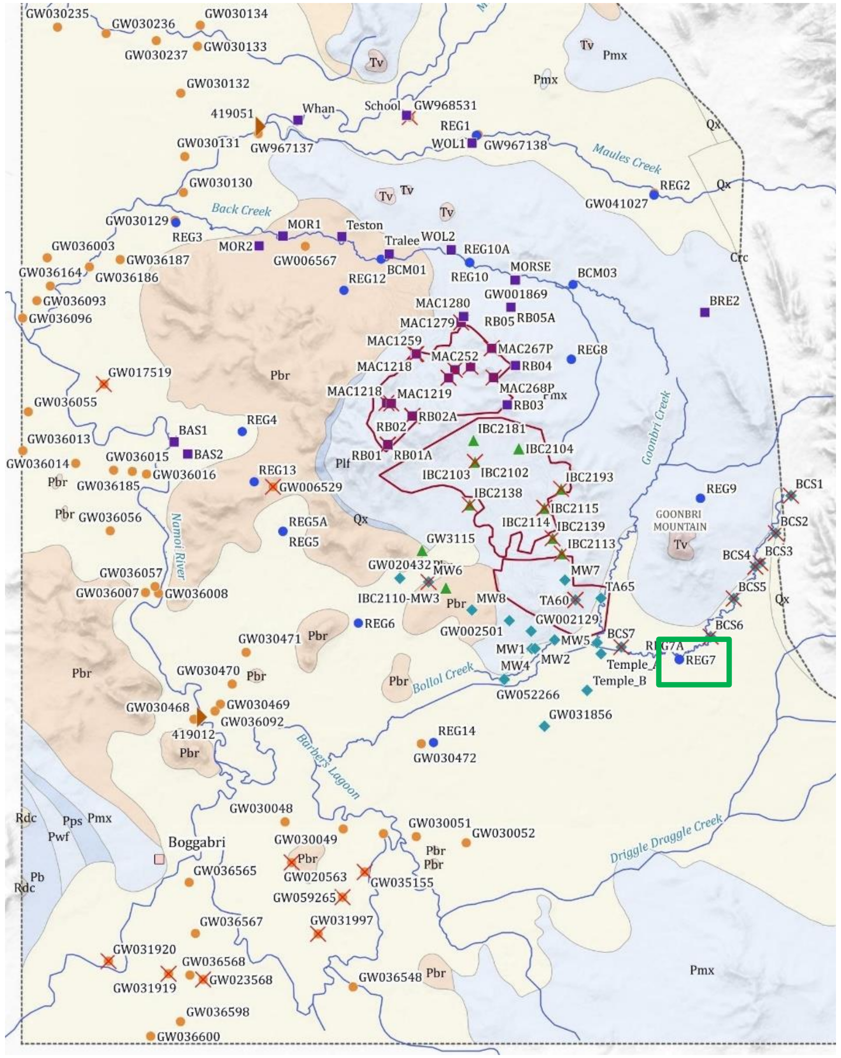


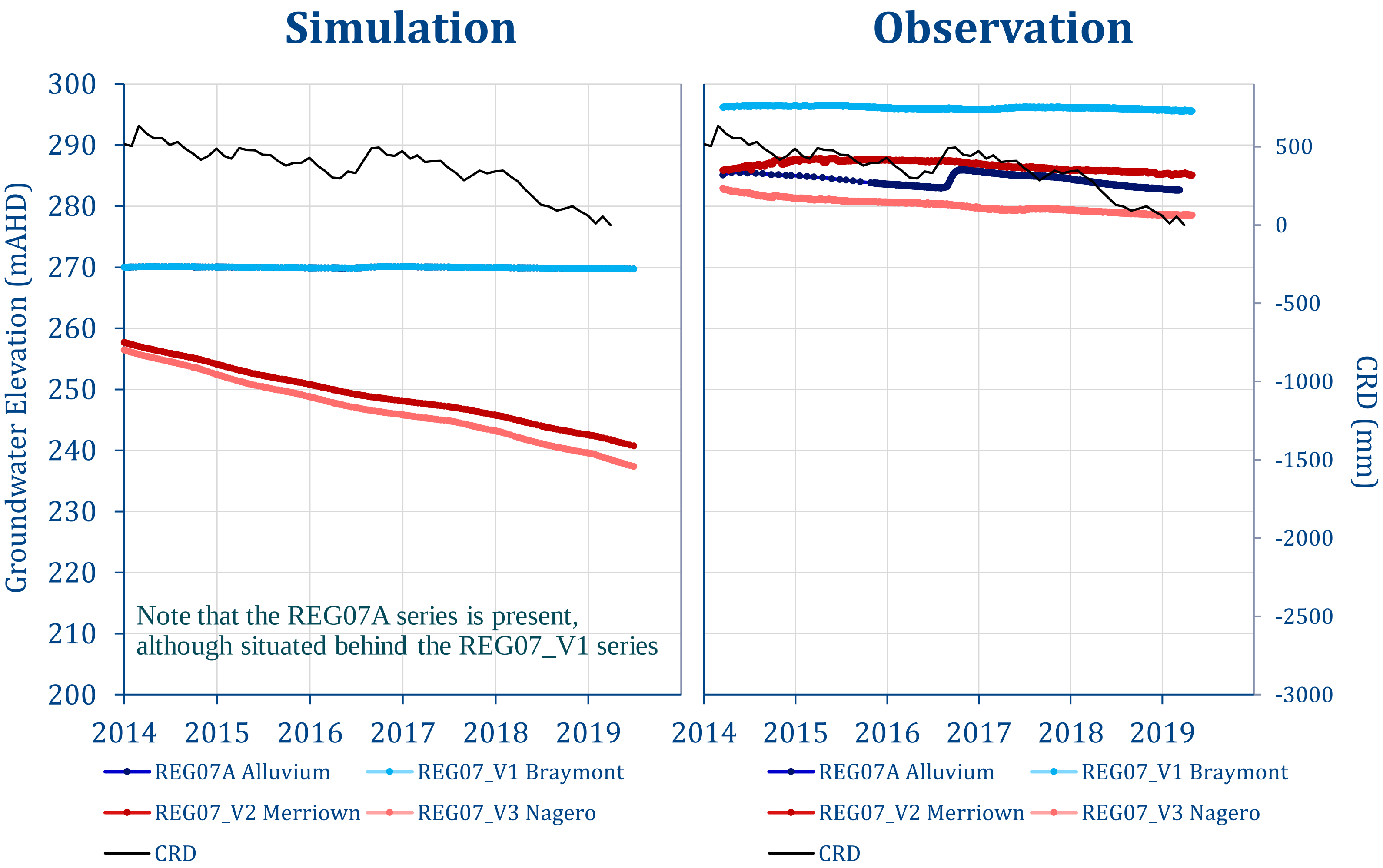
REG02 - Permian





REG07 - Permian





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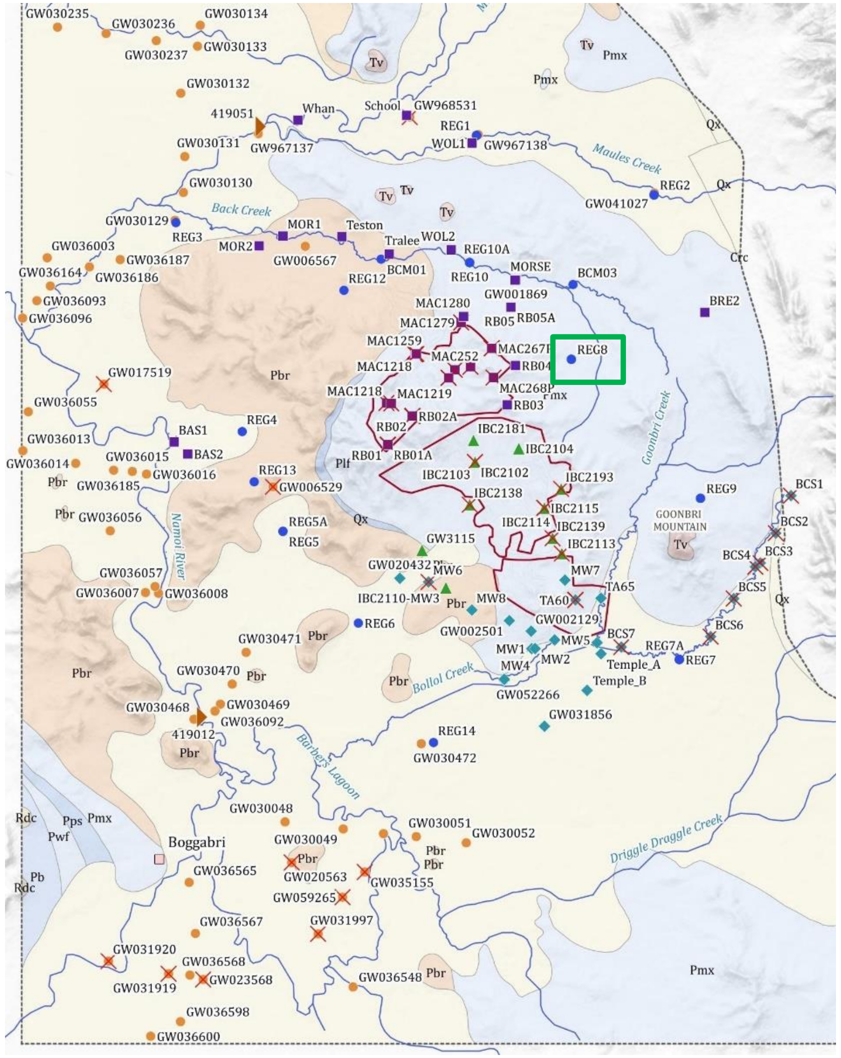
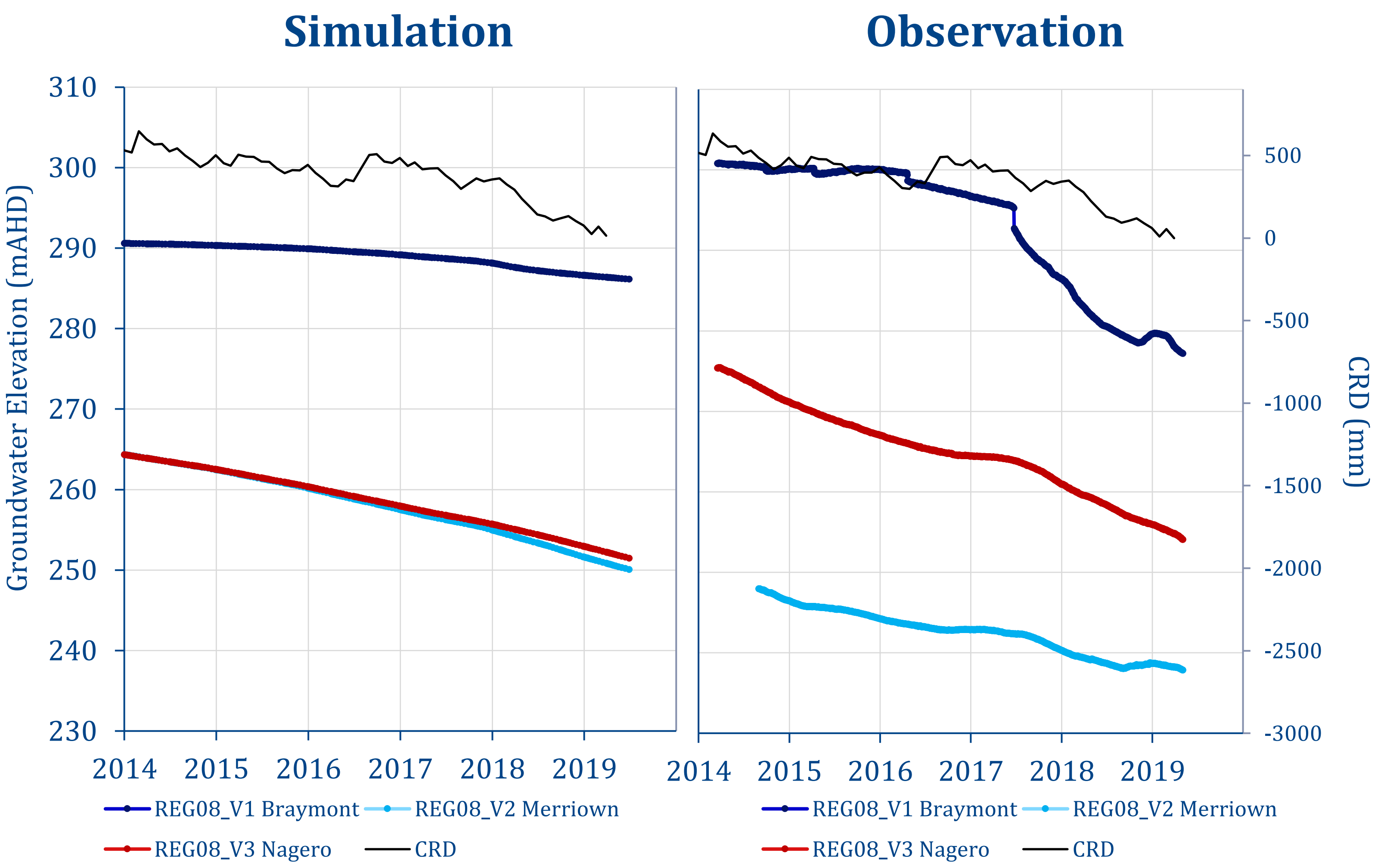
REG08 - Permian





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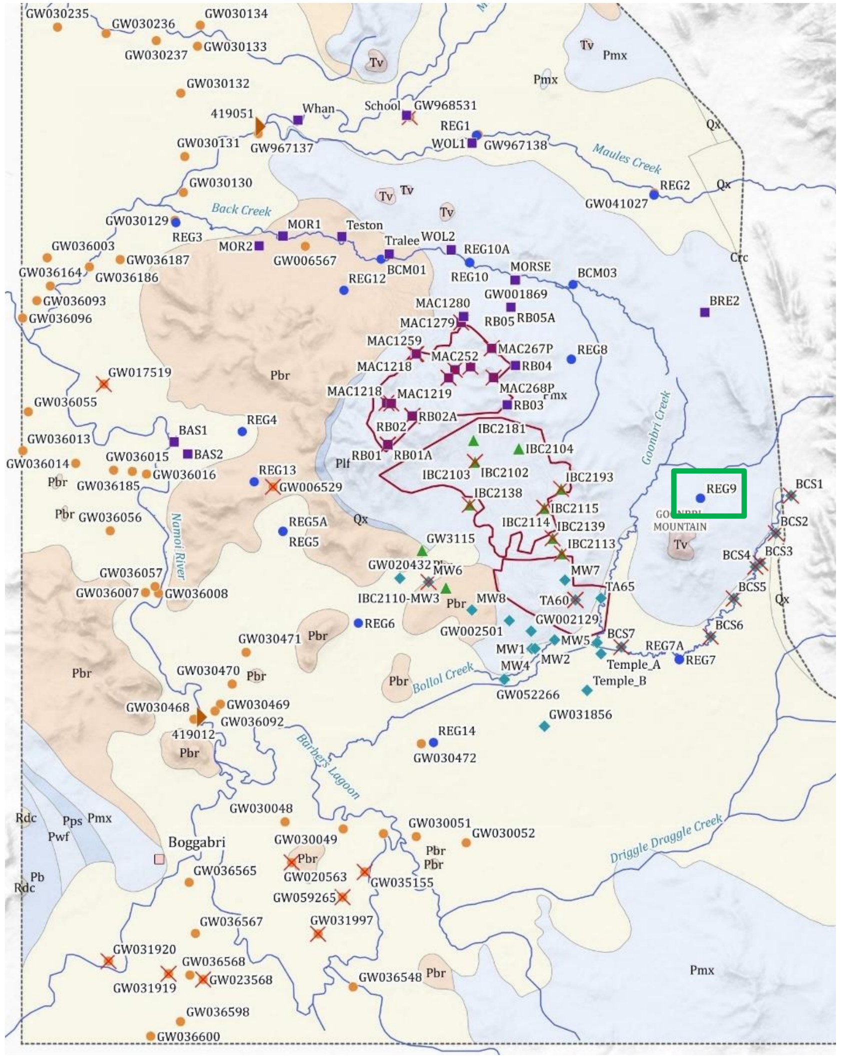
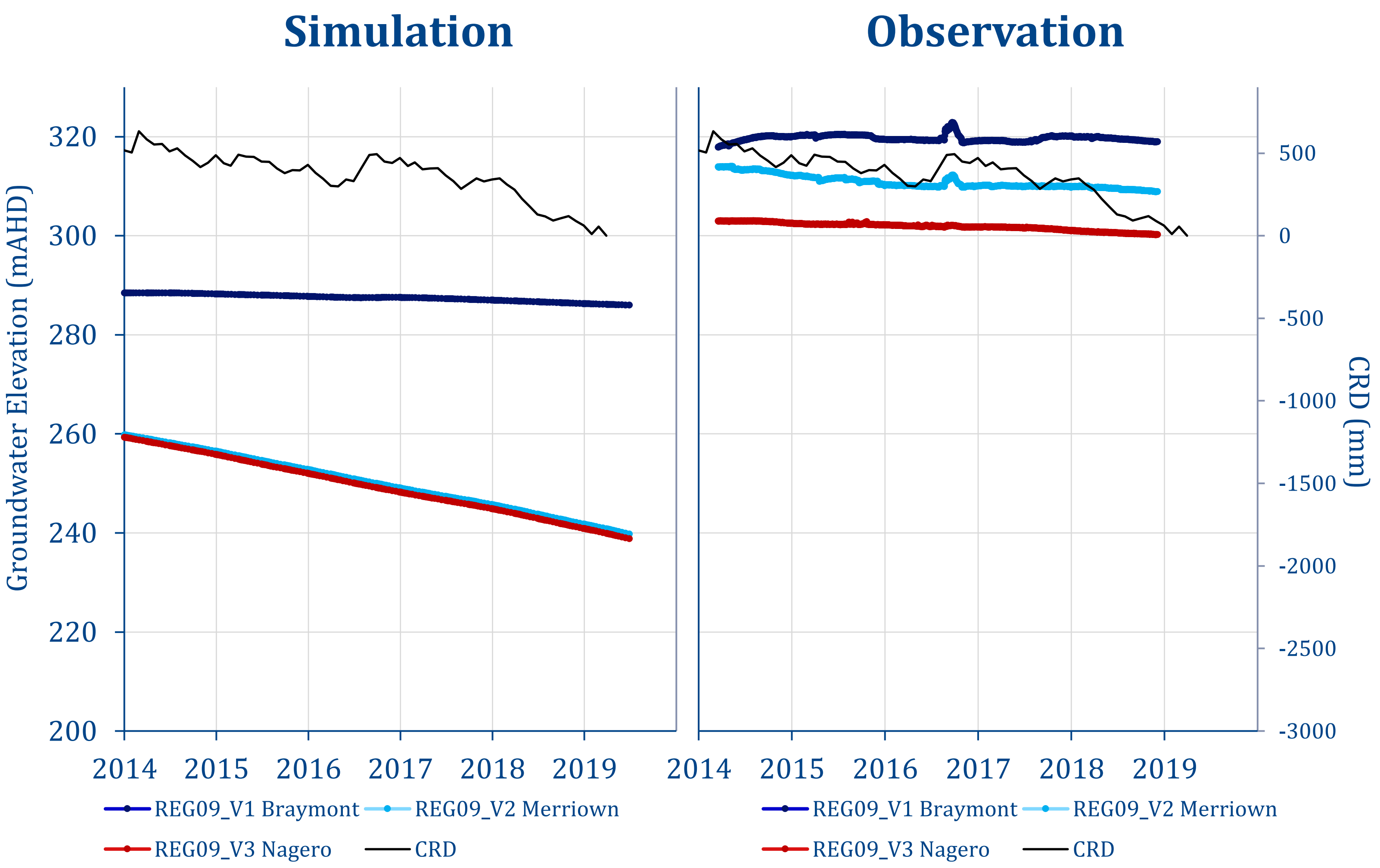
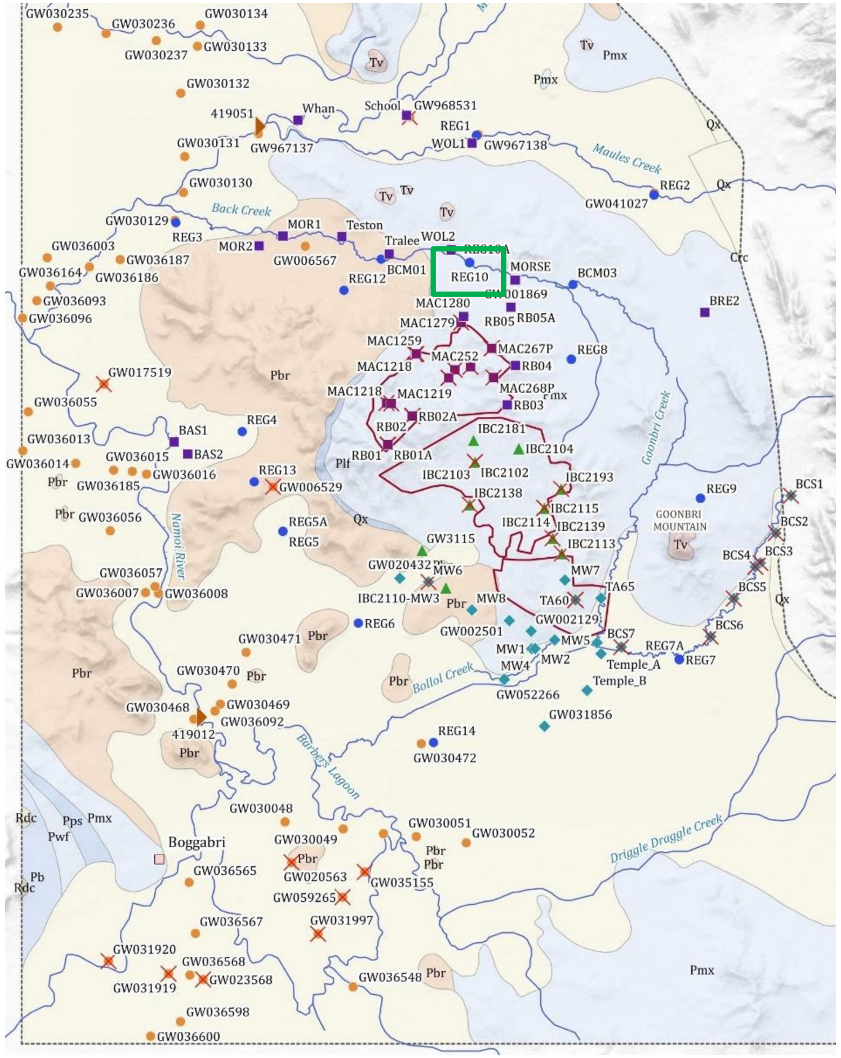
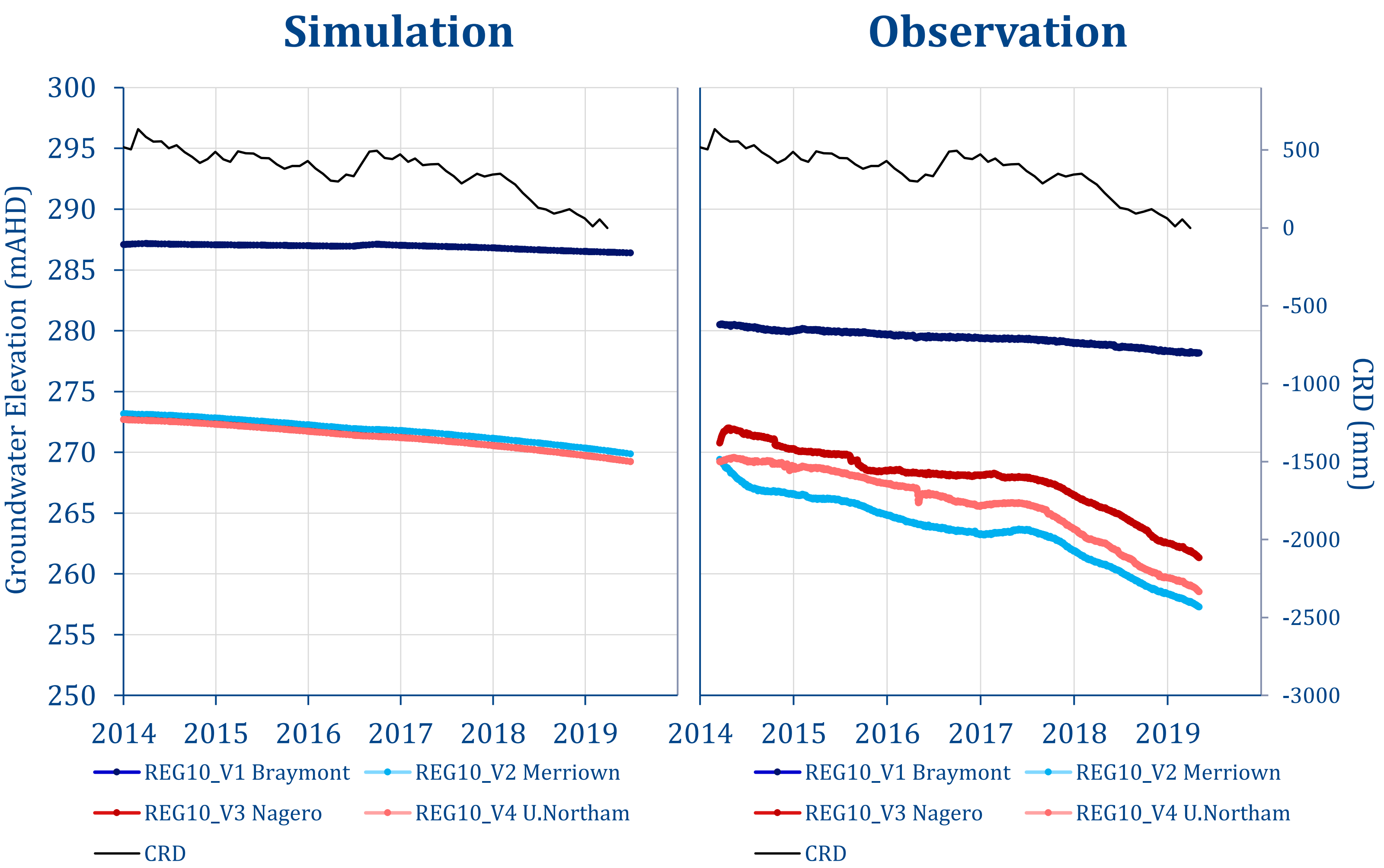




REG10 - Permian





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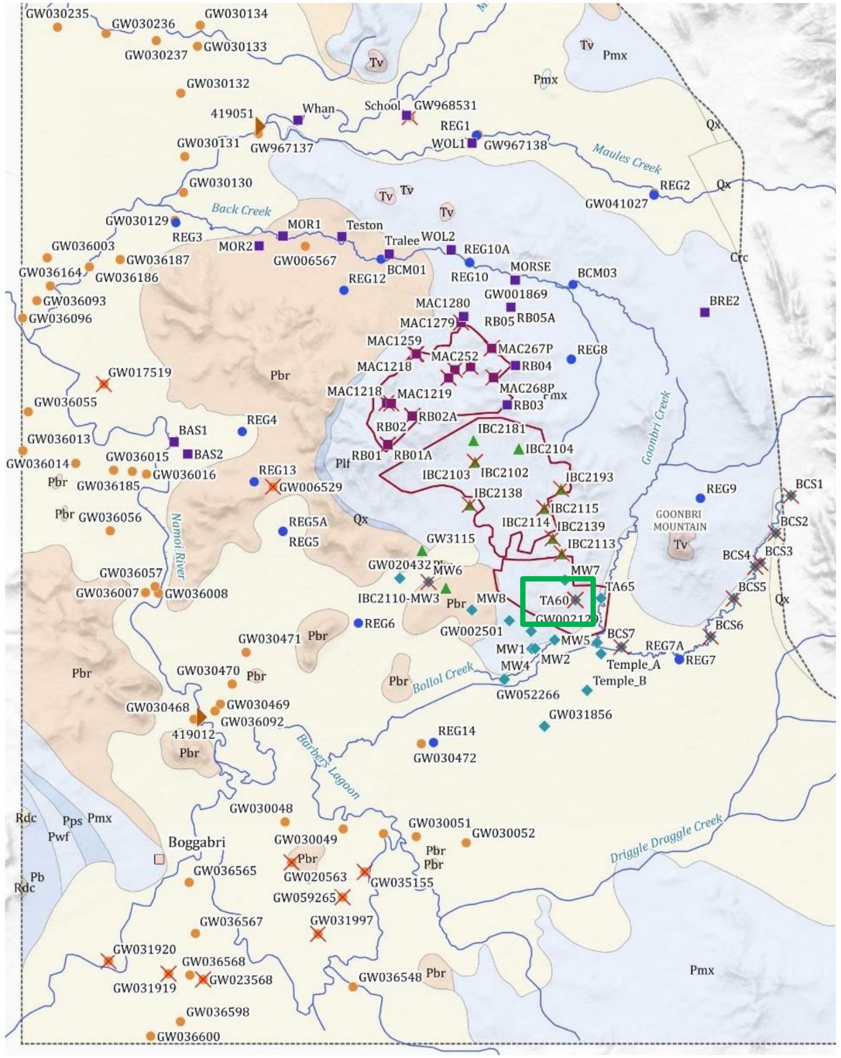
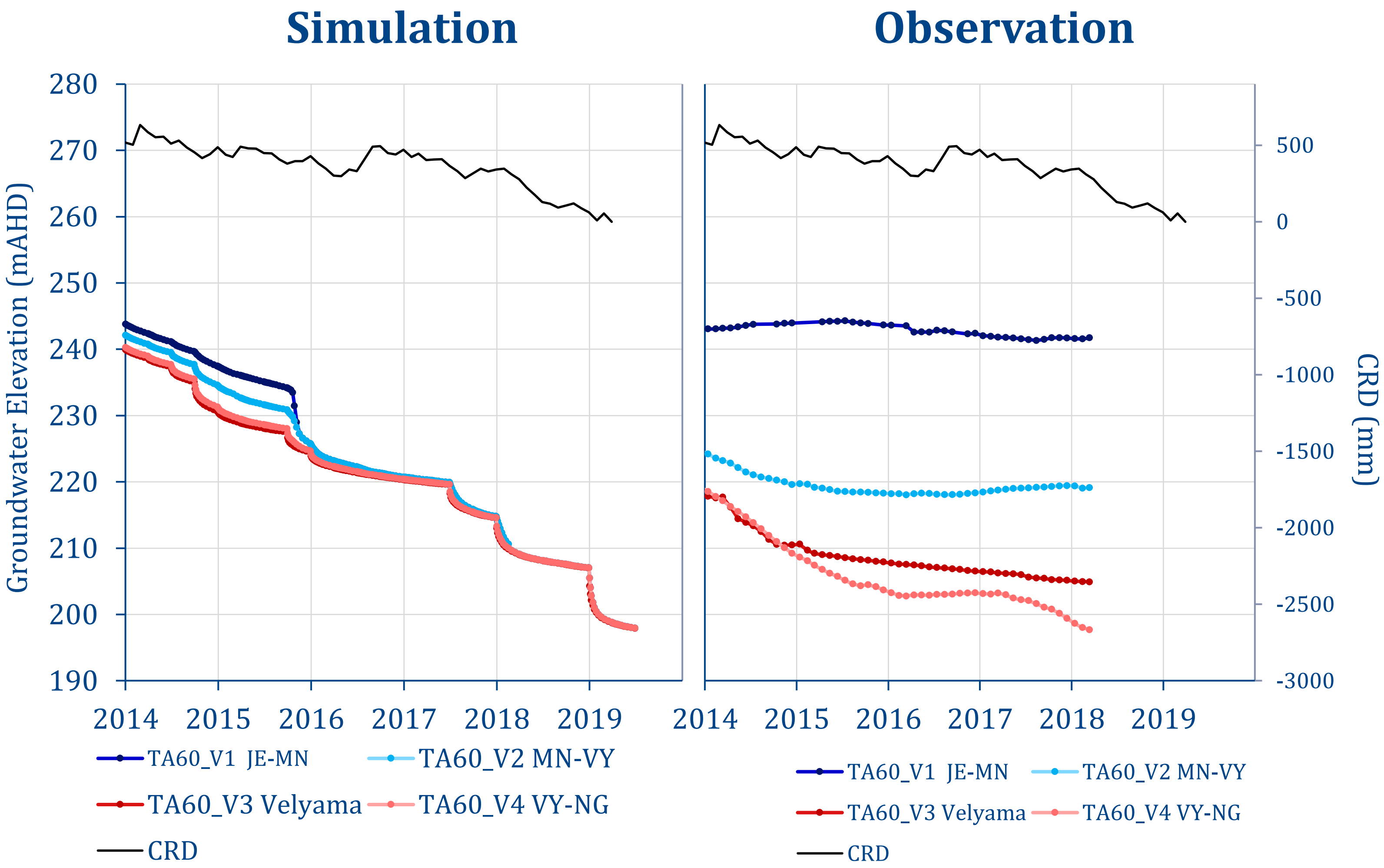
TA60 - Permian





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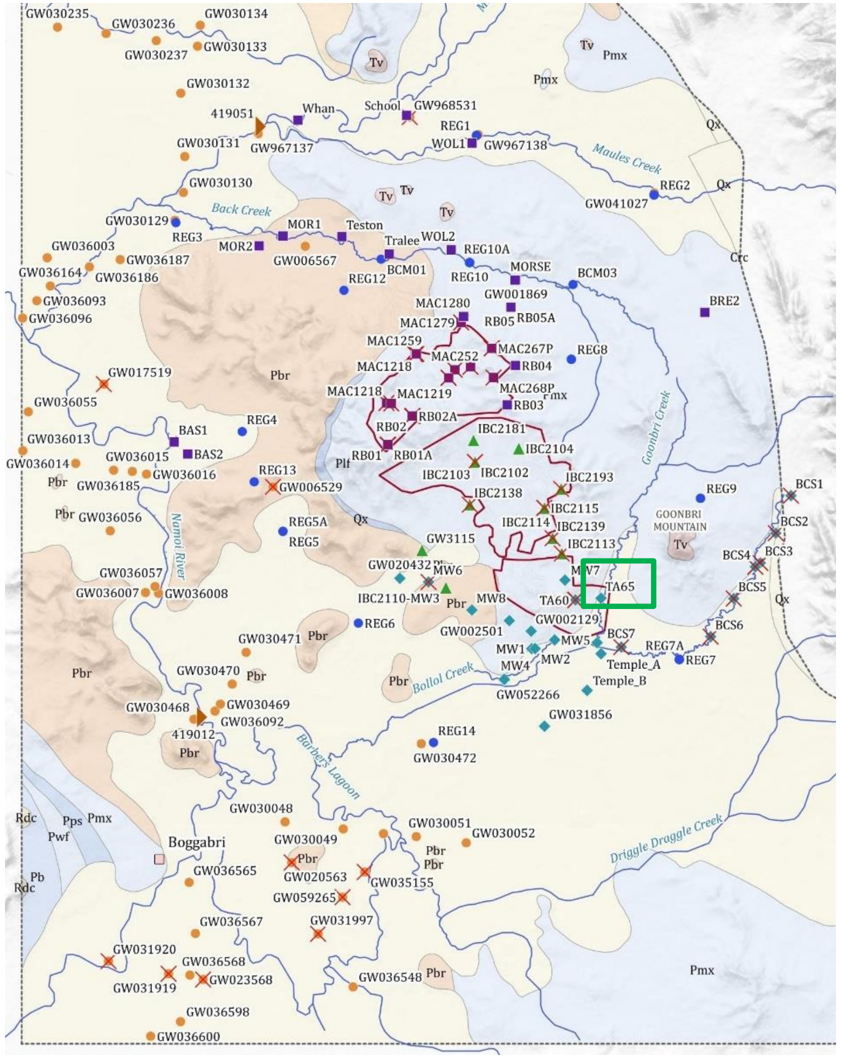
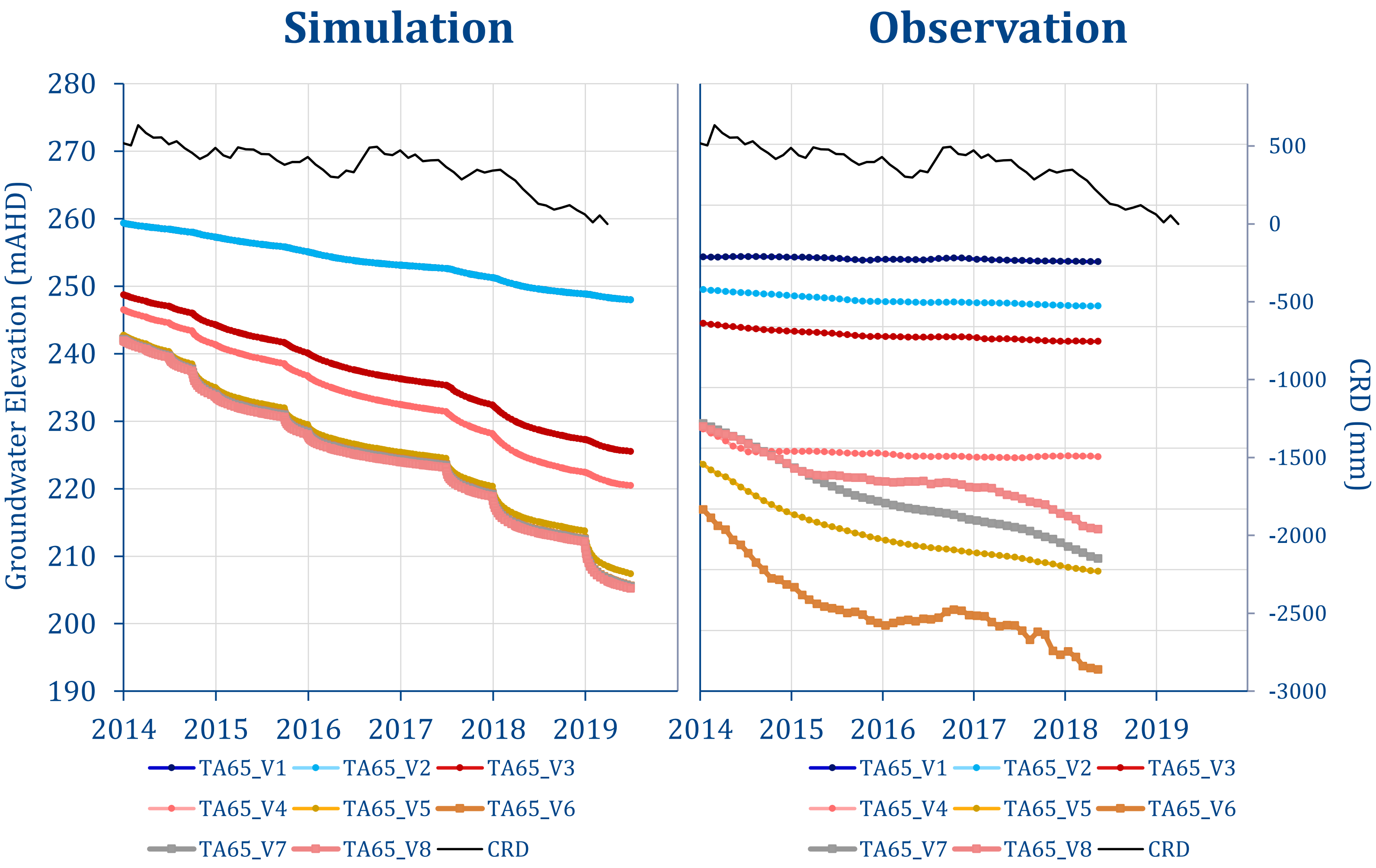
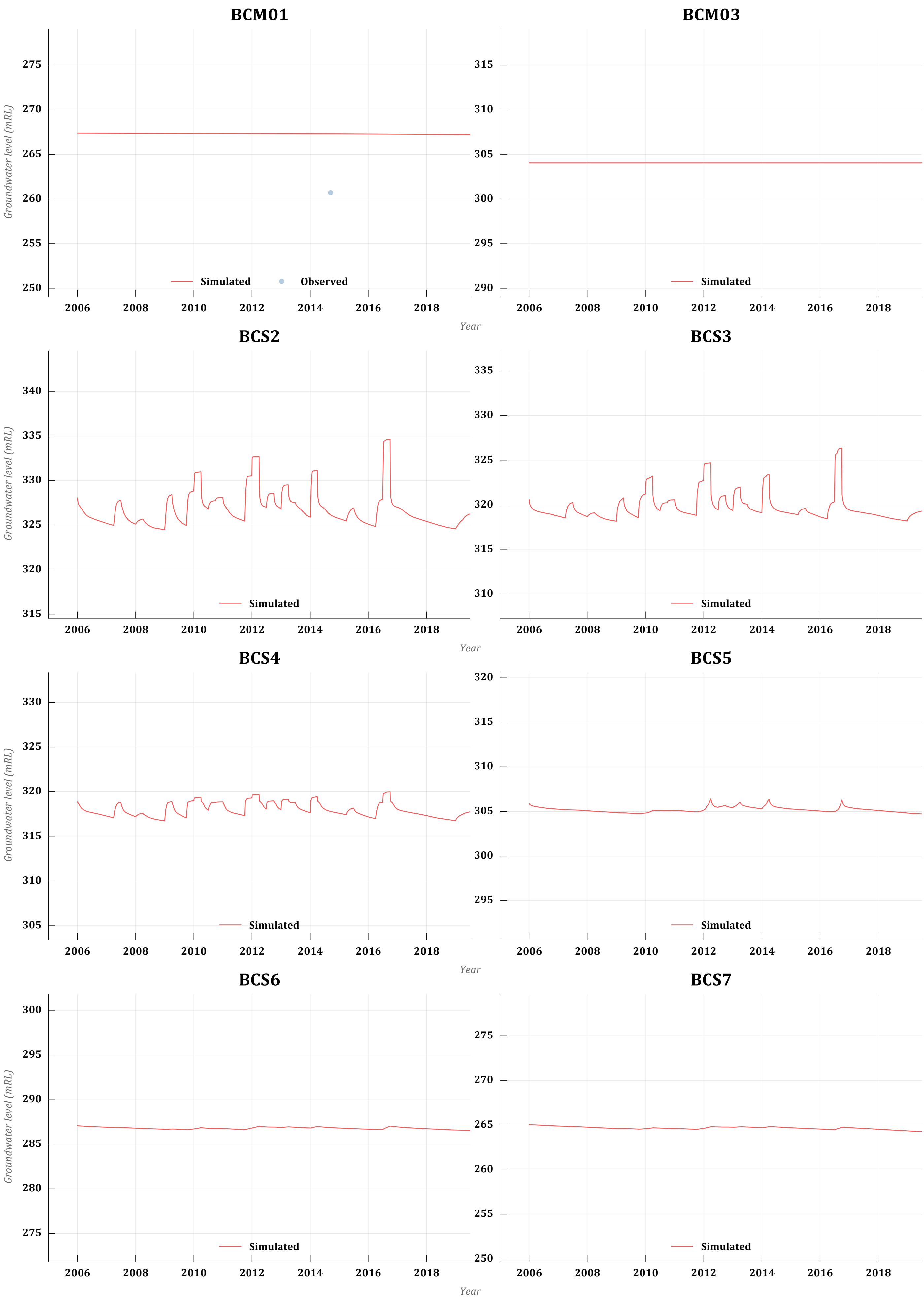
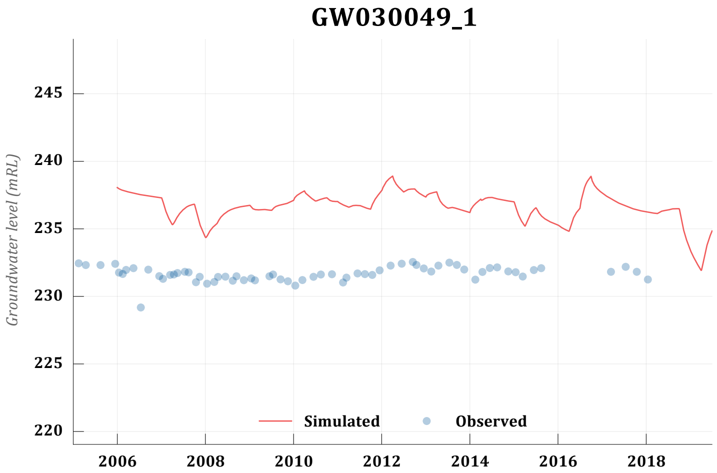
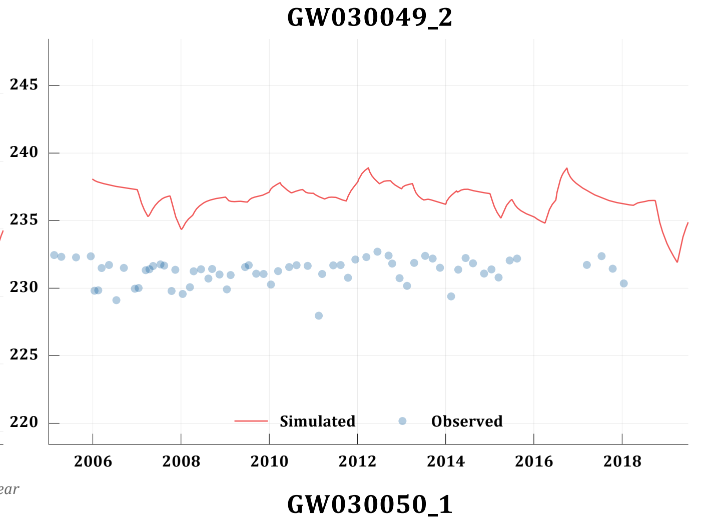





BCM01
Simulated
Observed
BCM03
Simulated
BCS2
Simulated
BCS3
Simulated
BCS4
Simulated
BCS5
Simulated
BCS6
Simulated
BCS7
Simulated
Groundwater level (mRL)
Year
2006
2008
2010
2012
2014
2016
2018


BRE2
GW001869
GW002129
GW002501
GW006567
GW020432
GW030048_1
GW030048_2
Groundwater level (mRL)
Year
Simulated
Observed
2006
2008
2010
2012
2014
2016
2018


GW030049_1
Groundwater level (mRL)
220
225
230
235
240
245
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed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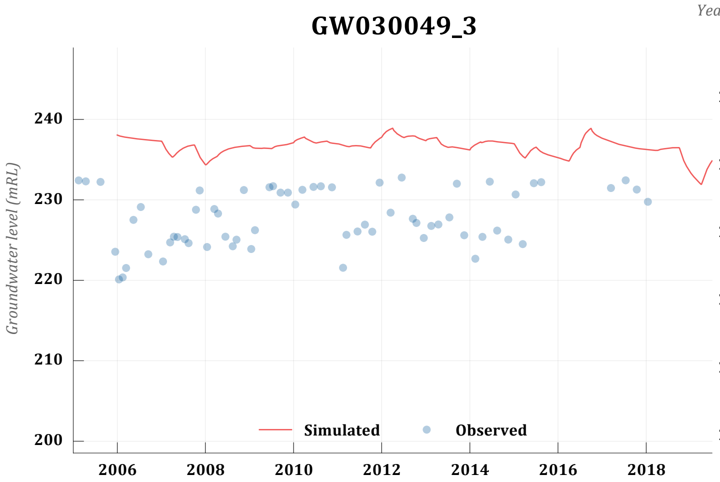
2010
2012
2014
2016
2018
Simulated
Observed
Year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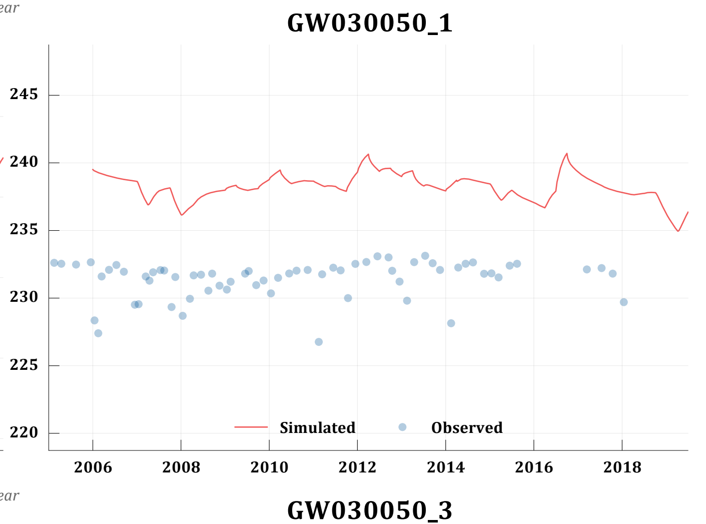
210
220
230
240
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed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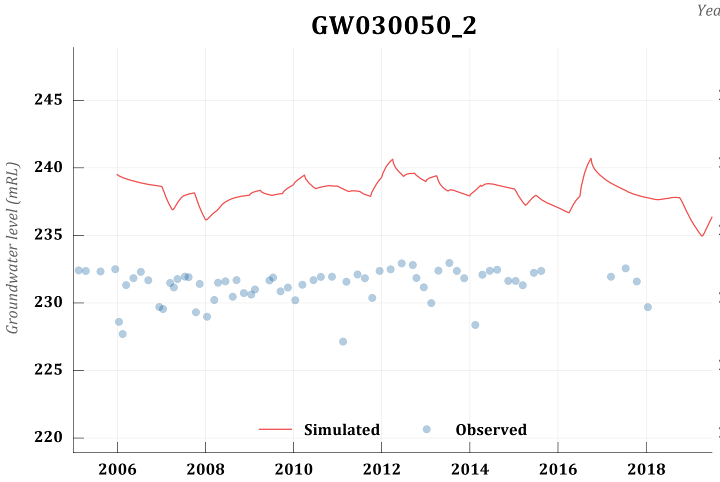
Simulated
Observed
Year


GW030050_2
Groundwater level (mRL)
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225
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240
245
2006
2008
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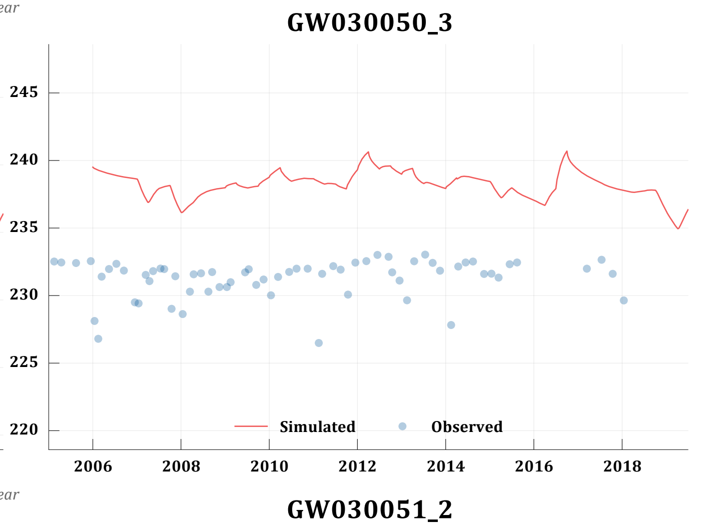
2014
2016
2018
Simulated
Observed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2006
2008
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2012
2014
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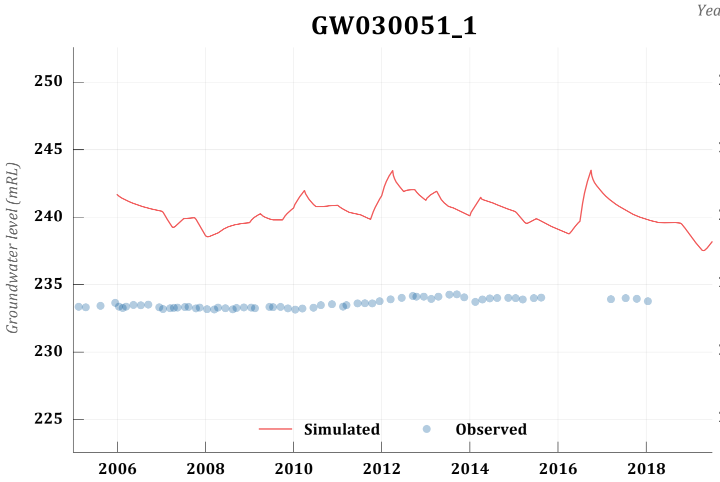
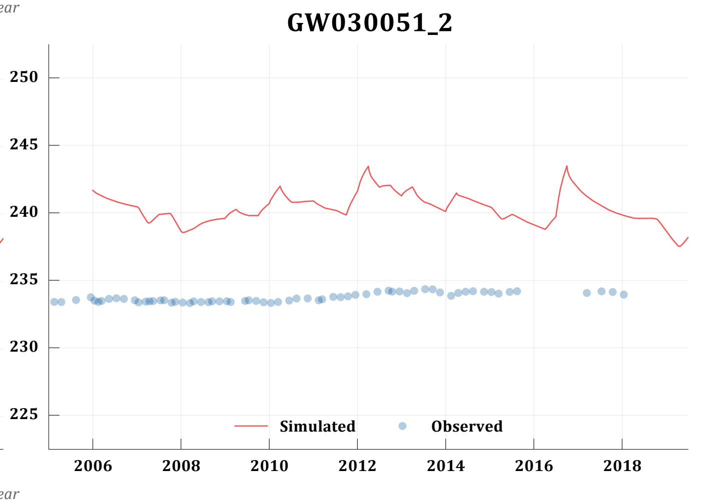
2018
Simulated
Observed
Year


GW030051_1
Groundwater level (mRL)
225
230
235
240
245
250
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed


GW030051_2
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2008
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Observed
Year

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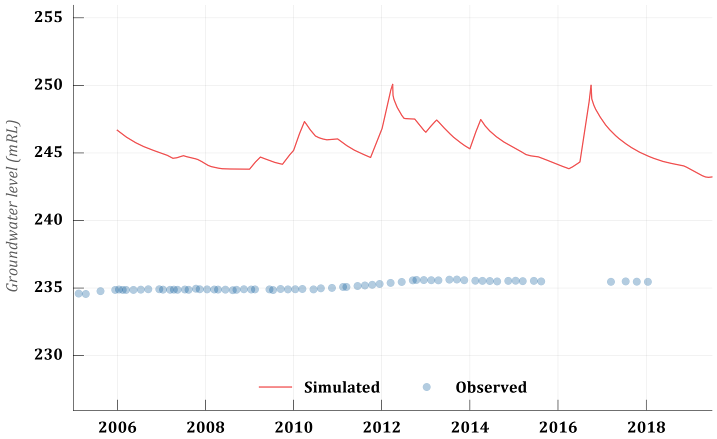

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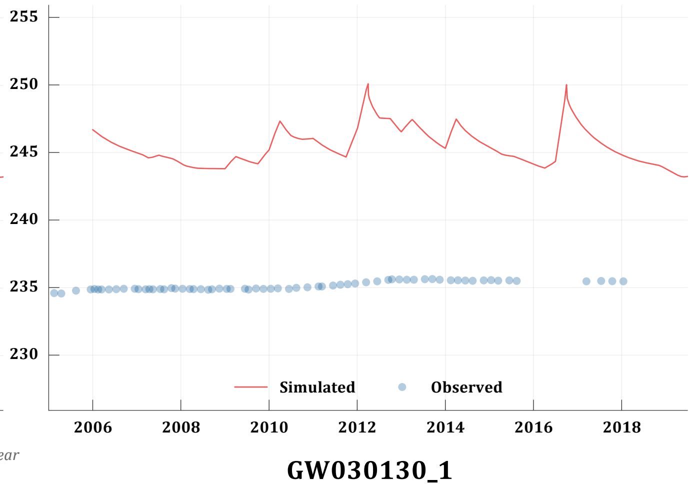

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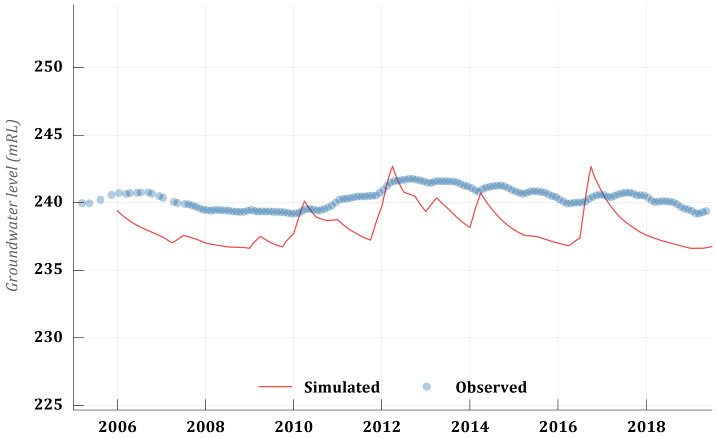

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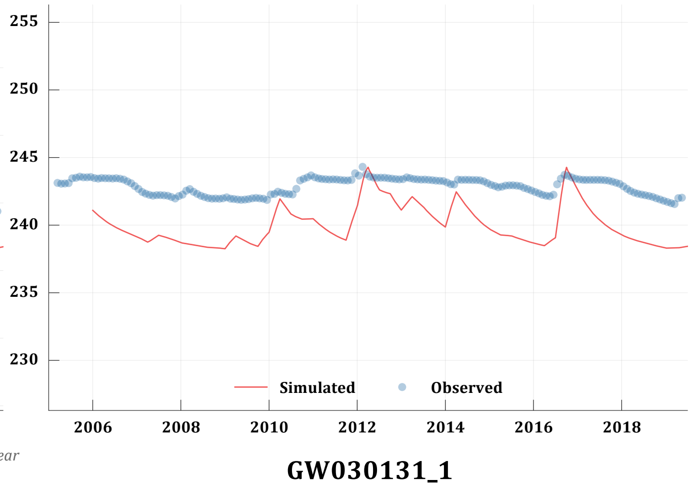

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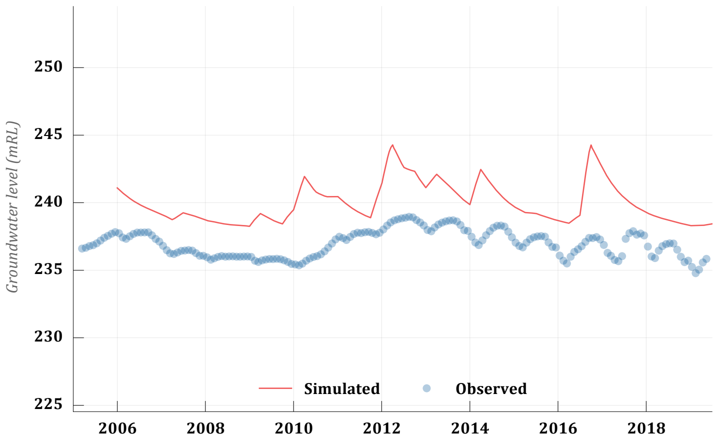

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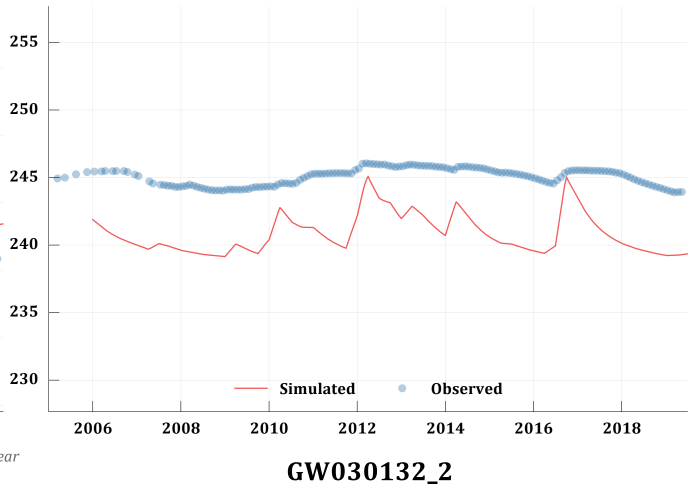

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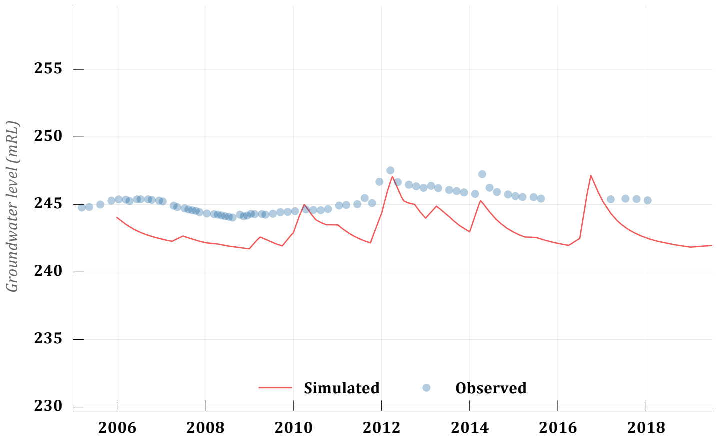

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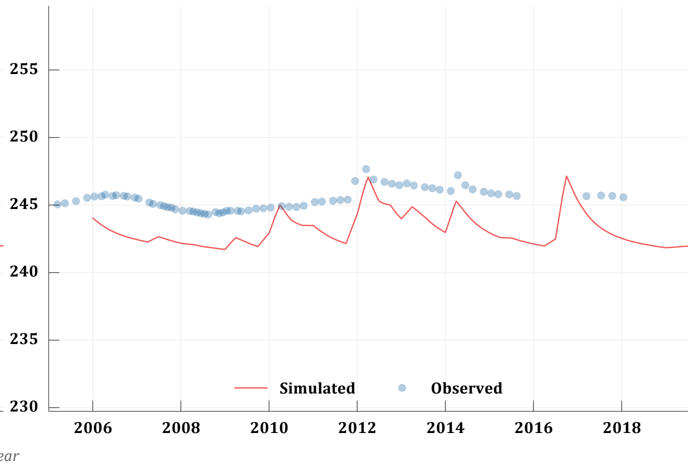

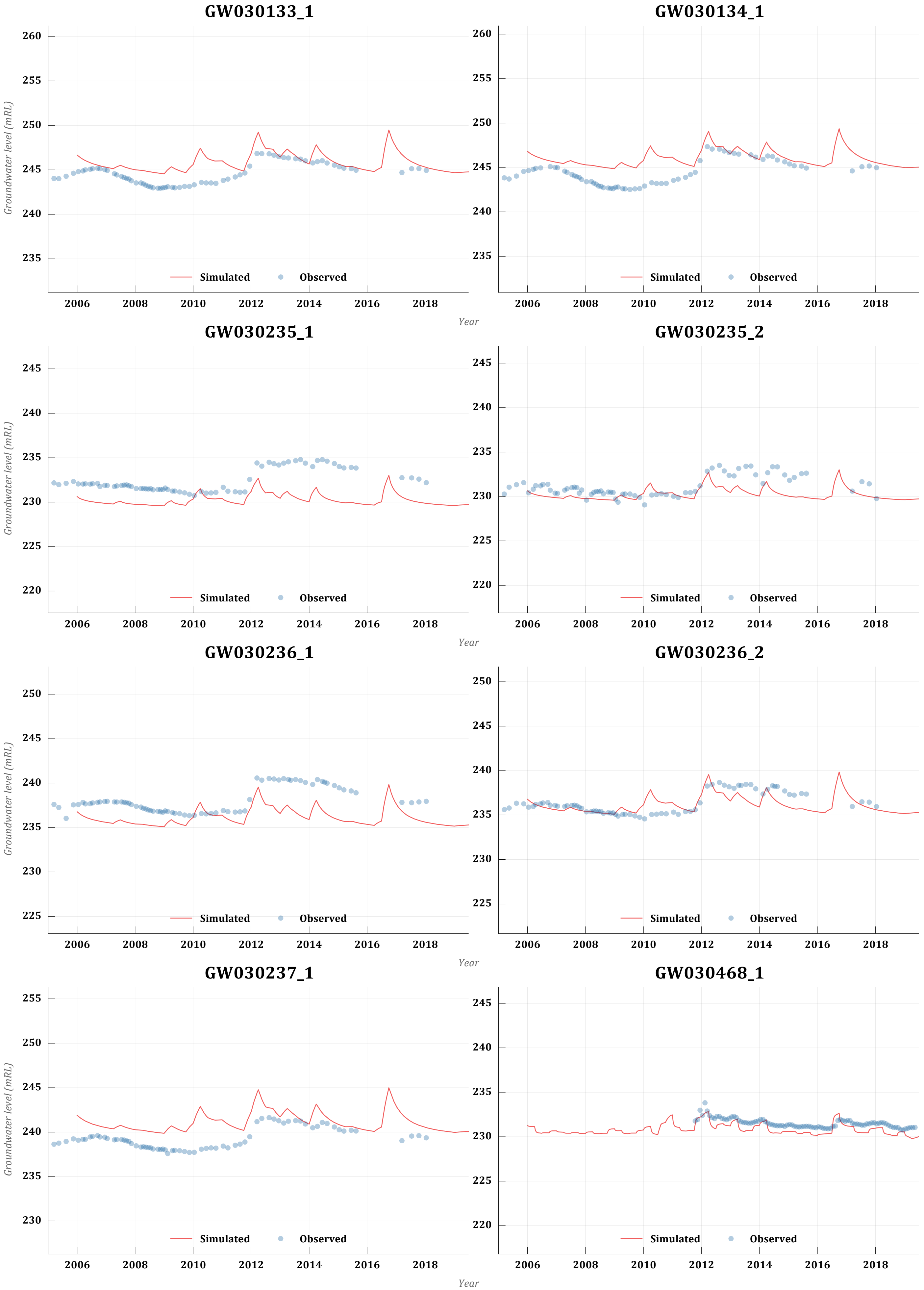
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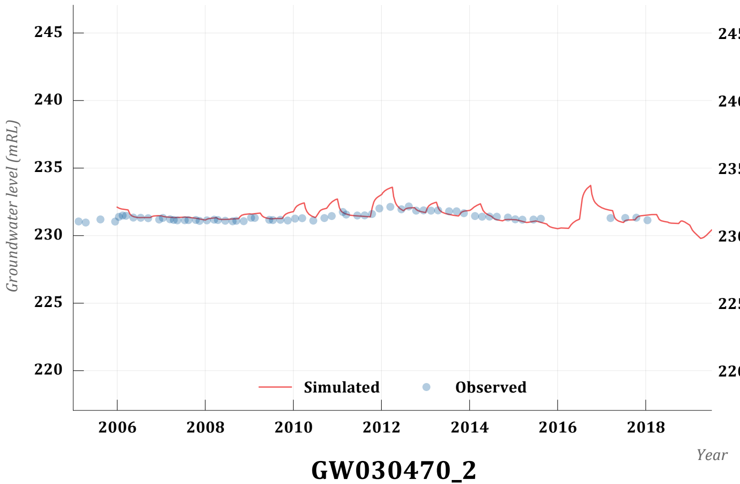
GW030235_1
GW030235_2
GW030236_1
GW030236_2
GW030237_1
GW030468_1
Groundwater level (mRL)
Year
Simulated
Observed

GW030469_1



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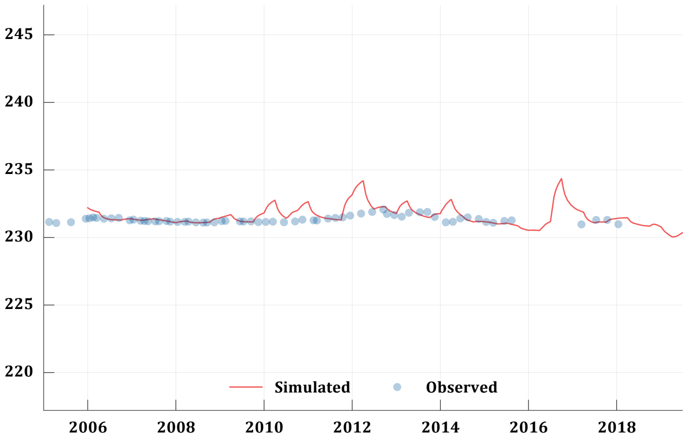

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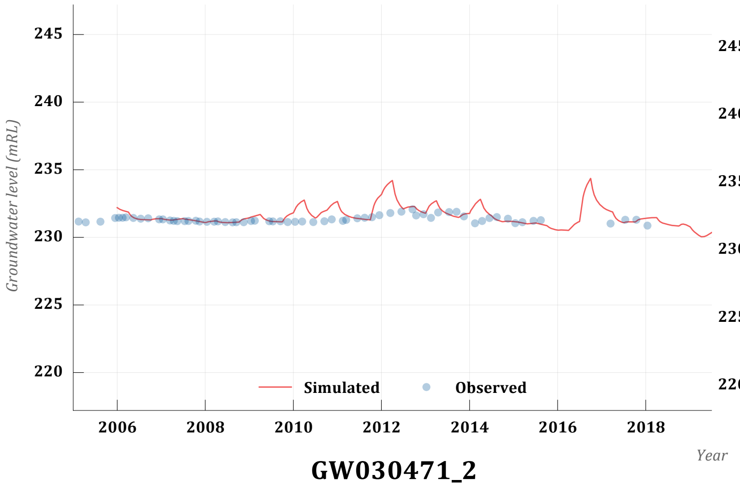

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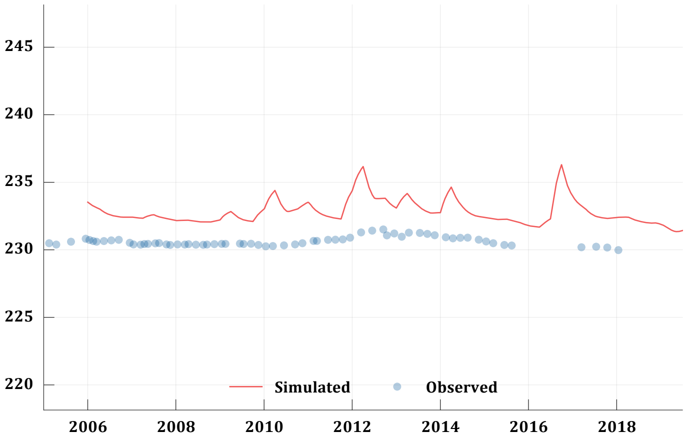

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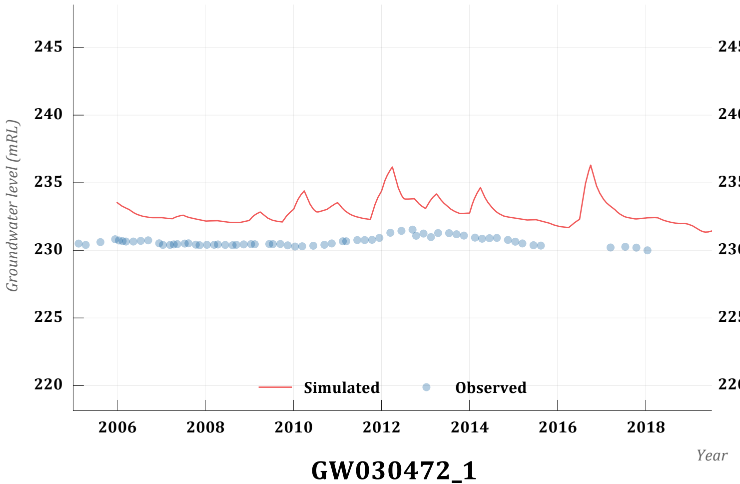

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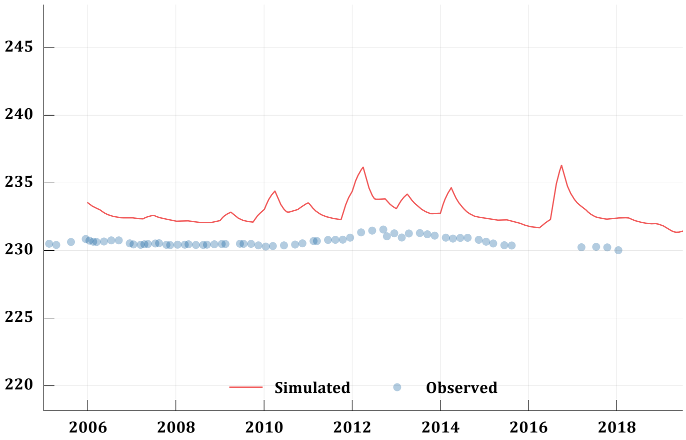

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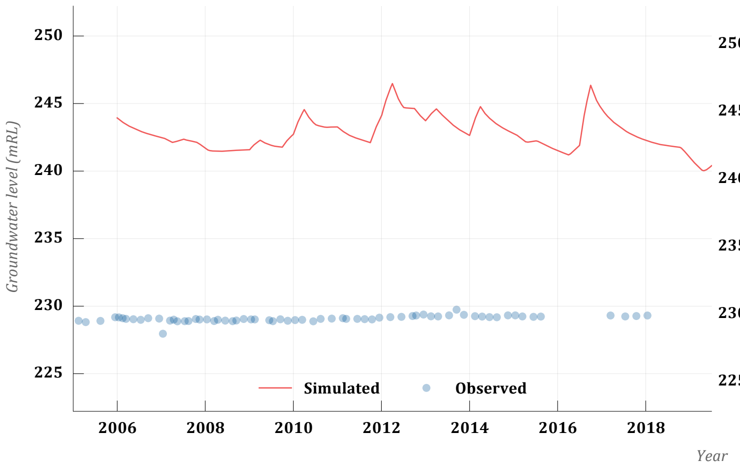

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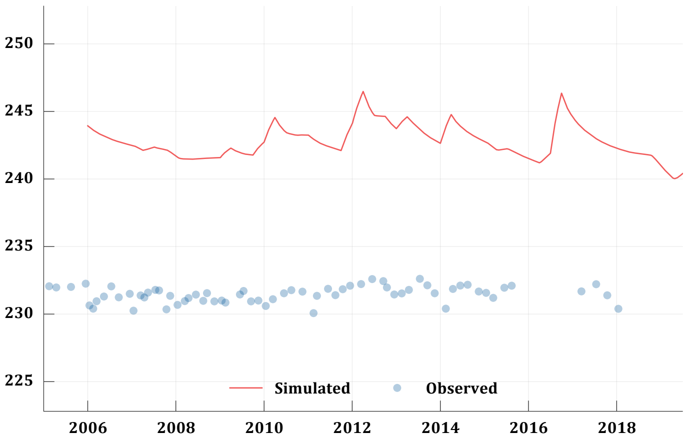
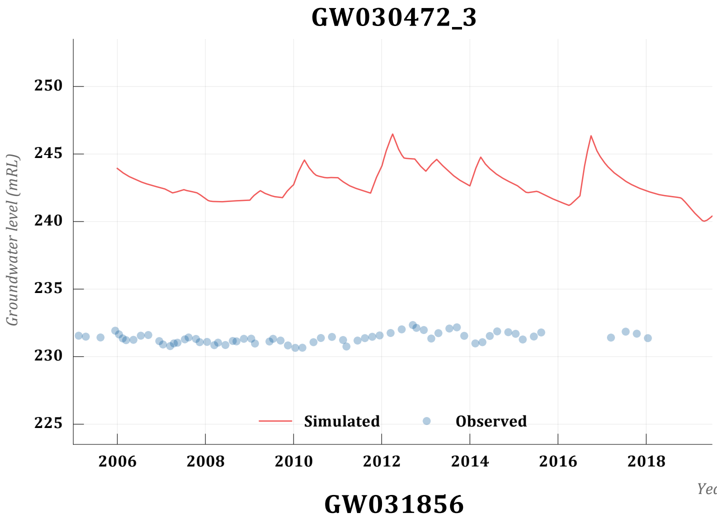
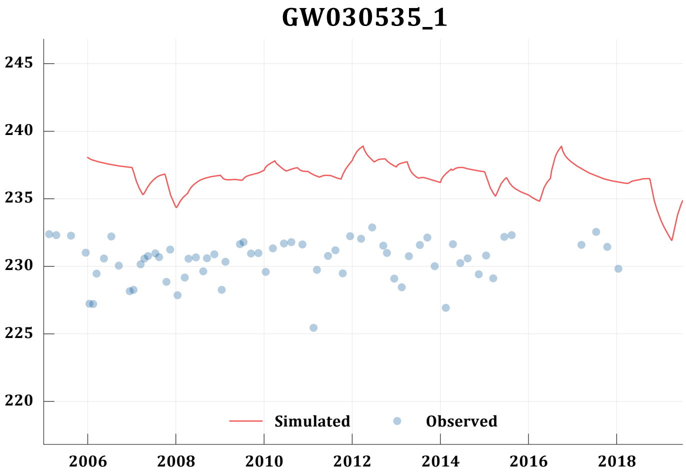



GW030472_3
Groundwater level (mRL)
250
245
240
235
230
225
2006
2008
2010
2012
2014
2016
2018
Year
Simulated
Observed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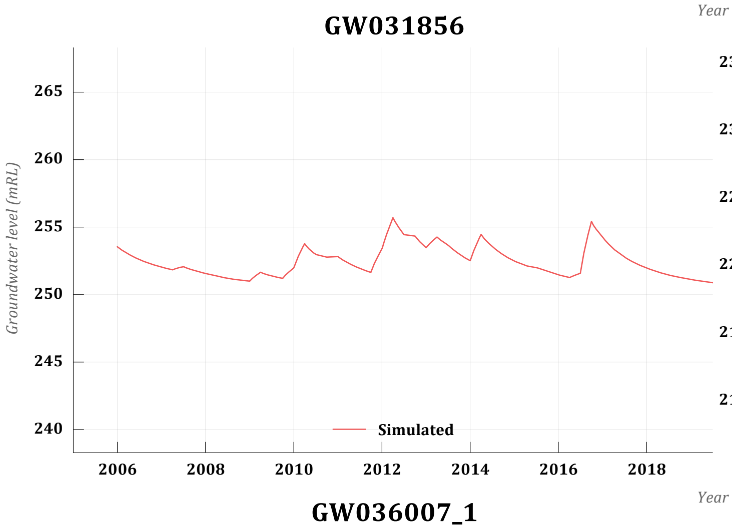
2018
Simulated
Observed


GW031856
Groundwater level (mRL)
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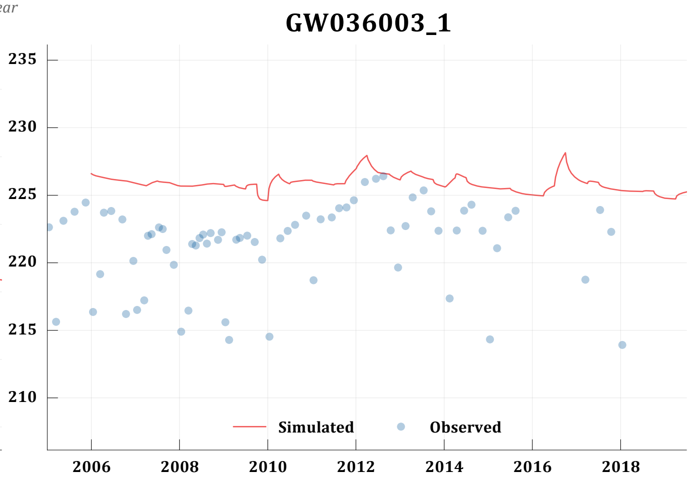
260
255
250
245
240
2006
2008
2010
2012
2014
2016
2018
Year
Simulated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235
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215
210
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2012
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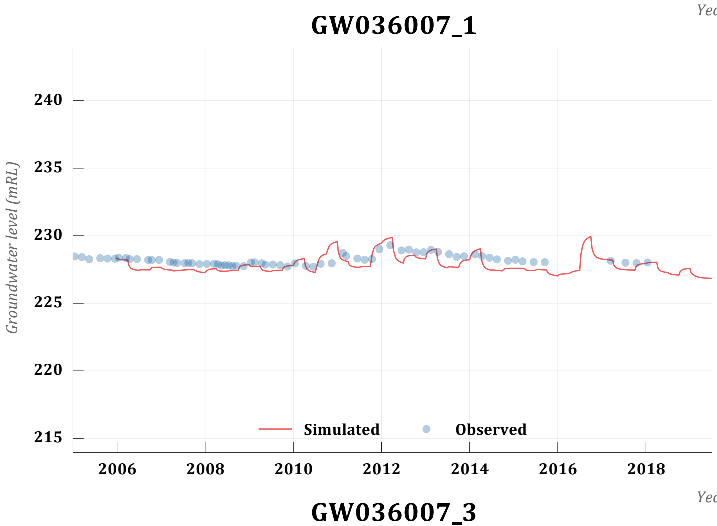
2016
2018
Simulated
Observed


GW036007_1
Groundwater level (mRL)
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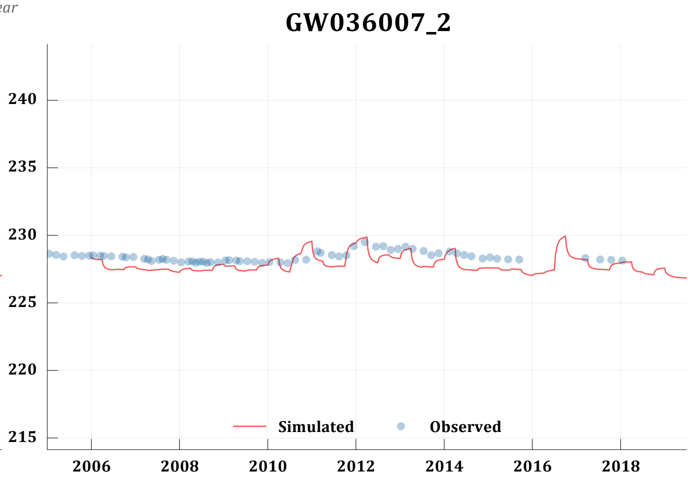
2006
2008
2010
2012
2014
2016
2018
Year
Simulated
Observed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2006
2008
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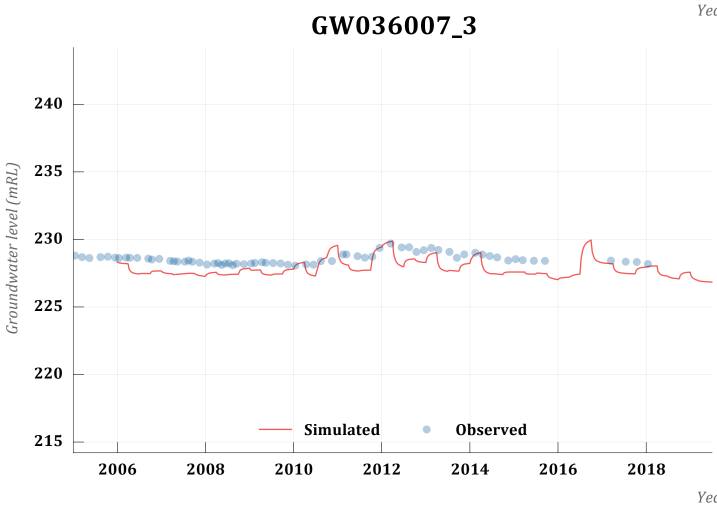
2018
Simulated
Observed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Groundwater level (mRL)
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215
2006
2008
2010
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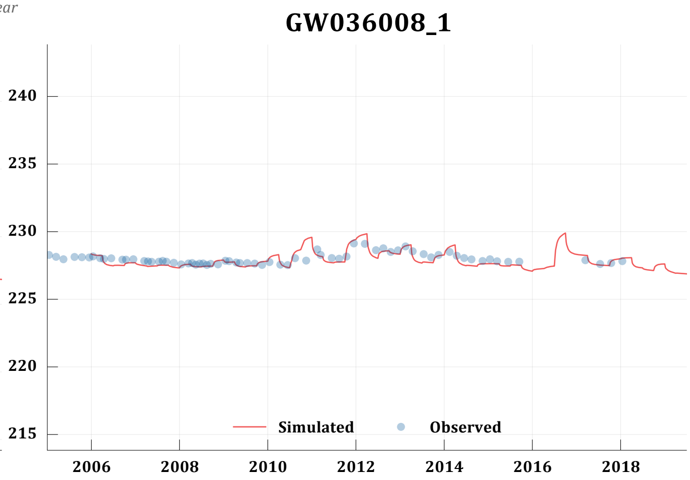
2018
Year
Simulated
Observed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2006
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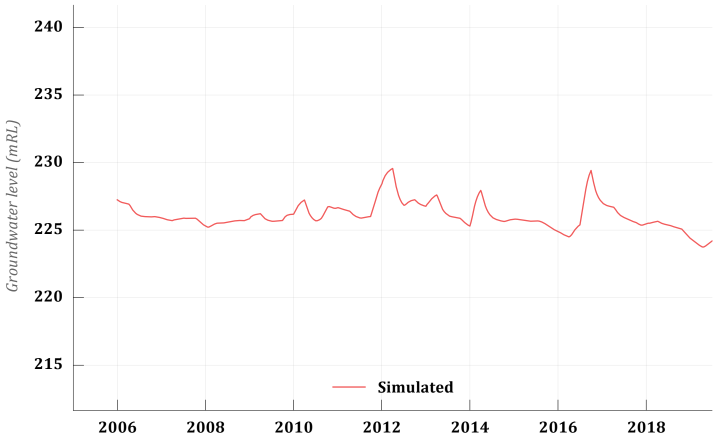
2018
Simulated
Observed

GW036013_1



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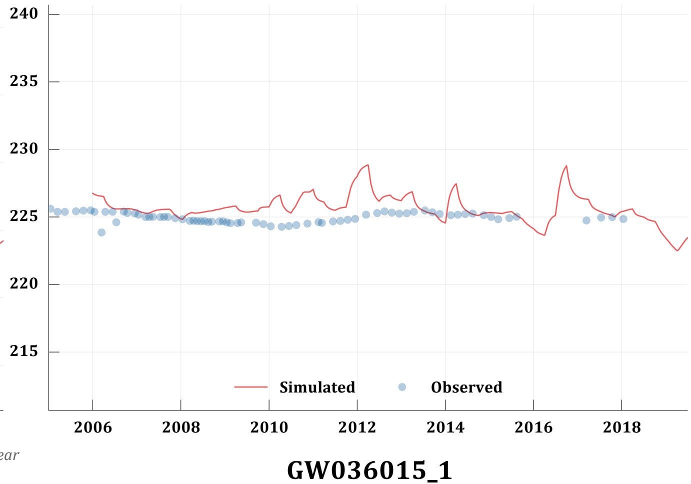

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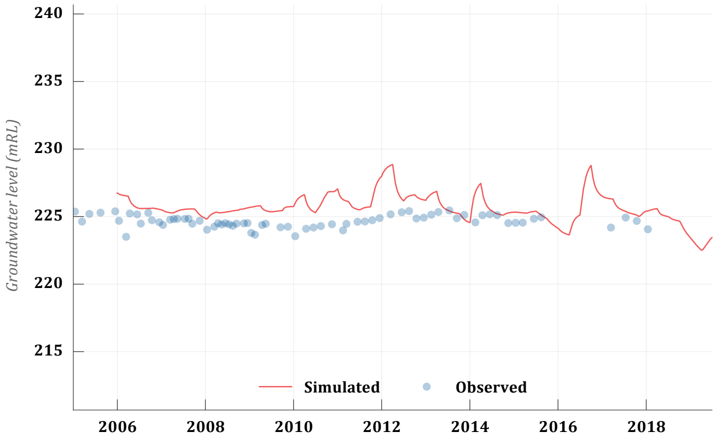

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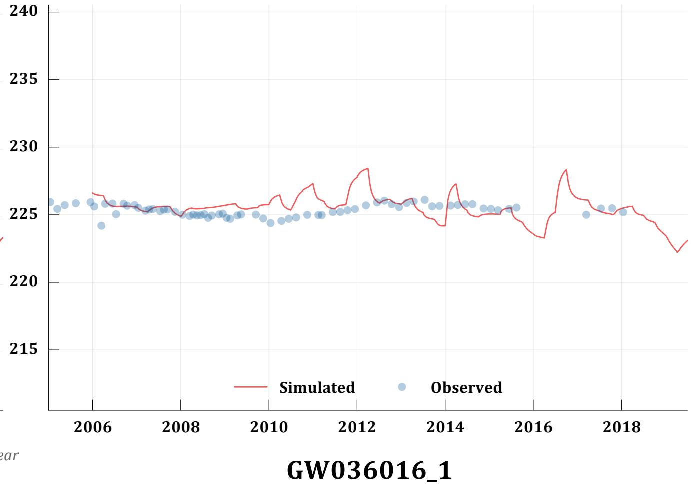

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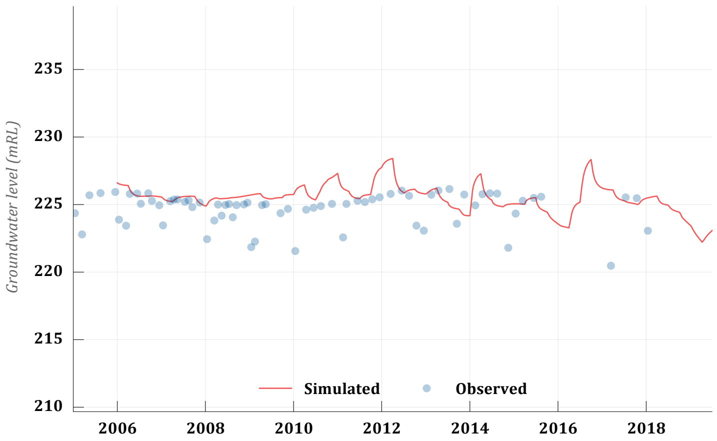

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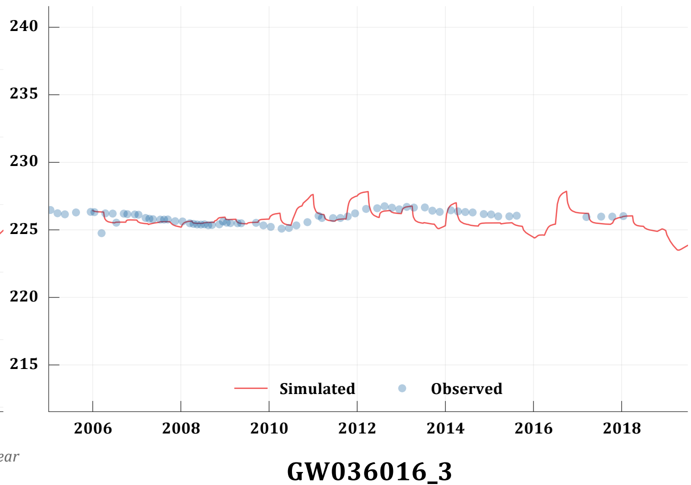

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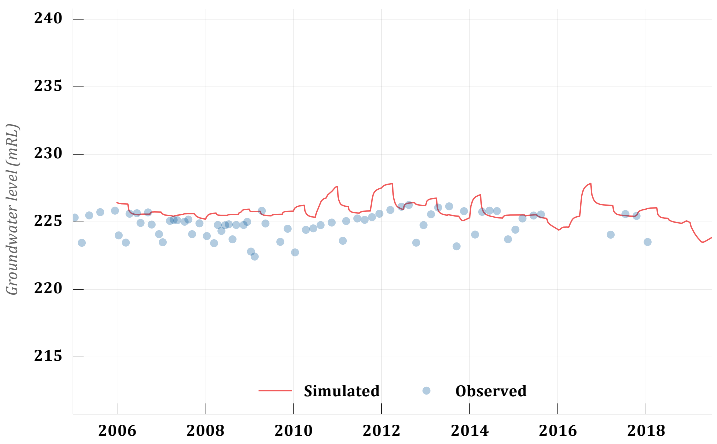

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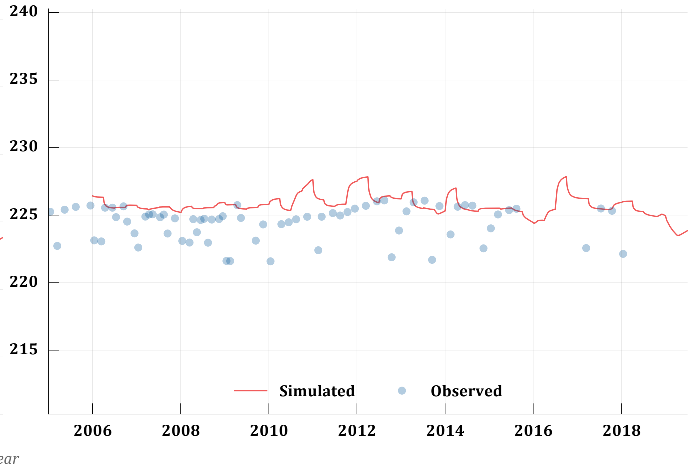
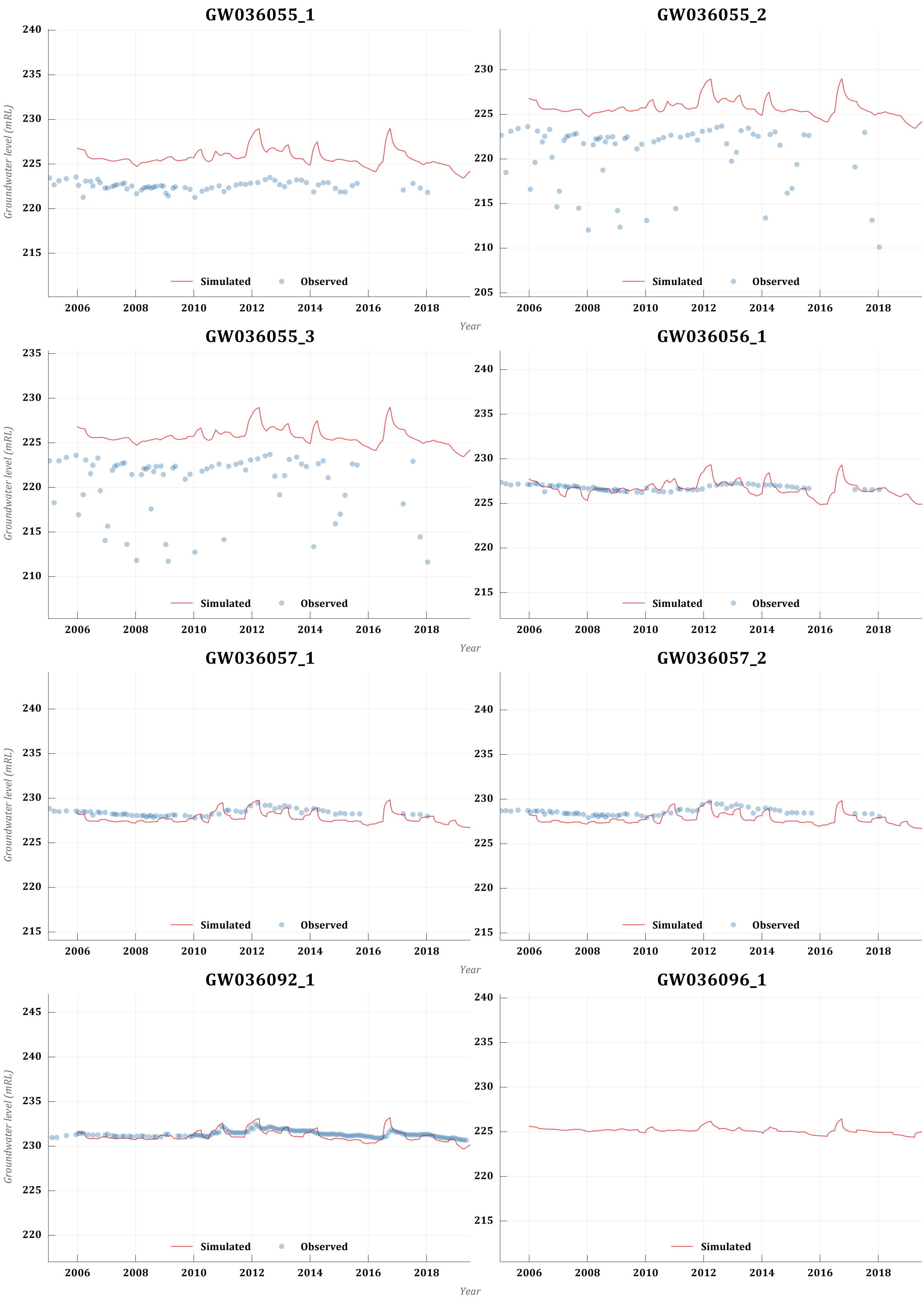
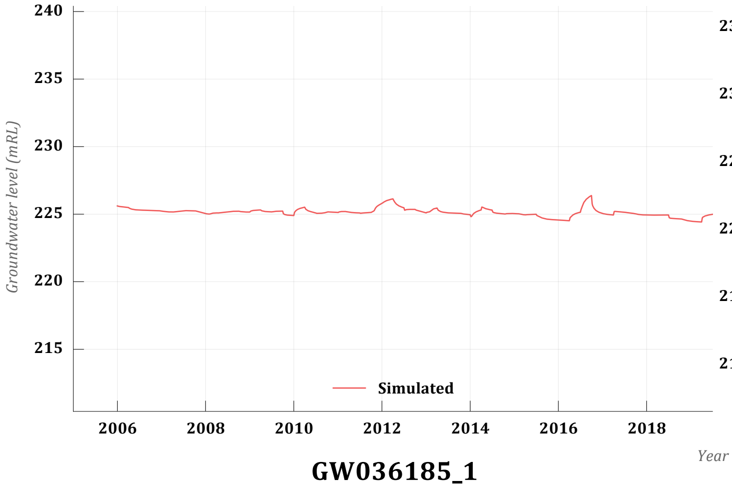
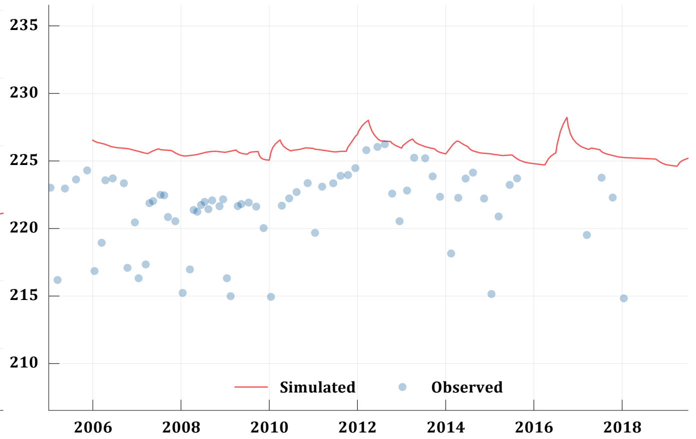



GW036055_1
GW036055_2
GW036055_3
GW036056_1
GW036057_1
GW036057_2
GW036092_1
GW036096_1
Groundwater level (mRL)
Year
Simulated
Observed

GW036096_2



GW036164_1



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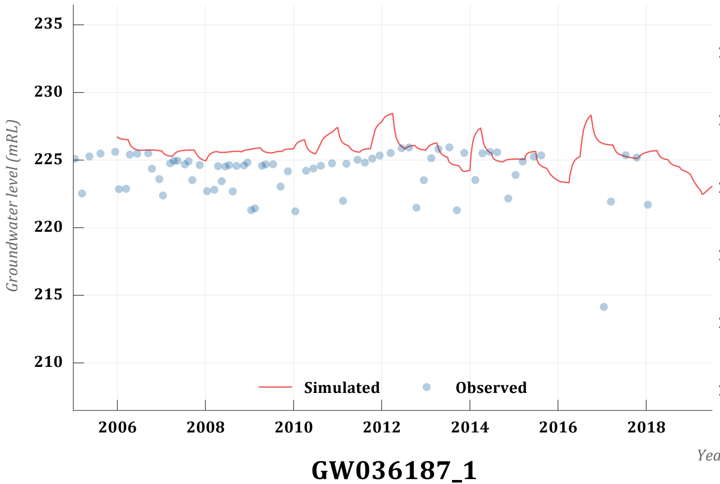

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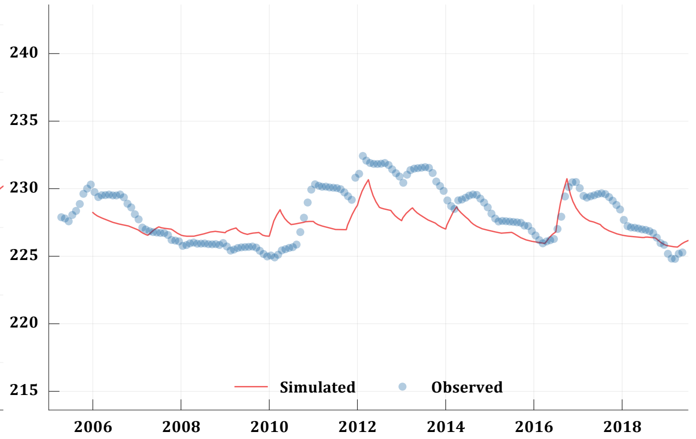
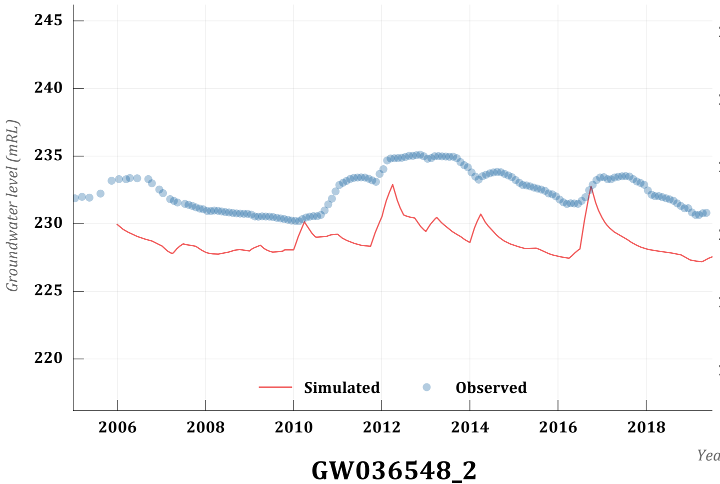
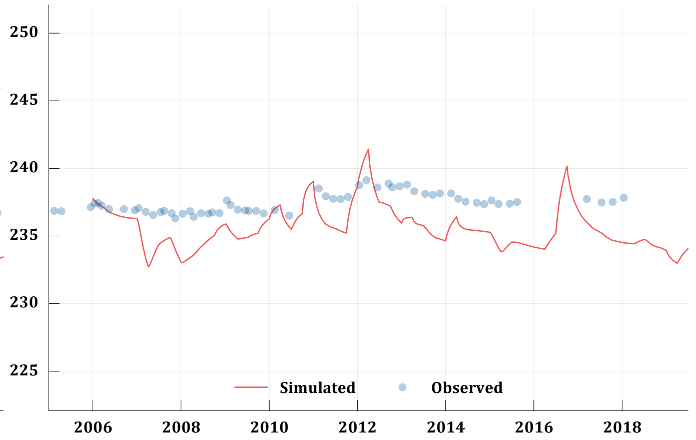


GW036187_1



GW036548_1



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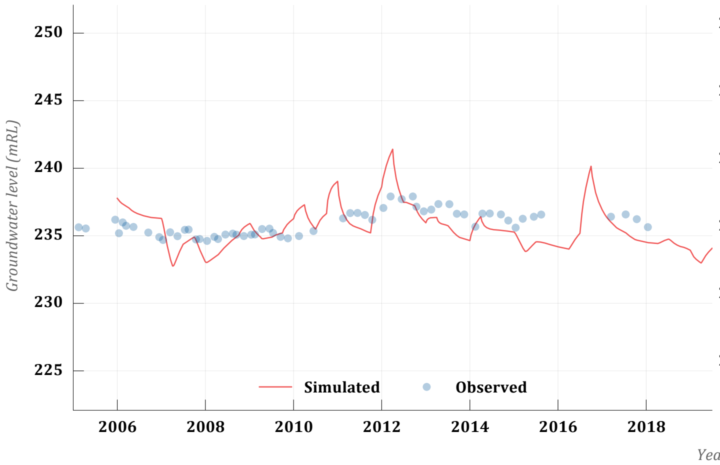

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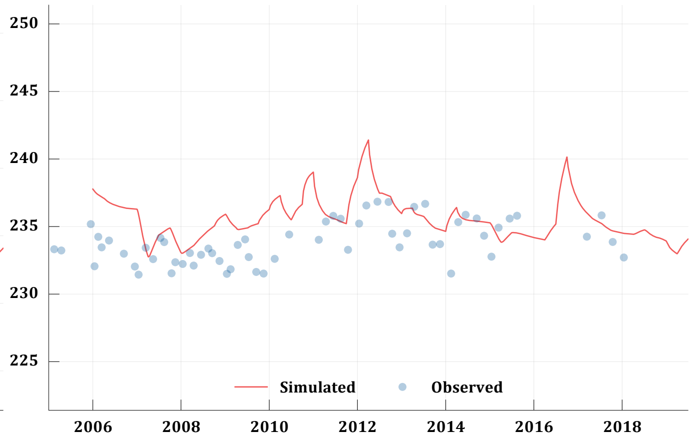
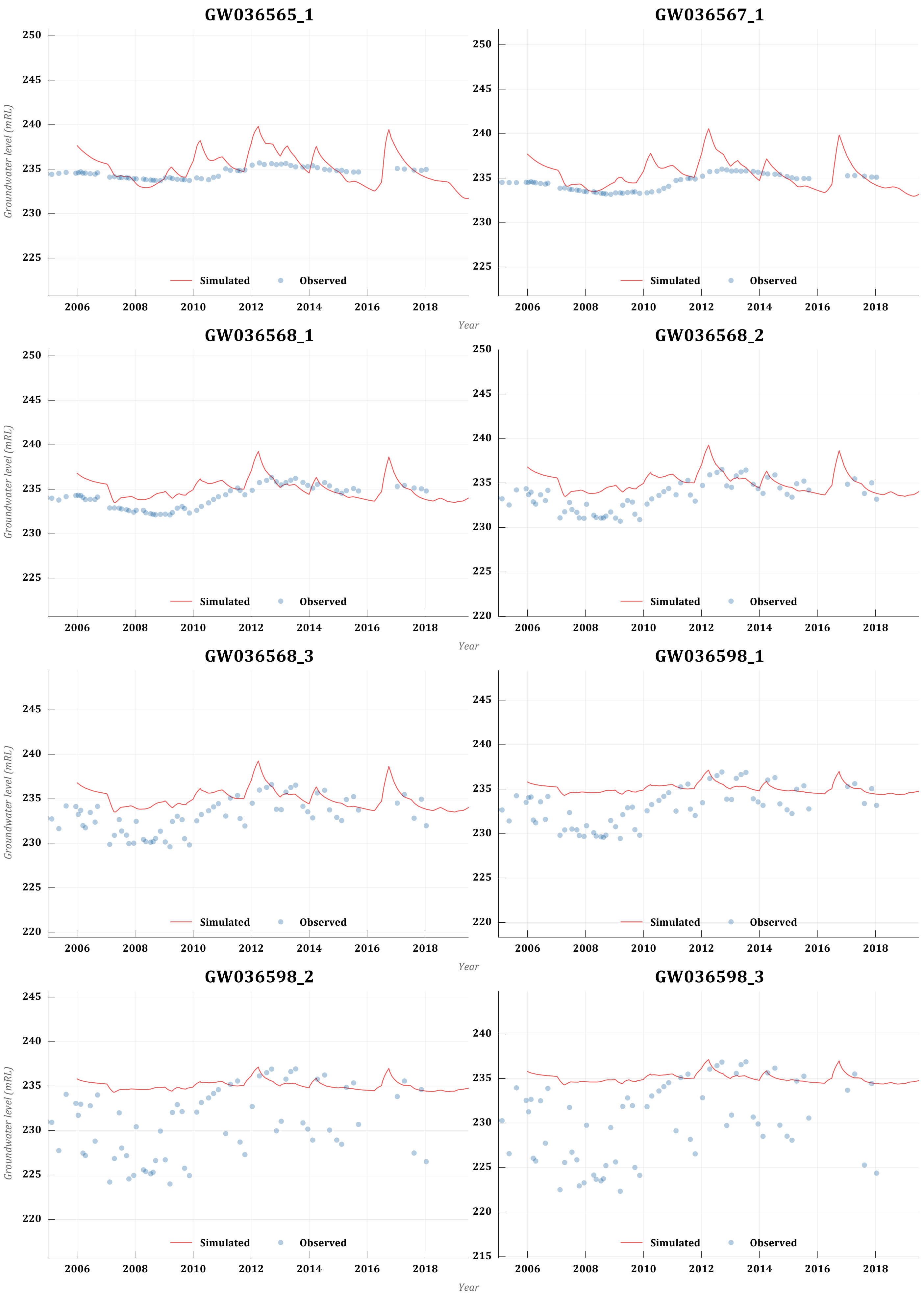
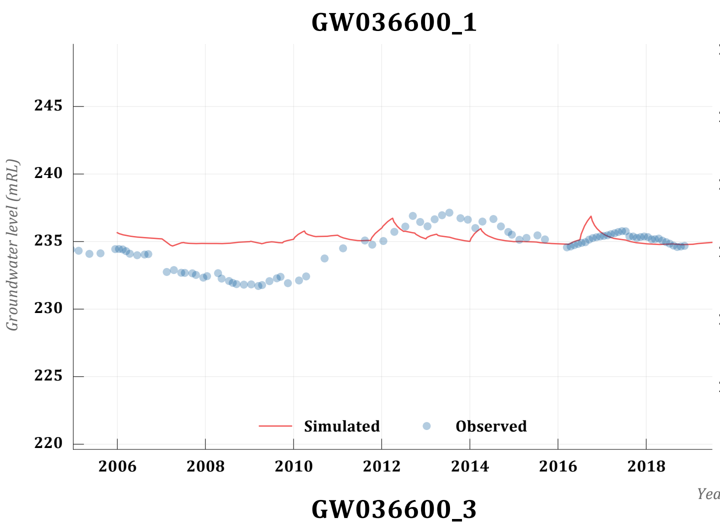



GW036565_1
GW036567_1
GW036568_1
GW036568_2
GW036568_3
GW036598_1
GW036598_2
GW036598_3
Groundwater level (mRL)
Year
Simulated
Observed


GW036600_1
Groundwater level (mRL)
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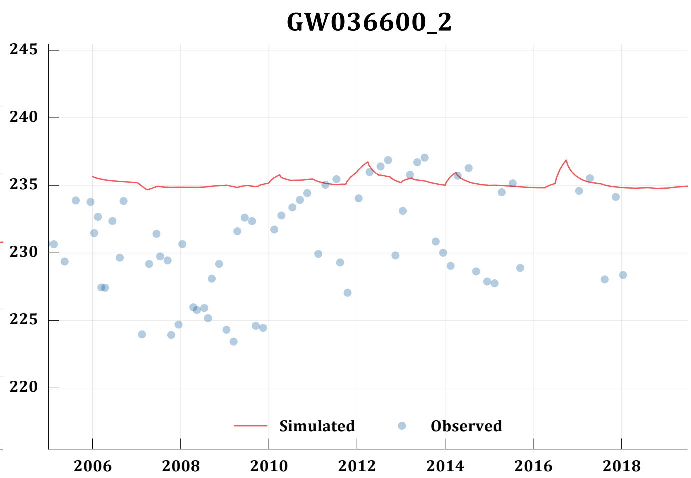
240
235
230
225
220
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed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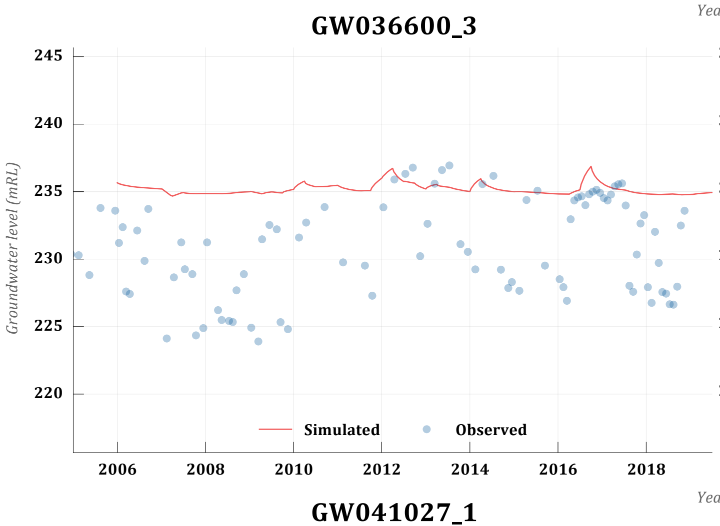
2018
Simulated
Observed
Year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Groundwater level (mRL)
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2006
2008
2010
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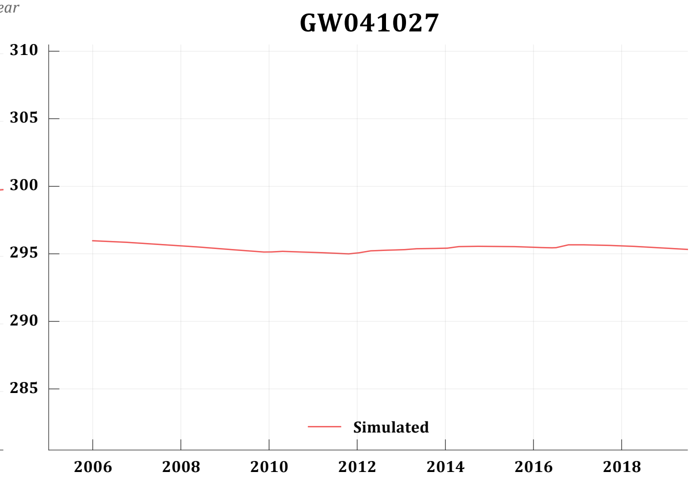
2018
Simulated
Observed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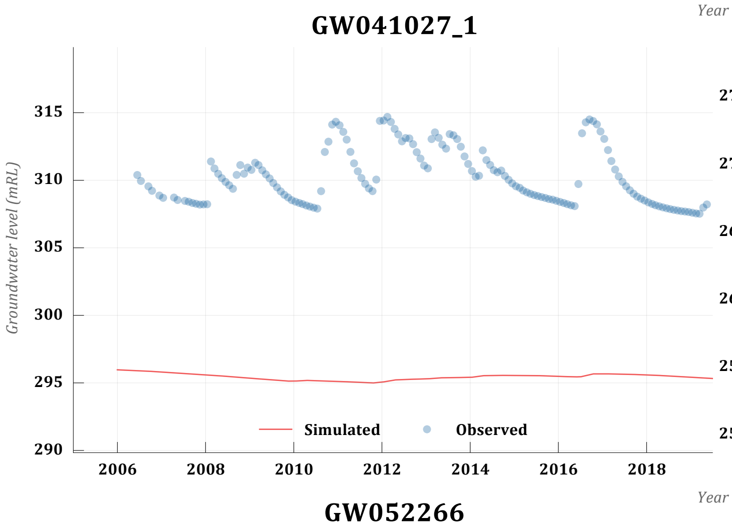
Simulated
Year


GW041027_1
Groundwater level (mRL)
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310
305
300
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290
2006
2008
2010
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2014
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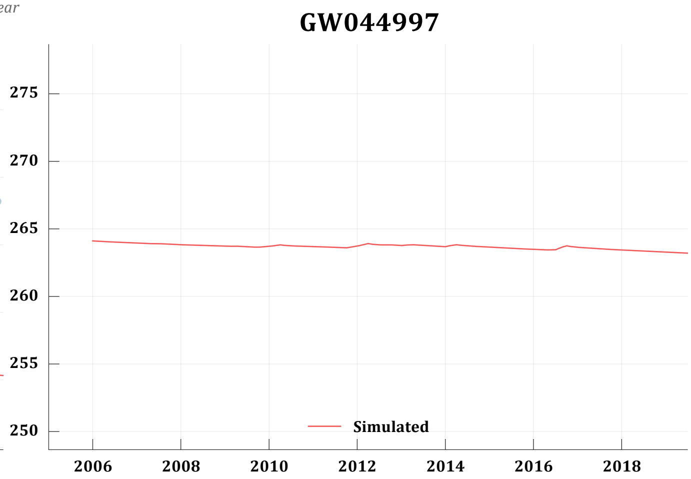
2018
Simulated
Observed


GW044997
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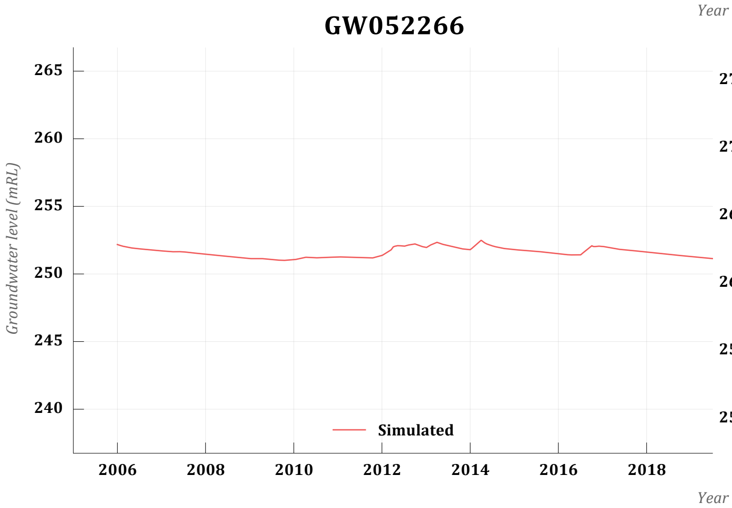
2018
Simulated
Year


GW052266
Groundwater level (mRL)
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250
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2008
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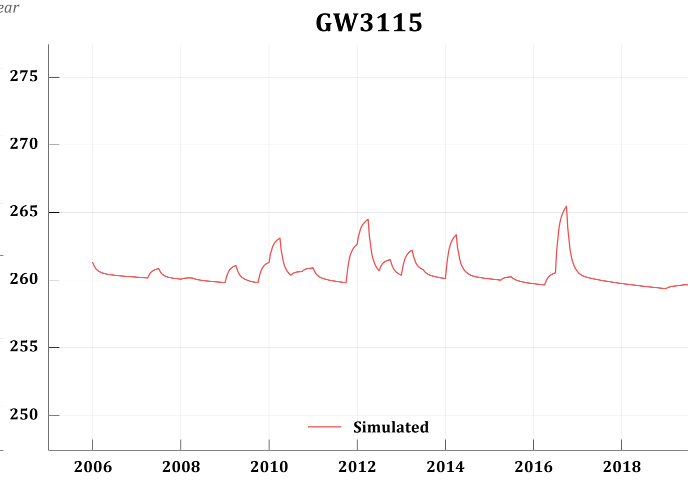
2012
2014
2016
2018
Simulated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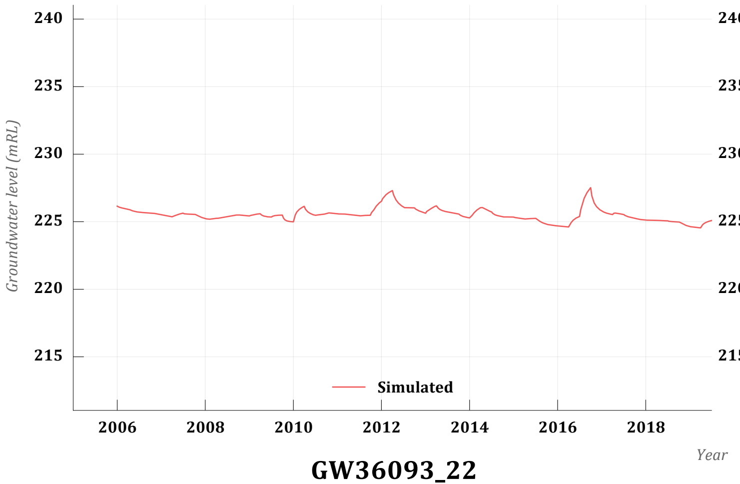
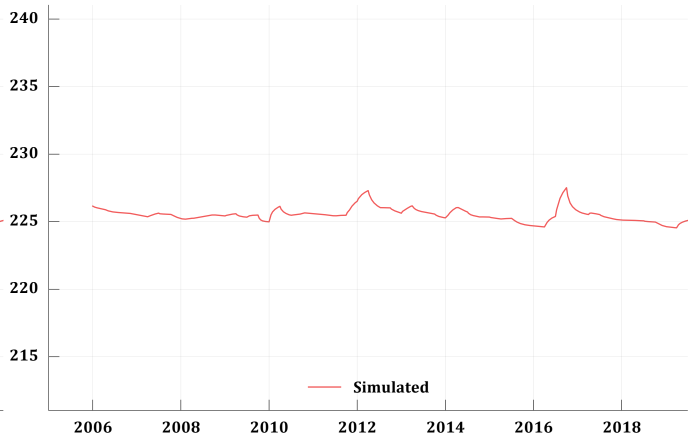
2014
2016
2018
Simulated
Year

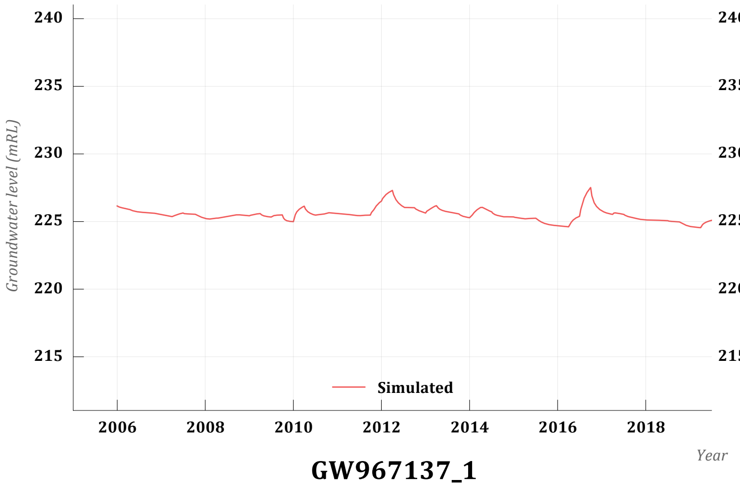
GW36093_1



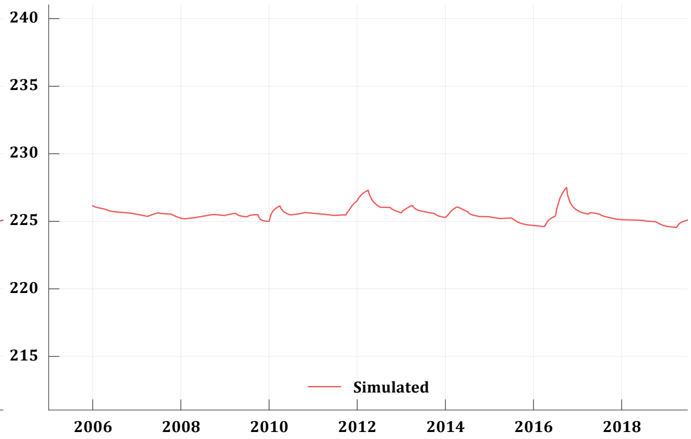
GW36093_21



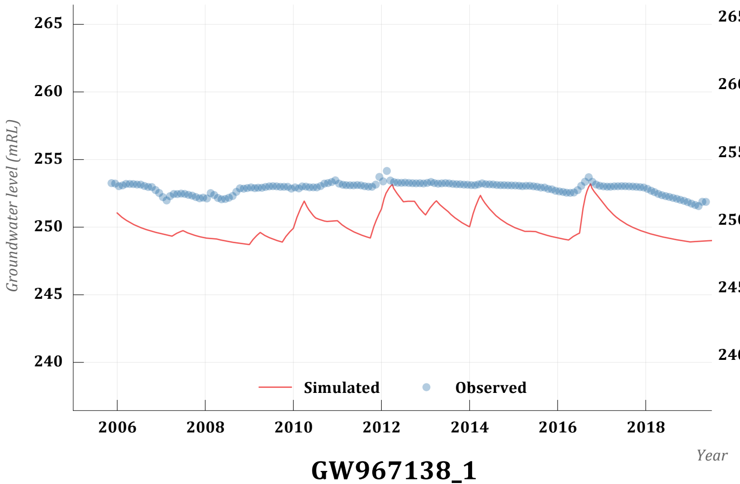
GW36093_22



GW36093_3



GW967137_1



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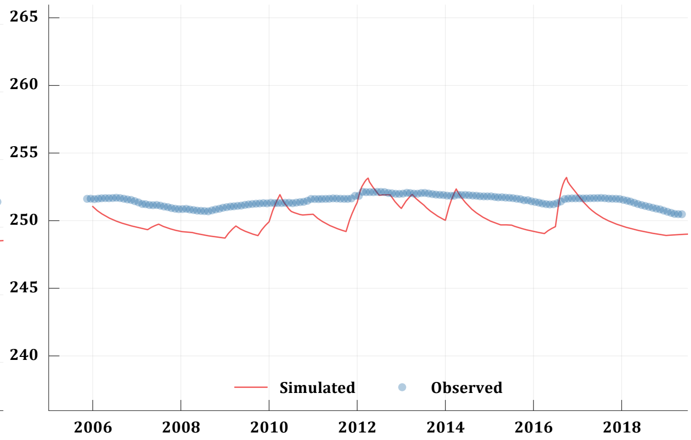

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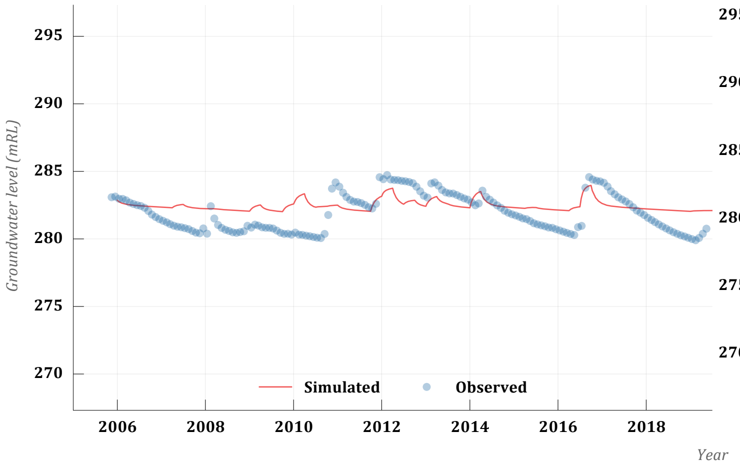

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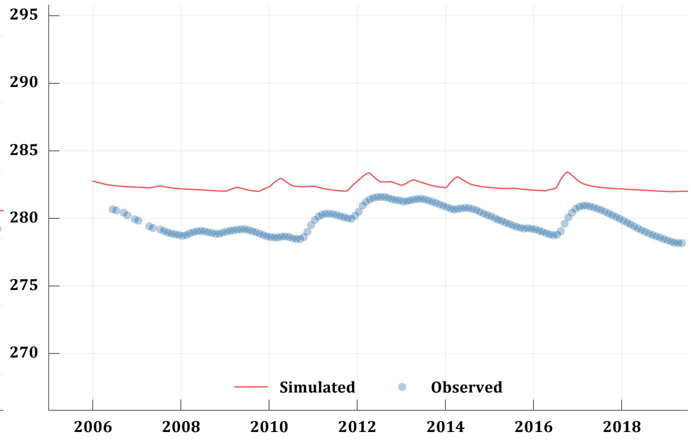

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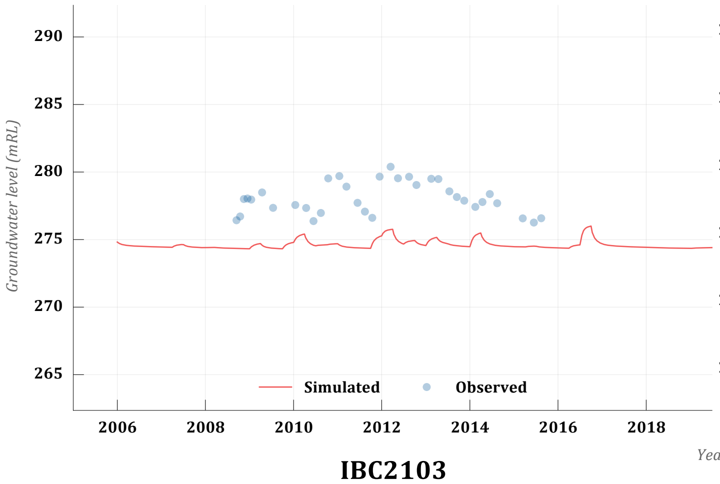

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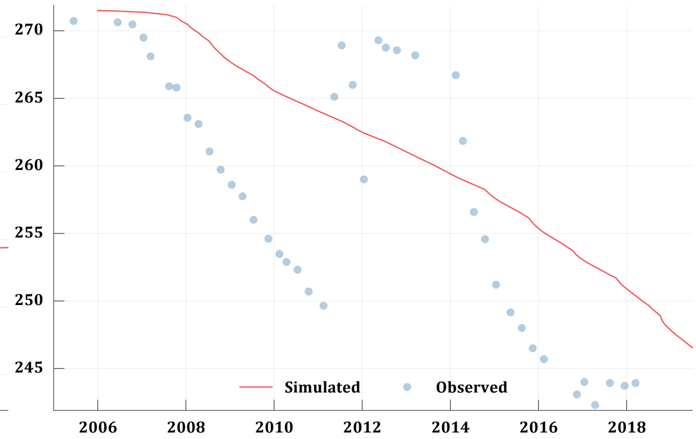

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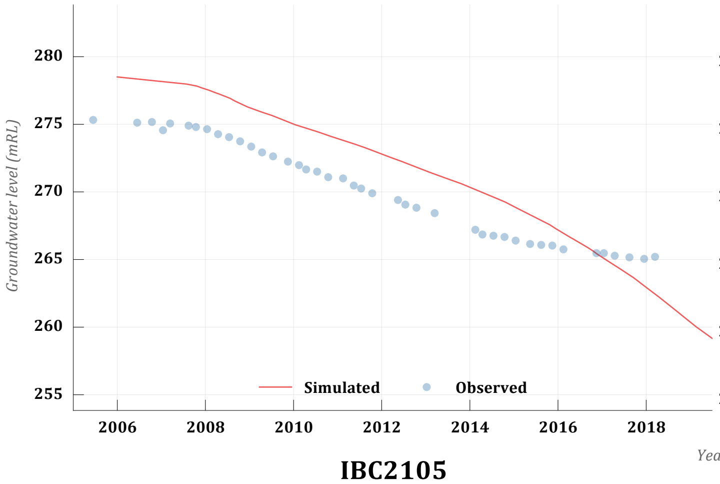

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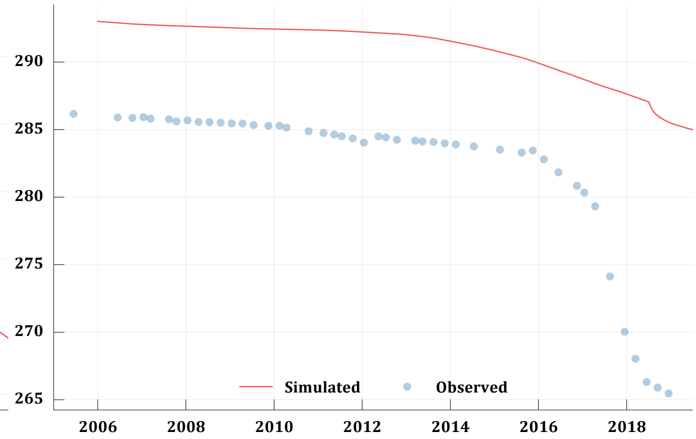

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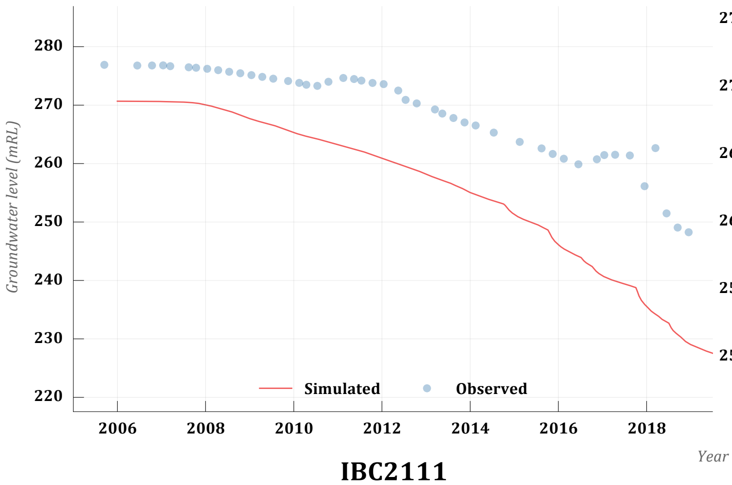

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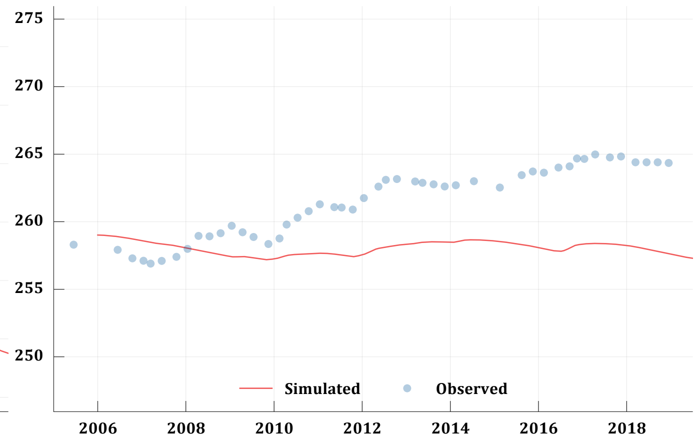

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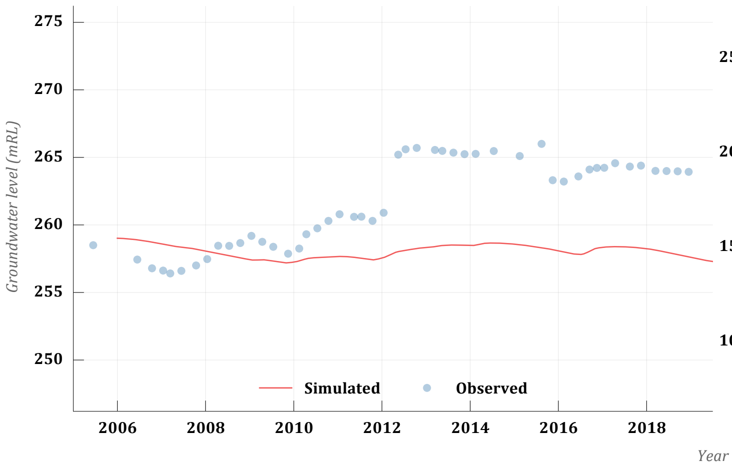

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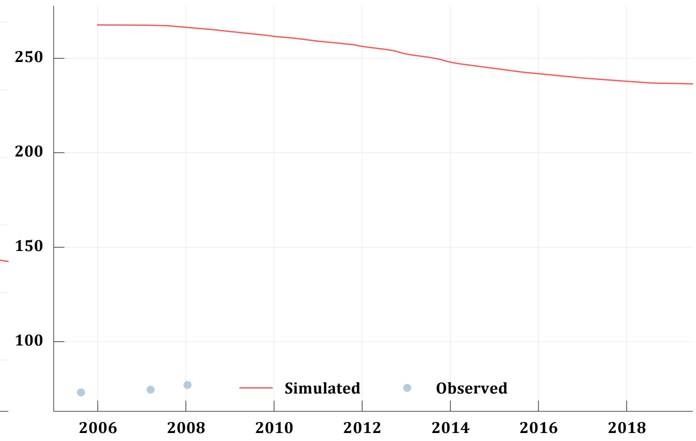

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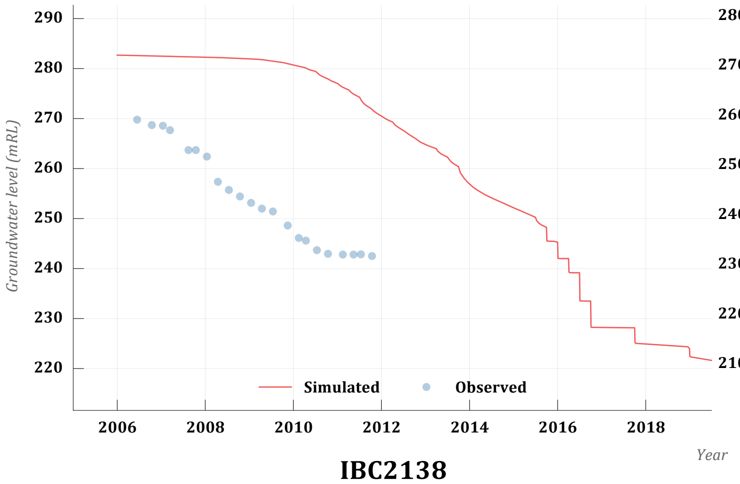

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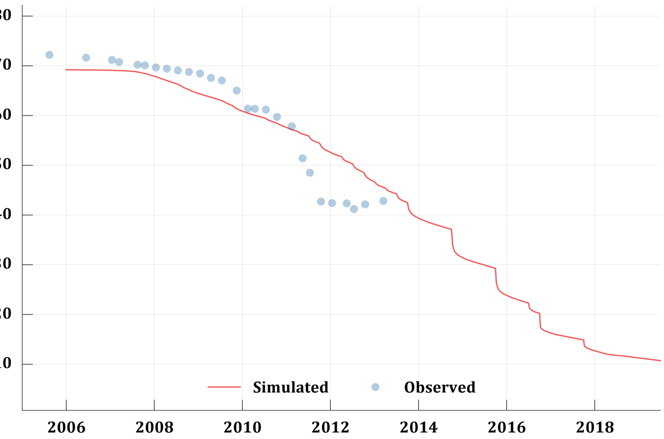
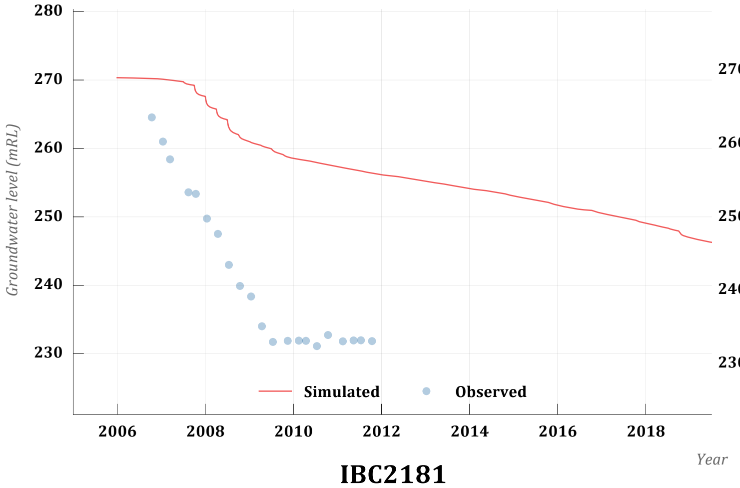
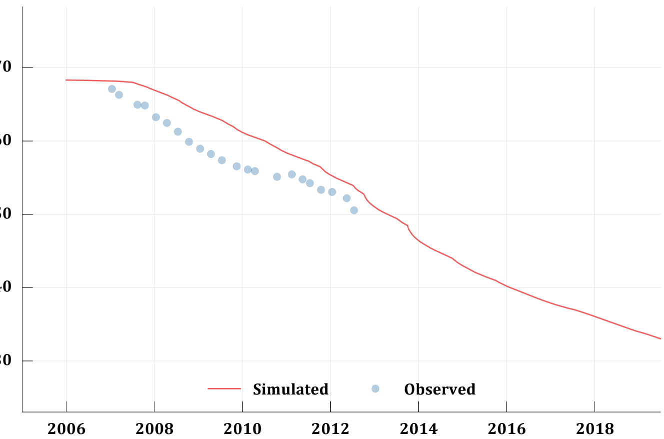


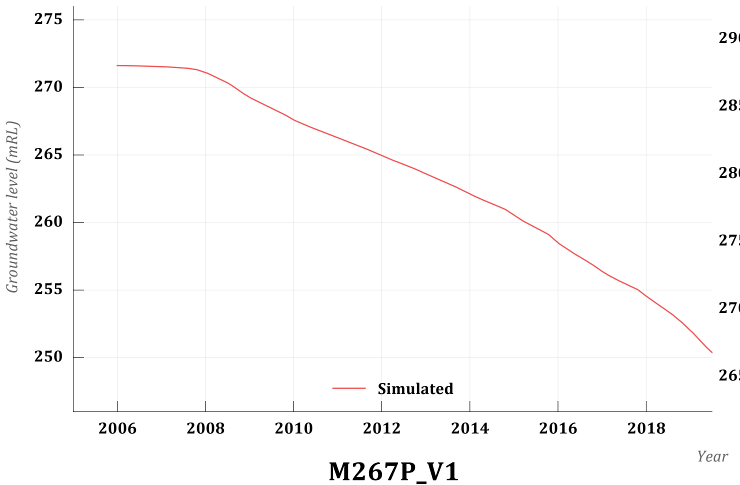
IBC2138



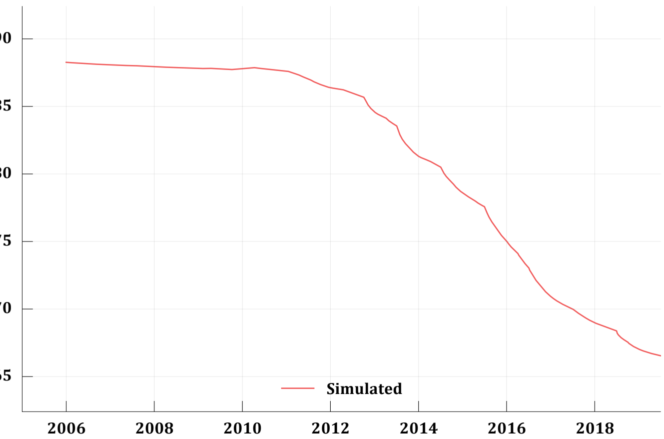
IBC2139



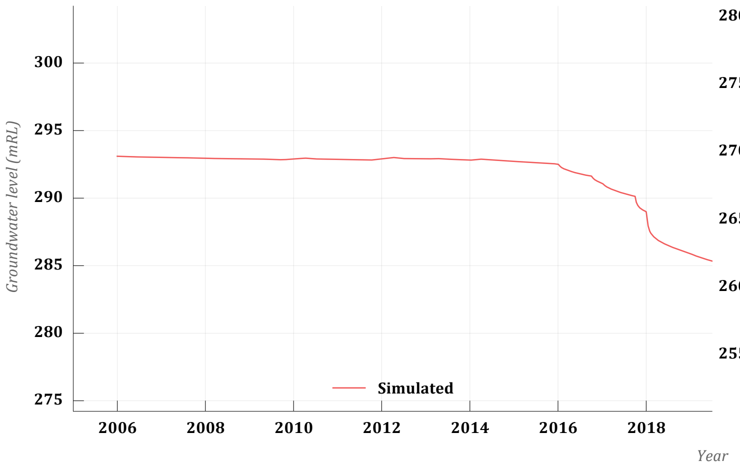
IBC2181



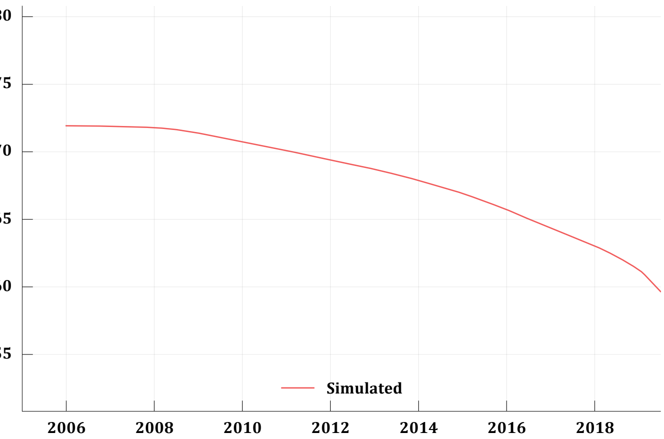
IBC2193

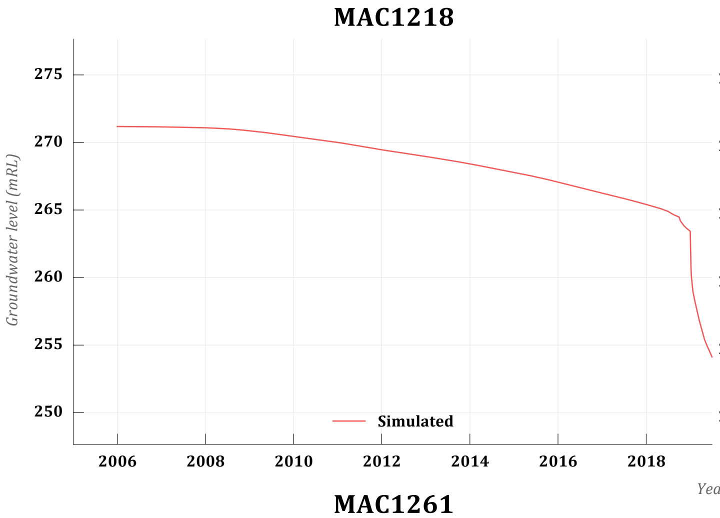


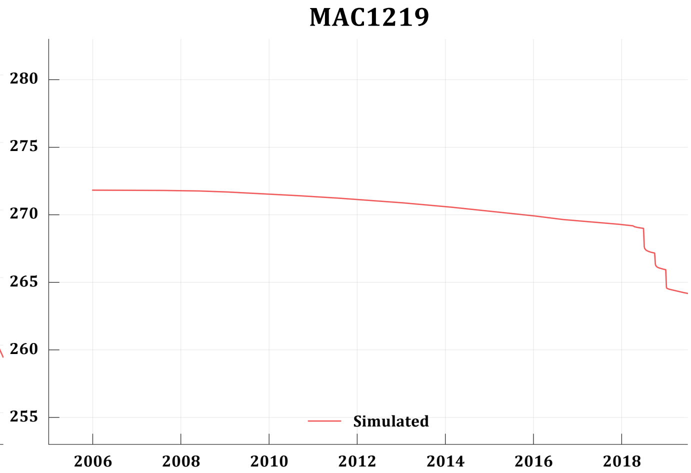
M267P_V1

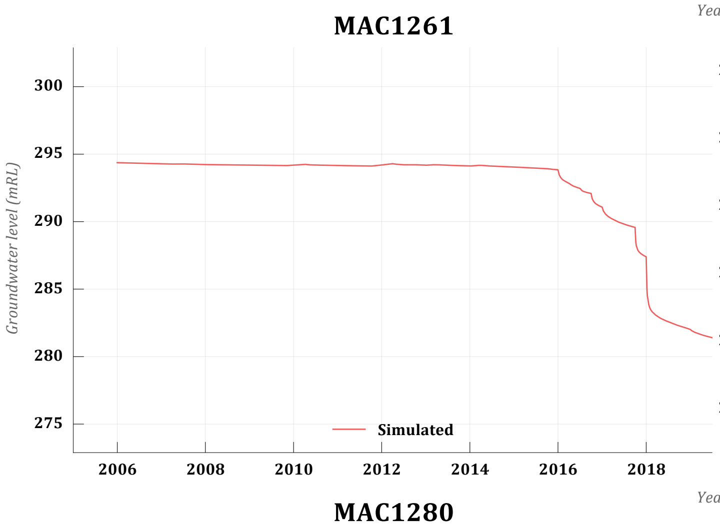


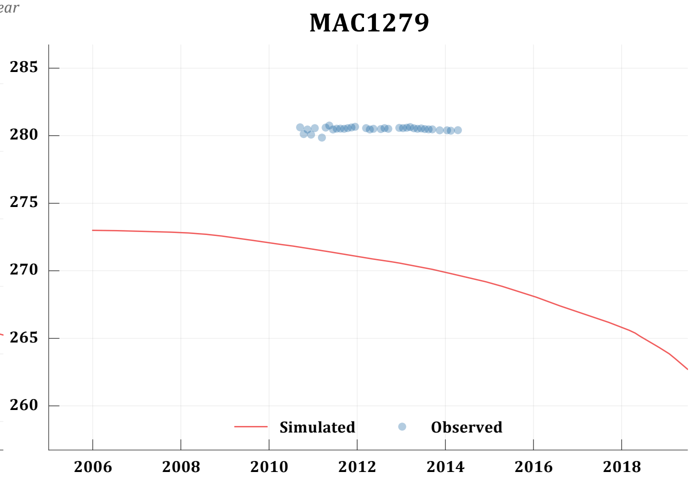
M267P_V2

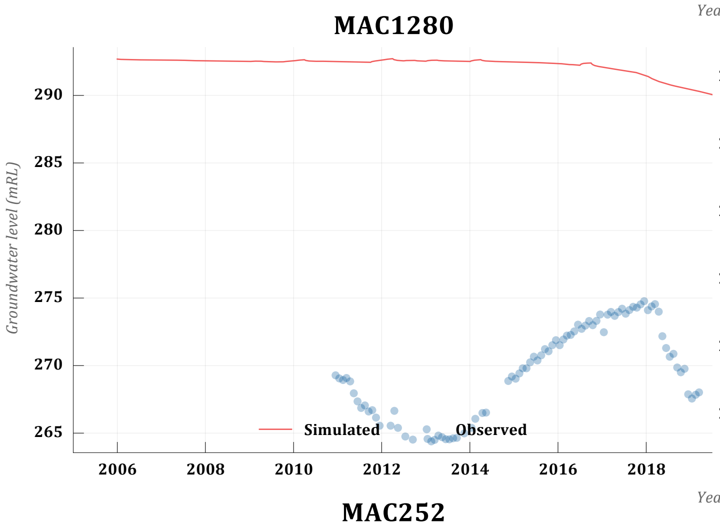


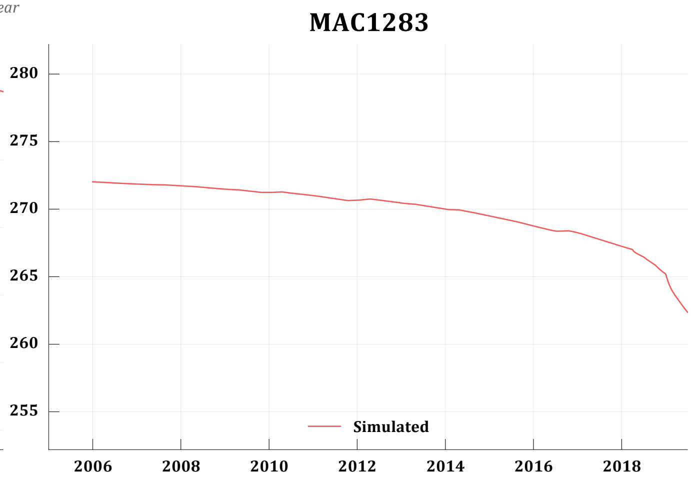

MAC1218
Groundwater level (mRL)
275
270
265
260
255
250
Simulated
2006
2008
2010
2012
2014
2016
2018
Year

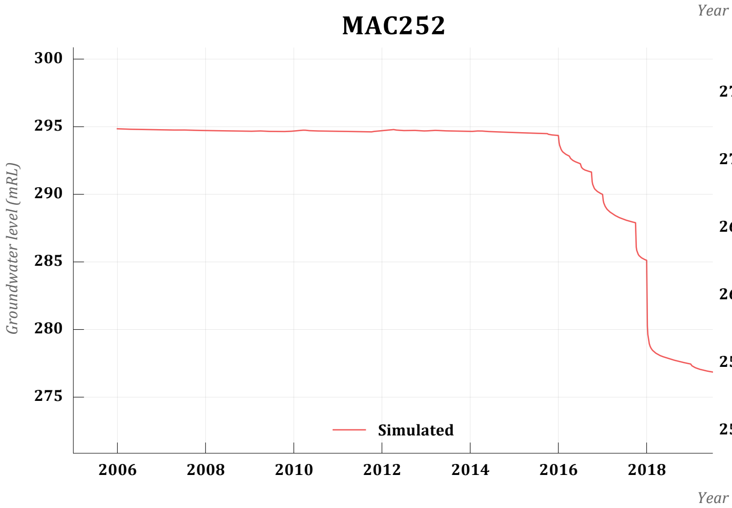

MAC1219
280
275
270
265
260
255
Simulated
2006
2008
2010
2012
2014
2016
2018

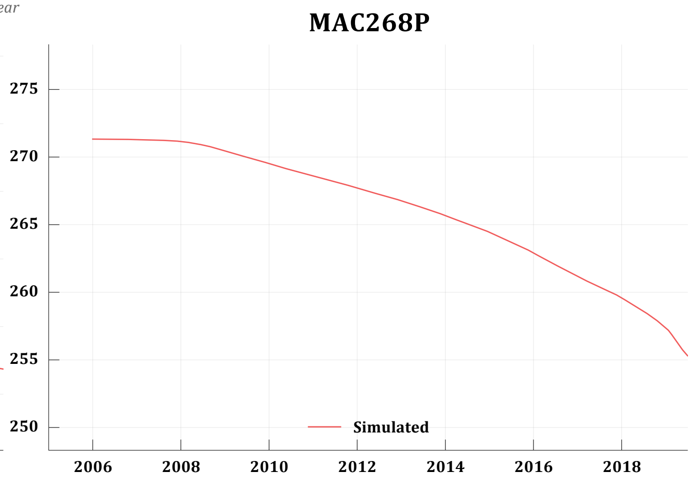

MAC1261
Groundwater level (mRL)
300
295
290
285
280
275
Simulated
2006
2008
2010
2012
2014
2016
2018
Year

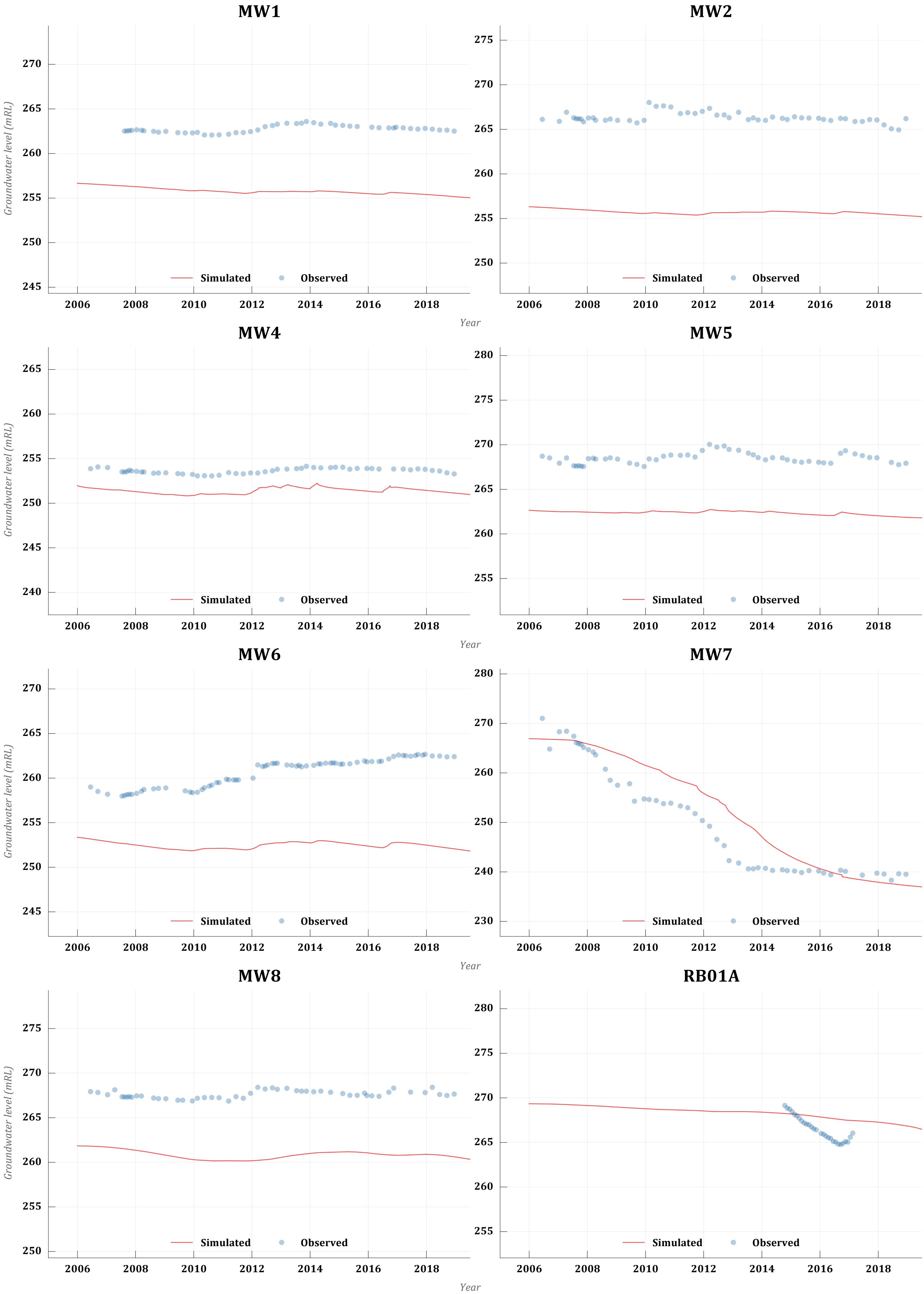

MAC1279
285
280
275
270
265
260
Simulated
Observed
2006
2008
2010
2012
2014
2016
2018


MAC1280
Groundwater level (mRL)
290
285
280
275
270
265
Simulated
Observed
2006
2008
2010
2012
2014
2016
2018
Year

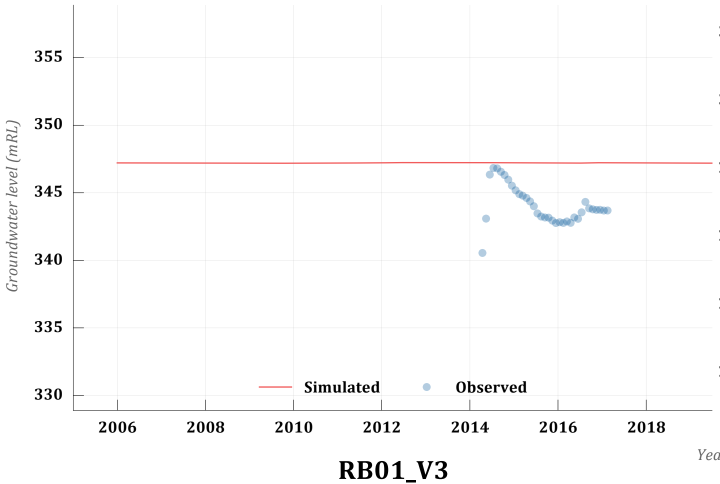

MAC1283
280
275
270
265
260
255
Simulated
2006
2008
2010
2012
2014
2016
2018


MAC252
Groundwater level (mRL)
300
295
290
285
280
275
Simulated
2006
2008
2010
2012
2014
2016
2018
Year

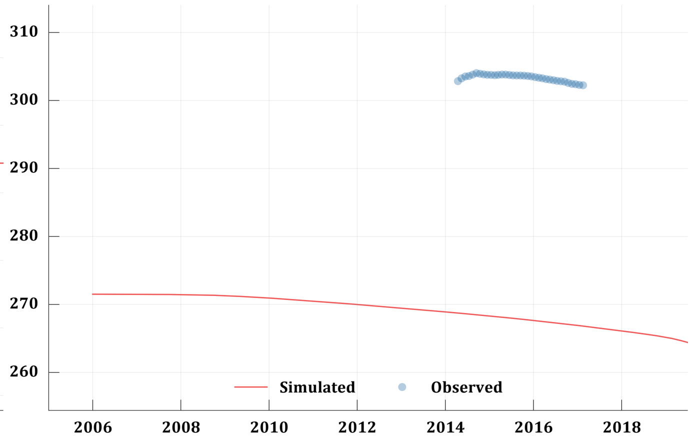

MAC268P
275
270
265
260
255
250
Simulated
2006
2008
2010
2012
2014
2016
2018


MW1
MW2
MW4
MW5
MW6
MW7
MW8
RB01A
Groundwater level (mRL)
Year
Simulated
Observed
2006
2008
2010
2012
2014
2016
2018

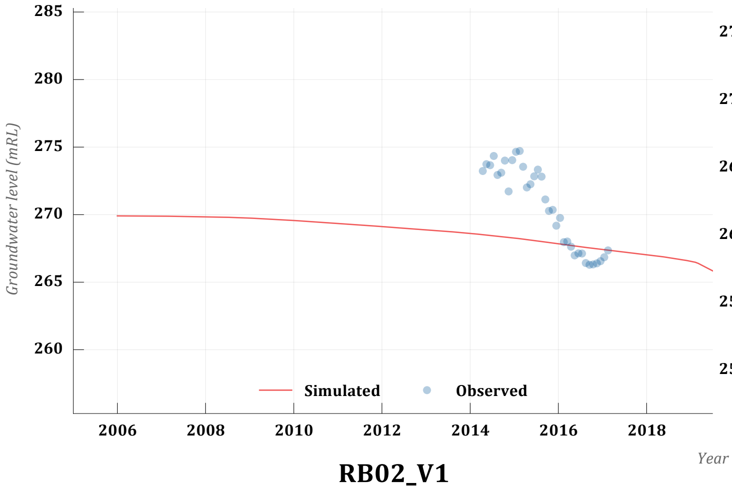
RB01_V1



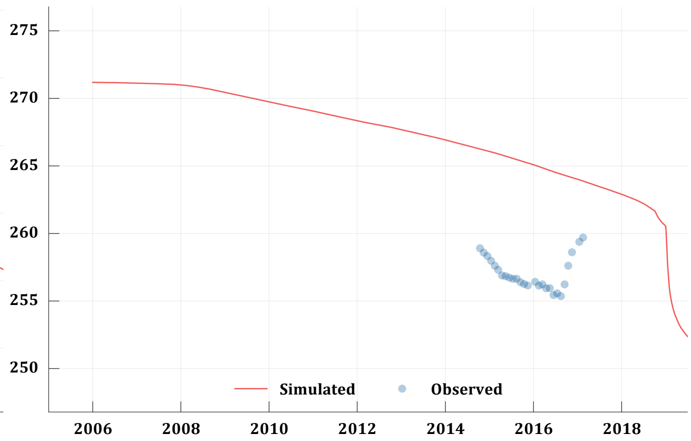
RB01_V2



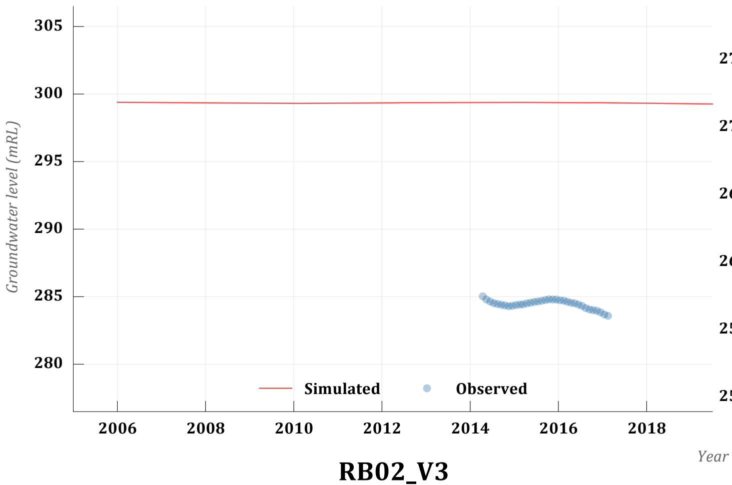
RB01_V3



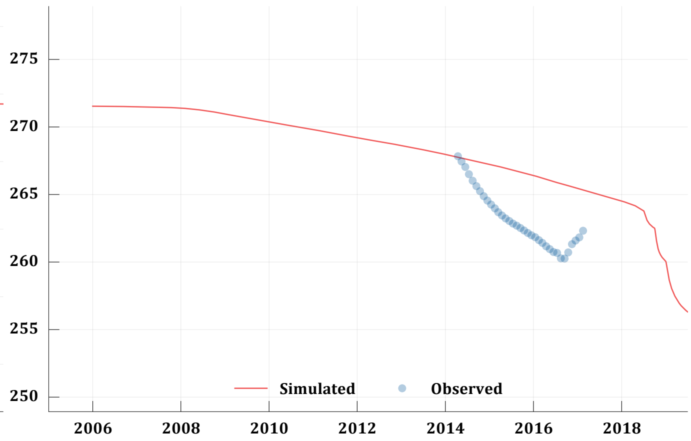
RB02A



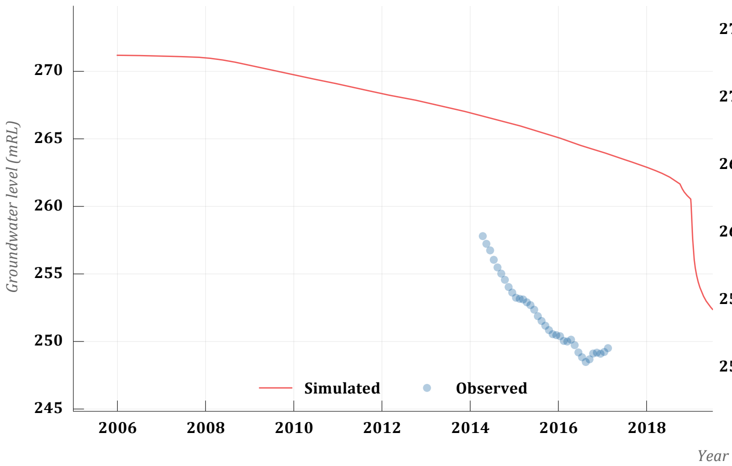
RB02_V1



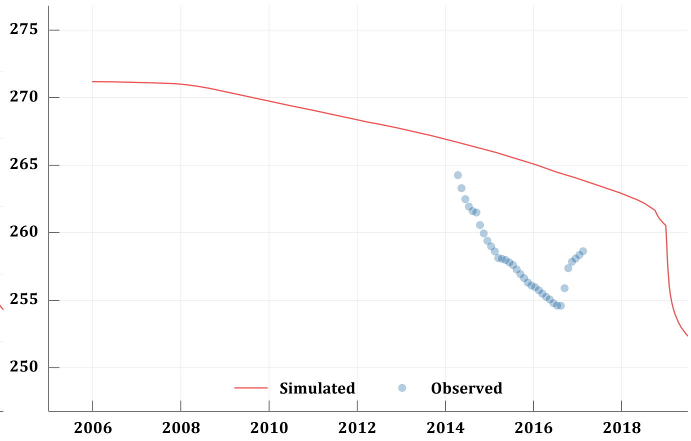
RB02_V2

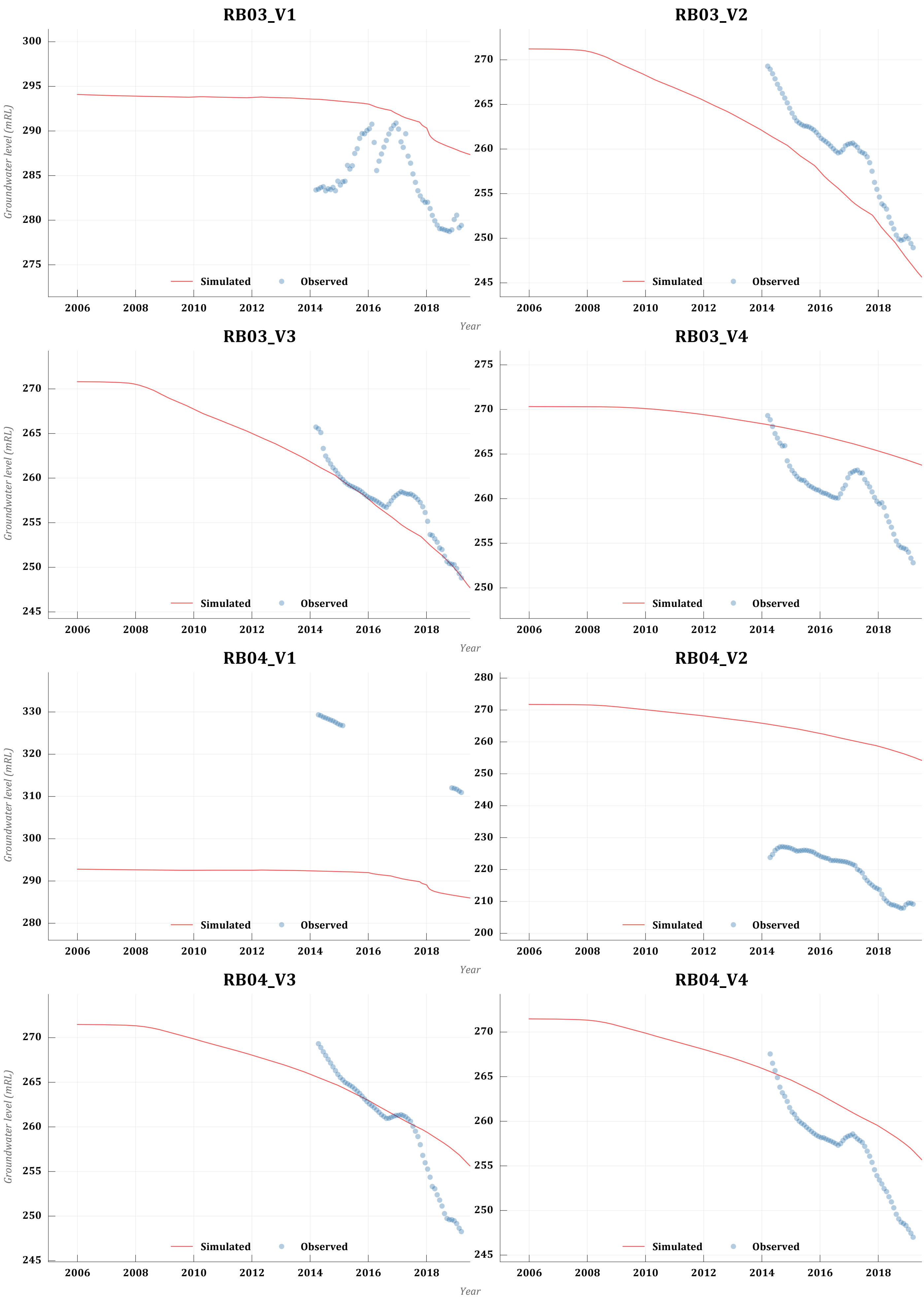


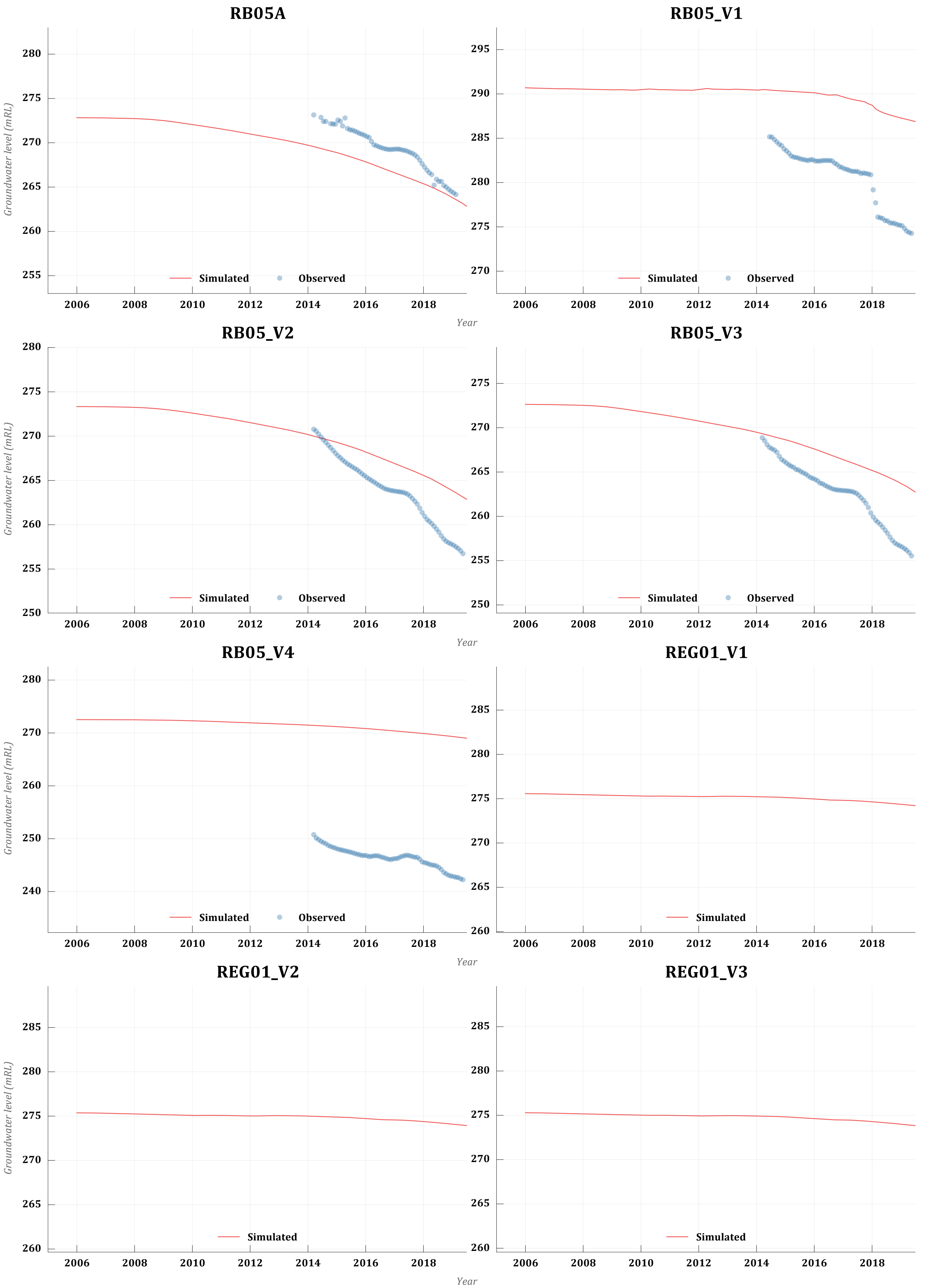
RB02_V3



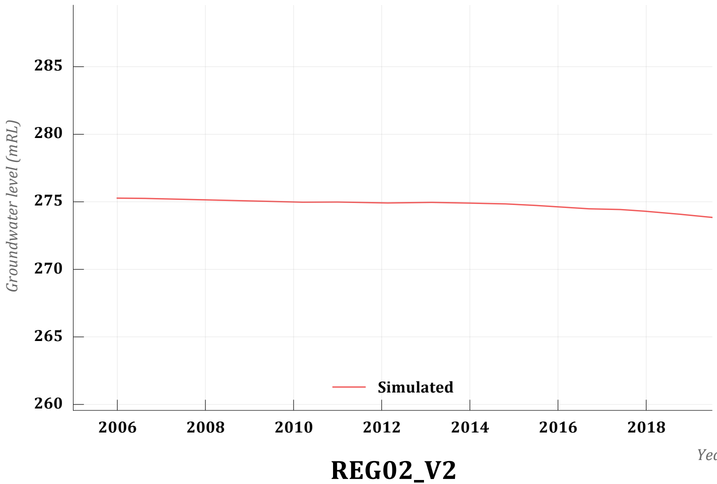
RB02_V4



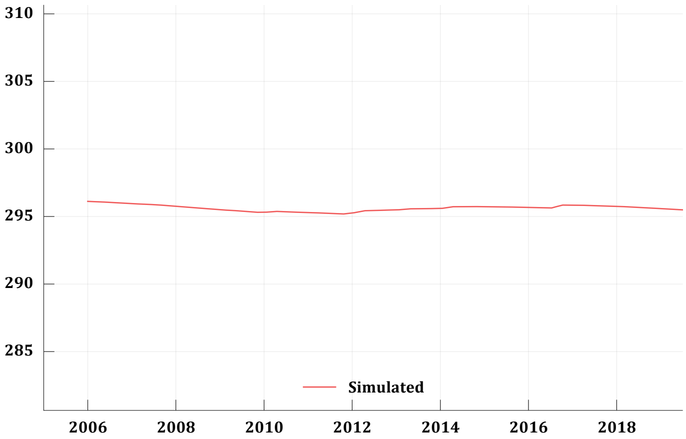

RB03_V1
RB03_V2
RB03_V3
RB03_V4
RB04_V1
RB04_V2
RB04_V3
RB04_V4
Groundwater level (mRL)
Year
Simulated
Observed
2006
2008
2010
2012
2014
2016
2018


RB05A
Groundwater level (mRL)
280
275
270
265
260
255
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed
Year
RB05_V1
295
290
285
280
275
270
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed
RB05_V2
Groundwater level (mRL)
280
275
270
265
260
255
250
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed
Year
RB05_V3
275
270
265
260
255
250
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed
RB05_V4
Groundwater level (mRL)
280
270
260
250
240
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed
Year
REG01_V1
285
280
275
270
265
260
2006
2008
2010
2012
2014
2016
2018
Simulated
REG01_V2
Groundwater level (mRL)
285
280
275
270
265
260
2006
2008
2010
2012
2014
2016
2018
Simulated
Year
REG01_V3
285
280
275
270
265
260
2006
2008
2010
2012
2014
2016
2018
Simulated

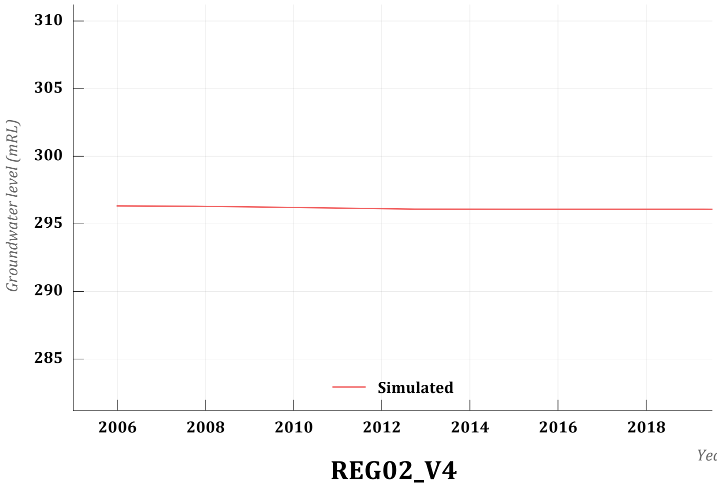
REG01_V4



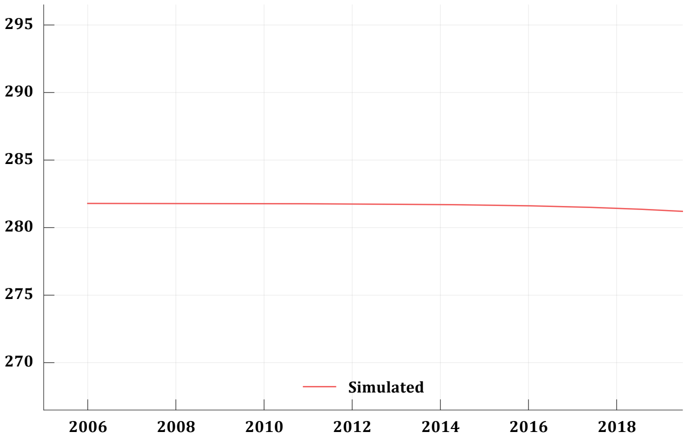
REG02_V1



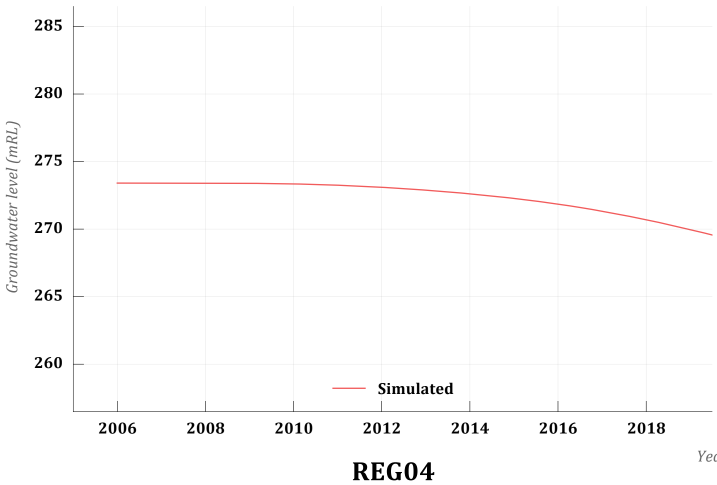
REG02_V2



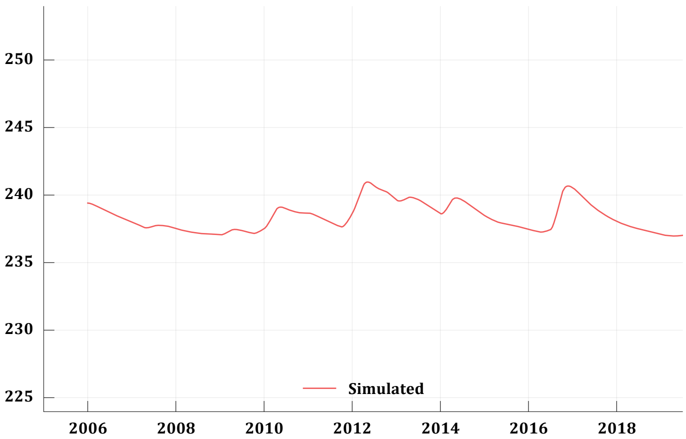
REG02_V3



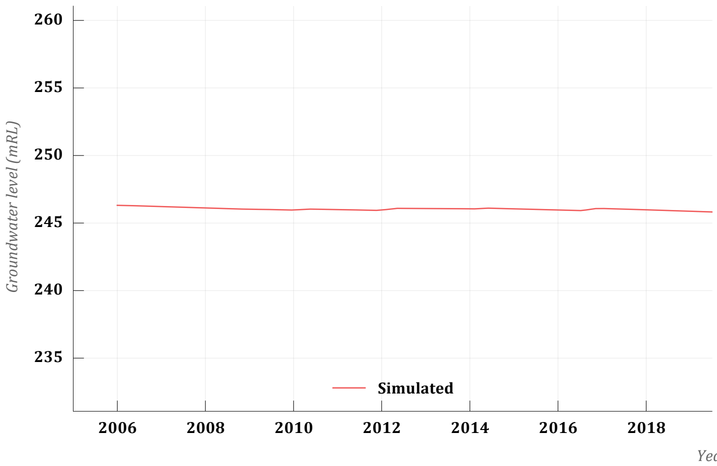
REG02_V4



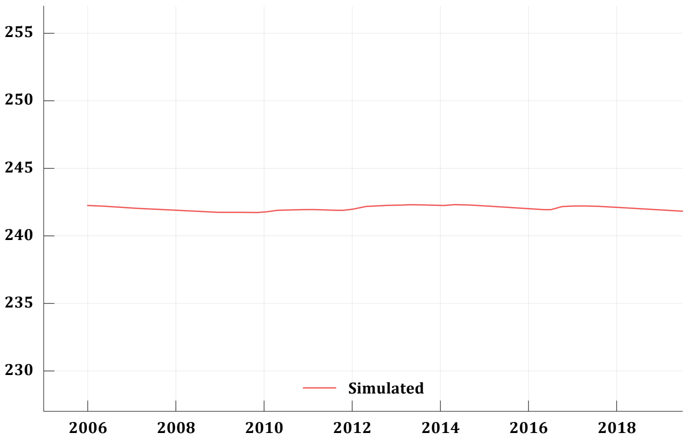
REG03



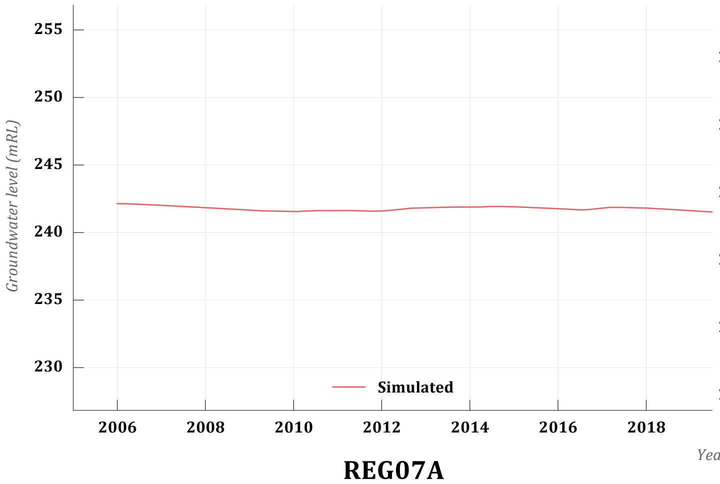
REG04



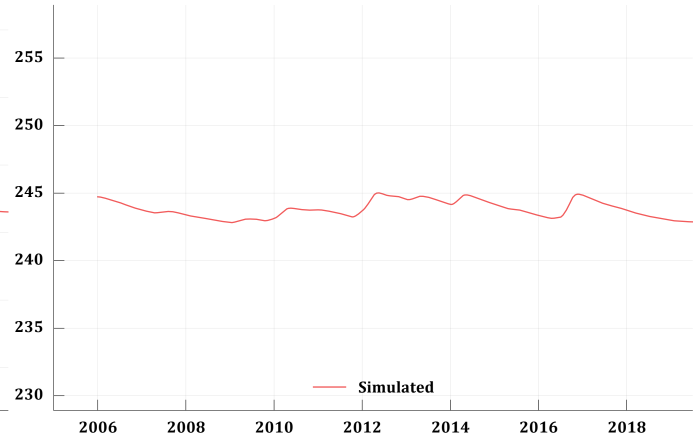
REG05A



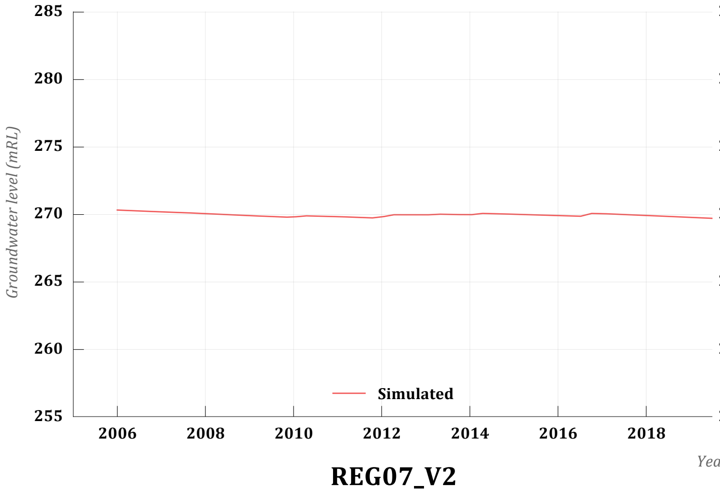
REG05B



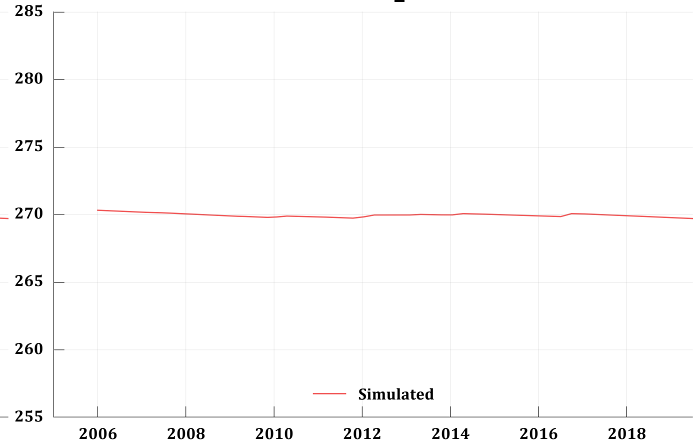
REG06



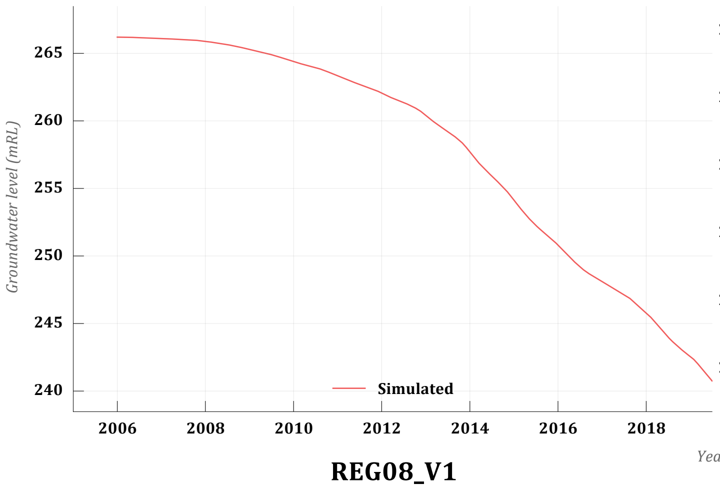
REG07A



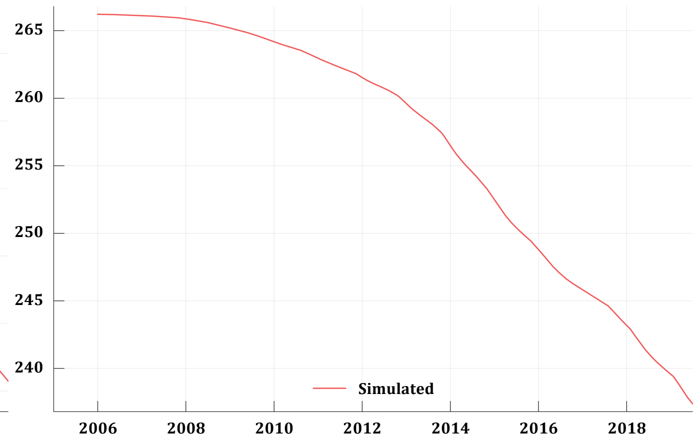
REG07_V1



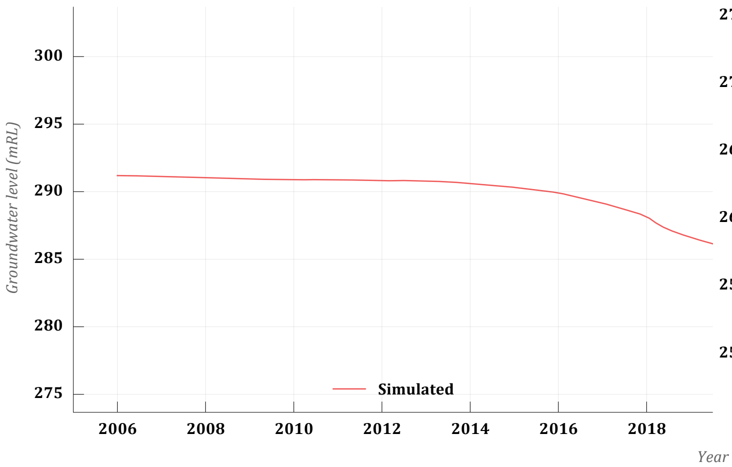
REG07_V2



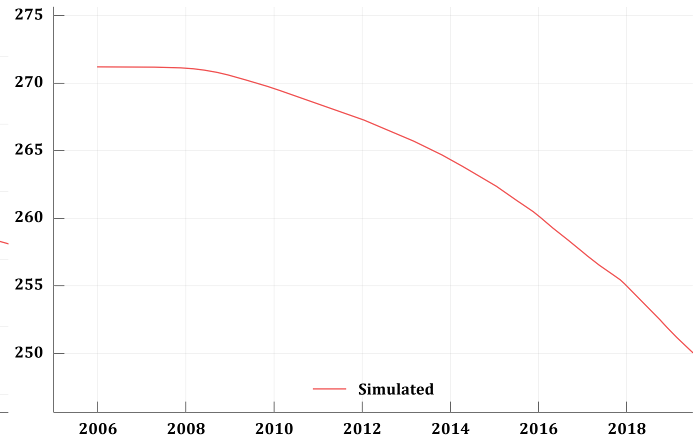
REG07_V3

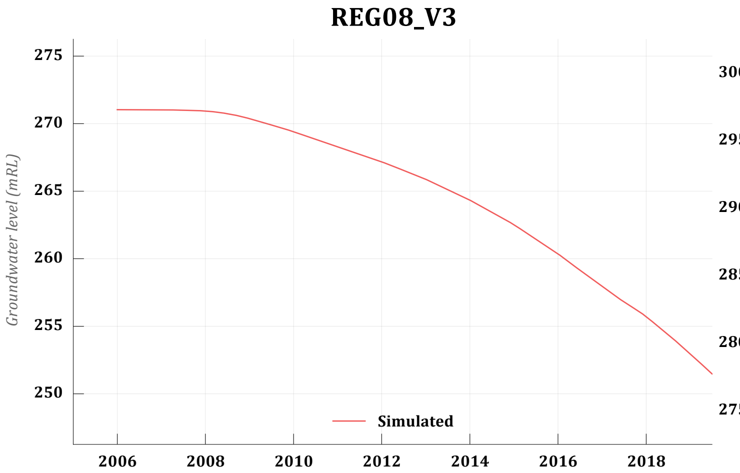


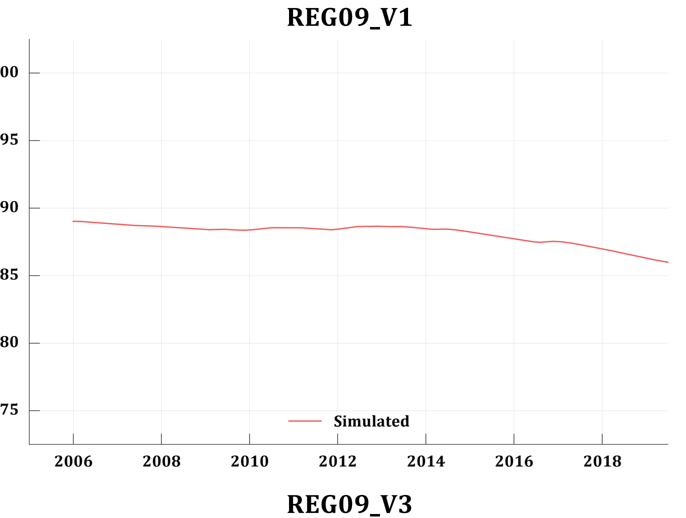
REG08_V1

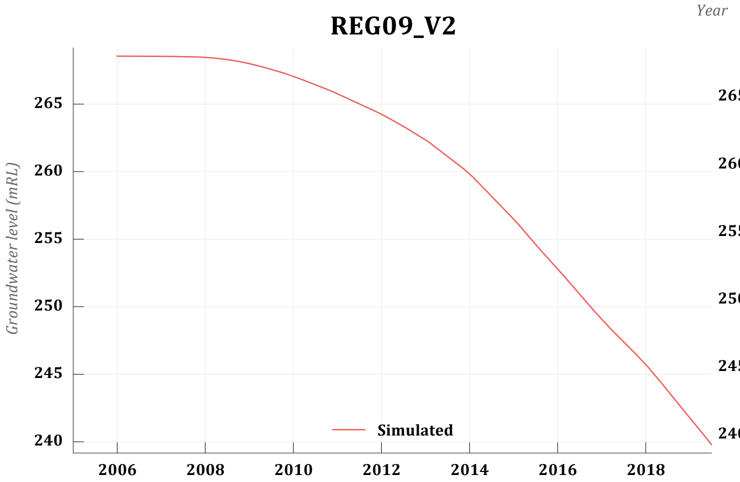


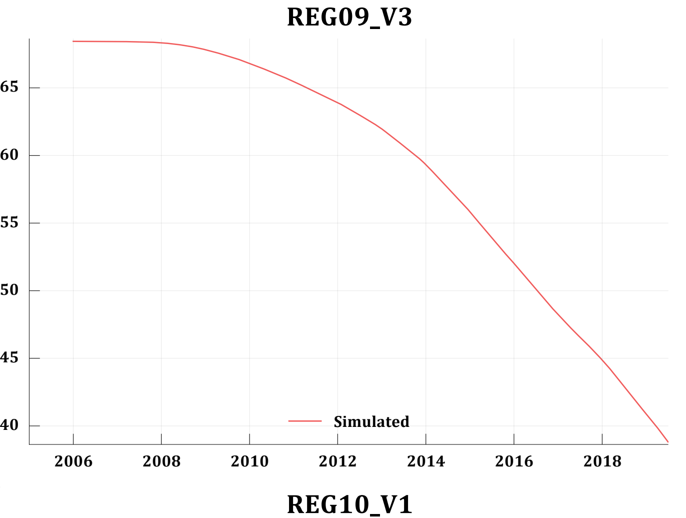
REG08_V2

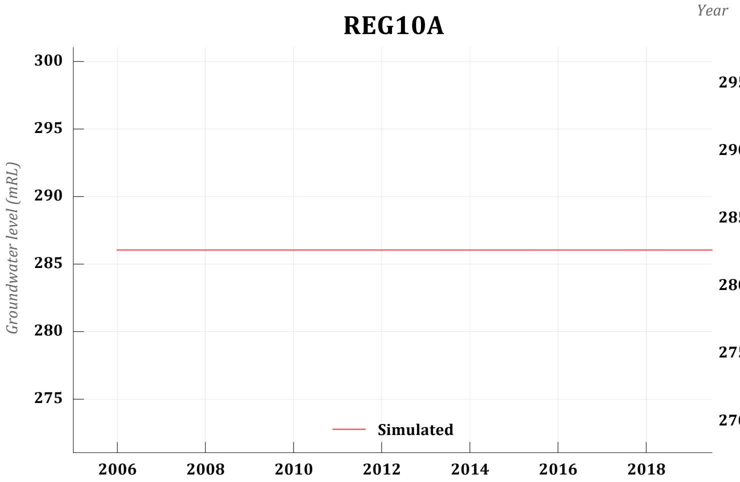


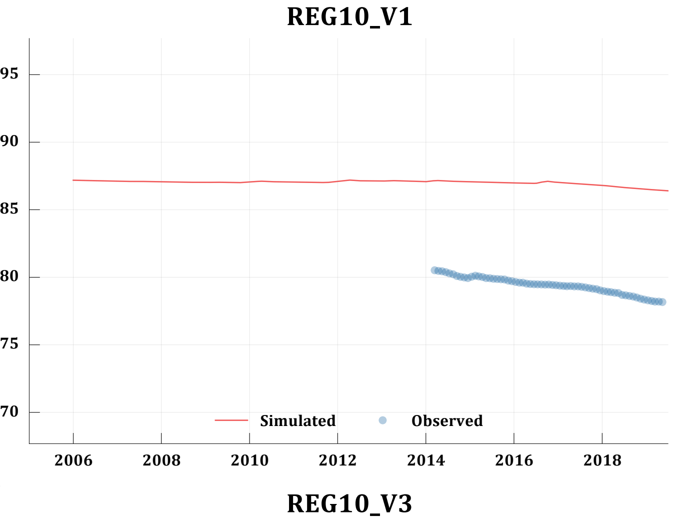

REG08_V3
Groundwater level (mRL)
275
270
265
260
255
250
2006
2008
2010
2012
2014
2016
2018
Simulated

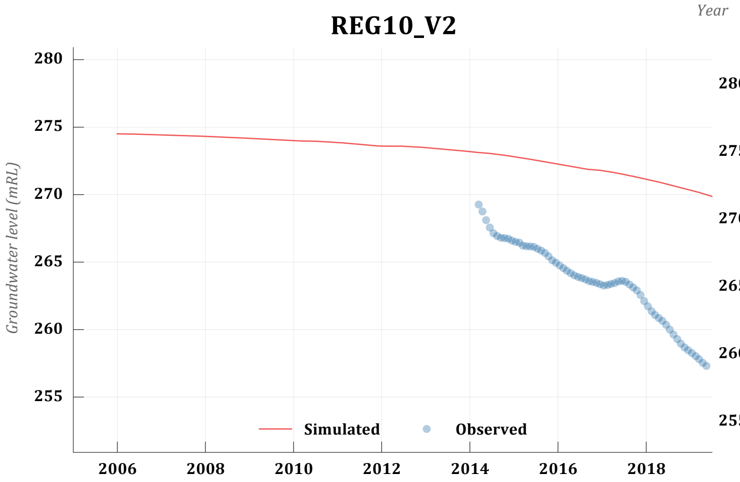

REG09_V1
300
295
290
285
280
275
2006
2008
2010
2012
2014
2016
2018
Simulated
Year

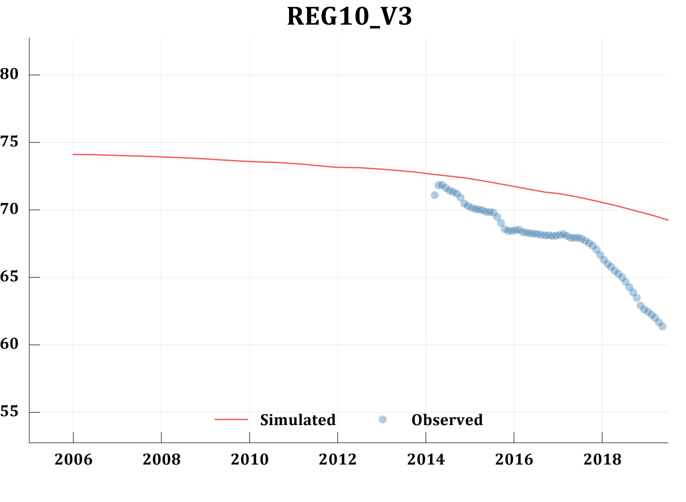

REG09_V2
Groundwater level (mRL)
265
260
255
250
245
240
2006
2008
2010
2012
2014
2016
2018
Simulated

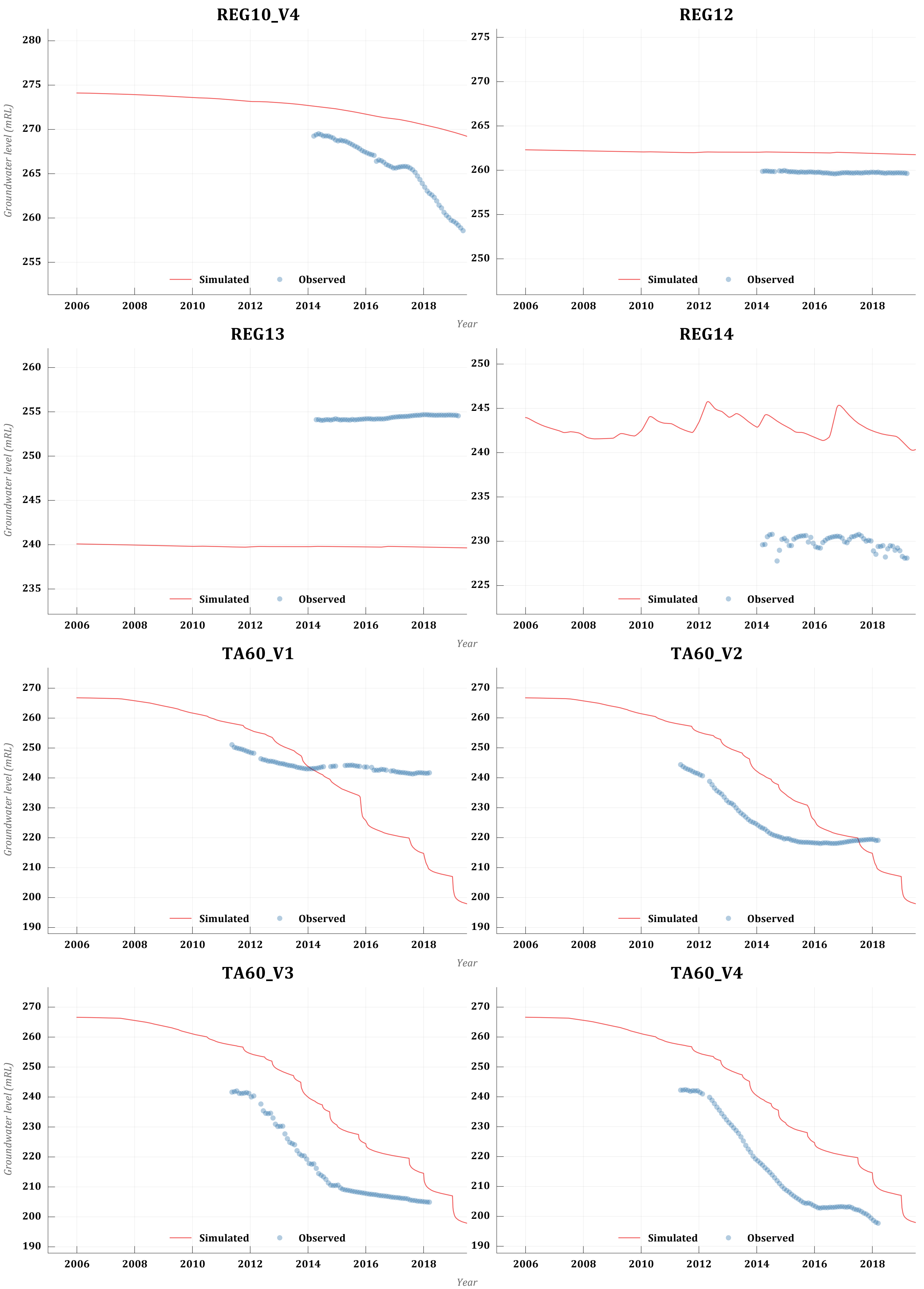

REG09_V3
265
260
255
250
245
240
2006
2008
2010
2012
2014
2016
2018
Simulated
Year

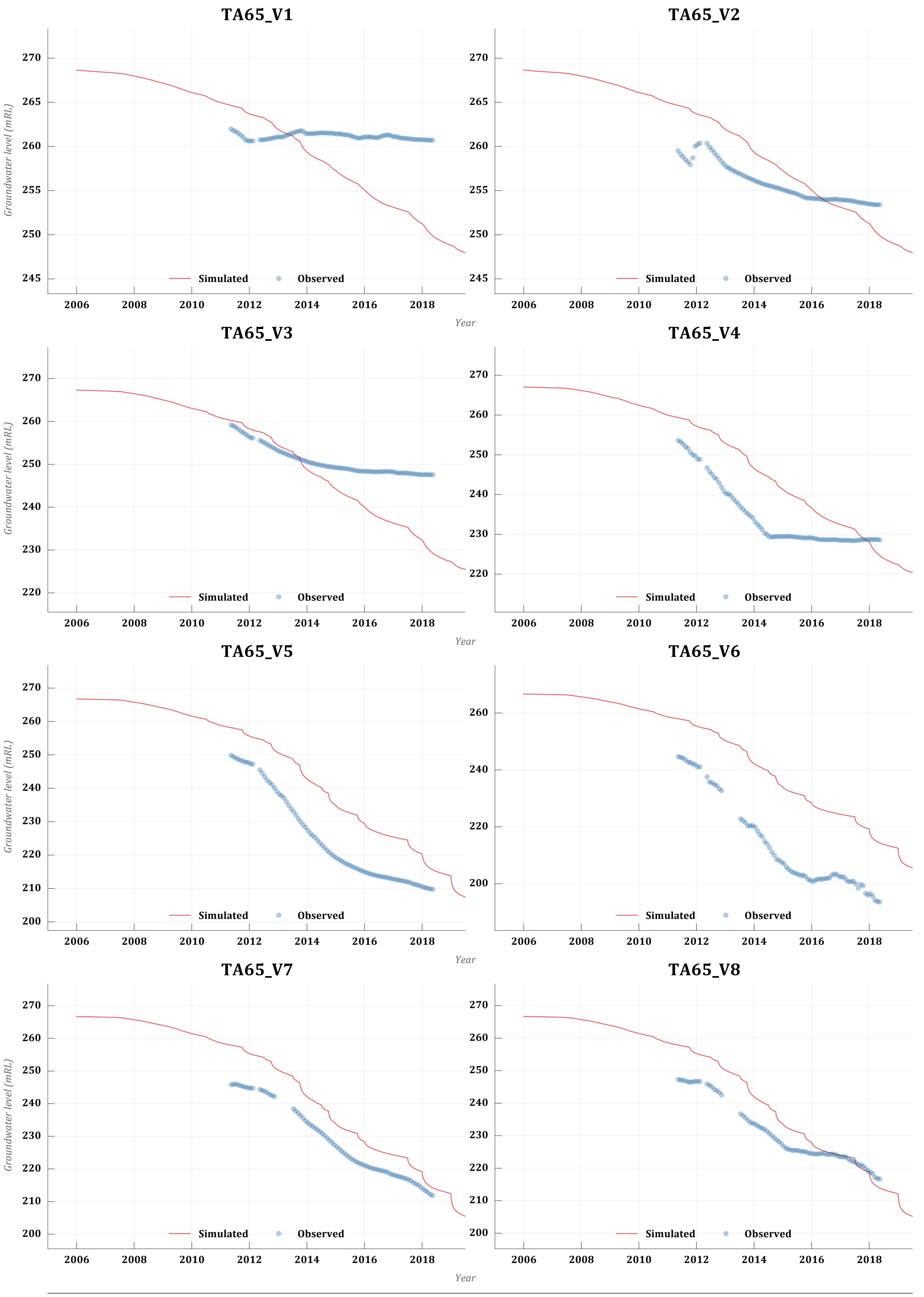

REG10A
Groundwater level (mRL)
300
295
290
285
280
275
2006
2008
2010
2012
2014
2016
2018
Simulated

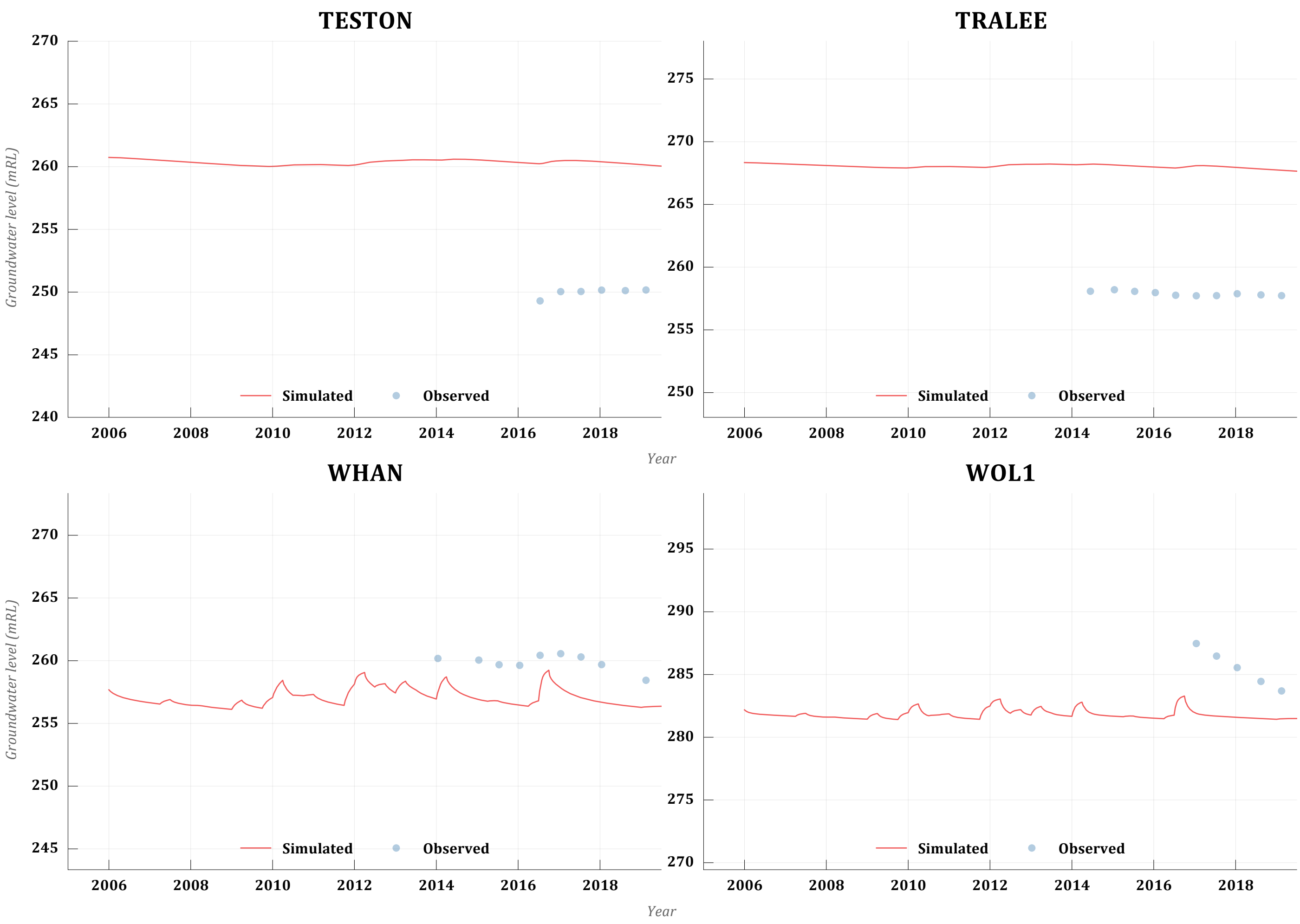

REG10_V1
295
290
285
280
275
270
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed
Year


REG10_V2
Groundwater level (mRL)
280
275
270
265
260
255
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed


REG10_V3
280
275
270
265
260
255
2006
2008
2010
2012
2014
2016
2018
Simulated
Observed
Year

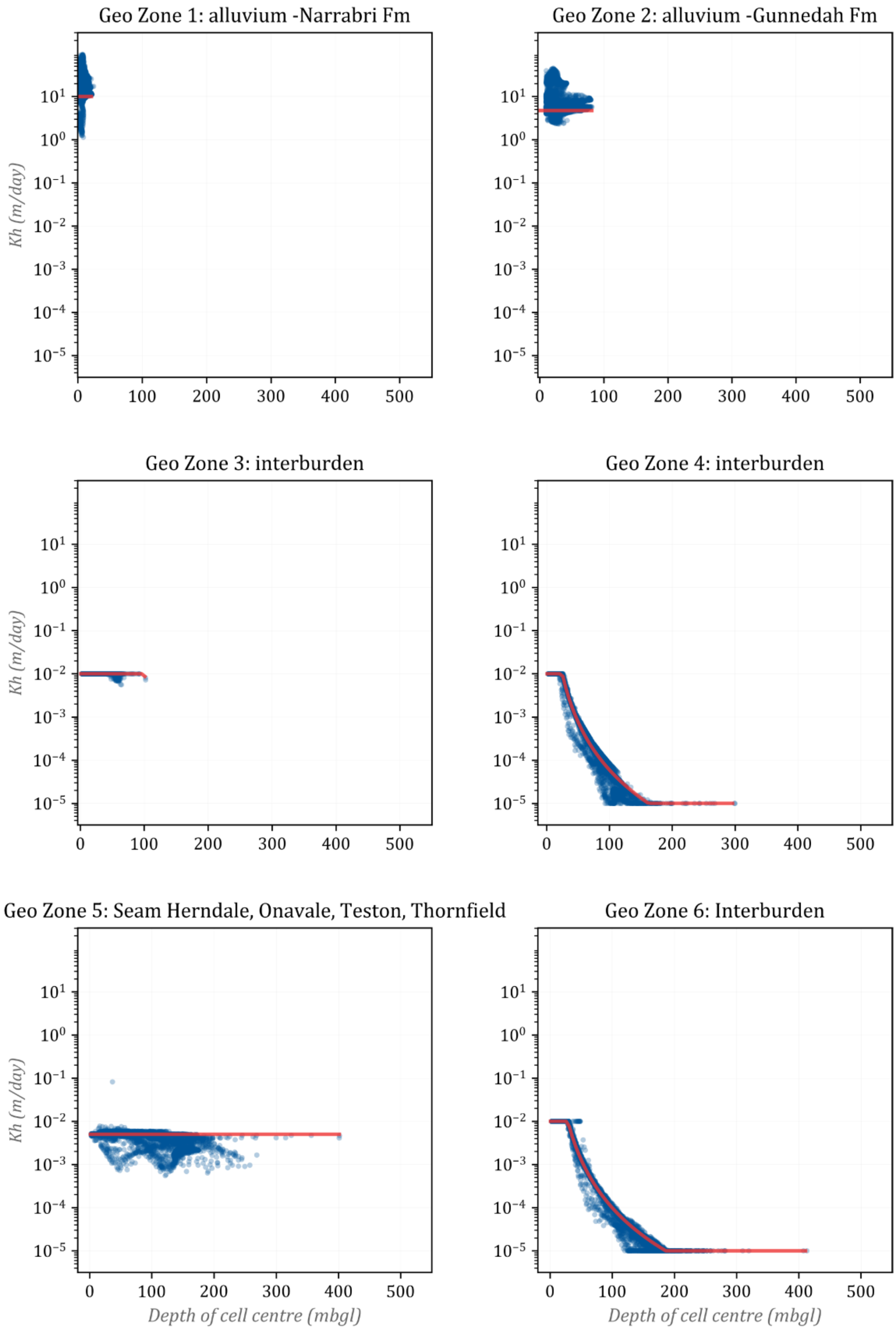

REG10_V4
REG12
REG13
REG14
TA60_V1
TA60_V2
TA60_V3
TA60_V4
Groundwater level (mRL)
Year
Simulated
Observed
2006
2008
2010
2012
2014
2016
2018


TA65_V1
TA65_V2
TA65_V3
TA65_V4
TA65_V5
TA65_V6
TA65_V7
TA65_V8
Groundwater level (mRL)
Year
Simulated
Observed
2006
2008
2010
2012
2014
2016
2018

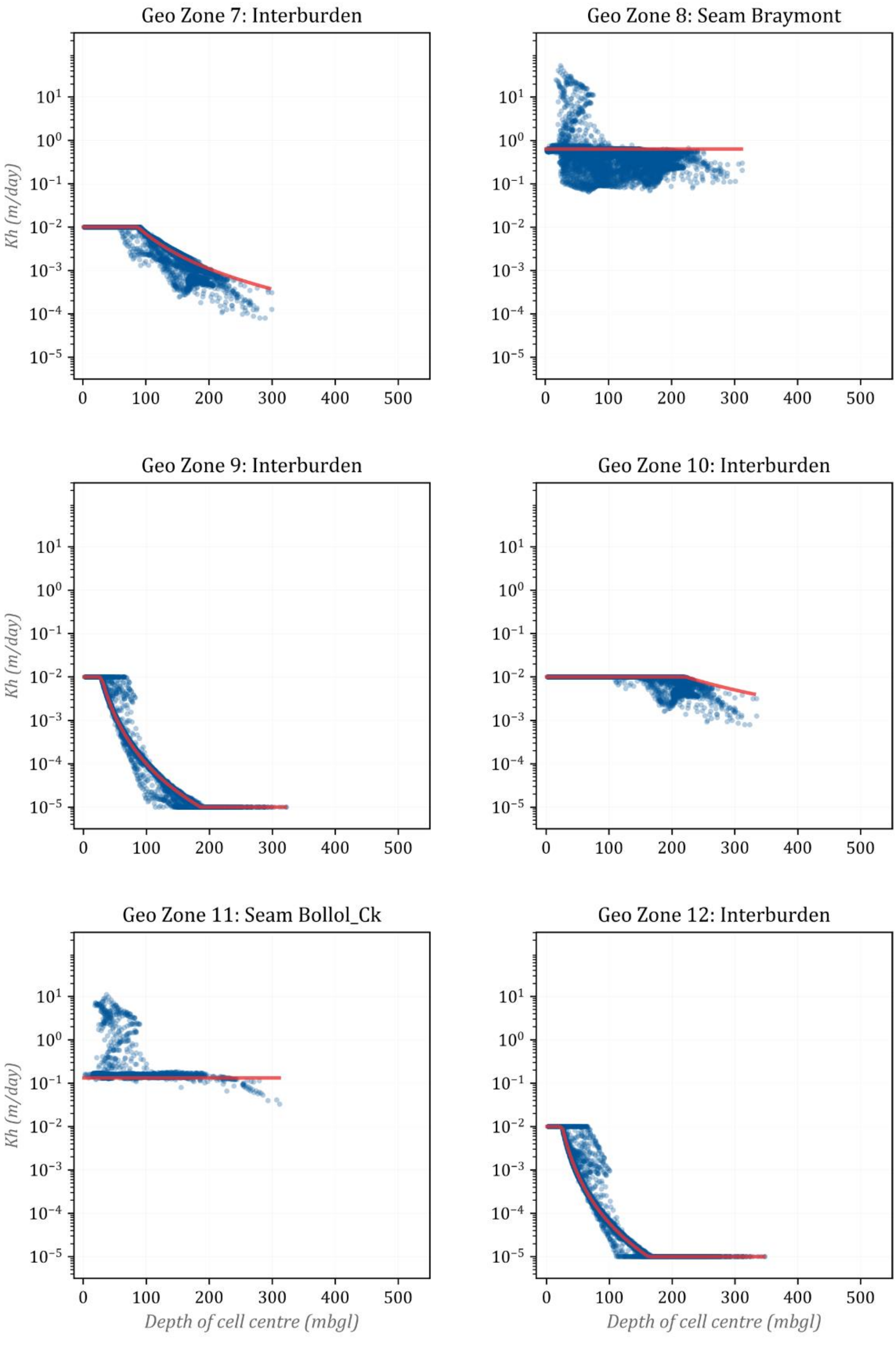

TESTON
TRALEE
WHAN
WOL1
Groundwater level (mRL)
Year
Simulated
Observed
2006
2008
2010
2012
2014
2016
2018
240
245
250
255
260
265
270
275
280
285
290
295

Appendix F

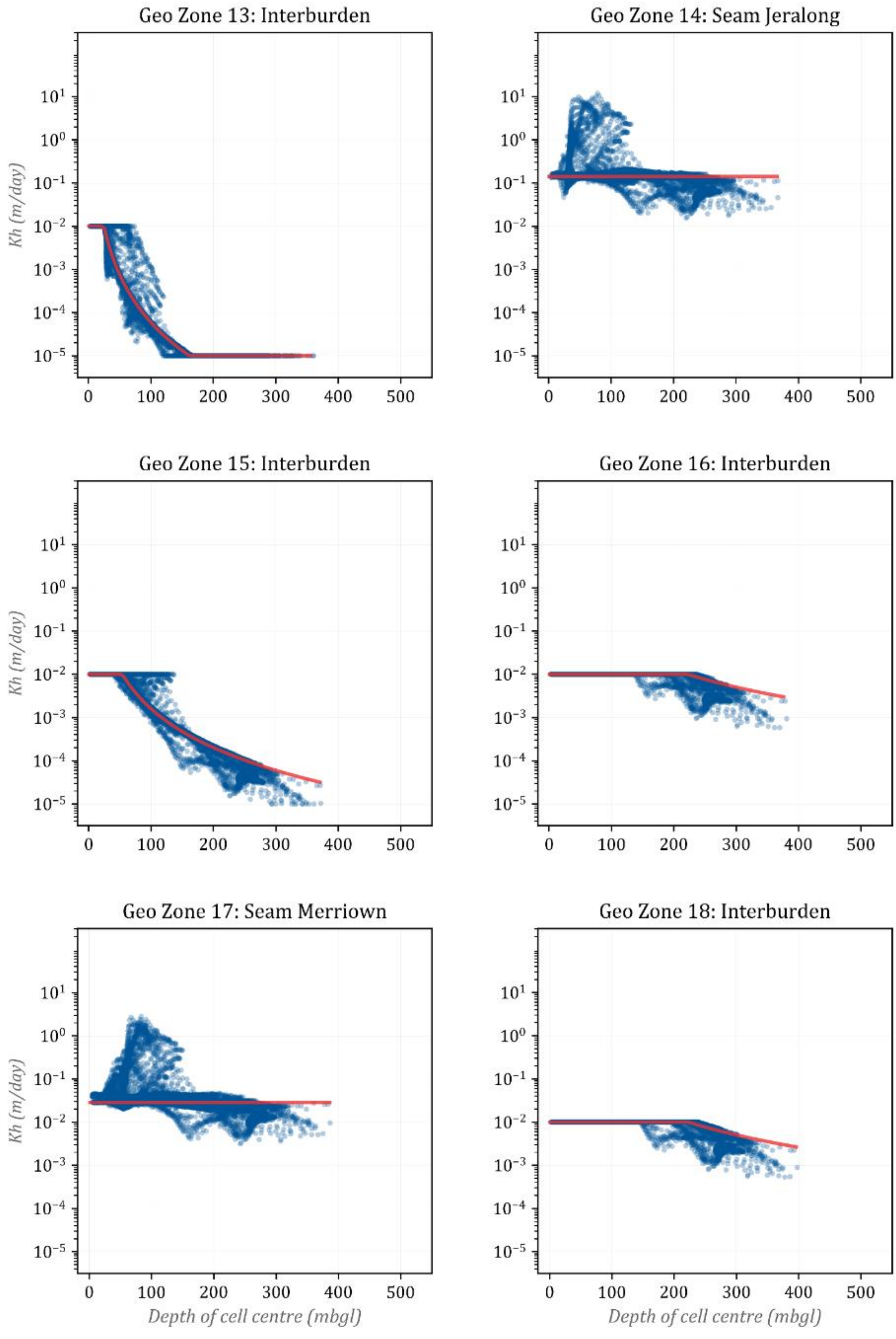
Model hydraulic properties



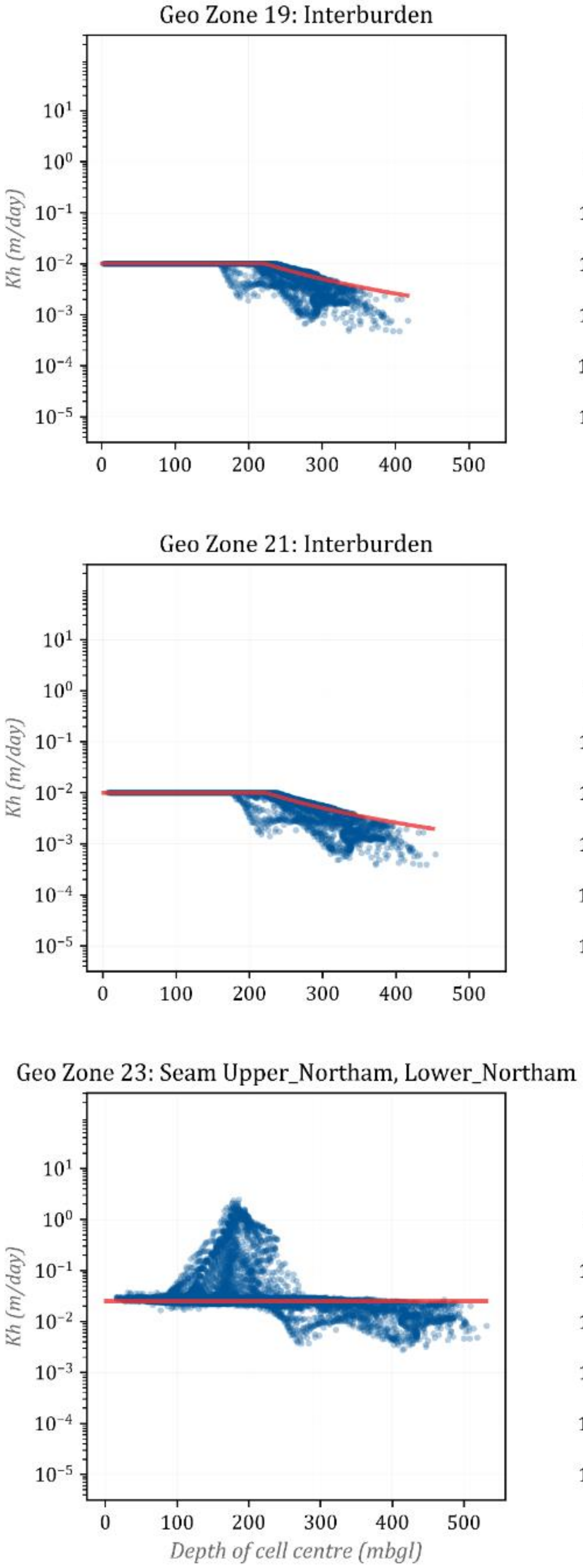
Cell horizontal hydraulic conductivity vs depth



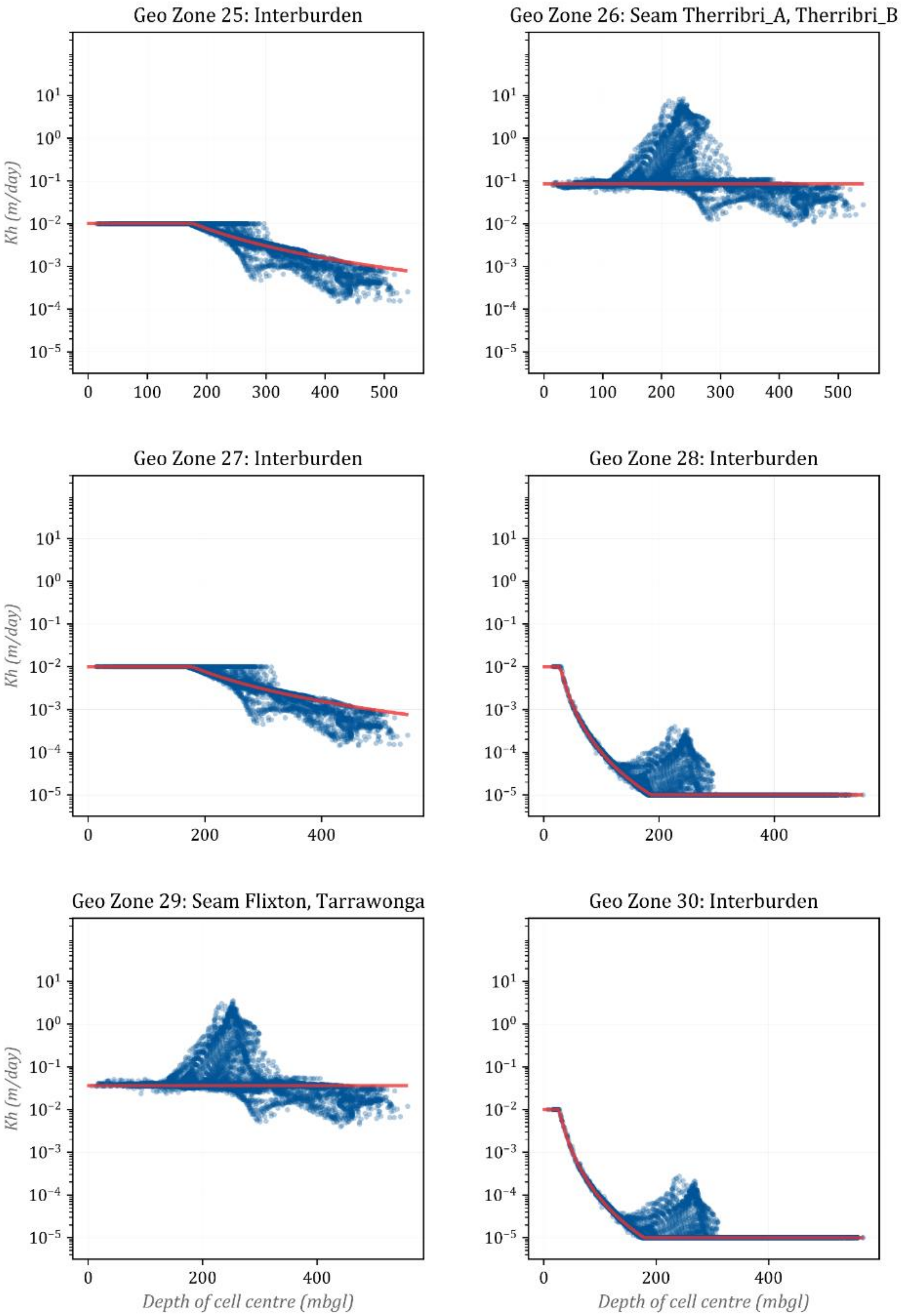
Cell horizontal hydraulic conductivity vs depth



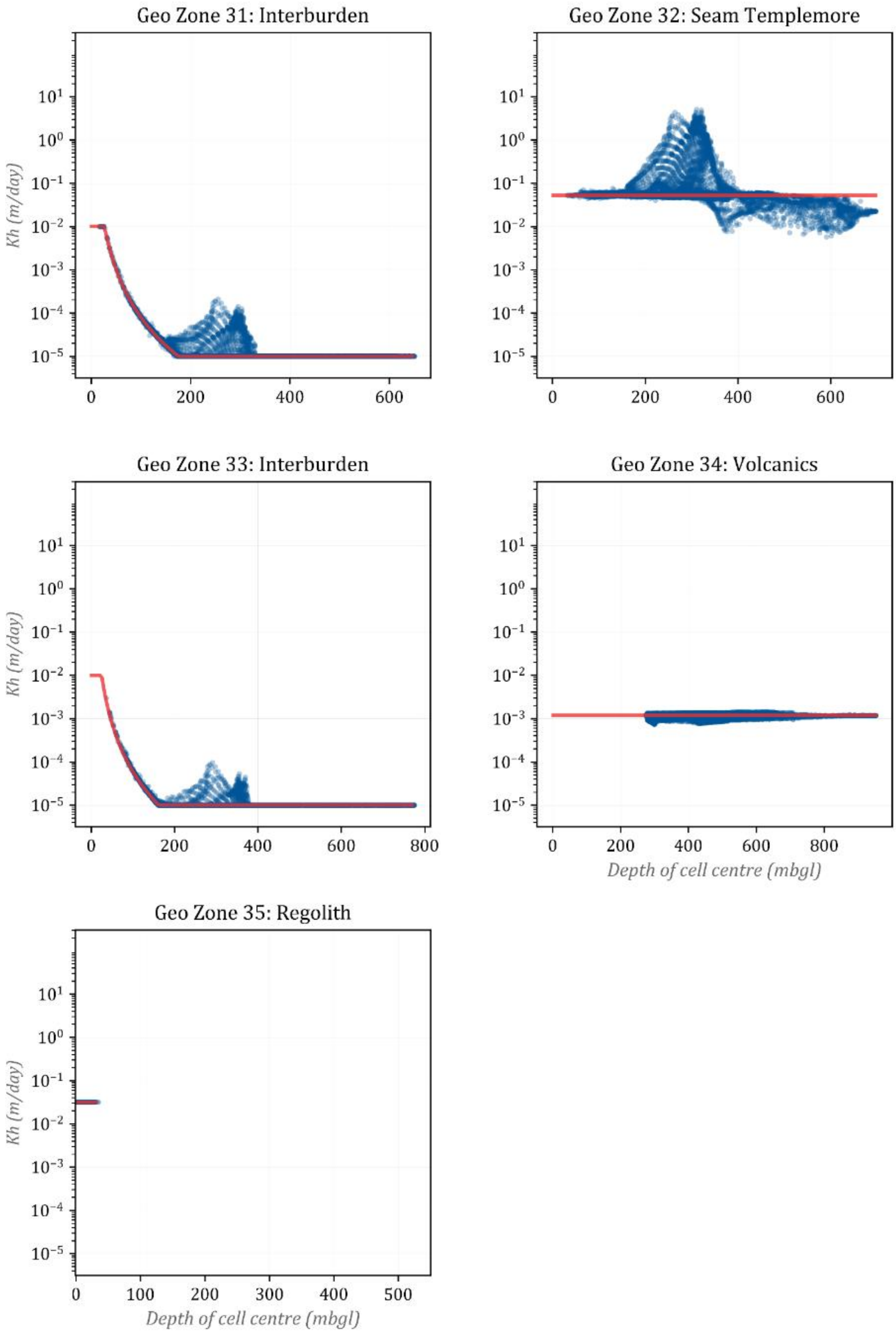
Cell horizontal hydraulic conductivity vs depth



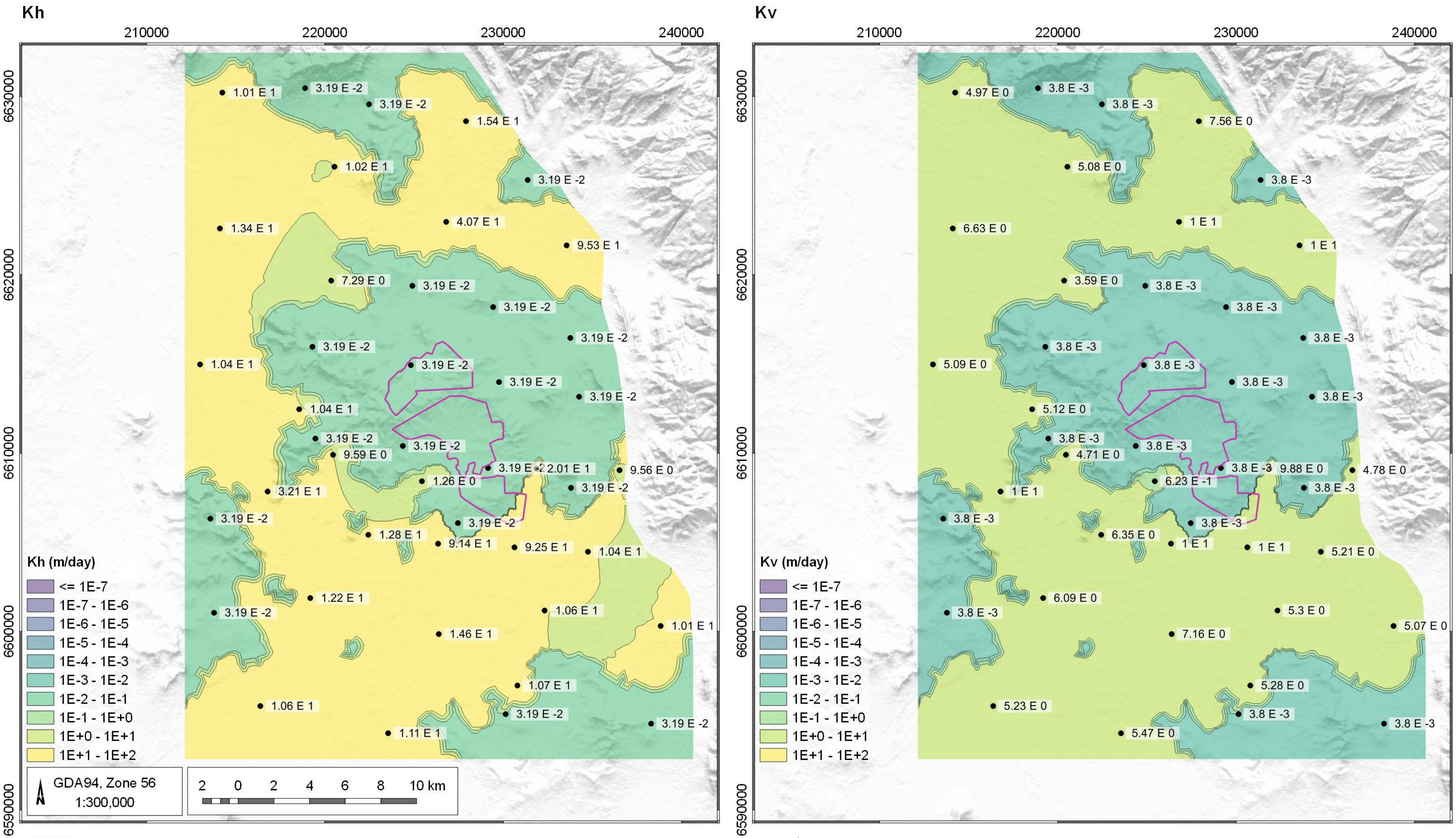
Cell horizontal hydraulic conductivity vs depth



Cell horizontal hydraulic conductivity vs depth



Cell horizontal hydraulic conductivity vs depth



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Mine outline

AGE

Layer 1 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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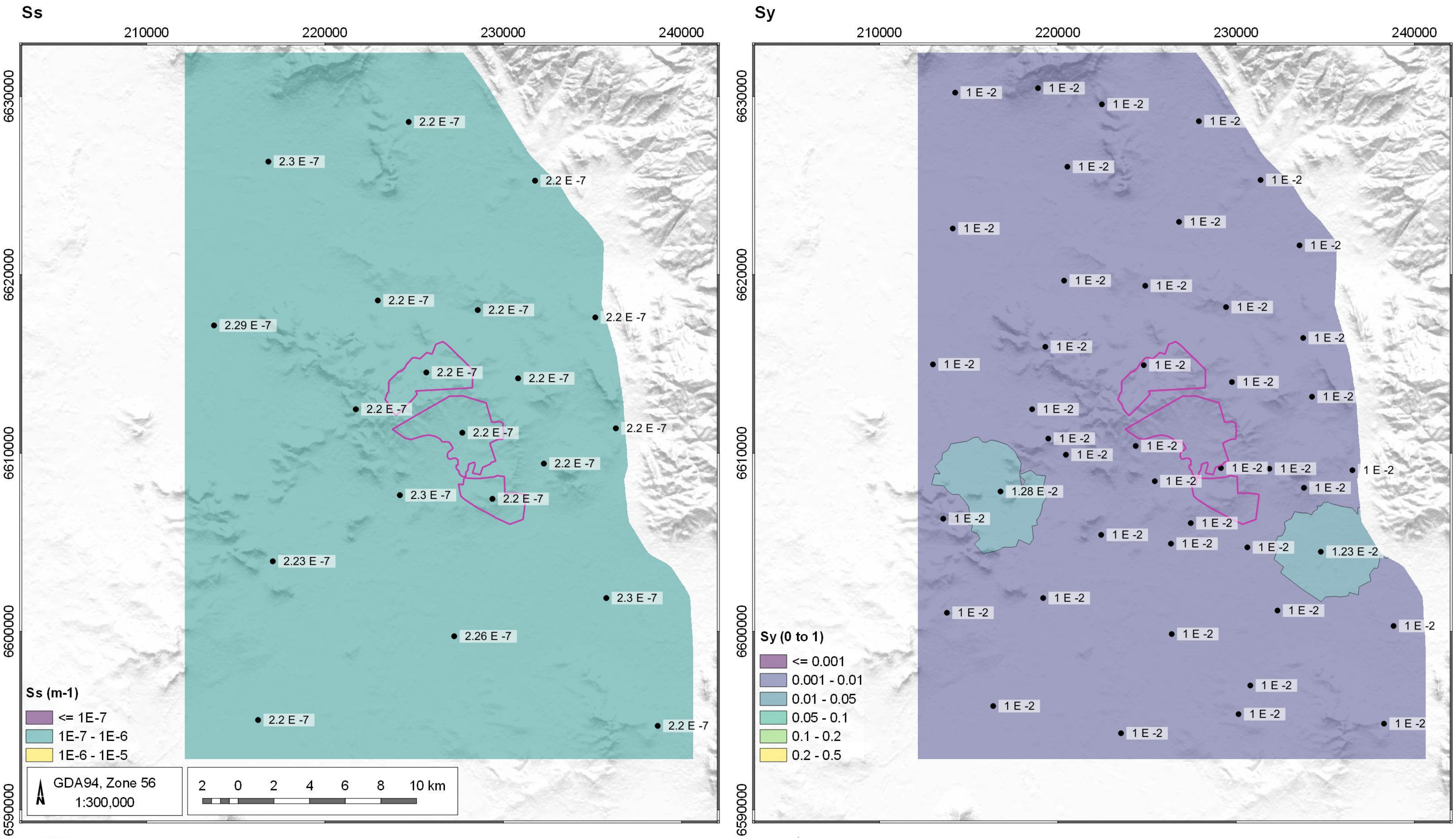
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Mine outline

AGE

Layer 1 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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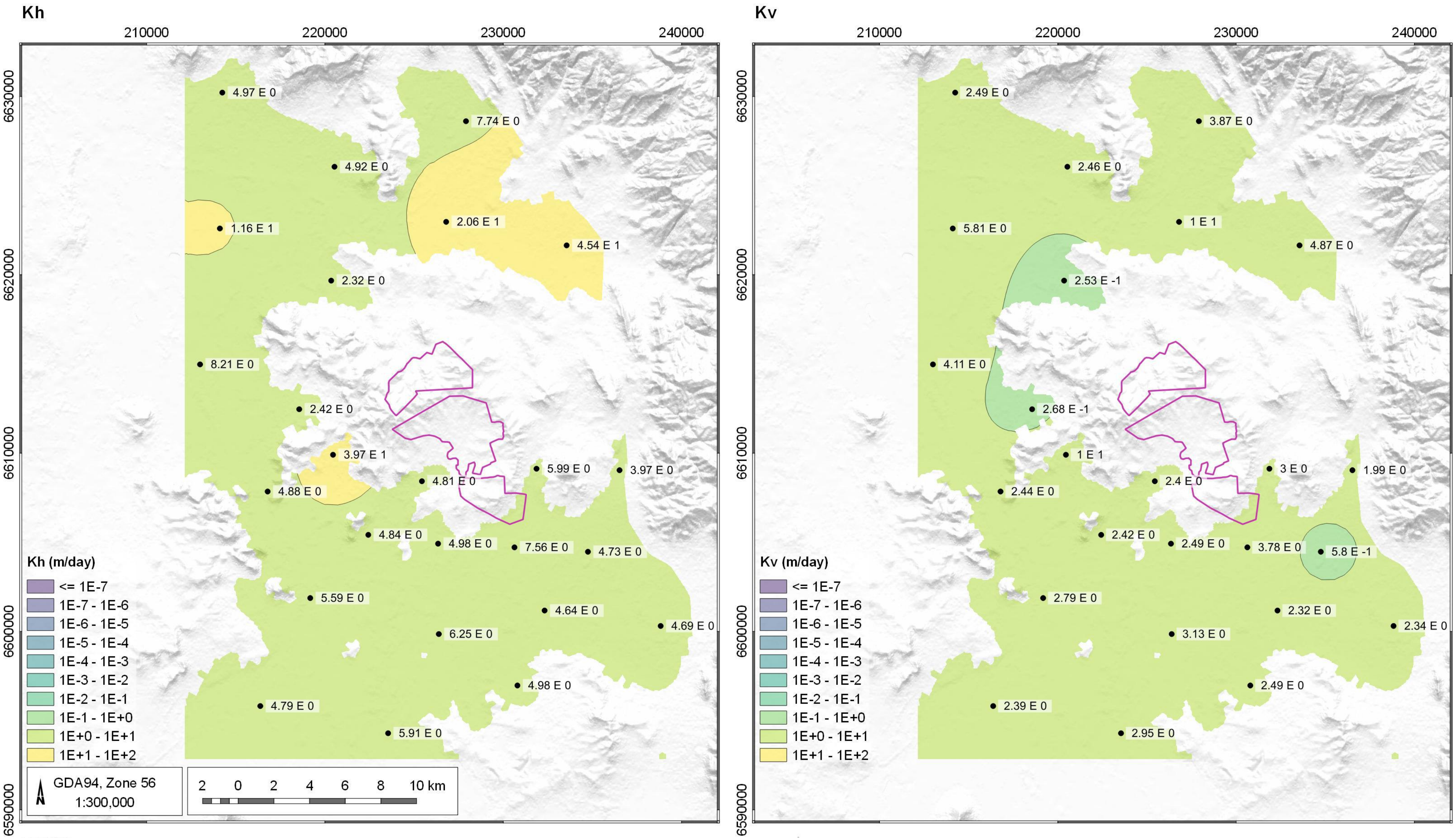

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Mine outline

AGE

Layer 2 - Kh and Kv

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FIGURE No:

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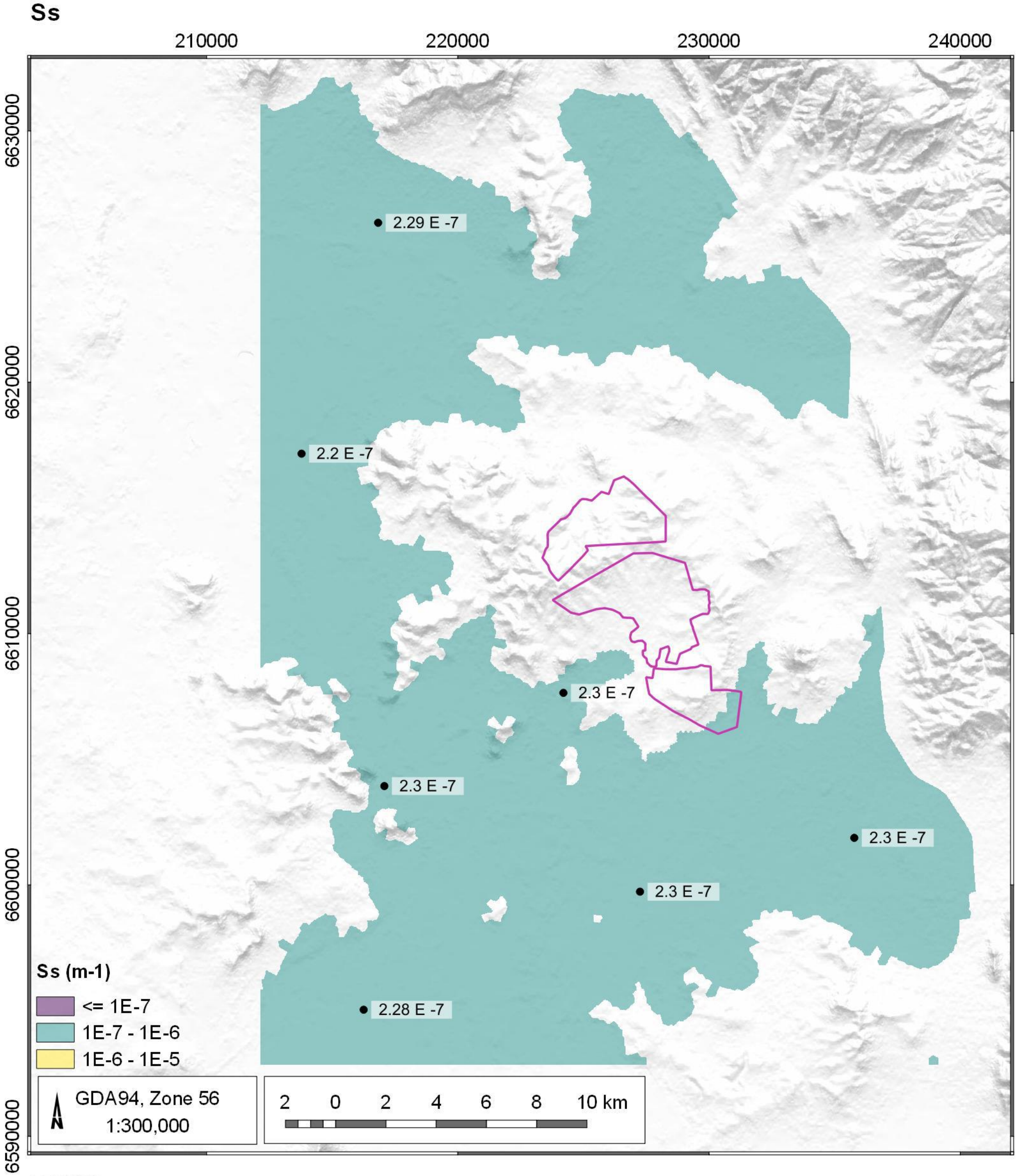

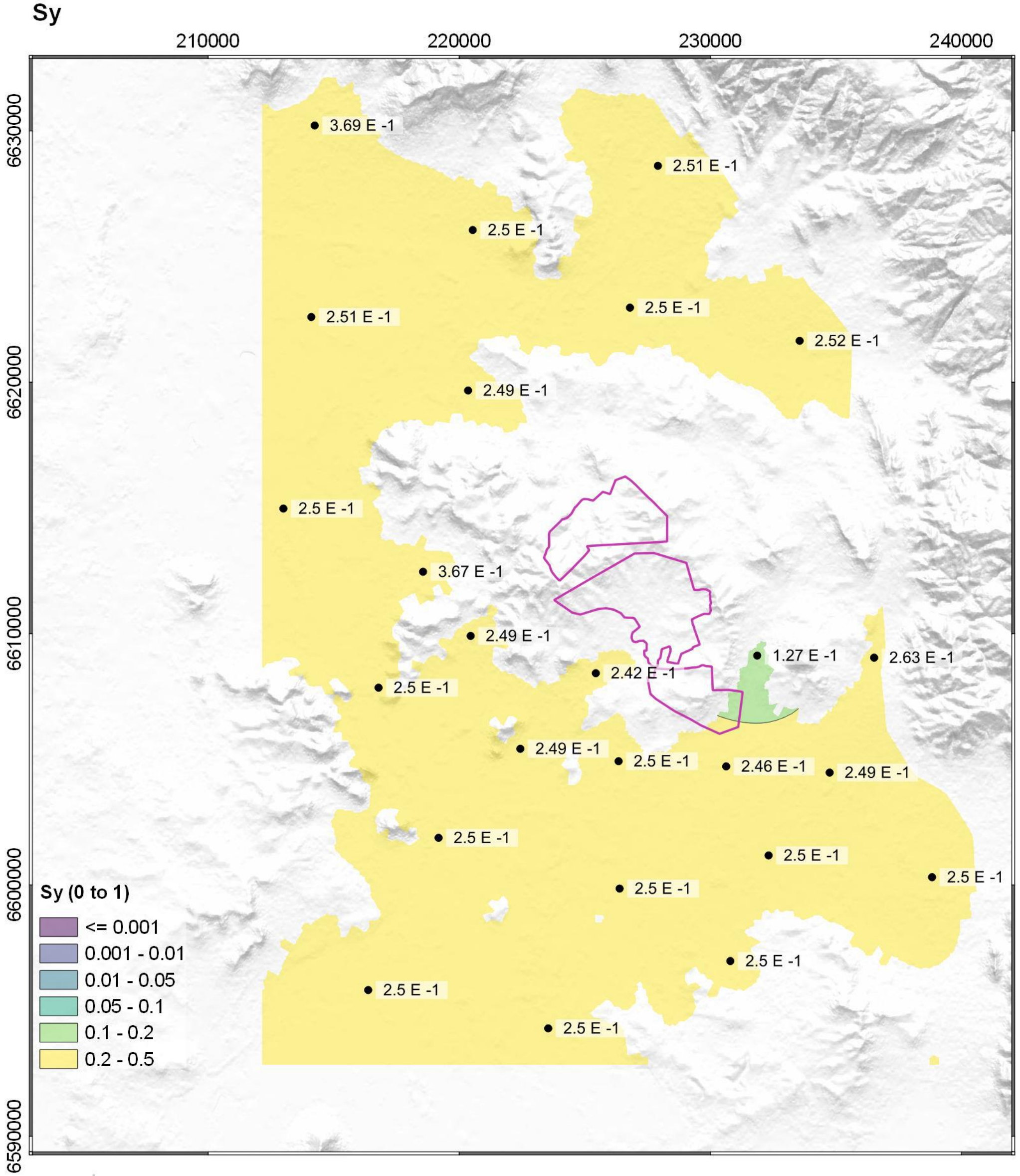

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Mine outline

AGE

Layer 2 - Ss and Sy

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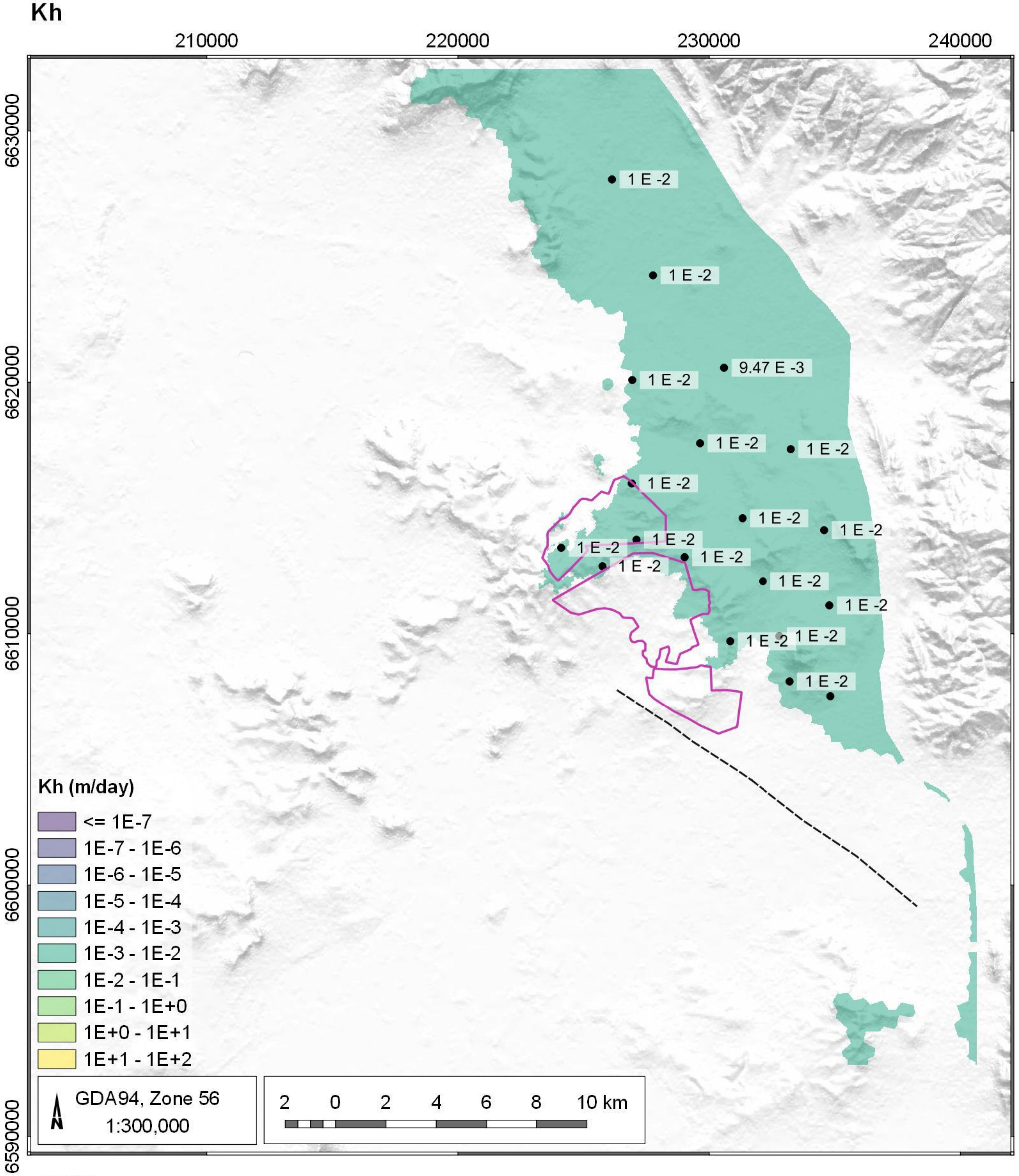

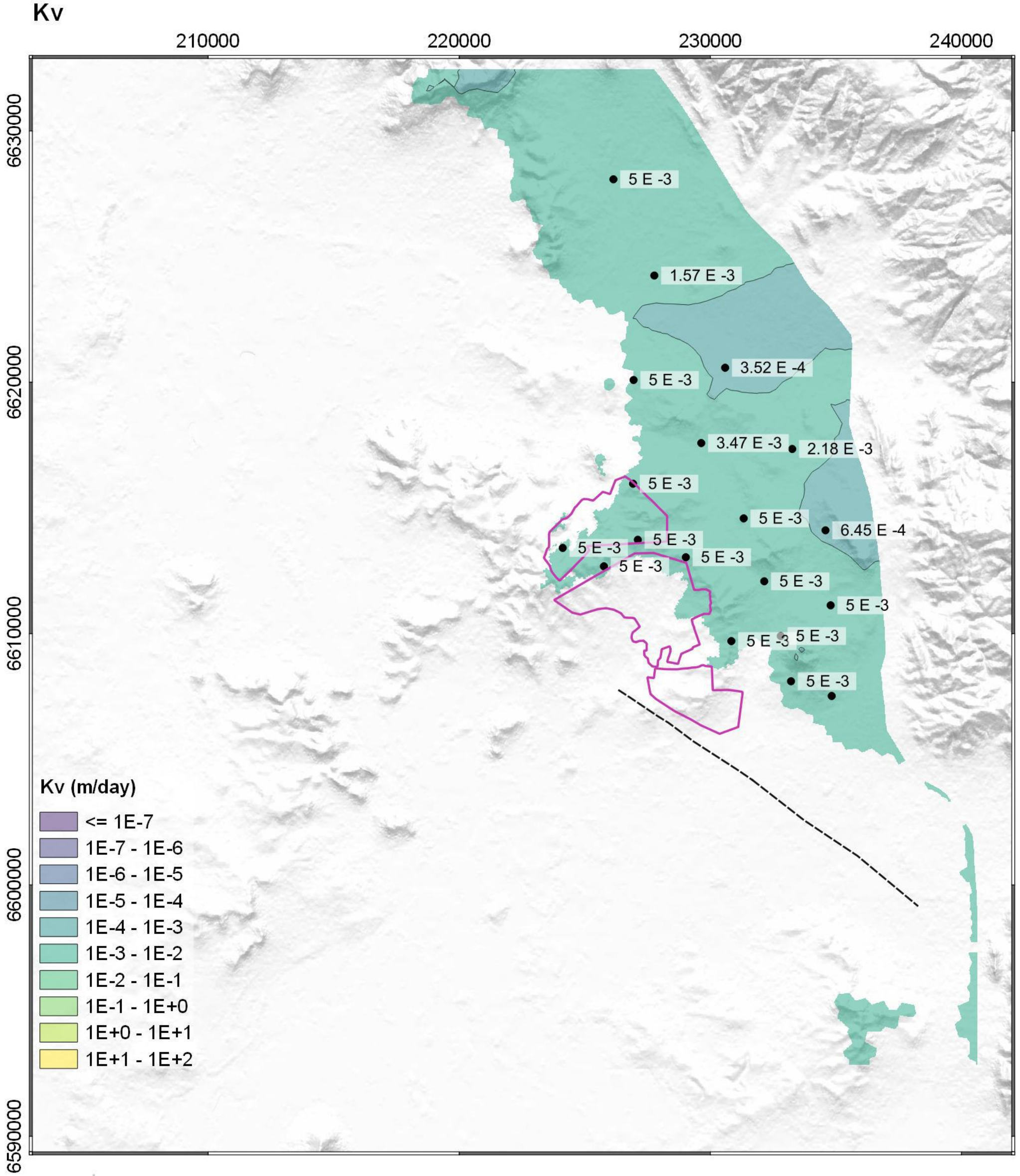

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 3 - Kh and Kv

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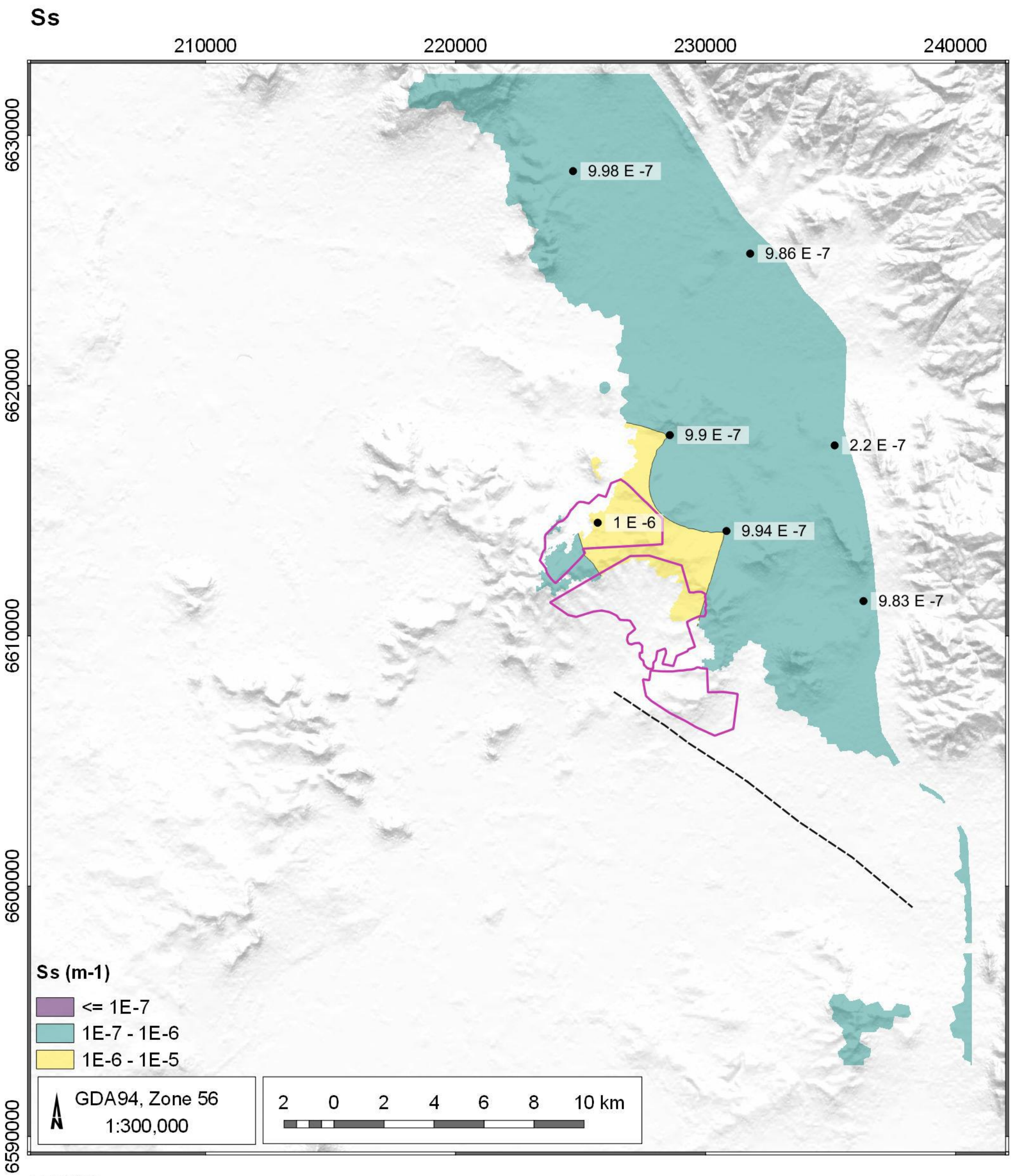

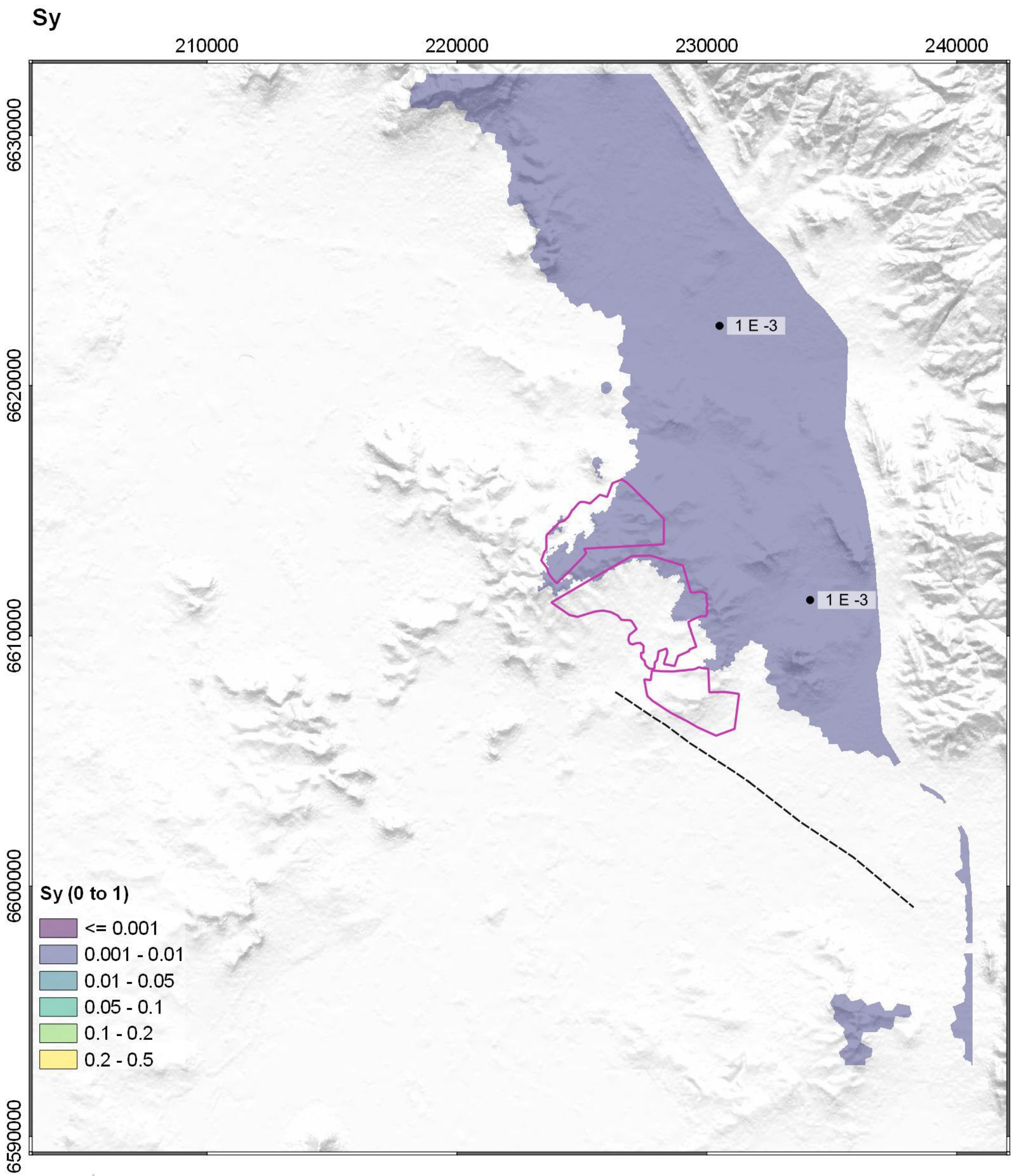

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 3 - Ss and Sy

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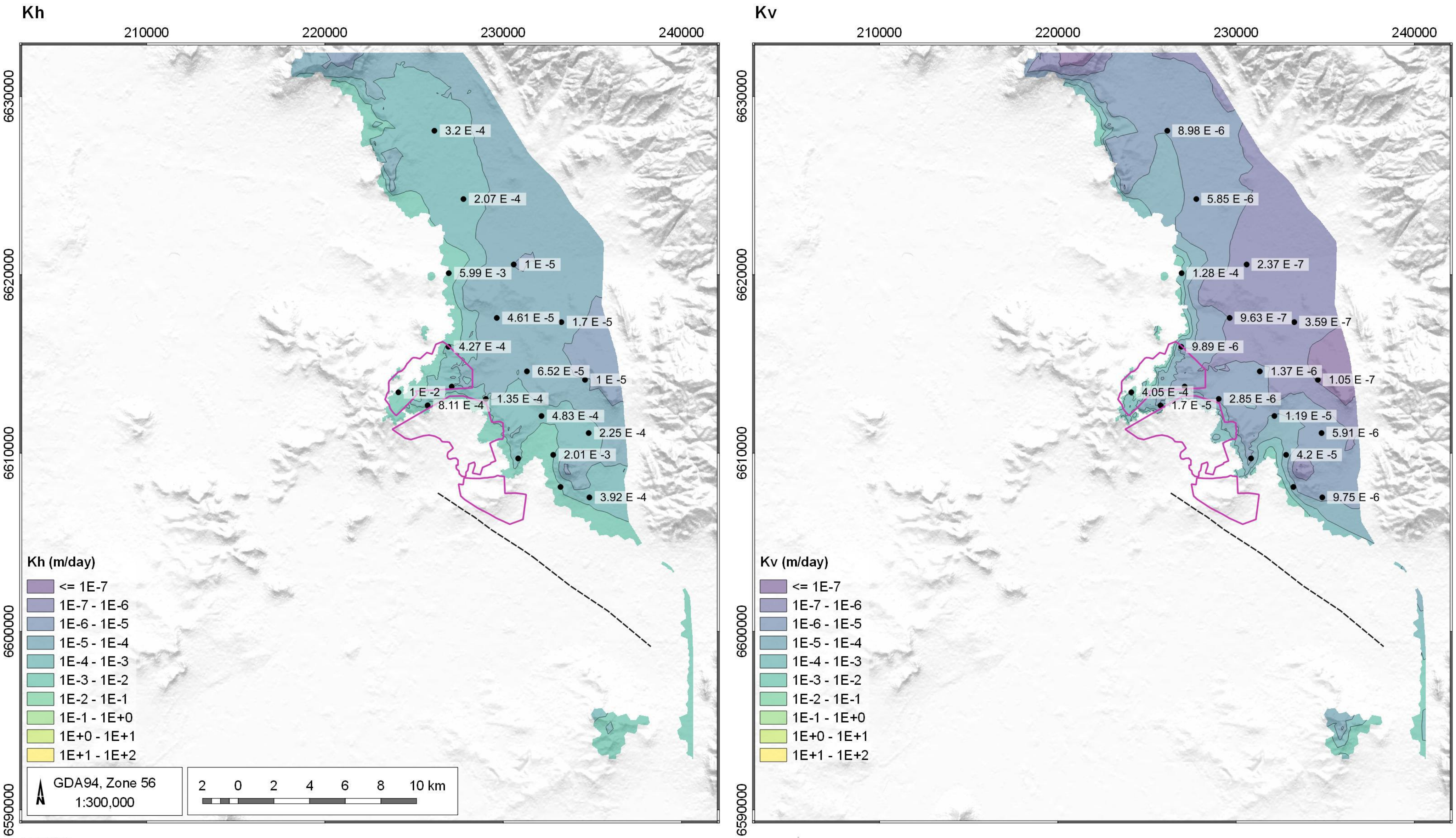

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

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Layer 4 - Kh and Kv

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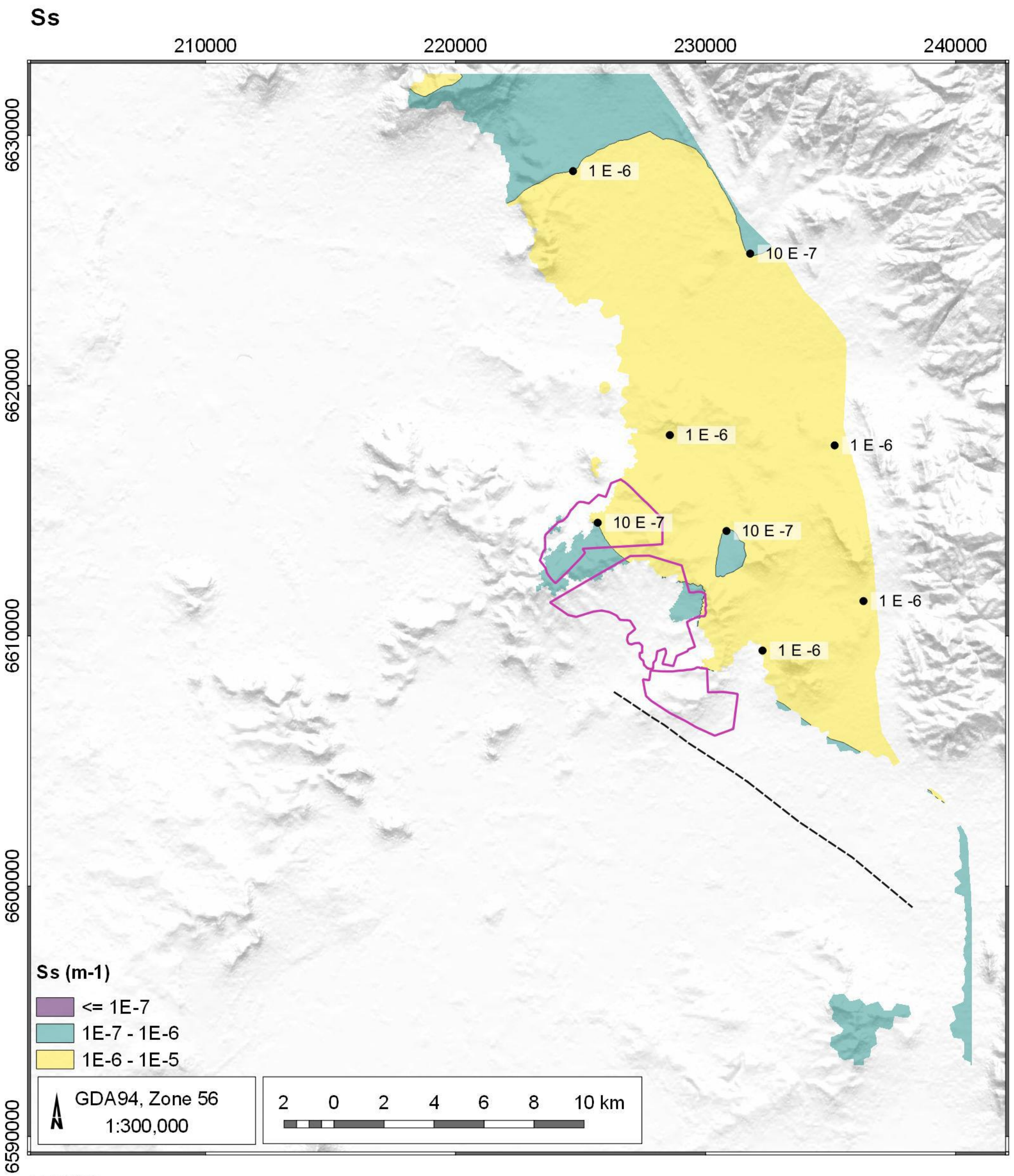

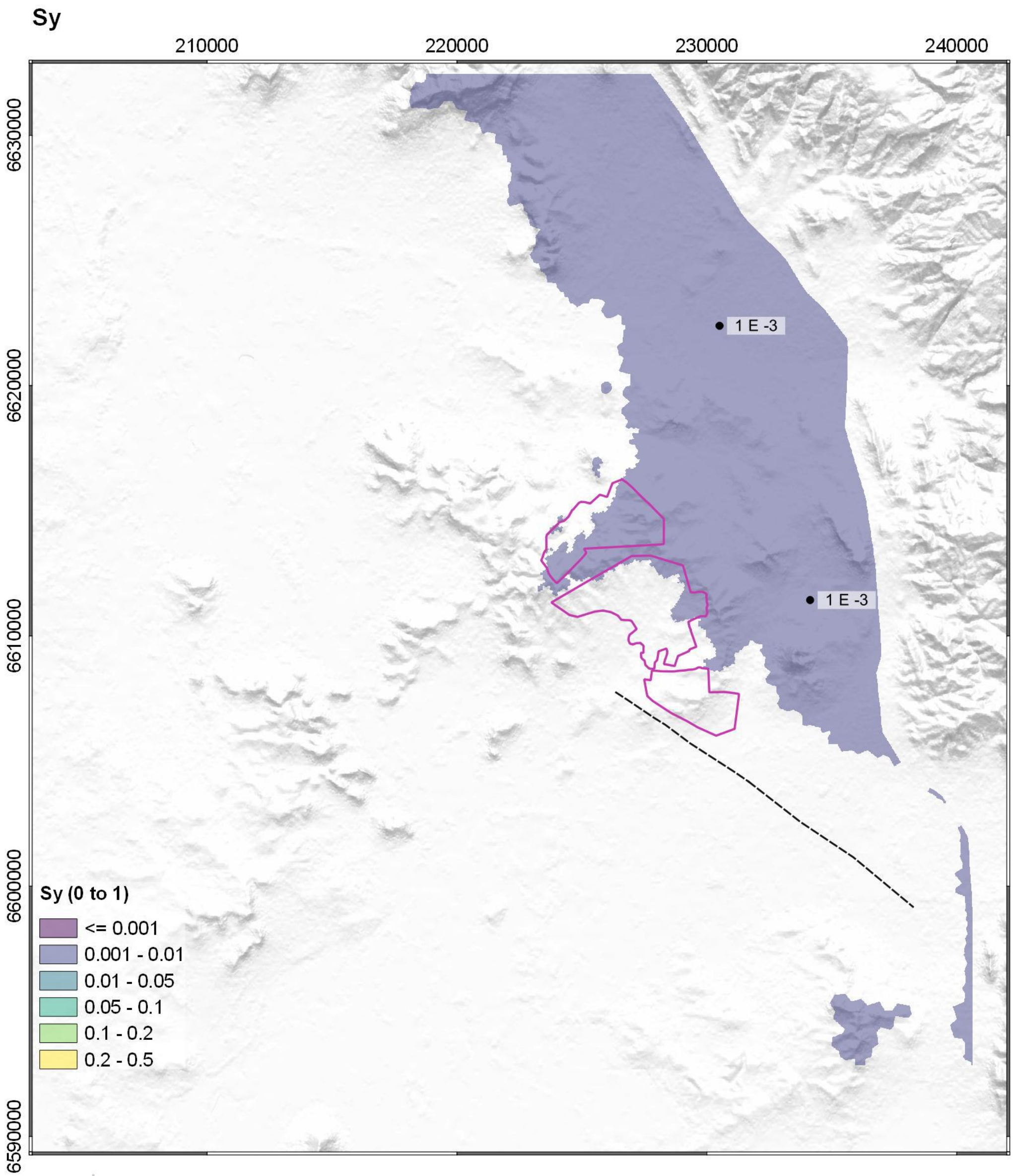

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 4 - Ss and Sy

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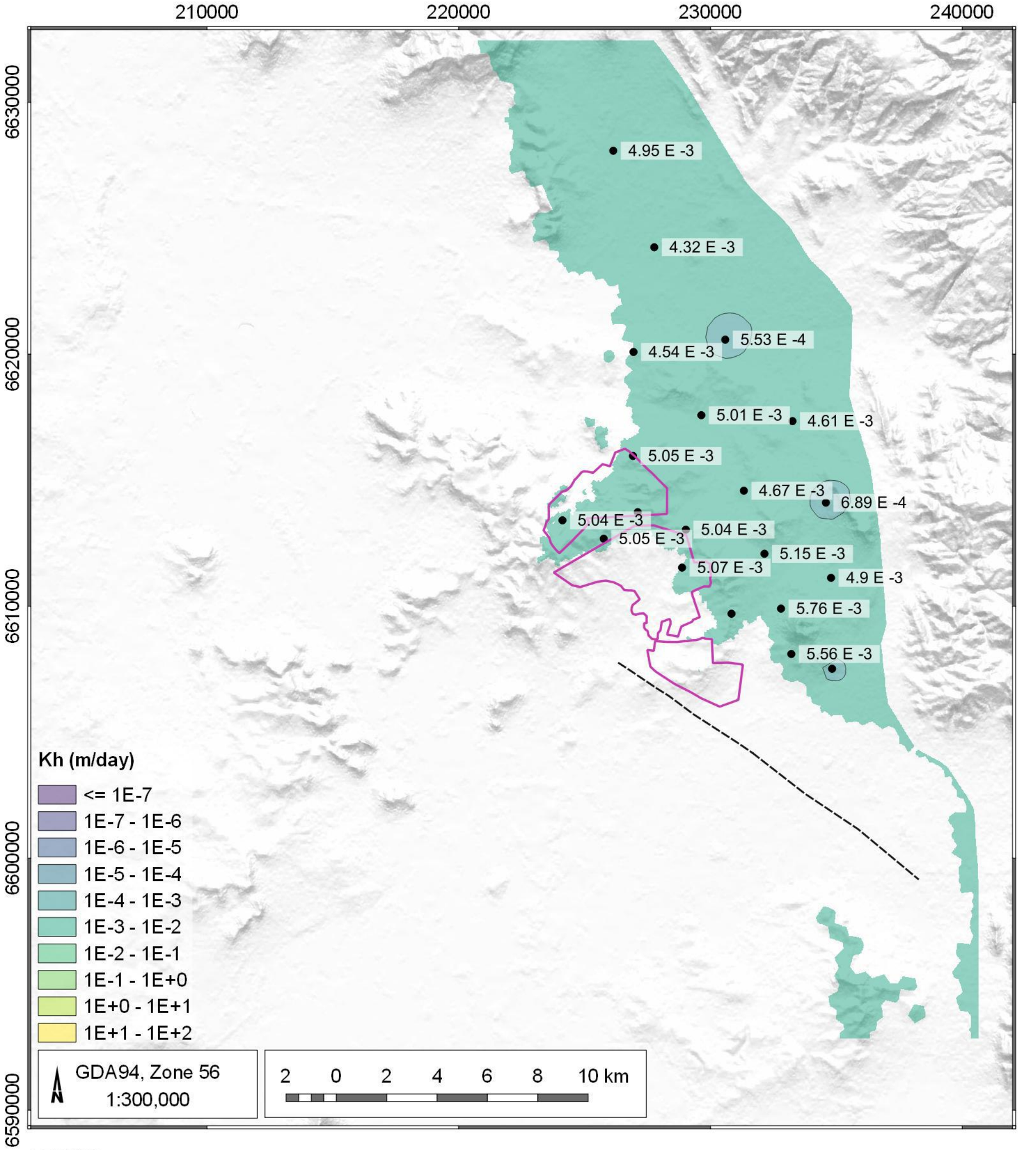
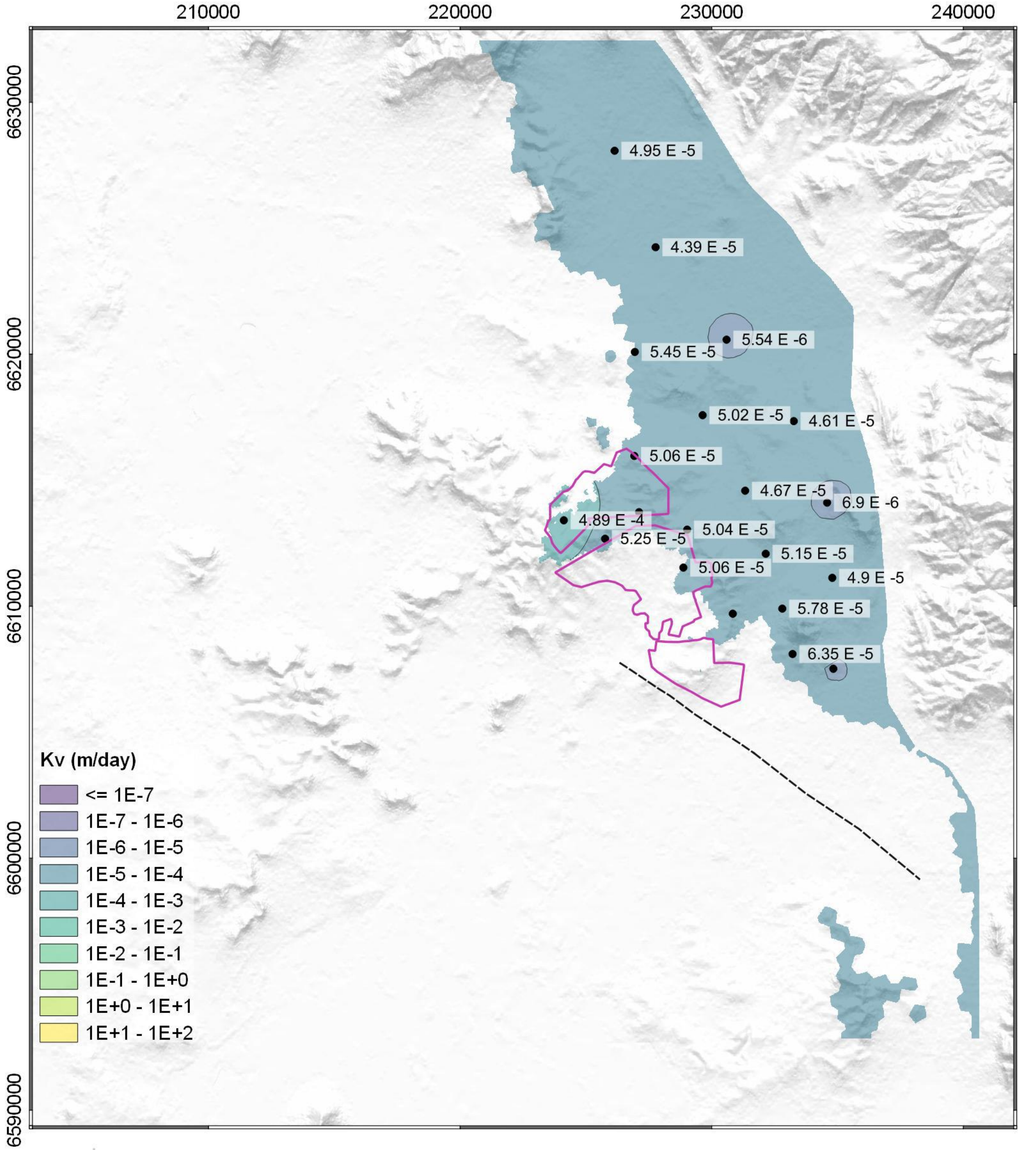
Kh



Kv



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

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Layer 5 - Kh and Kv

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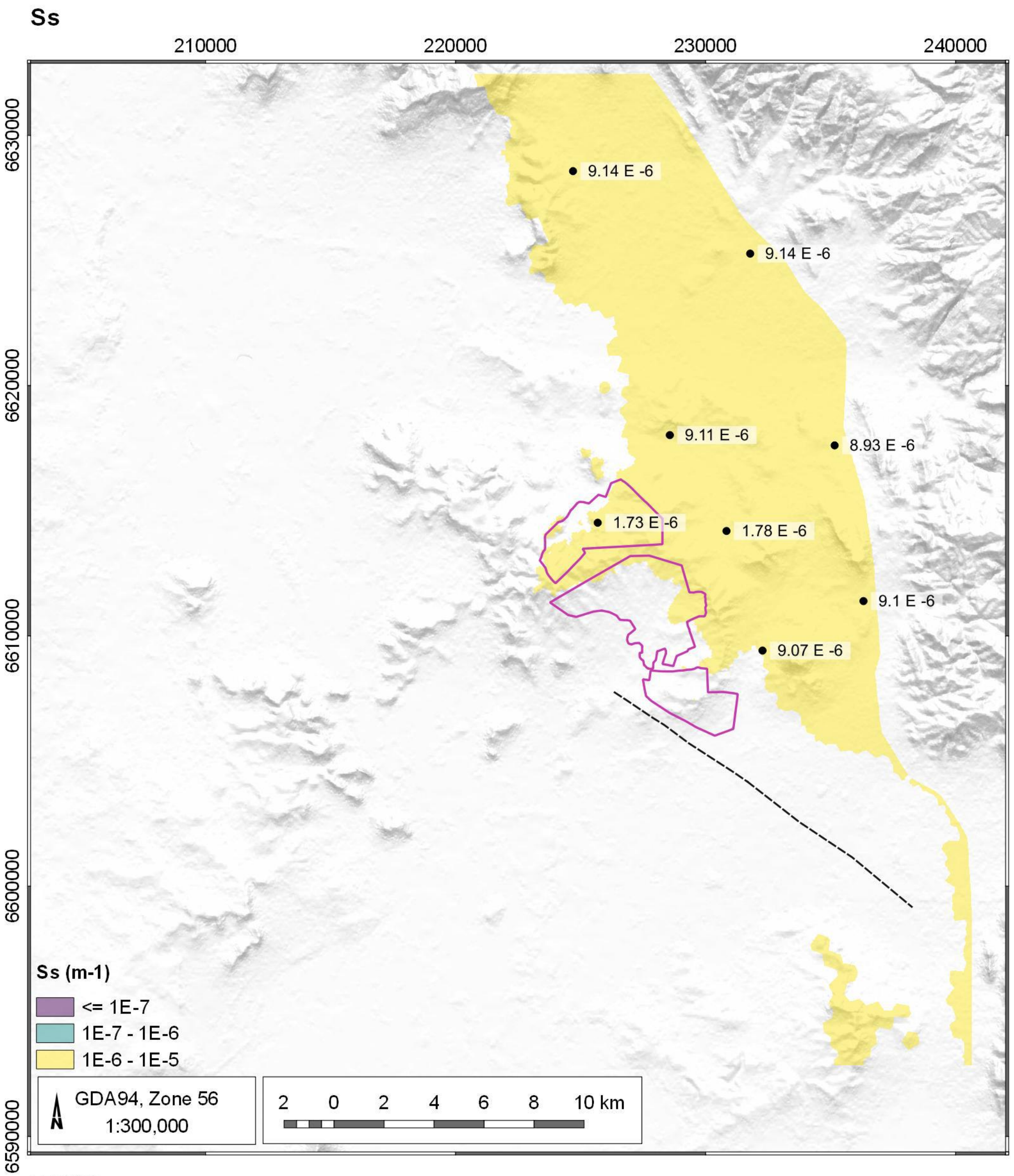

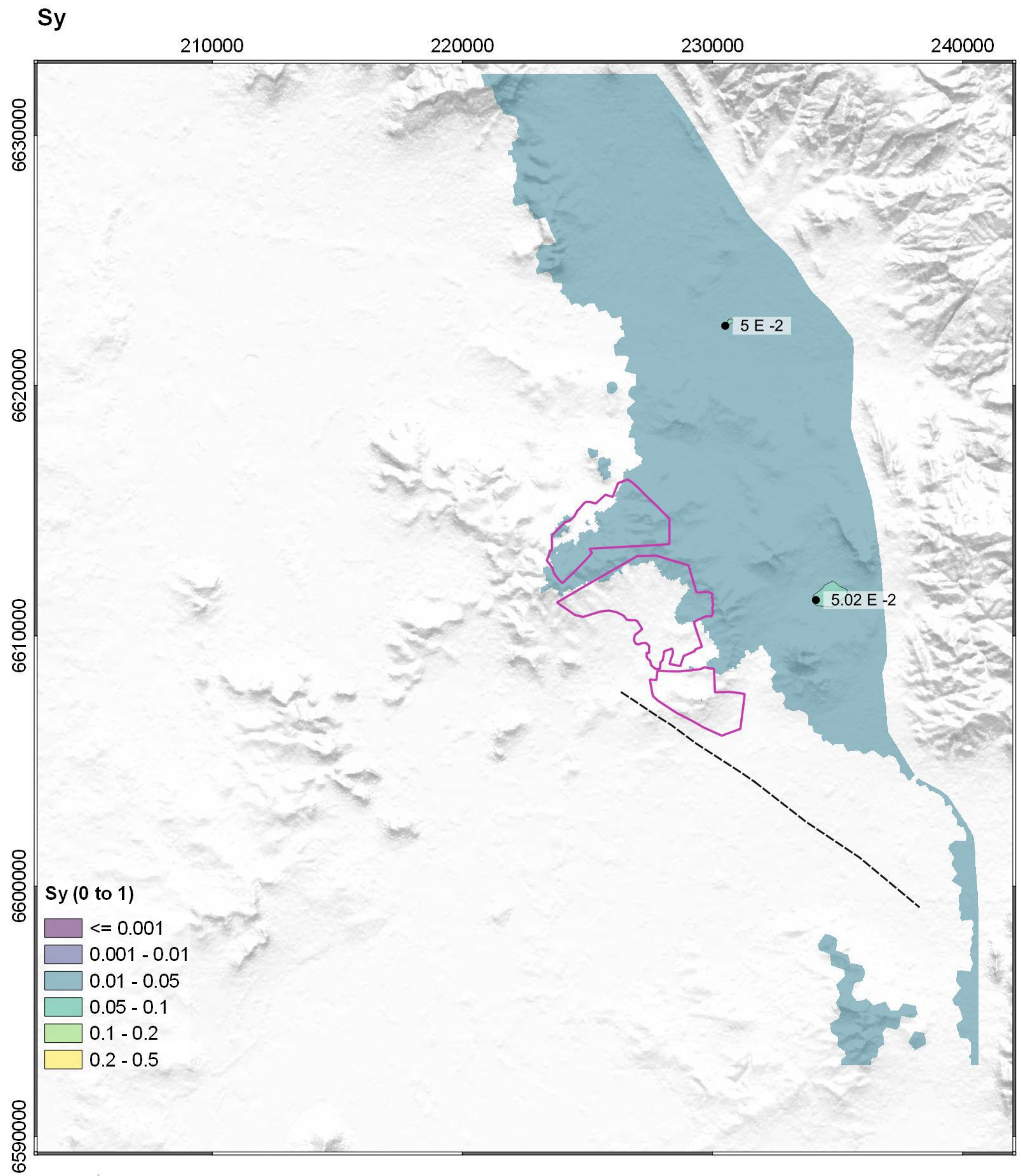

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 5 - Ss and Sy

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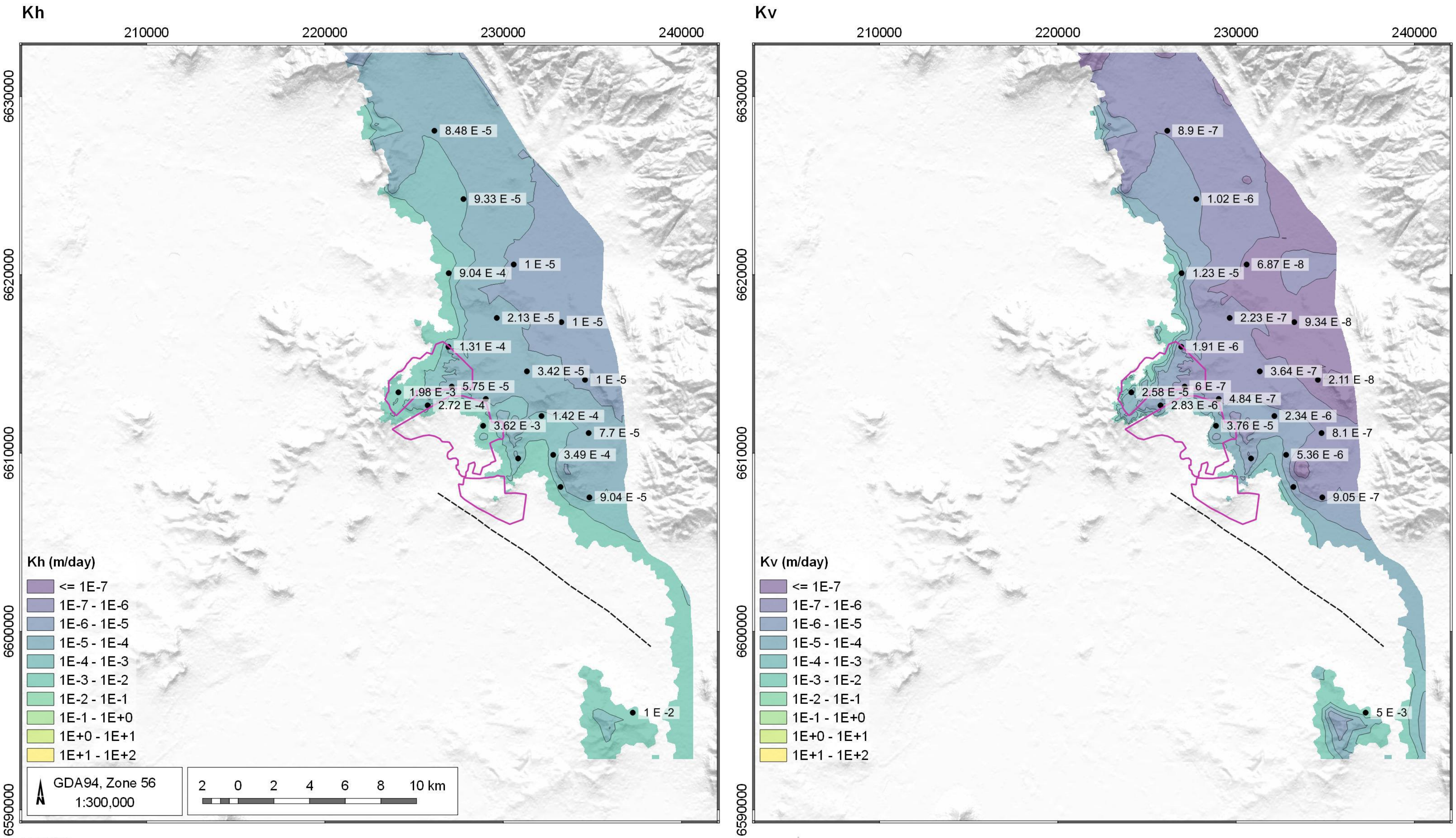

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 6 - Kh and Kv

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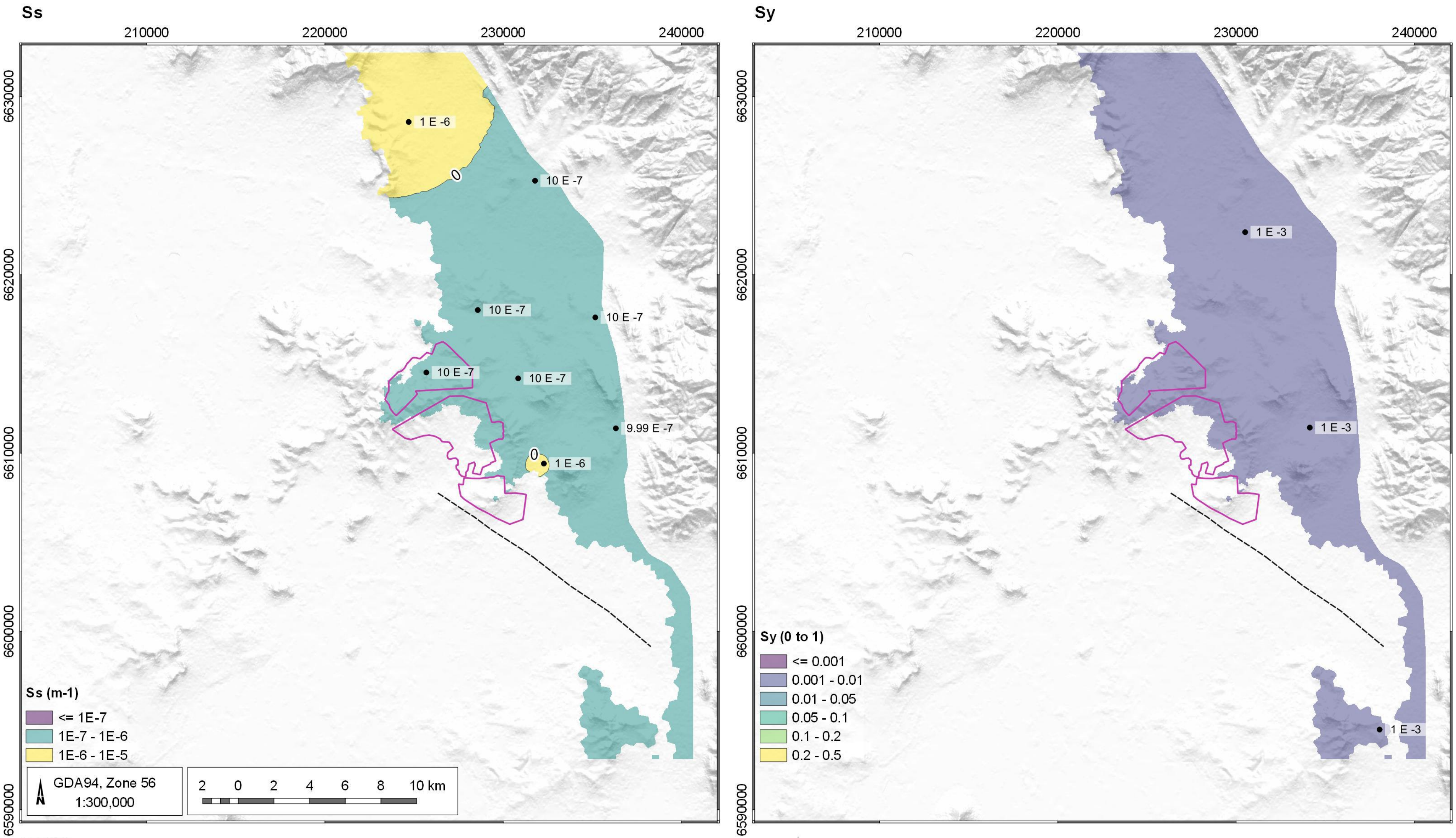

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 6 - Ss and Sy

DATE
15/06/2021

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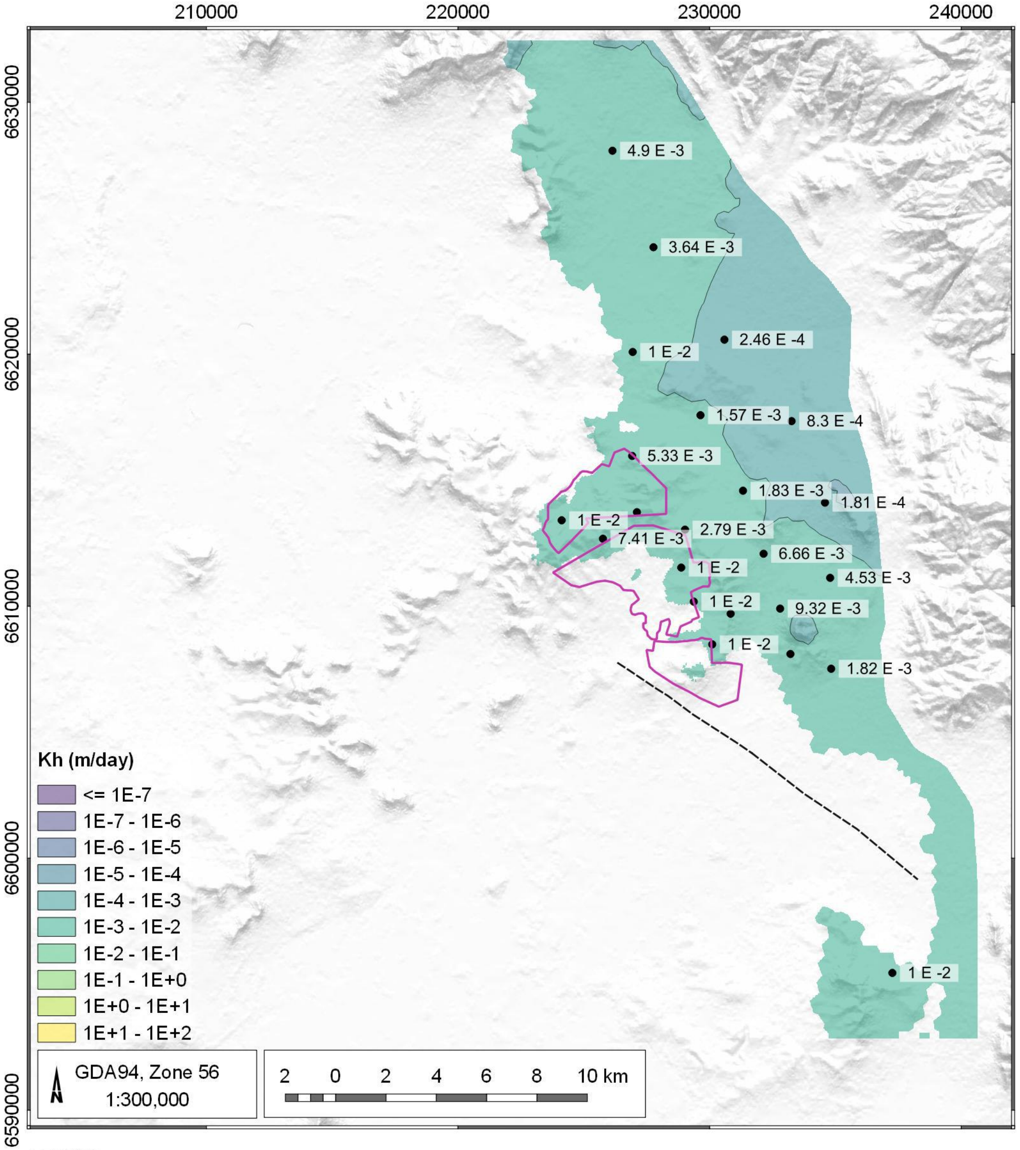
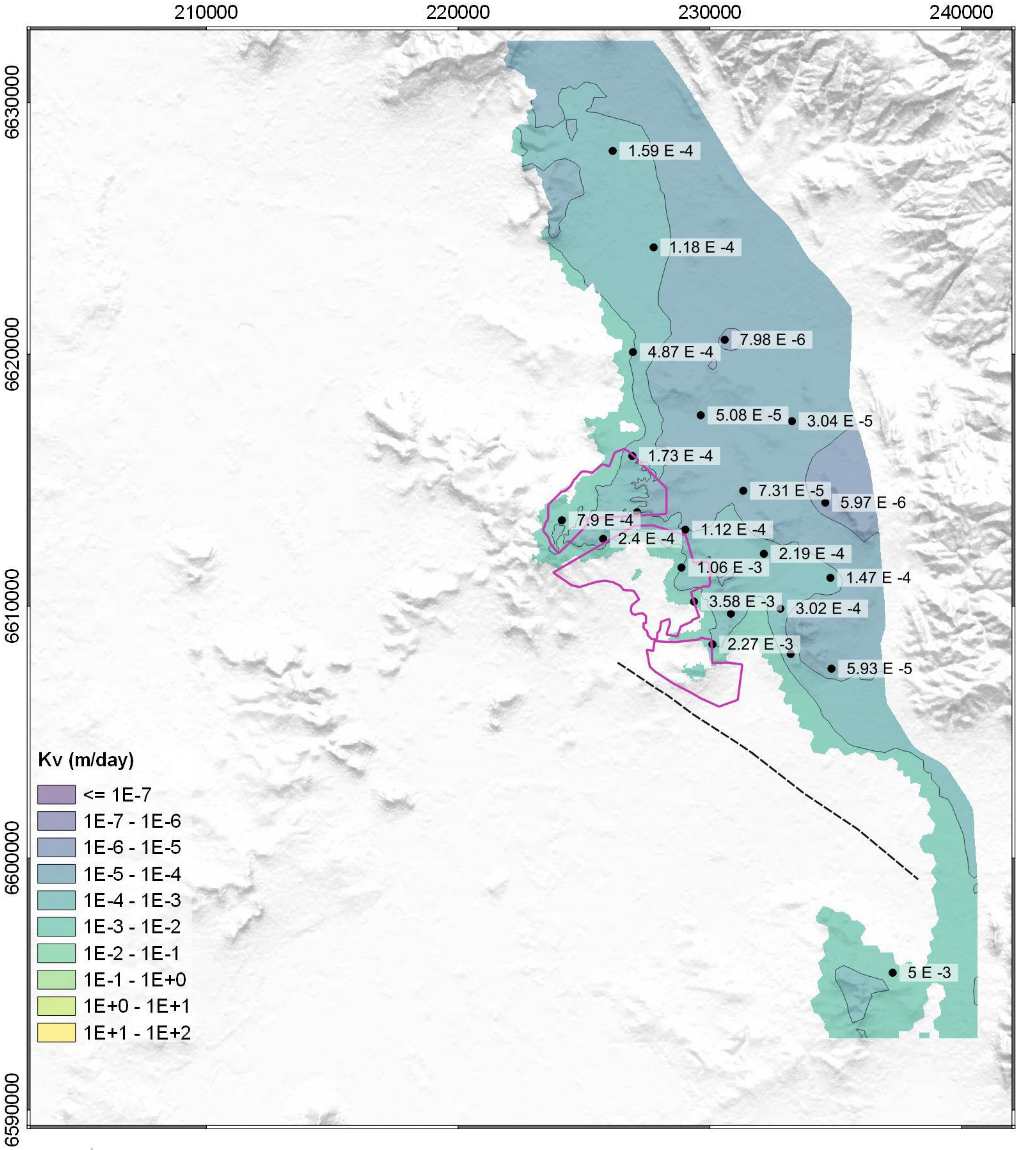
Kh



Kv



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 7 - Kh and Kv

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15/06/2021

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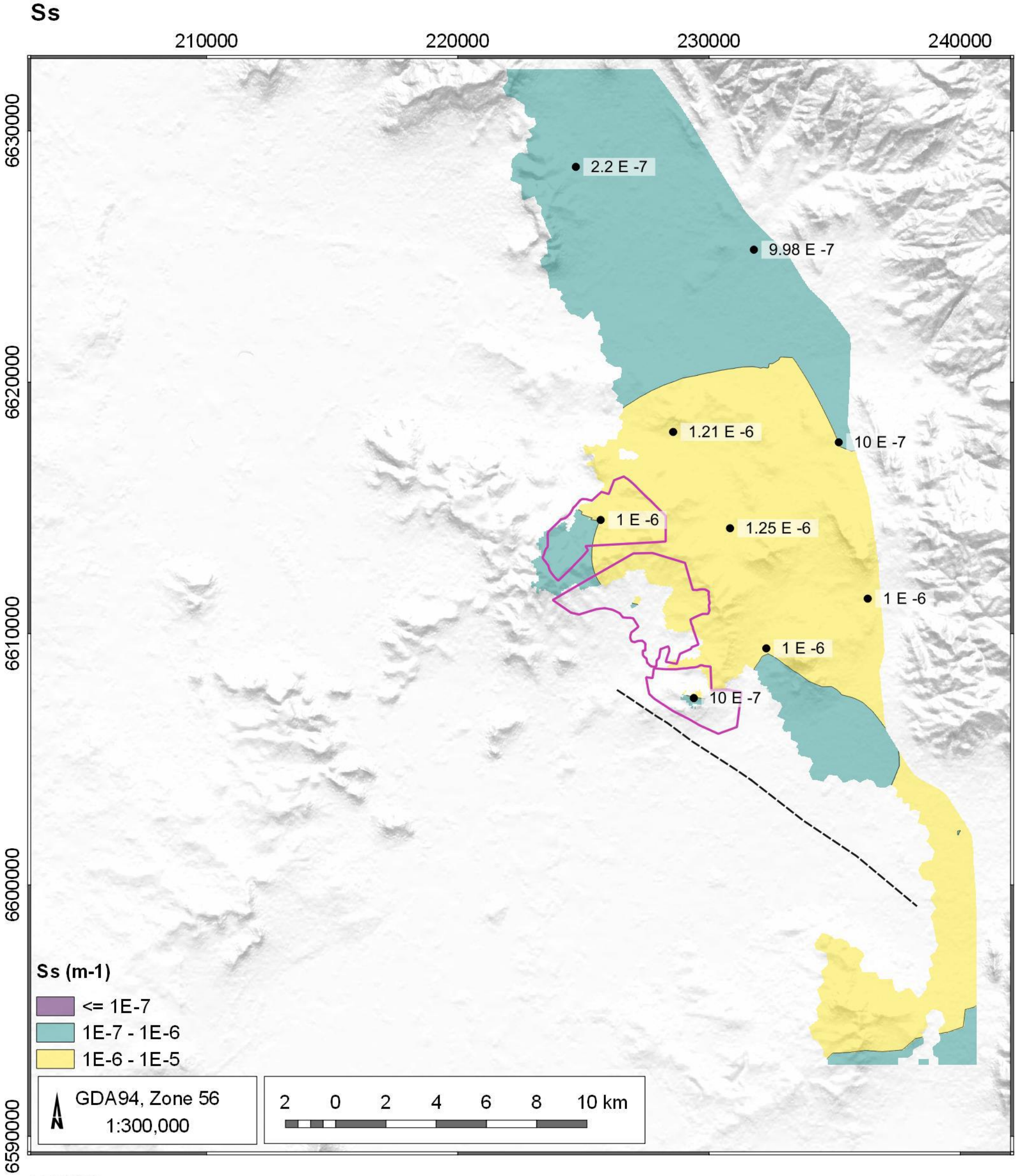

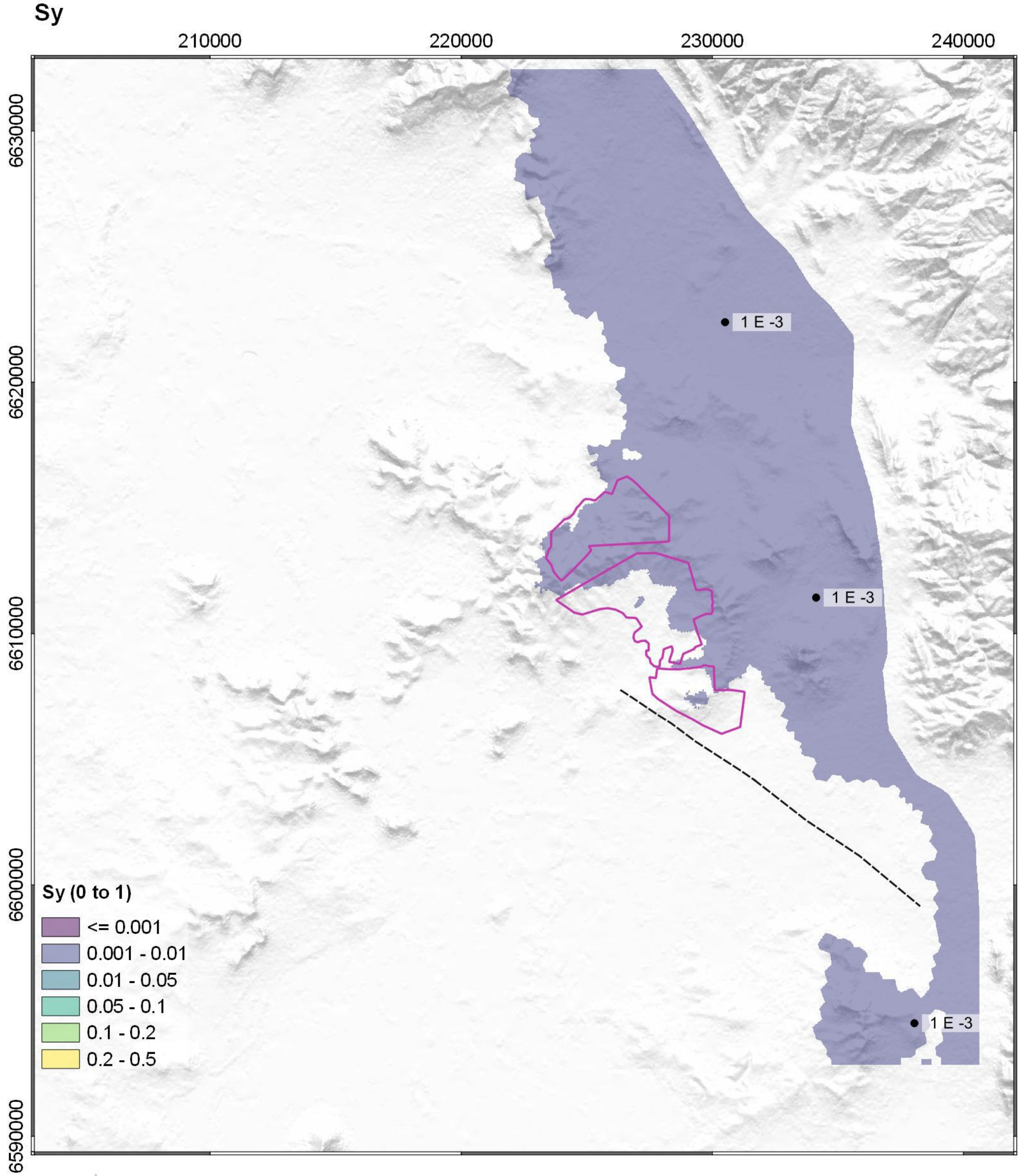

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 7 - Ss and Sy

DATE
15/06/2021

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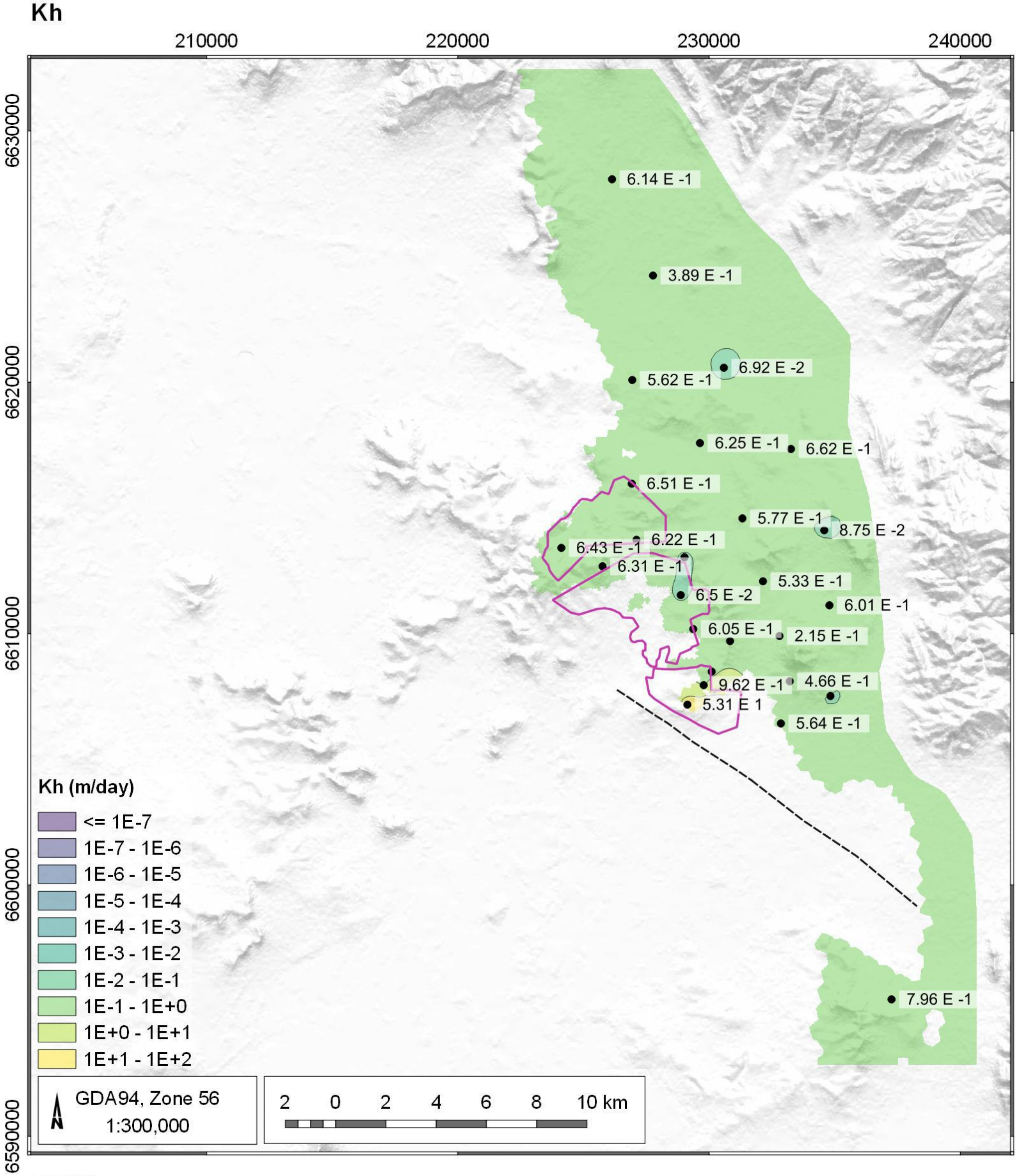

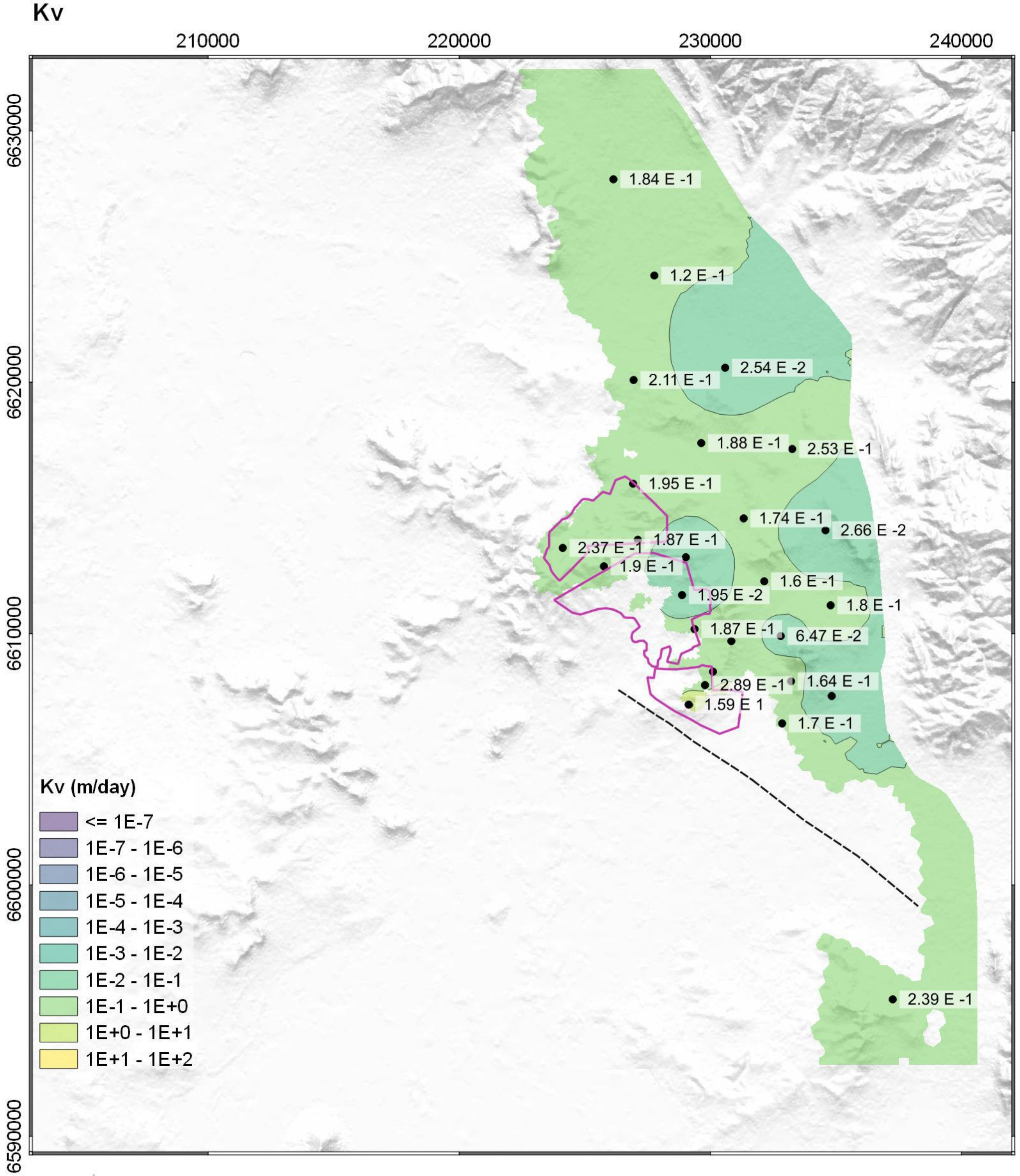

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 8 - Kh and Kv

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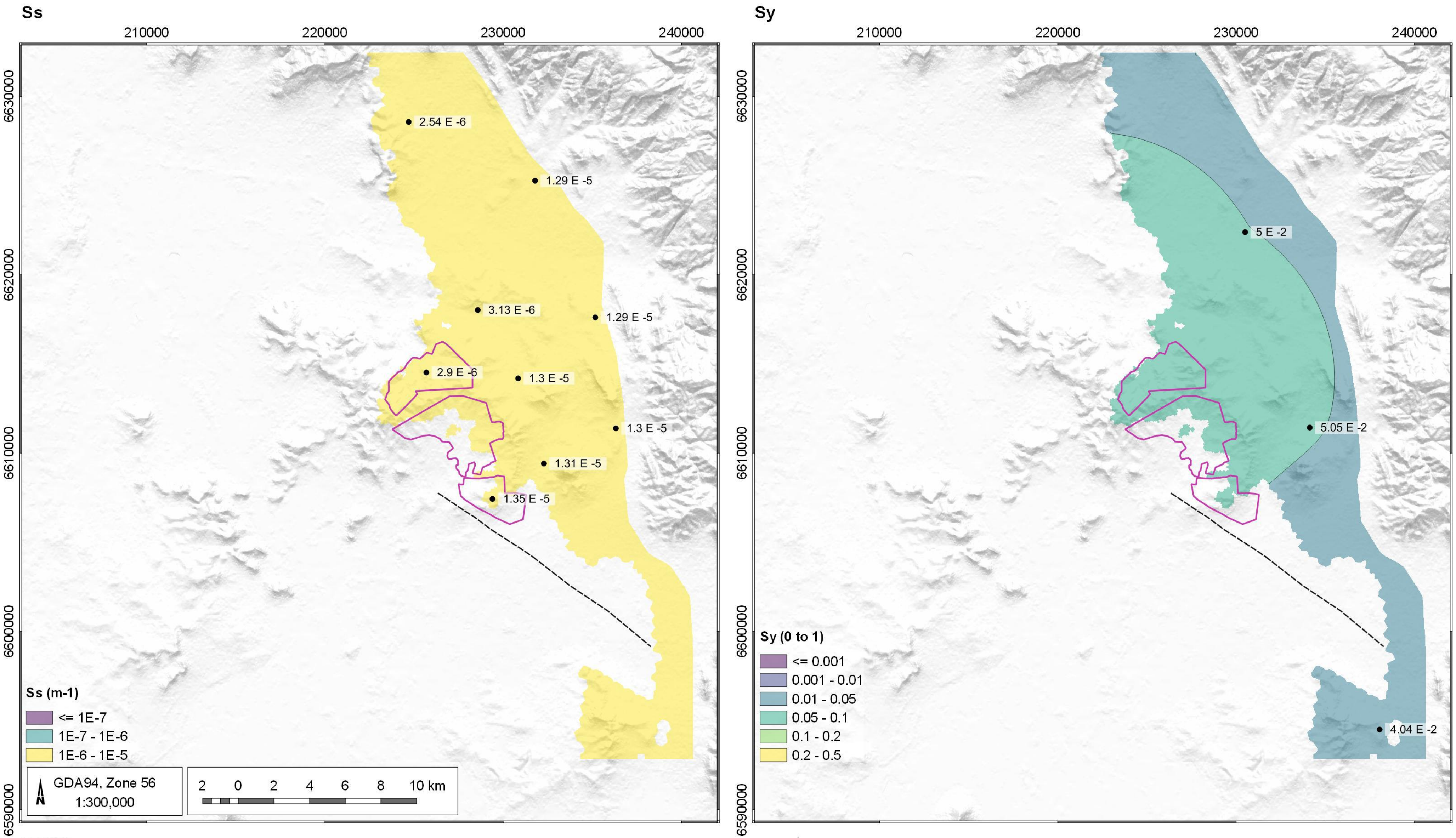

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 8 - Ss and Sy

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15/06/2021

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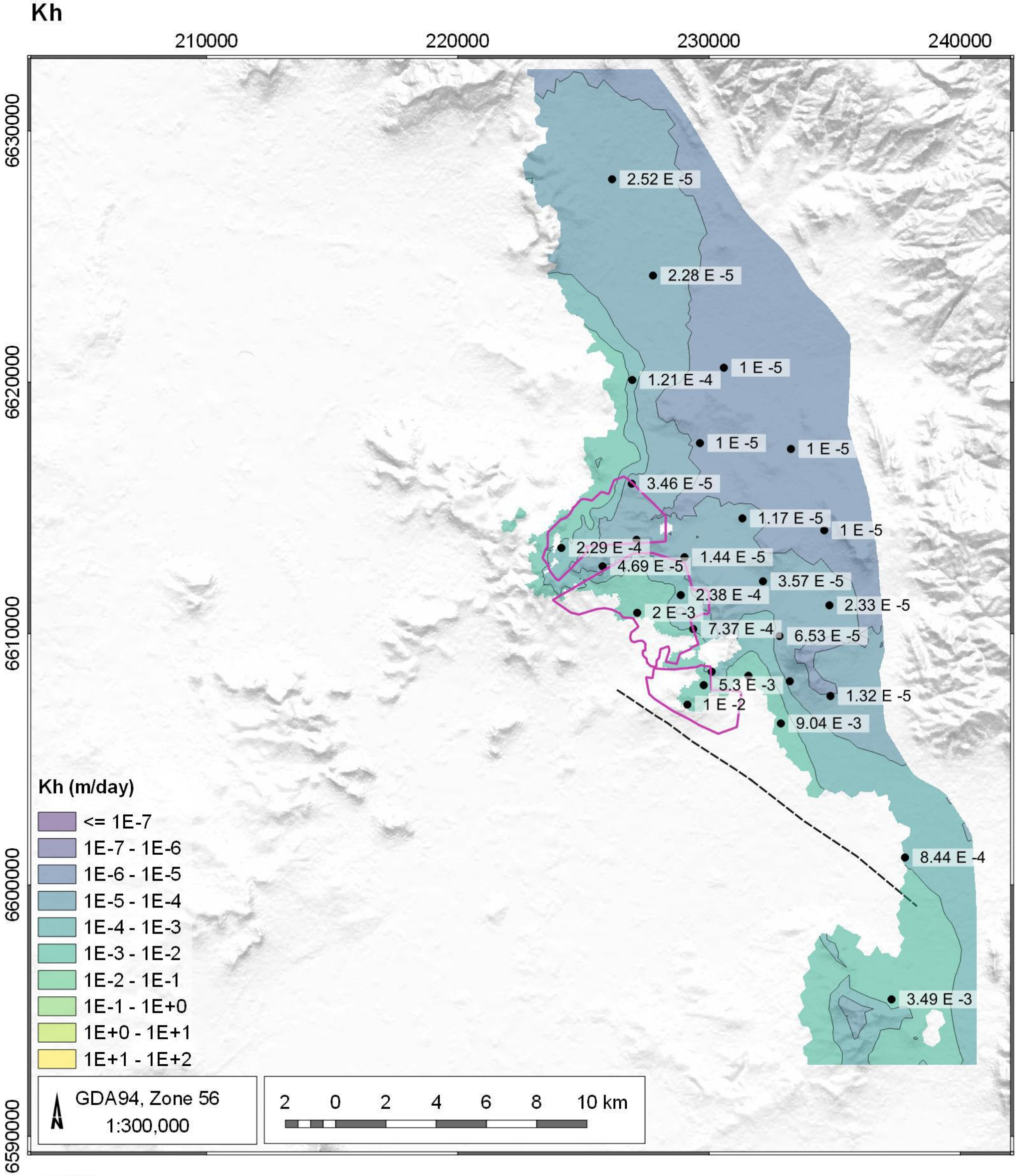

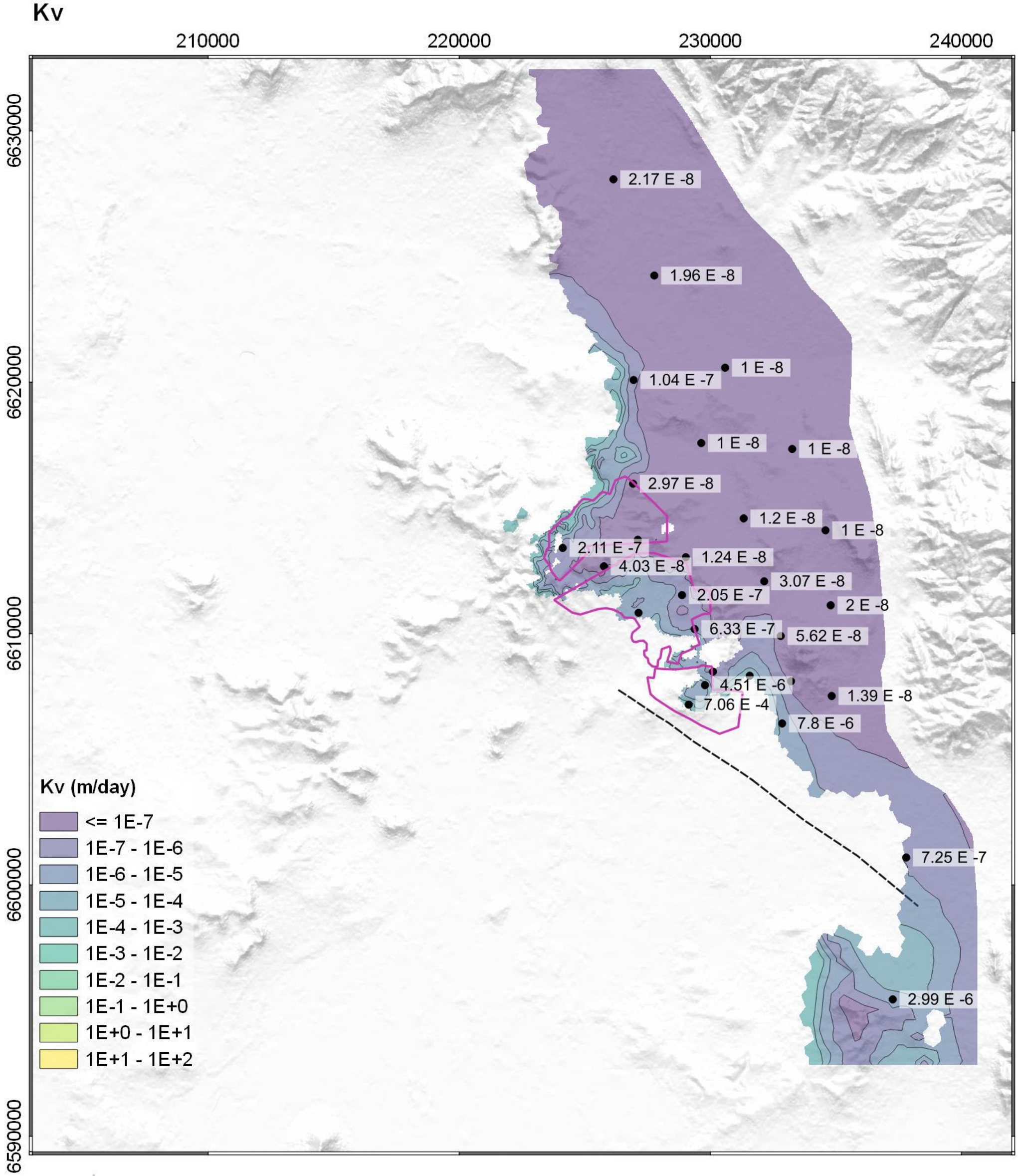

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 9 - Kh and Kv

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15/06/2021

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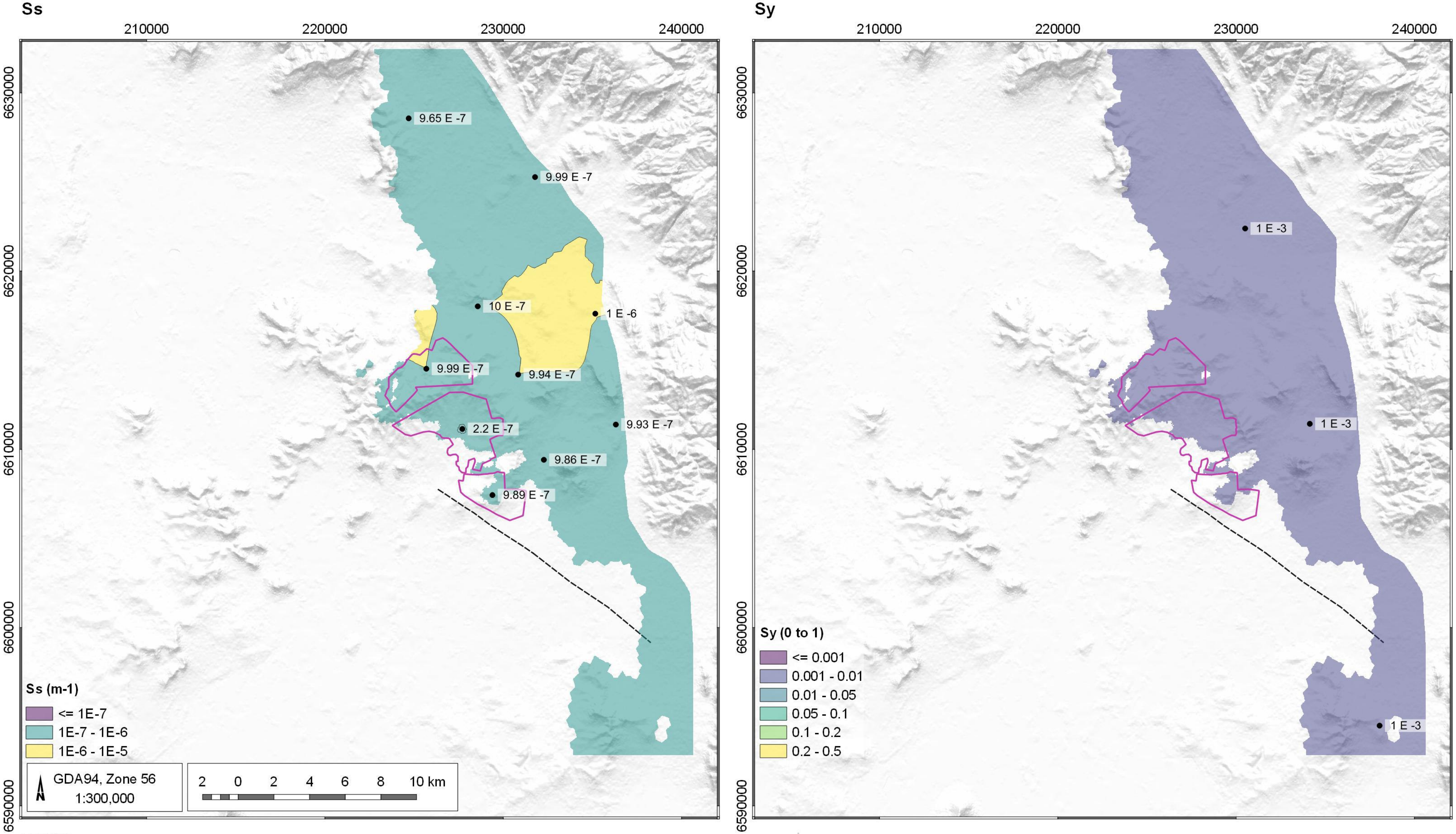

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 9 - Ss and Sy

DATE
15/06/2021

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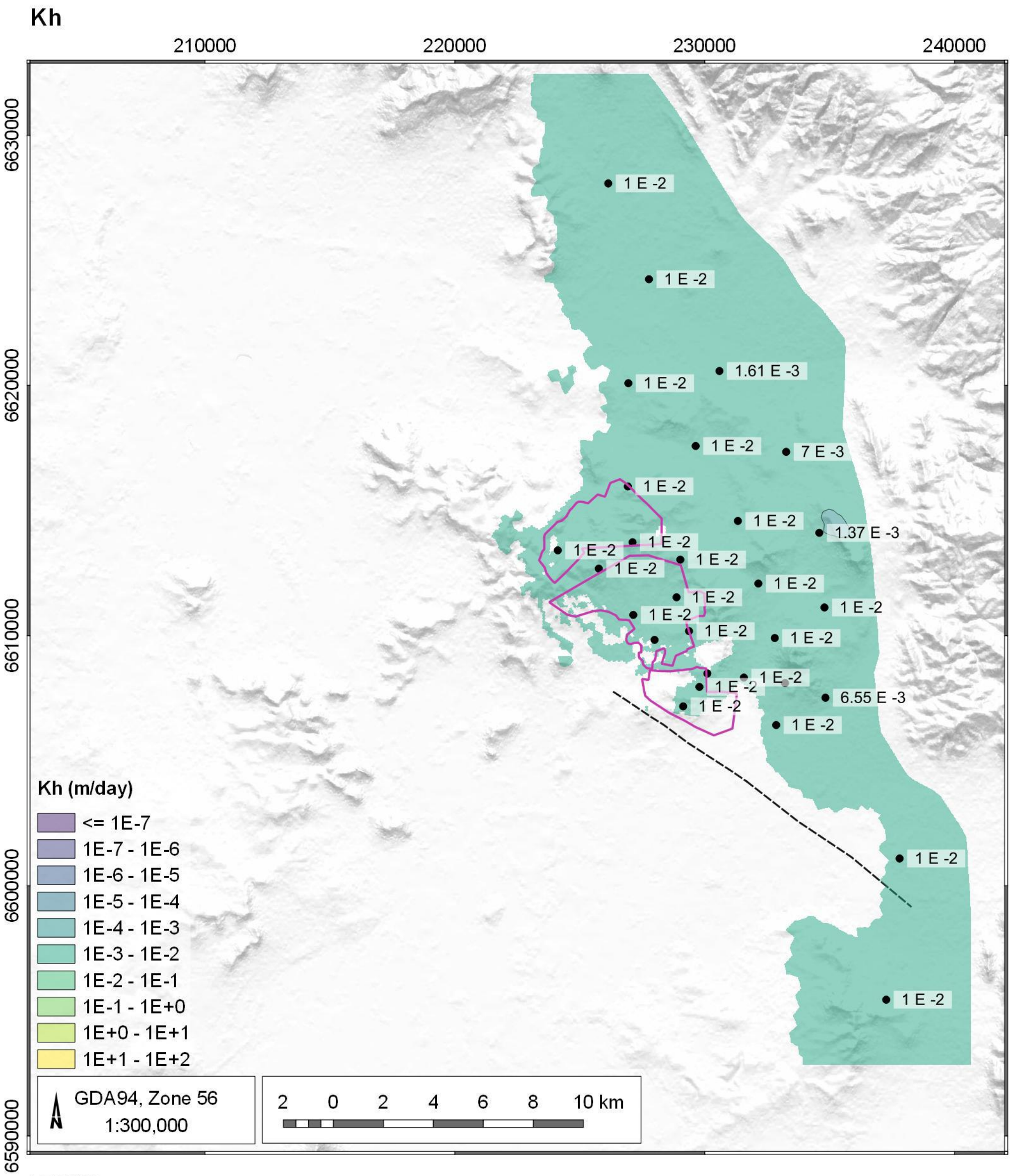

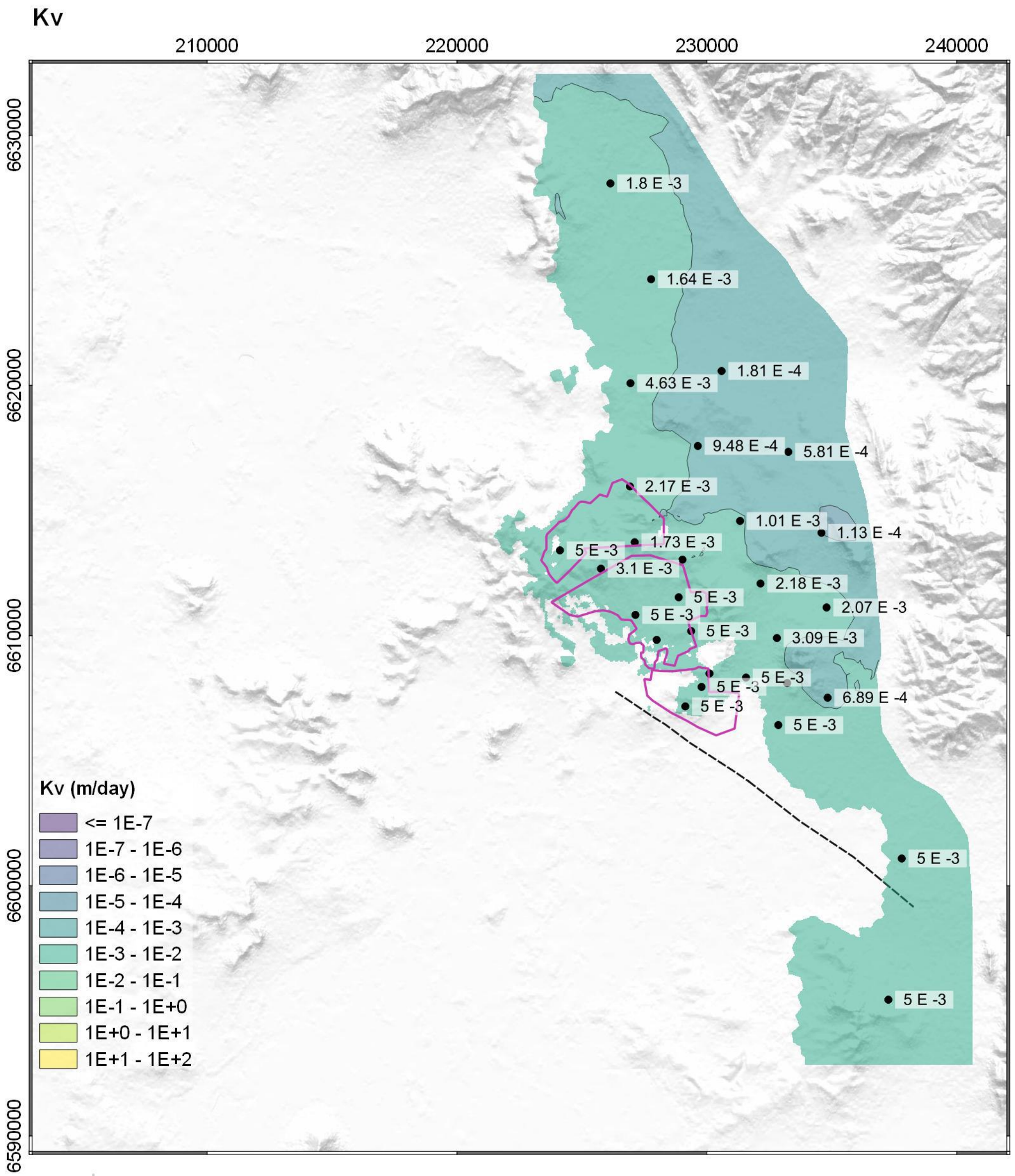

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 10 - Kh and Kv

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15/06/2021

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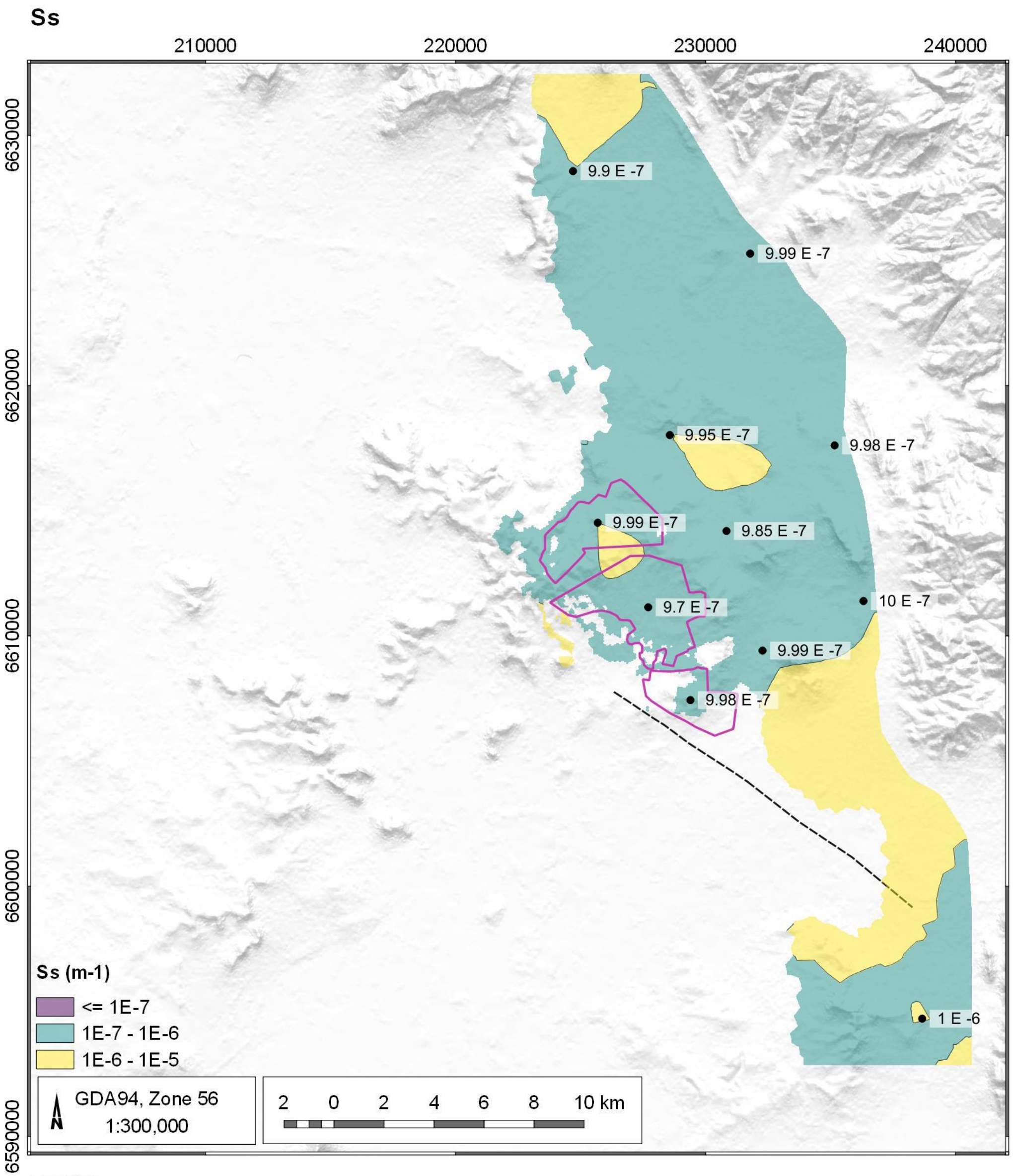

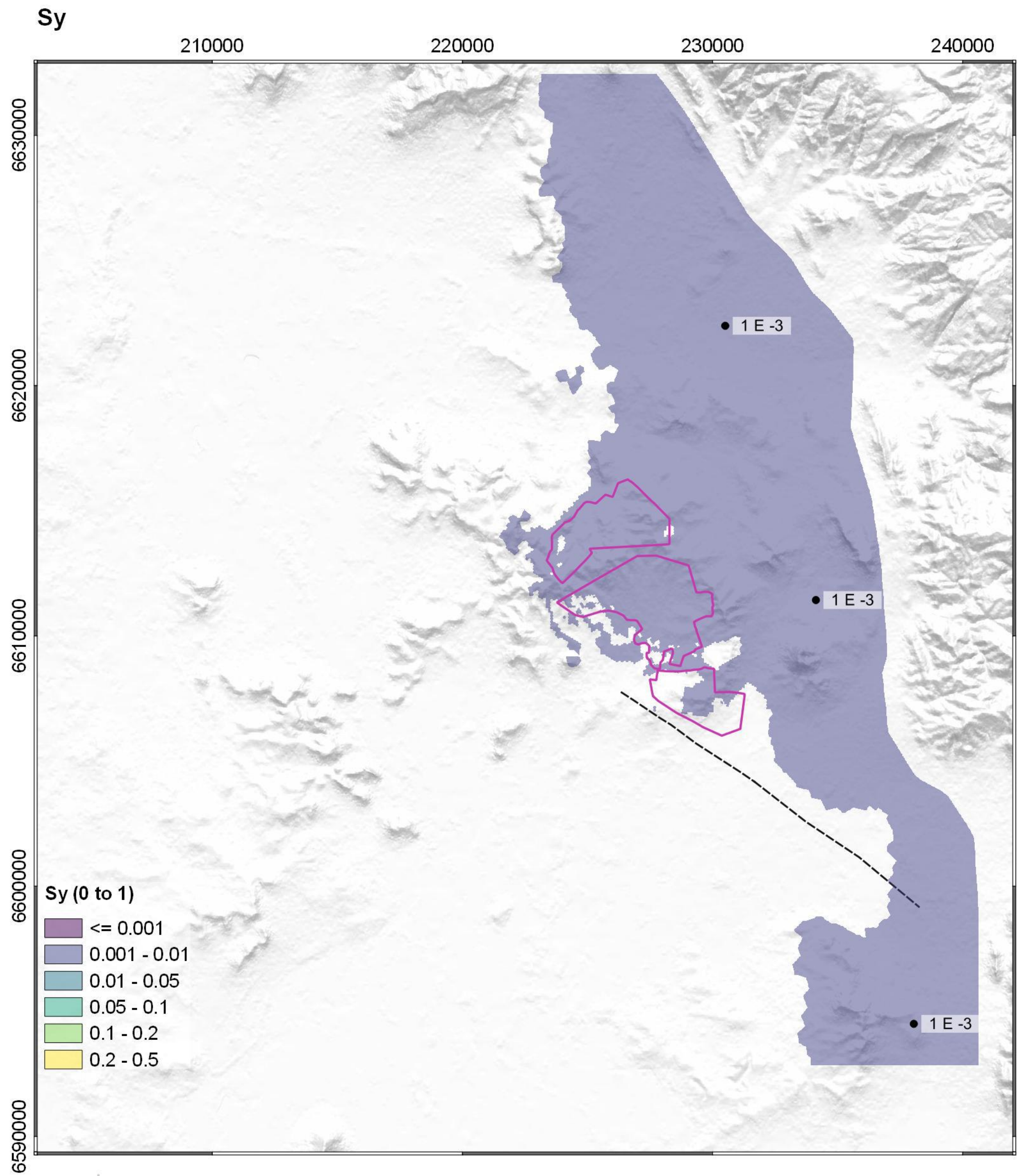

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 10 - Ss and Sy

DATE
15/06/2021

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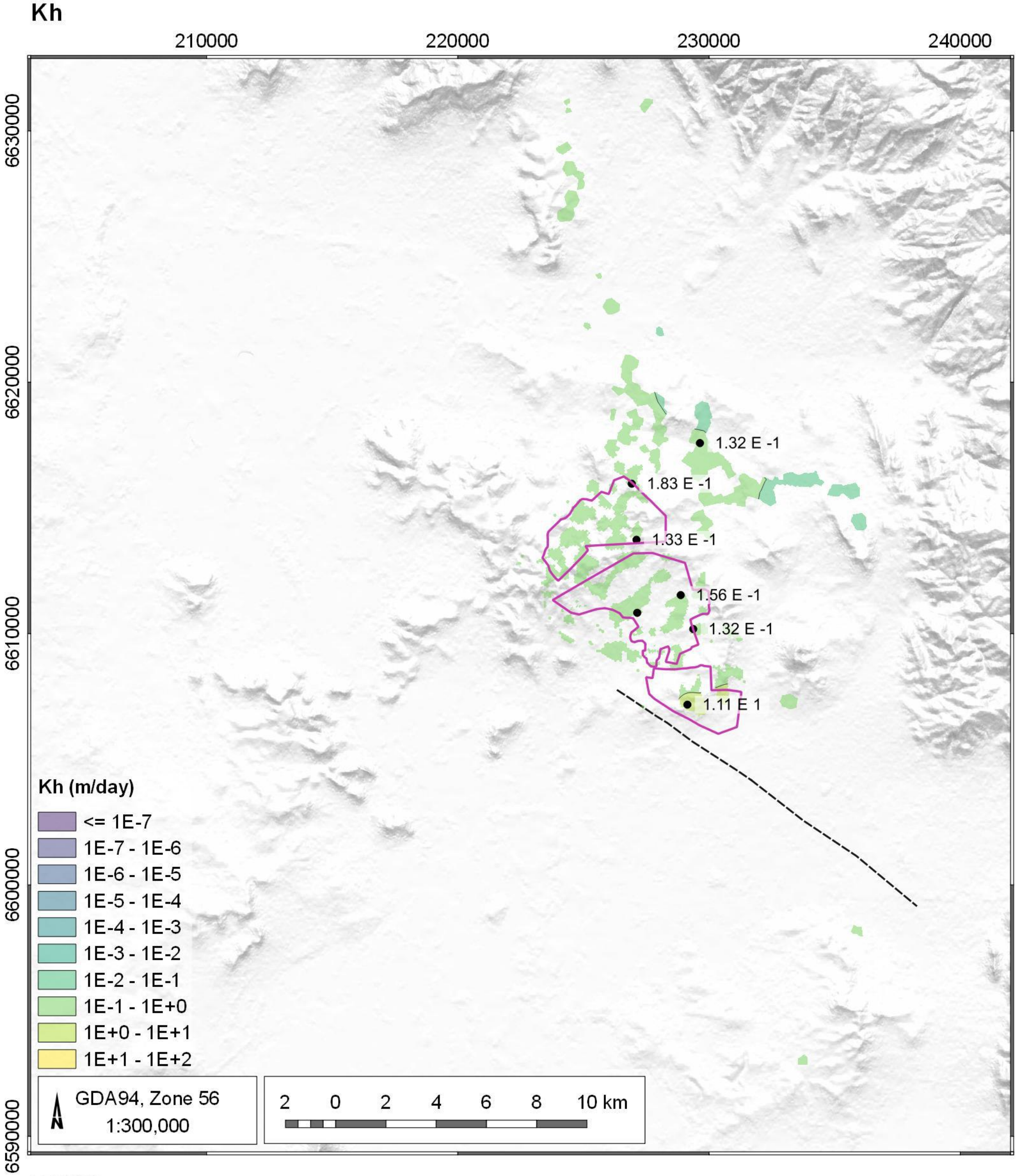

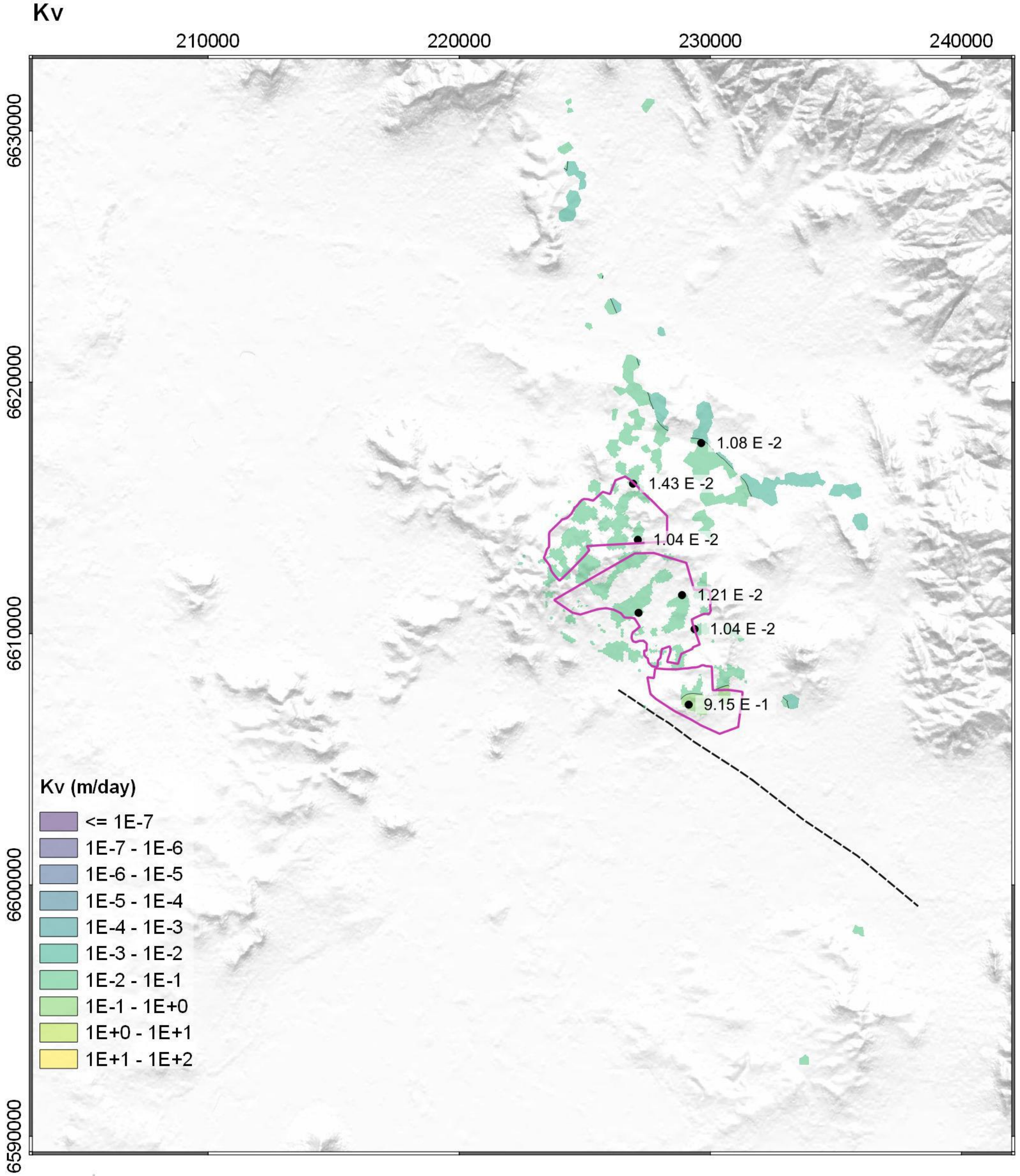

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 11 - Kh and Kv

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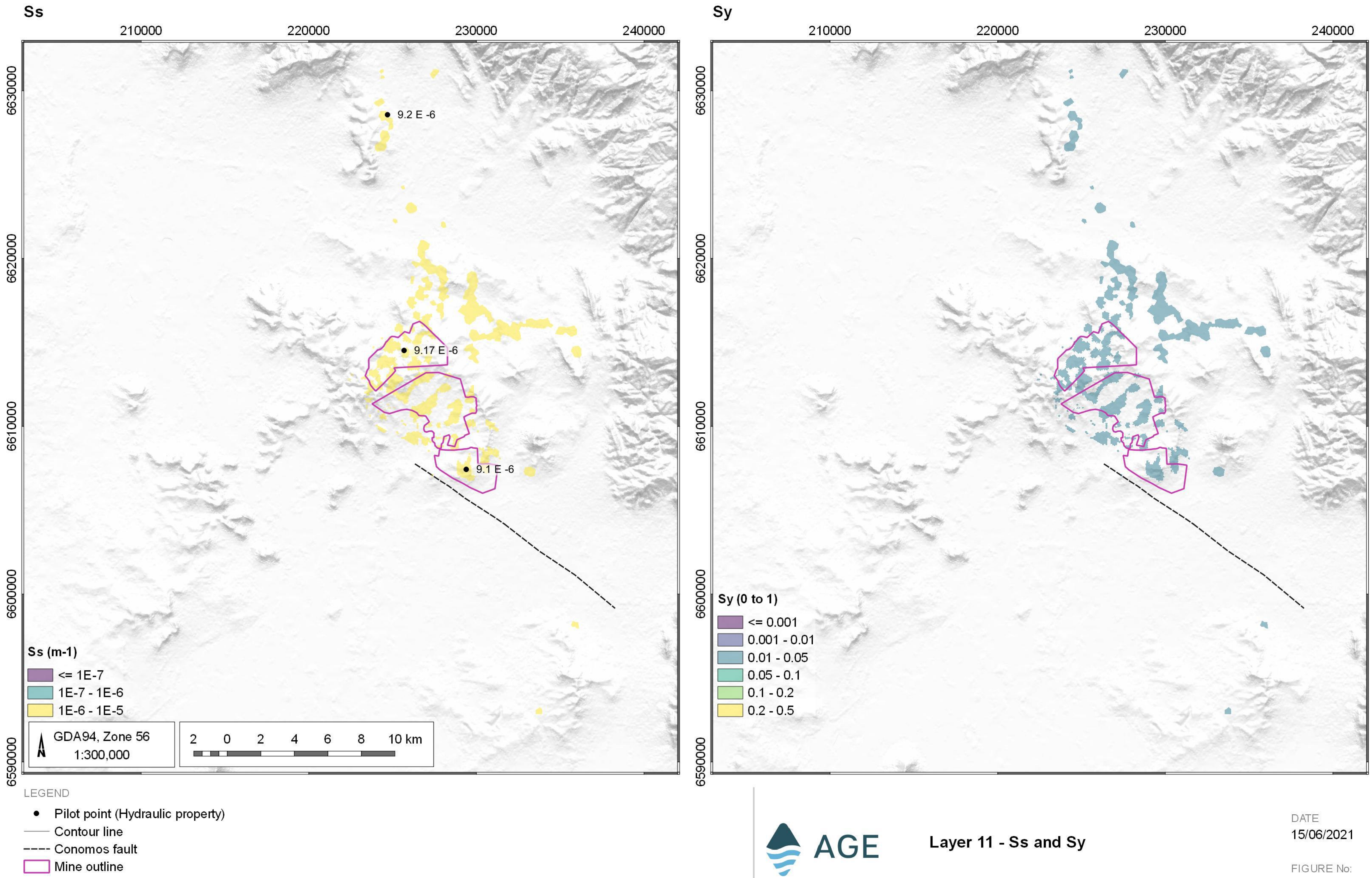

AGE

Layer 11 - Ss and Sy

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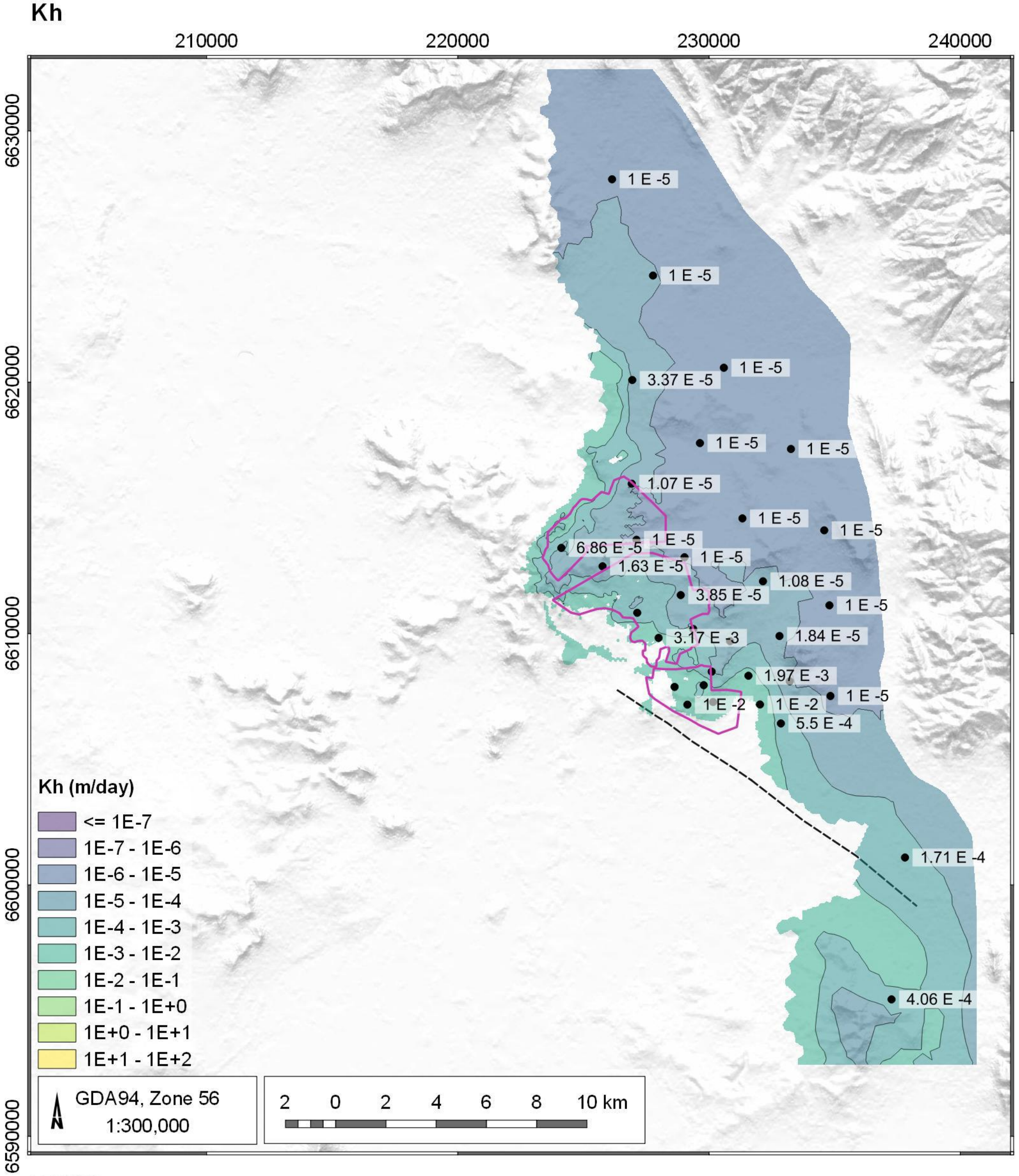

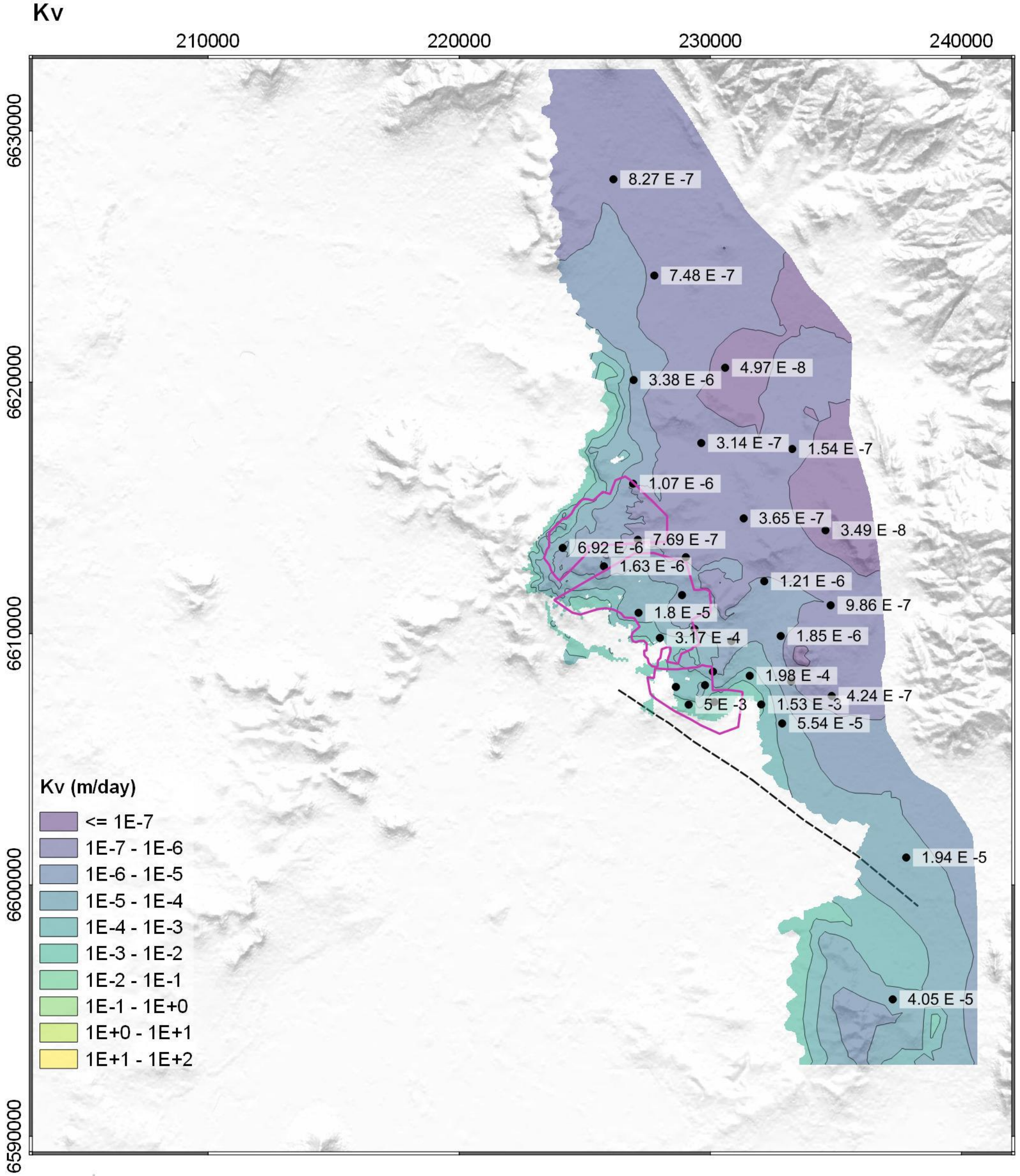

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 12 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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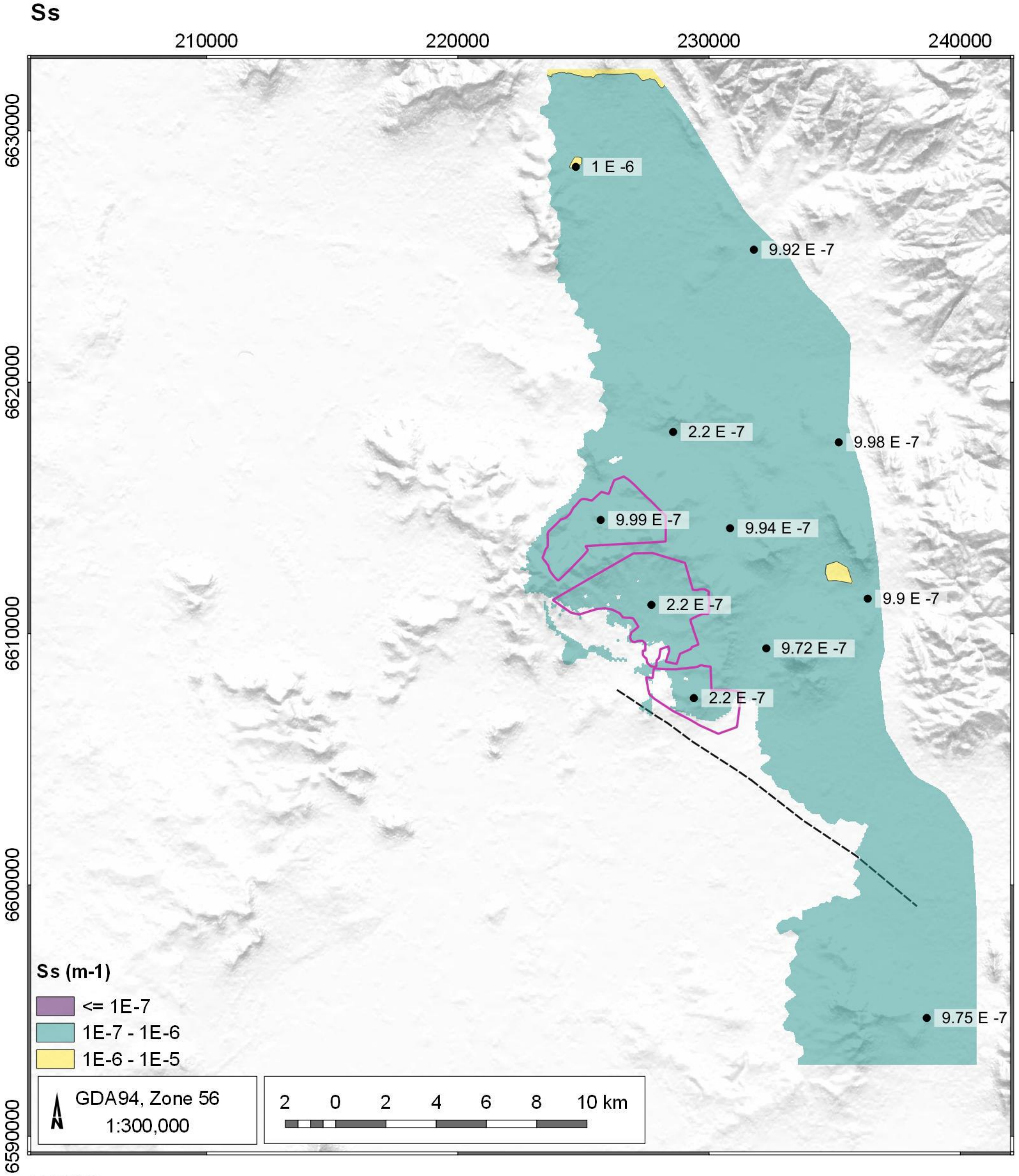
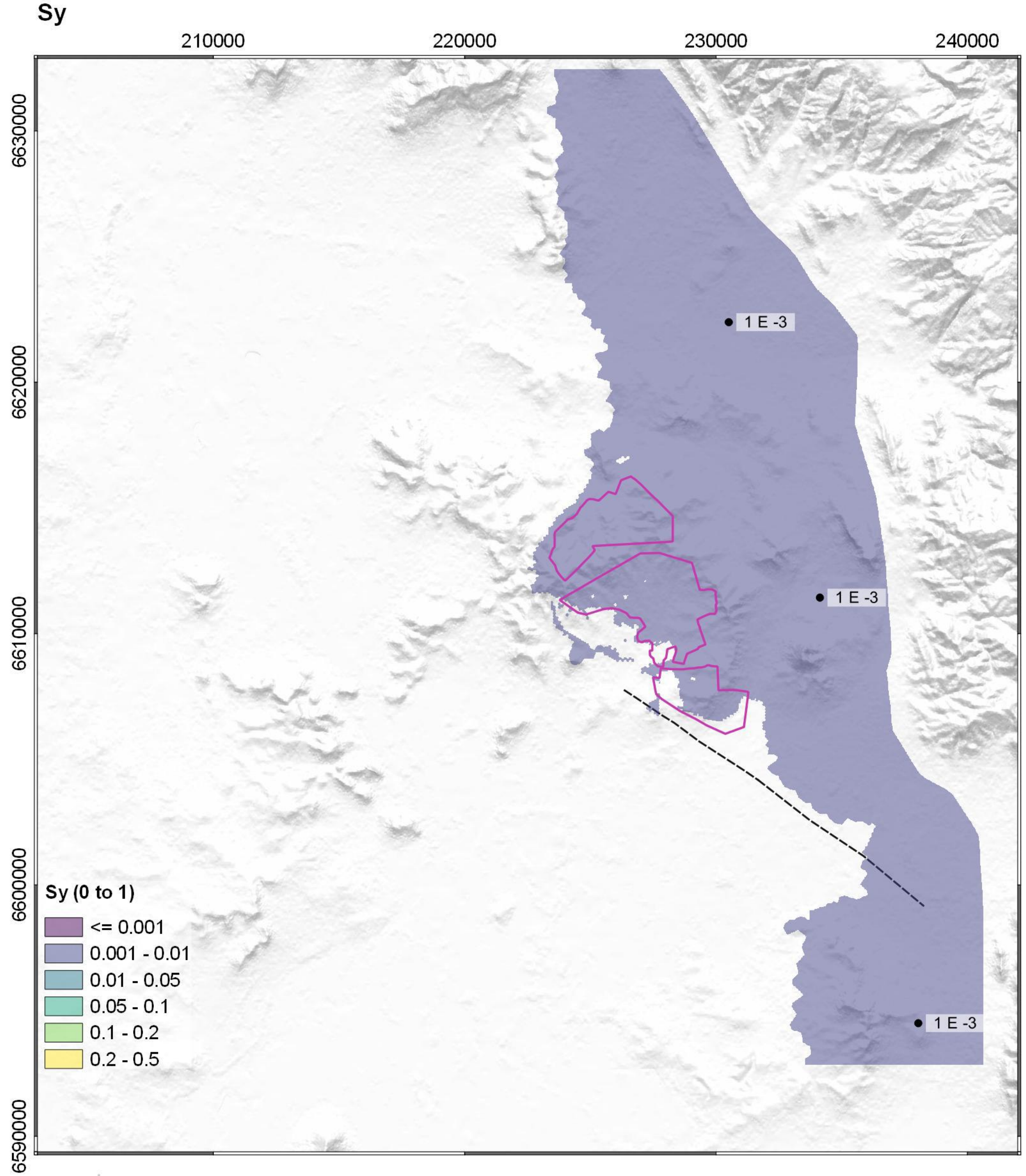
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 12 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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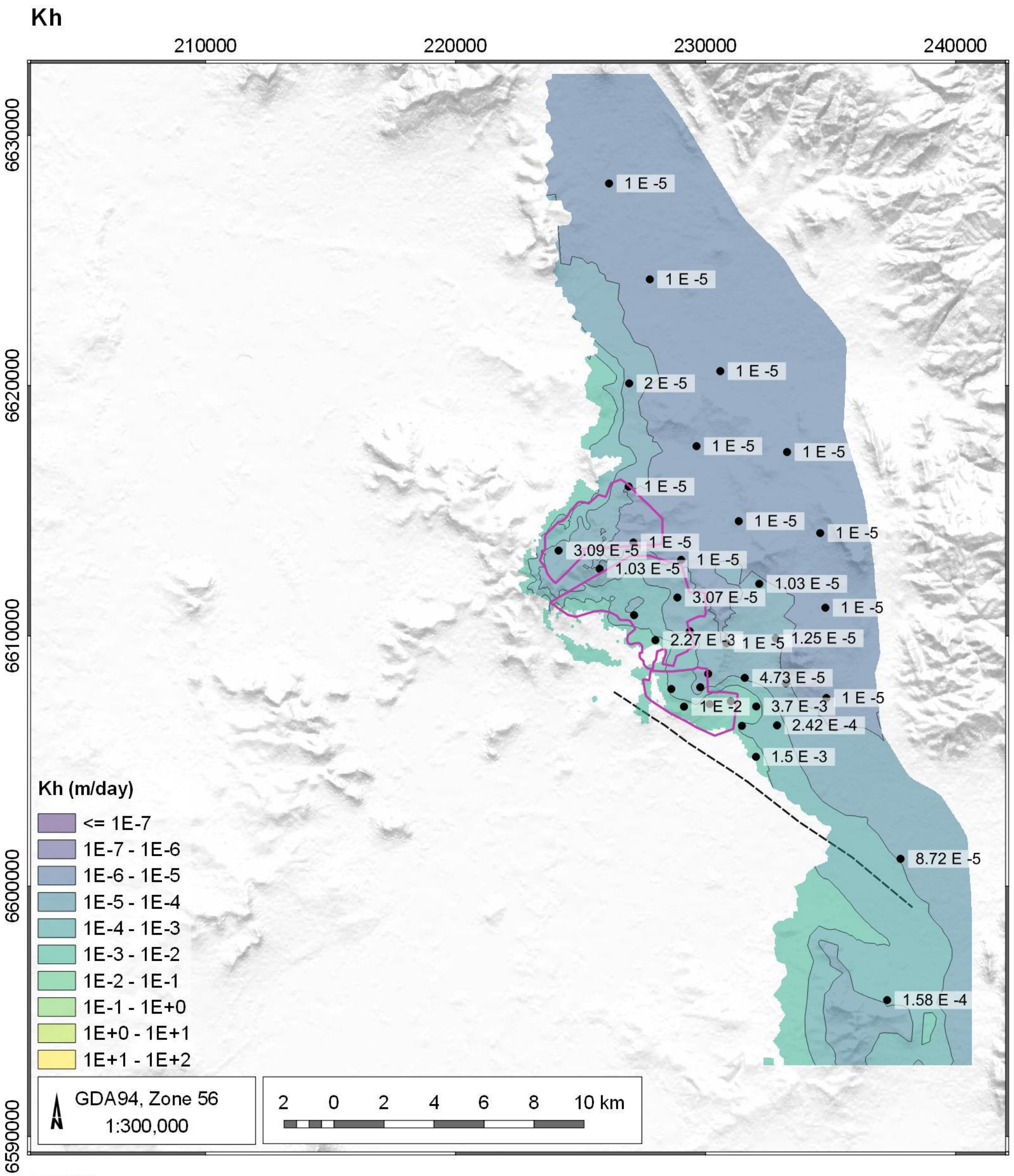

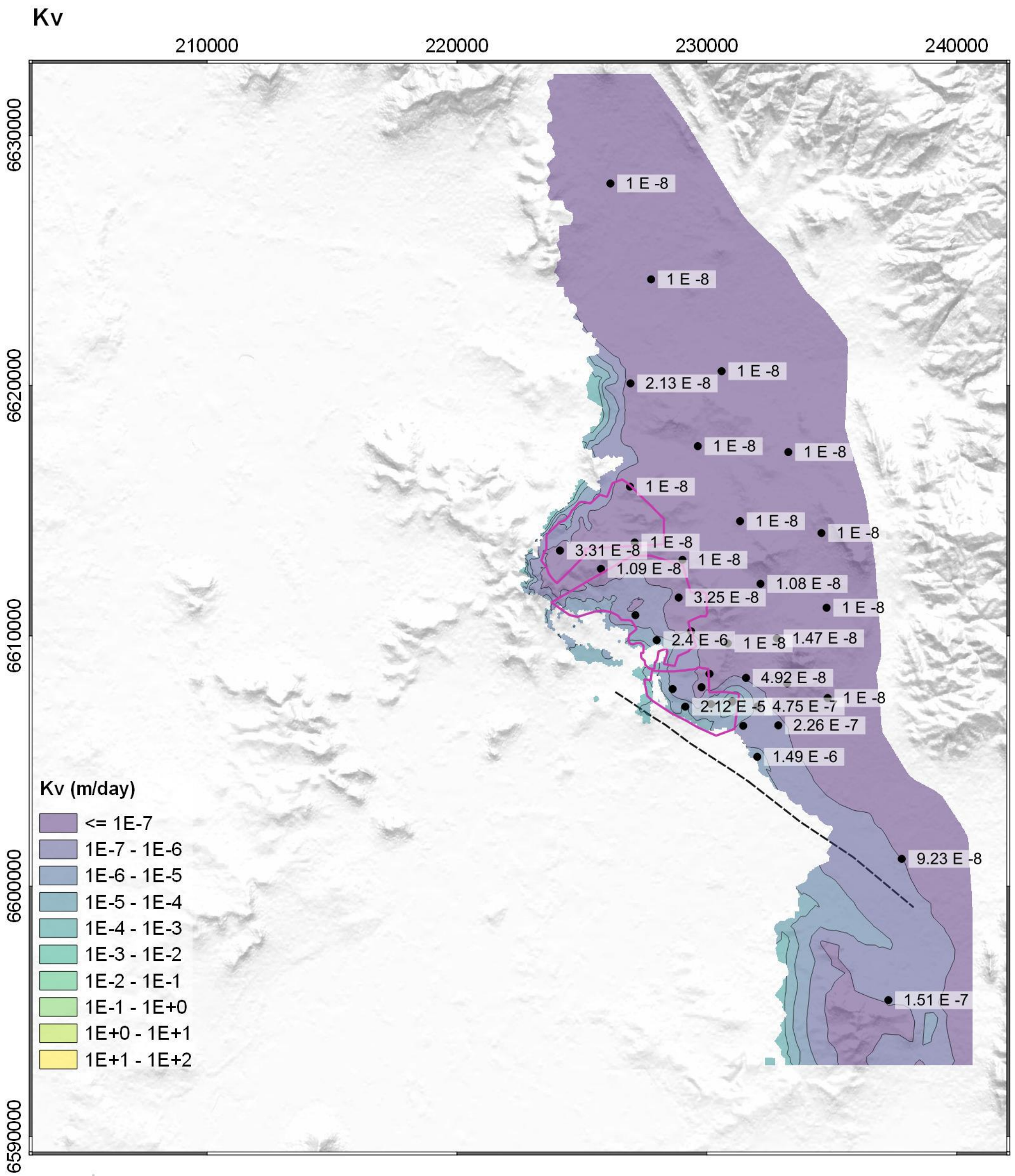

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 13 - Kh and Kv

DATE
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FIGURE No:

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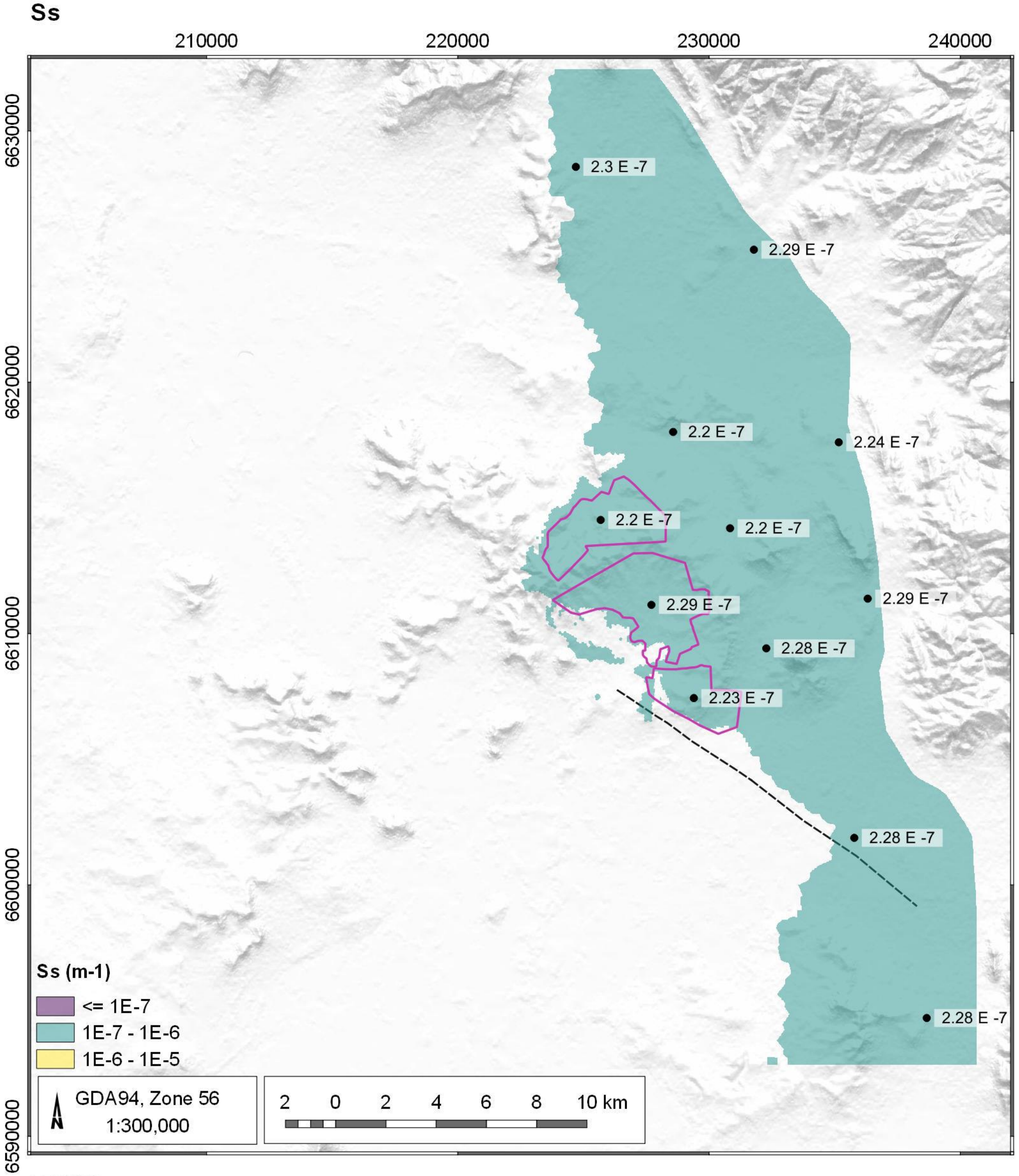

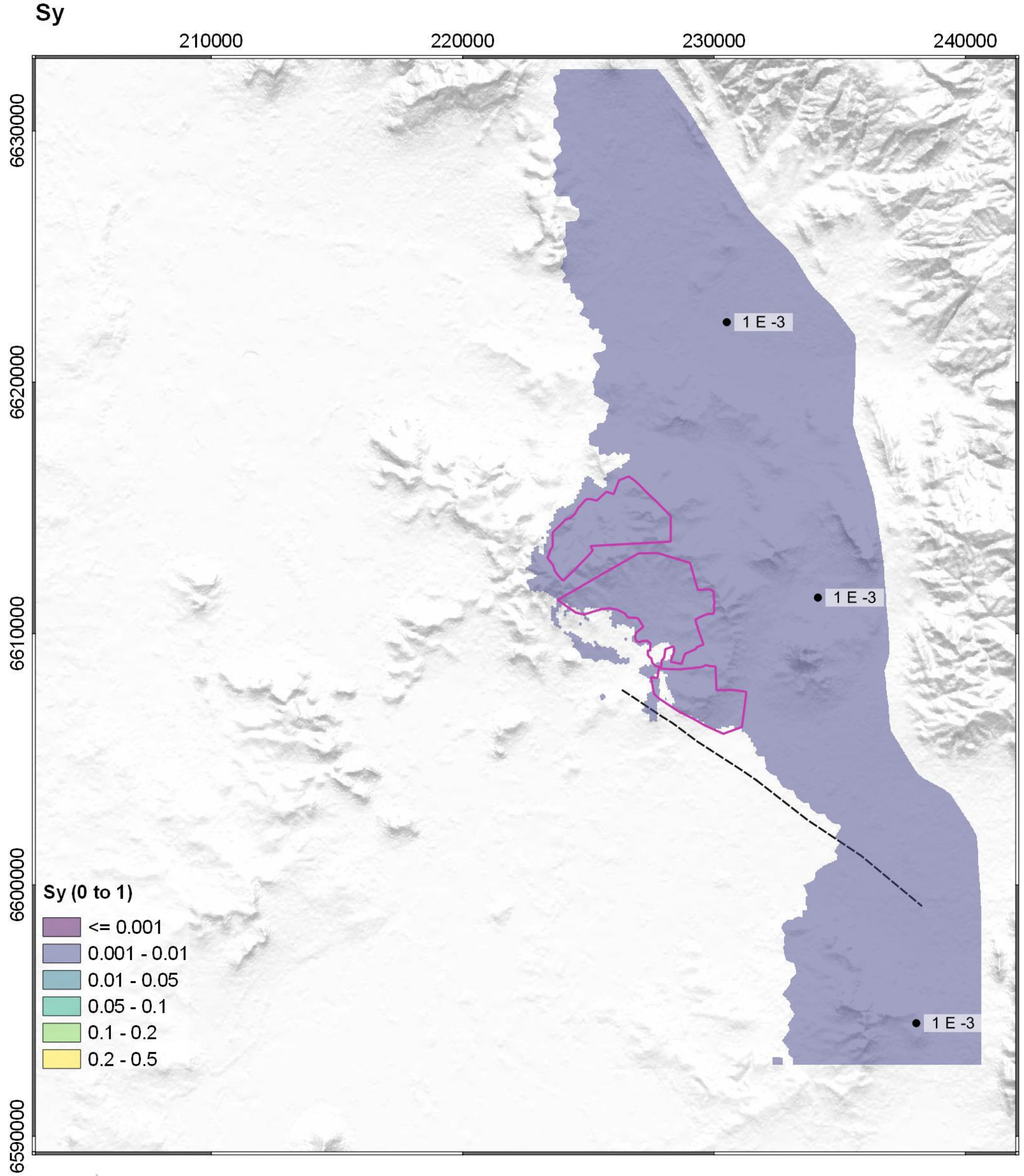

LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 13 - Ss and Sy

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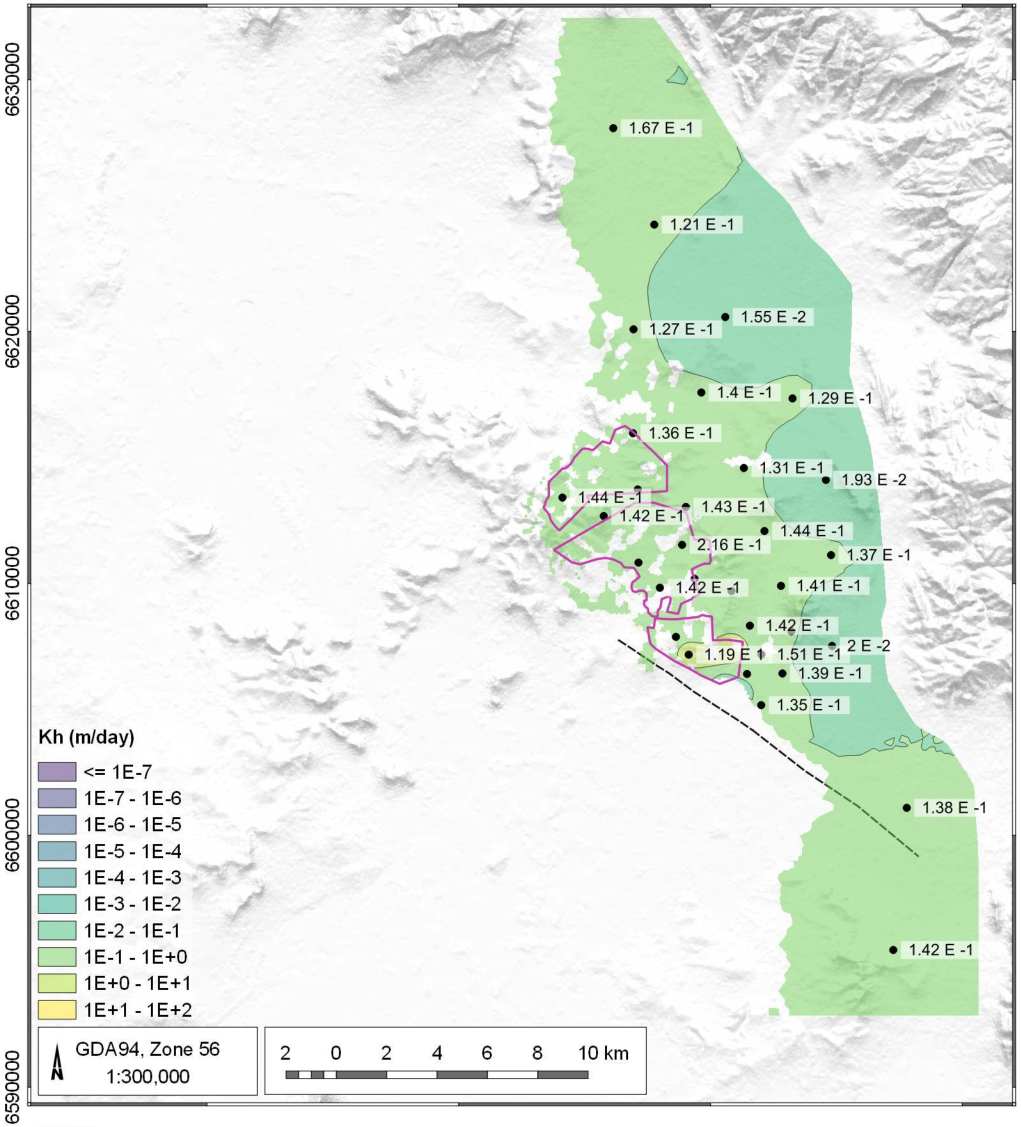

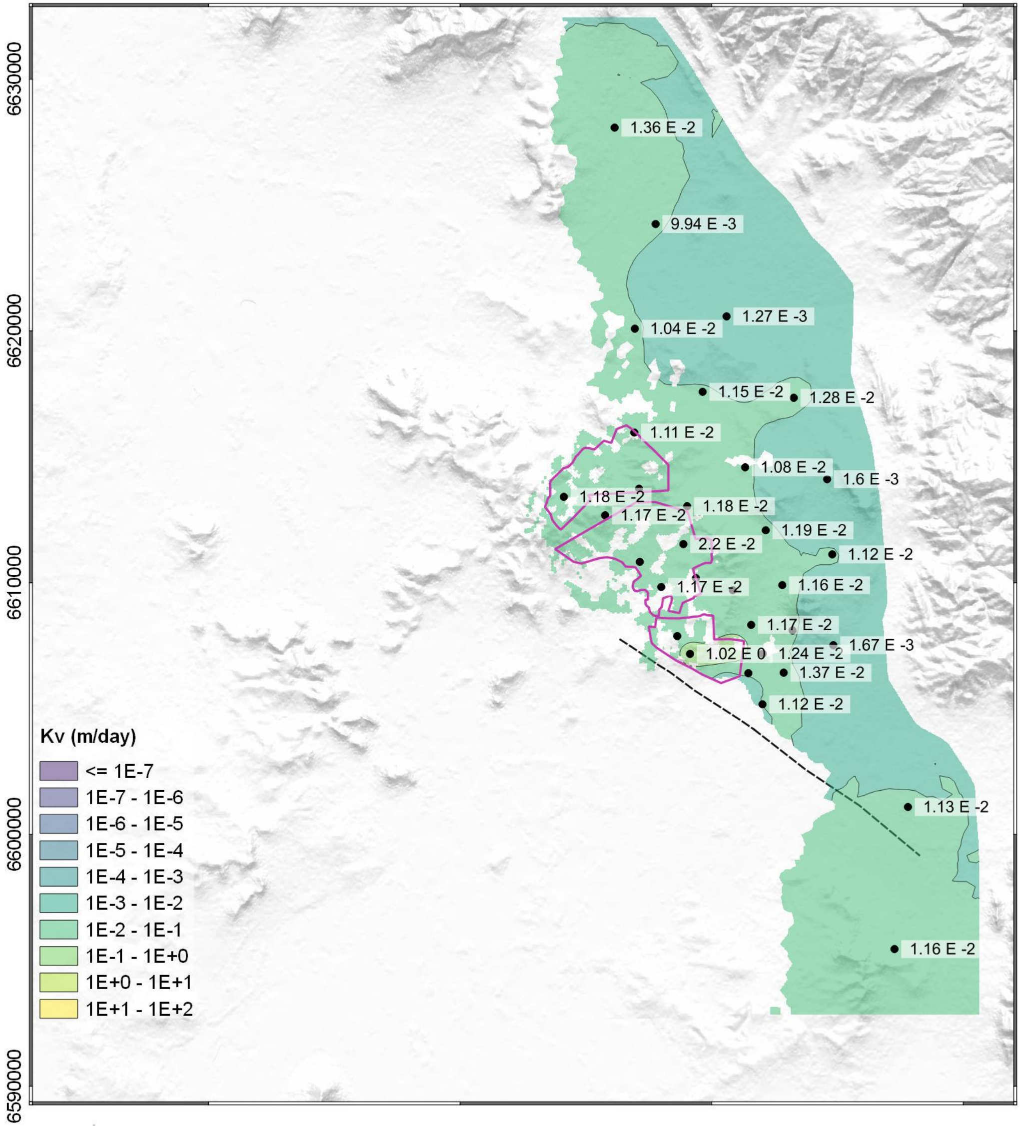

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 14 - Kh and Kv

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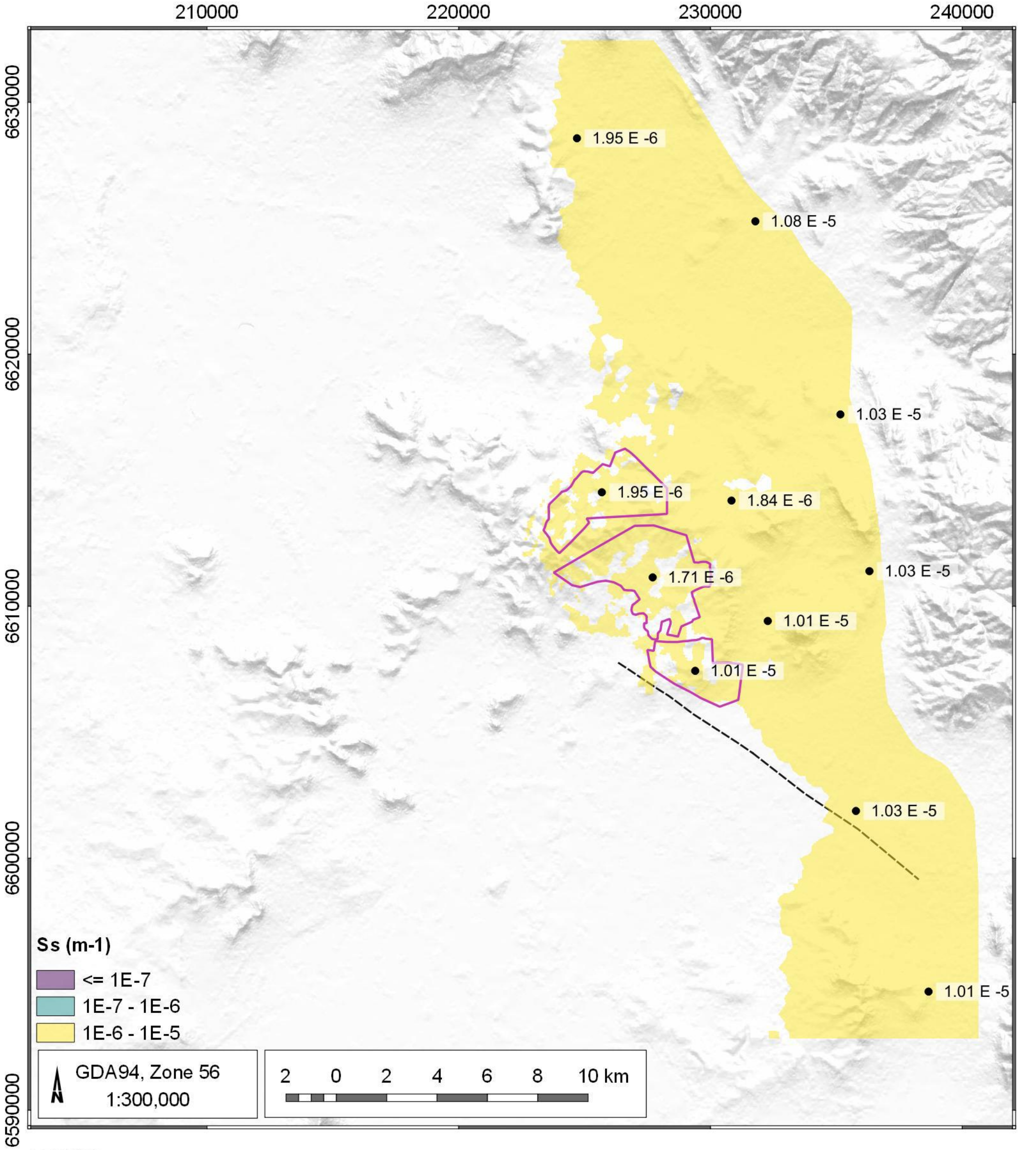
Ss



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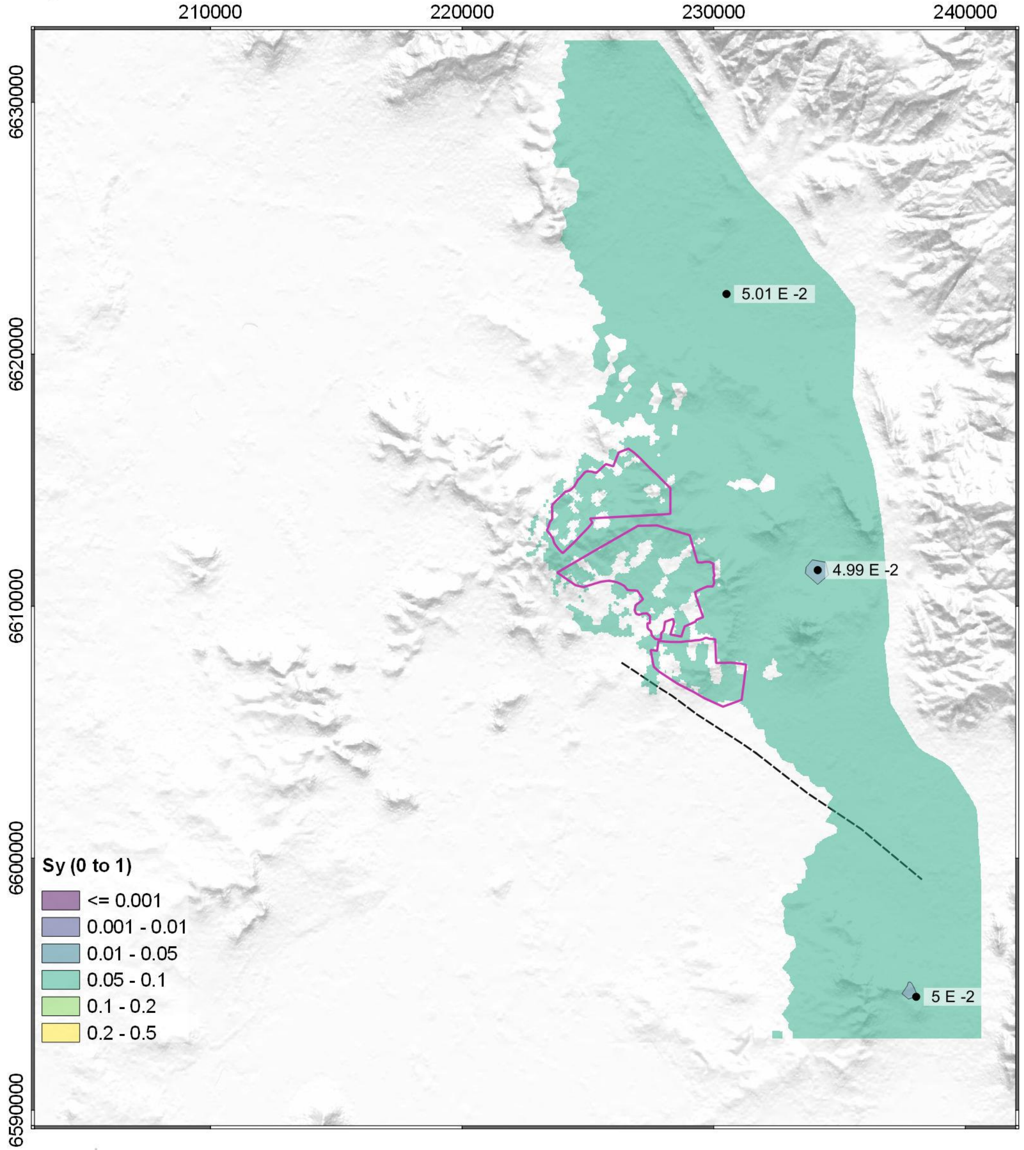

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 14 - Ss and Sy

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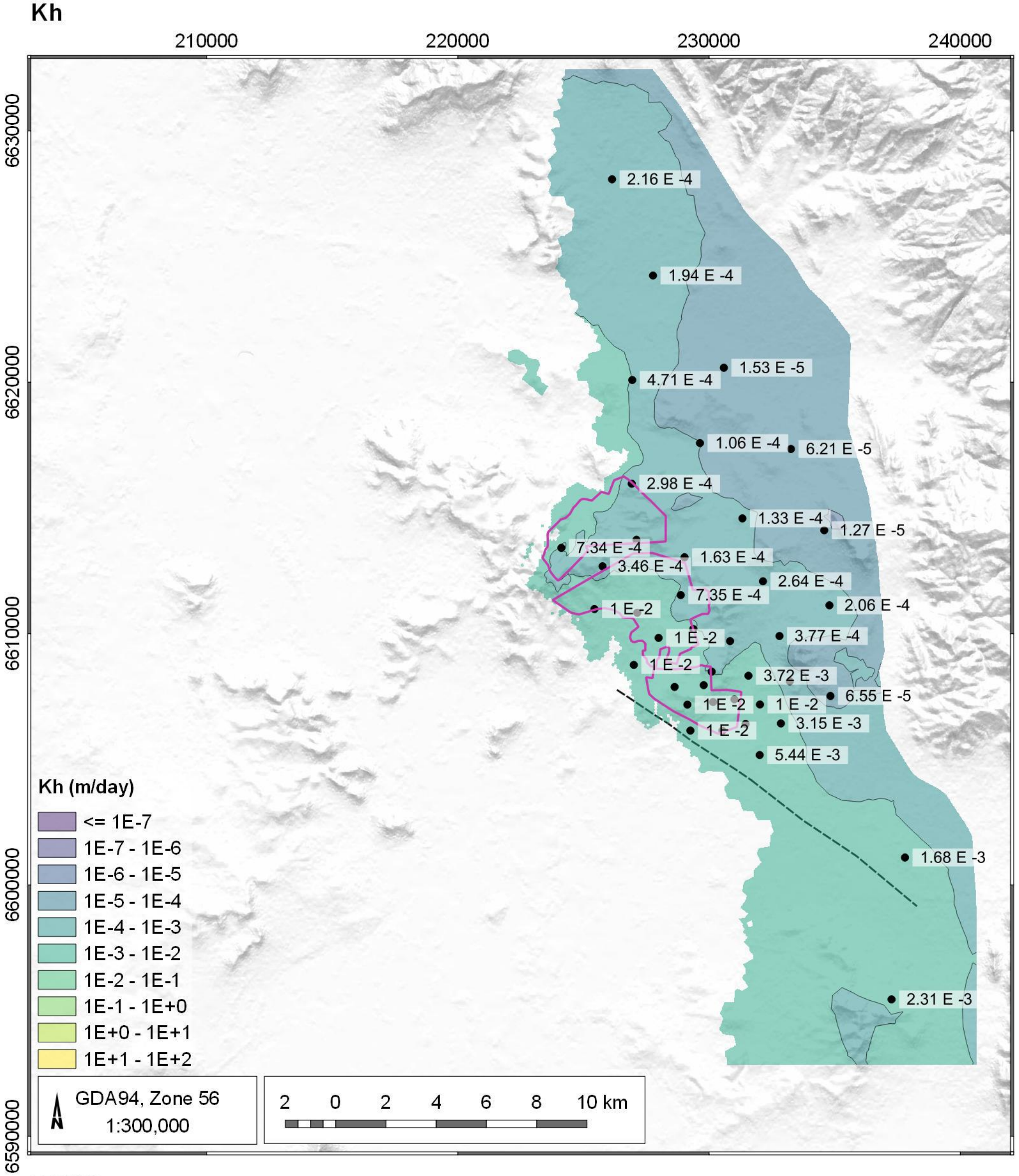

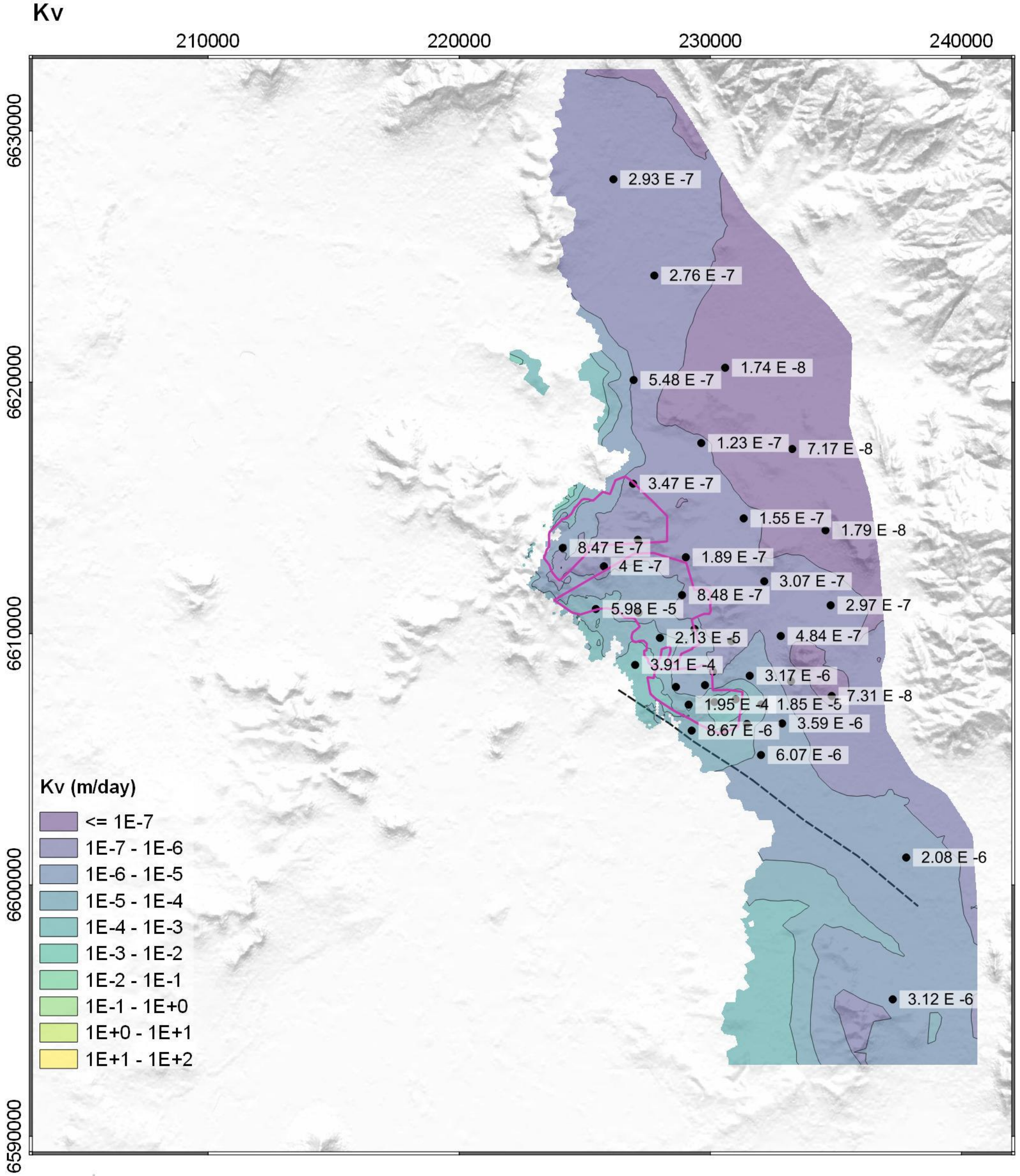

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

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Layer 15 - Kh and Kv

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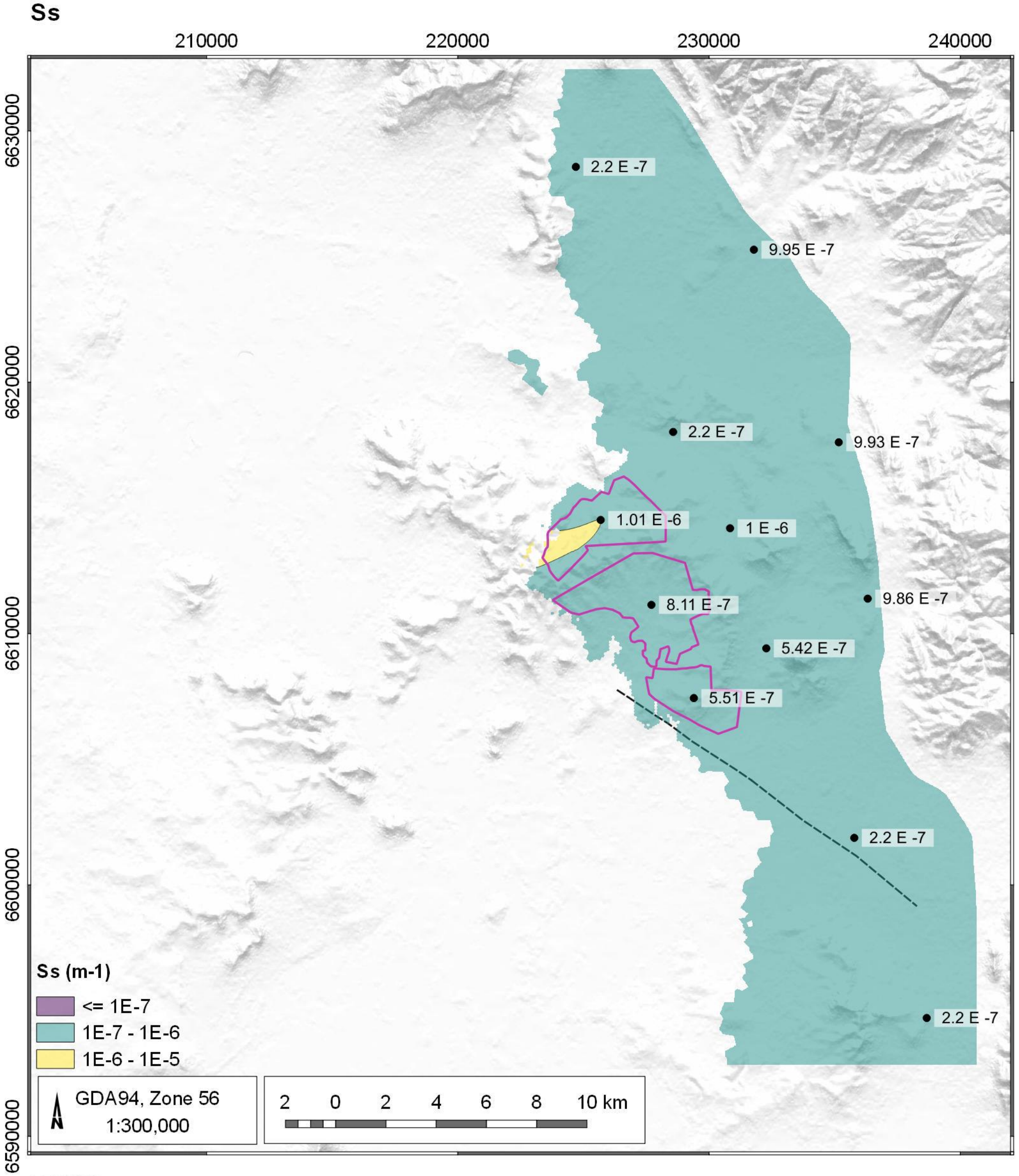

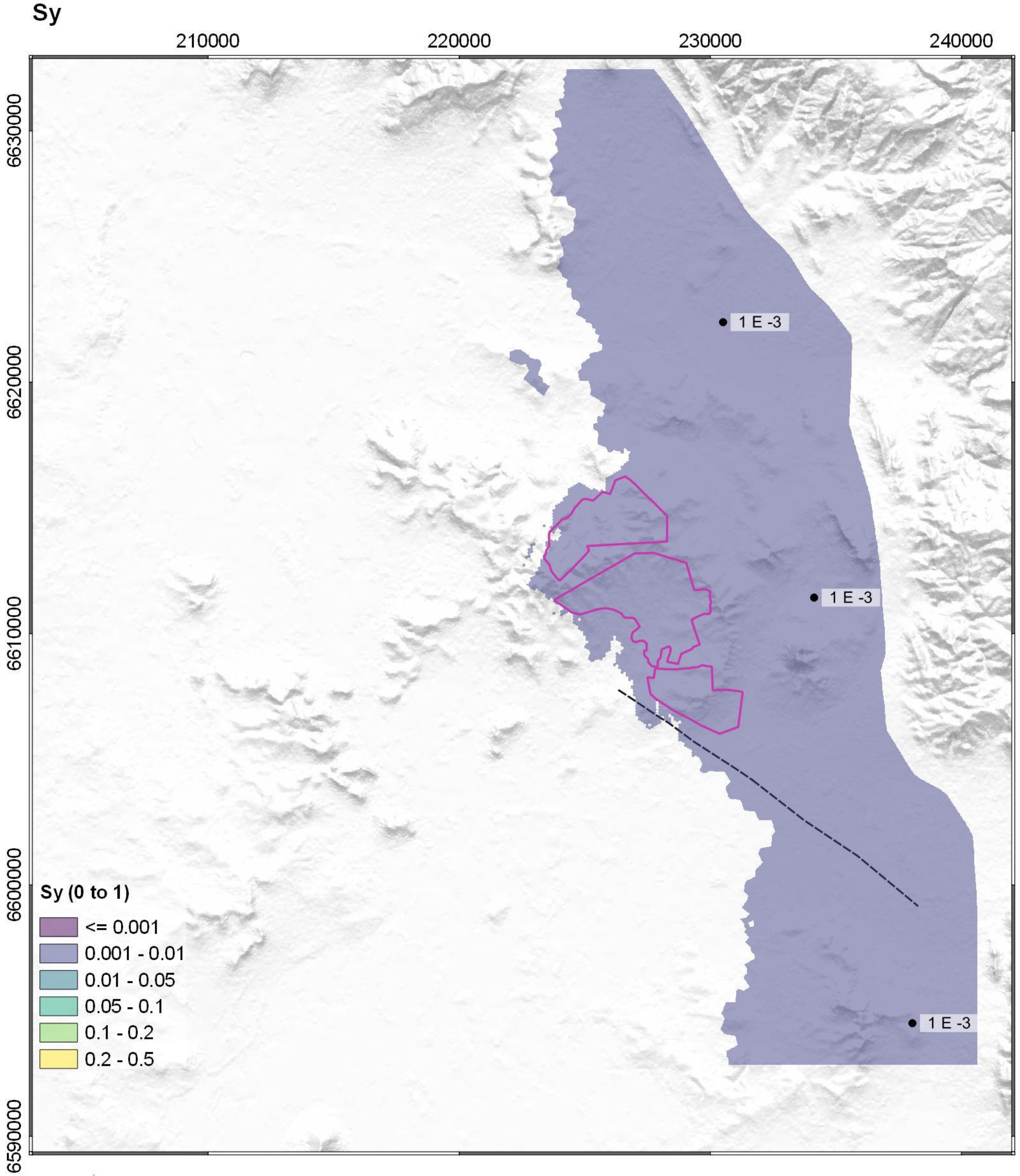

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 15 - Ss and Sy

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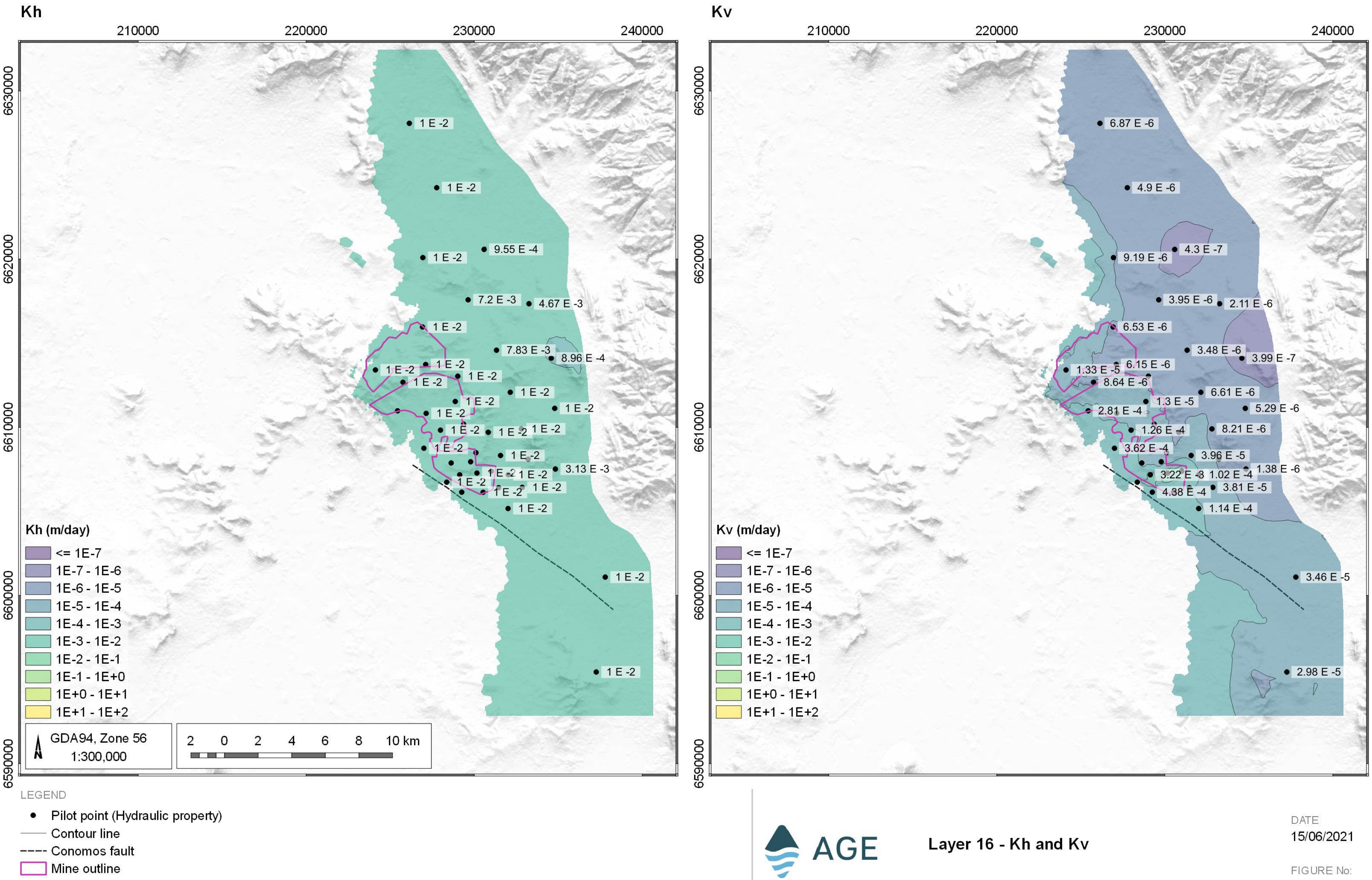

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Layer 16 - Kh and Kv

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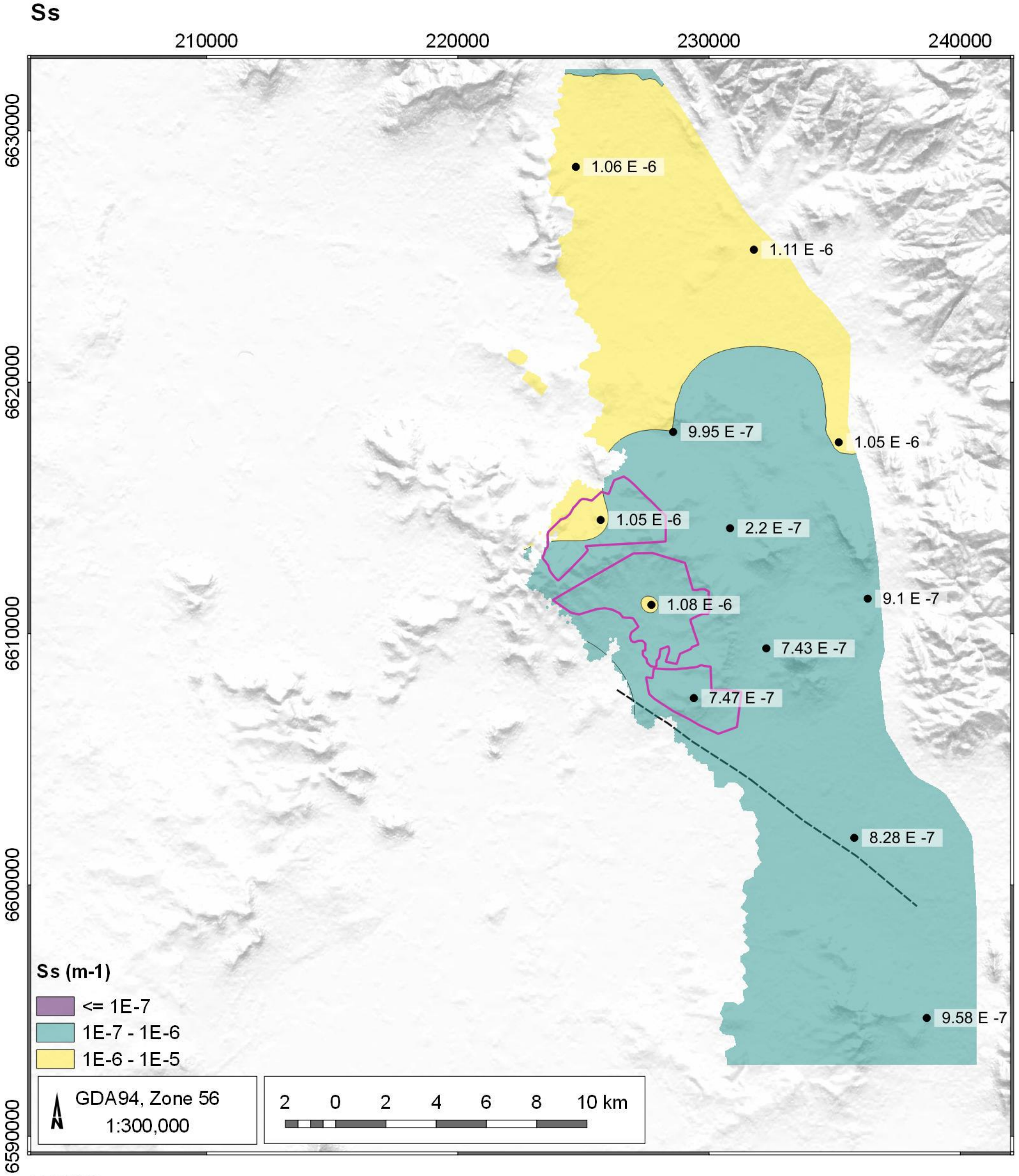

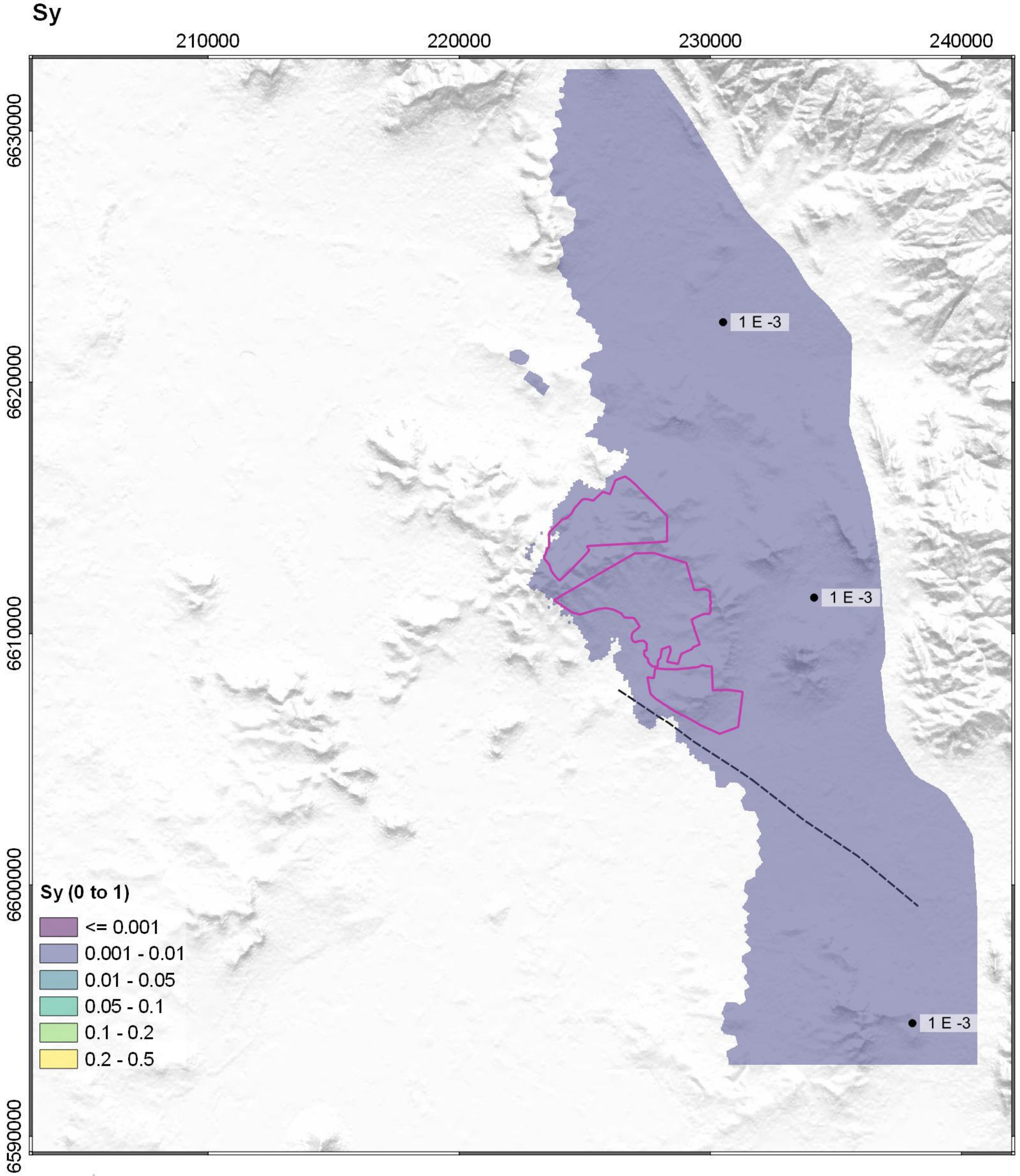

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 16 - Ss and Sy

DATE
15/06/2021

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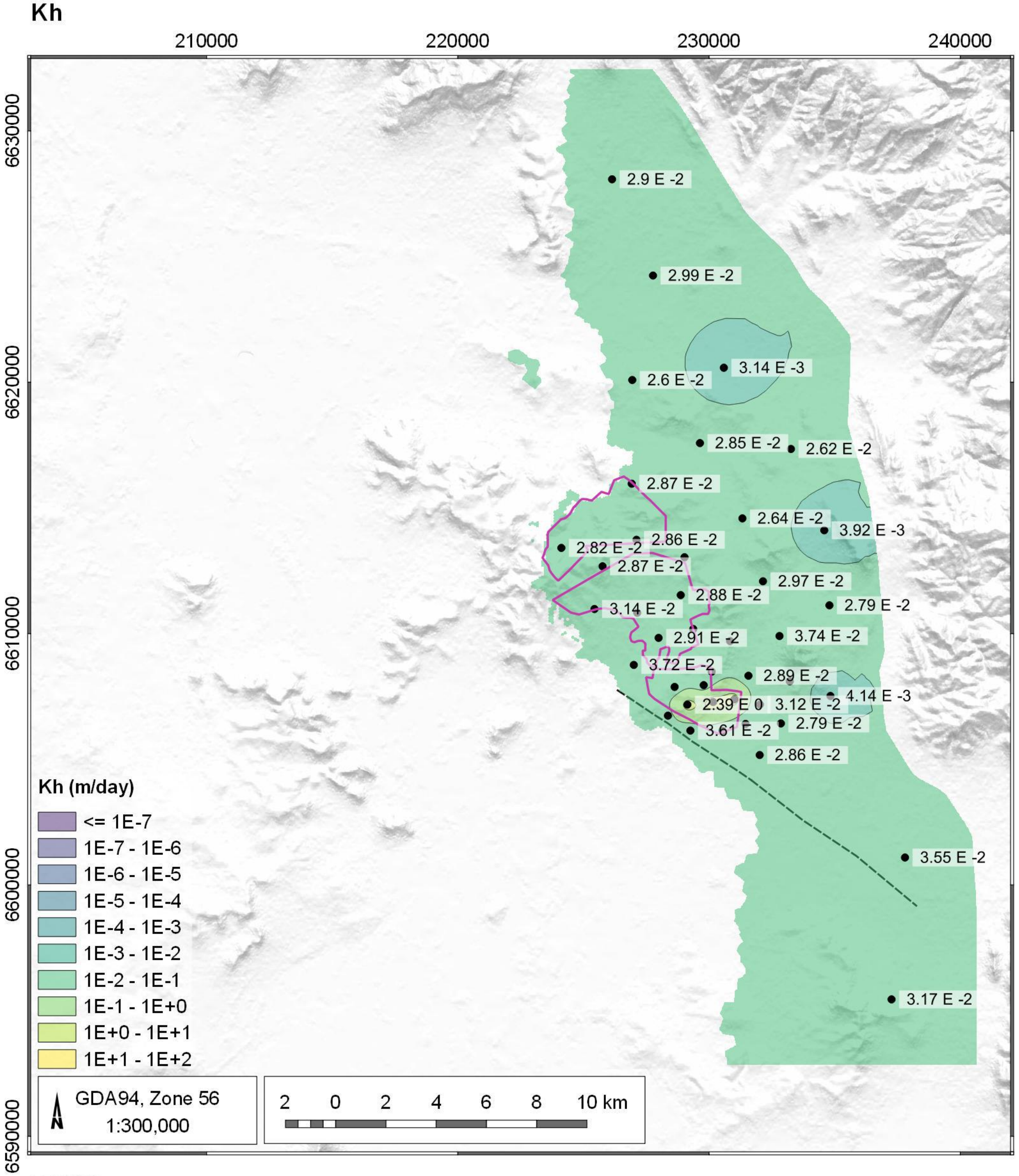

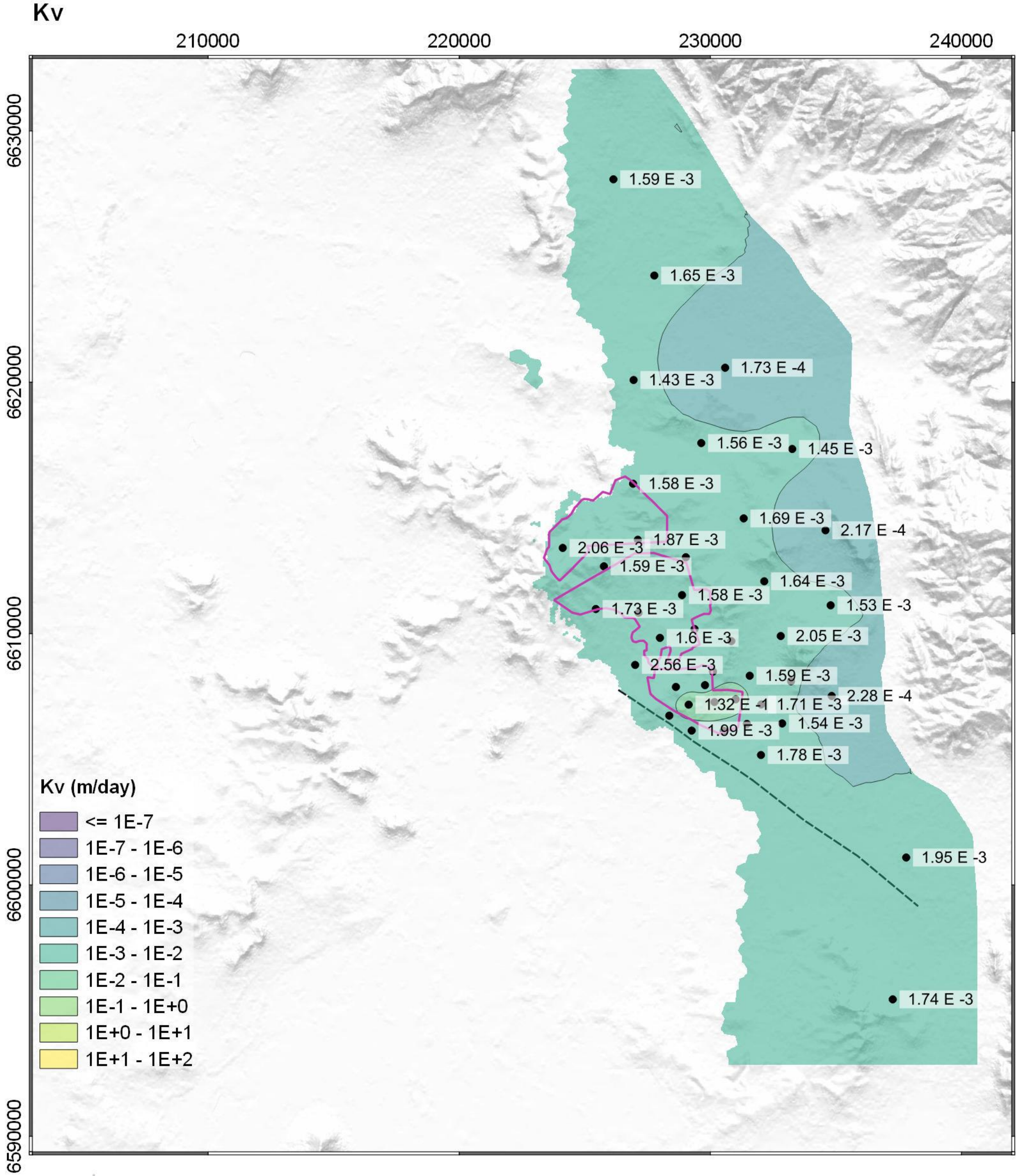

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 17 - Kh and Kv

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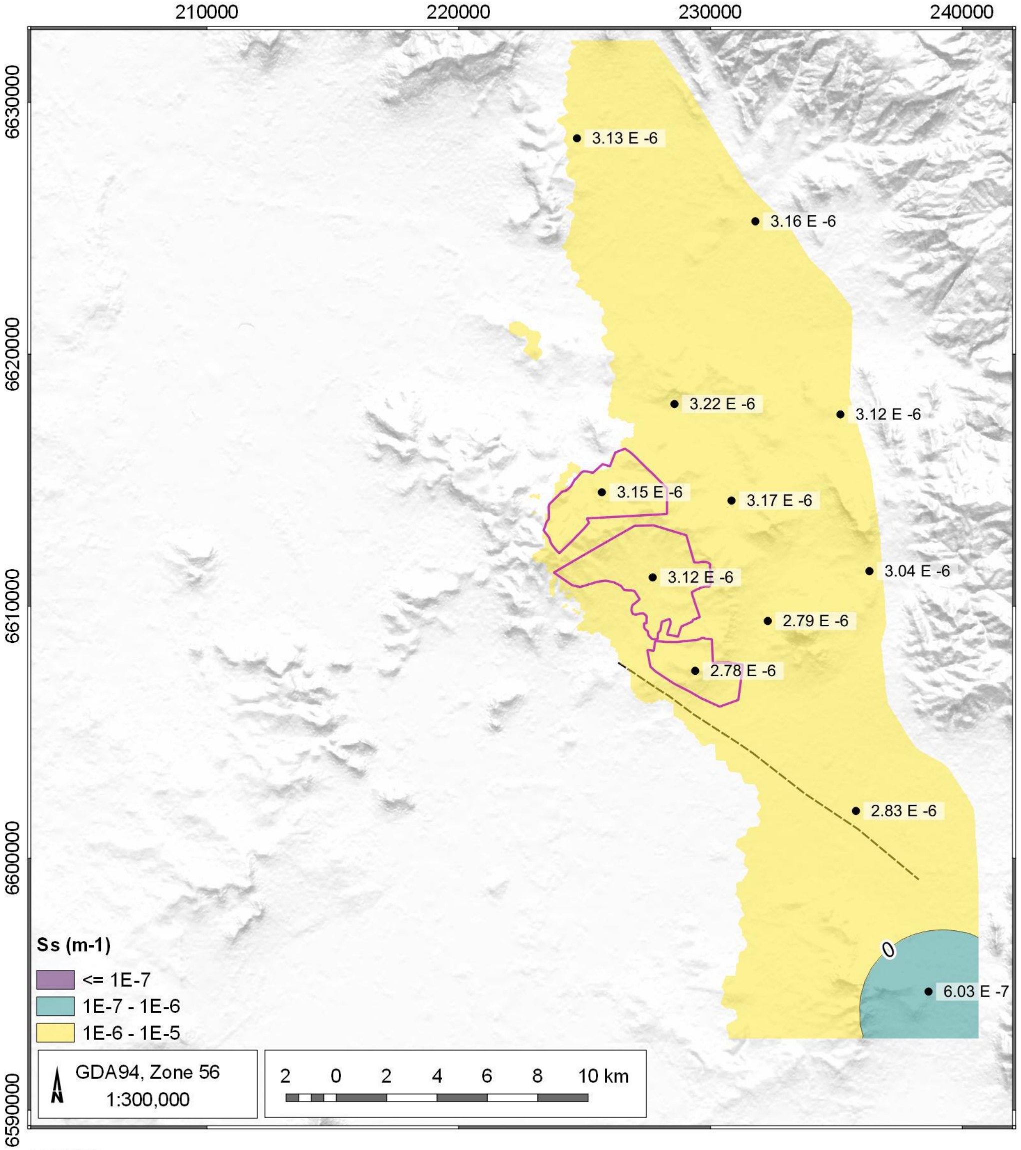
Ss



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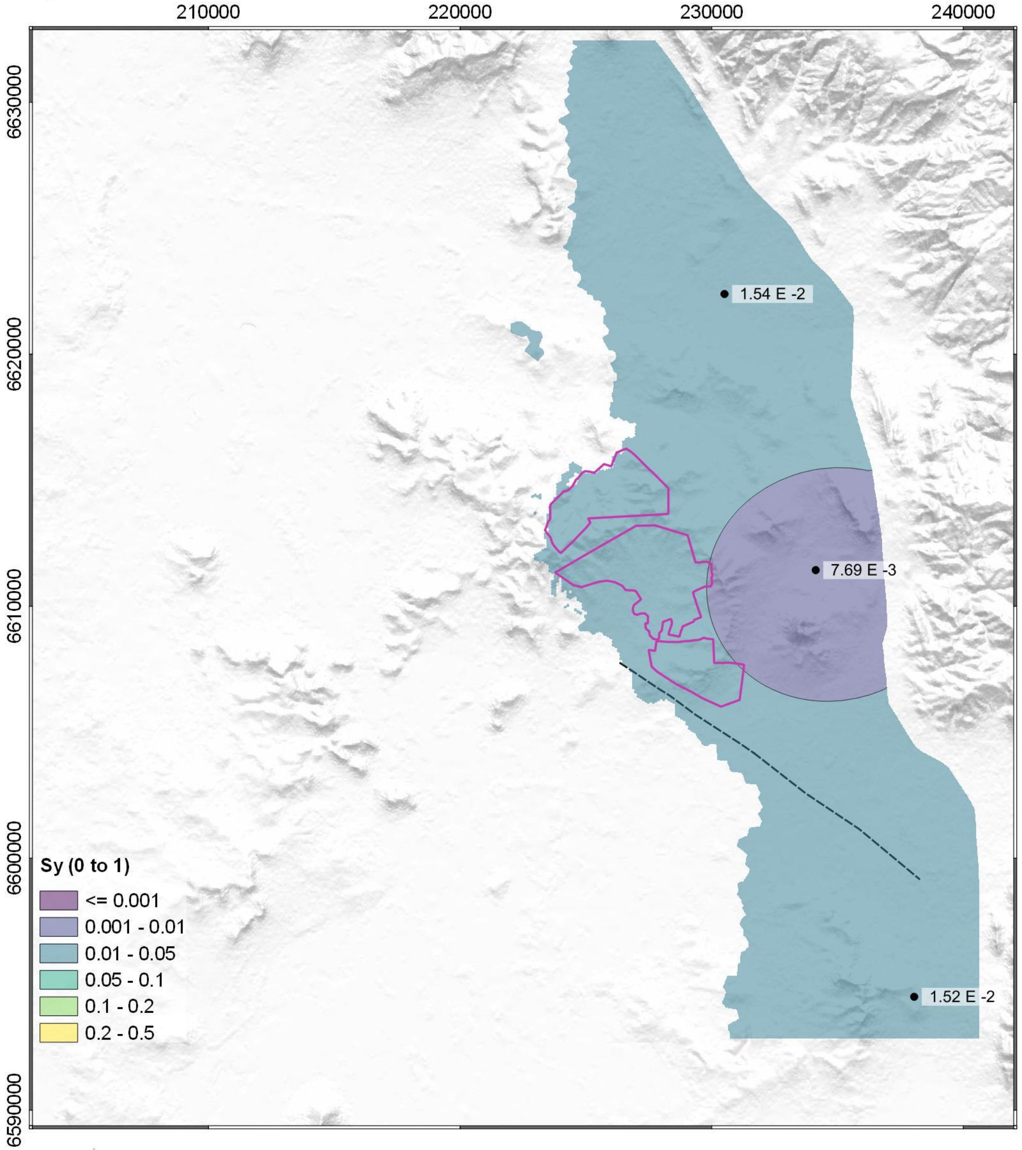

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 17 - Ss and Sy

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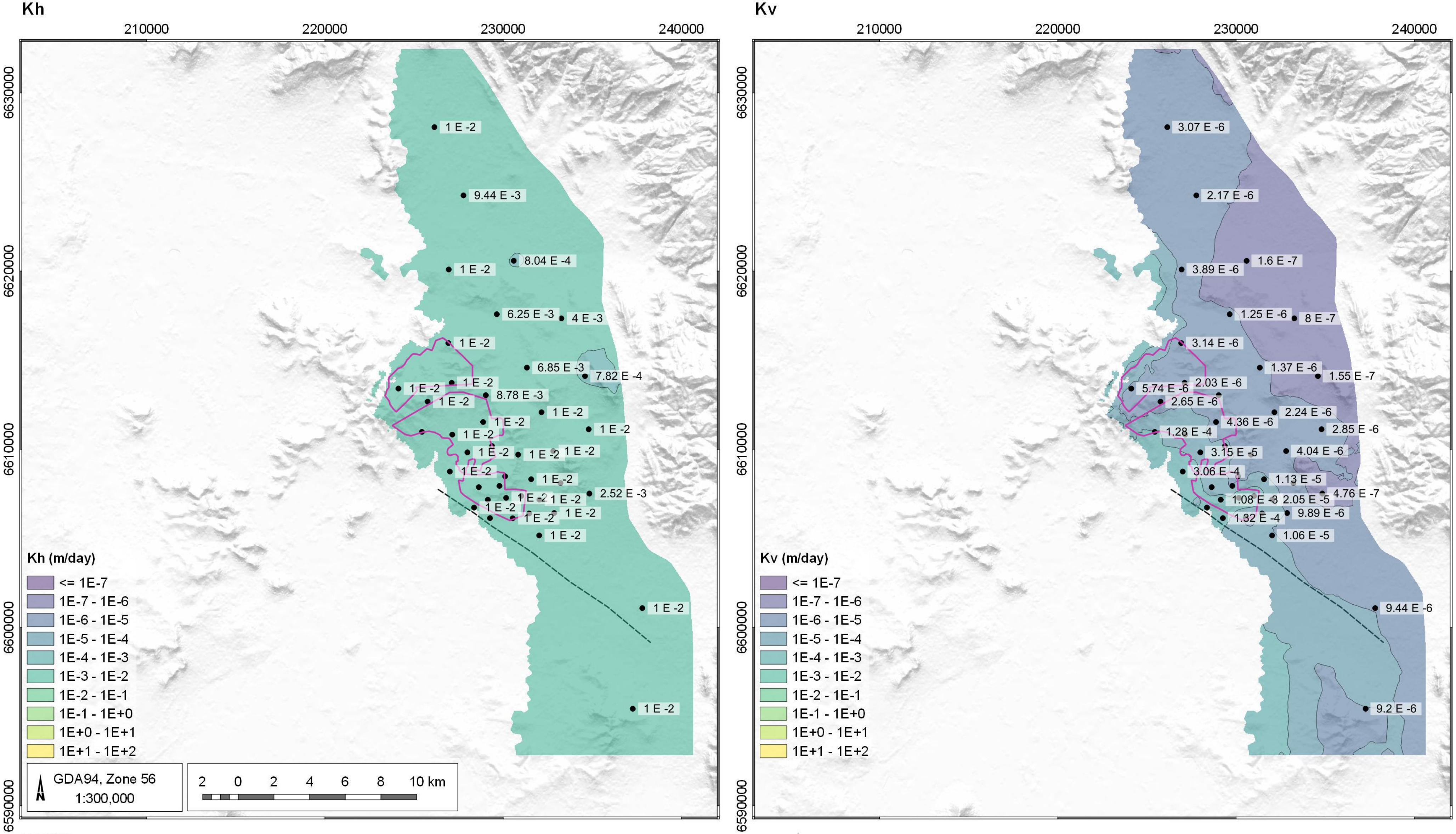

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 18 - Kh and Kv

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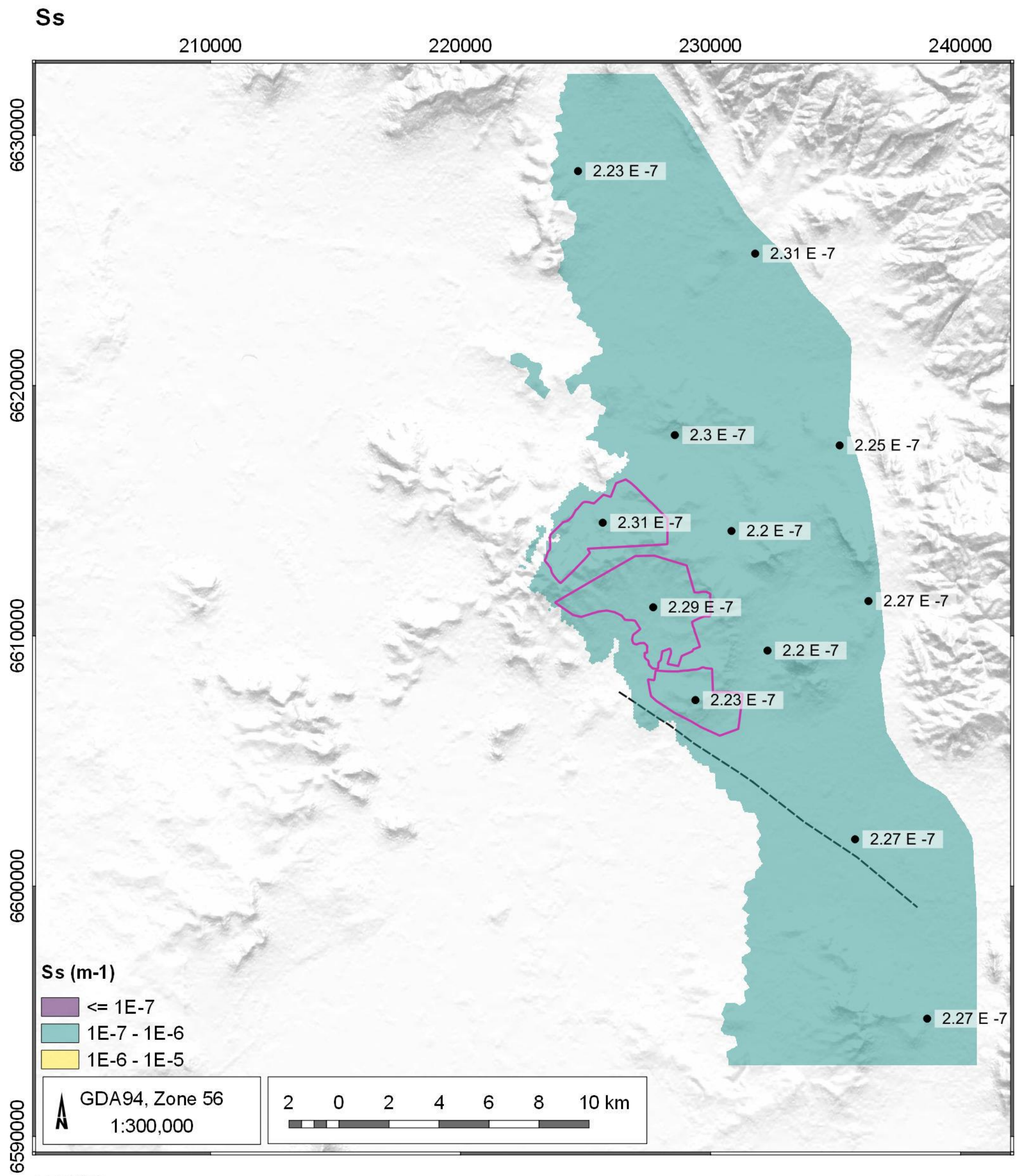

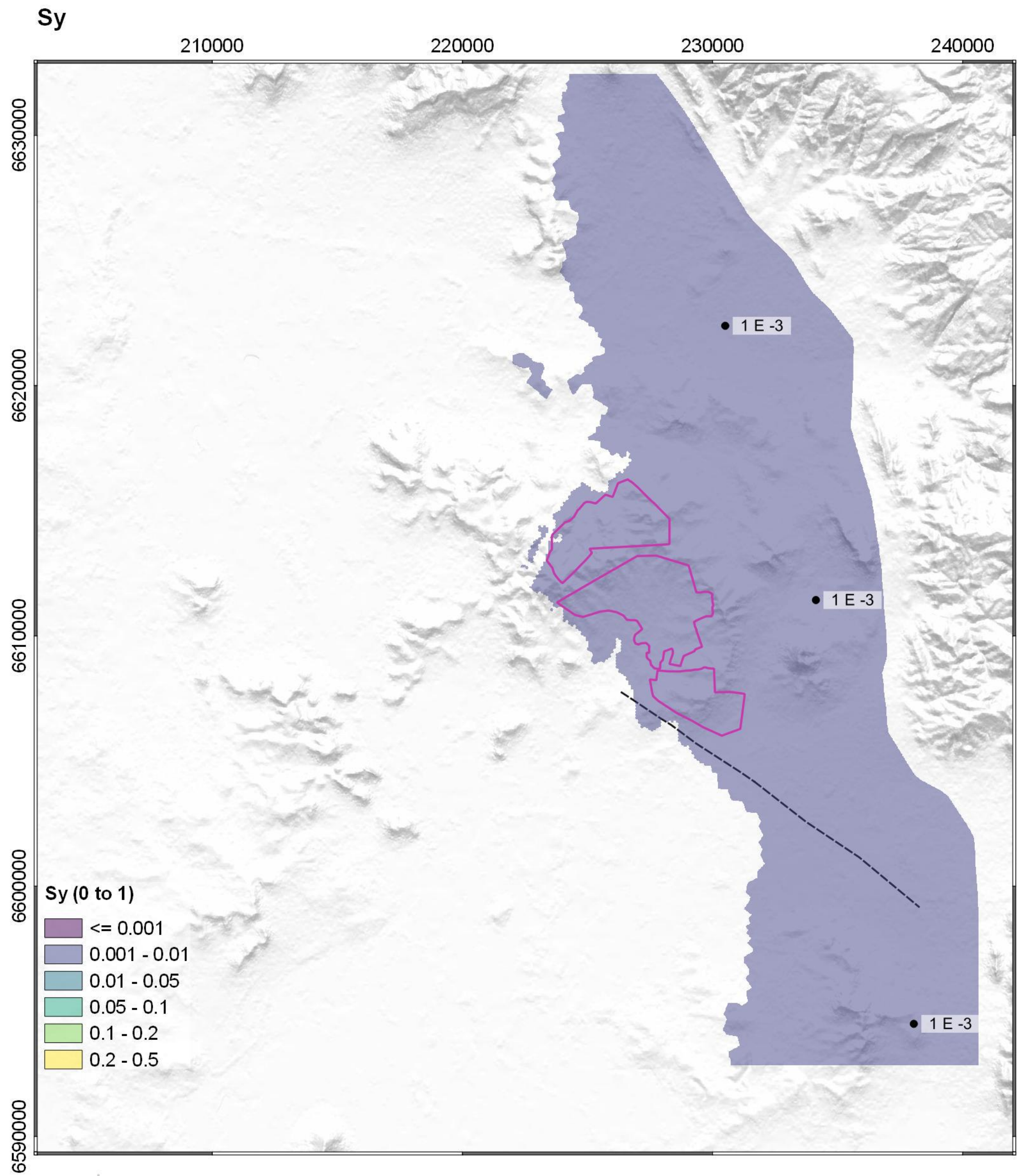

LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 18 - Ss and Sy

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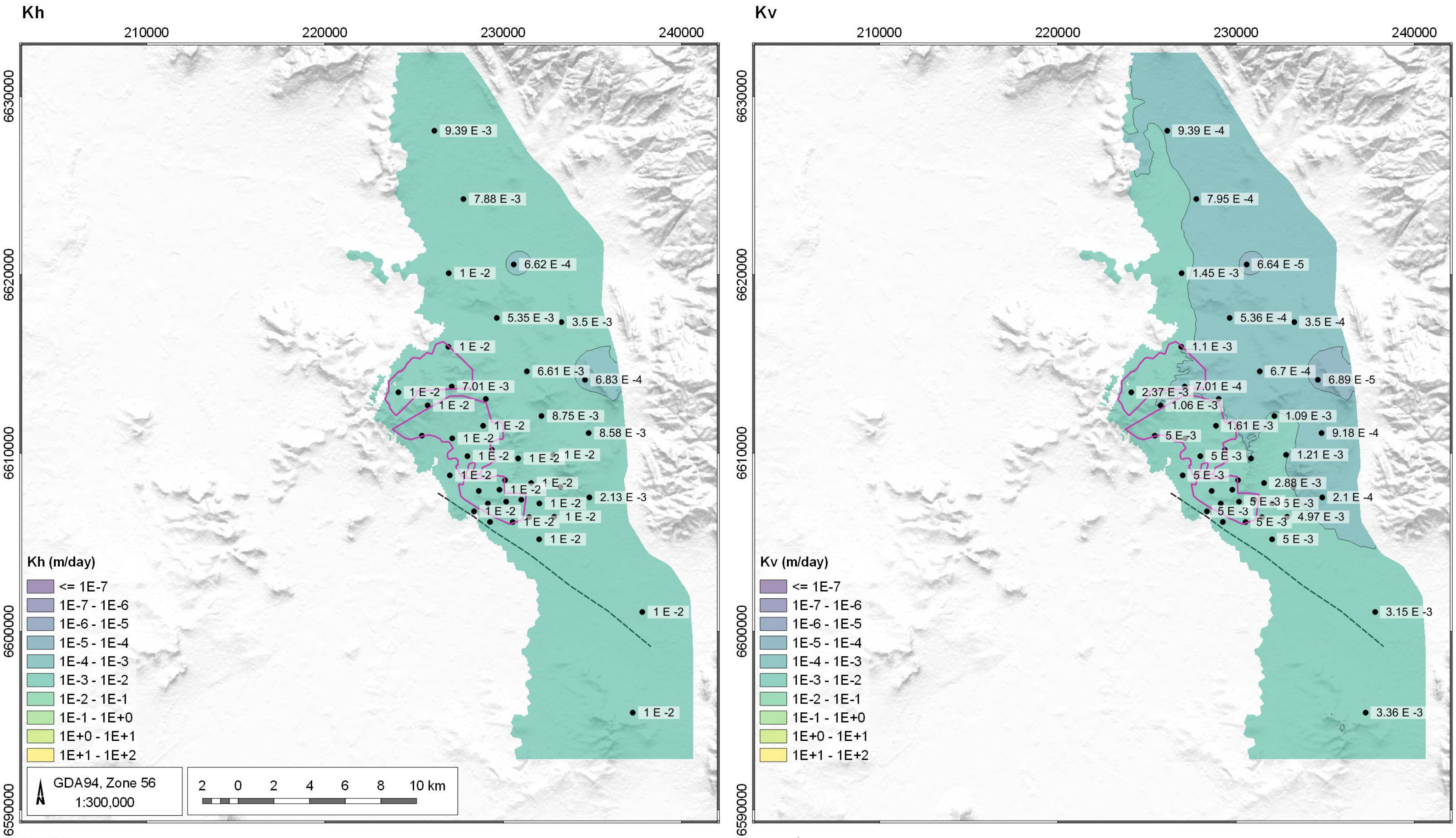

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 19 - Kh and Kv

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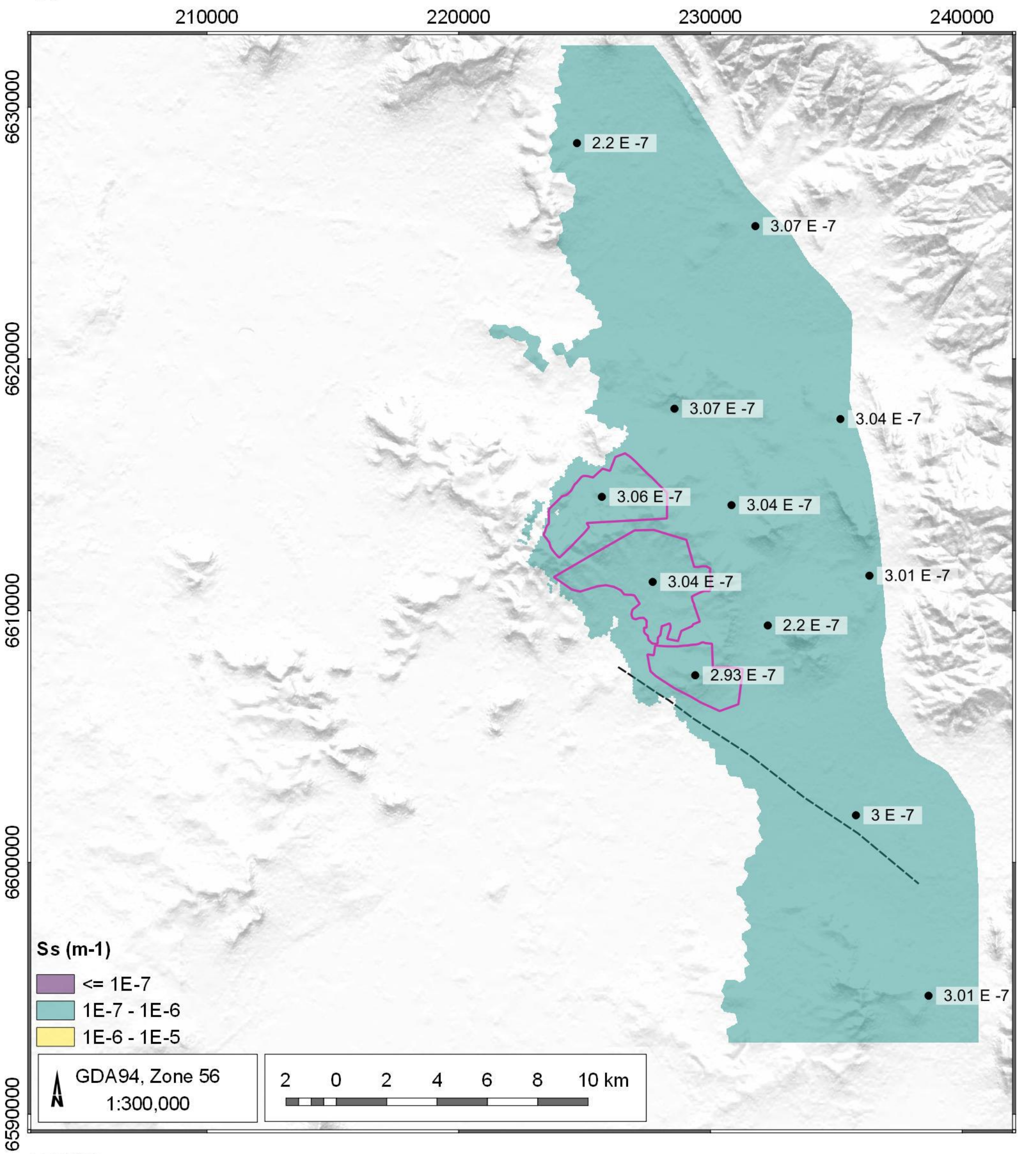
Ss



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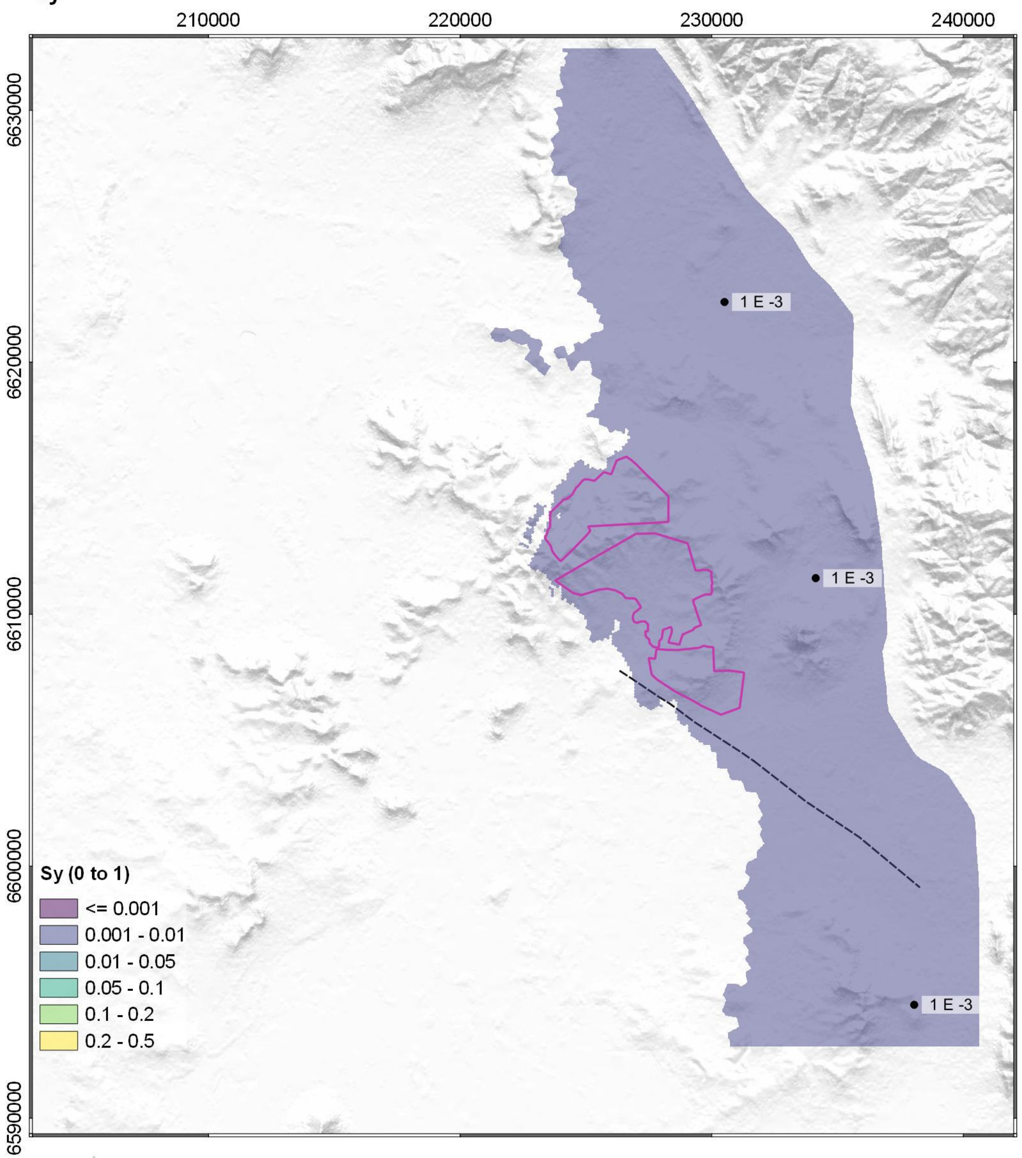

LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 19 - Ss and Sy

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15/06/2021

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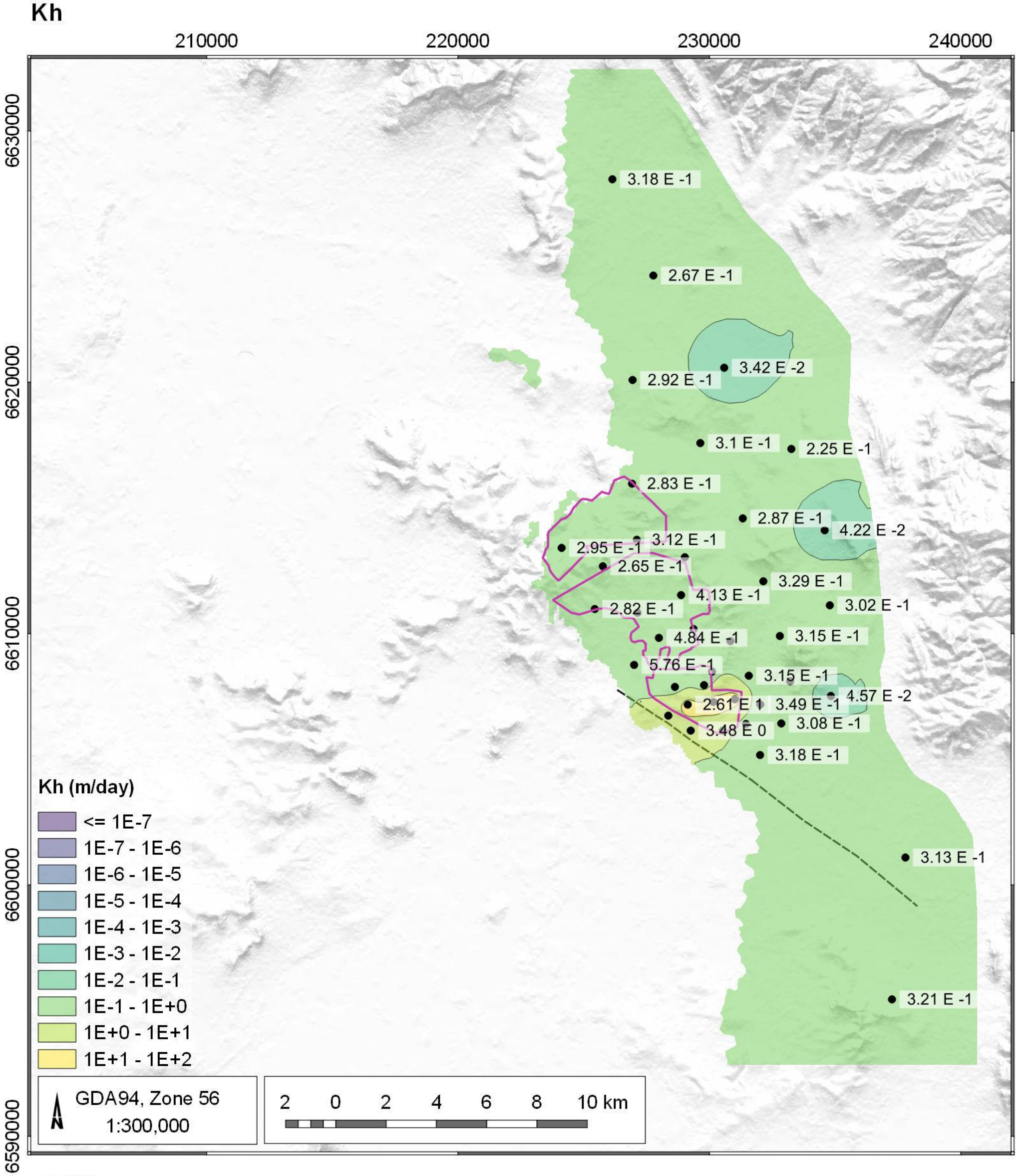
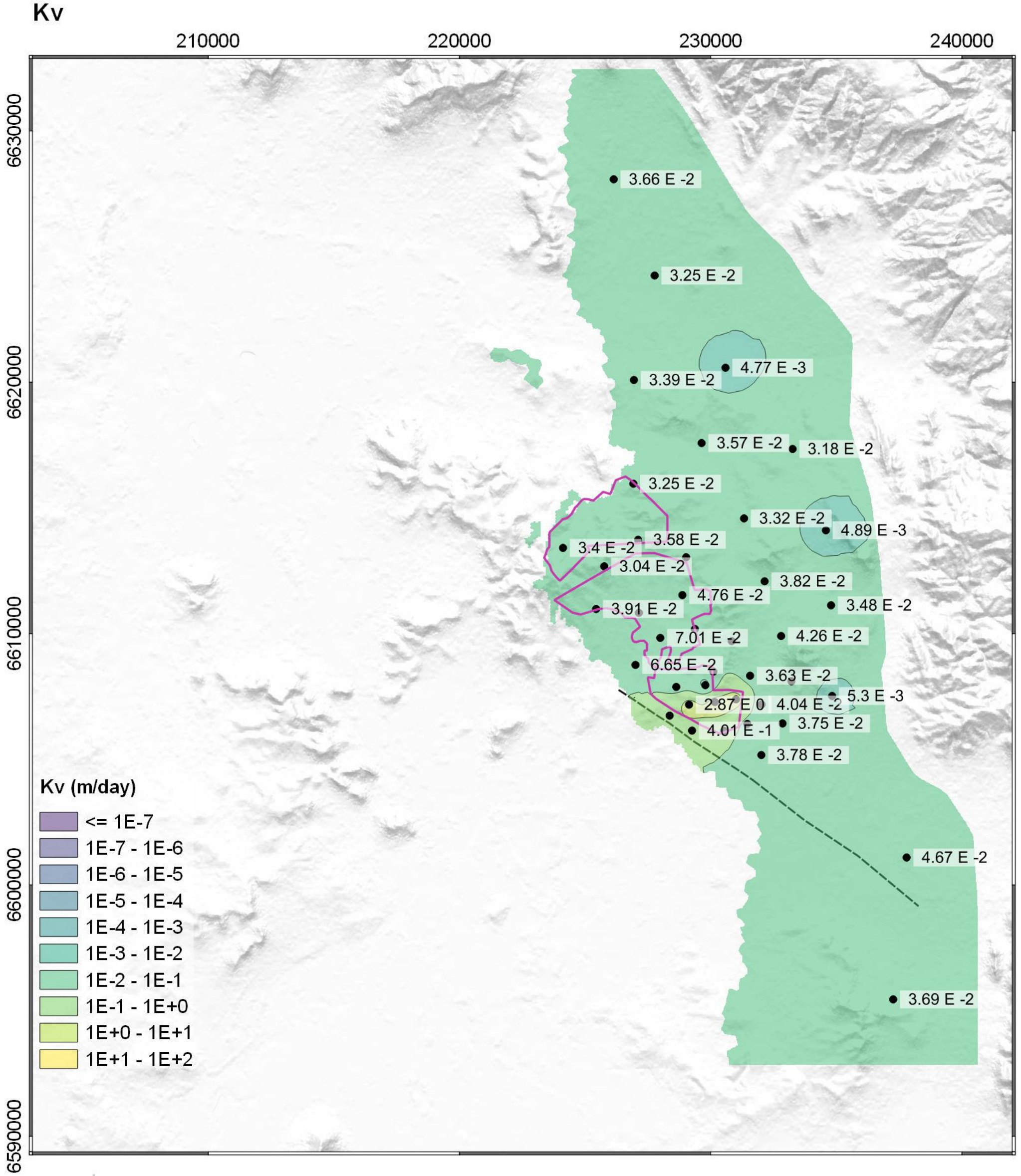
Kh



Kv



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 20 - Kh and Kv

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15/06/2021

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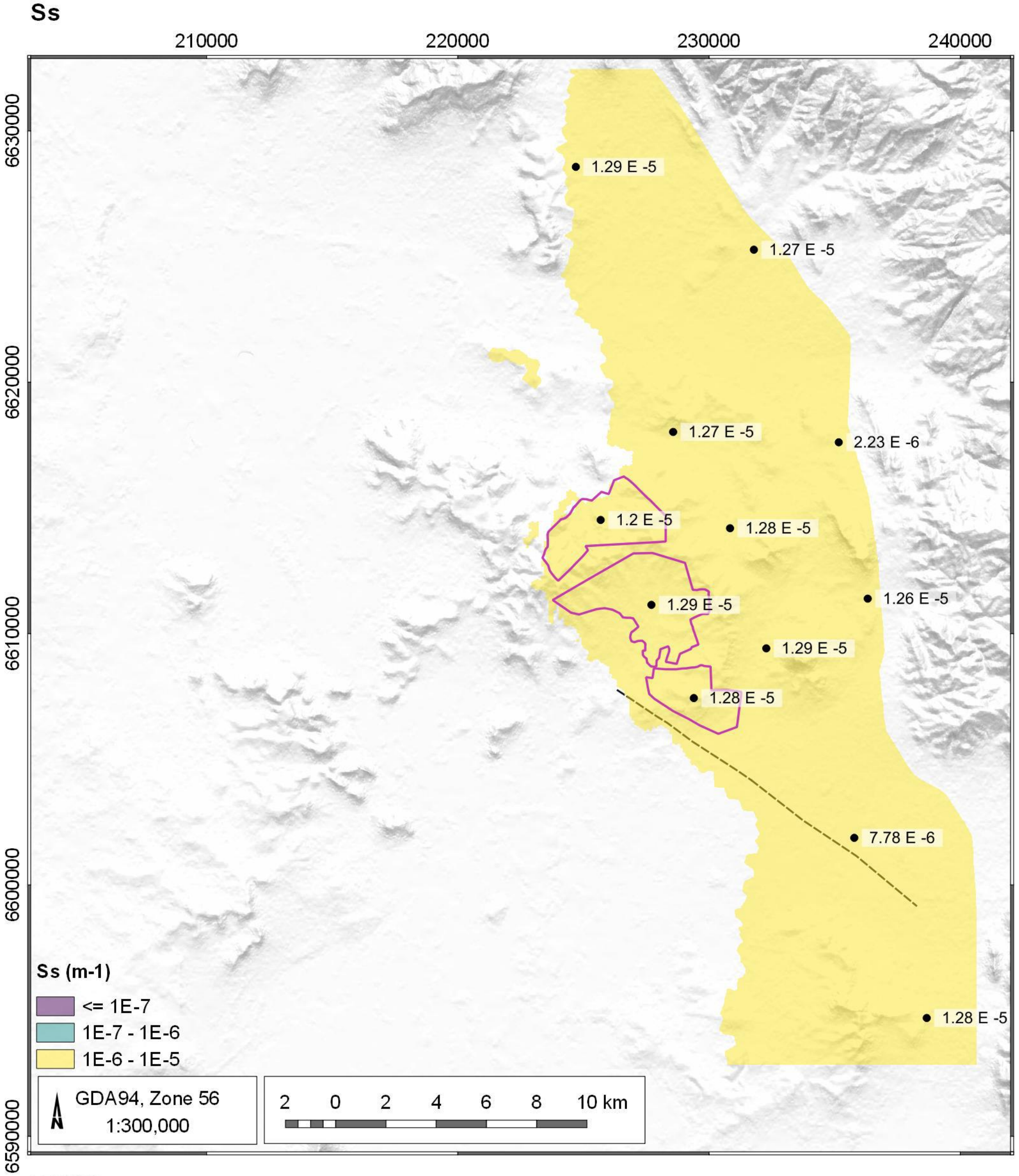

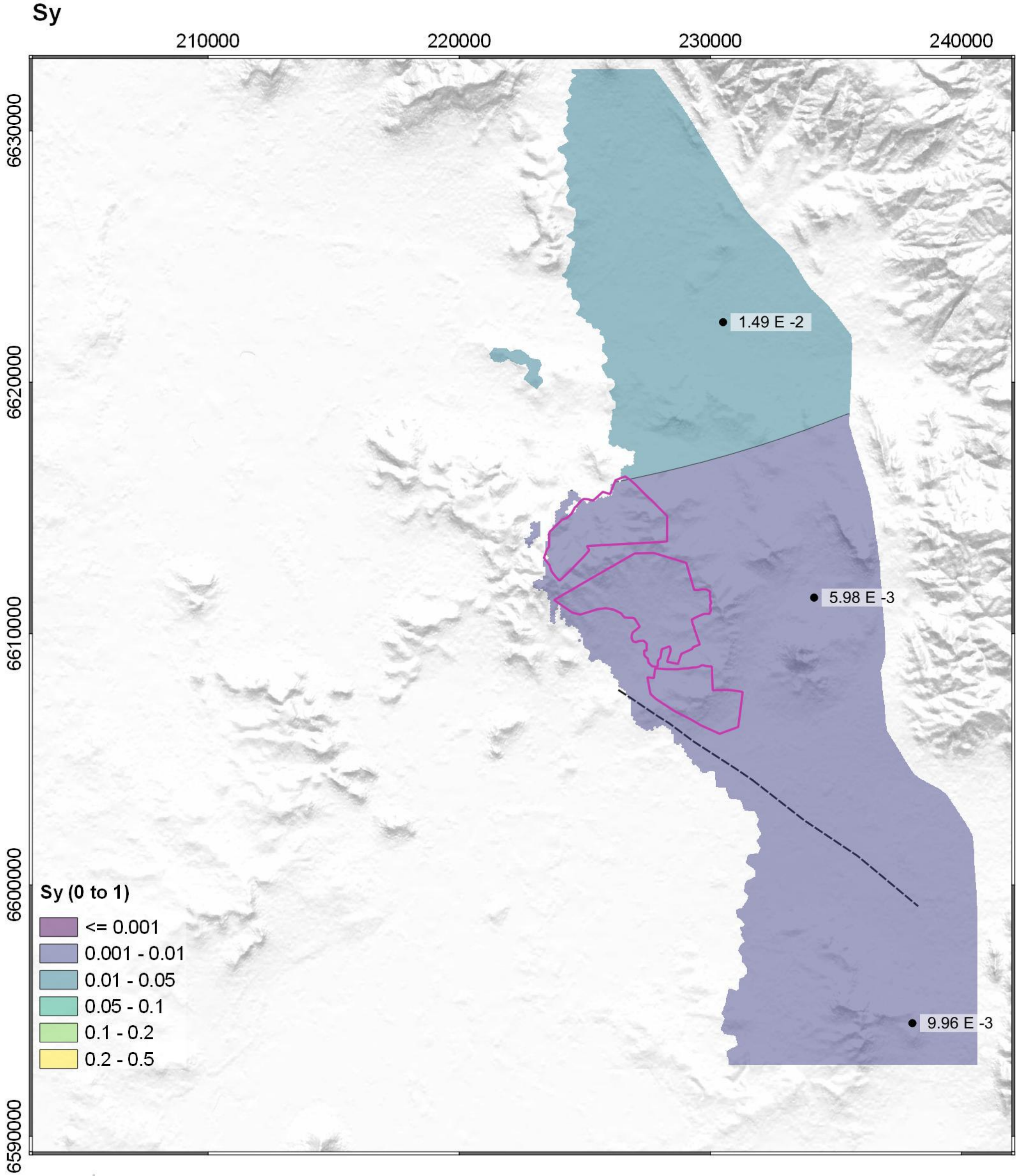

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 20 - Ss and Sy

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15/06/2021

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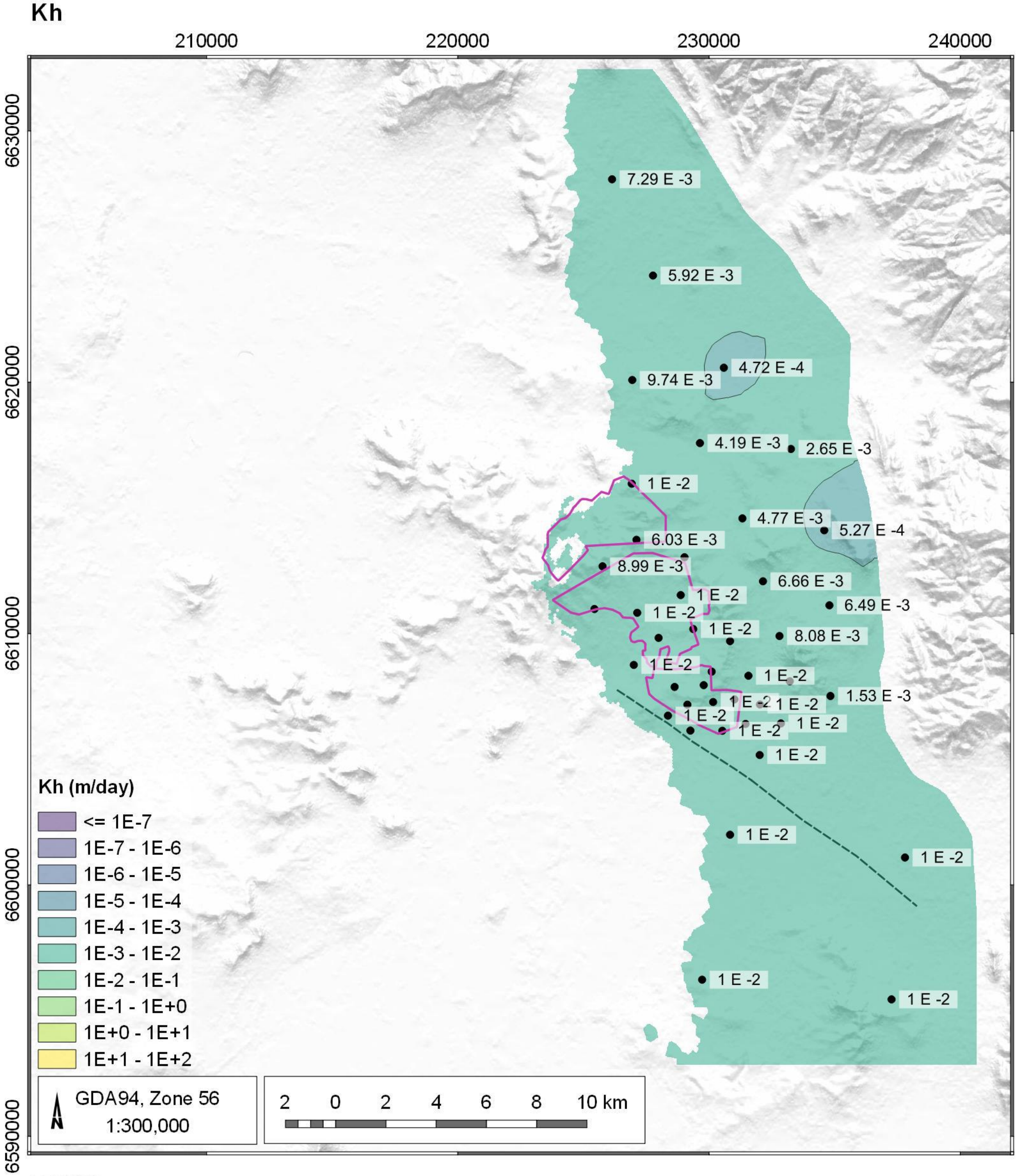

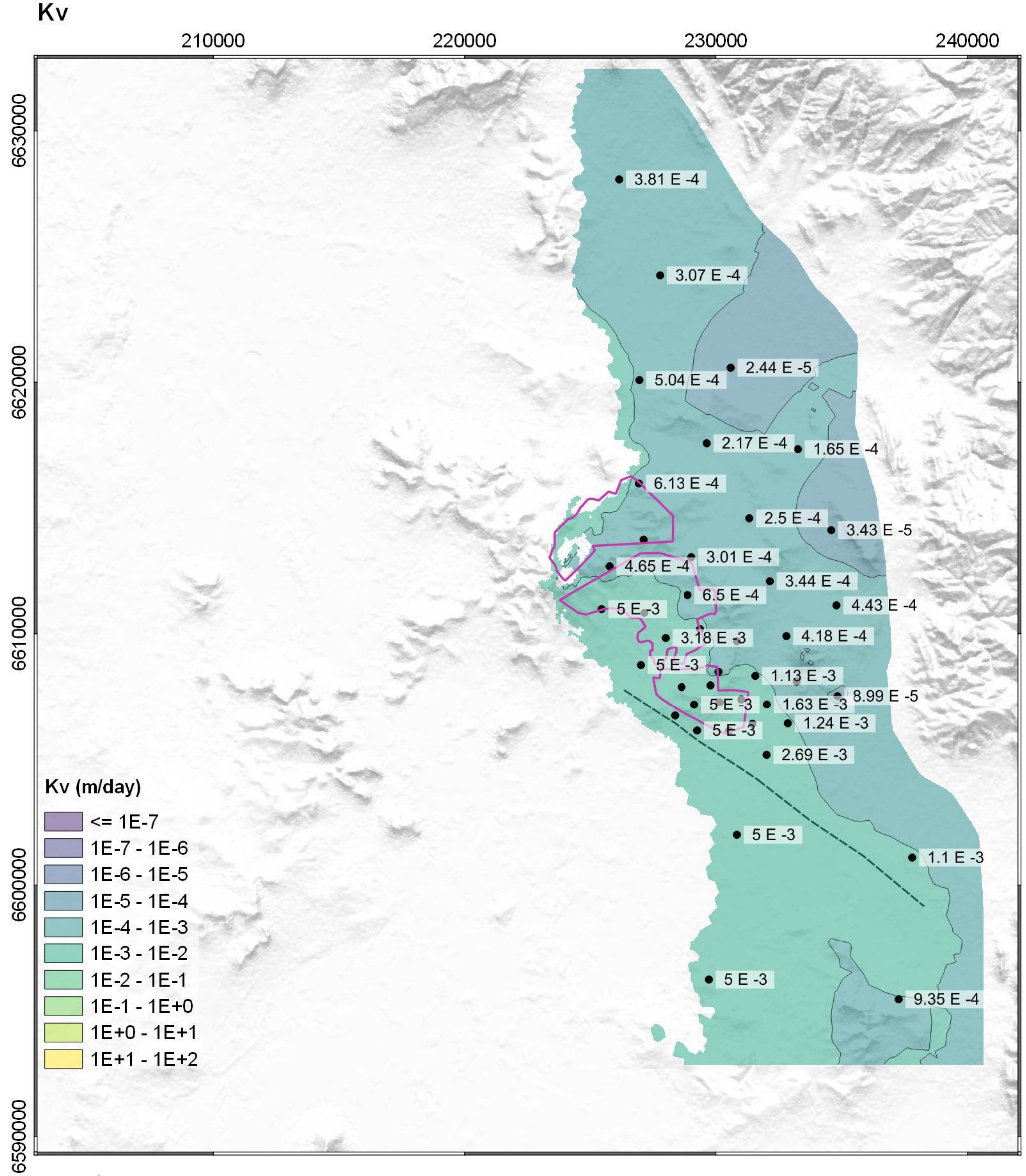

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 21 - Kh and Kv

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15/06/2021

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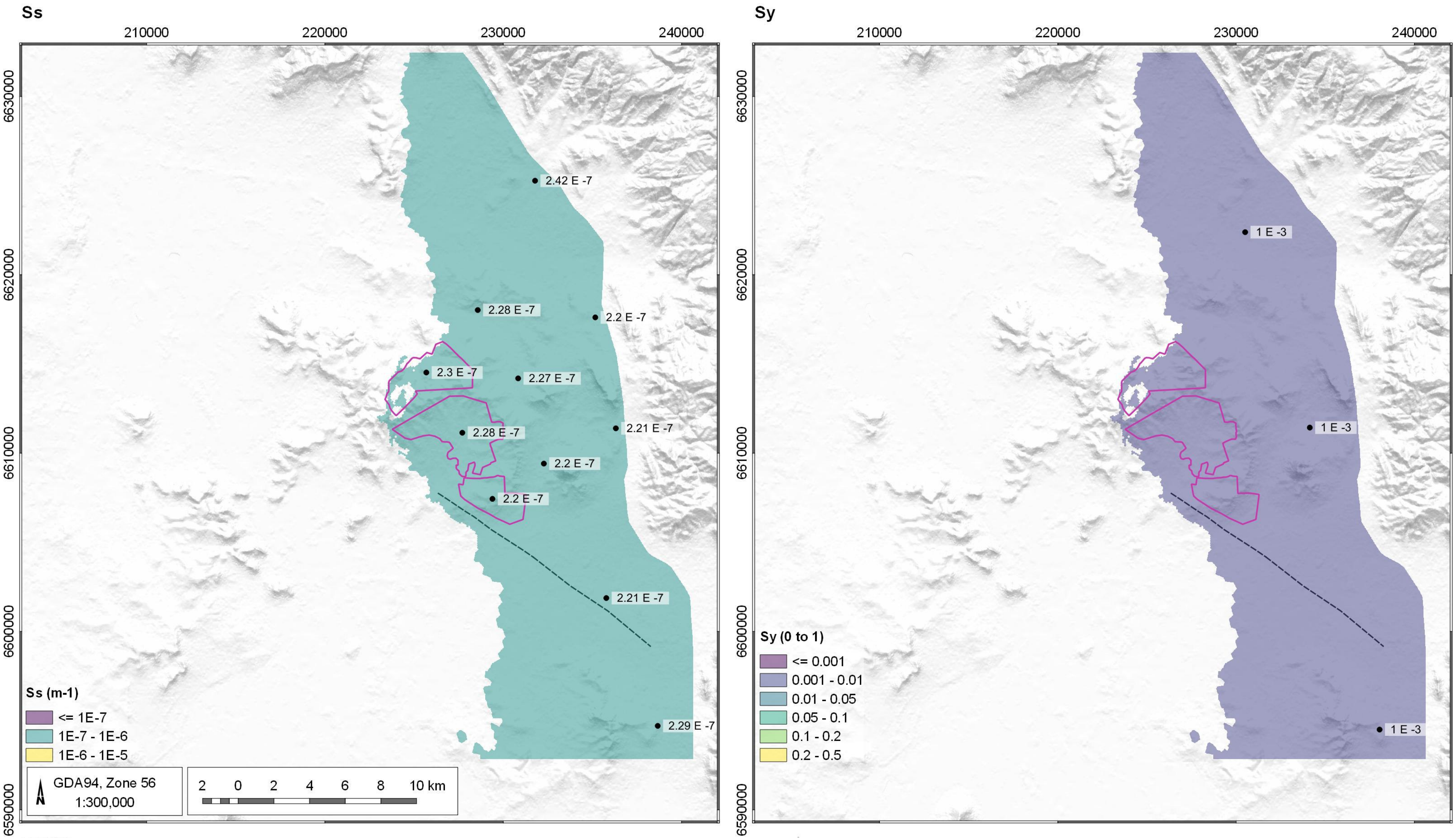

LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

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Layer 21 - Ss and Sy

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15/06/2021

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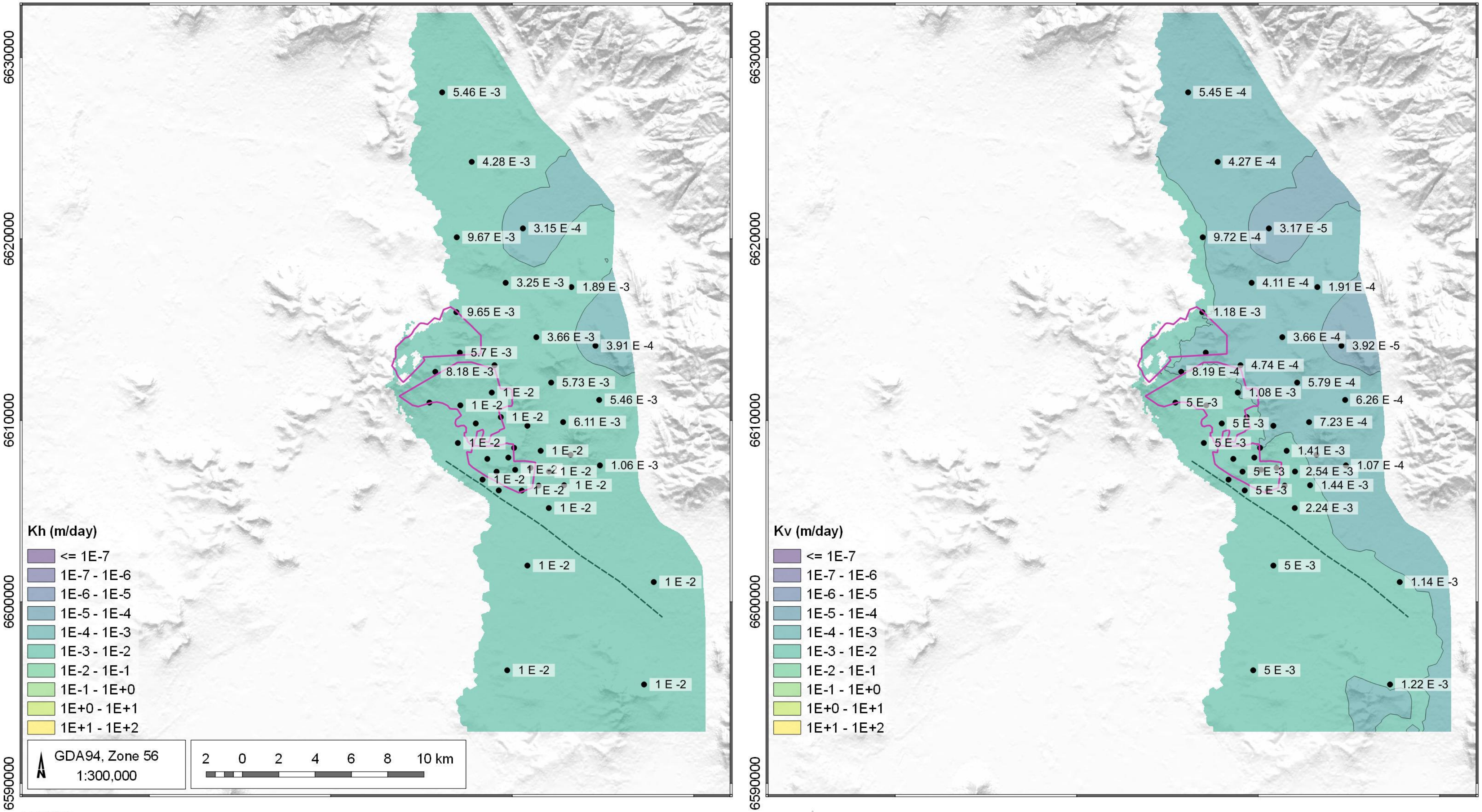
Kh

Kv



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

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Layer 22 - Kh and Kv

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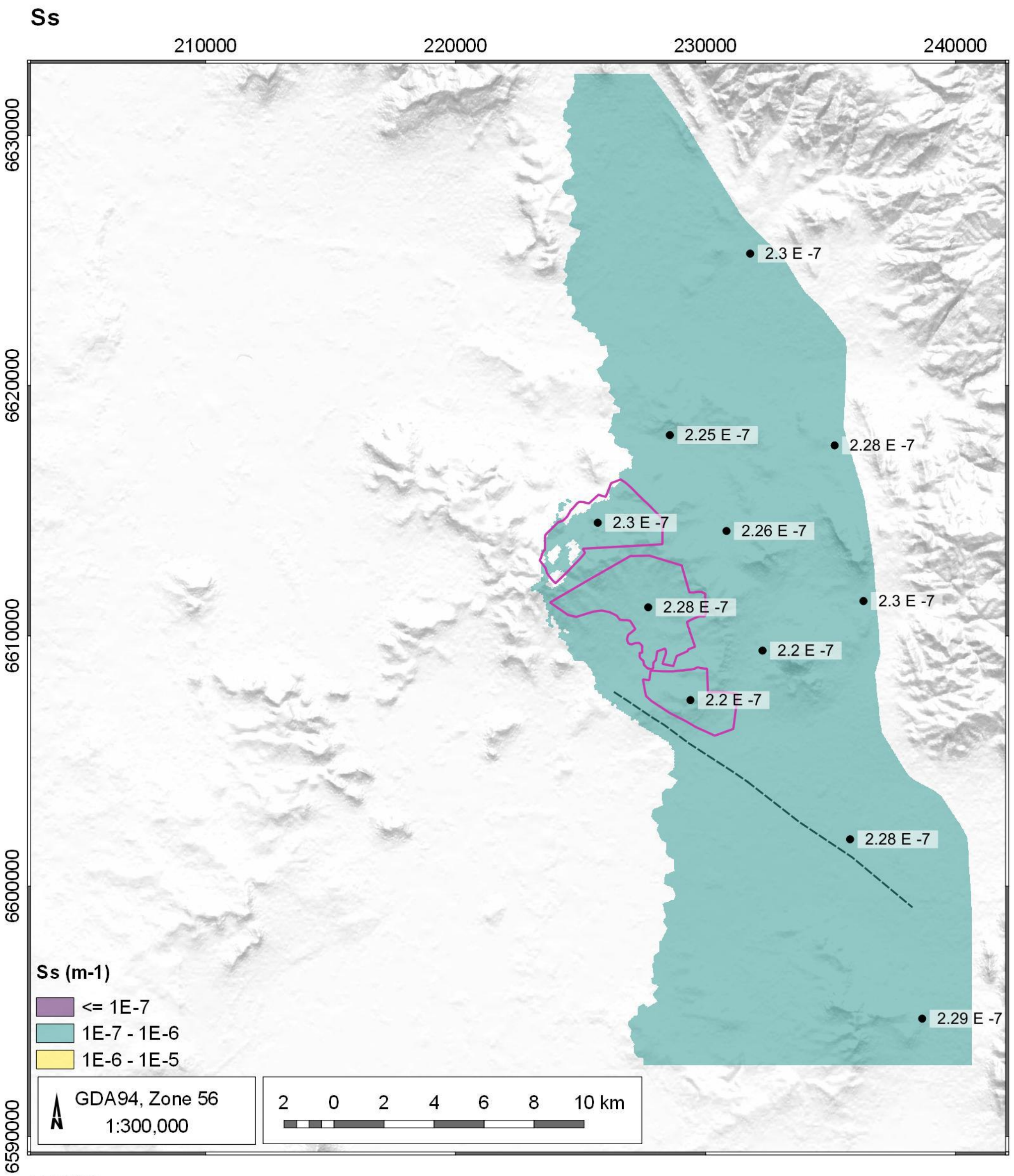

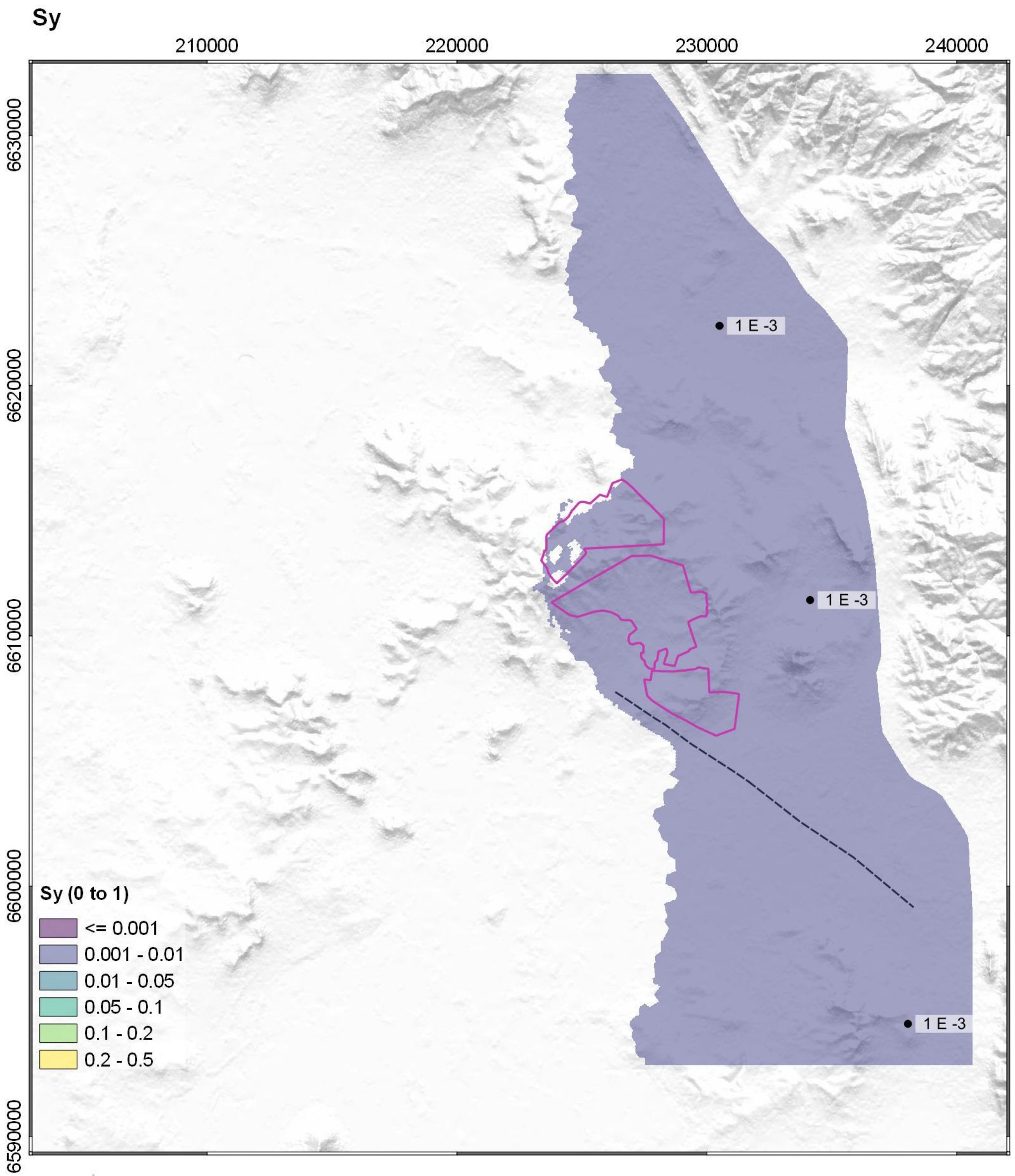

LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 22 - Ss and Sy

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15/06/2021

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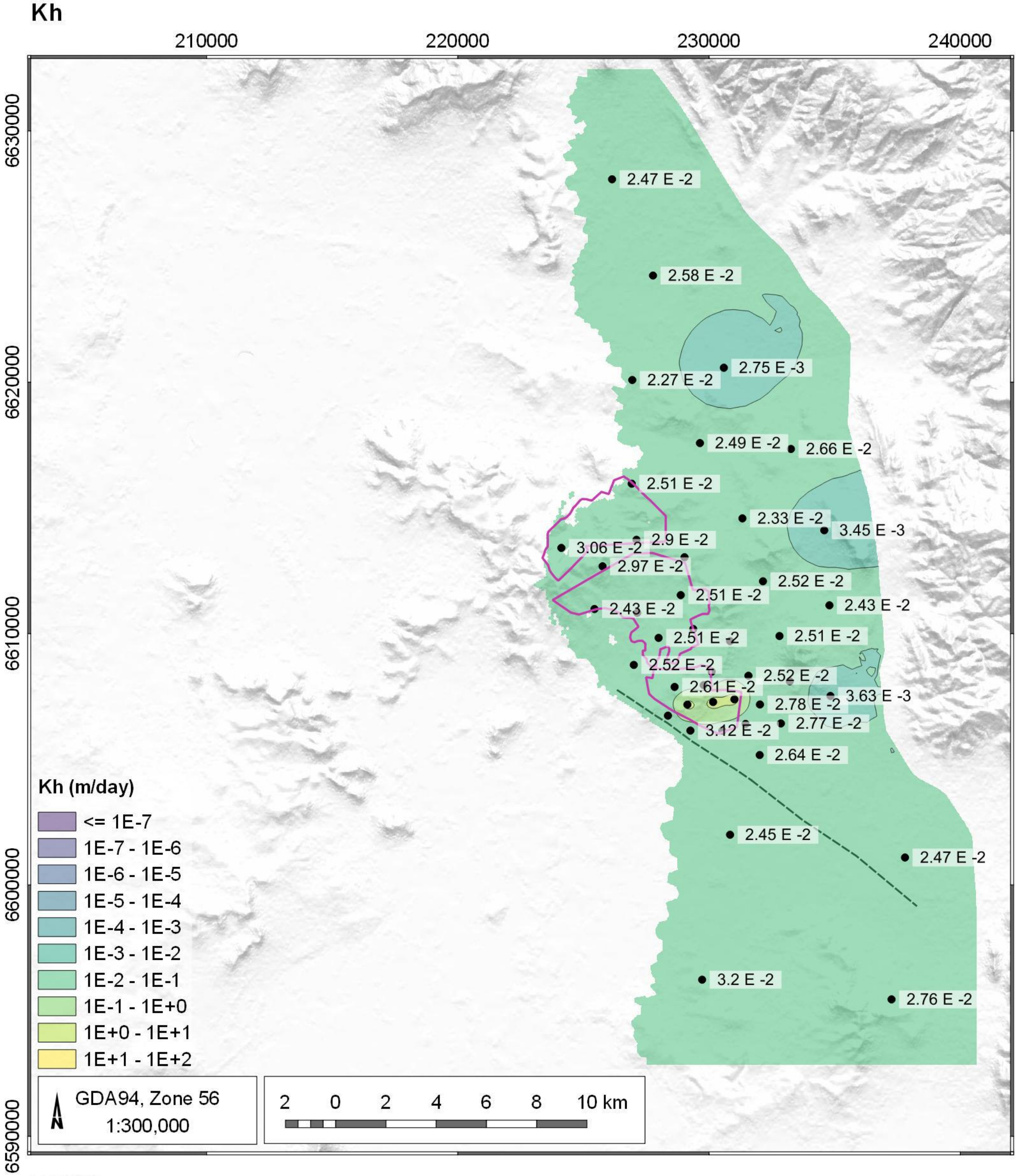
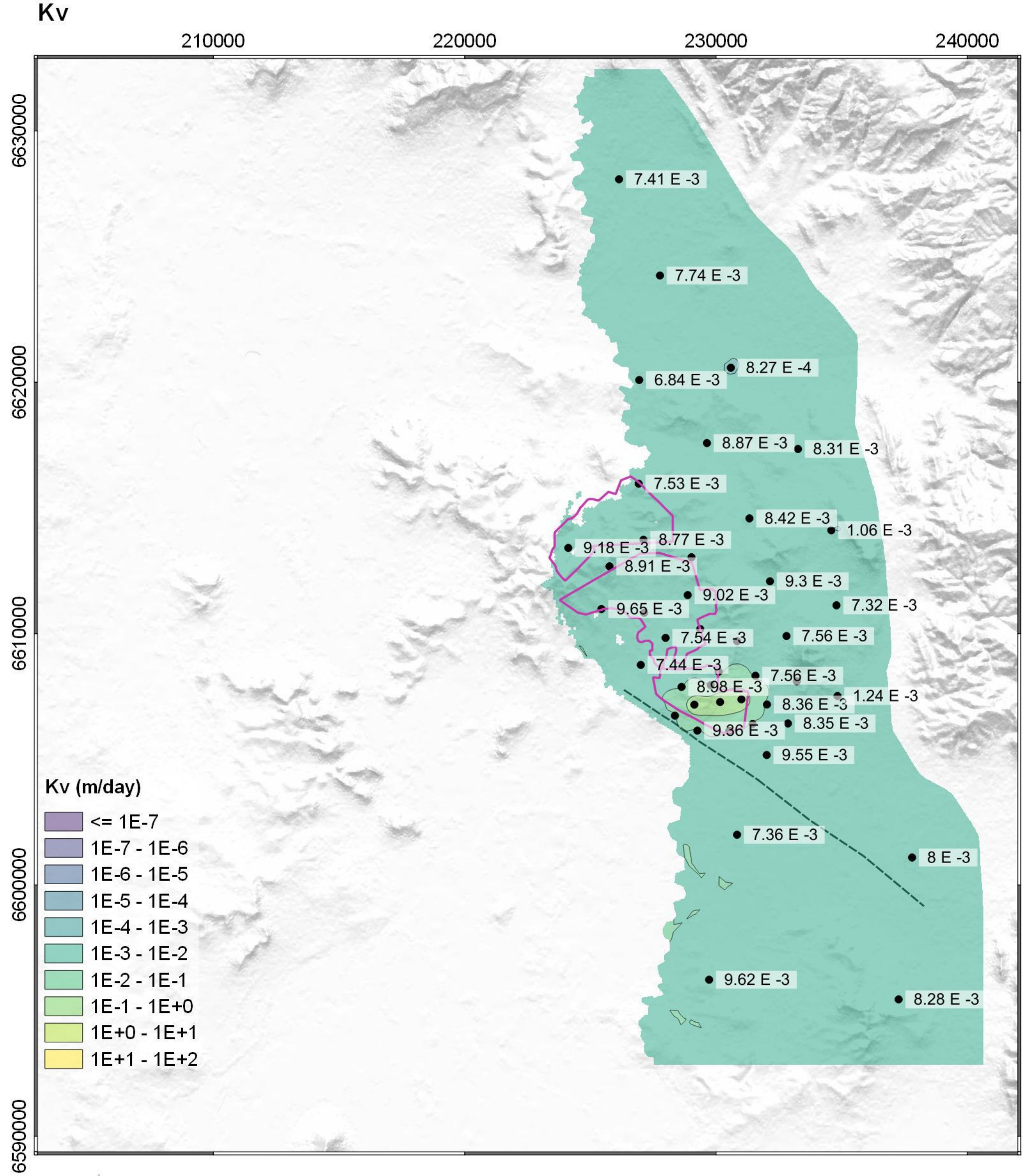




LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

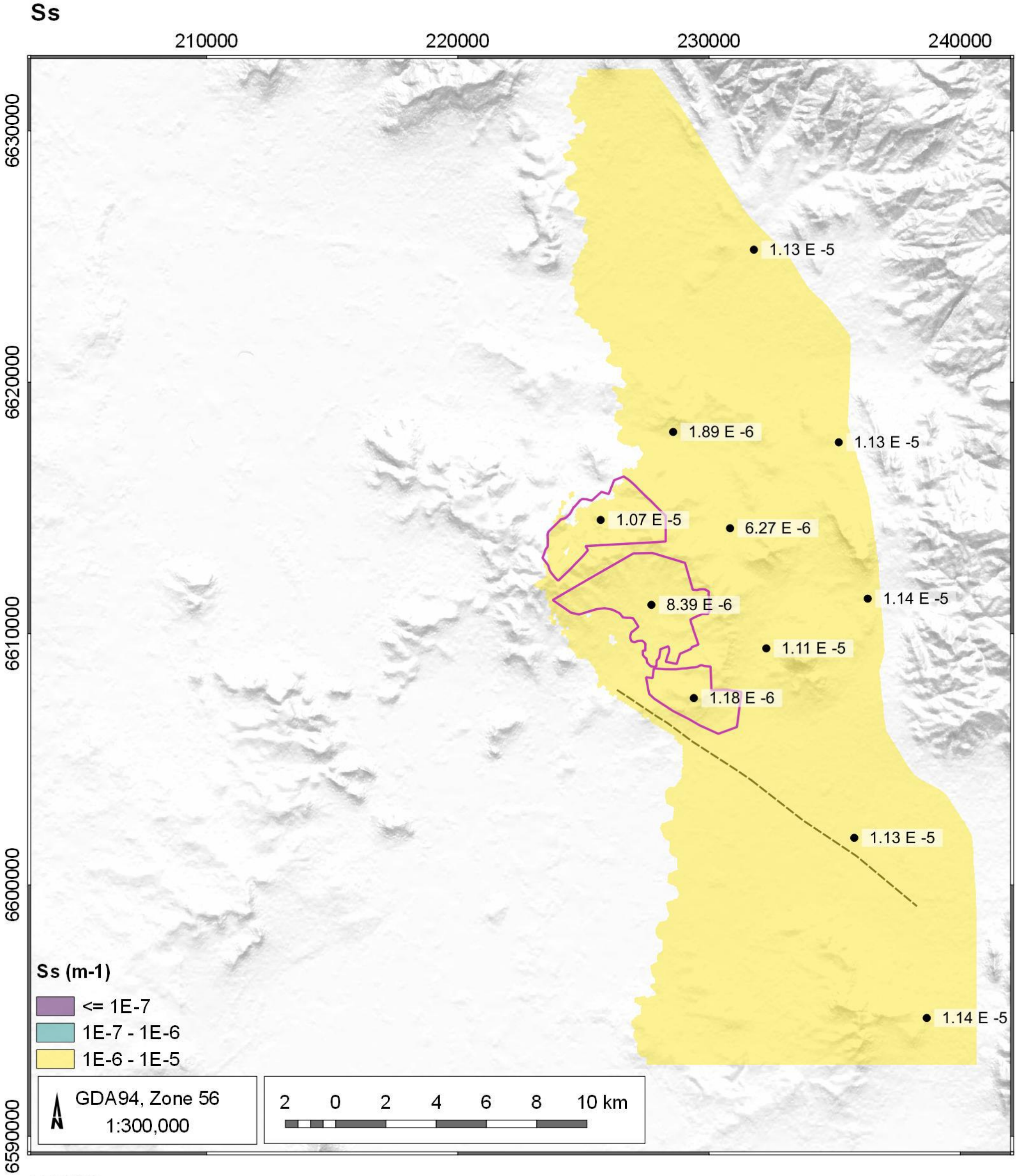
AGE

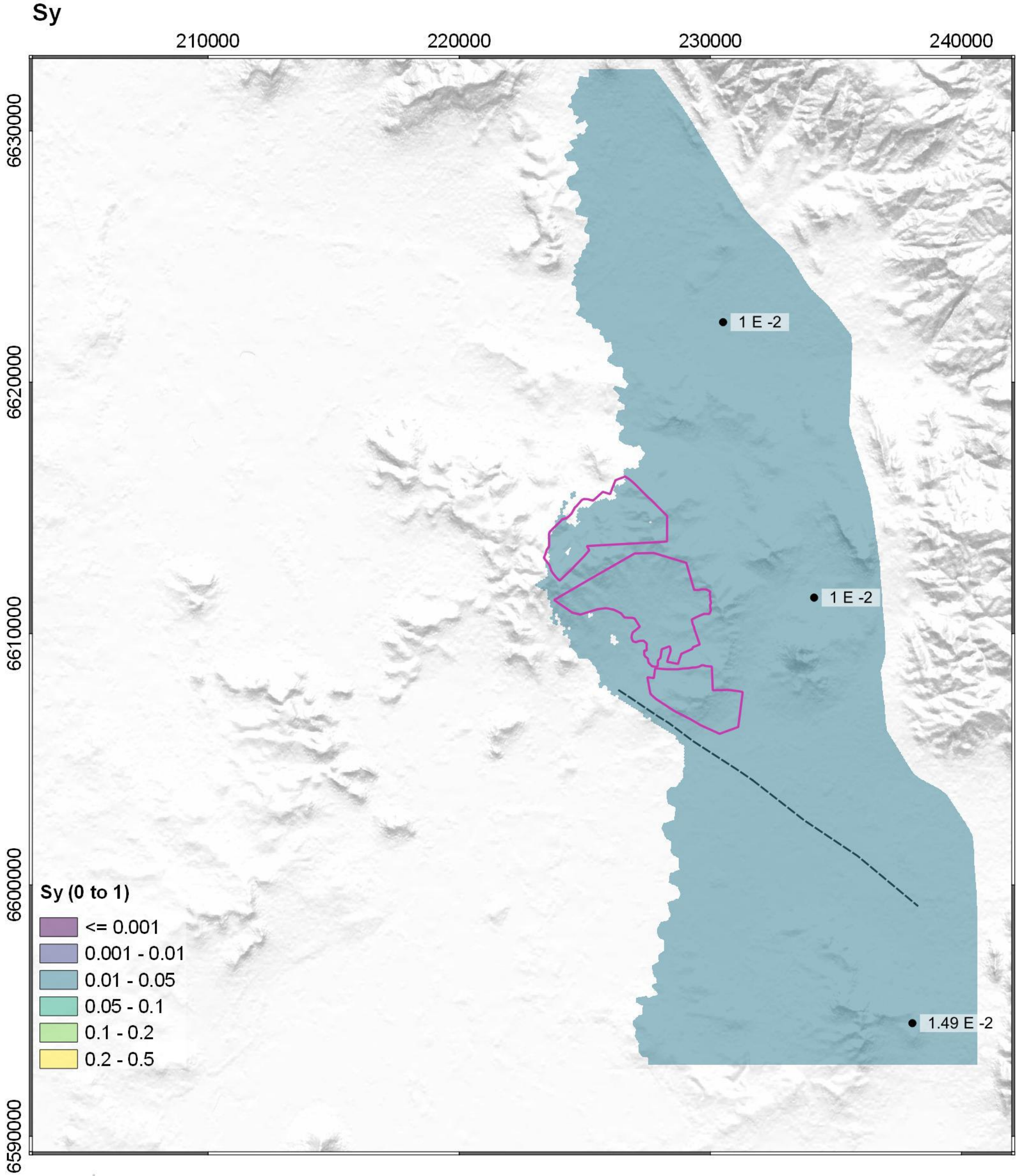
Layer 23 - Kh and Kv

DATE
15/06/2021

FIGURE No:

©2021 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 23 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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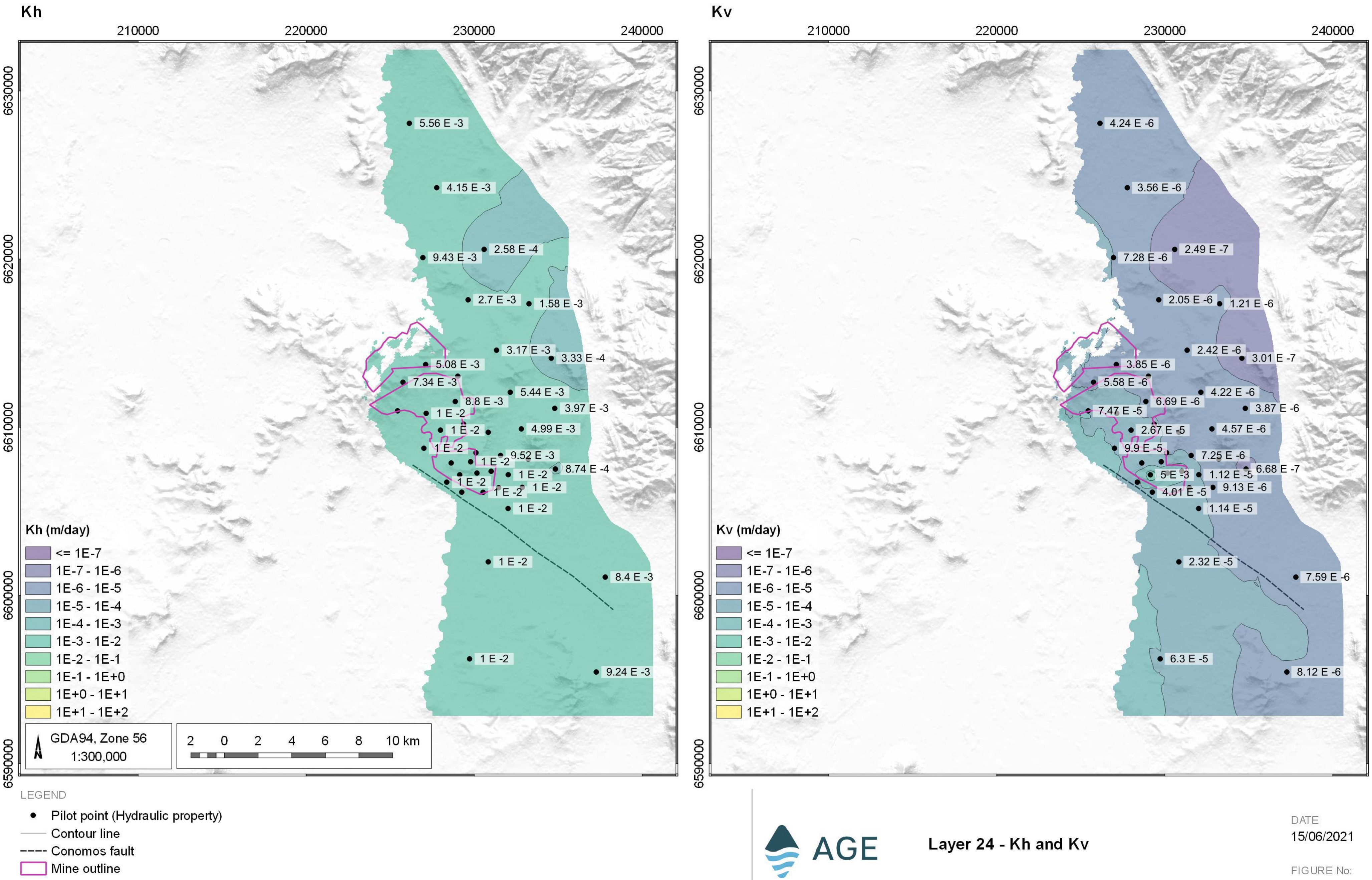
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs



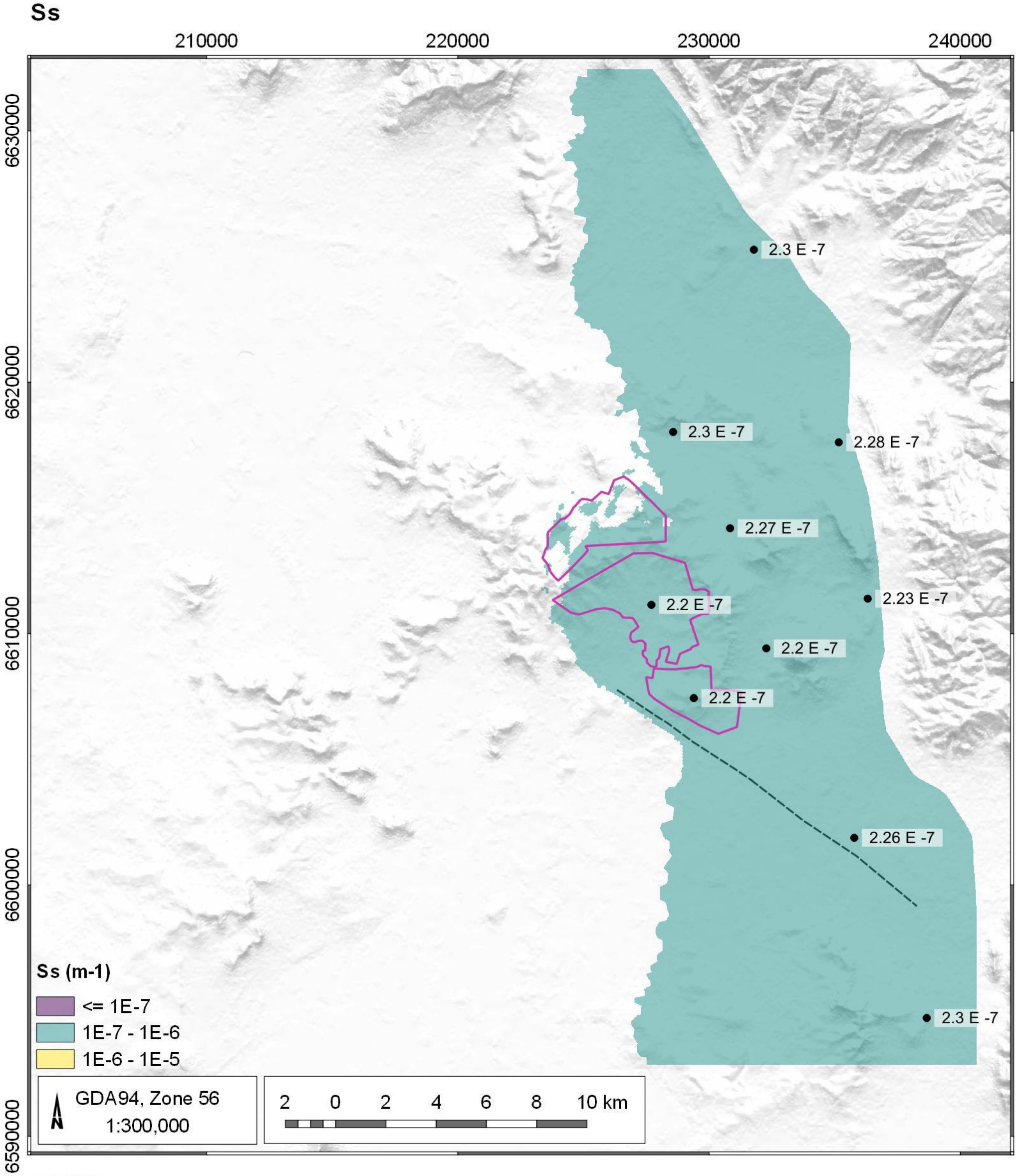
AGE

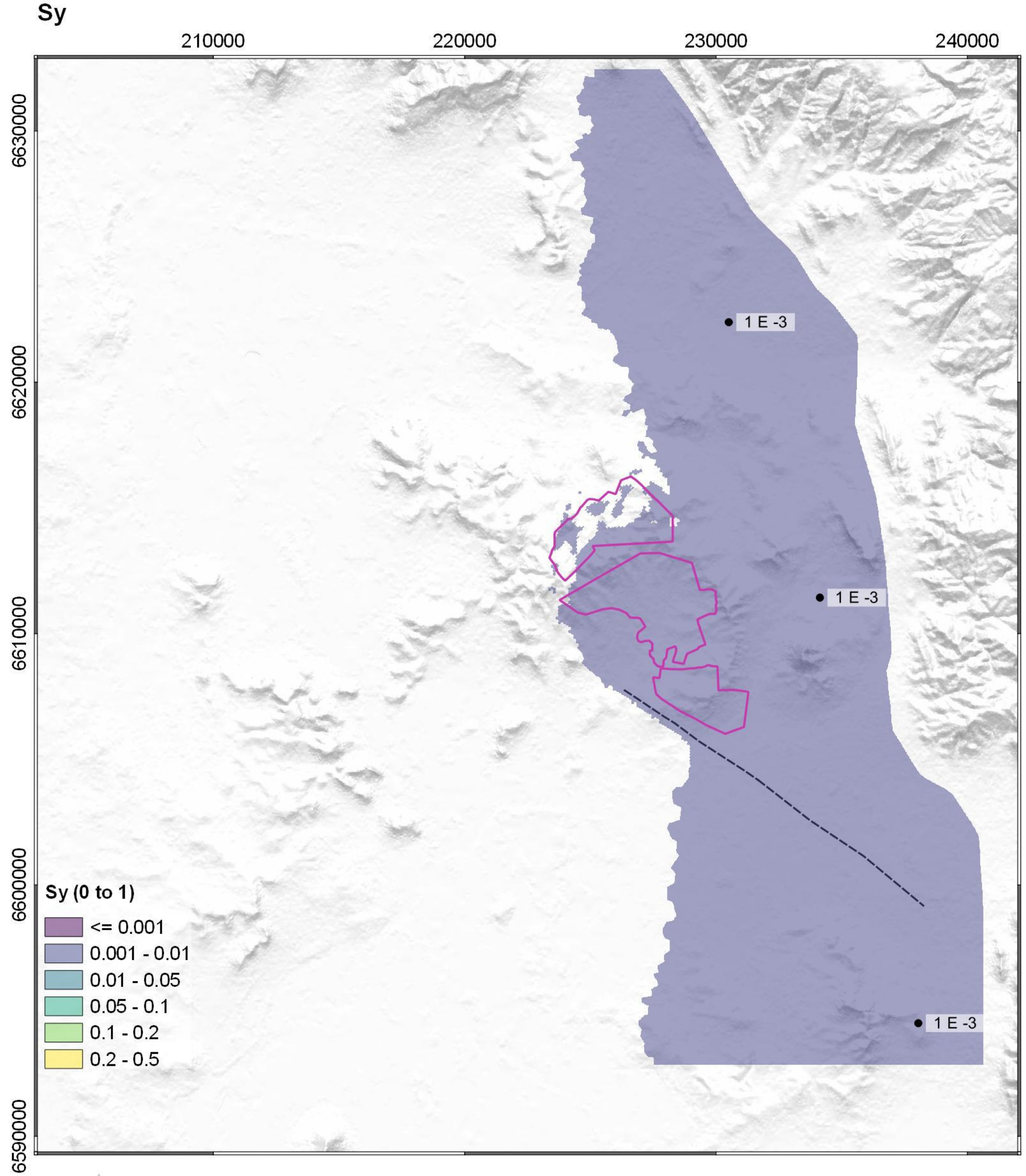
Layer 24 - Kh and Kv

DATE
15/06/2021

FIGURE No:

©2021 Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) - www.ageconsultants.com.au
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 24 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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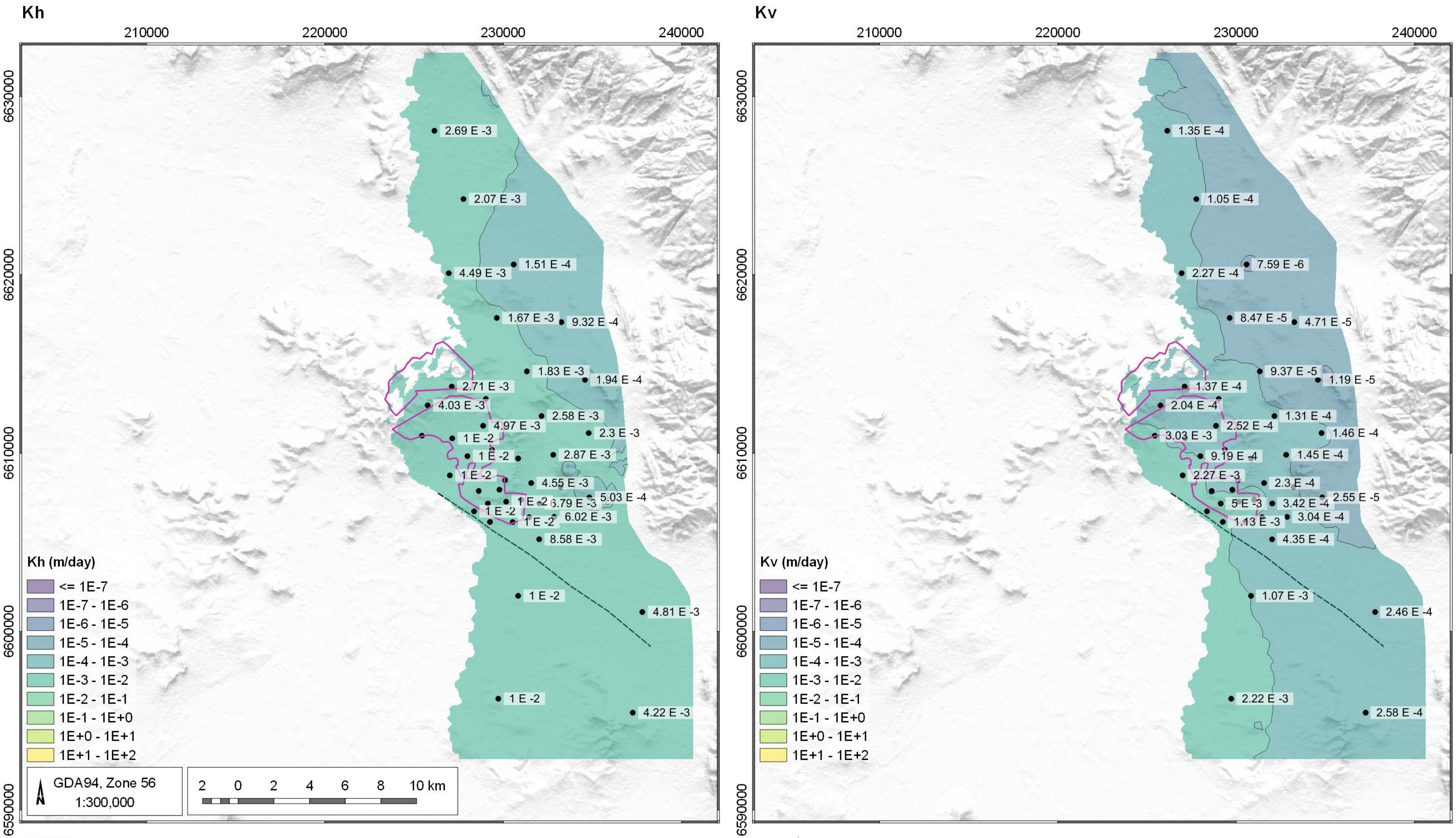
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 25 - Kh and Kv

DATE
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FIGURE No:

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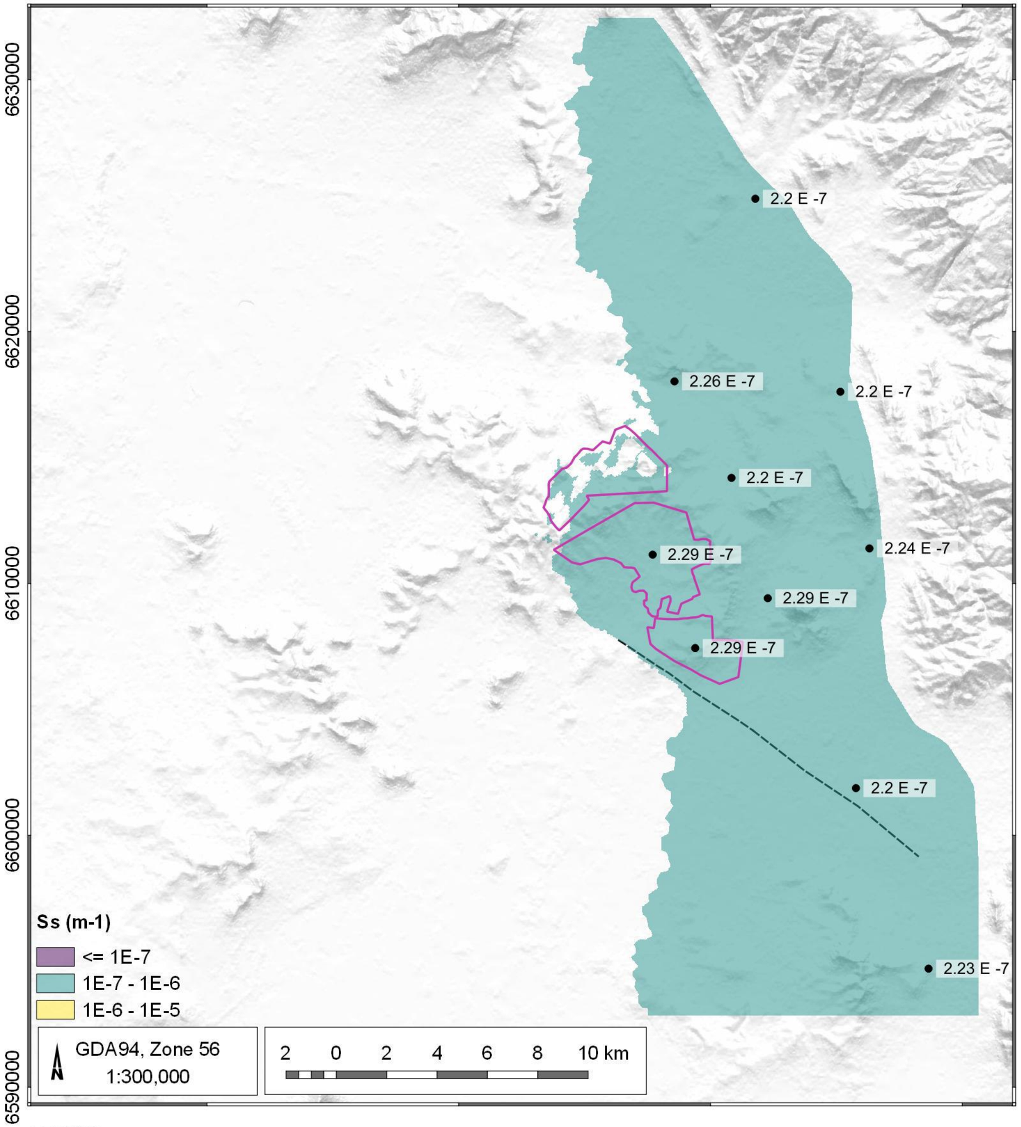
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs

Ss



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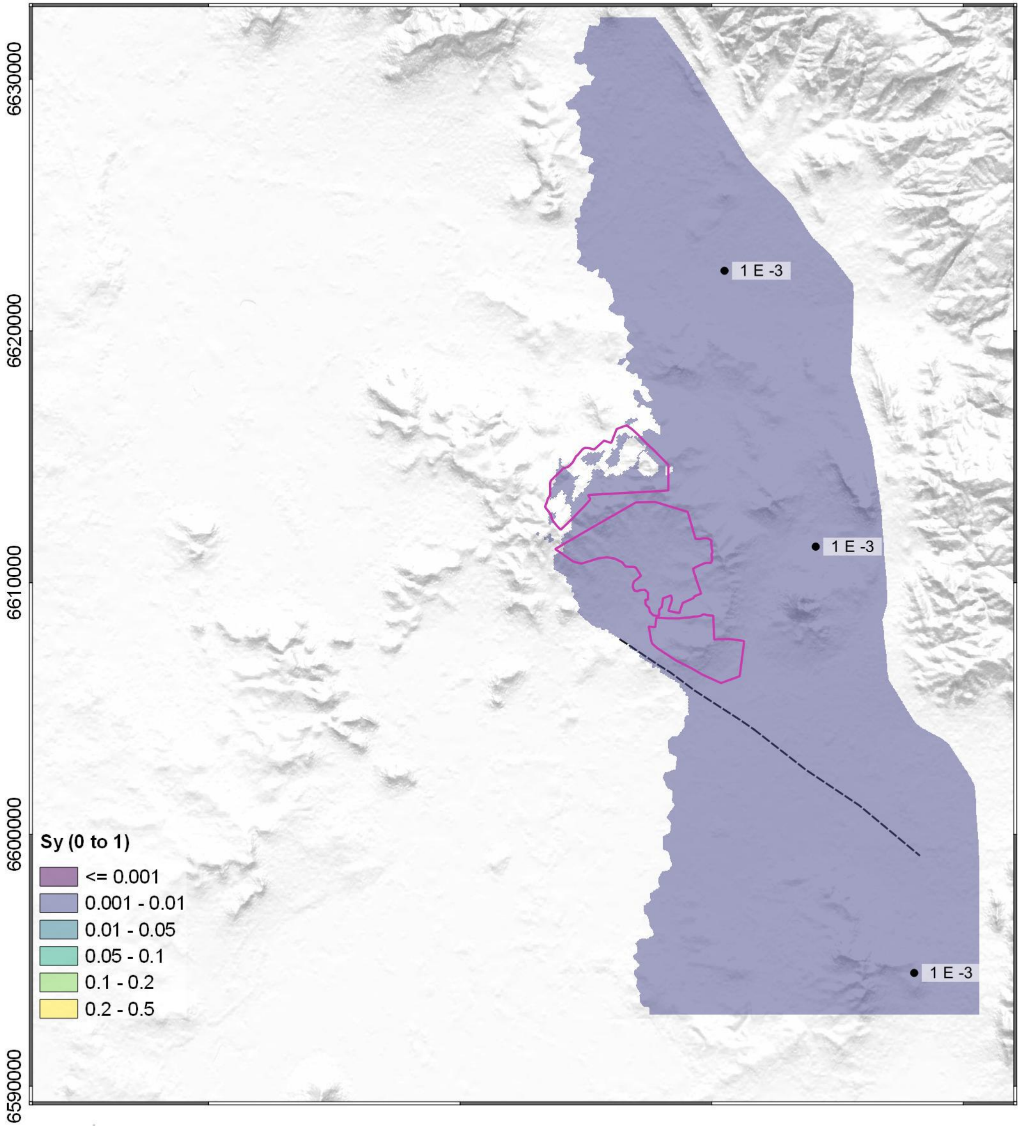

LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 25 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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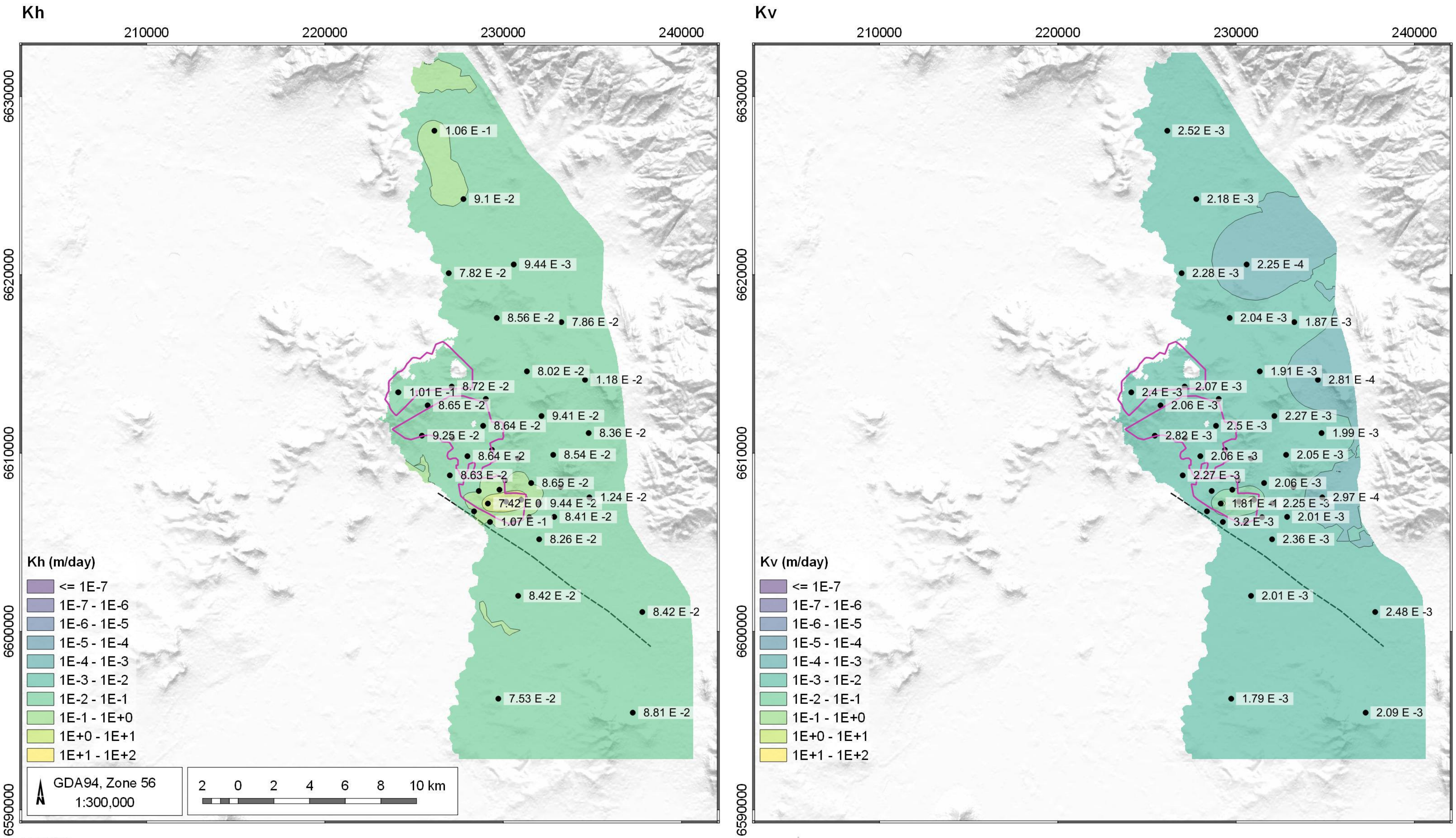
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 26 - Kh and Kv

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15/06/2021

FIGURE No:

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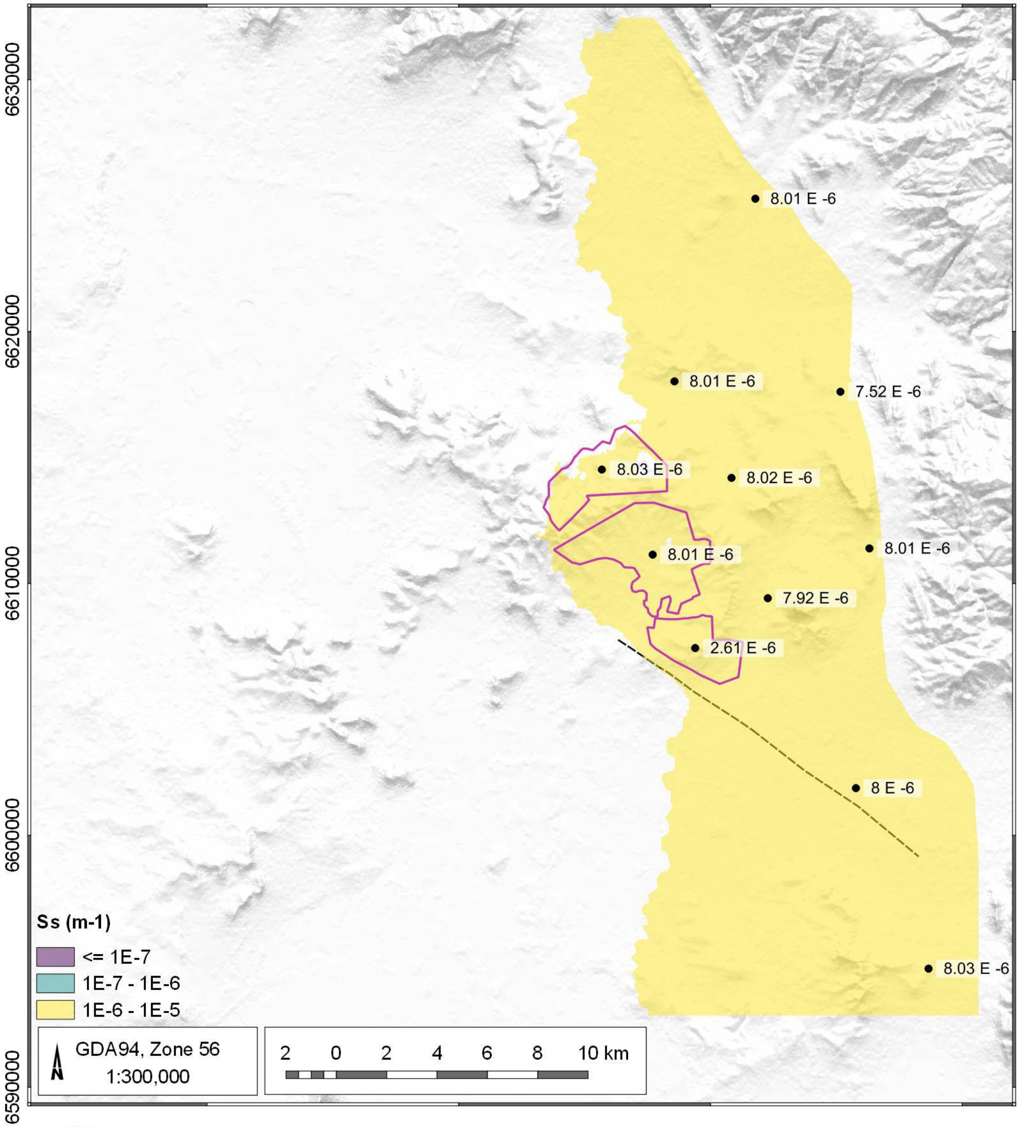
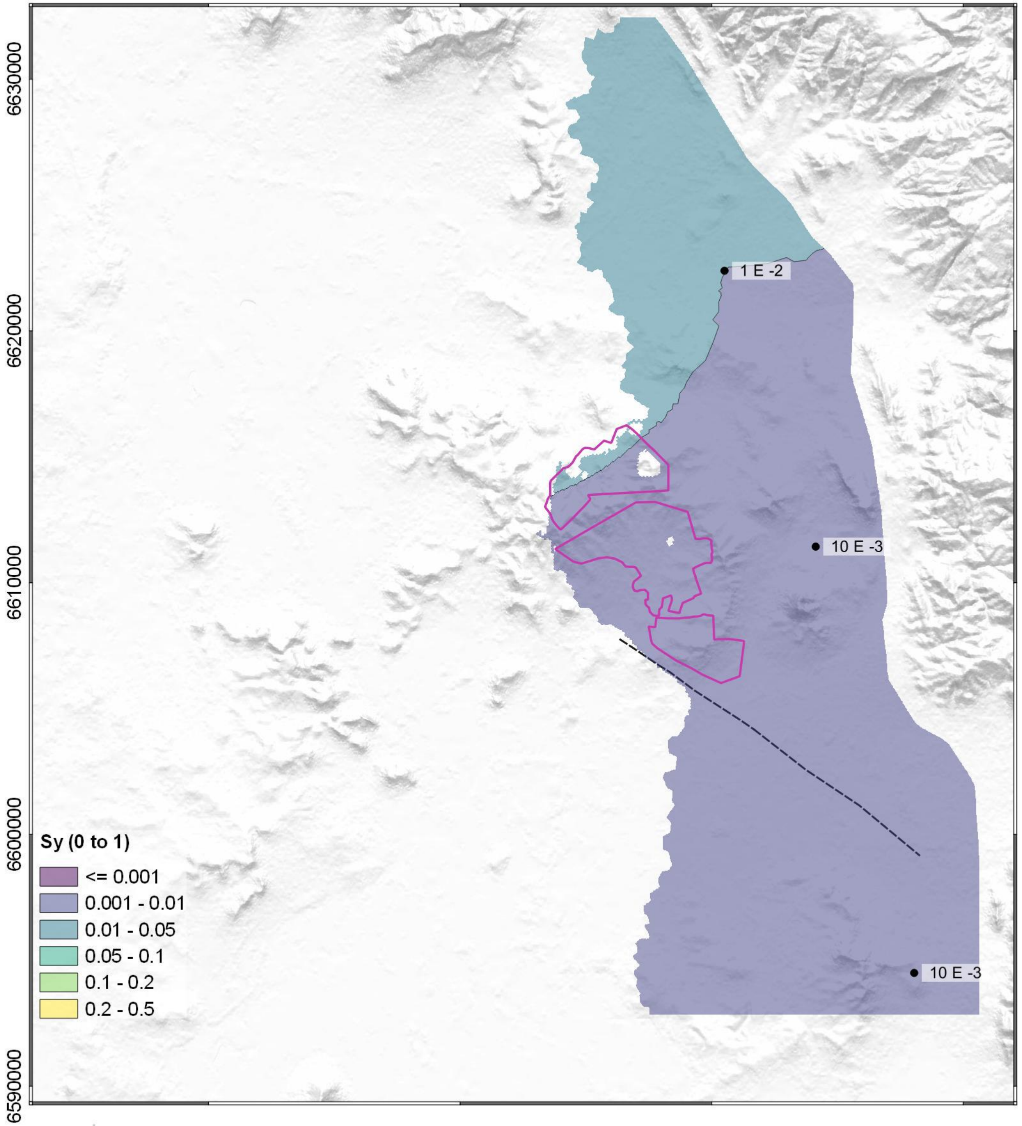
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs

Ss



Sy



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 26 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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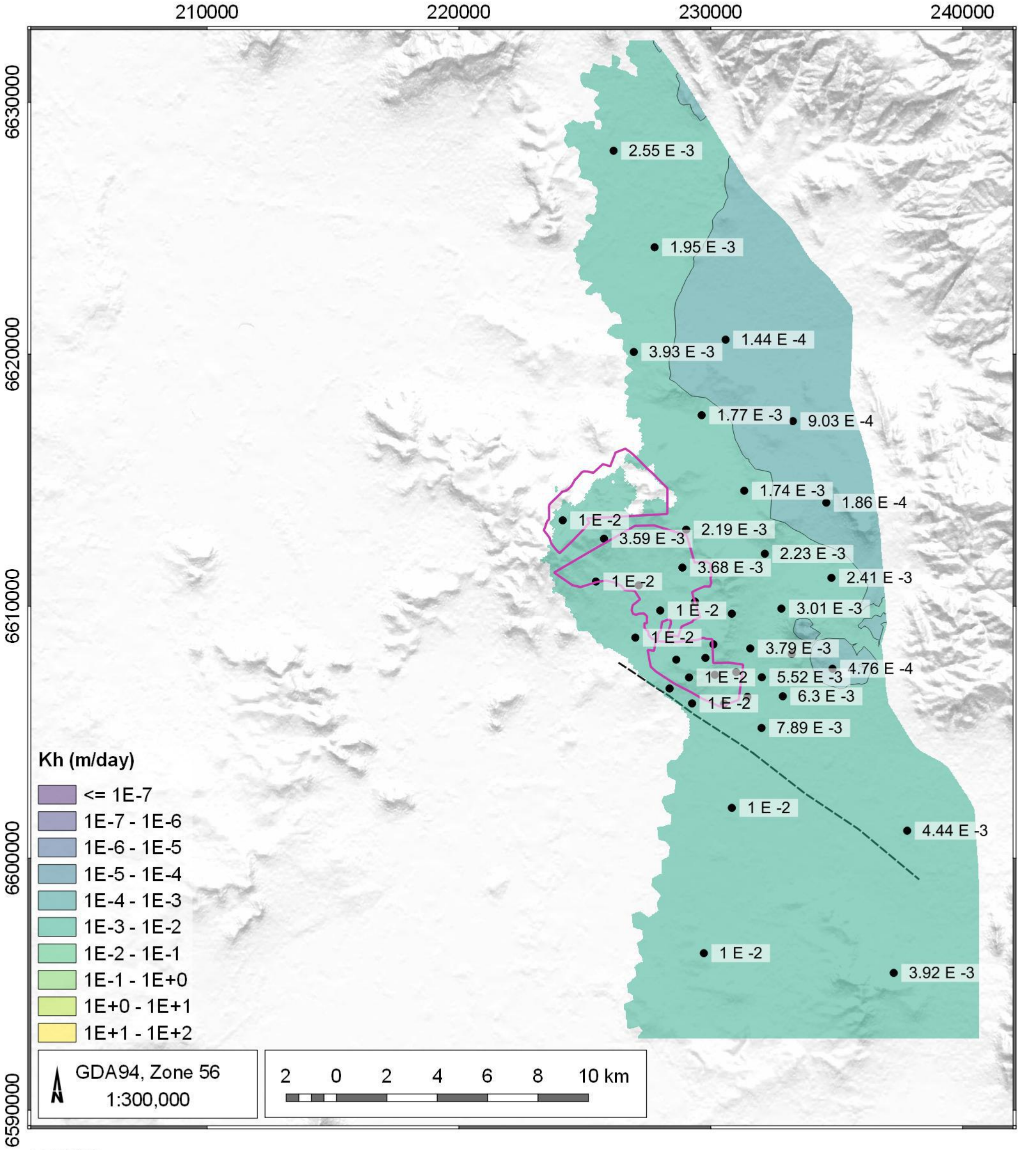
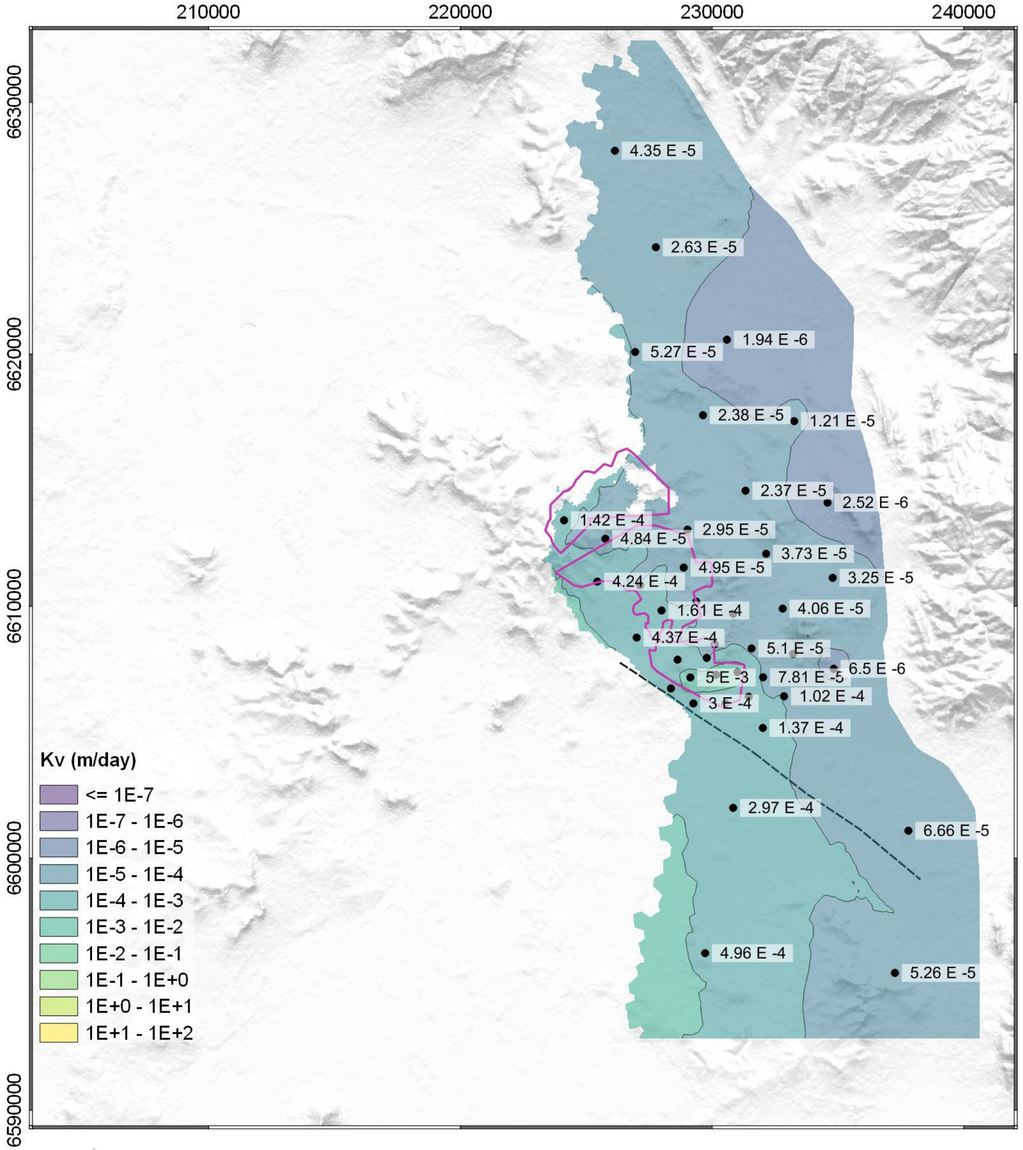
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs

Kh



Kv



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 27 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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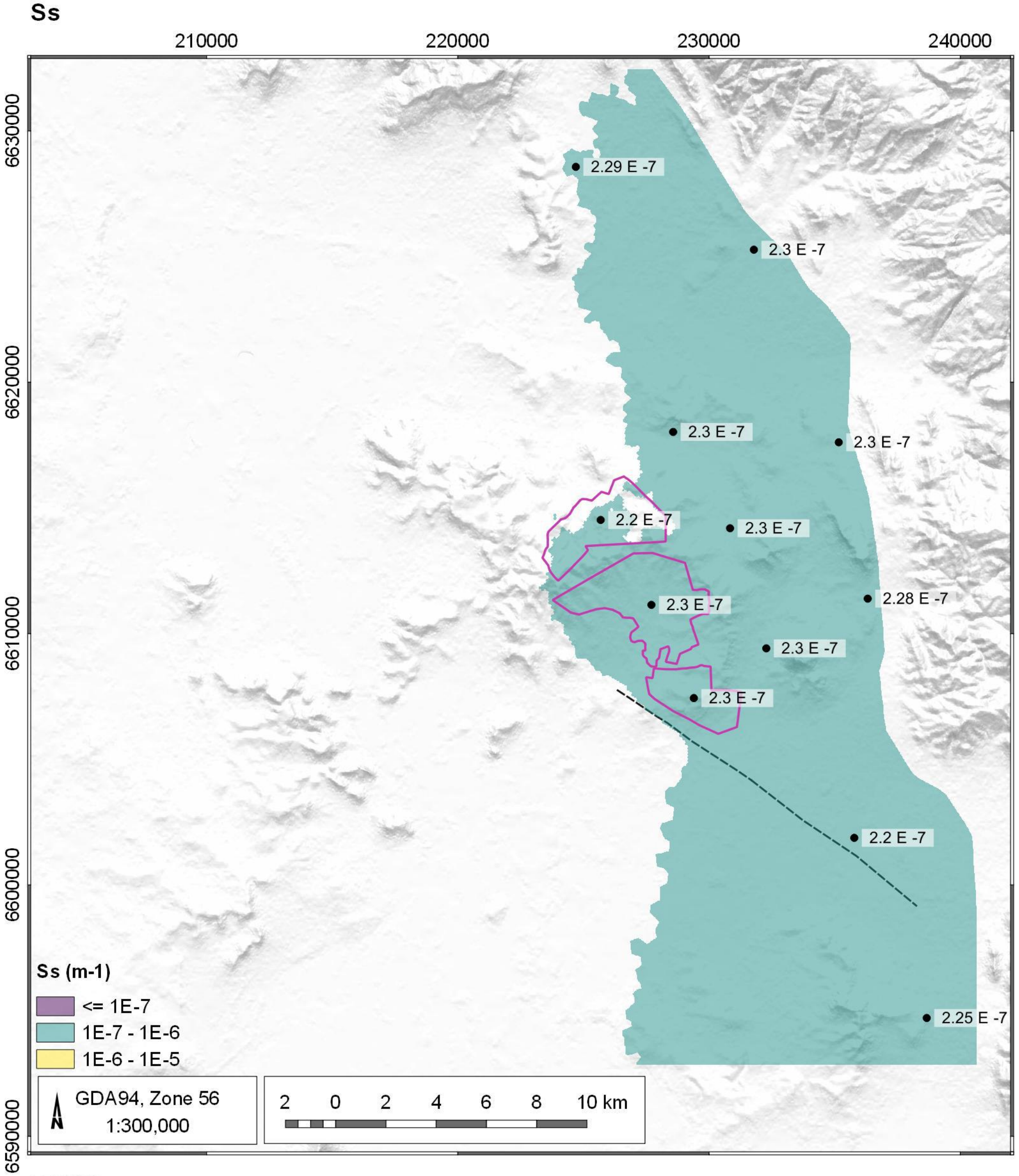
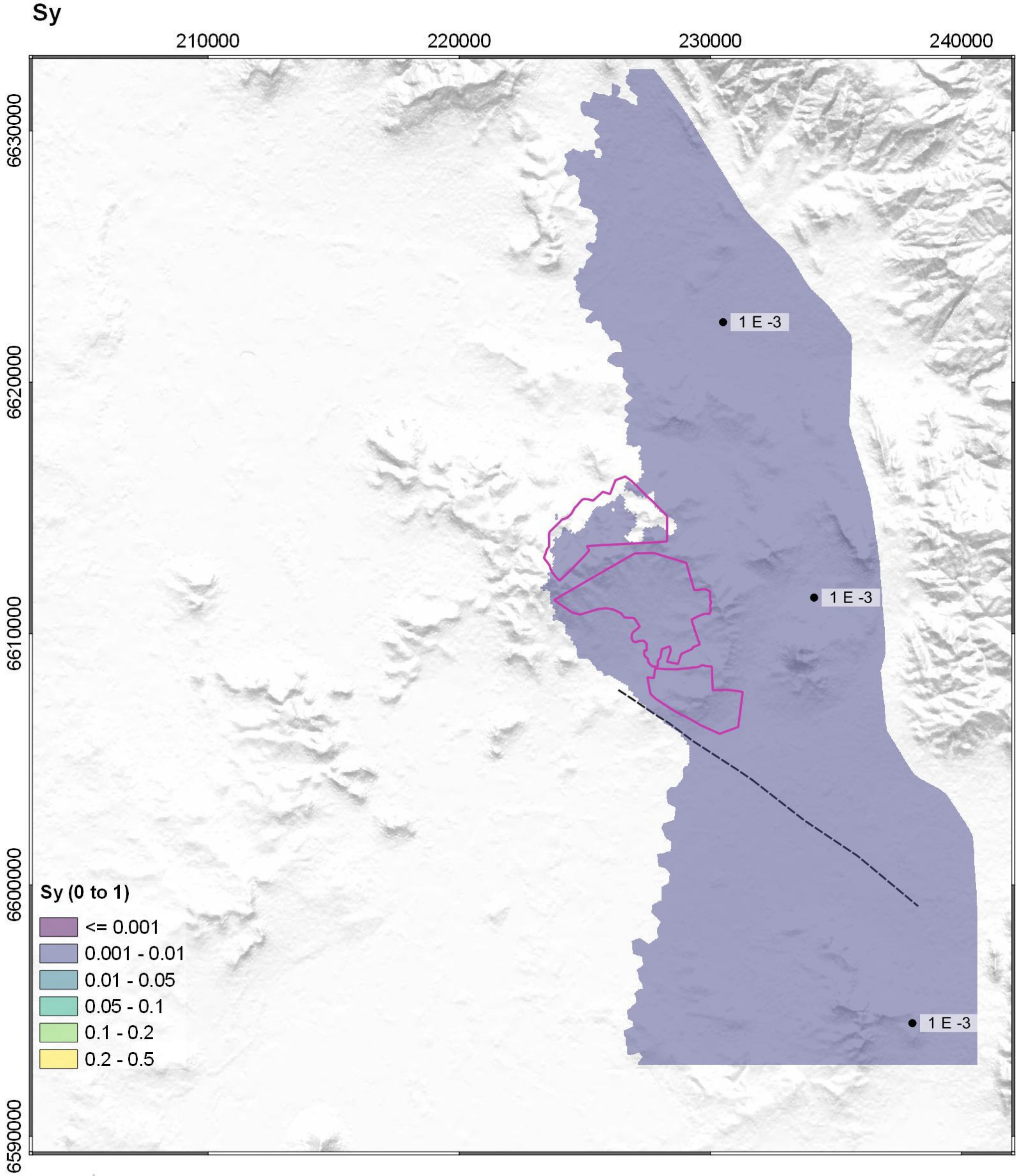
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 27 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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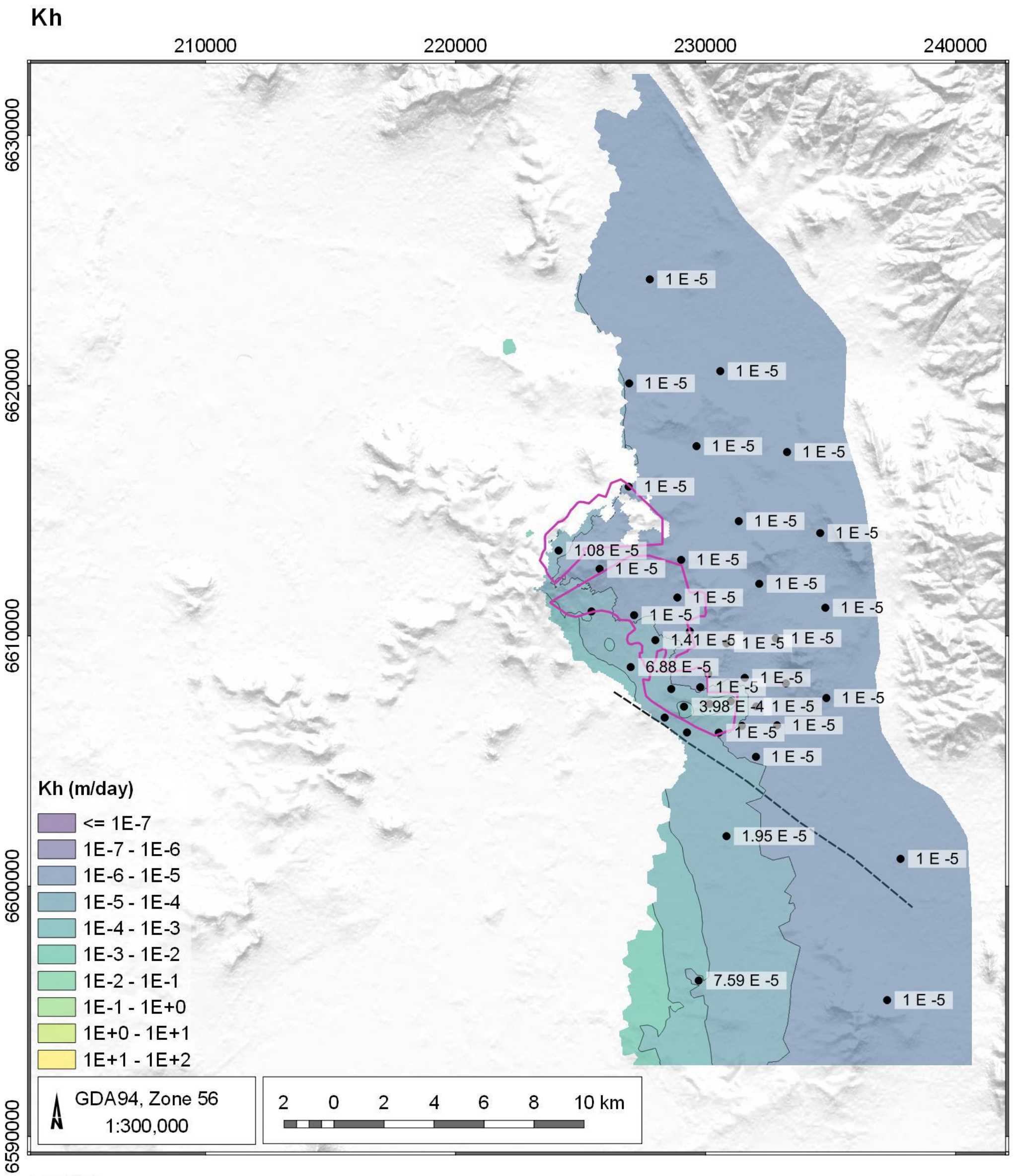
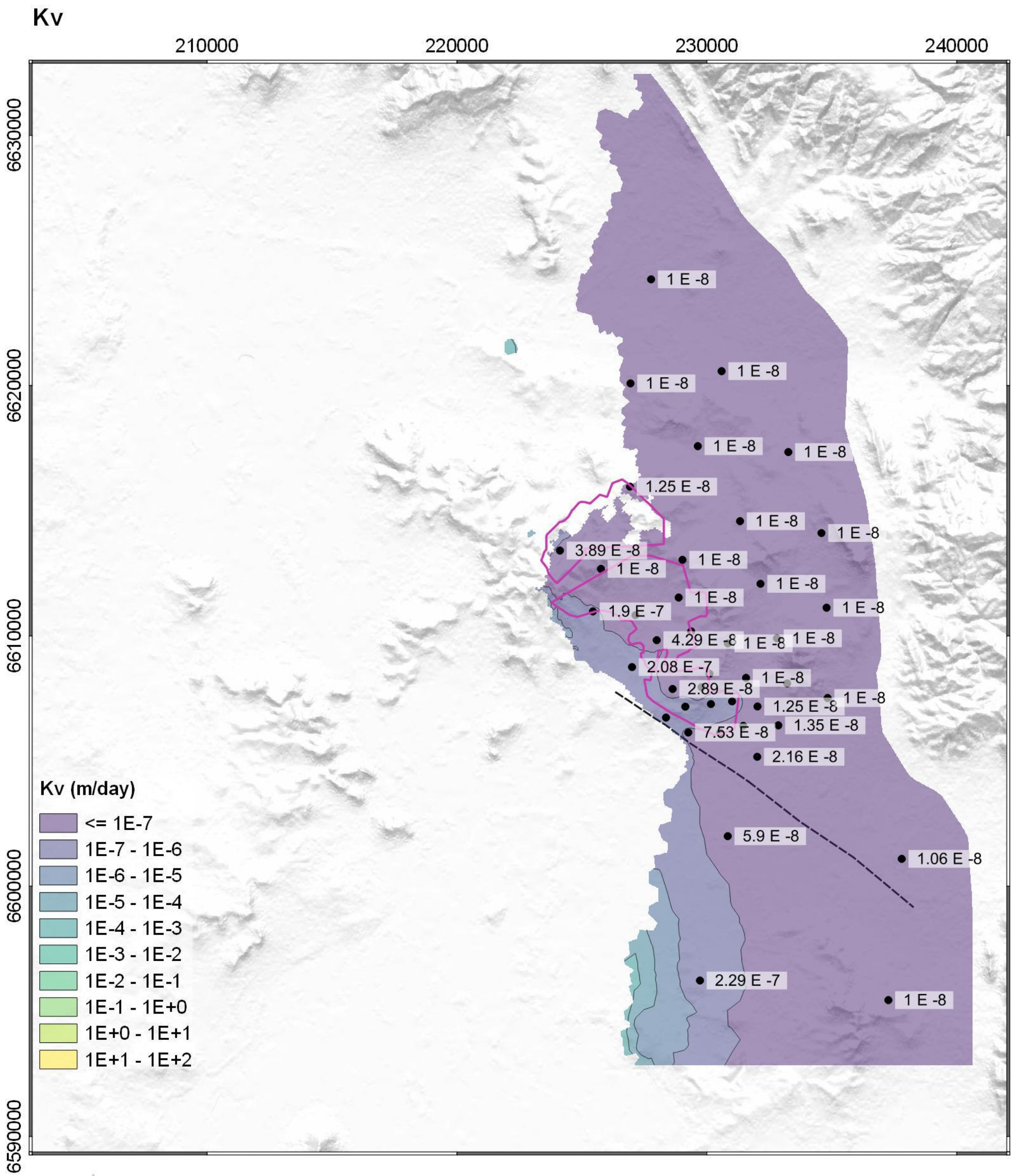
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 28 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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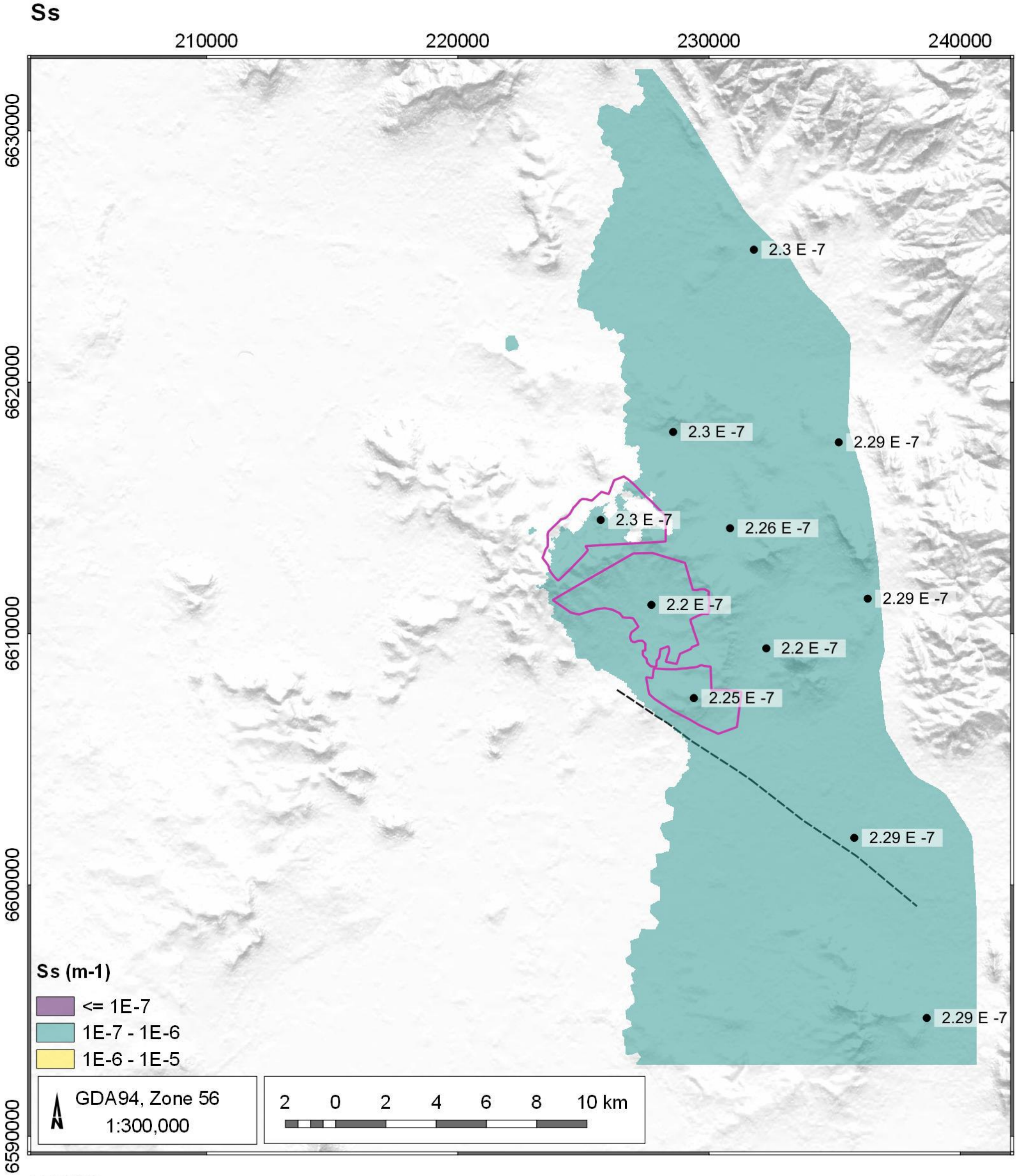
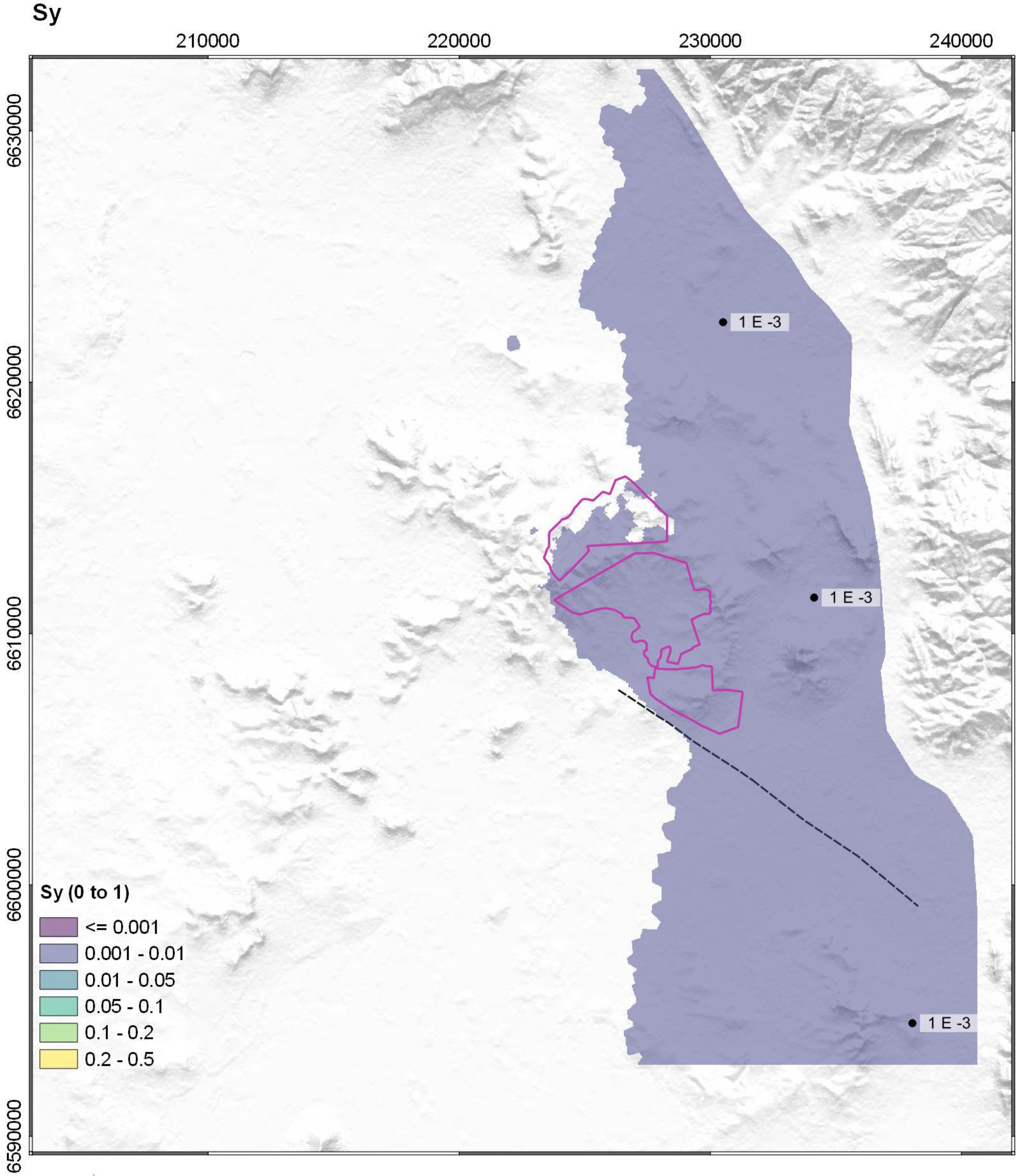
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 28 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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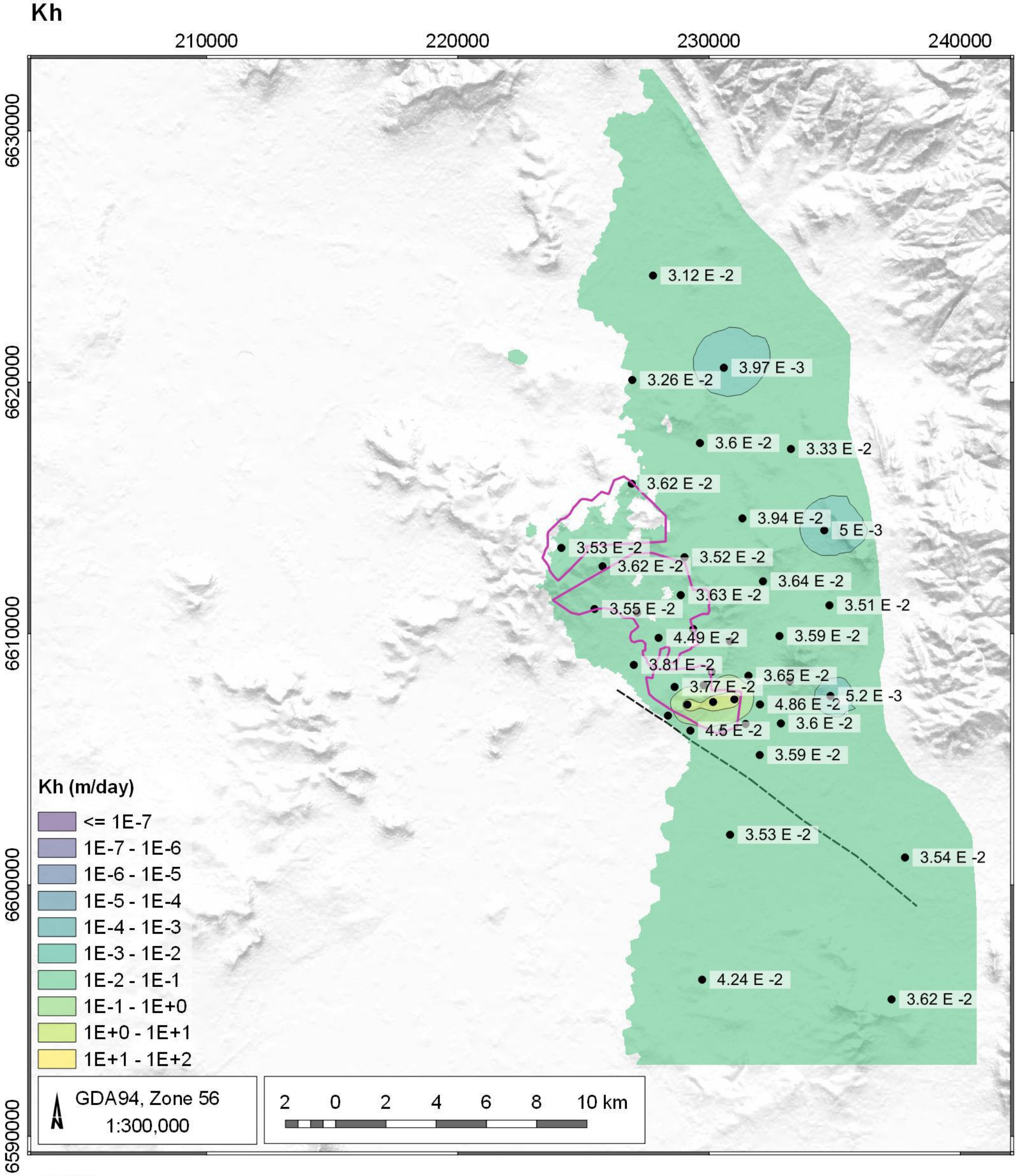
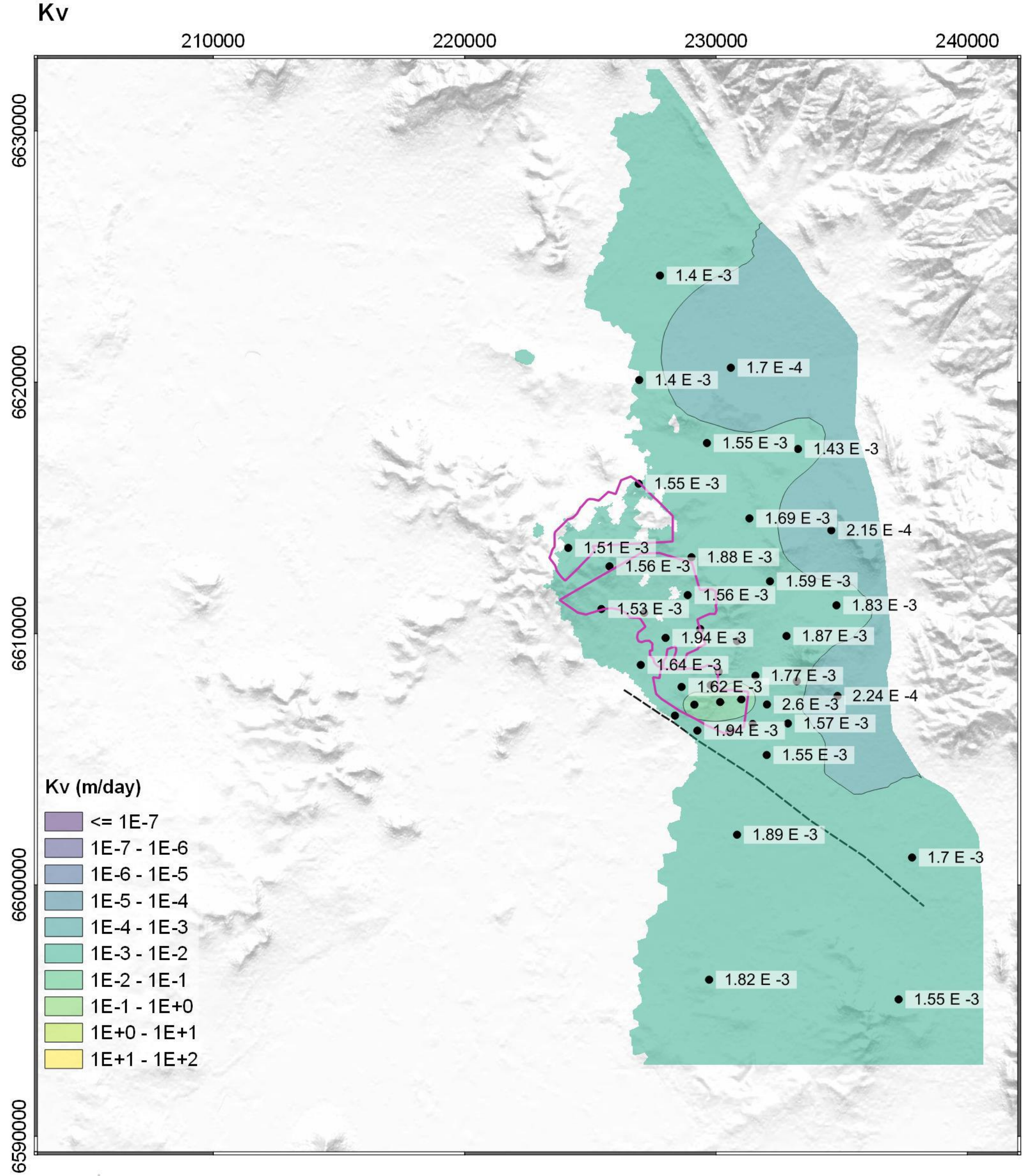
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 29 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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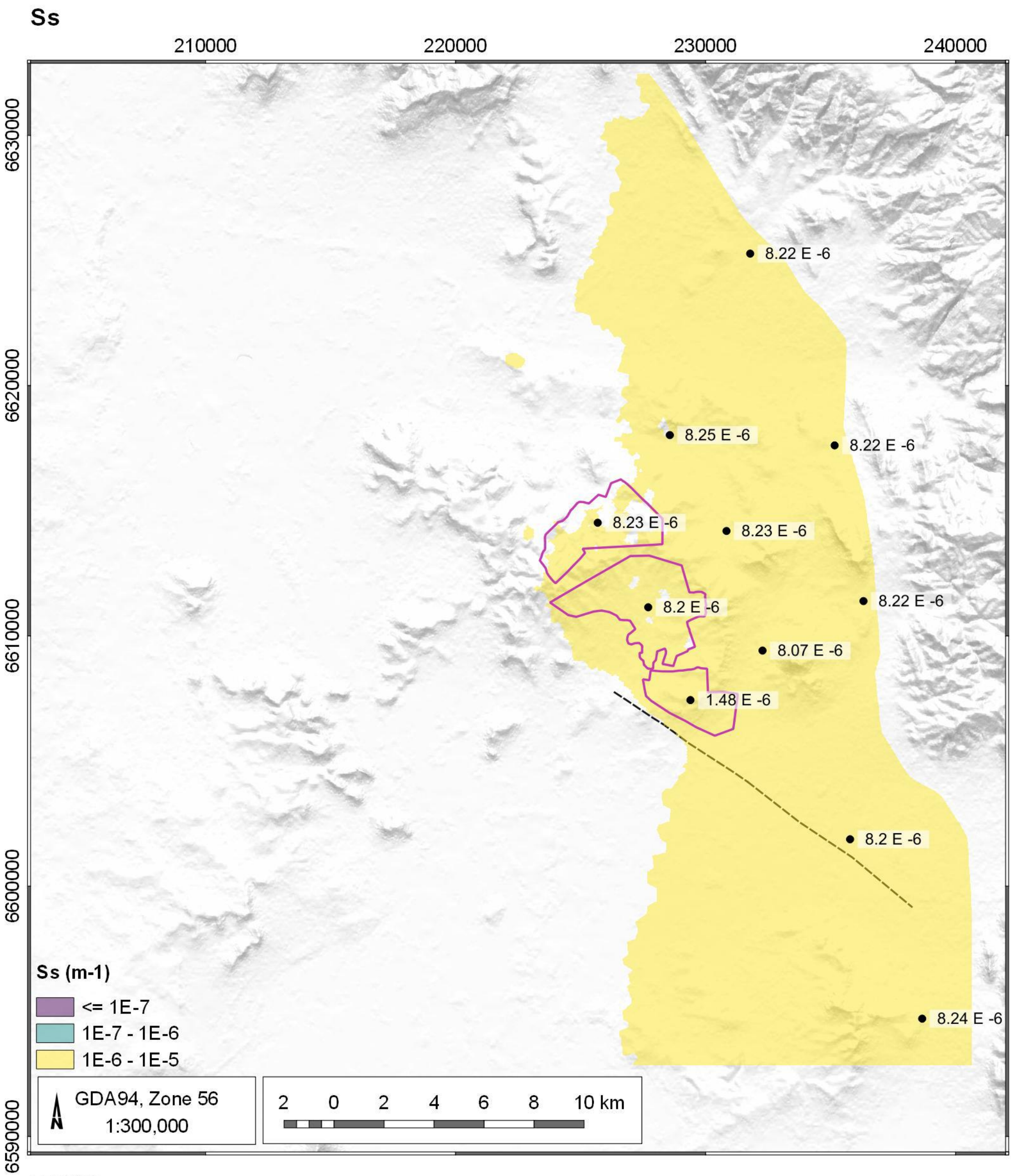
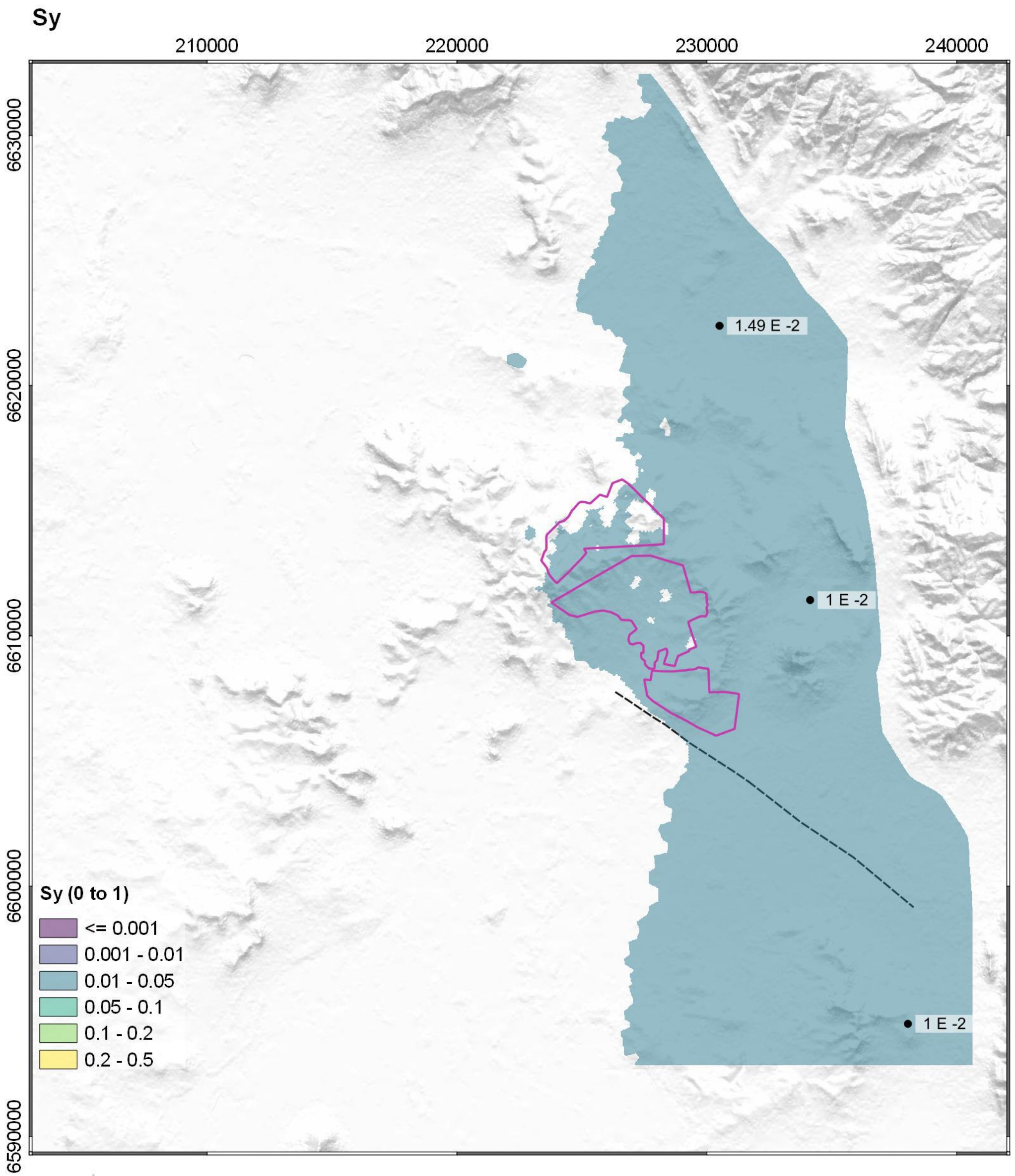
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 29 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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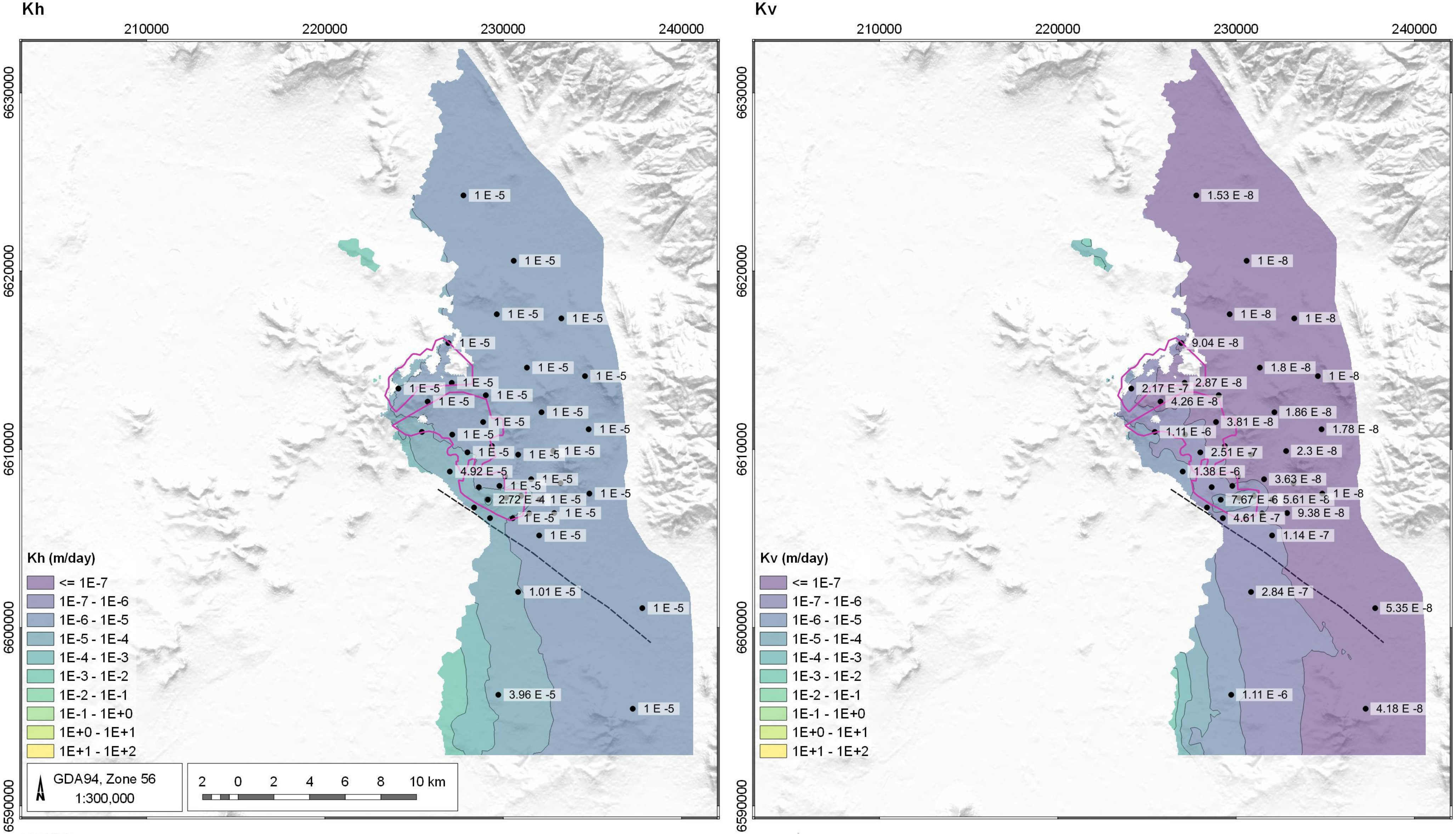
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 30 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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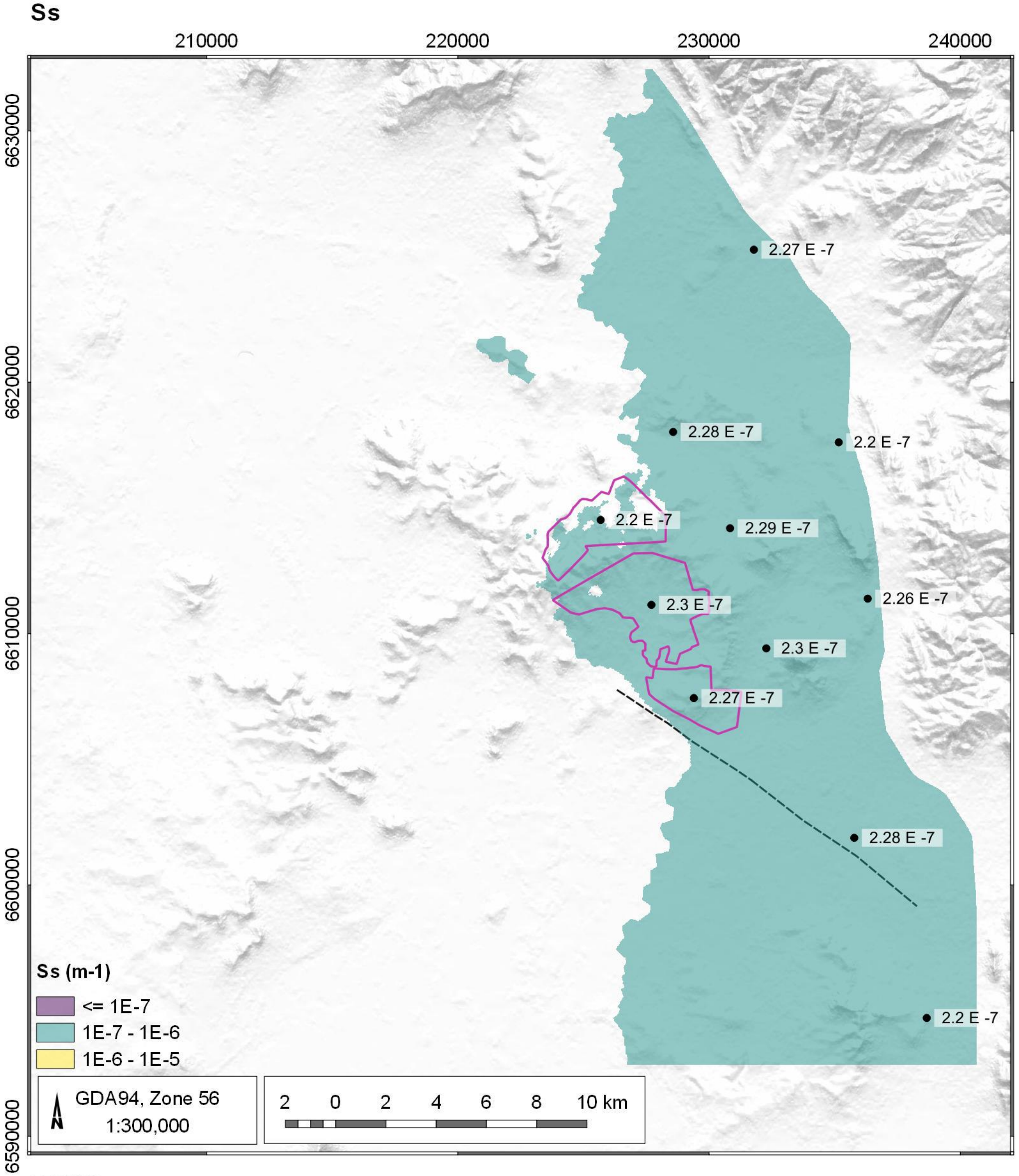
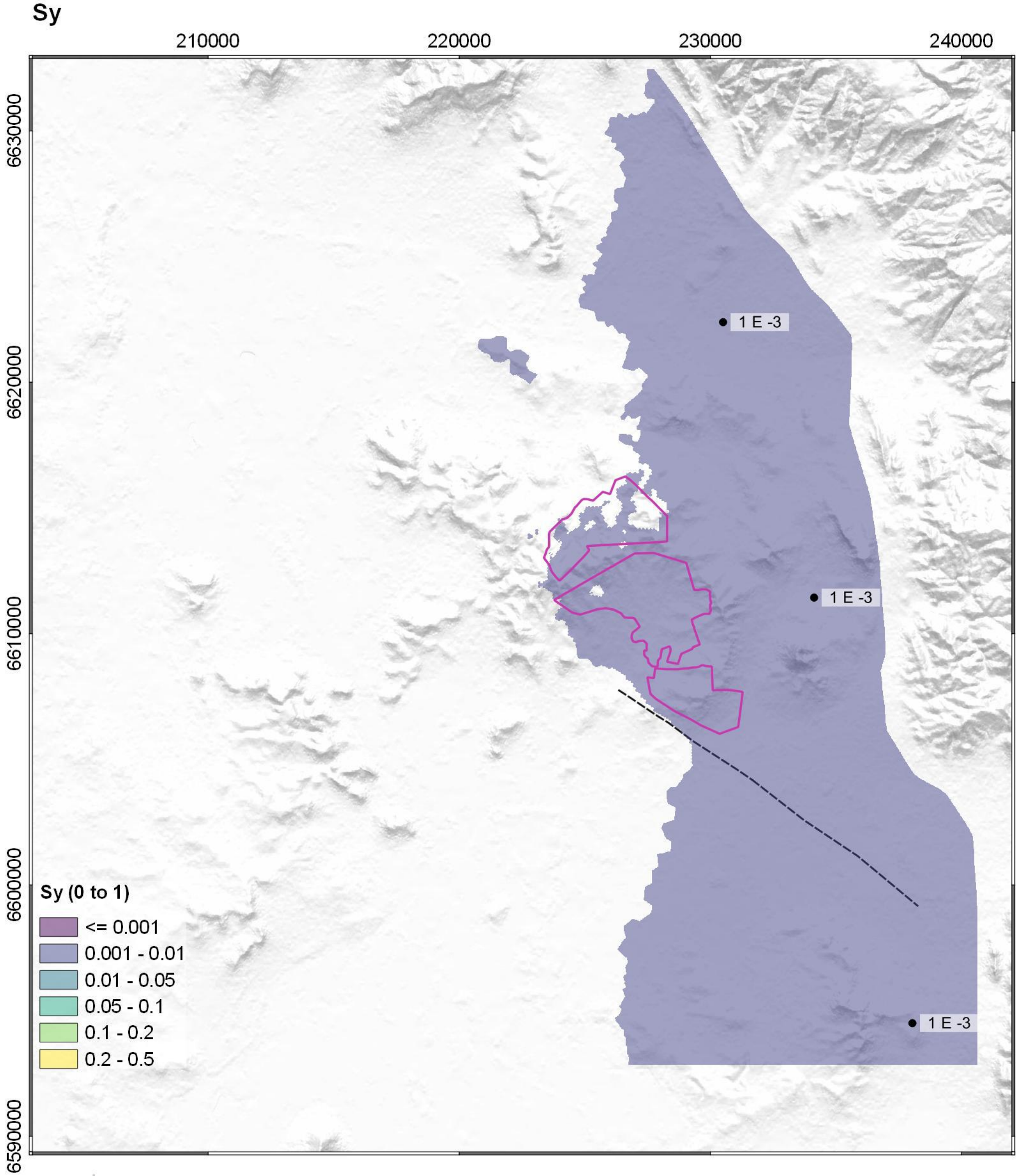
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 30 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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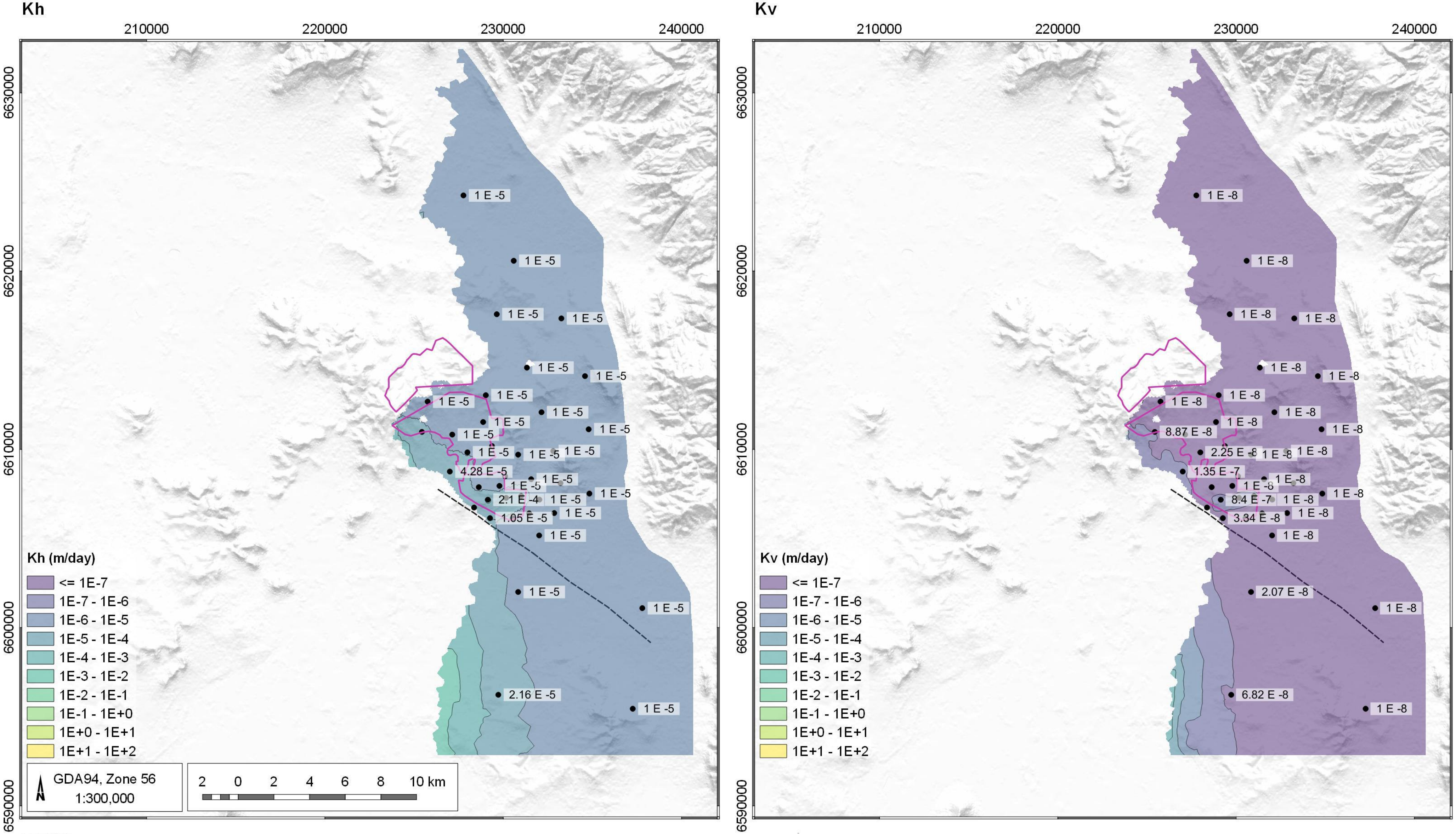
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 31 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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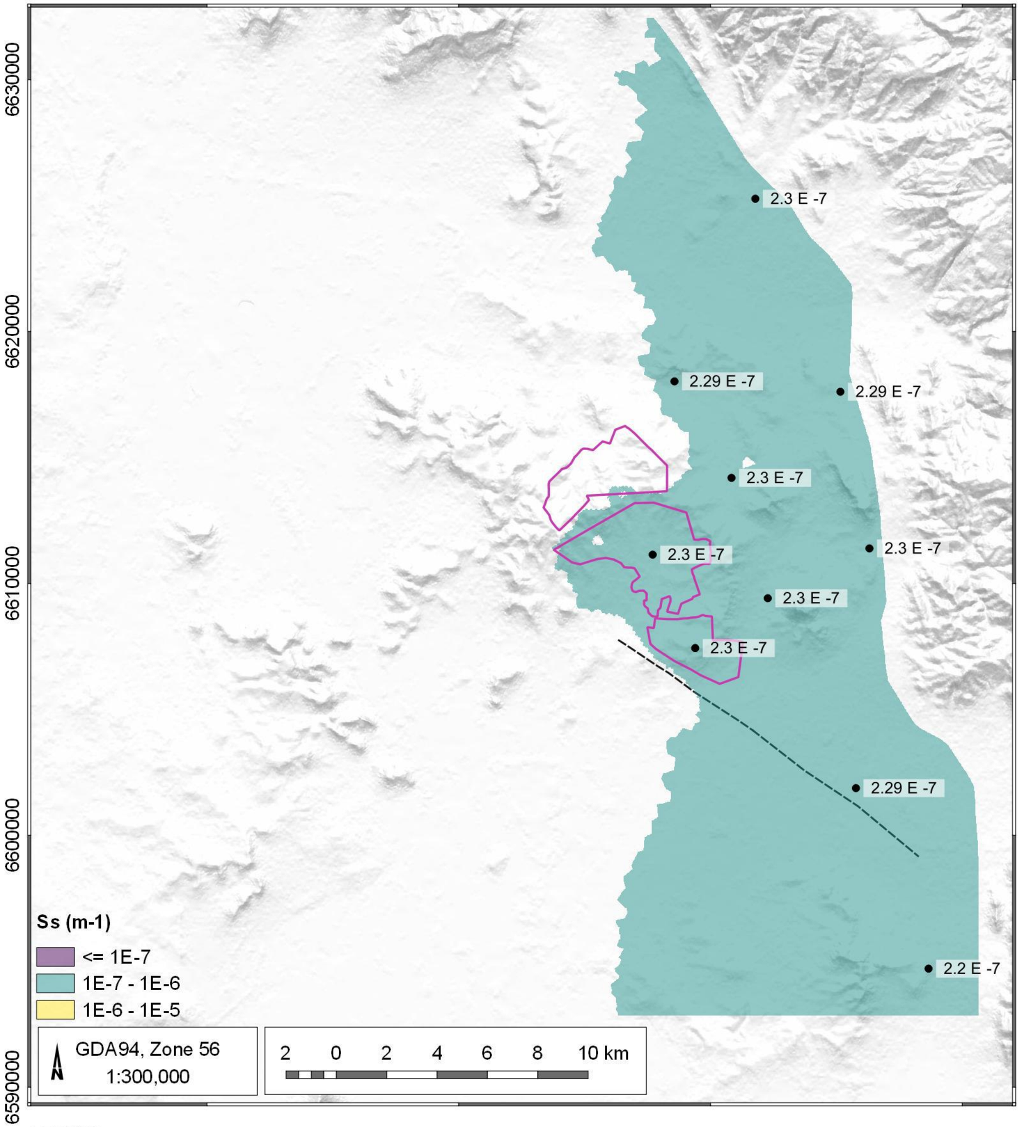
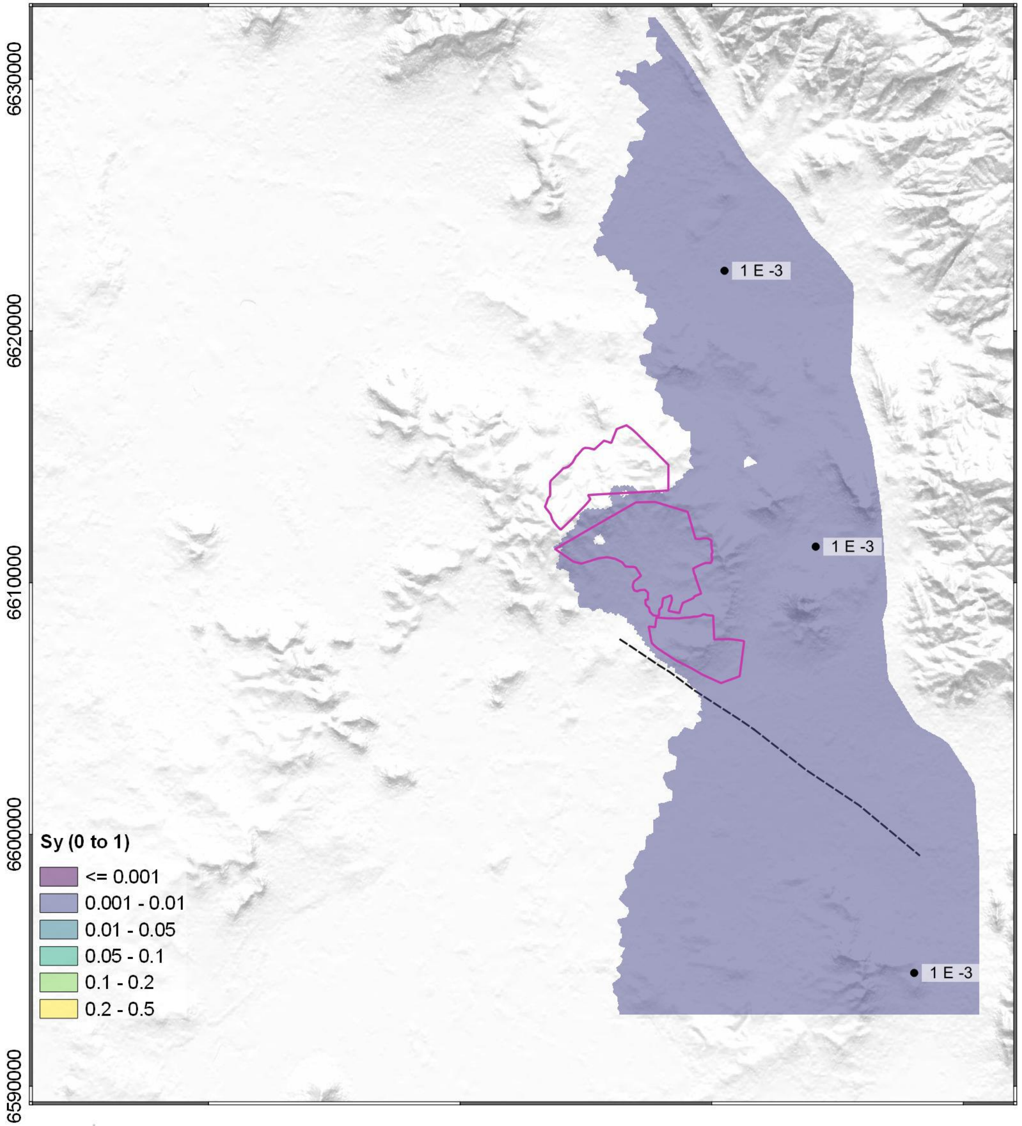
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs

Ss



Sy



LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 31 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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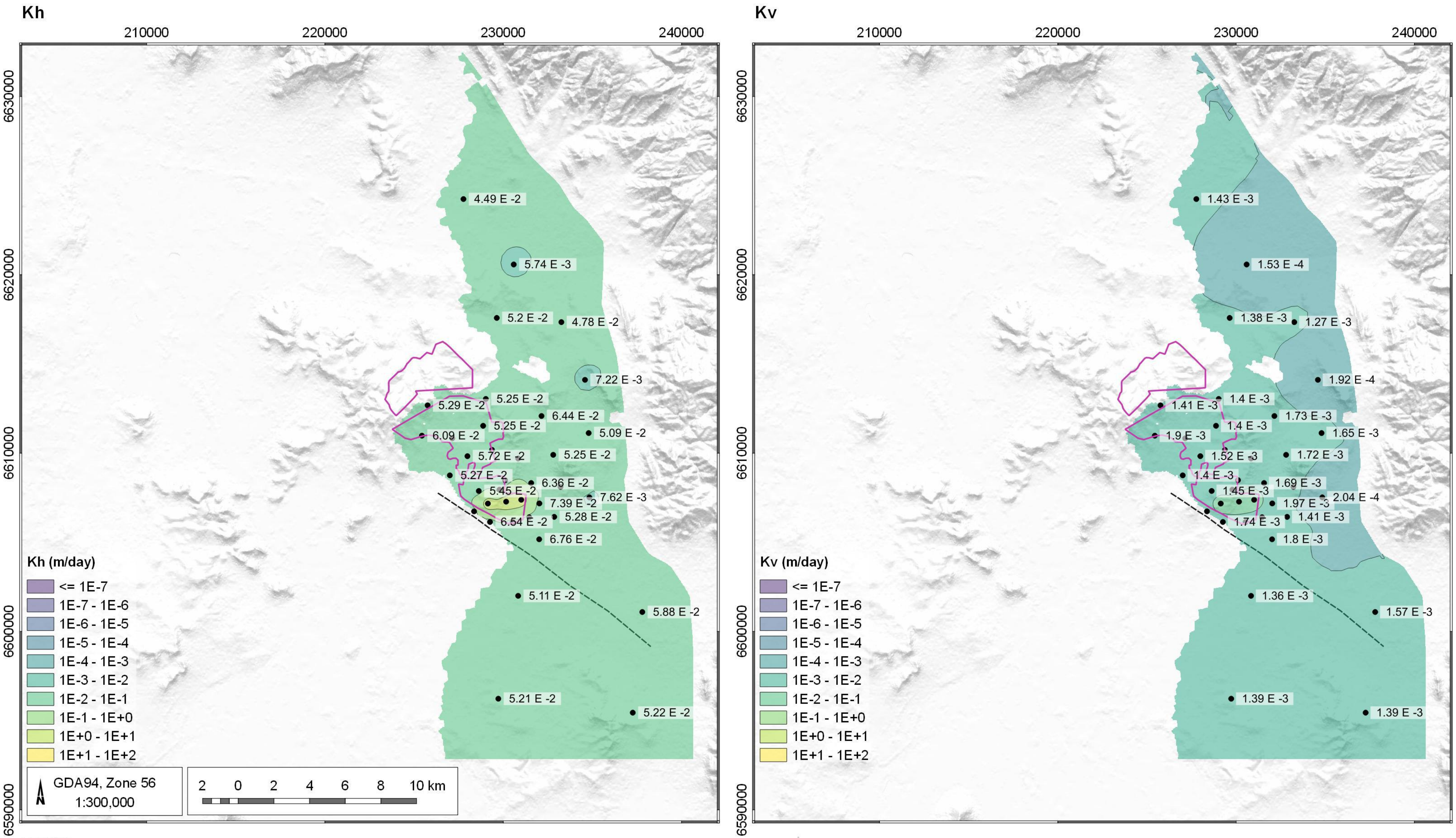
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 32 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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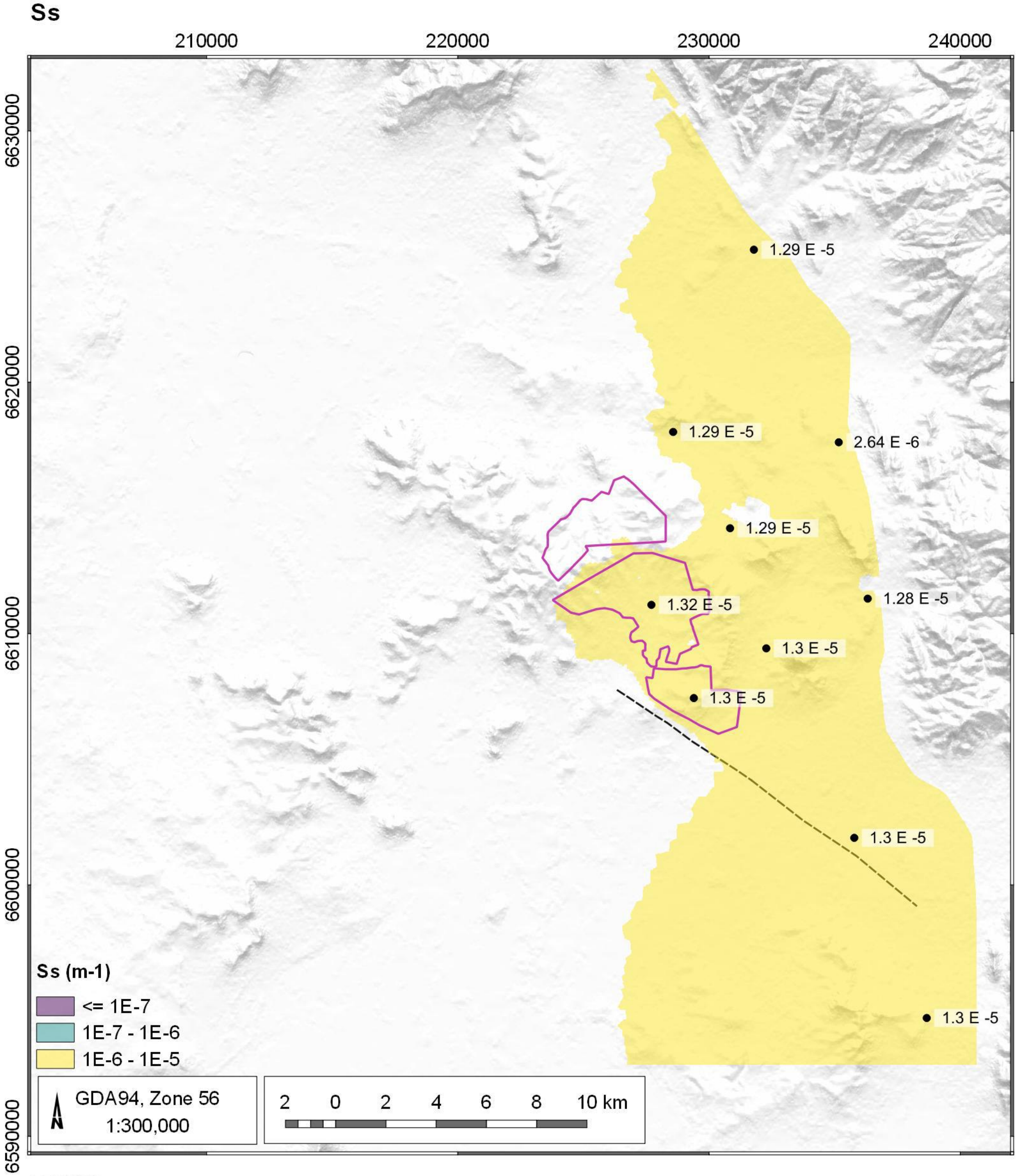
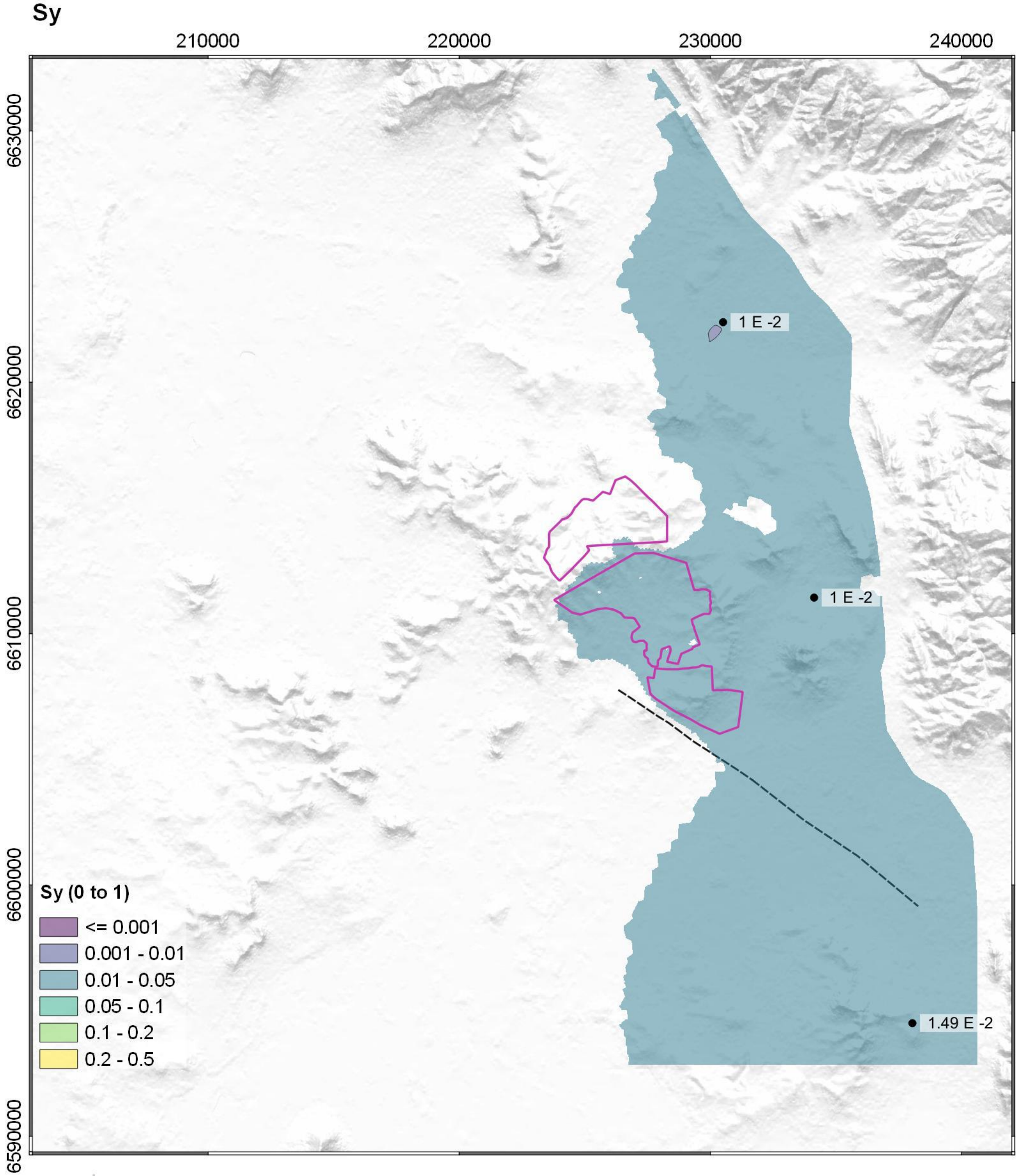
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs





LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 32 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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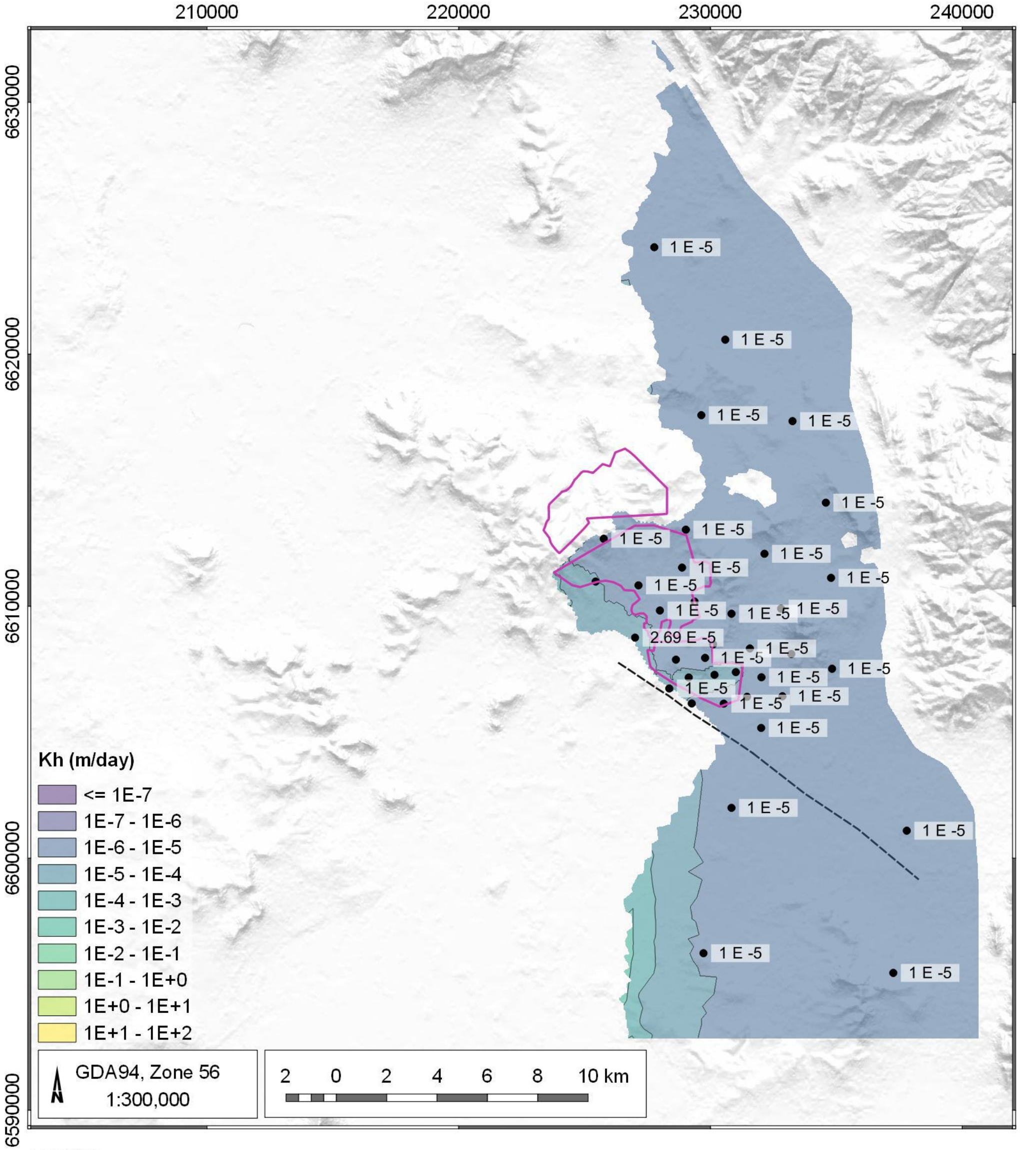
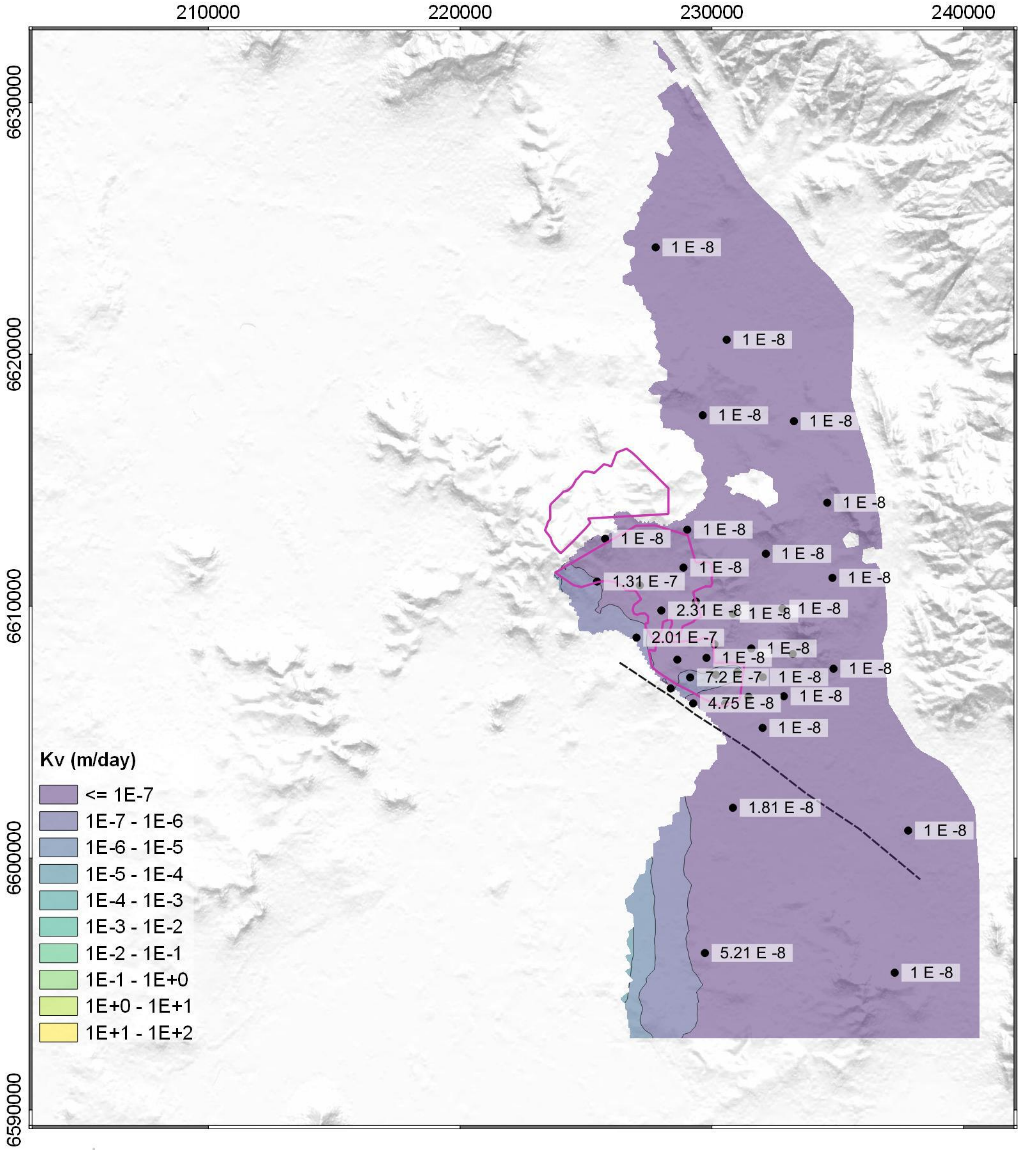
Source: 1 second SRTM Derived DEM-S - © Commonwealth of Australia (Geoscience Australia) 2011.; GEODATA TOPO 250K Series 3 - © Commonwealth of Australia (Geoscience Australia) 2006.;
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs

Kh



Kv



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 33 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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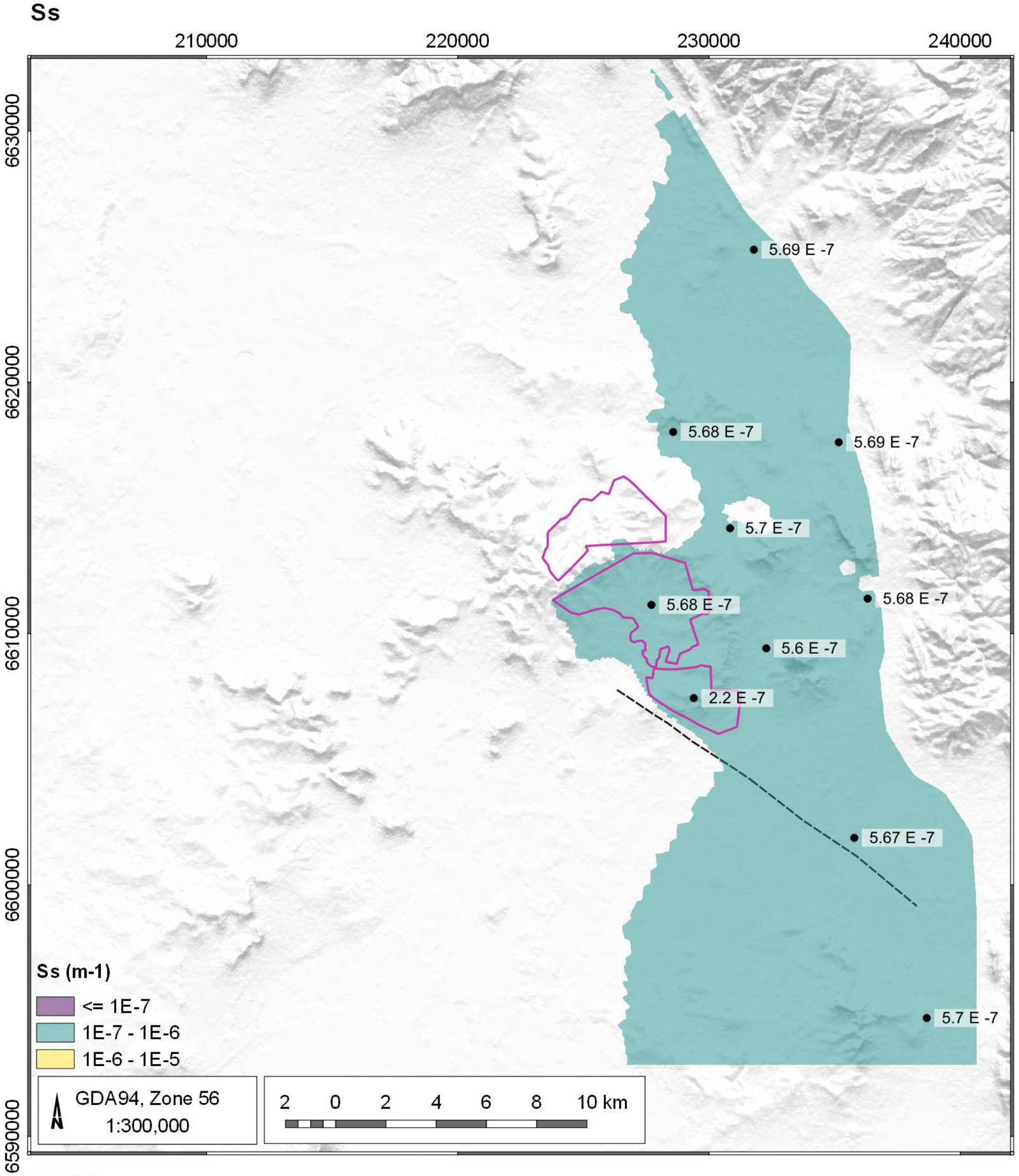

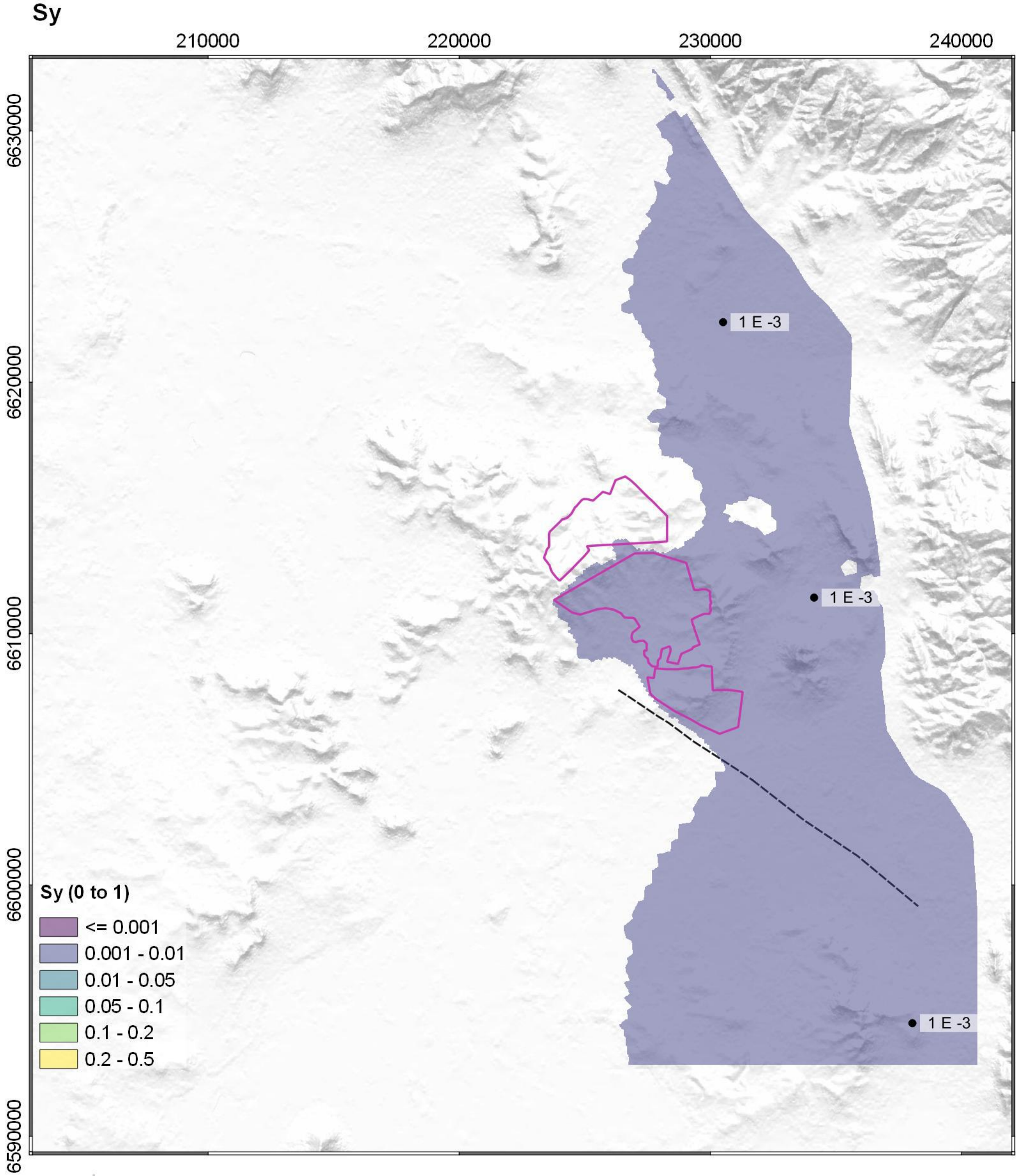

LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 33 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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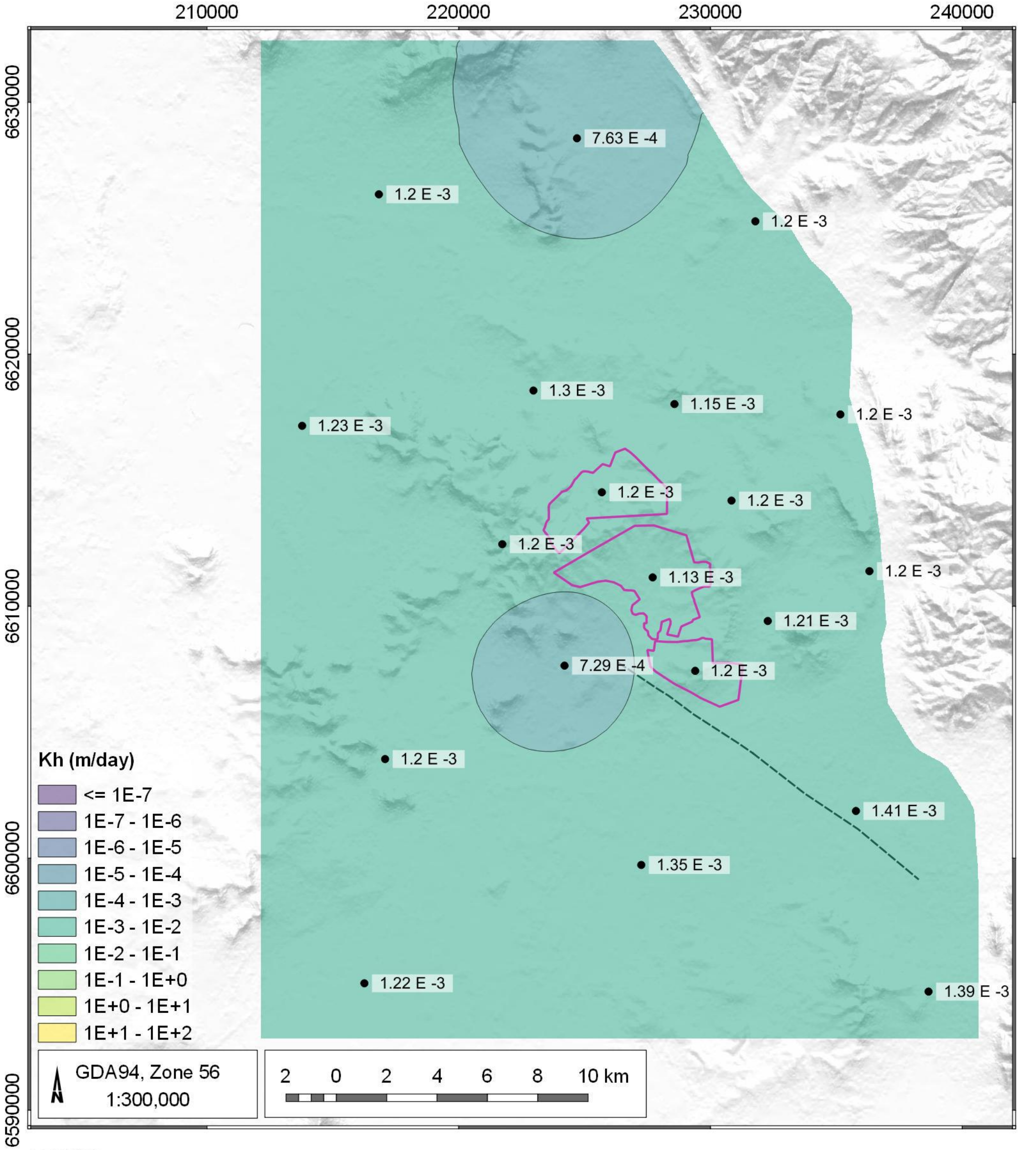
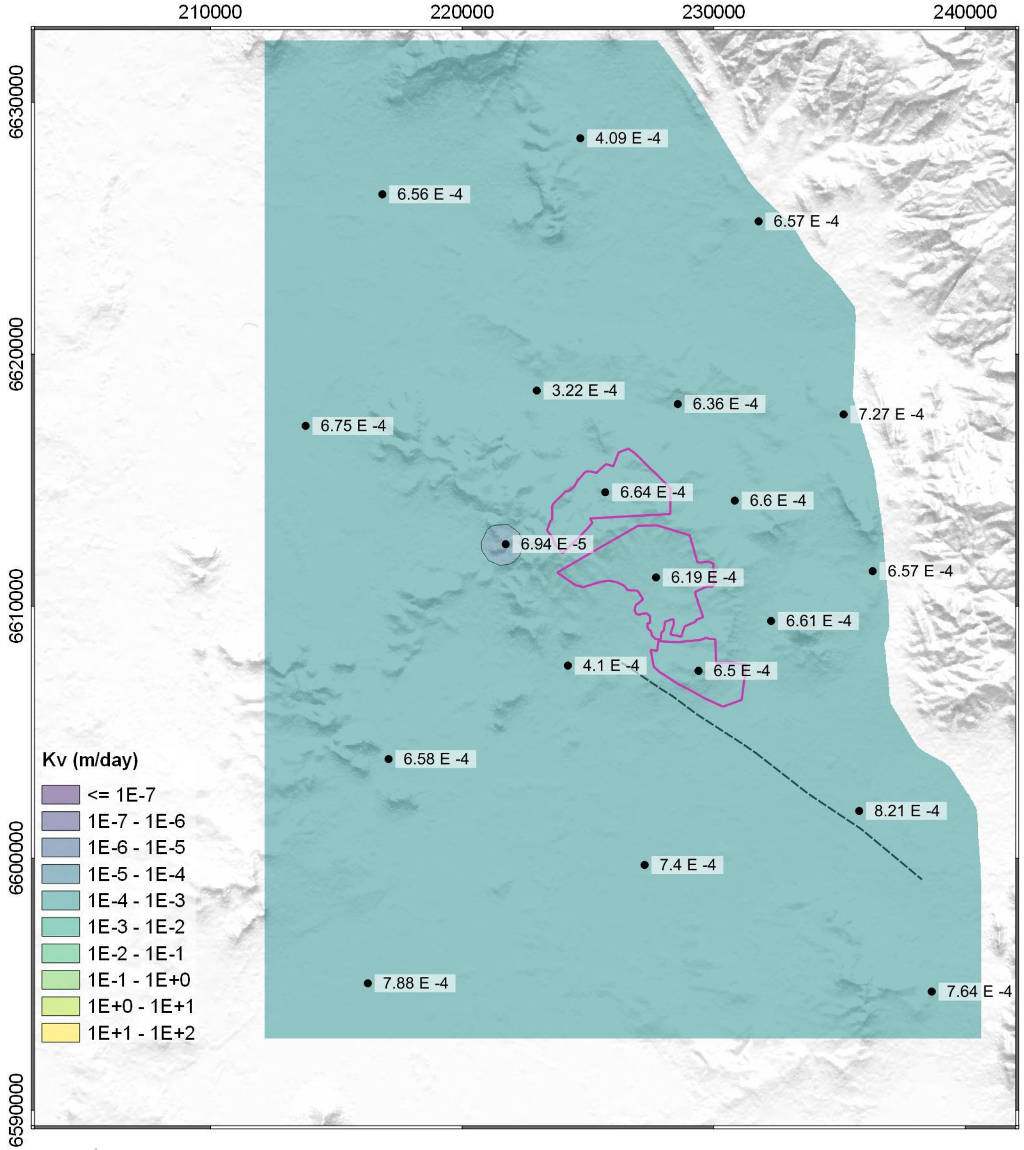
Kh



Kv



LEGEND

- Pilot point (Hydraulic property)
- Contour line
- Conomos fault
- Mine outline

AGE

Layer 34 - Kh and Kv

DATE
15/06/2021

FIGURE No:

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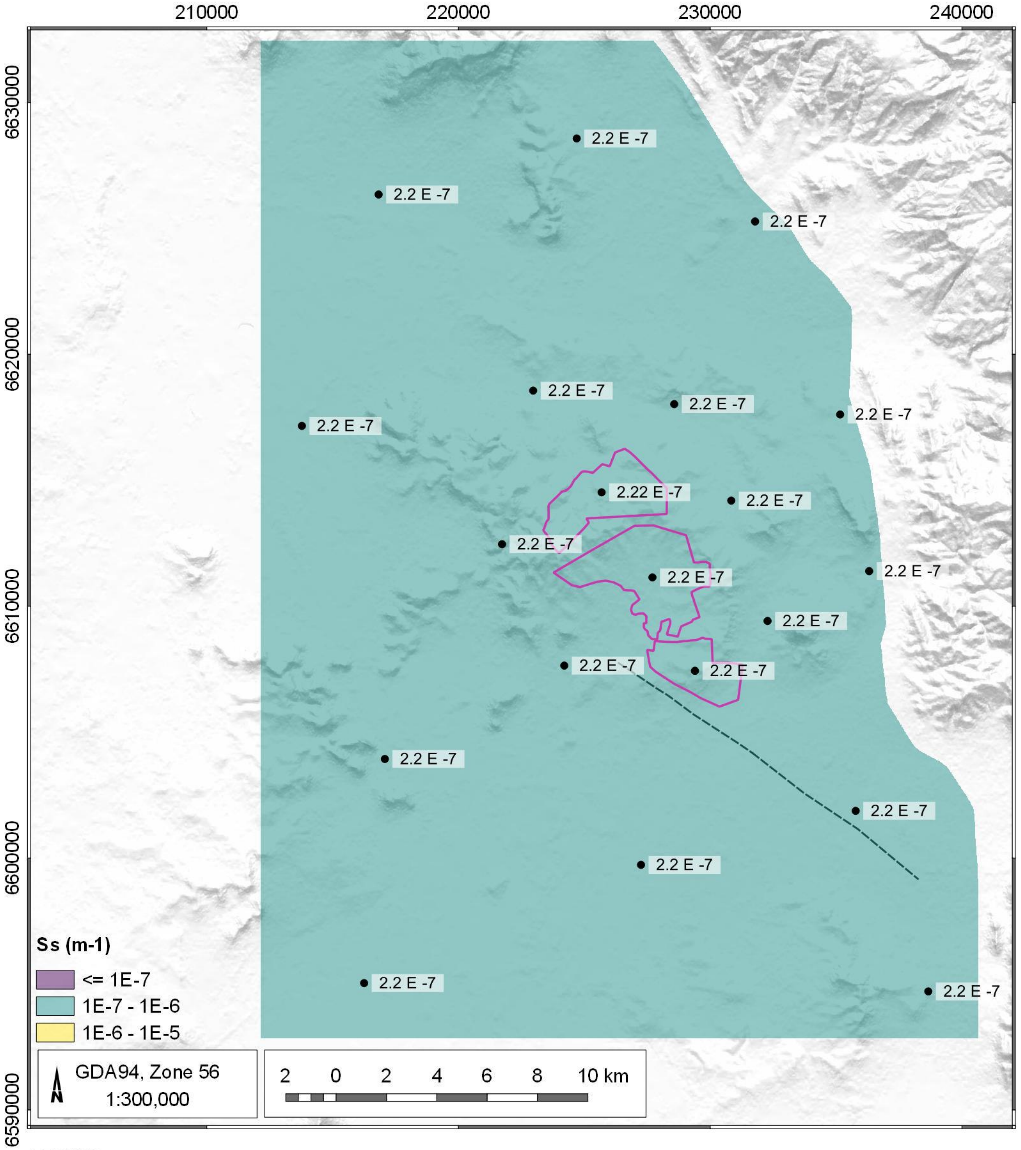
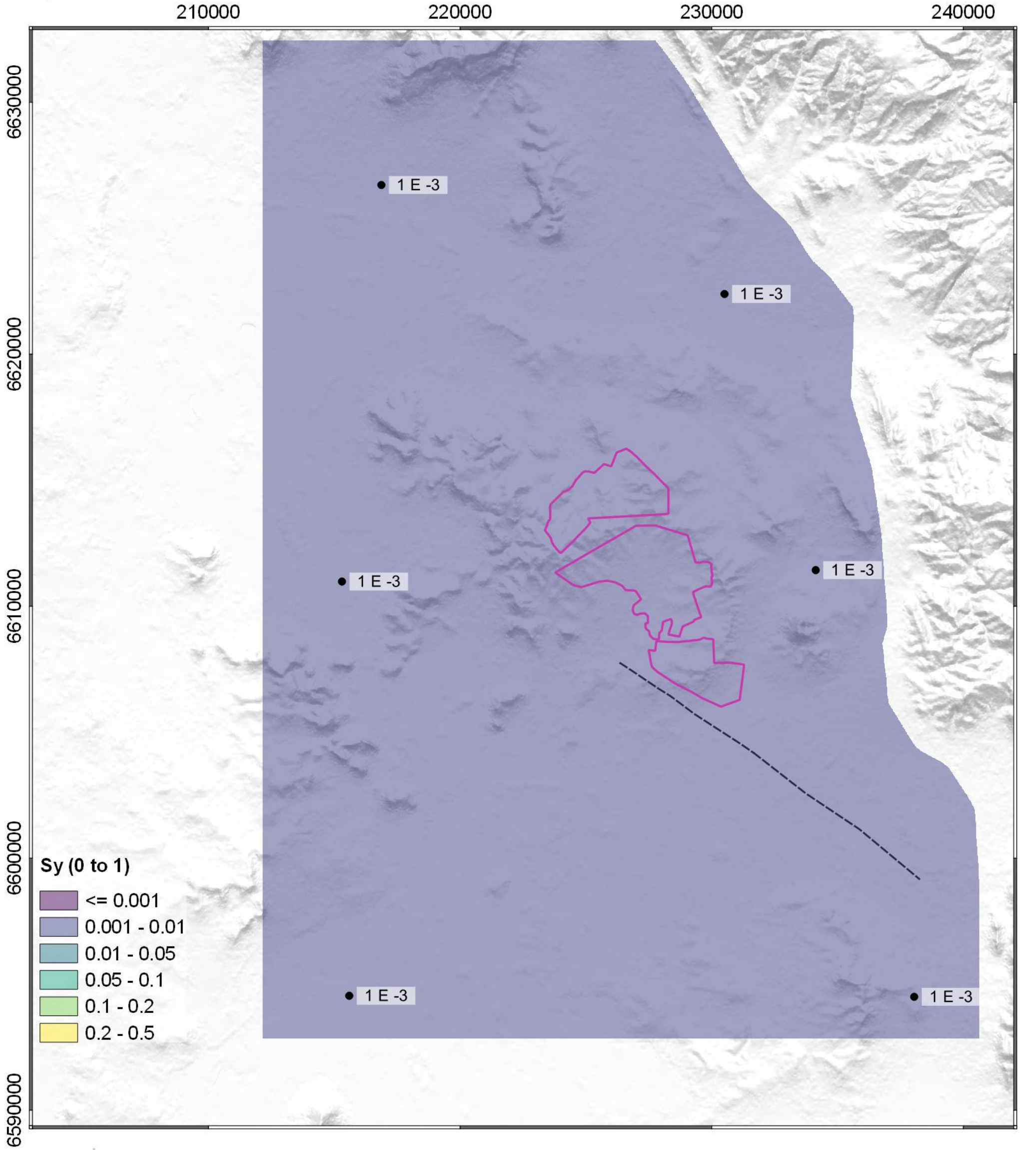
G:\Projects\G1850P.BTM model update\3_GIS\Workspaces\006_model_queries\G1850P_20210614_Hydraulic properties.qgs

Ss



Sy



LEGEND

- Pilot point (Hydraulic property)
- Conomos fault
- Mine outline

AGE

Layer 34 - Ss and Sy

DATE
15/06/2021

FIGURE No:

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