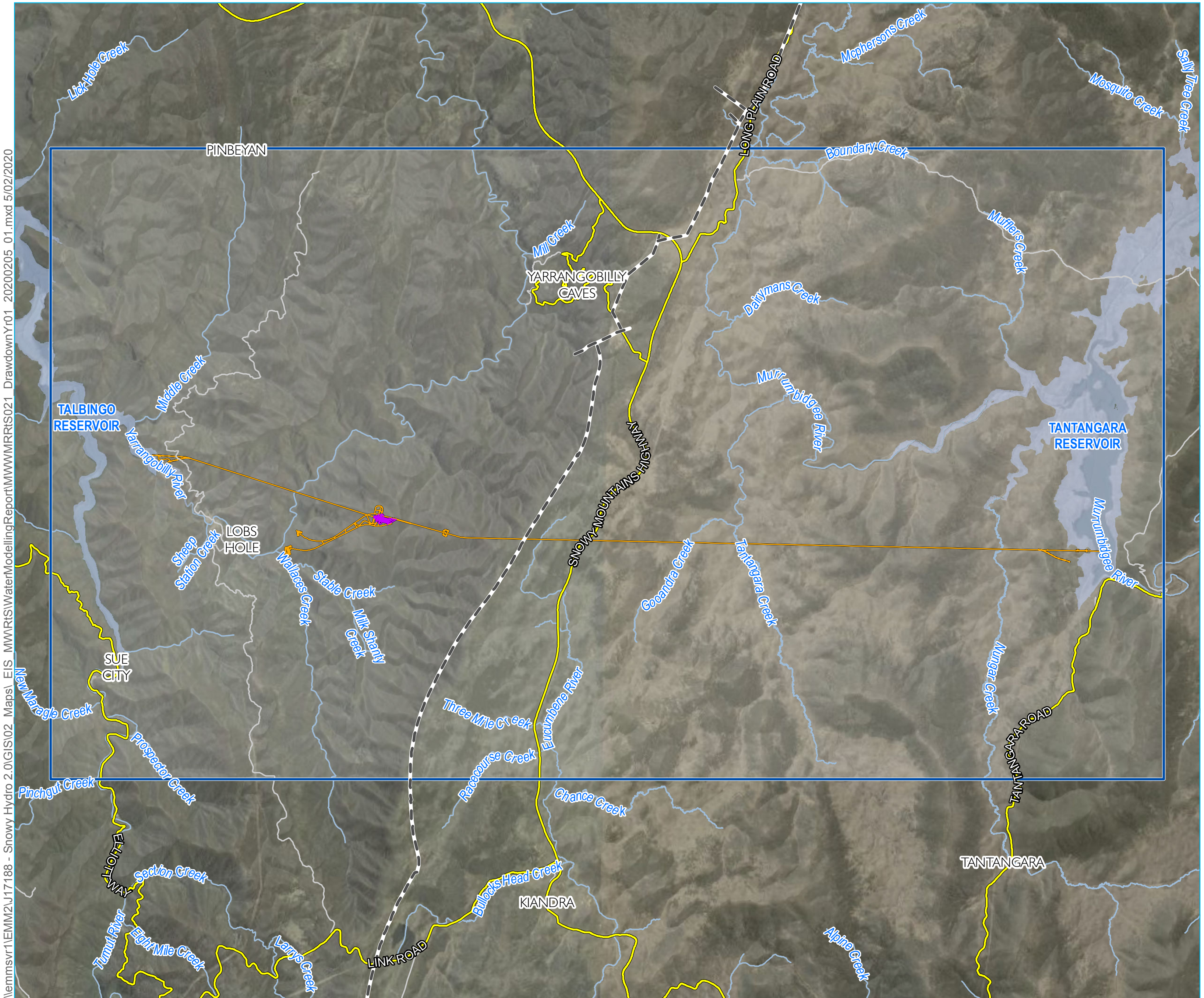


Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

0 2.5 5 km
GDA 1994 MGA Zone 55
N

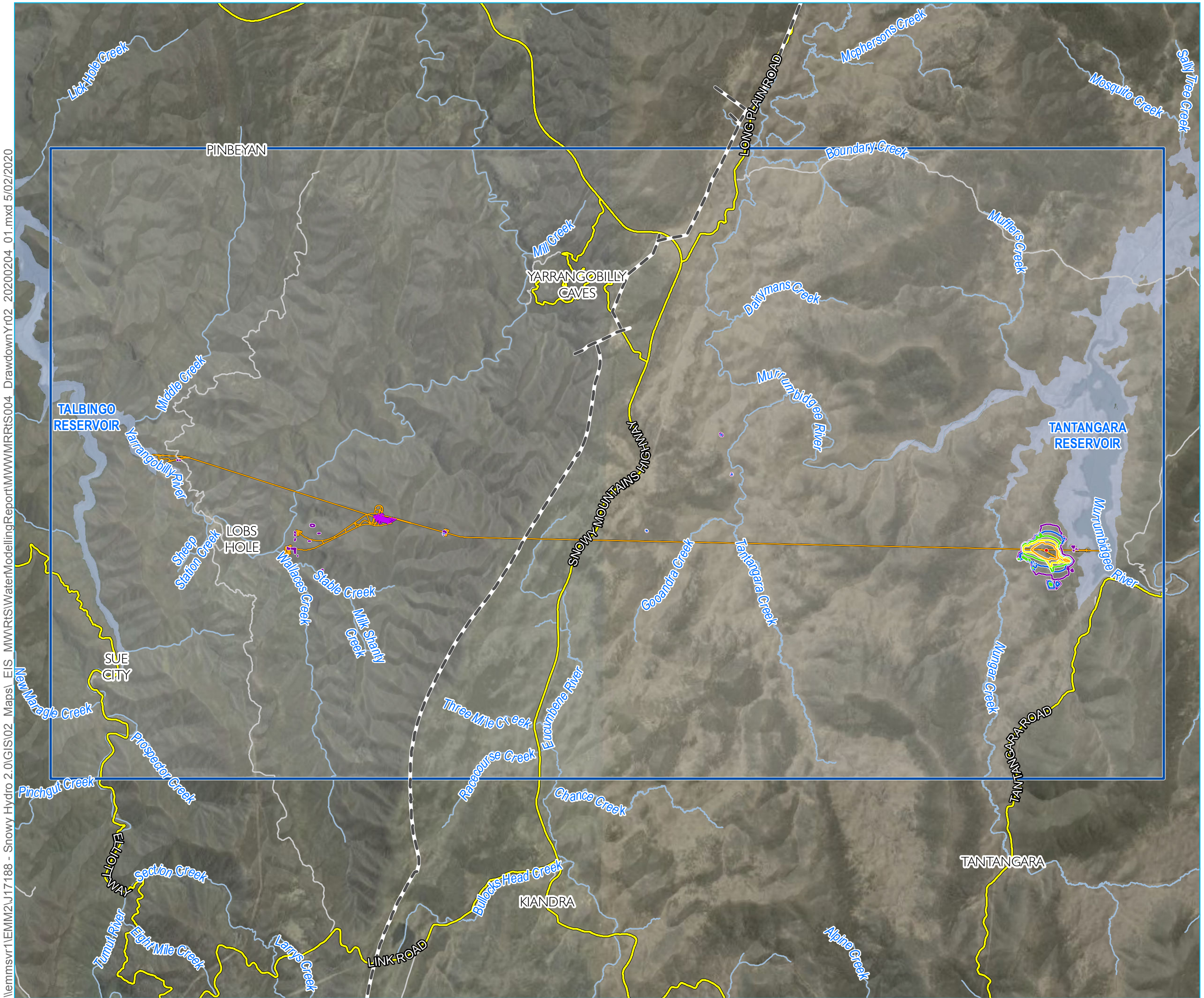
KEY

- Long Plain Fault
- Model domain
- Snowy 2.0 operational elements
  - Tunnels, portals, intakes, shafts
  - Power station
- Existing environment
  - Main road
  - Local road
  - Perennial watercourse
  - Scheme storage

Predicted base case drawdown after 1 years of construction, September 2020

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure 3.34

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWRt\SWaterModellingReport\MWWMRt\S004_DrawdownYr02_20200204_01.mxd 5/02/2020



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

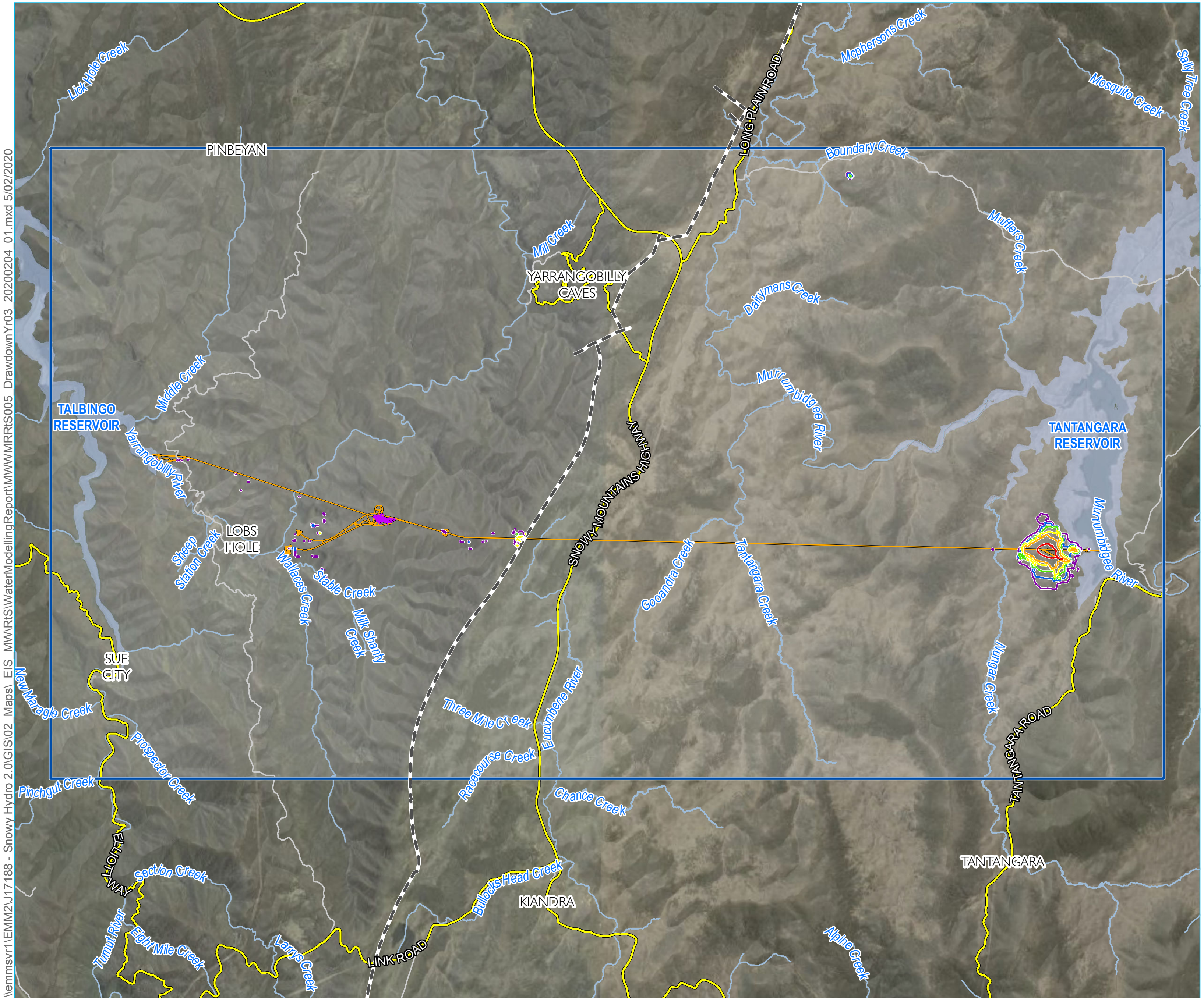
Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted base case drawdown after 2 years of construction, September 2021

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure 3.35



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

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KEY

Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

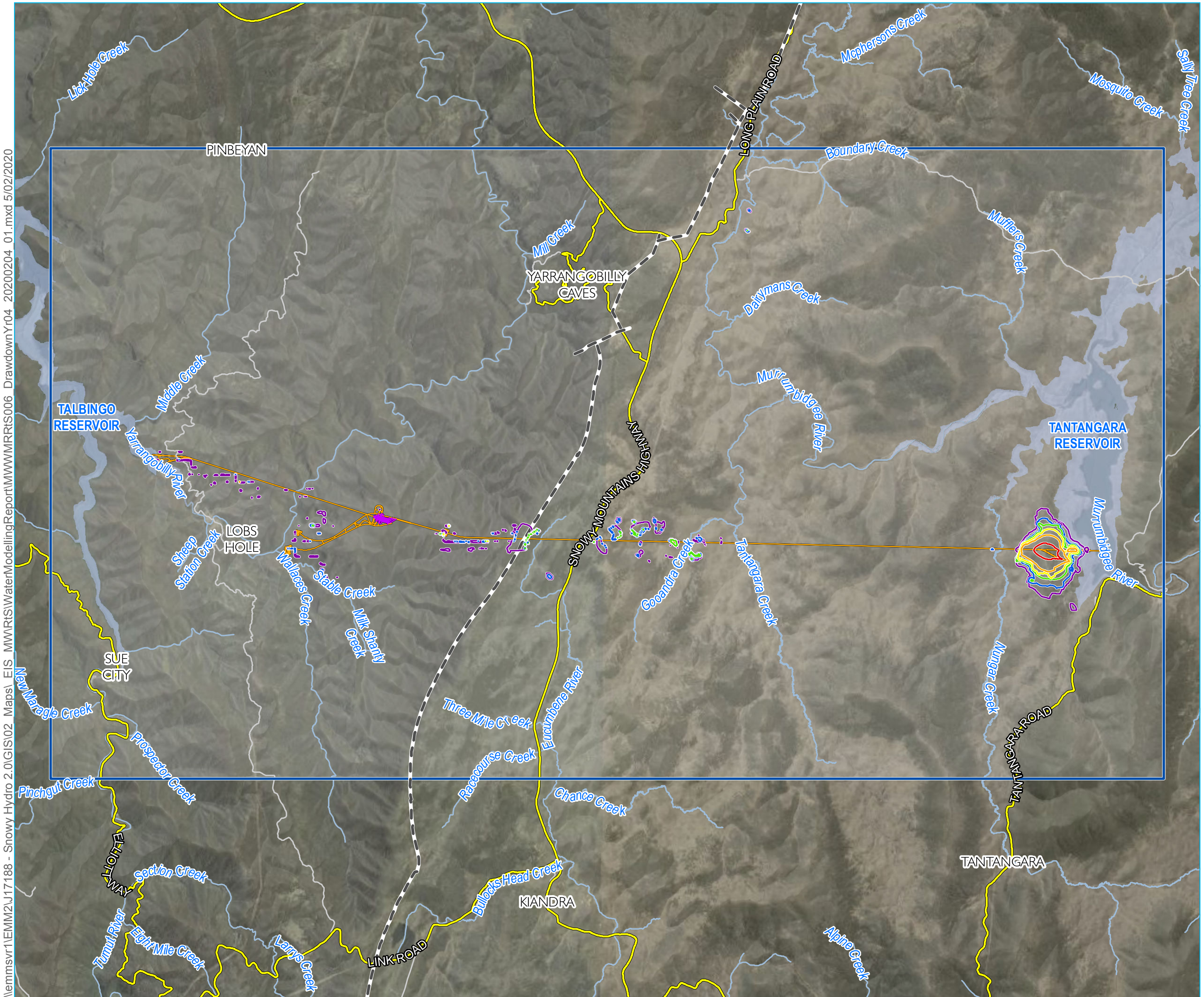
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted base case drawdown after 3 years of construction, September 2022

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure 3.36

snowy 2.0

EMM creating opportunities



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

0 2.5 5 km
GDA 1994 MGA Zone 55
N

KEY

Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

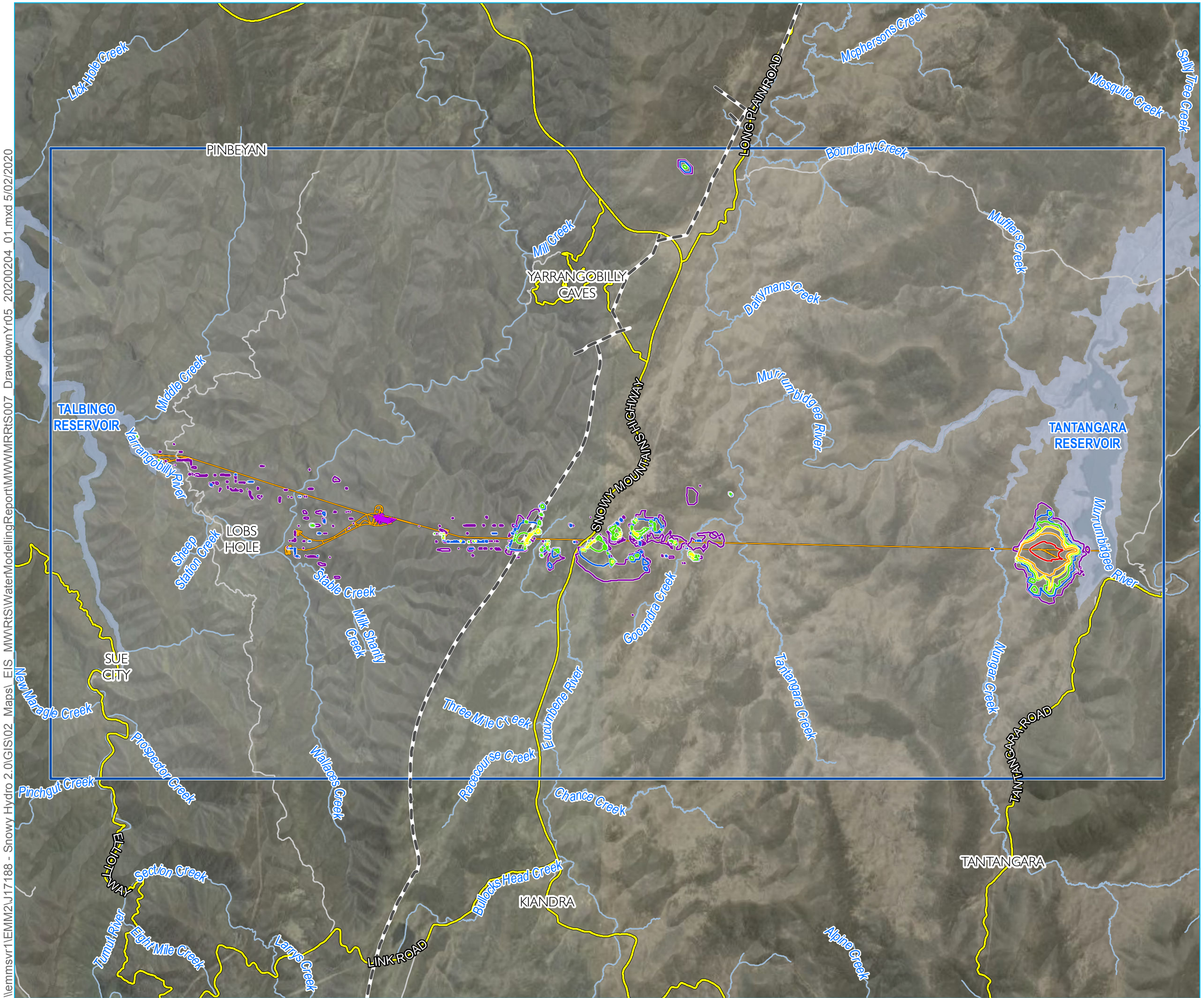
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted base case drawdown after 4 years of construction, September 2023

Snowy 2.0
Modelling report
Response to submissions
Main Works
Figure 3.37

snowy 2.0

EMM creating opportunities



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWR\tSWaterModellingReport\MWMRtS007_DrawdownYr05_20200204_01.mxd 5/02/2020

KEY

Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

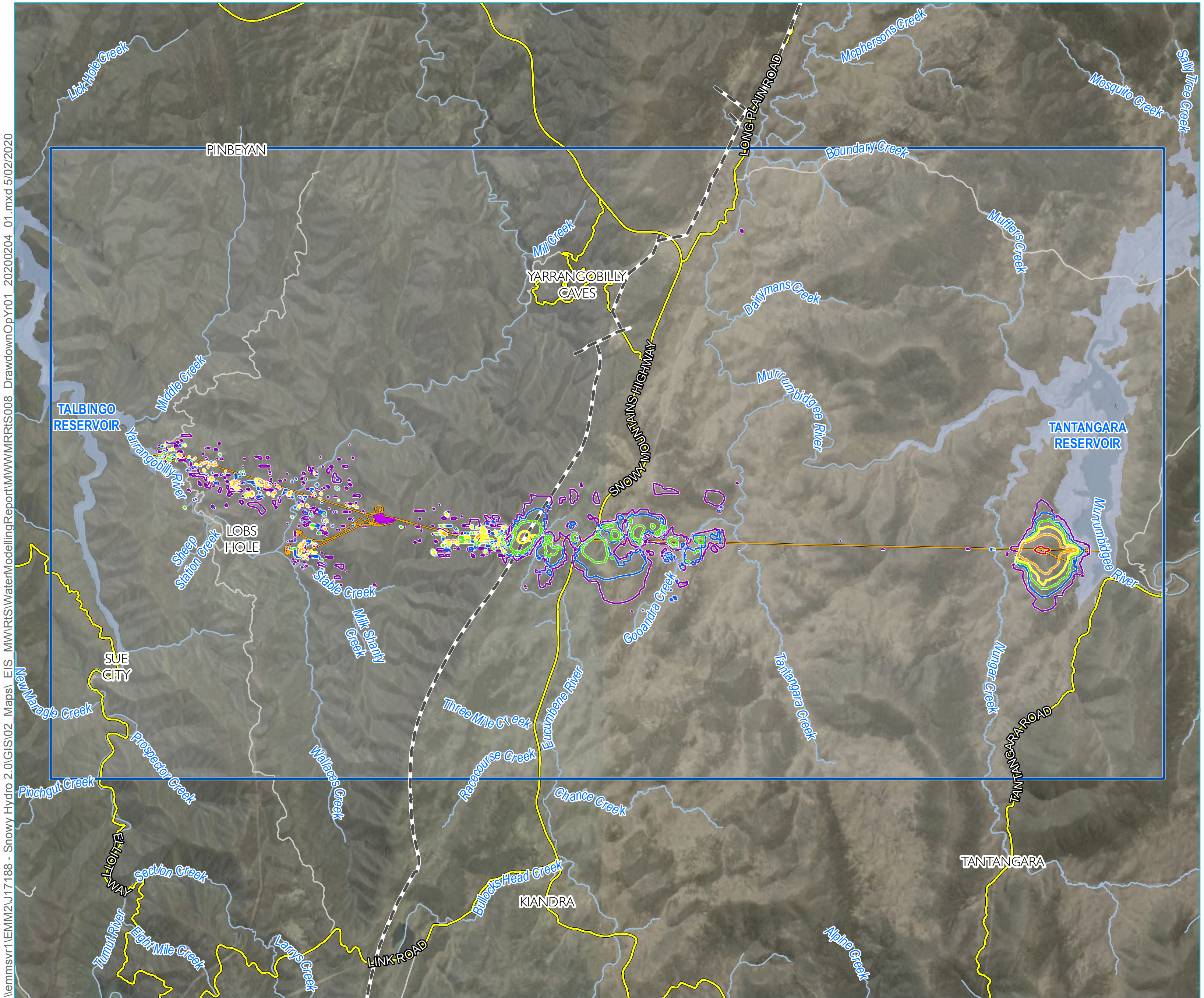
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted base case drawdown after 5 years of construction, September 2024

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure 3.38

snowy 2.0

EMM creating opportunities



KEY

Modelled drawdown (m)

- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Power station

Existing environment

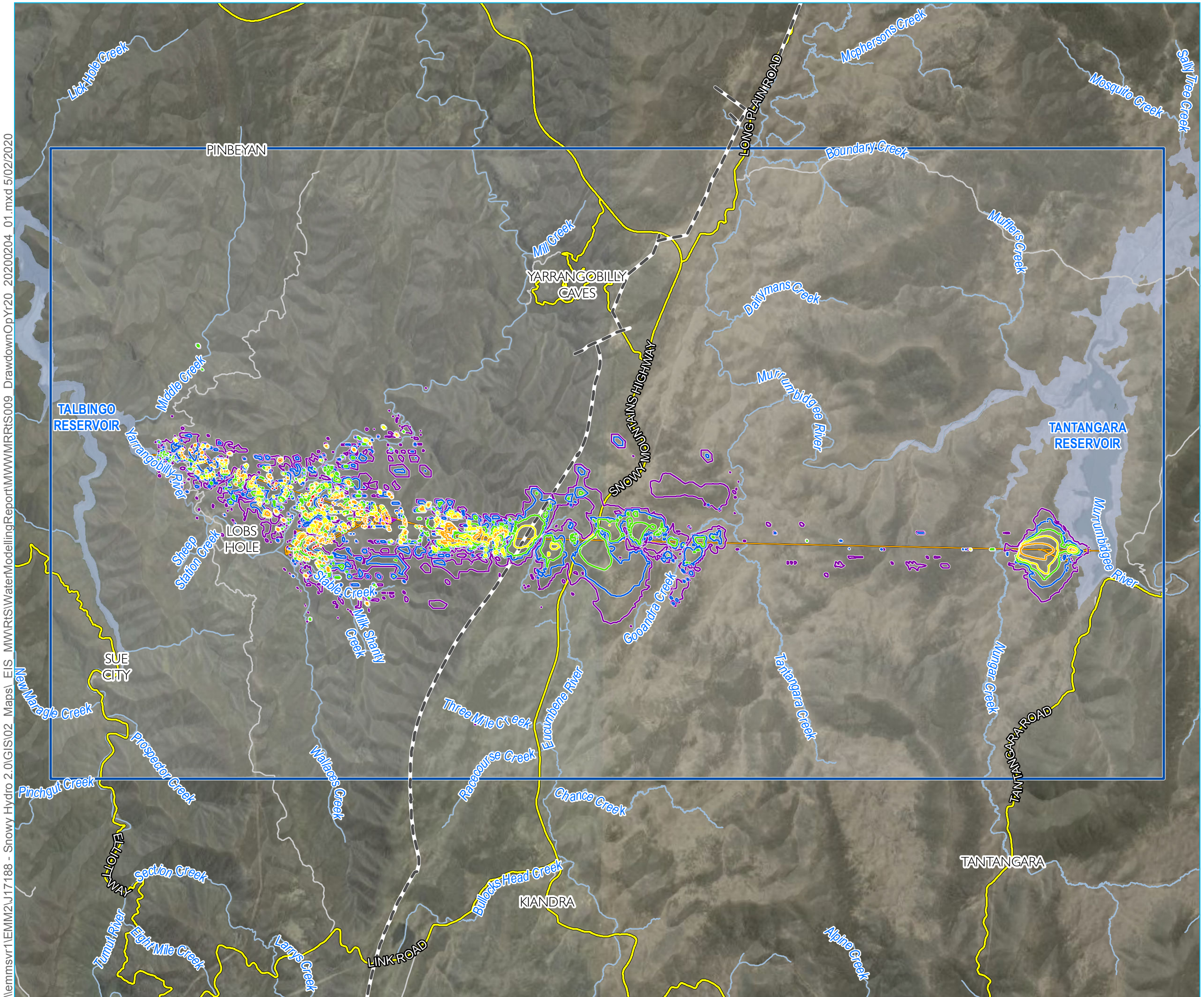
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted base case drawdown after 1 year of operation, March 2026

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure 3.39

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWWRtSWaterModellingReport\MWWMRRtS008_DrawdownOpYr01_20200204_01.mxd 5/02/2020



\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWR\RtS\WaterModellingReport\MWMRRtS009_DrawdownOpYr20_20200204_01.mxd 5/02/2020

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

0 2.5 5 km

GDA 1994 MGA Zone 55

N

KEY

Modelled drawdown (m)

- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements

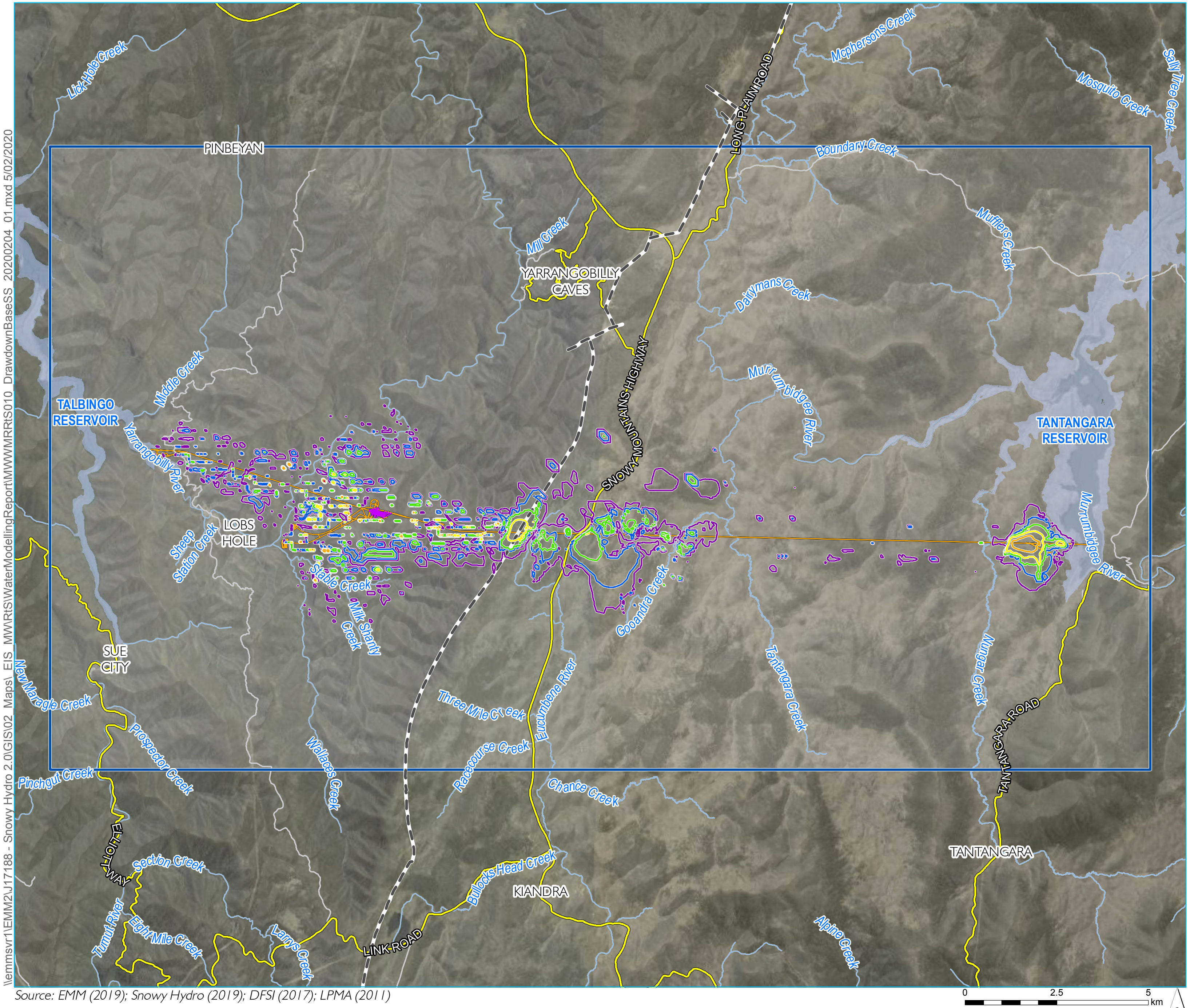
- Tunnels, portals, intakes, shafts
- Power station

Existing environment

- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted base case drawdown after 20 years of operation, March 2045

Snowy 2.0
Modelling report
Response to submissions
Main Works
Figure 3.40



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

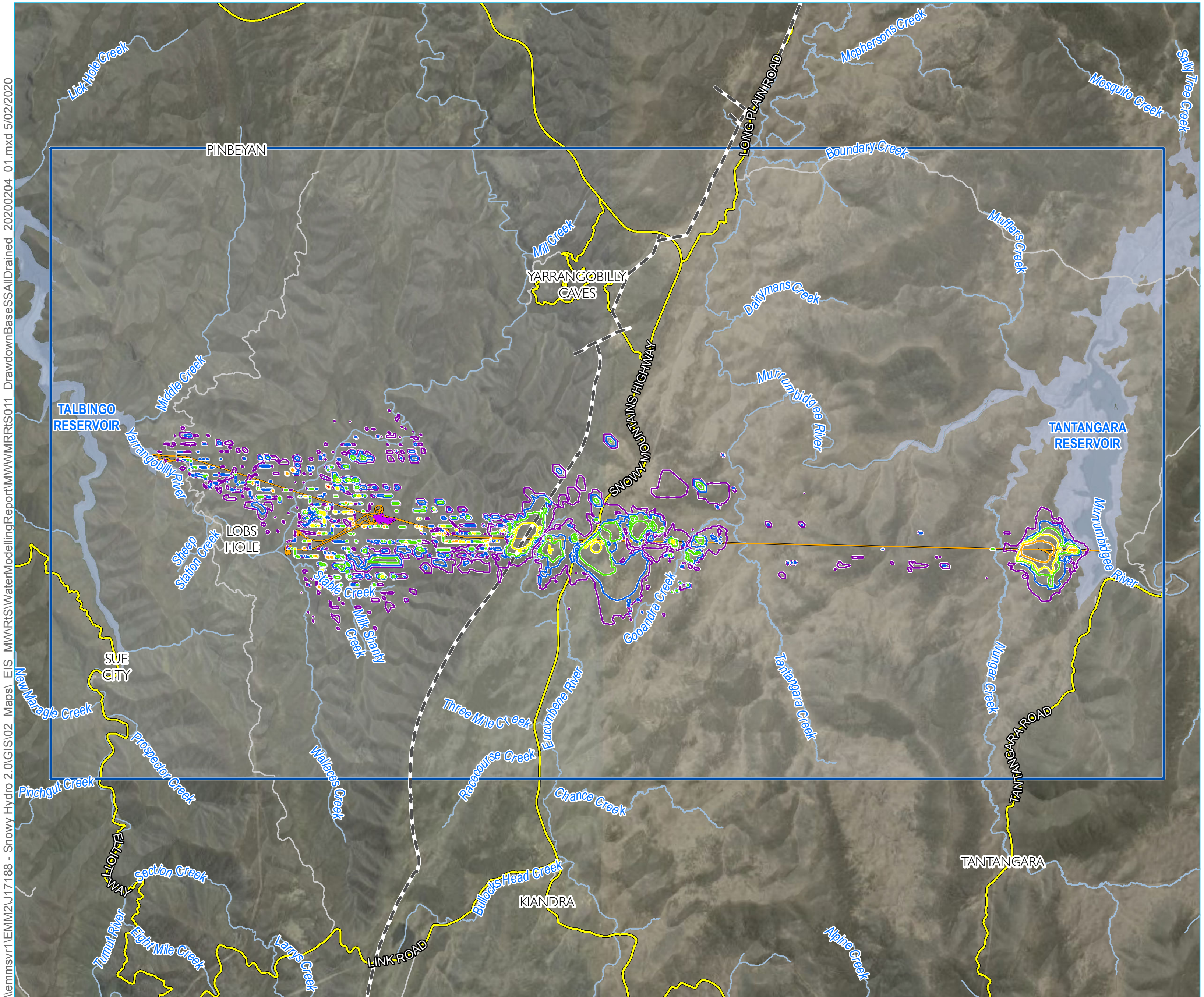
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted base case drawdown in steady state, operational

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure 3.41

snowy 2.0

EMM creating opportunities



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

0 2.5 5 km
GDA 1994 MGA Zone 55

KEY

Modelled drawdown (m)
- 0.5
- 2
- 5
- 10
- 20
- 50
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted base case drawdown in steady state, all excavations drained

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure 3.42

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWRtS\WaterModellingReport\MWMRRtS011_DrawdownBaseSSAllDrained_20200204_01.mxd 5/02/2020

3.4.3 Predictive uncertainty analysis

Predictive uncertainty associated with aquifer hydraulic properties was addressed using information from the calibration performance sensitivity analysis, results of field testing and the conceptual model. Information from these sources was used to define minimum and maximum plausible aquifer property values and river bed conductance, presented in Table 3.6 as multipliers applied to base case values. For each parameter, and river bed conductance, a steady state simulation of operational components was run, producing a total of 29 uncertainty analysis runs including the base case.

The uncertainty of predicted drawdown, associated with adopted aquifer and river properties, is presented in Figure 3.43 (0.5 m), Figure 3.44 (2 m) and Figure 3.45 (5 m).

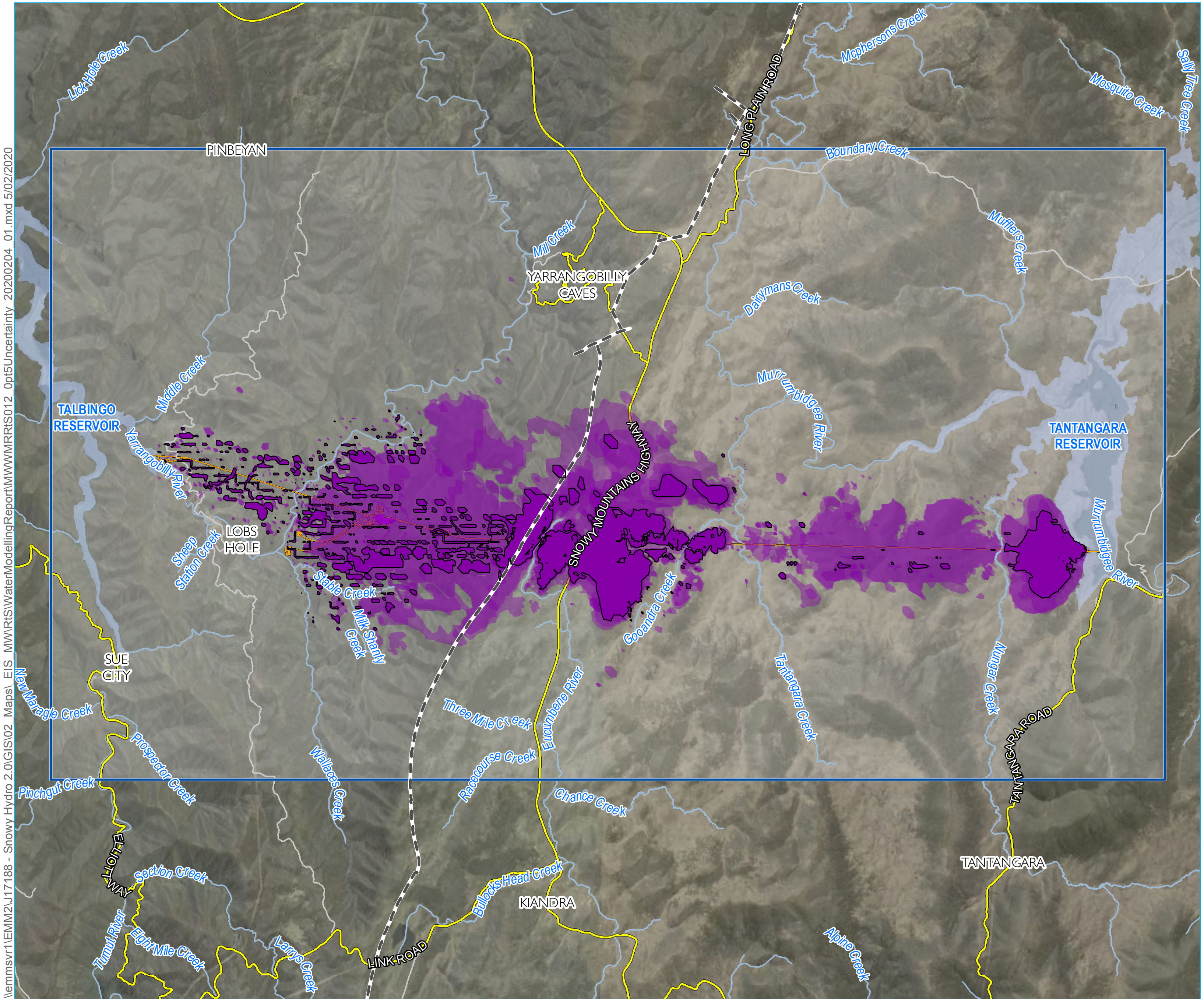
Even for the most conservative parameter values a drawdown magnitude of 0.5 m does not reach the Yarrangobilly Caves.

Whilst the range of drawdown footprints extend beyond that of the base case simulation, they do not extend much further from the project alignment than the furthest extent predicted by the base case and most of the additional drawdown is along the alignment itself.

Water balance data were not extracted for each of these runs and so the surface water model was not used to assess the possible change in streamflow due to each of these 29 runs, and the range in tunnel inflow rates has not been presented.

Table 3.6 Aquifer property uncertainty bounds

		Calibrated property				
Unit		**Kh (m/d)**	**Kv (m/d)**	**C (m^2/d)**	**Min multiplier**	**Max multiplier**
Weathered/Alluvium	WEATH	0.5	0.5	-	0.1	2
Tertiary Basalt	TBAS	0.5	0.5	-	0.1	2
Ravine Beds West	RBW	0.001	0.0001	-	0.5	2
Byron Range Group	BRG	0.0005	0.0001	-	0.5	100
Boraig Group	BOR	0.0005	0.0001	-	0.5	10
Ravine Beds East	RBE	0.0003	0.0003	-	0.5	10
Gooandra Volcanics	GOV	0.005	0.005	-	0.1	2
Shaw Hill Gabbro	SHG	0.01	0.01	-	0.01	2
Gooandra Volcanics Fractured Zone	GOVF	0.01	0.01	-	0.01	10
Temperance Formation	TPF	0.0001	0.0001	-	0.1	10
Boggy Plains Suite	BPS	0.0001	0.0001	-	0.01	20
Tantangara Formation	TTF	0.0001	0.0001	-	0.1	100
Granite/Basement	BAS	0.00001	0.00001	-	0.01	20
Kellys Plain Volcanics	KPV	0.01	0.01	-	0.05	20
Rivers		-	-	12.5-20,000	0.1	100



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

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Predicted operational 0.5 m drawdown in steady state, uncertainty due to aquifer

Snowy 2.0
Modelling report
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Main Works
Figure 3.43

snowy 2.0

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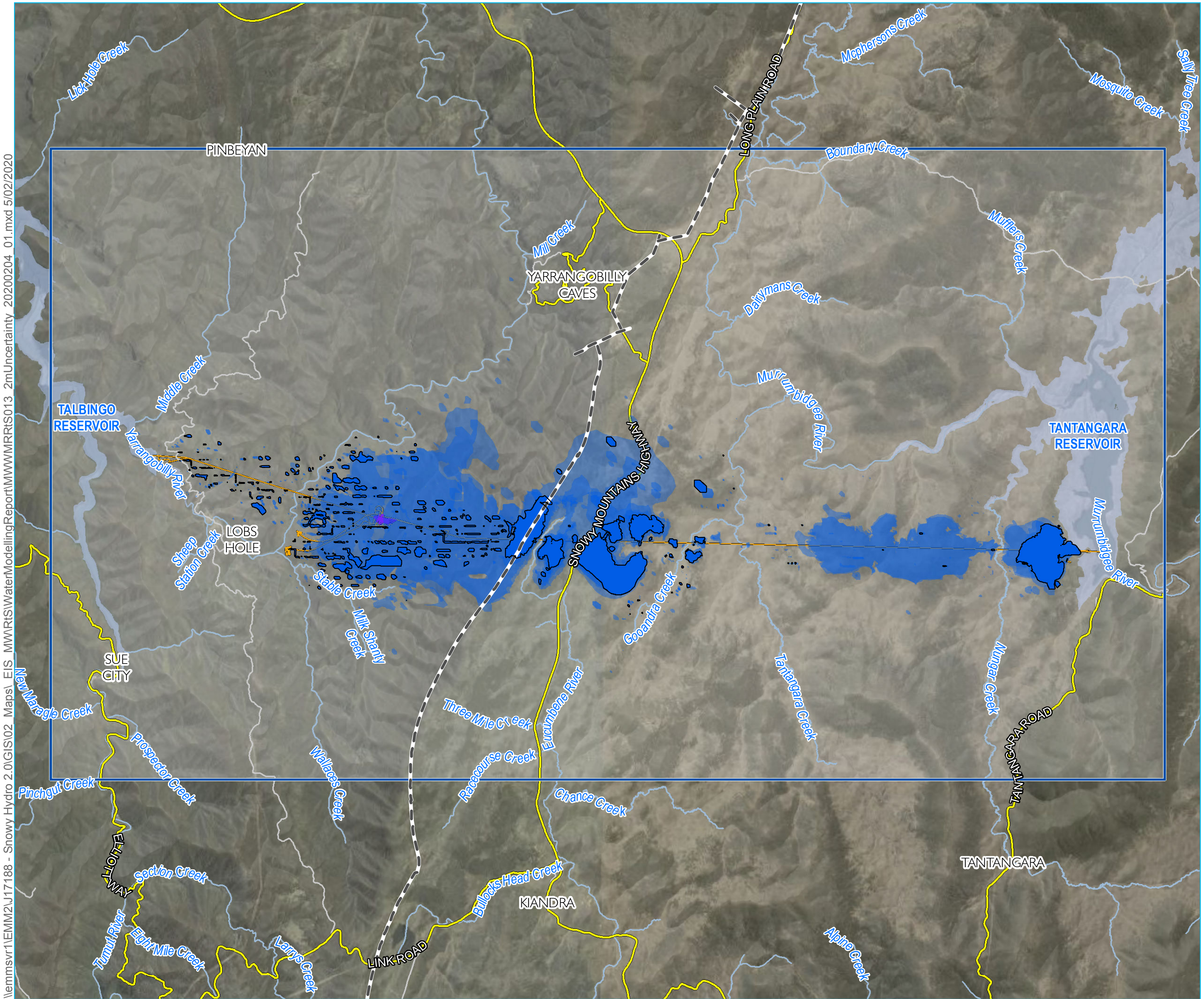
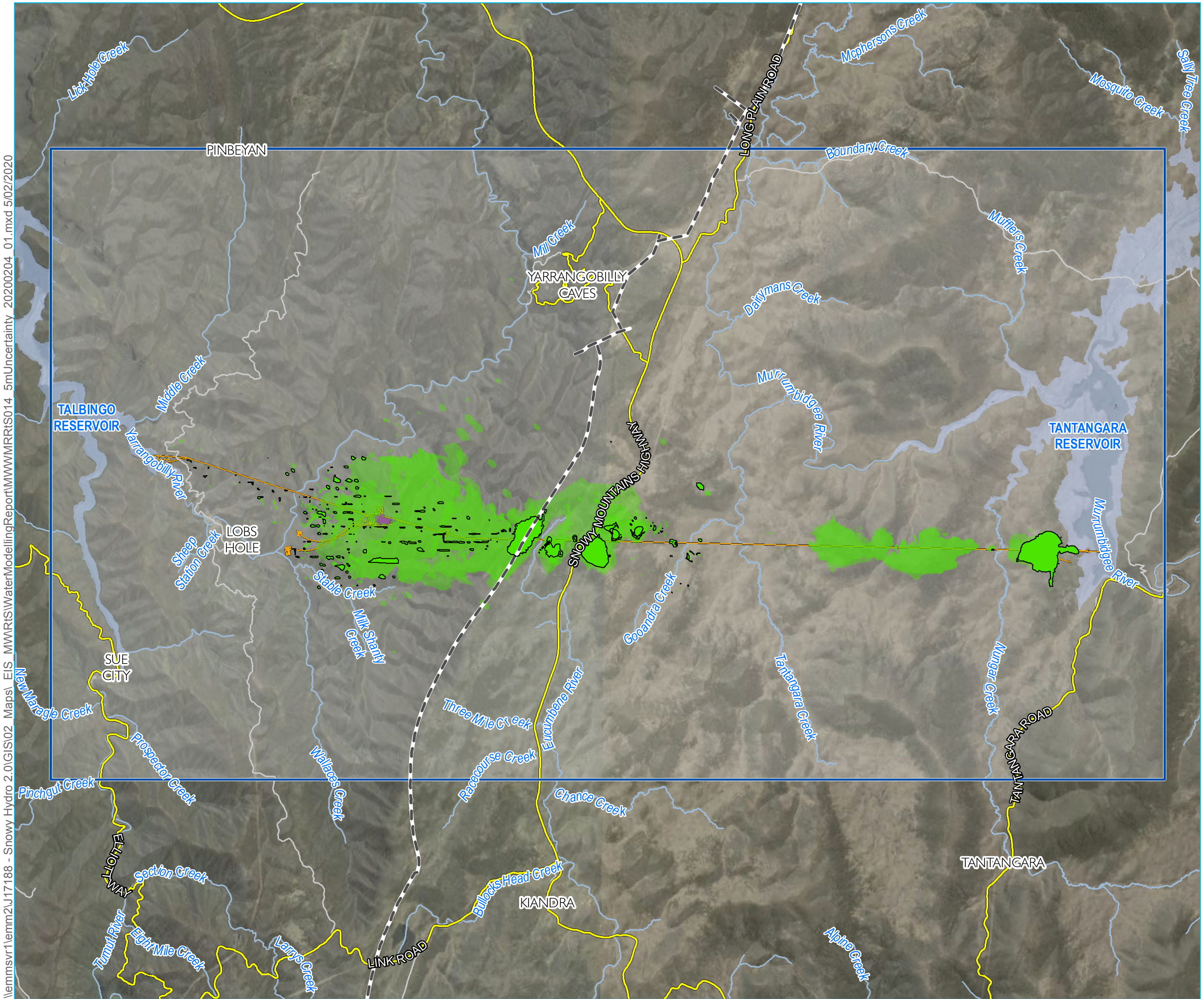


Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MW\MWRtS\WaterModellingReport\MWMRtS013_2mUncertainty_20200204_01.mxd 5/02/2020

Predicted operational 2 m drawdown in steady state, uncertainty due to aquifer

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure 3.44



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

- Base case
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Power station

Existing environment

- Main road
- Local road
- Perennial watercourse
- Scheme storage

Number of simulations

- 29
- 1

Predicted operational 5 m drawdown in steady state, uncertainty due to aquifer

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure 3.45

snowy 2.0

EMM creating opportunities

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Predicted base case groundwater hydrographs for all monitoring locations used in calibration history matching are presented in Attachment I. Figure 3.46 and Figure 3.47 present predicted base case groundwater hydrographs for selected sites across the project alignment, the same sites as those presented for the history matching period in Figure 3.16.

At BH5110, in the Boraig Group, hydraulic head is predicted to decline at all three monitoring depths during construction and operation. The site retains a downward hydraulic gradient, behaving as a recharge site, throughout the prediction.

At BH5114, in the Ravine Beds East, hydraulic head is predicted to decline at all three monitoring locations. During construction the deepest monitoring location is predicted to experience the least drawdown and, temporarily, has the highest head in a reversal of vertical gradient. During operation heads restabilise to a recharge site with downward vertical gradient but at reduced absolute head values.

BH4101, in the Gooandra Volcanics, displays a later drawdown than the previous two sites, because excavation of the underlying headrace tunnel does not occur until late in the construction schedule at this location. Drawdown equilibrates rapidly at all three depths at this site, likely due to the comparatively high hydraulic conductivity of the Gooandra Volcanics.

At BH2102, in the Tantangara Formation, construction and operation cause a reversal of the vertical gradient. What was an upward vertical gradient, supporting discharge to Nungar Creek approximately 100 m away laterally, becomes a downward gradient.

At GH01, located at Gooandra Hill above the highly permeable Gooandra Volcanics, the model predicts ongoing drawdown of around 2 m. Drawdown is predicted to stabilise within a few years of operation.

At NC01 and TC01, located near Nungar Creek and Tantangara Creek respectively, no drawdown is evident in model predictions.

Hypothetical monitoring points, spaced every 2 km along the project alignment (see Figure 3.48) and at various depths, were employed in the model to extract predicted hydraulic head profiles with depth. The resulting head profiles, at several times prior to construction, during construction and during operation, are presented in Figure 3.49 and Figure 3.50. Most sites experience little to no drawdown at the watertable but large drawdown at the tunnel depth during construction and operation. The large vertical gradients that develop at most sites are a result of the generally low hydraulic conductivity modelled (and measured) in the project area.

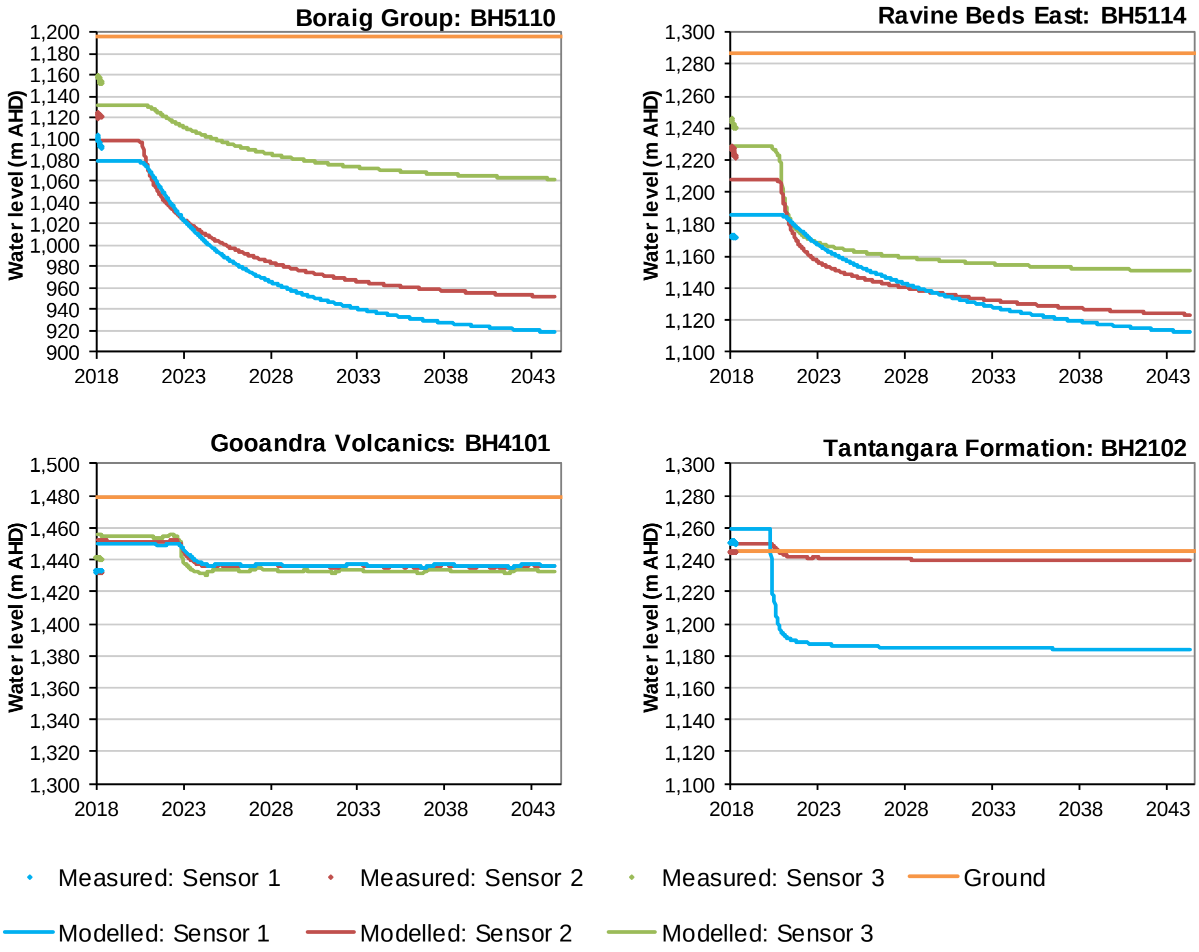


Figure 3.46 Selected predicted groundwater hydrographs

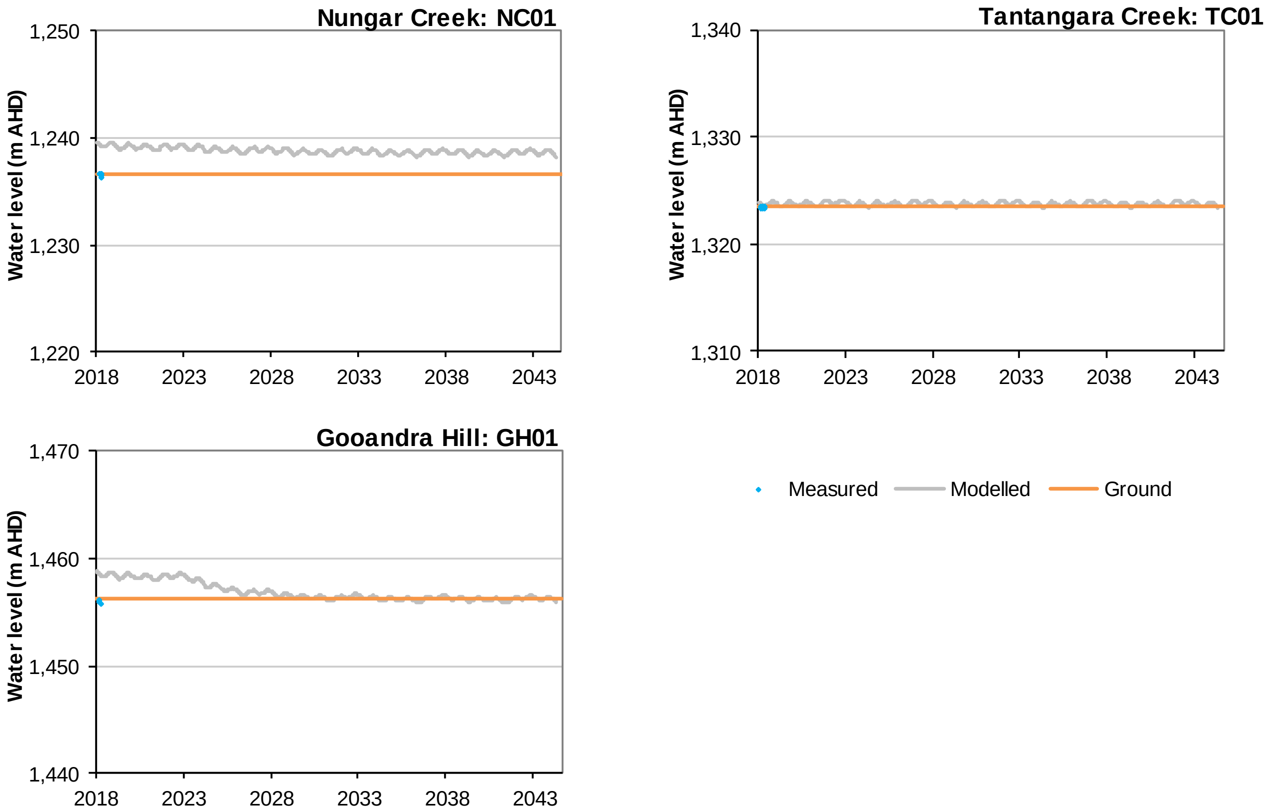
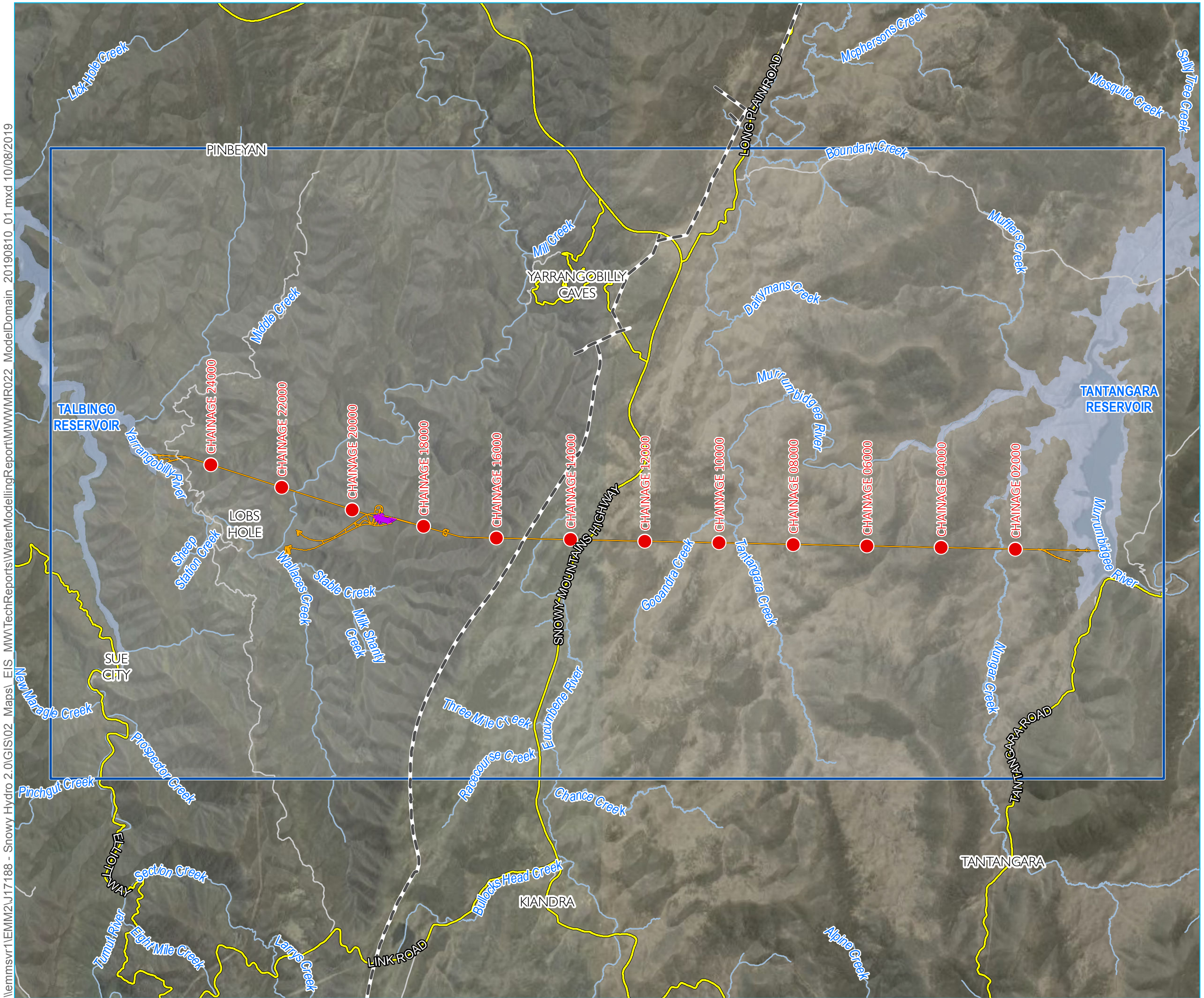


Figure 3.47 Selected predicted groundwater hydrographs for weathered / alluvial material



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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

- Hydraulic head monitoring location
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Power station

Existing environment

- Main road
- Local road
- Perennial watercourse
- Scheme storage

Hydraulic head monitoring locations along project alignment

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Figure 3.48

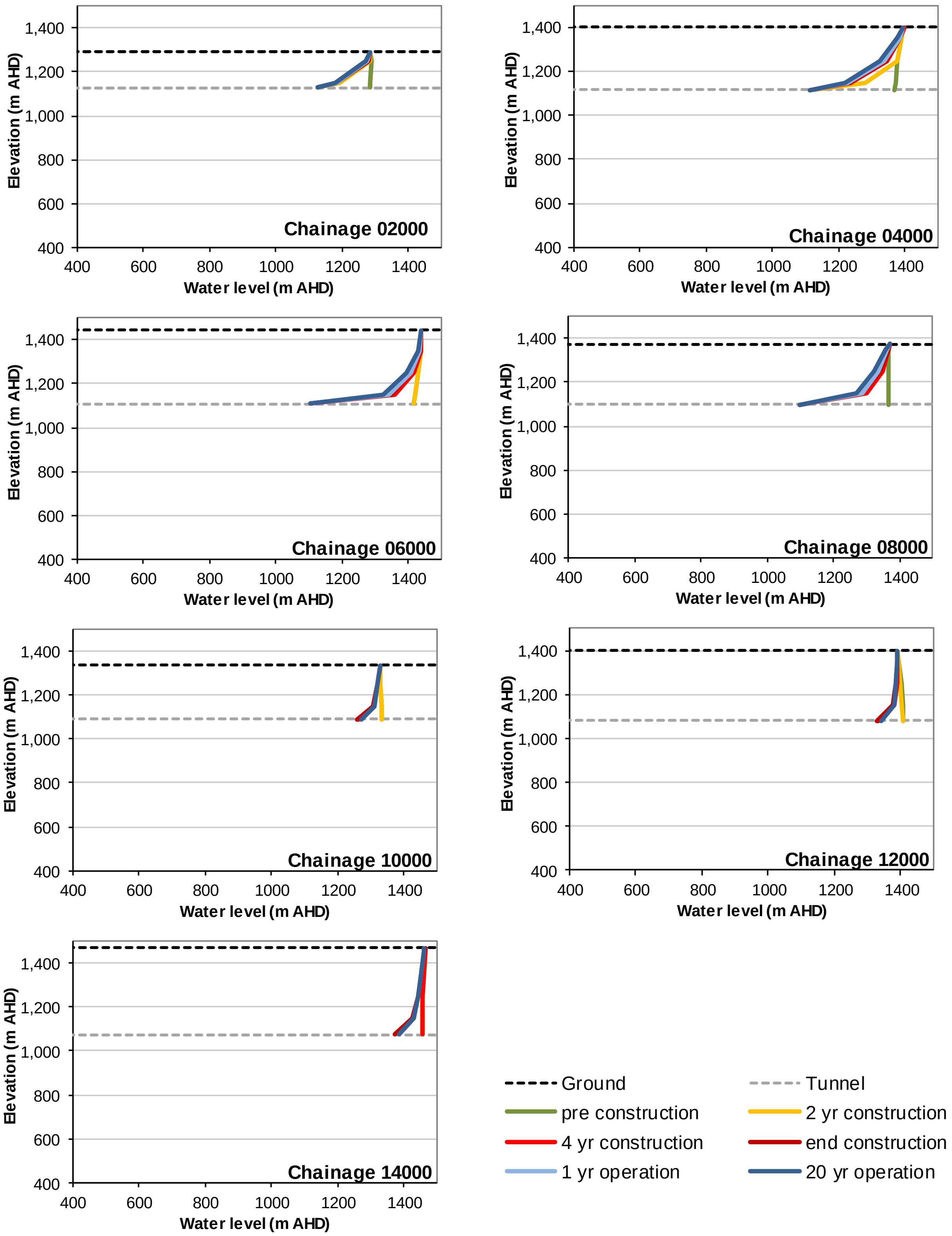

Figure 3.49 Predicted hydraulic head profiles along project chainage

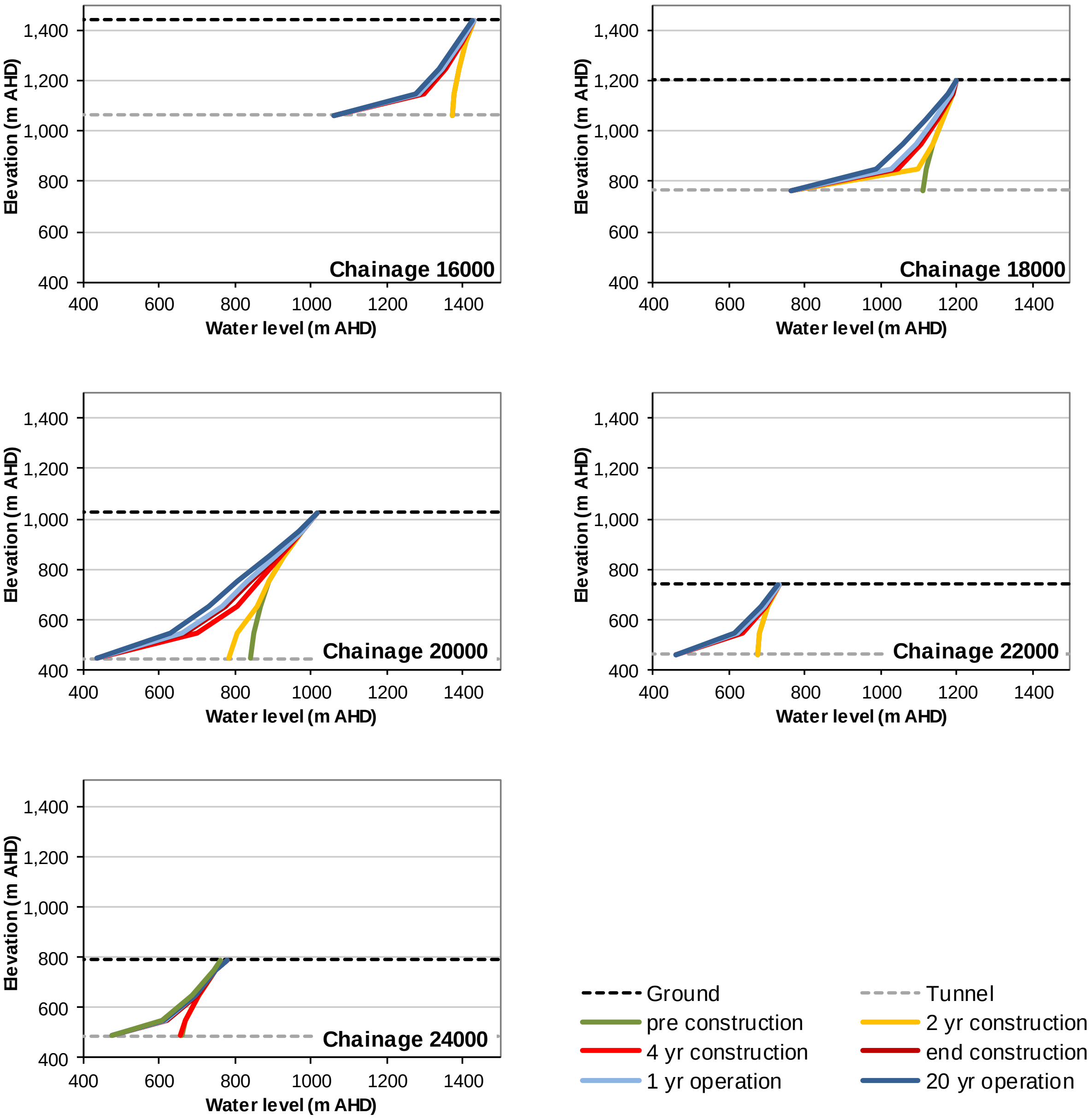

Figure 3.50 Predicted hydraulic head profiles along project chainage (cont.)

3.4.4 Predicted water balance

Figure 3.51 presents the modelled transient water balance, averaged over quarterly stress periods for the modelled construction and operation periods. The flow rates presented are for the entire 30 km by 17 km model domain. On this scale, as for the transient history matching period, the largest inflow component is recharge from rainfall, which is balanced primarily by distributed baseflow/evapotranspiration and, to a lesser degree, discharge as direct baseflow to modelled surface water features. Movement of water into and out of storage buffers the seasonality of climate stresses. The water balance components associated with construction and operation of Snowy 2.0 are almost undetectable on this regional scale, despite the evident drawdown impacts predicted at construction depths and at the watertable.

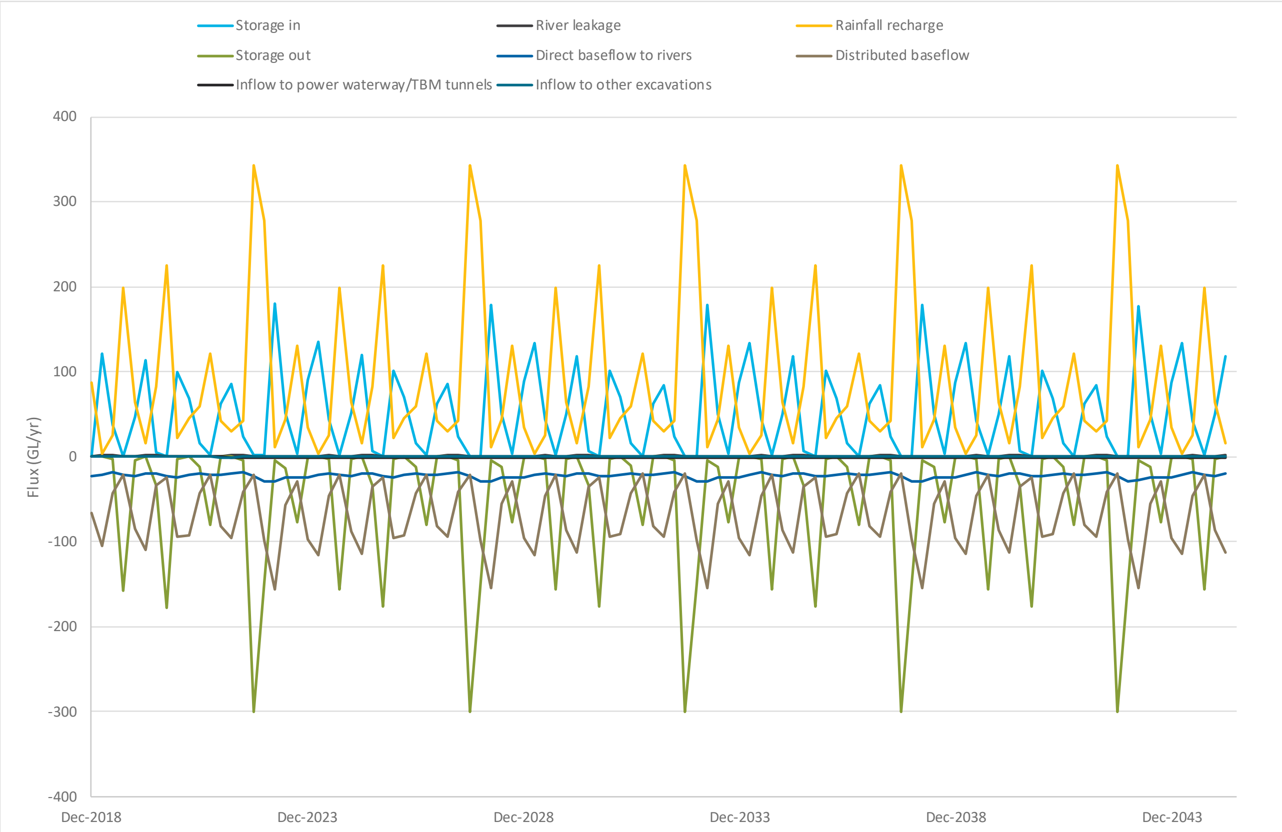

Figure 3.51 Modelled transient base case water balance

i Inflow to excavations

Predicted flows to excavation components over the construction and operation periods are presented in Figure **3.52**. By far the greatest inflows, peaking at 50 L/s in the quarter ending 1 March 2024, occur in the head race tunnel. This is the longest project component and, also, is excavated through the two deep rock units with the highest modelled hydraulic conductivity; the Kellys Plain Volcanics and the Gooandra Volcanics (and associated Gooandra Volcanics fractured zone and Shaw Hill Gabbro). Long term inflow to the headrace tunnel is predicted to reduce during operation and stabilise at around 35 L/s.

Total inflow to all excavated components peaks at 62 L/s and reduces to around 45 L/s.

The uncertainty in tunnel inflows associated with climate during the construction period was investigated using average (1 December 2012 to 1 December 2017), wet (1 December 1988 to 1 December 1993) and dry (1 December 2001 to 1 December 2006) climate sequences. The peak inflows varied from 61 L/s with the dry climate to 66 L/s with the wet climate sequence (Figure 3.53).

Table 3.7 presents annualised inflows to excavations. Annual volumes are reported for years ending 1 June, in line with the seasonal stress periods employed by the model. On an annual basis, groundwater inflows to excavations peak at 1,874 ML, 1,952 ML and 1,835 ML for the average, wet and dry climate scenarios.

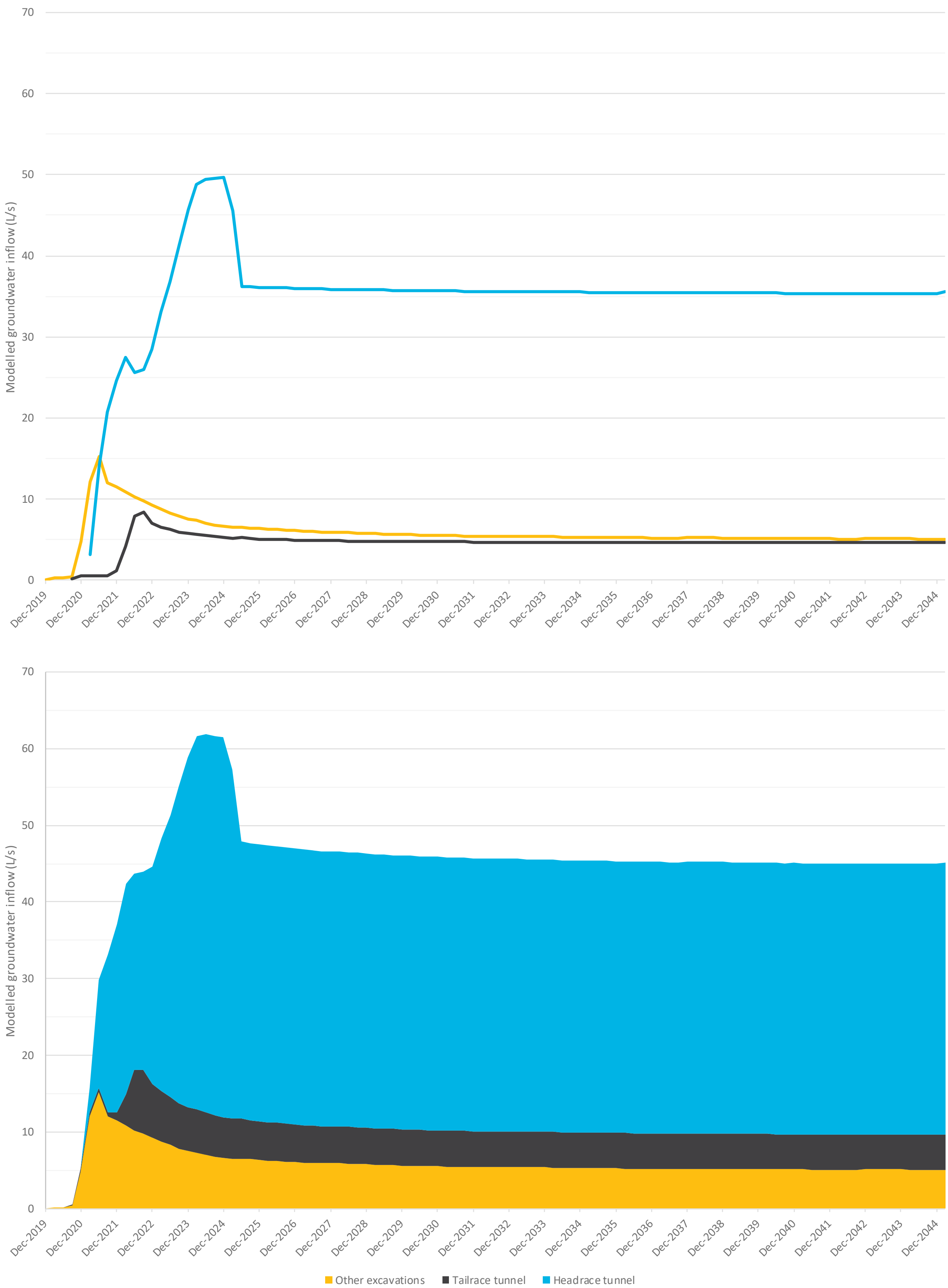

Figure 3.52 Predicted inflow to excavations during construction and operation

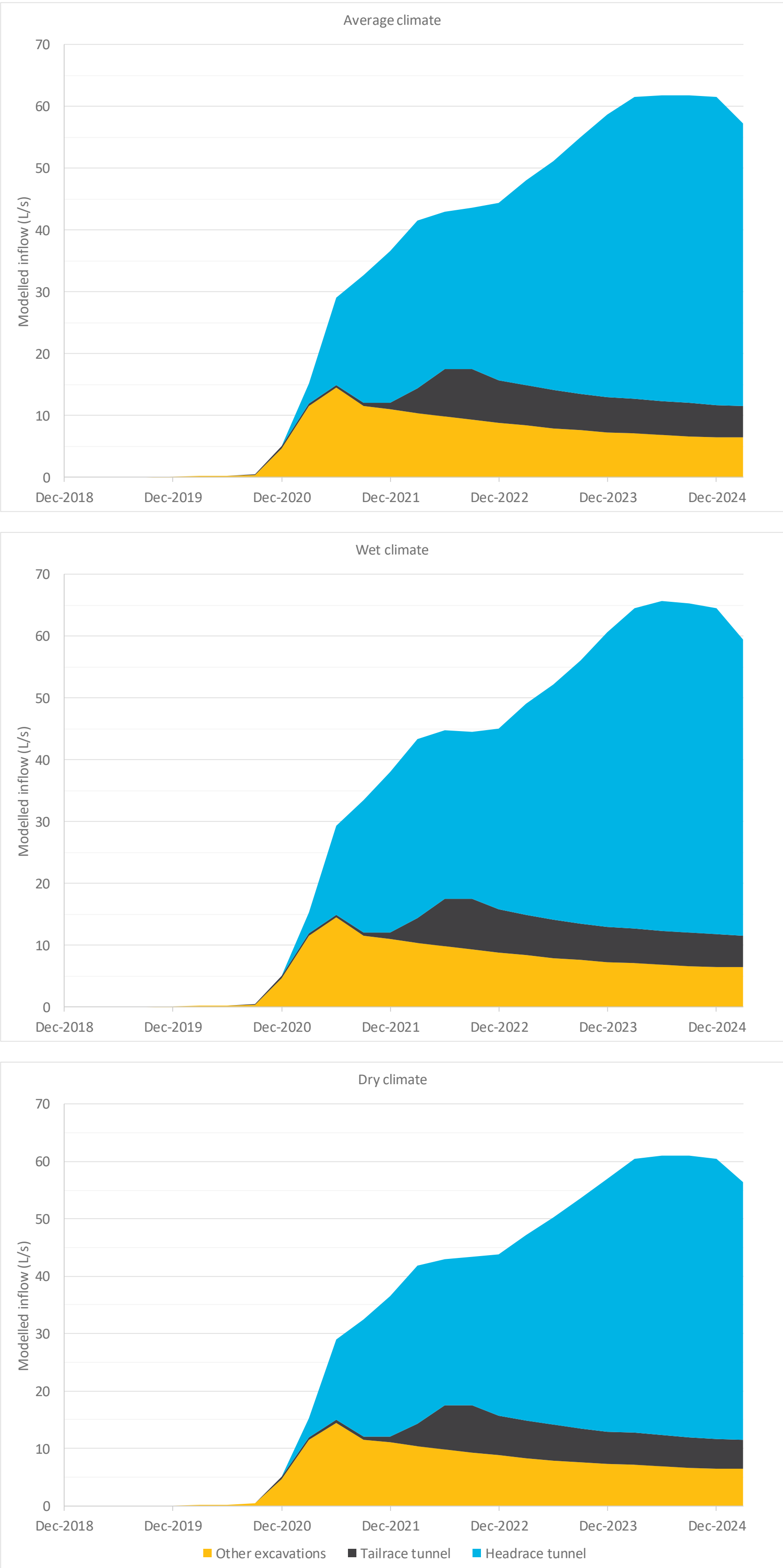

Figure 3.53 Predicted inflow to excavations during construction

Table 3.7 Predicted annual inflows to excavations for average, wet and dry climates

		Dry climate	Wet climate	Average climate
Project phase	**Year Ending**	**Inflow to excavations (ML)**	**Inflow to excavations (ML)**	**Inflow to excavations (ML)**
Construction	1-Jun-19	0	0	0
	1-Jun-20	3	3	3
	1-Jun-21	392	395	393
	1-Jun-22	1212	1259	1212
	1-Jun-23	1456	1503	1475
	1-Jun-24	1835	1952	1874
	1-Jun-25	1398*	1488*	1800
Operation	1-Jun-26			1496
	1-Jun-27			1479
	1-Jun-28			1473
	1-Jun-29			1460
	1-Jun-30			1452
	1-Jun-31			1446
	1-Jun-32			1445
	1-Jun-33			1439
	1-Jun-34			1436
	1-Jun-35			1432
	1-Jun-36			1433
	1-Jun-37			1427
	1-Jun-38			1426
	1-Jun-39			1425
	1-Jun-40			1426
	1-Jun-41			1421
	1-Jun-42			1419
	1-Jun-43			1420
	1-Jun-44			1423
	1-Mar-45			1060^
	Steady State			1407

* Simulation ends 1 March 2025 and volume is for previous 9 months only
^ Simulation ends 1 March 2045 and volume is for previous 9 months only

ii Changes to baseflow

The groundwater model predicted that localised baseflow discharges to creeks and rivers would be seen in the catchments upstream of Tantangara Reservoir, Lake Eucumbene, and Talbingo Reservoir (Figure 3.54 and Table 3.8). While inflows to the excavations are predicted to peak in the final year of construction (Figure 3.52), impacts to baseflow are predicted to develop more slowly, with peak impacts occurring several decades after the completion of construction (Figure 3.54). The total steady state reduction in baseflow is approximately equivalent to the tunnel inflow volume, as expected based on the whole of catchment water balance (Figure 1.3); inflows to the tunnel are directly offset by reduction in baseflow, with a time lag as the impact propagates to the surface.

A detailed breakdown of predicted baseflow discharge rates is included in Attachment J.

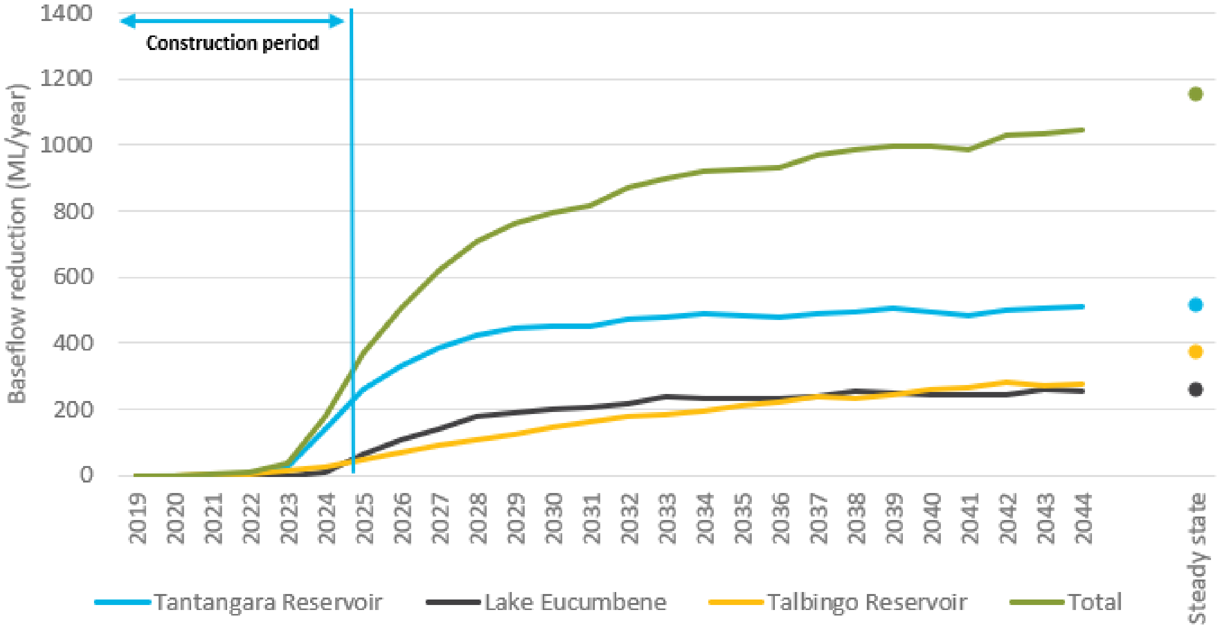

Figure 3.54 Predicted transient baseflow reduction by reservoir catchment

Table 3.8 Predicted steady state (long term) baseflow impacts

Receiving Waterbody	Catchment	Baseflow Reduction (ML/yr)	Total (ML/yr)
Tantangara Reservoir	Murrumbidgee River (including Gooandra Creek and Tantangara Creek)	477	**518**
	Nungar Creek	41	
Lake Eucumbene	Eucumbene River	258	**258**
Talbingo Reservoir	Yarrangobilly River (including Wallaces Creek and Stable Creek)	372	**375**
	Middle Creek	3	
Total			**1,151**

3.5 Summary, model limitations and recommendations

The SH4.0 model has been constructed, calibrated and used to predict watertable drawdown, inflows to excavations and associated changes to components of the water balance, particularly baseflow to rivers and creeks.

The model was designed to provide regional-scale predictions of potential impacts associated with Snowy 2.0 subsurface excavations and operation in accordance with the NSW Aquifer Interference Policy (DPI Water 2012). The model is not intended to provide absolute predictions of heads or flows on localised scales or at local features.

The SH4.0 numerical groundwater flow model was not designed to explicitly simulate soil water, surface water or perched groundwater nor water quality/solute transport.

For the purposes of modelling groundwater, a conservative approach of simulating all excavations as lined but unmitigated (ie no pre- or post-grouting of areas with elevated inflows) was adopted. The majority of the intercepted geological units have very low hydraulic conductivity values, and hence are predicted to contribute minimal relative inflow. However, the hydraulic properties for the Gooandra Volcanics and the Kellys Plain Volcanics are two orders of magnitude higher than adjacent geological units in the area.

The model predictions are considered conservative due to the design scenario assumptions (lined but unmitigated) and the adoption of conservative hydraulic parameters (as per field measurements). Therefore, it is considered that the actual inflow (and subsequent impacts) will be lower than predicted due to mitigation and management measures committed to during construction (ie pre-grouting and post-grouting).

Groundwater flow into the tunnel is expected to occur primarily as a function of secondary porosity (ie via fractures and along bedding planes). The groundwater model assumes significant connection between the tunnel and the watertable in the Gooandra Volcanics and the Kellys Plain Volcanics due to the hydraulic testing undertaken throughout the unit. It is possible that additional field testing may reveal that locations with vertical connection occur only in isolated locations.

The model cannot simulate individual fractures because the locations and conductivity of individual fractures will not be known until the tunnel intersects them. Because the exact locations and extent of inflow mitigation strategies are not yet known, the groundwater modelling adopted a conservative approach of simulating all excavations as non-mitigated/controlled. The modelling results are therefore conservative for two reasons:

- modelling does not consider mitigating activities:

- conservative as during construction the discrete fractures that yield excess water will be grouted and will reduce the actual overall tunnel inflow volume;

- hydraulic parameter values adopted in the numerical model for the Gooandra Volcanics and the Kellys Plain Volcanics assume significant connection to the watertable based on limited pumping test data:

  - potentially conservative as the entirety of the Gooandra Volcanics and the Kellys Plain Volcanics may not behave like this, with some parts being less permeable or less connected.

Therefore, the model predictions of tunnel inflow, baseflow reduction and watertable drawdown are likely to be over estimating project impacts. The results of this conservative model approach need to be considered within this overall context to accurately assess the project on its true merits for impacts to water resources.

Uncertainty analysis was conducted by adopting the maximum and minimum plausible parameter values for the modelled hydrostratigraphic units. It is very unlikely that the maximum bounds adopted for hydraulic conductivity apply on a regional scale. Therefore, the regional drawdown predictions are expected to be upper limits. Predictive uncertainty analysis for hydraulic properties of the groundwater system was conducted only in steady state due to the computational demands of the transient simulations. However, steady state predictions provide an appropriate assessment of long-term regional-scale impacts on the groundwater system.

Climate change has not been addressed in this study, although climate variability during construction was simulated. This indicated that short term variability in climate impacts primarily on near-surface components of the water balance and has only a minor impact (approximately 5%) on total groundwater inflows to underground excavations.

The SH4.0 model (and linked surface water model) should be kept as a live groundwater management tool. It should be validated and, if necessary, recalibrated to new groundwater monitoring data as the monitoring record increases. Of particular benefit will be measured groundwater responses to the commencement of excavations. Dewatering of excavations provides a much greater stress on the groundwater system, to which history matching can be conducted, than climate-driven stresses. It is recommended than assessment of the monitoring record and groundwater affecting activities, along with model updates, be undertaken at least annually as the Exploratory Works commence, through construction of Main Works and into operation until it is evident that the update frequency can be reduced.

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Attachment A

Peer review of modelling

SNOWY 2.0 MODELLING
PEER REVIEW

Prepared for:	EMM Consulting	28 August 2019

HydroGeoLogic

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Author	Hugh Middlemis	
Version 1	26 August 2019	Initial draft
Version 2	28 August 2019	Updated to include commentary on catchment modelling

THIS REPORT SHOULD BE CITED/ATTRIBUTED AS:

Middlemis H (2019). Snowy 2.0 Modelling Peer Review. Prepared by HydroGeoLogic for EMM Consulting. 28 August 2019.

1. Summary

The report documents the outcomes of a peer review of the Snowy 2.0 project numerical groundwater model (SH4 version), and the related surface water catchment model, developed by EMM Consulting for Snowy Hydro.

This review has a focus on the groundwater modelling that forms the quantitative basis of the groundwater assessment, rather than being a comprehensive hydrogeological review. It was conducted by Hugh Middlemis (HydroGeoLogic) in accordance with the principles of the best practice Australian Groundwater Modelling Guideline ('AGMG'; Barnett et al. 2012). The AGMG suggests a compliance checklist to summarise review outcomes; this is presented as Table 1.

This review has also considered the surface water catchment modelling investigations that applied the industry-leading SOURCE software in a manner that is consistent with the best practice surface water modelling guidelines (Rassam et al. 2011), which cite and augment the generic surface water modelling guideline of Black et al. 2011 and the groundwater modelling guideline of Middlemis, Merrick et al. 2001.

The review was conducted progressively during the investigation via a series of consultations and workshops with the EMM Consulting hydrogeology and modelling teams (i.e. consistent with best practice principles). The review began with a site visit on 12-14 February 2018 to the existing Tumut 2 Power Station and a helicopter fly-over of the tunnel alignment and surrounding catchment areas, including the Yarrangobilly River south from the caves area. The review process included a peer review of the Early Works groundwater modelling in May 2018 (Middlemis, 2018).

The main evidentiary basis for this peer review is the water assessment modelling report, which documents the surface water and the groundwater modelling:

- EMM Consulting (2019).Water Assessment. Annexure B Modelling Report. Prepared for Snowy Hydro Limited. August 2019.

It is my professional opinion that the Snowy 2.0 groundwater model (version SH4) and coupled surface water catchment modelling has been developed consistent with best practice, including careful model design and acceptable calibration to the available groundwater levels and with consideration of river baseflow estimates and sensitivity and uncertainty assessment. The Snowy 2.0 coupled groundwater and catchment modelling methodology is suitable for scenario modelling to assess drawdown and catchment water balance impacts and to inform management strategies and licensing.

Table 1 - AGMG Groundwater Model Compliance: 10-point essential summary - Snowy 2.0

Question	Y/N	Comments re Snowy 2.0 coupled modelling
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Class 2 model confidence level is justified, with a few class 1 and class 3 attributes (see Table 2). Catchment modelling purposes well defined and justified.
2. Are the objectives satisfied?	Yes	Competent model design and calibration to groundwater levels and baseflow estimates, demonstrating fitness for purpose. Where assumptions applied, conservative (over-estimated) settings adopted. Adequate sensitivity and uncertainty analysis conducted, given the constraints (data, schedule, etc), noting engineering treatments can be applied during construction. Catchment modelling designed and executed consistent with best practice, including alternate models and sensitivity tests.
3. Is the conceptual model consistent with objectives and confidence level?	Yes	Conceptualisation sound, consistent with data, objectives and confidence level, and for impact assessment and licensing purpose. Conservative assumptions applied where needed.
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes	Detailed and integrated hydrogeological, hydrological and ecological investigations and data acquisition, noting constraints apply due to National Park context. Short period of monitoring record locally, but good info regionally helped benchmark conceptual models. Baseflow estimates from catchment modelling are well justified. Some site specific testing but no major pumping stress test. All carefully considered and combined to develop sound conceptual models. Competent hydrogeologists, hydrologists and modellers have evaluated the data, conceptualisation, model design, execution & outcomes.
5. Does the model design conform to best practice?	Yes	Industry-leading model software application (Modflow-USG for groundwater and SOURCE-SYMHYD for catchment model). Groundwater model design, extent, layers, grid, boundaries and parameters consistent with best practice design and execution. Catchment model design, testing of alternates, calibration and climate scenarios justified and consistent with best practice.
6. Is the model calibration satisfactory?	Yes	Groundwater model calibration performance is acceptable, given focus on drawdown and baseflow impacts. SRMS errors ok, mostly <5%, mainly due to large range in heads. Model to measured offsets sometimes exceed 10m. Very good matches to estimated stream baseflows including seasonality. Steady state sensitivity analysis OK (Kh, Kv & stream bed conductance). Catchment model calibration performance good to very good re Moriasi (2007) criteria on NSE/RSR. Detailed sensitivity testing.
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	Model parameter values are consistent with the somewhat limited drilling & testing information. Acknowledged that no substantial pumping stress-test data is a data limitation. Catchment model parameters/fluxes plausible and constrained by catchment water balances and groundwater interactions.
8. Do the model predictions conform to best practice?	Yes	Construction and operations predictions and uncertainty analysis consistent with best practice and suitable for guiding impact assessment and management plans and licensing issues.
9. Is the uncertainty associated with the simulations/predictions reported?	Yes	Uncertainty assessment limited to parameters from sensitivity analysis. No climate change uncertainty scenarios but wet/dry construction sequences considered. Characterise as basic uncertainty assessment, adequate given constraints applying (data, schedule etc), consistent with best practice.
10. Is the model fit for purpose?	Yes	My professional opinion is that the Snowy 2.0 SH4 groundwater modelling and coupled catchment modelling assessment is fit for the purpose of environmental impact assessment and informing management strategies and licensing.

2. Model Confidence Level Classification

The Australian Groundwater Modelling Guidelines (AGMG) provide a model confidence classification schema that summarises the resources used to build a model in terms of the data on aquifer responses to hydrological stresses, and the model design, construction and performance. It is expected that any model will have attributes that fall into more than one 'class', with the overall 'confidence level' indicated from the weight of criteria that are met. It is also noted that there are plans in hand to revise the AGMG in relation to the acknowledged confidence classification schema limitations.

This review conducted an independent assessment of the model confidence level classification, consistent with the AGMG but based on the method outlined in Middlemis and Peeters (2018). This review finds that the weight of attributes indicates that a Class 2 model confidence level is indeed justified, with some elements of Class 1 and Class 3 applying (see Table 2 on the last page). This confirms that the Snowy 2.0 SH4 groundwater model is suitable for impact assessment scenario modelling purposes.

In this case, there are some 'class 1' attributes, including the short period of record of monitoring data and the lack of groundwater pumping stress. These uncertainties were addressed by applying considerable effort to investigate surface and groundwater interactions and to apply a coupled catchment and groundwater modelling methodology using the industry-standard SOURCE (SYMHYD) and MODFLOW (USG) modelling packages. This iteratively coupled methodology addresses model non-uniqueness by constraining the model calibration to stream-aquifer exchange fluxes as well as to groundwater levels. It is consistent with the coupled methodology applied to the Murray-Darling Basin Sustainable Yield study (CSIRO 2007, 2008). It is also consistent with the best practice guidance on surface water and groundwater interactions (Rassam et al. 2011) and the AGMG guiding principles on surface water interactions (Barnett et al. 2012, chapter 11).

Furthermore, where assumptions were required, a conservative approach was applied that would tend to over-estimate impacts. Sensitivity and uncertainty analyses were conducted in a manner consistent with the latest guidance (e.g. Middlemis et al. 2019), and the model capabilities and limitations are carefully described.

3. Discussion

The report (EMM 2019) is well-written and provides very good explanations of the catchment and groundwater conceptual models, and the computational model design and execution.

3.1 Coupled Catchment and Groundwater Modelling

The hydrogeological conceptual model was carefully designed to account for the geological and hydrological setting, with a coupled catchment and groundwater modelling methodology applied with calibration constraints to measured groundwater levels and sound baseflow flux and catchment water balance estimates.

Modelling of the groundwater flow system was undertaken using MODFLOW USG via the Groundwater Vistas graphical user interface, while modelling of the surface water system was undertaken using the eWater SOURCE package. These two models were loosely coupled (Figure 1; i.e. using a coupling methodology similar to that applied to the Murray-Darling Basin Sustainable Yield project; CSIRO 2007, 2008). The coupling methodology is consistent with best practice (Rassam et al. 2011, Barnett et al. 2012) with data transfer constraining the model calibration and scenario modelling phases, all lucidly explained in the very well-written report.

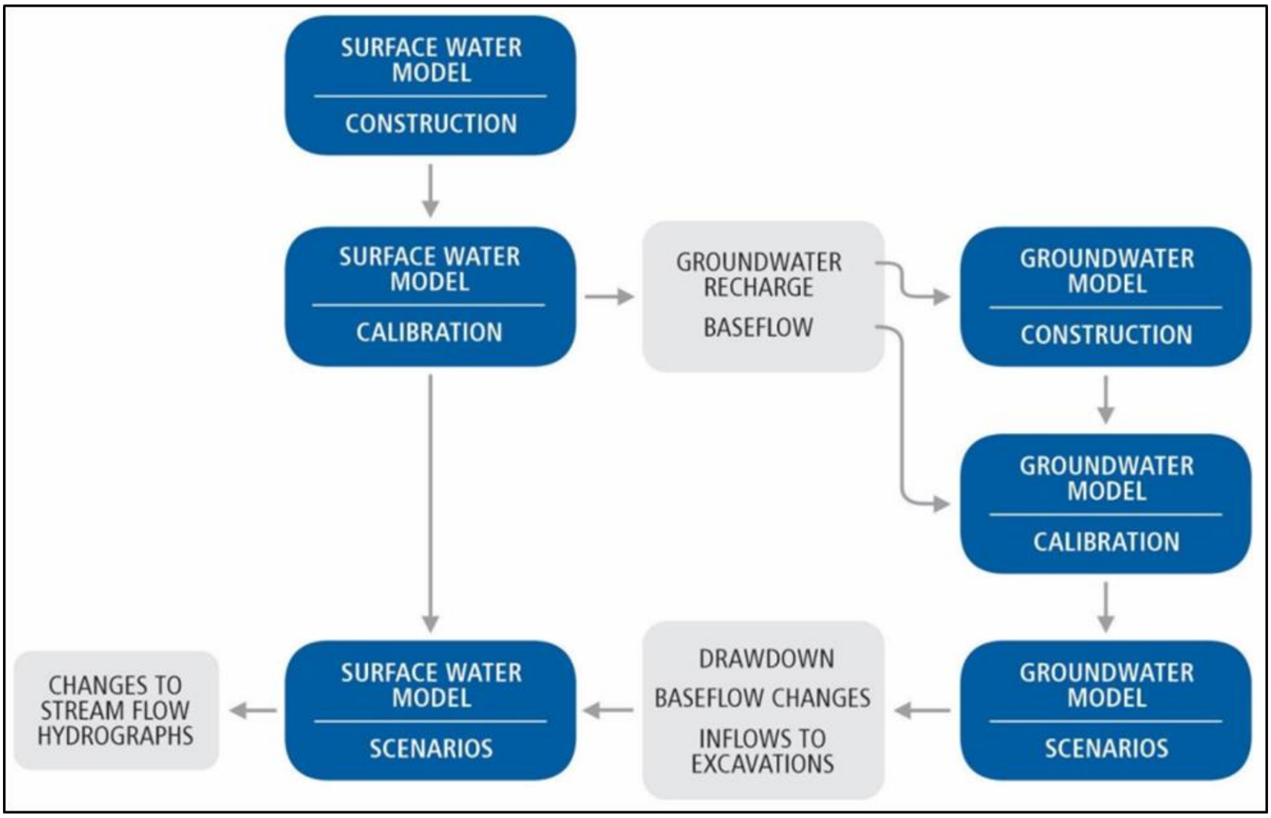

Figure 1 - groundwater and catchment model coupling methodology (after EMM 2019)

3.2 Surface Water Catchment Modelling

Baseflow estimation used available gauged stream flow data (e.g. for the Murrumbidgee, Eucumbene and Yarrangobilly Rivers) and considered several analytical methods (recession analysis, digital filtering and salinity mass balance) as well as Q-lag time lag assessments and cross-correlation analysis. The results were applied to estimate baseflow for various creeks in the project area and the results were benchmarked against manual flow measurements. The baseflow estimates were used to constrain the catchment modelling, which applied the SOURCE package to test several rainfall-runoff models (SYMHYD, AWBM and GR4J), and provides a sound justification for the adoption of the SYMHYD model, including the modifications that are warranted for the project setting.

Catchment model calibration was also constrained by data on rainfall, evapotranspiration, streamflow, LiDAR DEM and aerial imagery. Predictive uncertainty analysis was conducted for a wide range of parameters, with the results quantifying the effects of uncertainties on the project objectives. This is explained cogently in the report, and is suitable for application to environmental risk management.

The catchment modelling tasks were all conducted consistent with best practice principles, e.g.:

- iterative coupling of the catchment and groundwater modelling methods, with the surface water catchment domain resolved into sub-catchments based on topography that together encompassed the groundwater model domain;
- problem definition and conceptualisation that balances complexity against simplicity; options modelling and sound justification of the preferred option;
- consideration of saturated and unsaturated connections to groundwater and of head- and flux-based methods for exchange flux estimation, including time lags;
- calibration constraints including catchment water balance component estimates, sound metrics (Moriasi et al. 2007);
- sensitivity and uncertainty analysis, and careful explanation of limitations.

3.3 Groundwater Modelling

The groundwater modelling uses the Modflow-USG package with a detailed variable grid. Minimum cell sizes of 12.5 m apply near mapped streams and the tunnel alignment, with 5 additional sub-layers either side of the tunnel elements, and with pinching out of unnecessary layers and/or cells remote from such features. Even with this efficient discretisation, there are 42 layers in total and about 2.8 million active cells, which is a large model that involves fairly long run times, which is practically unavoidable for a project such as this.

The boundary conditions, recharge, surface-groundwater interactions and parameters applied are reasonable, with a bias towards conservative assumptions where warranted. For example, a storage depletion setup was adopted rather than regional groundwater throughflow, in cognisance of the limited data set. Stream-aquifer interaction was a key focus for the investigation, informed by the coupled catchment modelling, and the groundwater model parameters applying were also carefully selected and justified. For example, the detailed sensitivity testing of the stream bed conductance parameter is consistent with the AGMG (Barnett et al. 2012, section 11.3.5) and confirms that the conductance parameter values applied to the tunnel drain features do not artificially limit the inflows. This is another example of the conservatism that has been applied. It is also an example of the careful design of the modelling approach, in that it allows for testing of the effects of reducing the conductance parameter to emulate the effects of any engineering treatments that may be applied.

The model performance across the various monitoring sites meets statistical criteria for groundwater models (Barnett et al. 2012) and catchment models (Moriasi 2007). While the catchment model performance is very good, the groundwater model statistics are met mainly due to the large range in elevations, which is a properly acknowledged limitation. Residual values (measured minus modelled groundwater levels) often exceed

10 metres, but close matches are not expected in the fractured rock setting with the data limitations applying. Most time series matches are adequate in terms of overall and seasonal trends (where the data is available). It must be noted that the groundwater model calibration is more robust and acceptable than a simple view of the mismatches of absolute groundwater level might suggest, because it is also constrained by the catchment modelling estimates of recharge and baseflow. As the AGMG notes, this is because '*the sensitivity of fluxes to parameters is different from the sensitivity of heads to fluxes*', and thus fluxes contain '*important information about parameters, which helps to resolve non-uniqueness issues*'.

Model sensitivity and uncertainty scenarios have been run, consistent with best practice recommendations, and acknowledging the project context and constraints applying. In this case, a range of groundwater model parameter uncertainty scenarios have been run, based on the limited sensitivity analysis (Kh, Kv and stream bed conductance), noting that these are key parameters to test. While the confined aquifer storativity has a limited range and would likely not indicate sensitivity, the lack of testing of unconfined specific yield is an acknowledged limitation. The limitation arises due to model size (required for spatial discretisation), run times (due to model size and steep hydraulic gradients due to low permeabilities) and the project schedule constraints. Climate change uncertainty scenarios were not run, with reasonable arguments presented as justification.

The groundwater uncertainty testing methodology applied could be characterised as a basic uncertainty assessment, although this is arguably consistent with best practice guidance for the fairly low risk context applying (Barnett et al. 2012; Middlemis and Peeters, 2018). In any case, the ongoing monitoring program is well-designed to provide the data in due course for model improvements and improved assessment of uncertainties. In its current form, the groundwater assessment provides information that is suitable for impact assessments and management plan development, and for licensing decisions.

3.4 Results

The impact assessments and interpretations are supported by the data available and the evidence presented. The model prediction results are presented in terms of the null case compared to the project case (which helps minimise uncertainties), with details presented suitable to inform decision making (e.g. water balance volumes; time series of groundwater levels, drawdowns, tunnel inflows, stream flows, baseflows, etc.; flow duration curves; no flow days; other statistics, etc.).

The ongoing monitoring and other investigations will provide additional data for future model refinements and improvements in performance (e.g. to reduce residuals and improve stream baseflow calibration). This will support more detailed uncertainty analysis that should, in turn, be used to guide future monitoring and management programs.

4. Conclusion

It is my professional opinion that the Snowy 2.0 groundwater model (version SH4) and the coupled surface water catchment modelling has been developed consistent with best practice, including careful model design, calibration to groundwater levels and river baseflow estimates, and sensitivity and uncertainty assessment. The Snowy 2.0 coupled catchment and groundwater modelling is fit for the purpose of scenario modelling to assess drawdown and catchment water balance impacts and to inform management strategies and licensing.

5. Declarations

For the record, the peer reviewer, Hugh Middlemis, is an independent consultant specialising in groundwater modelling. He is a civil engineer with a master's degree in hydrology and hydrogeology and more than 38 years' experience. Hugh was principal author of the first Australian groundwater modelling guidelines (Middlemis et al. 2001) that formed the basis for the latest guidelines (Barnett et al. 2012) and was awarded a Churchill Fellowship in 2004 to benchmark groundwater modelling best practice. He is principal author on two guidance reports on modelling uncertainty (Middlemis and Peeters 2018; and Middlemis et al. 2019).

We assert no conflict of interest in relation to this project, but we note that the reviewer's son (Roger Middlemis) began working as an environmental engineer for EMM Consulting in their Adelaide office from March 2019, and we note the following in relation to previous independent reviews by Mr Middlemis of EMM models:

- McPhillamys gold project (NSW) groundwater model review (2019, for EMM).
- Kalbar mineral sands (Vic.) groundwater assessment (2019; for Kalbar Resources).
- Hume Coal project (NSW) groundwater assessment (2018-19; for NSW DPE).

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Table 2 - Snowy 2.0 SH4 groundwater model confidence level

Model Confidence Class characteristics: Snowy 2.0 SH4 model

Class	Data		Calibration		Prediction		Quantitative Indicators	
1 (simple)		Not much / Sparse coverage		Not possible.	~	Timeframe >> Calibration	√	Predictive Timeframe >10x Calib'n.
	√	No metered usage.		Large error statistic.	~	Large stresses/periods.	√	Predictive Stresses >5x Calib'n.
		Low resolution topo DEM.		Inadequate data spread.	~	Poor/no verification.		Mass balance > 1% (or one-off <5%)
		Poor aquifer geometry.		Targets incompatible with model purpose.		Transient prediction but steady-state calibration.		Properties <> field values.
		Basic/Initial conceptualisation.						Poor performance stats / no review
2 (impact assessment)	~	Some data / OK coverage.	~	Weak seasonal match.	x	Predictive Timeframe > Calib'n.	x	Predictive Timeframe = 3-10x Calib'n.
	x	Some usage data.	~	Some long term trends wrong.	x	Different stresses &/or periods.	x	Predictive Stresses = 2-5x Calib'n.
	√	Some Baseflow estimates and some K & S measurements.	√	Partial performance (e.g. some stats / part record / model-measure offsets).	~	No verification but key simulations constrained by data	√	Mass balance < 1% (all periods)
	√	Some high res. topo DEM and adequate aquifer geometry.	√	Head & Flux targets constrain calibration.	x	Calib. & prediction consistent (transient or steady-state).	~	Some properties maybe <> field values.
	~	Sound conceptualisation, reviewed & stress-tested.	~	Non-uniqueness, sensitivity and qualitative uncertainty addressed.	√	Magnitude & type of stresses outside range of calib'n stresses.	~	Some poor performance (but no coarse discretisation in key areas/times).
3 (complex simulator)	x	Plenty data, good coverage.	x	Good performance statistics	x	Timeframe ~ Calibration	x	Predictive Timeframe <3x Calib'n.
	x	Good metered volumes (all users).	x	Most long term trends matched.	x	Similar stresses &/or periods.	x	Predictive Stresses <2x Calib'n.
	√	Local climate data & baseflows.	x	Most seasonal matches OK.	x	Good verification or all simulations constrained by data	√	Mass balance < 0.5% (all periods)
	~	Kh, Kv & Sy measurements from range of tests.	~	Calibration to present day head and flux targets.	NA	Steady state prediction only when calibration in steady state.	~	Properties ~ field measurements.
	~	High res. topo DEM all areas & good aquifer geometry.	~	Non-uniqueness minimised &/or parameter identifiability &/or minimum variance or RCS assessed.	~	Suitable computational methods applied & parameters are consistent with conceptualisation	x	No poor performance or coarse discretisation in key areas (grid/time).
	x	Mature conceptualisation.	~	Sensitivity &/or Qualitative Uncertainty	~	Quantitive uncertainty analysis	√	Review by experienced Hydro/Modeller.

(after Table 2-1 of AGMG (Barnett et al. 2012) and Figure 5 of IESC uncertainty guidance (Middlemis & Peeters 2018))

	Criterion met at higher Class
~	Criterion partially met at the relevant Clas
√	Criterion met at the relevant Class
x	Criterion not met by current model study

Attachment B

Runoff model selection

B.1 Method

Source facilitates the use of a number of rainfall runoff models commonly used by hydrologists to describe catchment processes. Several published runoff models were trialled for the project site, in addition to a runoff model developed for the project by modifying the published SIMHYD code to represent complexity believed to be important at the site. Models tested included:

- SIMHYD;
- GR4J;
- Australian Water Balance Model (AWBM); and
- a runoff model developed by modifying the published SIMHYD code to include additional/alternate processes.

Optimal parameters for each of these models were selected through the use of the Rosenbrock optimiser, for each of the following objective functions:

- log daily Nash-Sutcliffe Efficiency[7] (NSE) with flow bias weighting; and
- square-root of daily flow and exceedance with flow bias weighting.

The calibration achieved by each model was assessed against the following metrics:

- NSE for daily flow, log daily flow, daily flow and log flow duration, and monthly flow at:
  - Murrumbidgee River gauge 410535; and
  - Yarrangobilly River gauge 410574.
- Flow exceedance goodness of fit, particularly the low flow (baseflow) portion of the curve, at:
  - Murrumbidgee River gauge 410535; and
  - Yarrangobilly River gauge 410574.
- Average split between baseflow and surface flow discharges from:
  - model sub-catchment 6, located in the plateau region, within the Murrumbidgee catchment; and
  - model sub-catchment 30, located in the ravine region, within the Yarrangobilly catchment.
- Recession rate at:
  - Murrumbidgee River gauge 410535; and

[7] The Nash-Sutcliffe Efficiency (NSE) is a normalised statistic that determines the relative magnitude of the residual variance ('noise') compared to the measured data variance ('signal' or 'information'). Values of NSE between 0.0 and 1.0 generally indicate acceptable levels of performance, with a value of NSE greater than 0.5 indicating nominally satisfactory performance. Values of NSE less than zero indicate that the mean observed value is a better predictor than the simulated value (ie NSE<0 indicates unacceptable model performance).

- Yarrangobilly River gauge 410574.

Streamflow data collected throughout creeks on the plateau through the project field program, and Wallaces Creek streamflow gauge (located within the Yarrangobilly catchment) data were used to validate model results post calibration.

B.2 SIMHYD runoff model

B.2.1 Model description

SIMHYD is a rainfall runoff model which estimates runoff from rainfall and potential evapotranspiration. The model contains three stores for interception loss, soil moisture, and groundwater. A model schematic is presented in Figure B.1.

The SIMHYD model suits the catchment model purpose through the explicit inclusion of groundwater recharge, a groundwater store, and baseflow.

One weakness of the SIMHYD model in representing the project catchments is that interflow is extracted from the infiltration component prior to recharging the soil moisture store. Soil moisture may evaporate or enter the groundwater store but does not contribute to interflow. This results in quickflow only occurring on days with rainfall. When using the SIMHYD model, all streamflow occurring on non-rain days must come exclusively from the groundwater store. In the case of the project catchment, it is expected that there are non-groundwater sources which may contribute to streamflow on non-rain days, such as water temporarily contained in bogs, fens, and alluvial material adjacent to creeks, which could lead to the model calibration requiring a higher groundwater discharge rate than actually occurs.

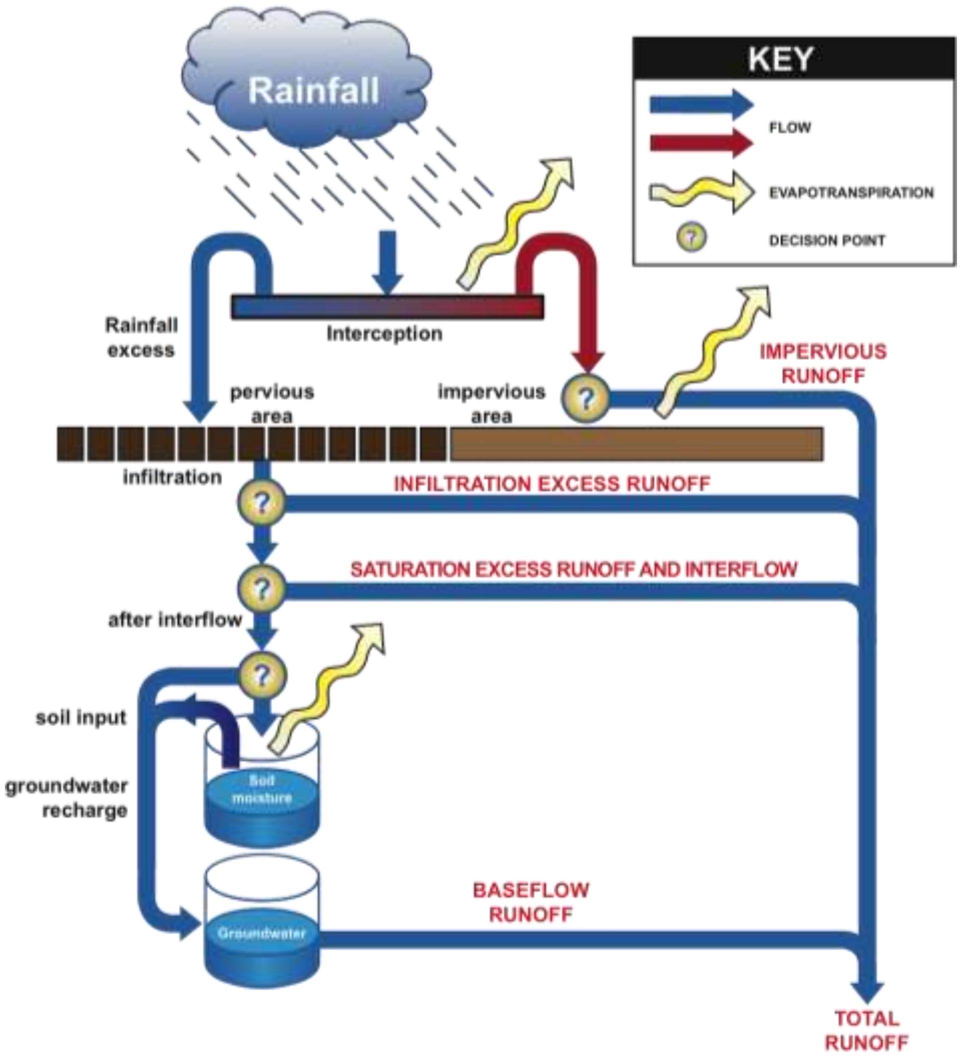


Figure B.1 SIMHYD model (eWater, n.d.)

B.2.2 Calibration

During calibration of the SIMHYD model, the baseflow discharge coefficient was set at 0.02, based on the studies presented in section 2.2. The impervious fraction was held at 0%.

When using SIMHYD, the model achieved good NSE statistics (>60%) for log daily, and daily and log flow duration, and monthly NSE statistics at both the Murrumbidgee and Yarrangobilly stream gauges (Table B.1), indicating a good general fit to the data. The model achieved a good mass balance, with the total flow past each gauge giving a close match to recorded streamflow data.

The baseflow index predicted by the calibrated SIMHYD model was >60%, much higher than the 40% expected from the studies presented in section 2.2. An alternate calibration with interflow and recharge parameters fixed to achieve 40% baseflow produced poorer calibration statistics and poorer hydrograph recession fit, and has not been reported.

Table B.1 SIMHYD model calibration statistics

	Yarrangobilly	Murrumbidgee
Volume Bias	-0.14%	-0.68%
NSE Daily	56%	42%
NSE Log Daily	74%	66%
NSE Daily and Log Flow Duration	76%	71%
NSE Monthly	80%	57%
Baseflow Index	65%	78%

The frequency of high flow events was well represented by the SIMHYD model at the Murrumbidgee gauge (Figure B.2) At low flow events, the model tends to over predict flow.

The frequency of high and low flow events were well represented at the Yarrangobilly gauge (Figure B.3), other than the lowest 10% of flows, which were under represented in the model.

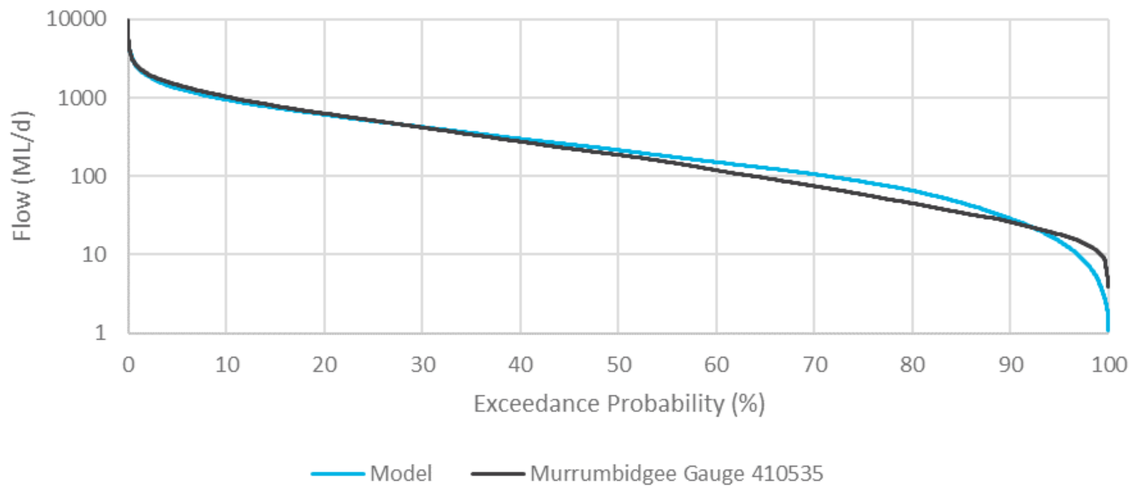


Figure B.2 Murrumbidgee flow duration curve (SIMHYD)

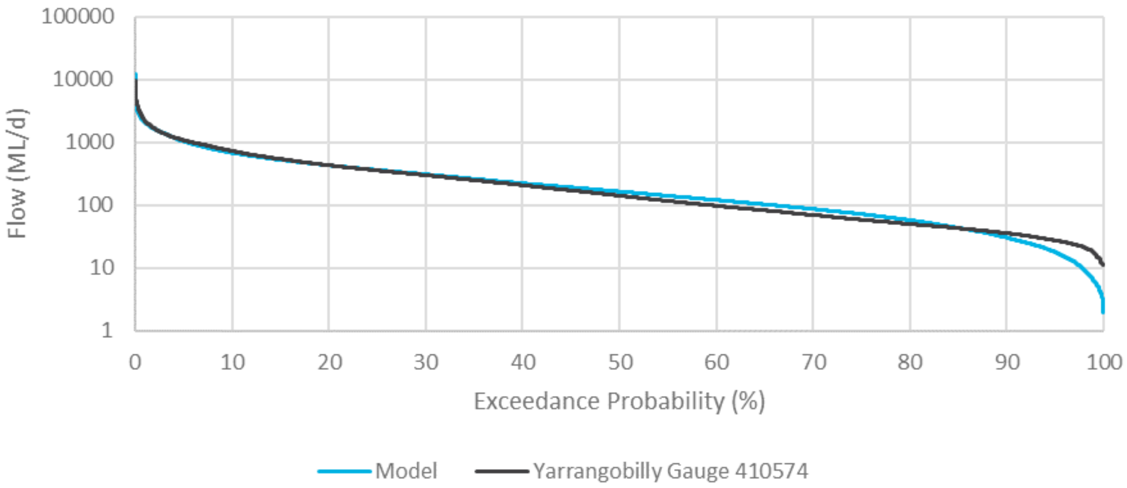


Figure B.3 Yarrangobilly flow duration curve (SIMHYD)

The modelled and recorded 1995 daily streamflow at both calibration gauges are presented in Figure B.4 and Figure B.5 as an example of model performance. These plots show:

- modelled hydrographs had accentuated peaks on rain days, often showing a more rapid rise and fall in flow rate than seen in the recorded streamflow data; and
- modelled streamflow recession adequately matched the recorded data between October 1995 and February 1996, but poorly matched the gauge data at other times.

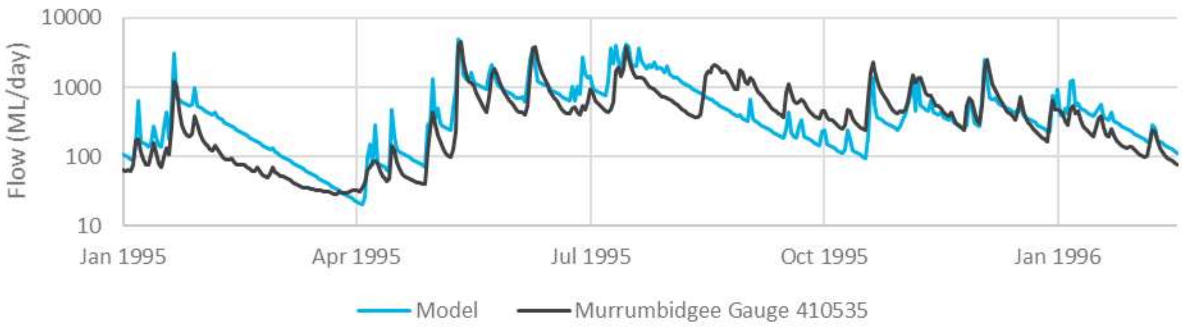


Figure B.4 Murrumbidgee 1995 modelled and recorded flow (SIMHYD)

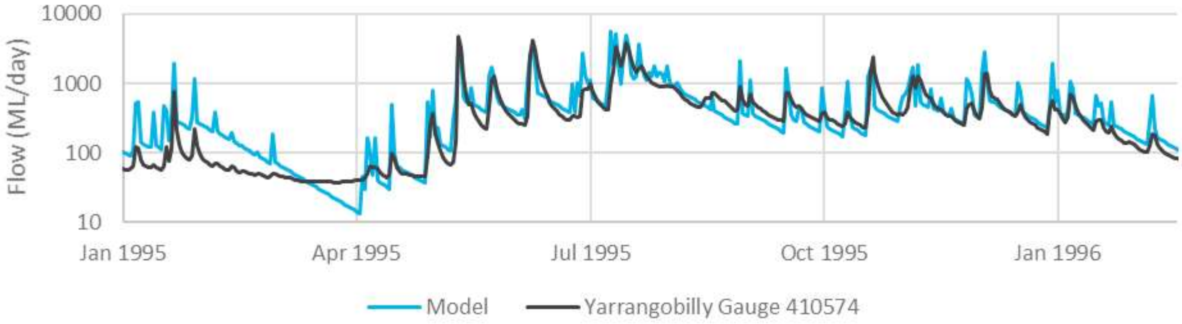


Figure B.5 Yarrangobilly 1995 modelled and recorded flow (SIMHYD)

B.3 AWBM runoff model

B.3.1 Model description

The AWBM rainfall runoff model contains three soil moisture stores, a groundwater store, and a surface routing storage.

Within the AWBM model, the catchment is apportioned into three parts, each of which typically requires a different depth of water to achieve saturation. Runoff occurs from each catchment portion separately when saturation is achieved, allowing for increases in catchment contribution to runoff as rain intensity and duration increase. The baseflow index is explicitly specified as a parameter and is used to divert a portion of runoff into a groundwater store. The surface routing store allows for runoff to be temporarily detained and is particularly useful in large catchments in which runoff may not reach the gauge location within a single day following rain. The model schematic is represented in Figure B.6.

The AWBM model suits the catchment model purpose through the explicit inclusion of groundwater recharge, a groundwater store, and baseflow. Due to the catchment size and stream slopes, the travel time for runoff to reach the gauge is in the order of 1 day once in a creek. The surface routing store is thus not required for modelling routing but may be used to simulate the effect of alluvial storage adjacent to creeks, which is expected to retain water following flow events with release over a period of days.

Weaknesses of the AWBM model in modelling the project catchment inlude:

- interflow processes are not modelled, and runoff to the routing store occurs only on rain days; and
- the baseflow index remains constant through time, and does not vary through seasons due to changes in catchment saturation.

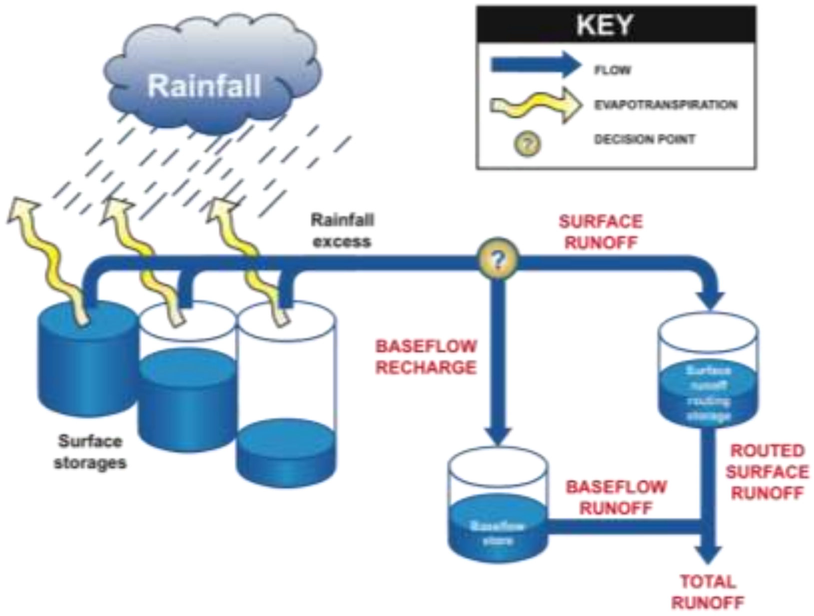


Figure B.6 AWBM model (eWater, n.d.)

B.3.2 Calibration

During calibration of the AWBM model, the baseflow index was set to 40% in each catchment and the baseflow recession coefficient was set at 0.98, based on the studies presented in section 2.2.

When using AWBM, the model achieved good NSE statistics (>60%) for log daily, and daily and log flow duration, and monthly at both the Murrumbidgee and Yarrangobilly stream gauges (Table B.2), indicating a good general fit to the data. The Murrumbidgee daily flow and monthly flow NSE were barely acceptable, indicating that individual rainfall runoff events and seasonality were poorly represented for the plateau catchments. The model achieved a good mass balance, with the total flow past each gauge giving a close match to recorded streamflow data.

Table B.2 AWBM model calibration statistics

	Yarrangobilly	Murrumbidgee
Volume Bias	1.86%	-4.50%
NSE Daily	66%	45%
NSE Log Daily	76%	63%
NSE Daily and Log Flow Duration	82%	72%
NSE Monthly	74%	53%
Baseflow Index	40%	40%

The frequency of high flow events was well represented by the AWBM model at the Murrumbidgee gauge (Figure B.7). At low flow events, the model tends to over predict flow.

The frequency of high and flow events were well represented at the Yarrangobilly gauge (Figure B.8), other than the lowest 15% of flows, which were under represented in the model.

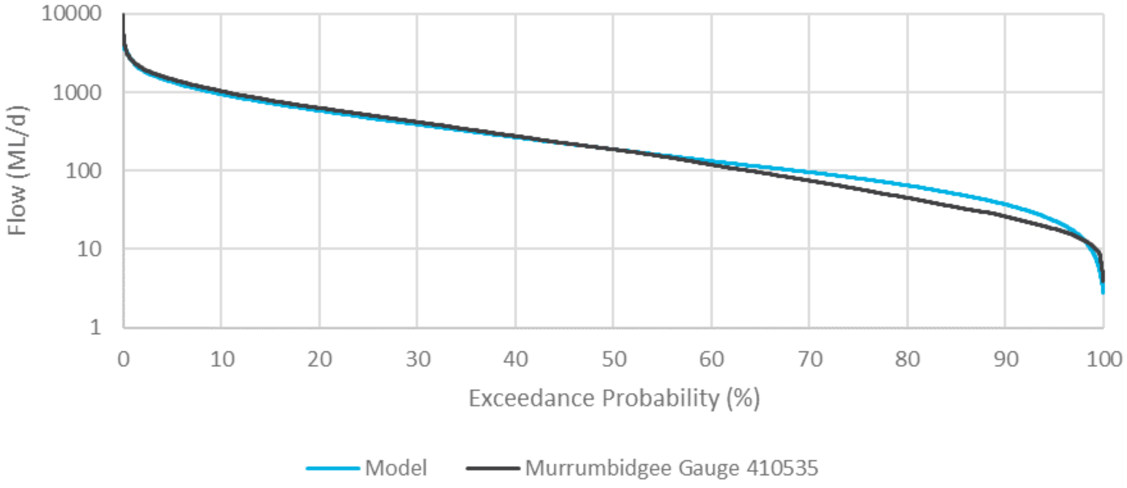


Figure B.7 Murrumbidgee flow duration curve (AWBM)

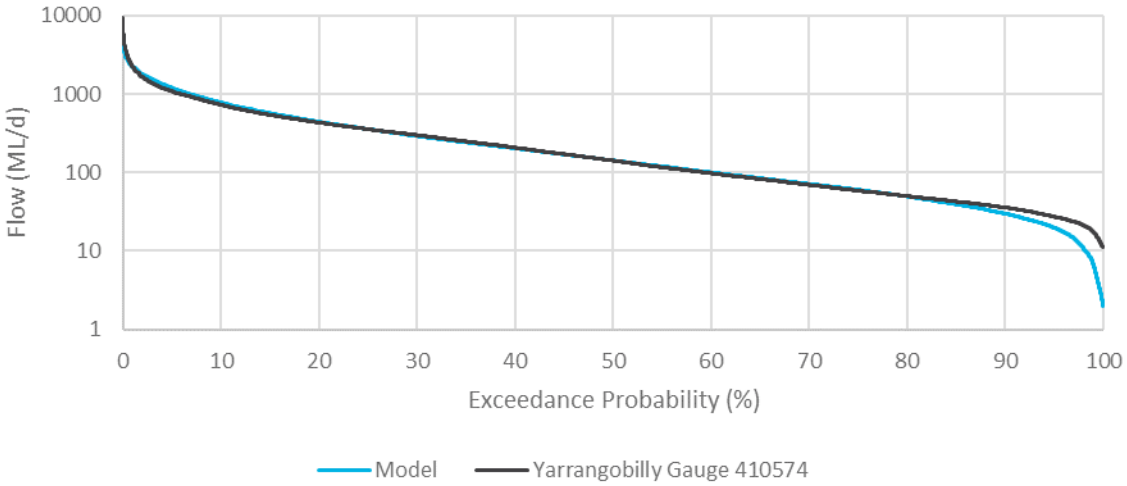


Figure B.8 Yarrangobilly flow duration curve (AWBM)

The modelled and recorded 1995 daily streamflow at both calibration gauges are presented in Figure B.9 and Figure B.10 as an example of model performance. These plots show:

- there was a good fit between measured and modelled runoff event magnitudes at both gauges;
- the modelled recession rate closely matched the measured data at both gauges;
- there is deviation between measured and modelled streamflow at the Murrumbidgee gauge during July to September 1995, which is likely caused by rainfall in the Murrumbidgee catchment not reflected in the SILO record; and

- during June 1995, the model almost perfectly replicated the peak flow and recession from three runoff events.

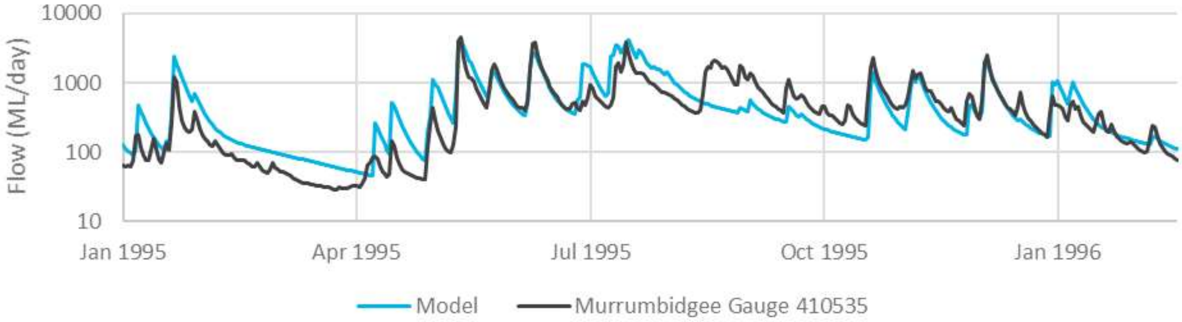


Figure B.9 Murrumbidgee 1995 modelled and recorded flow (AWBM)

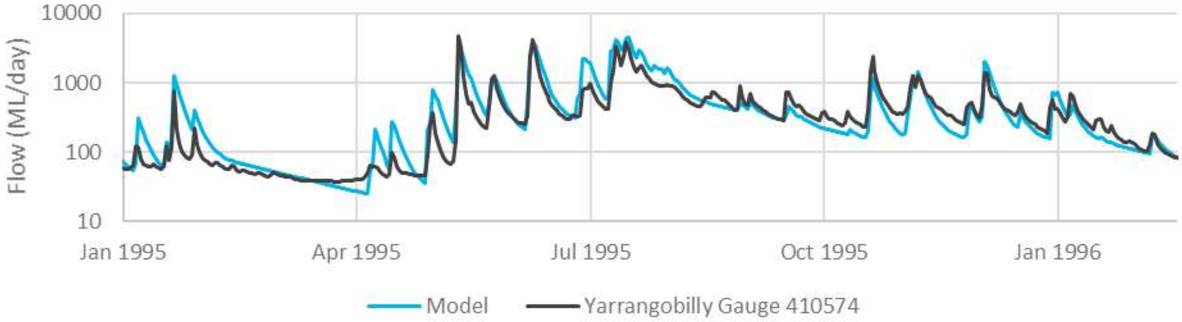


Figure B.10 Yarrangobilly 1995 modelled and recorded flow (AWBM)

B.4 GR4J runoff model

B.4.1 Model description

The GR4J model utilises four parameters and two water stores to represent catchment processes. Key parts of the GR4J include non-linear routing, and the possibility for groundwater transfer in/out of the catchment. The relationship of the model parameters and stores is illustrated in Figure B.11.

In a comparative study undertaken in 2010 using data from 240 Australian catchments, the CSIRO found that "*for practically every measure, GR4J outperformed every other model considered*" (Pagano, Hapuarachchi, & Wang, 2010), and recommended that due to its strong performance, GR4J should be considered in future studies.

The model production store represents soil moisture, from which evapotranspiration is extracted. As the soil moisture and groundwater stores are not separated, and evapotranspiration is removed from the production store, this model does not provide an explicit estimate of net groundwater recharge. The percolation term results in a slow flow of water discharged to creeks on non-rain days, and may be used to simulate both baseflow and interflow processes.

Where groundwater recharge estimates are required, one possible method would be to assume that net groundwater recharge equals groundwater discharge, and to aggregate the data over a sufficient time scale such that the delay within the production store has minimal effect on the resulting recharge time series. Within the Source implementation of the GR4J model, quickflow and slow flow estimates are developed via post processing the resultant total streamflow hydrograph (eWater, n.d.) utilising a baseflow filter requiring both a recession parameter and fitting parameter (Equation B1), resulting in a baseflow time series that is decoupled from the pathway water takes through the GR4J model.

The x_2 term nominally represents groundwater entering/leaving the catchment from an external aquifer, and has the potential to violate the landscape water balance. Pagano, Hapuarachchi & Wang (2010) described this parameter as a term which could also be used to account for rainfall and evapotranspiration scaling, such that its use may be justified even in catchments with no net loss or gain of groundwater. In the project predictive scenarios, this parameter could be used to simulate changes in baseflow due to project effects such as tunnelling.

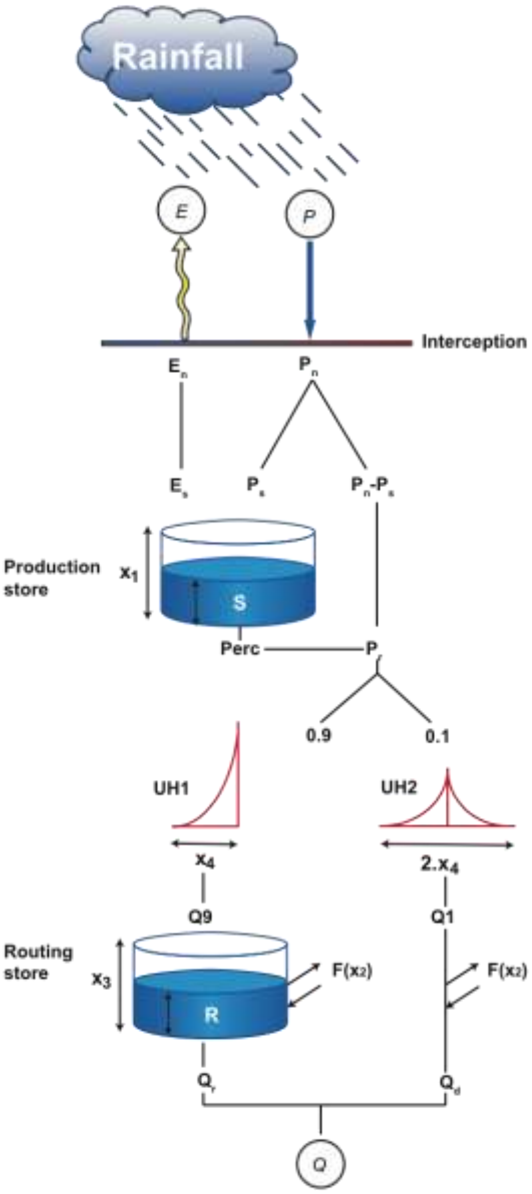


Figure B.11 GR4J model (eWater, n.d.)

Equation B.1 Baseflow separation filter used with the GR4J model in Source

$$Q_b(i) = \frac{k}{1+C} Q_b(i-1) + \frac{C}{1+C} Q(i)$$

Where

- k is a recession constant as per section 2.2
- C is an adjustable shape parameter
- Q is total daily streamflow
- Q_b is daily baseflow.

i Calibration

During calibration of the GR4J model, the groundwater transfer term x_2 was given a value of zero, so that it might be available for explicitly modelling project groundwater impacts in predictive scenarios. The Source baseflow filter parameters were set based on the data presented in section 2.2, with k taking a value of 0.98, and C adjusted such that the baseflow index was 40% over the gauge record. Three parameters were adjusted during calibration, being x_1, x_2, and x_3.

When using GR4J, the model achieved a very good NSE statistics (80-90%) within the Yarrangobilly catchment, and good NSE statistics (>60%) for the Murrumbidgee catchment (Table B.3). The model achieved a good mass balance in the Yarrangobilly catchment, and slightly underestimated flow in the Murrumbidgee catchment.

Table B.3 GR4J model calibration statistics

	Yarrangobilly	Murrumbidgee
Volume Bias	-1.92%	-6.45%
NSE Daily	81%	57%
NSE Log Daily	91%	78%
NSE Daily and Log Flow Duration	90%	76%
NSE Monthly	90%	68%
Baseflow Index	38%	38%

The frequency of high flow events was well represented by the GR4J model. The frequency of flow events under 100 ML/day were slightly over estimated in the Murrumbidgee catchment (Figure B.12) and slightly under estimated in the Yarrangobilly catchment (Figure B.13).

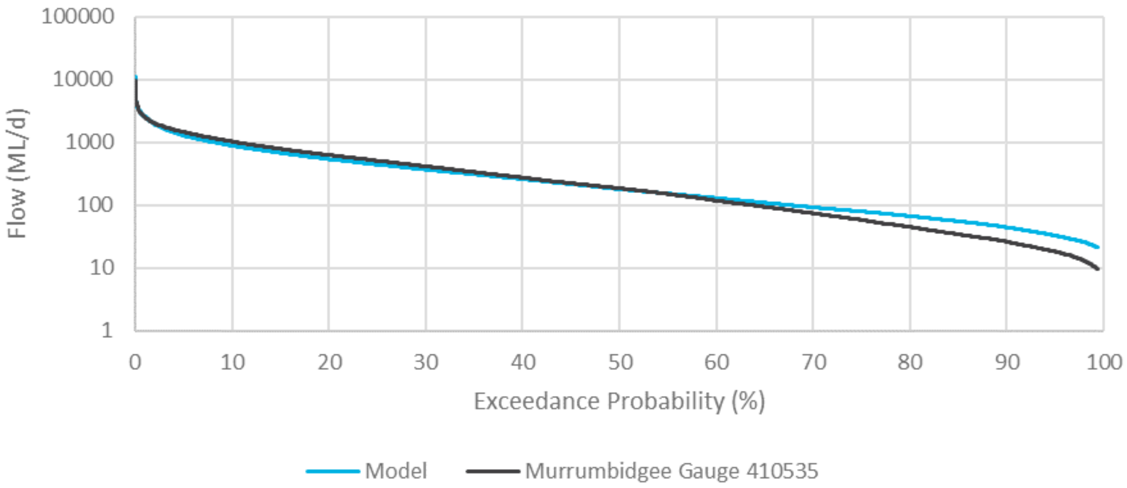


Figure B.12 Murrumbidgee flow duration curve (GR4J)

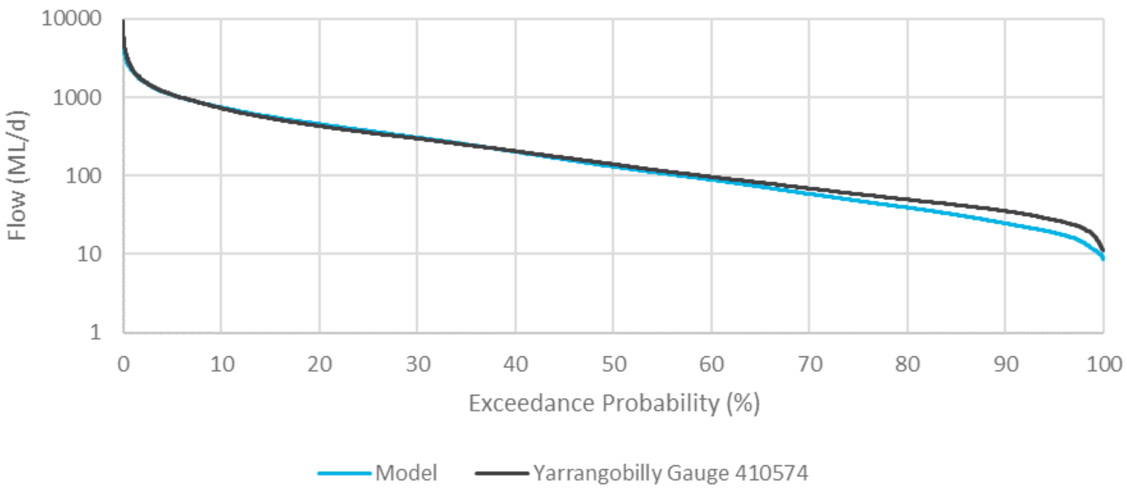


Figure B.13 Yarrangobilly flow duration curve (GR4J)

The modelled and recorded 1995 daily streamflow at both calibration gauges are presented in Figure B.14 and Figure B.15 as an example of model performance. These plots show:

- there was a very good fit between measured and modelled runoff event magnitudes at both gauges, particularly between June 1995−February 1996;
- the modelled recession rate closely matched the measured data at both gauges; and
- there is deviation between measured and modelled streamflow at the Murrumbidgee gauge during July–September 1995, which is likely caused by rainfall in the Murrumbidgee catchment not reflected in the SILO record.

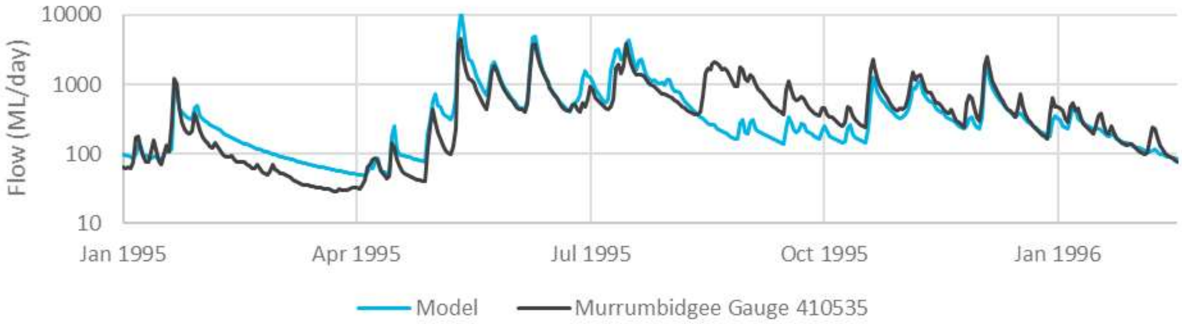


Figure B.14 Murrumbidgee 1995 modelled and recorded flow (GR4J)

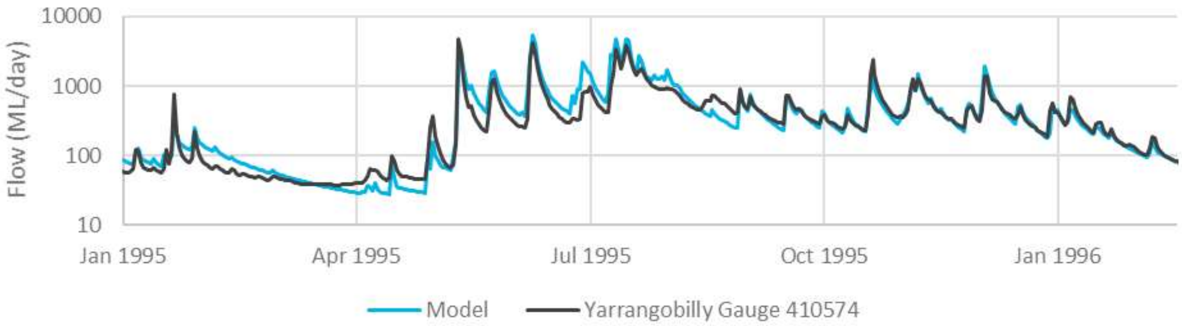


Figure B.15 Yarrangobilly 1995 modelled and recorded flow (GR4J)

B.5 Modified SIMHYD runoff model

B.5.1 Model description

As discussed in the preceding report sections, SIMHYD, AWBM and GR4J each contained weaknesses that made their use less than ideal:

- the SIMHYD model did not allow interflow processes to occur on days following rain;
- the AWBM model utilised a fixed baseflow index that did not respond to seasonality or catchment wetness; and
- the GR4J model did not provide an explicit groundwater recharge and discharge pathway.

A custom runoff model was created to address these weaknesses. This custom model was conceptualised as a modification of SIMHYD, utilising the explicit groundwater recharge and discharge pathways but altering the recharge and discharge equations to align with the conceptual model of the site hydrology. A number of alterations were tested (described below), with those contributing to improved calibration retained in the final model.

B.5.2 Trialled model alterations

i Non-rain day recharge and runoff

To allow groundwater recharge and interflow to occur on non-rain days, the equations relating to flow out of the soil moisture store were altered.

A new variable was introduced describing the minimum soil saturation threshold required for recharge to the groundwater store or interflow. A ‘saturation variable’ utilised for scaling recharge and interflow rates was then calculated as per the example in Figure B.16. When the soil moisture store was saturated, groundwater recharge and interflow occurred at the maximum allowed rate, while when the soil moisture was at or below the saturation threshold no recharge or interflow was allowed. At intermediate soil moisture saturation the rates were linearly interpolated.

The groundwater recharge and interflow equations were altered to take the form shown in Equation B.2. The soil moisture minimum threshold, interflow coefficient, and recharge coefficient were each varied through the model calibration process.

Evapotranspiration equations were not altered and were not subject to the minimum soil moisture threshold.

This alteration to the standard SIMHYD model significantly improved model calibration, and was included in the final model.

Equation B.2 Altered interflow and recharge equations

$$Interflow\ (\frac{mm}{d}) = \ Interflow\ Coefficient(\frac{mm}{d}).Saturation\ Variable(\%)$$

$$Recharge(\frac{mm}{d}) = Recharge\ Coefficient(\frac{mm}{d}).Saturation\ Variable(\%)$$

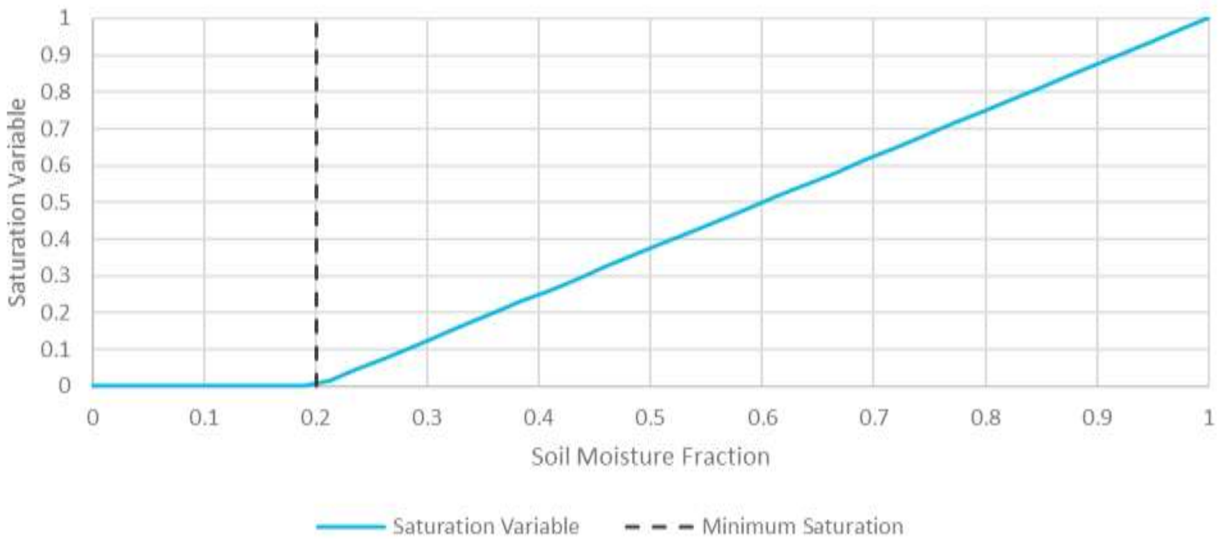


Figure B.16 Example saturation variable using a minimum saturation for drainage of 20%

ii Perching

There are a number of locations within the plateau region at which field investigations identified saturated soil conditions at the surface, when groundwater bores showed that the regional watertable did not reach the surface.

A 'perched' land fraction was simulated in the Modified SIMHYD model, in which the groundwater store was removed as illustrated by the flow paths on the right hand side of Figure B.17. In this conceptualisation, when the perched soil moisture store was full, additional infiltration resulted in saturation excess quickflow rather than groundwater recharge.

No change to model calibration statistics was observed for perched area percentages between 0%–5% of the total catchment area, and so the final model framework did not include the perched flow pathway.

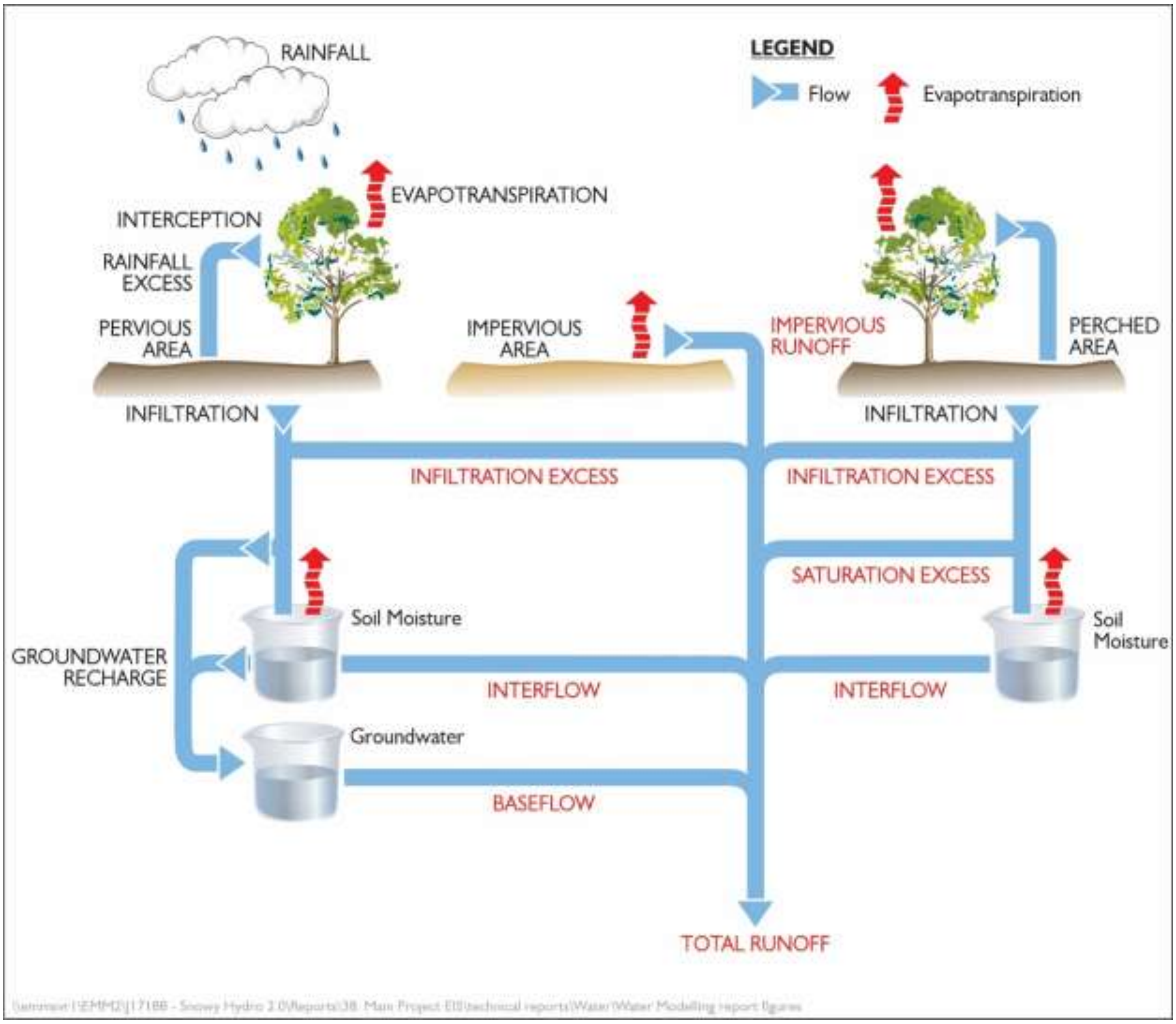


Figure B.17 Trialled model framework with perching

iii Snow

The project area experiences snowfall during colder months. Precipitation falling as snow will melt and generate runoff and infiltration at a date some time after the precipitation date. The project does not have data describing snow fall depths, extents, and durations.

A theoretical snowfall and snowmelt model was developed for testing with the catchment model based on degree day methods as published by Braithwaite (1995) (Equation B.3) and assumptions regarding timing of snow fall.

Equation B.3 Daily ablation

$$a = \alpha + \beta D + \varepsilon$$

$$D = T.d$$

Where:

- a is daily ablation in mm/day
- α is the melting rate at a temperature of 0°C
- β is the rate of ablation with temperatures above 0°C
- D is the degree day factor
- T is the temperature above zero degrees C
- d is the number of days to which T applies
- ε is an error term.

Braithwaite (1995) listed positive degree day factors for a number of ice and snow locations, with snow degree day ablation factors (β) ranging from 3 to 5.7 mm d^{-1} $°C^{-1}$, averaging 4.4 mm d^{-1} $°C^{-1}$. α and ε may be taken as 0 mm/day for simple models.

It was assumed that precipitation would fall as snow when ground temperatures were below 0°C.

On days with a portion of the day with temperatures below 0°C, the minimum and maximum daily temperatures were used to estimate the proportion of the day with ground temperature below 0°C as per the example in Figure B.18. This proportion of precipitation was assumed to fall as snow.

On days with a proportion of the day with temperatures above 0°C, the degree day factor was calculated as the average above zero °C temperature multiplied by the proportion of the day with ground temperature above zero, as per the example in Figure B.18. In the example shown in Figure B.18, D would be calculated as 2.5°C . 62% = 1.55°C.days.

Snow melt was added to non-snow precipitation (rain) to generate a new time series of effective precipitation.

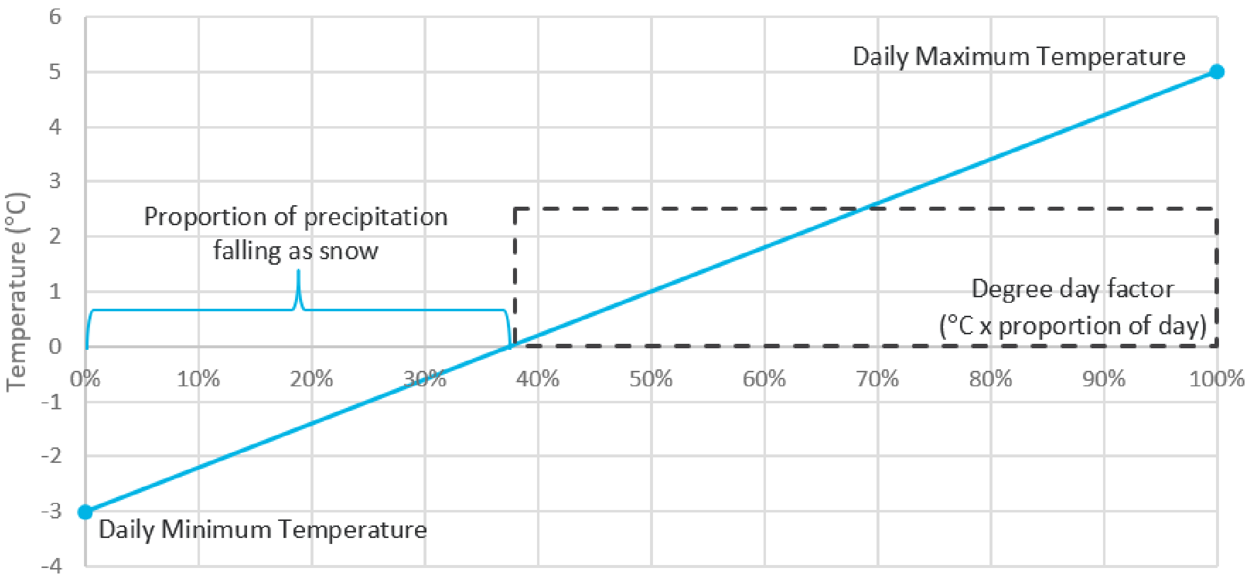


Figure B.18 Example of modelled snow fall proportion of precipitation and degree day factor based on daily minimum and maximum temperature

Daily minimum ground temperatures as provided by SILO dropped below 0°C each winter (Figure B.19), allowing the model to generate snow packs. However, daily maximum temperatures rarely dropped below 0°C (Figure B.20), meaning that snow melt was modelled to occur on most days, and modelled snow packs were short lived.

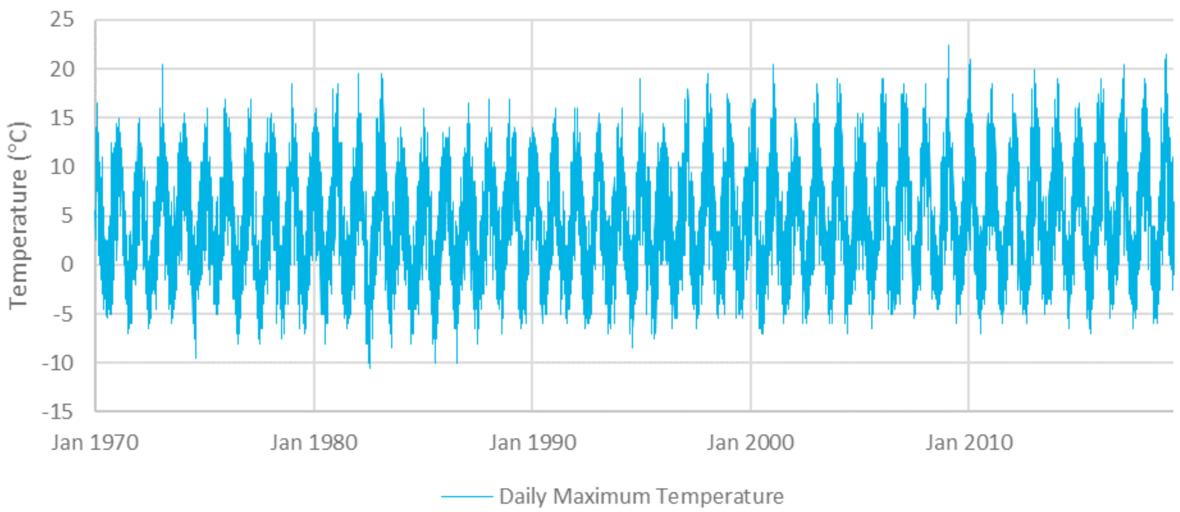


Figure B.19 Daily minimum temperature on the Murrumbidgee catchment plateau

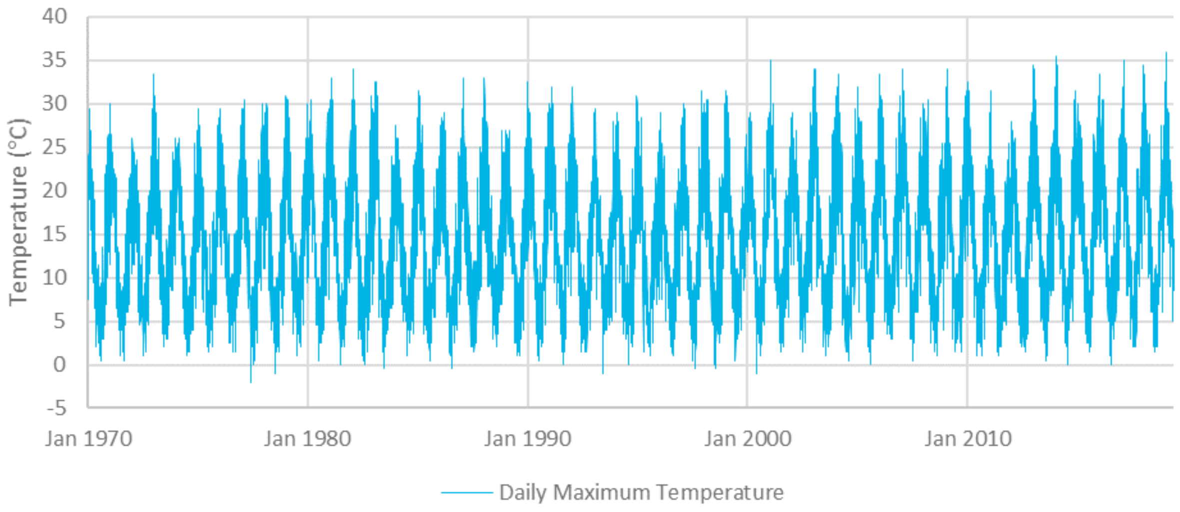


Figure B.20 Daily maximum temperature on the Murrumbidgee catchment plateau

This model resulted in snow pack depths of up to 90 mm precipitation as illustrated in Figure B.21. Snow density may range between 10 and 800 kg/m^3 depending on age and settlement (Seibert, Jenicek, Huss, & Ewen, 2015). In the case of a fresh snow with density of 100 kg/m^3, snow depths would be 10x the precipitation depths shown in Figure B.21 (ie up to 1 m deep on average across the catchment).

The store and release effect of the snow model on precipitation can be seen in Figure B.22, in which the frequency of days with no effective precipitation reduced from 51.8% of days to 51.3% of days. The frequency of days with effective precipitation of less than 10 mm/day increased slightly, while the frequency of days with effective precipitation greater than 10 mm/day decreased slightly. This change in effective precipitation was not of a large enough magnitude to affect the modelled streamflow (Figure B.23).

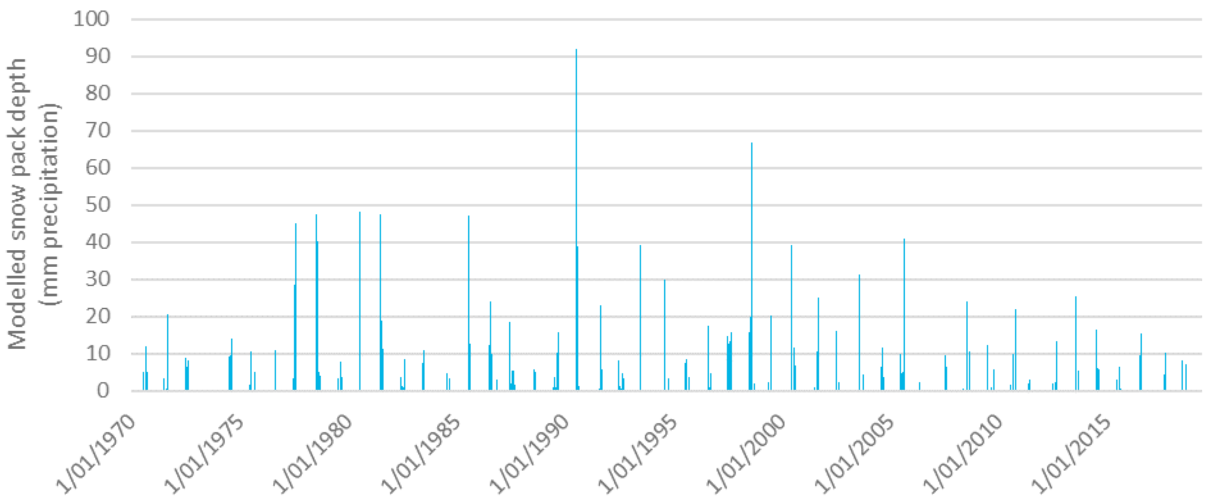


Figure B.21 Modelled snow pack depth

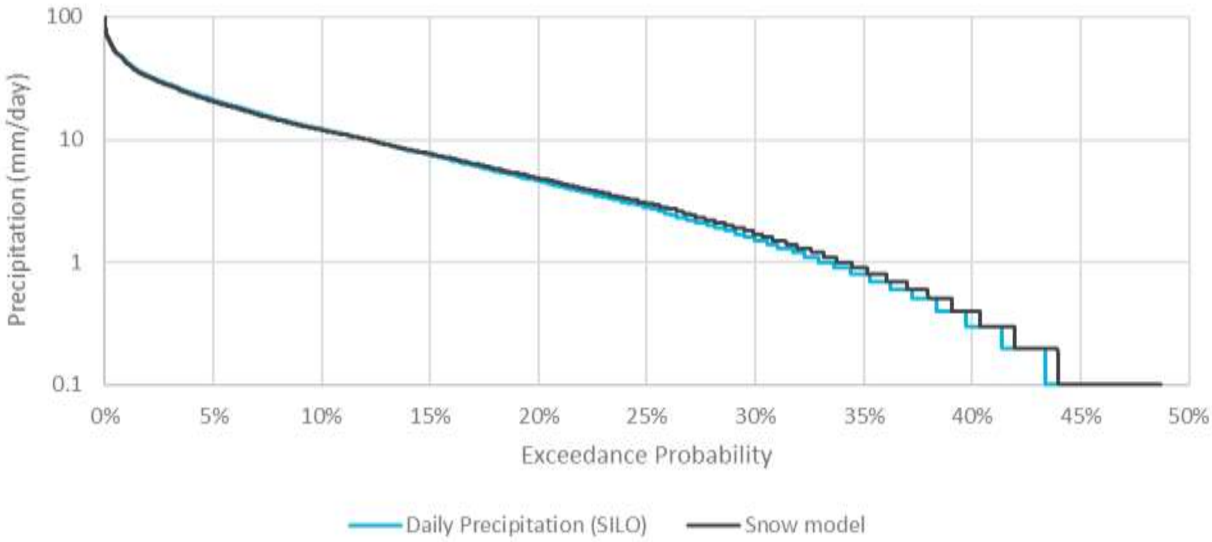


Figure B.22 Effective precipitation (rainfall plus snow melt)

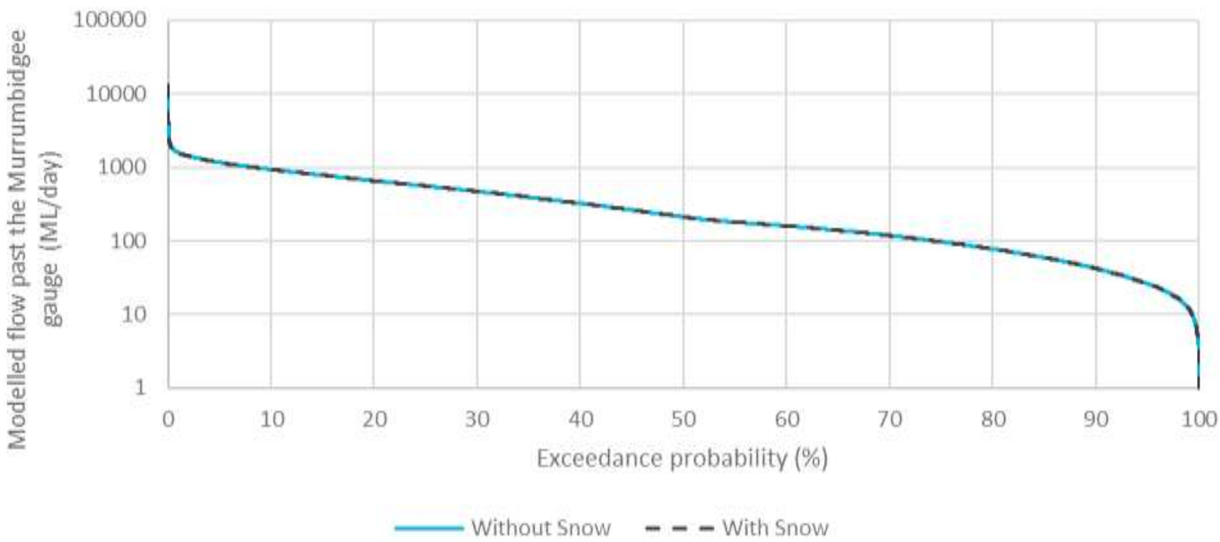


Figure B.23 Modelled Murrumbidgee gauge flow duration curve with and without snow model

It is possible that the snow pack model tests were confounded by the precipitation data utilised, as Chubb et al (2016) report that Bureau of Meteorology AWAP precipitation data and SILO precipitation data may under-record snowfall when the snowfall rate exceeds 3 mm/hr as at these snowfall rates the gauge heating is not sufficient to convert all snow into liquid water for gauging prior to wind effects removing some snow volume.

It is also possible that a more complex snow pack model could have produced a different result, as:

- the snow pack model tested did not utilise topographic data. It is likely that snow could remain in 'frost hollows' and shaded areas for longer than snow on open plains or in wide valleys receiving sunlight throughout the day;
- the temperature data utilised may not be applicable to the highest peaks within each sub-catchment. It is possible that the highest points are colder than the temperature dataset utilised indicates, leading to increased snowfall and snowfall retention in parts of some subcatchments; and
- the tested model melt rate calculation is relatively simple and not calibrated to local conditions.

As the snow modelling tests did not result in an alteration to model results, it was not included in the final Modified SIMHYD model.

iv Post-runoff evapotranspiration

During field investigations within the plateau region, it was noted that:

- downstream from groundwater discharge locations there was often a significant area of saturated soil, with vegetation utilising the discharged water prior to it reaching the larger creeks. In many cases, saturated alluvial material; and
- adjacent to some creeks was a significant width of saturated alluvial material supporting dense populations of grasses.

Based on these observations, it was thought that post-discharge/runoff evapotranspiration could be an important part of the plateau water balance.

An analysis of the project stream network spatial dataset was undertaken to determine the approximate portion of the plateau catchments that might contribute to post-discharge/runoff evapotranspiration. While some creeks appeared to support saturated alluvial systems in the order of 100 m wide, tributaries to these creeks and vegetation supported by groundwater seeps covered a smaller area. Spatial analysis showed that that approximately 5% of the plateau lies within 10 m of a mapped creek or creek tributary, which was taken as a reasonable estimate of the area that might contribute to post-discharge/runoff evapotranspiration.

Two methods for including post-discharge/runoff evapotranspiration were tested, as described below.

Method 1 (not implemented in the final model) utilised an 'alluvial' soil moisture store. This soil store was placed downstream of quickflow and baseflow elements, as shown in Figure B.24. Runoff and baseflow discharges wetted the alluvial soil store. Evapotranspiration was removed from the alluvial soil store as per the evapotranspiration function applied to the main soil moisture store. When the alluvial store filled due to runoff events, water was spilled to the creek. On non-rain days, the alluvial store was allowed to discharge to the creek using a linear recession equation.

The alluvial store acted as a buffer, or sponge, between the creek and the rest of the run off model. When using this method, the flow duration curves showed that a portion of the flows during runoff periods were detained and released some time later when streamflow was lower (Figure B.25). This resulted in two undesirable effects which ultimately led to this method being discarded:

- the modelled flow duration curves contained an inflection point not seen in the gauged flow data (Figure B.25); and
- the model over estimated total flow during low flow periods when compared to the gauged flow data.

This model result is consistent with the findings of Western et al (2009), who concluded that the conceptualisation of peatlands as 'sponges' that maintain baseflow does not conform with detailed hydrologic modelling, and that catchment baseflows appear to be driven by other mechanisms.

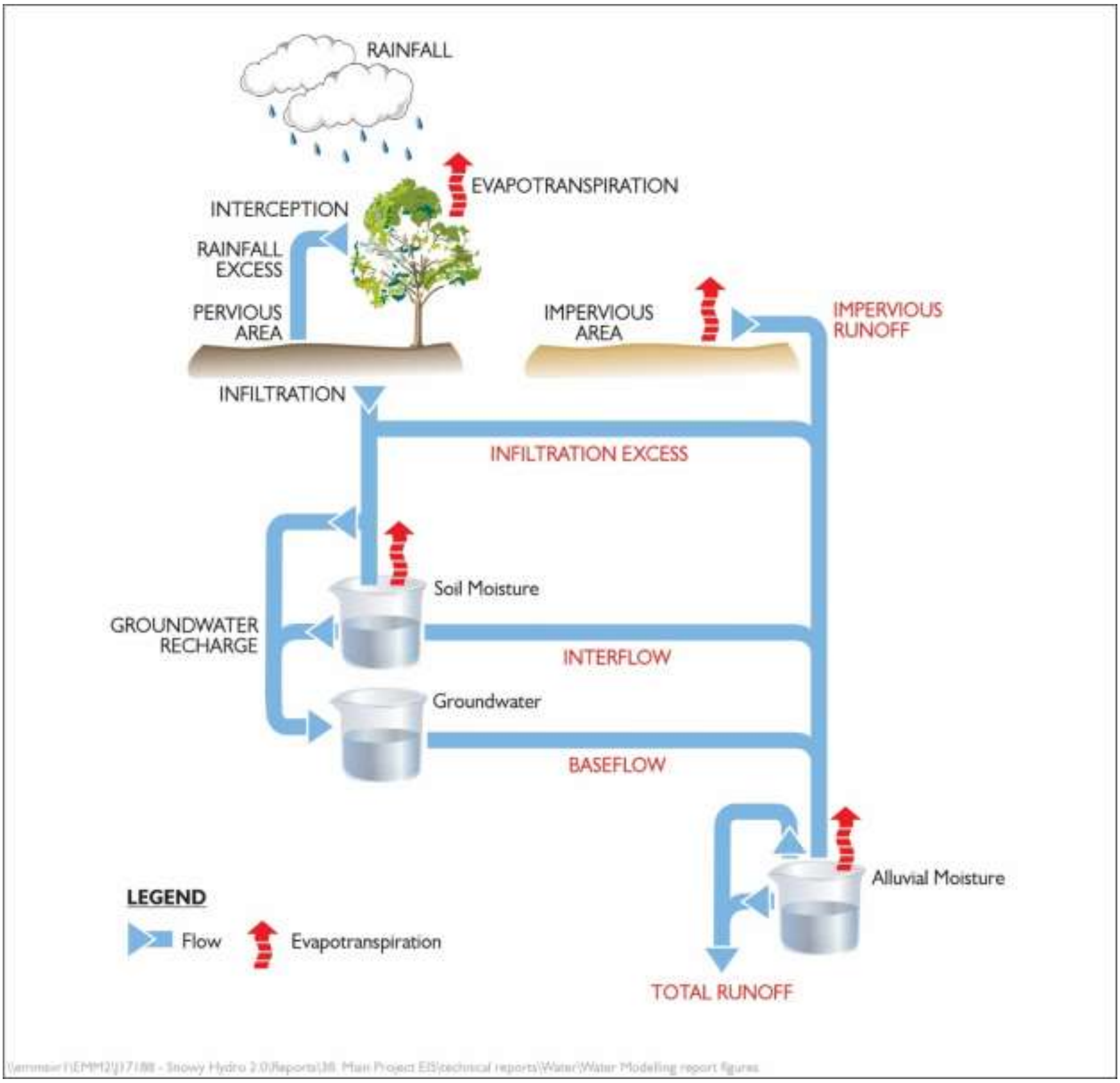


Figure B.24 Post-discharge ET Method 1 model arrangement

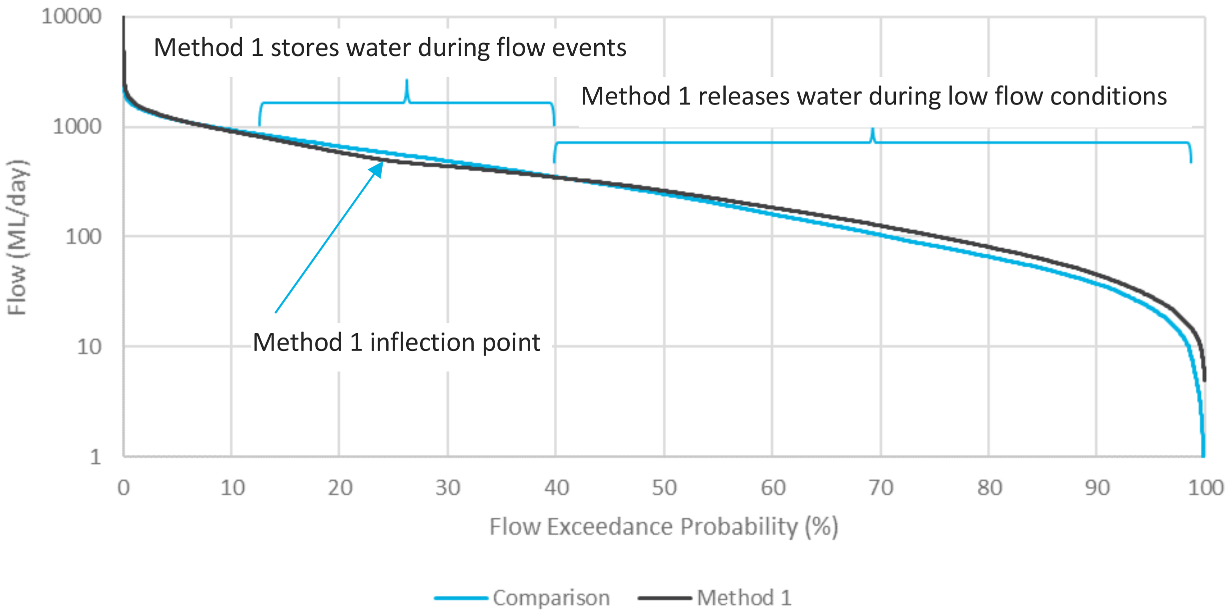


Figure B.25 'Method 1' for post-discharge ET modelling effects on flow duration curve

Method 2 (implemented in the final model) removed the estimated post-discharge evapotranspiration directly from the estimated daily runoff volume. Initial tests showed that this method improved calibration for flows above the 90th percentile, but that low flows were significantly reduced, resulting in an over estimation of the number of dry or no flow days that might occur. The calibration of low flows was markedly improved by introducing a scaling factor to the estimated post-discharge evapotranspiration when total daily runoff was less than 1 mm/day (illustrated in Figure B.26). This reduction of evapotranspiration when runoff is small appears appropriate, as less of the catchment would be saturated during dry conditions, and utilisation of water by vegetation would reduce. The scaling process applied was based on calibration of the flow duration curve, and was not based on physical characteristics of the catchment or vegetation.

The Method 2 post-discharge evapotranspiration function used in the final model is described in Equation B.4.

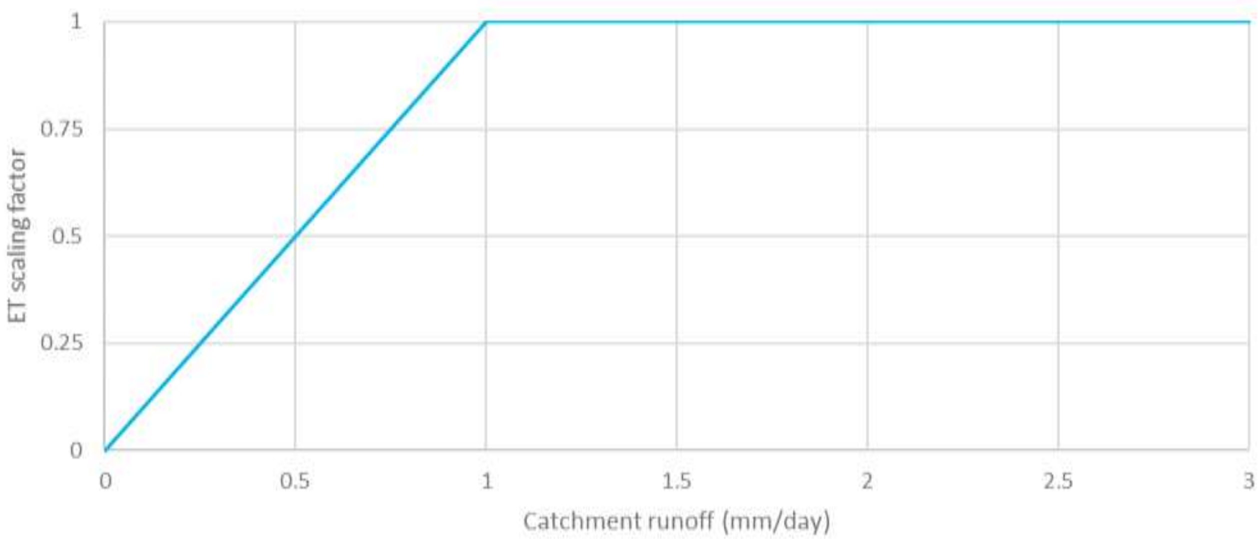


Figure B.26 Post-discharge ET scaling factor

Equation B.4 Post-discharge evapotranspiration

$$Post\ Discharge\ ET\left(\frac{mm}{day}\right) = ET\left(\frac{mm}{day}\right).Area(\%).ScaleFactor(\%)$$

v Tunnelling impacts

Two methods for applying the baseflow loss due to tunnel excavation predicted by the groundwater model were considered as described below. An example of the application of these methods targeting a 30% reduction in baseflow is provided in Figure B.27.

Method 1 (applied in the final model) was to add a 'leakage' term to the Modified SIMHYD groundwater store.

Method 2 (not applied) was to scale the daily baseflow time series with the reduction factor obtained from the groundwater model. When compared to the leakage method, this method would result in greater loss of baseflow during high flow periods, and smaller loss of baseflow during low flow periods (Figure B.27). This method would not result in a prediction of total loss of baseflow. This method would have been simple to apply, but is not based on a physical loss mechanism and so was discounted. This method would also have been less conservative, predicting a smaller impact during dry periods than the chosen method.

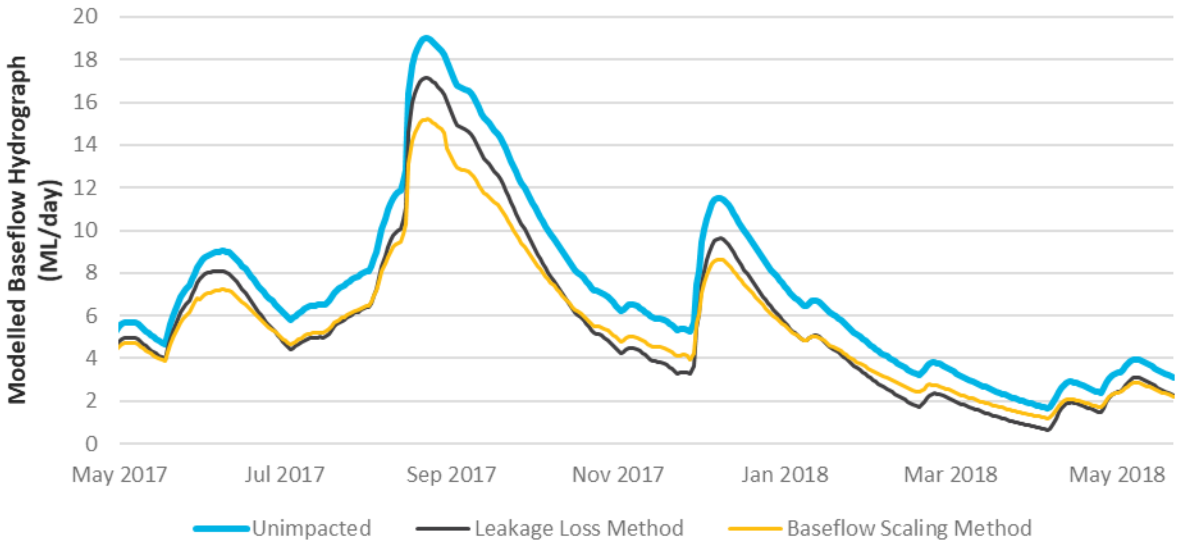


Figure B.27 Example modelled baseflow hydrographs

vi Groundwater discharge lag

The Q-Lag analysis (section 2.3) indicated that there is a lag between precipitation within the project area and discharge of groundwater as baseflow within local creeks and rivers. Accounting for such lags can be of importance when modelling the movement of water through the landscape (Rassam, Jolly, & Pickett, 2012).

Incorporation of a such a lag in the rainfall runoff model was tested by modifying the groundwater change equation as per Equation B.5 using a lag of 20 days as per the Q-Lag cross-correlation analysis presented in Figure 2.9. This method resulted in an increase in flow on low flow days, and a decrease in flow on higher flow days.

Equation B.5 Delayed groundwater recharge

$$GroundwaterStore_i = GroundwaterStore_{i-1} + Recharge_{i-x}$$

Where i represents the current model day, and x represents the lag in days.

The method presented in Equation B.5 may be an over simplification of the processes at work in the environment, as it is likely that baseflow discharges would increase in magnitude soon after rainfall. This method did not improve calibration, and was not included in the final model.

Groundwater discharge lag is included in the eWater Source rainfall runoff model PERFECT GWlag (eWater, n.d.). This rainfall runoff model was not tested as it was developed for irrigated farmland, and requires crop and soil horizon parameters which are either not appropriate or for which data doesn’t exist at the project site. The GWlag portion of this model could possibly be recoded to work with the modified SIMHYD model presented here, but such coding was not undertaken during this project.

vii Final model configuration

The modified model is illustrated in Figure B.28, in which the following alterations to the SIMHYD model can be seen:

- interflow is extracted from the soil moisture store, and may occur on non-rain days;
- groundwater recharge from the soil moisture store may occur on non-rain days;
- quickflow and baseflow from the upper catchment are subject to evapotranspiration immediately prior to being added to creek flow; and
- leakage may be extracted from the groundwater store, allowing simulation of the effects of the power waterway excavation.

The model equation set is provided in Attachment C. The following parameters remain in the modified model unchanged from their definition in the standard SIMHYD model:

- interception capacity;
- impervious capacity;
- infiltration coefficient;
- infiltration exponent SQ; and
- groundwater recession.

Parameters not found in the standard SIMHYD model include:

- interflow coefficient;
- minimum saturation;
- groundwater leakage; and
- ‘Alluvial’ area.

The recharge parameter in the modified model is similar to the recharge parameter found in the standard SIMHYD model, but utilises the concept of a minimum saturation required for groundwater recharge.

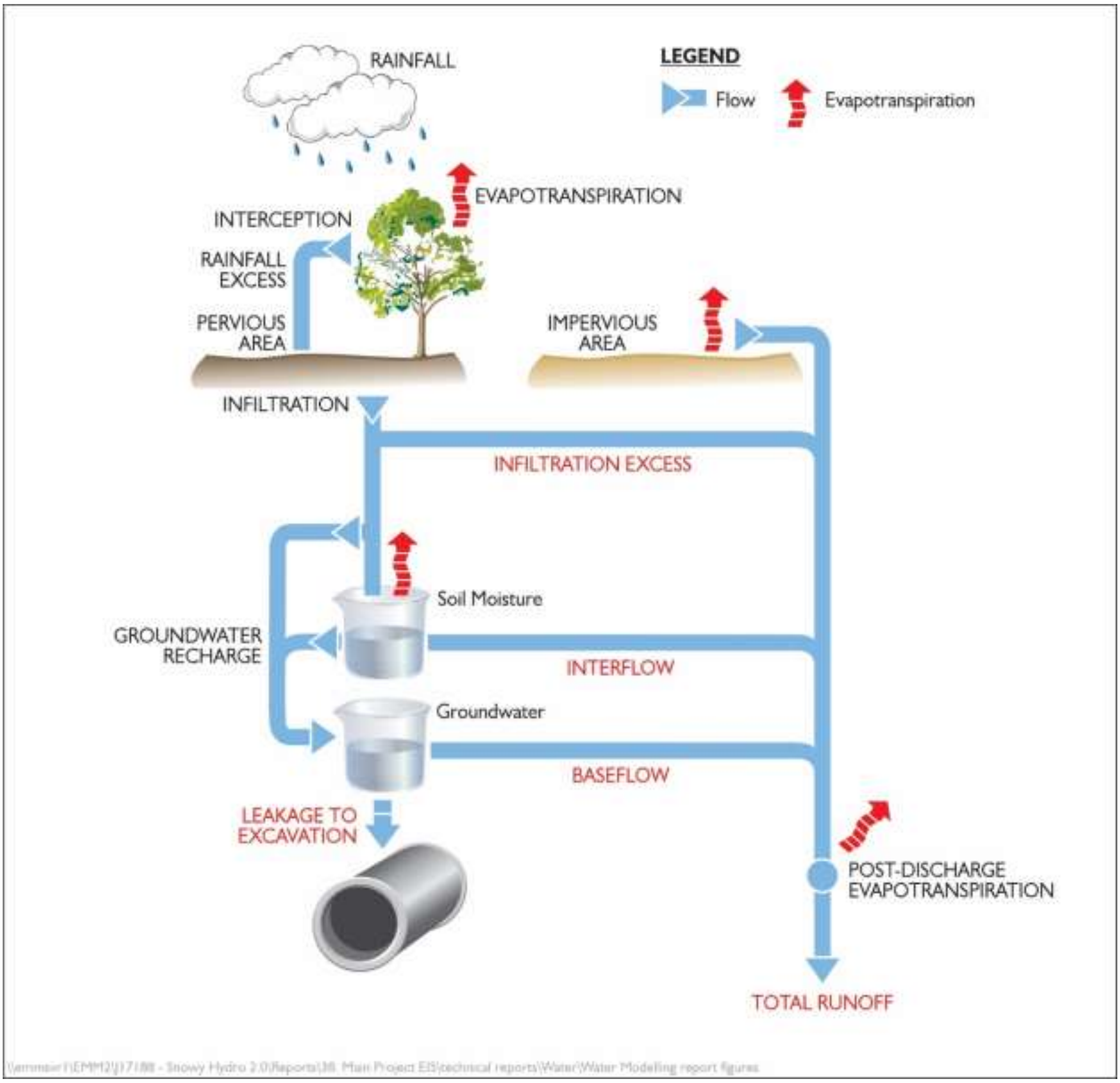


Figure B.28 Modified SIMHYD

B.5.3 Calibration

During calibration of the modified SIMHYD model the impervious fraction was held at 0% for all catchments as the region is undeveloped other than roads and tracks.

The groundwater linear recession parameter was held at 2%, based on the studies presented in section 2.2.

When using the modified SIMHYD model, good NSE statistics (>60%) were obtained for all reported metrics other than the Yarrangobilly daily flow (Table B.4).

A range of parameter sets were found to provide similar NSE statistics. Those which produced a BFI of approximately 40% were selected for reporting.

Table B.4 Modified SIMHYD model calibration statistics

	Yarrangobilly	Murrumbidgee
Volume Bias	-0.59%	-8.64%
NSE Daily	48%	61%
NSE Log Daily	79%	75%
NSE Daily and Log Flow Duration	69%	80%
NSE Monthly	83%	72%
Baseflow Index	39%	39%

The frequency of flow events between 20−1,000 ML/day was well matched by the modified SIMHYD model at the Murrumbidgee gauge, with the frequency of higher and lower flow events slightly under estimated (Figure B.29). The model provided a good estimate of the frequency of flow events between 50−700 ML/day at the Yarrangobilly gauge, but predicted lower flows than have been recorded (lowest flow of 1 ML/day in the model vs 10 ML/day recorded at the gauge) (Figure B.30).

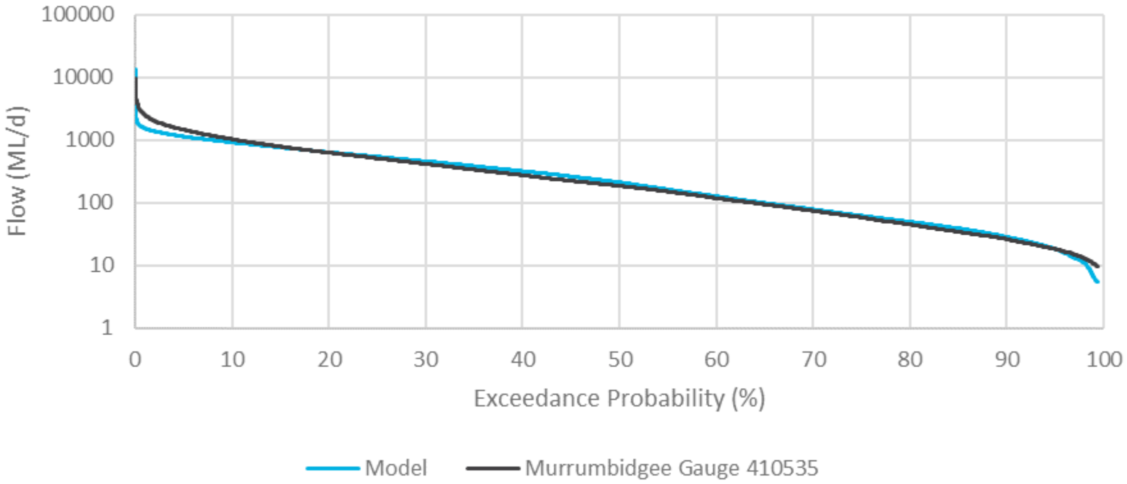


Figure B.29 Murrumbidgee flow duration curve (modified SIMHYD)

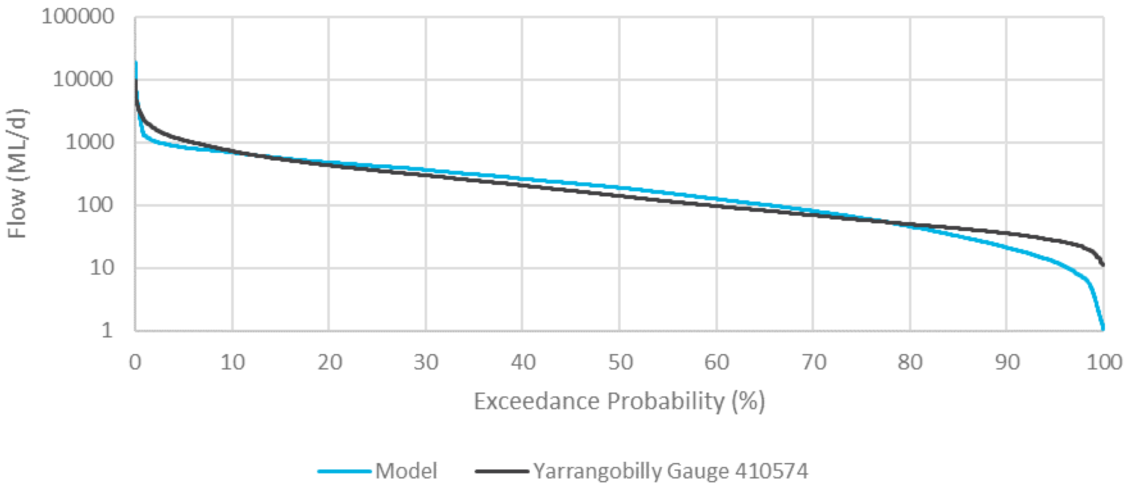


Figure B.30 Yarrangobilly flow duration curve (modified SIMHYD)

The modelled and recorded 1995 daily streamflow at both calibration gauges are presented in Figure B.31 and Figure B.32 as an example of model performance. These plots show:

- there was a very good fit between measured and modelled runoff event magnitudes at the Murrumbidgee gauge;
- the modelled recession rate closely matched the measured data at the Murrumbidgee gauge; and
- the calibrated parameters for the Yarrangobilly gauge produced hydrographs with accentuated peaks on rain days and a poor match for recession rates.

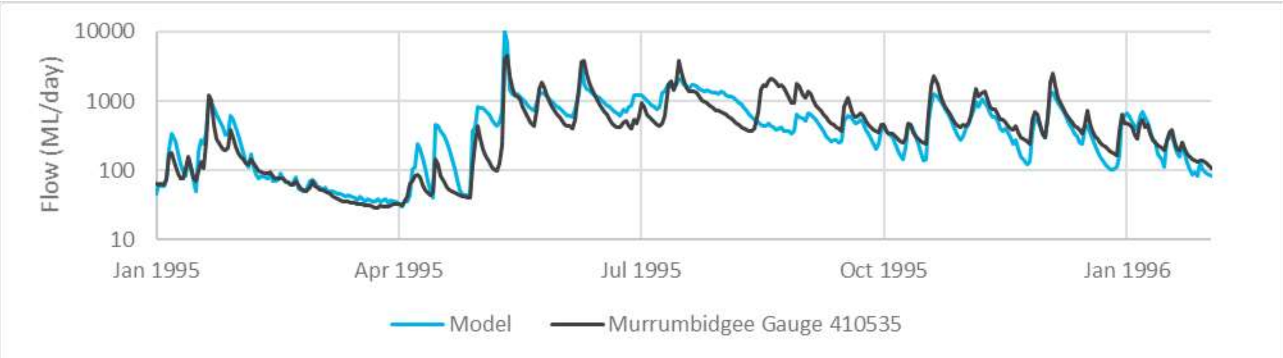


Figure B.31 Murrumbidgee 1995 modelled and recorded flow (modified SIMHYD)

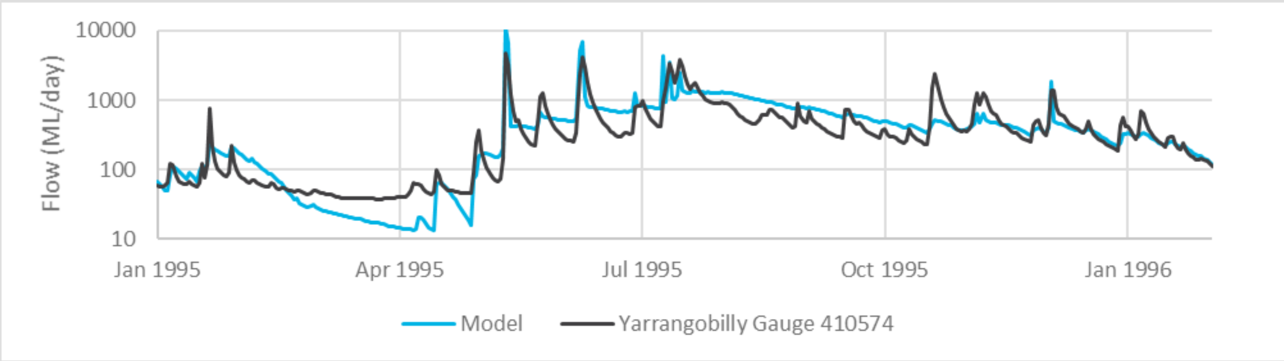


Figure B.32 Yarrangobilly 1995 modelled and recorded flow (modified SIMHYD)

B.6 Calibration summary

The calibration statistics calculated from the full model output series for each of the tested catchment runoff models are summarised in Table B.5. These statistics were used to compare the relative performance of the runoff model candidates in terms of volume bias, the general fit of the hydrograph as described by several NSE statistics, and the baseflow proportion.

It was anticipated that project impacts on streamflow may be of more importance during summer when streamflow is generally low, and so the calibration statistics for each of the model considering the months January to April (inclusive) (presented in Table B.6) were also investigated. The primary statistic investigated using this reduced data set was the low flow volume bias. These statistics show that each of the runoff models over estimated flow during the low flow summer period, other than the Modified SIMHYD model when simulating the Yarrangobilly catchment. Within the Murrumbidgee catchment, the GR4J model produced the smallest overestimate of flow (37% overestimate), followed by the Modified SIMHYD model (51% overestimate). Within the Yarrangobilly catchment, the Modified SIMHYD model produced the smallest mass error, with an under prediction of 8%.

Within both the Yarrangobilly and Murrumbidgee catchments, the GR4J model produced excellent NSE metrics and favourable volume biases. However, the baseflow proportion of streamflow was based on a numerical filter with filter parameters selected such that the baseflow index matched a value selected prior to modelling, reducing the utility of the model as a baseflow prediction tool. The model was ultimately discounted as the groundwater recharge-discharge pathway was not modelled explicitly and data required by the groundwater model calibration process could not be provided when using the GR4J runoff model.

When considering the Murrumbidgee catchment, the Modified SIMHYD model:

- explicitly modelled water pathways of interest to the project;
- produced good calibration statistics when using the full model outputs:
  - achieved the best average of NSE metrics from amongst the tested models;
  - was the only model with a Daily NSE of >60%;
  - produced a baseflow index within the expected range (see section 2.2.5); and
- produced a lower January–May volume bias than the SIMHYD and AWBM models (though not as low as GR4J).

Given the above, the Modified SIMHYD model was chosen for simulating catchment processes within the plateau catchments.

When considering the Yarrangobilly catchment:

- each of the models produced similar NSE statistics when considering the full model outputs, with the average of the presented statistics >70% for each model;
- the SIMHYD model produced a baseflow index outside the expected range (see section 2.2.5) and so was discounted as a candidate for further modelling; and
- the Modified SIMHYD model produced the closest estimate of the volume of low flows during January–April.

Given the above, either the AWBM or the Modified SIMHYD runoff models could have been applied. The AWBM model produced a better fit to the Yarrangobilly full streamflow hydrograph, while the Modified SIMHYD model provided a better representation of the flow processes thought to be important within the catchment and the volume of summer flows.

As the purpose of modelling was to develop information regarding catchment flow processes with the expectation that summer flows would likely be ecologically important, the Modified SIMHYD model was chosen over the AWBM model for modelling the ravine area.

Table B.5 Comparison of calibration statistics for the trialled runoff models (full year)

		SIMHYD	AWBM	GR4J	Mod SIMHYD
Murrumbidgee catchment					
	Volume Bias	-1%	-5%	-6%	-8%
	NSE Daily	42%	45%	57%	61%
	NSE Log Daily	66%	63%	78%	75%
	NSE Daily and log flow Duration	71%	72%	76%	80%
	NSE Monthly	57%	53%	68%	72%
	Average of NSE metrics	**59%**	**58%**	**70%**	**72%**
	Baseflow Index	78%	40%	38%	39%
Yarrangobilly catchment					
	Volume Bias	0%	2%	-2%	0.6%
	NSE Daily	56%	66%	81%	48%
	NSE Log Daily	74%	76%	91%	79%
	NSE Daily and log flow Duration	76%	82%	90%	69%
	NSE Monthly	80%	74%	90%	83%
	Average of NSE metrics	**72%**	**74%**	**88%**	**70%**
	Baseflow Index	65%	40%	38%	39%

Table B.6 Comparison of calibration statistics for the trialled runoff models (1 Jan–1 May)

		SIMHYD	AWBM	GR4J	Mod SIMHYD
Murrumbidgee catchment					
	Volume Bias	**82%**	**88%**	**37%**	**51%**
	NSE Daily	29%	15%	70%	54%
	NSE Log Daily	18%	15%	58%	46%
	NSE Daily and log flow Duration	47%	41%	74%	71%
	NSE Monthly	36%	22%	74%	61%
	Average of NSE metrics	32%	23%	69%	58%
Yarrangobilly catchment					
	Volume Bias	**39%**	**24%**	**21%**	**-7.6%**
	NSE Daily	53%	64%	79%	30%
	NSE Log Daily	39%	46%	79%	66%
	NSE Daily and log flow Duration	63%	74%	85%	48%
	NSE Monthly	77%	80%	89%	92%
	Average of NSE metrics	58%	66%	83%	59%

B.7 Opportunities for model calibration improvement during project delivery

The groundwater model predicts evapotranspiration from the regional watertable, particularly in low lying areas such as land adjacent to creeks and reservoirs, while the surface water framework does not allow modelling of evapotranspiration from the groundwater store. This leads to a disconnect between the discharge portions of the water balance of the two models. This disconnect is acknowledged in the presented modelling work and as a result the groundwater baseflow impacts due to tunnelling are scaled to reduce the influence of evapotranspiration uncertainty. If monitoring during construction indicates that model recalibration is warranted, a possible model linkage improvement that could be made at that time is:

- investigate the magnitude of evapotranspiration from the regional groundwater predicted by the groundwater model;
- alter the modified SIMHYD model such that a portion of the soil moisture evapotranspiration instead is withdrawn from the groundwater store, with that portion informed by the groundwater model results;
- recalibrate the modified SIMHYD model, as increased recharge would be required to sustain evapotranspiration from the groundwater store;
- rerun the groundwater model with the increased recharge, and recalibrate river boundary conditions to the new conditions; and
- the groundwater model recalibration would alter evapotranspiration estimates, leading to iteration of the above process until consistent results are obtained.

The above process would be complicated by the scale and precision of the groundwater model, as it is expected that some of the evapotranspiration predicted by the groundwater model would be better described as baseflow in locations where groundwater reaching the surface on hill slopes runs off and forms creek headwaters.

The calibration of the ravine region could be further investigated if monitoring during construction indicates that impacts in Wallaces Creek or Stable Creek may be greater than anticipated. Opportunities for calibration improvement include:

- analysis of data from the Snowy Hydro precipitation network, particularly focussing on the Lobs Hole data, which shows lower average rainfall than the SILO grid at that location. As the Snowy Hydro precipitation data record does not coincide with the Wallaces Creek streamflow record, scaling of the pre-1990 SILO data could be employed to allow re-calibration to that gauge;
- use of alternate parameter sets within Wallaces and Stable Creek reflecting the increased relief within these catchments (compared to the rest of the Yarrangobilly catchment); and
- investigation of cross-catchment groundwater flow paths, as the Yarrangobilly River may be receiving baseflow discharge from groundwater originating on the plateau.

The above potential sources of calibration improvement were not investigated during the EIS as the model calibration obtained indicated that the models appear to be suitable for the purpose of transforming the predicted groundwater impacts into predicted streamflow impacts. These opportunities are documented to illustrate that a pathway exists for prediction improvement if monitoring during construction indicates a departure from the model results.

Attachment C

Modified SIMHYD model

C.1 Model Description

The runoff model presented here was based on the SIMHYD model, with a number of additions and alterations made in an attempt to represent flow pathways believed to be important at the Snowy 2.0 project site.

The modified SIMHYD model equation set is provided below. The following variables are inputs to the set of equations:

- Rainfall (or precipitation) as a daily time series.
- Potential evapotranspiration as a daily time series.
- Interception capacity (mm/day) — Standard SIMHYD model rainfall interception capacity, eg due to vegetation. Applied across pervious, perched, and alluvial catchment fractions.
- Impervious capacity (mm/day) — Standard SIMHYD model impervious area capacity.
- SMSC (mm) — Standard SIMHYD model Soil Moisture Store Capacity.
- Infiltration Coefficient (mm/day) — Standard SIMHYD model maximum infiltration rate parameter.
- Interflow Coefficient (mm/day) — Interflow rate at saturation.
- Recharge Coefficient (mm/day) — Groundwater recharge rate at saturation.
- SQ — Standard SIMHYD model infiltration shape parameter.
- Minimum Saturation (%) — Minimum saturation percent before interflow and recharge processes activate.
- Groundwater recession (1/day) — Standard SIMHYD model groundwater recession parameter.
- Groundwater leakage (mm/day) — Loss rate or time series from the groundwater store.
- $Fraction_{Pervious}$ and $Fraction_{Impervious}$ — Fractional area of catchment.
- Alluvial Area — The percentage of the catchment in which post discharge ET processes are thought to take place. Included within the $Fraction_{Pervious}$ area for calculation of runoff.

C.2 Impervious Runoff

$$Runoff_{Impervious} = (Rainfall - ImperviousCapacity)$$

C.3 Pervious Runoff

$$Throughfall = Rainfall - InterceptionCapacity$$

$$Moisture\ Fraction_t = \frac{SoilMoisture_t}{SMSC}$$

$$MaxInfiltration = InfiltrationCoefficient^{-SQ.MoistureFraction_t}$$

$$Infiltration = Min(MaxInfiltration, Throughfall)$$

$$InfiltrationExcess = Throughfall - Infiltration$$

$$SoilMoisture_X = SoilMoisture_t + Infiltration$$

$$Moisture\ Fraction_X = \frac{SoilMoisture_X}{SMSC}$$

$$Saturation\ Variable = \frac{Moisture\ Fraction_X - MinSat}{1 - MinSat}$$

$$Interflow = Interflow\ Coefficient.Saturation\ Variable$$

$$Recharge = Recharge\ Coefficient.Saturation\ Variable$$

$$SoilMoisture_Y = SoilMoisture_X - Interflow - Recharge$$

$$If\ SoilMoisture_Y > SMSC$$

$$Recharge = Recharge + SoilMoisture_Y - SMSC$$

$$SoilMoisture_Y = SMSC$$

$$GroundwaterStore_X = GroundwaterStore_t + Recharge$$

$$[Optional: GroundwaterStore_X = GroundwaterStore_X - Leakage]$$

$$Baseflow = GroundwaterStore_{t+1}.BaseflowRecessionConstant$$

$$GroundwaterStore_{t+1} = GroundwaterStore_X - Baseflow$$

$$InterceptionET = Min(Rainfall, PET, InterceptionCapacity)$$

$$SoilET = Min\ (SMSC, PET - InterceptionET, Moisture\ Fraction_X.SIMHYD\_ET\_CONSTANT)$$

$$SoilMoisture_{t+1} = SoilMoisture_Y - SoilET$$

$$Runoff_{Pervious} = InfiltrationExcess + Interflow + Baseflow$$

C.4 Post-discharge ET

$$Runoff_{Pre} = Runoff_{Impervious}.Fraction_{Impervious} + Runoff_{Pervious}.Fraction_{Pervious}$$

$$ScaleFactor = If\ (Runoff_{Pre} > 1\ mm/day)\ then\ 1\ Else\ \left(\frac{Runoff_{Pre}}{1\ mm/day}\right)$$

$$PostDischargeET = PET.AlluvialArea.ScaleFactor$$

$$Runoff_{Post} = Runoff_{Pre} - PostDischargeET$$

Attachment D

Construction period streamflow hydrographs

D.1 Gooandra Creek

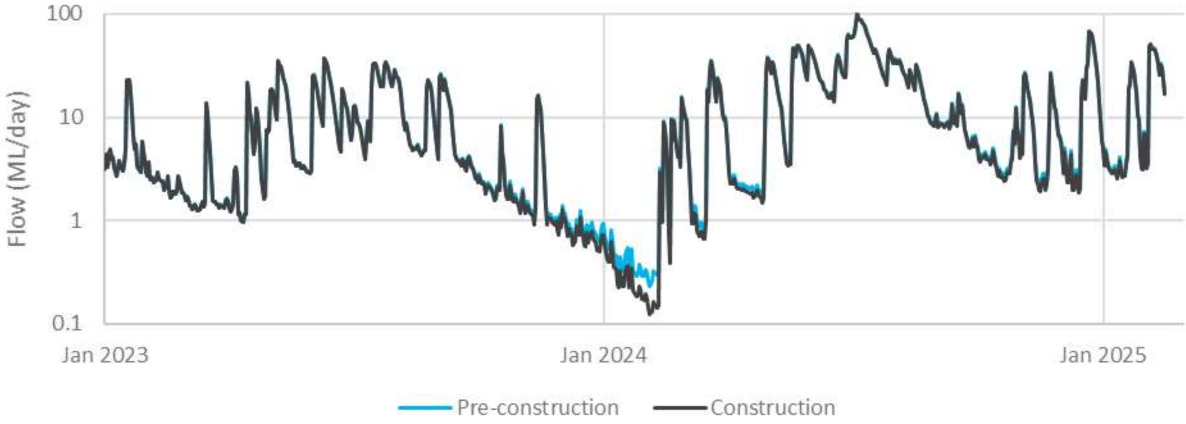


Figure D.1 Gooandra Creek Site 3 streamflow hydrograph during construction (dry climate)

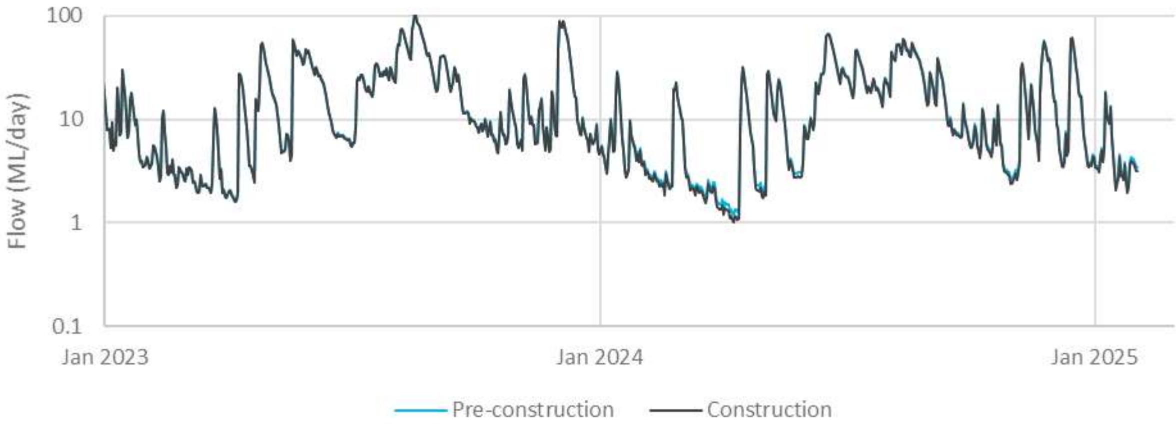


Figure D.2 Gooandra Creek Site 3 streamflow hydrograph during construction (average climate)

Figure D.3 Gooandra Creek Site 3 streamflow hydrograph during construction (wet climate)

D.2 Eucumbene River

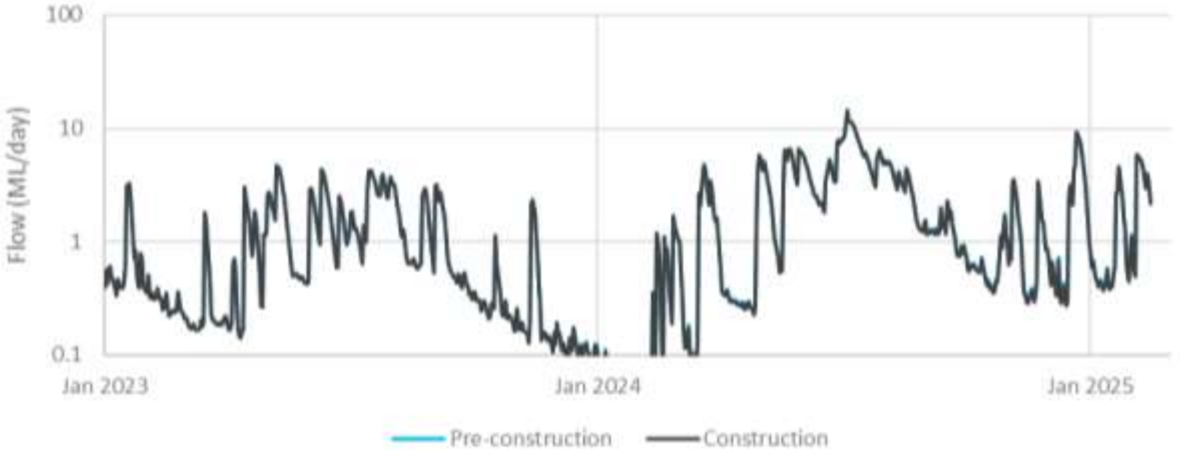


Figure D.4 Eucumbene River Site 9 streamflow hydrograph during construction (dry climate)

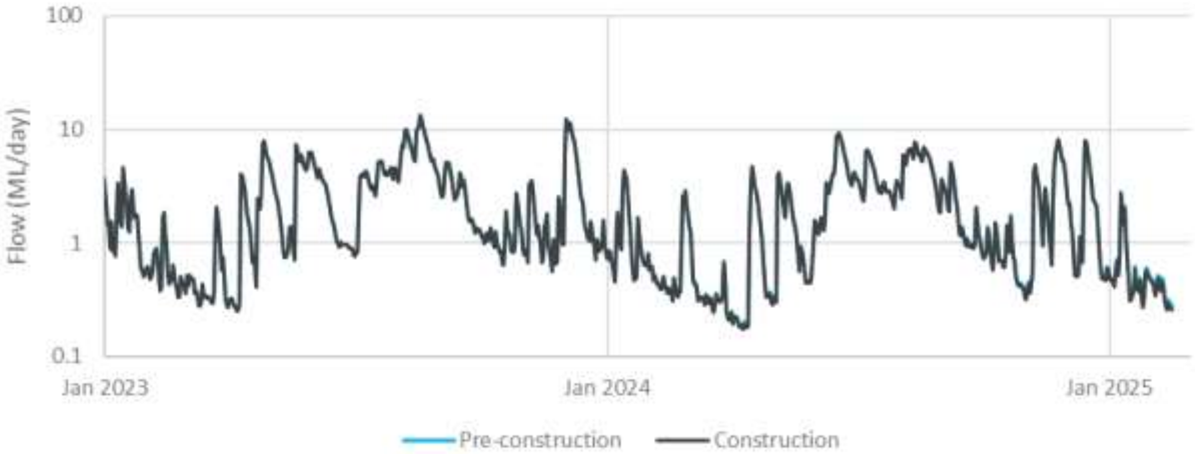


Figure D.5 Eucumbene River Site 9 streamflow hydrograph during construction (average climate)

Figure D.6 Eucumbene River Site 9 streamflow hydrograph during construction (wet climate)

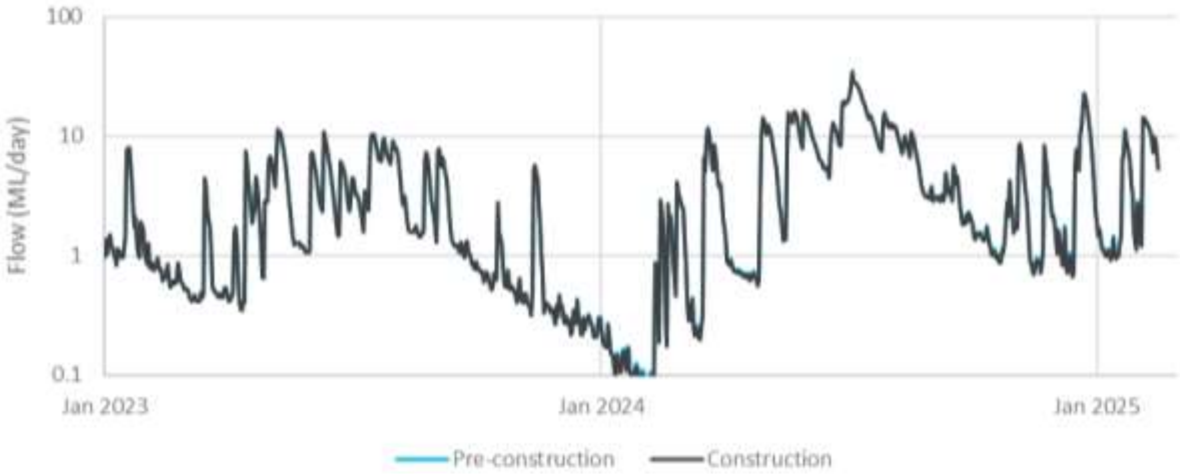


Figure D.7 **Eucumbene River Site 10 streamflow hydrograph during construction (dry climate)**

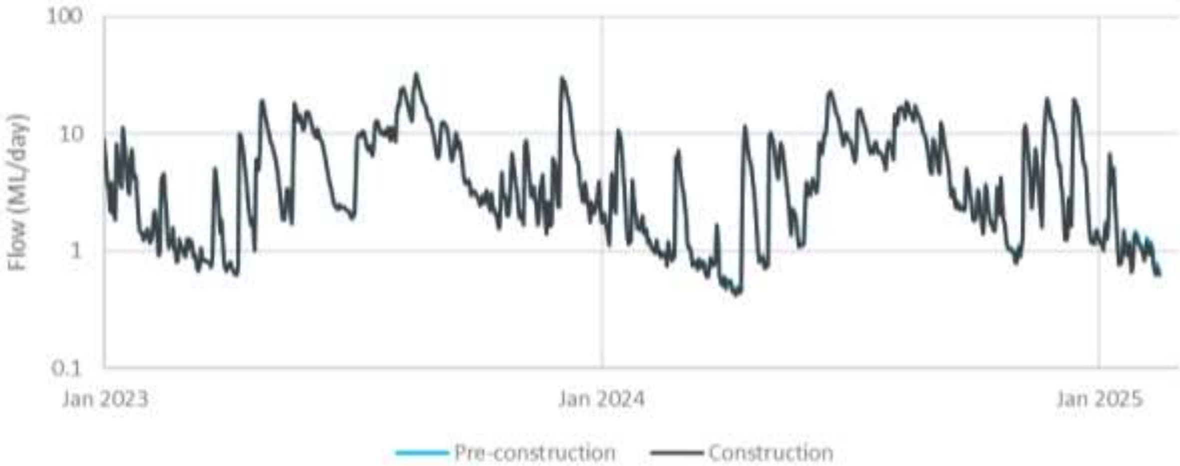


Figure D.8 **Eucumbene River Site 10 streamflow hydrograph during construction (average climate)**

Figure D.9 **Eucumbene River Site 10 streamflow hydrograph during construction (wet climate)**

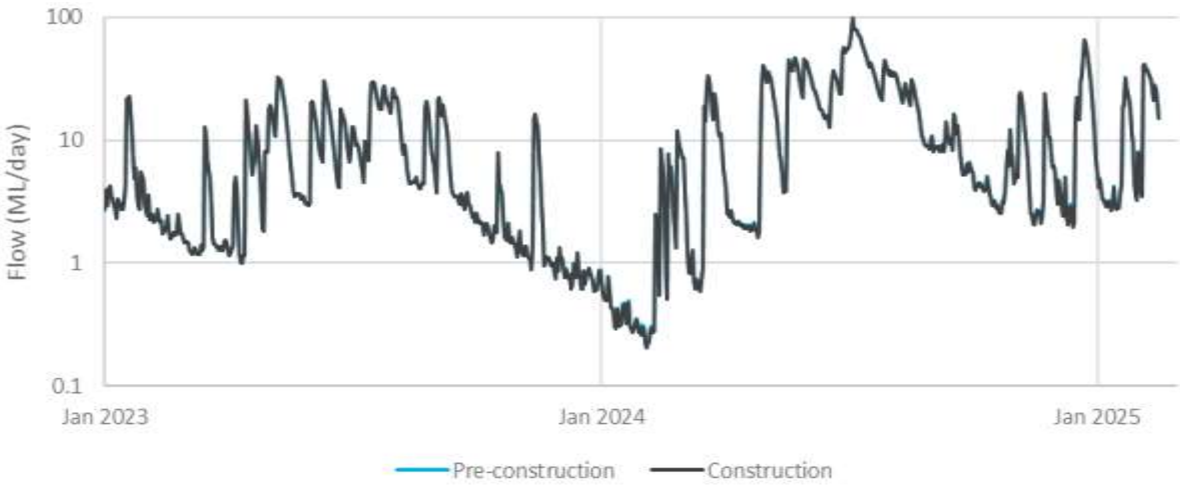


Figure D.10 Eucumbene River Site 11 streamflow hydrograph during construction (dry climate)

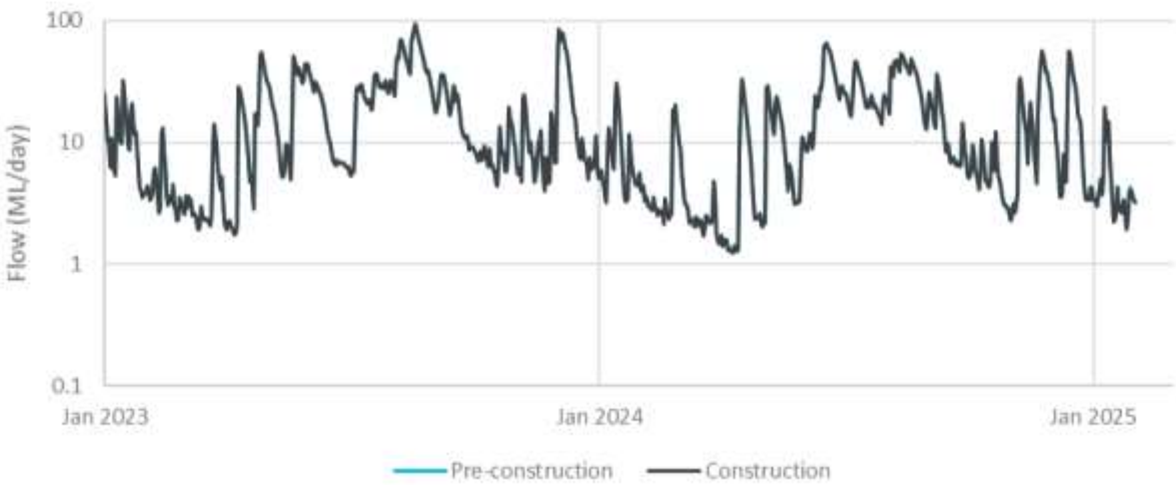


Figure D.11 Eucumbene River Site 11 streamflow hydrograph during construction (average climate)

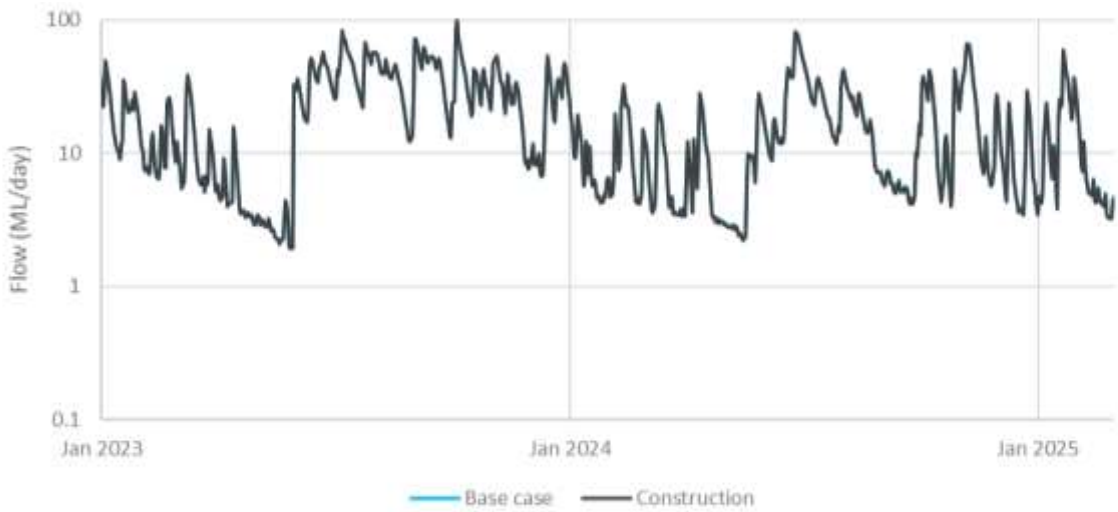
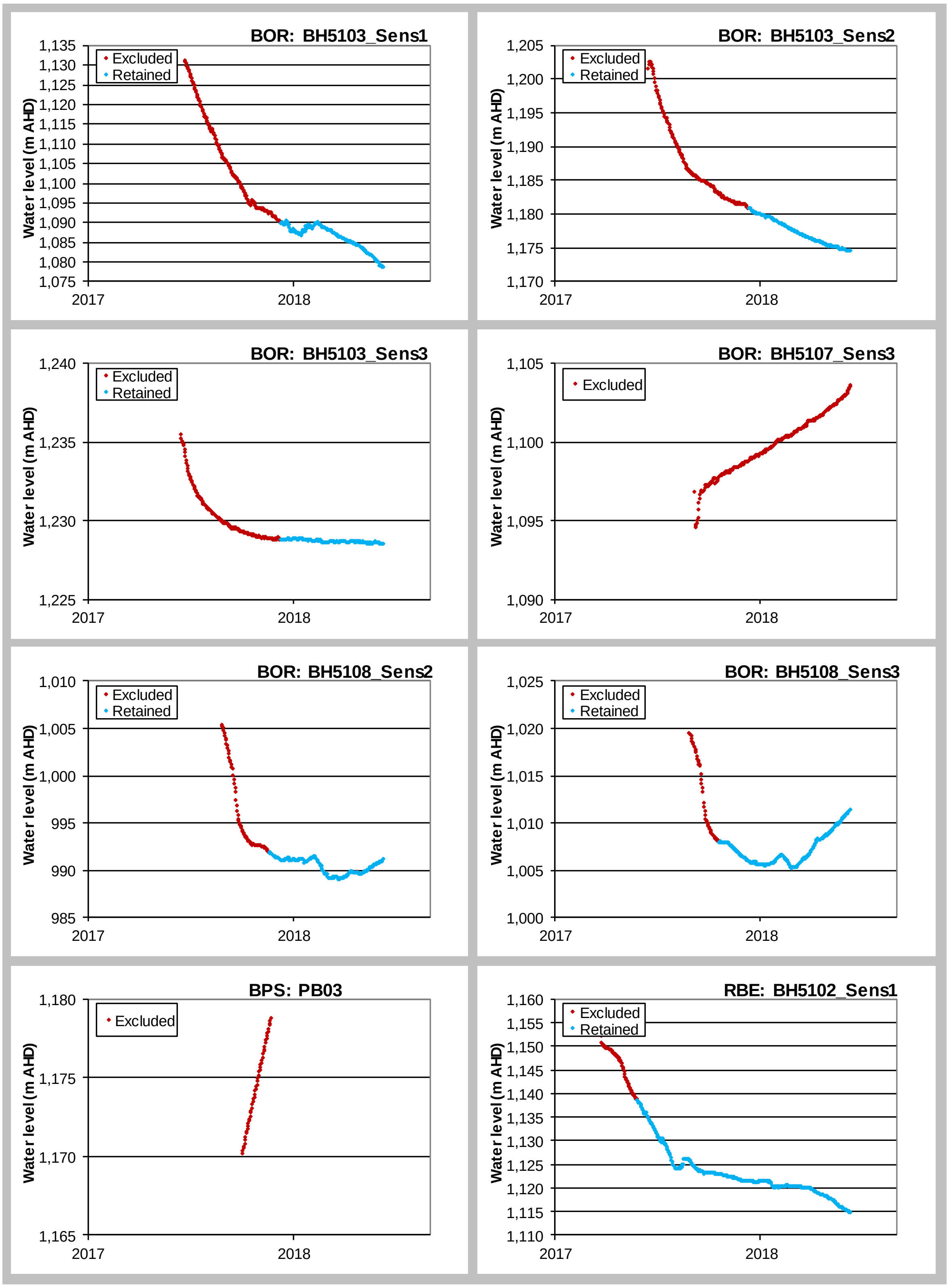


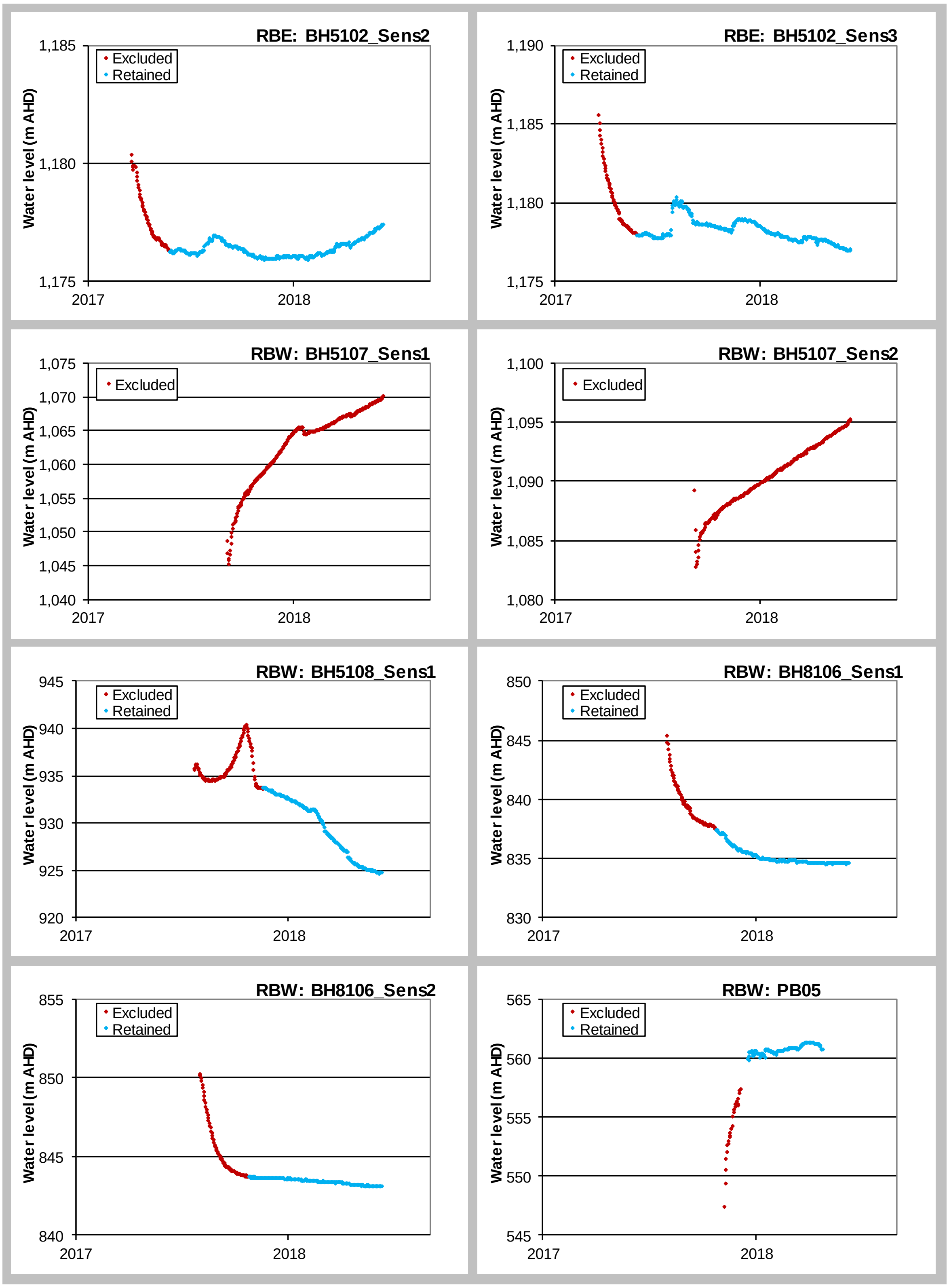
Figure D.12 Eucumbene River Site 11 streamflow hydrograph during construction (wet climate)

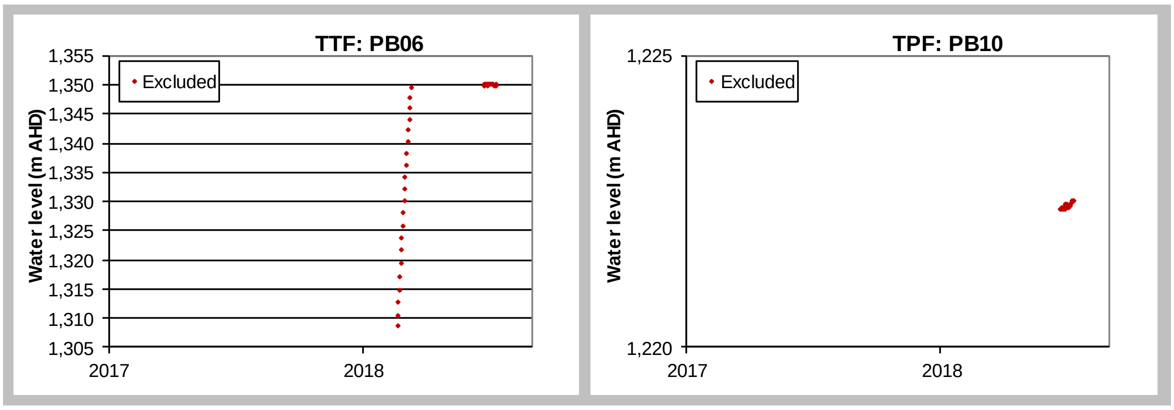
Attachment E

Data excluded from the groundwater model calibration



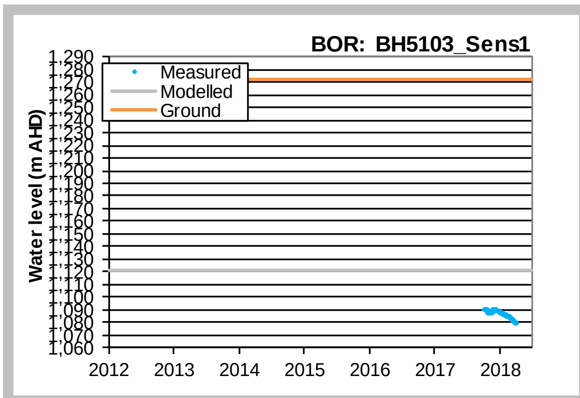
BOR: BH5103_Sens1
Excluded
Retained
Water level (m AHD)
1,135
1,130
1,125
1,120
1,115
1,110
1,105
1,100
1,095
1,090
1,085
1,080
1,075
2017
2018
BOR: BH5103_Sens2
Excluded
Retained
Water level (m AHD)
1,205
1,200
1,195
1,190
1,185
1,180
1,175
1,170
2017
2018
BOR: BH5103_Sens3
Excluded
Retained
Water level (m AHD)
1,240
1,235
1,230
1,225
2017
2018
BOR: BH5107_Sens3
Excluded
Water level (m AHD)
1,105
1,100
1,095
1,090
2017
2018
BOR: BH5108_Sens2
Excluded
Retained
Water level (m AHD)
1,010
1,005
1,000
995
990
985
2017
2018
BOR: BH5108_Sens3
Excluded
Retained
Water level (m AHD)
1,025
1,020
1,015
1,010
1,005
1,000
2017
2018
BPS: PB03
Excluded
Water level (m AHD)
1,180
1,175
1,170
1,165
2017
2018
RBE: BH5102_Sens1
Excluded
Retained
Water level (m AHD)
1,160
1,155
1,150
1,145
1,140
1,135
1,130
1,125
1,120
1,115
1,110
2017
2018

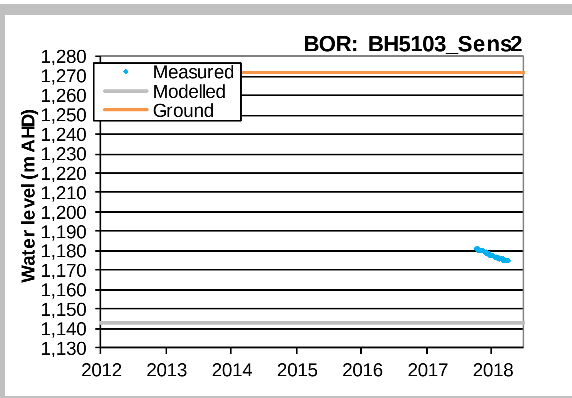

RBE: BH5102_Sens2
Excluded
Retained
Water level (m AHD)
1,185
1,180
1,175
2017
2018
RBE: BH5102_Sens3
Excluded
Retained
Water level (m AHD)
1,190
1,185
1,180
1,175
2017
2018
RBW: BH5107_Sens1
Excluded
Water level (m AHD)
1,075
1,070
1,065
1,060
1,055
1,050
1,045
1,040
2017
2018
RBW: BH5107_Sens2
Excluded
Water level (m AHD)
1,100
1,095
1,090
1,085
1,080
2017
2018
RBW: BH5108_Sens1
Excluded
Retained
Water level (m AHD)
945
940
935
930
925
920
2017
2018
RBW: BH8106_Sens1
Excluded
Retained
Water level (m AHD)
850
845
840
835
830
2017
2018
RBW: BH8106_Sens2
Excluded
Retained
Water level (m AHD)
855
850
845
840
2017
2018
RBW: PB05
Excluded
Retained
Water level (m AHD)
565
560
555
550
545
2017
2018

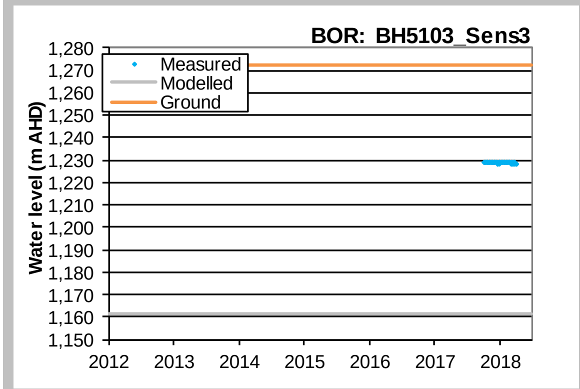

TTF: PB06
Excluded
Water level (m AHD)
1,355
1,350
1,345
1,340
1,335
1,330
1,325
1,320
1,315
1,310
1,305
2017
2018
TPF: PB10
Excluded
Water level (m AHD)
1,225
1,220
2017
2018

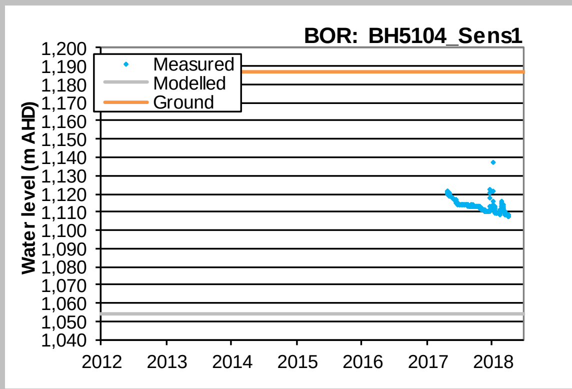
Attachment F

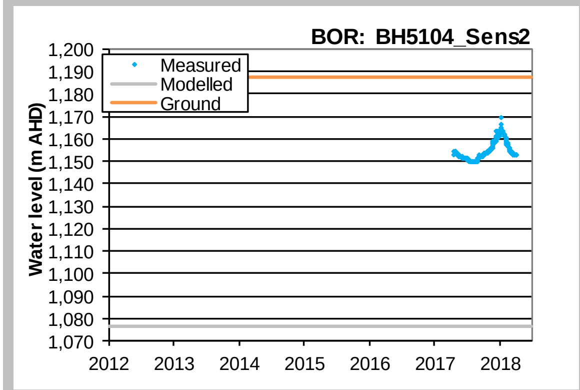
Modelled and measured historical groundwater hydrographs

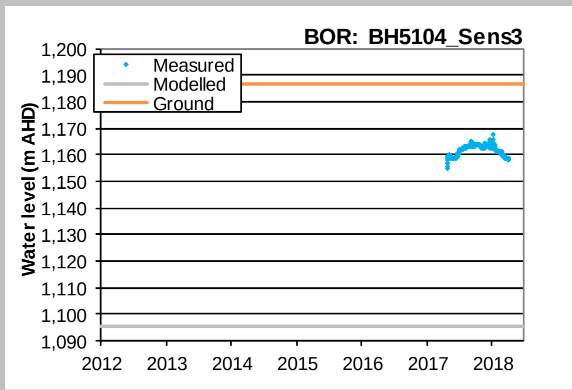

BOR: BH5103_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,290
1,060
2012 2013 2014 2015 2016 2017 2018

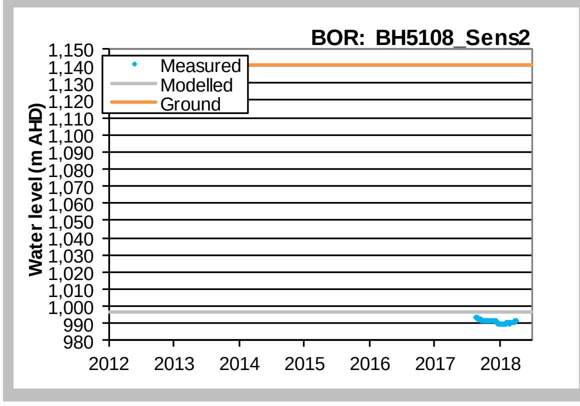

BOR: BH5103_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,280 1,270 1,260 1,250 1,240 1,230 1,220 1,210 1,200 1,190 1,180 1,170 1,160 1,150 1,140 1,130
2012 2013 2014 2015 2016 2017 2018

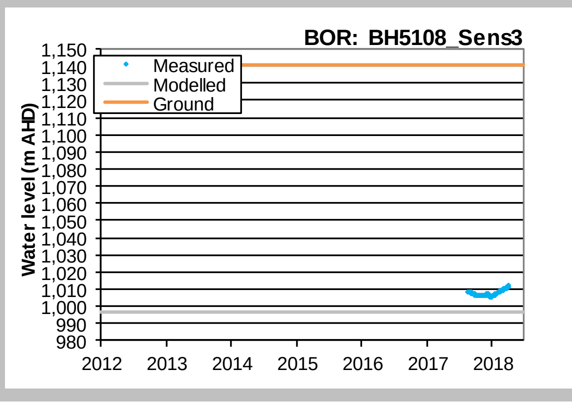

BOR: BH5103_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,280 1,270 1,260 1,250 1,240 1,230 1,220 1,210 1,200 1,190 1,180 1,170 1,160 1,150
2012 2013 2014 2015 2016 2017 2018

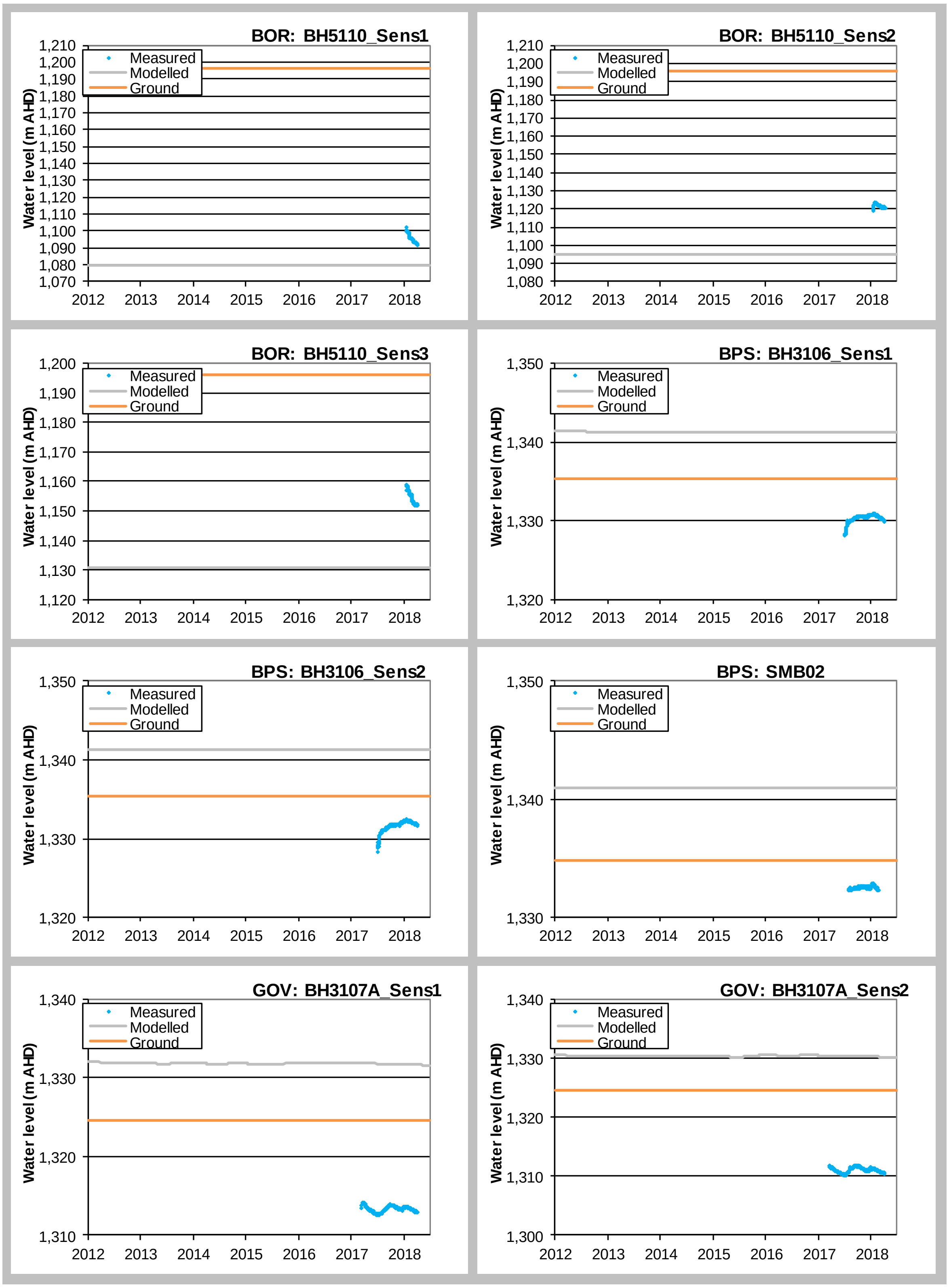

BOR: BH5104_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,200 1,190 1,180 1,170 1,160 1,150 1,140 1,130 1,120 1,110 1,100 1,090 1,080 1,070 1,060 1,050 1,040
2012 2013 2014 2015 2016 2017 2018

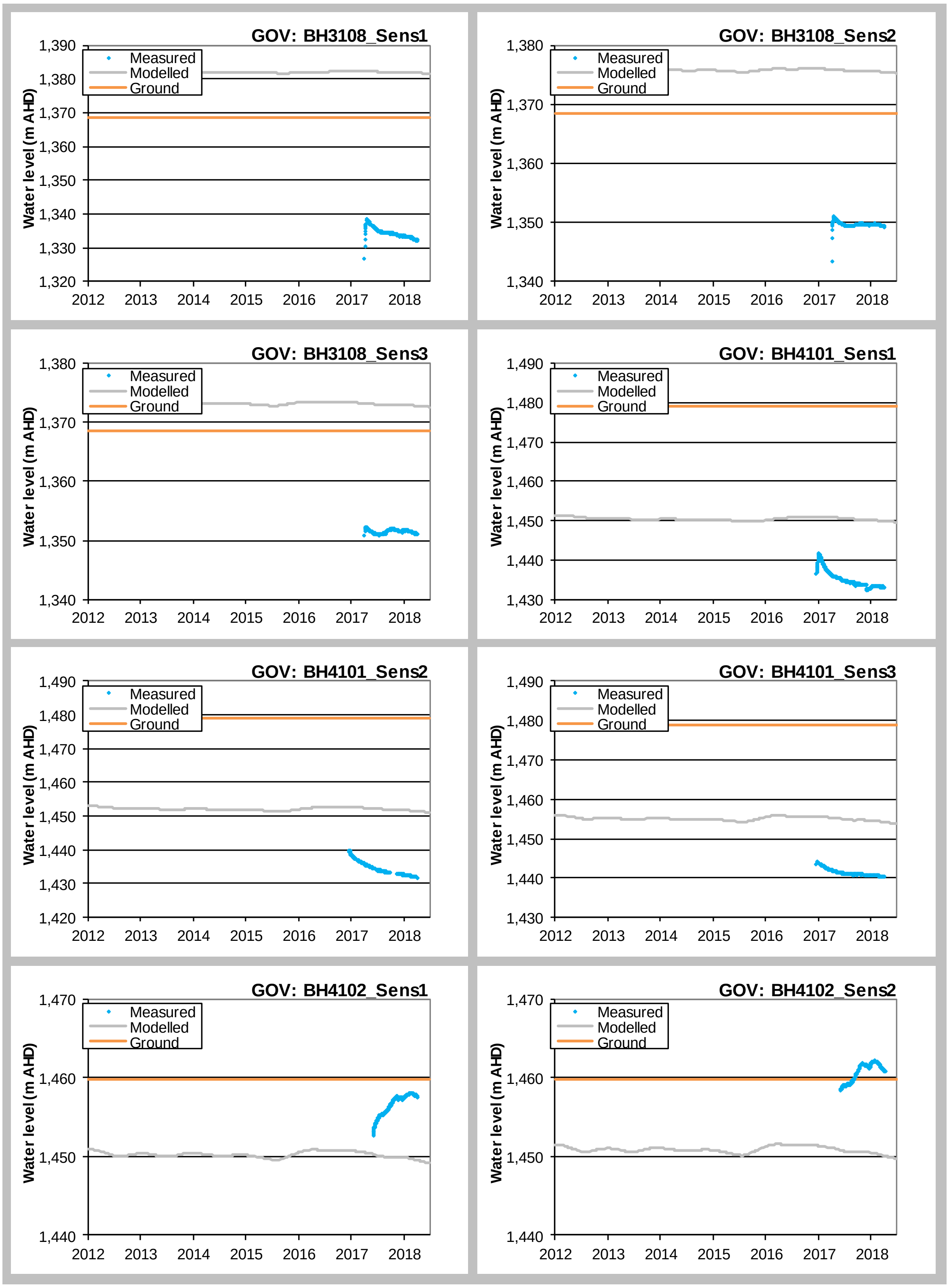

BOR: BH5104_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,200 1,190 1,180 1,170 1,160 1,150 1,140 1,130 1,120 1,110 1,100 1,090 1,080 1,070
2012 2013 2014 2015 2016 2017 2018

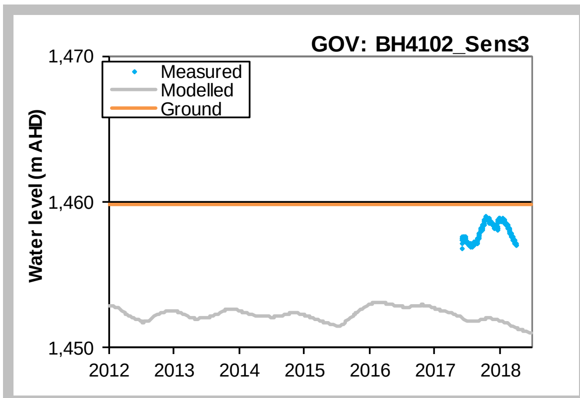

BOR: BH5104_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,200 1,190 1,180 1,170 1,160 1,150 1,140 1,130 1,120 1,110 1,100 1,090
2012 2013 2014 2015 2016 2017 2018

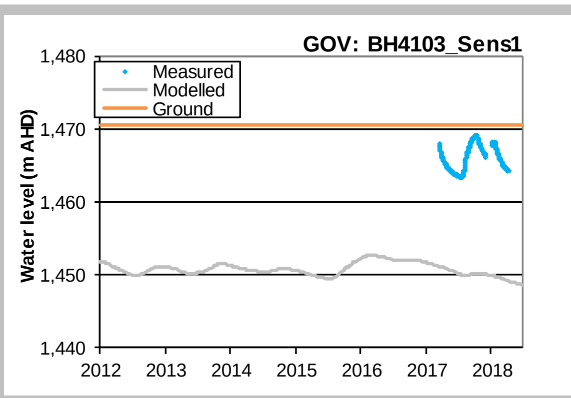

BOR: BH5108_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,150 1,140 1,130 1,120 1,110 1,100 1,090 1,080 1,070 1,060 1,050 1,040 1,030 1,020 1,010 1,000 990 980
2012 2013 2014 2015 2016 2017 2018

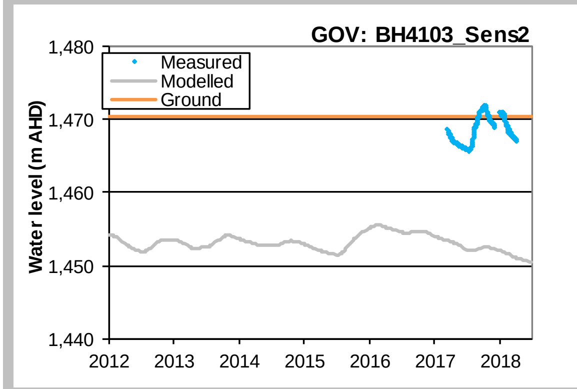

BOR: BH5108_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,150 1,140 1,130 1,120 1,110 1,100 1,090 1,080 1,070 1,060 1,050 1,040 1,030 1,020 1,010 1,000 990 980
2012 2013 2014 2015 2016 2017 2018

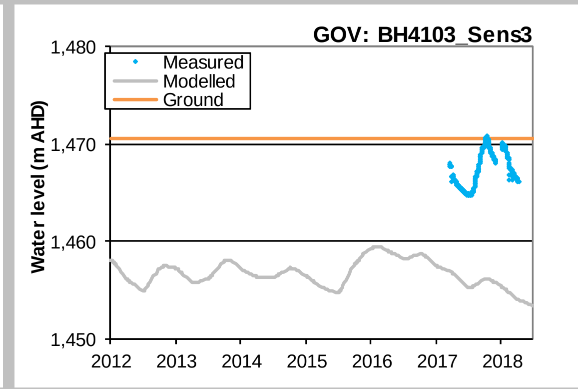

BOR: BH5110_Sens1
BOR: BH5110_Sens2
BOR: BH5110_Sens3
BPS: BH3106_Sens1
BPS: BH3106_Sens2
BPS: SMB02
GOV: BH3107A_Sens1
GOV: BH3107A_Sens2
Measured
Modelled
Ground
Water level (m AHD)
2012
2013
2014
2015
2016
2017
2018

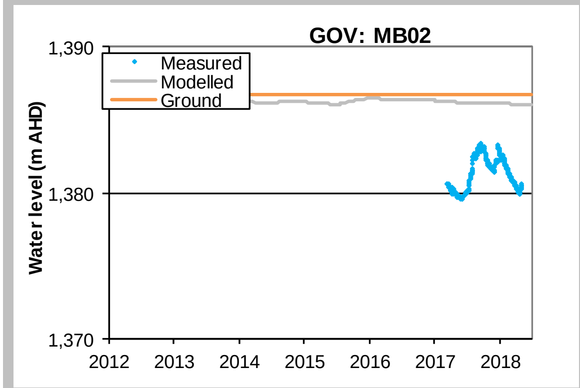

GOV: BH3108_Sens1
GOV: BH3108_Sens2
GOV: BH3108_Sens3
GOV: BH4101_Sens1
GOV: BH4101_Sens2
GOV: BH4101_Sens3
GOV: BH4102_Sens1
GOV: BH4102_Sens2
Measured
Modelled
Ground
Water level (m AHD)
2012
2013
2014
2015
2016
2017
2018

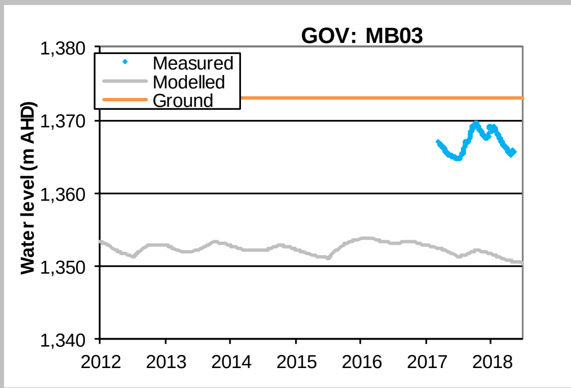

GOV: BH4102_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,470
1,460
1,450
2012
2013
2014
2015
2016
2017
2018

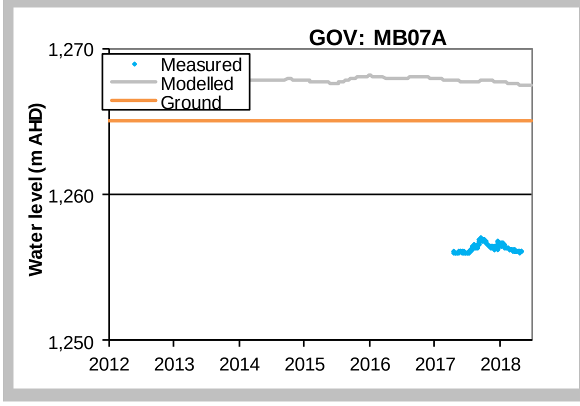

GOV: BH4103_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,480
1,470
1,460
1,450
1,440
2012
2013
2014
2015
2016
2017
2018

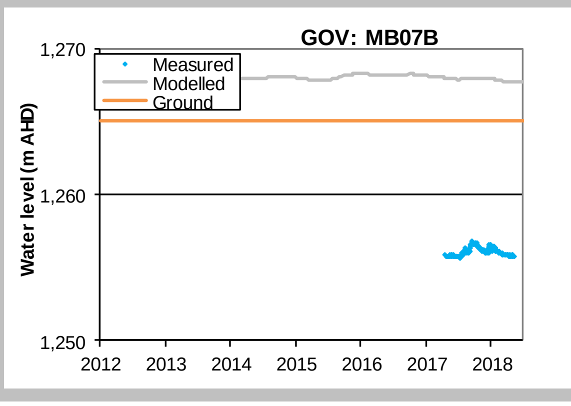

GOV: BH4103_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,480
1,470
1,460
1,450
1,440
2012
2013
2014
2015
2016
2017
2018

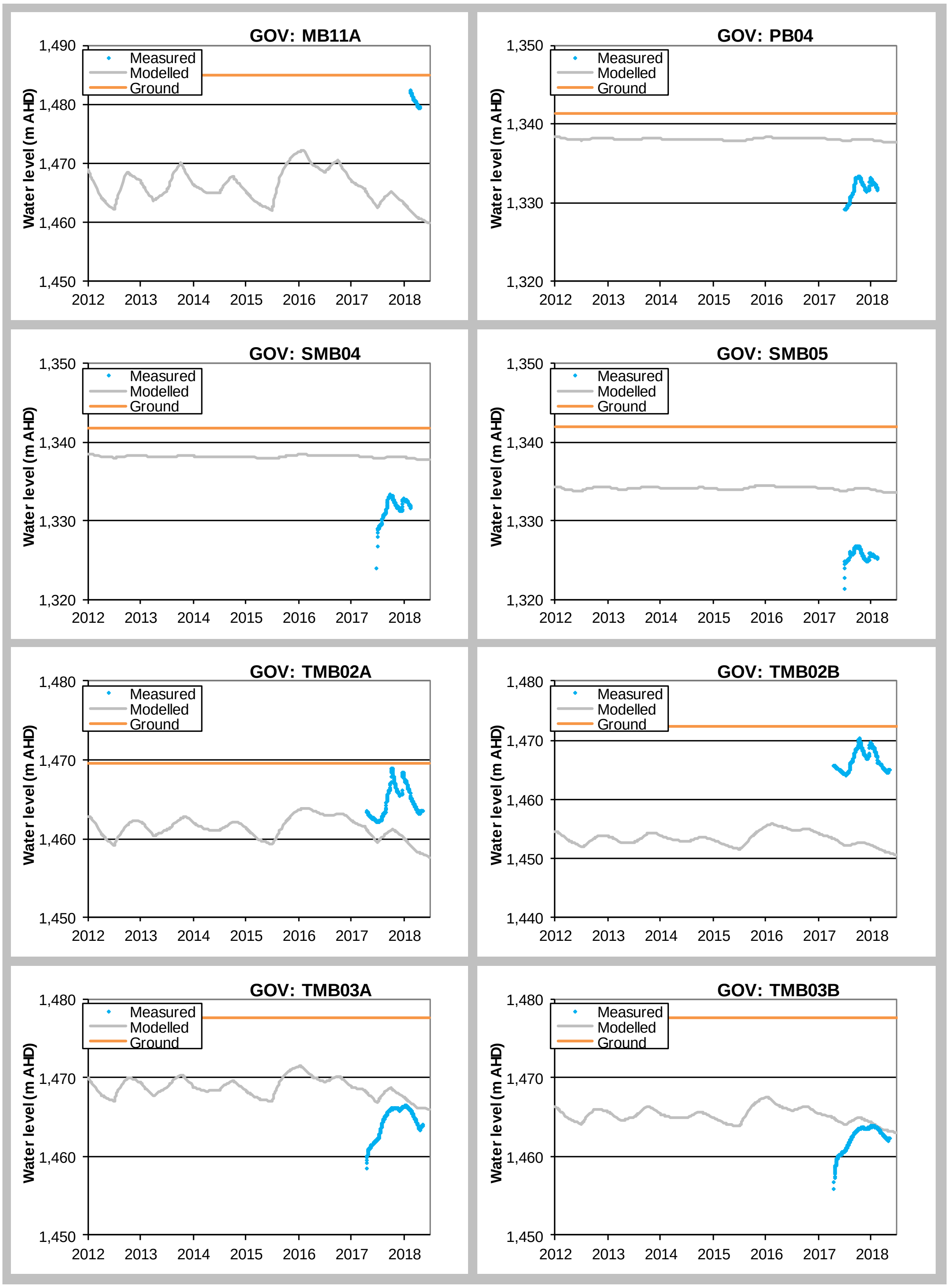

GOV: BH4103_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,480
1,470
1,460
1,450
2012
2013
2014
2015
2016
2017
2018

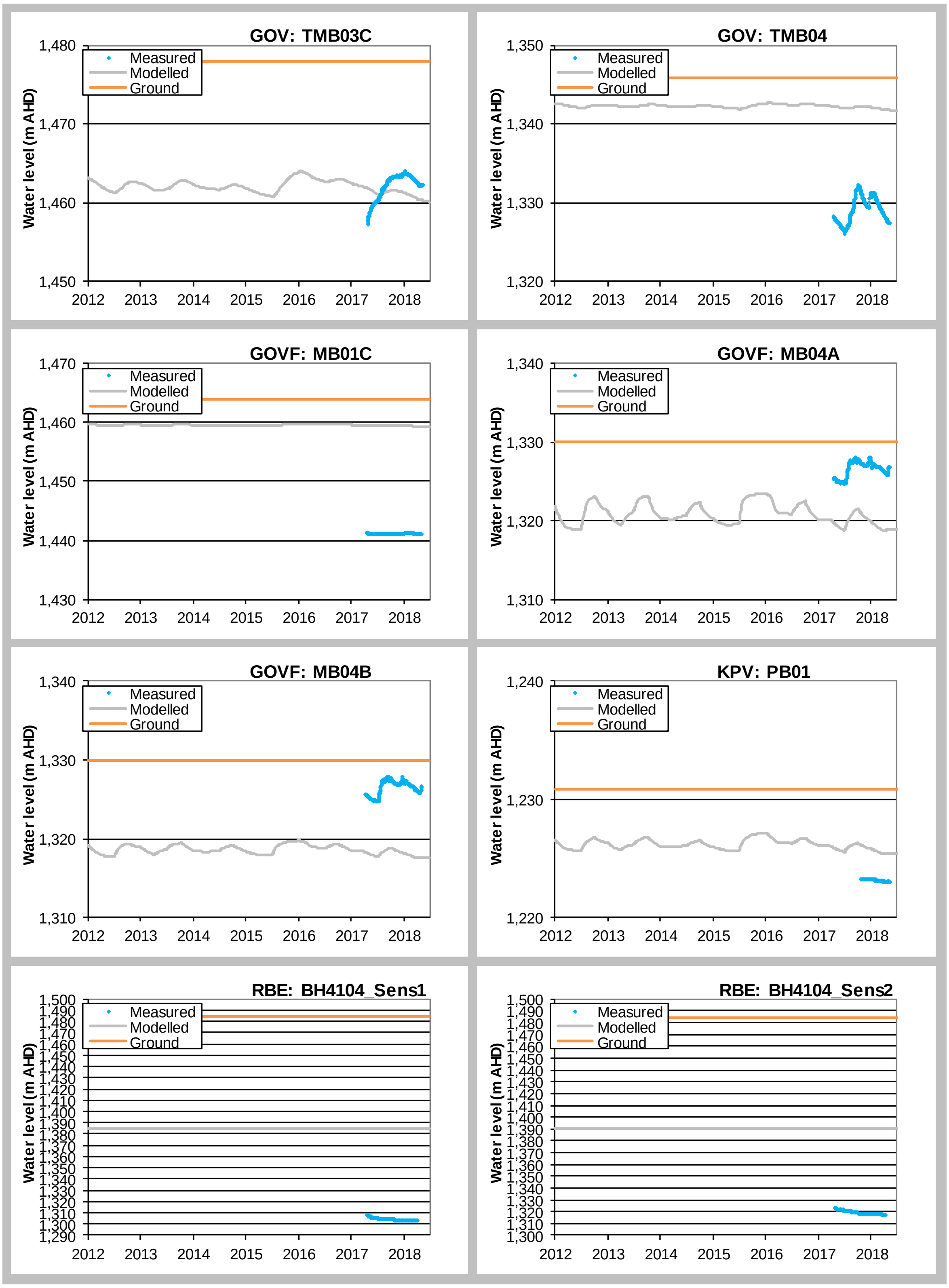

GOV: MB02
Measured
Modelled
Ground
Water level (m AHD)
1,390
1,380
1,370
2012
2013
2014
2015
2016
2017
2018

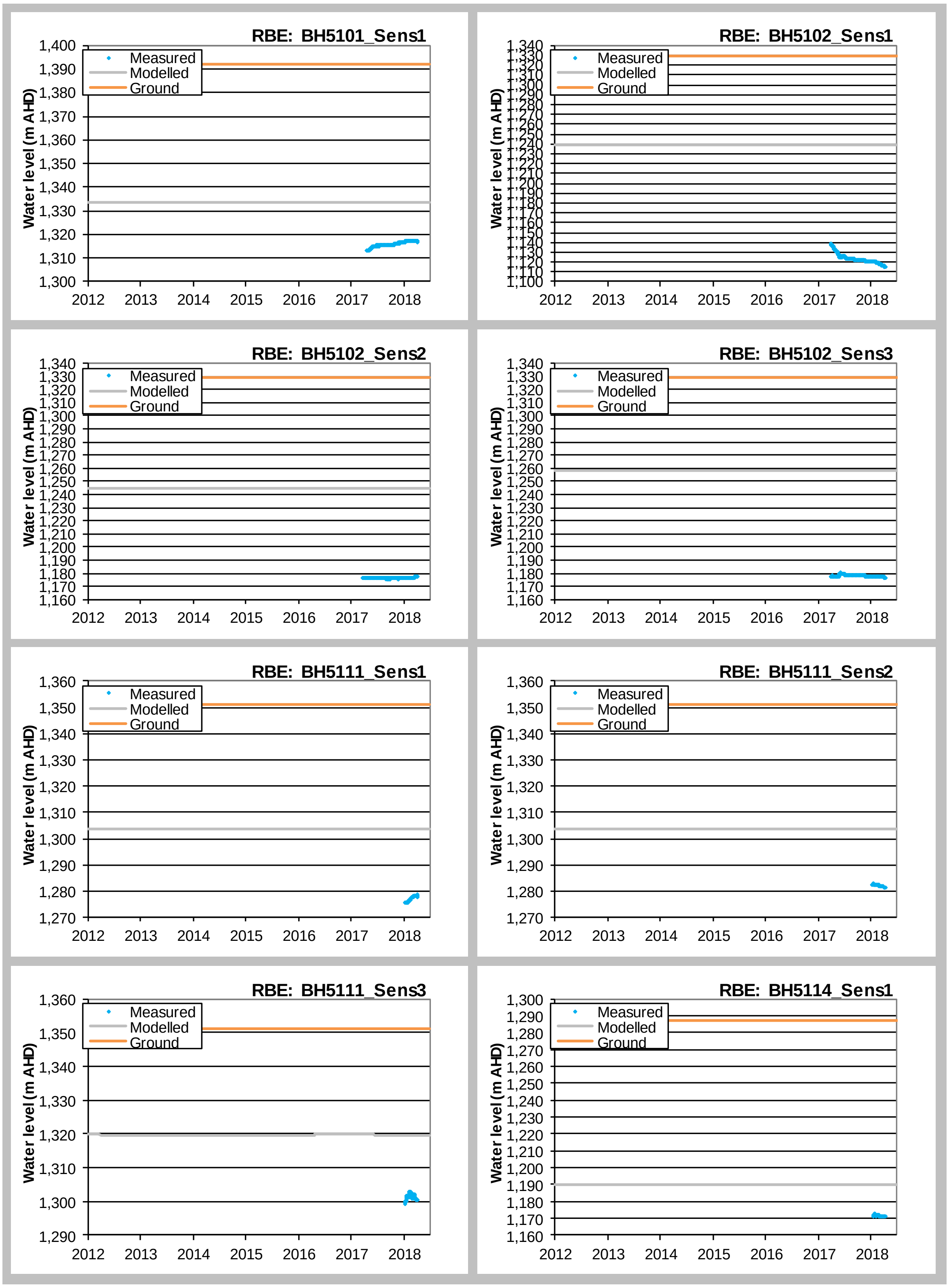

GOV: MB03
Measured
Modelled
Ground
Water level (m AHD)
1,380
1,370
1,360
1,350
1,340
2012
2013
2014
2015
2016
2017
2018

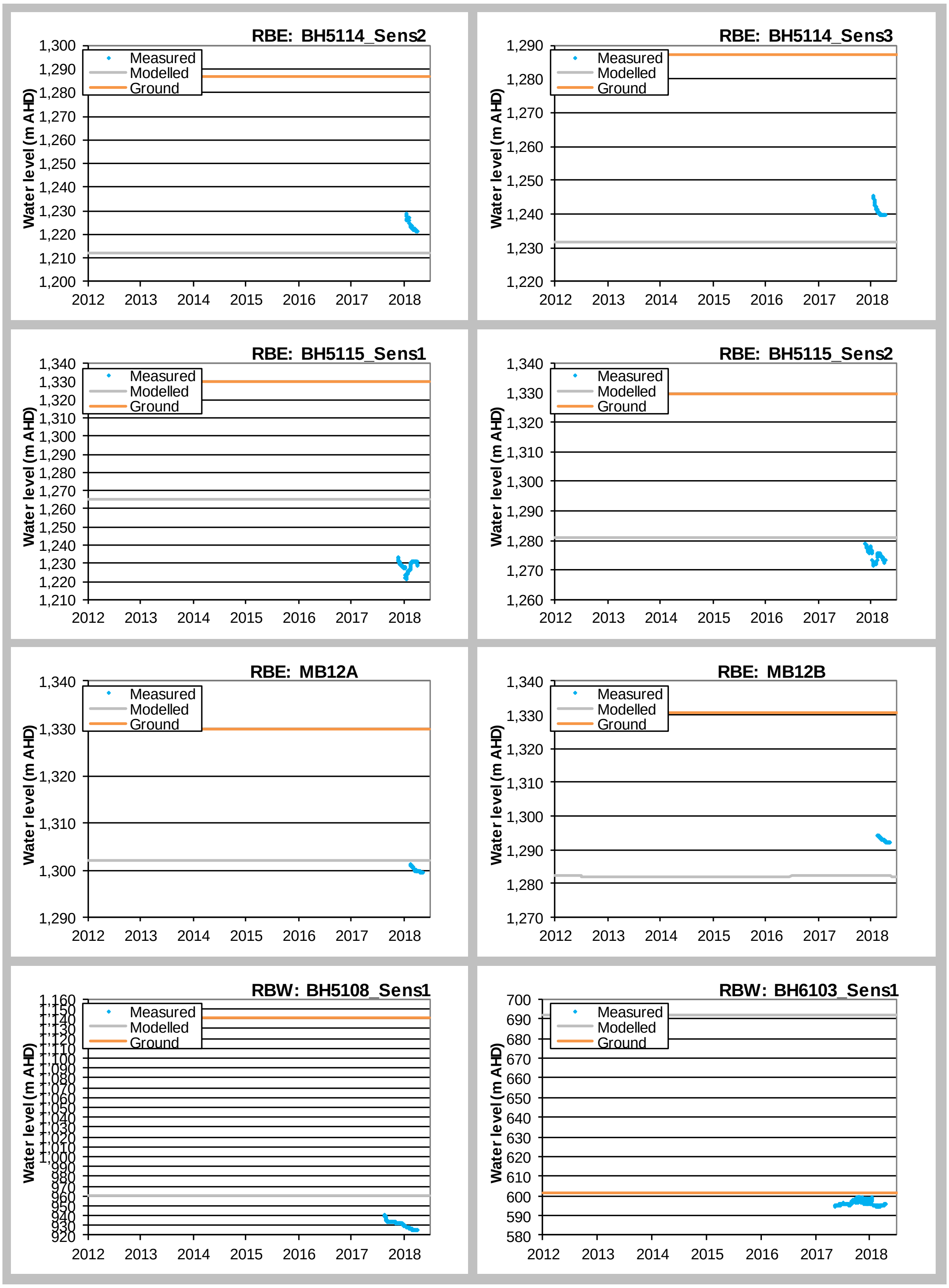

GOV: MB07A
Measured
Modelled
Ground
Water level (m AHD)
1,270
1,260
1,250
2012
2013
2014
2015
2016
2017
2018

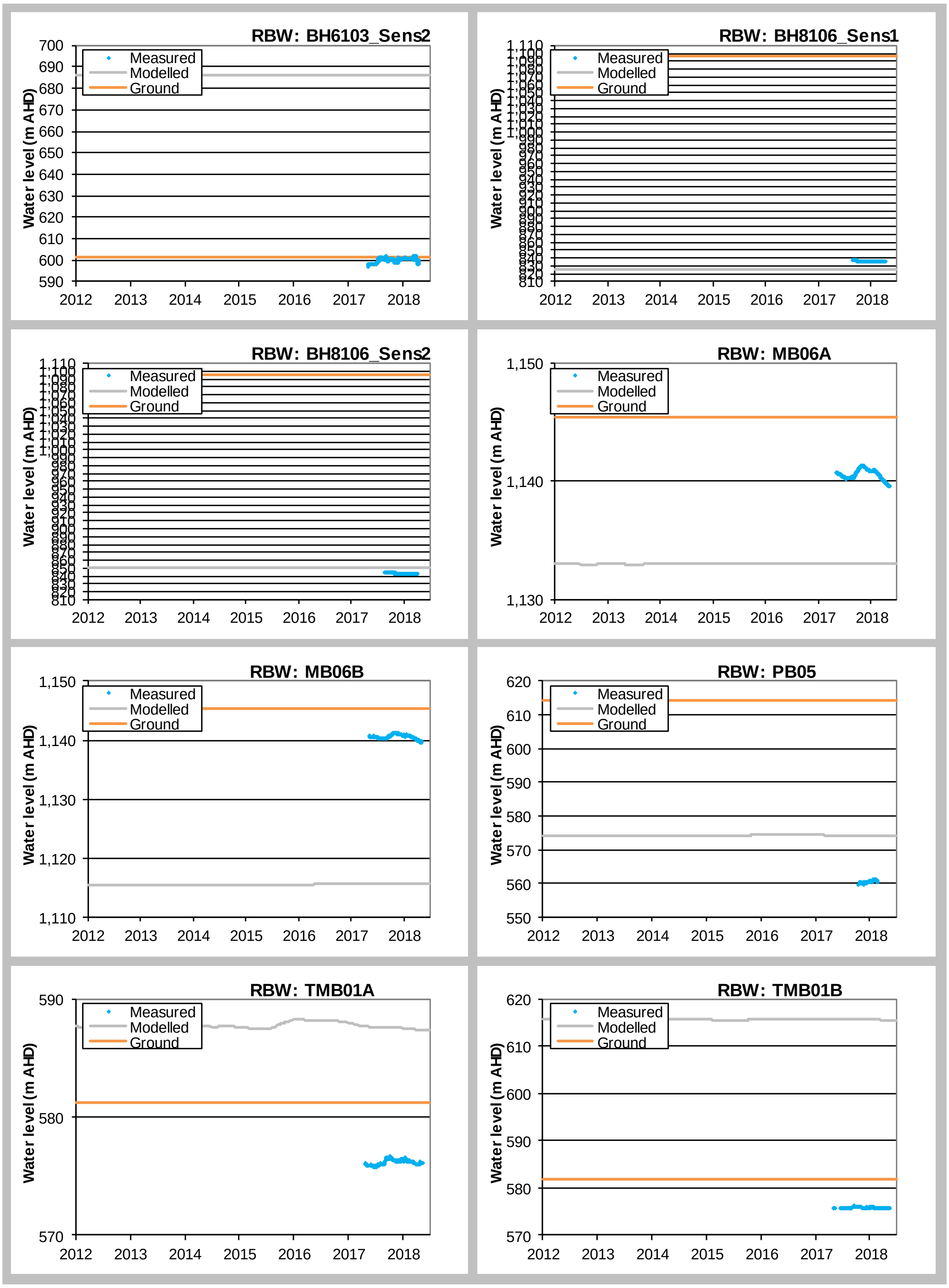

GOV: MB07B
Measured
Modelled
Ground
Water level (m AHD)
1,270
1,260
1,250
2012
2013
2014
2015
2016
2017
2018

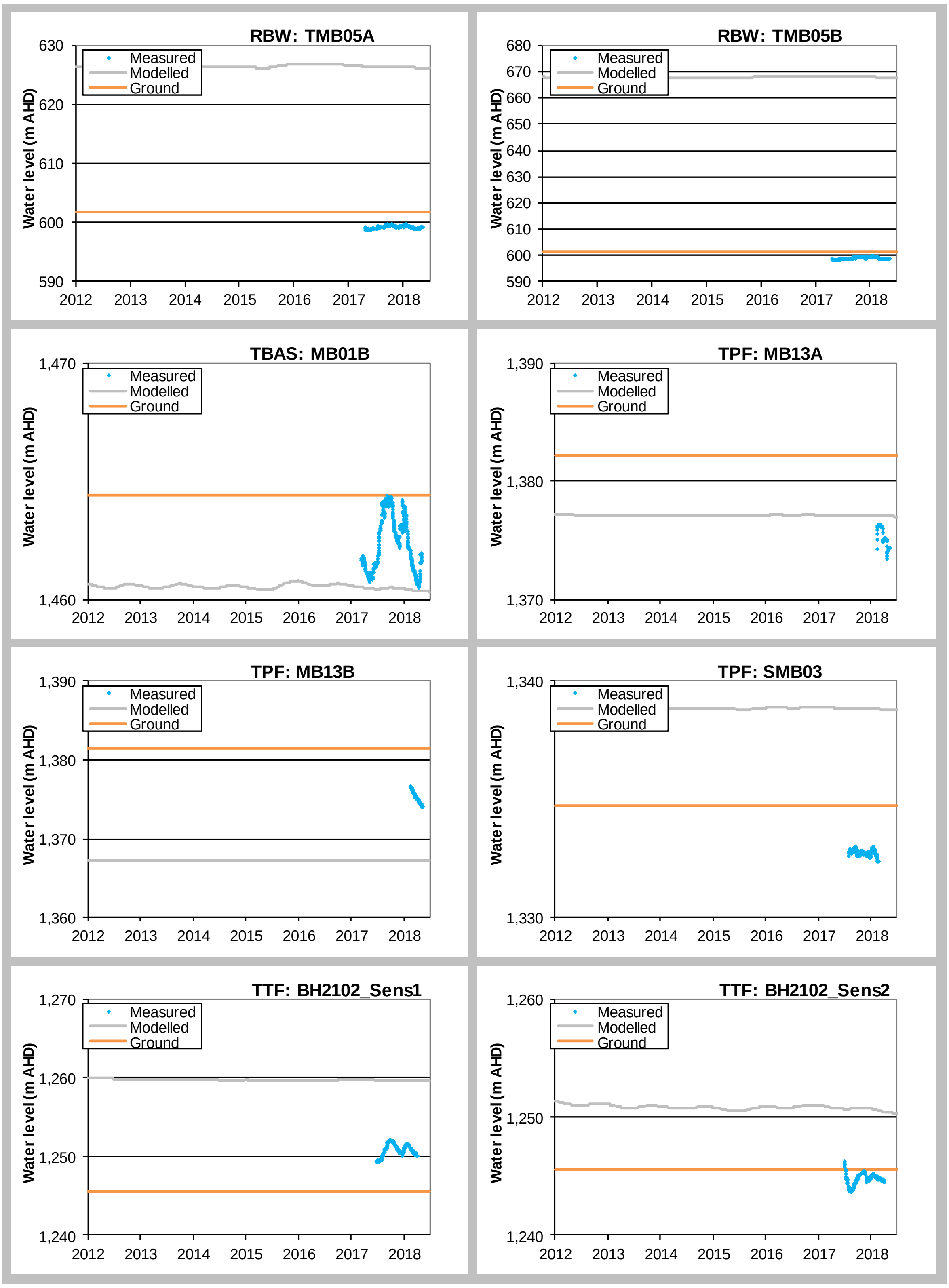

GOV: MB11A
GOV: PB04
GOV: SMB04
GOV: SMB05
GOV: TMB02A
GOV: TMB02B
GOV: TMB03A
GOV: TMB03B
Measured
Modelled
Ground
Water level (m AHD)
2012
2013
2014
2015
2016
2017
2018

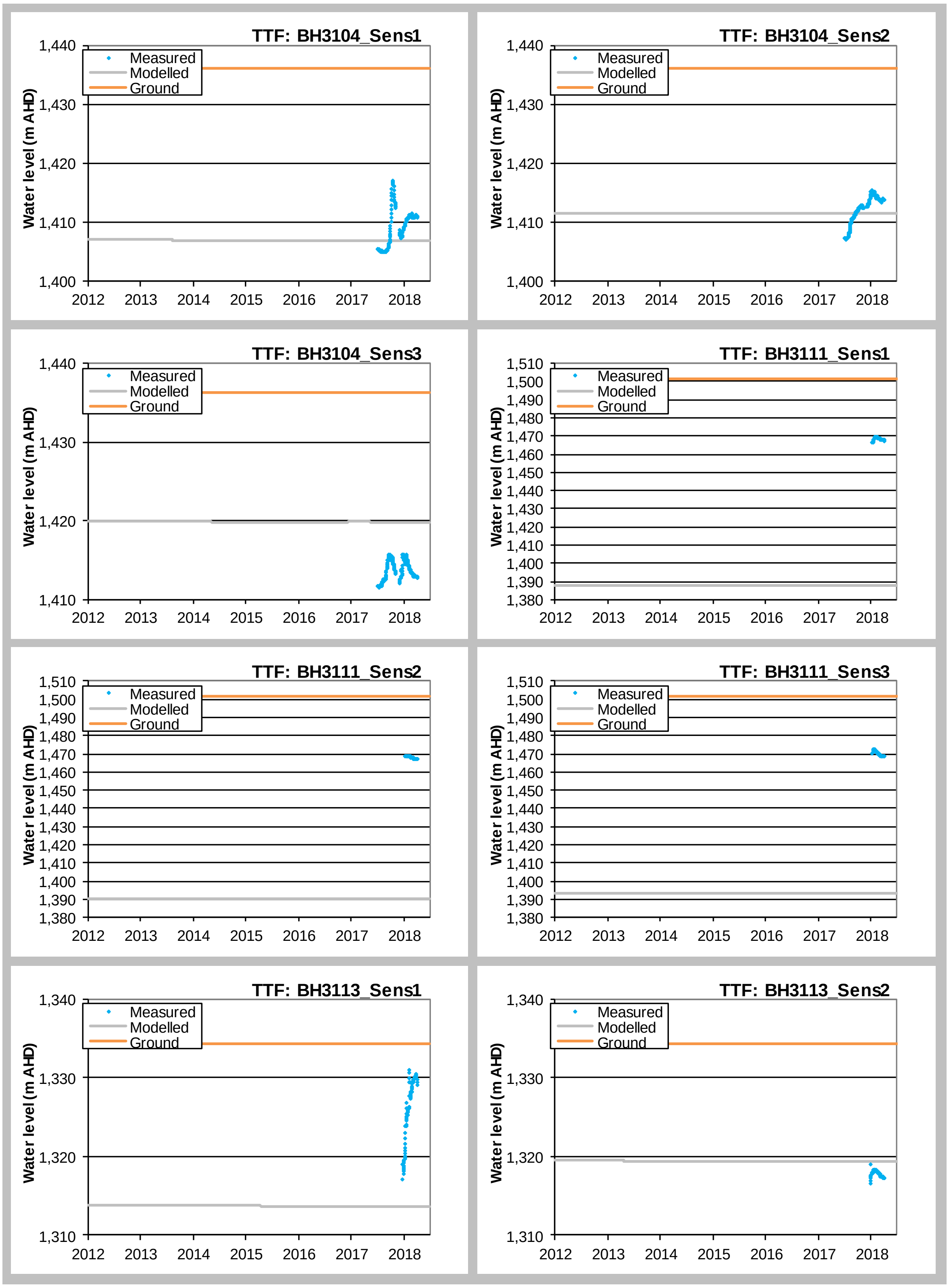

GOV: TMB03C
Measured
Modelled
Ground
Water level (m AHD)
1,480
1,470
1,460
1,450
2012
2013
2014
2015
2016
2017
2018
GOV: TMB04
1,350
1,340
1,330
1,320
GOVF: MB01C
1,470
1,460
1,450
1,440
1,430
GOVF: MB04A
1,340
1,330
1,320
1,310
GOVF: MB04B
KPV: PB01
1,240
1,230
1,220
RBE: BH4104_Sens1
RBE: BH4104_Sens2
1,500
1,490
1,480
1,470
1,460
1,450
1,440
1,430
1,420
1,410
1,400
1,390
1,380
1,370
1,360
1,350
1,340
1,330
1,320
1,310
1,300
1,290

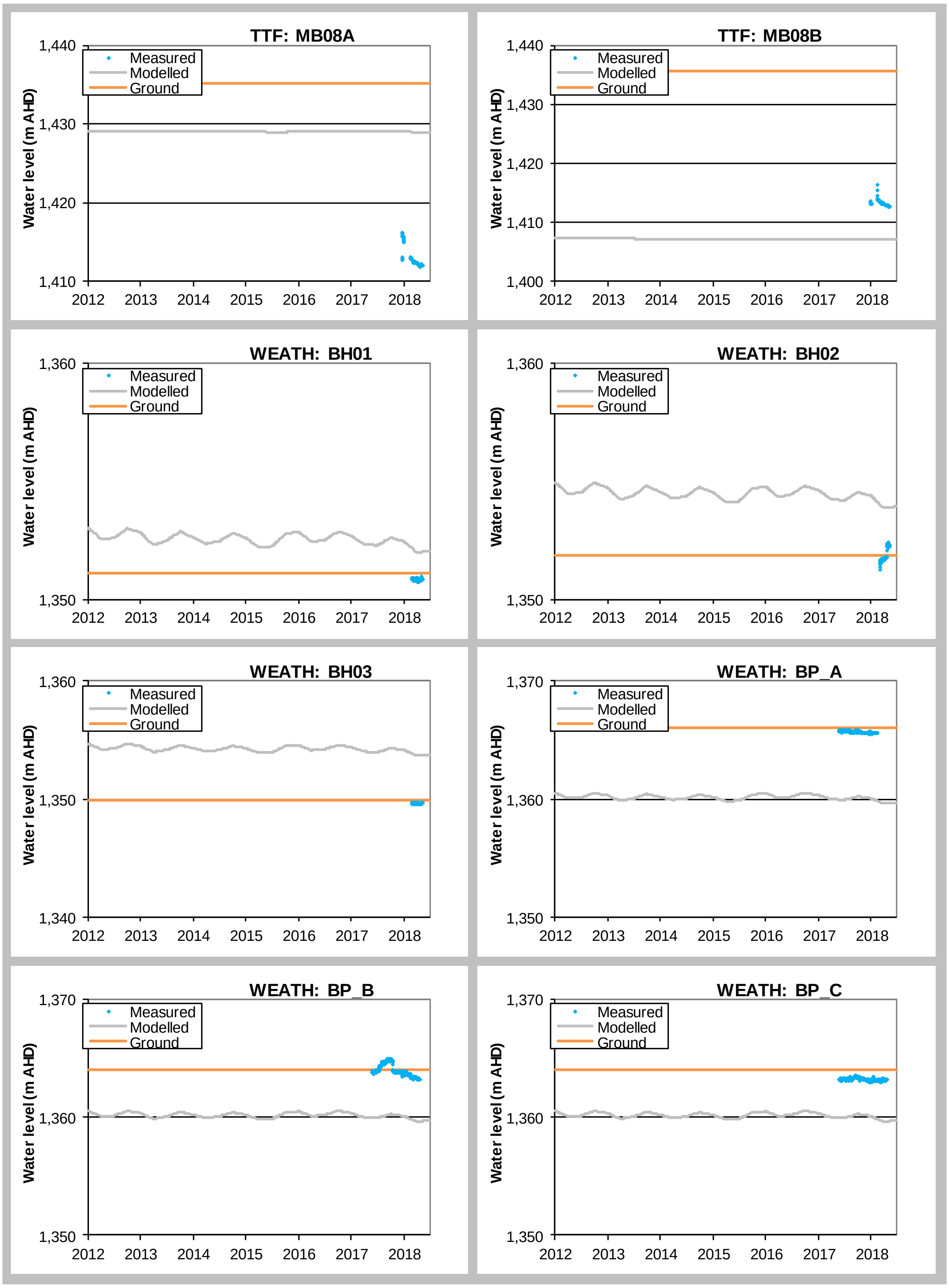

RBE: BH5101_Sens1
RBE: BH5102_Sens1
RBE: BH5102_Sens2
RBE: BH5102_Sens3
RBE: BH5111_Sens1
RBE: BH5111_Sens2
RBE: BH5111_Sens3
RBE: BH5114_Sens1
Measured
Modelled
Ground
Water level (m AHD)
2012
2013
2014
2015
2016
2017
2018

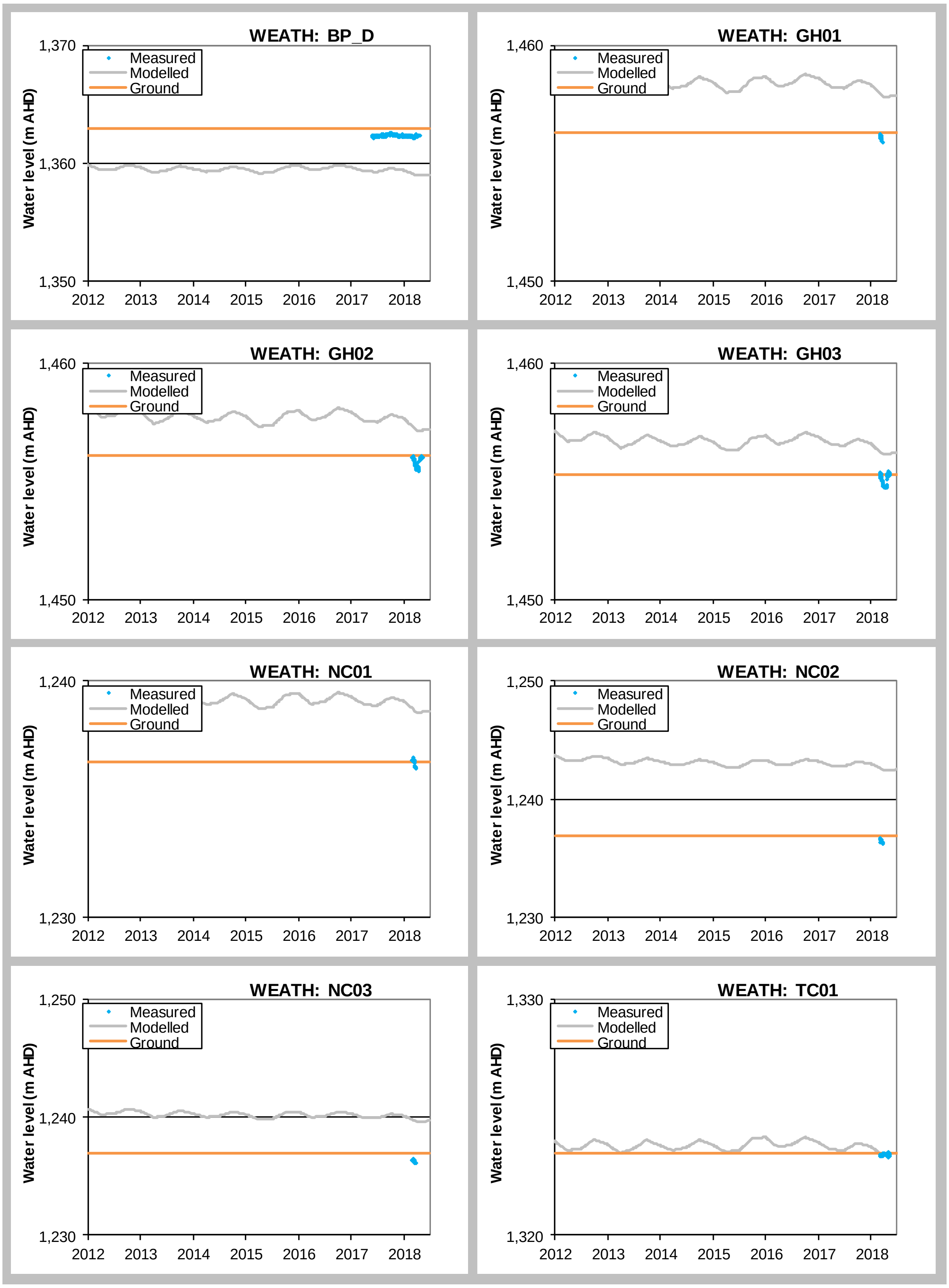

RBE: BH5114_Sens2
Water level (m AHD)
1,300
1,290
1,280
1,270
1,260
1,250
1,240
1,230
1,220
1,210
1,200
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018
RBE: BH5114_Sens3
Water level (m AHD)
1,290
1,280
1,270
1,260
1,250
1,240
1,230
1,220
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018
RBE: BH5115_Sens1
Water level (m AHD)
1,340
1,330
1,320
1,310
1,300
1,290
1,280
1,270
1,260
1,250
1,240
1,230
1,220
1,210
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018
RBE: BH5115_Sens2
Water level (m AHD)
1,340
1,330
1,320
1,310
1,300
1,290
1,280
1,270
1,260
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018
RBE: MB12A
Water level (m AHD)
1,340
1,330
1,320
1,310
1,300
1,290
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018
RBE: MB12B
Water level (m AHD)
1,340
1,330
1,320
1,310
1,300
1,290
1,280
1,270
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018
RBW: BH5108_Sens1
Water level (m AHD)
980
970
960
950
940
930
920
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018
RBW: BH6103_Sens1
Water level (m AHD)
700
690
680
670
660
650
640
630
620
610
600
590
580
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018

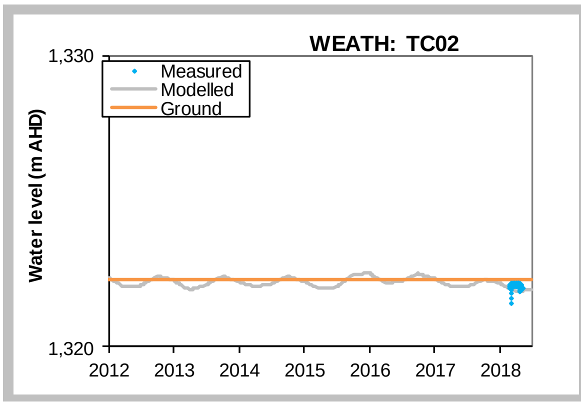

RBW: BH6103_Sens2
Measured
Modelled
Ground
Water level (m AHD)
700
690
680
670
660
650
640
630
620
610
600
590
2012
2013
2014
2015
2016
2017
2018
RBW: BH8106_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,110
810
2012
2013
2014
2015
2016
2017
2018
RBW: BH8106_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,110
810
2012
2013
2014
2015
2016
2017
2018
RBW: MB06A
Measured
Modelled
Ground
Water level (m AHD)
1,150
1,140
1,130
2012
2013
2014
2015
2016
2017
2018
RBW: MB06B
Measured
Modelled
Ground
Water level (m AHD)
1,150
1,140
1,130
1,120
1,110
2012
2013
2014
2015
2016
2017
2018
RBW: PB05
Measured
Modelled
Ground
Water level (m AHD)
620
610
600
590
580
570
560
550
2012
2013
2014
2015
2016
2017
2018
RBW: TMB01A
Measured
Modelled
Ground
Water level (m AHD)
590
580
570
2012
2013
2014
2015
2016
2017
2018
RBW: TMB01B
Measured
Modelled
Ground
Water level (m AHD)
620
610
600
590
580
570
2012
2013
2014
2015
2016
2017
2018

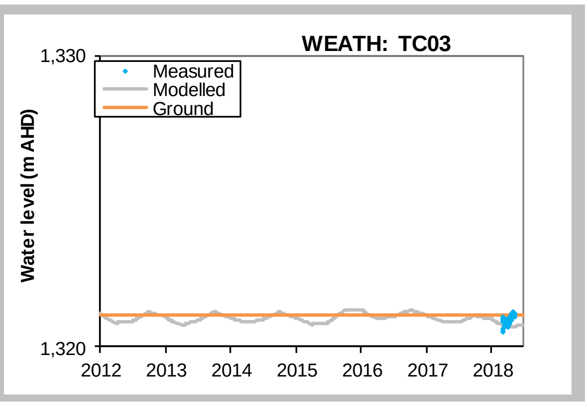

RBW: TMB05A
Water level (m AHD)
630
620
610
600
590
2012 2013 2014 2015 2016 2017 2018
Measured
Modelled
Ground
RBW: TMB05B
Water level (m AHD)
680
670
660
650
640
630
620
610
600
590
2012 2013 2014 2015 2016 2017 2018
Measured
Modelled
Ground
TBAS: MB01B
Water level (m AHD)
1,470
1,460
2012 2013 2014 2015 2016 2017 2018
Measured
Modelled
Ground
TPF: MB13A
Water level (m AHD)
1,390
1,380
1,370
2012 2013 2014 2015 2016 2017 2018
Measured
Modelled
Ground
TPF: MB13B
Water level (m AHD)
1,390
1,380
1,370
1,360
2012 2013 2014 2015 2016 2017 2018
Measured
Modelled
Ground
TPF: SMB03
Water level (m AHD)
1,340
1,330
2012 2013 2014 2015 2016 2017 2018
Measured
Modelled
Ground
TTF: BH2102_Sens1
Water level (m AHD)
1,270
1,260
1,250
1,240
2012 2013 2014 2015 2016 2017 2018
Measured
Modelled
Ground
TTF: BH2102_Sens2
Water level (m AHD)
1,260
1,250
1,240
2012 2013 2014 2015 2016 2017 2018
Measured
Modelled
Ground


TTF: BH3104_Sens1
TTF: BH3104_Sens2
TTF: BH3104_Sens3
TTF: BH3111_Sens1
TTF: BH3111_Sens2
TTF: BH3111_Sens3
TTF: BH3113_Sens1
TTF: BH3113_Sens2
Measured
Modelled
Ground
Water level (m AHD)
2012
2013
2014
2015
2016
2017
2018


TTF: MB08A
TTF: MB08B
WEATH: BH01
WEATH: BH02
WEATH: BH03
WEATH: BP_A
WEATH: BP_B
WEATH: BP_C
Measured
Modelled
Ground
Water level (m AHD)
2012
2013
2014
2015
2016
2017
2018


WEATH: BP_D
WEATH: GH01
WEATH: GH02
WEATH: GH03
WEATH: NC01
WEATH: NC02
WEATH: NC03
WEATH: TC01
Measured
Modelled
Ground
Water level (m AHD)
2012
2013
2014
2015
2016
2017
2018
1,370
1,360
1,350
1,460
1,450
1,240
1,230
1,250
1,330
1,320

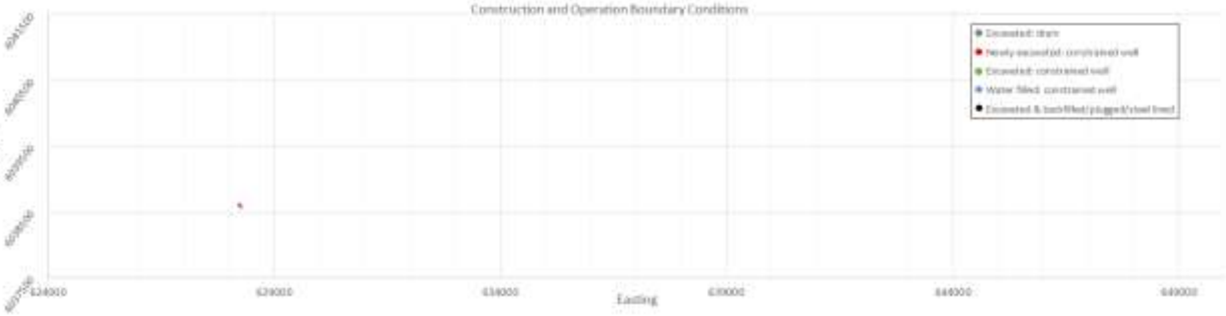

WEATH: TC02
1,330
1,320
Water level (m AHD)
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018


WEATH: TC03
1,330
1,320
Water level (m AHD)
Measured
Modelled
Ground
2012
2013
2014
2015
2016
2017
2018

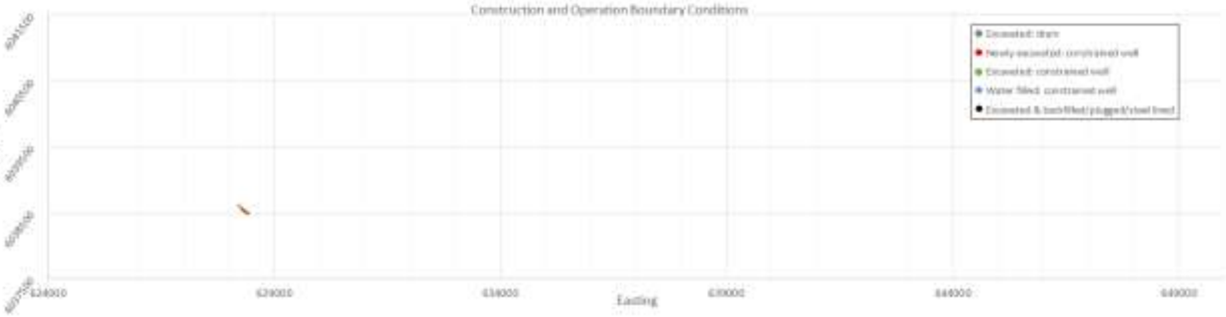
Attachment G

Excavation sequencing boundary conditions employed in the groundwater model

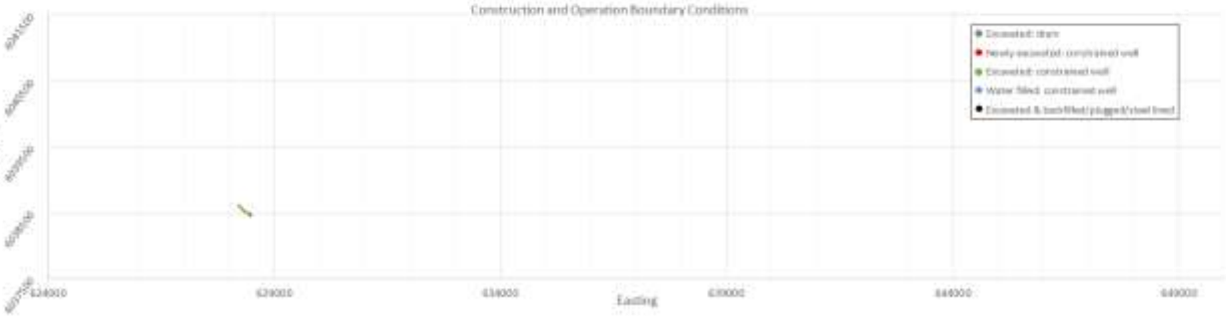
Stress period 5, ending December 2019:



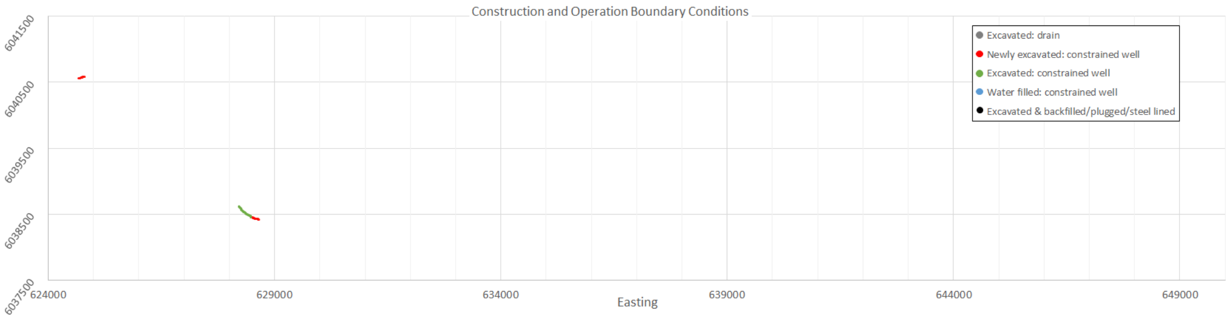
Stress period 6, ending March 2020



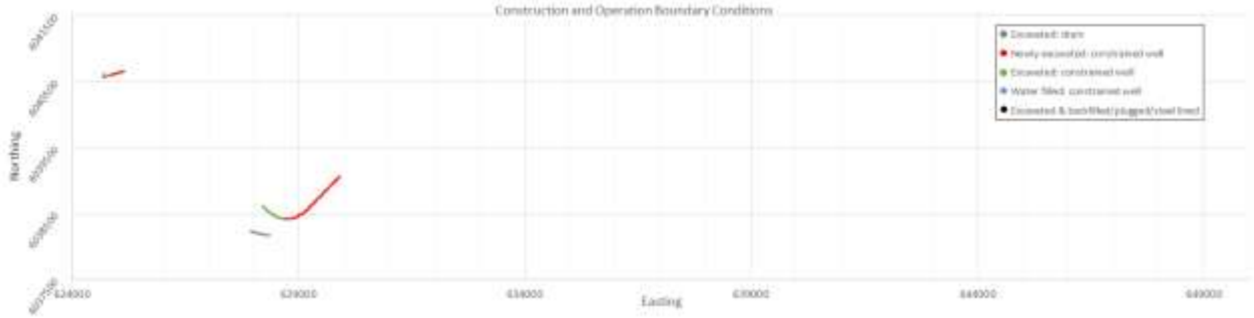
Stress period 7, ending June 2020:



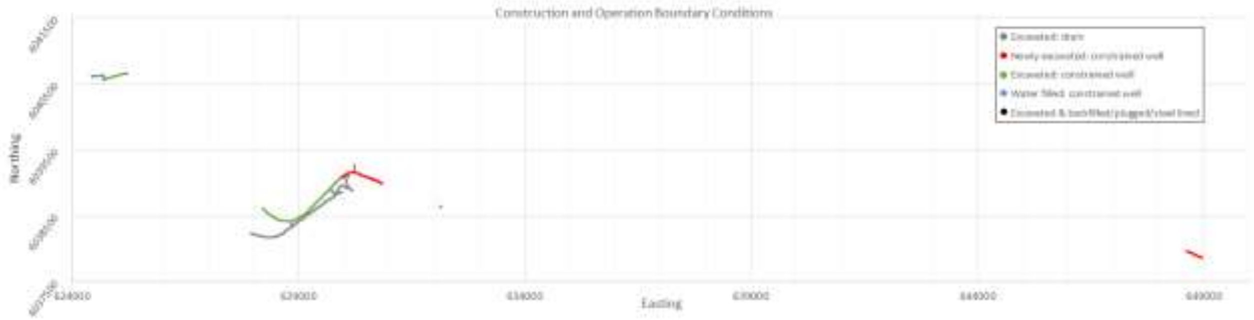
Stress period 8, ending September 2020:



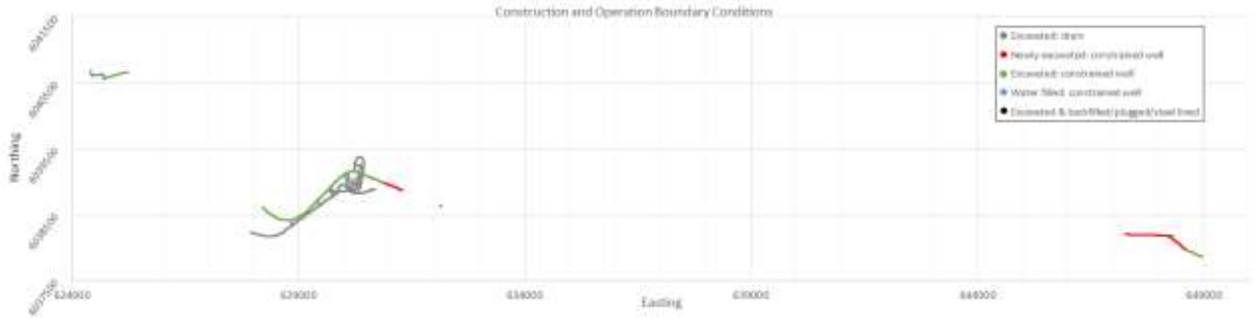
Stress period 9, ending December 2020:



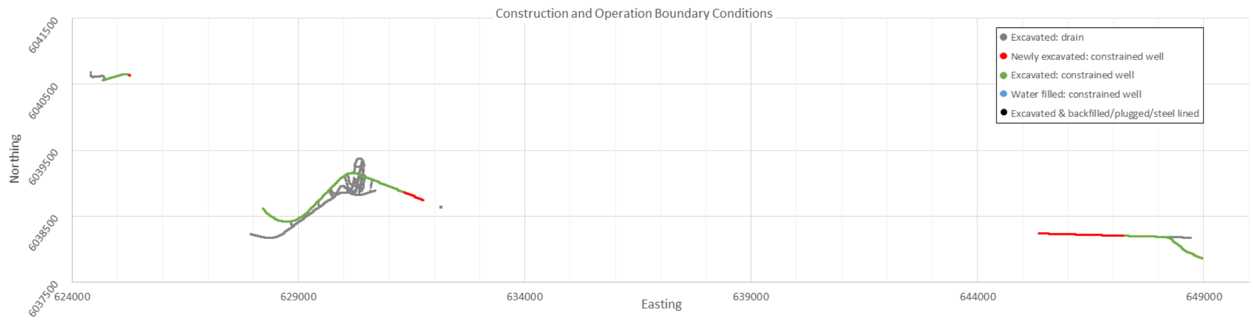
Stress period 10, ending March 2021



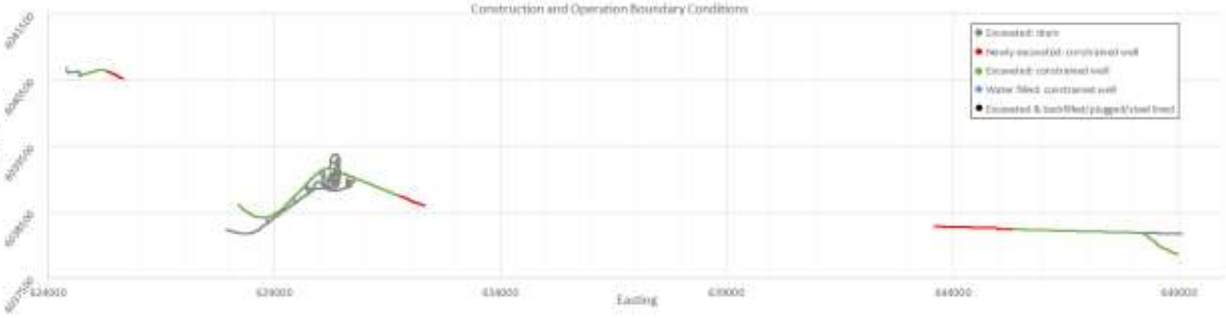
Stress period 11, ending June 2021:



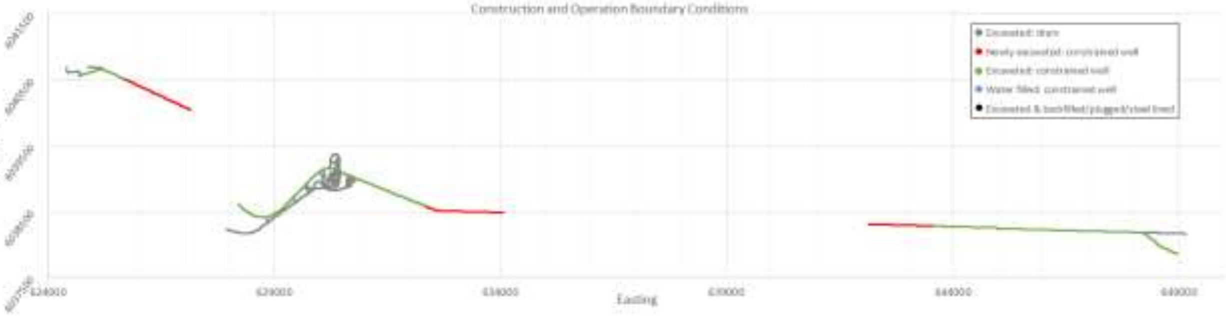
Stress period 12, ending September 2021:



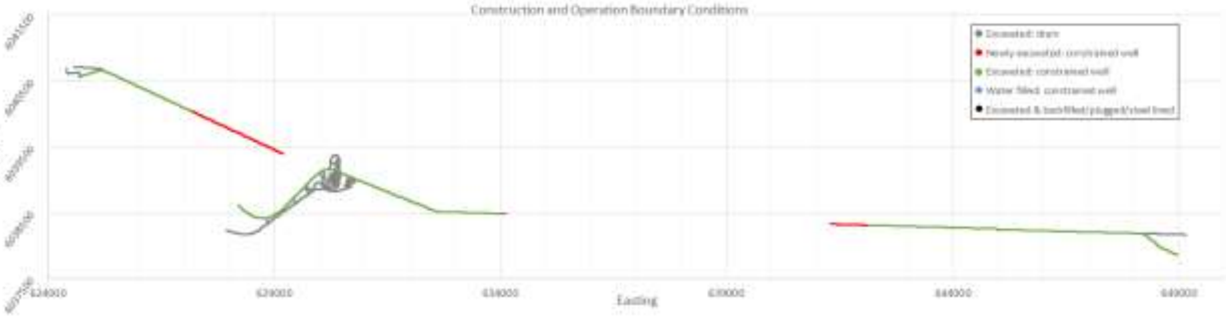
Stress period 13, ending December 2021:



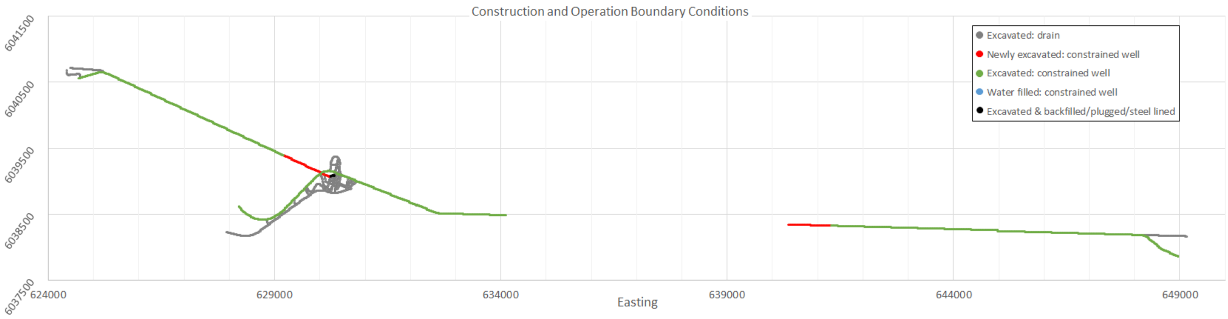
Stress period 14, ending March 2022



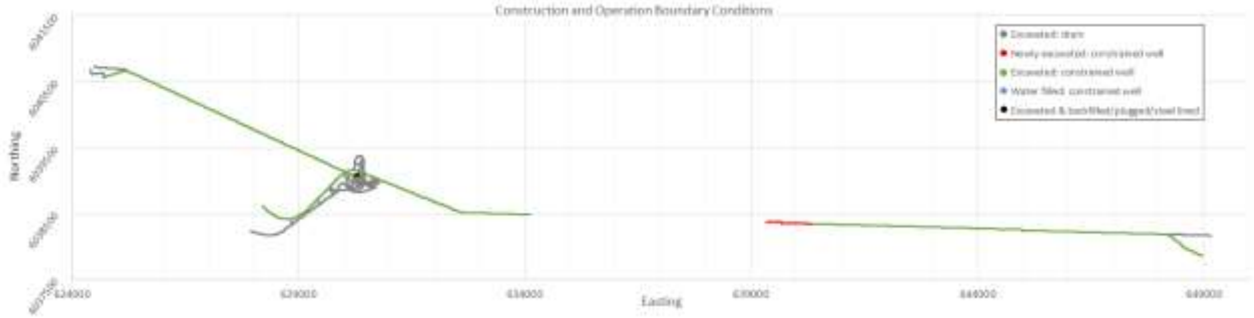
Stress period 15, ending June 2022:



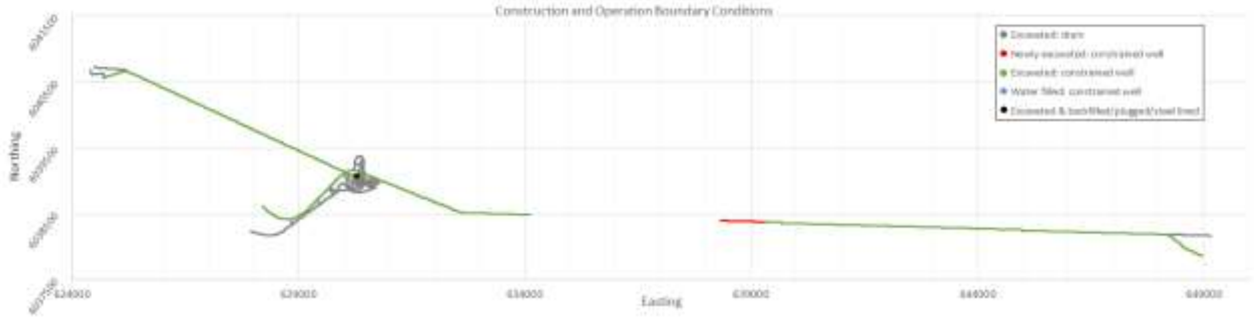
Stress period 16, ending September 2022:



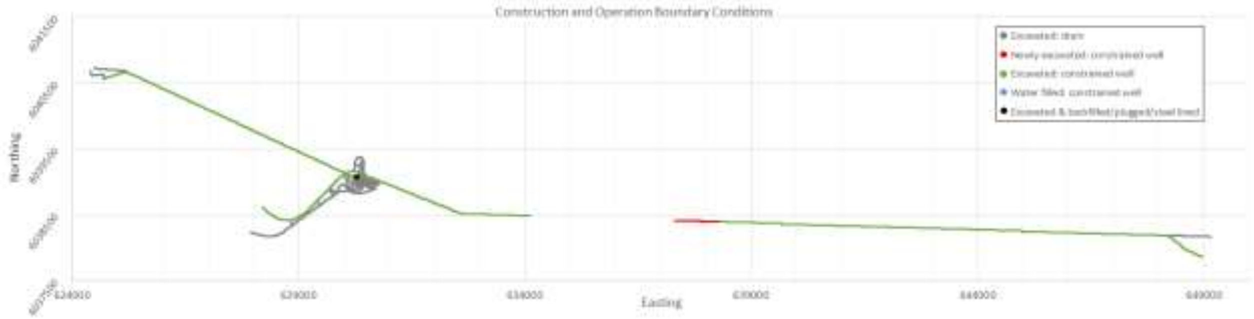
Stress period 17, ending December 2022:



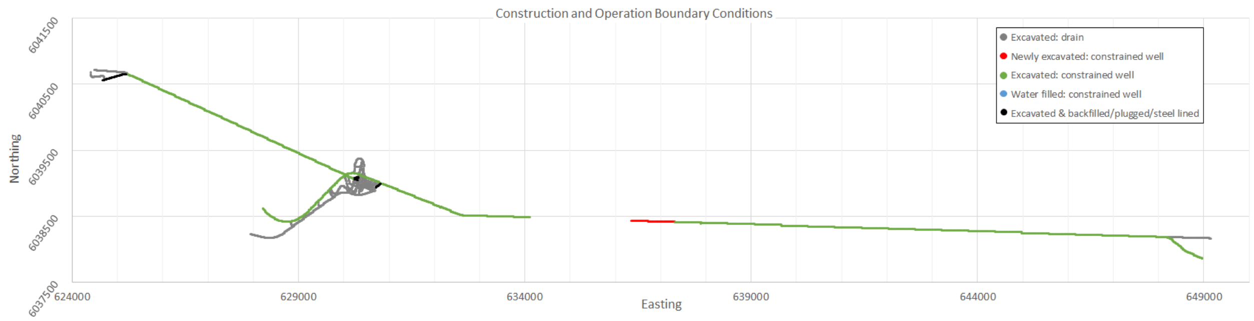
Stress period 18, ending March 2023



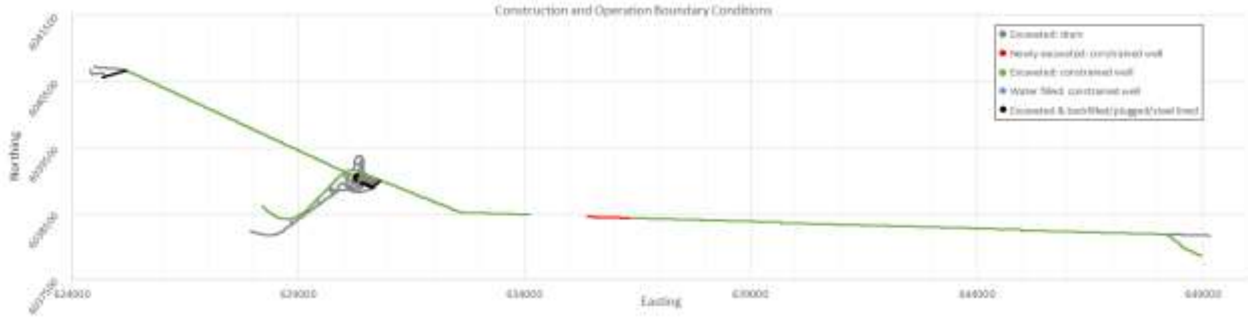
Stress period 19, ending June 2023:



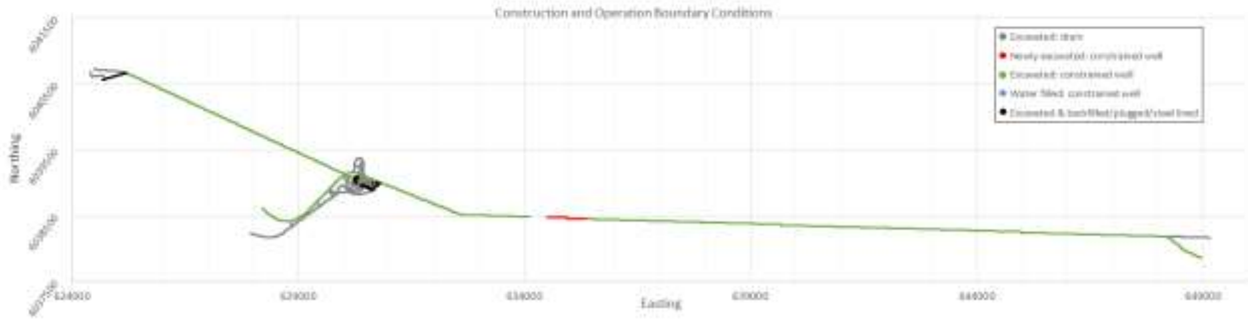
Stress period 20, ending September 2023:



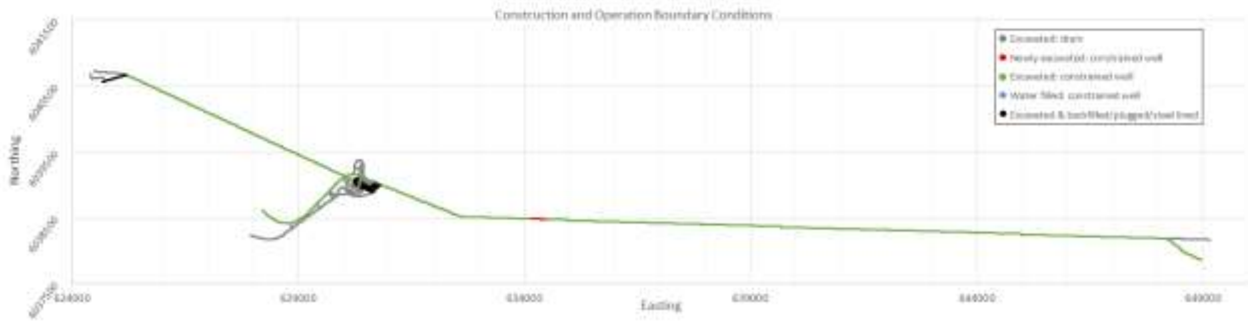
Stress period 21, ending December 2023:



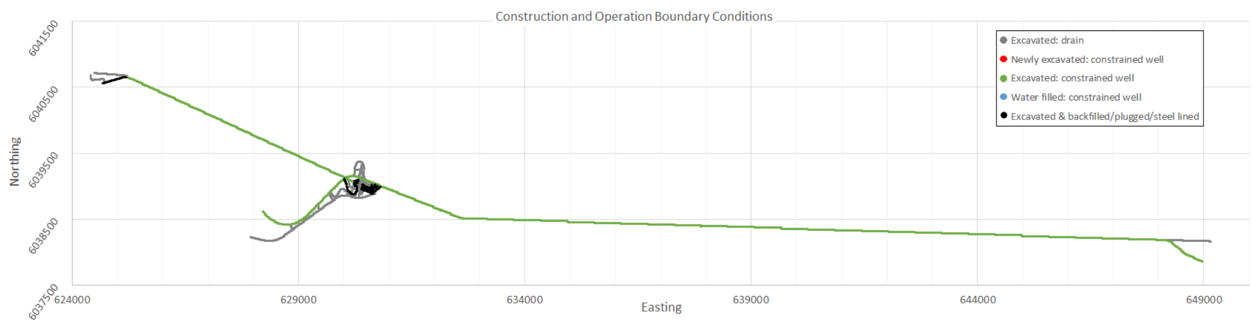
Stress period 22, ending March 2024



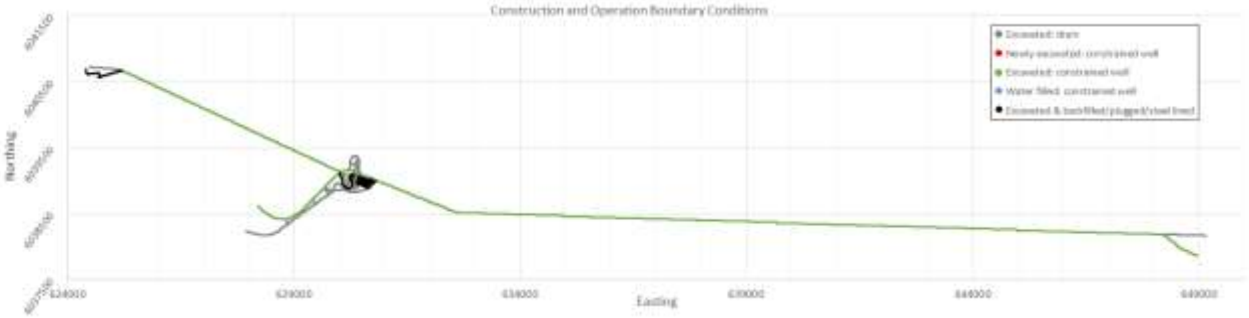
Stress period 23, ending June 2024:



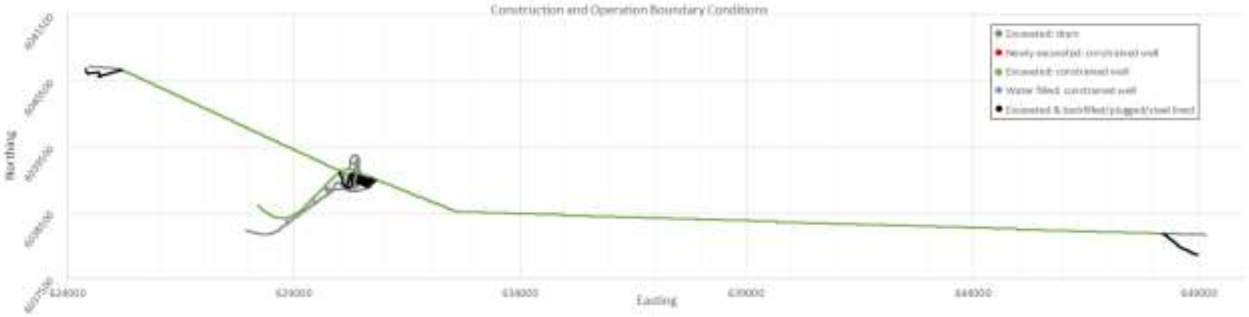
Stress period 24, ending September 2024:



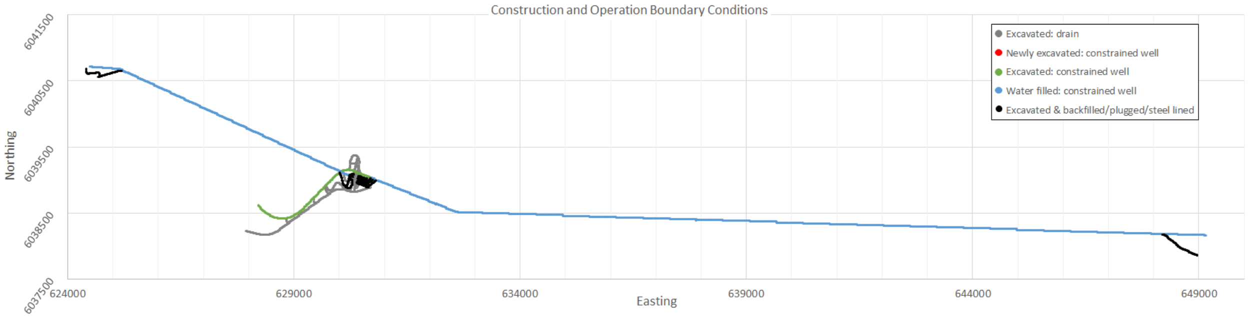
Stress period 25, ending December 2024:



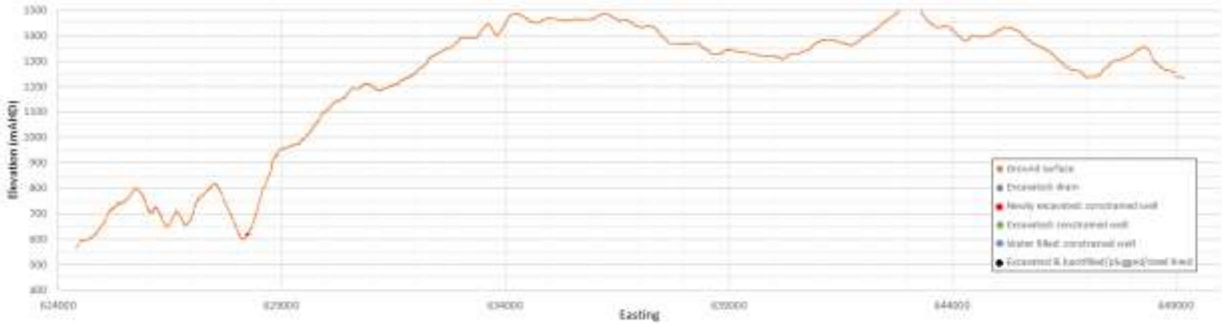
Stress period 26, ending March 2025



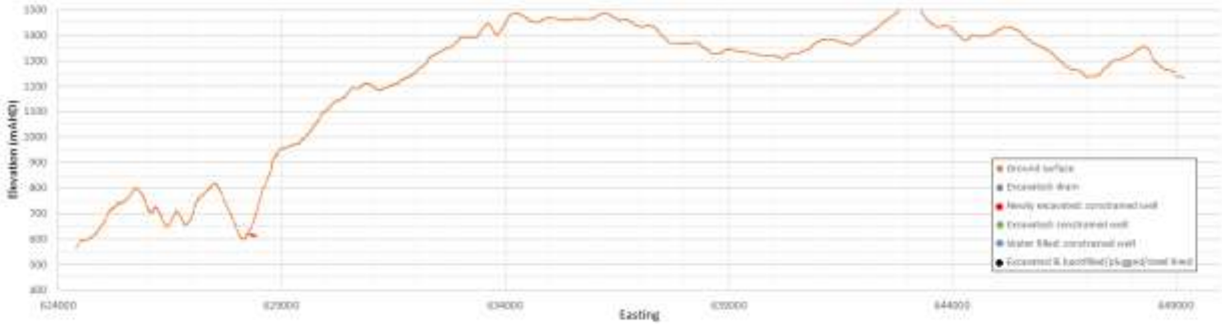
Stress period 27, ending June 2025:



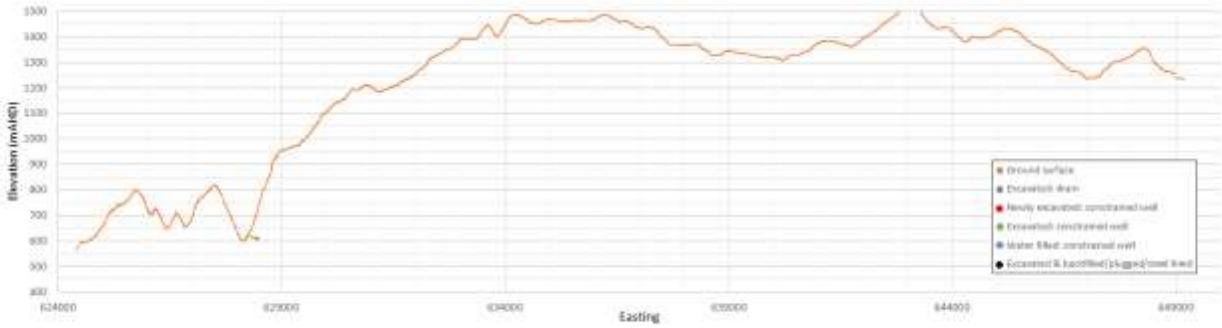
Stress period 5, ending December 2019:



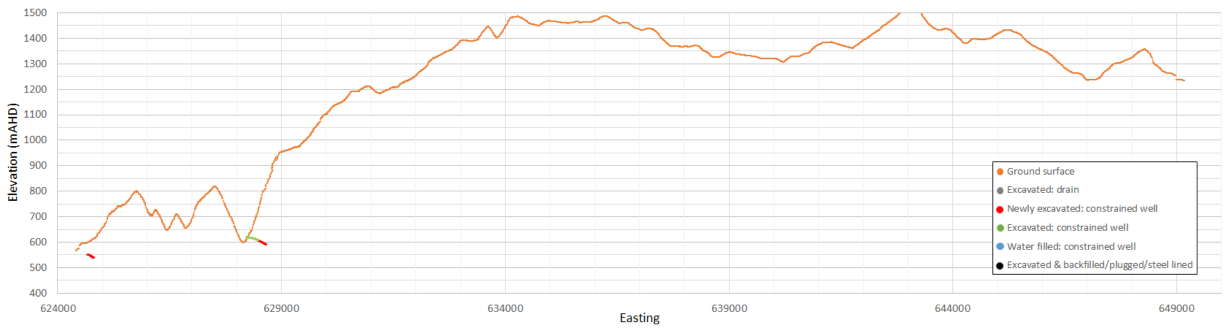
Stress period 6, ending March 2020



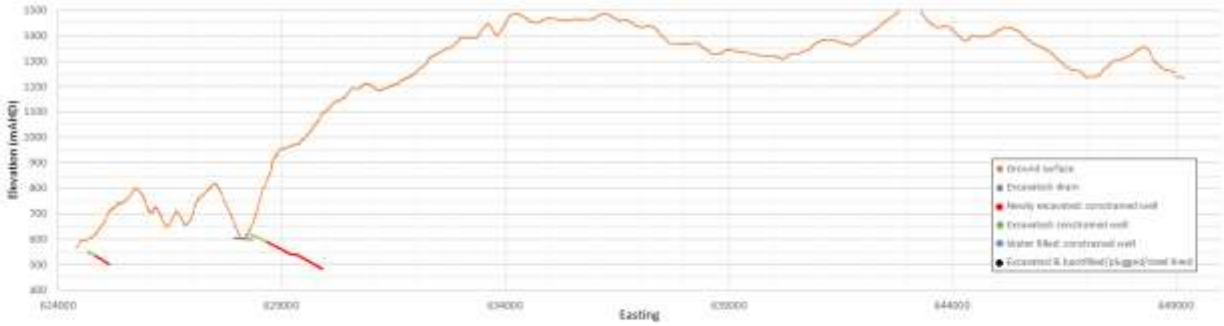
Stress period 7, ending June 2020:



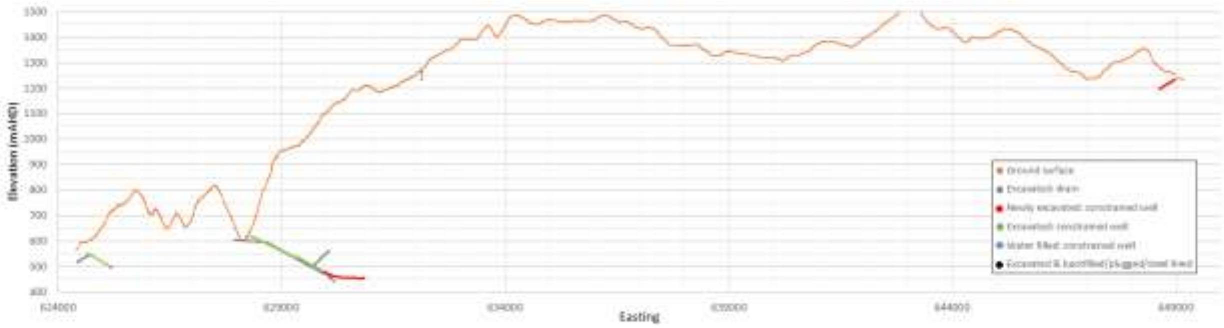
Stress period 8, ending September 2020:



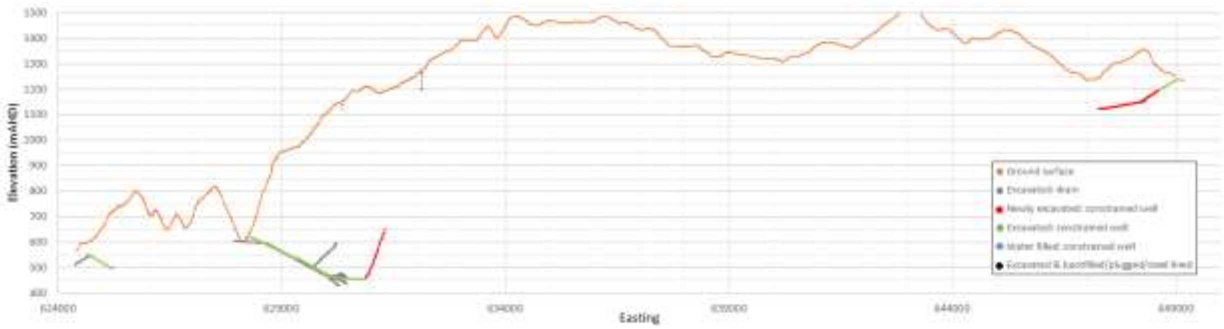
Stress period 9, ending December 2020:



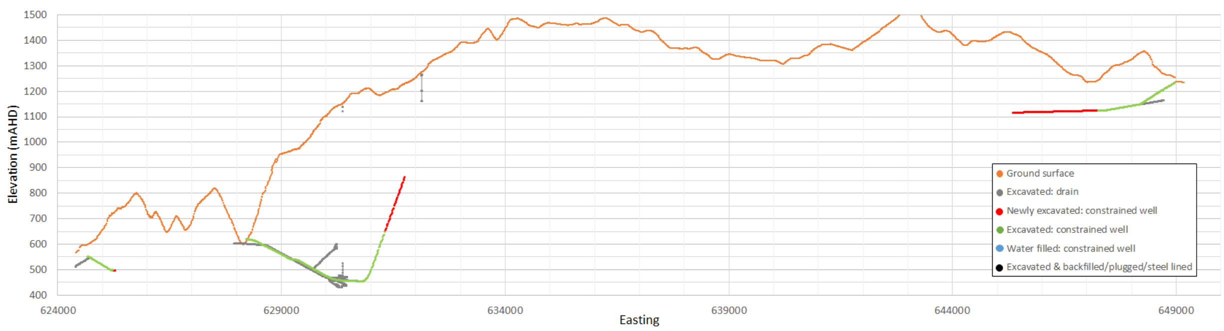
Stress period 10, ending March 2021



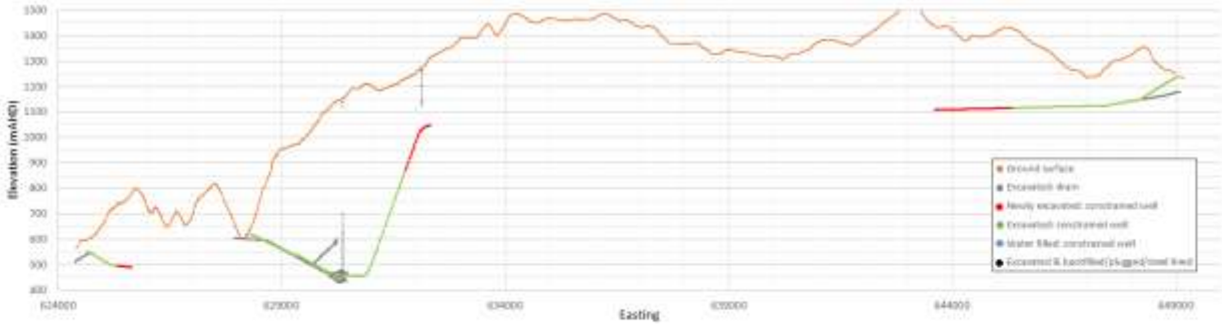
Stress period 11, ending June 2021:



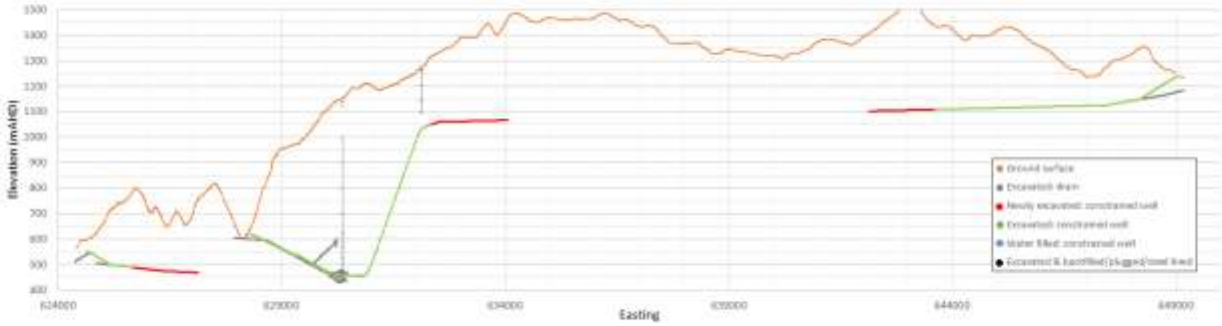
Stress period 12, ending September 2021:



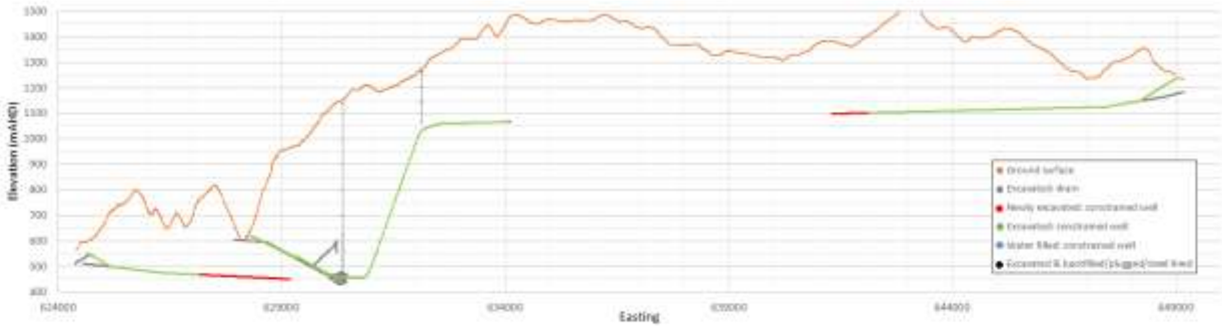
Stress period 13, ending December 2021:



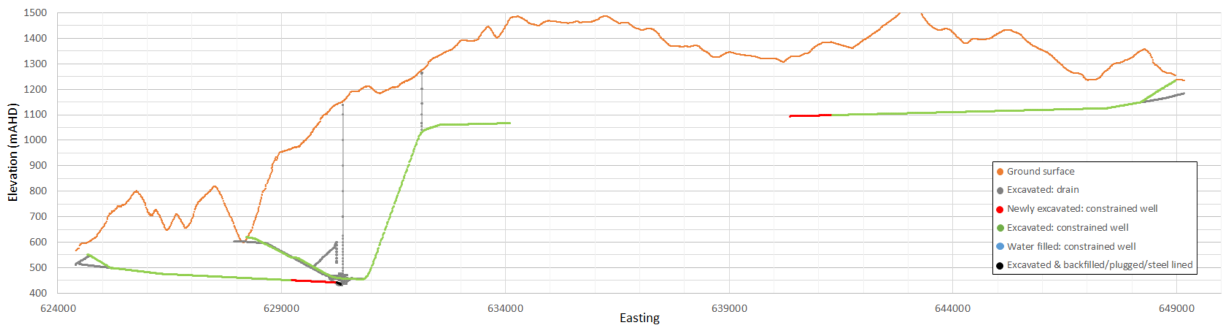
Stress period 14, ending March 2022



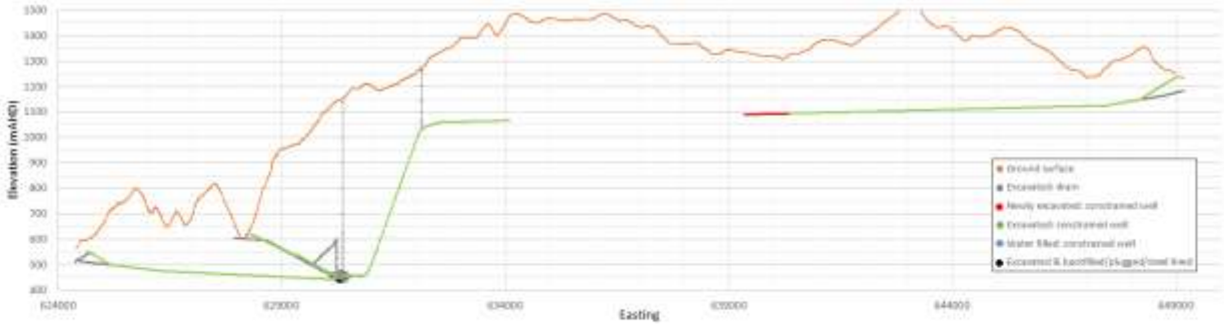
Stress period 15, ending June 2022:



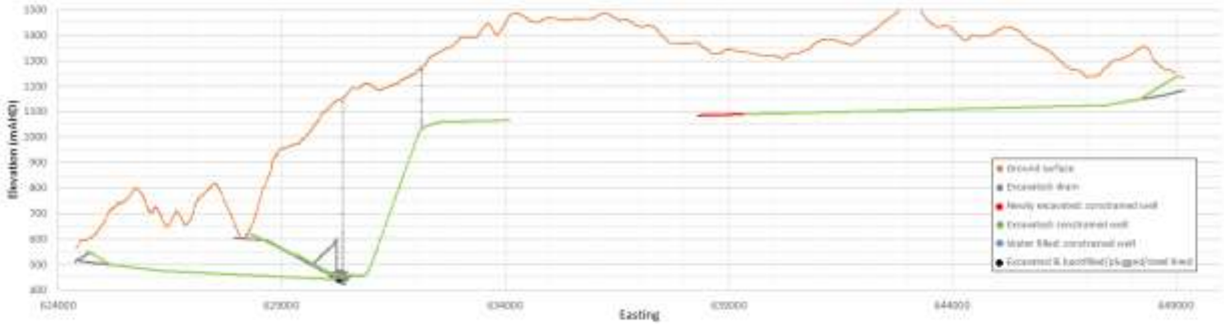
Stress period 16, ending September 2022:



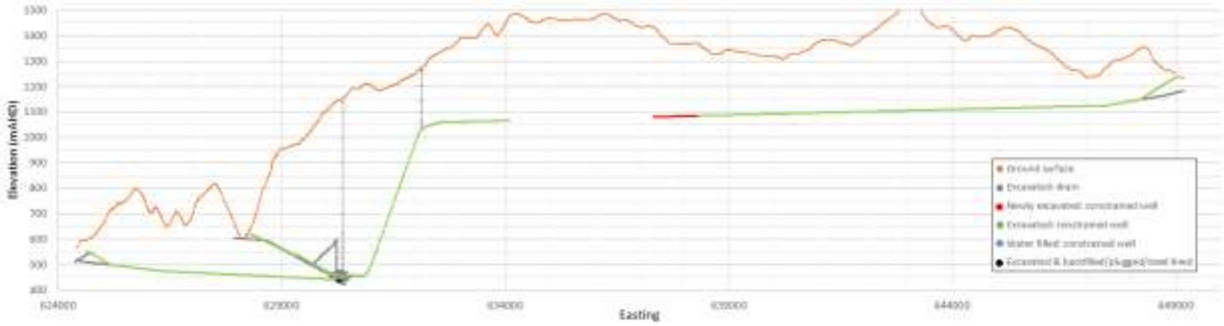
Stress period 17, ending December 2022:



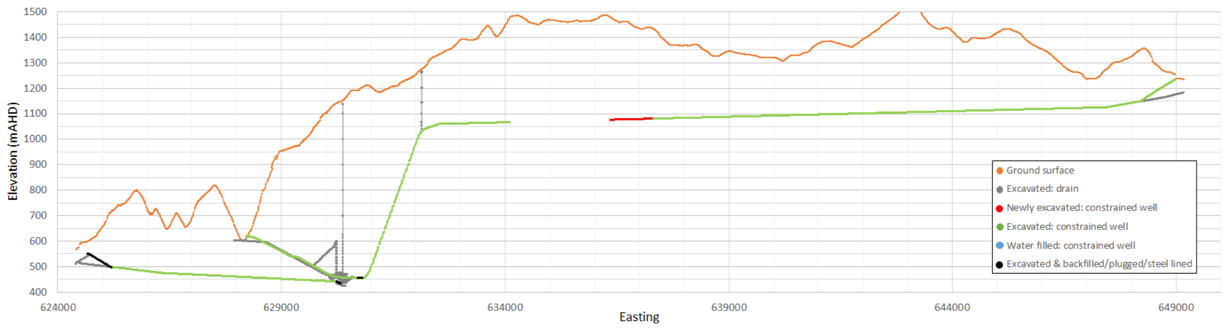
Stress period 18, ending March 2023



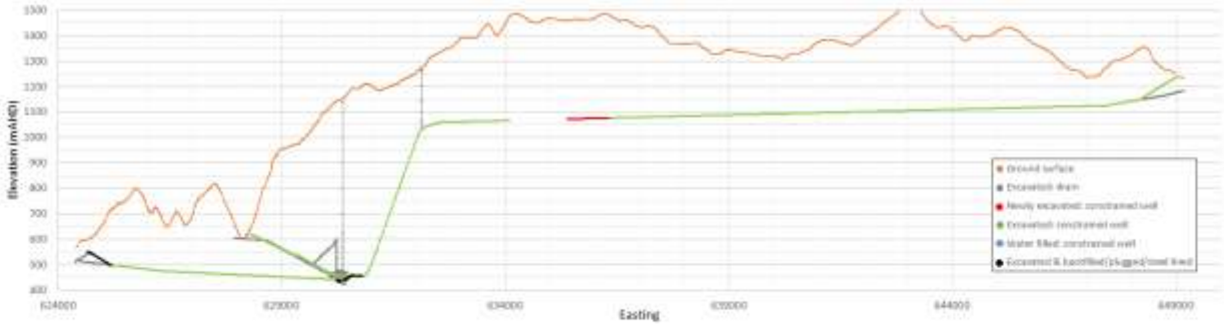
Stress period 19, ending June 2023:



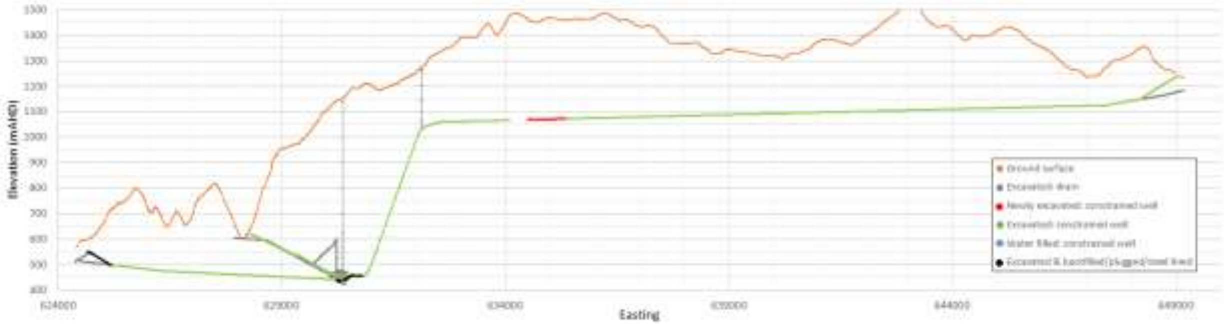
Stress period 20, ending September 2023:



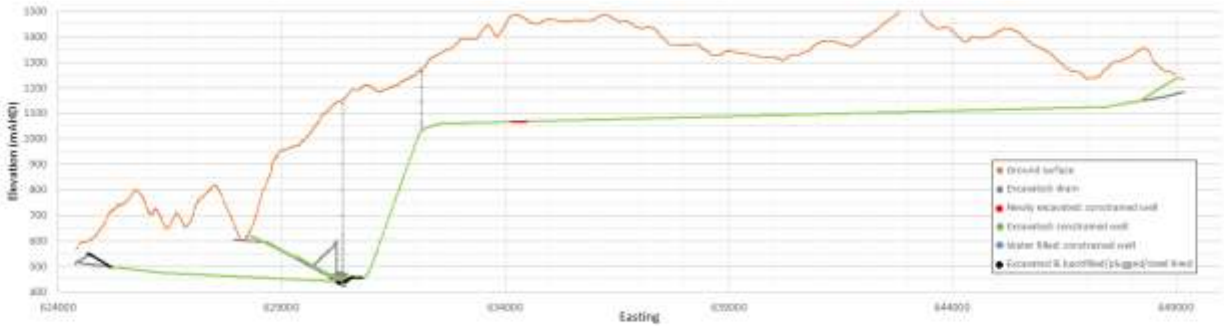
Stress period 21, ending December 2023:



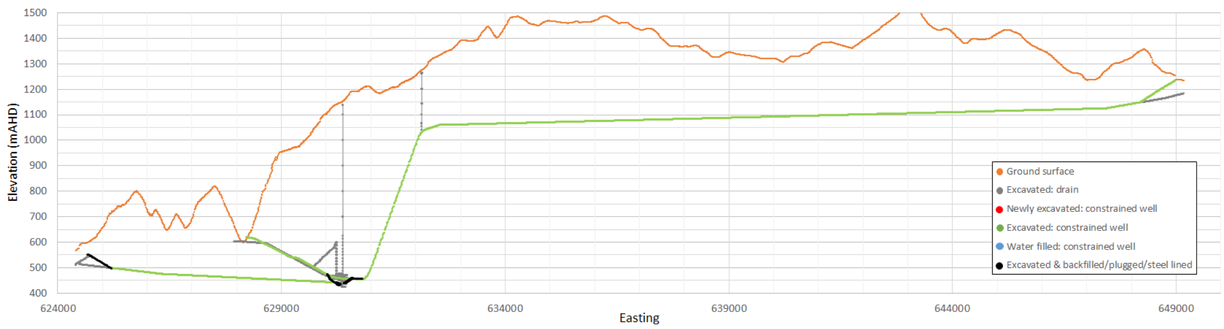
Stress period 22, ending March 2024



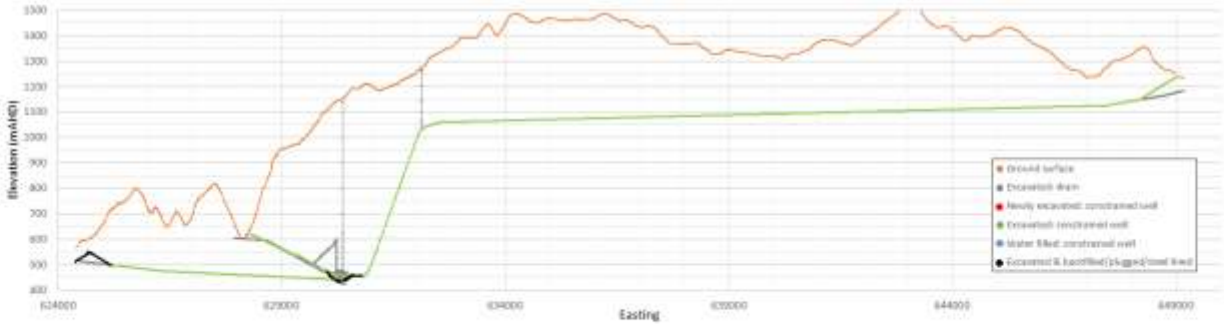
Stress period 23, ending June 2024:



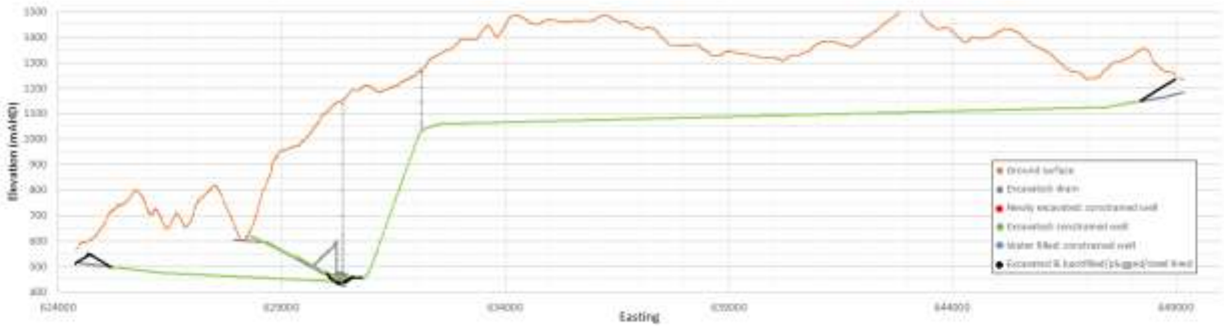
Stress period 24, ending September 2024:



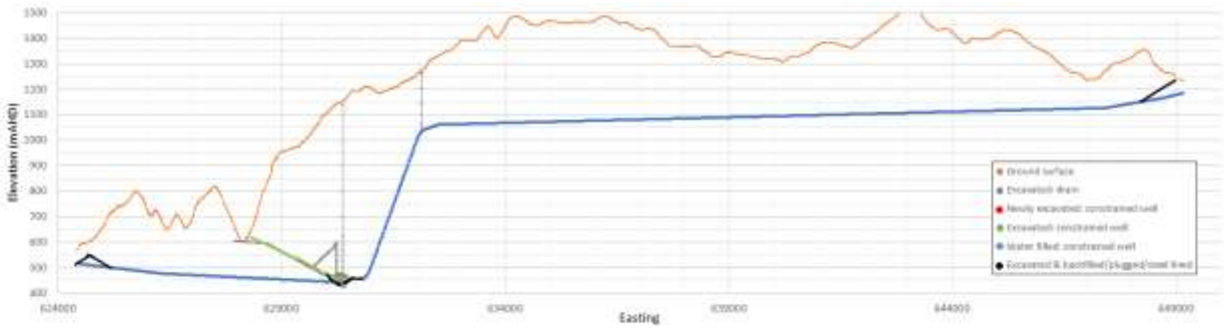
Stress period 25, ending December 2024:



Stress period 26, ending March 2025



Stress period 27, ending June 2025:



Attachment H

Groundwater model scenario inputs

Table H.1 Schedule of model inputs

Stress period	End date	Mode	Season	Excavations commenced	Excavations completed	Excavations ongoing	Excavations steel lined/ backfilled	Excavations water filled
1	01-Dec-2018	Steady State	Average					
2	01-Mar-2019	Transient	Spring					
3	01-Jun-2019	Transient	Summer					
4	01-Sep-2019	Transient	Autumn					
5	01-Dec-2019	Transient	Winter	MAT01				
6	01-Mar-2020	Transient	Spring			MAT01		
7	01-Jun-2020	Transient	Summer			MAT01		
8	01-Sep-2020	Transient	Autumn	TRT02		MAT01		
9	01-Dec-2020	Transient	Winter	ECVT01, TRT03		MAT01, TRT02		
10	01-Mar-2021	Transient	Spring	CP-1, CP-2, CT01, CT02, CT07, CT10bis, CT17, HRT01, HST, MAT02, TRT01	CP-1, CP-2, CT10bis, CT17, MAT01, TRT02	ECVT01, TRT03		
11	01-Jun-2021	Transient	Summer	CP-3, CP-4, CT03, CT04, CT05, CT10, CT15, CT16, ECVT02, HRT02, TH, VS	CP-3, CP-4, CT01, CT02, CT04, CT05, CT10, CT15, CT16, ECVT01, ECVT02, MAT02, TRT03	CT07, HRT01, HST, TRT01		
12	01-Sep-2021	Transient	Autumn	CO02, CO03, CT09, CT13, MH, PB, TST	CO03, CT03, CT07, CT09	HRT01, HRT02, HST, TH, TRT01, VS		
13	01-Dec-2021	Transient	Winter	CO01, HSR, PM02, PM03	CO01, CO02, CT13, HST, PB	HRT01, HRT02, MH, TH, TRT01, TST, VS		
14	01-Mar-2022	Transient	Spring	PM01	HRT02, PM02, PM03	HRT01, HSR, MH, TH, TRT01, TST, VS		
15	01-Jun-2022	Transient	Summer	IPB, PT05, PT06	PM01, VS	HRT01, HSR, MH, TH, TRT01, TST		
16	01-Sep-2022	Transient	Autumn		HSR, IPB, TH, TRT01	HRT01, MH, PT05, PT06, TST	CO01	
17	01-Dec-2022	Transient	Winter	PT03, PT04	PT05, PT06	HRT01, MH, TST		
18	01-Mar-2023	Transient	Spring	PT01, PT02	MH, PT03, PT04, TST	HRT01	CO02	
19	01-Jun-2023	Transient	Summer		PT01, PT02	HRT01		
20	01-Sep-2023	Transient	Autumn			HRT01	TRT02	

Table H.1 Schedule of model inputs

Stress period	End date	Mode	Season	Excavations commenced	Excavations completed	Excavations ongoing	Excavations steel lined/ backfilled	Excavations water filled
21	01-Dec-2023	Transient	Winter			HRT01	CO03, PM03, PT05, PT06	
22	01-Mar-2024	Transient	Spring			HRT01		
23	01-Jun-2024	Transient	Summer		HRT01		PM01, PT03, PT04	
24	01-Sep-2024	Transient	Autumn				CT02, PM02	
25	01-Dec-2024	Transient	Winter				PB, PT01, PT02, TRT03	
26	01-Mar-2025	Transient	Spring				CT03, HRT02	
27	01-Jun-2025	Transient	Summer					HRT01, TRT01
28	01-Sep-2025	Transient	Autumn					HRT01, TRT01
29	01-Dec-2025	Transient	Winter					HRT01, TRT01
30	01-Mar-2026	Transient	Spring					HRT01, TRT01
31	01-Jun-2026	Transient	Summer					HRT01, TRT01
32	01-Sep-2026	Transient	Autumn					HRT01, TRT01
33	01-Dec-2026	Transient	Winter					HRT01, TRT01
34	01-Mar-2027	Transient	Spring					HRT01, TRT01
35	01-Jun-2027	Transient	Summer					HRT01, TRT01
36	01-Sep-2027	Transient	Autumn					HRT01, TRT01
37	01-Dec-2027	Transient	Winter					HRT01, TRT01
38	01-Mar-2028	Transient	Spring					HRT01, TRT01
39	01-Jun-2028	Transient	Summer					HRT01, TRT01
40	01-Sep-2028	Transient	Autumn					HRT01, TRT01
41	01-Dec-2028	Transient	Winter					HRT01, TRT01

Table H.1 Schedule of model inputs

Stress period	End date	Mode	Season	Excavations commenced	Excavations completed	Excavations ongoing	Excavations steel lined/ backfilled	Excavations water filled
42	01-Mar-2029	Transient	Spring					HRT01, TRT01
43	01-Jun-2029	Transient	Summer					HRT01, TRT01
44	01-Sep-2029	Transient	Autumn					HRT01, TRT01
45	01-Dec-2029	Transient	Winter					HRT01, TRT01
46	01-Mar-2030	Transient	Spring					HRT01, TRT01
47	01-Jun-2030	Transient	Summer					HRT01, TRT01
48	01-Sep-2030	Transient	Autumn					HRT01, TRT01
49	01-Dec-2030	Transient	Winter					HRT01, TRT01
50	01-Mar-2031	Transient	Spring					HRT01, TRT01
51	01-Jun-2031	Transient	Summer					HRT01, TRT01
52	01-Sep-2031	Transient	Autumn					HRT01, TRT01
53	01-Dec-2031	Transient	Winter					HRT01, TRT01
54	01-Mar-2032	Transient	Spring					HRT01, TRT01
55	01-Jun-2032	Transient	Summer					HRT01, TRT01
56	01-Sep-2032	Transient	Autumn					HRT01, TRT01
57	01-Dec-2032	Transient	Winter					HRT01, TRT01
58	01-Mar-2033	Transient	Spring					HRT01, TRT01
59	01-Jun-2033	Transient	Summer					HRT01, TRT01
60	01-Sep-2033	Transient	Autumn					HRT01, TRT01
61	01-Dec-2033	Transient	Winter					HRT01, TRT01

Table H.1 Schedule of model inputs

Stress period	End date	Mode	Season	Excavations commenced	Excavations completed	Excavations ongoing	Excavations steel lined/ backfilled	Excavations water filled
62	01-Mar-2034	Transient	Spring					HRT01, TRT01
63	01-Jun-2034	Transient	Summer					HRT01, TRT01
64	01-Sep-2034	Transient	Autumn					HRT01, TRT01
65	01-Dec-2034	Transient	Winter					HRT01, TRT01
66	01-Mar-2035	Transient	Spring					HRT01, TRT01
67	01-Jun-2035	Transient	Summer					HRT01, TRT01
68	01-Sep-2035	Transient	Autumn					HRT01, TRT01
69	01-Dec-2035	Transient	Winter					HRT01, TRT01
70	01-Mar-2036	Transient	Spring					HRT01, TRT01
71	01-Jun-2036	Transient	Summer					HRT01, TRT01
72	01-Sep-2036	Transient	Autumn					HRT01, TRT01
73	01-Dec-2036	Transient	Winter					HRT01, TRT01
74	01-Mar-2037	Transient	Spring					HRT01, TRT01
75	01-Jun-2037	Transient	Summer					HRT01, TRT01
76	01-Sep-2037	Transient	Autumn					HRT01, TRT01
77	01-Dec-2037	Transient	Winter					HRT01, TRT01
78	01-Mar-2038	Transient	Spring					HRT01, TRT01
79	01-Jun-2038	Transient	Summer					HRT01, TRT01
80	01-Sep-2038	Transient	Autumn					HRT01, TRT01
81	01-Dec-2038	Transient	Winter					HRT01, TRT01

Table H.1 Schedule of model inputs

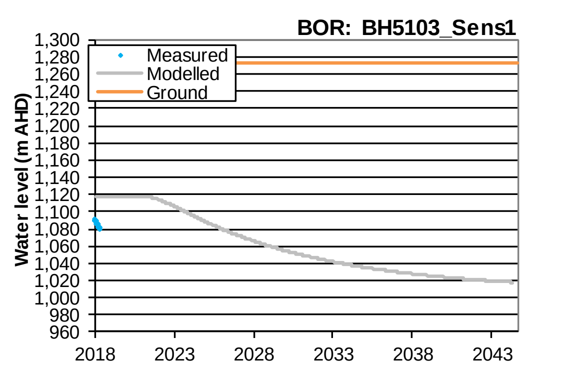
Stress period	End date	Mode	Season	Excavations commenced	Excavations completed	Excavations ongoing	Excavations steel lined/ backfilled	Excavations water filled
82	01-Mar-2039	Transient	Spring					HRT01, TRT01
83	01-Jun-2039	Transient	Summer					HRT01, TRT01
84	01-Sep-2039	Transient	Autumn					HRT01, TRT01
85	01-Dec-2039	Transient	Winter					HRT01, TRT01
86	01-Mar-2040	Transient	Spring					HRT01, TRT01
87	01-Jun-2040	Transient	Summer					HRT01, TRT01
88	01-Sep-2040	Transient	Autumn					HRT01, TRT01
89	01-Dec-2040	Transient	Winter					HRT01, TRT01
90	01-Mar-2041	Transient	Spring					HRT01, TRT01
91	01-Jun-2041	Transient	Summer					HRT01, TRT01
92	01-Sep-2041	Transient	Autumn					HRT01, TRT01
93	01-Dec-2041	Transient	Winter					HRT01, TRT01
94	01-Mar-2042	Transient	Spring					HRT01, TRT01
95	01-Jun-2042	Transient	Summer					HRT01, TRT01
96	01-Sep-2042	Transient	Autumn					HRT01, TRT01
97	01-Dec-2042	Transient	Winter					HRT01, TRT01
98	01-Mar-2043	Transient	Spring					HRT01, TRT01
99	01-Jun-2043	Transient	Summer					HRT01, TRT01
100	01-Sep-2043	Transient	Autumn					HRT01, TRT01
101	01-Dec-2043	Transient	Winter					HRT01, TRT01

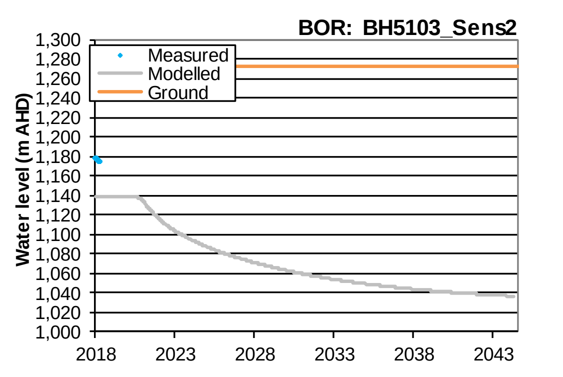
Table H.1 Schedule of model inputs

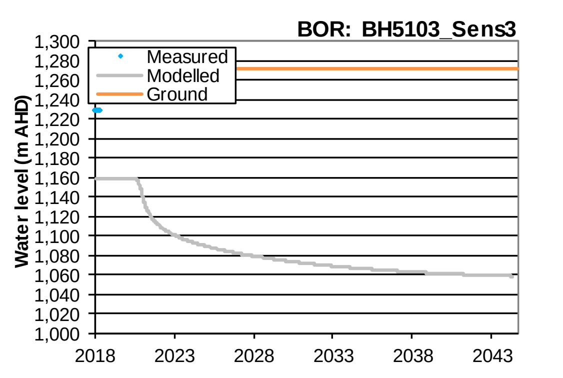
Stress period	End date	Mode	Season	Excavations commenced	Excavations completed	Excavations ongoing	Excavations steel lined/ backfilled	Excavations water filled
102	01-Mar-2044	Transient	Spring					HRT01, TRT01
103	01-Jun-2044	Transient	Summer					HRT01, TRT01
104	01-Sep-2044	Transient	Autumn					HRT01, TRT01
105	01-Dec-2044	Transient	Winter					HRT01, TRT01
106	01-Mar-2045	Transient	Spring					HRT01, TRT01

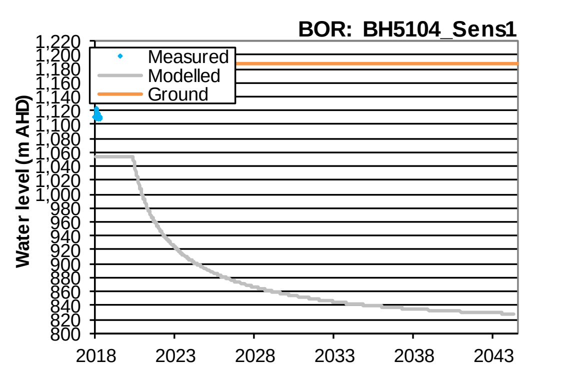
Attachment I

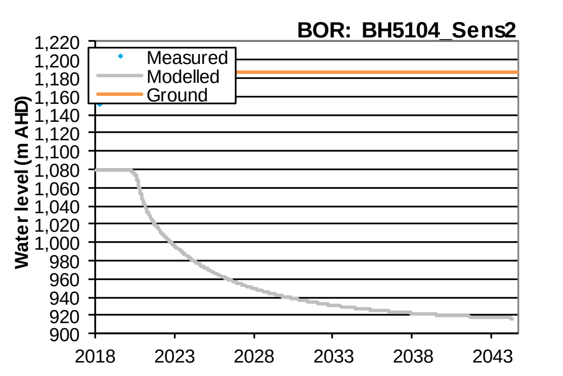
Groundwater hydrograph predictions

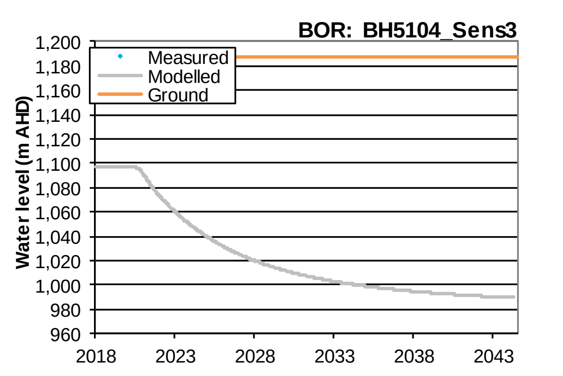

BOR: BH5103_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
2018
2023
2028
2033
2038
2043

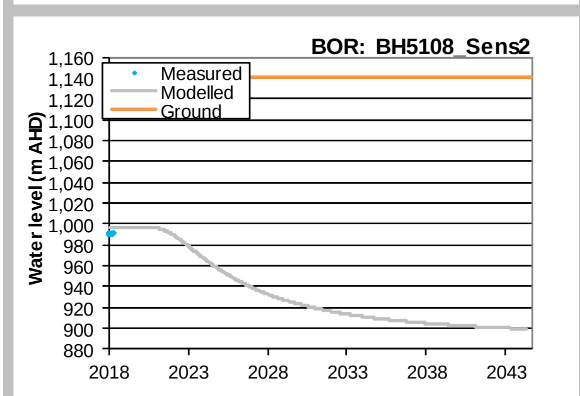

BOR: BH5103_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
2018
2023
2028
2033
2038
2043

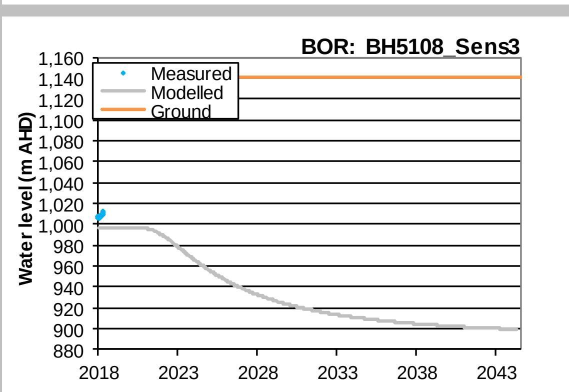

BOR: BH5103_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
2018
2023
2028
2033
2038
2043

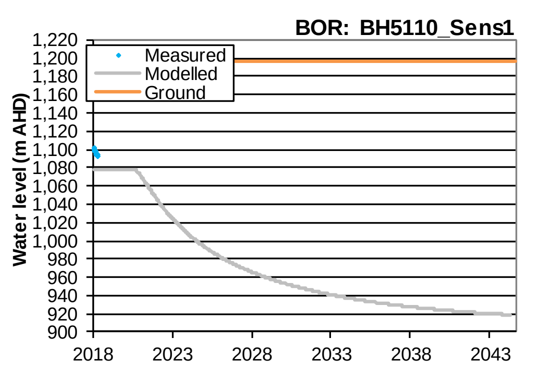

BOR: BH5104_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
880
860
840
820
800
2018
2023
2028
2033
2038
2043

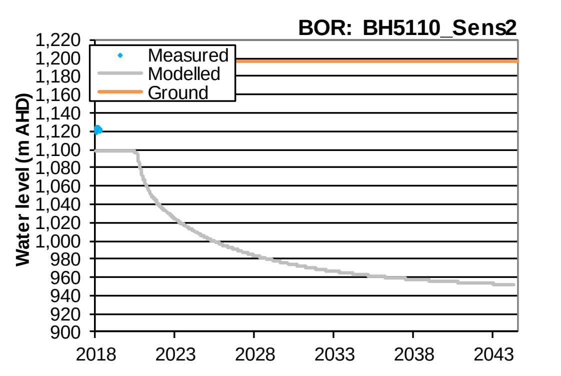

BOR: BH5104_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
2018
2023
2028
2033
2038
2043

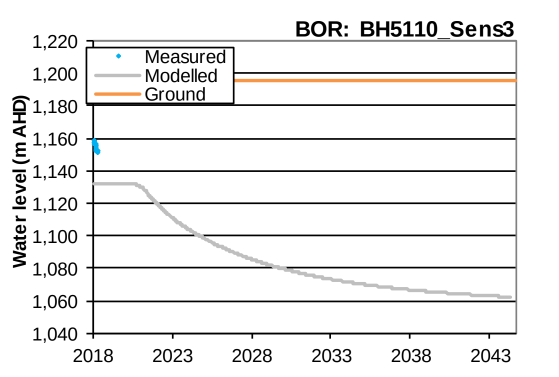

BOR: BH5104_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
2018
2023
2028
2033
2038
2043

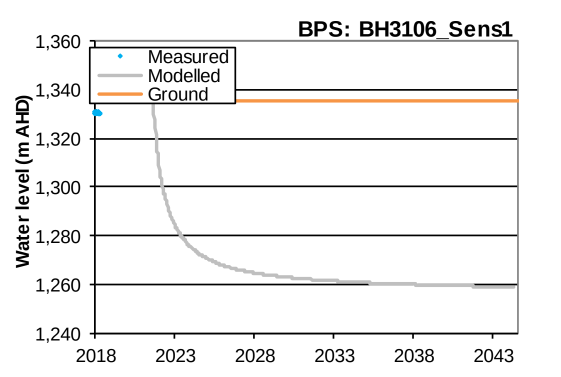

BOR: BH5108_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
880
2018
2023
2028
2033
2038
2043

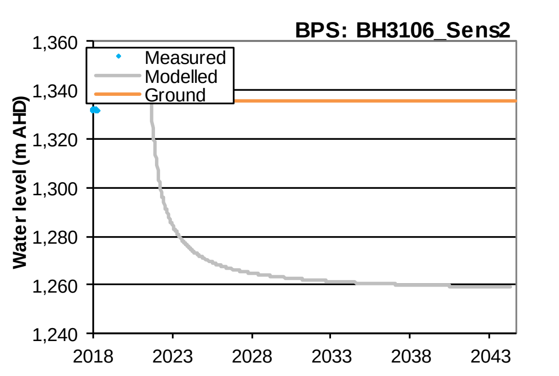

BOR: BH5108_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
880
2018
2023
2028
2033
2038
2043

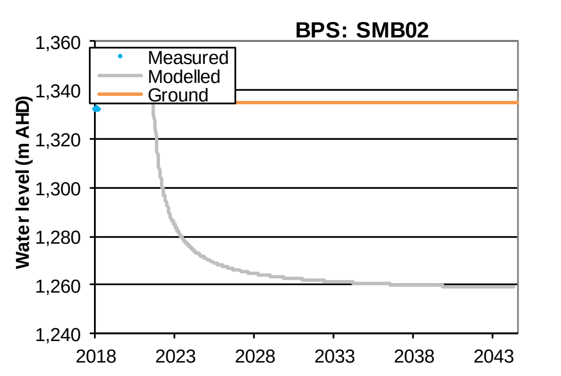

BOR: BH5110_Sens1
Water level (m AHD)
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground

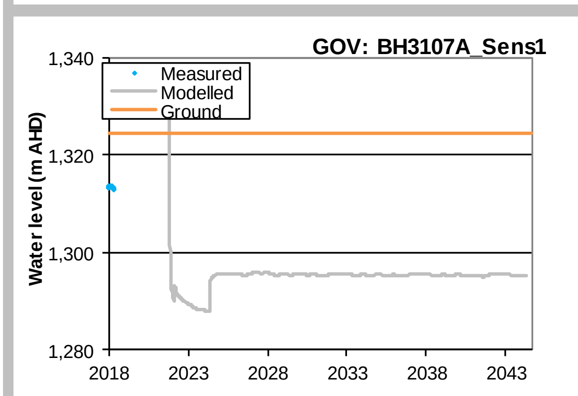

BOR: BH5110_Sens2
Water level (m AHD)
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground

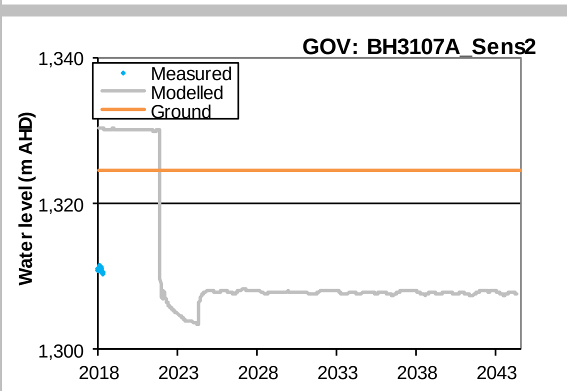

BOR: BH5110_Sens3
Water level (m AHD)
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground

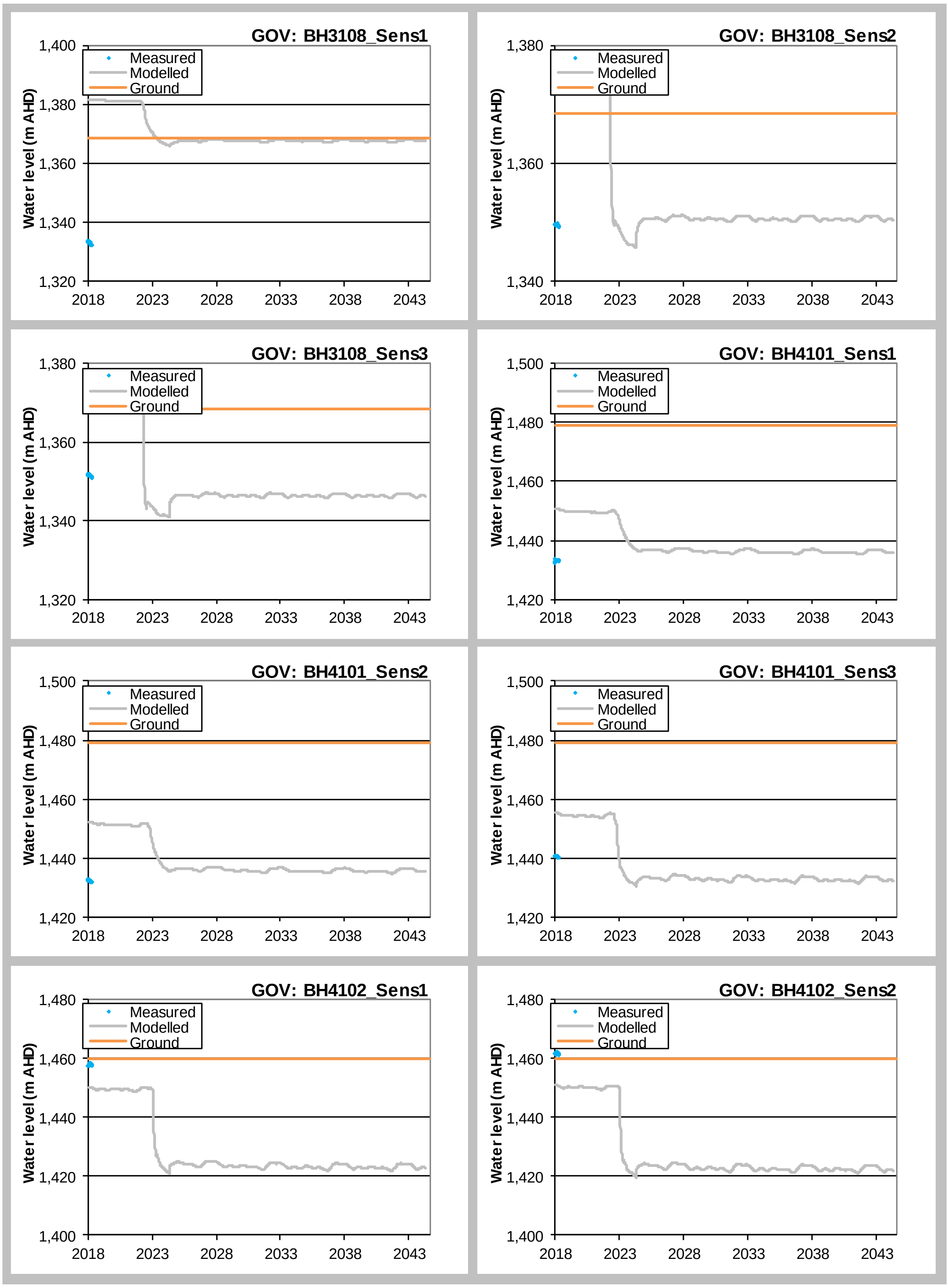

BPS: BH3106_Sens1
Water level (m AHD)
1,360
1,340
1,320
1,300
1,280
1,260
1,240
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground


BPS: BH3106_Sens2
Water level (m AHD)
1,360
1,340
1,320
1,300
1,280
1,260
1,240
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground


BPS: SMB02
Water level (m AHD)
1,360
1,340
1,320
1,300
1,280
1,260
1,240
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground


GOV: BH3107A_Sens1
Water level (m AHD)
1,340
1,320
1,300
1,280
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground


GOV: BH3107A_Sens2
Water level (m AHD)
1,340
1,320
1,300
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground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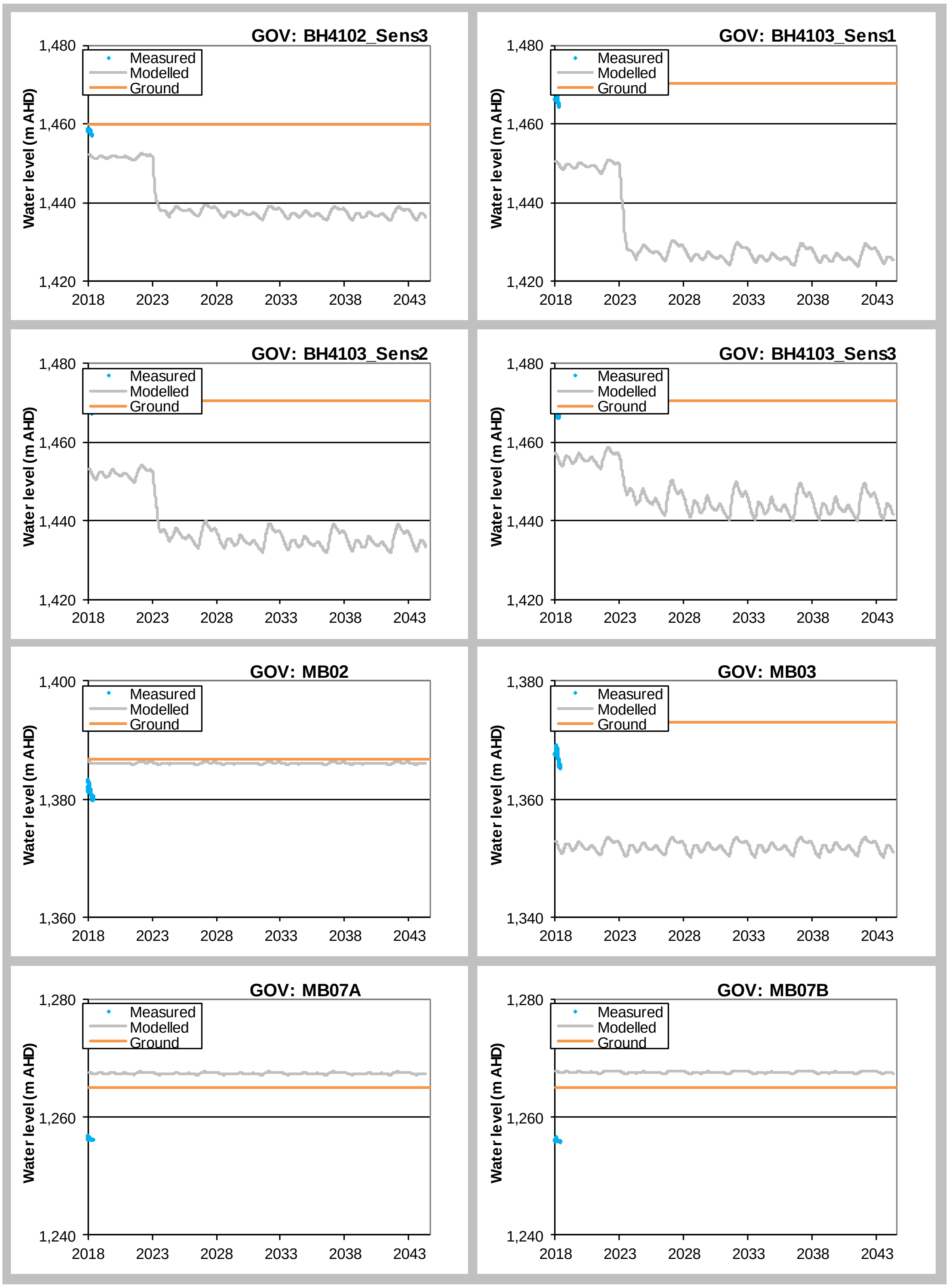
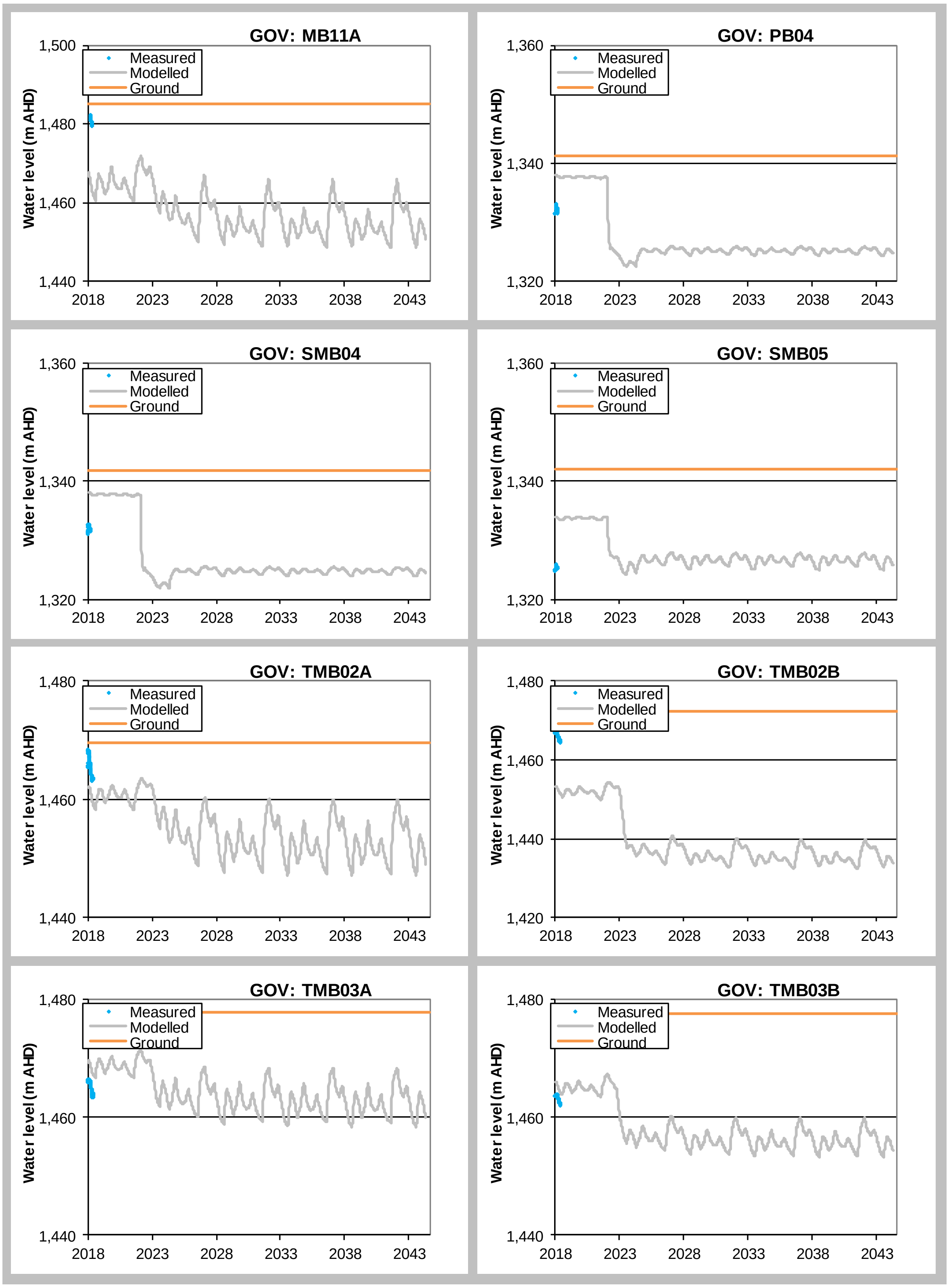
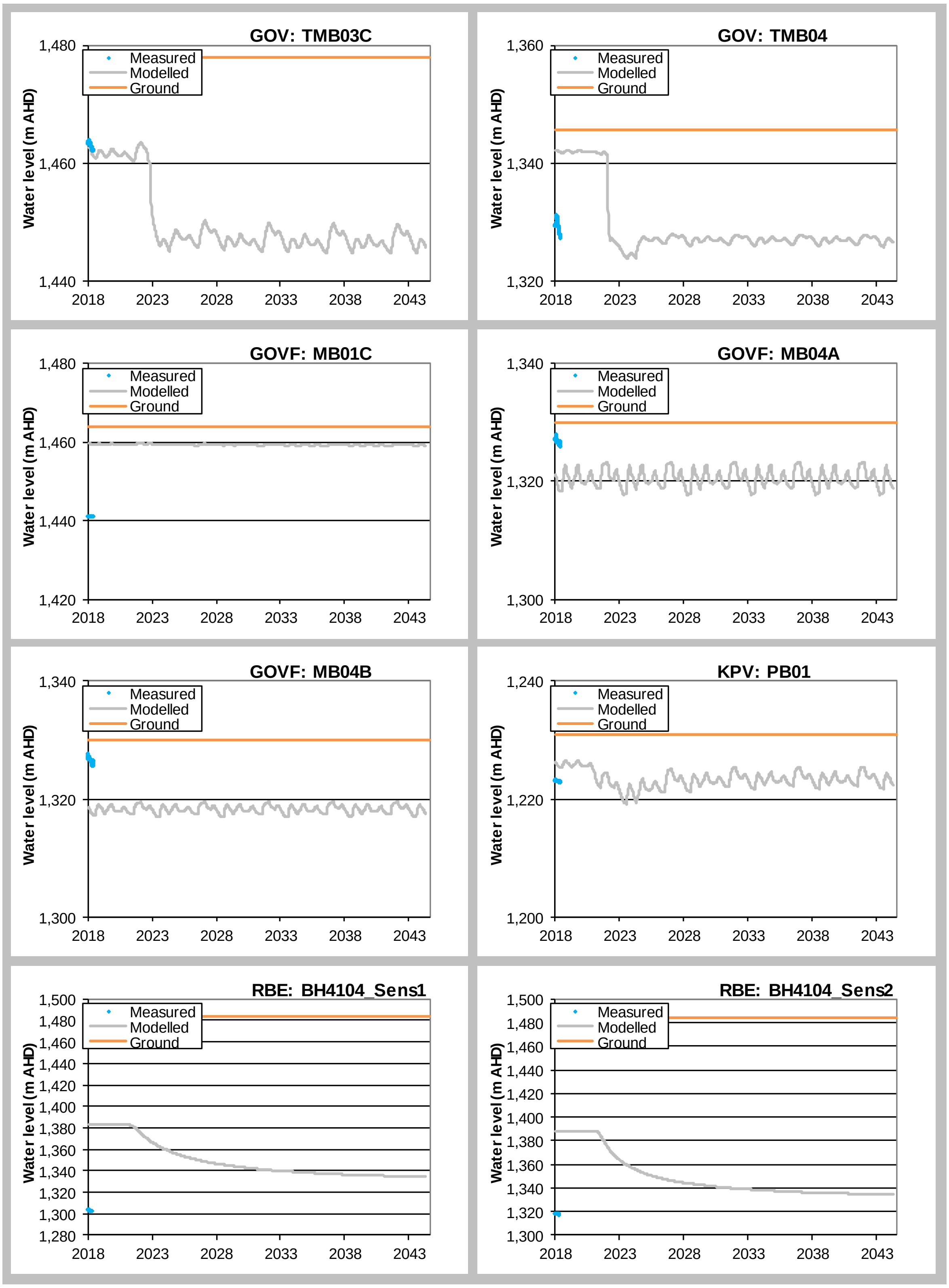
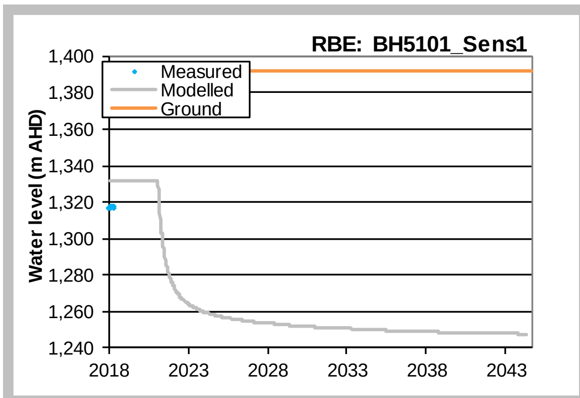
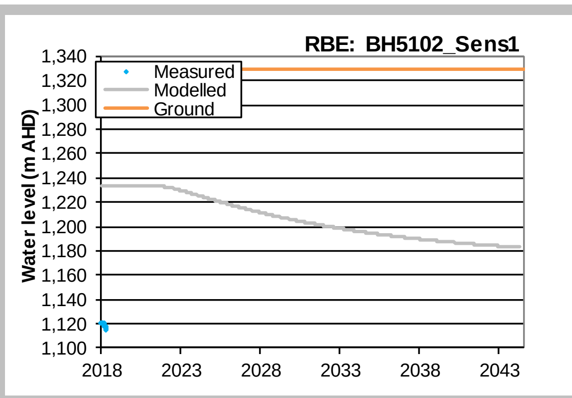
GOV: BH3108_Sens2
GOV: BH3108_Sens3
GOV: BH4101_Sens1
GOV: BH4101_Sens2
GOV: BH4101_Sens3
GOV: BH4102_Sens1
GOV: BH4102_Sens2
Measured
Modelled
Ground
Water level (m AHD)
2018
2023
2028
2033
2038
2043

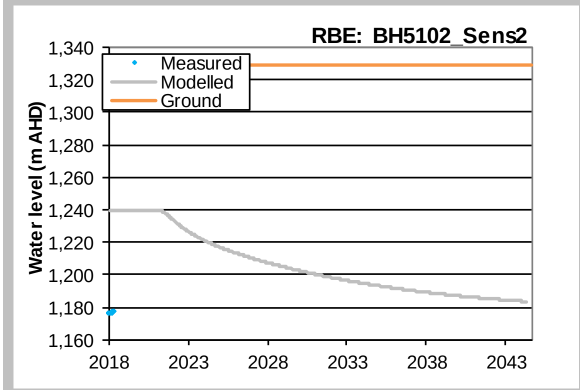

GOV: BH4102_Sens3
GOV: BH4103_Sens1
GOV: BH4103_Sens2
GOV: BH4103_Sens3
GOV: MB02
GOV: MB03
GOV: MB07A
GOV: MB07B
Measured
Modelled
Ground
Water level (m AHD)
1,480
1,460
1,440
1,420
1,400
1,380
1,360
1,340
1,280
1,260
1,240
2018
2023
2028
2033
2038
2043

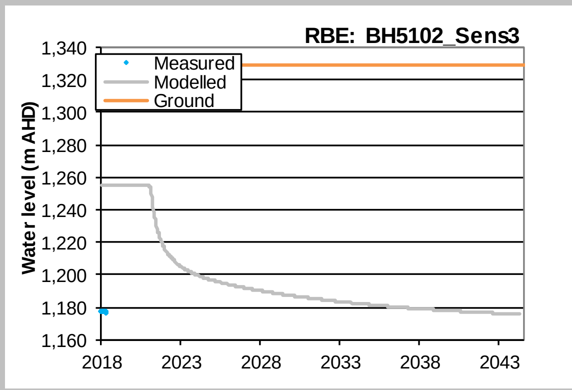

GOV: MB11A
GOV: PB04
GOV: SMB04
GOV: SMB05
GOV: TMB02A
GOV: TMB02B
GOV: TMB03A
GOV: TMB03B
Measured
Modelled
Ground
Water level (m AHD)
1,500
1,480
1,460
1,440
1,420
1,360
1,340
1,320
2018
2023
2028
2033
2038
2043

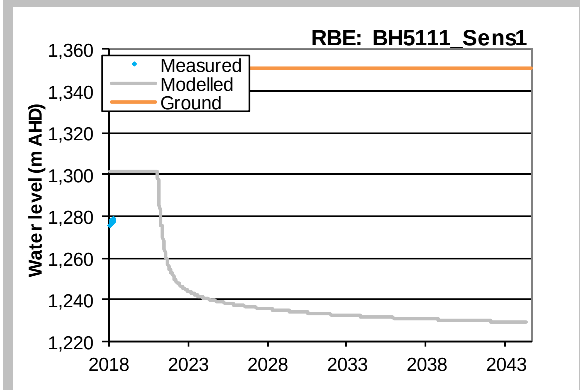

GOV: TMB03C
GOV: TMB04
GOVF: MB01C
GOVF: MB04A
GOVF: MB04B
KPV: PB01
RBE: BH4104_Sens1
RBE: BH4104_Sens2
Measured
Modelled
Ground
Water level (m AHD)
2018
2023
2028
2033
2038
2043

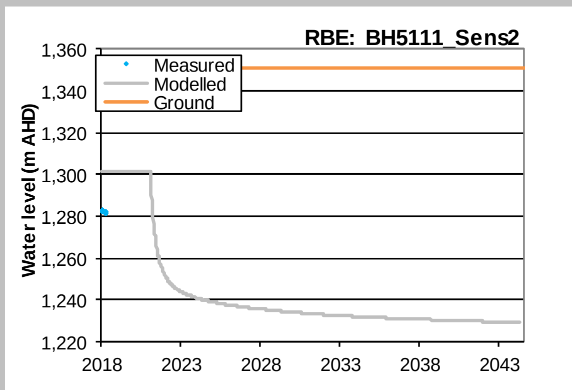

RBE: BH5101_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,400
1,380
1,360
1,340
1,320
1,300
1,280
1,260
1,240
2018
2023
2028
2033
2038
2043

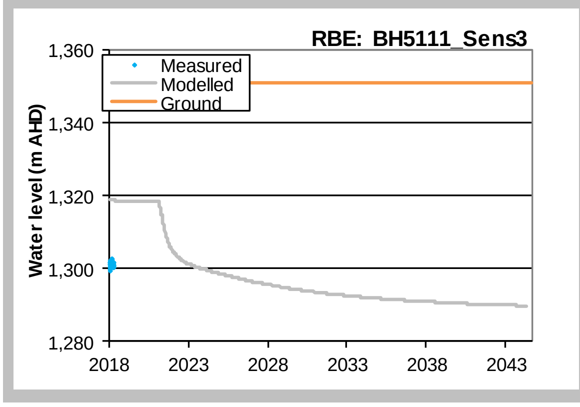

RBE: BH5102_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,340
1,320
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
1,120
1,100
2018
2023
2028
2033
2038
2043

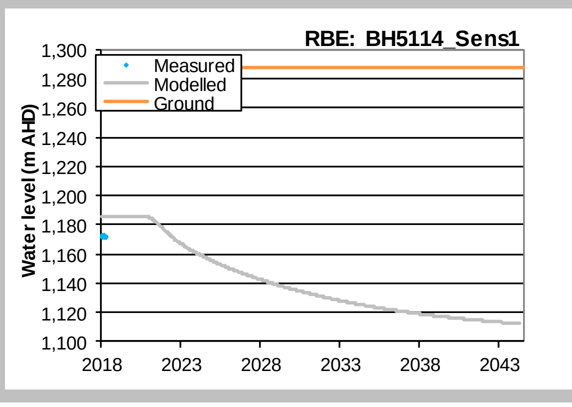

RBE: BH5102_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,340
1,320
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
2018
2023
2028
2033
2038
2043

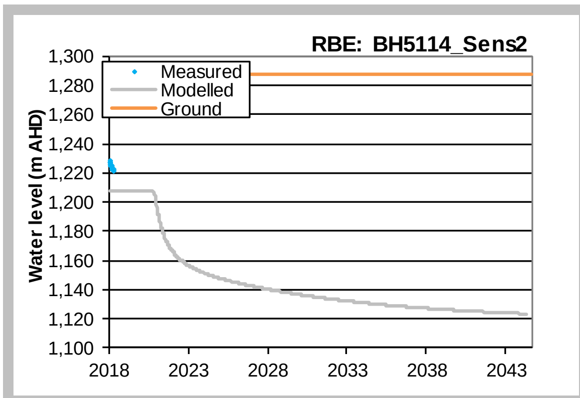

RBE: BH5102_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,340
1,320
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
2018
2023
2028
2033
2038
2043

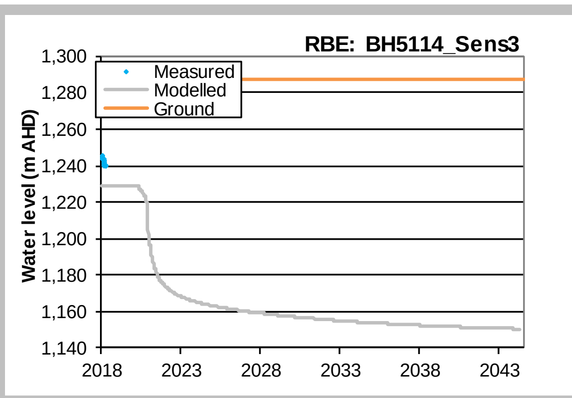

RBE: BH5111_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,360
1,340
1,320
1,300
1,280
1,260
1,240
1,220
2018
2023
2028
2033
2038
2043

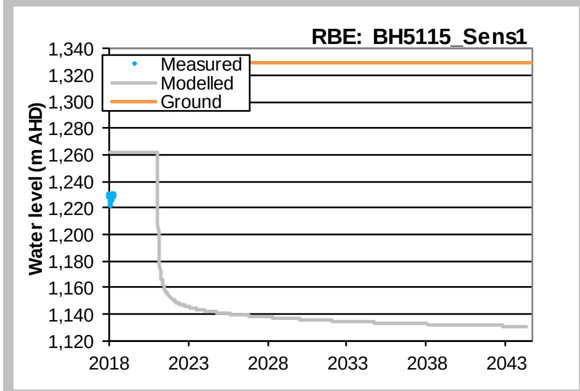

RBE: BH5111_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,360
1,340
1,320
1,300
1,280
1,260
1,240
1,220
2018
2023
2028
2033
2038
2043

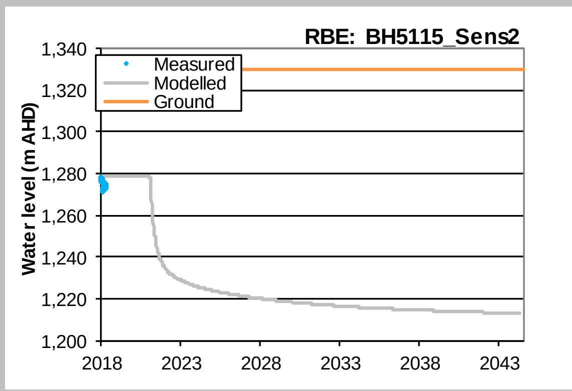

RBE: BH5111_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,360
1,340
1,320
1,300
1,280
2018
2023
2028
2033
2038
2043

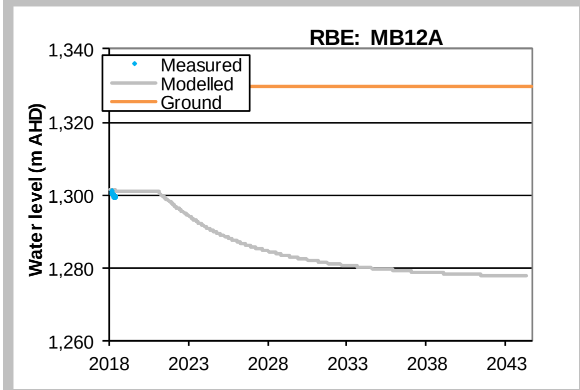

RBE: BH5114_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
1,120
1,100
2018
2023
2028
2033
2038
2043

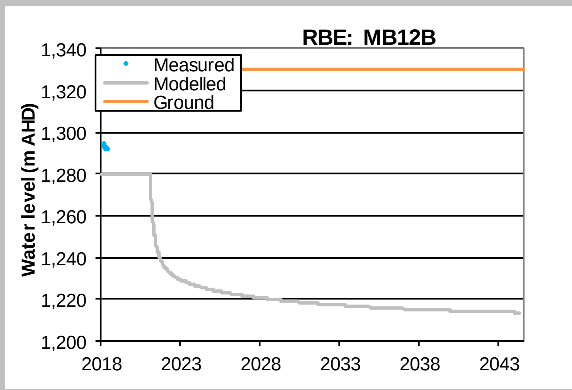

RBE: BH5114_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
1,120
1,100
2018
2023
2028
2033
2038
2043

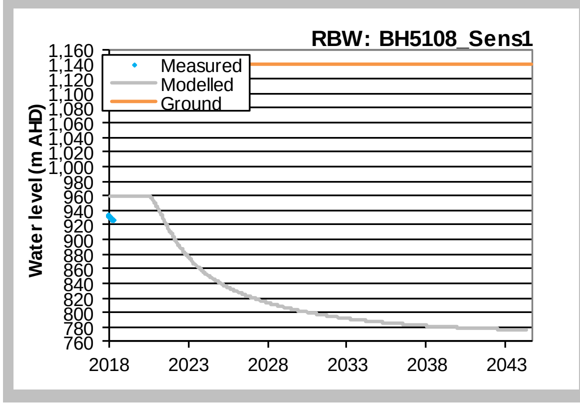

RBE: BH5114_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
2018
2023
2028
2033
2038
2043

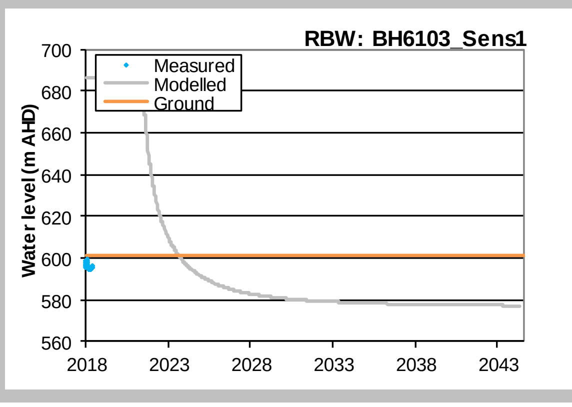

RBE: BH5115_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,340
1,320
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
1,120
2018
2023
2028
2033
2038
2043

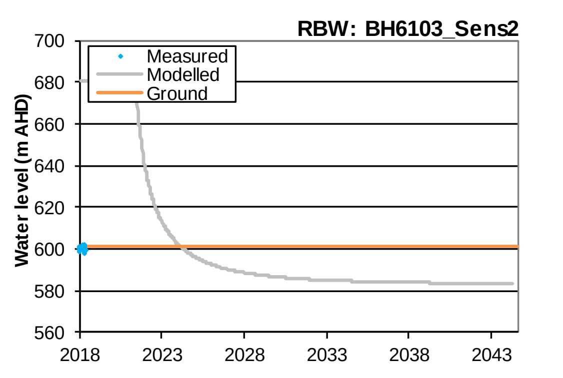

RBE: BH5115_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,340
1,320
1,300
1,280
1,260
1,240
1,220
1,200
2018
2023
2028
2033
2038
2043

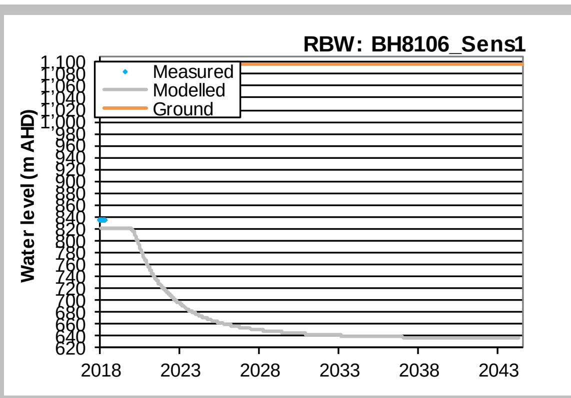

RBE: MB12A
Measured
Modelled
Ground
Water level (m AHD)
1,340
1,320
1,300
1,280
1,260
2018
2023
2028
2033
2038
2043

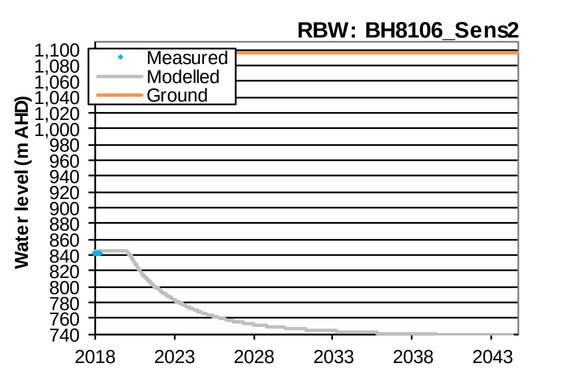

RBE: MB12B
Measured
Modelled
Ground
Water level (m AHD)
1,340
1,320
1,300
1,280
1,260
1,240
1,220
1,200
2018
2023
2028
2033
2038
2043

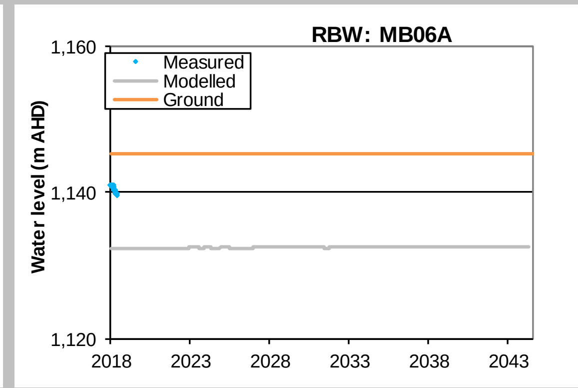

RBW: BH5108_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
880
860
840
820
800
780
760
2018
2023
2028
2033
2038
2043

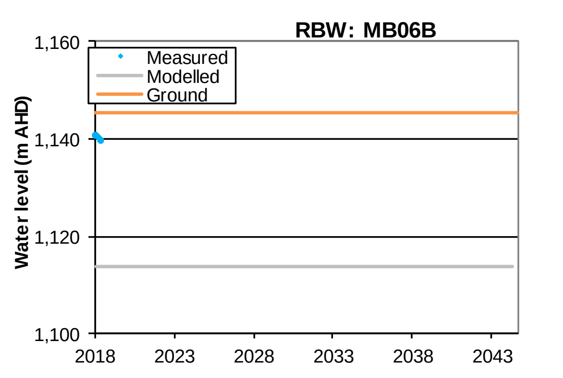

RBW: BH6103_Sens1
Measured
Modelled
Ground
Water level (m AHD)
700
680
660
640
620
600
580
560
2018
2023
2028
2033
2038
2043

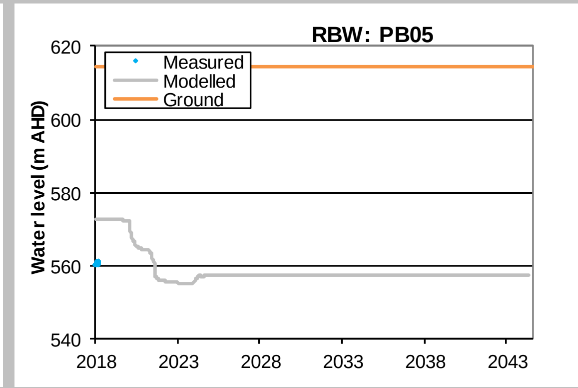

RBW: BH6103_Sens2
Measured
Modelled
Ground
Water level (m AHD)
700
680
660
640
620
600
580
560
2018
2023
2028
2033
2038
2043

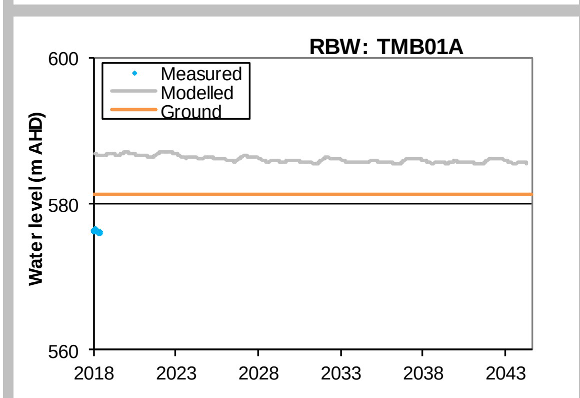

RBW: BH8106_Sens1
Measured
Modelled
Ground
Water level (m AHD)
2018
2023
2028
2033
2038
2043

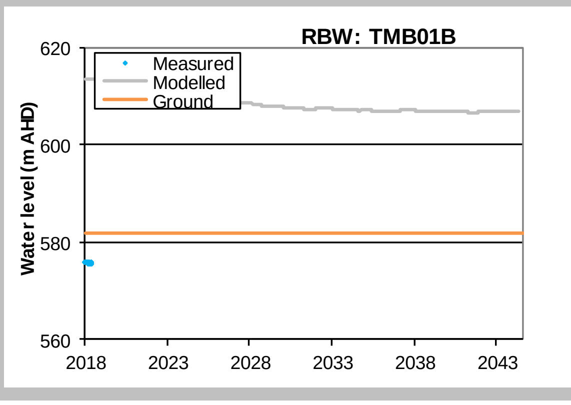

RBW: BH8106_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
880
860
840
820
800
780
760
740
2018
2023
2028
2033
2038
2043

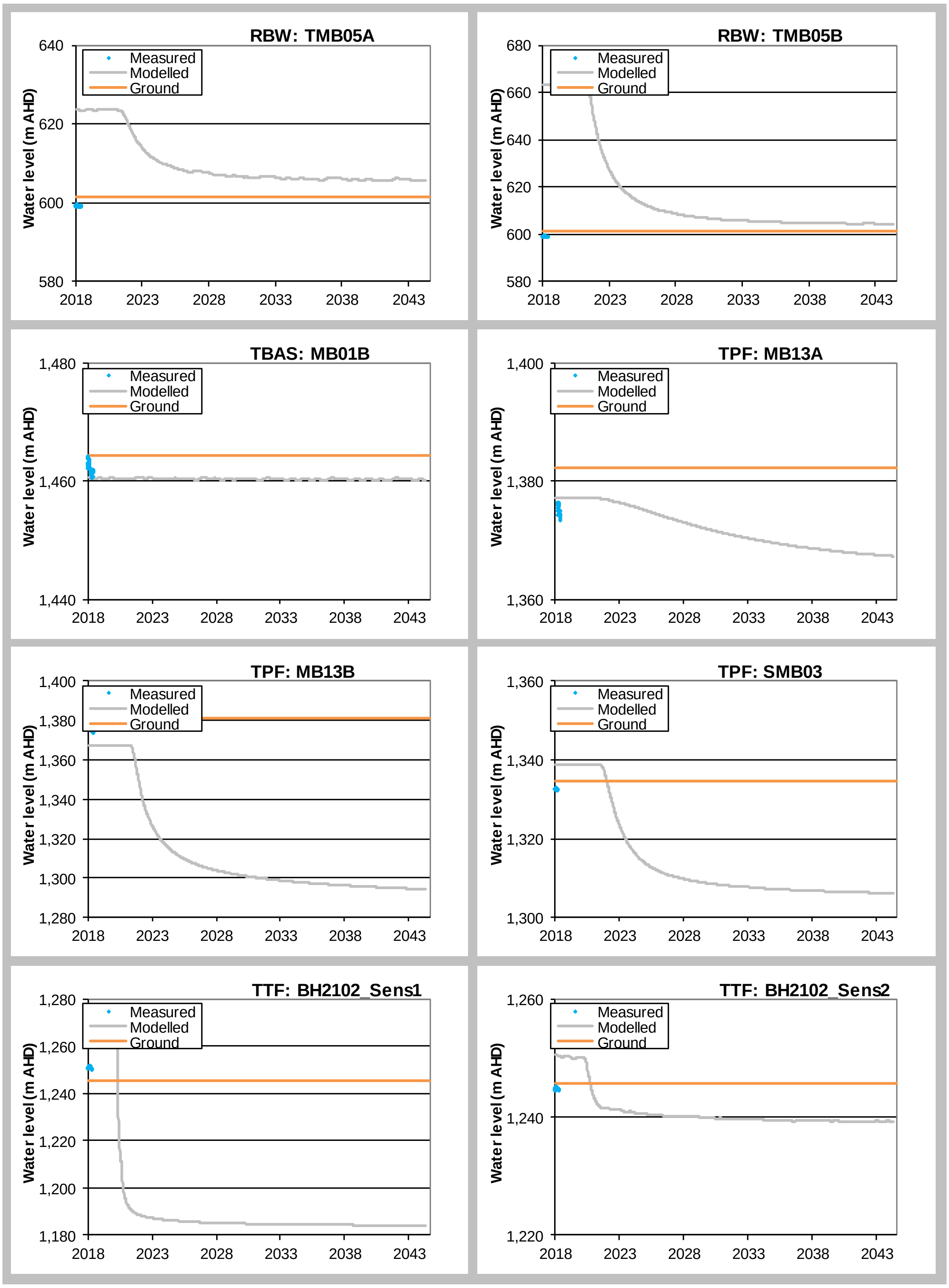

RBW: MB06A
Measured
Modelled
Ground
Water level (m AHD)
1,160
1,140
1,120
2018
2023
2028
2033
2038
2043

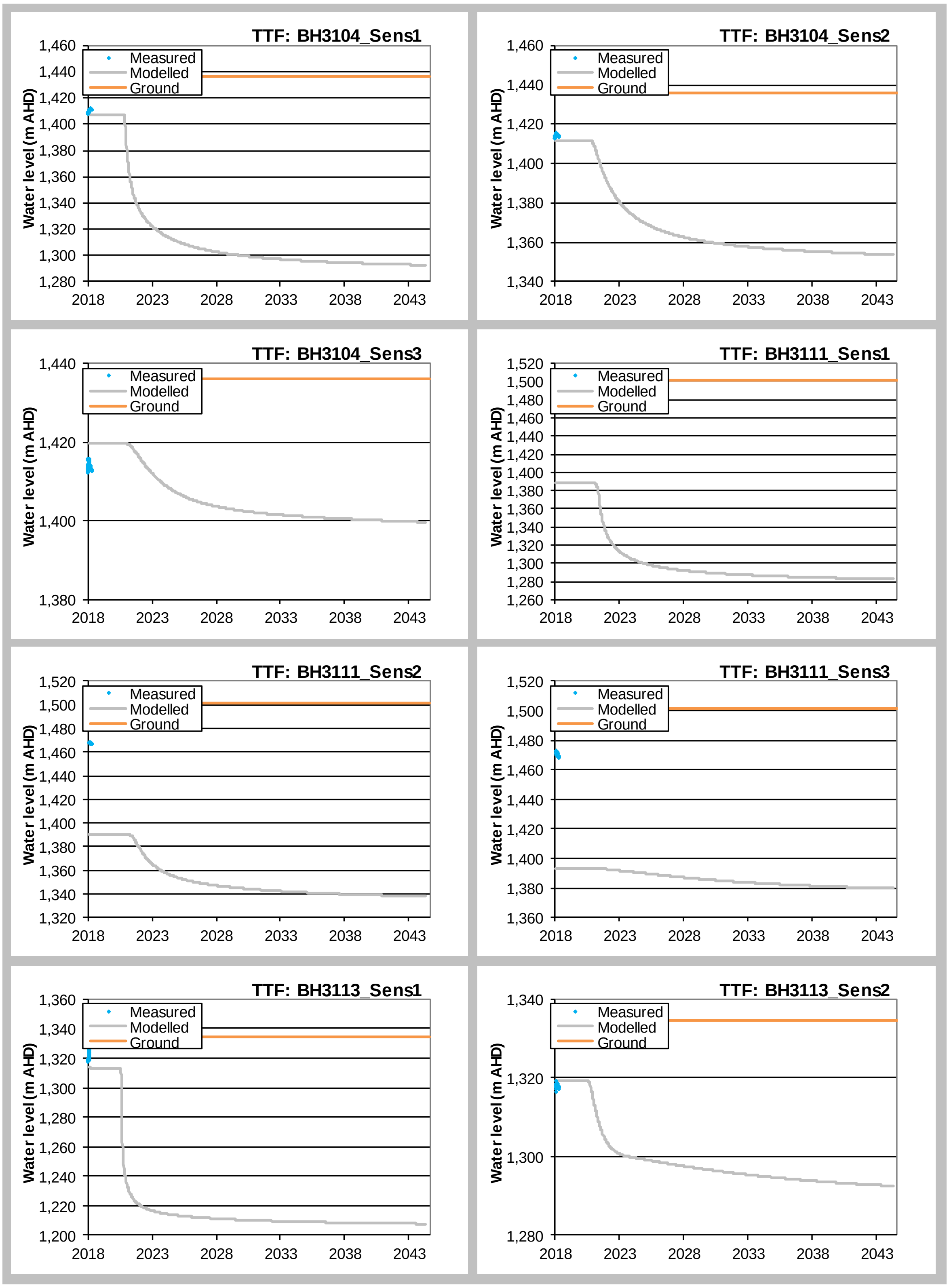

RBW: MB06B
Measured
Modelled
Ground
Water level (m AHD)
1,160
1,140
1,120
1,100
2018
2023
2028
2033
2038
2043


RBW: PB05
Measured
Modelled
Ground
Water level (m AHD)
620
600
580
560
540
2018
2023
2028
2033
2038
2043

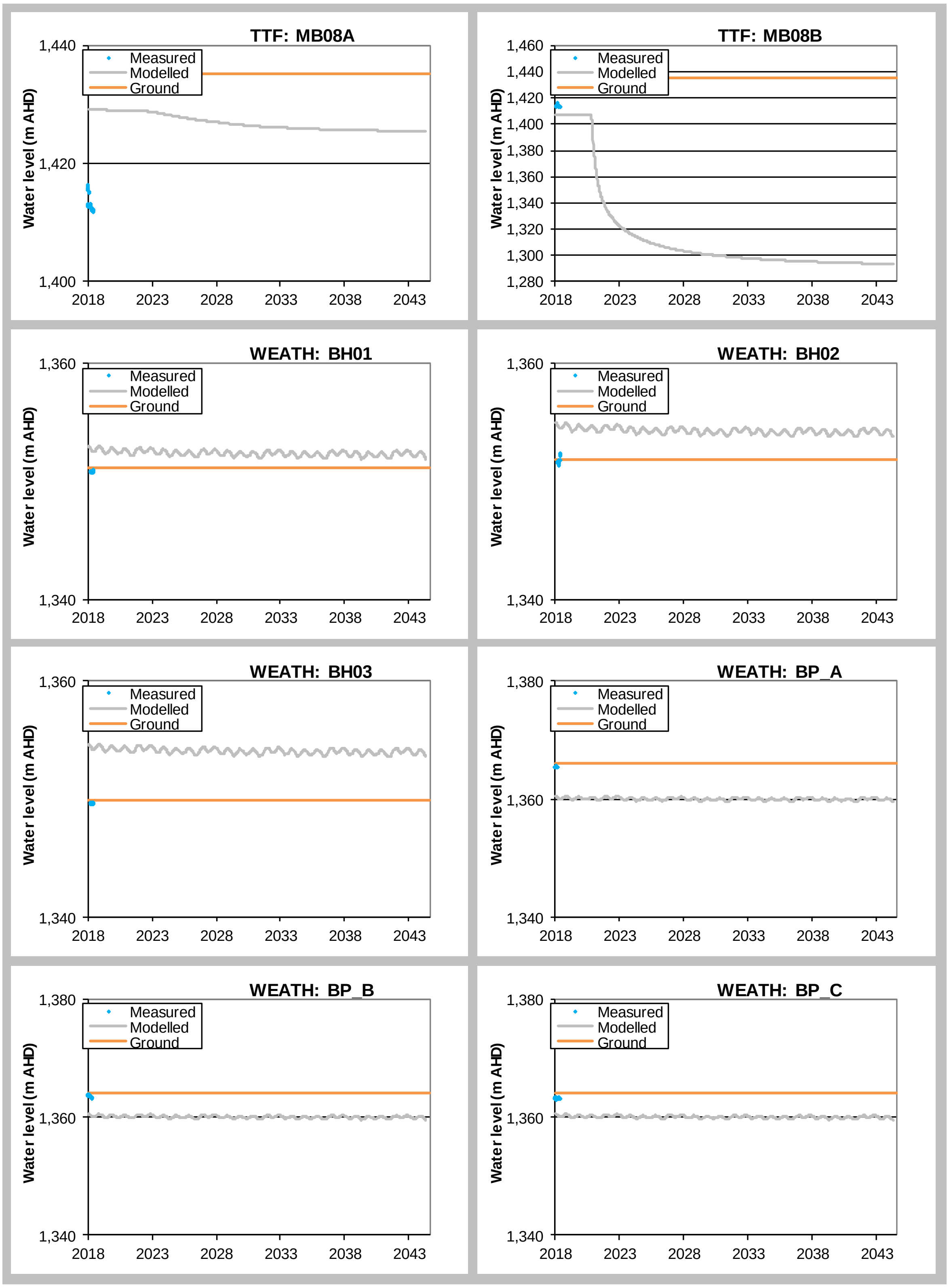

RBW: TMB01A
Measured
Modelled
Ground
Water level (m AHD)
600
580
560
2018
2023
2028
2033
2038
2043

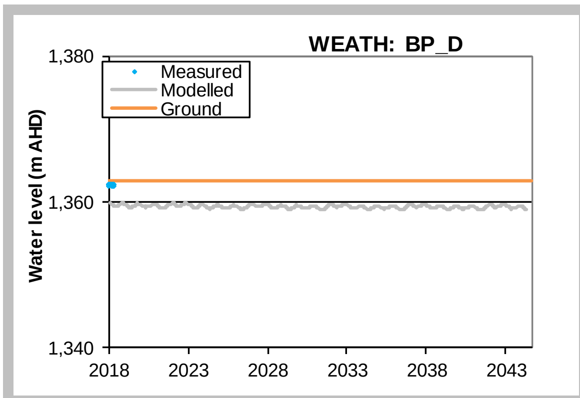

RBW: TMB01B
Measured
Modelled
Ground
Water level (m AHD)
620
600
580
560
2018
2023
2028
2033
2038
2043

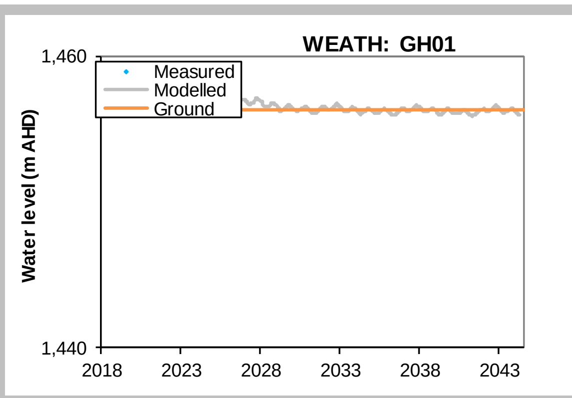

RBW: TMB05A
RBW: TMB05B
TBAS: MB01B
TPF: MB13A
TPF: MB13B
TPF: SMB03
TTF: BH2102_Sens1
TTF: BH2102_Sens2
Measured
Modelled
Ground
Water level (m AHD)
2018
2023
2028
2033
2038
2043

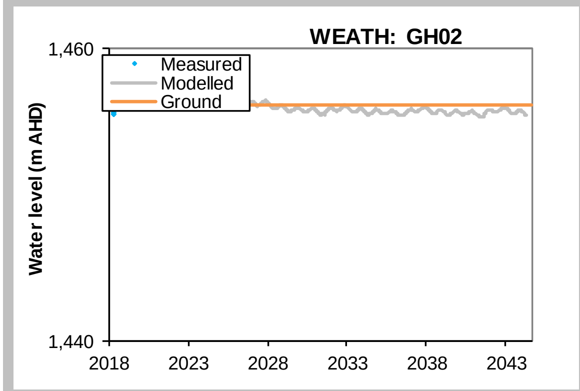


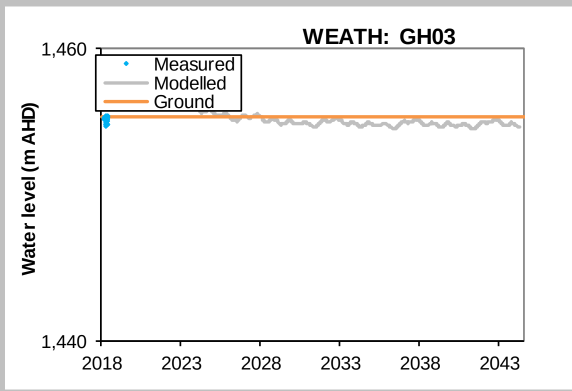
TTF: BH3104_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,460
1,440
1,420
1,400
1,380
1,360
1,340
1,320
1,300
1,280
2018
2023
2028
2033
2038
2043
TTF: BH3104_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,460
1,440
1,420
1,400
1,380
1,360
1,340
2018
2023
2028
2033
2038
2043
TTF: BH3104_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,440
1,420
1,400
1,380
2018
2023
2028
2033
2038
2043
TTF: BH3111_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,520
1,500
1,480
1,460
1,440
1,420
1,400
1,380
1,360
1,340
1,320
1,300
1,280
1,260
2018
2023
2028
2033
2038
2043
TTF: BH3111_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,520
1,500
1,480
1,460
1,440
1,420
1,400
1,380
1,360
1,340
1,320
2018
2023
2028
2033
2038
2043
TTF: BH3111_Sens3
Measured
Modelled
Ground
Water level (m AHD)
1,520
1,500
1,480
1,460
1,440
1,420
1,400
1,380
1,360
2018
2023
2028
2033
2038
2043
TTF: BH3113_Sens1
Measured
Modelled
Ground
Water level (m AHD)
1,360
1,340
1,320
1,300
1,280
1,260
1,240
1,220
1,200
2018
2023
2028
2033
2038
2043
TTF: BH3113_Sens2
Measured
Modelled
Ground
Water level (m AHD)
1,340
1,320
1,300
1,280
2018
2023
2028
2033
2038
2043

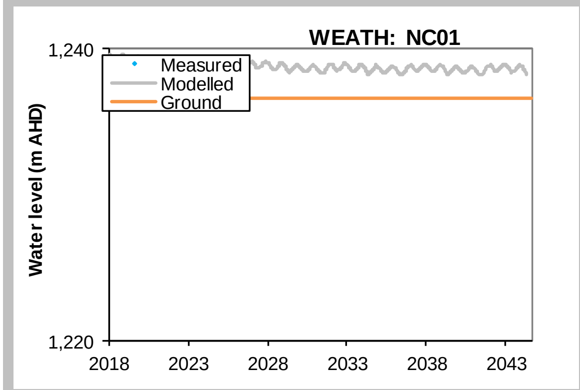

TTF: MB08A
TTF: MB08B
WEATH: BH01
WEATH: BH02
WEATH: BH03
WEATH: BP_A
WEATH: BP_B
WEATH: BP_C
Measured
Modelled
Ground
Water level (m AHD)
1,280
1,300
1,320
1,340
1,360
1,380
1,400
1,420
1,440
1,460
2018
2023
2028
2033
2038
2043

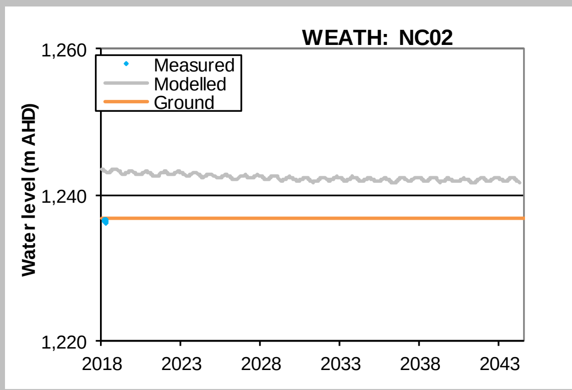

WEATH: BP_D
Water level (m AHD)
1,380
1,360
1,340
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground

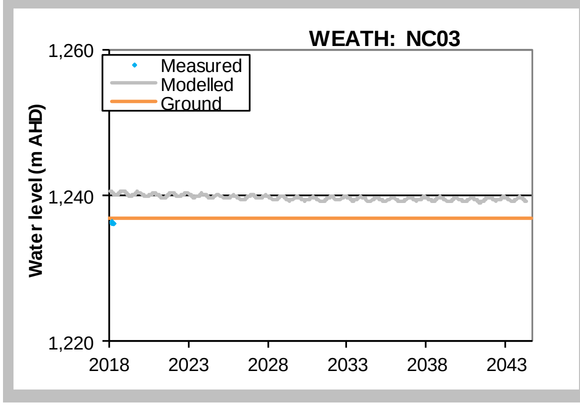

WEATH: GH01
Water level (m AHD)
1,460
1,440
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground

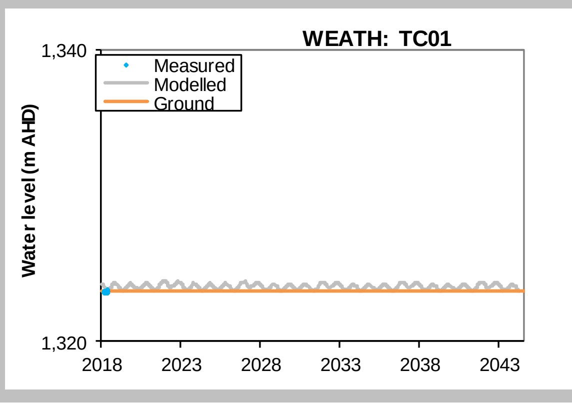

WEATH: GH02
Water level (m AHD)
1,460
1,440
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground

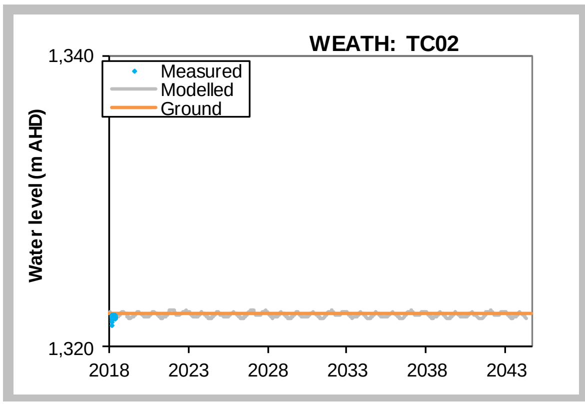

WEATH: GH03
Water level (m AHD)
1,460
1,440
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground

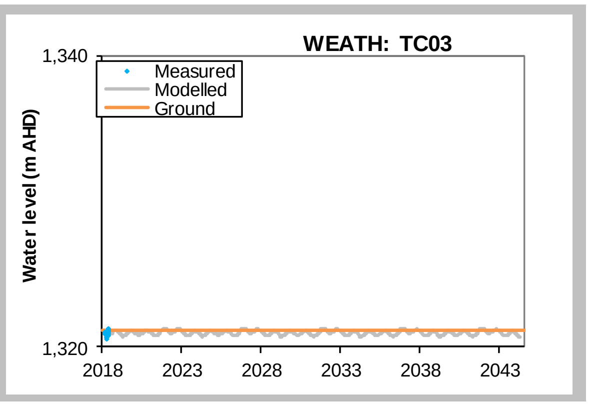

WEATH: NC01
Water level (m AHD)
1,240
1,220
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground


WEATH: NC02
Water level (m AHD)
1,260
1,240
1,220
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground


WEATH: NC03
Water level (m AHD)
1,260
1,240
1,220
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground


WEATH: TC01
Water level (m AHD)
1,340
1,320
2018
2023
2028
2033
2038
2043
Measured
Modelled
Ground


WEATH: TC02
1,340
1,320
Water level (m AHD)
Measured
Modelled
Ground
2018
2023
2028
2033
2038
2043


WEATH: TC03
1,340
1,320
Water level (m AHD)
Measured
Modelled
Ground
2018
2023
2028
2033
2038
2043

Attachment J

Groundwater model predicted baseflow impacts

Table J.1 Yearly baseflow discharge rates to creeks and rivers (ML)

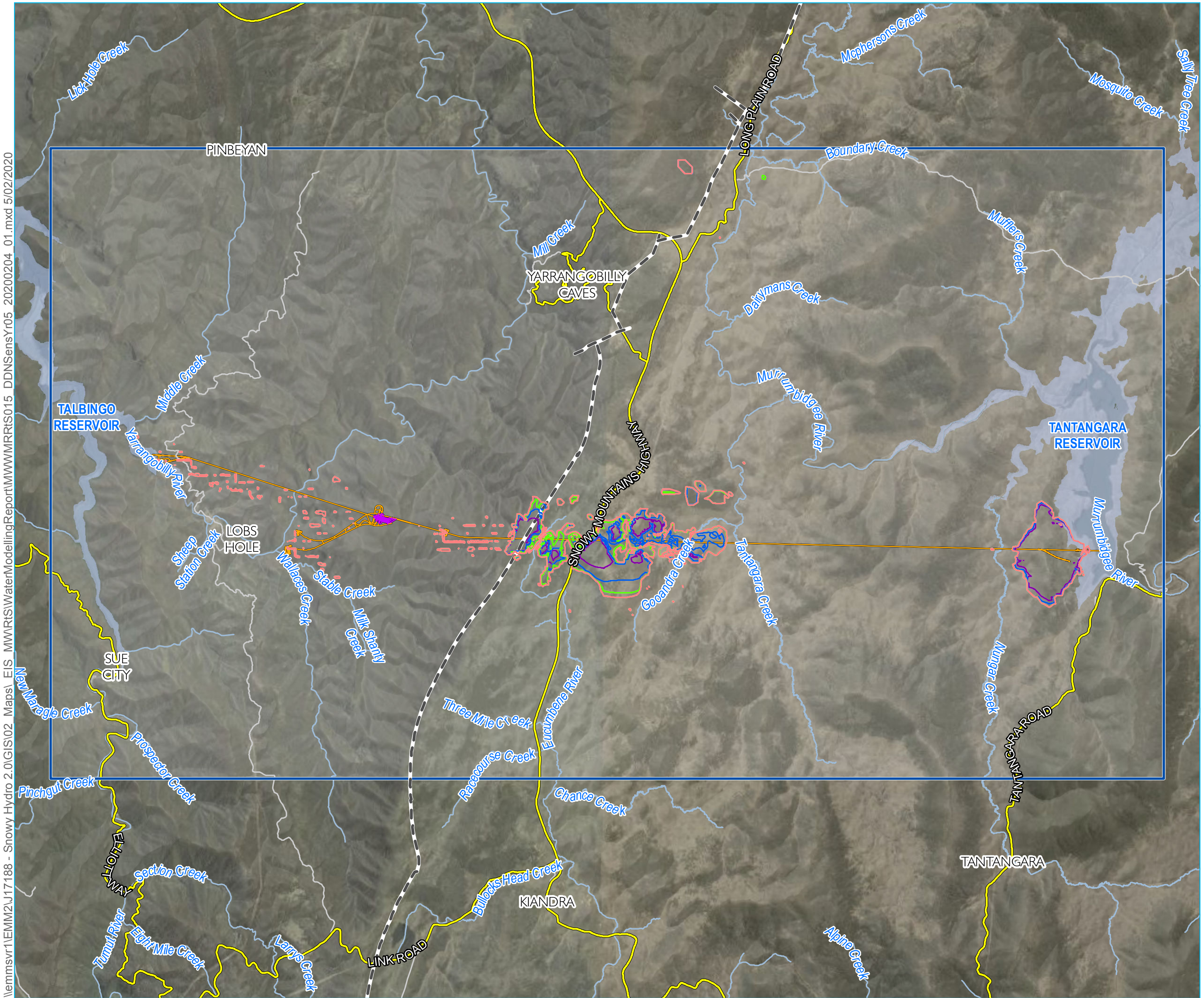
	Middle Creek		Yarrangobilly River		Wallaces Creek		Stable Creek		Eucumbene River		Murrumbidgee River U/S of gauge		Tantangara Creek		Gooandra Creek		Nungar Creek	
Year Ending	**Null[1]**	**Base Case[2]**	**Null**	**Base Case**	**Null**	**Base Case**	**Null**	**Base Case**	**Null**	**Base Case**	**Null**	**Base Case**	**Null**	**Base Case**	**Null**	**Base Case**	**Null**	**Base Case**
1-Jun-19	1576	1576	5471	5471	737	737	1078	1078	3558	3558	6465	6465	5501	5501	1781	1781	3175	3175
1-Jun-20	3098	3098	10511	10511	1441	1441	2018	2018	6140	6140	11370	11370	9536	9536	3127	3127	5392	5392
1-Jun-21	3601	3601	11726	11725	1656	1656	2309	2309	6021	6021	11152	11152	9344	9344	3048	3048	5234	5234
1-Jun-22	2958	2958	9911	9908	1350	1350	1928	1926	5942	5941	10940	10940	9212	9212	3004	3004	5214	5212
1-Jun-23	6058	6058	18642	18633	2773	2772	3758	3753	6890	6889	12523	12523	10606	10602	3319	3311	5829	5819
1-Jun-24	4595	4595	14132	14113	2048	2048	3021	3012	6354	6344	11647	11646	9800	9777	3190	3096	5536	5512
1-Jun-25	3791	3791	12172	12139	1735	1735	2503	2490	5941	5880	10955	10954	9199	9160	2999	2812	5194	5161
1-Jun-26	3922	3921	12505	12455	1793	1792	2535	2519	5912	5803	10919	10917	9157	9107	2966	2726	5117	5077
1-Jun-27	3131	3130	10325	10257	1427	1426	2051	2030	5860	5717	10773	10770	9074	9016	2939	2659	5127	5081
1-Jun-28	6164	6164	18919	18837	2817	2816	3823	3800	6855	6679	12443	12439	10544	10478	3282	2980	5781	5731
1-Jun-29	4625	4625	14197	14101	2061	2060	3035	3007	6280	6090	11511	11506	9683	9615	3139	2816	5459	5407
1-Jun-30	3829	3828	12273	12163	1753	1752	2524	2492	5912	5714	10900	10894	9149	9080	2972	2643	5160	5112
1-Jun-31	3947	3946	12574	12453	1805	1803	2548	2511	5889	5684	10879	10873	9119	9049	2946	2616	5091	5047
1-Jun-32	3159	3158	10411	10275	1443	1441	2069	2026	5861	5644	10778	10772	9071	8996	2932	2585	5123	5079
1-Jun-33	6153	6152	18886	18748	2813	2811	3812	3770	6811	6574	12370	12362	10477	10396	3256	2909	5737	5693
1-Jun-34	4644	4644	14255	14106	2070	2068	3045	2999	6276	6040	11506	11499	9673	9594	3132	2773	5450	5406
1-Jun-35	3841	3840	12309	12151	1760	1757	2530	2481	5906	5675	10894	10886	9136	9058	2966	2609	5152	5111
1-Jun-36	3966	3966	12637	12472	1815	1812	2560	2506	5903	5671	10908	10900	9137	9059	2950	2599	5101	5062
1-Jun-37	3152	3151	10387	10211	1441	1438	2062	2003	5833	5595	10734	10725	9026	8944	2917	2556	5096	5057
1-Jun-38	6159	6159	18909	18736	2817	2814	3815	3758	6811	6555	12373	12365	10475	10388	3254	2894	5734	5694
1-Jun-39	4649	4648	14271	14090	2073	2070	3047	2988	6274	6024	11507	11498	9670	9584	3130	2761	5447	5406
1-Jun-40	3857	3856	12362	12173	1768	1765	2541	2478	5925	5681	10931	10922	9164	9080	2974	2609	5168	5128
1-Jun-41	3952	3951	12593	12401	1809	1806	2549	2483	5875	5634	10862	10854	9094	9012	2937	2581	5075	5038
1-Jun-42	3156	3155	10400	10196	1443	1440	2064	1993	5832	5585	10733	10724	9023	8937	2916	2549	5093	5055
1-Jun-43	6162	6161	18918	18722	2819	2815	3816	3748	6809	6547	12374	12364	10472	10381	3252	2889	5731	5692
1-Jun-44	4664	4663	14321	14117	2081	2078	3058	2988	6292	6036	11542	11533	9697	9608	3139	2766	5463	5422
1-Jun-45[3]	3233	3232	10434	10260	1495	1492	2168	2108	4975	4769	8997	8989	7636	7563	2432	2134	4347	4314
Steady State	3134	3131	10647	10379	1437	1432	2031	1932	6715	6457	12352	12344	10394	10295	3352	2982	5825	5784

Note:

1. Null case: simulation without tunnelling impacts, using best estimate parameters and average climate conditions
2. Base case: simulation with tunnelling impacts, using best estimate parameters and average climate conditions
3. Simulation ends 1 March 2045
4. In some largely unaffected catchments such as Middle Creek, individual years may show slightly higher baseflow discharge in the base case than the null case. This is not a prediction that the project will induce additional groundwater discharge, but rather reflects the numerical accuracy of the solution.

Attachment K

Predicted watertable drawdown sensitivity to inflow constraints



\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWRtSWaterModellingReport\MWWMRRtS015_DDNSensYr05_20200204_01.mxd 5/02/2020

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

0.5 m drawdown sensitivity
- Maximum inflow
- High inflow
- Medium inflow (RtS base case)
- Low inflow
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

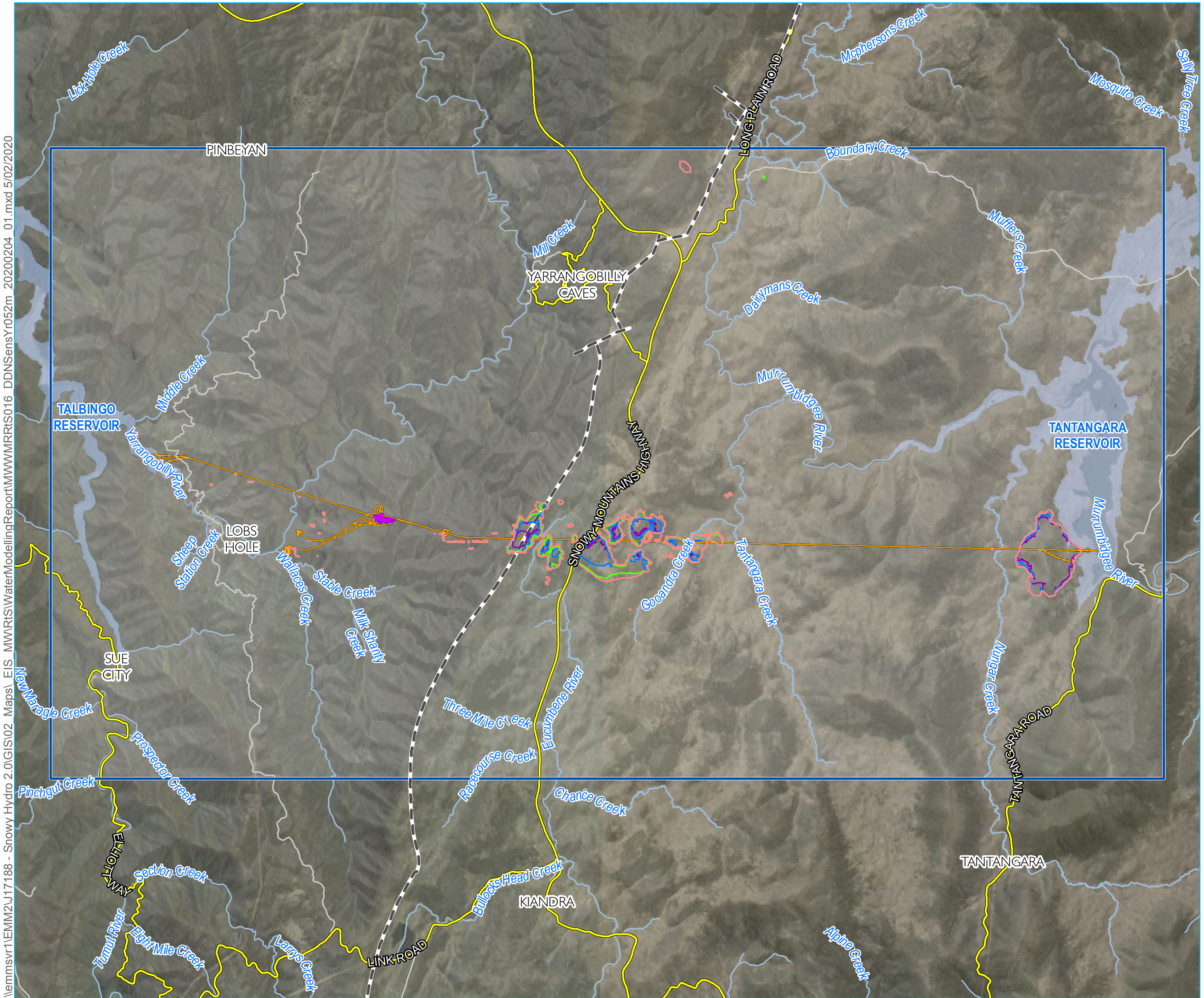
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted 0.5 m drawdown sensitivity to inflow after 5 years of construction, September 2024

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure K1

snowy 2.0

EMM creating opportunities



\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWRtSWaterModellingReport\MWWMRRtS016_DDNSensYr052m_20200204_01.mxd 5/02/2020

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

0 2.5 5 km
GDA 1994 MGA Zone 55
N

KEY

2 m drawdown sensitivity
- Maximum inflow
- High inflow
- Medium inflow (RtS base case)
- Low inflow
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

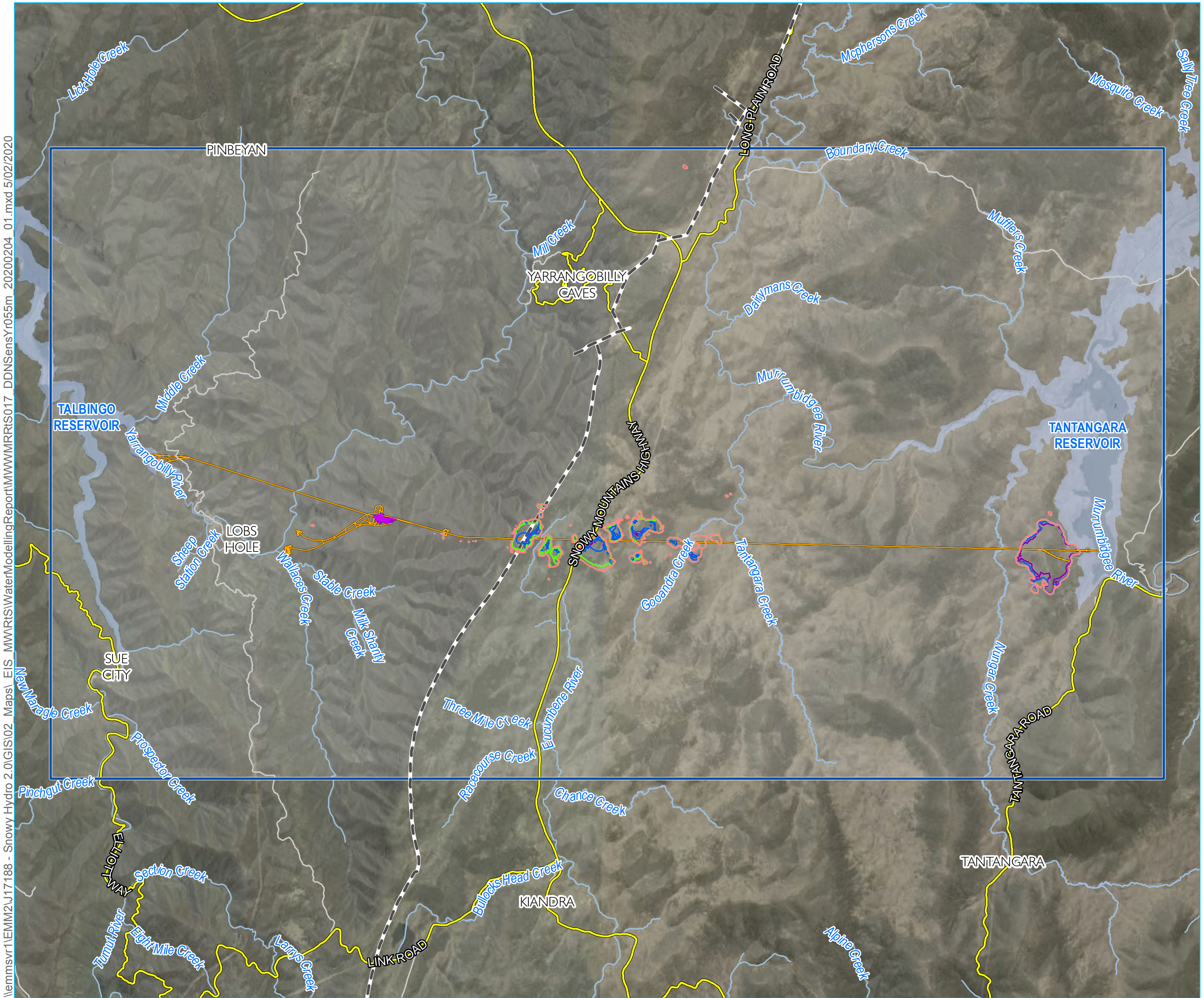
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted 2 m drawdown sensitivity to inflow after 5 years of construction, September 2024

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure K2

snowy 2.0

EMM creating opportunities



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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

5 m drawdown sensitivity
- Maximum inflow
- High inflow
- Medium inflow (RtS base case)
- Low inflow
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

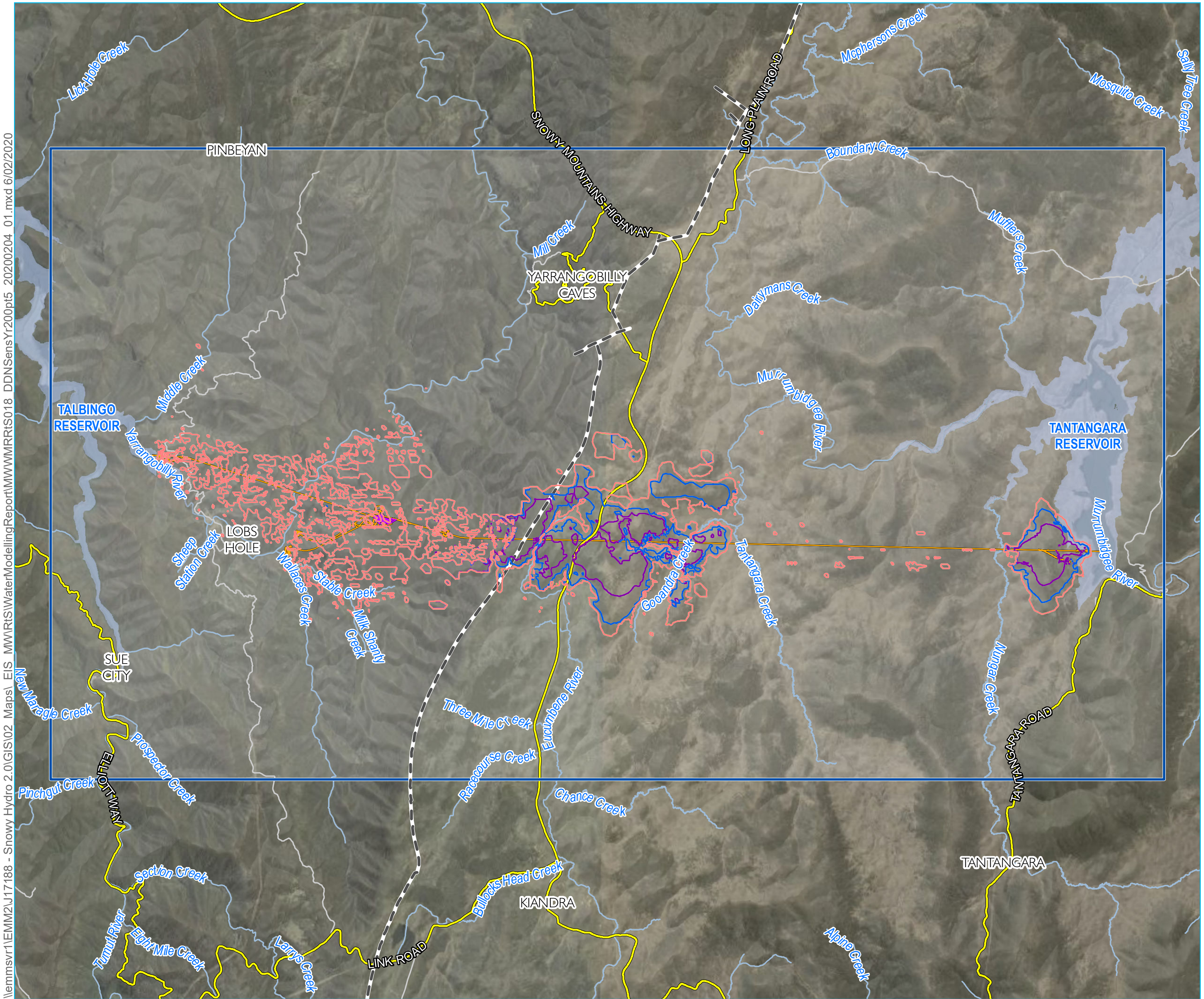
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted 5 m drawdown sensitivity to inflow after 5 years of construction, September 2024

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure K3

snowy 2.0

EMM creating opportunities



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

0.5 m drawdown sensitivity
- Maximum inflow
- High inflow
- Medium inflow (RtS base case)
- Low inflow
- Long Plain Fault
- Model domain

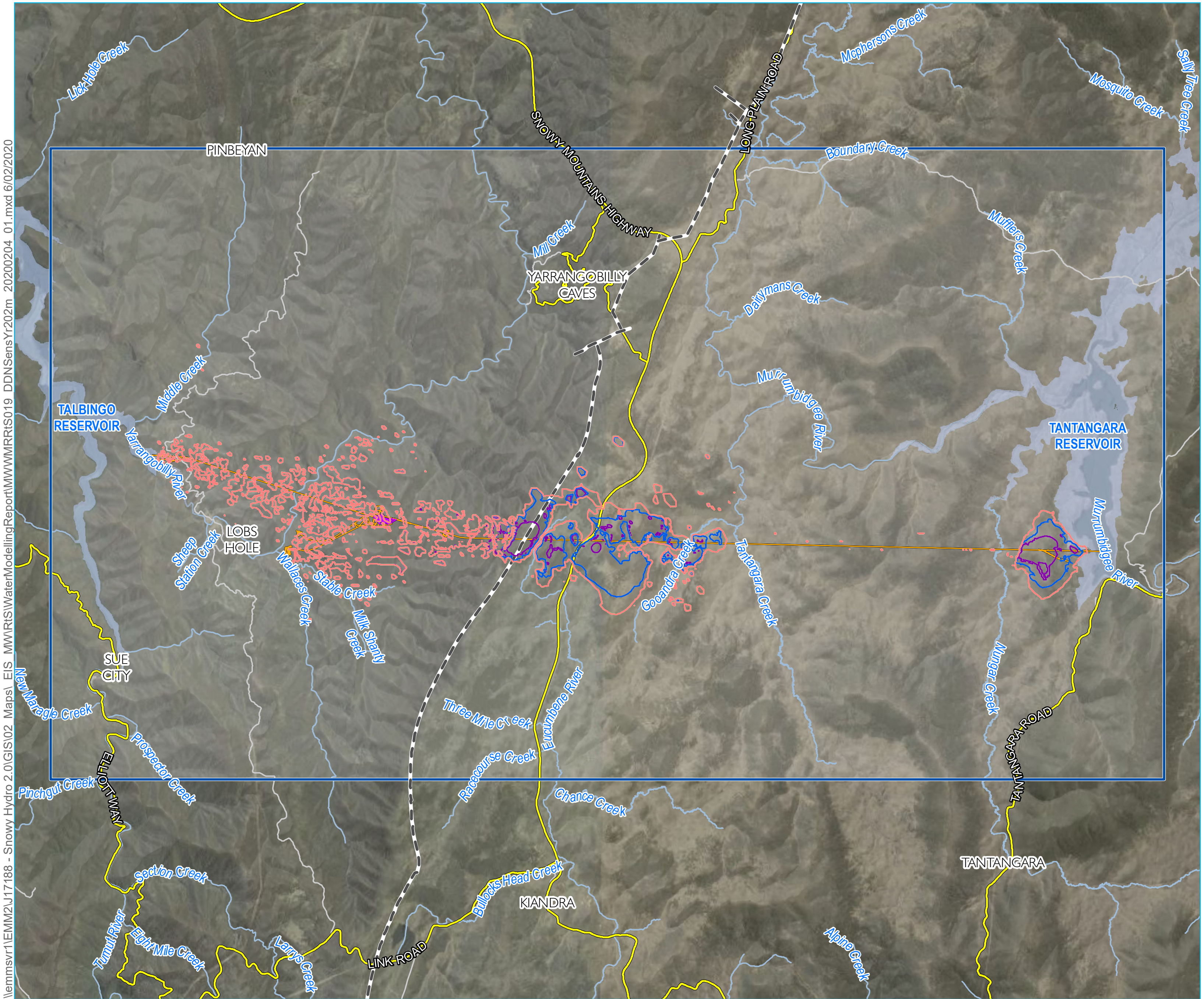
Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted 0.5 m drawdown sensitivity to inflow after 20 years of operation, September 2044

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure K4

snowy 2.0
EMM creating opportunities



\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MW\RtS\WaterModellingReport\MWWMRtS019_DDNSensYr202m_20200204_01.mxd 6/02/2020

Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

2 m drawdown sensitivity
- Maximum inflow
- High inflow
- Medium inflow (RtS base case)
- Low inflow
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

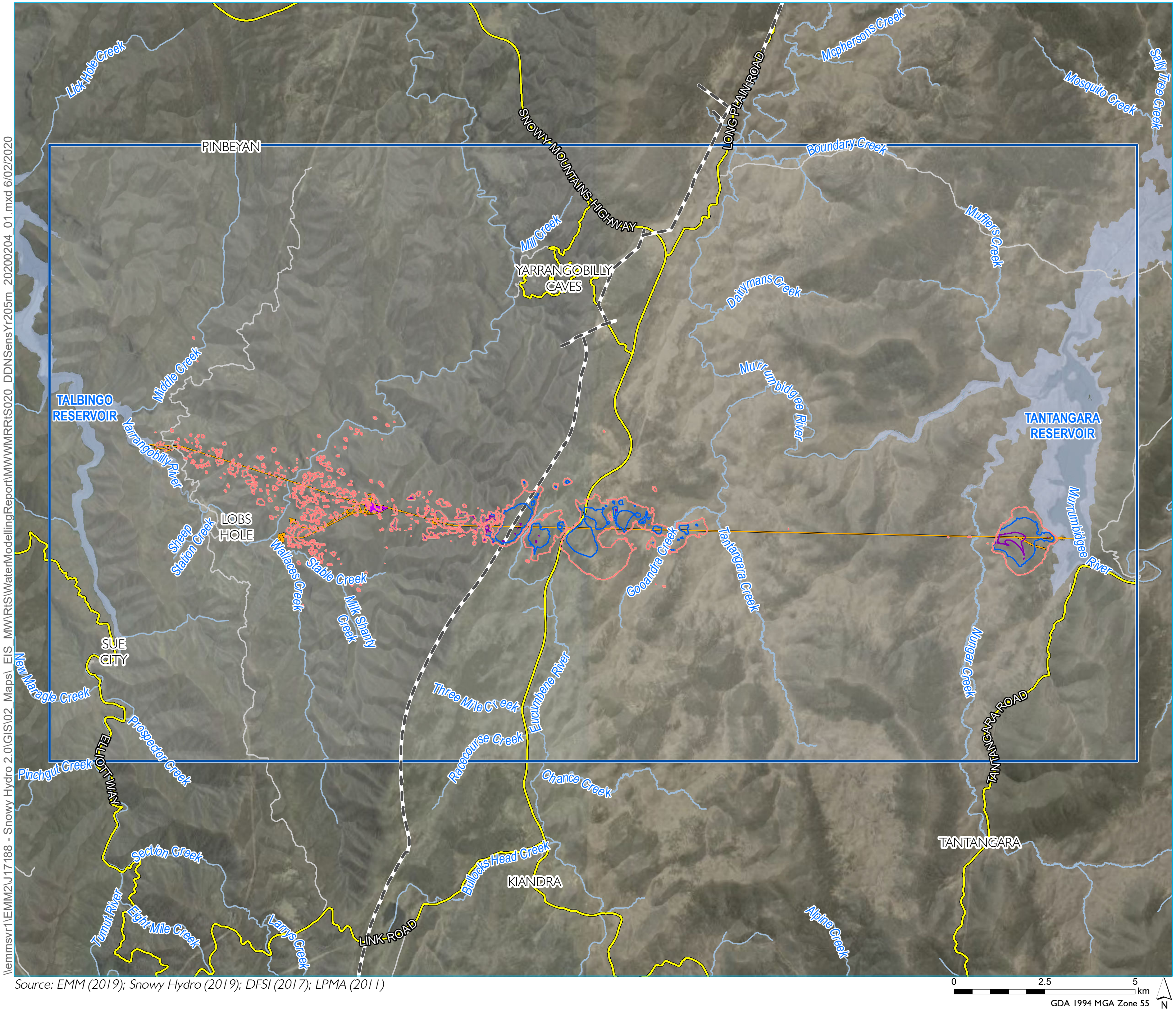
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted 2 m drawdown sensitivity to inflow after 20 years of operation, September 2044

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure K5

snowy 2.0

EMM creating opportunities



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Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

5 m drawdown sensitivity
- Maximum inflow
- High inflow
- Medium inflow (RtS base case)
- Low inflow
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

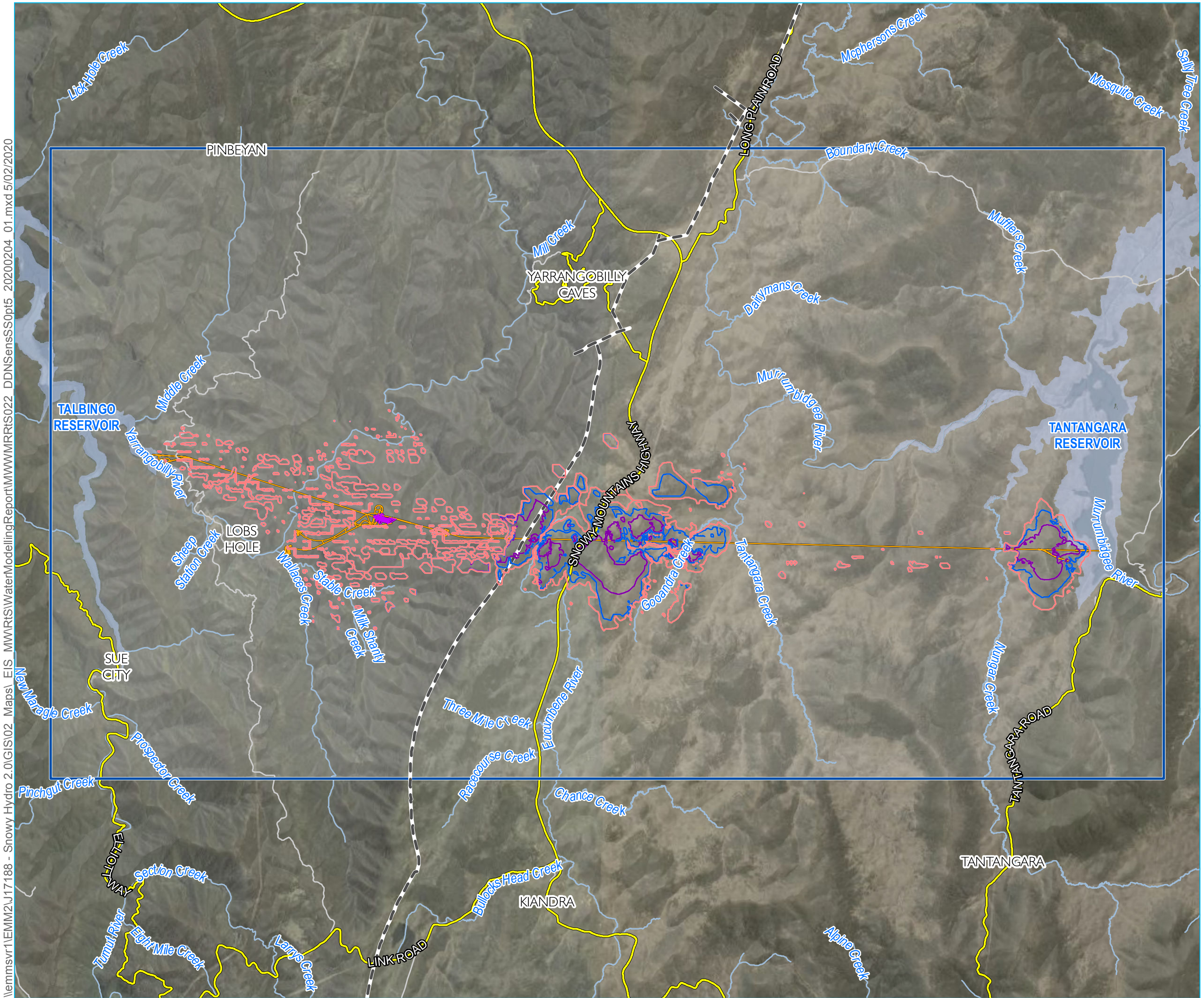
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted 5 m drawdown sensitivity to inflow after 20 years of operation, September 2044

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure K6

snowy2.0

EMM creating opportunities



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

\\emmsvr1\EMM2\J17188 - Snowy Hydro 2.0\GIS\02_Maps_EIS_MWRtSWaterModellingReport\MWWMRRtS022_DDNSensSS0pt5_20200204_01.mxd 5/02/2020

KEY

0.5 m drawdown sensitivity
- Maximum inflow
- Medium inflow (RtS base case)
- Low inflow
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

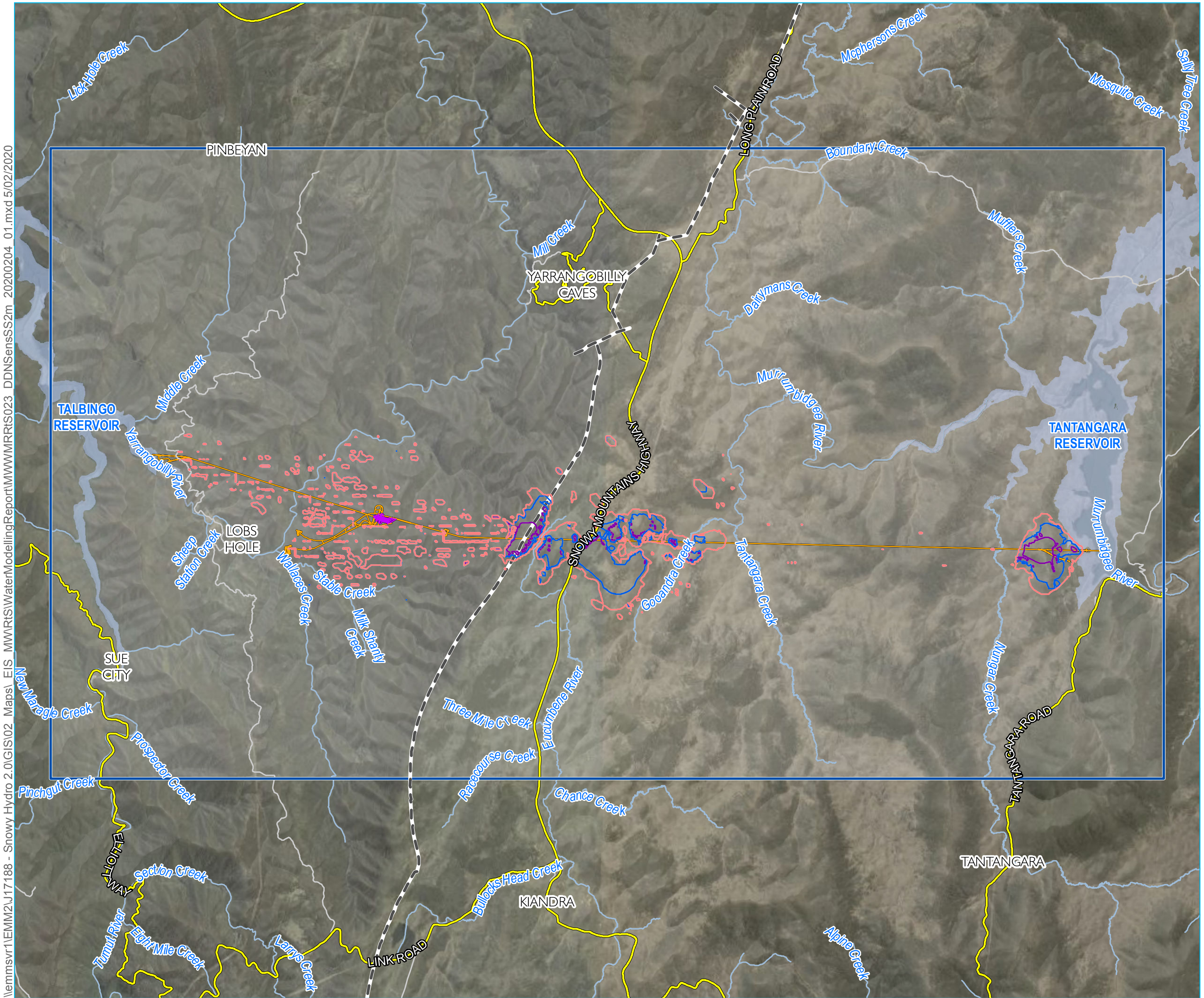
Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted 0.5 m drawdown sensitivity to inflow in steady state, operational

Snowy 2.0
Modelling report
Preferred infrastructure report and response to submissions
Main Works
Figure K7

snowy 2.0

EMM creating opportunities



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

KEY

2 m drawdown sensitivity
- Maximum inflow
- Medium inflow (RtS base case)
- Low inflow
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements
- Tunnels, portals, intakes, shafts
- Power station

Existing environment
- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted 2 m drawdown sensitivity to inflow in steady state, operational

Snowy 2.0
Modelling report
Preferred infrastructure report
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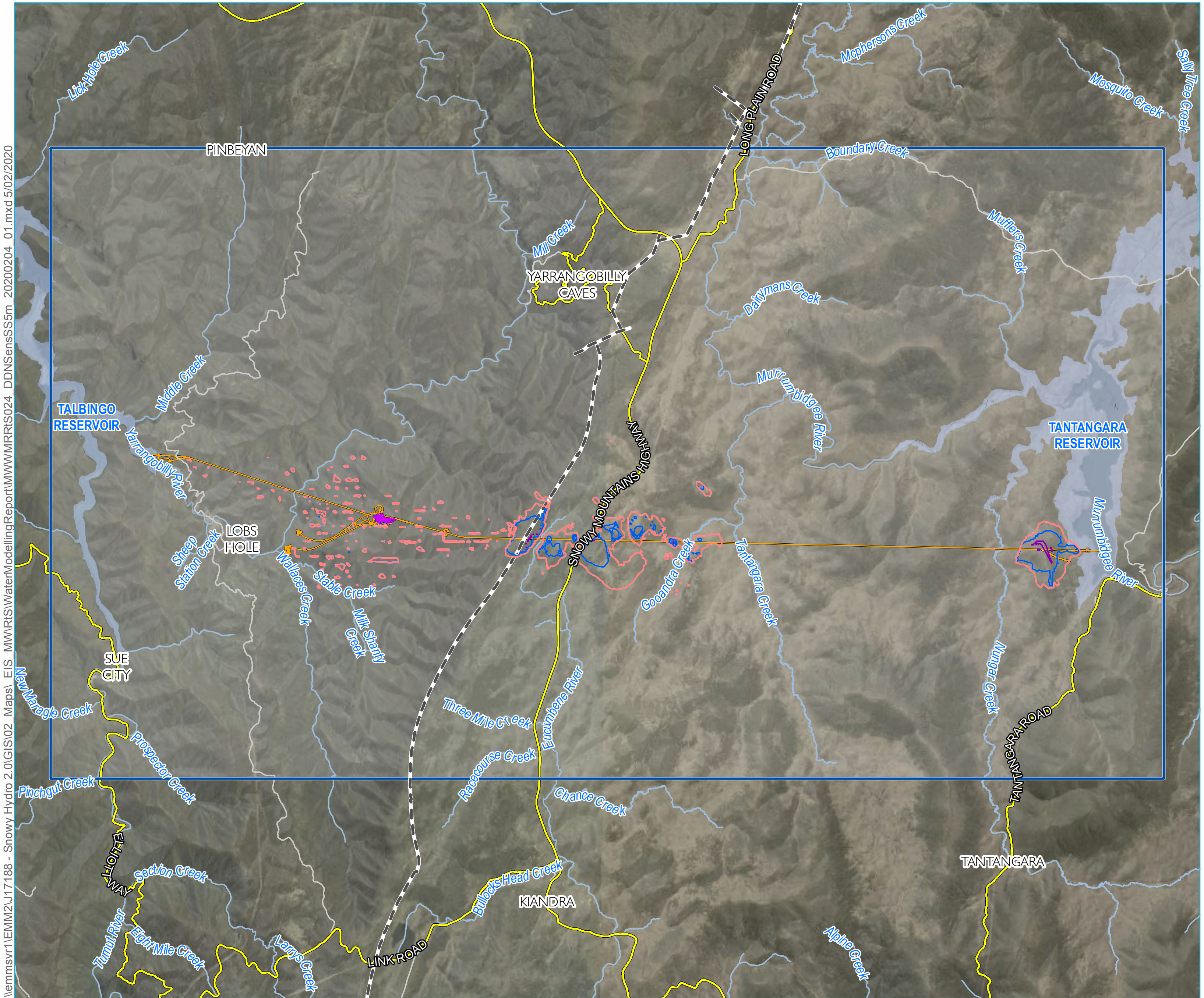
Main Works
Figure K8

snowy2.0

EMM
creating opportunities



Source: EMM (2019); Snowy Hydro (2019); DFSI (2017); LPMA (2011)

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KEY

5 m drawdown sensitivity

- Maximum inflow
- Medium inflow (RtS base case)
- Low inflow
- Long Plain Fault
- Model domain

Snowy 2.0 operational elements

- Tunnels, portals, intakes, shafts
- Power station

Existing environment

- Main road
- Local road
- Perennial watercourse
- Scheme storage

Predicted 5 m drawdown sensitivity to inflow in steady state, operational

Snowy 2.0
Modelling report
Preferred infrastructure report
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Figure K9