



Ensham Resources

Residual Void Project - Groundwater Assessment Stage 3

FOR

Ensham Resources Pty Ltd

BY

NPM Technical Pty Ltd

trading as

HydroSimulations

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EXECUTIVE SUMMARY

Ensham Mine is required to complete a documented “Residual Void Project” (RVP) by 31 March 2019. This is a condition of the Environmental Authority (EA) (issued by the Department of Environment and Heritage Protection (DEHP) (now Department of Environment and Science [DES]) on 9 August 2018.

Groundwater studies are required under Condition G20 of the EA:

“Void hydrology, addressing the long-term water balance in the voids, connections to groundwater resources and water quality parameters in the long term.”

The groundwater investigation has been based on groundwater flow modelling using a model developed by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE), most recently updated in 2016. During the Stage 2 study, this model was left unchanged during the calibration period (to August 2016) but was modified for predictive purposes. For the current stage (Stage 3) of the RVP, the model was re-calibrated to additional data up to and including February 2018.

The objectives of the groundwater component of the RVP are to predict the following:

- A. for each individual residual void, the final water levels once the groundwater table has equilibrated and the water level in the void is only influenced by climate variations and management practices;
- B. for each individual residual void, the groundwater fluxes through the backfill zone, spoil piles and underground mining area, as a function of time and head; and
- C. the groundwater table drawdown and piezometric decline as a function of time and the degree of recovery of the groundwater table across the model domain and at selected locations.

Predictive simulations have been run for three management scenarios being investigated by Ensham Mine:

- Preferred Option 1: Landform Levee.
- Preferred Option 2: Flood Mitigation and Beneficial Use.
- Preferred Option 3: Backfill to PMF.

For each of Options 1 to 3, the model has been used to predict time-varying groundwater inflows/outflows and water levels in each of eight residual voids, as well as regional groundwater levels with focus on key bores in the groundwater monitoring network.

While Options 1 and 3 are examined for natural water level response, Option 2 is focused on void water level variations as water is added to or removed from the voids for flood management or beneficial use. For this option, discharge-stage¹ curves for all pits have been generated for use in surface water specialist modelling of final pit waterbody levels and salinities.

¹ In this context “stage” is the technical term for the water level in a pit, not to be confused with sequential components of the project

The main findings of the modelling are that:

- 1) Under Option 1, dynamic pit waterbody stages have been simulated, taking into account the interactions of adjacent pits and underground workings. The estimated pit water stages increase to the north and south of the floodplain in line with the regional groundwater levels. However, as each pit water elevation remains lower relative to the pre-mine natural water levels, neither pit water nor groundwater would accumulate on the land surface outside the voids.
- 2) Under Option 3 where pits B, C and D are backfilled to approximately the pre-mining floodplain elevation, these pits are simulated to not generate pit waterbodies. As groundwater would remain below the backfilled pit land levels, no groundwater would accumulate above ground. Groundwater levels in the backfilled areas would exceed the pit water levels of Option 1 by up to 20 metres. Pits F and Y are similar in Option 1 and Option 3 with small areas in the lowest parts of the pits below groundwater rest level. However, groundwater in these pits could be eliminated by raising the minimum pit floor level above the simulated groundwater rest level.
- 3) Under Option 2, pit waterbody stage-groundwater discharge modelling implies that substantial ingress or egress of water between ground and pit could occur if dynamic water levels should occur that are more than a few metres from rest equilibrium conditions.
- 4) A key finding is that under all Option scenarios, pit stages are expected to take many decades to achieve equilibrium level conditions. The underground workings scheduled for development between 2018 and 2020 are close to the open cut areas which either currently hold water or are simulated to hold water in the future. During near-future mine advancement, water from these areas is anticipated to recharge the underground mine. Following cessation of active dewatering in the underground, the enhanced groundwater connection between pit voids and underground voids would result in several decades of underground mine rebound at the expense of pit void stage recovery. Only after rebound of the underground water levels would pit water rise to predicted equilibrium levels.

Pit waterbodies are therefore expected to have low water levels for several decades, before the waterbodies are able to recover towards (but never reaching) pre-mining water levels. Ultimately, predicted final equilibrium pit water levels for each option are as shown below. In practice, water levels for Option 2 will vary over time in response to inputs and outputs for beneficial use.

Pit	Option 1 [mAHD]	Option 2 [mAHD]	Option 3 [mAHD]
A south	136.2	120.6	147.2
A north	135.2	128.8	144.6
B	133.4	109.2	146.6
C	127.6	121.0	147.8
D	121.9	119.7	141.4
E	139.0	134.1	129.0
F	150.3	146.3	149.3
Y	171.2	164.0	170.5

In summary, the main consequences of the findings are:

- Option 1 – If the water in the residual voids is allowed to recover naturally, subject to landform levee works, it is expected that the rises in water level for the southern and central pits would be slow due to losses to the adjacent underground mine.
- Option 2 – The benefit of additional water inputs to the pit waterbodies for flood mitigation and beneficial use is expected to be compromised by ongoing losses to the underground mine adjacent to the southern and central pits.
- Option 3 – Groundwater levels are expected to recover at a slightly faster rate and to be generally higher (by a few metres) in the long term adjacent to the residual voids.

An assessment of the potential impacts of each of the three preferred options on relevant environmental values (EVs) has been undertaken based on the outcomes of the studies presented in this report. The table below provides a summary of the assessment using the adopted ranking criteria ranging from -3 (significant negative impact) to +3 (significant benefit).

Environment Aspect	Environmental Value	Criteria	Scoring Notes	Option 1 Landform Levee	Option 2 FMBU	Option 3 Backfill to PMF
Water	Aquatic ecosystems (biodiversity & habitat)	Groundwater drawdown	Compared to regional groundwater level	-1	0	-1
		Groundwater quality	Impact on aquatic ecosystem water quality objectives for life of option	0	0	0
	Irrigation use	Groundwater drawdown	Groundwater drawdown impact on users	0	0	0
		Groundwater quality	Impact on groundwater quality objectives for life of option	0	0	0
	Farm supply	Groundwater drawdown	Groundwater drawdown impact on users	-1	-1	-1
		Groundwater quality	Impact on groundwater quality objectives for life of option	0	0	0
	Stock use	Groundwater drawdown	Groundwater drawdown impact on users	-1	-1	-1
		Groundwater quality	Impact on groundwater quality objectives for life of option	0	0	0

The EV of aquatic ecosystems (biodiversity and habitat) was assessed by considering water table drawdown. There is predicted to be negligible drawdown in most riverine alluvium, and consequently negligible effect on river-aquifer interaction in general. However, due to moderate short-term drawdown close to Pit B, Options 1, 2 and 3 were ranked respectively at -1, zero, and -1 for the groundwater drawdown criterion. Option 3 is expected to cause more drawdown than Option 1 in the alluvium close to Pit B. Option 2 should be benign with respect to the groundwater drawdown criterion as pit water levels would be maintained high for flood mitigation and beneficial use.

Although the three options differ in their degree of effect on river-aquifer interaction, close to Pit B there would be a marginal effect on the natural leakage of water from the Nogoia River to its associated alluvium. It is expected that the natural leakage from the entire Nogoia River would be increased by an average of 12% over the next 70 years, following which there would be a reduction of the natural leakage by about 14%, thereby increasing flow in the river. This would have no effect on river water quality and a marginal beneficial effect on groundwater quality. All options were ranked zero for the expected effect on aquatic ecosystem water quality objectives,

The EV of irrigation use was assessed by considering water table drawdown at the locations of known irrigation bores. Due to negligible drawdown at the one known irrigation bore, for all preferred options, and consequently negligible effect on groundwater flow direction at that bore, Options 1, 2 and 3 were ranked zero for both groundwater drawdown and groundwater quality criteria.

The EV of farm supply was assessed by considering water table drawdown at the locations of known stock and domestic bores, other existing bores with unknown use, and bores not currently in use. Due to drawdown of less than 5 m at all identified bores for all preferred options, Options 1, 2 and 3 were ranked -1 for the groundwater drawdown criterion. As there is no feasible mechanism for a change in beneficial use at the identified bores, Options 1, 2 and 3 were ranked zero for the groundwater quality criterion.

The EV of stock use was assessed by considering water table drawdown at the locations of known stock bores. Due to drawdown of less than 5 m at all identified bores for all preferred options, Options 1, 2 and 3 were ranked -1 for the groundwater drawdown criterion. As there is no feasible mechanism for a change in beneficial use at the identified bores, Options 1, 2 and 3 were ranked zero for the groundwater quality criterion.

1 INTRODUCTION

1.1 BACKGROUND

Ensham Mine, an open cut and underground bord and pillar coal mine located approximately 35km east of Emerald, is operated by Ensham Resources Pty Ltd (Ensham), a wholly owned subsidiary of Idemitsu Australia Resources Pty Ltd (Idemitsu), on behalf of the Ensham Mine joint venture (JV) partners. The JV partners, and holders of the Environmental Authority, are Bligh Coal Limited, Idemitsu and Bowen Investment (Australia) Pty Ltd. EA EPML00732813 (the EA), dated 9 August 2018, is the relevant environmental authority under which Ensham operates the mine.

Condition G16 of the EA states that a Residual Void Project (RVP) must be completed and submitted to the administering authority for review and comment by 31 March 2019. The minimum content of the RVP is specified within Condition G16 of the EA as:

- a) Terms of Reference
- b) Residual Void Study
- c) Progress Reports
- d) Rehabilitation success criteria for voids.

In compliance with Condition G19 of the EA, “the Residual Void Project must be carried out in accordance with the approved Terms of Reference”. Terms of Reference (ToR) (Ensham Resources, 2017a) were approved by Queensland’s Department of Environment and Science (DES, formerly the Department of Environment and Heritage Protection, DEHP) on 21 July 2017.

Condition G20 of the EA identifies the minimum content of the RVP identified in Condition G16.

In accordance with the ToR, the project has been divided into five stages:

- Stage 1 - Project definition and options identification
- Stage 2 - Preferred options technical studies
- Stage 3 - Preferred options detail design
- Stage 4 - Most preferred option Identification
- Stage 5 - Regulatory documentation.

Stage 1 - Project definition and options identification for the RVP have been completed. The Stage 1 Options Assessment report has been finalised and issued to DES, the Department of Natural Resources Mines and Energy (DNRME) and the Community Reference Group (CRG) for comment. The report was independently peer reviewed and revised to address peer review comments. The final report has been delivered to DES, DNRME and the CRG.

The Options Analysis workshop held in Stage 1 of the RVP identified two options:

- Option 1: Landform Levee
- Option 2: Flood Mitigation and Beneficial Use.

DES required a third option, Backfill to Probable Maximum Flood (PMF) level, be included in the study.

All three options have been advanced through Stage 2 and into Stage 3 of the RVP and are referred to as the 'preferred options'. The preferred options are discussed in Section 1.3 to Section 1.6 of this report.

Stage 2 identified the Environmental Values (EVs) in the immediate and surrounding area of Ensham Coal Mine and determined which EVs are likely to be affected by each preferred option. Similar to Stage 1, the Stage 2 EV report and technical studies have been Independently Peer Reviewed and issued in final to DES, DNRME and the CRG.

Stage 3 builds on the technical studies completed in Stage 2 to develop feasibility level designs required to prevent or minimise the potential impacts to EVs from each preferred option. Detailed designs for each of the preferred options will inform a risk assessment of each option and include, as a minimum:

- the long-term stability of the final landform;
- safety of access to the site; and
- the short, medium and long-term risks associated with each preferred option.

The output of Stage 3, in addition to the associated technical reports, will be an Environmental Assessment report for each preferred option which identifies the design and management practices which will be implemented to minimise impacts on the identified EVs.

On completion, each preferred option report will be peer reviewed by an independent suitably qualified third party before submission to the administering authority for review and comment.

1.2 PURPOSE OF THIS REPORT

The purpose of this document is to present the findings of the groundwater assessment to evaluate groundwater effects associated with each of the three preferred options identified in Stage 1 of the RVP. The report will identify benefits/impacts where applicable for each option and will inform the overall Environmental Impact Assessment, the Economic Impact Assessment and the Social Impact Assessment reports.

1.3 SCOPE

Previous groundwater investigations have been conducted by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE):

- 2006: EIA Groundwater Impact Assessment (AGE, 2006)
- 2015: Modelling of residual voids (AGE, 2015)
- 2017: Modelling of underground mining (AGE, 2017a)

AGE has also prepared quarterly groundwater monitoring reports (e.g. AGE, 2017b).

The groundwater model developed by AGE was provided to HydroSimulations for use and adaptation on the RVP. The supplied version of the groundwater model was converted by AGE in 2016 from a structured grid using MODFLOW-SURFACT software to a Voronoi unstructured grid using MODFLOW-USG + AlgoMesh software. This allowed finer spatial resolution along the streams, across the open-cut pits, and over the underground mine footprint.

At Stage 2 of the RVP, HydroSimulations (April 2018) applied the AGE model with minor alterations, but without re-calibration, to the objectives of the RVP by undertaking preliminary investigations of the three preferred options for residual voids designs.

The scope of work for the groundwater investigations has four phases:

1. Phase 1: Groundwater model review.
2. Phase 2: Groundwater modelling for Stage 2 of the RVP.
3. Phase 3: Groundwater modelling for Stage 3 of the RVP.
4. Phase 4: Groundwater modelling for Stage 4 of the RVP.

Phase 1 (completed in January 2018) had the following tasks:

- to assess the objectives of the RVP and the requirements and implications of three options (for minimising final void area and volume) as they relate to groundwater;
- to reconsider the suitability of the conceptual hydrogeological model underlying the numerical model and the merit of alternative conceptualisations;
- to confirm the suitability of interpretation of the conceptual model or models in the numerical model with which further calibration and predictive work will be conducted to explore the merits of each of the three options;
- to examine previously documented recommendations and their implementation; and
- to identify key information and data, the incorporation of which into any model revision within the timescale for the project, is required to achieve the objectives of the study.

Phase 2 (completed in March 2018) had the following tasks:

- to conduct test runs on the existing AGE model (2017a);
- to modify the existing model for significant changes to the mine plan since it was modelled in AGE (2017a);
- to modify the existing model for advised changes in final landforms and timing; and
- to conduct scenario model runs for the three preferred options.

Note that Phase 2 specifically excludes any re-calibration of the AGE model or re-meshing of the adopted AGE Voronoi grid. Those activities are to be considered in Phase 3 and Phase 4, respectively.

Phase 3 (documented in this report) has the following tasks:

- to extend datasets for groundwater levels and pit water levels;
- to undertake cause-and-effect analysis to confirm the conceptual model;
- to re-calibrate the numerical model with extended datasets;
- to document changes made to the AGE model during the re-calibration process;
- to document model performance by means of various calibration metrics;
- to conduct scenario runs of the modified model for the three preferred options;
- to prepare stage-discharge curves for input to surface water modelling;
- to undertake sensitivity analysis with and without enhanced spoil recharge; and
- to assign a model confidence classification level according to national groundwater modelling guidelines.

The spatial discretisation of the model area, by re-meshing (if necessary), is deferred to Phase 4.

Phase 4 (future work) has the following tasks:

- to re-mesh model space if necessary;
- to conduct scenario runs of the modified model for a single preferred option;
- to explore uncertainty in conceptualisation through the consideration of alternative conceptualisations of the hydrogeological characteristics or functions pertinent to model predictions; and
- to explore uncertainty in numerical representation of model variables.

1.4 FORMAT OF REPORT

The objectives of this report are:

1. To identify significant causative factors on groundwater responses through a cause-and-effect analysis of extended datasets.
2. To document changes made to the AGE model through the re-calibration process.
3. To define the simulation assumptions for the three preferred options.
4. To present the results of Option 1.
5. To present the results of Option 2.
6. To present the results of Option 3.
7. To comment on the significance of sensitivity experiments.
8. To summarise findings to date.

An overview of the layout of this report is presented below:

Preamble	Executive Summary
Section 1	Introduction
Section 2	Preferred Options Description
Section 3	Existing Conditions
Section 4	Groundwater Model
Section 5	Option 1 Assessment – Landform Levee
Section 6	Option 2 Assessment – Flood Mitigation and Beneficial Use
Section 7	Option 3 Assessment – Backfill to PMF
Section 8	Surface water / groundwater interactions
Section 9	Environmental Values
Section 10	Conclusion
Section 11	References.

2 PREFERRED OPTIONS DESCRIPTION

2.1 PREFERRED OPTION 1: LANDFORM LEVEE

Having conceptually evolved since Stage 1, proposed Option 1 will develop permanent landforms along the existing levee alignment to provide flood immunity for the 0.1% (1 in 1,000) Annual Exceedance Probability (AEP) flood event having had consideration of the risk of a PMF level event (as proposed in the Stage 2 assessment). Figure 1 illustrates the current placement of the landform.

When compared to the landform levee designed at a PMF level (as considered in Stage 2) the proposed 0.1% AEP landform along the existing levee alignment:

- Eliminates afflux impacts for upstream landholders in a flood event rarer than 0.1% AEP
- Eliminates any potential increased impacts on downstream landholders associated with widening the river floodplain.
- Eliminates the need to realign the Nogoia anabranch.

It is proposed to incorporate the existing levees into the landform design with overburden emplacement areas behind the levee being reshaped in a manner that achieves the minimum stable landform slope requirements.

In addition to any impacts associated with the existing farm levees and mining pit levees, flood levels in the vicinity of Ensham Mine are significantly affected by the confluence of flood flows from the Comet River and Nogoia River, which occurs immediately downstream of the mine. Pits would be subject to rehabilitation in accordance with the approved Ensham site Rehabilitation Management Plan and the landform design criteria.

A biodiversity corridor will be developed along the western (highwall) side of the rehabilitated A and B pits to provide connectivity between Corkscrew Creek and the Nogoia River floodplain as seen in Figure 1.

2.2 PREFERRED OPTION 2: FLOOD MITIGATION AND BENEFICIAL USE

Option 2 proposes to utilise the post-mining voids to form water storages to capture a proportion of high flow flood water and store this water for potential beneficial use as shown in Figure 2. Flood water harvesting is able to quickly fill the post-mining voids with minimal downstream impact, achieving improved water quality to support a range of reuse options, and/or environmental, and social values.

This option is founded on the concept of capturing a small fraction of flood event flows in the Nogoia River, storing this water in residual voids and releasing it back to irrigation and industrial users via a series of pipes to the Weemah Channel and Yamala Inland Port. There will be no discharge to the Nogoia River by this option.

The design of rehabilitation should comply with the current site Rehabilitation Management Plan and landform design criteria to optimise water capacity. Overburden emplacement areas located adjacent to the water storage voids are to be reshaped in a

manner that achieves stable landform slopes without resulting in significant void backfilling. Low wall areas are to be reshaped in-pit to achieve minimum stable slope requirements to ensure safe access and stability of exposed slope surfaces.

Option 2 would utilise storage afforded by residual voids remaining in A Pit and B Pit south of the Nogoa River, and C Pit and D Pit north of the river. The quantity of water likely to be required to operate the system – or put another way, the headroom storage in the pits – is likely to be negligible when compared to overall discharges during flood events from the Nogoa River catchment into the Mackenzie River located downstream of the Ensham Coal Mine. However, in the context of irrigation usage, the headroom storage represents a significant volume and a potential economic asset.

Future assessment and optimisation of Option 2 will consider the potential for interactive operation of the voids with Fairbairn Dam to improve water use efficiency across the water supply system.

Currently Fairbairn Dam's southern irrigation channel, known as the Weemah Channel, extends eastward to within approximately 10 km of Ensham Coal Mine. Water captured from the upper Nogoa River catchment and retained in Queensland's second largest but relatively shallow Fairbairn Dam, is subject to significant evaporative losses. Furthermore, allocated water releases from the dam into the Weemah Channel (and the corresponding northern Channel, the Selma Channel) experience significant seepage and seasonal evaporative losses before reaching their intended customers, particularly where these customers are close to the end of the Weemah Channel. This option includes linking the residual voids located to the south of the Nogoa River to the existing Weemah Channel with large diameter pipes and pumps to transfer water to and from the voids.

Water captured in Fairbairn Dam would be released into the Weemah Channel when hydrologic conditions are likely to result in minimal evaporative and seepage losses (i.e. at times when the catchment is receiving rainfall, the ground is saturated and evaporation is minimal). Whilst the water may not be required by customers at these times, the water would be transferred to the residual voids via the proposed Weemah channel(s) (refer **red** line on Figure 3) and stored in the residual voids at Ensham, which would reduce evaporation losses, as the voids would have a much smaller surface area than the water supply dams. In times of irrigation water demand at the lower reaches of the Weemah Channel (i.e. where the evaporative and seepage distribution losses are likely to be greatest), water would be returned to the Weemah Channel from the residual voids via the Weemah channel.

Because the Weemah Channel and proposed channel(s) lie on the southern side of the Nogoa River floodplain, it would be necessary to maintain a hydraulic connection between the residual voids on the northern flanks of the floodplain and those on the southern flanks. It is proposed that an upgrade of the existing water distribution main, that runs parallel with the main haulage route between B Pit and C Pit, be undertaken early in the project to provide the required hydraulic connection (refer **blue** line on Figure 3).

Option 2 proposes that pontoon-based pumping stations would be sited at each pit to transfer water as required. The Weemah channel coming into the mining lease would be

configured to deliver water initially to A pit. Similarly, pumping from the mine to the Weemah Channel would be done from A Pit.

An offtake from the pipe to Weemah channel would be used to meet water demand for the prospective Yamala Inland Port located to the south west of Ensham Mine.

The intakes from the Nogoa River to B and C Pits would allow temporary storage of peak flood flows during flood events. As the river rises during a flood event, it would reach the overflow level of the inlet structures constructed in the levee (the intakes) and flow into the residual voids. The water would rise in the voids to reflect the height of the flood. As flood levels recede, water would ebb back into the river floodplain through the intakes to the base level of the intakes leaving the voids at full level. The intake level for B and C Pits has been considered as part of Stage 3.

A further key aspect of Option 2 is the depth of the residual voids. Shallow expansive voids experience greater evaporative water losses and hence potential salt concentration. Hence improved water quality outcomes are likely to be delivered with deeper inundated pits.

There remain several opportunities to manage power demands of the scheme including solar-power to generate an income to cover some or all of the overall annual operating cost of this option.

Residual voids that are not within the floodplain, for example E, F and Y pits, would be rehabilitated to achieve minimum stable slope requirements and comply with currently approved site Rehabilitation Management Plan and landform design criteria

A biodiversity corridor will be developed along the western (highwall) side of the rehabilitated A and B pits to provide connectivity between Corkscrew Creek and the Nogoa River floodplain as seen in Figure 2.

2.3 PREFERRED OPTION 3: BACKFILL TO PMF

Preferred Option 3 comprises backfilling residual mining voids located within the pre-mining floodplain up to the elevation of the original floodplain within the lateral extent of the pre-mining Probable Maximum Flood (PMF) level.

Conceptually, the residual voids lying within this PMF extent would be backfilled up to the approximate original (pre-mining) topography with an additional surcharging to accommodate settlement of the backfill. In practice, it may be necessary to extend the backfilling beyond the modelled extent of the PMF to ensure stability of the backfilled areas within the PMF extent and protect against collapse into the adjacent residual voids. Excess mining spoil that is currently present in the floodplain and that is not required for backfilling of residual mining voids, would be retained as seen in Figure 4.

The existing levees constructed to protect the voids from flooding would be removed, with the material re-used for backfilling voids. Material required to backfill residual voids would be drawn from the nearest cost-effective source e.g. low wall spoil. Any negative material balance will need to be met from adjacent low wall and high wall spoils.

Virgin rock typically exhibits an increase in volume when excavated - this is referred to as 'bulking'. The degree of bulking will vary with the geo-mechanical properties and size distribution of the excavated rocks and the methods used in excavation and transport. Furthermore, it is likely to vary both along the linear extent of the open cut mine and within different parts of spoil tips created through the extraction of rock dominated by lithologies characterising the local stratigraphy. Re-excavation of spoil and re-emplacement within voids within the modelled PMF will again exhibit bulking. Whether subjected to dynamic compaction or allowed to settle with subsequent loading by overlying backfill, the spoil within the voids will inevitably exhibit uncontrolled settlement. This will lead to the development of low areas within the PMF extent which, though shallow, lie below the original level of the floodplain. These low areas will not necessarily be connected and are likely to collect surface water runoff but be subject to intense evaporation and surface accumulation of evaporative salts which would be flushed clean by fluvial flood events.

Static surcharging of the replaced spoil material may reduce the risk of long-term settlement below original floodplain. However, this will require material to be placed above the original floodplain elevation in direct contradiction of the intent of this option.

Beyond the modelled extent of the PMF, residual voids would be rehabilitated in accordance with a combination of Option 1 and Option 2 landform criteria requirements.

Replaced spoil, however comprehensively compacted, is unlikely to provide durability equal to the original virgin rock and hence during times of fluvial flood, of magnitudes such that the current floodplain pinch point between B Pit and C Pit begins to develop afflux, it is likely that the Nogoia River would scour spoil within the adjacent backfilled pits. This has the potential over time to result in sink holes and ultimately a repeat of the 2008/2010 inundation events with the Nogoia River cutting a channel into one or more backfilled pits and flooding the remaining un-backfilled parts of each pit. Additionally, impacts on turbidity downstream of the backfilled areas would need to be considered.

As part of the rehabilitation process, the establishment of a biodiversity corridor along the western (highwall) side of the rehabilitated A and B pits is proposed to link Corkscrew Creek and the Nogoia River floodplain as seen in Figure 4.

3 EXISTING CONDITIONS

3.1 SITE OVERVIEW

The terrain is generally low-lying, and the few hills within the area are capped by duricrusts. The main drainage of the area is via the Nogoa River, which flows in an easterly and south-easterly direction through the mining leases before joining the Mackenzie River near the town of Comet. The river is used for irrigation and stock water supply, with flow maintained by releases from Fairbairn Dam south of Emerald (Section 2.3, AGE, 2017a). The low-lying area includes floodplains and riparian zones along the Nogoa River and an anabranch which runs to the north of the Nogoa River (Figure 5).

The Ensham mine site covers an along-strike length of over 20 km, from Pit A in the south to Pit Y (Yongala) in the north (Figure 5). Pits A South, A North and B are located south of the Nogoa River, with Pits C, D, E, F and Y all located north of the Nogoa River and its anabranch. Pits A and B have contained significant water volumes since 2009.

The mining operation at Ensham comprises both open-cut and underground workings, with open-cut operations ramping down due to increasing strip ratios as the coal seams have been followed down-dip to increasing depths. Underground operations commenced in 2011, as a small trial bord and pillar mine, with the main working seam followed through a high-wall portal from Pit C, as shown in Figure 6, progressing in a south-westerly direction underneath the Nogoa floodplain.

3.2 GEOLOGY OVERVIEW

The Ensham Mine is located in the western Bowen Basin, which is one of five major foreland sedimentary basins formed along the eastern side of Australia during the Permian period. The Bowen Basin is the largest productive coal basin in the country.

The stratigraphic sequence across Ensham Mine comprises unconsolidated Quaternary sediments unconformably overlying consolidated Permian and Triassic sequences. The Permian and Triassic strata form regular layered fluvio-deltaic sedimentary sequences, while the Quaternary sediments are more complex and irregular. The coal deposits mined at Ensham are found within the Rangal Coal Measures, which is the uppermost Permian unit. Table 1 provides a summary of the stratigraphy encountered at Ensham (Table 2.1, AGE, 2017a).

3.2.1 QUATERNARY SEDIMENTS

The Quaternary alluvial sediments unconformably overlie the Triassic Rewan Group and Permian coal measures. A weathering surface is evident at the contact. Within the Nogoa floodplain, the alluvial sequence is comprised of silts and clays underlain by a basal unit of sands and gravels. The alluvium is itself overlain by a deep clay-rich black soil, which tends to be highly absorbent during rainfall events. The alluvial sequence varies in thickness, but typically does not exceed more than 25 m below surface (Section 2.1, Table 2.1, AGE, 2017a).

Table 1. Summary of Site Stratigraphy (Table 2.1, AGE 2017a)

Age	Unit	Description
Quaternary	-	Alluvium – comprising soil, silt, clay, sand and gravel
Tertiary	Emerald Formation	Mudstone, sandstone, conglomerate, siltstone sediments, weakly consolidated in parts. Tertiary volcanics (basalt) are also mapped as being present over 10km west of the site.
Triassic	Rewan Group	Mudstone with lithic sandstone interbeds
Permian	Rangal Coal Measures	Feldspathic and lithic sandstone, carbonaceous mudstone, siltstone, tuff and coal seams. Coal seams include the Aries, Castor, Pollux and Orion seams. The main economic seams at Ensham are the Aries 2 and Castor seams.
	Burngrove Formation	Sandstones, siltstones and mudstones, and banded coal seams frequently interbedded with tuff and tuffaceous mudstones - coal seams include the Virgo and Leo seams.
	Fair Hill Formation	Lithic and feldspathic labile sandstone, siltstone, mudstone and conglomerate.
	Macmillan Formation	Lithic and feldspathic sublabile mudstone, siltstone and sandstone.

3.2.2 TRIASSIC REWAN GROUP

The Rewan Group has generally been removed by erosion in the subcrop area of the Rangal Coal Measures at Ensham. Where present, the Rewan Group has a distinct greenish tint in colour and is composed of siltstone and mudstone, with interbeds of lithic and volcanic sandstones.

3.2.3 PERMIAN RANGAL COAL MEASURES

The Rangal Coal Measures consist of sandstone, siltstone, mudstone, coal and tuff (towards the base) and have a thickness of up to 100 m. The seams subcrop over a strike length of about 80 km around the northern and eastern limits of the area. The coal seams that occur at Ensham include the Aries A1 Seam, Aries 2-Castor Seam (A2C) which is about 4.3 m thick, and the Castor Seam Lower Split (C22) which is between 0.2 m to 0.4 m thick. The seams are separated by a mudstone parting that varies between 0.1 m and 0.4 m in thickness. The Pollux Seam is between 6 m to 12 m below the C22 Seam in the central Ensham area. The Pollux Seam is a banded seam and is only mined at Yongala (Y Pit) where it is cleaner and close to the C22 Seam (Section 2.1.3, AGE, 2016).

The Permian stratigraphy at Ensham is structurally relatively simple, with minimal folding or faulting. The strata dip at generally less than 5° towards a synclinal axis that is plunging to the southwest, with only minor faulting noted. Where present, faulting is generally normal, trending east-west to southeast-northwest, with throws of less than 10

m, although occasional low angle thrust faulting has been noted (Section 2.1.4, AGE, 2016).

3.3 HYDROGEOLOGY OVERVIEW

The principal groundwater bearing strata at Ensham Mine are associated with the Permian coal seams and the Quaternary alluvium, with the siltstones and sandstones that make up the majority of the overburden largely found to have low permeabilities.

3.3.1 QUATERNARY SEDIMENTS

An AGE investigation in 2004 (Section 6.2.2, AGE 2006) found that groundwater occurrence in the alluvium was highly variable, with thin saturated zones of poor quality water in deeper sections of an otherwise largely unsaturated formation.

Water level data show the seasonal variability in groundwater to be limited and coincident with the heterogeneous distribution of these sediments (Figure 7). Shallow silts and clays are anticipated to be partially isolating the Nogoa River, limiting leakage from the river into the basal sands and gravels. It is possible that leakage may occur where these clays are absent or where the basal sands are exposed within the river. However, this is conceptually thought to occur only in localised areas. This hydraulic separation of the alluvium from the Nogoa River means that whilst the water in the river is fresh, the underlying alluvium can be brackish to highly saline.

The alluvium can, therefore, be considered as a largely unconfined system which is recharged by rainfall, irrigation campaigns and potential upward leakage from the underlying Rewan Group or Rangal Coal Measures. The alluvium may also receive localised baseflow recharge from the Nogoa River, where clay and silt layers are absent.

3.3.2 REWAN GROUP

There is no hydraulic data for the Rewan Group available at site or from the immediately surrounding regions (Section 2.1.2, AGE, 2017a). However, regional data in the Bowen Basin is presented in Section 2.4, AGE, 2017a).

It is noted by AGE that experience of the Rewan Group in other regions has shown it is likely to have similar hydraulic properties to the Permian overburden units.

3.3.3 PERMIAN RANGAL COAL MEASURES

The most permeable lithological units at Ensham are the coal seams, which form aquifers that generally exhibit low transmissivities, and are confined by overlying and underlying shales and mudstones (AGE, 2017a). Groundwater storage and movement largely occur within the coal seams, along cleats and fissures and occasionally within minor fault zones that intercept the seams. The other lithologies present in the overburden and interburden sequence are usually considered to be relatively impermeable and form aquitards. The Permian strata can be categorised into the following hydrogeological units:

- very low to low permeability sandstone and siltstone that comprise the majority of the Permian interburden / overburden; and

- low to moderately permeable coal seams, of varying degrees of competency (and therefore fracturing).

There are no site-specific data on the hydraulic conductivity of the interburden material (according to Section 2.1.3, AGE 2017a). However, field data collected at Baralaba North (SKM, 2013) indicate a range in horizontal hydraulic conductivity of between 1.8×10^{-2} m/day and 1.15 m/day, with decreasing conductivity with increased depth. Additional regional data are summarised in Section 2.4 (AGE, 2017a).

The Rangal Coal Measures outcrop along the eastern edge of Ensham Mine, where recharge would occur from direct rainfall on the ground surface, infiltrating into the underlying formations through the thin soil cover, weathered profile and spoil at site. The coal measures also subcrop in localised zones beneath alluvium associated with the Nogoa River, where the unit may be recharged by downward seepage where there is an absence of clay and silt layers. Recharge may also occur via downward leakage from the Triassic Rewan Group and from areas of site surface water storage (i.e. in-pit water storages). It is also possible that direct recharge to the coal seams may occur down exploration boreholes that have not been effectively grout-sealed within the Nogoa floodplain. As underground mining expands, there is a risk of interception of mining with open holes from historical drilling programmes, with the consequent possibility of water inflows through boreholes connecting upper strata or the floodplain with underground workings.

The regional groundwater flow direction in the Rangal Coal Measures, particularly south to southwest of the mine, is not well defined regionally. However, based on available data to the west and northwest, groundwater in the Rangal Coal Measures would flow primarily towards the active underground mine area (Figure 8). Slightly elevated groundwater levels around A Pit and B Pit are likely due to water storage within the pits. A currently weak connection between the A and B Pits and underground is implied by the presence of retained surface water in these pits and local elevated groundwater conditions. Fracture flow and flow through seams as depicted in Figure 8 is likely. This would have the effect of prolonged drainage of the southern and central pits into the underground void until underground mining is completed and groundwater levels recover towards pre-mining elevations.

3.4 LITERATURE REVIEW

Reported hydraulic and storage properties of key formations in the broader Bowen Basin have been gathered from many sources into Table 2. Not unexpectedly, there is a very wide range of values in each formation.

Coffey (2014) compiled packer testing data from many mines in the northern Bowen Basin, and found that although there was a degree of variability in the dataset due to irregular fracturing, there is a general trend of reducing hydraulic conductivity with depth. This is likely due to increasing overburden pressure resulting in a reduction in fracture aperture with depth. Hydraulic conductivity of the coal seams is typically three times higher than that of the interburden.

Table 2. Summary of Adopted Hydraulic Properties from Other Bowen Basin Studies

Formation	Age	Kh [m/d]	Kv [m/d]	Sy	Ss [m ⁻¹]	Source
Alluvium	Quaternary	1 to 40	0.1 to 25	0.05 to 0.18	5.0E-4	2
		100	10	0.25	1.0E03	1
		0.7 to 1.5				3
		10	1	0.2	1.0E-4	7
		0.088 to 0.38				5
		10	1	0.1	1.0E-5	10
			0.38 to 8.4			12
		1.5	0.38	0.12	8.6E-6	14
		1				15
		0.007 to 4.2				16
		0.02	4.0E-03			15
Basalt	Tertiary	0.1 to 10	5.0E-3 to 1	0.05 to 0.2	5.0E-7 to 5.0E-5	2
		6.1E-3 to 0.62				13
		0.11				16
		0.5	0.1			15
Undifferentiated Tertiary Sediments	Tertiary	0.43				13
		0.5	0.13	0.05	8.6E-6	14
		0.01	2.0E-3			15
Rewan Fm	Triassic	1.0E-5 to 1.0E-4	1.0E-6 to 1.0E-4	5.0E-3	1.0E-6	1
		0.1		5.0E-2	5.0E-6	6
		1.0E-4	1.0E-5	1.0E-2	1.0E-5	10
		3.6E-4	7.4E-6			11
		1.3E-5 to 2.7E-3	5.8E-9	3.0E-5		12
			2.2E-8			13
		5.0E-4 to 5.0E-2	1.0E-7 to 1.0E-4	1.0E-1 to 2.5E-1	5.0E-6 to 5.0E-4	2
		2.0E-3	5.0E-4			14
		1.0E-3	2.0E-4	3.0E-2	8.6E-6	15
		9.0E-4	5.4E-5			9
Rangal Coal Measures	Permian	2.8E-3 to 4.7E-2				4
		1.0E-5 to 5.0E-2	5.0E-4 to 5.0E-3	0.01 to 0.12	5.0E-6 to 5.0E-4	2
		0.01	2.5E-3	0.05	8.6E-6	14
		2.0E-5 to 2.3	2.0E-6 to 0.1			15

						3
		1.0E-6 to 1	1.0E-6 to 1	0.01	1.0E-6	1
		0.11 to 0.9		0.08	4.0E-4	7
		5.0		0.05	5.0E-6	6
		0.05	5.0E-03	0.01	1.0E-5	10
		9.0E-4	1.8E-5			9
Rangal Interburden		1.0E-4	7.0E-8	0.05	1.0E-5	2
		0.12	0.03	0.03	8.6E-6	14
		2.0E-5 to 0.02	2.0E-0 to 2.0E-3			15
		0.1		0.05	5.0E-6	6
		1.0E-3	1.0E-5	0.01	1.0E-05	10

1: AGE (2006) 2: Ausenco-Norwest (2012) 3: JBT (2012) 4: Parsons Brinckerhoff (2011)
5: URS (2009) 6: BHP Billiton Mitsubishi Alliance (2009) 7: Matrix Plus (2010)
9: AGE (2013) 10: CDM Smith (2013) 11: GHD (2013) 12: OGIA (2016)
13: Coffey (2014) 14: JBT(2016) 15: KCB (2016) 16: AGE (2016)

In comparison with packer test hydraulic conductivities of coal measures in the Sydney Basin, the conductivities in the Bowen Basin are approximately one order of magnitude higher than those of the Sydney Basin at the same given depth. This is associated with a lower horizontal stress field in the Bowen Basin, and is one of the reasons that the Bowen Basin is targeted for gas extraction.

3.5 CONCEPTUAL MODEL

The hydrogeological regime of the Ensham area comprises two main groundwater systems:

- Alluvial groundwater system.
- Porous rock groundwater system.

Section 2.6 of AGE (2017a) summarises the conceptual model for the Ensham area, as illustrated in Figure 7 and Figure 8.

To confirm AGE's conceptualisation, HydroSimulations has conducted a cause-and-effect analysis on groundwater level datasets extended to February 2018, as discussed in Section 3.6.

3.6 CAUSE-AND-EFFECT ANALYSIS

The locations of bores in the groundwater monitoring network are shown in Figure 9, with particular highlighting of a subset of bores used for cause-and-effect analysis and re-calibration. All observed hydrographs are presented in Appendix A.

3.6.1 CANDIDATE CAUSATIVE FACTORS

Natural and artificial processes that are anticipated to have an effect on groundwater levels and flows are:

- Rainfall.
- Irrigation.
- Streamflow and floods.
- Open cut pits.
- Underground workings.
- Landholder pumping.

Examples of each are exhibited in the following sections.

3.6.2 EFFECT OF RAINFALL

Rainfall events are observed to influence the underground pumping rates. The definition of what areas are dewatered and the magnitude of that volume at any given time are unclear and therefore this dataset is considered indicative only. It is however a daily record and both prolonged rainfall events and dry periods are evident in the pumping requirements. Conversely, singular sub-day duration high intensity rainfall events are rarely noted in the pumping record, either on the day of the rainfall or the subsequent period. Collectively these rainfall-response data imply indirect transmission of water to the underground with a short (days duration) transit time. This is in keeping with the previously conceptualised spoil infiltration and drain-down mechanism.

Observed groundwater levels are typically recorded quarterly. The resolution of these data does not provide insight into the proportion of rainfall which is able to directly, rapidly, infiltrate to groundwater. The majority of shallow boreholes (those in the upper 20m), however, do reflect responses to seasonal rainfall patterns and flood events. All deeper boreholes show no discernible response to rainfall events or sub-annual seasonality. Responses in the deeper sandstone and silts are highly attenuated.

An example of a clear correlation with rainfall is afforded by Figure 10 at the Karanga Bore to the south of Pit A. The groundwater level is correlated with the rainfall residual mass, defined as the cumulative sum of monthly residuals between actual rainfall and long-term average rainfall. If rainfall infiltration is significant, a groundwater hydrograph and the residual mass curve can be expected to trend similarly. When there is no correlation, such as at the Yongala bore to the east of Pit Y, this indicates poor rainfall infiltration in that location.

3.6.3 EFFECT OF IRRIGATION

The area southeast and west of the mine, on the floodplain and to the south of the floodplain, is dominated by intense agricultural activity and associated irrigation, sourced from river water and channel water from Fairbairn Dam. Groundwater pumping is expected to be a minor source given lower water quality in general.

There is little evidence for the effect of irrigation in the groundwater monitoring network. The only example of a probable irrigation effect is bore EC01, as shown in Figure 11, because it shows a rising trend in addition to streamflow and flood event accessions, whereas downgradient bores in the EC-series show recessions from those events.

3.6.4 EFFECT OF STREAMFLOW AND FLOODS

Shallow boreholes consistently show the effect of flood events. The EC-Series boreholes in shallow alluvium which parallels the Nogoia River demonstrate receding groundwater levels for 9-12 months following flood events, with recessions from a peak of 4m relative to 'normal' levels. The peak, however, may be higher but not recorded in the quarterly dataset.

Other shallow holes (up to 20m depth) typically show similar responses but the uplift ranges from 0.5 to 1m. The rate of recession is often too subtle to determine but is anticipated to be less than 3 months on the alluvium floodplain area.

A good example of rapid response to the two flood events of 2008 and 2011 is shown in Figure 12 for bore EC11.

3.6.5 EFFECT OF OPEN CUT PITS

The influence of the pit workings on the WSMB and RB5 holes are evident and enlightening for model calibration. WSMB 2 deep (2D), 3 deep (3D) and RB5 are each successively farther from the A and B pits and monitoring the primary coal seam or interburden. These holes show an increasingly attenuated response to mine dewatering. Furthermore, in WSMB3D and RB5 the signal associated with the flooding event (cessation of pumping and a potentially recharging body of water) helps to constrain the conductivity and storage properties of the bulk sandstone and coal formations. WSMB2D is within 500m of Pit A North and responds very rapidly to mining activity and changes in pit stage levels (Figure 13).

The WSMB holes are nested and show considerably different responses in their shallow counterparts. This implies a poorer vertical hydraulic connection than formerly simulated. The shallow holes tend to have a static level and show more of a response to recharge as opposed to mining activity, despite proximity to the pit. The latest data from WSMB2S however does demonstrate a sharp reduction in groundwater levels (Figure 14). It is anticipated this could be in response to water level changes in the pit.

Boreholes east of the pit consistently demonstrate substantially higher groundwater levels and no clear effect from pit activity. Groundwater gradients are much steeper in the east and hydraulic conductivities therefore lower.

The data from the south is conclusive and useful for vertical and horizontal hydraulic parameter constraint. There are no similar datasets for the northern pits and the concepts strengthened by the southern data are considered equally appropriate in the north and west but not the east.

3.6.6 EFFECT OF UNDERGROUND WORKINGS

As the Underground workings were not very extensive during the calibration period, there is little evidence to date of the effect they would have ultimately. The effect of underground workings is evident at only one site for certain, namely at bore RB3 which is within 5-6km of the current workings. A downward trend in levels is noted from when monitoring commenced in 2016 (Figure 15). This trend implies mining induced depression in groundwater levels has propagated to this distance although the magnitude is subtle. It is simulated that the transmission of this water is dominantly through the coal seams and not a reduction of groundwater levels in the shallow zone.

The neighbouring RB2 and RB4 are farther from the worked area, at about 7km and 8km respectively, with no discernible drawdown observed to date.

It is anticipated that the influence of the underground workings will transmit readily through the coal seam layers; however, vertical impediments would restrict the dewatering of bounding lithologies in a similar manner to the observed impact of open cut mining in the south.

This observed vertical anisotropy is currently represented in the model and has been increased to be more significant than in the former version of the model.

3.6.7 EFFECT OF LANDHOLDER PUMPING

There is very little evidence of landholder pumping affecting any of the bores in the groundwater monitoring network. An exception is the Jamar Bore which is less than 1km from bore RB4 (Figure 16). The Jamar Bore shows an amplitude of about 16m, with high water levels during the wet period in 2011, and low water levels in 2014 and 2015 corresponding to the residual mass trend. A slight increase in the RB4 water level in late 2015 could be due to the Jamar Bore reducing pumping as more normal weather conditions returned. The water levels in the RB4 area are generally considered depressed relative to what is anticipated under natural conditions, lending weight to the prevalence of an abstraction signal in this area. The RB4 borehole has a comparatively low groundwater level of 136mAHD (40m unsaturated zone thickness) relative to the unsaturated zone thickness of 25m at RB2 (on the floodplain to the north).

In general, groundwater levels are deeper than expected in this area. The boreholes analysed are typically deep and monitoring the coal. It is possible that there could be mining induced drawdown; however, the distance and mine schedule make this an improbable cause for the depressed groundwater levels. Also, the level from 2016 through 2018 is notably static.

In previous Stage 2 modelling, this area consistently simulated hydraulic heads 10-20m in excess of observed levels. Model-based sensitivity analysis coupled with the cause-and-effect analysis in the Stage 3 investigation found that the combined increased hydraulic conductivities, reduced recharge (which was already low) and storage changes that would be required to replicate the observed groundwater levels would be extreme and inconsistent with the range of credible properties for these lithologies and field test results. It was also confirmed that this was not an issue associated with the hydraulic heads used to start the simulation, or edge boundary conditions. It is believed that the

depressed levels in this area are a function of unrepresented evapotranspiring phreatophytes and/or irrigation pumping - most probably, a combination of both with consumptive irrigation pumping requirements dominating in the south.

Landholder pumping, like irrigation requirements, need not be explicitly defined in the model. Although some groundwater level data at pumped holes imply abstraction of noteworthy volumes, such as Jamar Bore, the volumes and schedules are unknown.

4 GROUNDWATER MODEL

4.1 SOFTWARE

The groundwater model was built in 2016 by AGE (2017a) using MODFLOW-USG (Panday et al., 2013) software coupled with mesh generation AlgoMesh software developed by HydroAlgorithmics Pty Ltd (Merrick and Merrick, 2015), plus bespoke toolsets. Functionality of the MODFLOW-USG package has been employed to represent discontinuous lithology, time-variant hydraulic properties and improved model stability under desaturated conditions.

The spatial discretisation is an unstructured grid of Voronoi cells. Enhanced spoil and underground void properties are represented by the Time Variant Materials (TVM) process developed by HydroAlgorithmics Pty Ltd (Merrick and Merrick, 2017), as implemented in MODFLOW-USG beta.

An earlier model (AGE, 2015) used MODFLOW-SURFACT with a structured grid. This is believed to have been built in 2012, with changes only to the mine plan and final landform between 2012 and 2015.

Figure 17 shows the model scale, pit areas (purple) and the underground mined area (pink) at the time of model development by AGE (2017a). The mine plan has since changed. The Voronoi polygon mesh is shown in grey.

The model utilised in this study retains the Voronoi polygon mesh as developed in the 2017 model without change.

4.2 MODEL SETUP

4.2.1 MODEL GRID

There are 12 layers in the model. However, as a fully unstructured model, the layers are not required to be present in all areas as was the case in former versions of MODFLOW. The Ensham model utilises the pinching capability of MODFLOW-USG so that the maximum number of cells is 770,190 in the overall model compared to 952,236 cells in an equivalent layered model. This represents a saving of about 20%, given that the maximum number of cells in any layer is 79,353.

The stratigraphic units which are represented by each model layer are summarised in Table 3.

4.2.2 BOUNDARY CONDITIONS

The mine and associated spoils are implemented through the use of MODFLOW drain cells and the Time Variant Materials (TVM) process. The underground mine simulates the gradually developing underground workings. The Open Cut region of the model is also simulated through drain cells but was more rapidly emplaced in the AGE model than has occurred in reality. This aspect of the model has been improved in the current study with a more gradual development. Waste Rock from the operation is backfilled and the TVM package is used to ensure appropriate hydraulic conductivity and storage properties are

applied as the voids and backfills evolve. This functionality permits more realistic simulation of mine operational management of waste material which is pertinent for groundwater level and pit water level predictions. Waste material is backfilled into formerly excavated areas. As this material partially fills the void, the rate of void water rebound, and evaporation, is affected. Spoil is given a hydraulic conductivity of 1 m/d and a specific yield of 4%.

Table 3. Stratigraphy – Model Layer Summary (Table 3.1, AGE, 2017a)

Model layer	Geological age	Stratigraphic unit	
1	Quaternary	Regolith (CSIRO, 2015) and less productive alluvium (Qa)	
2		Highly productive alluvium (basal gravels)	
3 - 4	Triassic	Rewan Group – fine grained sandstone and siltstone	
5	Permian	Rangal Coal Measures	Sandstone / siltstone / shale
6			Aries 1 Seam
7			Sandstone / siltstone / shale
8			Aries 2 Seam and Castor Seam
9			Sandstone / siltstone / shale
10			Pollux Seam
11			Sandstone / siltstone / shale
12		Burngrove Formation	Sandstone / siltstone / shale / coal

Groundwater interaction with surface drainage was modelled using the stream (STR) package for major rivers and creeks, and using the river (RIV) package for minor drainage lines

Stream cells are set up to use the dynamic stage functionality of the STR package. This represents a basic flow volume - stage relationship. During the flood periods in particular, stream stages are elevated and increased water leaks into the groundwater system. Conductances are fairly high, in the 200-300 m²/day range.

River cells have more moderate conductances ranging from 5 to 20 m²/day and are set up such that they act as drain cells (gaining but never losing) (AGE 2017a; Table 3.5).

In the model, irrigation by groundwater pumping is not explicitly represented because it is considered minor. Non-consumptive return of irrigation water is also not represented, although evapotranspiration extinction depth has been used as a surrogate mechanism.

4.2.3 TEMPORAL DISCRETISATION

Two models are used in sequence: (1) a calibration period model; and (2) a prediction period where mining is in operation immediately followed by a recovery period model on cessation of mining in each area. The calibration model runs for 23 years from 1 September 1995 to 31 August 2018. The first 10 years are split into two 5-year stress periods. Subsequent progression is quarterly. In all there are 55 stress periods in the calibration simulation.

The prediction model runs for 43 years from 1 September 2018 to 30 September 2061 with a quarterly time interval. Long-term recovery simulation follows for another 200

years until 1 October 2261 in annual steps. In all there are 372 stress periods in the prediction and recovery simulation.

4.2.4 CALIBRATION

AGE (2017a) conducted manual and automated steady-state and transient calibration to 72 groundwater level monitoring sites, for data to August 2016, and achieved calibration performance statistics of 7.6 mRMS and 4.9 %RMS². Generally, there was bias towards overestimation of heads by the model, especially at large distances from the open cut pits.

Although not part of the RMS statistics, calibration also considered observed underground mine inflows. While general agreement with the magnitude of inflow (about 2-5 ML/day) was achieved, the model produced an opposite trend over time.

4.2.5 RE-CALIBRATION

For the groundwater monitoring network as shown in Figure 9, simulated hydrographs at key sites (marked as purple squares) during the calibration period are presented in Appendix B as Figures B-1 to B-14. Additional calibration hydrographs for the UG bores in Pit C spoil are shown in Figures B-15 to B-18. The residuals map is at Figure B-20 and Figure B-22, while those for the pre-calibration model are shown in Figure B-19 and Figure B-21. The agreement between simulated and measured groundwater levels is best close to the pits.

The simulated inflows to the underground workings are presented in Figure B-23 and Figure B-24 for pre and post calibration respectively. They are in general agreement with the recorded magnitude of inflows (about 2-5 ML/day).

At the key sites, the calibration statistics are 4.6 %RMS and 6.8 mRMS, compared with 6.5 %RMS and 9.5 mRMS for the previous model for the same set of data. The improvement in overall performance is illustrated by the comparative scatter plots in Figure 18. An improvement in individual key bores is demonstrated in Figure 19 for all bores but one, in terms of sum-of-squared-residuals and the reduction in misfit of water levels at the end of the calibration period.

Most of the key sites were selected to examine far-field behaviour. AGE (2017a) notes that the largest residuals occur distant from the pits (Figure B-19), and that is borne out by this analysis.

The cumulative discrepancy is 0.00% at the end of the run and the discrepancy in any one stress period ranges between -1.1% and 1.9%.

Changes were investigated in the model for the following parameters and boundary conditions:

- Constant head boundaries
- General head boundaries

² Root Mean Square

- Stream boundaries
- Evapotranspiration boundaries
- Vertical hydraulic conductivity
- Horizontal hydraulic conductivity
- Specific yield
- Confined storage

Material changes were required for:

- Evapotranspiration boundary extinction depth
- Vertical hydraulic conductivity
- Horizontal hydraulic conductivity
- Specific yield
- Confined storage

Simulated groundwater levels and flows were found to be insensitive to other property and boundary condition changes. In particular, changes to global rainfall recharge offered little improvement in the levels of initial heads.

Improvements to modelled calibration were made by a general decrease in storage values (Table 4) and localised changes to vertical and horizontal hydraulic conductivity (Appendix G).

Property changes include:

- Doubling horizontal hydraulic conductivity in layers 5, 6, 7 which results in a significant reduction in overestimated heads at RB3. This change is applied consistently across the model, however neither assists or derogates model representation of observed data elsewhere.
- In layer 2, increasing horizontal hydraulic conductivity of the Permian subcrop from 1.5×10^{-2} to 3.0×10^{-2} m/day and increasing the horizontal hydraulic conductivity of the Regolith from 0.14 to 0.28 m/day led to improvements in shallow boreholes especially at WSMB2S. Figures E-2 and E-3 show the areas changed in this refinement.
- In layer 12, the lower horizontal hydraulic conductivity value of the Burngrove Formation was decreased from 7.03×10^{-5} to 3.2×10^{-5} m/day, and greatly improves the calibration at the Yongala borehole. This change is applied consistently across the western area of the model encompassing the Burngrove Formation. Figures E-4 and E-5 show the areas changed in this refinement.
- The western area of the model consistently over-estimated groundwater levels. Changes to initial heads, surface drainage setup, regional hydraulic conductivity

and recharge did not result in producing lower values for the heads. In the north, the groundwater levels are anticipated to be related to phreatophytes. Denser natural vegetation is evident in satellite images. In the southern area, general groundwater abstraction, arable practices and/or spray irrigation demands are believed to be affecting the water table. The evapotranspiration properties have been adapted in the north permitting evapotranspiration to occur to a depth of 10m. The rate of evapotranspiration however is linearly limited with depth such that it is at its maximum potential rate if the ground is fully saturated and zero when the water table is deeper than 10m (which is typical). In the arable area the depth is high at 15m. This however is not representing pure evapotranspiration but compensating for the lack of anticipated consumptive groundwater abstraction. The pit area is unchanged. The eastern area which demonstrates sparse vegetation is unchanged (2m limit). The revised distribution is shown in Figure E-1.

For the few selected bores with a lengthy historical record, good water level trends are reproduced by simulation at sites WSMB2D (Figure B-10) and WSMB3D (Figure B-12). However, the hydrographs at EC01 (Figure B-1) and EC11, EC13 and EC14 (in alluvium, Figures B-2 to B-4) show contrary trends. At the other sites, the data record is too short to confirm or deny the simulated trends.

Bore EC14 (Figure B-4), in alluvium on the northern side of Pit B, performs extremely well. EC01, also in alluvium but to the west of Pit C, does not replicate the observed rising trend; its residual varies from 4 m to zero. As EC01 has a rising trend, this bore is likely to be responding to irrigation recharge.

The WSMB series are installed in “Coal Measures Overburden” [S] or “Coal Measures” [D]. As WSMB2S (Figure B-11) and WSMB2D (Figure B-10) are within the outline of Pit A North, a mining effect should be noticeable. However, only a mild decline is evident in the observed data. The model performs very well at the deeper WSMB2D, WSMB3S and WSMB3D which are close (1.5km) to the western edge of Pit A South. The observed trend at WSMB3D is replicated very well by the model, with a low point around 2010, although the residual is about 8 m. The residual at WSMB3S (Figure B-13) is about 6 m.

The RB series of bores (Figure B-5 to B-9) is installed in coal seams at depths of about 100-240 m. RB5 is 2 km from Pit A South but the others are generally 4-5 km from any mining stress. There is no definitive mining effect at any bore in the observed dataset, but the model indicates quite plausibly that RB5 would have been affected if measurements had commenced earlier. The model is consistently overestimating the heads at these bores by 0.5-7.0m, relative to 6-17m prior to calibration.

The Yongala bore (Figure B-14) in the Burngrove Formation, at 74 m depth, performs well with absolute simulated levels within 0.5m of the observations relative to 14m prior to phase 3 calibration.

In general, the model reproduces historically observed response to streamflow and flood events quite well. This relates to both 1) stream stage change in response to flooding (effectively inducing leakage from the river to groundwater and back again after the stages reduce), and 2) from the quarterly recharge inputs which reflect the flood inducing rainfall events regionally.

Simulated groundwater levels in the pit and spoil areas are very well represented, partly because the model imposes drained conditions consistent with the mine designs. The observed groundwater levels are a reflection of these designed dewatered levels. Coal seam bore water levels in this area, typically monitored at 100 m depth, are generally well reproduced.

The performance of the model at bores nearest the mine area is summarised here, although more detail is provided in the foregoing paragraphs:

- EC14: very good match with water levels; recent declining trend is greater than observed.
- WSMB2S: water levels are overestimated by about 3 m; the declining trend is honoured, although the observed decline is greater in 2018.
- WSMB2D: the agreement is very good; the declining trend is honoured well.
- WSMB3S: water levels are underestimated by about 6 m; the declining trend is honoured.
- WSMB3D: the temporal water level pattern match is excellent, although water levels are overestimated by about 8 m.

Only at the northern pits F and Y does the model give a net inflow of water to the pits (at the end of the calibration period). At the southern pits, the model predicts a net outflow from 0.1 to 0.5 ML/day at each pit. It is not possible to compare a net flow with anecdotal observed inflows as outflows are not observable.

4.2.6 MODEL PROPERTIES

Summaries of the model layer properties in general, and the hydraulic conductivities relative to field data, are presented in Table 4 and Table 5 respectively. Recharge rates are summarised in Table 6.

Table 4. Simulated Aquifer Properties

Model layer	Lithology	Horizontal Hydraulic conductivity (Kh) (m/day)		Vertical Hydraulic conductivity (Kv) (m/day)		Specific Yield (Sy) (-)	Specific Storage (Ss) (m ⁻¹)
		From (lower value)	To (upper value)	From (lower value)	To (upper value)		
1	Surficial alluvium (clay / silt)	1.00E-03	1.00E-03	5.00E-05	5.00E-05	7.50E-03	1.00E-06
1,2	Regolith	2.80E-01	2.80E-01	7.00E-03	7.00E-03	7.50E-03	1.00E-06
1,2	Permian subcrop	3.00E-02	3.00E-02	1.20E-04	1.20E-04	1.50E-02	1.00E-06
2	Basal alluvium (sand / gravel)	1.00E+01	1.00E+01	5.00E-01	5.00E-01	1.50E-01	5.00E-06
3	Rewan Group	4.20E-02	4.20E-02	2.10E-04	2.10E-04	7.50E-03	1.70E-06
4	Rewan Group	1.20E-04	1.20E-04	6.00E-07	6.00E-07	7.50E-03	1.50E-06
5	Sandstone / siltstone / shale	2.00E-04	2.00E-01	4.55E-06	4.55E-03	3.75E-02	1.00E-07
6	Aries 1 Seam	1.00E-02	1.00E+01	2.78E-04	2.78E-01	7.50E-03	1.00E-07
7	Sandstone / siltstone / shale	4.00E-04	2.00E-01	3.57E-06	3.57E-03	1.38E-03	5.00E-07
8	Aries 2 and Castor Seam	5.00E-03	5.00E-01	2.50E-04	2.50E-01	7.50E-03	5.00E-07
9	Sandstone / siltstone / shale	1.00E-04	1.00E-01	5.00E-06	5.00E-03	7.80E-04	5.00E-07
10	Pollux Seam	5.00E-03	5.00E+00	2.78E-04	2.78E-01	7.50E-03	5.00E-07
11	Sandstone / siltstone / shale	1.00E-04	1.00E-01	4.17E-06	4.17E-03	7.73E-04	5.00E-07
12	Burngrove Formation	3.02E-05	1.00E-04	5.56E-06	5.56E-06	7.50E-04	5.00E-06
-	Spoil	1.00E+00	1.00E+00	1.00E-01	1.00E-01	4.00E-02	1.00E-03
-	Void	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+00	1.00E-04
-	Bord and Pillar zone	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+00	1.00E-04
-	Faults	1.00E-05	1.00E-04	1.00E-06	1.00E-05	1.00E-02	1.00E-05

Table 5. Simulated properties relative to field data ranges

Model layer	Lithology	Post-calibration Horizontal Hydraulic conductivity (Kh) (m/day)		Field data Horizontal Hydraulic conductivity (Kh) (m/day)		Pre-calibration Horizontal Hydraulic conductivity (Kh) (m/day)	
		From (lower value)	To (upper value)	From (lower value)	To (upper value)	From (lower value)	To (upper value)
1	Surficial alluvium (clay / silt)	1.00E-03	1.00E-03	9.00E-04	1.00E-03	1.00E-03	1.00E-03
1,2	Regolith	2.80E-01	2.80E-01	4.30E-01	4.30E-01	1.40E-01	1.40E-01
1,2	Permian subcrop	3.00E-02	3.00E-02	-	-	1.50E-02	1.50E-02
2	Basal alluvium (sand / gravel)	1.00E+01	1.00E+01	9.00E-02	1.30E+02	1.00E+01	1.00E+01
3	Rewan Group	4.20E-02	4.20E-02	-	-	4.20E-02	4.20E-02
4	Rewan Group	1.20E-04	1.20E-04	-	-	1.20E-04	1.20E-04
5	Sandstone / siltstone / shale	2.00E-04	2.00E-01	4.00E-03	4.00E-03	1.00E-04	1.00E-01
6	Aries 1 Seam	1.00E-02	1.00E+01	9.00E-03	5.90E+00	5.00E-03	5.00E+00
7	Sandstone / siltstone / shale	4.00E-04	2.00E-01	1.80E-02	1.19E+00	1.00E-04	1.00E-01
8	Aries 2 and Castor Seam	5.00E-03	5.00E-01	9.00E-03	5.90E+00	5.00E-03	5.00E+00
9	Sandstone / siltstone / shale	1.00E-04	1.00E-01	1.80E-02	1.19E+00	1.00E-04	1.00E-01
10	Pollux Seam	5.00E-03	5.00E+00	9.00E-03	5.90E+00	5.00E-03	5.00E+00
11	Sandstone / siltstone / shale	1.00E-04	1.00E-01	1.80E-02	1.19E+00	1.00E-04	1.00E-01
12	Burngrove Formation	3.02E-05	1.00E-04	-	-	7.03E-05	1.00E-04
-	Spoil	1.00E+00	1.00E+00	-	-	1.00E+00	1.00E+00

Table 6. Recharge Values

Zone	Diffuse recharge rate	
	mm/yr	% of annual rainfall
Surficial alluvium	5.18	0.8
Regolith	0.64	0.01
Permian subcrop	0.64	0.01
Spoil	53.1	8.2
Open cut void	647.5	100

4.3 SCHEDULING

The AGE (2017a) model has been interrogated to reveal the open cut pit schedule displayed in Figure 20. At each pit, mining has progressed from east to west. The outline of future underground mining is also shown on Figure 20.

There have been many revisions of the underground mine plan. That modelled by AGE (2017a), indicated in Figure 17, extended beyond the mine lease and has been reduced

in extent and changed in design for ongoing modelling. The current underground mining schedule is presented in Figure 21.

4.4 MODEL REFINEMENT

Changes were made to the AGE model used for Stage 2 prediction, so as to be suitable for void closure option assessment which was not undertaken with the AGE (2017a) model. Model enhancements are listed below.

4.4.1 OPEN CUT UPDATES

1. Pit and spoil areas were updated to be consistent with current mine plans. With the exception of storage, the hydraulic properties for void and spoil have been replicated from the former model's setup and applied to these new volumes.
2. Pit and spoil confined storage have been reduced substantially. All other properties are retained. The former model configuration (prior to Stage 2 modelling) resulted in double counting of storage as model layers saturate during rebound³.
3. Pit and spoil hydraulic properties that do not change in the rebound simulation have been ported from the time-variant materials (TVM) package to the static Layer Property Flow (LPF) package. This simplifies model setup.
4. Active dewatering of the open pits is simulated with MODFLOW 'Drain' cells. The distribution, elevation and timing of mine advance and pump shut-off has been updated as the mine plan has evolved. The current timings for each pit are summarised in Table 7.

Table 7. Pit Dewatering Timing

Pit	Water Management
A south	Water storage, no active level control or top-up
A north	Water storage, no active level control or top-up
B	Water storage, no active level control or top-up
C	Actively dewatered to end 2028. Following this time natural rebound permitted
D	Actively dewatered to end 2028. Following this time natural rebound permitted
E	Actively dewatered to end 2028. Following this time natural rebound permitted
F	Actively dewatered to end 2022. Following this time natural rebound permitted
Y	Actively dewatered to end 2017. Following this time natural rebound permitted

³ The AGE (2015) modelling of residual voids used an erroneous specific storage value of 1 m^{-1} instead of the more appropriate $4.6\text{E-}6 \text{ m}^{-1}$

4.4.2 UNDERGROUND MINE UPDATES

1. The underground mine development is represented through the use of MODFLOW drain cells. Although these underground extractions are spatially isolated from the equivalent cells used to represent the open pit drainage (as illustrated in Figure 6), they are proximal to each other (as illustrated in Figure 22 for Pit B and Figure 23 for Pits C-D).
2. The underground mine plan has been updated to the current plan and terminates in 2028 (Figure 21).
3. The Underground Specific Yield storage has been reduced to 75% to account for pillar volumes.
4. The original MODFLOW-USG model represented active drainage for 2 years from the commencement of mining within an area. The underground mine plan for this tranche of work initially did not include the 2-year limit on drainage per worked area and remained actively drained for the life of underground mining. This setup was subsequently changed, and the 2-year limit has been implemented into the current mine plan. This is what has been presented herein. It is however useful to note that this change does affect the predicted inflows to the underground mine, and these assumptions may need to be revisited. Clarification is required on underground practices, such as bulkhead installations on worked panels, and locations of active sumps.
5. TVM properties have been updated to be consistent with the new underground mine progression.

4.4.3 CLIMATIC UPDATES⁴

1. Pit and spoil recharge zones have been updated to be consistent with the new void and spoil surface areas.
2. Pit and spoil evaporation/evapotranspiration zones have been updated to be consistent with the new void and spoil surface areas.
3. The method of evapotranspiration representation in the model has been adjusted. The former model implemented this only in upper layers, which prevented the process from occurring under depressed water level conditions within the void areas. The updated method permits evapotranspiration also to occur within the pit.

4.4.4 PIT WATER REPRESENTATION

1. Currently, pits holding water are represented with a constant head in calibration models, and with an initial fixed head at the start (only) of the prediction models.

⁴ Although in-stream flood events are incorporated in the calibration period, they are not included in prediction given their unknown frequency and quarterly time-stepping in the model. Cyclonic events would hasten the recovery of predicted water levels.

In the prediction models the pit waterbody stage is not forced. The constant heads applied are included in all void cells which imparts a small improvement at the start of the model run relative to the original model. The stage in each pit has been updated with onsite recorded levels up to May 2018.

2. Within the original model, pits holding water were held at constant water levels. This is not the case in the revised predictive models. There is freedom for the pit water levels to adjust to dynamic inflows and outflows.

4.4.5 OTHER REFINEMENTS

1. Model time discretisation has been improved to be consistent with mine plan dates and more closely follow calendar quarters. The model runs at an equivalent temporal resolution to the previous work.
2. The former model does not explicitly represent private pumping, enhanced arable evapotranspiration or regional phreatophyte evapotranspiration. These processes would depress the groundwater levels. In the absence of data and its implicit detail, the evapotranspiration characteristics of the model have been adapted to permit extraction of water from greater depths. This better simulates the effects of regional phreatophytes and compensates for point abstraction deficiency.
3. Initially, Options 1 and 2 were modelled with the same geometry and the backfill scenario (Option 3) included refinement to the model geometry (backfill) and its hydraulic properties. In the final model runs, each option has separate landforms that align with the latest designs.
4. An error in the MODFLOW-USG and MODFLOW-USG Beta code was identified during the Stage 2 modelling. This bug affects the study as it is related to constant heads. We have corrected the error and tested to confirm appropriate simulation.

In all predictive simulations, the cumulative discrepancy is <0.01% at the end of a run; the discrepancy in any one stress period is <2% (typically substantially lower).

4.5 MODEL CONFIDENCE

Groundwater modelling has been conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) and the Murray Darling Basin Commission Groundwater Flow Modelling Guideline (Middlemis et al., 2001). As these are mostly generic guides, there are no specific guidelines on special applications, such as coal mine modelling or mine closure.

Under the earlier MDBC modelling guideline (Middlemis et al., 2001), the model is best categorised as an Impact Assessment Model of medium complexity. That earlier guide (Middlemis et al., 2001) describes this model type as follows:

“Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.”

The 2012 guide has replaced the model complexity classification of the previous guideline by a "model confidence level", (Class 1, Class 2 or Class 3 in order of increasing confidence) typically depending on:

- Available data (and the accuracy of that data) for the conceptualisation, design and construction phases of a model.
- Calibration procedures that are undertaken during model development.
- Consistency between the calibration and predictive analysis.
- Level of stresses applied in predictive models.

Table 8 (based on Table 2.1, Barnett et al., 2012) summarises the classification criteria and shows a scoring system allowing model classification. Based on Table 8, the groundwater model developed for this Groundwater Assessment may be classified as a mixture of Class 2 (about 40%) and Class 3 (about 60%).

Table 8. Groundwater Model Classification

Class	Data		Calibration		Prediction		Indicators		TOTAL
1	Not much Sparse		Not Possible Large error statistics		Timeframe>>calibration Long stress periods		Timeframe>10x Stresses>5x		1
	No metered usage	✓	Inadequate data spread		Transient prediction but steady state calibration		Mass balance>1% (or single 5%)		
	Remote climate data		Targets incompatible with model purpose		Bad verification		Properties<>Field		
							Bad discretisation		
							No review		
2	Some	✓	Partial performance	✓	Timeframe>calibration	✓	Timeframe=3-10x	✓	9
	Poor coverage		Long-term trends wrong		Long stress periods		Stresses=2-5x	✓	
	Some usage info	✓	Short time record	✓	New stresses not in calibration	✓	Mass balance<1%		
	Baseflow estimates		Weak seasonal replication		Poor verification	✓	Some properties<>Field measurements		
			No use of targets compatible with model purpose				Some key coarse discretisation		
							Reviewed by hydrogeologist		
3	Lots		Good performance stats		Timeframe~calibration		Timeframe<3x		14
	Good aquifer geometry	✓	Long-term trends replicated	✓	Similar stress periods	✓	Stresses<2x		
	Good usage info		Seasonal fluctuations OK	✓	Similar stresses to those in calibration	✓	Mass balance<0.5%	✓	
	Local climate info		Present day data targets	✓	Steady state prediction consistent with steady state calibration	✓	Properties~Field measurements	✓	
	K measurement	✓	Head and flux targets	✓	Good verification		Some key coarse discretisation	✓	
	Hi -res DEM	✓					Reviewed by modeller	✓	

5 OPTION 1 - ASSESSMENT OF LANDFORM LEVEE

The Landform scenario applies the final landform data for void elevation and dewatering level control where and when active open pit operations are in progress. In this option, the voids are allowed to fill or adjust existing water levels naturally. Pits A south, A north and B start at the existing water levels as applied in the AGE (2017a) model, as recorded onsite and supplied in May 2018.

The relevant prediction models are:

- Run 061 [G1812_pred_GS135_061] – 243-year simulation (includes enhanced recharge in the spoil zones) for preliminary landforms.
- Run 080 [G1812_pred_GS135_080] – 243-year simulation (recharge removed in spoil areas to assure no double counting with hydrology team's analyses).
- Run 110 [G1812_pred_GS115_110] – 243-year simulation (includes enhanced recharge in the spoil zones) for the final landforms.

Run 110 supersedes Run 061. The results of Run 080 are not presented here (in comparison to Run 061) as the influence of recharge change in the spoil zones is simulated to be insubstantial with respect to long term evolution of pit stages. Comparisons between Option 1 and Option 2 results, and Option 1 and Option 3 results, for pit inflows/outflows and pit water levels are provided in the plots within Appendix D and Appendix E, respectively. These Appendices show the precise locations at which model outputs have been extracted for each pit.

5.1 VOID WATER LEVELS AND FLOWS

Figure 24 to Figure 31 present the results for each pit in turn, for 45 years from time zero at 1 September 2018 to 30 September 2063. Underground mining is planned to finish in 2028 (mining year 10) with adjoining pits dewatered until that time.

In those figures, the simulated pit waterbody stage is shown in **red**, active dewatering in **blue** and general net groundwater flow to, or void water from, the pit in **green**. The **blue** quantity is the water that reports to the MODFLOW drain cells and is assumed to be pumped out of the pit. The **green** quantity is the net flow of water into or out of the pit through the pit faces and floor. This is the transfer of water between pits and the groundwater system that is induced by all sources and discharge mechanisms (e.g. recharge, evaporation, abstraction and/or relative groundwater levels). This water transfer between the pit and groundwater system varies spatially throughout the pit; however, the **green** line shows only the net inflow or outflow through the pit faces and floor. Both the magnitude and the direction of flow through the pit faces and floor can vary spatially within the model. Note that in the long-term, all pits are receiving water from the surrounding regional groundwater system. This is discussed in more detail in Section 5.3. Where time-series data stabilise to an equilibrium condition with non-zero flow rates, this shows a simulated transfer of water from or to the pit to balance extraction from evaporation or flow to a neighbouring pit.

Flow polarity is defined as follows:

- Negative represents water flowing out of the void under losing conditions, with the void acting as a source of water.

- Positive represents water flowing into the void under gaining conditions, with the void acting as a sink for water.

Conceptual icons are added to each figure to reinforce whether net inflow or net outflow is predicted. The direction of net water exchange is very sensitive to the degree of simulated interaction between the residual voids and the underground voids, and that depends primarily on the adopted (calibrated) hydraulic conductivities in the groundwater model. Although the groundwater model predicts an outflow from many pits to the underground in the short term (this represents a flow from the pit into the underground workings in the early stages of underground mining water level recovery), a change in flow direction could occur sooner than is currently predicted. The regional groundwater level is higher than the groundwater levels in the pit area, hence no loss into the regional groundwater is predicted at any point in time. The groundwater model also does not take into account external inputs of water to the pits, climatic variations in water levels, or cyclonic events which could accelerate groundwater recovery. All of these mechanisms have the potential to alter the direction of flow between the residual voids and the underground voids.

5.2 UNDERGROUND FLOWS

Figure 32 presents the results for the entire underground mine until closure in 2028, for 45 years from time zero at 1 September 2018.

The flow represented by the **dark blue** line is raw model output and includes artificial high instantaneous inflows. This is an artefact of quarterly advances in mine plans and the associated storage release. The **green** line is the flow entering the cells hosting underground workings. This shows inflow to the underground void after active dewatering ceases (that is, after the drain cells are deactivated). This does not represent the full inflow into the dewatered, or at least depressurised, surrounding aquifer material - only the flow to the cells directly hosting mined voids.

5.3 SCENARIO SUMMARY

Pits A south and north (Figure 24 and Figure 25) start from a water storage condition at 144 and 108 mAHD, respectively. As there is no active dewatering (no drain cells), the **blue** line is constant at zero. Both pits show some seasonal outflow (**green** line) at early time. While Pit A north maintains a very low discharge, Pit A south receives inflow consistently, with a stable value after about 10 years. Steady pit levels of about 137 and 118 mAHD are simulated in Pits A south and A north, respectively, at about 20 years after the end of mining (that is, mining year 30). While Pit A south remains stable out to 45 years, the water level in Pit A north starts to increase by then. Relatively steady conditions do not represent cessation of inflow/outflow but rather a balance between groundwater exchanges, evaporation and rainfall surcharge. The seasonality is evident in the groundwater flows.

As the water level in Pit A south is always higher than in Pit A north, there would be a transfer of water from south to north through the intervening pit wall. In the model, this is reported as a groundwater flow out of Pit A south and a matching groundwater inflow to Pit A north. For Pit A south, inflow from high water levels in the regional groundwater

system would exceed the loss to Pit A north. For Pit A north, the inflow of water from Pit A south would almost balance the outflow of water to Pit B.

Pit B (Figure 26) starts from a shallow pond stage of 71 mAHD and settles around 99 mAHD through the next three decades, at which time water level starts to rise. The pit initially receives inflow from regional groundwater and from Pit A north, but then loses water to the underground mine until year 35, after which time it reverts to a net gaining condition.

As Pit B has a lower water level than Pit A north, it would receive water from Pit A north through the intervening pit wall.

Pit C (Figure 27) starts to rebound about year 35, at the same time as water levels start to rise from depressed values due to losses to the underground mine. Pit D (Figure 28) rebounds a little later. In the period prior to pond level rise, any water entering the pits would seep to groundwater, replenishing depleted storage following underground mining, or would evaporate within the hydrological year. Given its proximity, Pit C loses more to the underground mine than does Pit D.

Pits E, F and Y (Figure 29, Figure 30, Figure 31) all have rapid rebound after a decade or less, being isolated from the effects of the underground mine. Pit E has an initial loss to groundwater, but both Pits F and Y simulate a net gain from groundwater (and loss to evaporation).

As the water level in Pit E is always higher than in Pit D, water would transfer from Pit E to Pit D through the intervening pit wall, at the same time that regional groundwater would be discharging into both pits.

The predicted flow to the underground workings (Figure 32) is significant for this scenario. Mine inflows of approximately 10-20 ML/day are predicted in the next three years, to 2020. While peak rates might reach 20 ML/day, average rates are anticipated to be approximately 15 ML/day during early years and about 10 ML/day until underground mining completes. The future predicted rates of underground mine inflow are elevated with respect to current underground inflows of 2-5 ML/day. The increase relates to advancement of the underground mine, between 2018 and 2020, coming close to the open cut areas of Pits A north, B and D. Following 2020, lateral flows into the underground workings are anticipated to reduce to between 5 and 10 ML/day for the next 10 years and to taper off to zero after mining has finished, as the underground voids fill.

In the mine workings near dry worked pits C and D, this water is primarily simulated to be released from local storage. In the southern areas a substantial portion would also be derived from pit voids or the surrounding near-surface areas. As the underground mine develops, the dewatered, or at least depressurised, volume surrounding the mine would expand and a greater proportion of pit water, or water which otherwise would have gone to the pits, is simulated to flow into that depleted volume. With the simulated high storages and moderate hydraulic conductivities, this process takes some time. The **green** line (Figure 32) does not represent the full volume of flow into the depleted zone, only the underground void areas, but does show an inflow from 10 to 20 ML/day sustained for the duration of the simulation.

The evolution of groundwater derived inflows or outflows to pits and pit stages is influenced by four anthropogenic factors:

- 1) The enhanced groundwater connection to the proximal underground workings which rebound prior to equilibrated pit waterbody formation.
- 2) The lateral connection with higher permeability backfilled material within the historical pit volume. This material is anticipated to have a higher infiltration potential than undisturbed rock and additionally the elevation reduces the evaporative potential on infiltrating water. The effect is an enhanced recharge to the underground, reducing groundwater rebound times, and a short travel time indirect flowpath into the pits.
- 3) The interconnectivity between adjacent pits with different waterbody levels. Water would transfer from one pit to another through the intervening pit walls, from Pit A south towards Pit B (south of Nogoia River), and from Pit E towards Pit C (north of Nogoia River).
- 4) Regional groundwater levels. As these water levels are always higher than pit waterbody levels, pits would always gain water from the shallow groundwater system, but pits proximal to the underground workings would lose water to the deep groundwater system in early years.

For the groundwater monitoring network as shown in Figure 9, simulated hydrographs at key sites are presented in Appendix C as Figures C-1 to C-14 during calibration and long-term prediction periods.

5.4 EQUILIBRIUM

As equilibrium water levels were not achieved after 45 years at all pits, a longer simulation was run for an additional 200 years with annual time stepping (no seasonality). The results are shown in Figure 33 continuing from year 45, for Pits B, C and D nearest the underground mine, and for all pits in Appendix D. The rise in level towards equilibrium commences at different times for each pit. This indicates the time required to satisfy the demand of the underground voids and overlying desaturated rocks.

Ultimate equilibrium water levels are listed in Table 9, relative to minimum pit floor levels. The final waterbody rest levels show the lowest level at Pit D (122 mAHD), gradually increasing to 136 mAHD at Pit A south in the south, and to 171 mAHD at Pit Y in the north. Each pit is anticipated to ultimately hold water to a maximum depth varying from about 3 m at Pit A north to 50 m at Pit C.

Table 9. Option 1 Rest Water Levels

Pit	Rest Level [mAHD]	Minimum Pit Floor [mAHD]	Max Free Water [m]
A south	136.18	127.86	8.3
A north	135.21	132.23	3.0
B	133.43	100.36	33.1
C	127.57	77.59	50.0
D	121.87	83.20	38.7
E	138.96	126.59	12.4
F	150.33	137.20	13.1
Y	171.18	160.94	10.2

6 OPTION 2 - ASSESSMENT OF BENEFICIAL USE

The Beneficial Use scenario aims to take advantage of potential flood waters that could be captured in those pits proximal to Nogoia River.

Levees would be equipped with engineered inflow structures to regulate ingress of water from the Nogoia River at or above specified flood frequencies. Other regulating structures would permit controlled transfer of water between adjoining pit waterbodies and pumping equipment would be used to distribute water for beneficial use. Pits adjoining the river (B and C) would capture a portion of flood flows in the pits for storage until required for distribution to water users; e.g. irrigators. Minimum pit water levels would be managed to minimise saline groundwater ingress whilst providing adequate freeboard to provide storage for economic quantities of irrigation water.

6.1 DISCHARGE-STAGE CURVES

HEC, the surface water consultant, requires from the groundwater model a discharge-stage curve for each pit. Sequential steady-state simulation using progressively increasing constant heads is a common procedure requested by surface water specialists to enable generation of a discharge-stage curve which they use in combination with rain, runoff and evaporation to better simulate final void water level and salinity. This approach is an approximation because the pit water levels have a forced synchronicity. That is, the water level in each pit is assumed to rise at much the same rate. If the water levels were to rise at different rates, the interactions between the pits would give a different set of discharge-stage curves. Another complication is that, because steady-state conditions are assumed for each pit water level step, the ambient groundwater levels are effectively fully recovered. This means that the model would show groundwater discharging into the pits initially (when pit water levels are assumed low), and losses of water from the pits to groundwater finally (when pit water levels are assumed high).

As the steady-state methodology is equivalent to an assumption of negligible interaction between the open cut voids and the underground void, more detailed discharge-stage curves have been generated by taking the output from the full transient simulation for the Option 2 landform and doing a cross-plot of net flow to/from the pit with pit water level, for every reported instant of time. This is a more rigorous way to produce discharge-stage curves because the assumptions of equilibrium (steady-state) and synchronised pit interactions are avoided. The downside is a more complex curve and a lower upper limit on pit water level than surface water modellers need to investigate in order to assess external inputs of water (e.g. flood inputs). The curves require projection to higher water levels than would occur naturally without external inputs of water. This projection has been done by close examination of the simulated equilibrium water tables in the vicinity of each pit, and estimating that water level where the pit should convert from a net gaining condition to a net losing condition. This point has zero flow by definition, and identifies the approximate crossover of the discharge-stage curve to the opposite polarity; that is, it is the point at which flow changes from one direction to the other.

The transient discharge-stage curves have complex patterns because they account for detailed underground mine scheduling. Along with simplified composite projected curves, they are presented in Appendix F for Option 2, and also for Options 1 and 3. The Tabulated sampling of the discharge-stage curves is provided in Table 10, Table 11 and Table 12. The net groundwater flow represents the balance between all the components of groundwater flows (flow to coal measures and underground workings,

flow from and to waste rock material). Net groundwater flow is used because the model results are too complex to split the flow into individual components. For Option 3, Pits B, C and D are backfilled to a sufficient elevation that a free waterbody would not form. The composite curves for Pits F and Y assume backfilling to about 5 m above simulated water rest levels.

As the landforms transition across to their final forms during the period of groundwater simulation, the net groundwater exchanges with pits are estimated separately at early-time (before the final landforms) and at late-time (for the final landforms). The composite discharge-stage curves in Appendix F are simplified representations of curves continuous in time.

Table 10. Option 1 Stage-Discharge Table

STAGE	As_Flow	An_Flow	B_Flow	CD_Flow	E_Flow	F_Flow	Y_Flow
50							
55							
60							
65							
70			2.0	2.0			
75			1.88	1.6			
80			1.68	0			
85			1.54	-2.0			
90			1.37	-2.40			
95			1.16	-2.72			
100			1.0	-2.84			
105			-0.40	-3.12			
110		0.5	-0.80	-3.42			
115		0.43	-1.14	-3.78			
120		0.21	-1.36	-4.0	0.5		
125	0.0	0.0	-1.46	-3.54	0.25	0.0	
130	-0.11	-0.03	-1.52	-2.72	0.0	0.0	
135	-0.29	-0.11	-1.18	-1.4	-0.19	0.0	
140	-0.14	0	0.0	0.0	-0.50	0.0	
145	0.11	0.11	1.2	1.0	-0.41	0.0	0.0
150	0.33	0.21	2.4	1.7	0.0	0.0	0.0
155	0.5	0.33			0.36	0.0	0.0
160					0.8	0.08	0.0
165						0.27	0.0
170						0.39	0.0
175						0.5	0.0
180						0.6	0.6
Pit Floor Min	127.86	132.23	100.36	77.59	126.59	137.20	160.94
mAHD	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day

Negative: Pit receives net water from the groundwater system
Positive: Pit loses net water to the groundwater system

Table 11. Option 2 Stage-Discharge Table

STAGE	As_Flow	An_Flow	B_Flow	CD_Flow	E_Flow	F_Flow	Y_Flow
50							
55							
60				2.0			
65			0.17	1.6			
70			0.54	1.2			
75			0.00	0.65			
80			-0.64	-0.78			
85			-1.00	-1.44			
90			-1.39	-1.86			
95			-1.54	-2.40			
100			-1.76	-3.00			
105			-1.94	-3.18			
110	0.0		-1.89	-3.48			
115	-0.2	0.0	-1.67	-4.0	0.3		
120	-0.32	-0.21	-1.32	-4.0	0.2	0.0	
125	-0.21	-0.25	-1.00	-3.5	0.1	0.0	
130	-0.08	-0.21	-0.67	-2.4	0.0	0.0	
135	0.08	0.19	-0.26	-1.1	-0.4	0.0	
140	0.22	0.5	0.13	0.0	-0.3	0.0	0.0
145	0.38	0.6	0.35	0.9	0.00	0.0	0.0
150				1.6	0.16	0.0	0.0
155					0.3	0.0	0.0
160						0.1	0.0
165							0.0
170							0.14
175							0.65
Pit Floor Min	109.77	117.19	78.47	68.28	128.00	125.91	148.47

mAHD	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day
Negative: Pit receives net water from the groundwater system							
Positive: Pit loses net water to the groundwater system							

Table 12. Option 3 Stage-Discharge Table

STAGE	As_Flow	An_Flow	B_Flow	CD_Flow	E_Flow	F_Flow	Y_Flow
50							
55							
60							
65							
70							
75							
80							
85							
90							
95							
100							
105					0.5		
110					-0.13		
115					-0.15		
120					-0.05		
125					-0.77	0.0	
130					-0.92	0.0	
135		0.50			-0.80	0.0	
140	0.0	0.10			-0.64	0.0	
145	-0.19	-0.25			-0.33	0.0	
150	0.06	0.22			0.0	0.0	0.0
155	0.30	0.48			0.27	0.0	0.0
160	0.46					0.08	0.0
165						0.20	0.0
170						0.34	0.0
175						0.43	0.0
180			FLOODPLAIN	FLOODPLAIN		0.5	0.5
Pit Floor Min	140.0	137.0	152.0	147.33	117.0	137.20	160.94

mAHD	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day	ML/day
Negative: Pit receives net water from the groundwater system							
Positive: Pit loses net water to the groundwater system							

Water balance modelling by the surface water specialist includes rainfall-runoff simulation that is not directly simulated in a groundwater model, and is better able to investigate climate scenarios by using a much shorter time interval than is possible in a groundwater model. However, the water balance model would have an underlying assumption of pits being isolated from each other, whereas the groundwater model allows for complex temporally varying interactions between pits. As a result, differences are to be expected between the final pit water levels and ultimate pit inflows generated

by the two types of models. Where there are differences, preference should be given to the water balance model because of the finer time scale (daily), the inclusion of the runoff component in the water balance and a better ability to represent pit geometry.

6.2 EQUILIBRIUM

The relevant prediction model is:

- Run 112 [G1812_pred_GS115_112] – 243 year simulation.

Option 2 pits have steeper sides than the Option 1 and Option 3 pits to provide more water storage capacity. Appendix H shows representative profiles through each pit for each option to show their relative landforms. Also shown is a comparison of actual and modelled landform profiles, and equilibrium water levels. The modelled profiles are slightly lower due to model discretisation constraints. As model cells are generally 50-100 m wide at the pits, the void profiles have been sampled conservatively to give the minimum elevation in each cell.

A comparison between Option 1 and Option 2 results for pit inflows/outflows and pit water levels is provided in full in the plots within Appendix D. Summary plots are provided in Figure 34 to Figure 37, with underground inflows in Figure 38. These plots show the full 245 years of simulation.

Ultimate equilibrium water levels are listed in Table 13 relative to minimum pit floor levels. The final waterbody rest levels show the lowest level at Pit B (109 mAHD), generally increasing to 164 mAHD at Pit Y in the north. However, Pit A north is predicted to have a higher water level than at Pit A south. Each pit is anticipated to ultimately hold water to a maximum depth varying from about 6 m at Pit E to about 50 m at Pit D.

Option 2 pit water levels are higher than those of Option 1 by 2 to 24 m, with a median of 7 m.

Table 13. Option 2 Rest Water Levels

Pit	Rest Level [mAHD]	Minimum Pit Floor [mAHD]	Max Free Water [m]
A south	120.56	109.77	10.8
A north	128.82	117.19	11.6
B	109.16	78.47	30.7
C	120.96	84.00	37.0
D	119.69	68.28	51.4
E	134.13	128.00	6.1
F	146.27	125.91	20.4
Y	164.04	148.47	15.6

7 OPTION 3 - ASSESSMENT OF BACKFILL TO PMF

The Backfill to PMF scenario applies regraded pit landform data for Pits E-Y which are permitted to rebound. Similarly Pits A north and A south are permitted to form waterbodies. A backfill elevation which is similar to pre-mining topography is applied for Pits B, C and D. No pits remain within the PMF area.

The relevant prediction model is:

- Run 111 [G1812_pred_GS115_111] – 243 year simulation.

A comparison between Option 1 and Option 3 results for pit inflows/outflows and pit water levels is provided in the plots within Appendix E.

7.1 VOID WATER LEVELS AND FLOWS

Figure 39 to Figure 42 present the results for each pair of pits, for 243 years from time zero at 1 September 2018. Underground mining is planned to finish in 2028 (mining year 10) with adjoining pits dewatered until that time.

The simulated pit waterbody stage is shown in **red**, active dewatering in **blue** and general net groundwater flow to, or void water from, the pit in **green**. For pits that are backfilled, the groundwater level beneath the land surface is shown in **red**.

Flow polarity is defined as follows:

- Negative represents water flowing out of the void under losing conditions, with the void acting as a source of water.
- Positive represents water flowing into the void under gaining conditions, with the void acting as a sink for water.

The direction of net water exchange is very sensitive to the degree of simulated interaction between the residual voids and the underground voids, and that depends primarily on the adopted (calibrated) hydraulic conductivities in the groundwater model. Although the groundwater model predicts some outflow from Pit A north to the underground, reversal of polarity could occur sooner than is currently predicted. The groundwater model also does not take into account external inputs of water to the pits, climatic variations in water levels, or cyclonic events which could accelerate groundwater recovery. All of these mechanisms have the potential to alter the polarity of flow between the residual voids and the underground voids.

7.2 UNDERGROUND FLOWS

Figure 43 presents the results for the entire underground mine for 243 years from time zero at 1 September 2018.

The flow represented by the **light blue** line is the smoothed inflow. The **grey** line is the flow entering the cells hosting underground workings. This shows inflow to the underground void after active dewatering ceases (that is, after the drain cells are

deactivated). This does not represent the full inflow into the dewatered, or at least depressurised, surrounding aquifer material - only the flow to the cells directly hosting mined voids.

The predicted flow to the underground workings (Figure 38) is not significantly different from that predicted for Option 1 and Option 2. Mine inflows of approximately 10-20 ML/d are predicted during the life of the underground mine (to 2028).

7.3 EQUILIBRIUM

A comparison between Option 1 and Option 3 results for pit inflows/outflows and pit water levels is provided in full in the plots within Appendix E. Summary plots are provided in Figure 39 to Figure 42, with underground inflows in Figure 43. These plots show the full 245 years of simulation.

Ultimate equilibrium water levels are listed in Table 14 relative to minimum pit floor levels. The final waterbody rest levels show the lowest level at Pit B (109 mAHD), generally increasing to 164 mAHD at Pit Y in the north. However, Pit A north is predicted to have a higher water level than at Pit A south. Each pit is anticipated to ultimately hold water to a maximum depth varying from about 6 m at Pit E to about 50 m at Pit D.

Option 3 Pit A water levels are higher than those of Option 1 by about 10 m, but are lower by 1 m at Pits F and Y. The Pit E water level is 10m lower. At the three backfilled pits (B, C and D), the groundwater levels are expected to be 2 to 6 m beneath the design landform. They would be 13 to 20 m higher than the open water levels for the corresponding Option 1 pits. The expected maximum depth of water at Pit Y is expected to be about 10 m for the design landform.

Table 14. Option 3 Rest Water Levels

Pit	Rest Level [mAHD]	Minimum Pit Floor [mAHD]	Max Free Water [m]
A south	147.20	140.00	7.2
A north	144.63	137.00	7.6
B	146.58	152.00	-5.4
C	147.76	150.00	-2.2
D	141.38	147.33	-5.9
E	129.01	117.00	12.0
F	149.33	137.20	12.1
Y	170.54	160.94	9.6

As Pits E, F and Y do not require any backfill, their responses are expected to be similar to those of Option 1. This is indeed the case for the more distant Pits F and Y, but the water levels at Pit E remain about 10 m lower.

For the groundwater monitoring network as shown in Figure 9, simulated hydrographs at key sites are presented in Appendix C as Figures C-1 to C-14 during calibration and long-term prediction periods, and are compared with the predicted hydrographs for Option 1 and Option 2.

8 SURFACE WATER / GROUNDWATER INTERACTIONS

Estimation of regional groundwater levels proximal to Pits A-E has been undertaken by examining detailed long-term equilibrium groundwater level contours for Options 1-3. While noting much variability along the western and eastern edges of each pit, estimates of the regional groundwater levels are listed in Table 15 along the water level predictions in the final rehabilitated land form from the surface water model (HEC, 2020 and HEC, 2019).

Table 15. Option 1 Rest Water Levels

Option	Parameter	Pit A	Pit B ²	Pit CD ²	Pit E
1	Regional Groundwater level [mAHD]	144	142	142	152
2	Regional Groundwater level [mAHD]	144	142	142	150
	Average final water level in the final rehabilitated landform [mAHD] ¹	133	123	125.5	140
3	Regional Groundwater level [mAHD]	148	-	-	152

Notes: 1. Average Final water Level in the final rehabilitated landform is calculated over the last 50 years of simulation
2. Pits B and CD are infilled in Option 3.

Groundwater “rest level” is the prediction of final water level in the rehabilitated landform by the groundwater model which does not incorporate runoff. Not surprisingly, it is always lower than the predicted water level using the surface water model. The differences are:

- Pit A: 8 m
- Pit B: 14 m
- Pit CD: 6 m
- Pit E: 6 m

HEC, 2020 suggests that flow should occur from Pit A to Pit B, due to 10m head difference (using surface water model levels), and from Pit E to Pit D, due to 14m head difference. HEC (2020) does predict “groundwater outflow” from Pit A and from Pit E. This “outflow” is actually downgradient to the adjacent pit, and not to the regional groundwater system, as Table 15 shows that the regional levels are always much higher than the water levels in the final rehabilitated landform. The movement downgradient is called “groundwater outflow” because there is a narrow strip of “aquifer” material separating adjacent pits in the groundwater model. The model reports a loss to groundwater, but it is a short-term transfer of water from the waterbody in one rehabilitated landform to another through intervening aquifer material.

9 ENVIRONMENTAL VALUES

An assessment of the potential impacts of each of the three preferred options on relevant environmental values (EVs) has been undertaken based on the outcomes of this study. The EVs relevant to this report are described in the Ensham Residual Void Project Stage 2 Environmental Values Workshop Report (March, 2018).

9.1 ASSESSMENT OF POTENTIAL IMPACTS

The assessment of impacts on EVs has been undertaken by assigning a ranking for each of the preferred options to each EV. The adopted scoring criteria, definitions of impacts and summary of the EV assessment are shown in Table 16.

The EV of aquatic ecosystems (biodiversity and habitat) was assessed by considering water table drawdown. There is predicted to be negligible drawdown (from current conditions) in most riverine alluvium, and consequently negligible effect on river-aquifer interaction in general; e.g. see Figure C-1 for monitoring bore EC01. However, due to moderate drawdown close to Pit B, e.g. see Figure C-3 for monitoring bore EC13, Options 1, 2 and 3 were ranked respectively at -1 ("minor negative impact"), zero ("no impact"), and -1 ("minor negative impact") for the groundwater drawdown criterion. Option 3 is expected to cause more drawdown than Option 1 in the alluvium close to Pit B (see Figure C-3 and Table 16). Option 2 should be benign with respect to the groundwater drawdown criterion if pit water levels are maintained high. The drawdown in the alluvium is expected to be a short-term effect until groundwater levels recover in that area, being about 5-10 years for Option 1 and 15-20 years for Option 3.

Although the three options differ in their degree of effect on river-aquifer interaction, there would be a marginal effect on the natural leakage of water from the Nogoia River to its associated alluvium over a 1 km reach adjacent to Pit B. It is expected that the natural leakage from the entire Nogoia River of about 11 ML/day would be increased by an average of 12% over the next 70 years, following which there would be a reduction of the natural leakage by about 14%, thereby increasing flow in the river. This would have no effect on river water quality and a marginal beneficial effect on groundwater quality. All options were ranked zero ("no impact") for the expected effect on aquatic ecosystem water quality objectives,

The EV of irrigation use was assessed by considering water table drawdown at the locations of known irrigation bores. Due to negligible drawdown at the one known irrigation bore, for all preferred options, and consequently negligible effect on groundwater flow direction at that bore, Options 1, 2 and 3 were ranked zero ("no impact") for both groundwater drawdown and groundwater quality criteria. More detail on drawdown assessment is provided in Section 8.2.

The EV of farm supply was assessed by considering water table drawdown at the locations of known stock and domestic bores, other existing bores with unknown use, and bores not currently in use. Due to drawdown of less than 5 m at all identified bores for all preferred options, Options 1, 2 and 3 were ranked -1 ("minor negative impact") for the groundwater drawdown criterion. More detail on drawdown assessment is provided in Section 8.2. As there is no feasible mechanism for a change in beneficial use at the identified bores, Options 1, 2 and 3 were ranked zero ("no impact") for the groundwater quality criterion.

The EV of stock use was assessed by considering water table drawdown at the locations of known stock bores. Due to drawdown of less than 5 m at all identified bores for all preferred options, Options 1, 2 and 3 were ranked -1 (“minor negative impact”) for the groundwater drawdown criterion. More detail on drawdown assessment is provided in Section 8.2. As there is no feasible mechanism for a change in beneficial use at the identified bores, Options 1, 2 and 3 were ranked zero (“no impact”) for the groundwater quality criterion.

Table 16. Environmental Values Assessment

Environment Aspect	Environmental Value	Criteria	Scoring Notes	Option 1 Landform Levee	Option 1 Evidence (short description/reference to section in technical report)	Option 2 FMBU	Option 2 Evidence (short description/reference to section in technical report)	Option 3 Backfill to PMF	Option 3 Evidence (short description/reference to section in technical report)
Water	Aquatic ecosystems (biodiversity & habitat)	Groundwater drawdown	Compared to regional groundwater level	-1	Minor drawdown in riverine alluvium adjacent to Pit B (see Figure C-2).	0	Reduced drawdown in riverine alluvium due to high Pit B water level.	-1	Moderate drawdown in riverine alluvium adjacent to Pit B (see Figure C-2).
		Groundwater quality	Impact on aquatic ecosystem water quality objectives for life of option	0	Minor effect on river-aquifer interaction causing leakage from river but no change in water quality.	0	Negligible effect on river-aquifer interaction	0	Substantial effect on river-aquifer interaction causing leakage from river but no change in water quality.
	Irrigation use	Groundwater drawdown	Groundwater drawdown impact on users	0	One identified bore 10km from Pit Asouth beyond drawdown extent	0	One identified bore 10km from Pit Asouth beyond drawdown extent	0	One identified bore 10km from Pit Asouth beyond drawdown extent
		Groundwater quality	Impact on groundwater quality objectives for life of option	0	No change in groundwater flow direction at 10km	0	No change in groundwater flow direction at 10km	0	No change in groundwater flow direction at 10km
	Farm supply	Groundwater drawdown	Groundwater drawdown impact on users	-1	All identified bores to have less than 5m water table drawdown	-1	All identified bores to have less than 5m water table drawdown	-1	All identified bores to have less than 5m water table drawdown
		Groundwater quality	Impact on groundwater quality objectives for life of option	0	No feasible mechanism for change in beneficial use	0	No feasible mechanism for change in beneficial use	0	No feasible mechanism for change in beneficial use
	Stock use	Groundwater drawdown	Groundwater drawdown impact on users	-1	All identified bores to have less than 5m water table drawdown	-1	All identified bores to have less than 5m water table drawdown	-1	All identified bores to have less than 5m water table drawdown
		Groundwater quality	Impact on groundwater quality objectives for life of option	0	No feasible mechanism for change in beneficial use	0	No feasible mechanism for change in beneficial use	0	No feasible mechanism for change in beneficial use

Scoring Criteria	Ranking
Significant negative impact for this criterion	-3
Medium negative impact for this criterion	-2
Minor negative impact for this criterion	-1
No impact for this criterion	0
Minor benefit for this criterion	1
Medium benefit for this criterion	2
Significant benefit for this criterion	3

Definitions
Significant impact/benefit - results in a change which is important, notable or of consequence to the EV having regard to its intensity/frequency. For an impact the change will result in the criterion not being able to meet published standards (if there are any). For a benefit the change should meet best practice standards (if there are any published)
Medium impact/benefit - results in a change which is potentially important, notable or of consequence to the EV having regard to its intensity/frequency. For an impact, the change will result in occasions where the criterion will not meet published standards (if there are any). For a benefit the change should meet good practice standards (if there are any published)
Minor impact/benefit - results in a change which is identifiable but is not important, notable or of consequence to the EV having regard to its intensity/frequency
<i>Note: The definition of significant impact has been based on the Federal Government's definition of significant impact contained within its "Matters of National Environmental Significance, Significant Impact Guidelines 1.1, Environment Protection and Biodiversity Conservation Act 1999"</i>

9.2 GROUNDWATER DRAWDOWN

AGE (2017a) reported on a bore census conducted in September 2014 coupled with a database search for registered bores on the National Groundwater Information System. A summary of identified extant bores is provided in Table 17. Overall, groundwater usage is not significant in the district, given access to better quality water from the perennial Nogoia River.

Table 17. Extant Private Groundwater Bores

Registered RN (ID)	Bore Name	Easting (mMGA)	Northing (mMGA)	Bore Depth (m)	Use
100035	Forest Hills	648924	7418972	-	Not in use
103788	Conmurra	657954	7390072	66	Irrigation (stock & domestic)
132040	Currimundi	650966	7395998	-	Not in use
57402	Kensington	644749	7386154	-	Not in use
84403	-	636913	7404293	-	Unknown
89380	Fair Hills	658696	7416877	77	Stock & domestic
89383	Yongala	657586	7415693	74	Stock
90140	Railway	663591	7412470	61	Stock
-	Chelbrook1	648661	7409238	24	Not in use
-	Chelbrook2	650303	7409481	>100	Not in use
-	Currimundi (Field 5 Bore)	653687	7398270	29	Not in use
-	Cypress	644408	7400570	>160	Not in use
-	Euro Park	639581	7398327	74	Not in use
-	Jamar	642025	7399084	90	Stock
-	Jenson	657364	7387906	41	Stock
-	Karanga	649043	7388304	~50	Stock
-	Twin Bores	641319	7401567	18	Stock
-	Winton Creek	642771	7400758	60	Stock

The distribution of private bores, categorised according to use, is shown in Figure 44. Most bores access groundwater for stock use, or are no longer in use.

The drawdown from simulated pre-mining heads, at the water table, is shown in Figure 45 for present day conditions (year 2018) and in Figure 46 (Option 1), Figure 47 (Option 2) and Figure 48 (Option 3) for predicted conditions 60 years into the future (year 2078) when some pit water levels would still be rising and deep groundwater levels not fully recovered.

For present day conditions (Figure 45), modelling suggests an elongated drawdown cone that is about 15 km long (north-south) and 2-4 km wide (at the 5 m drawdown level).

The cone is expected to lengthen in 60 years' time for Option 1 (Figure 46) to more than 20 km, the major expansion being to the north. It is expected also to broaden to about 5 km adjacent to the southern pits, 2-3 km near the central pits, and 2-5 km adjacent to and north-west of the northern pits.

Slightly more drawdown is expected for Option 2 in 60 years' time (Figure 47), but significantly less for Option 3 due to backfilling of Pits B, C and D (Figure 48).

Comparison of Figure 44 with Figure 46 to Figure 48 shows that none of the identified private bores lies within the 5m water table drawdown envelope.

Time-varying drawdowns at the monitoring bores marked on Figure 9 are shown in Appendix C, for the formations in which the bores are screened. The maximum drawdown at each monitoring bore (from 2018), for each of Options 1 and 3, is listed in Table 18. Of the examined monitoring bores, the median maximum drawdown is 4.5 m and the median year of occurrence is about 2044 (26 years from present day). At most of the examined bores, drawdown would persist for a limited time.

Table 18. Maximum Drawdown at Representative Groundwater Monitoring Bores

Bore Name	Option 1 Drawdown (m)	Option 1 Year	Option 3 Drawdown (m)	Option 3 Year
EC01	0.15	2075	0.15	2075
EC13	1.0	2025	2.5	2065
RB1	12	2057	13	2067
RB2	32	2044	33	2052
RB3	65	2037	66	2039
RB4	20	2044	20	2052
RB5	7	2044	0	2032
WSMB2D	6	204	3	2044
WSMB2S	2.8	2091	2.3	2074
WSMB3D	7	2040	0	2031
WSMB3S	3.0	2230	0.4	2086
Yongala	0.0	-	0.0	-

Note; Option 2 is excluded as it would be operated with artificially high water levels, causing lower drawdown

Simulated equilibrium water table levels are presented in Figure 49, Figure 50 and Figure 51 for Options 1, 2 and 3, respectively. The Option 1 and Option 3 maps are very similar apart from the floodplain between pits A north and E. Option 2 has generally lower levels adjacent to the pits. Each option maintains a strong groundwater ridge to the east of the northern pits. This would drive groundwater from the east towards the northern pits. The southern pits would receive groundwater from the west and north-west across a very shallow hydraulic gradient.

10 CONCLUSIONS

The main finding of the modelling is that the adjacent underground workings are expected to take many decades to be replenished with water. With underground workings in close proximity to open cut void areas and relatively high hydraulic conductivities, the water entering the underground is anticipated to be drawn substantially from the open water in proximal pit waterbodies. The consequences of these predictions are that the enhanced connection to the underground workings has the effect of holding nearby pit water at low elevations for a long time in Option 1 and Option 2, before the waterbodies are able to recover towards (but never reaching) pre-mining water levels. The duration of depressed levels and rates of rebound are summarised in Figure 24 through to Figure 42 for the three options.

Similarly, a portion of the water added to the pits under Option 2, for flood mitigation and beneficial use, would be lost to the underground workings if the forced water levels exceed final Option 2 equilibrium levels. Rebound to the equilibrium pit water levels would follow the rebound of the underground voids.

The presence of backfill material in the former pit areas additionally influences the rate of underground and pit rebound. High infiltration potential and the reduced capacity for evaporation in these areas provides a short travel time indirect pathway for recharging water to enter the underground and pit.

The consequences of the backfill option (Option 3) relative to natural recovery of void waters subject to landform levee works (Option 1) are comparatively higher ultimate rest groundwater levels and more rapid rebound. Rest groundwater levels in Option 3 are generally higher as pit water (in open voids) or groundwater (beneath backfilled voids) is subject to less evaporation.

There is little difference between the three options in terms of underground mine inflows. Mine inflows of approximately 10-20 ML/day are predicted in the next three years to 2020, while the underground mine advances near to the open cut areas of Pits A north, B and D. Following 2020, inflows are anticipated to reduce to between 4 and 10 ML/day for the next 10 years and to taper off to zero as the underground voids fill.

Ultimately, final equilibrium pit water levels are predicted to be:

Pit	Option 1 [mAHD]	Option 2 [mAHD]	Option 3 [mAHD]
A south	136.2	120.6	147.2
A north	135.2	128.8	144.6
B	133.4	109.2	146.6
C	127.6	121.0	147.8
D	121.9	119.7	141.4
E	139.0	134.1	129.0
F	150.3	146.3	149.3
Y	171.2	164.0	170.5

For Option 1 there is a clear pattern of high final water levels at the southern and northern pits, and lower levels proximal to the underground workings and the Nogoia River. The relative pit waterbody stages are influenced by the prevailing regional groundwater gradients which converge on the Nogoia River floodplain and are further reduced by the evaporative losses from each void.

For Option 2, the pits are expected to gain water until their natural rest levels are achieved (see Option 2 results from the table above). For higher forced water levels, the pits would lose water, at significant rates, to the underground groundwater system which would not have fully recovered within the next 100 years. This means that artificial topping up of water in storages from flood inflows could incur losses to the groundwater system.

For Option 3, where pits B, C and D are backfilled and built up, ultimate rest groundwater levels are elevated and not subject to direct evaporation. Groundwater levels are limited by the valley floor elevation and relatively high connection afforded by backfill hydraulic properties as opposed to undisturbed rock.

It should be noted that the direction and duration of net water exchange are very sensitive to the degree of simulated interaction between the residual voids and the underground voids, and that depends primarily on the adopted hydraulic properties in the groundwater model. Reversal of polarity could occur sooner than is currently predicted. The groundwater model does not take into account external inputs of water to the pits, climatic variations in water levels, or cyclonic events which could accelerate groundwater recovery. All of these mechanisms have the potential to alter the polarity of flow between the residual voids and the underground voids.

An assessment of the potential impacts of each of the three preferred options on relevant environmental values (EVs) was undertaken based on the outcomes of the studies presented in this report. The findings of this assessment are:

- Minor groundwater drawdown impacts on private bores used for farm or stock water supply, with negligible impact on the one identified irrigation bore due to its distance from the mine.
- Negligible impact on groundwater quality at any private bores due to generally poor quality natural groundwater and the lack of a feasible mechanism for changing beneficial use.
- No impact on aquatic ecosystem water quality as project activities would not cause additional groundwater discharge to any rivers.
- A slight beneficial effect on groundwater quality beneath the Nogoia River close to Pit B, due to a marginal increase in the natural leakage from the Nogoia River over the next 70 years.
- Longer term marginal increase in the flow in the Nogoia River due to a reduction in the natural loss of water from the Nogoia River to its associated alluvium.
- A finite period (of about 15-20 years) of moderate drawdown in riverine alluvium adjacent to Pit B for Option 3.
- A finite period (of about 5-10 years) of minor drawdown in riverine alluvium adjacent to Pit B for Option 1.
- Relatively reduced drawdown in riverine alluvium adjacent to Pit B for Option 2, as pit water levels would be held high for flood mitigation and beneficial use.

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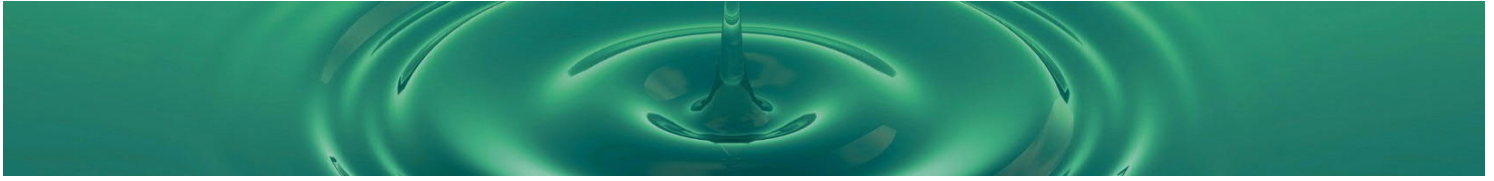
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ILLUSTRATIONS



Figure 1. Option 1 - Landform Levee



Figure 2. Option 2 – Flood Mitigation and Beneficial Use



Figure 3. Conceptual drawing of the Weemah Channel and Yamala Inland Port (red) pipeline connection and the mine internal pump system (blue)



Figure 4. Option 3 – Backfill to PMF

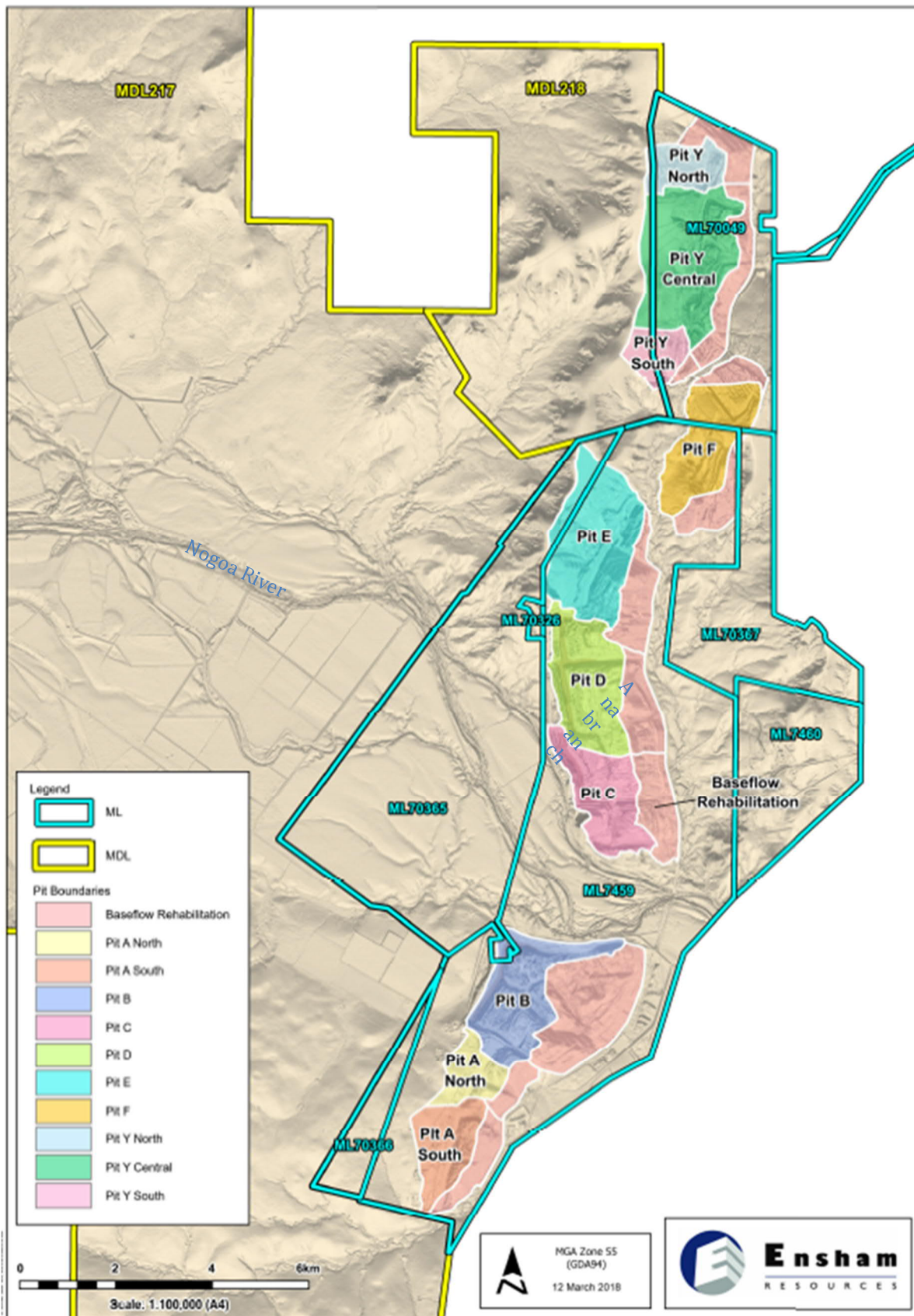


Figure 5. Pit shell boundaries

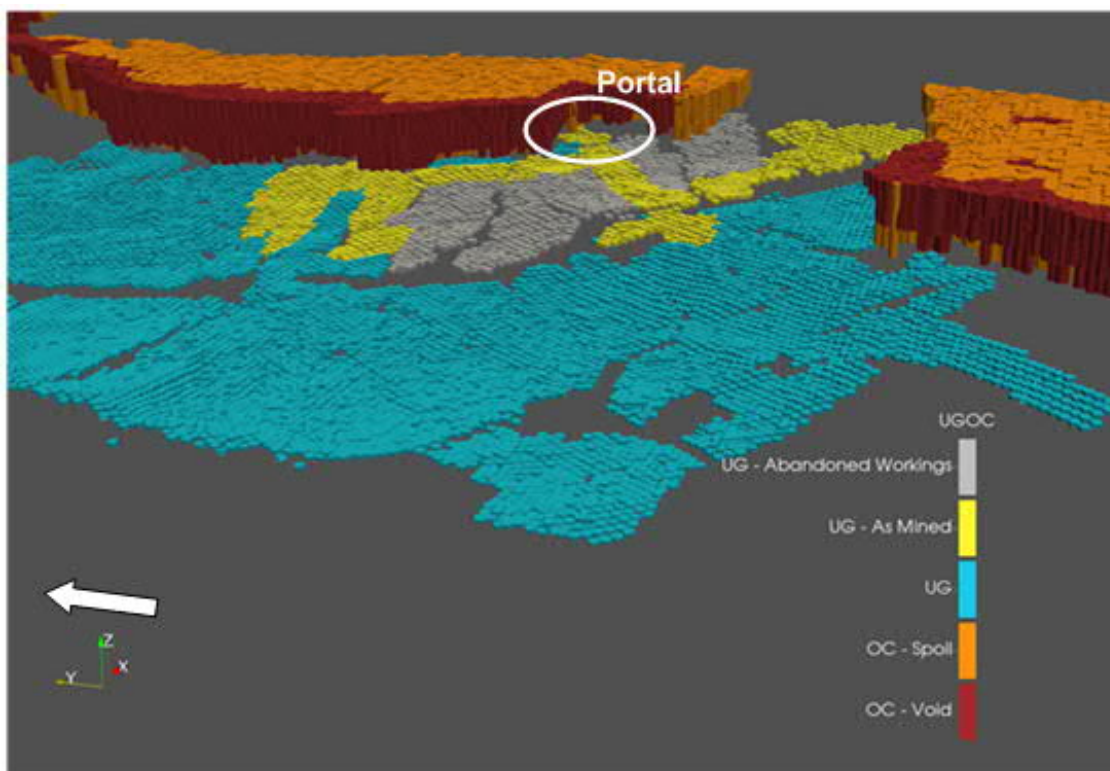
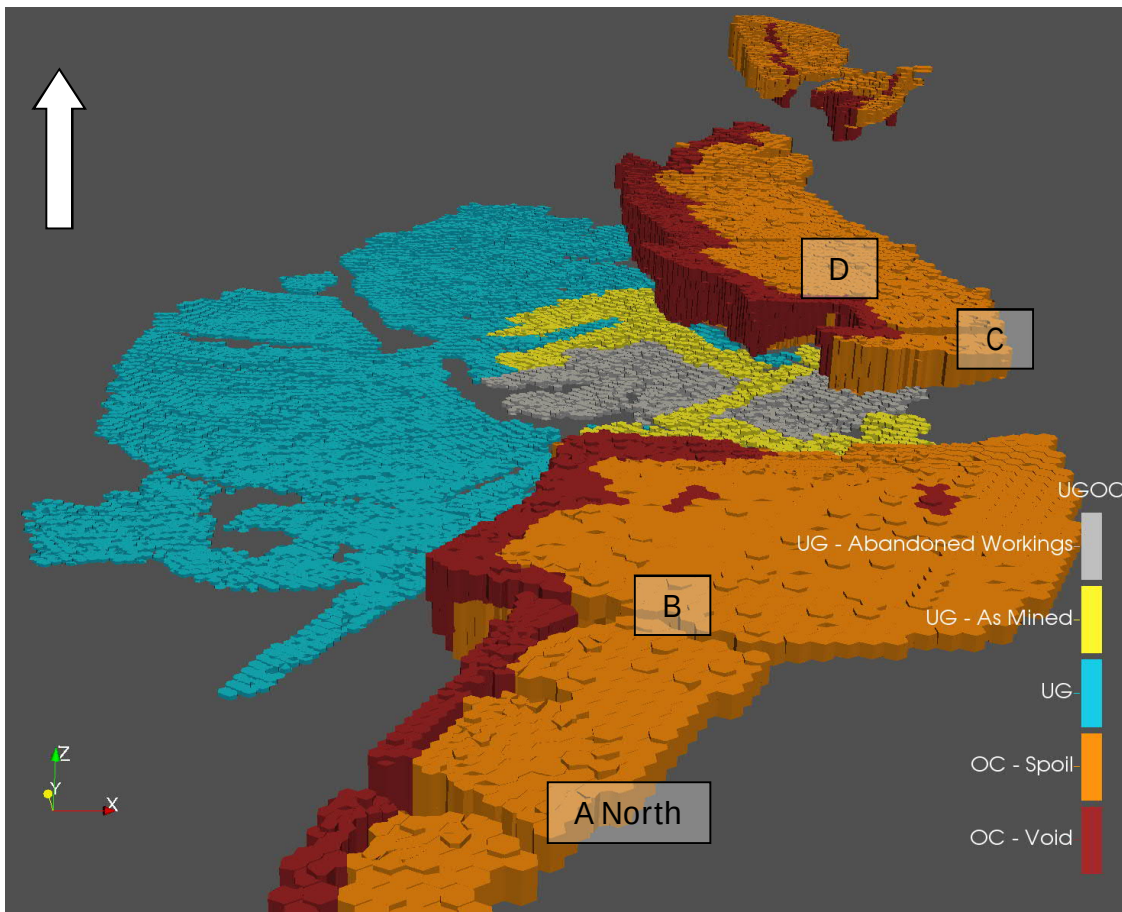


Figure 6. Perspective views of current and future mined volumes, with undisturbed rock hidden

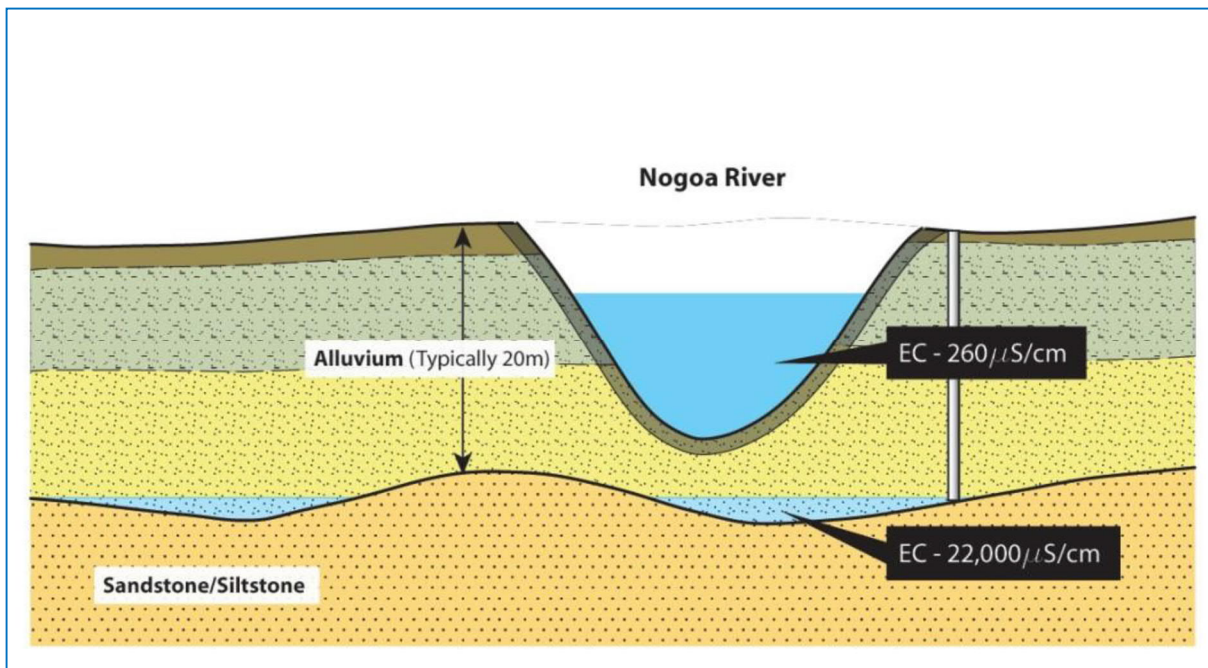


Figure 7. Conceptual cross section through Nogoia River and Quaternary sediments (Figure 8, AGE, 2006)

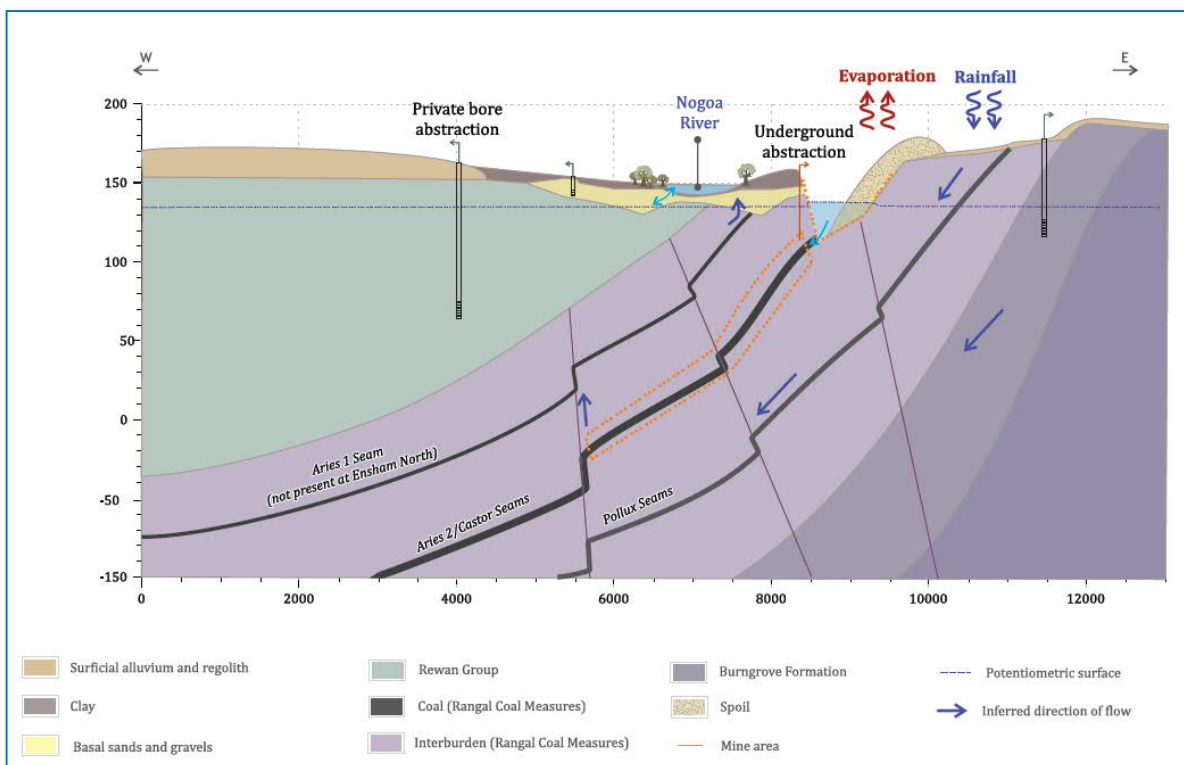


Figure 8. Conceptual hydrogeological model of Ensham Mine (Figure 2.13, AGE, 2017a)

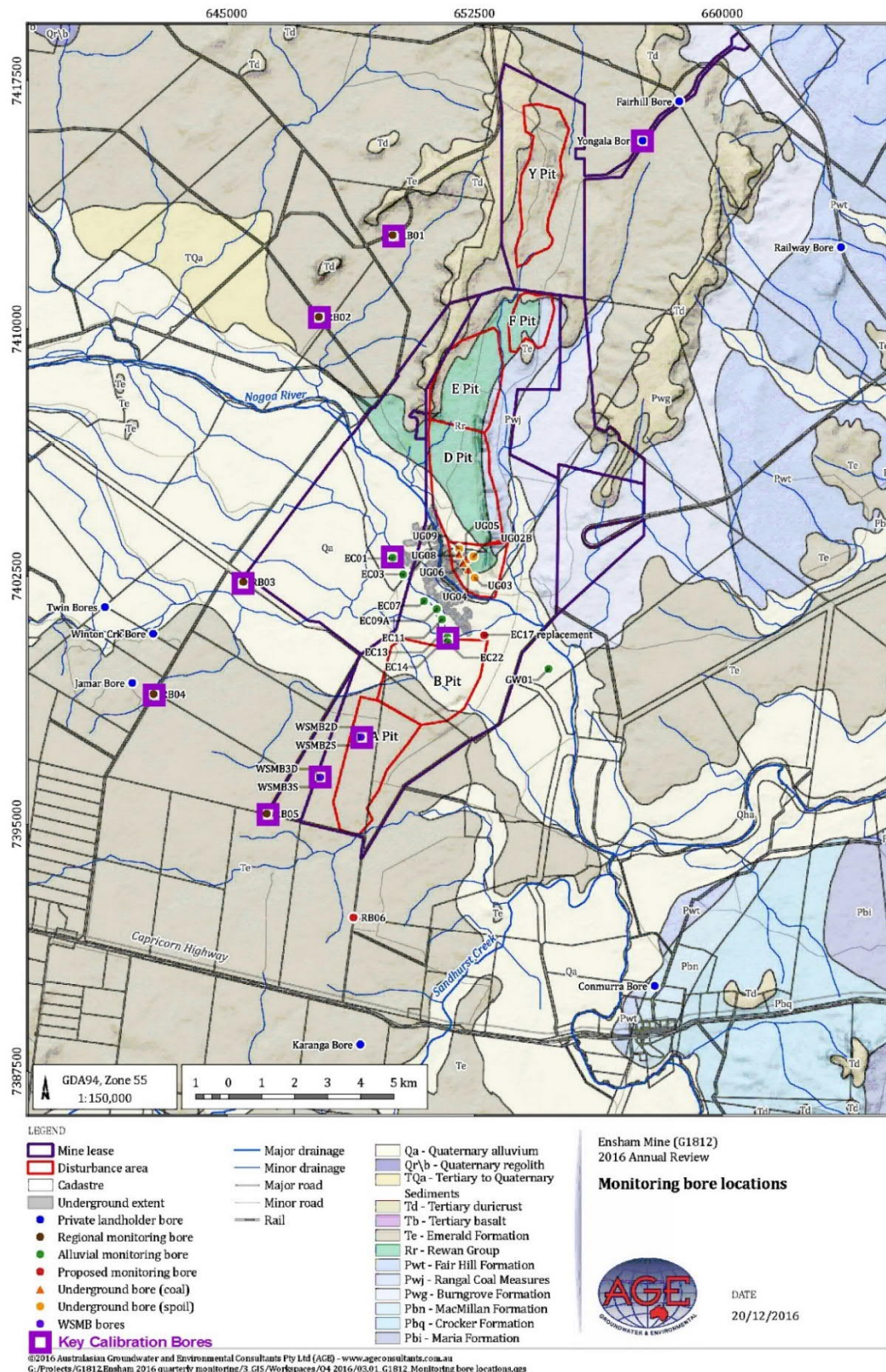


Figure 9. Groundwater monitoring network [after AGE, 2017a]

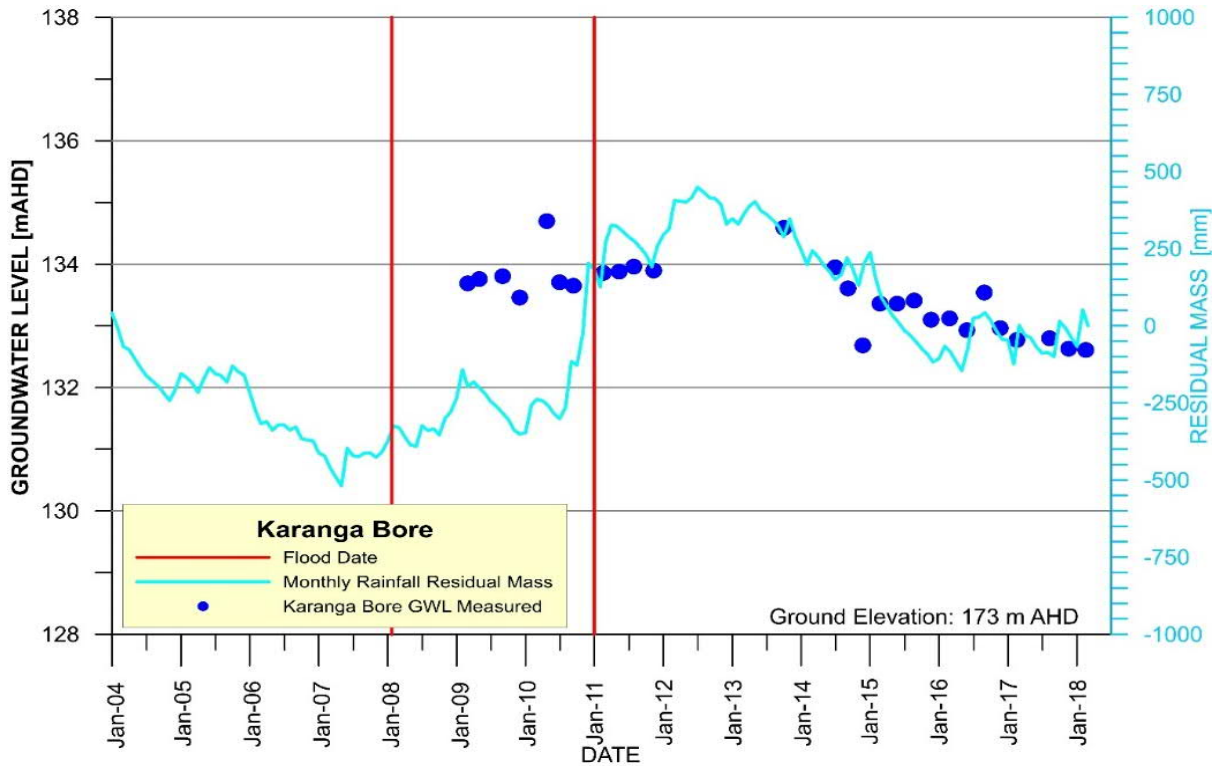


Figure 10. An example of groundwater response to rainfall

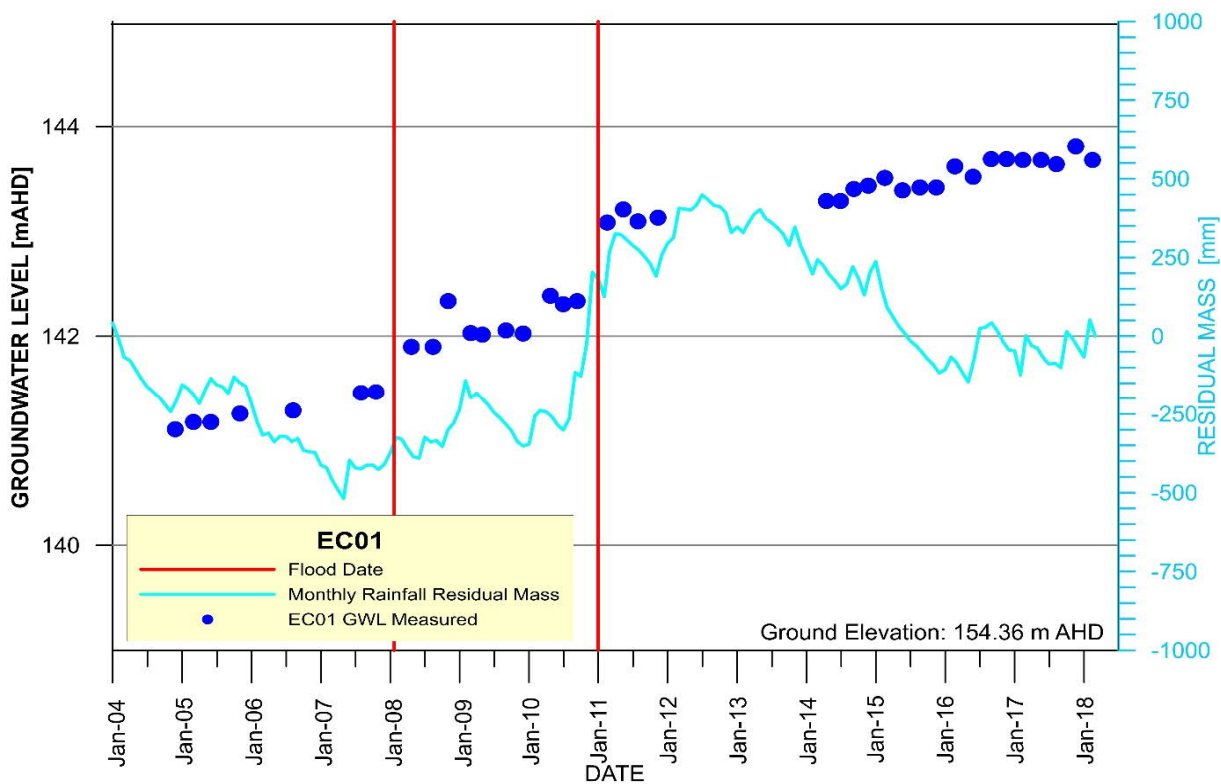


Figure 11. An example of groundwater response to irrigation

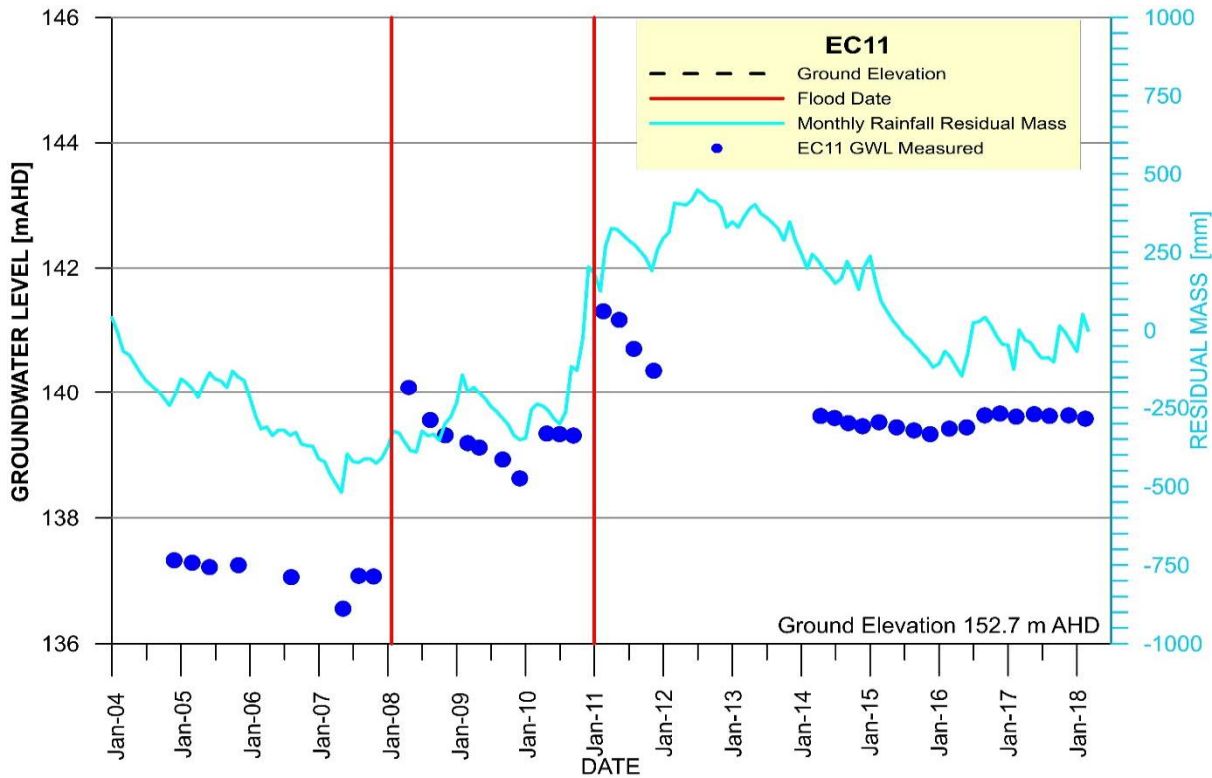


Figure 12. An example of groundwater response to flood events

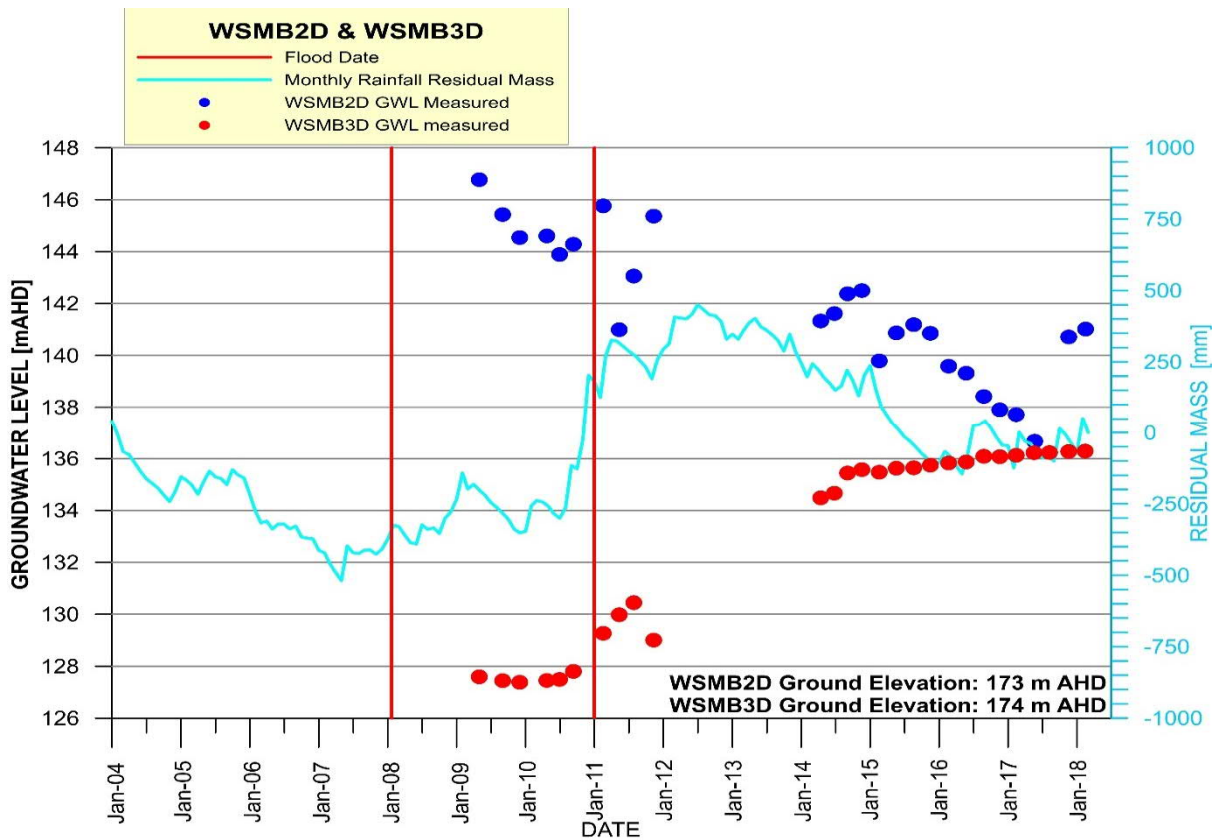


Figure 13. An example of groundwater response to open cut mining

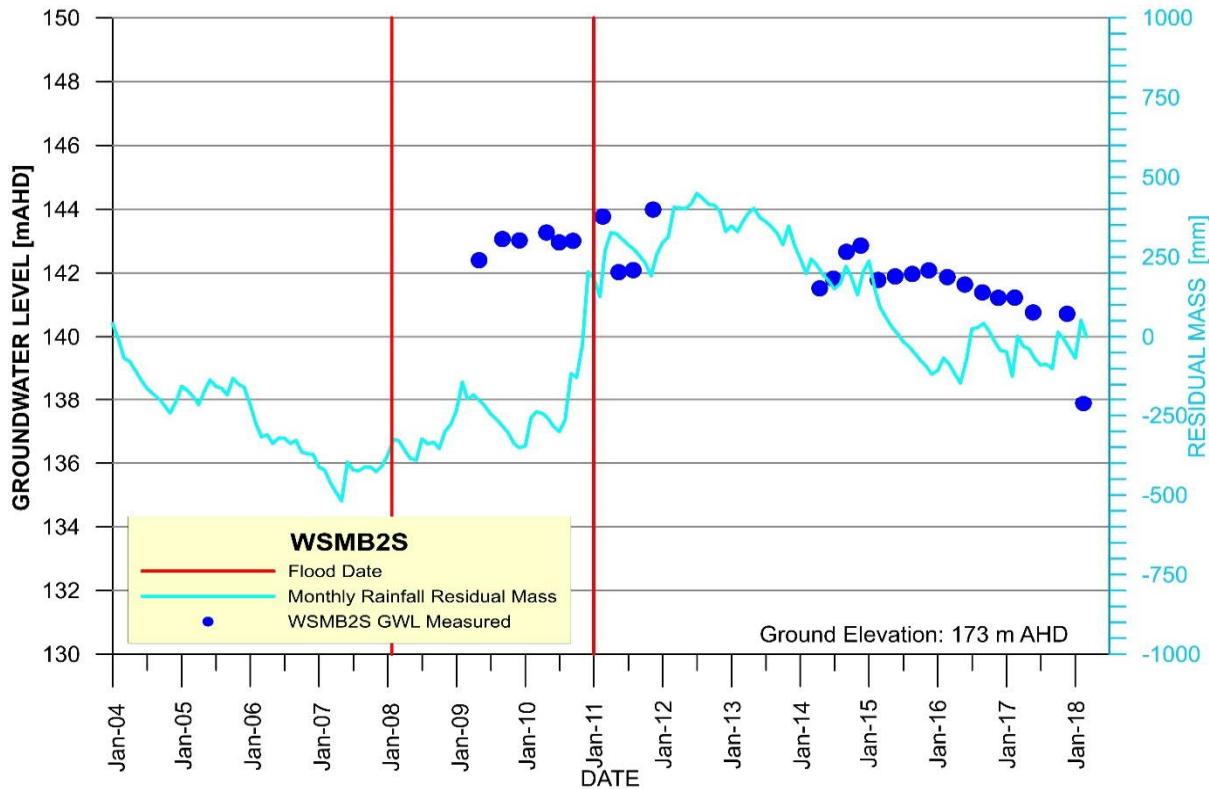


Figure 14. Another example of groundwater response to open cut mining

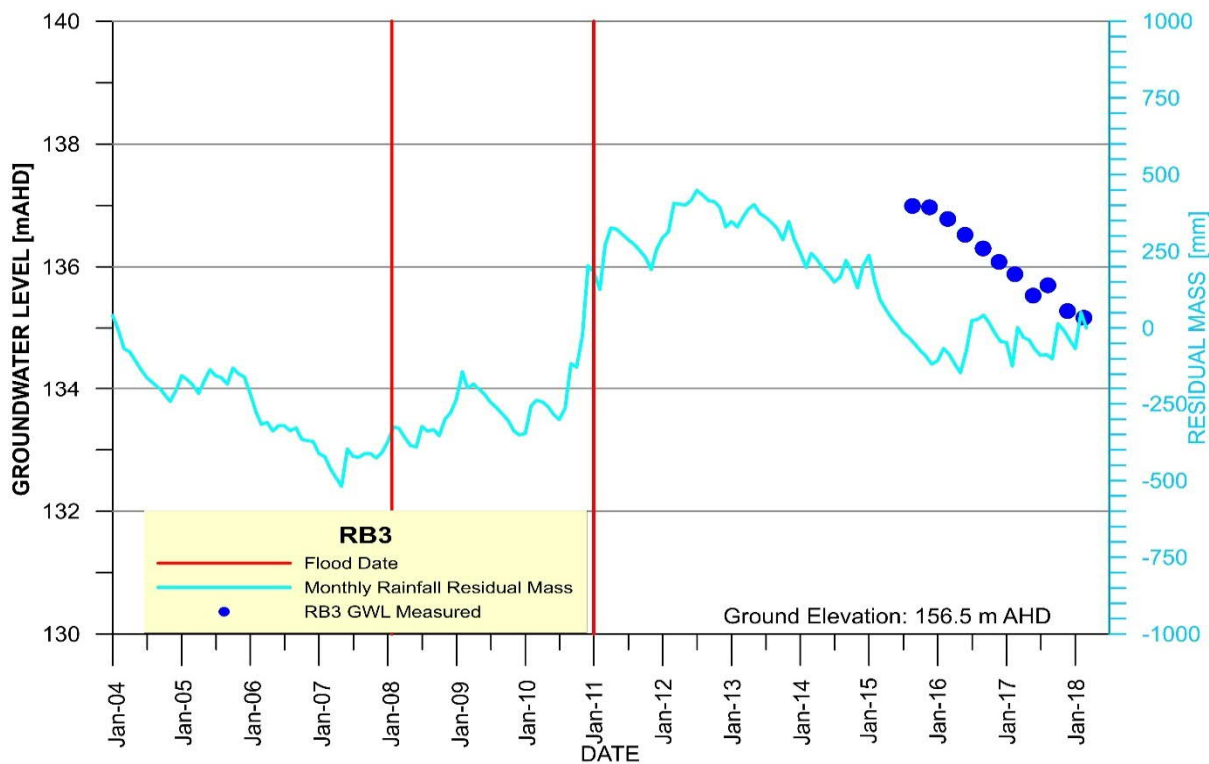


Figure 15. An example of groundwater response to underground mining

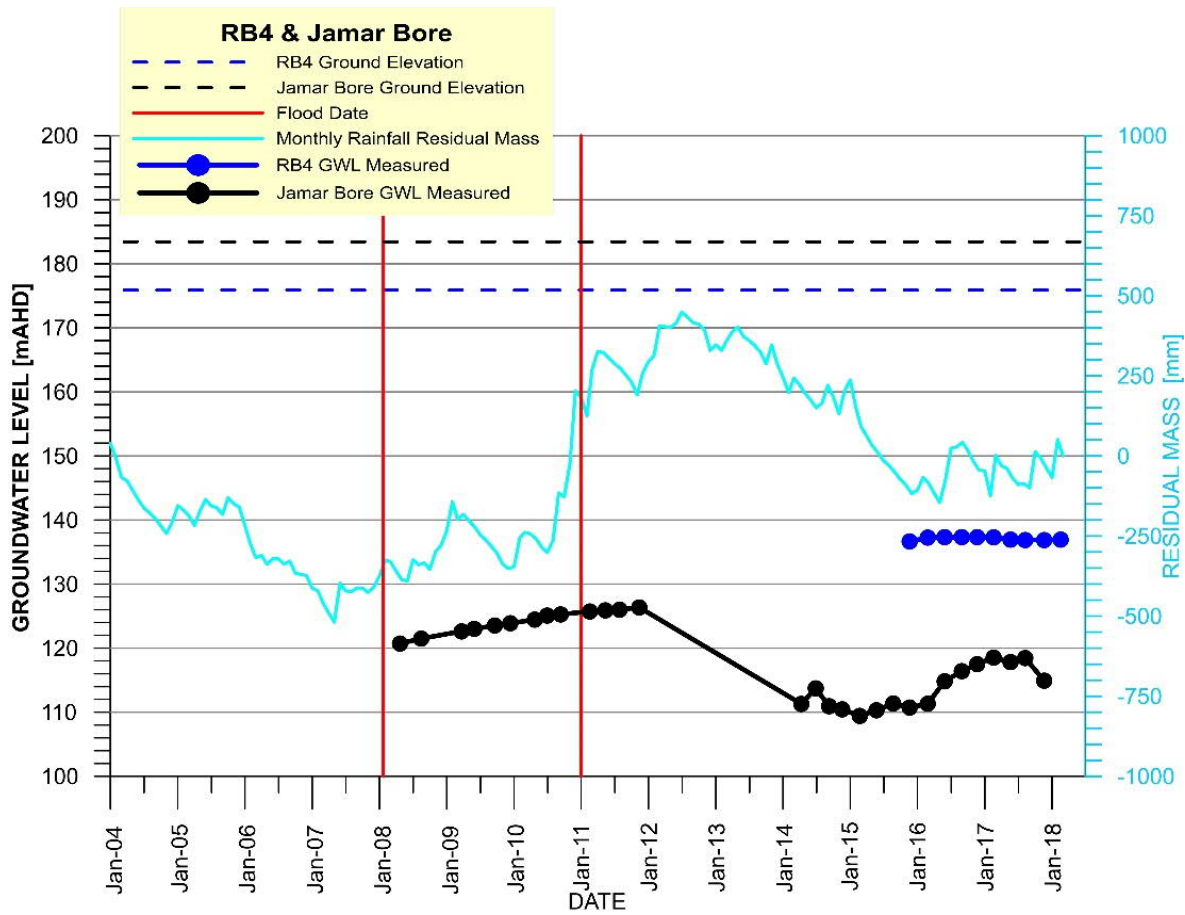


Figure 16. An example of groundwater response to landholder pumping

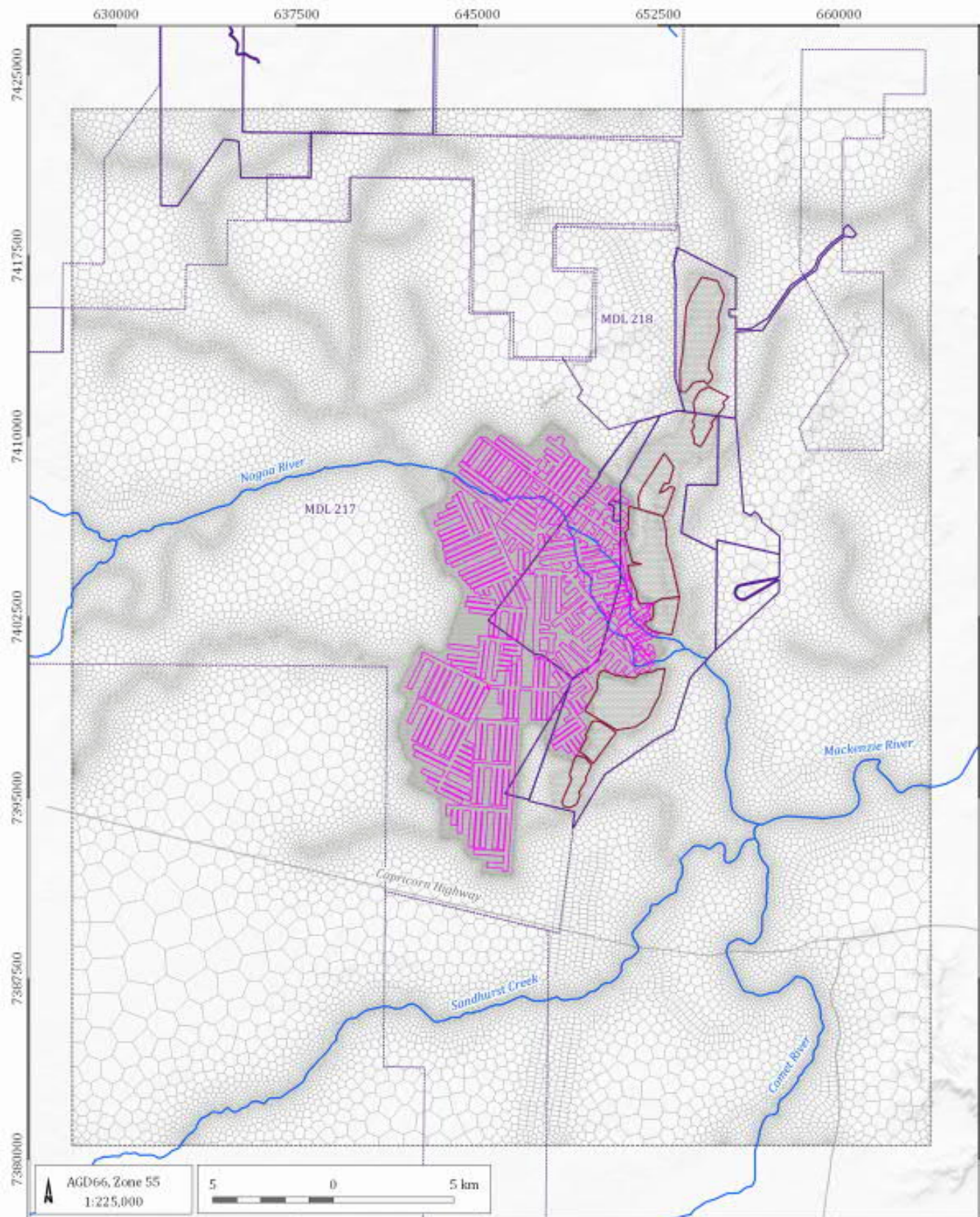


Figure 17. Former underground mine plan (pink), pits (brown), model mesh and rivers (Figure 3.1, AGE, 2017a)

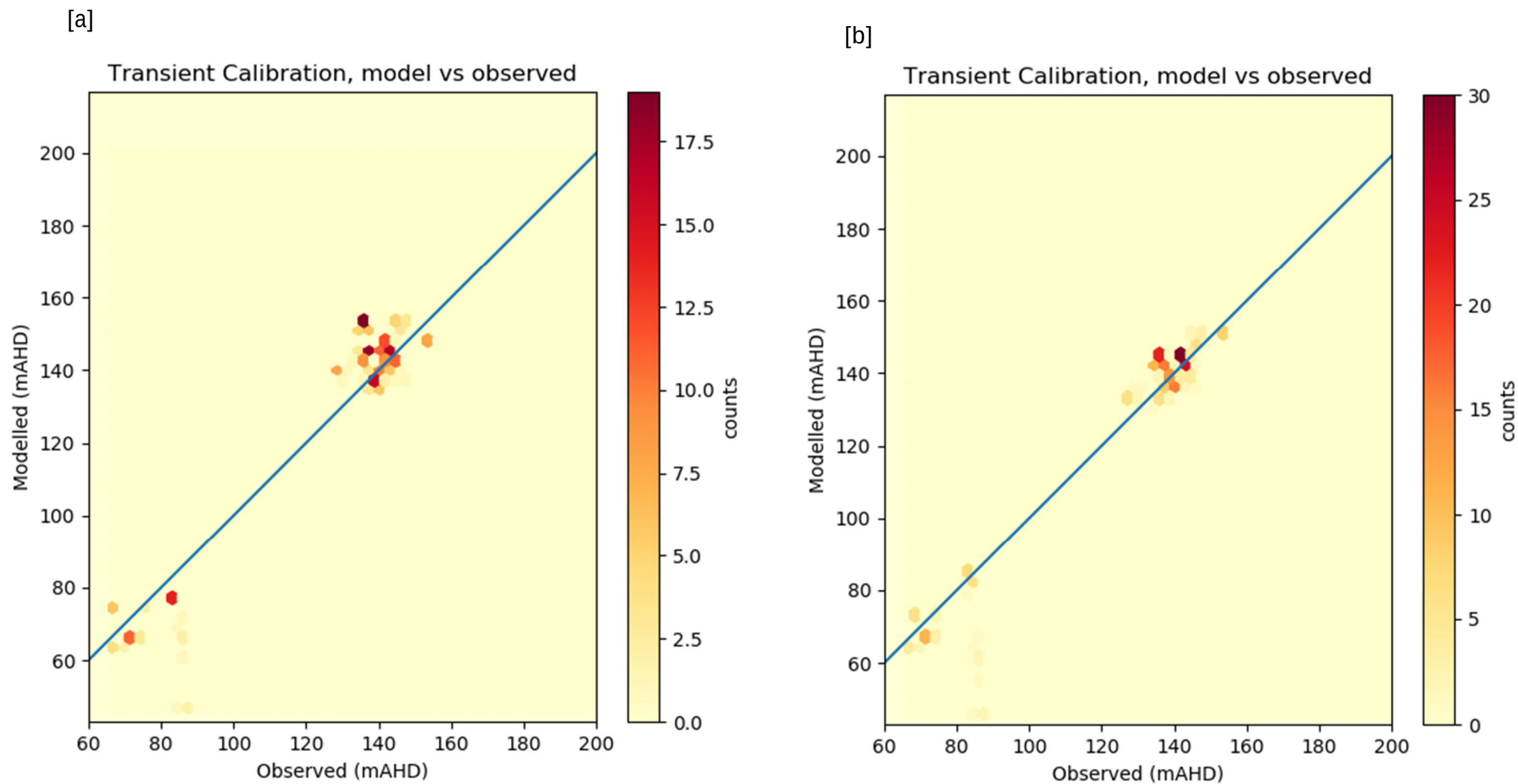
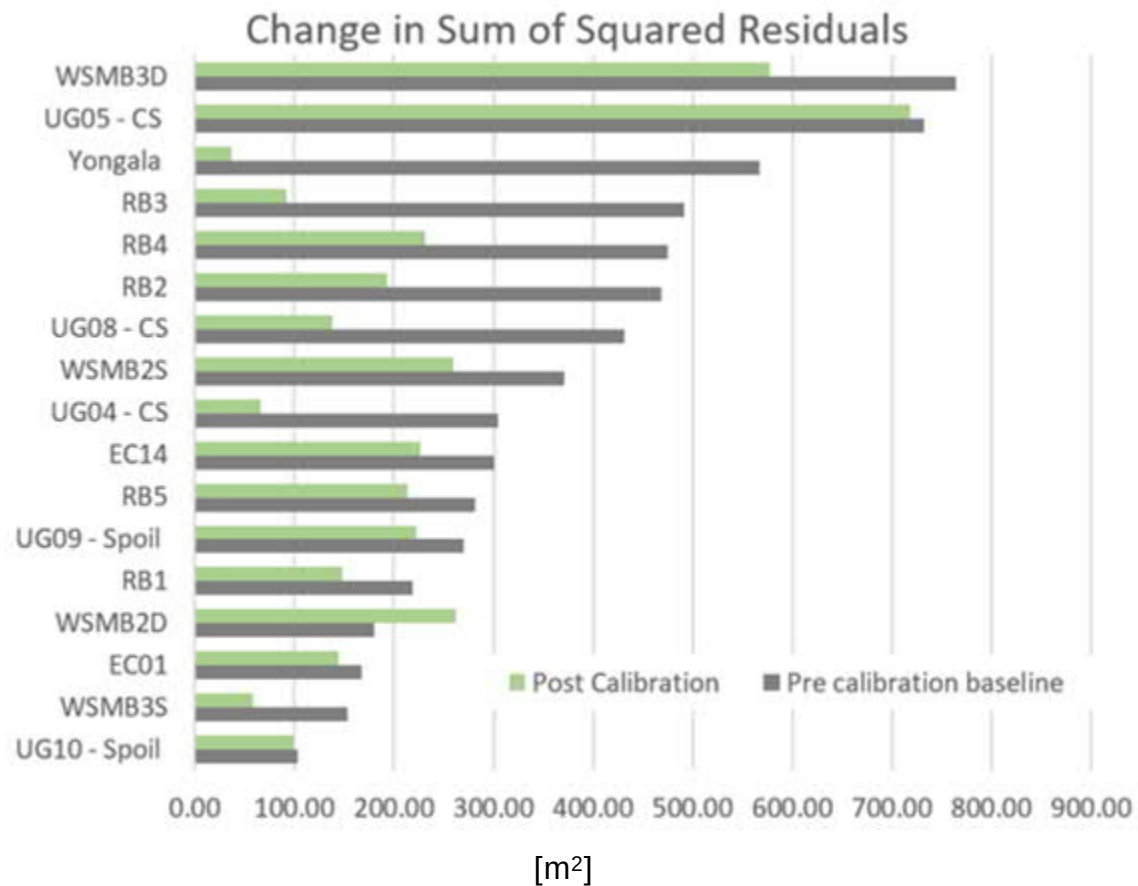


Figure 18. Transient calibration to groundwater levels [a] Previous model; [b] Recalibrated model

The legend is the frequency of Modelled vs Observed posts within each hexagonally binned region.



Select Location	Pre Calibration	Post Calibration	Reduction in Misfit
EC01	167.19	144.18	0.86
EC14	300.70	225.94	0.75
RB1	218.41	148.14	0.68
RB2	467.91	193.48	0.41
RB3	490.86	92.50	0.19
RB4	475.04	231.48	0.49
RB5	281.99	213.54	0.76
UG04 - CS	304.40	66.67	0.22
UG05 - CS	732.74	717.60	0.98
UG08 - CS	431.45	137.87	0.32
UG09 - Spoil	269.63	222.69	0.83
UG10 - Spoil	103.25	99.37	0.96
WSMB2D	179.96	262.48	1.46
WSMB2S	371.09	259.51	0.7
WSMB3D	763.79	577.30	0.76
WSMB3S	152.73	59.07	0.39
Yongala	566.70	37.20	0.07

[mAHD]

[m]

Figure 19. Comparative calibration performance at each key monitoring site

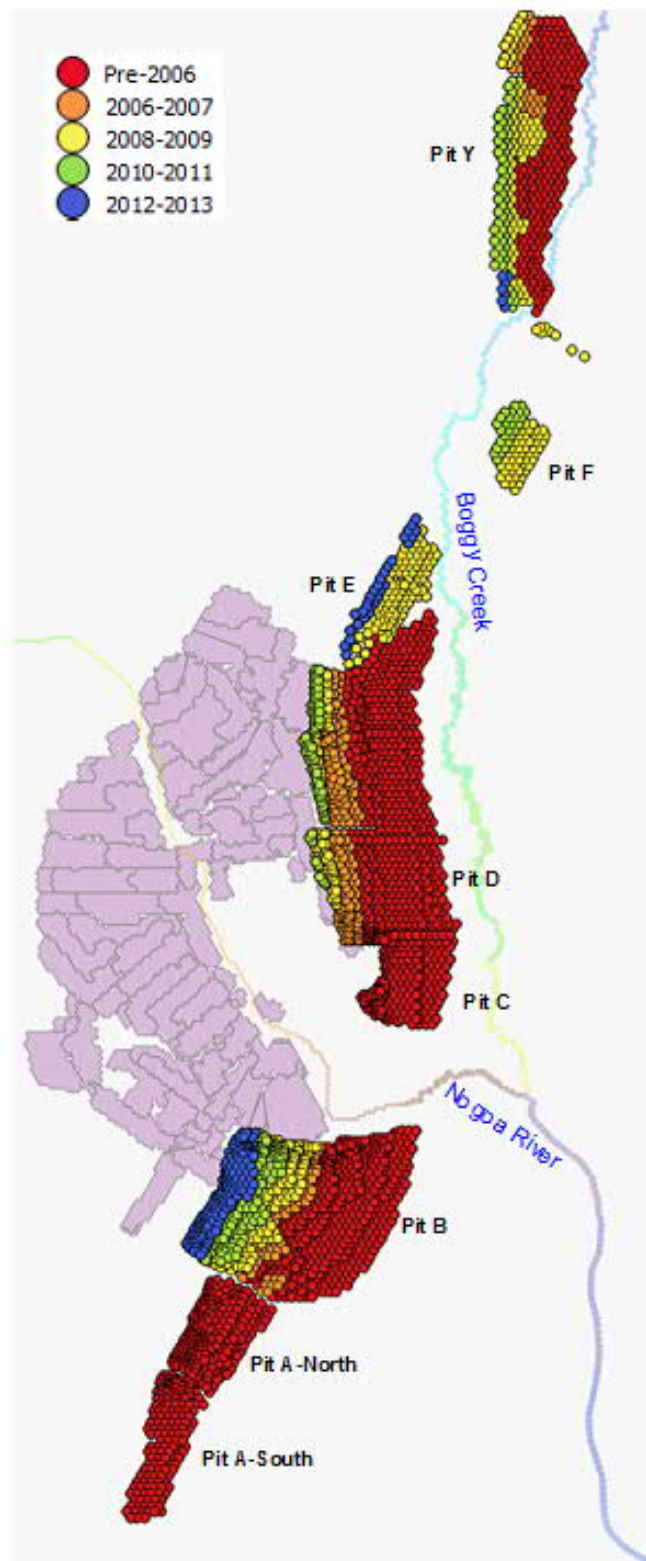


Figure 20. Past open cut mining schedule

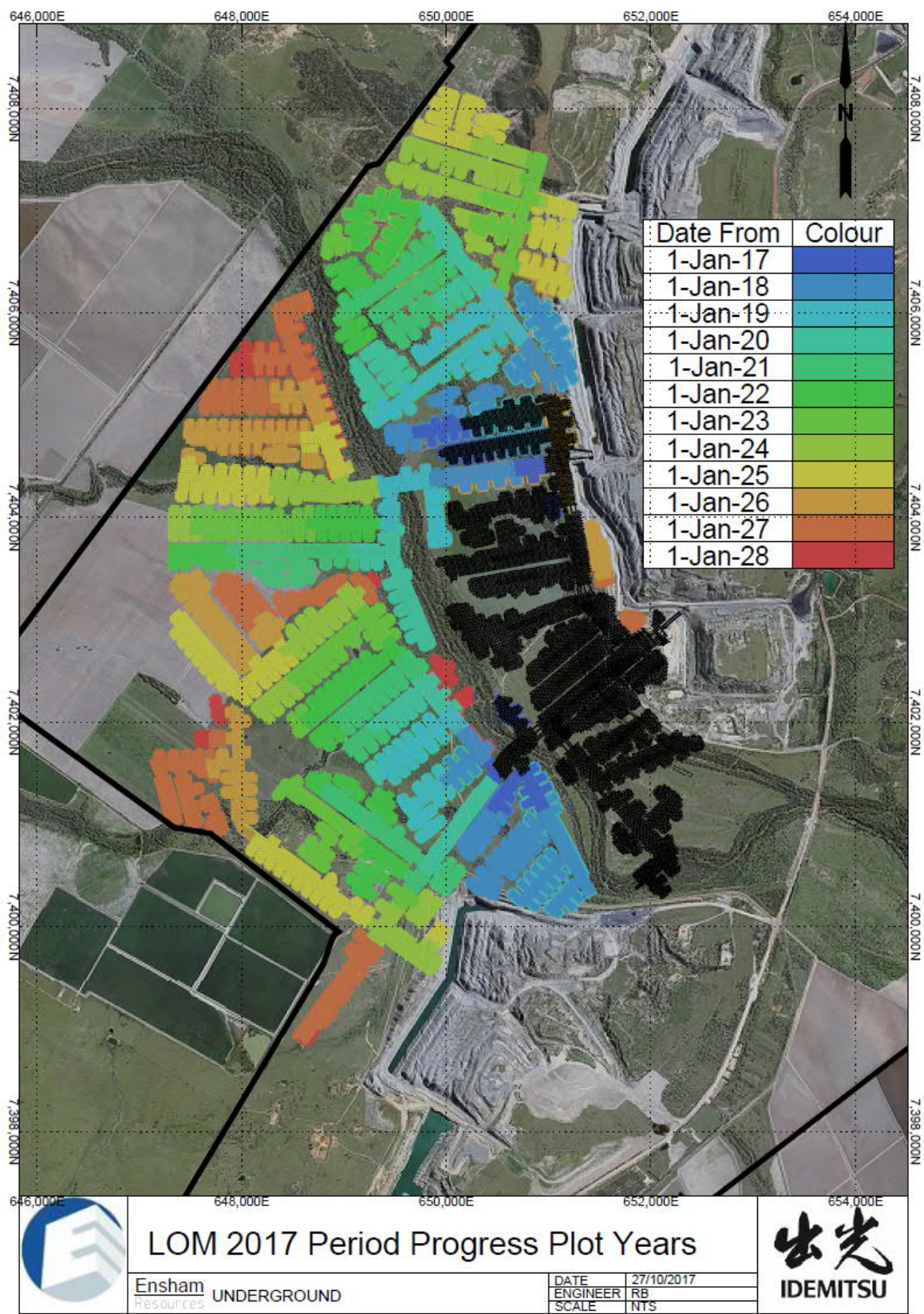


Figure 21. Future underground mining schedule [black areas already mined]

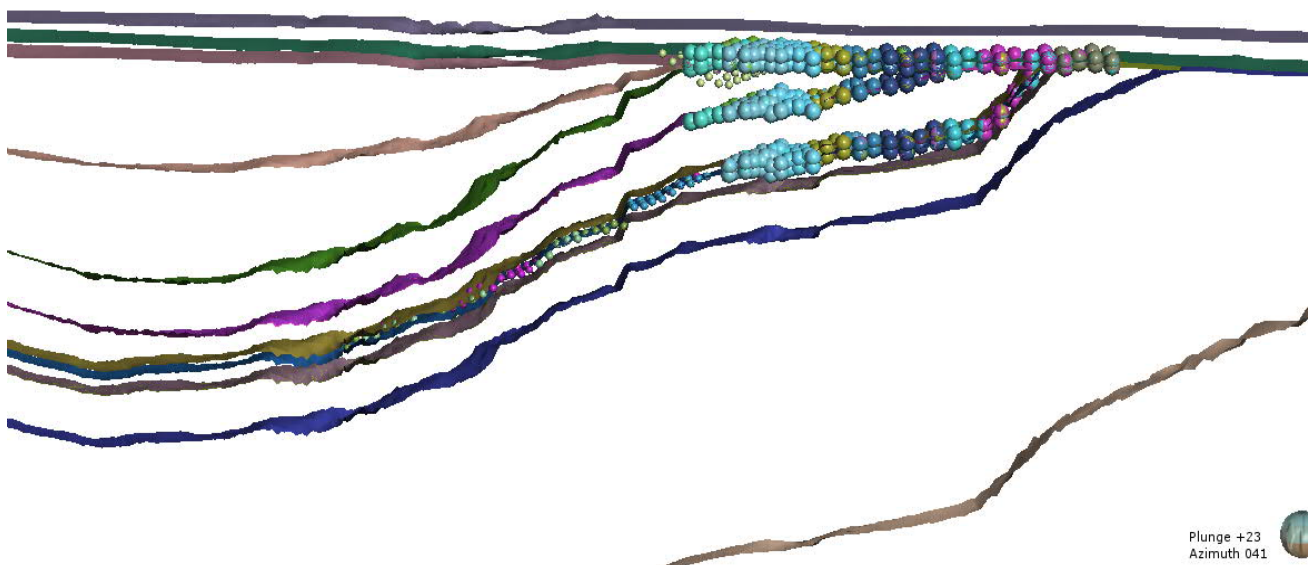
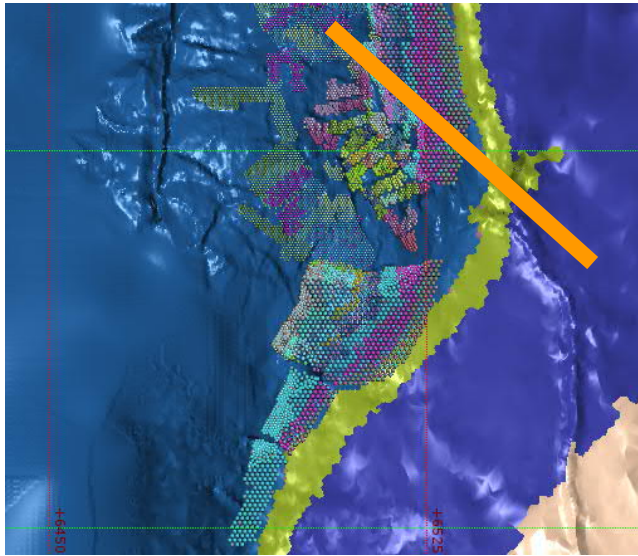
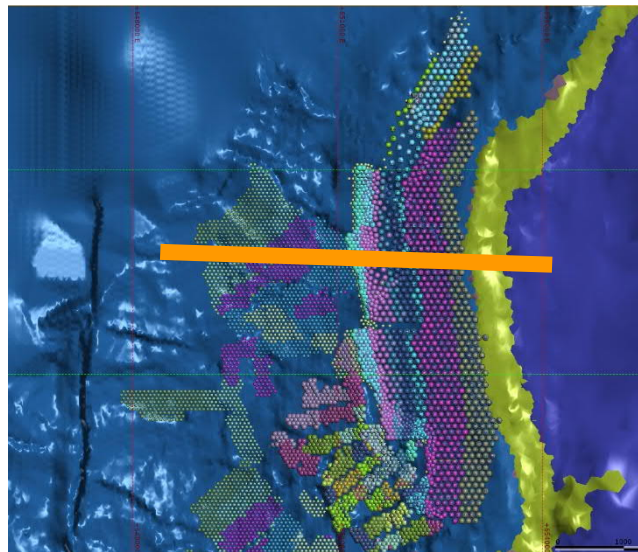


Figure 22. Proximity of Pit B extraction to future underground mining

Coloured 'ribbons' are simulated base of geological layers. Large circles are the Open Cut pit area boundary conditions. The small circles are underground working boundary conditions.



leapfrog

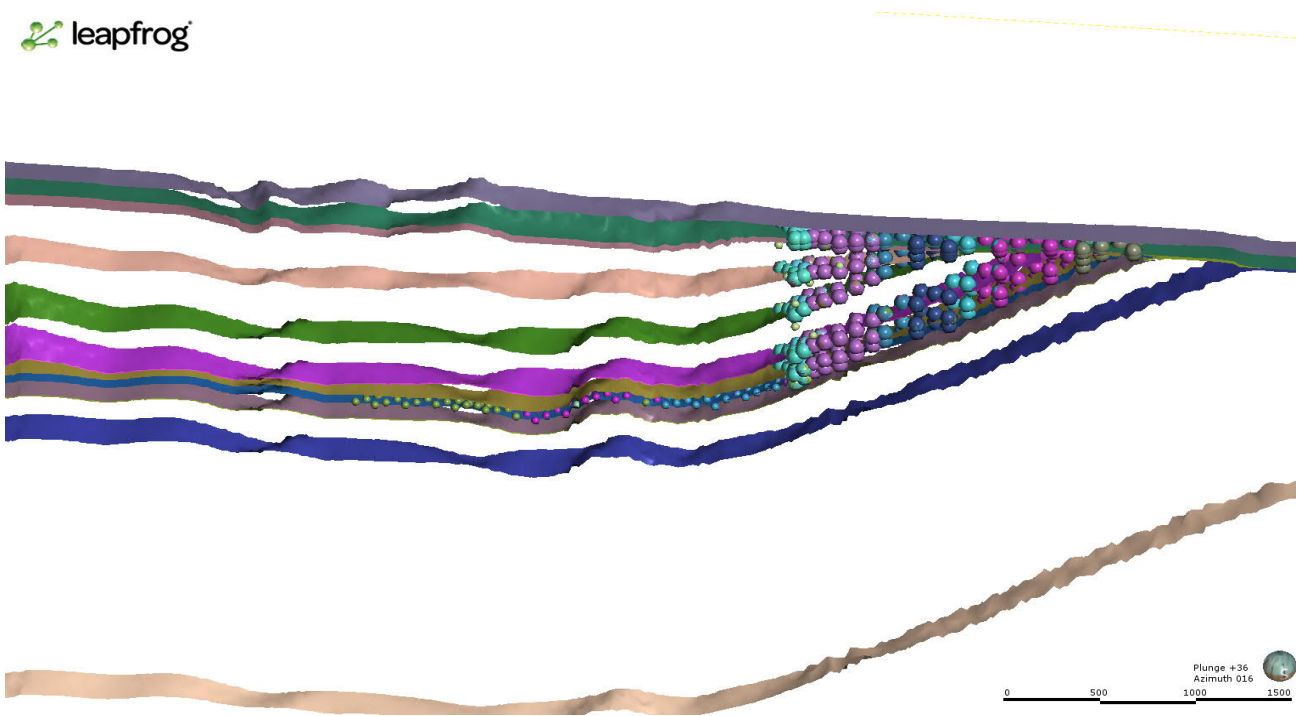


Figure 23. Proximity of Pits C-D extraction to future underground mining

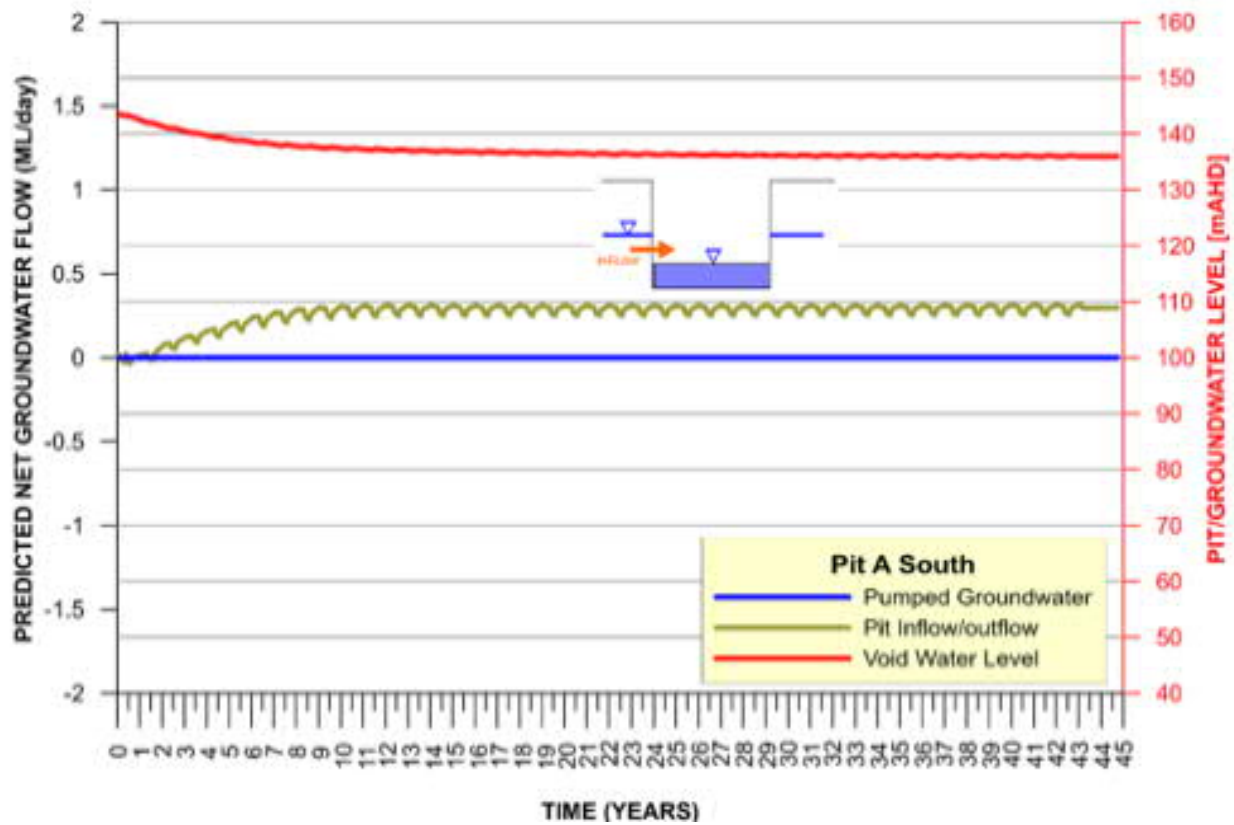


Figure 24. Option 1 predicted water levels and flows – Pit A South (from 1/9/2018)

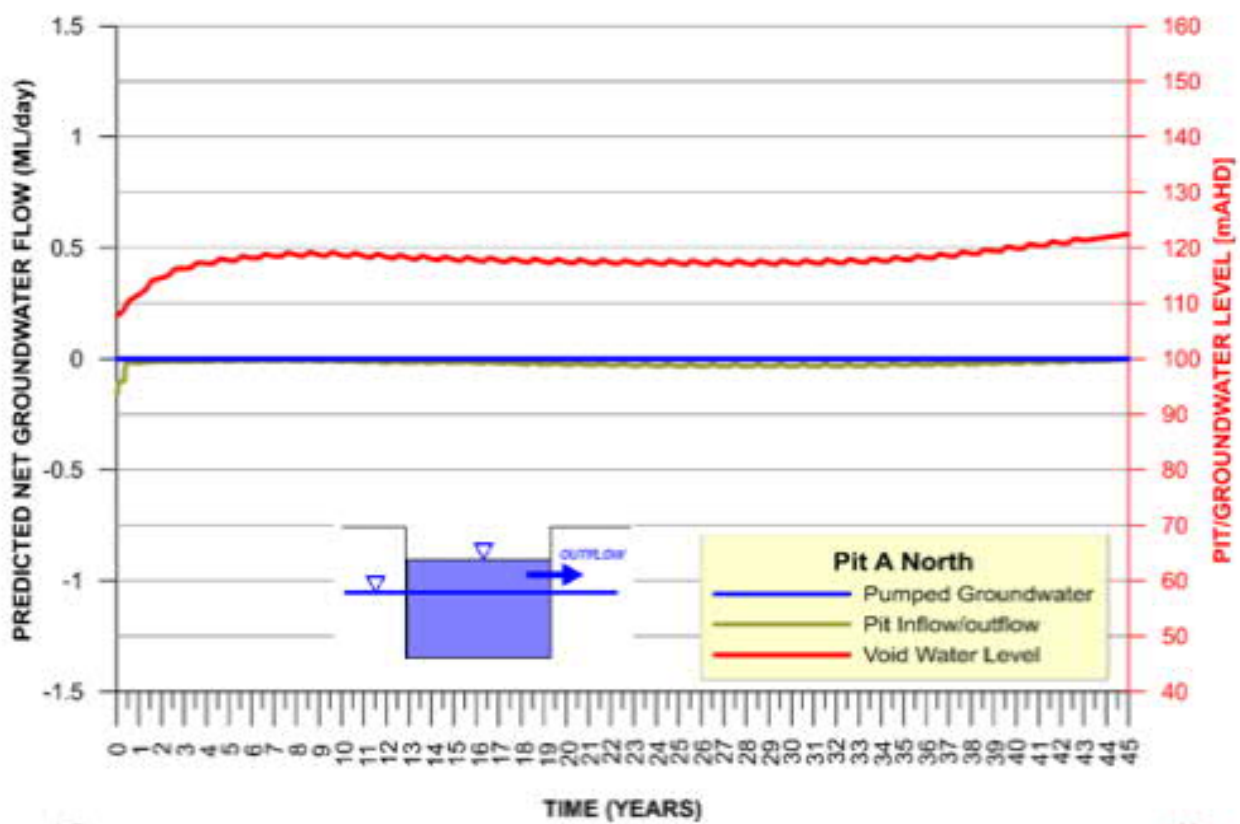


Figure 25. Option 1 predicted water levels and flows – Pit A North (from 1/9/2018)

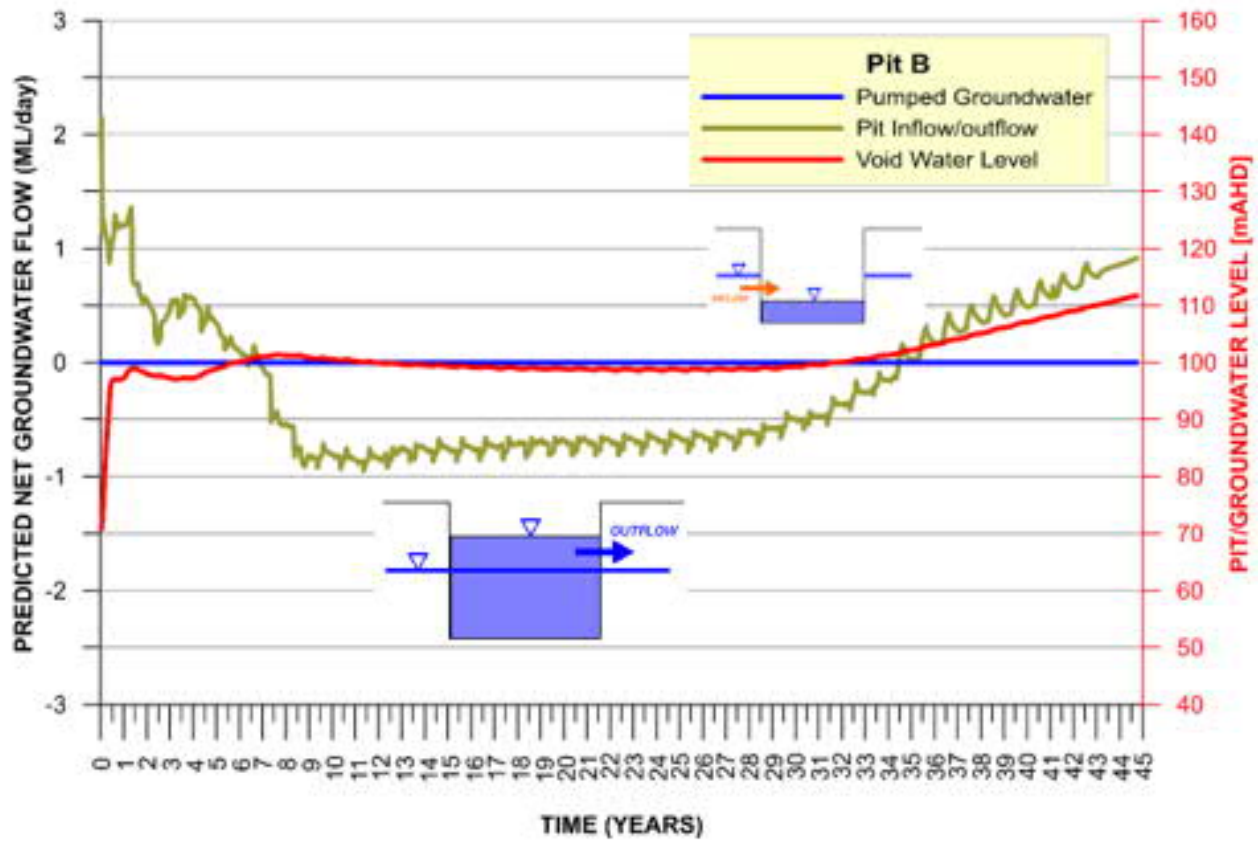


Figure 26. Option 1 predicted water levels and flows – Pit B (from 1/9/2018)

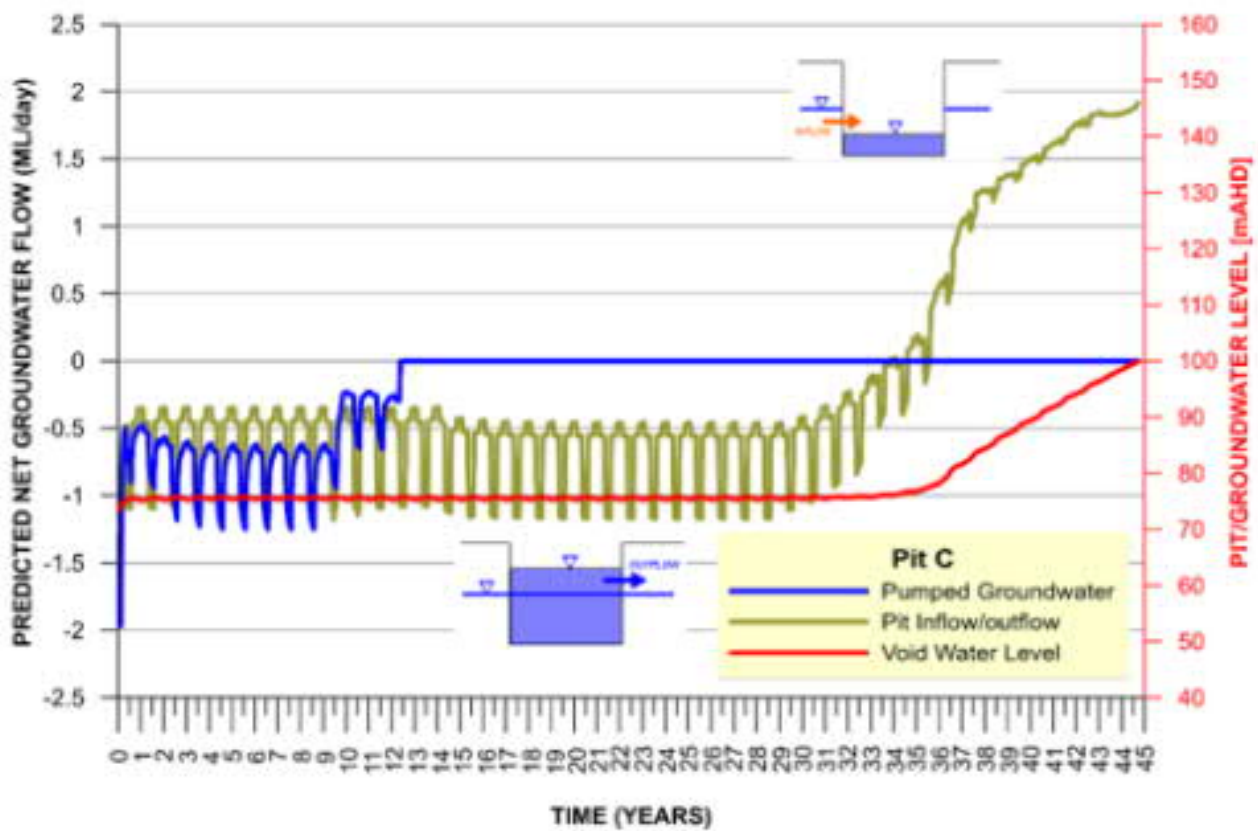


Figure 27. Option 1 predicted water levels and flows – Pit C (from 1/9/2018)

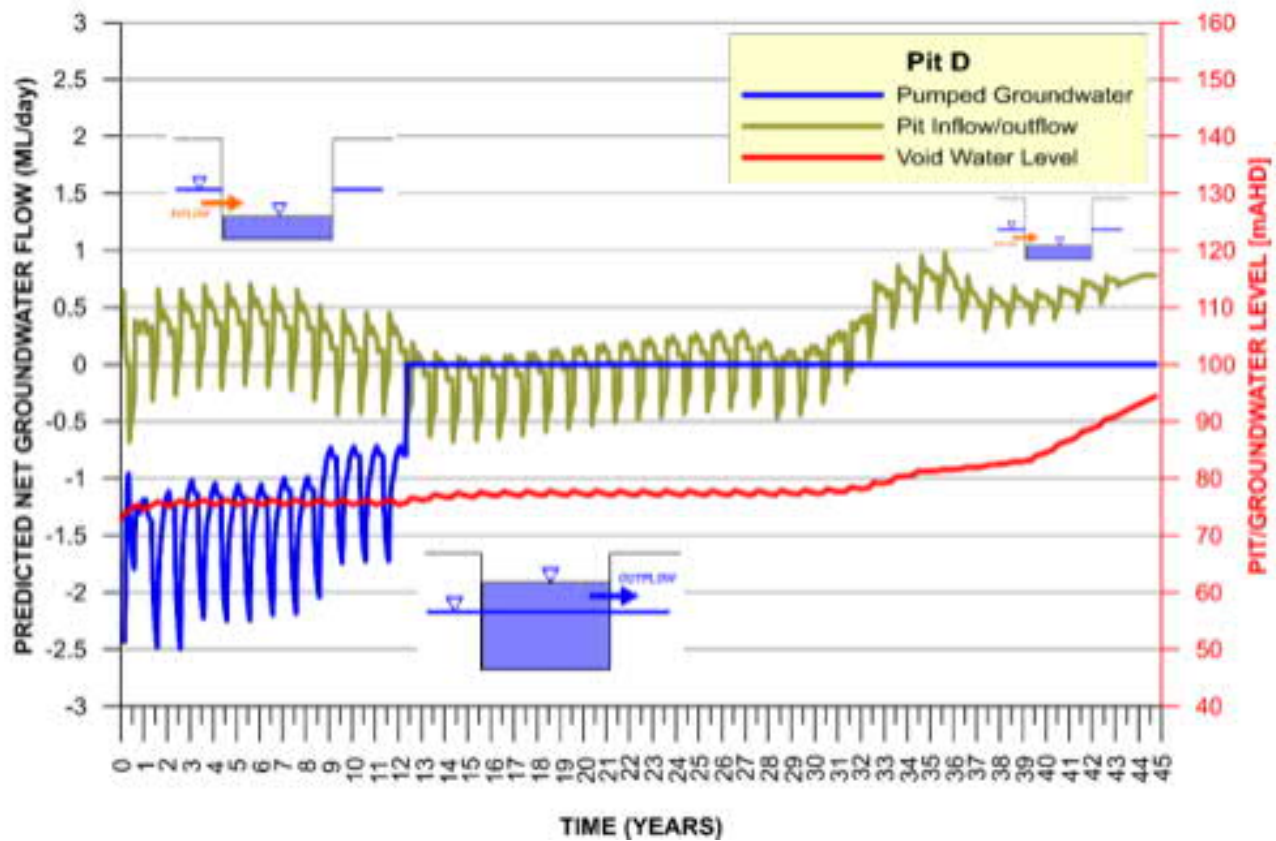


Figure 28. Option 1 predicted water levels and flows – Pit D (from 1/9/2018)

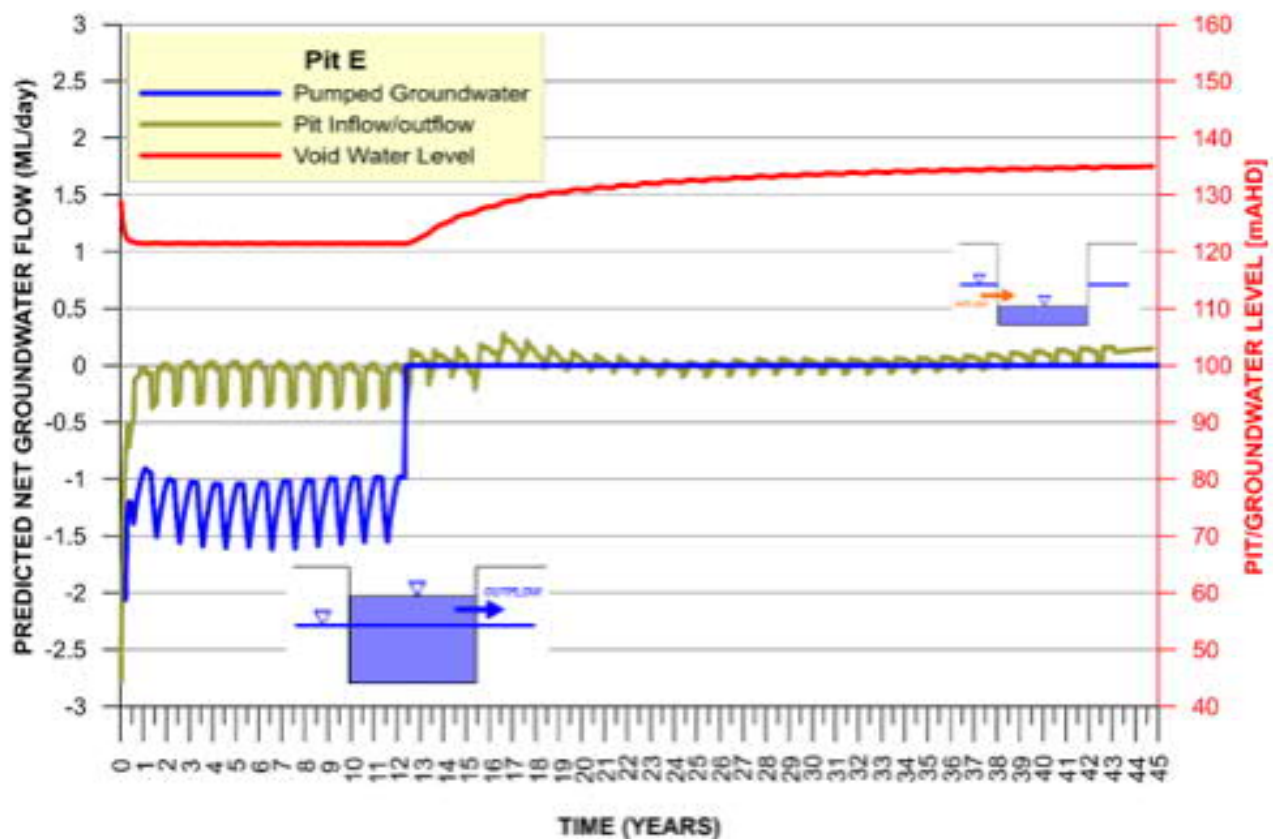


Figure 29. Option 1 predicted water levels and flows – Pit E (from 1/9/2018)

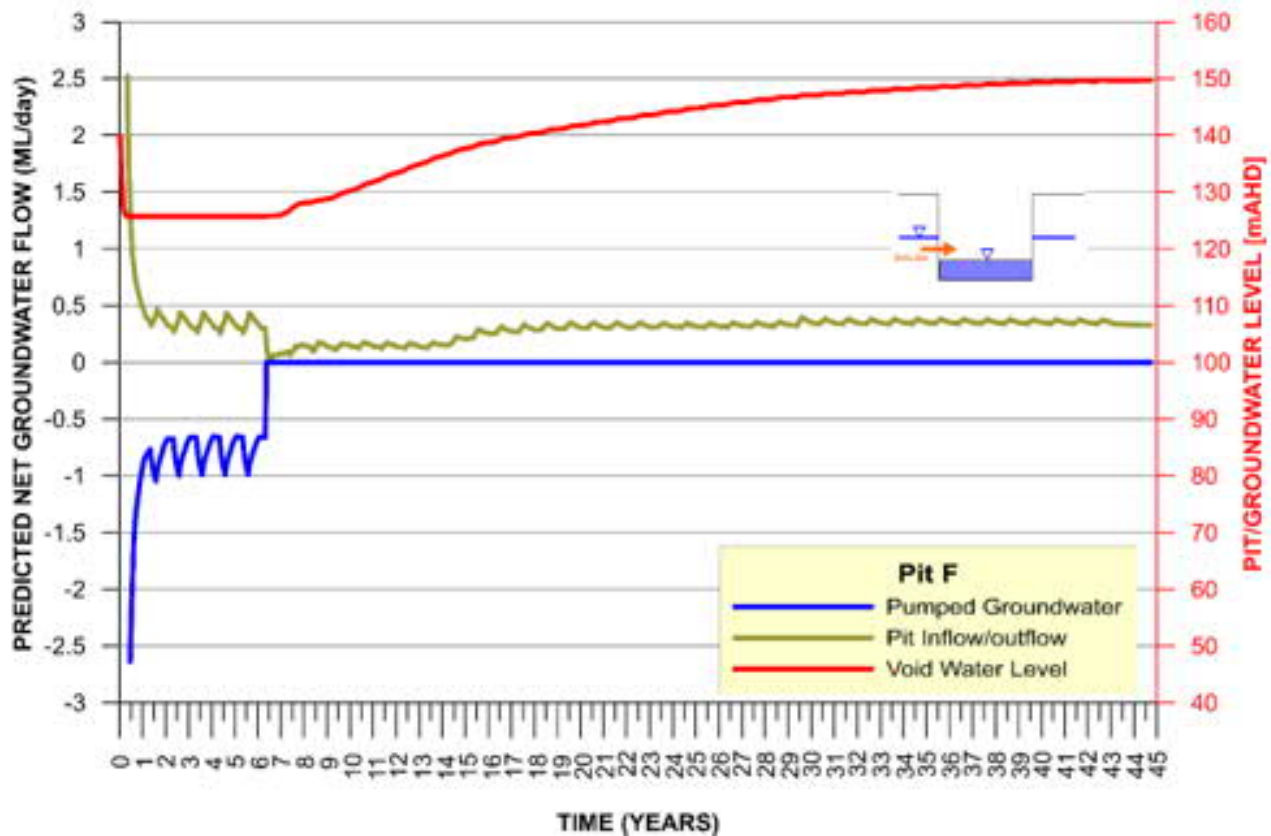


Figure 30. Option 1 predicted water levels and flows – Pit F (from 1/9/2018)

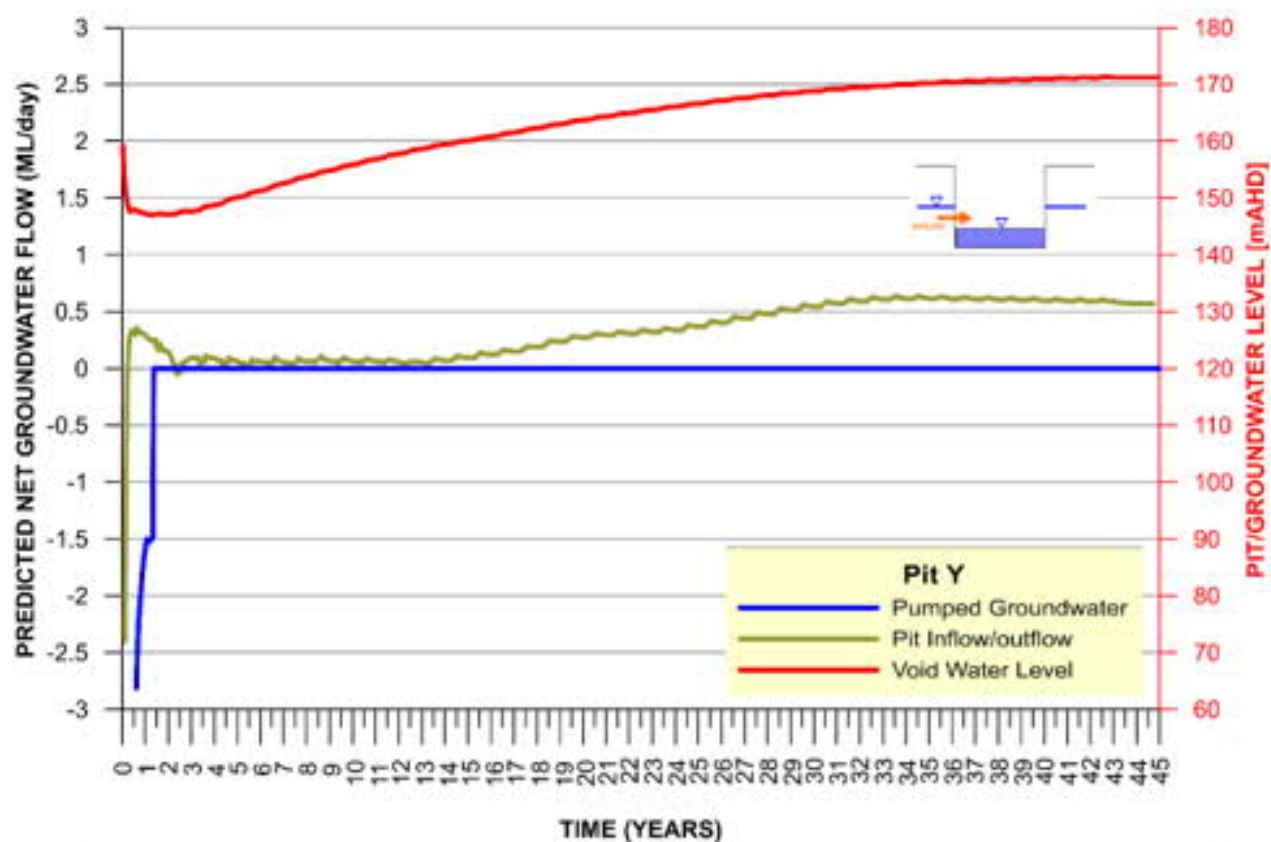


Figure 31. Option 1 predicted water levels and flows – Pit Y (from 1/9/2018)

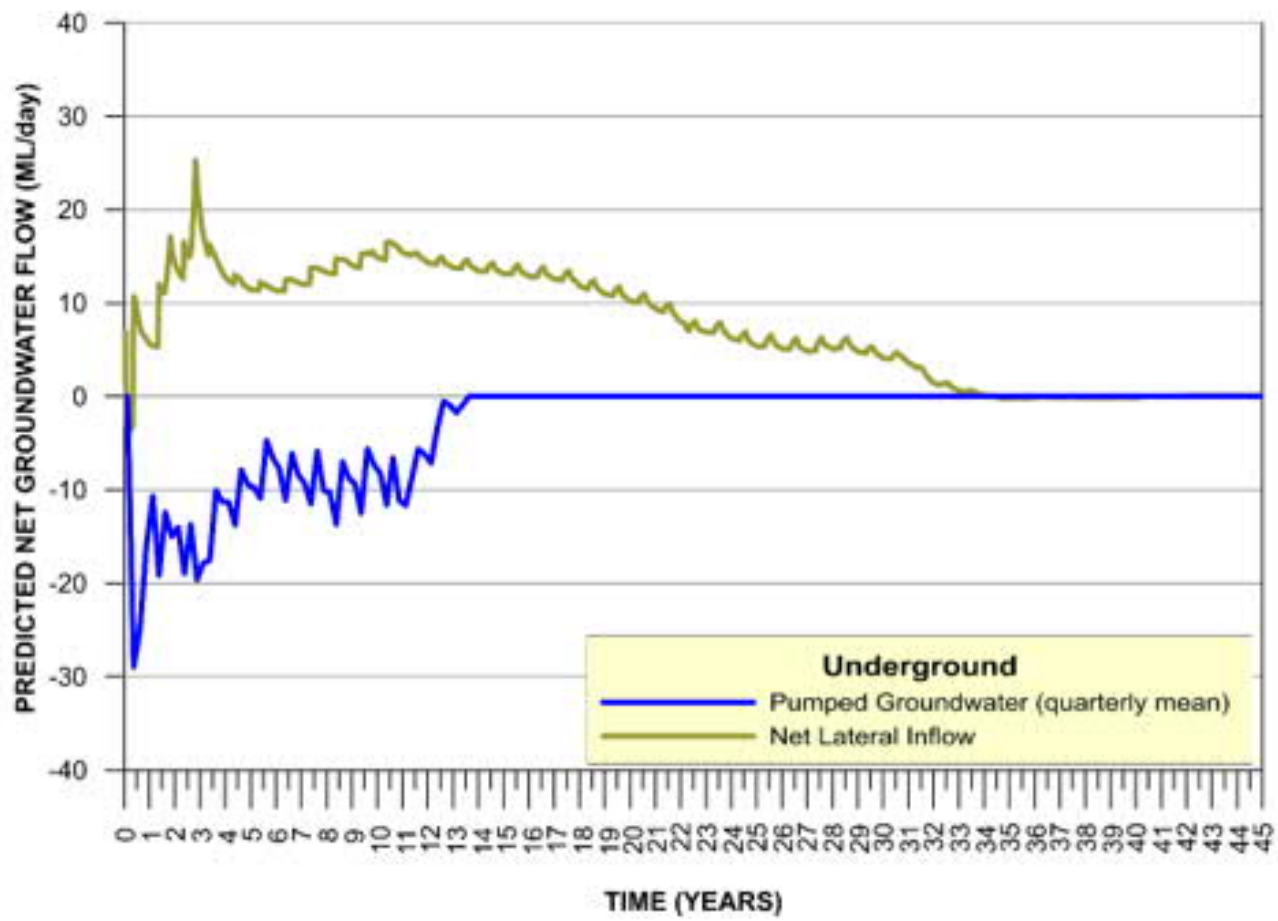


Figure 32. Option 1 predicted underground mine inflow (from 1/9/2018)

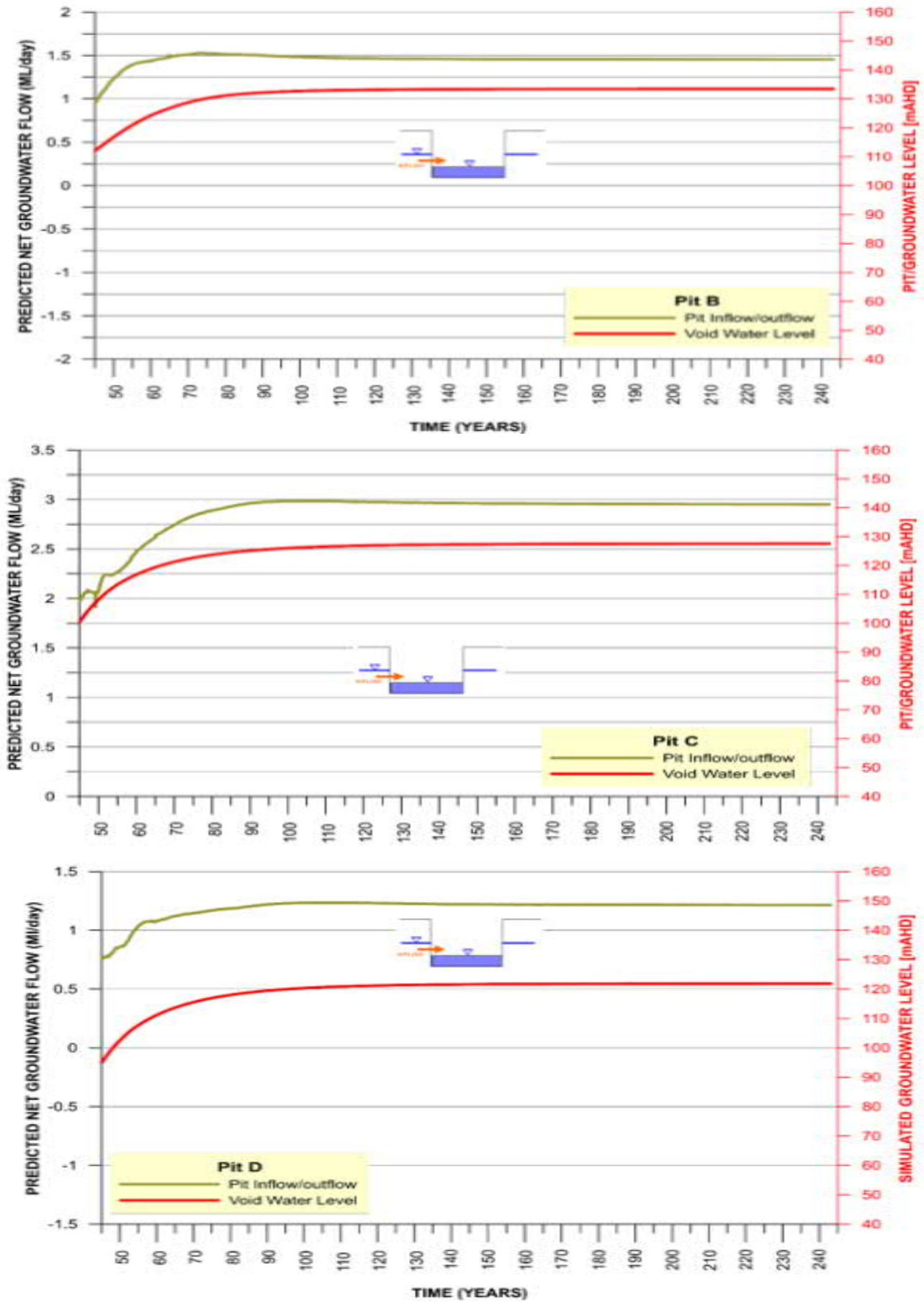


Figure 33. Option 1 predicted long-term water levels and flows – Pits B, C, D (from 1/9/2063)

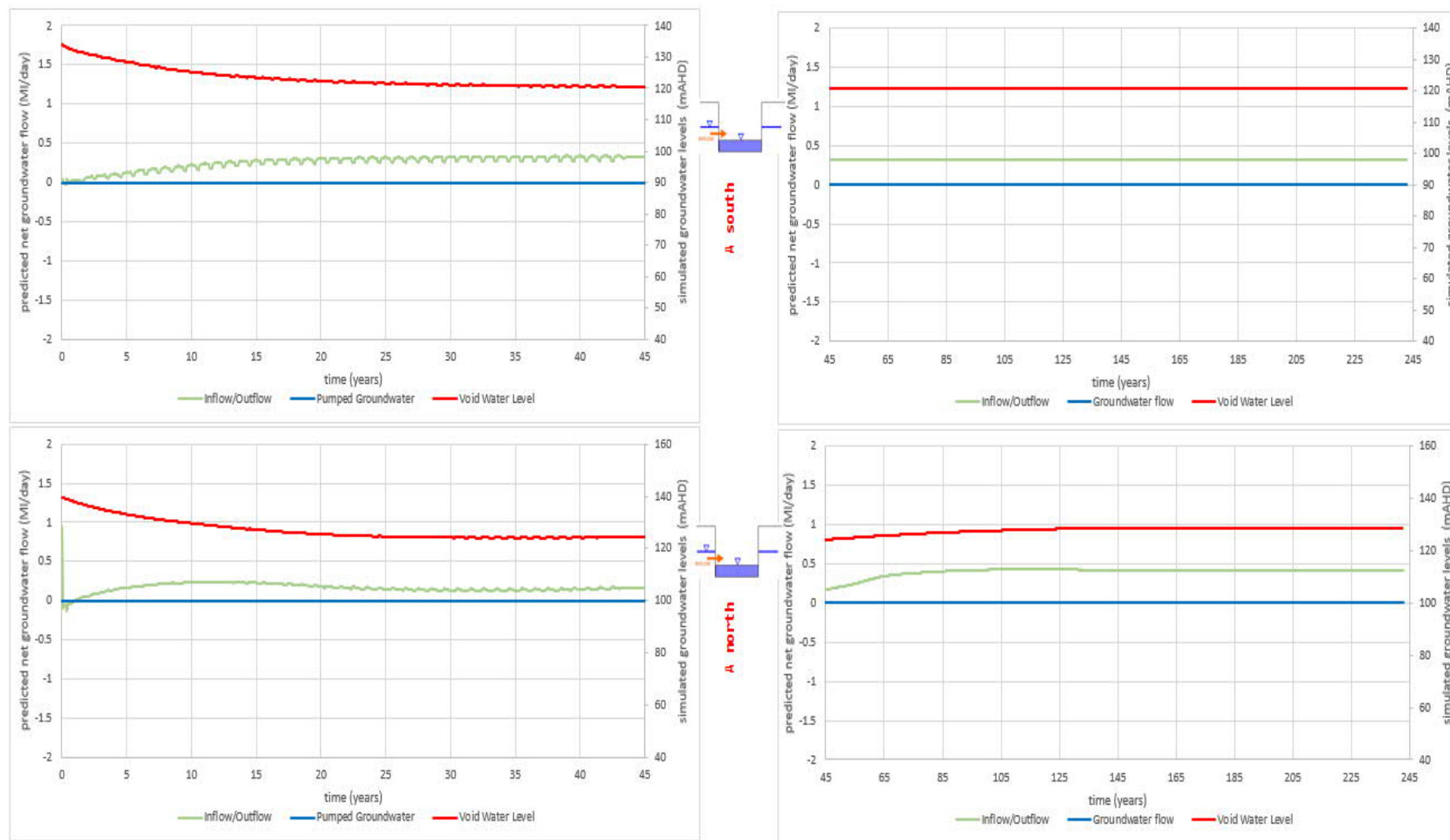


Figure 34. Option 2 predicted long-term water levels and flows – Pits A South and A North (from 1/9/2018)

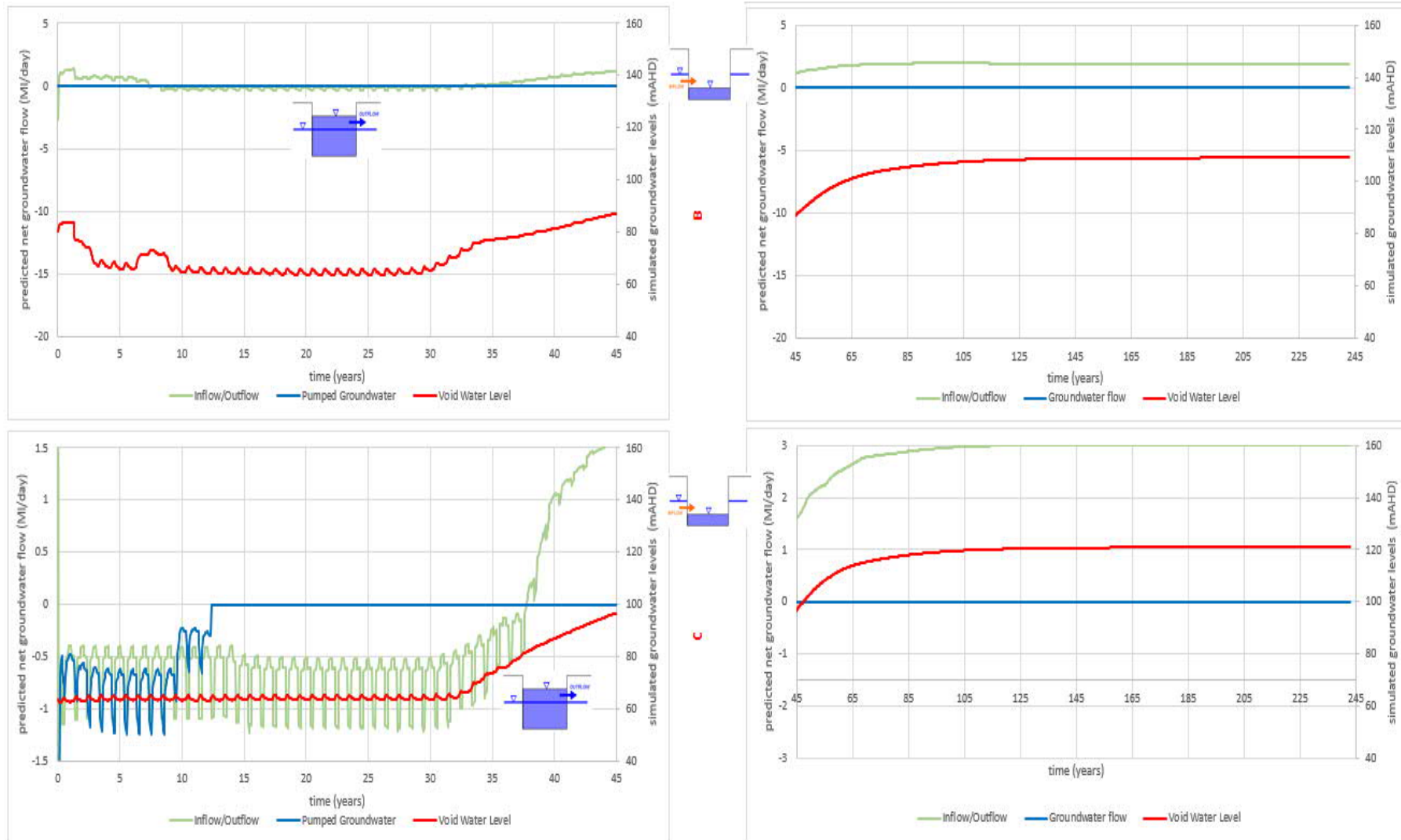


Figure 35. Option 2 predicted long-term water levels and flows – Pits B and C (from 1/9/2018)

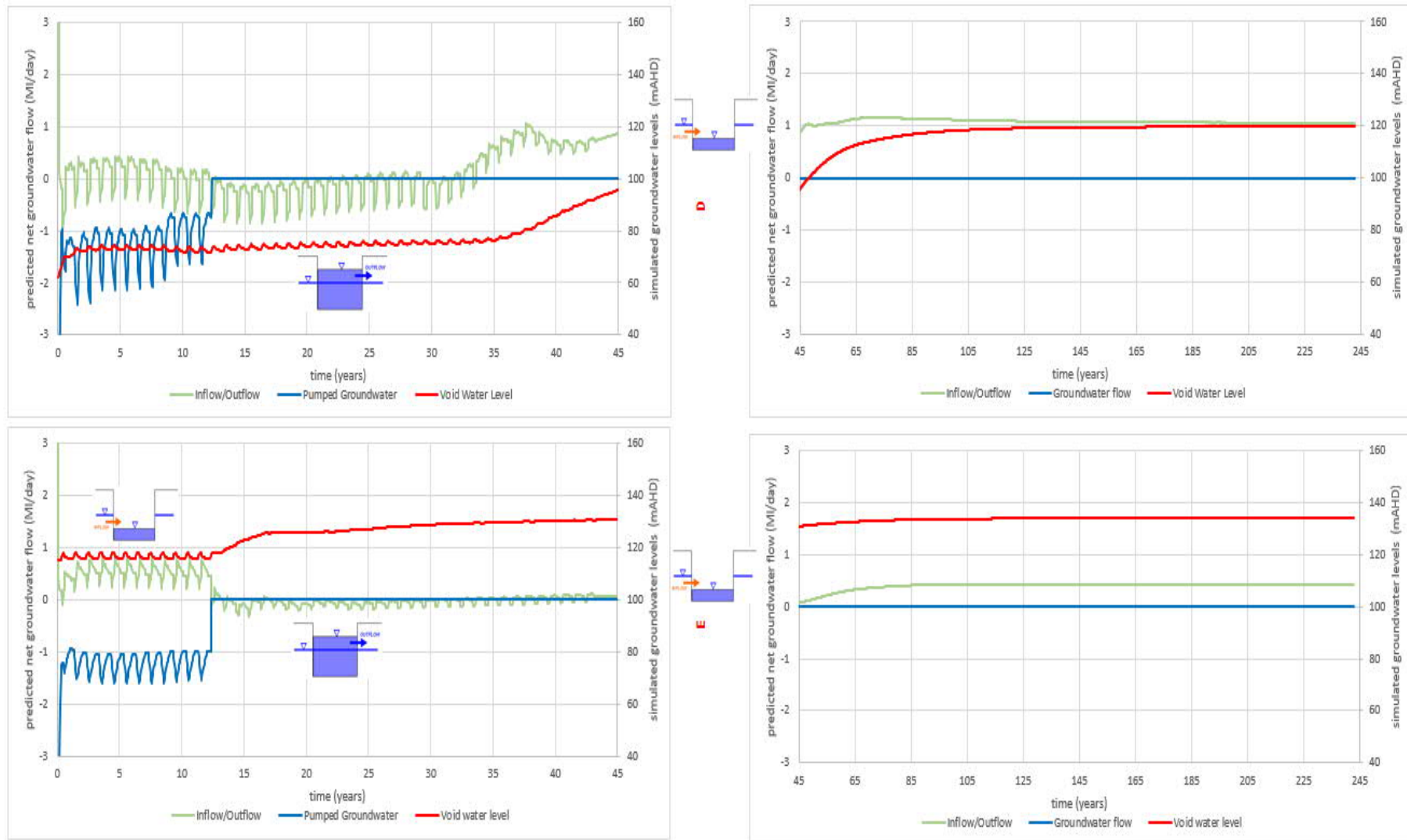


Figure 36. Option 2 predicted long-term water levels and flows – Pits D and E (from 1/9/2018)

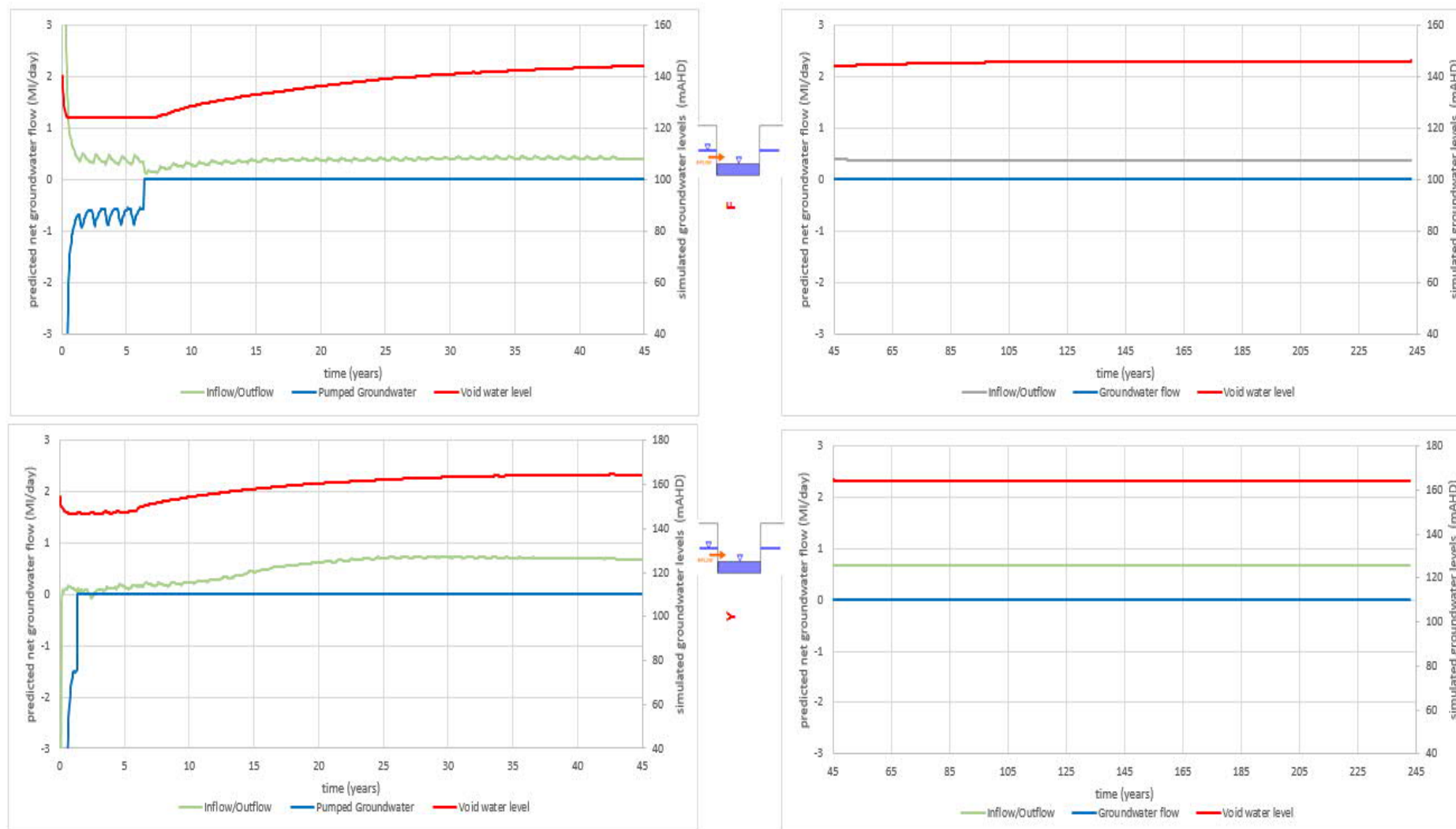
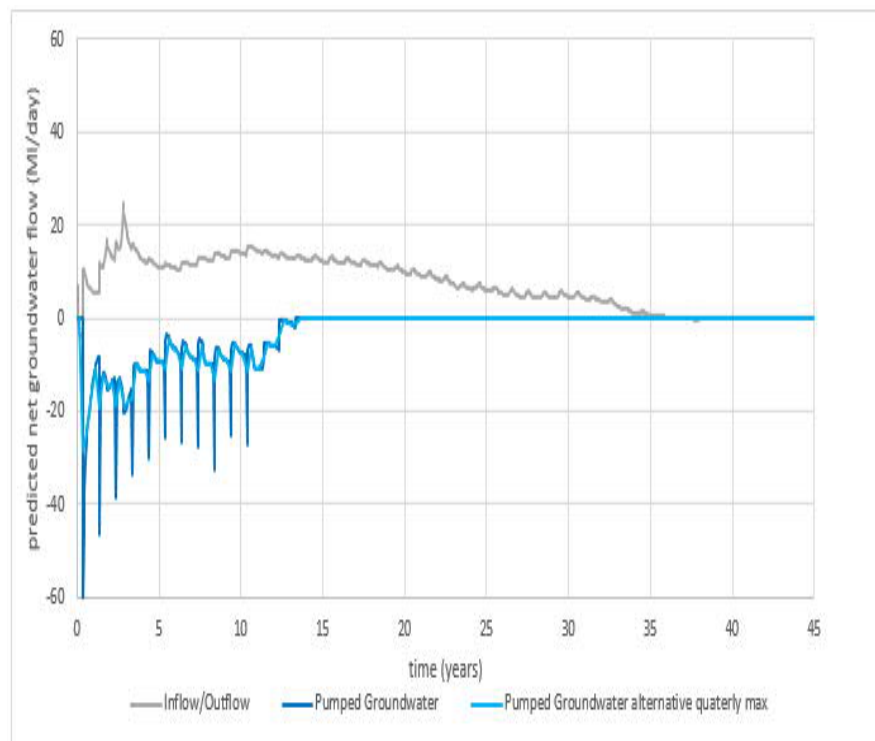


Figure 37. Option 2 predicted long-term water levels and flows – Pits F and Y (from 1/9/2018)



All Underground

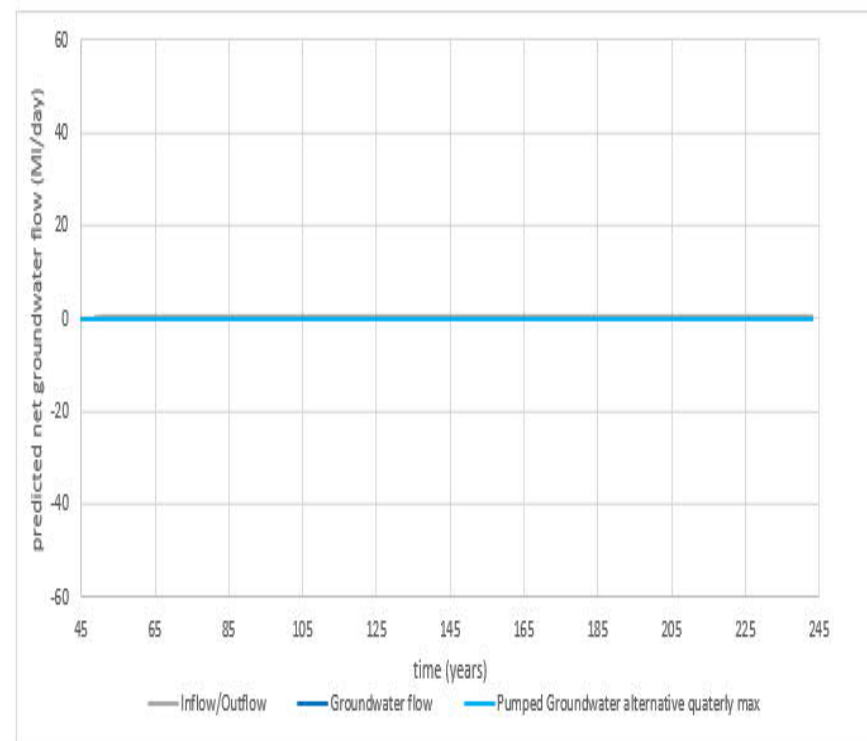


Figure 38. Option 2 predicted underground mine inflow (from 1/9/2018)

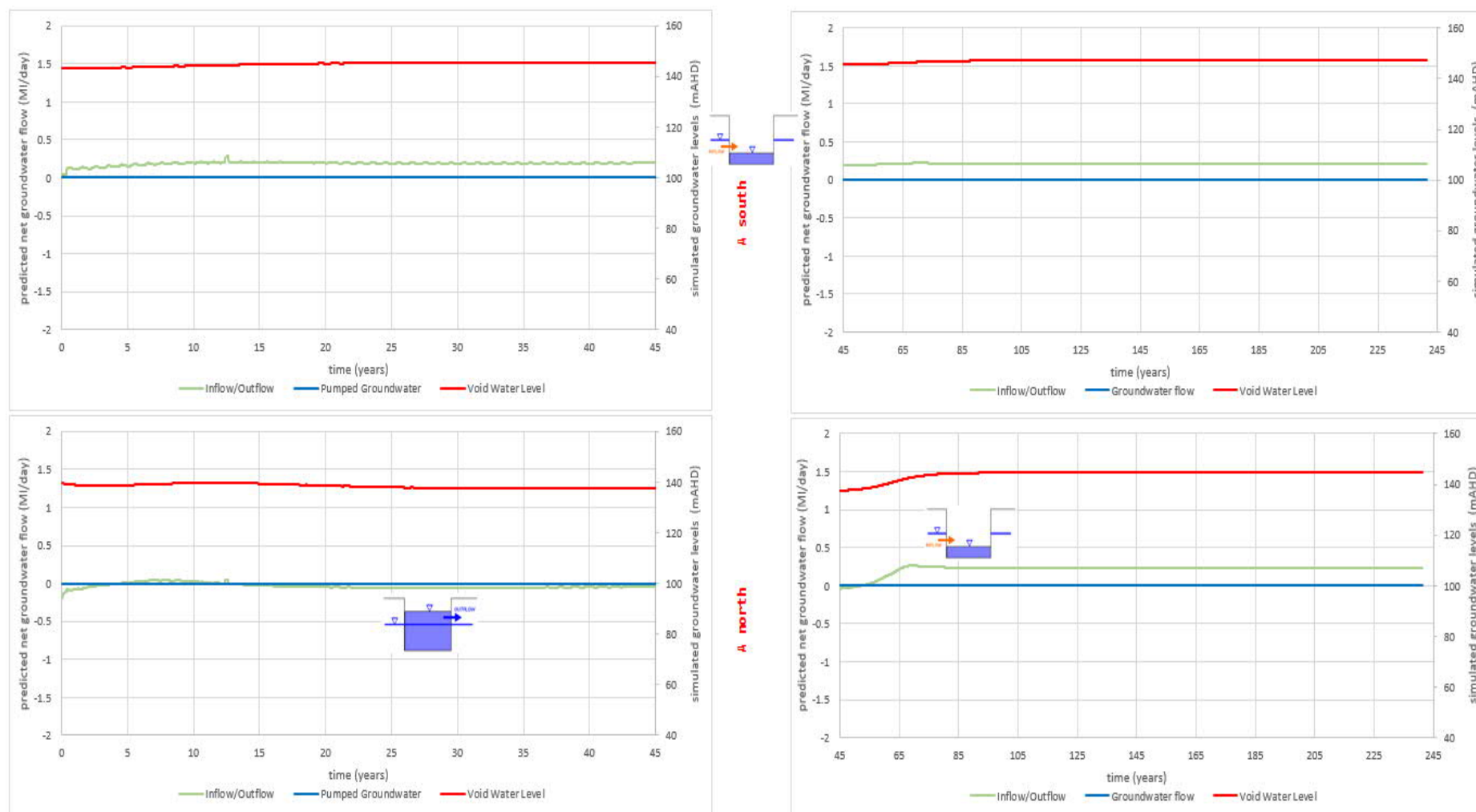
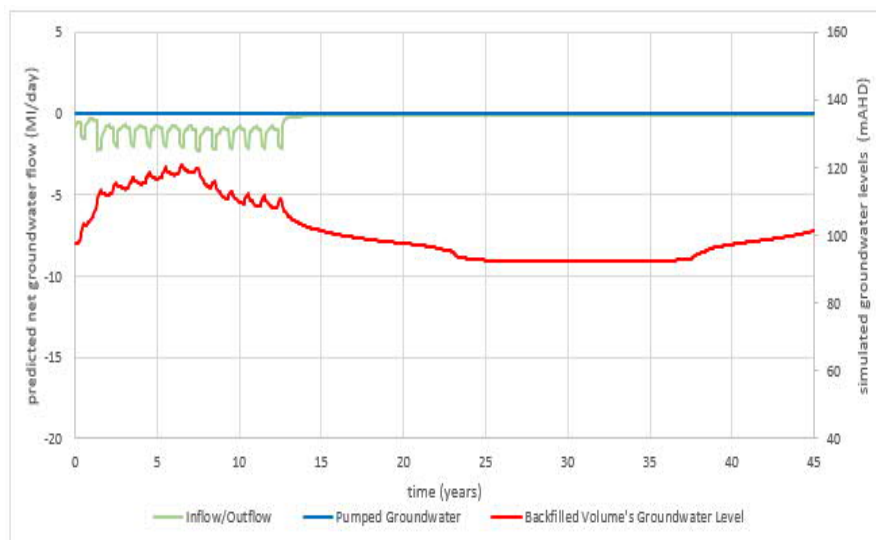
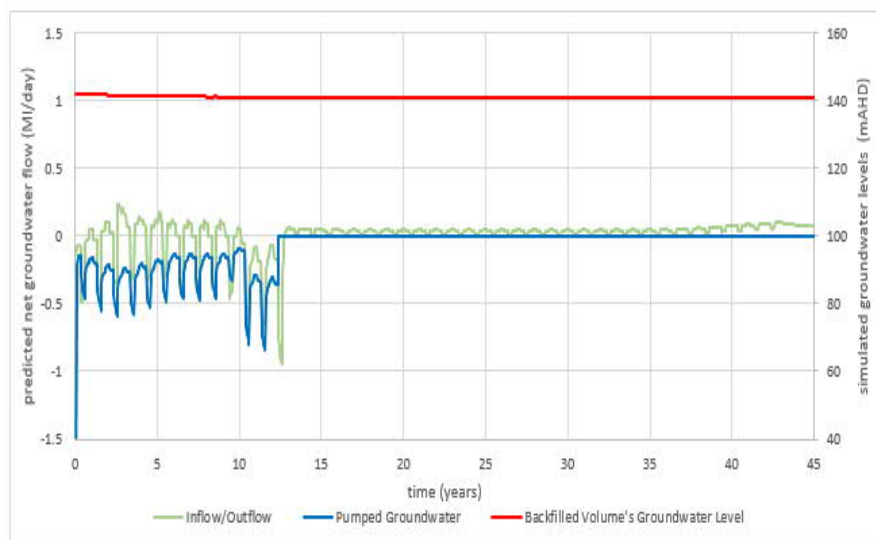
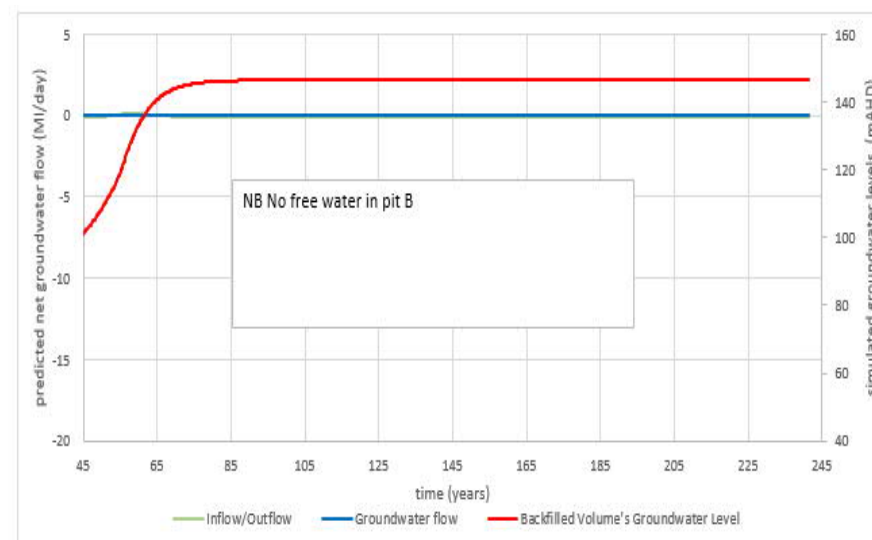


Figure 39. Option 3 predicted long-term water levels and flows – Pits A South and A North (from 1/9/2018)



B



C

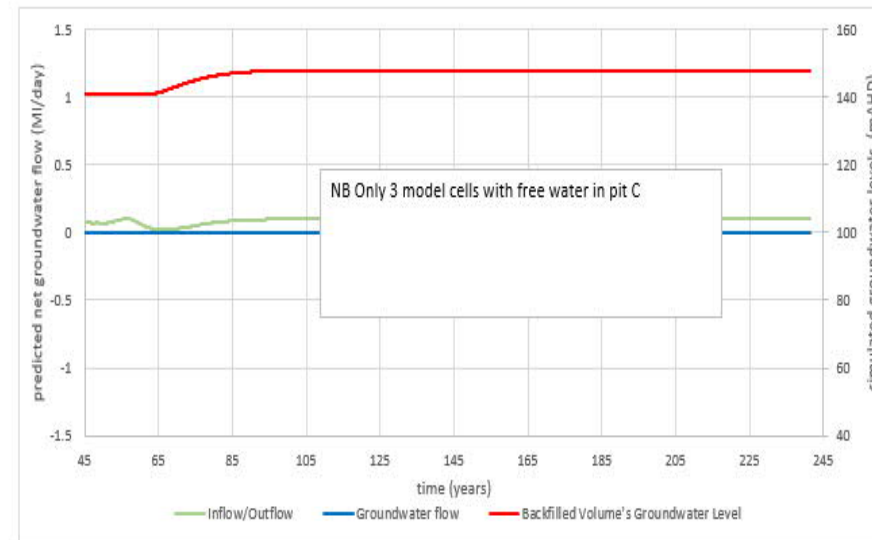


Figure 40. Option 3 predicted long-term water levels and flows – Pits B and C (from 1/9/2018)

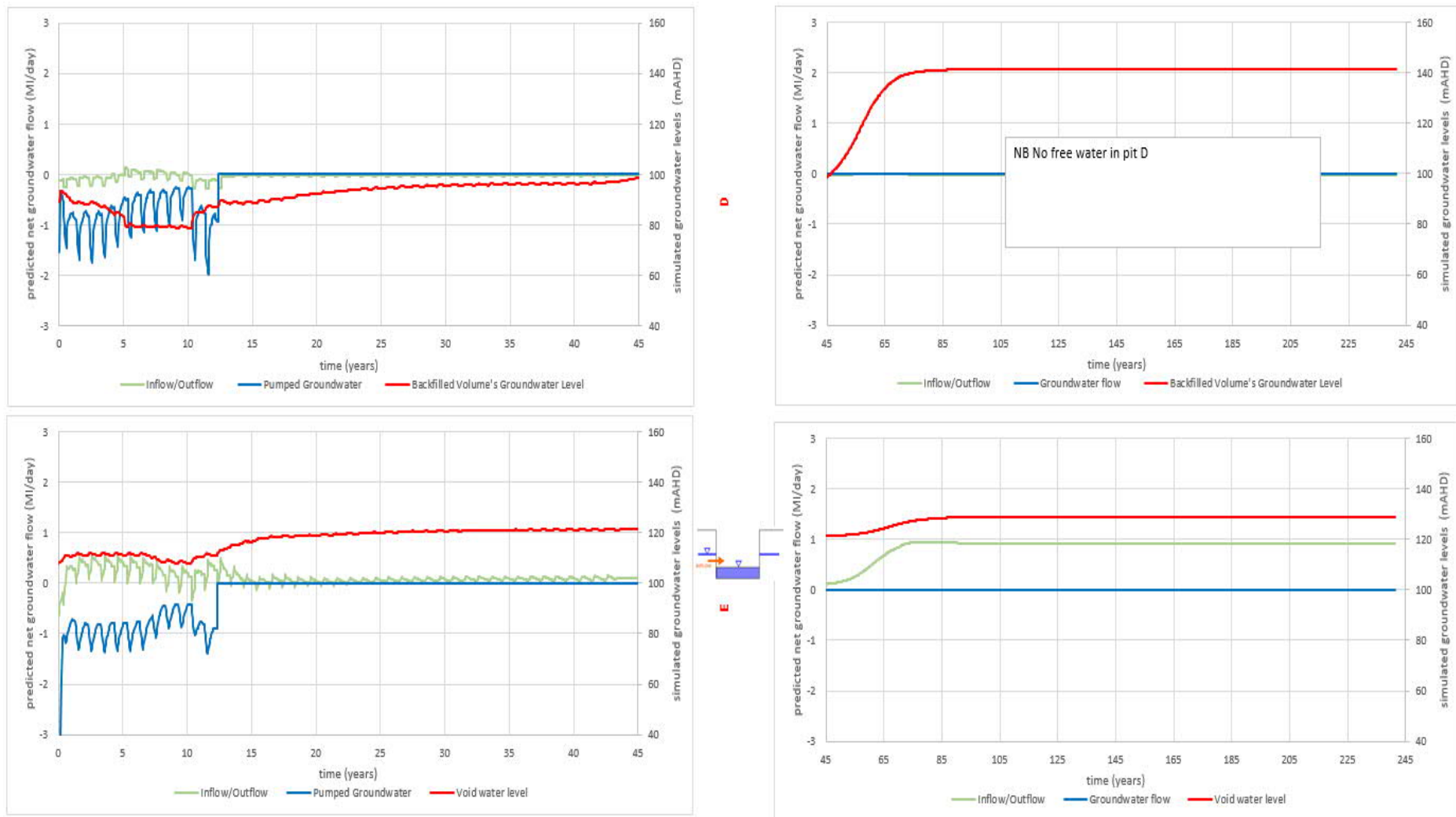


Figure 41. Option 3 predicted long-term water levels and flows – Pits D and E (from 1/9/2018)s

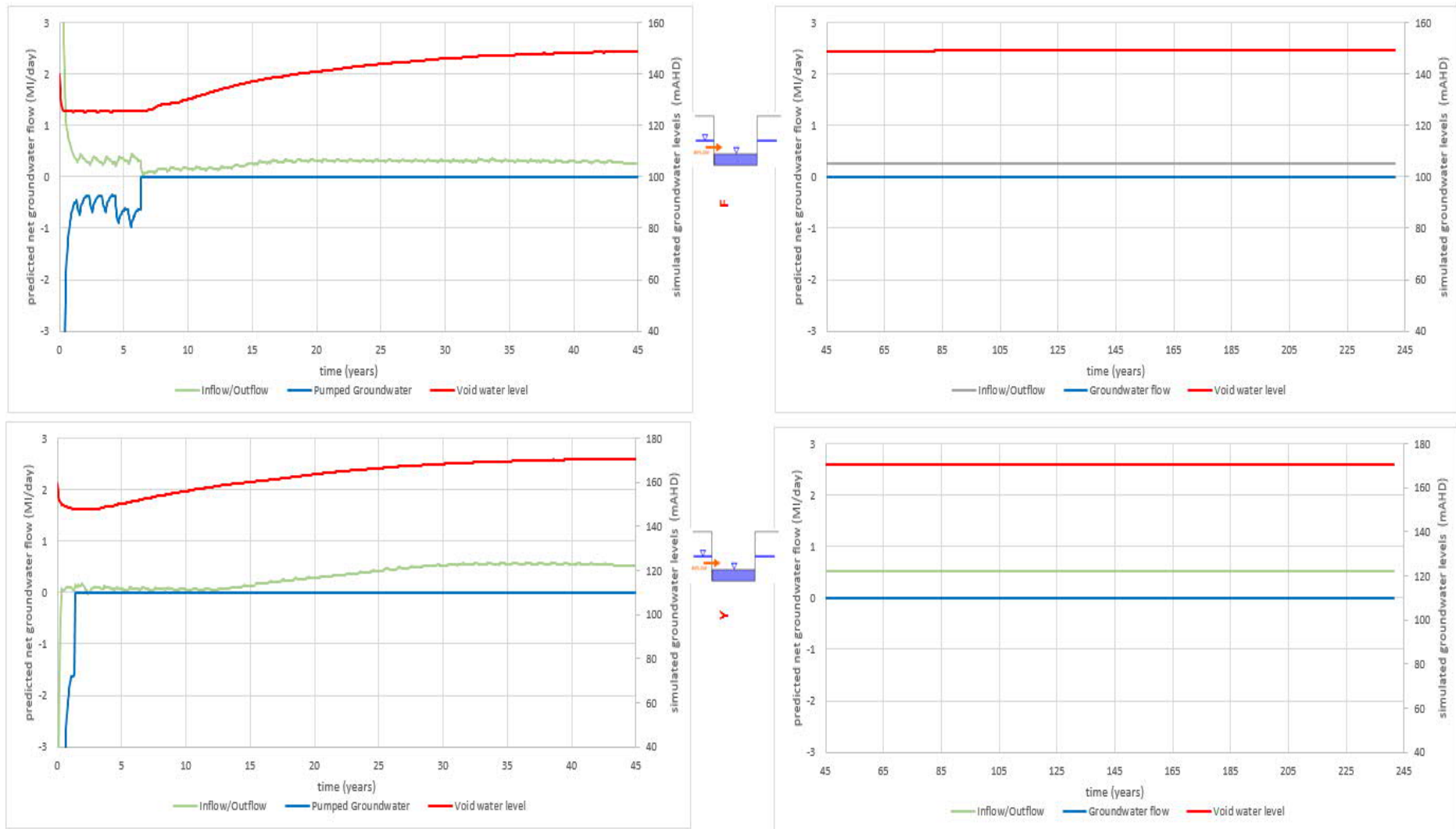
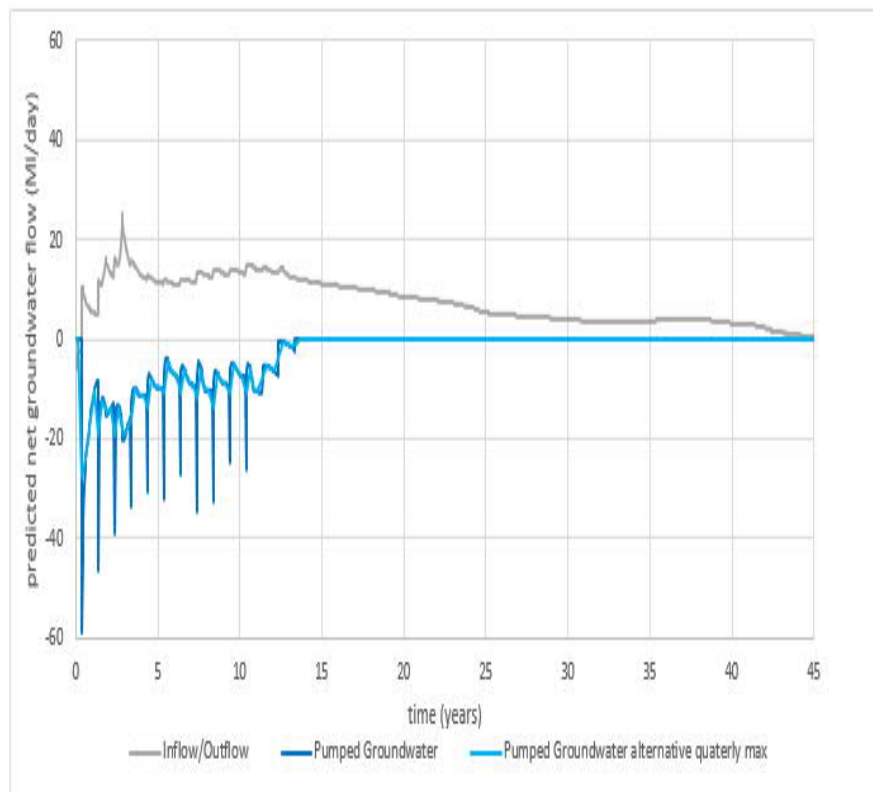


Figure 42. Option 3 predicted long-term water levels and flows – Pits F and Y (from 1/9/2018)



All Underground

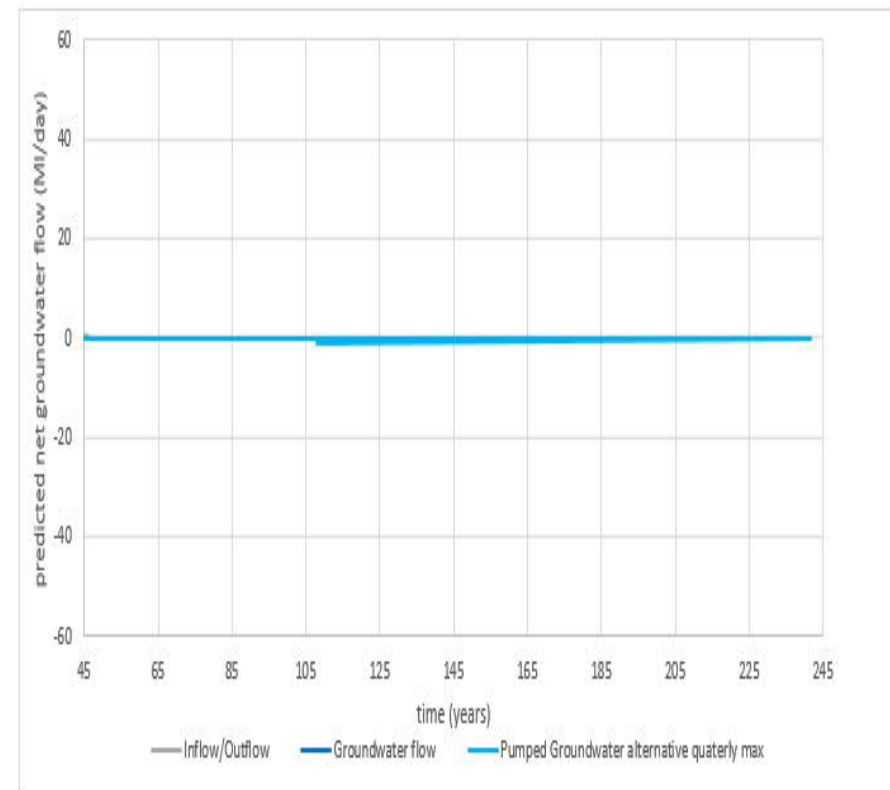


Figure 43. Option 3 predicted underground mine inflow (from 1/9/2018)

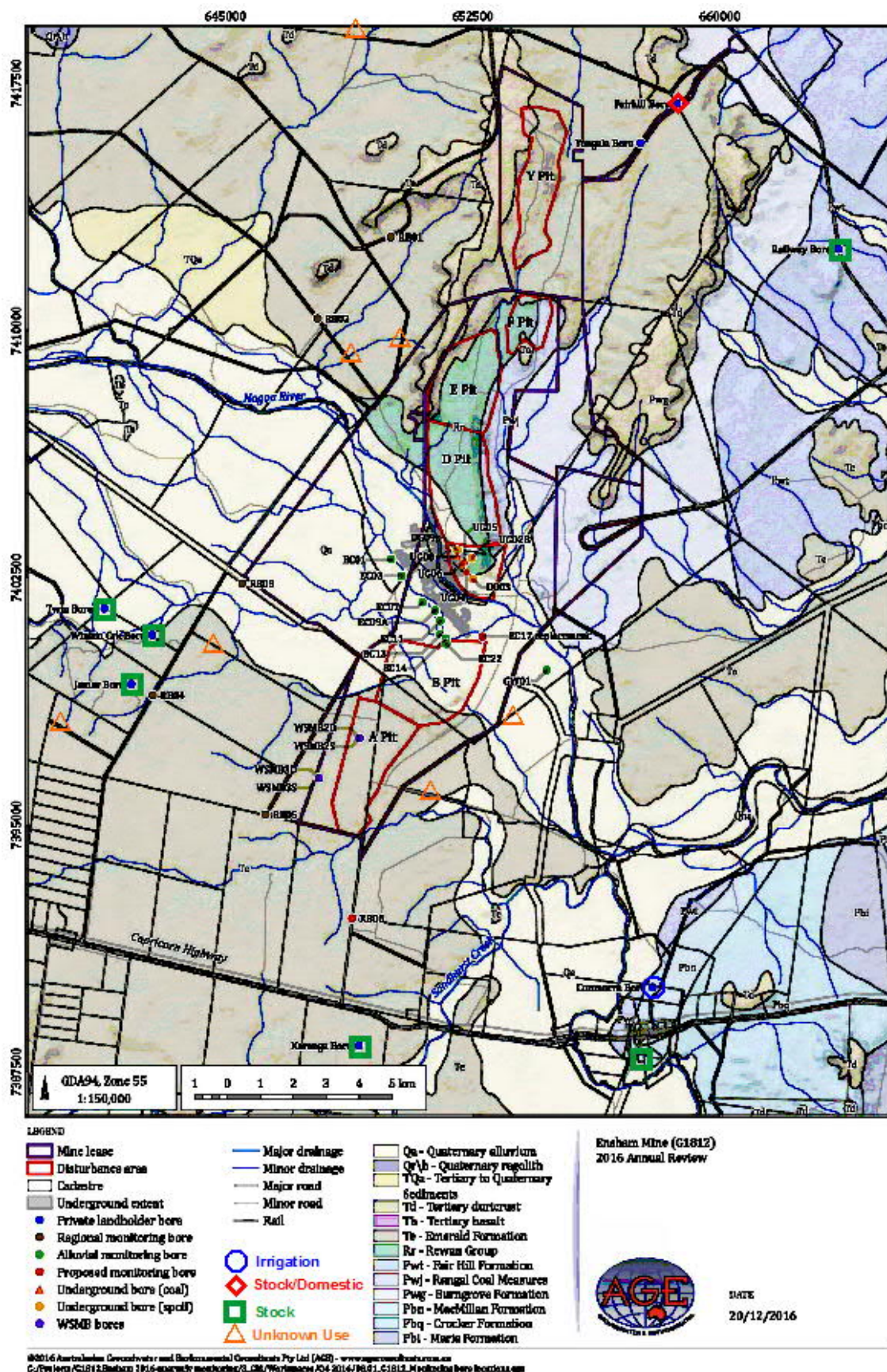


Figure 44. Groundwater use

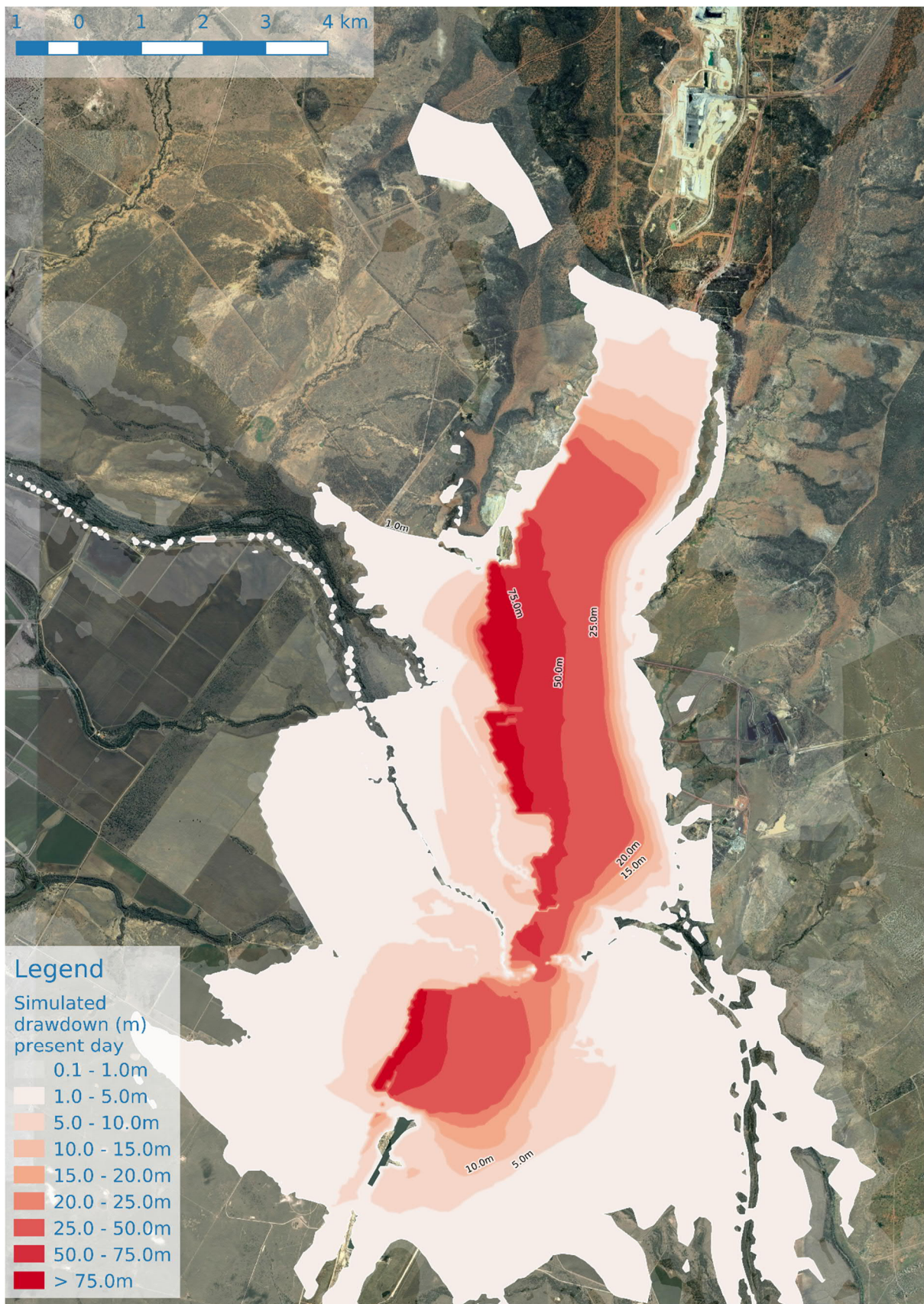


Figure 45. Simulated water table drawdown - 2018

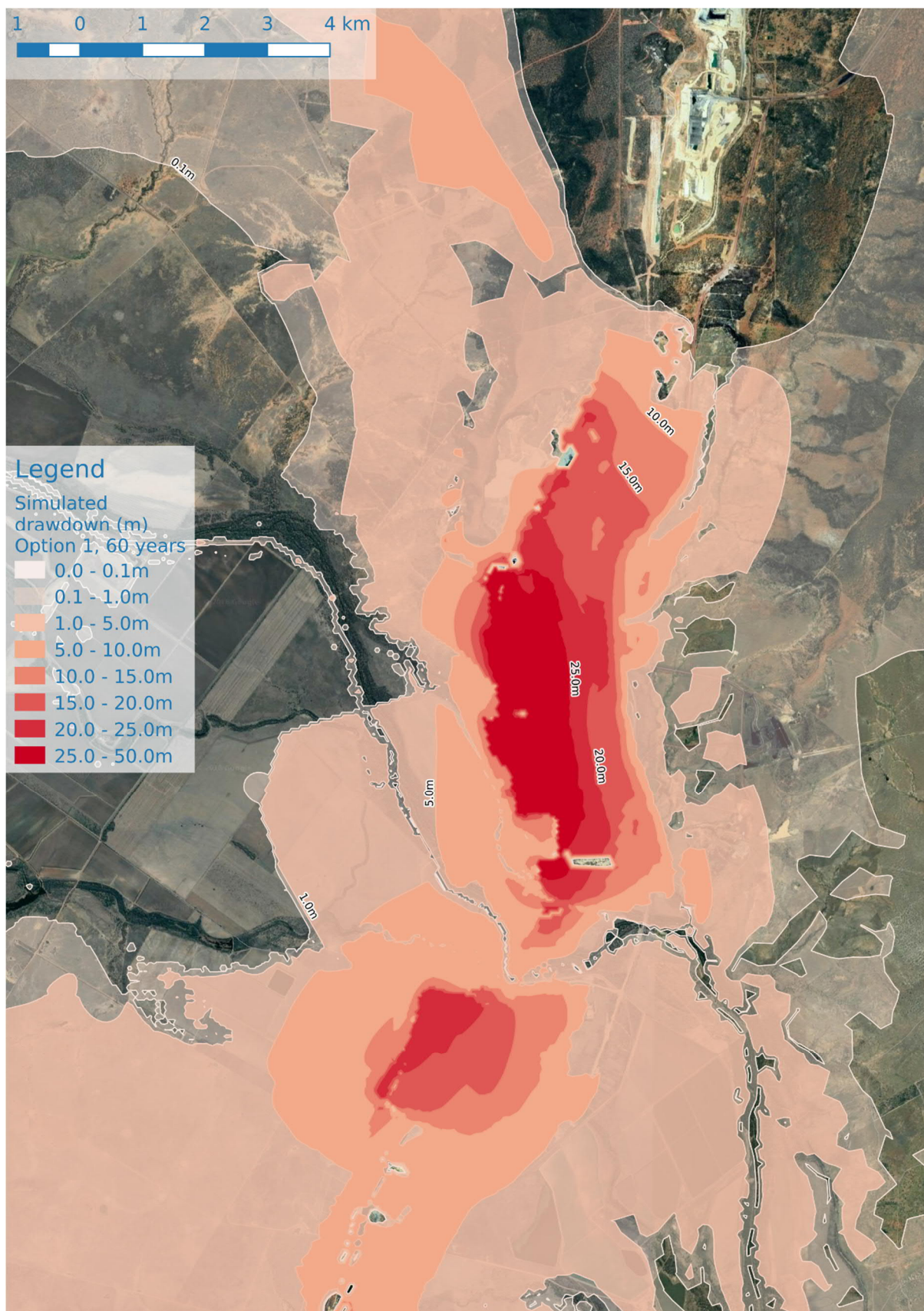


Figure 46. Simulated Option 1 water table drawdown - 2078

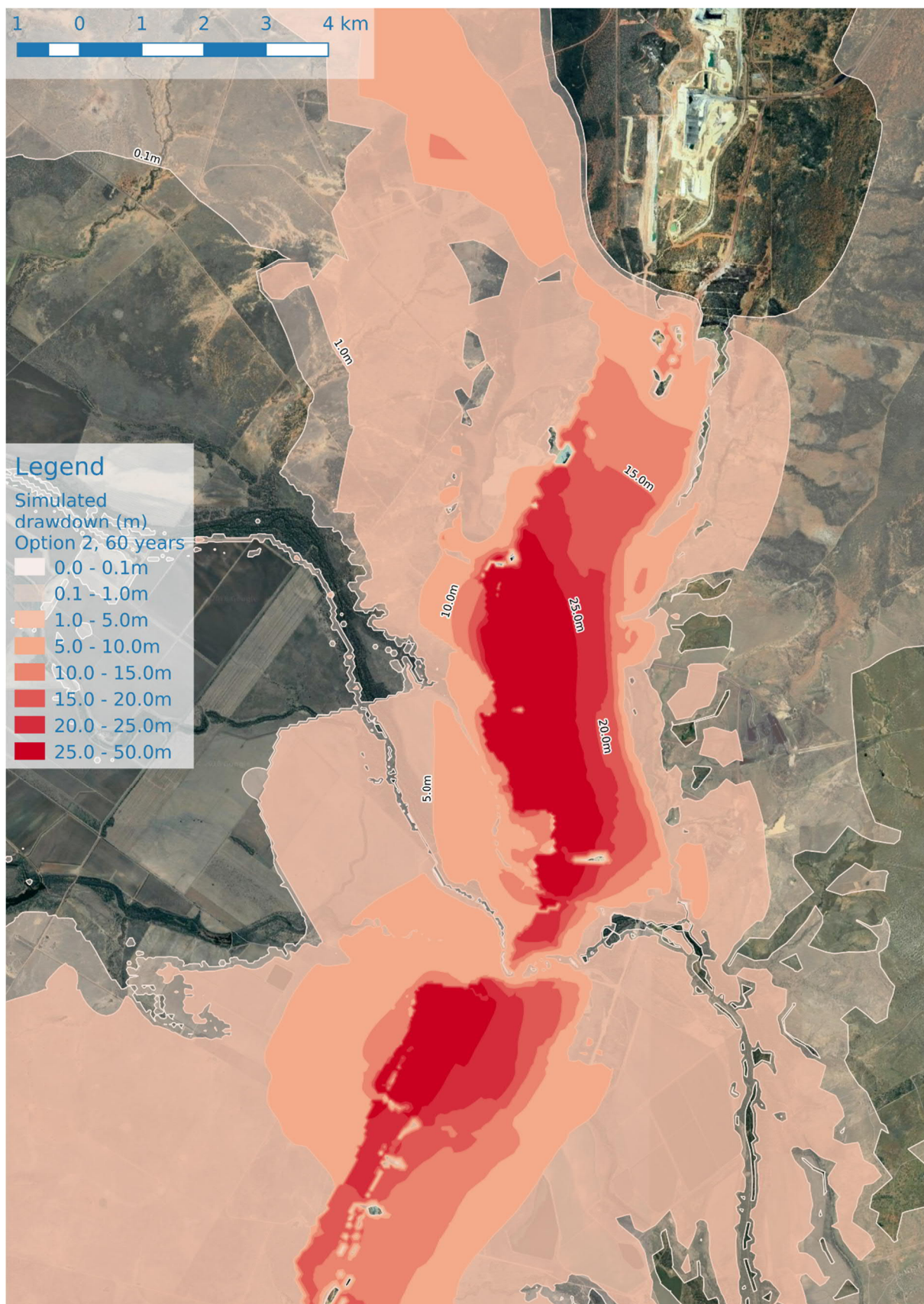


Figure 47. Simulated Option 2 water table drawdown – 2078

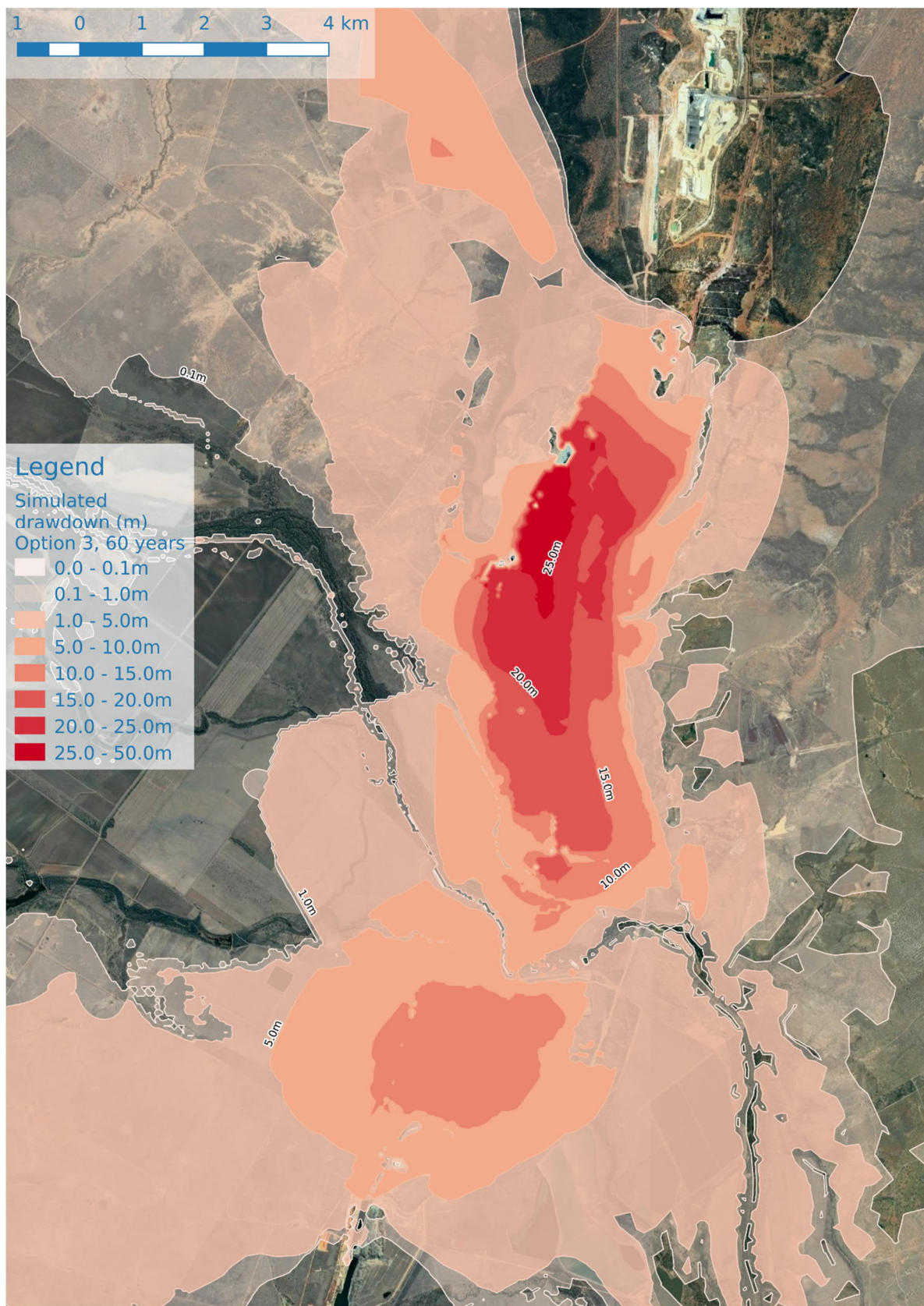


Figure 48. Simulated Option 3 water table drawdown – 2078

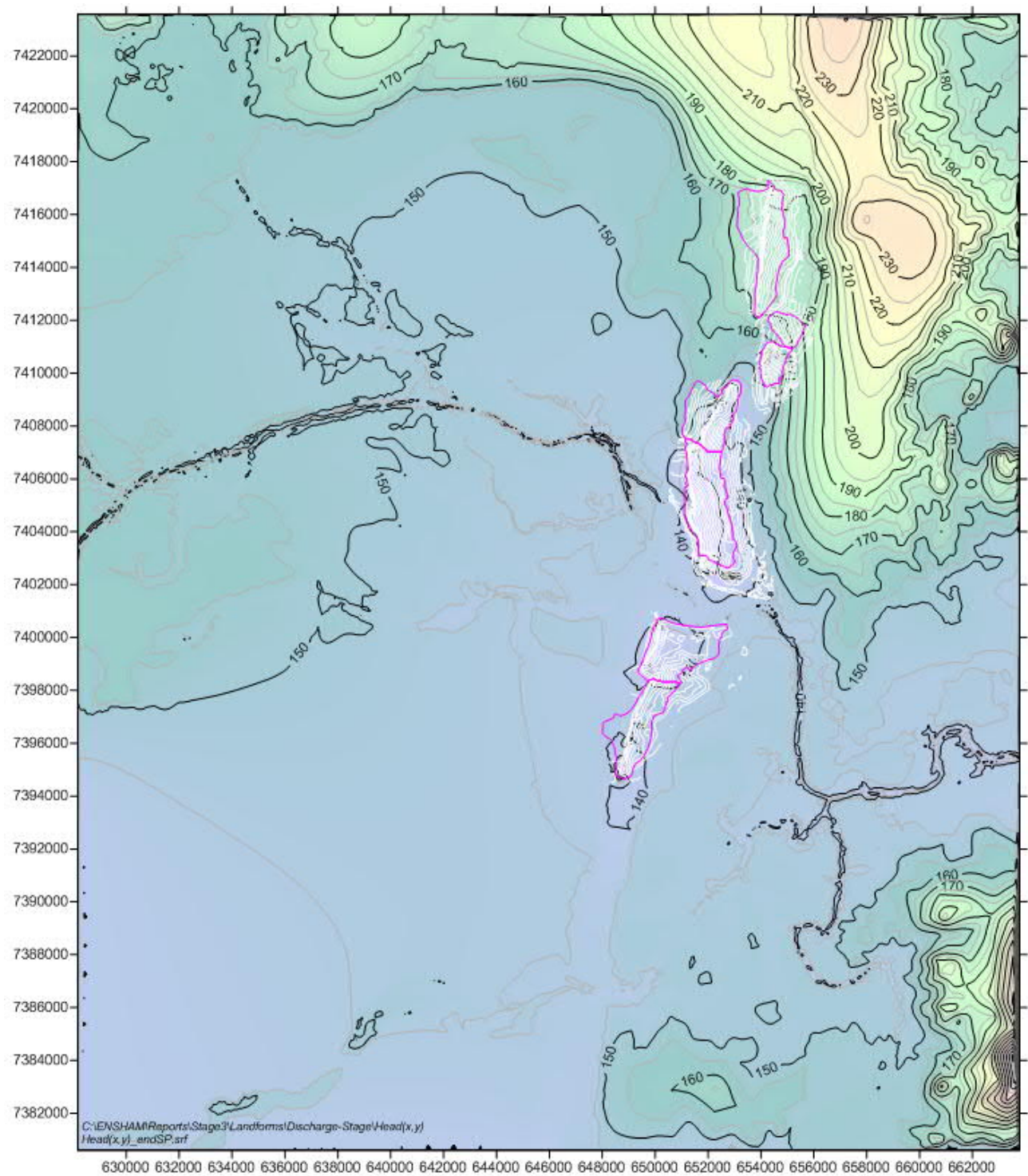


Figure 49. Simulated Option 1 equilibrium water table – 2260

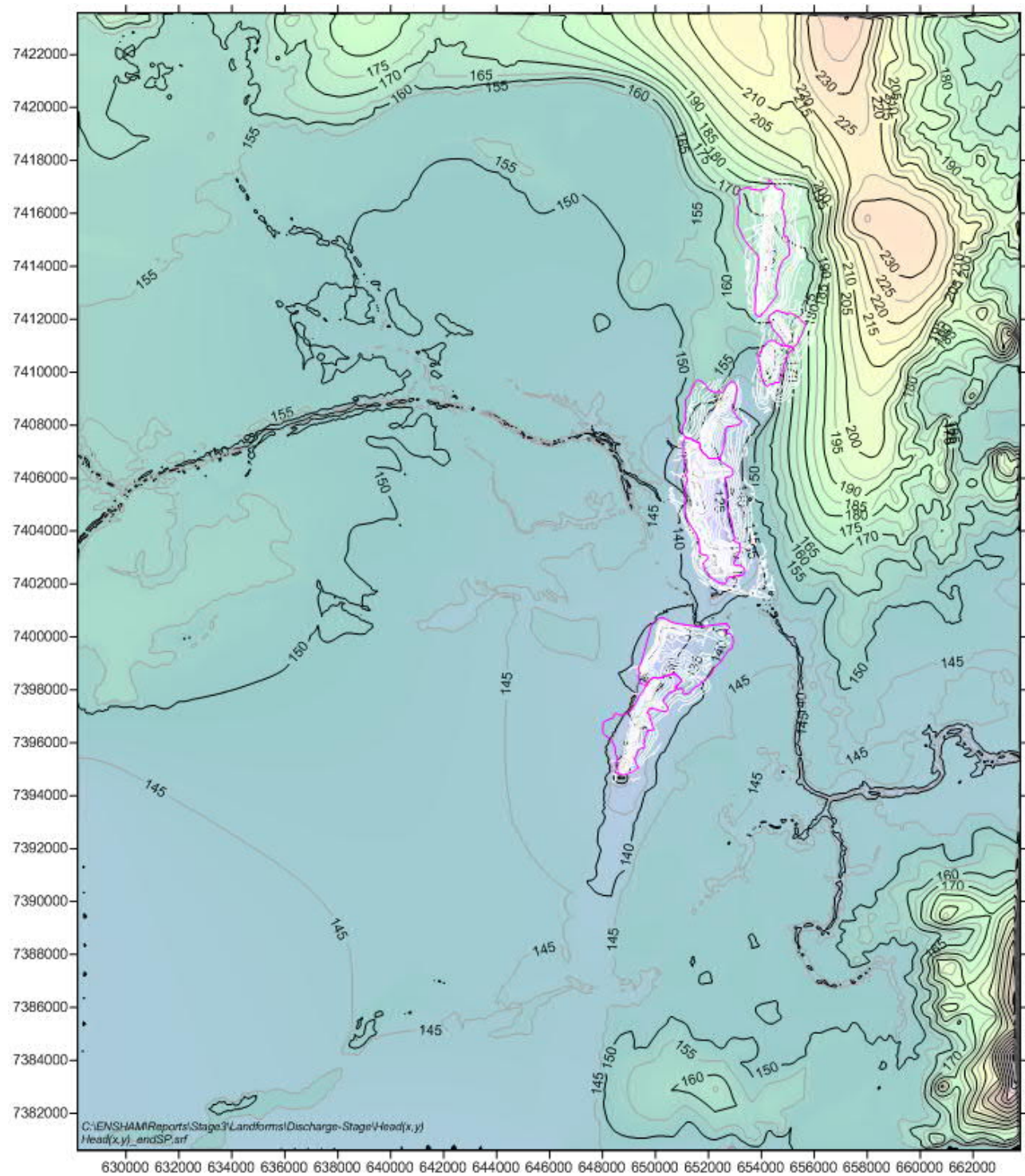


Figure 50. Simulated Option 2 equilibrium water table – 2260

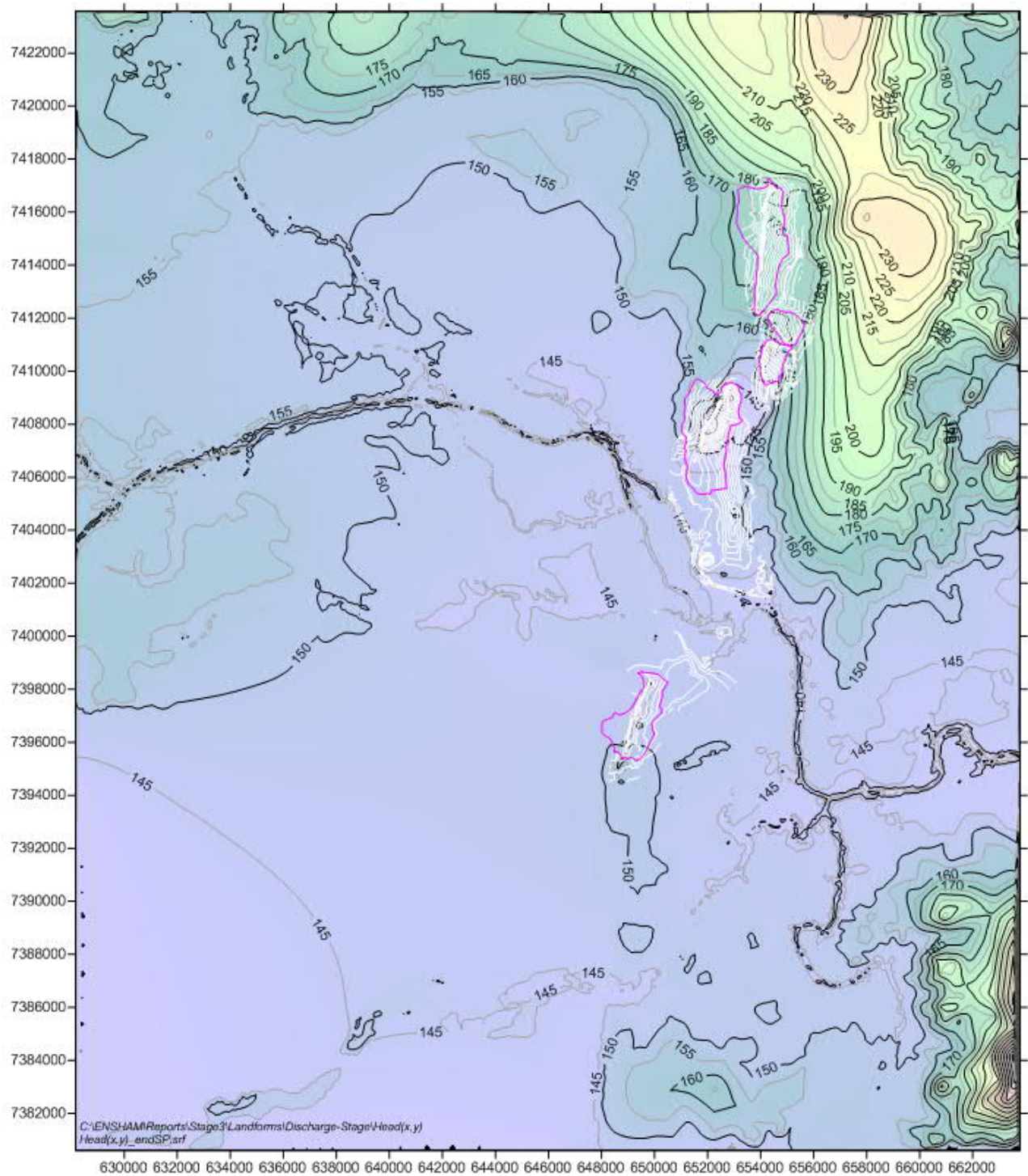
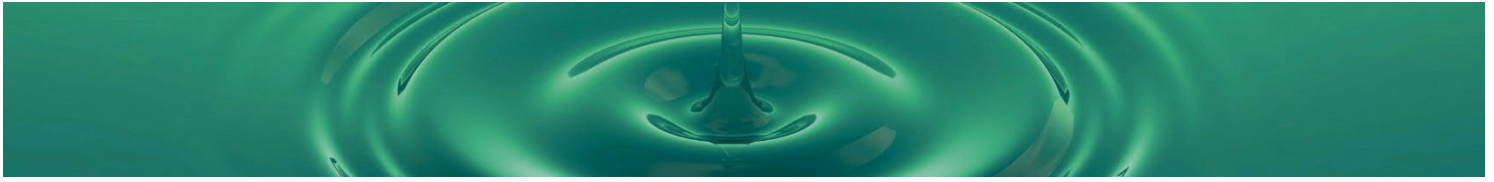


Figure 51. Simulated Option 3 equilibrium water table – 2260



APPENDIX A

Observation Groundwater Hydrographs

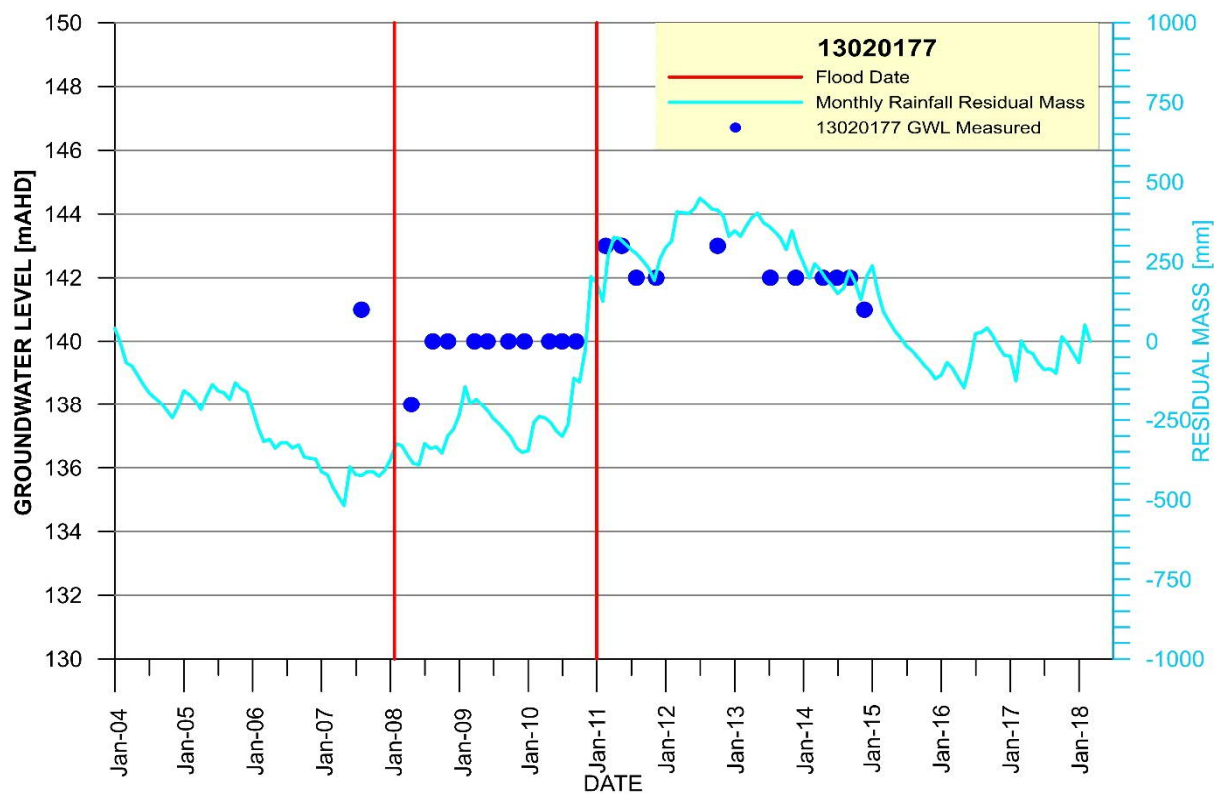


Figure A - 1: 13020177

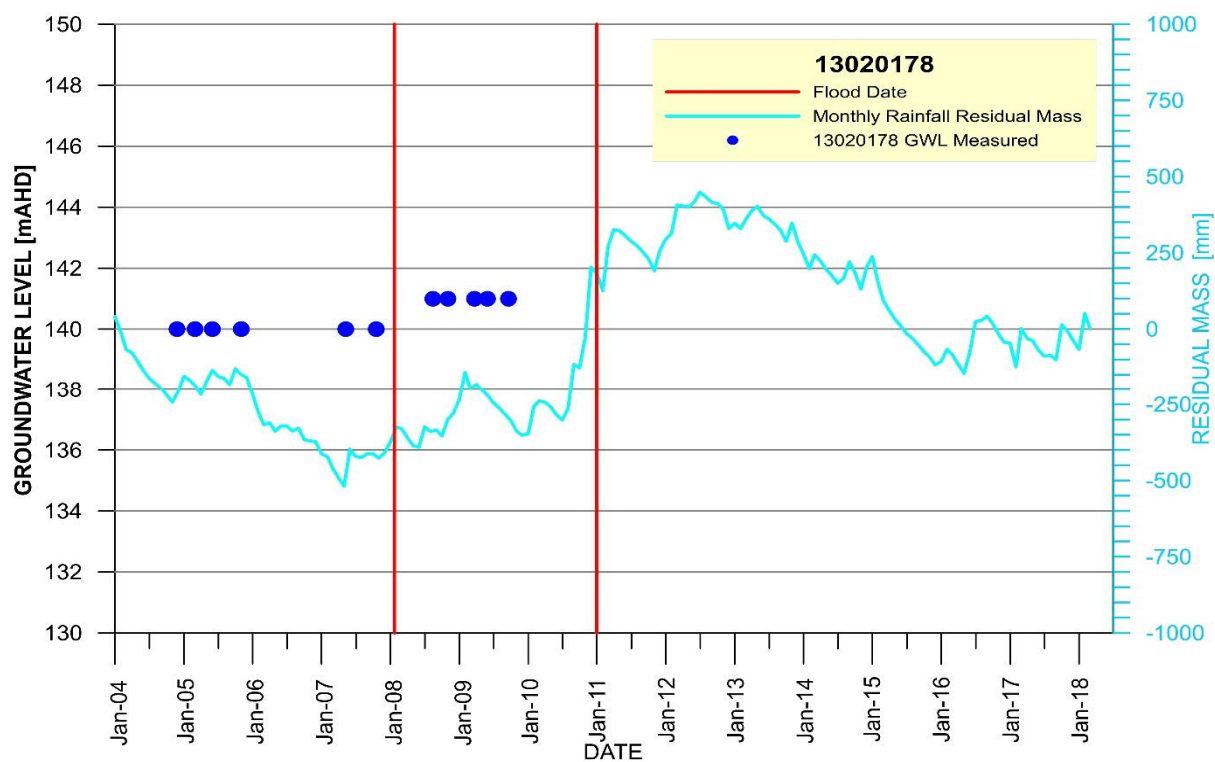


Figure A - 2: 13020178

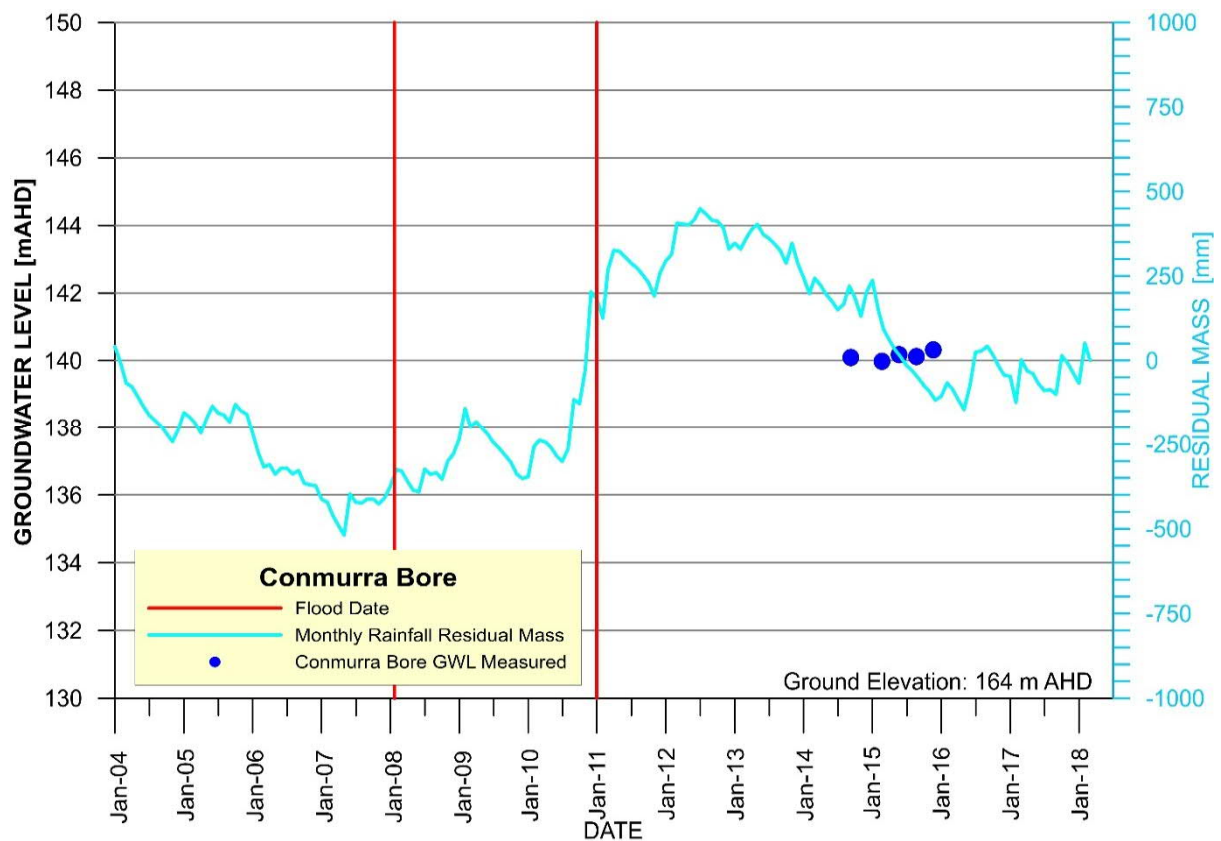


Figure A - 3: Conmurra Bore

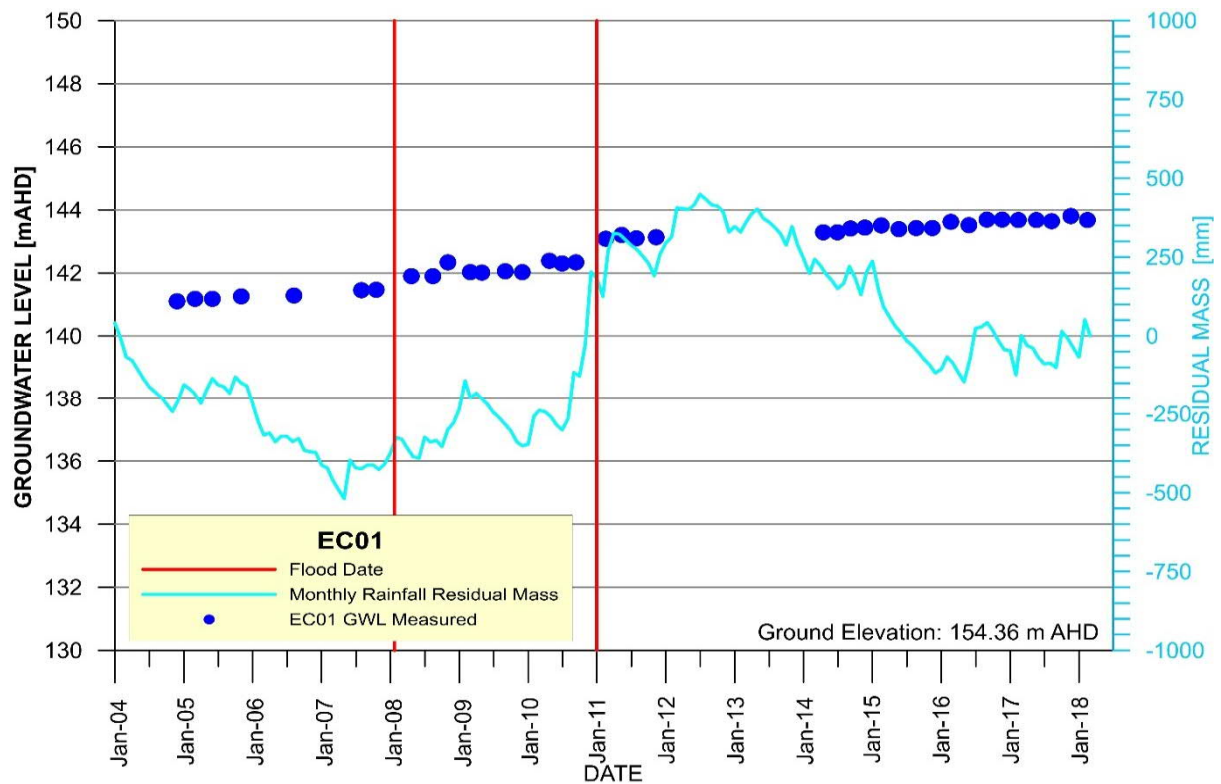


Figure A - 4: EC01

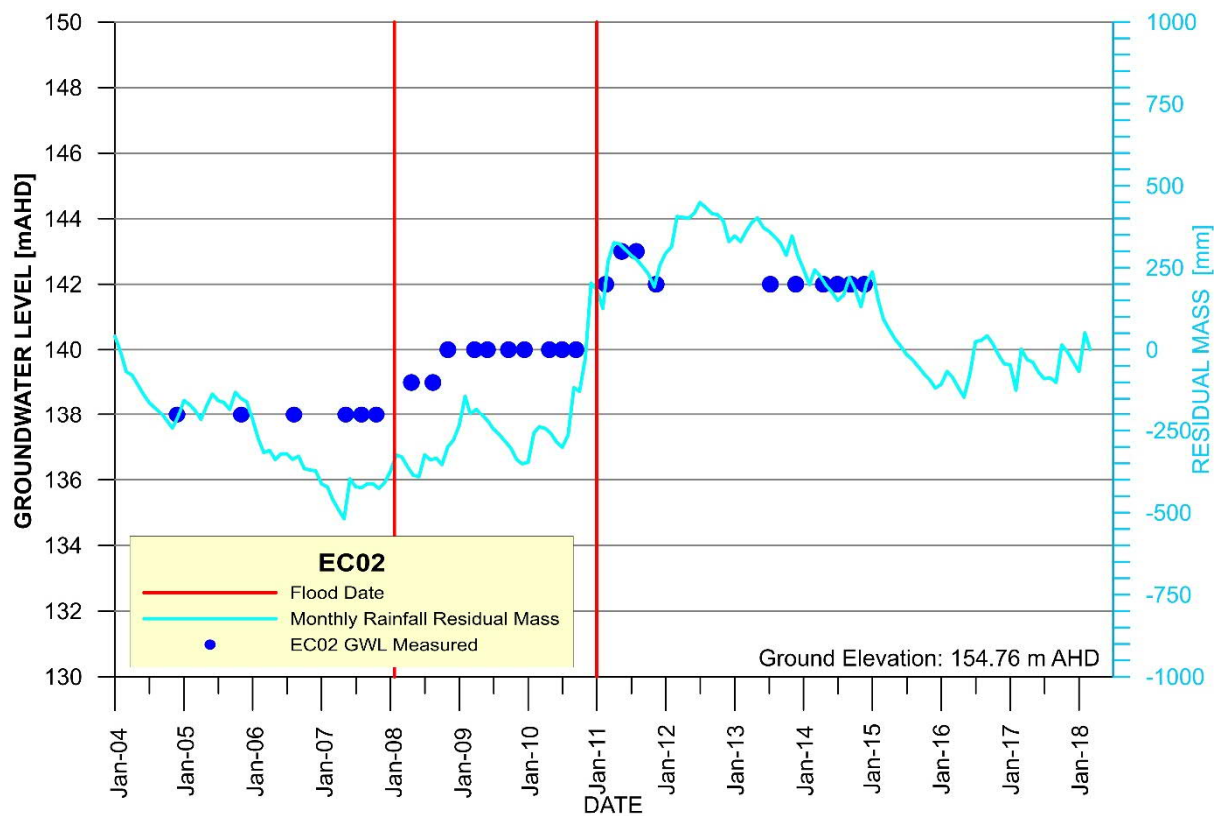


Figure A - 5: EC02

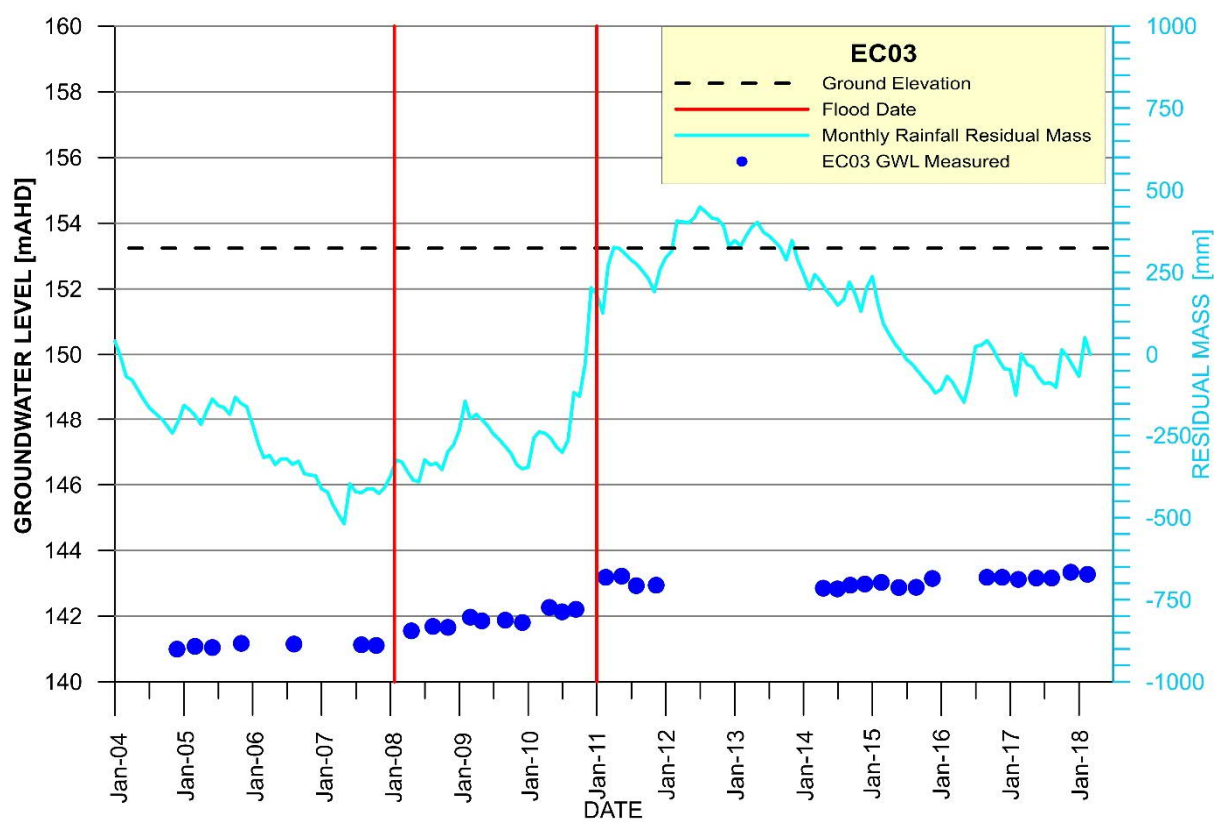


Figure A - 6: EC03

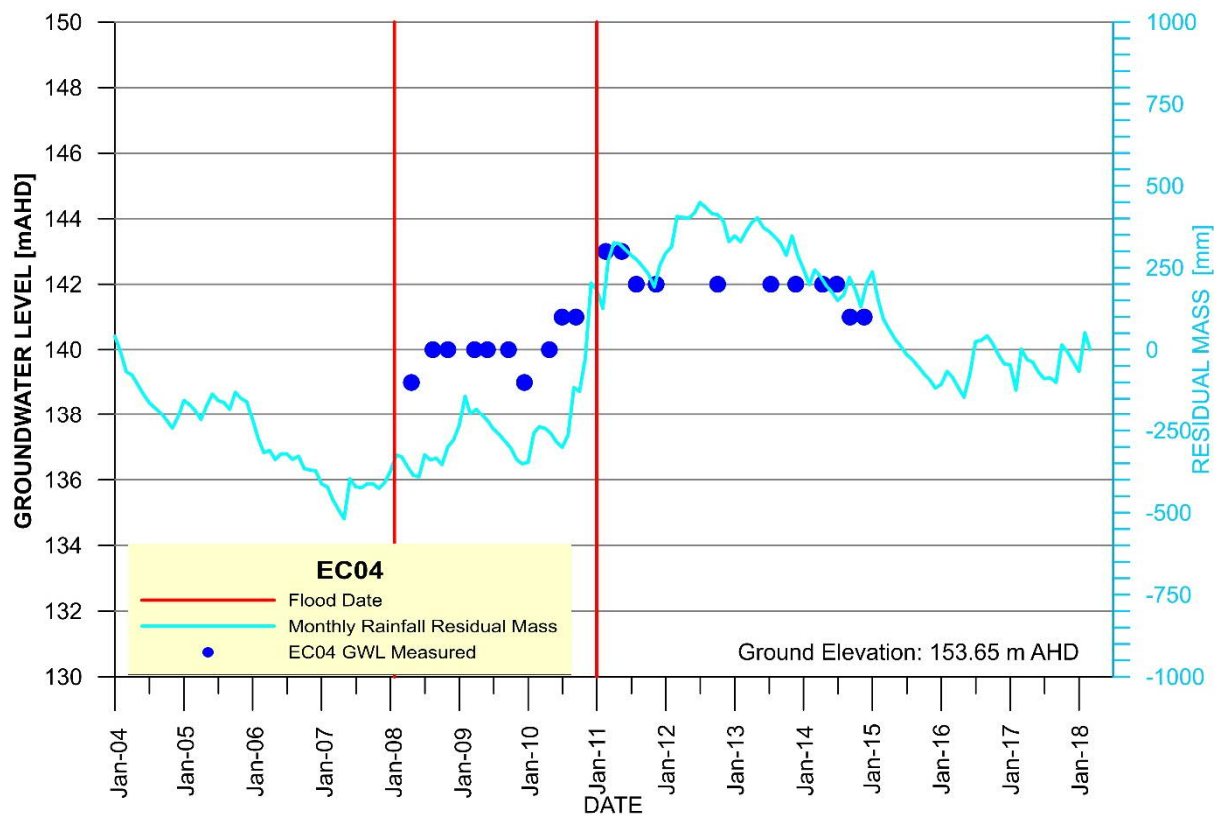


Figure A - 7: EC04

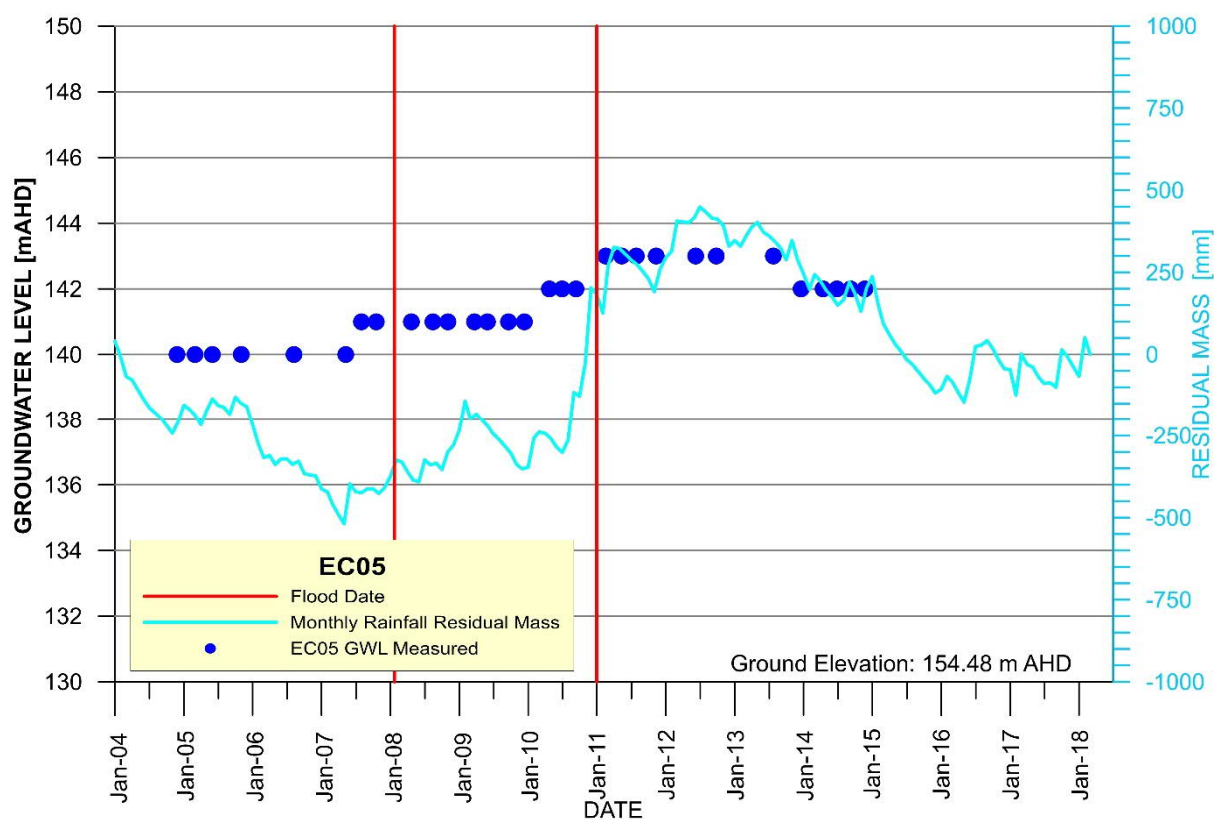


Figure A - 8: EC05

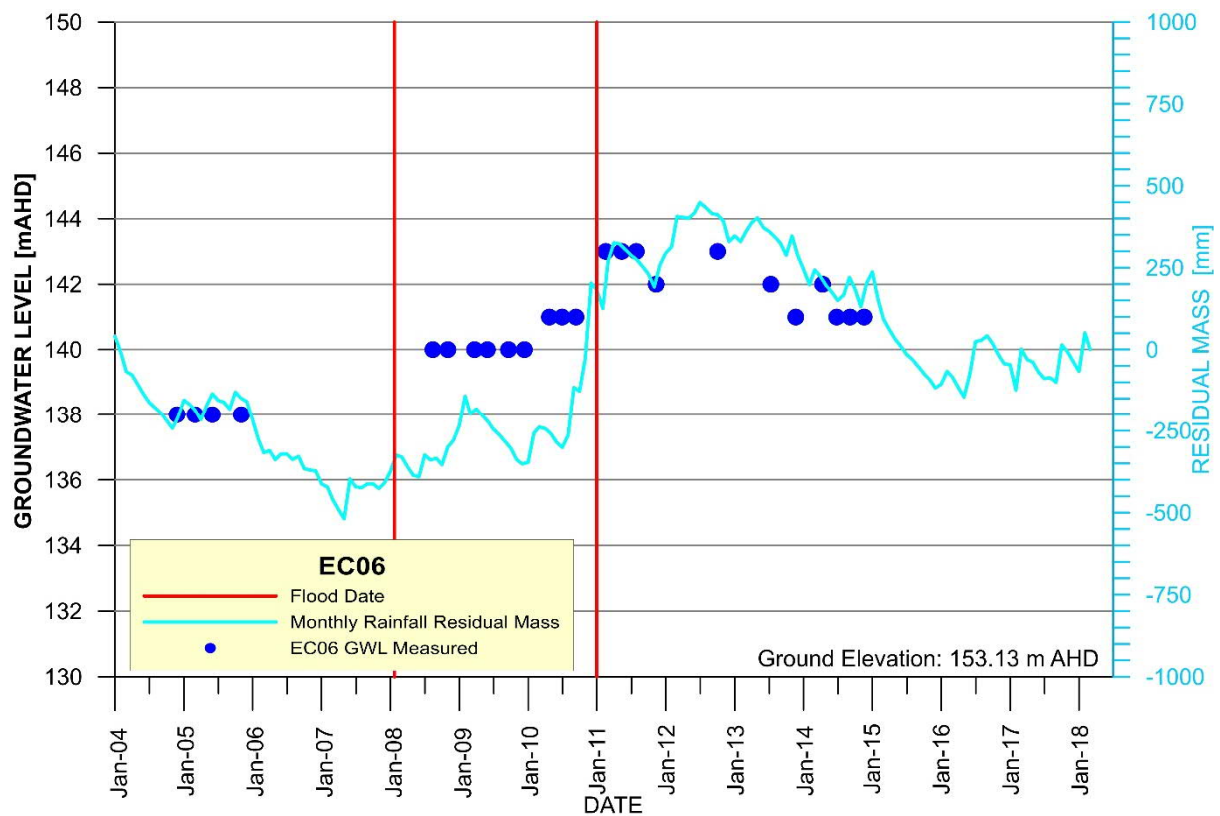


Figure A - 9: EC09

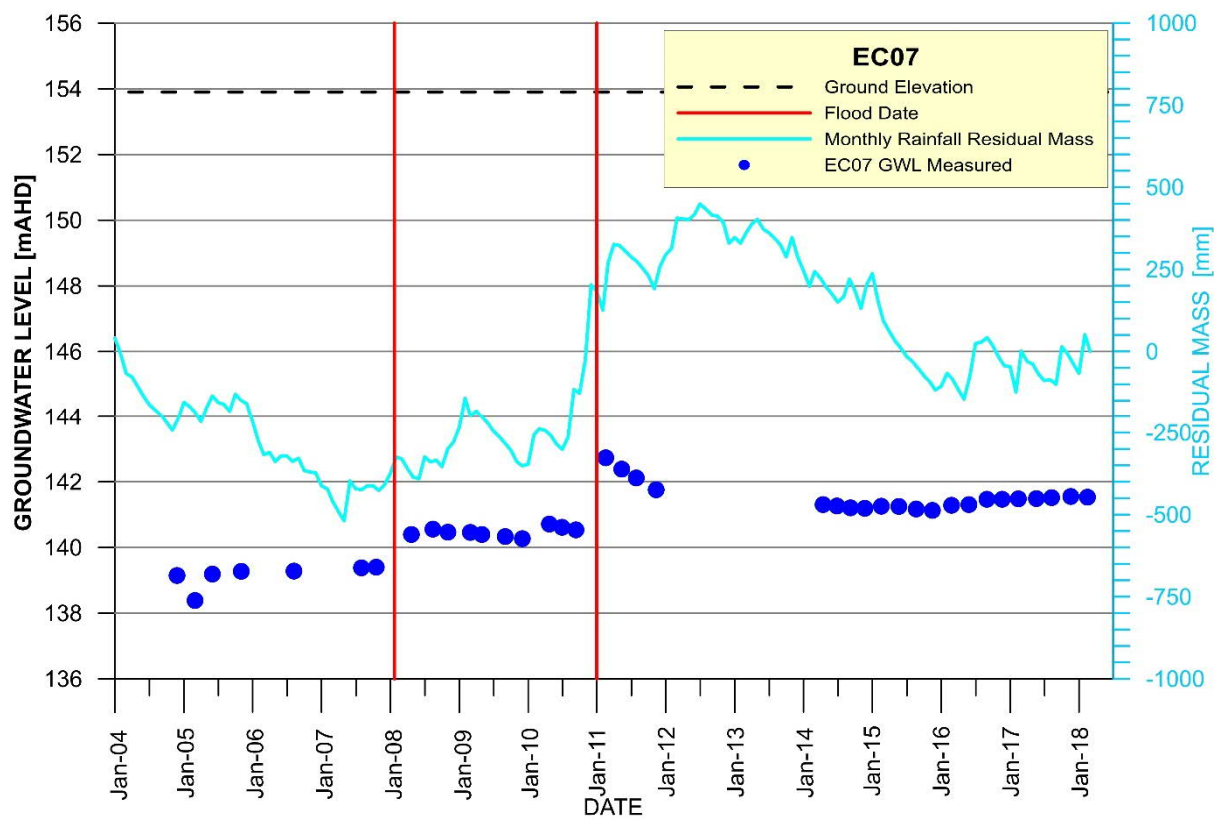


Figure A - 10: EC07

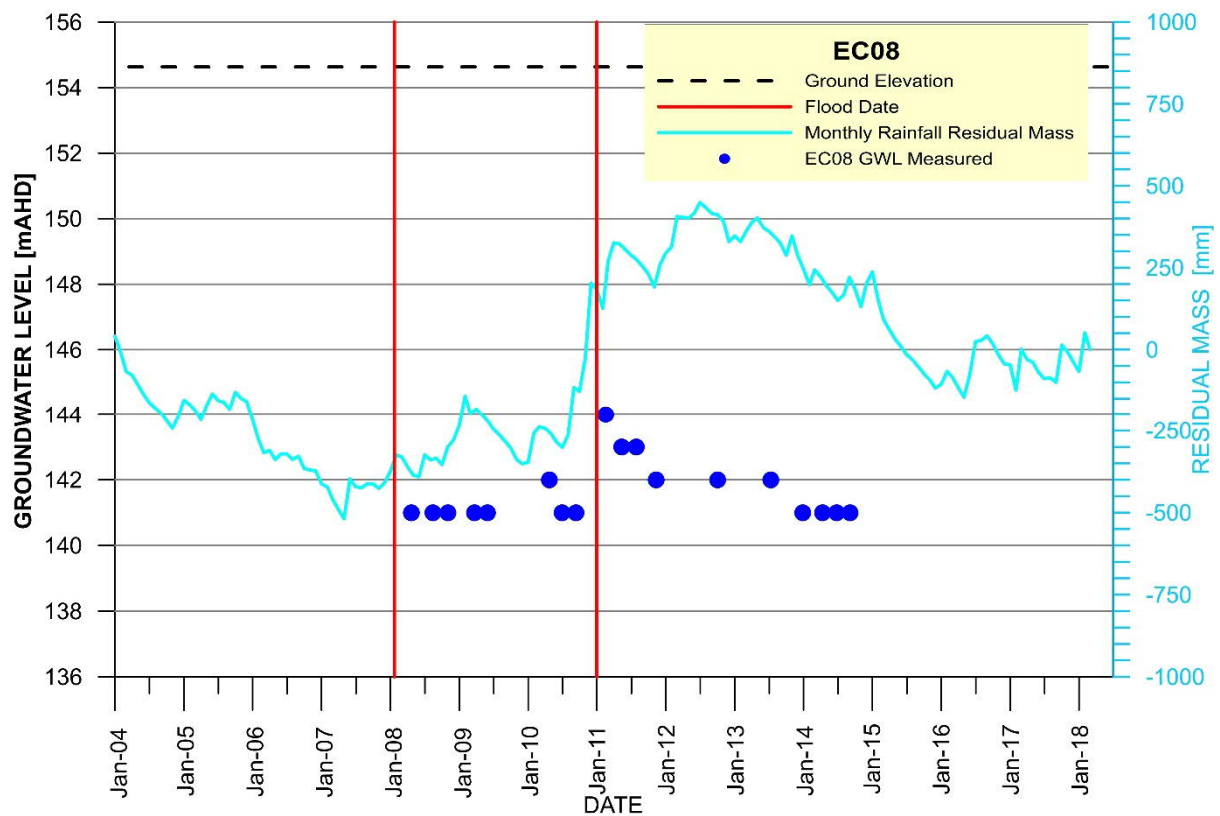


Figure A - 11: EC08

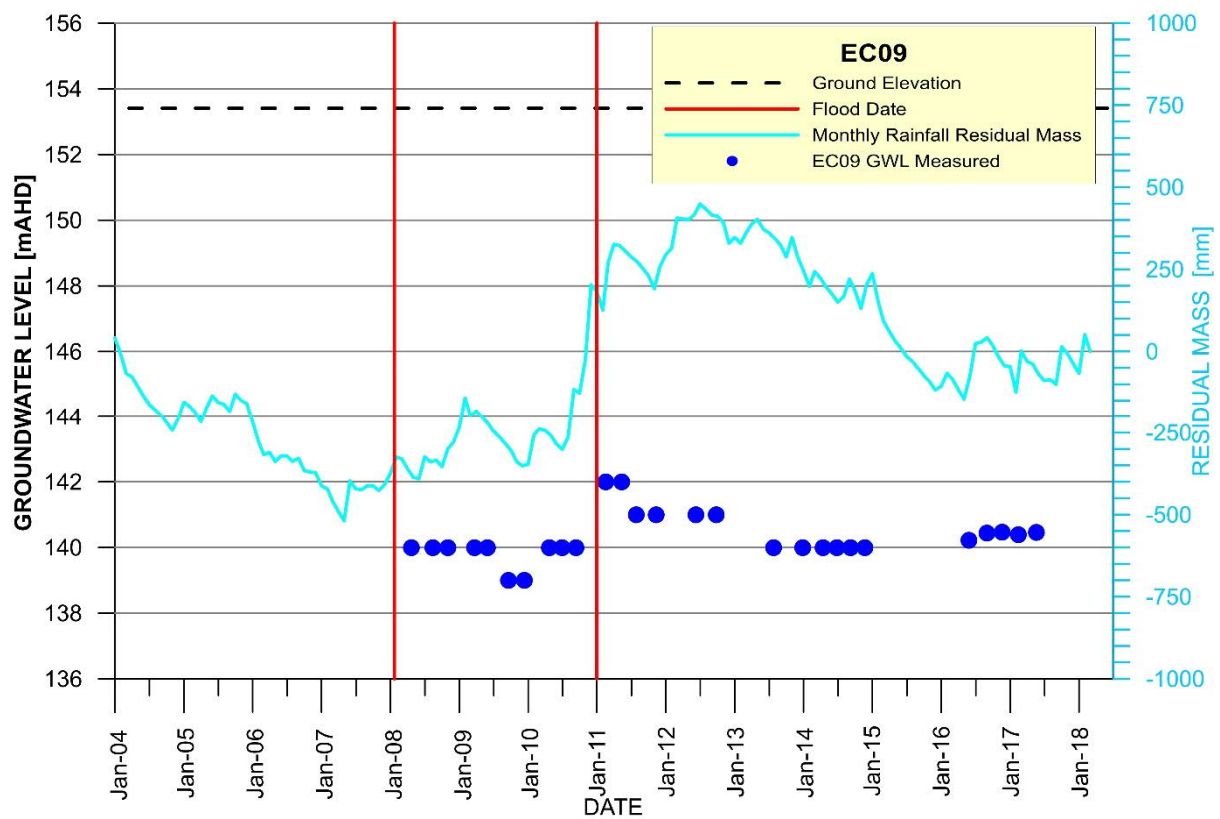


Figure A - 12: EC09

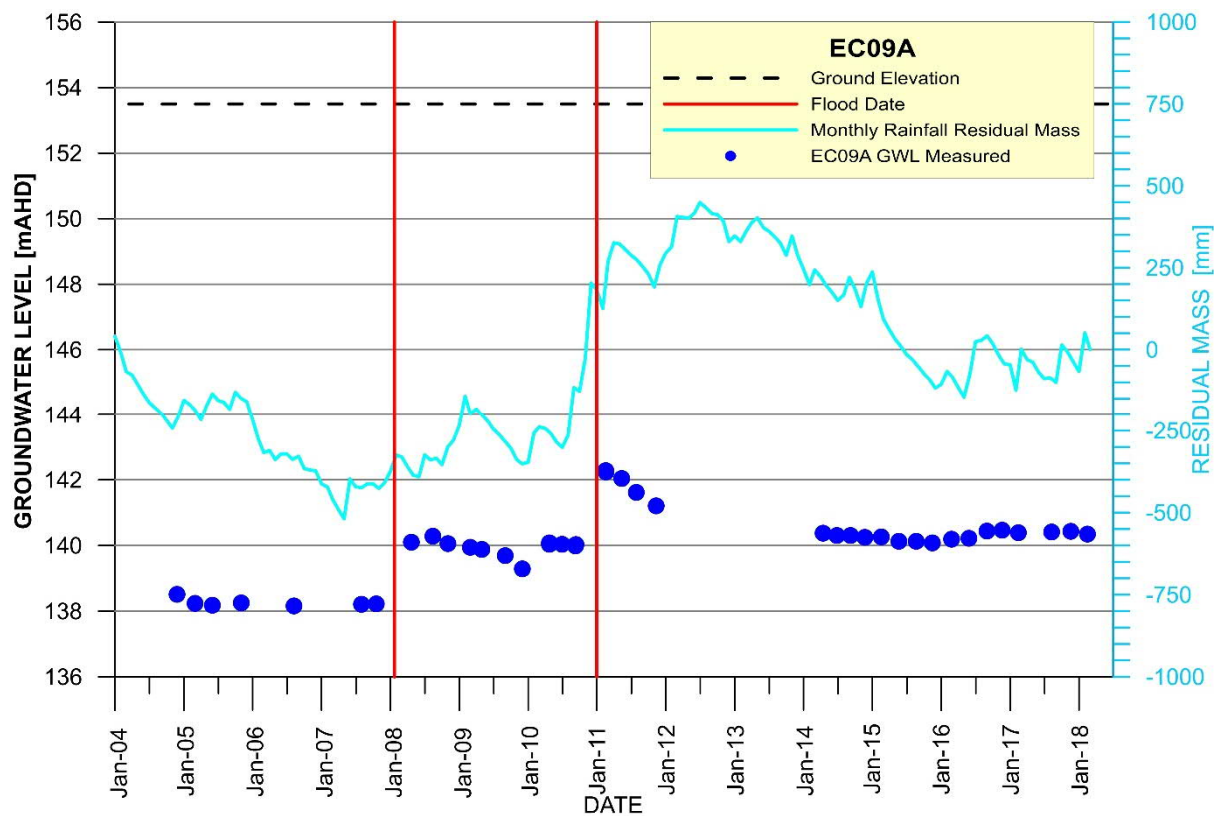


Figure A - 13: EC09A

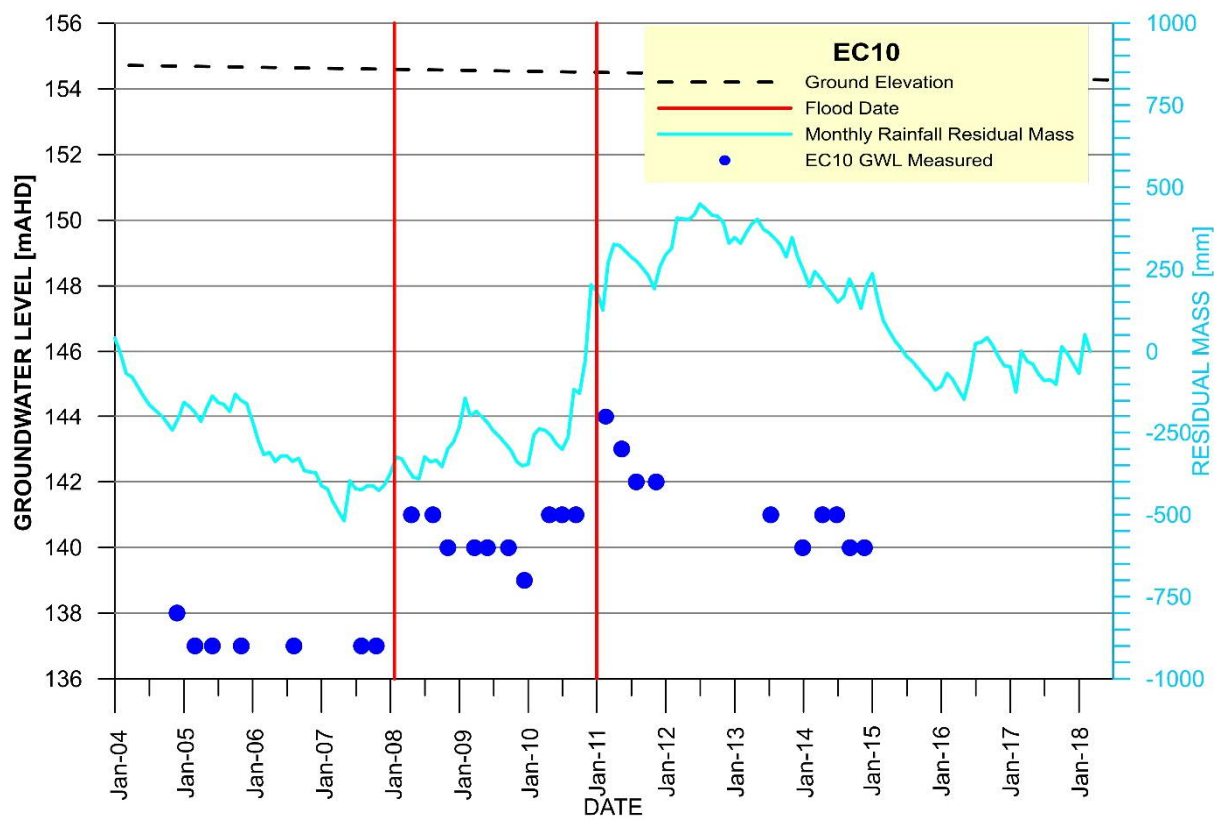


Figure A - 14: EC10

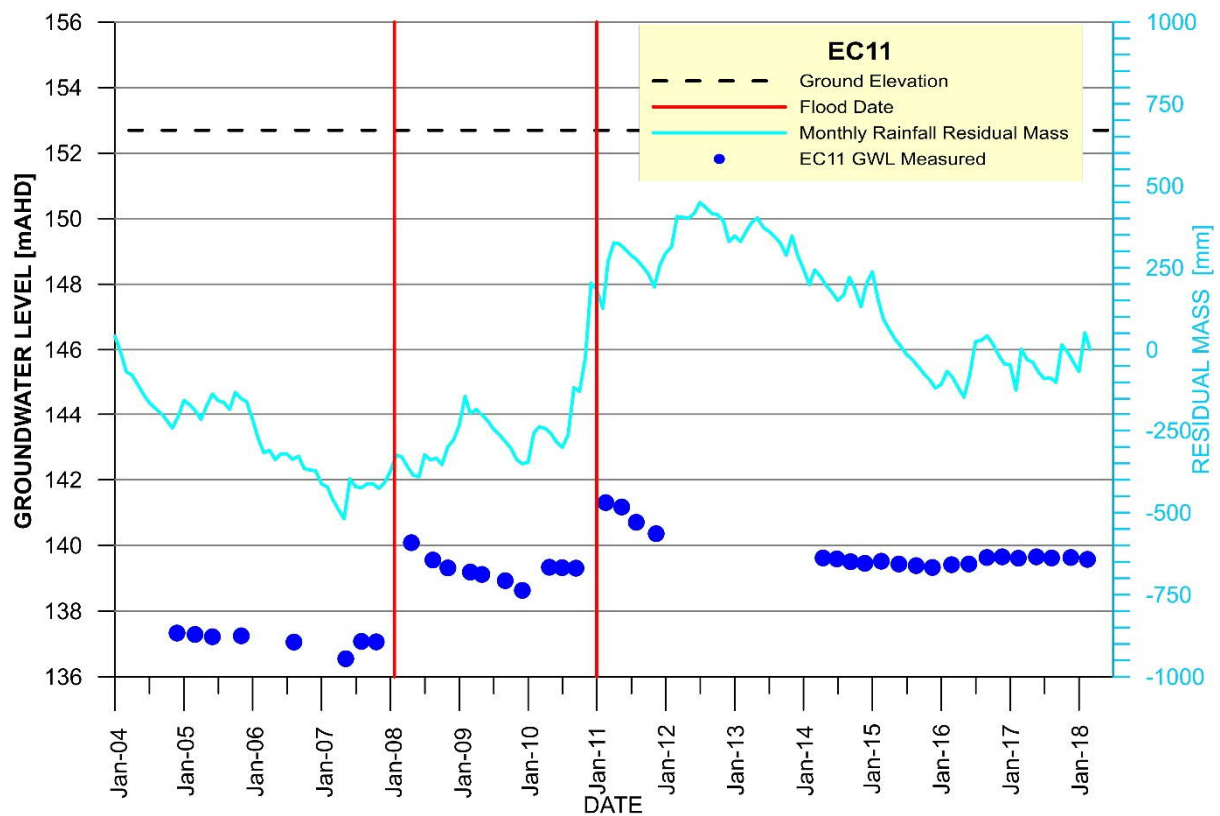


Figure A - 15: EC11

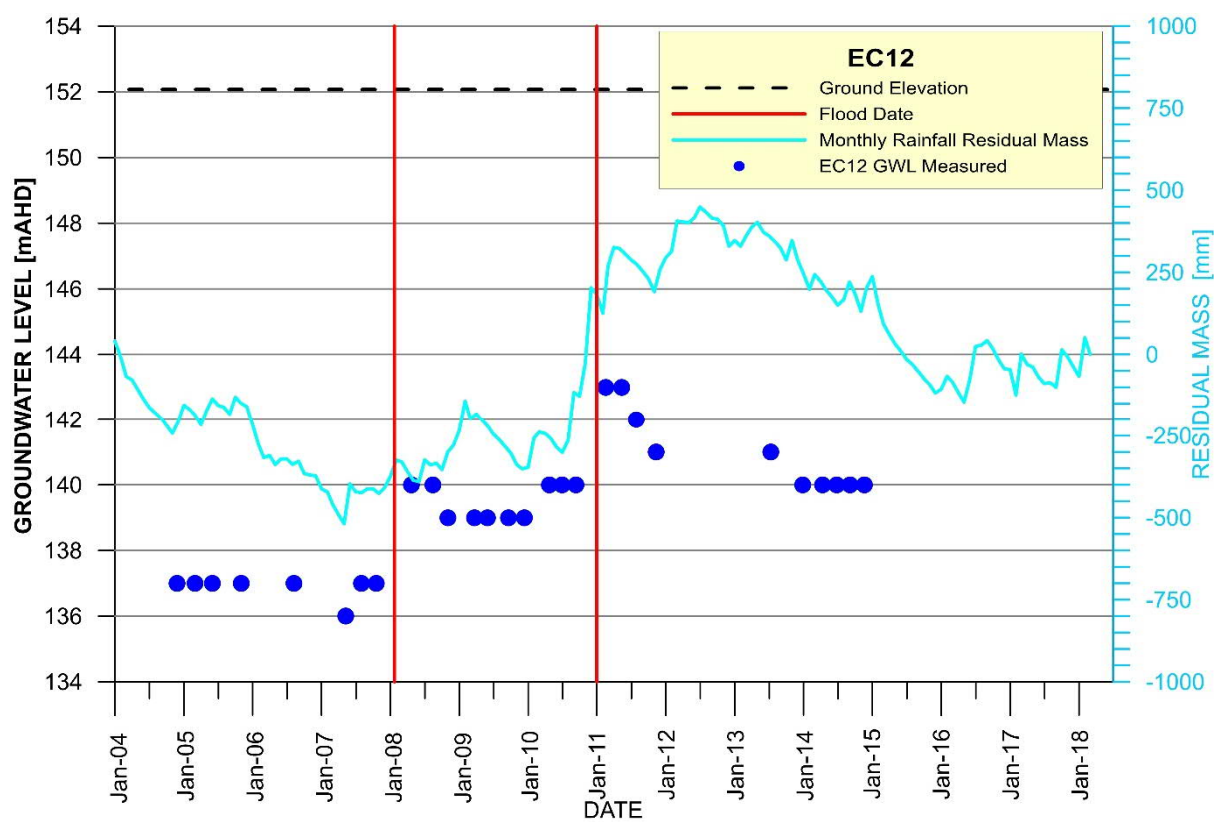


Figure A - 16: EC12

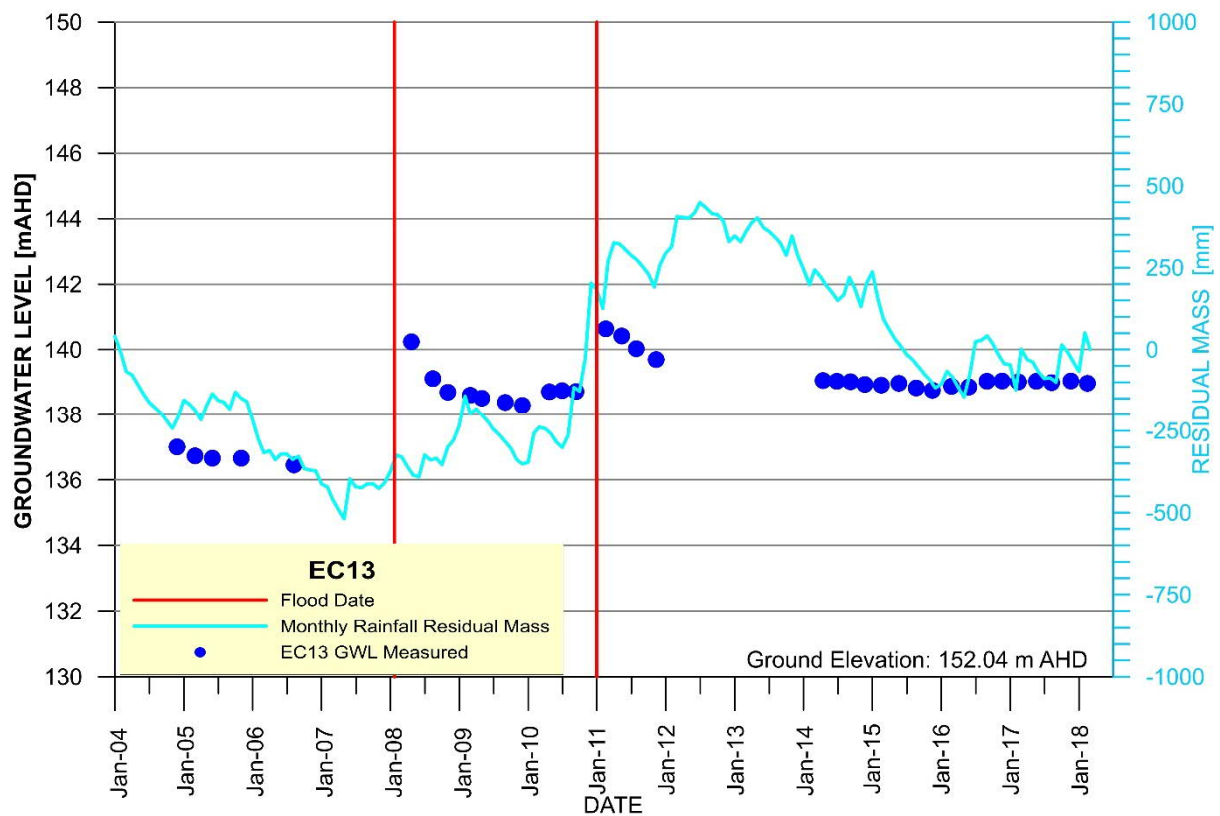


Figure A - 17: EC13

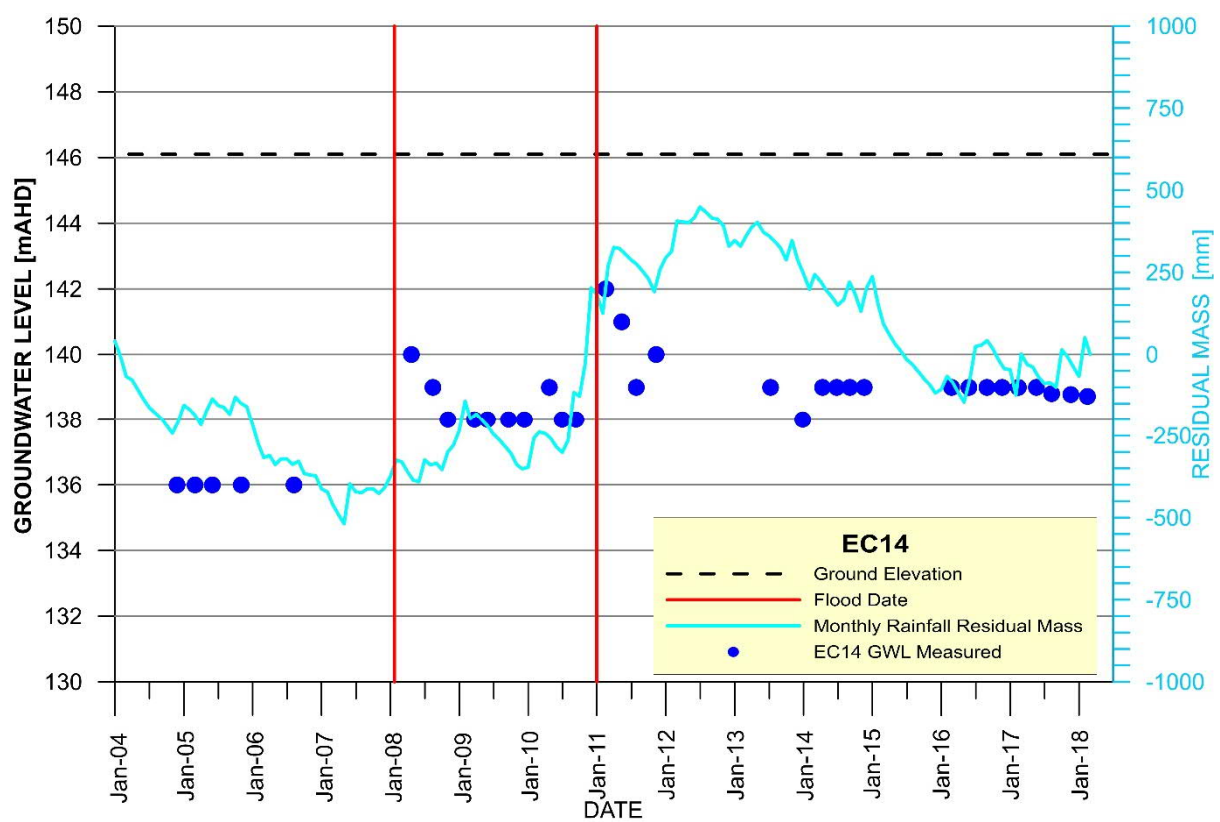


Figure A - 18: EC14

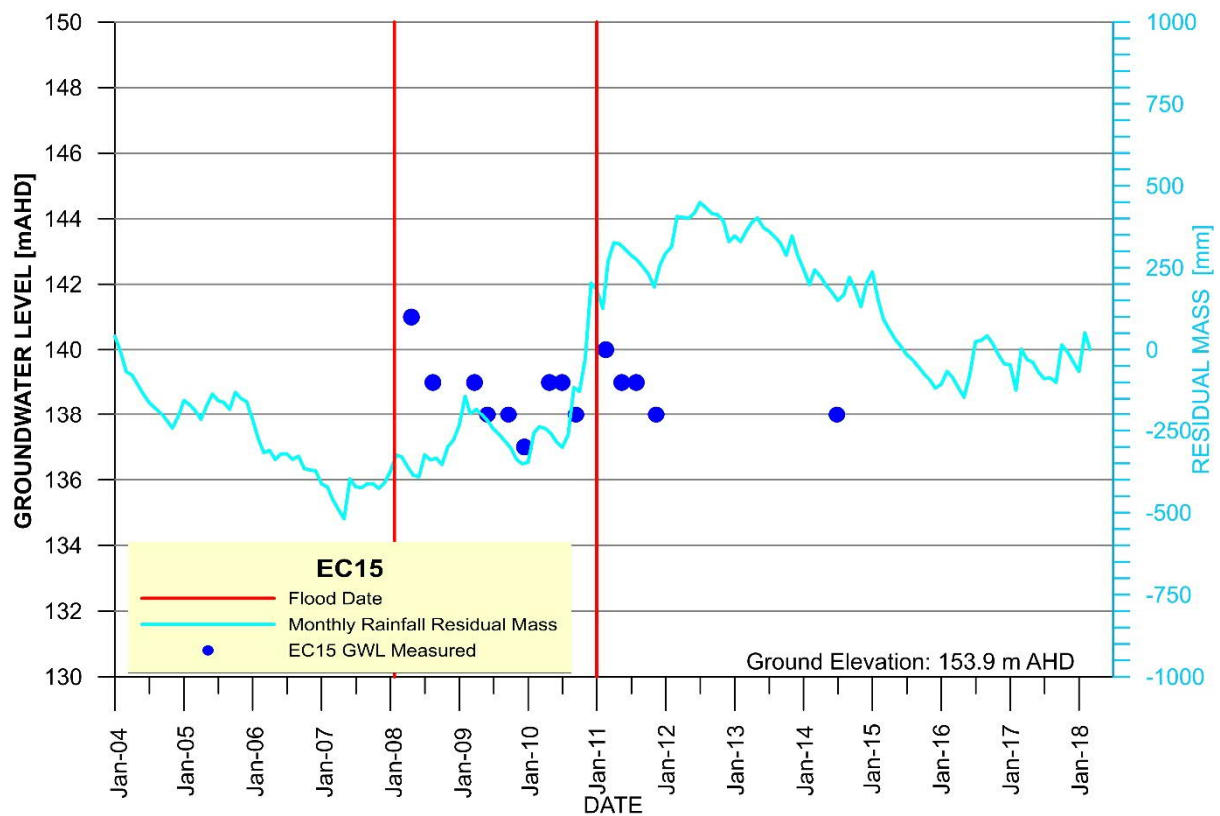


Figure A - 19: EC15

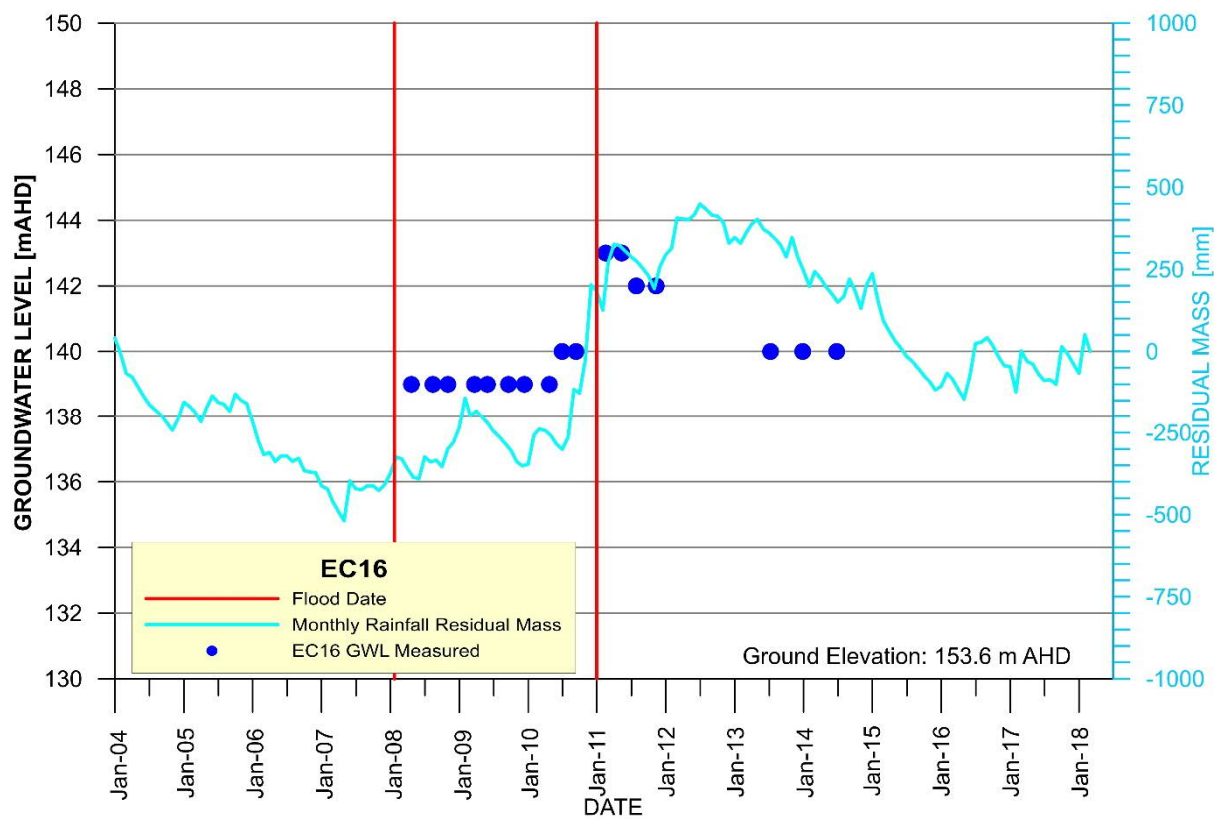


Figure A - 20: EC16

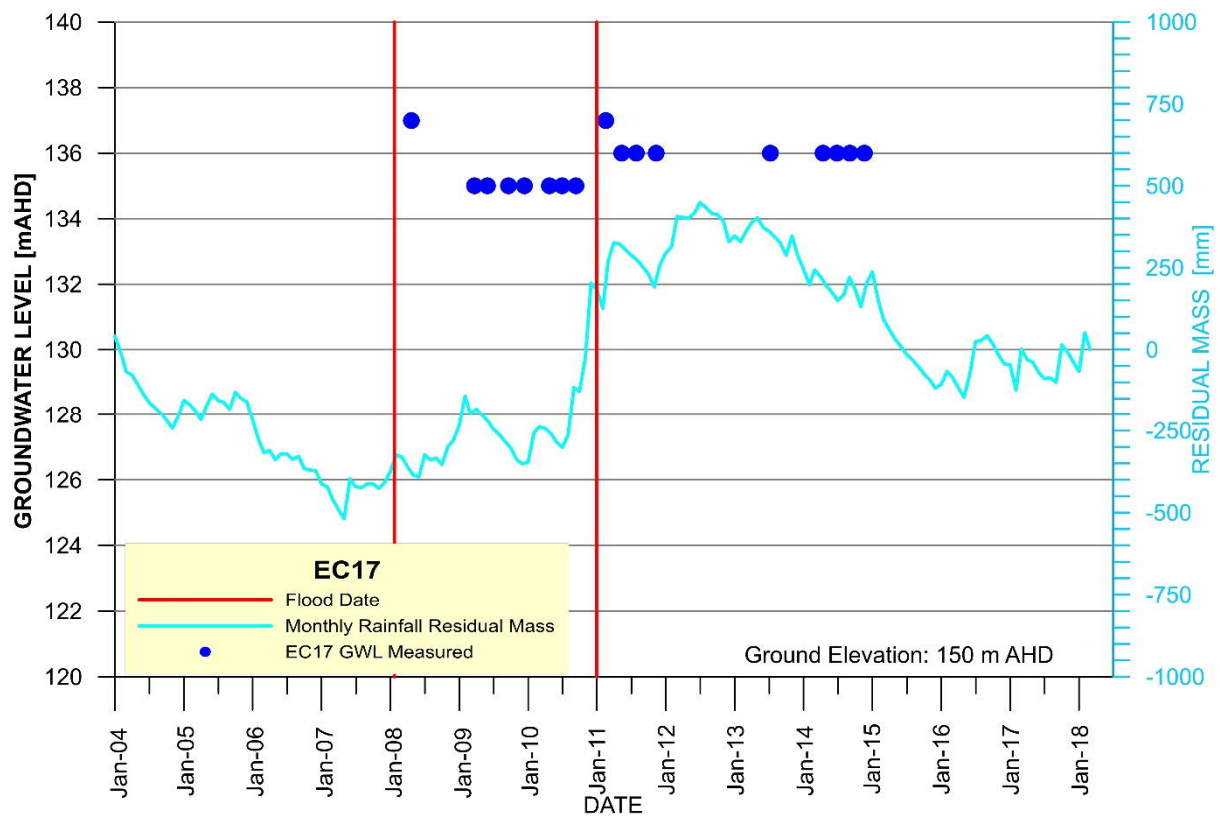


Figure A - 21: EC17

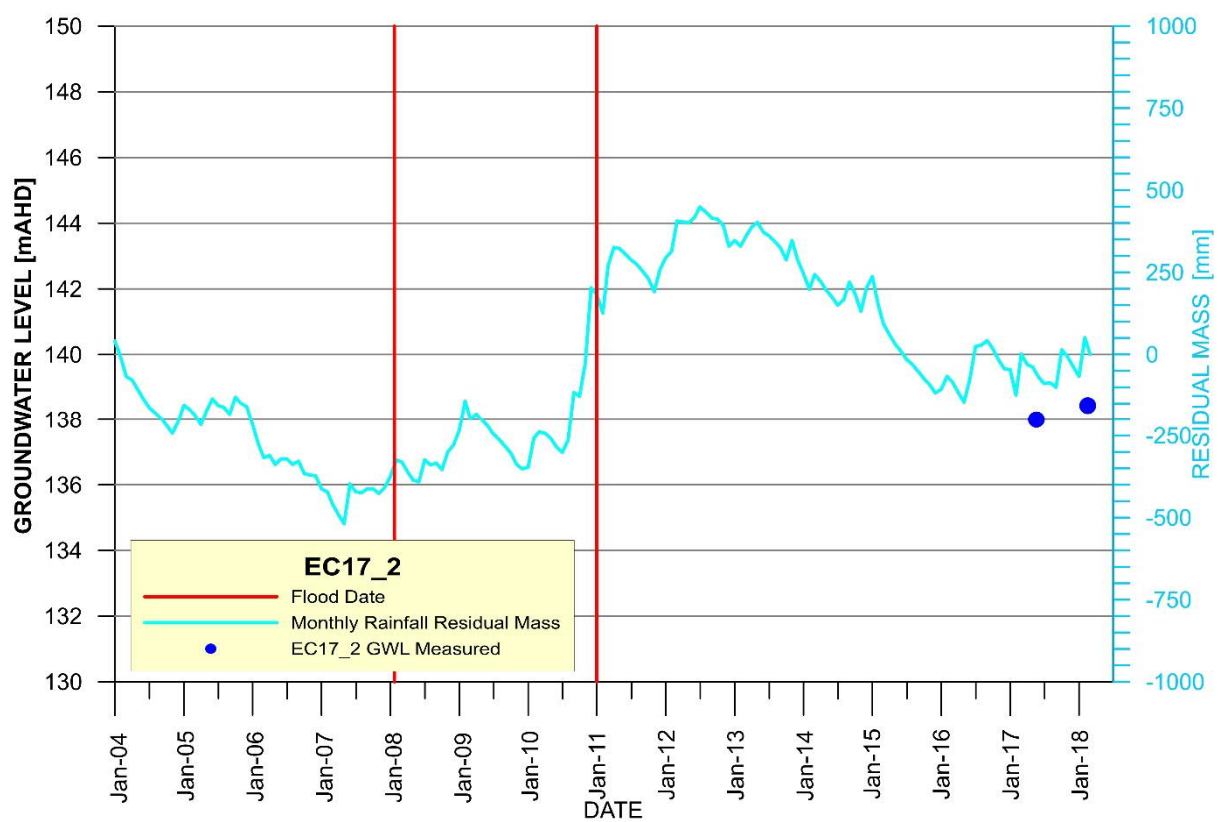


Figure A - 22: EC17_2

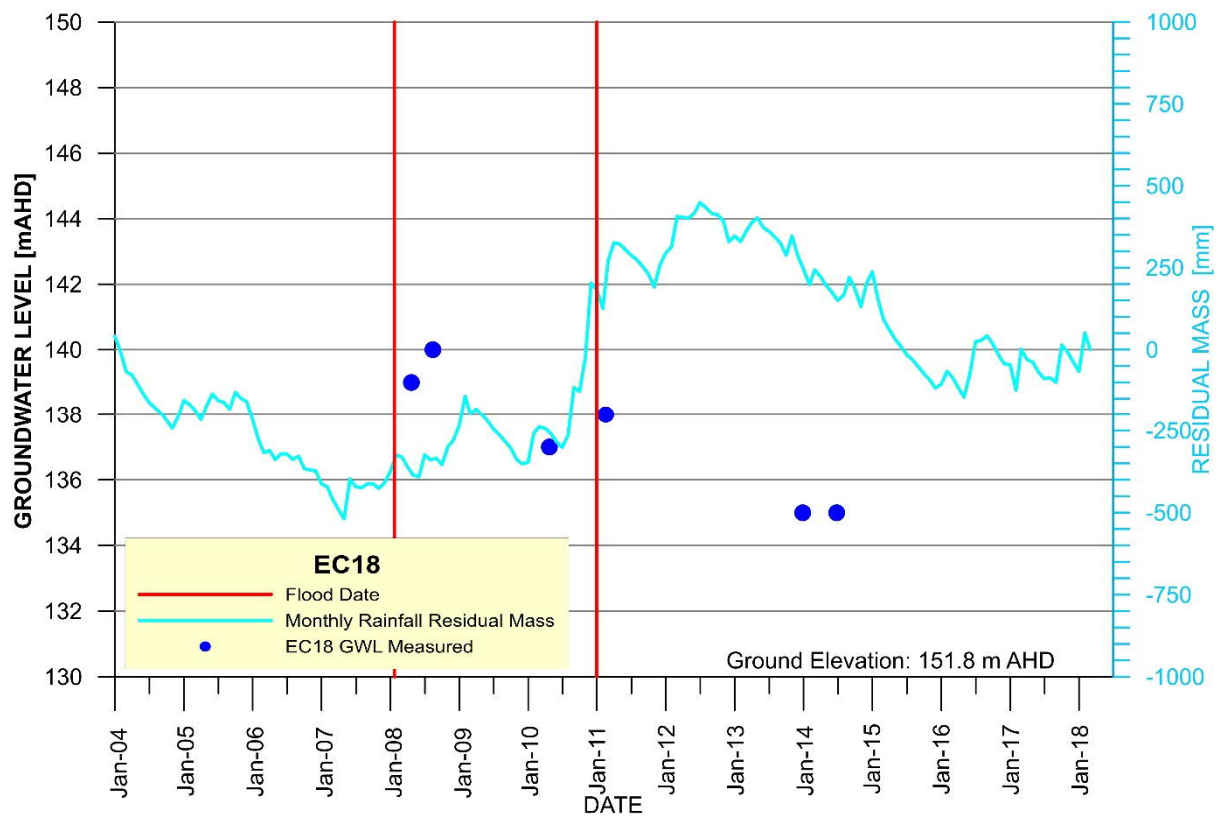


Figure A - 23: EC18

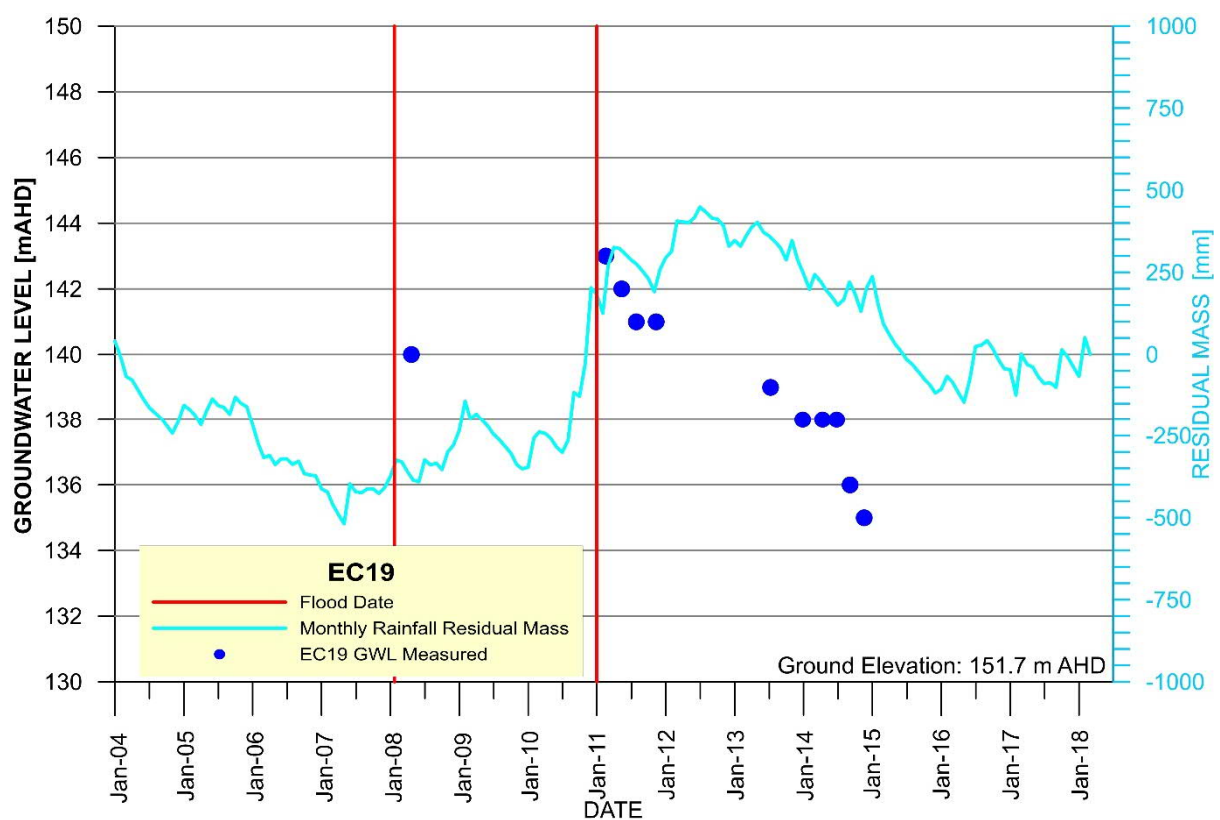


Figure A - 24: EC19

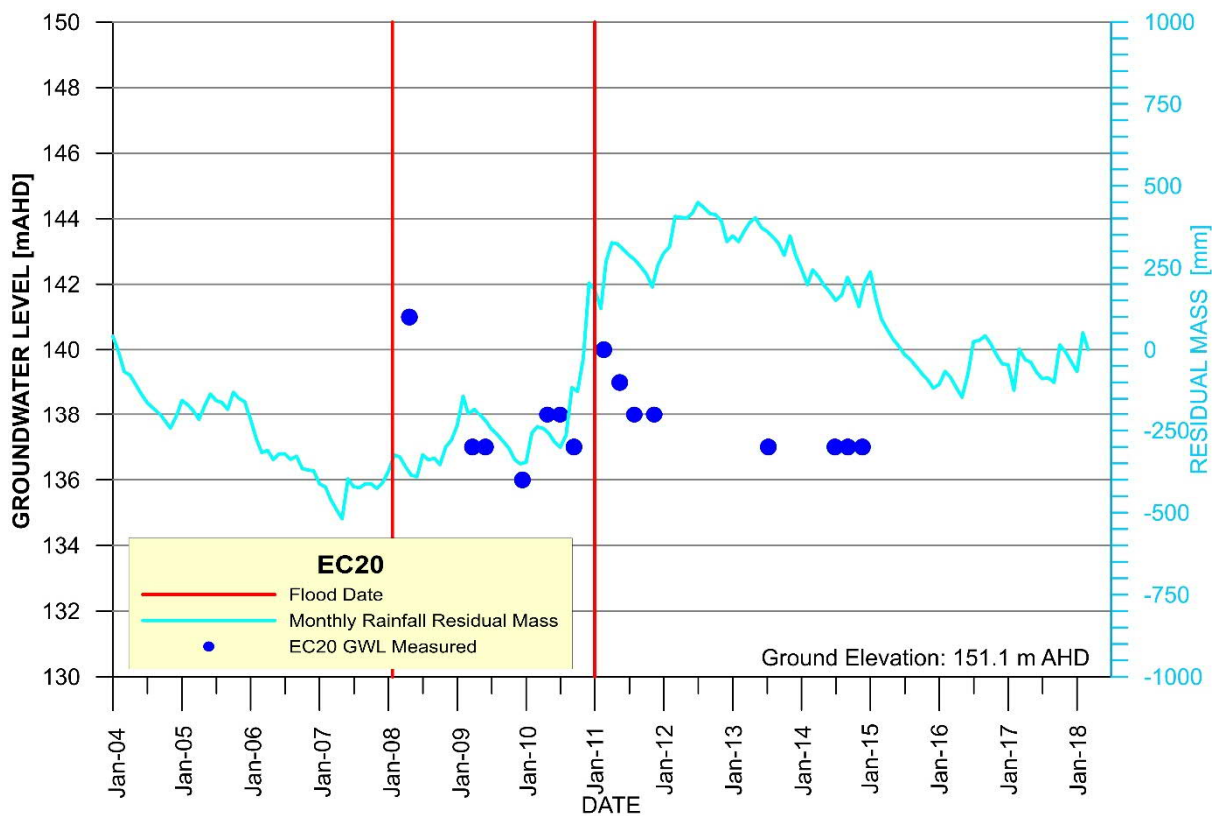


Figure A - 25: EC20

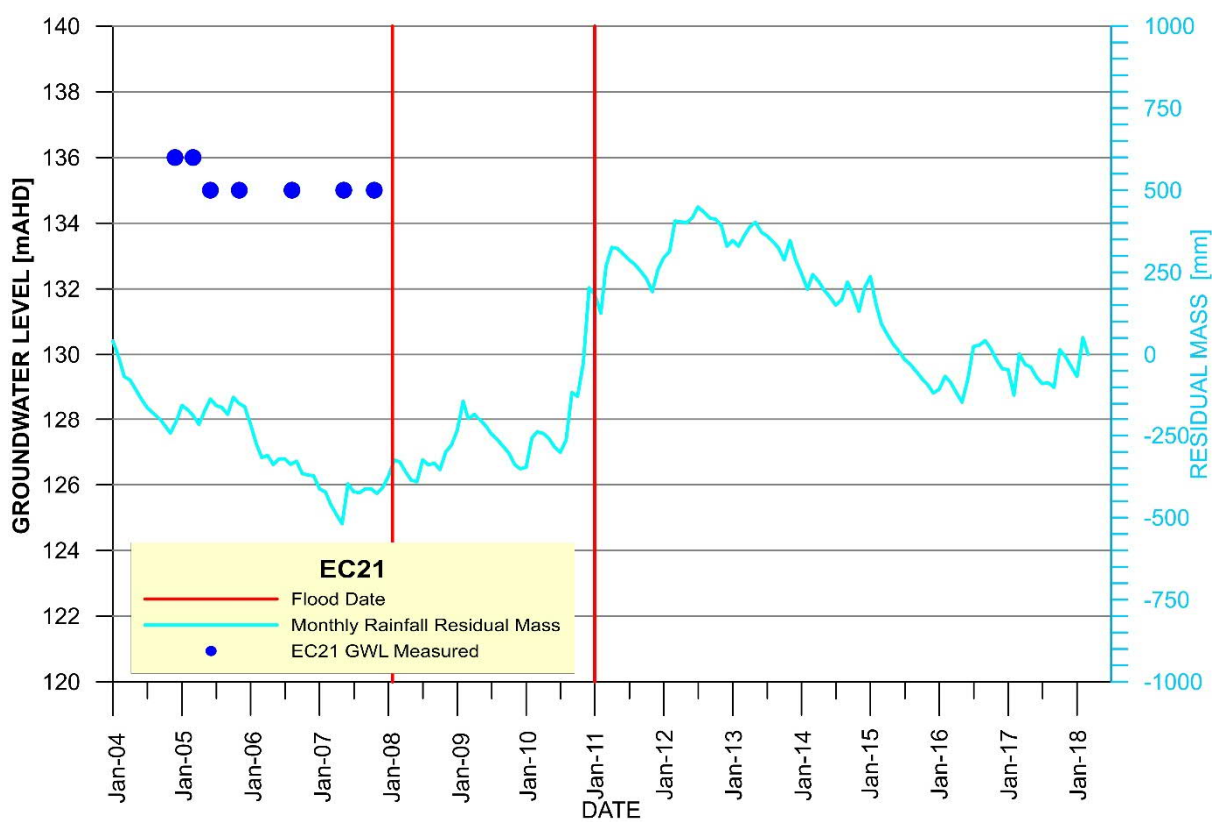


Figure A - 26: EC21

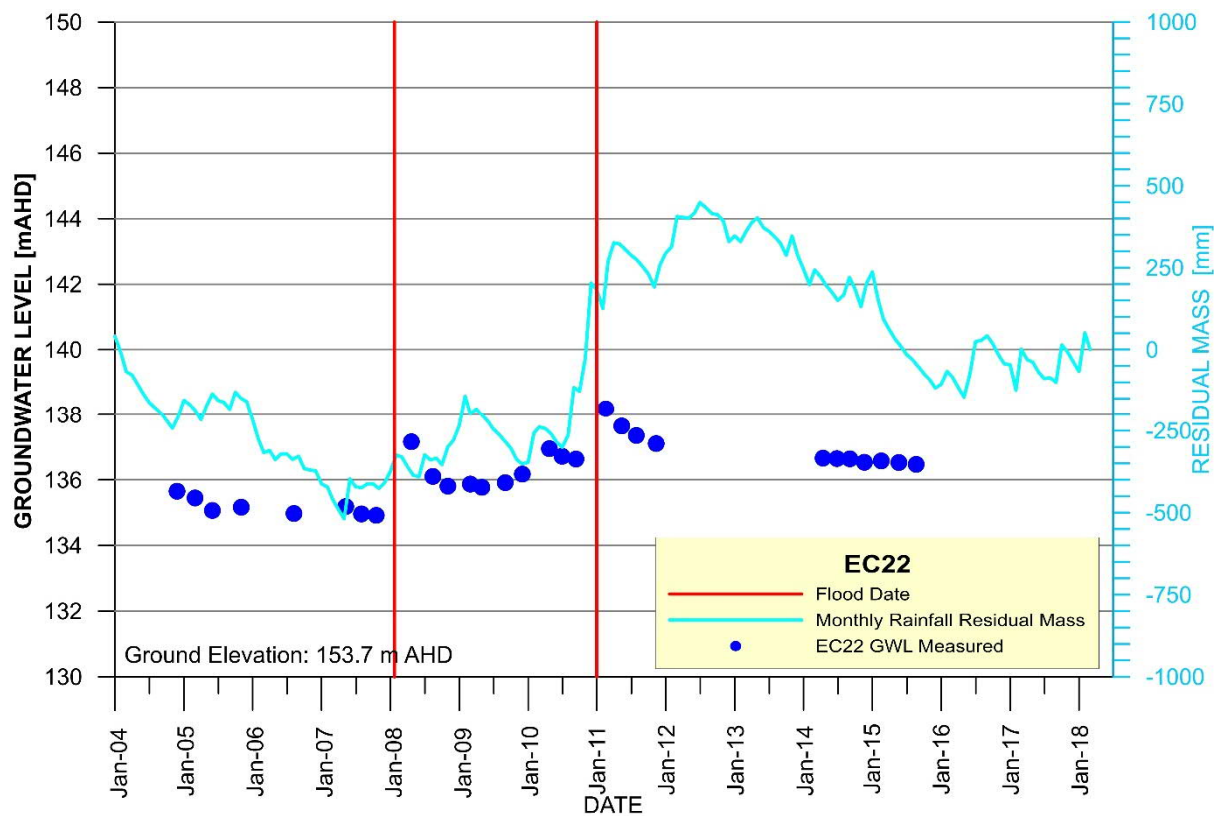


Figure A - 27: EC22

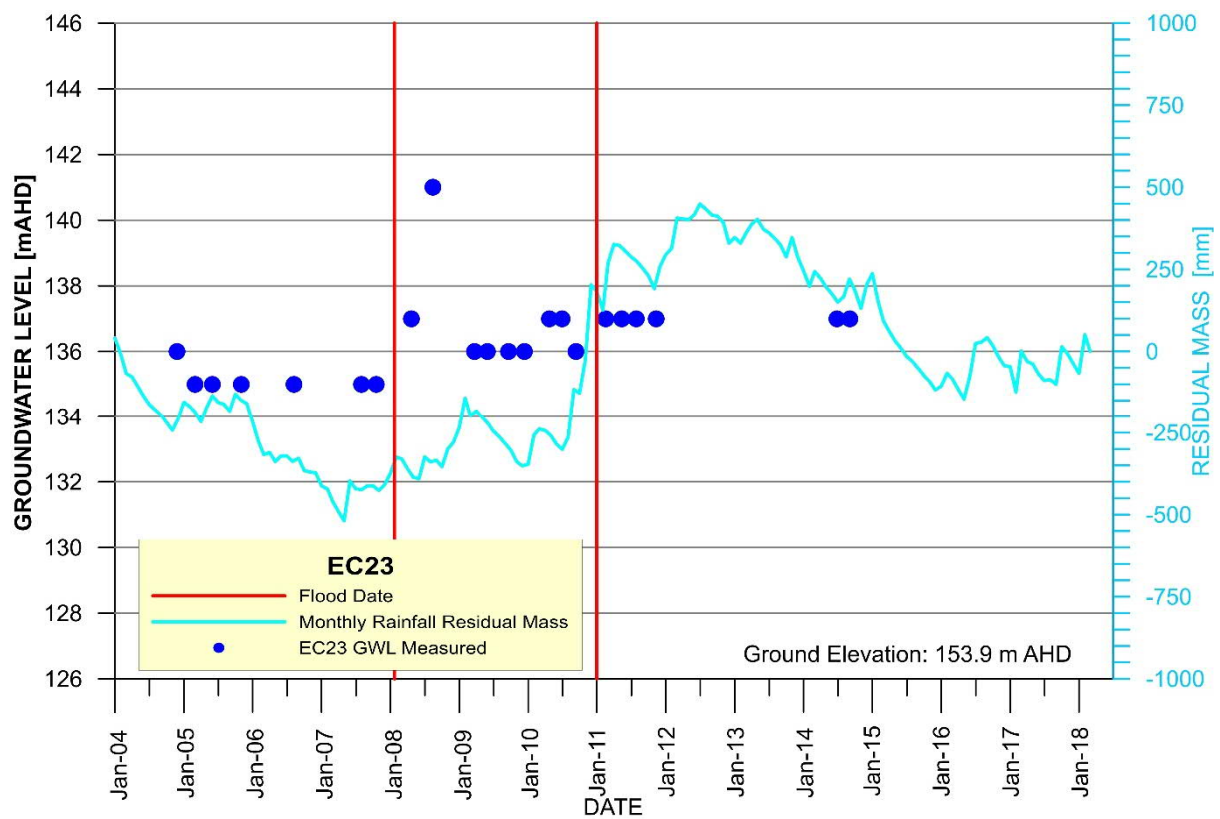


Figure A - 28: EC23

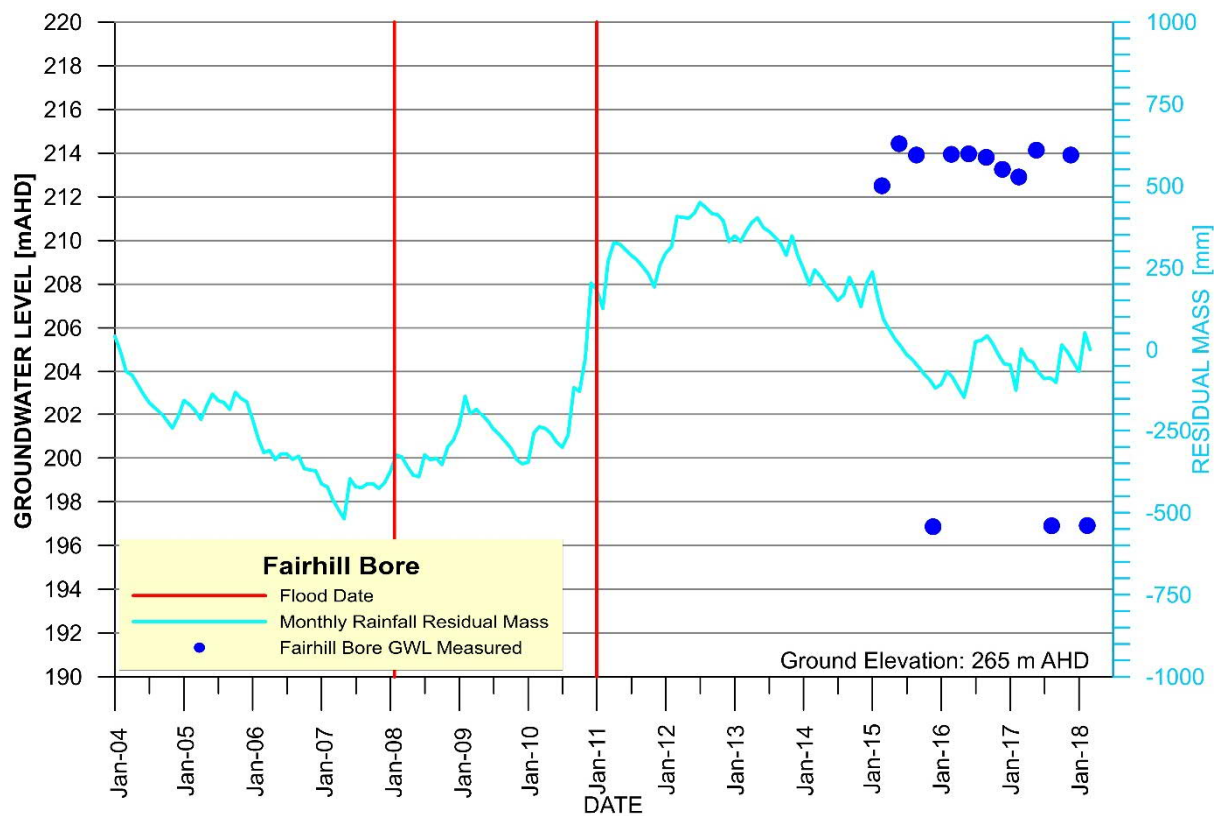


Figure A - 29: Fairhill Bore

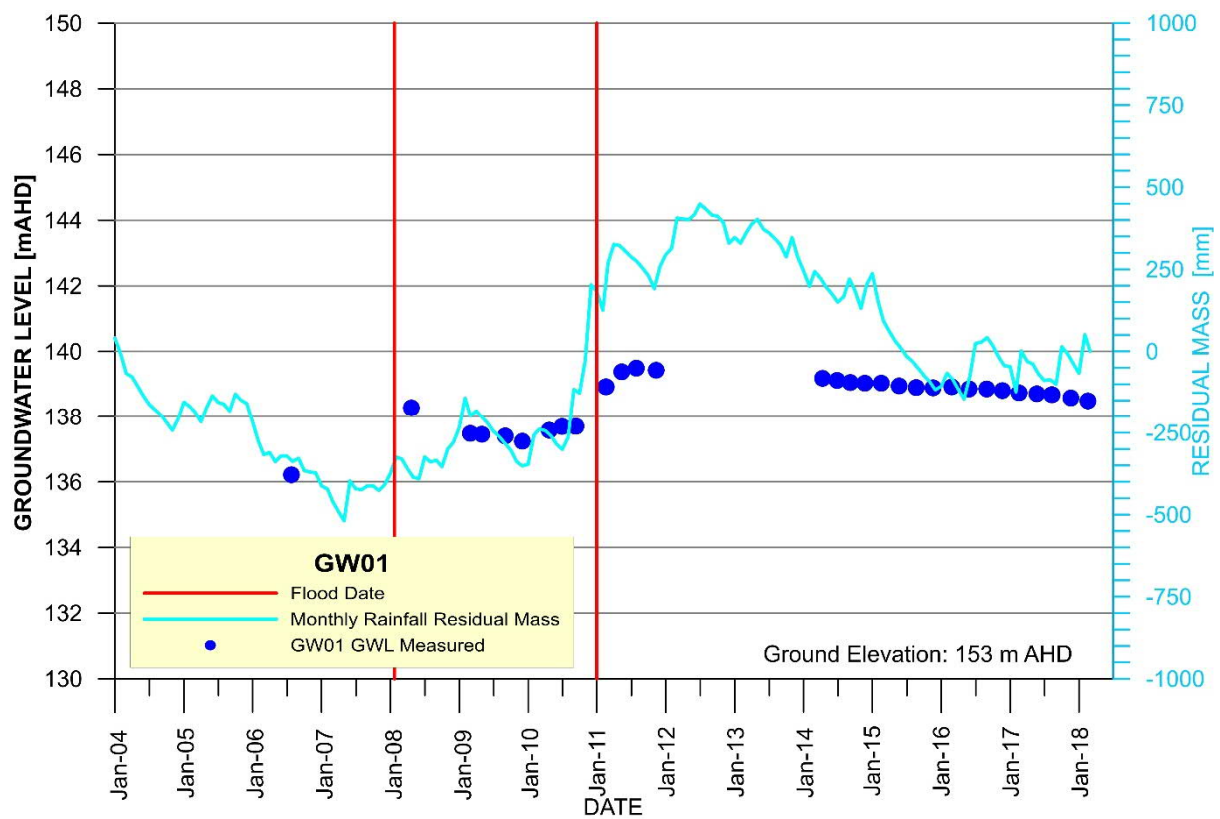


Figure A - 30: GW01

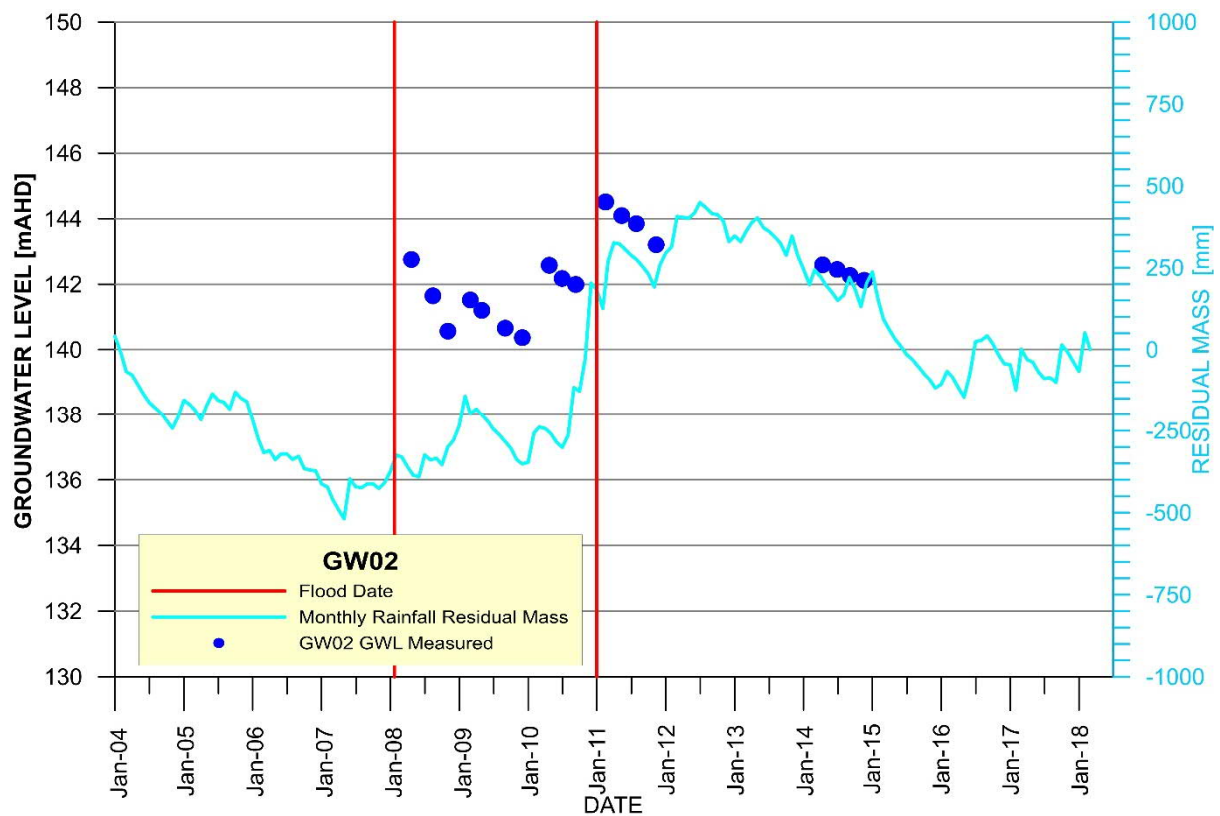


Figure A - 31: GW02

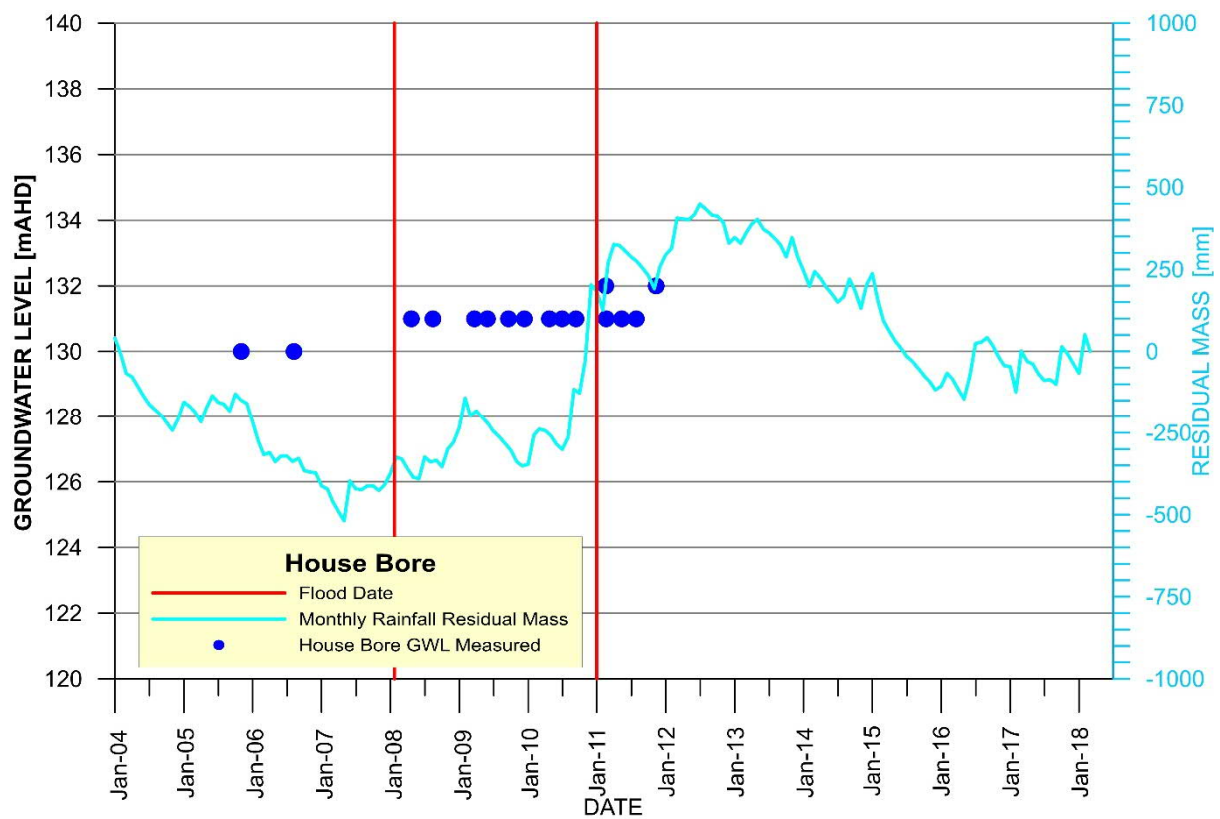


Figure A - 32: House Bore

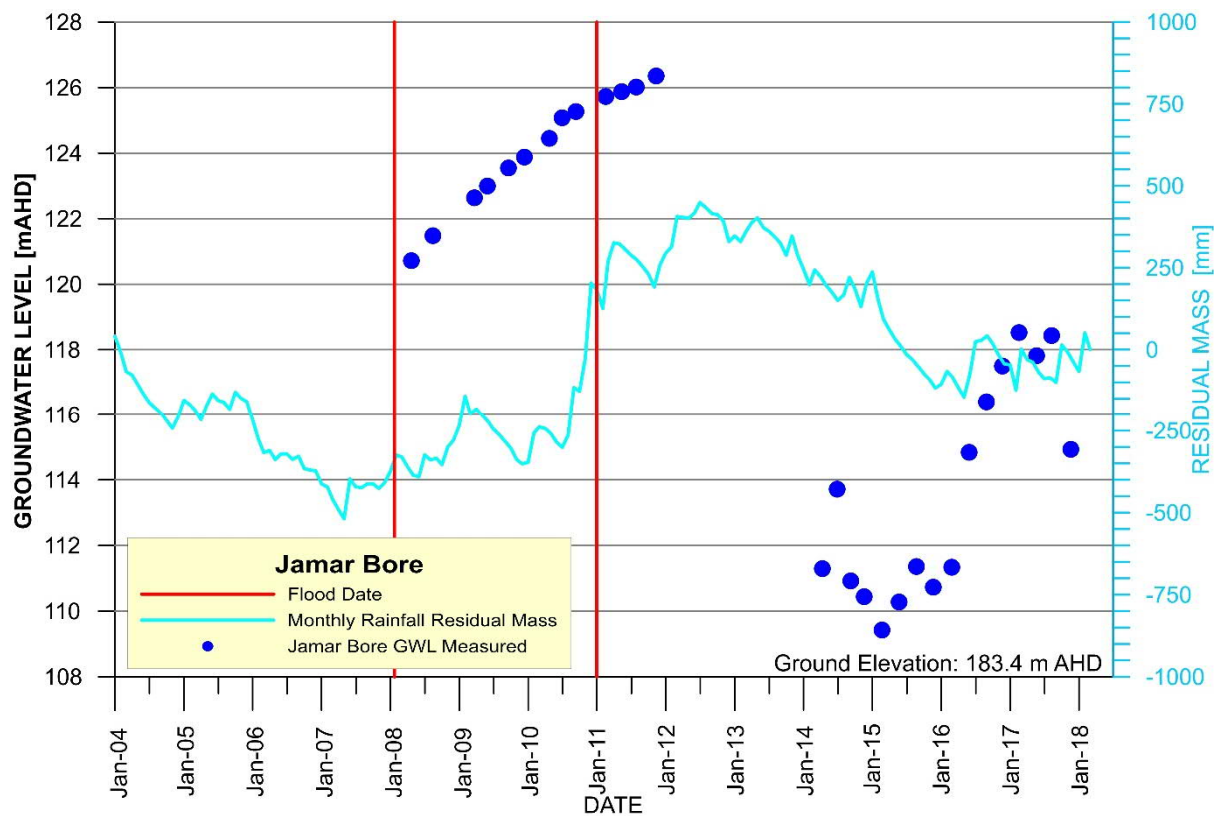


Figure A - 33: Jamar Bore

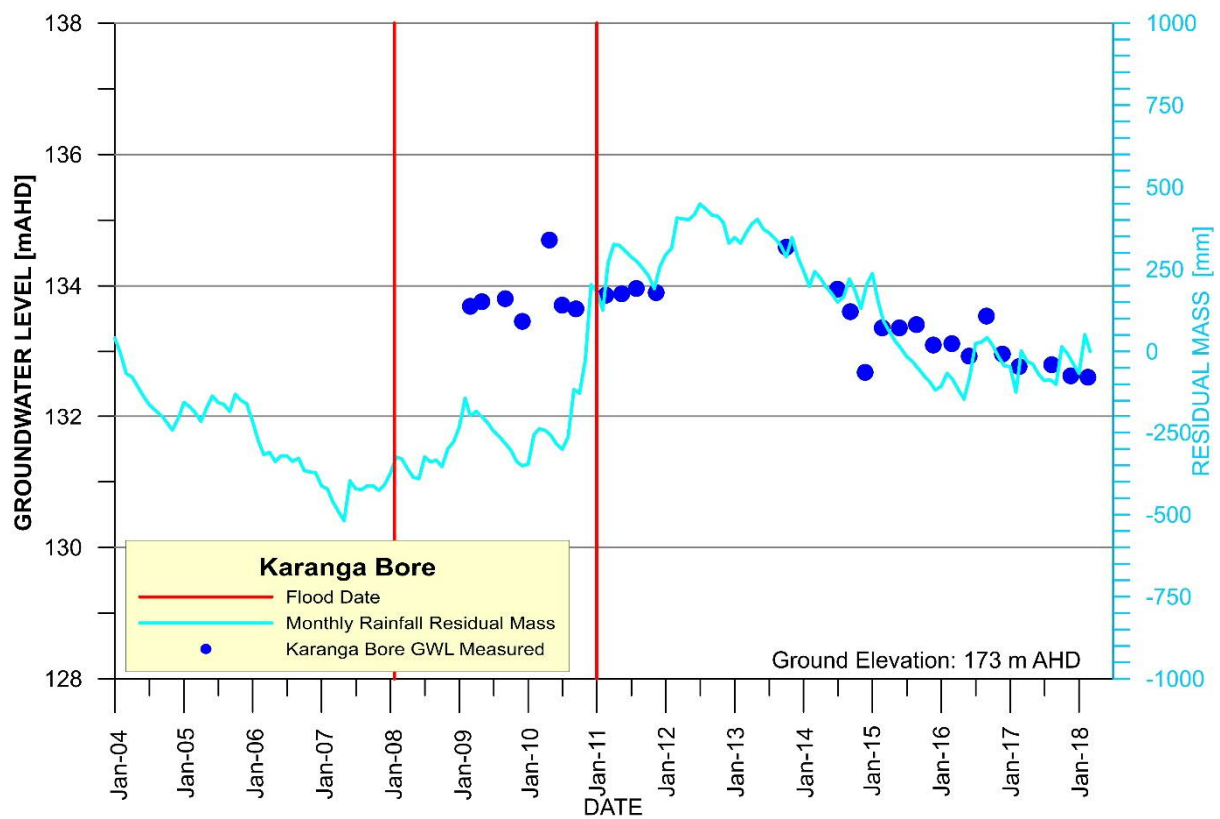


Figure A - 34: Karanga Bore

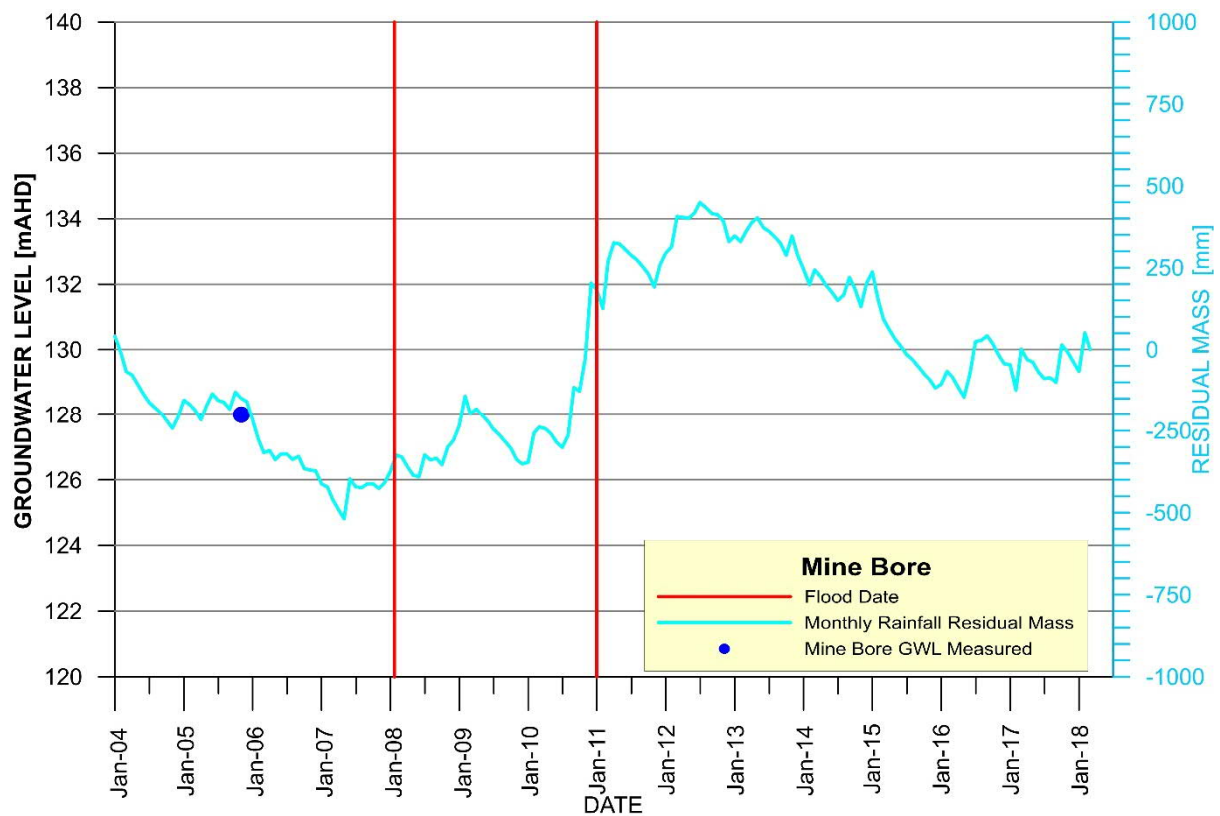


Figure A - 35: Mine Bore

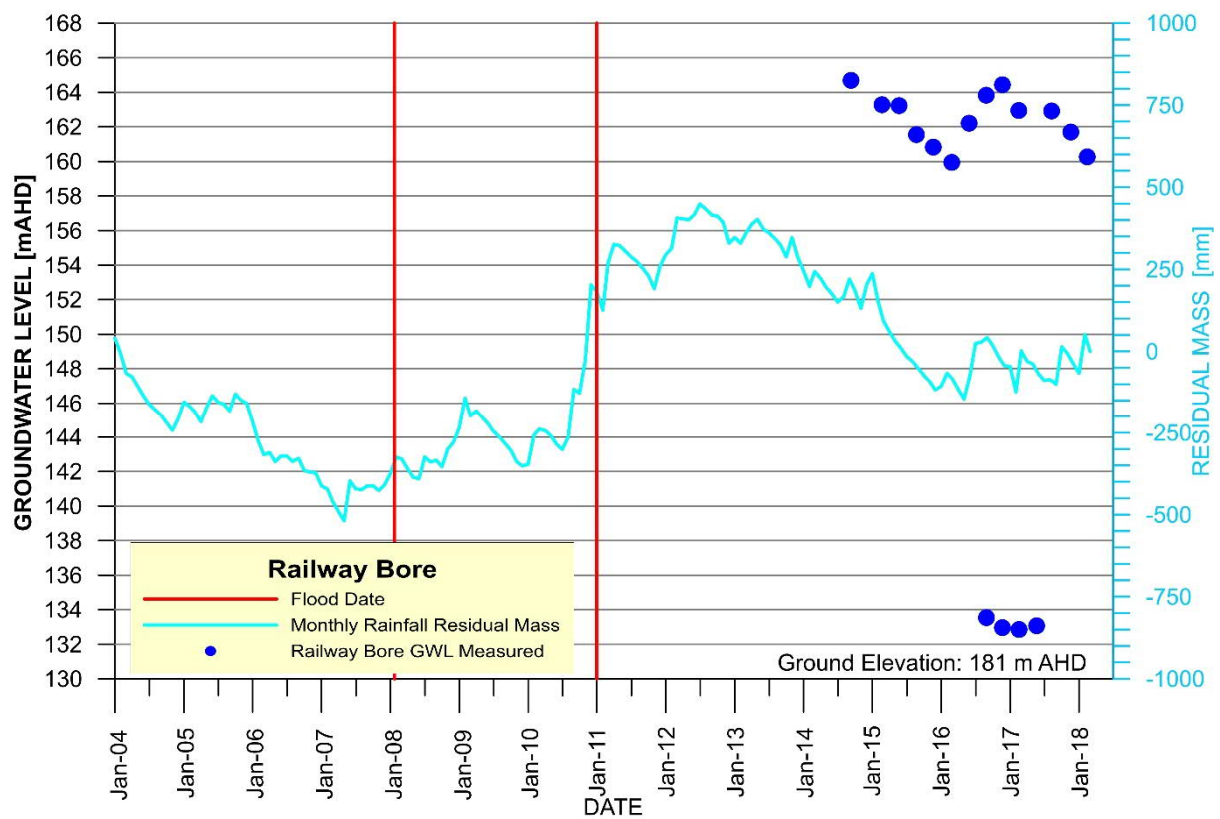


Figure A - 36: Railway Bore

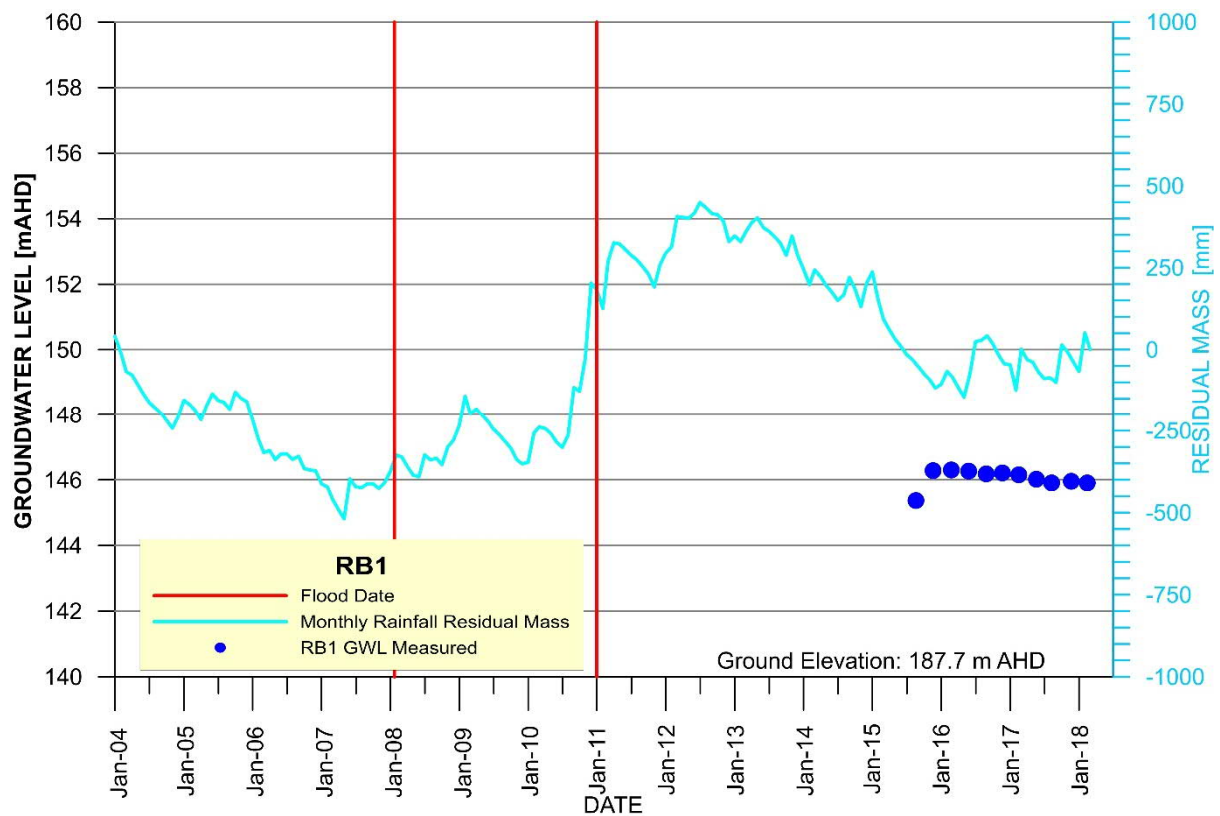


Figure A - 37: RB1

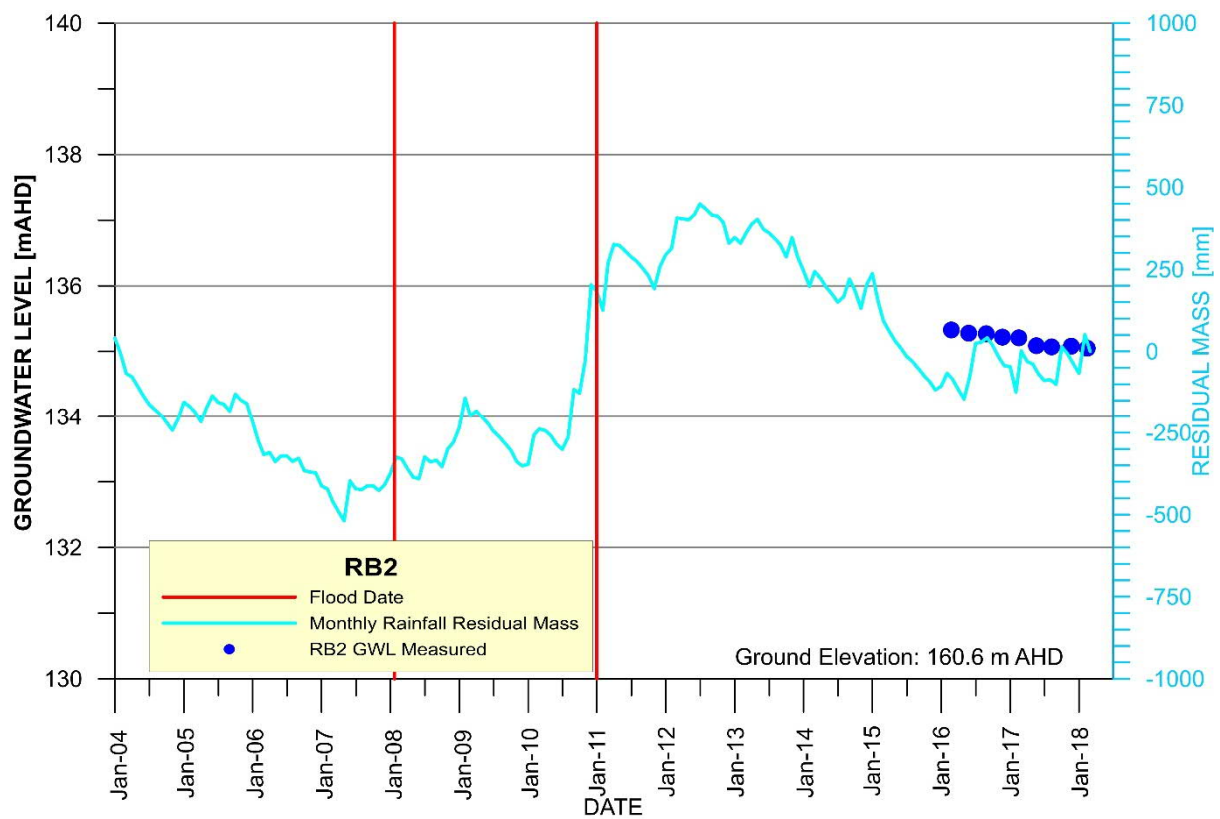


Figure A - 38: RB2

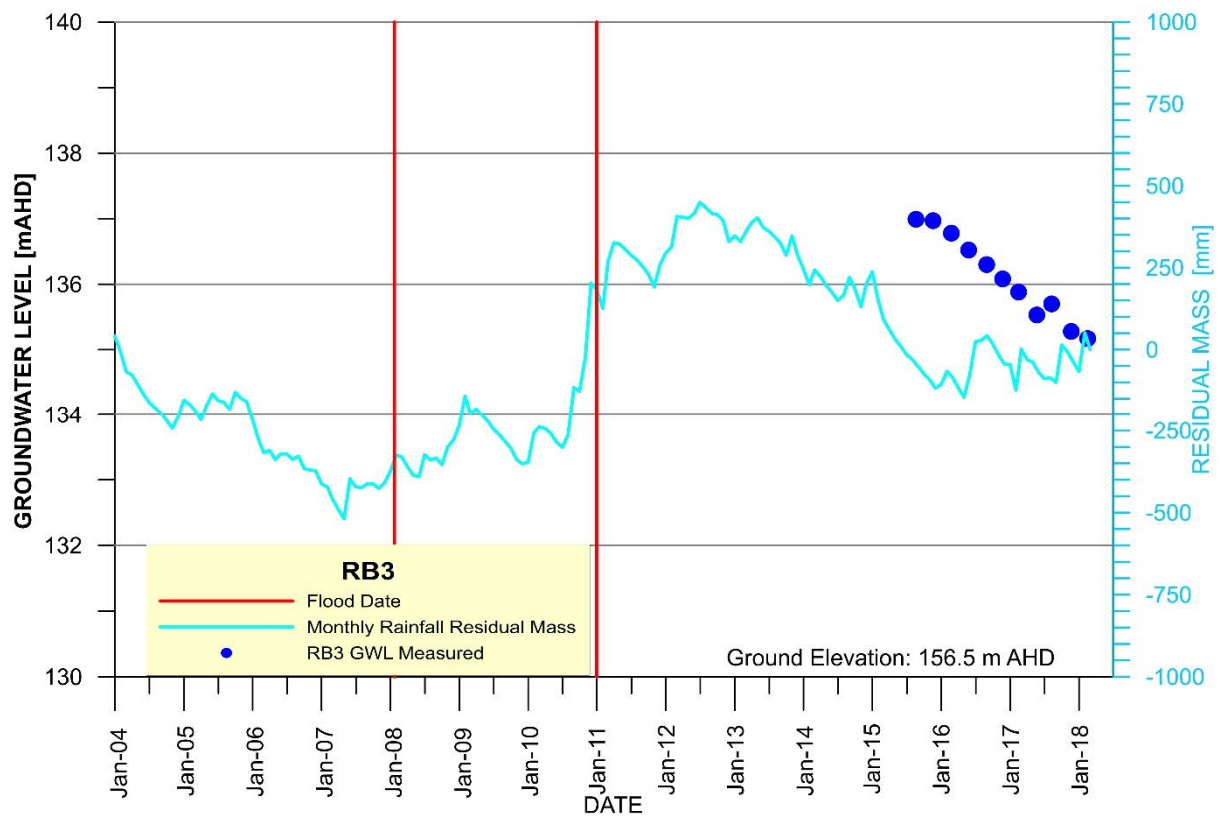


Figure A - 39: RB3

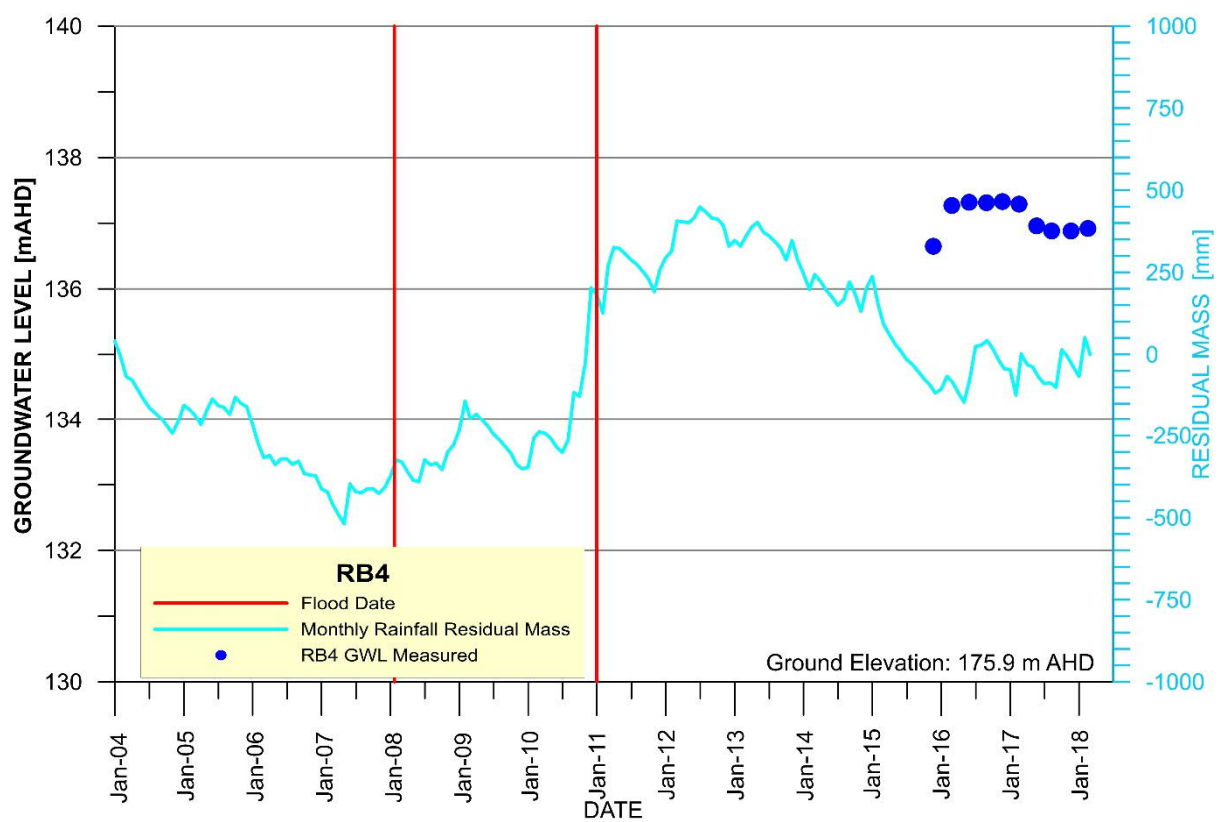


Figure A - 40: RB4

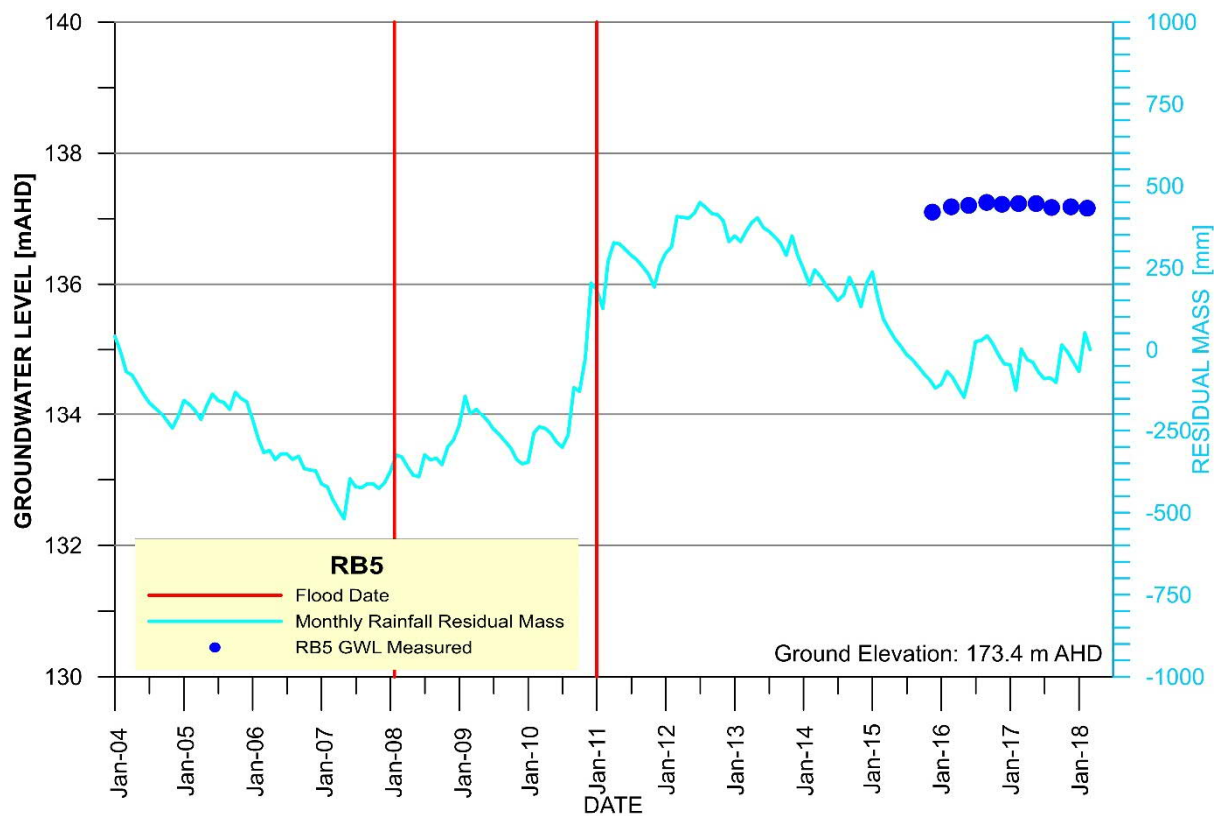


Figure A - 41: RB5

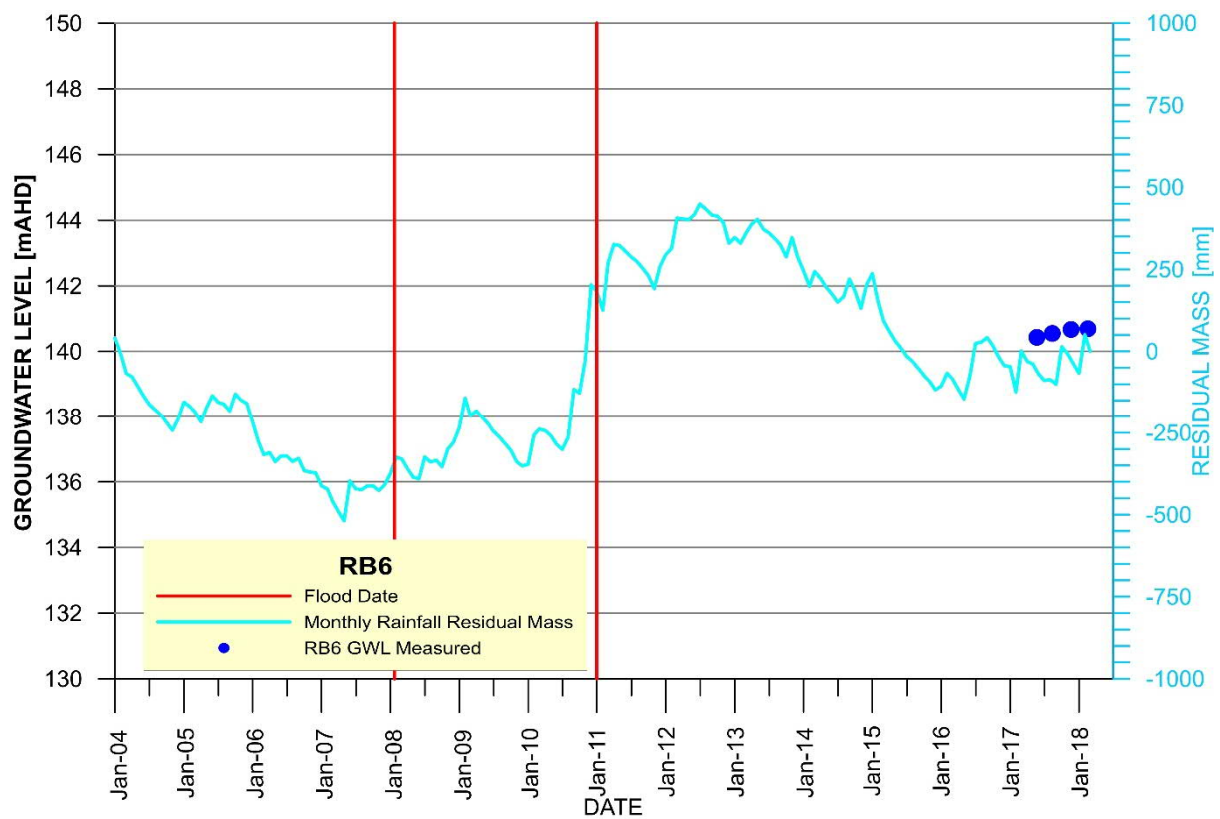


Figure A - 42: RB6

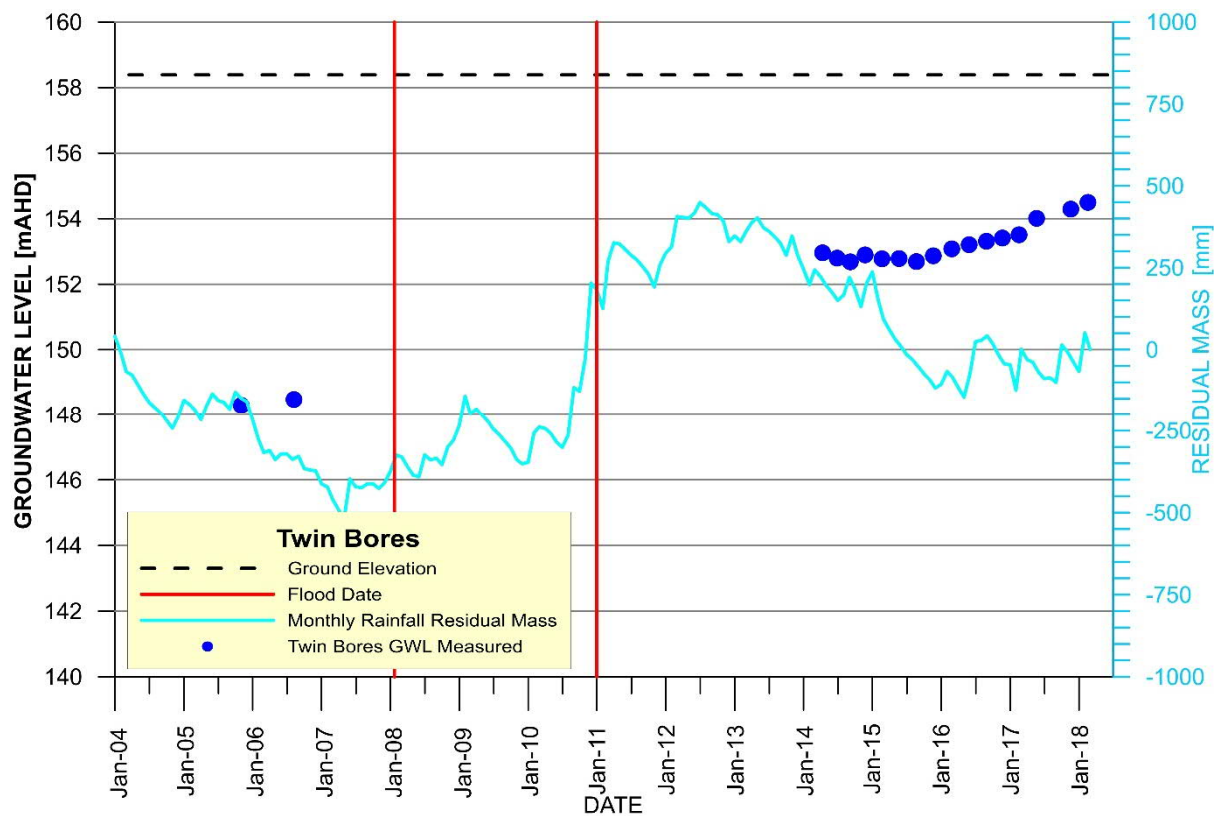


Figure A - 43: Twin Bores

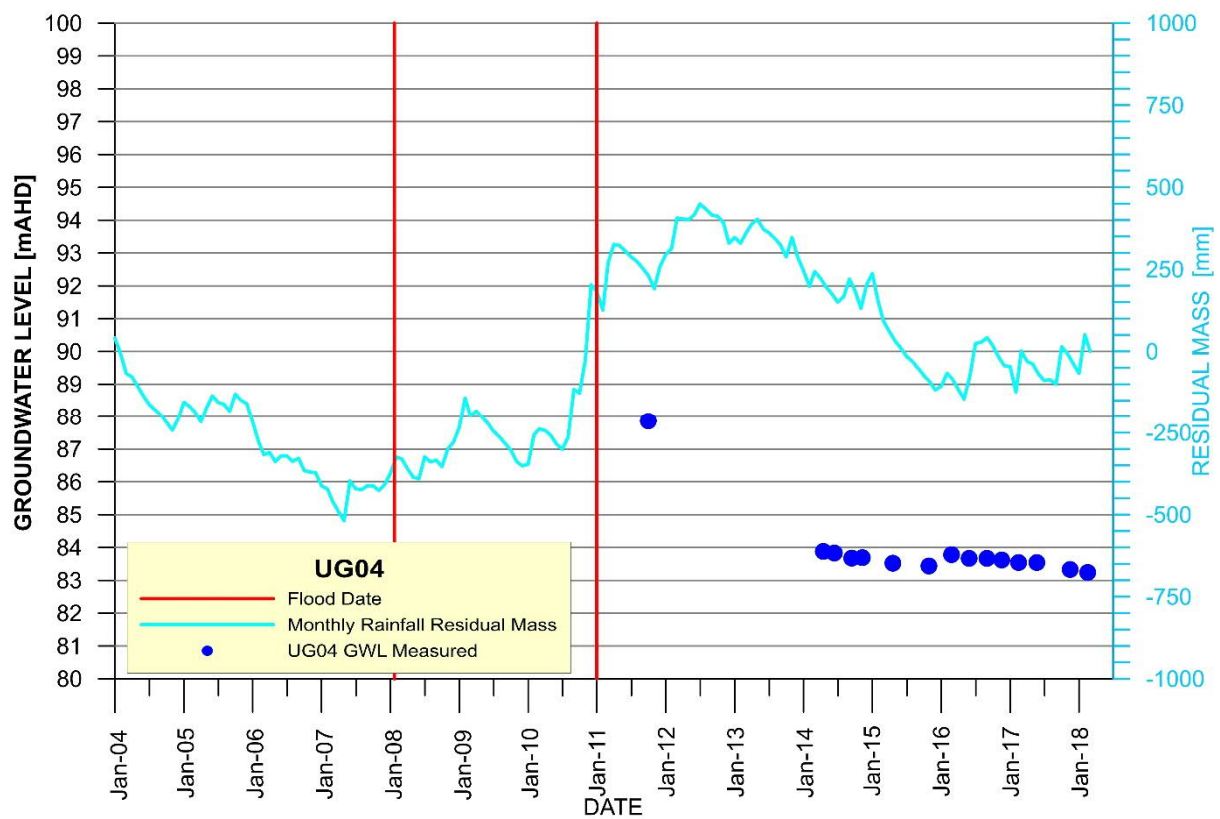


Figure A - 44: UG04

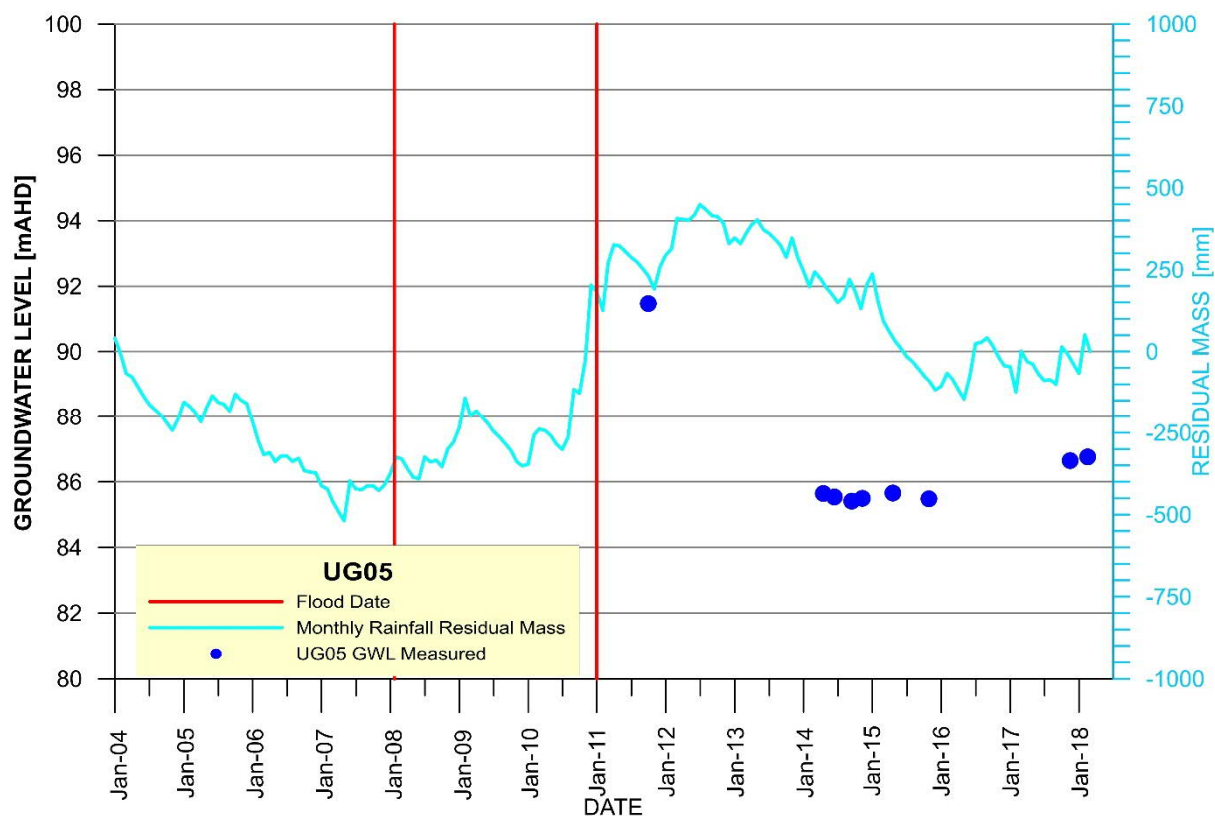


Figure A - 45: UG05

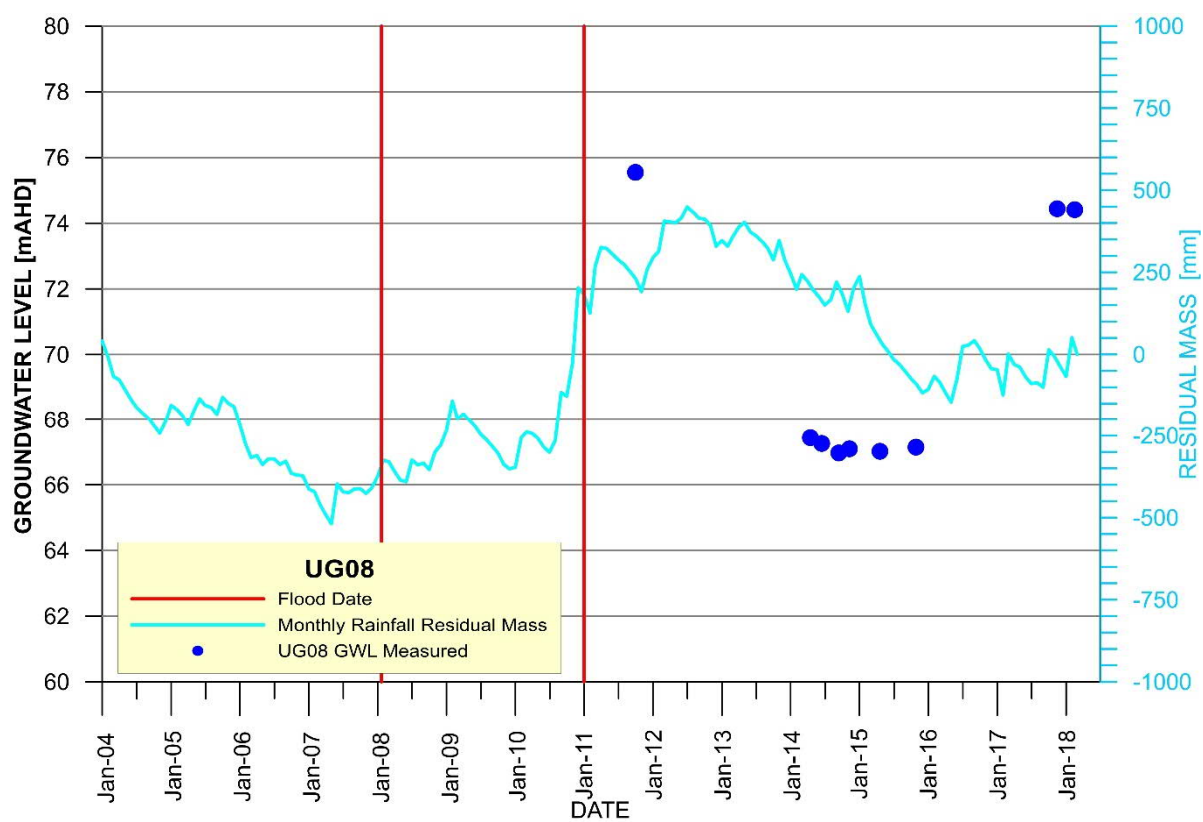


Figure A - 46: UG08

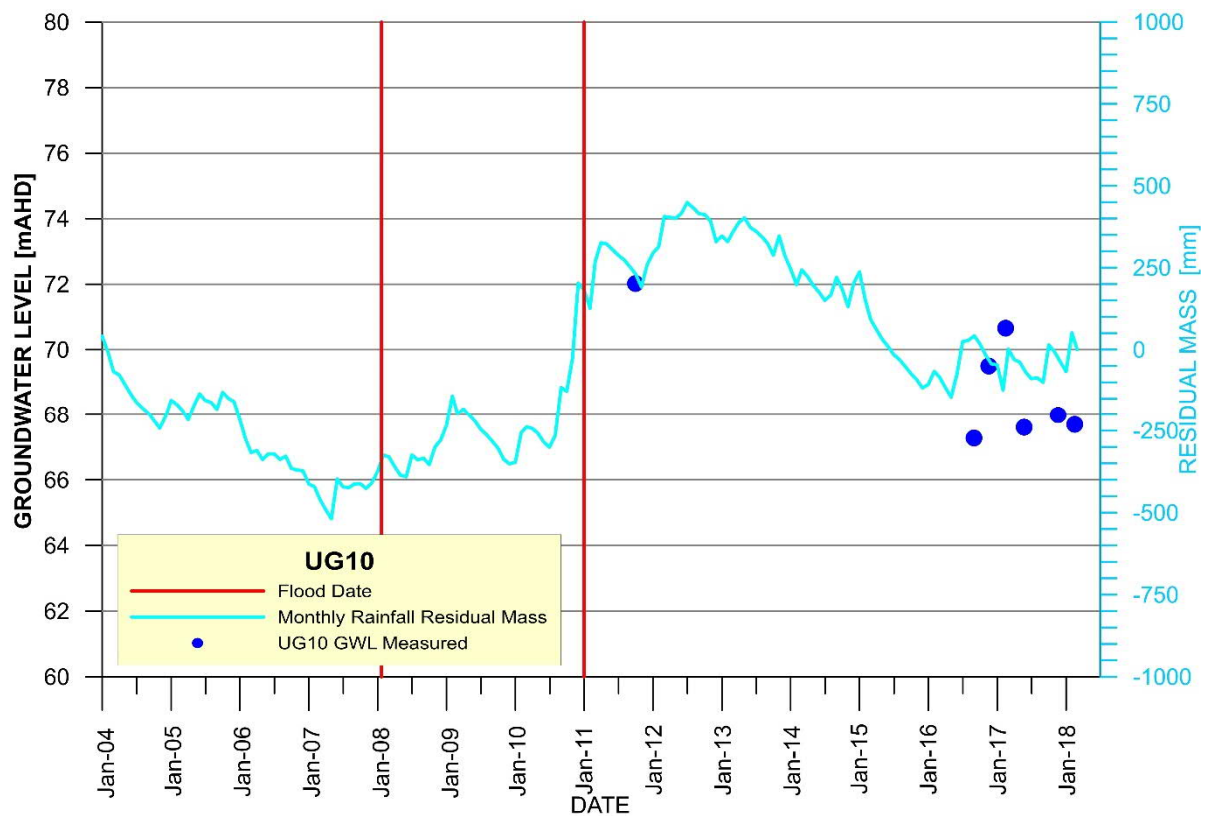


Figure A - 47: UG10

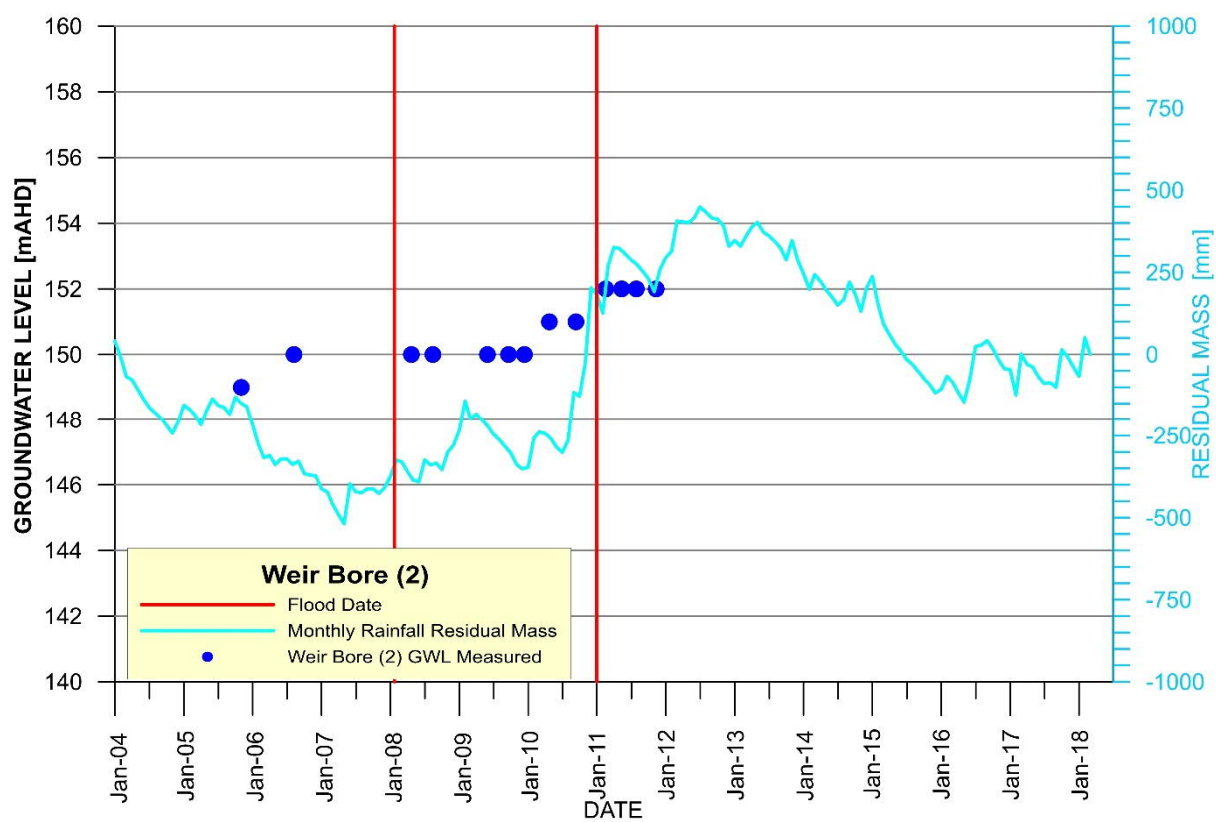


Figure A - 48: Weir Bore (2)

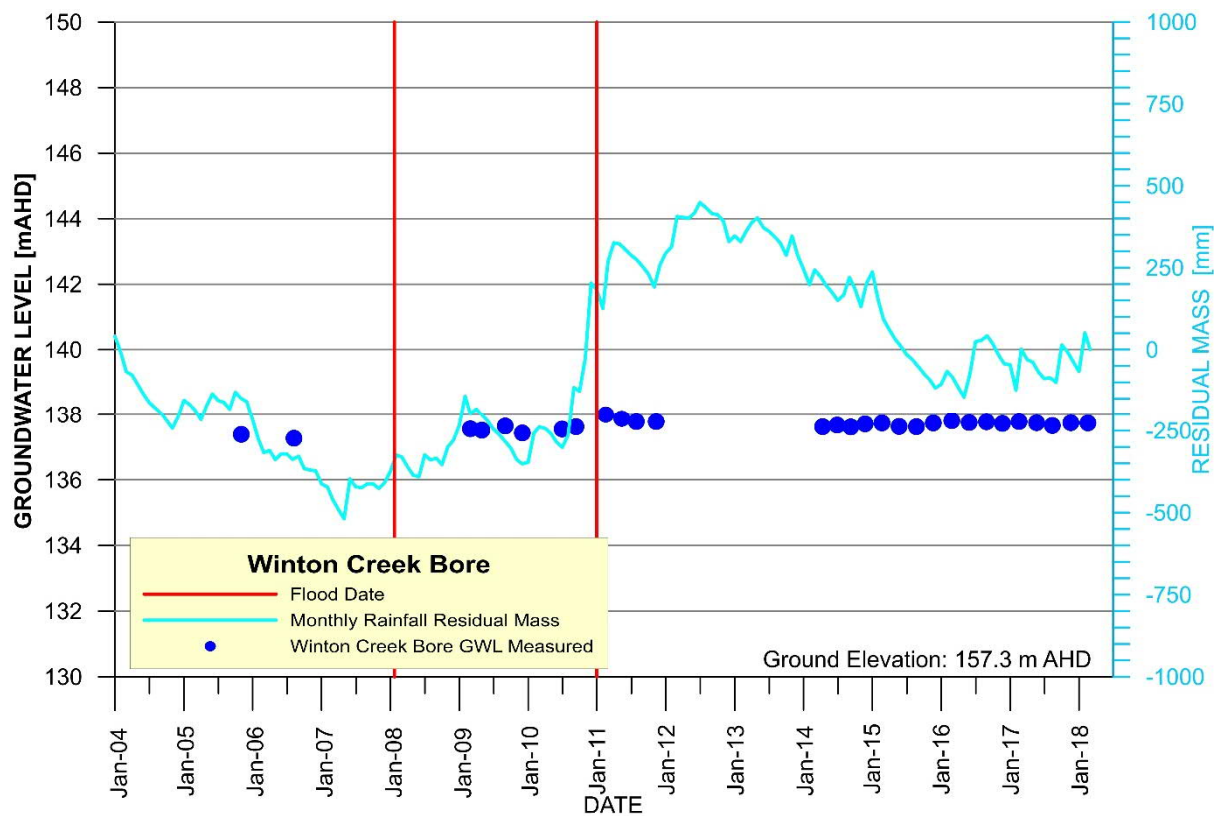


Figure A - 49: Winton Creek Bore

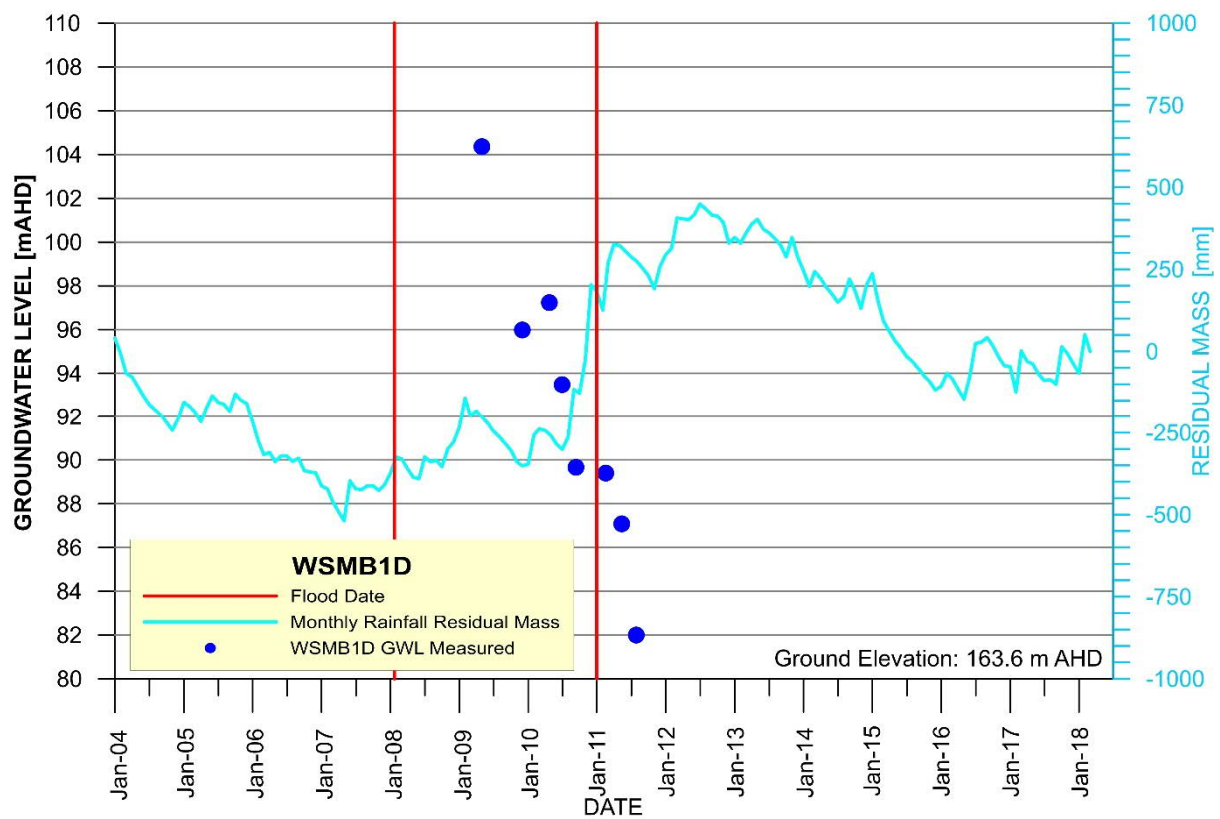


Figure A - 50: WSMB1D

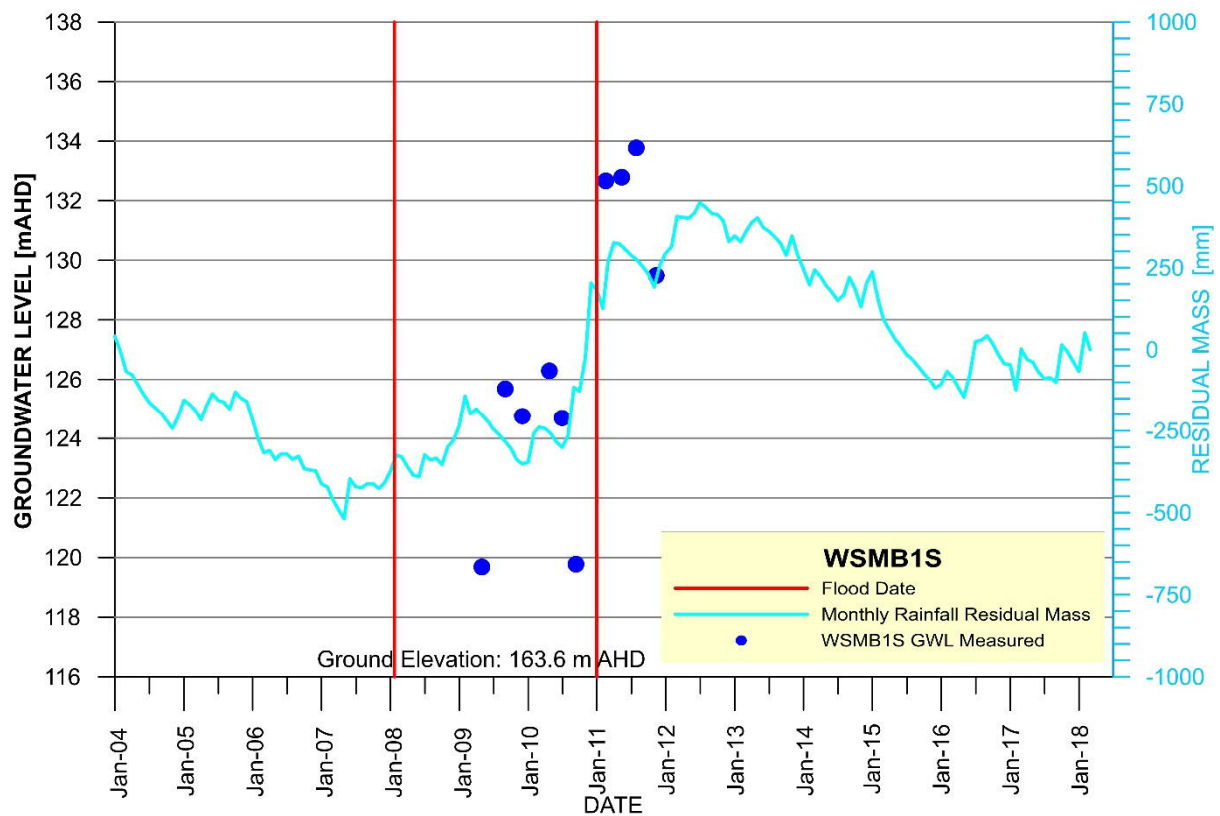


Figure A - 51: WSMB1S

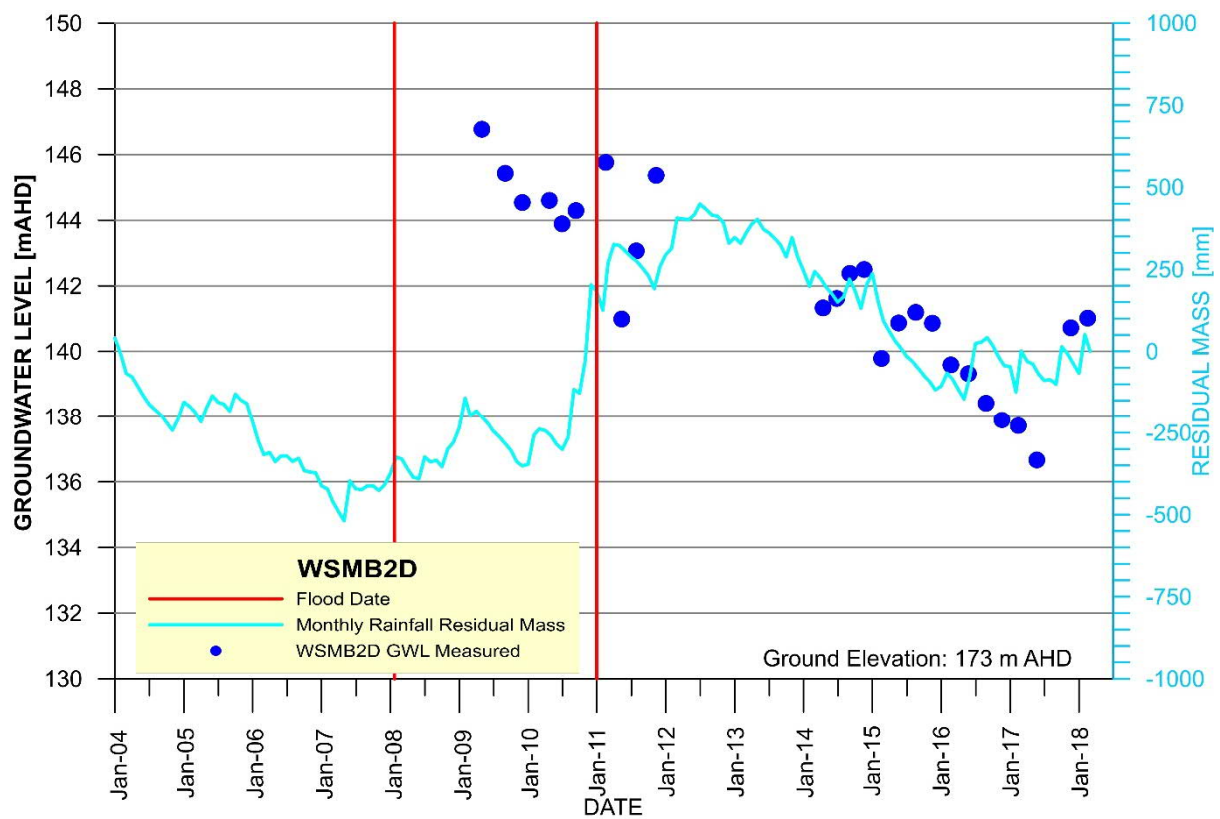


Figure A - 52: WSMB2D

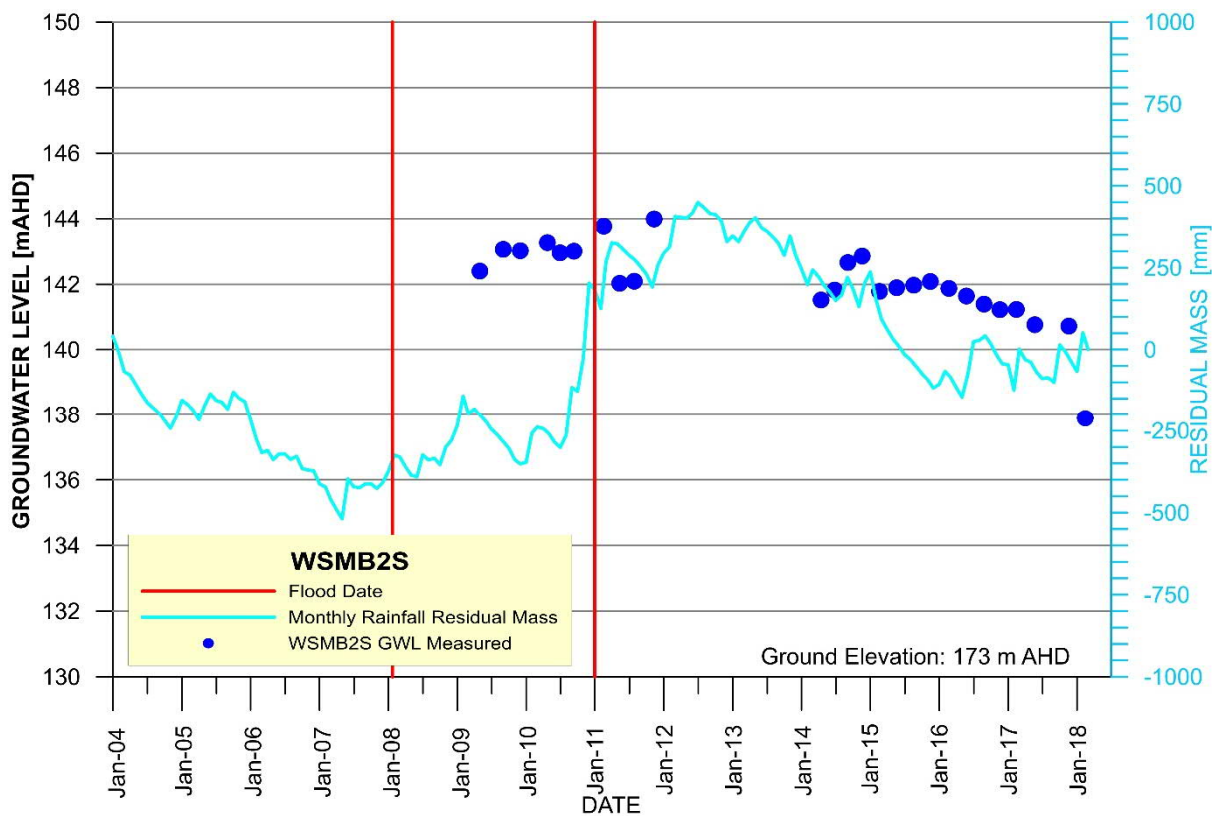


Figure A - 53: WSMB2S

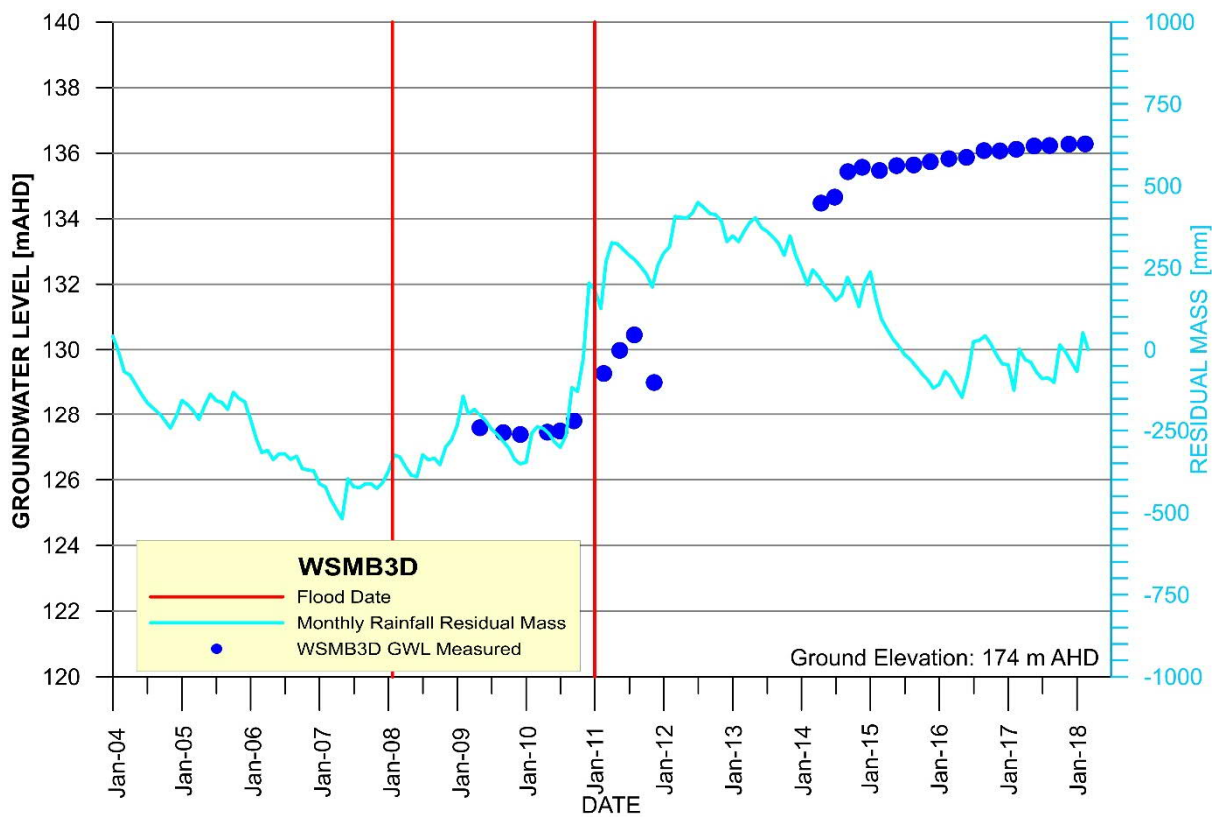


Figure A - 54: WSMB3D

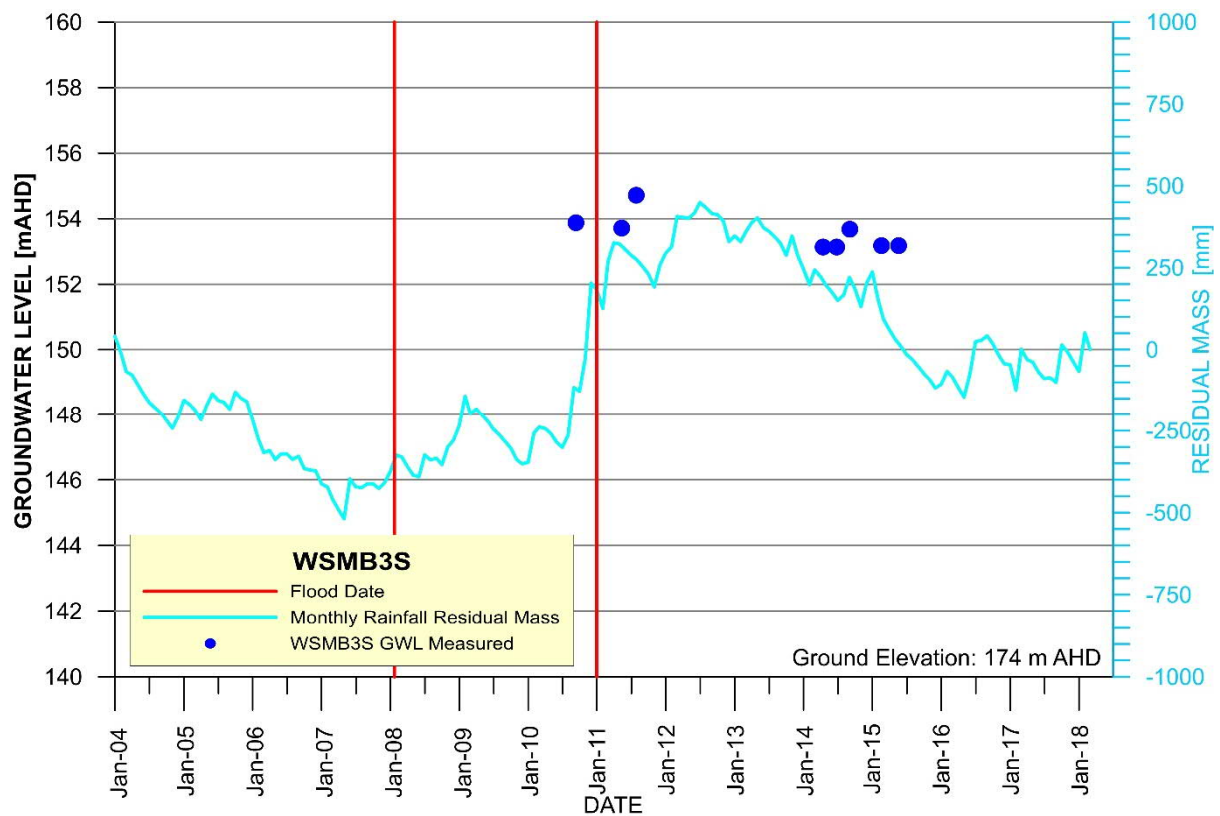


Figure A - 55: WSMB3S

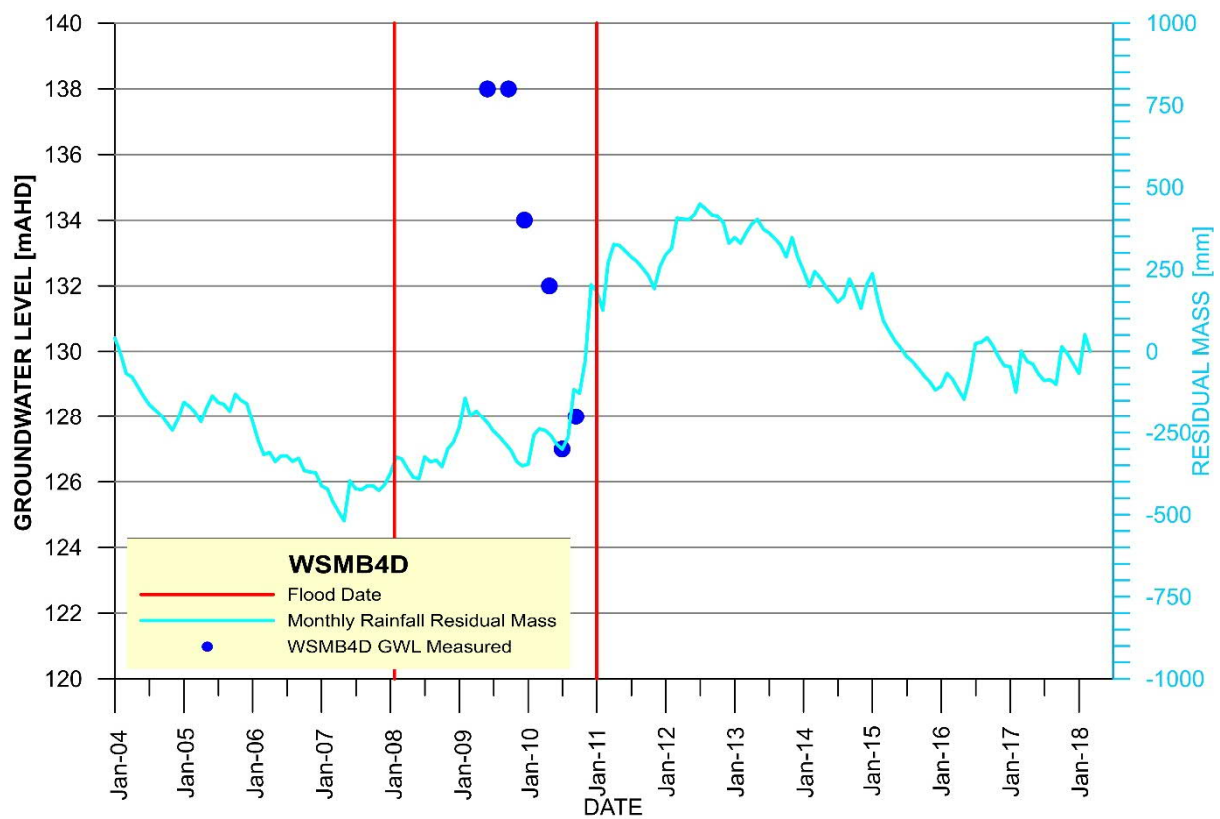


Figure A - 56: WSMB4D

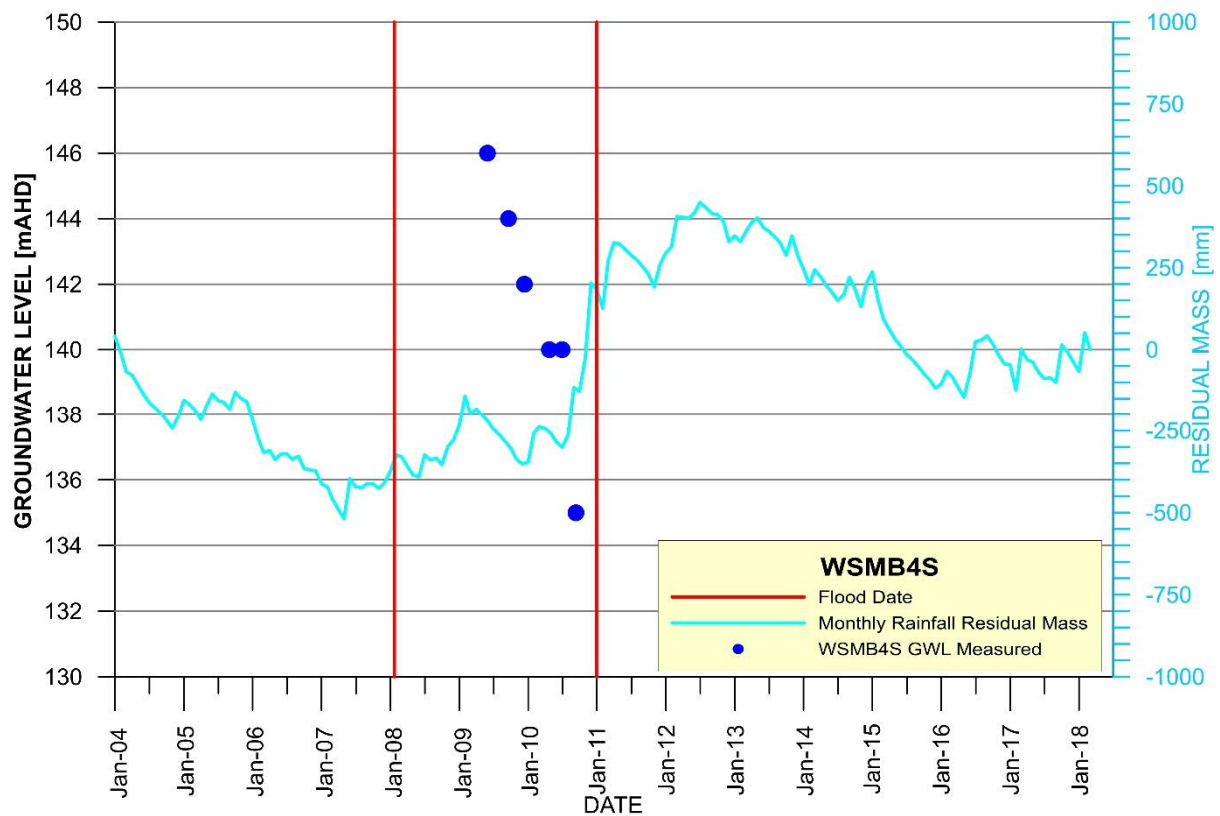


Figure A - 57: WSMB4S

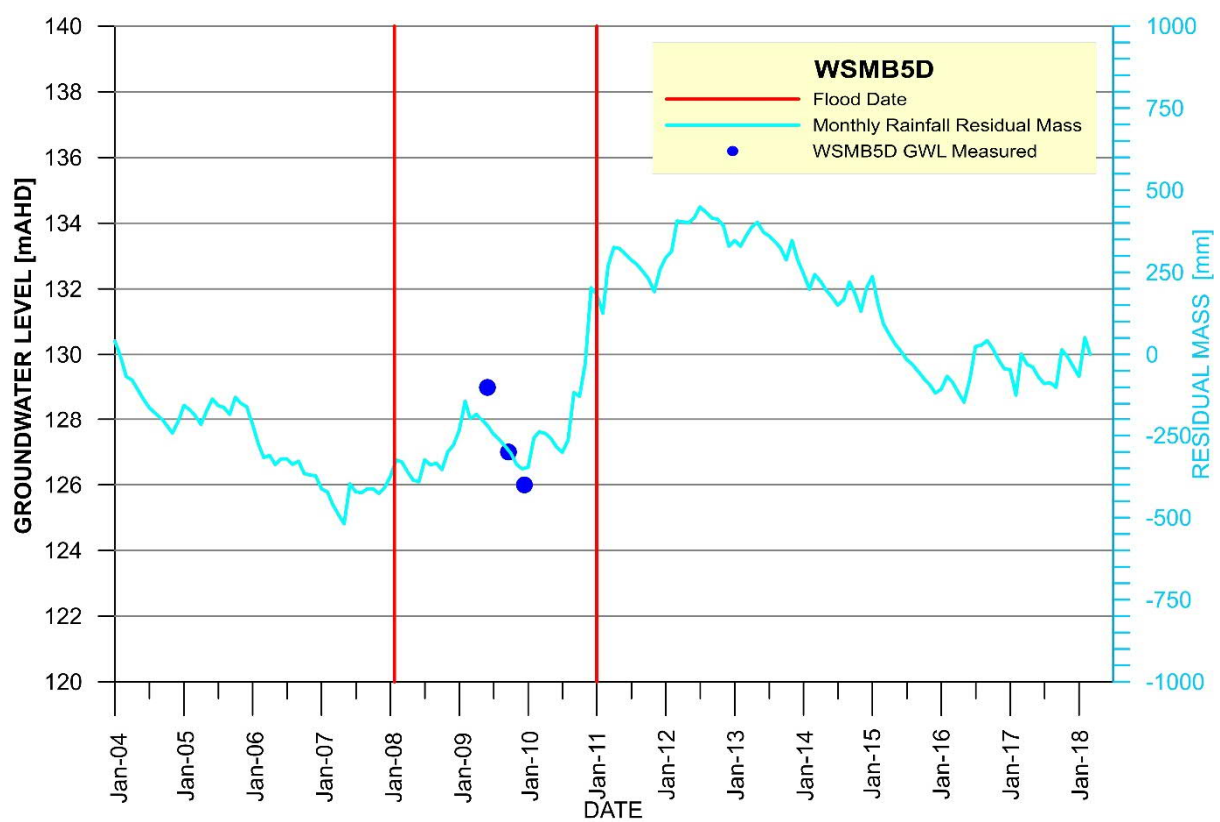


Figure A - 58: WSMB5D

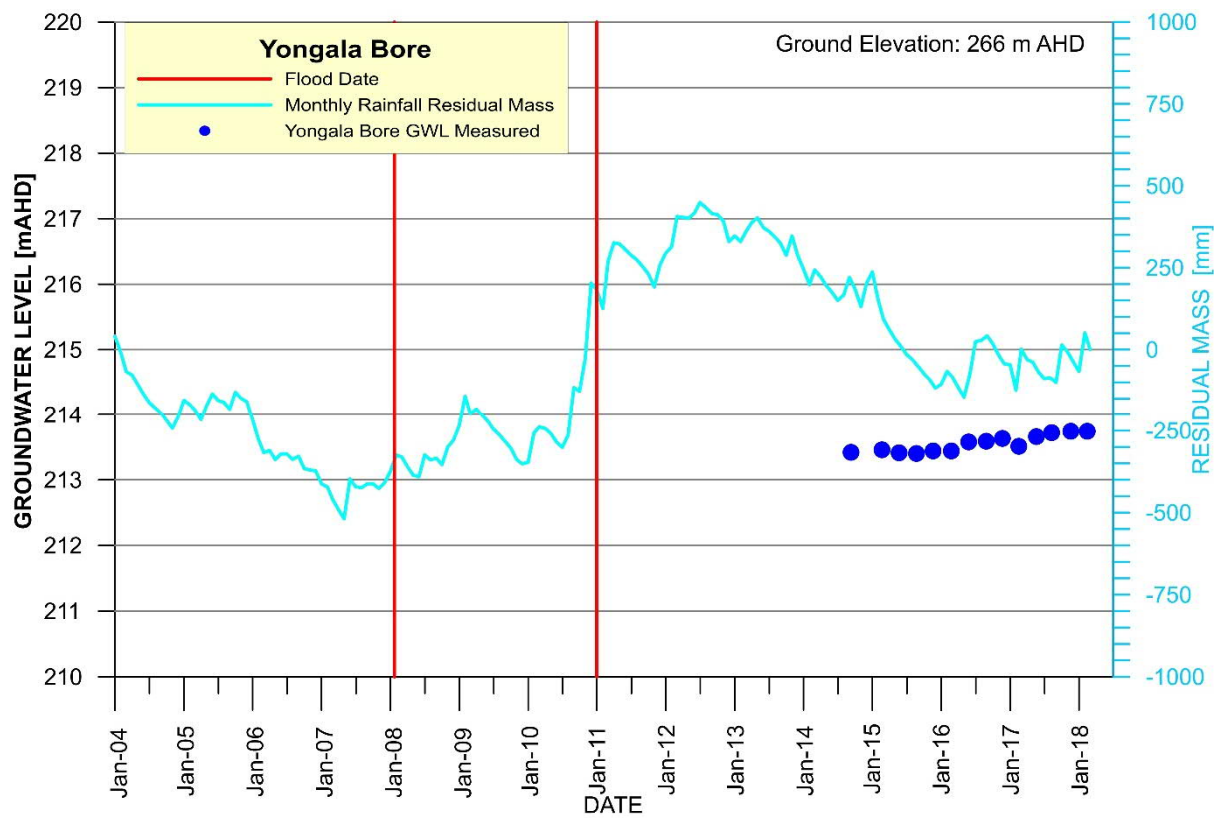
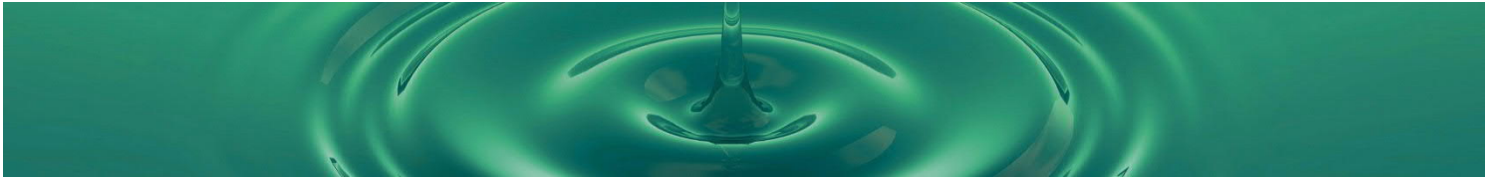


Figure A - 59: Yongala Bore



APPENDIX B

Calibration Groundwater Hydrographs

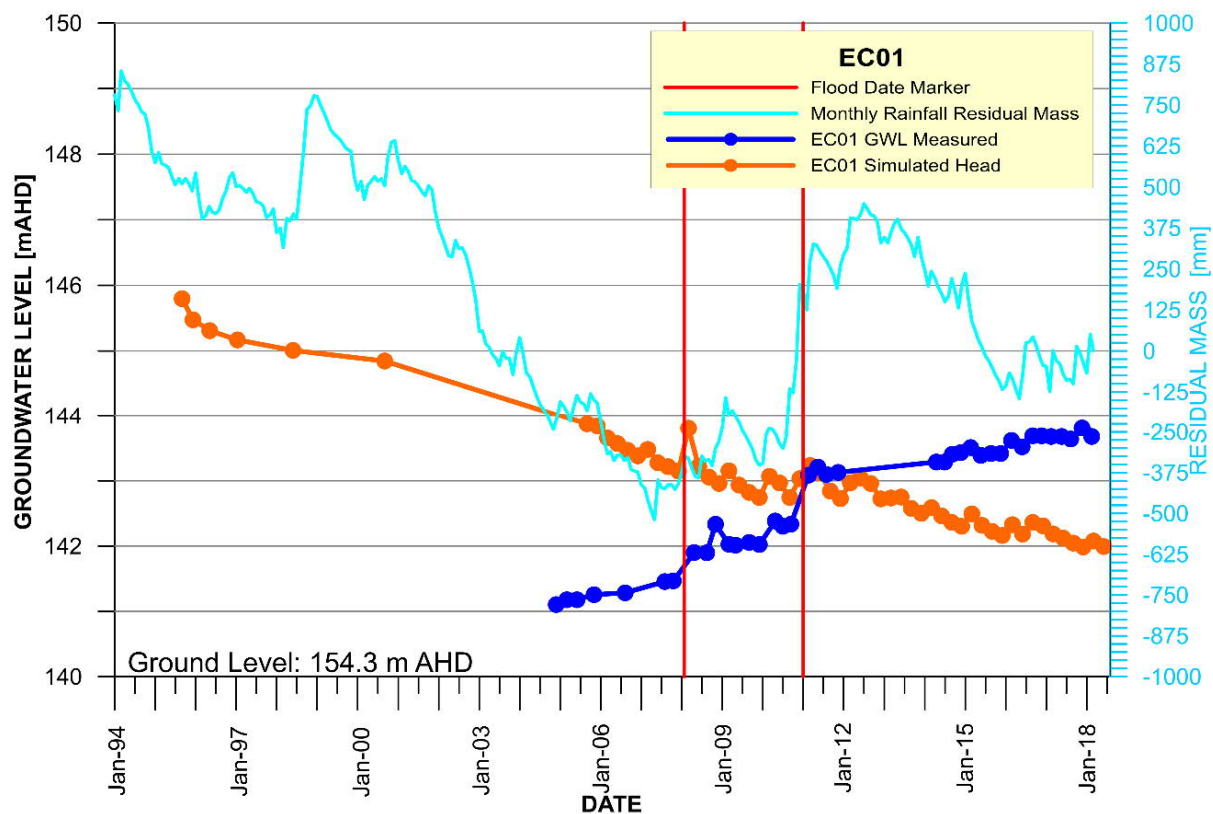


Figure B- 1: EC01

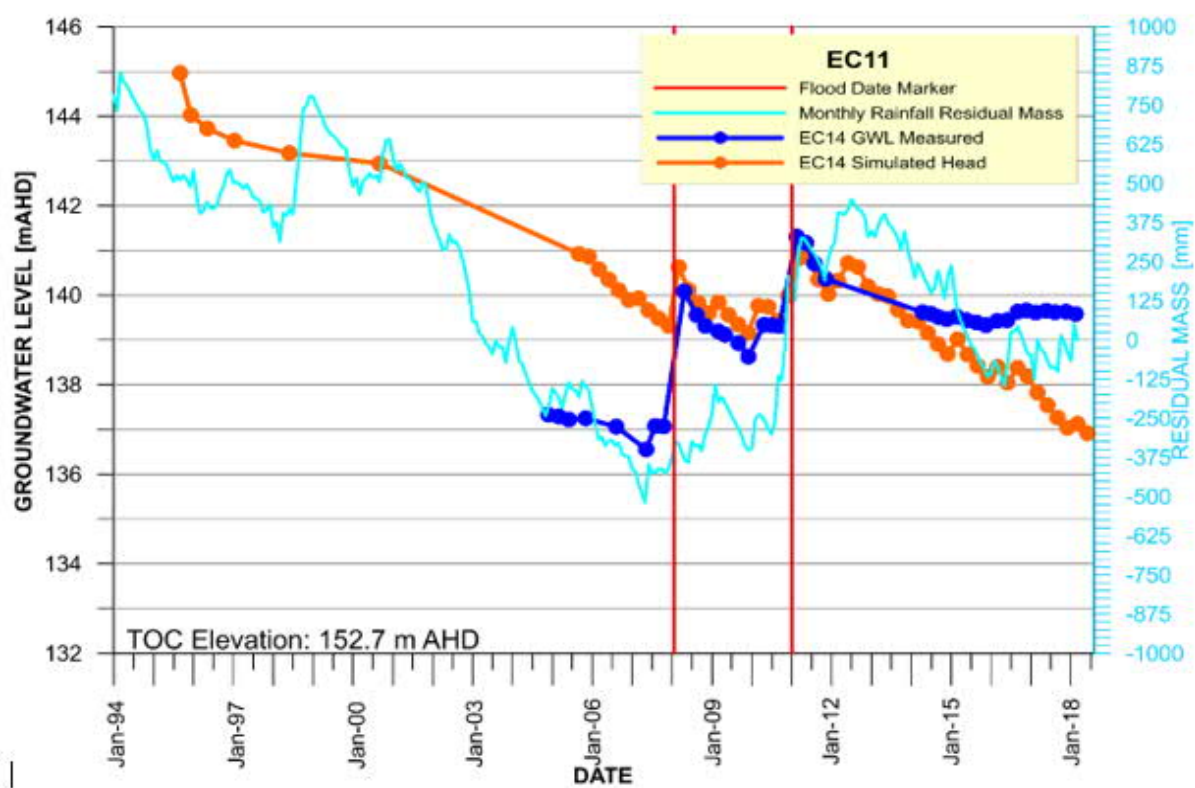


Figure B- 2: EC11

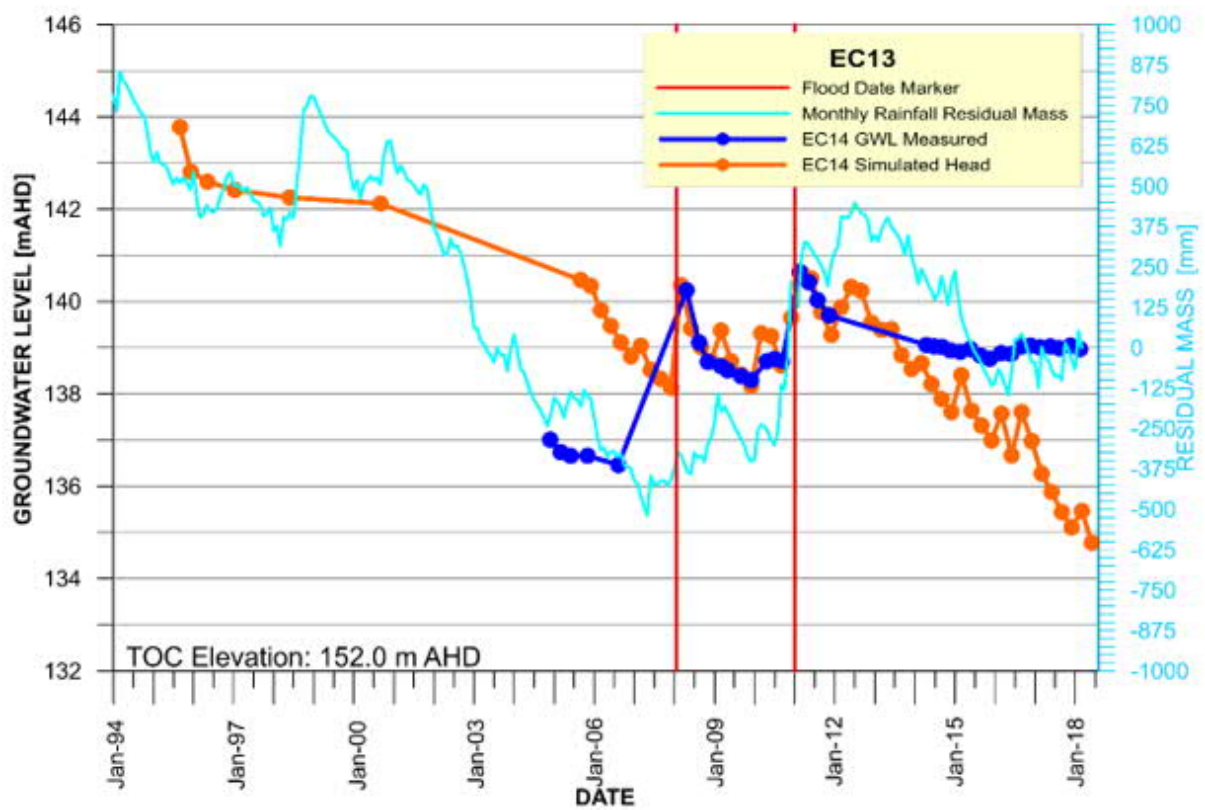


Figure B- 3: EC13

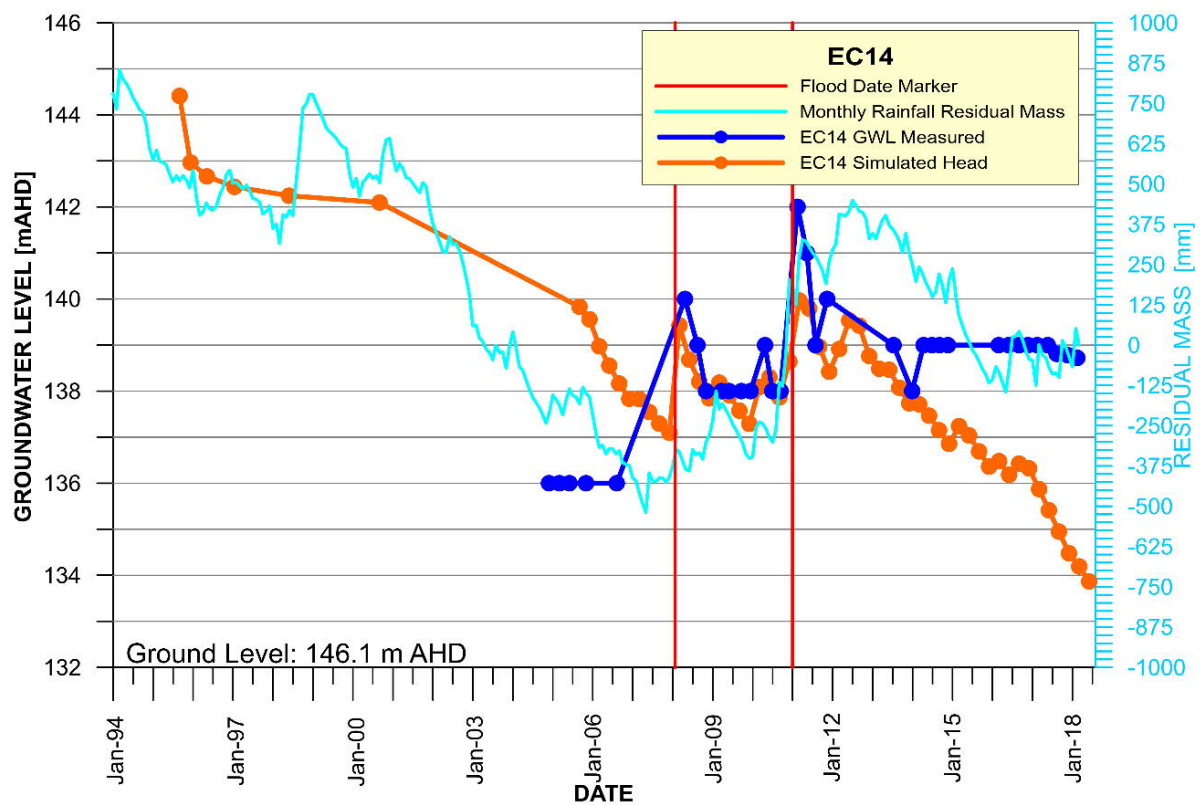


Figure B- 4: EC14

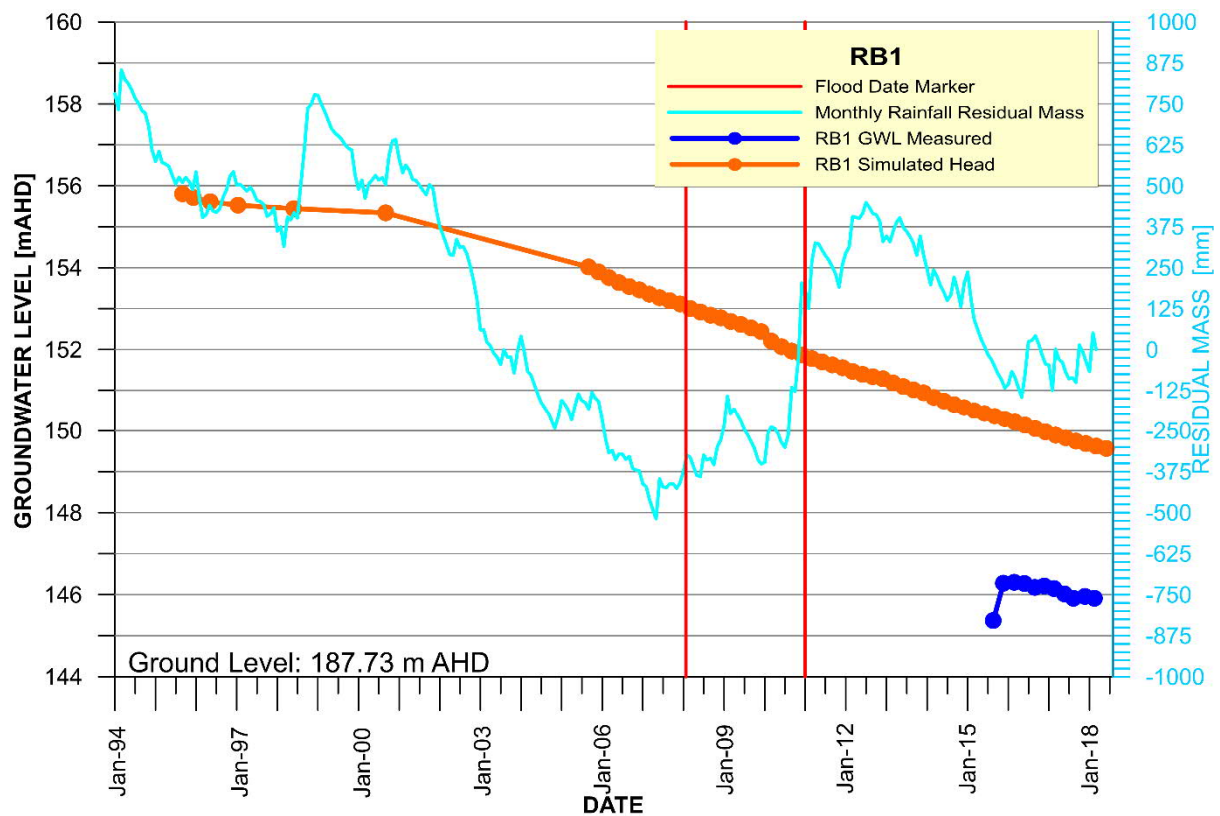


Figure B- 5: RB1

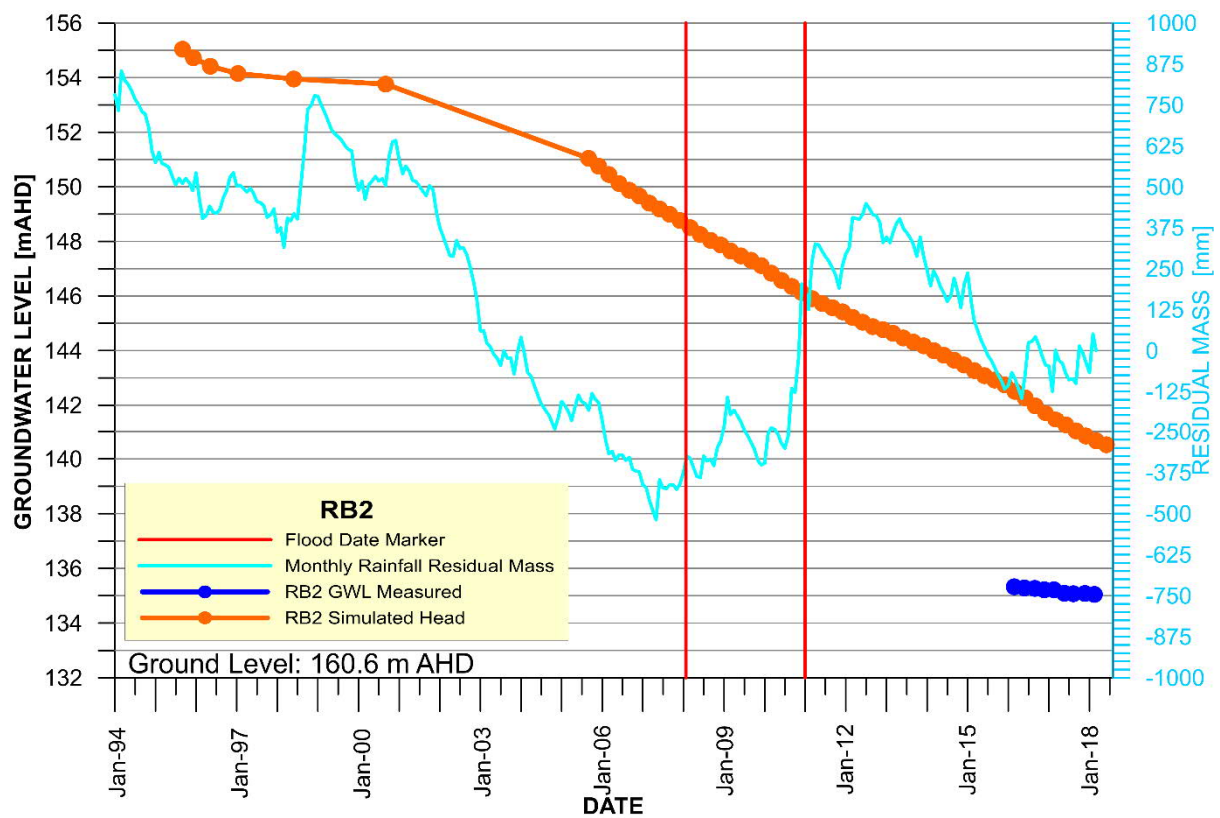


Figure B- 6: RB2

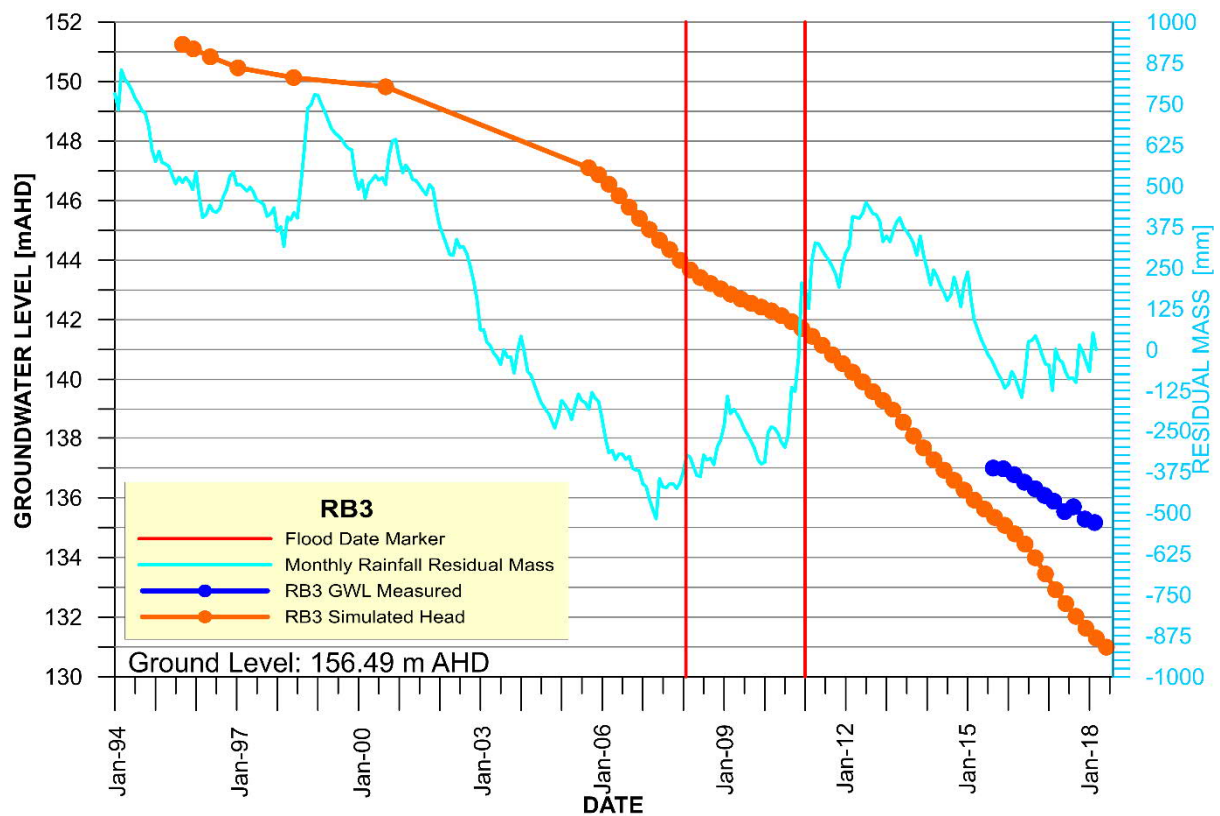


Figure B- 7: RB3

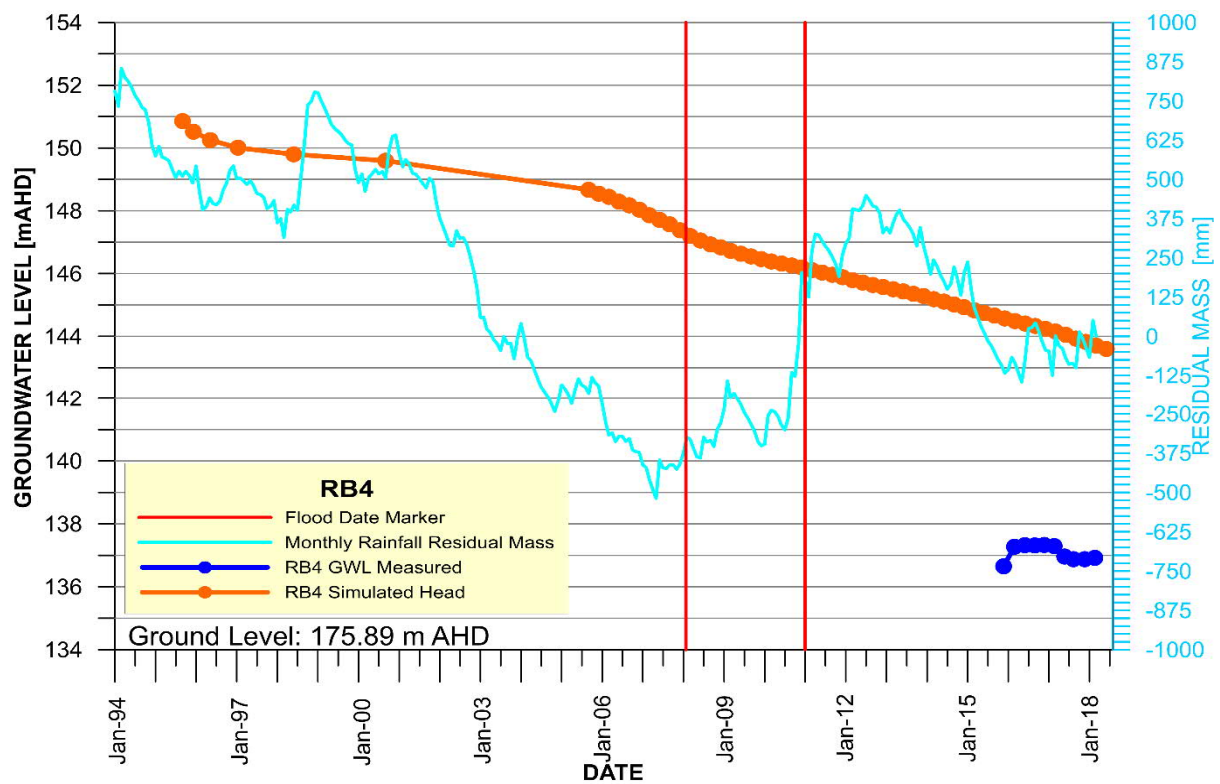


Figure B- 8: RB4

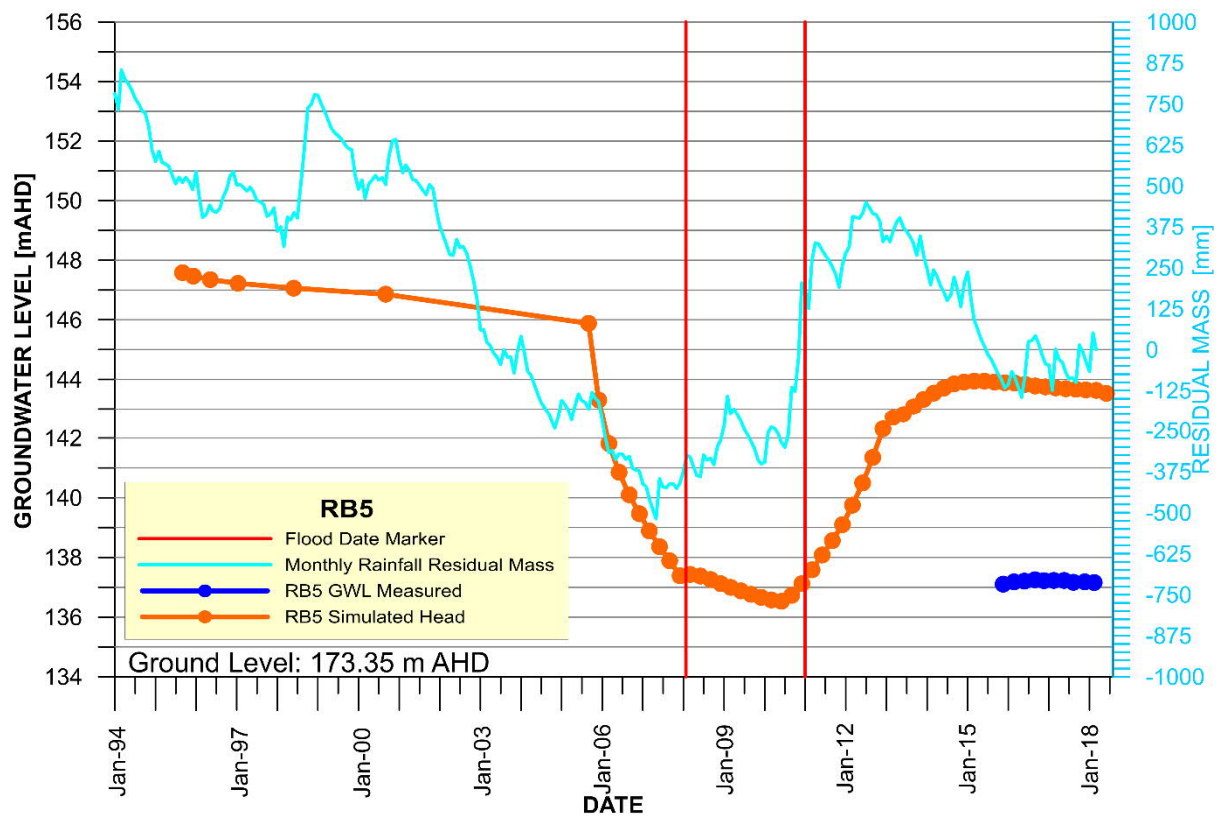


Figure B- 9: RB5

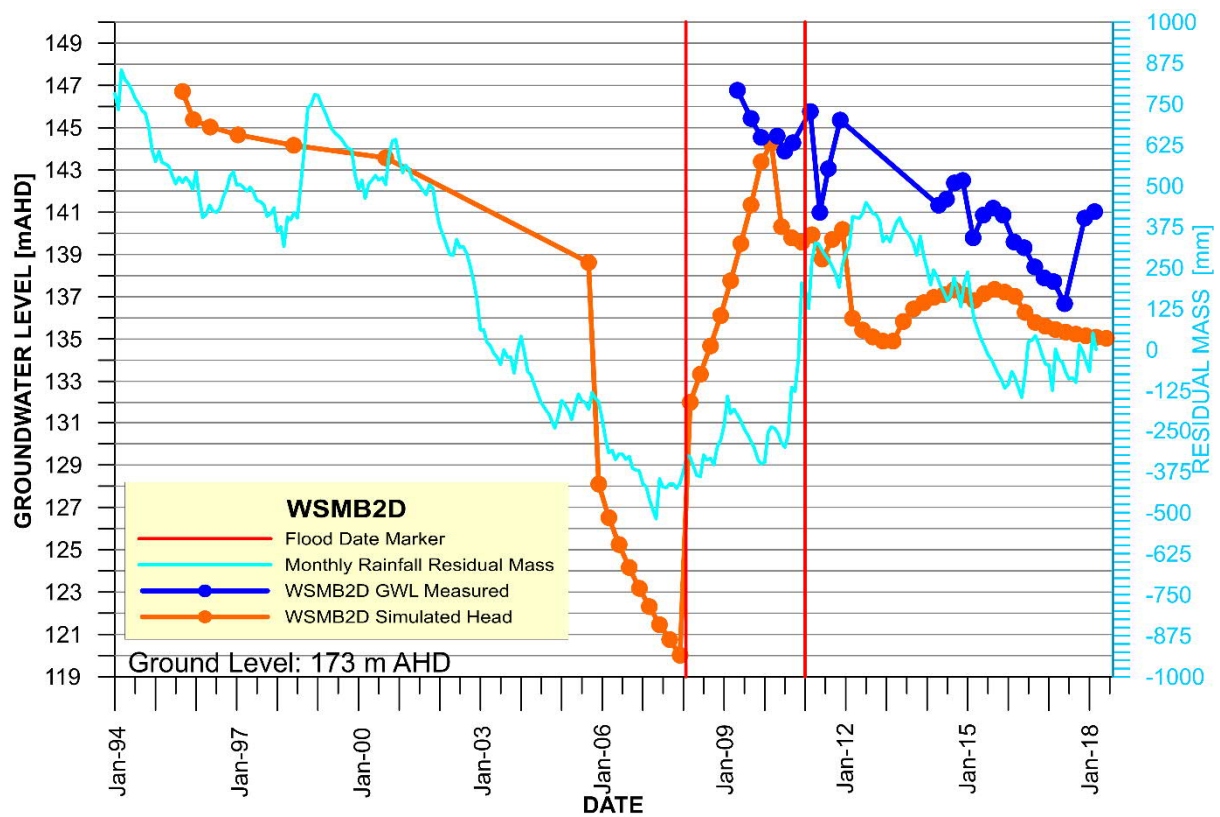


Figure B- 10: WSMB2D

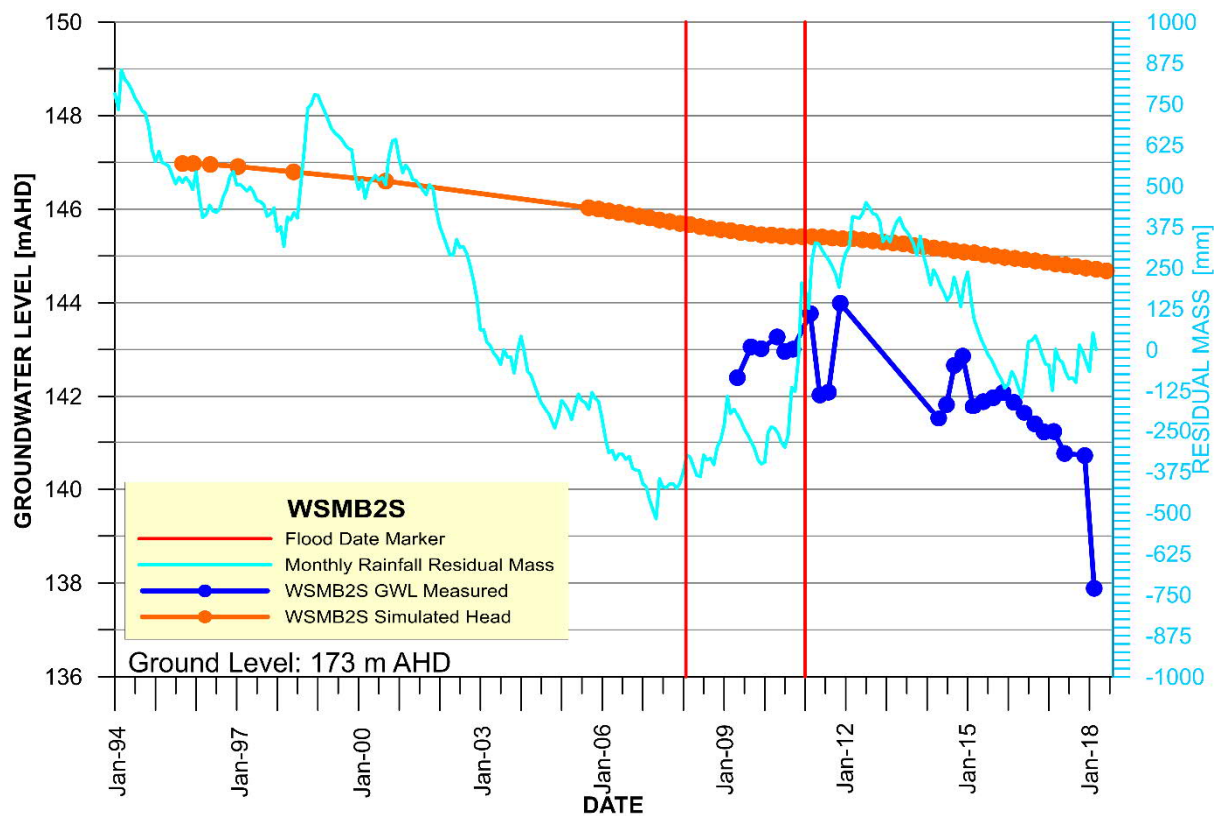


Figure B- 11: WSMB2S

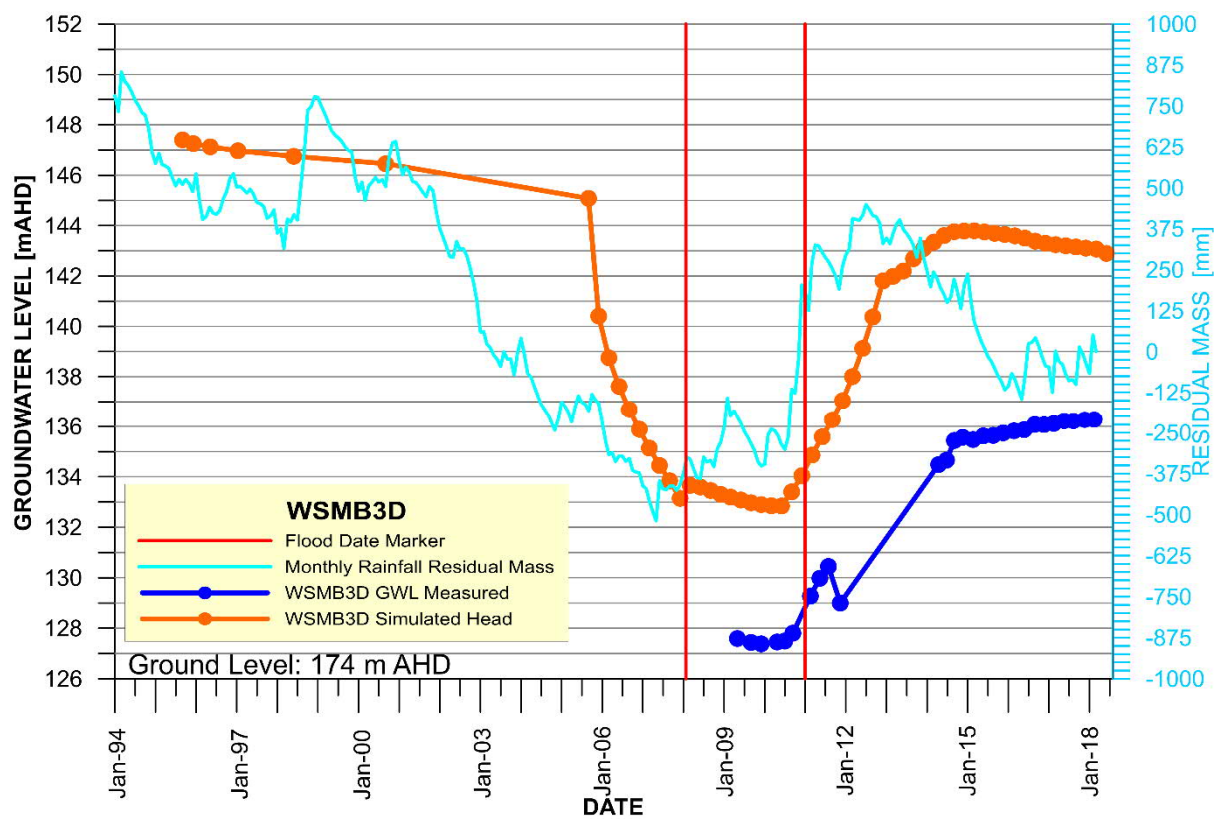


Figure B- 3: WSMB3D

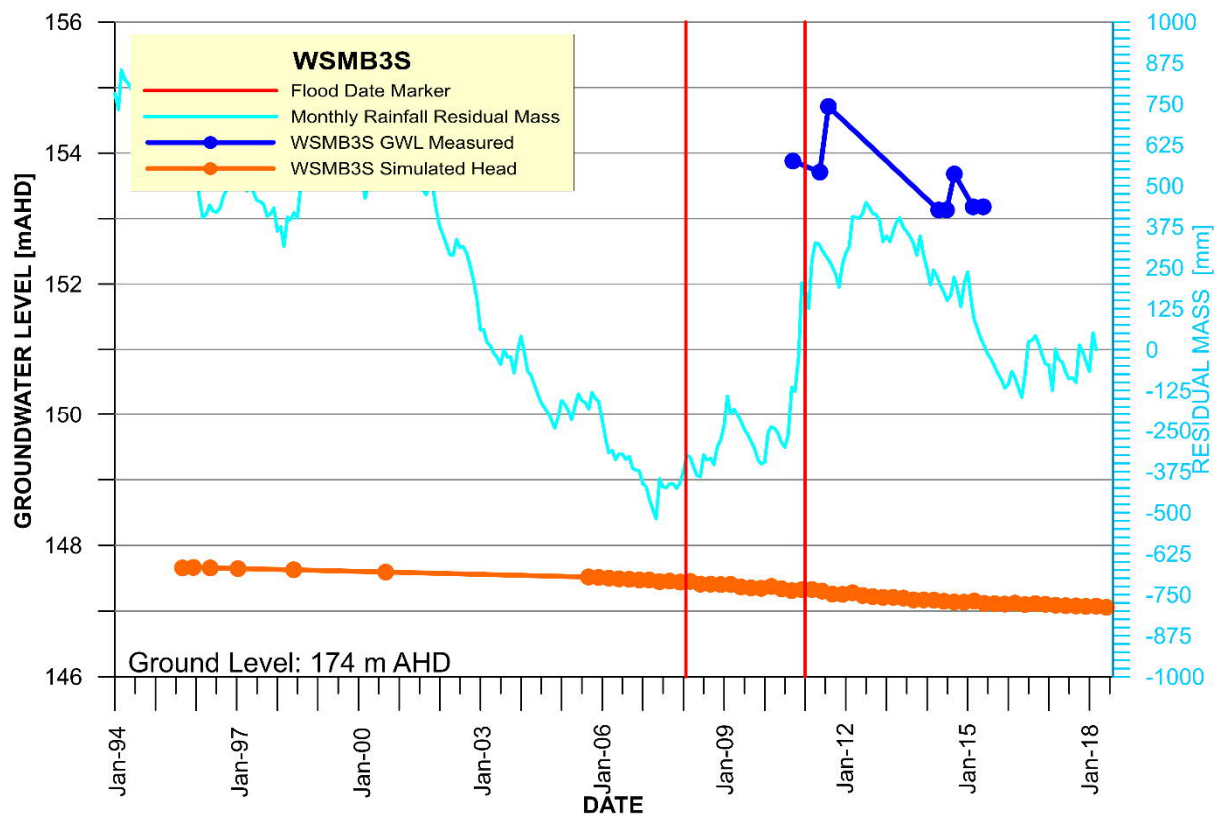


Figure B- 4: WSMB3S

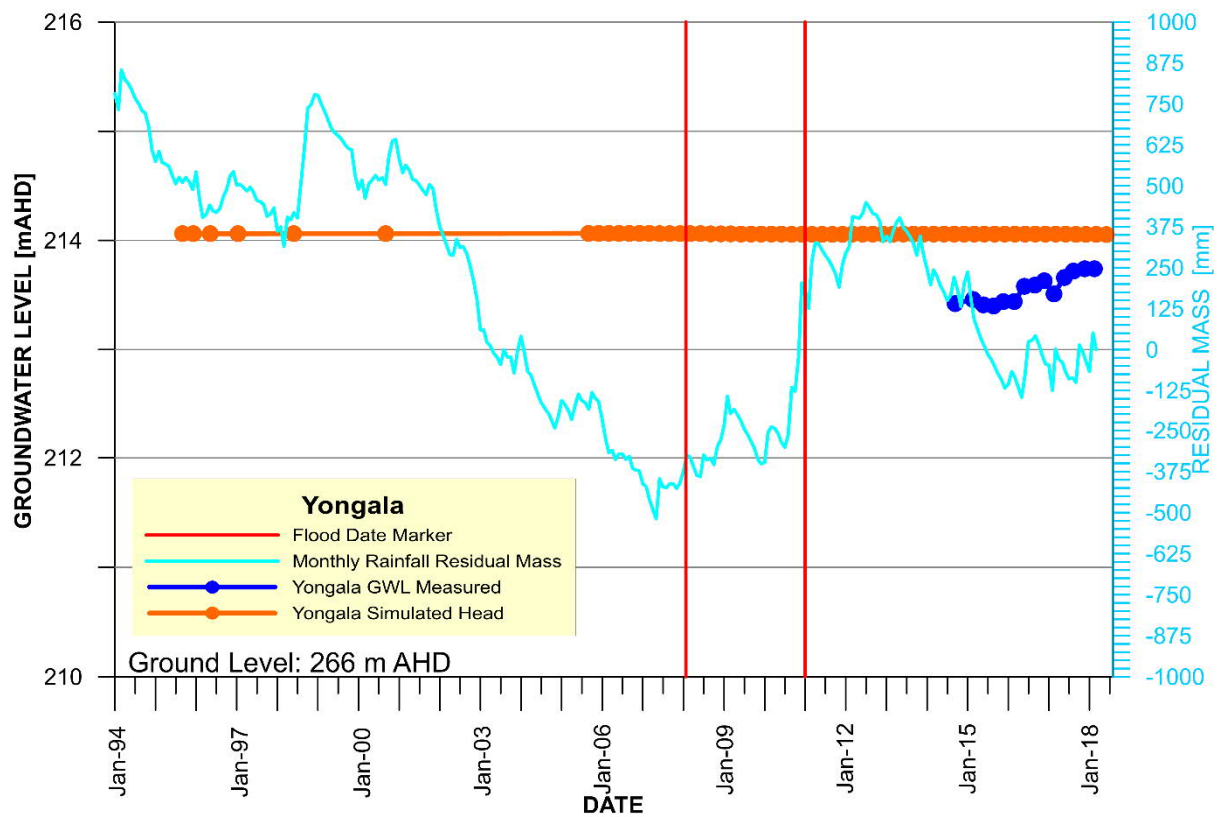


Figure B- 5: Yongala Bore

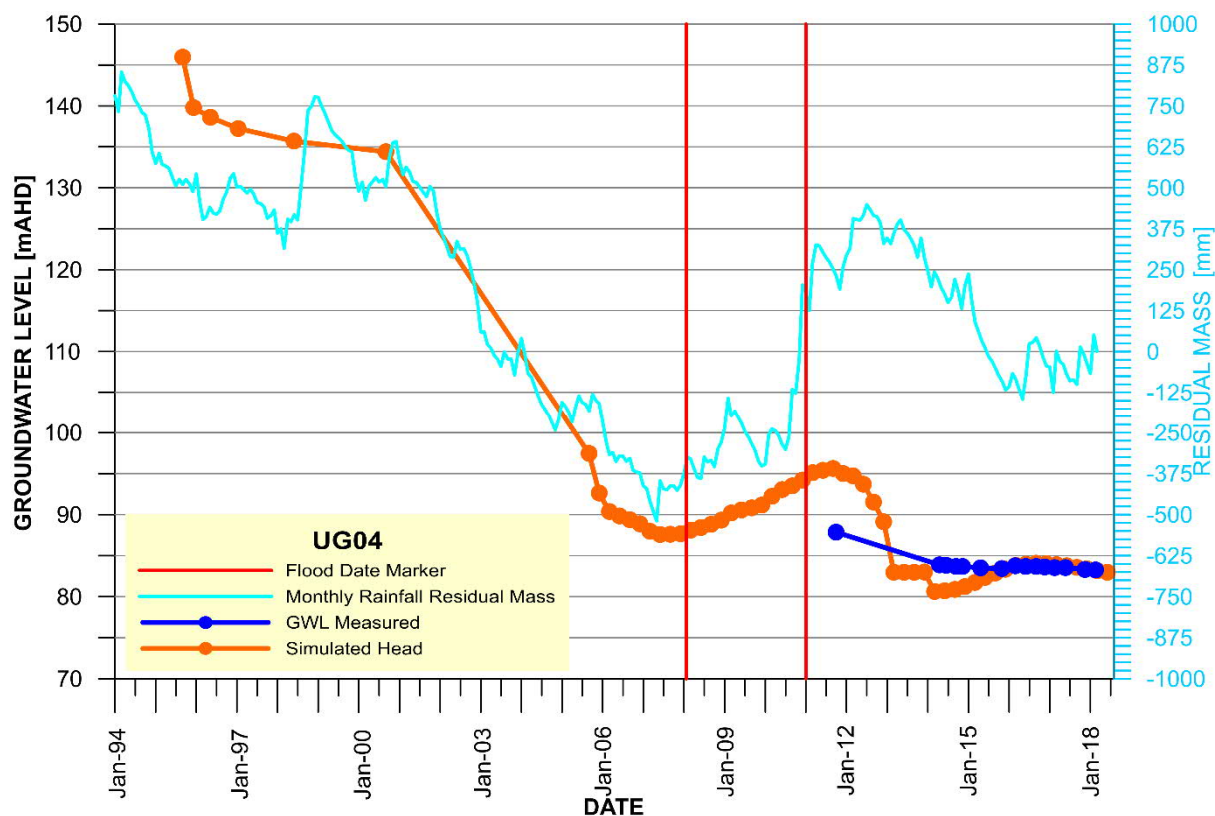


Figure B- 6: UG04

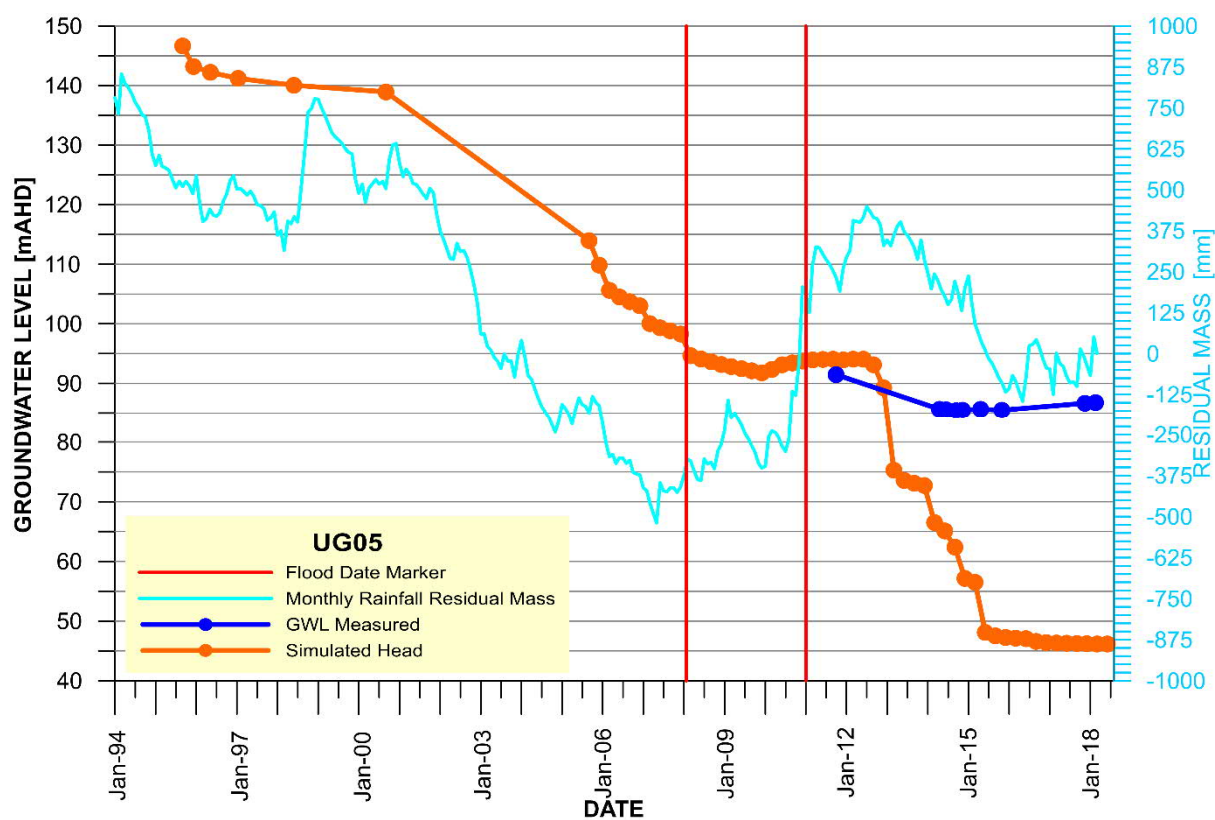


Figure B- 7: UG05

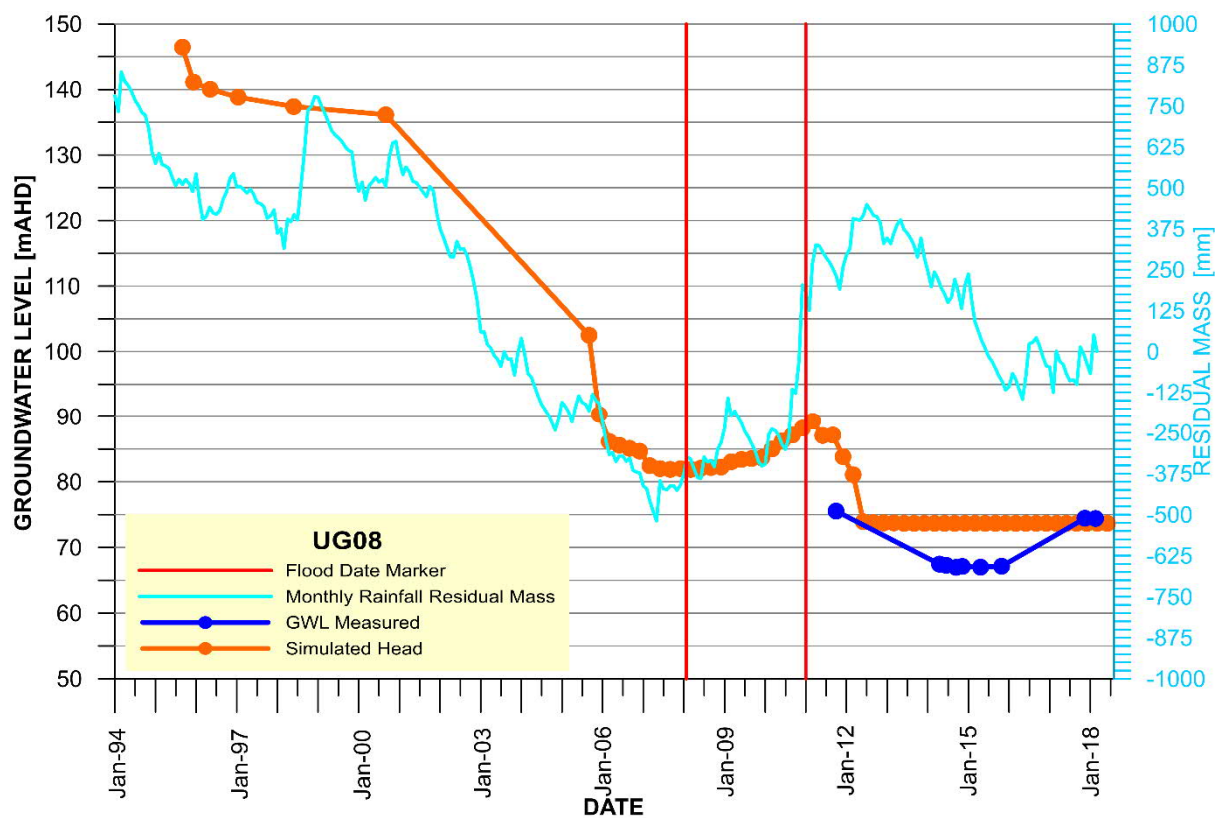


Figure B- 8: UG08

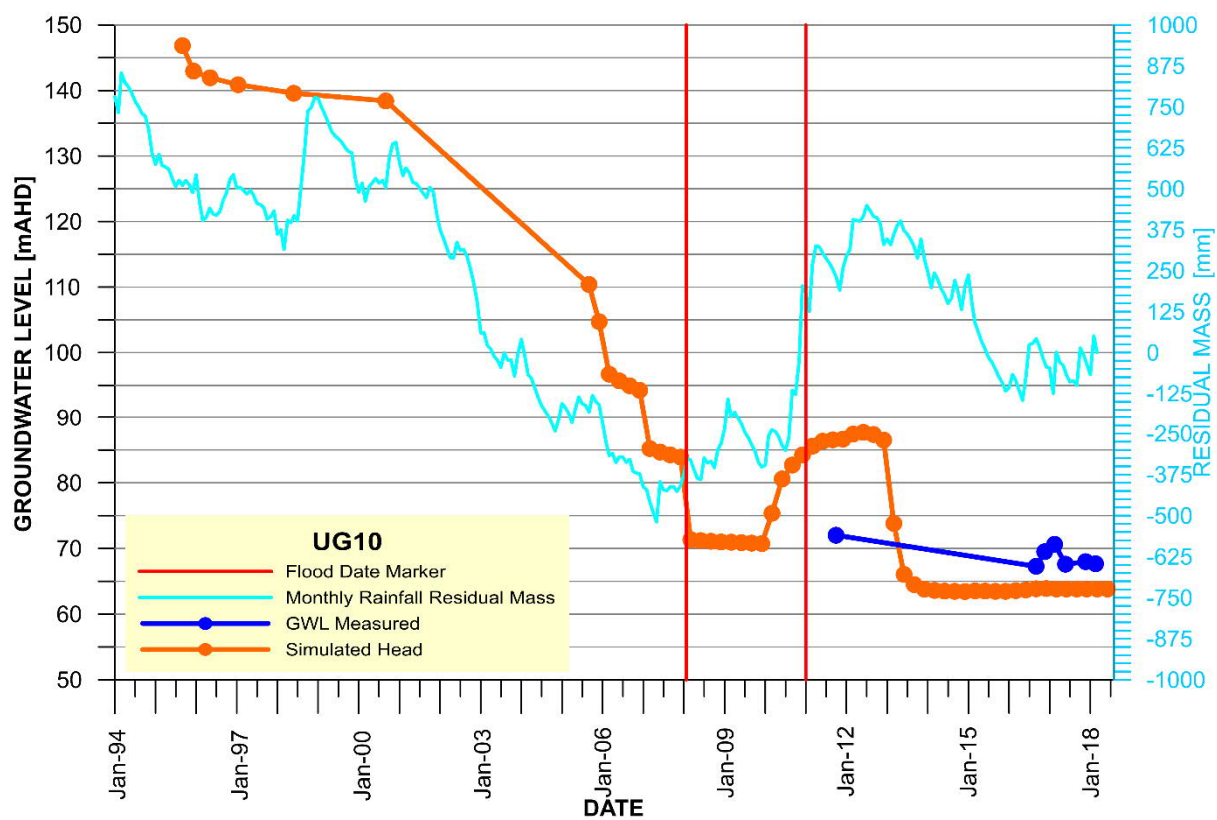


Figure B- 9: UG10



Figure B-19: Pre-calibration residuals



Figure B-20: Post-calibration residuals

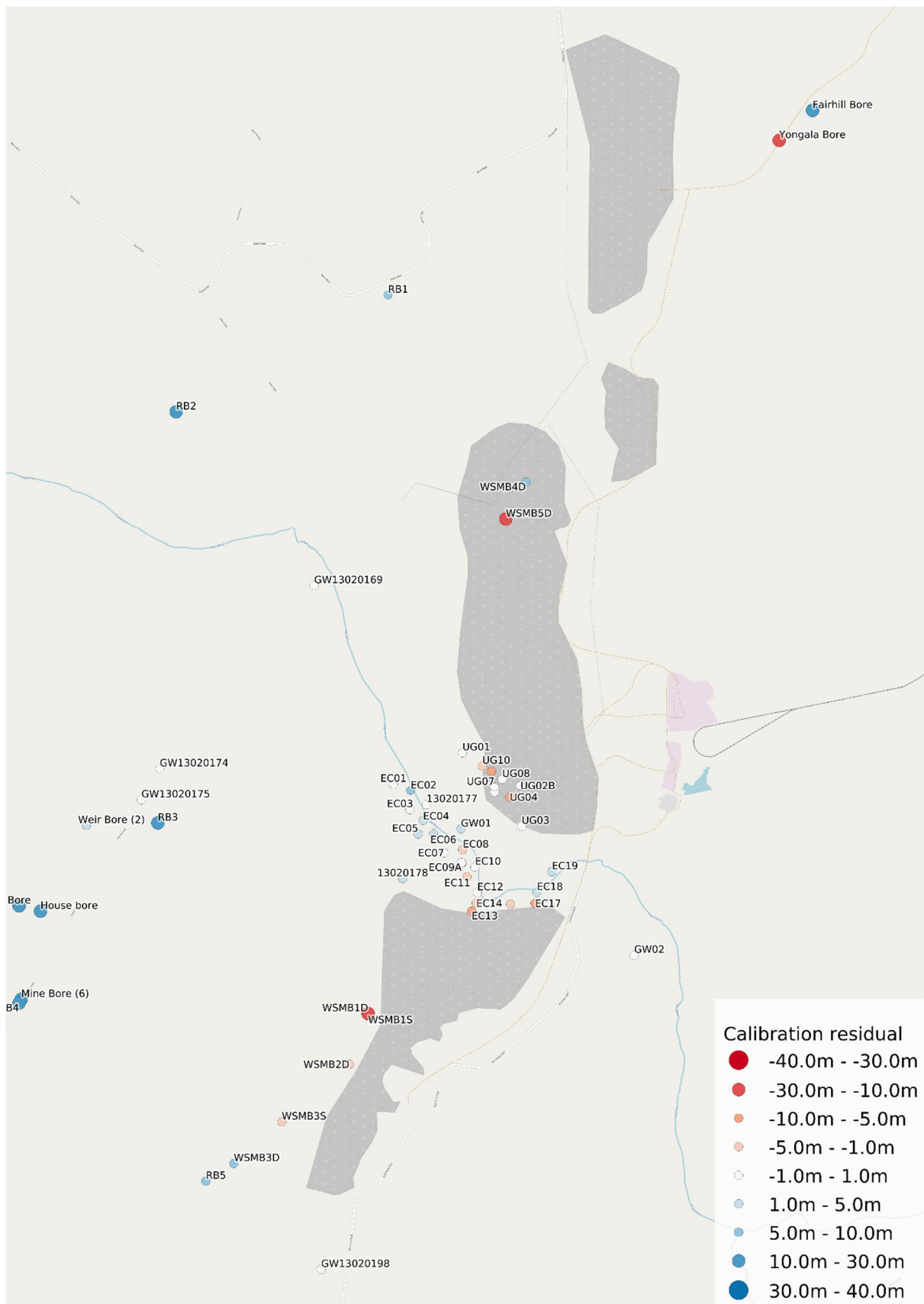


Figure B-21: Pre-calibration residuals focused on mine area

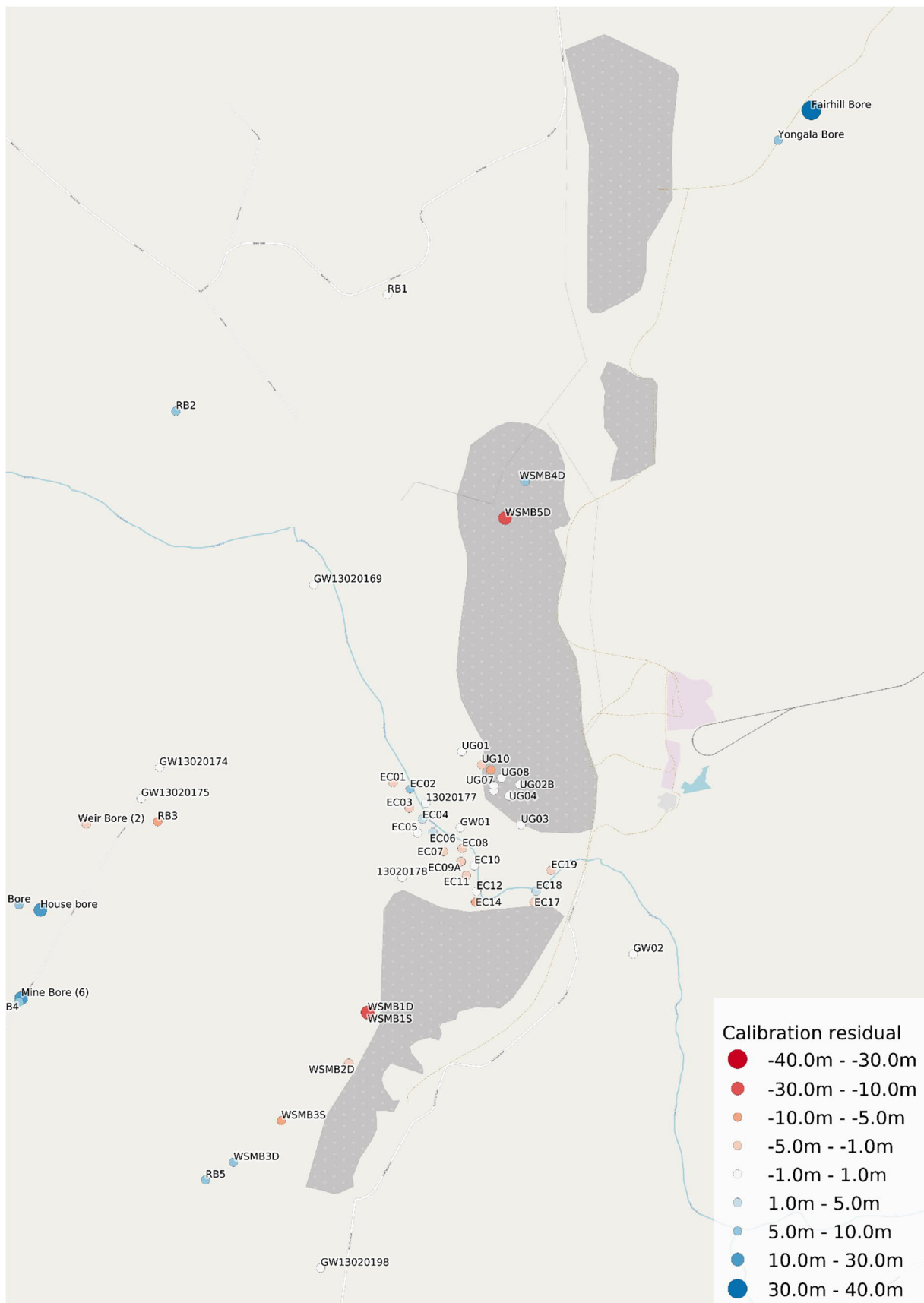


Figure B-22: Post-calibration residuals focused on mine area

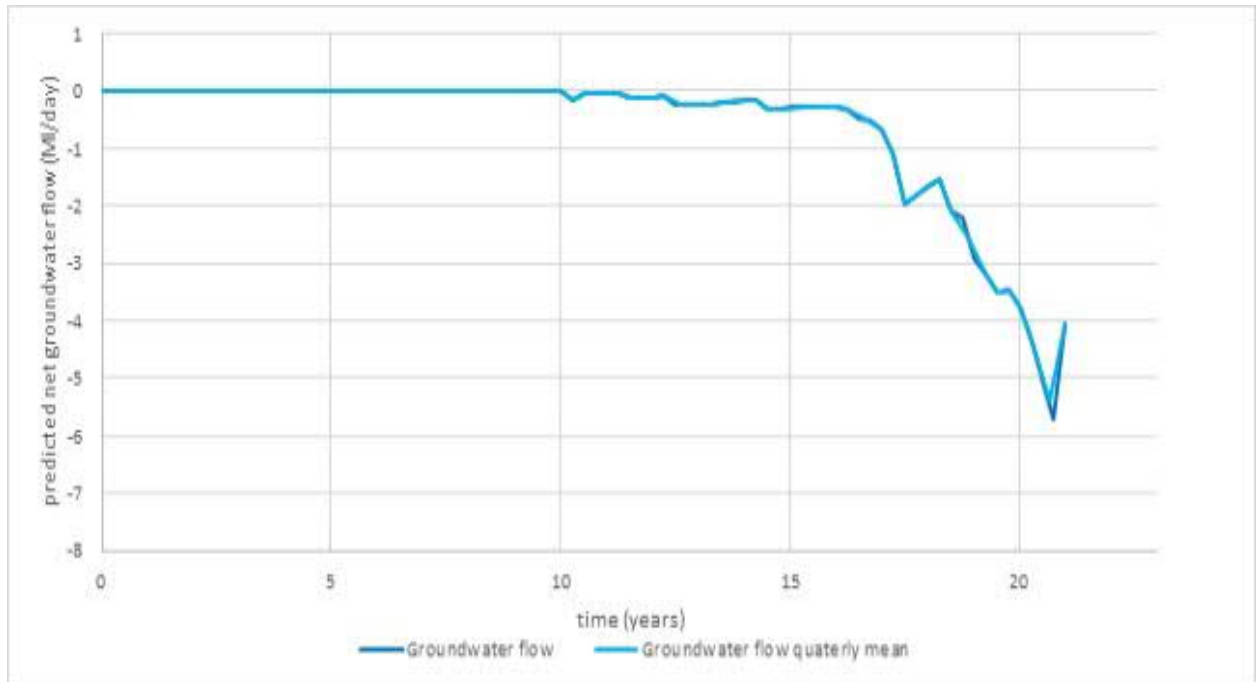


Figure B-23: Pre-calibration inflows to underground mine area

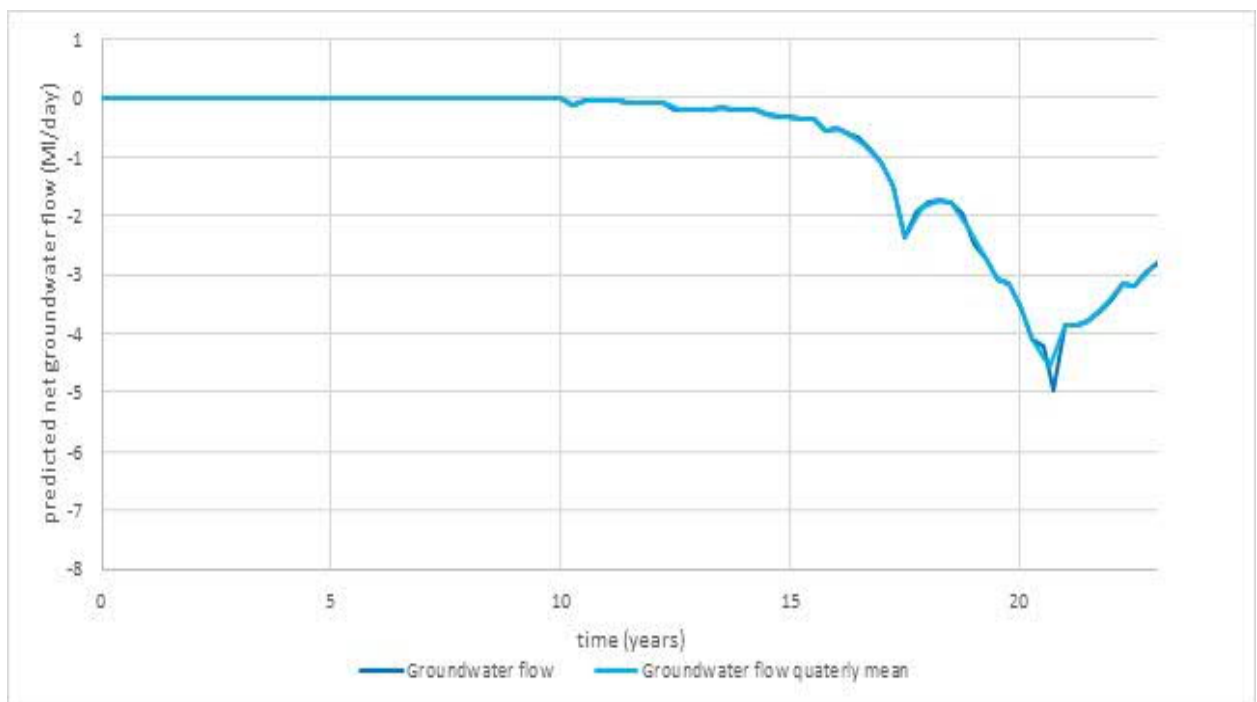
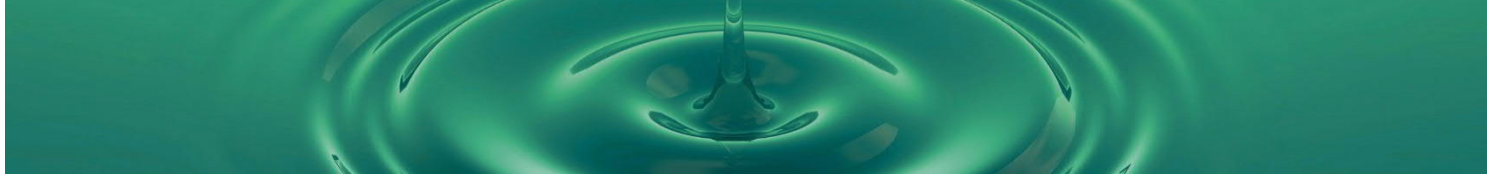


Figure B-24: Post-calibration inflows to underground mine area



APPENDIX C

Prediction Groundwater Hydrographs

Option 1 : Run 110

Option 2 : Run 112

Option 3 : Run 111

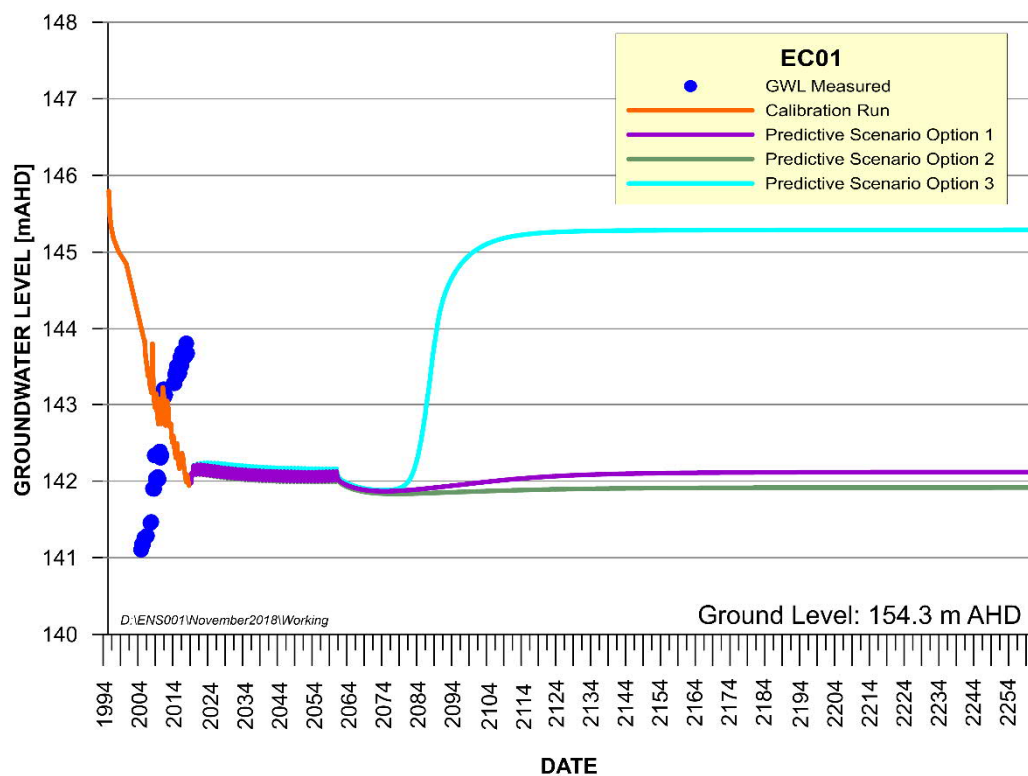


Figure C- 1: EC01

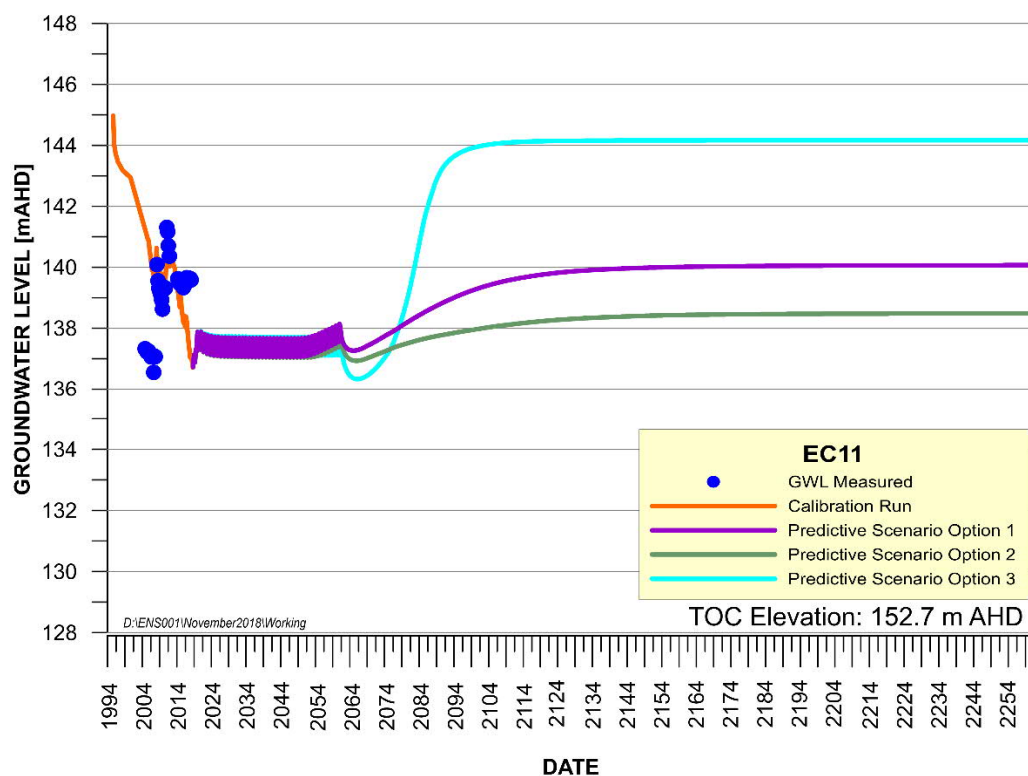


Figure C- 2: EC11

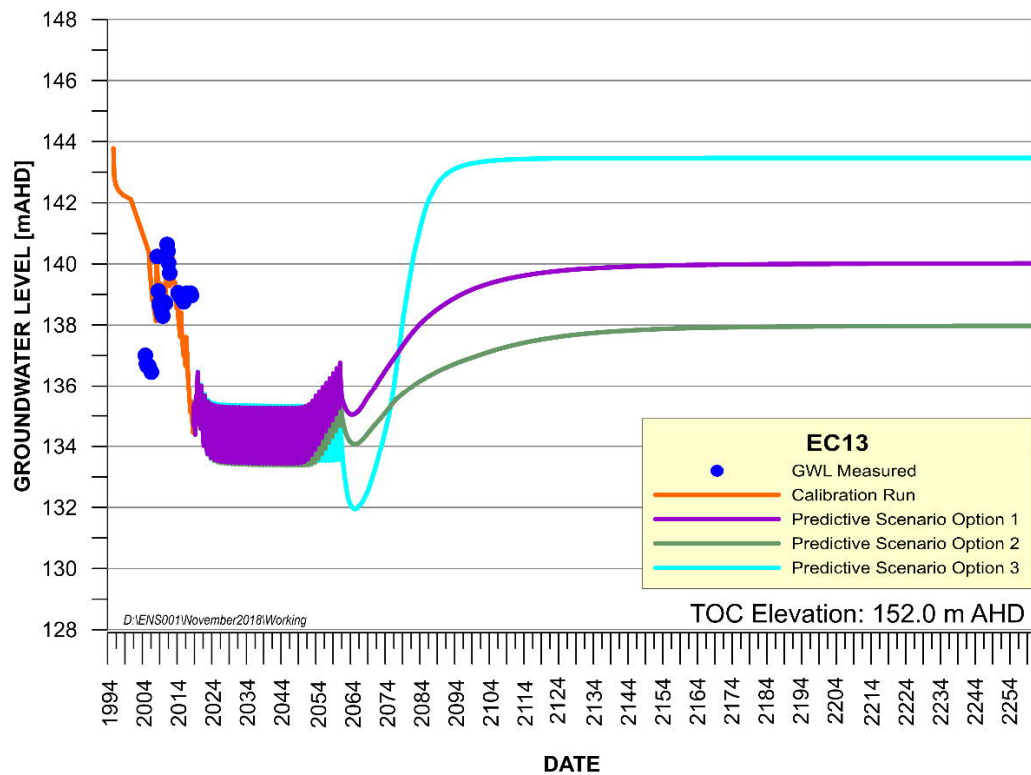


Figure C- 3: EC13

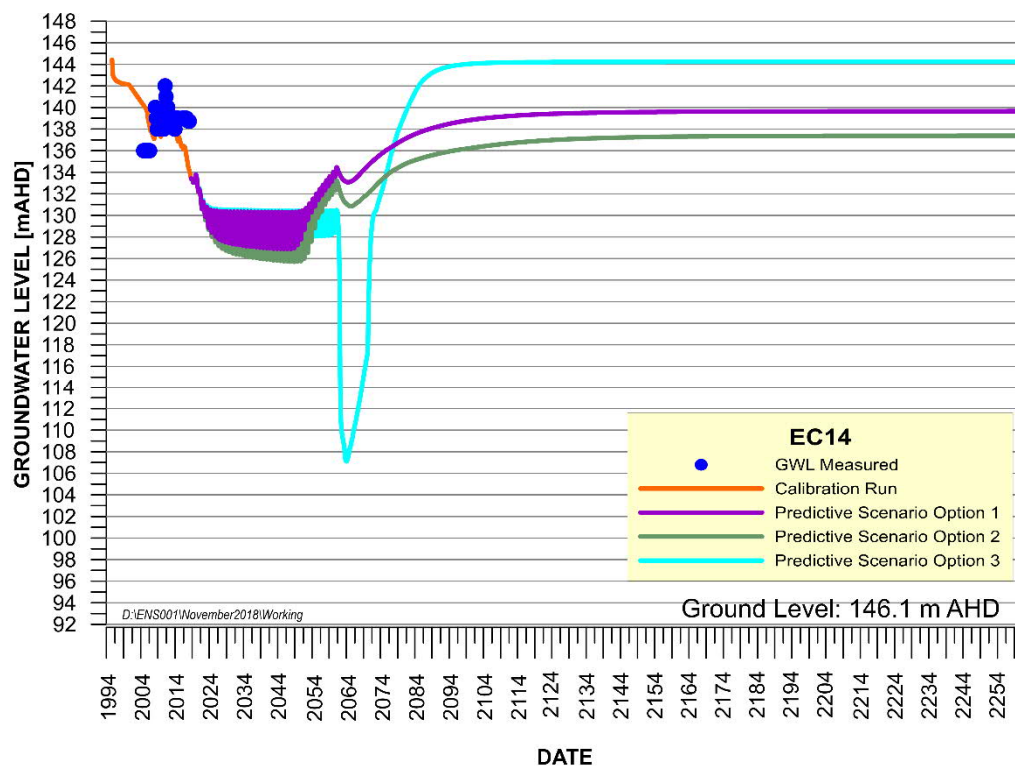


Figure C- 4: EC14

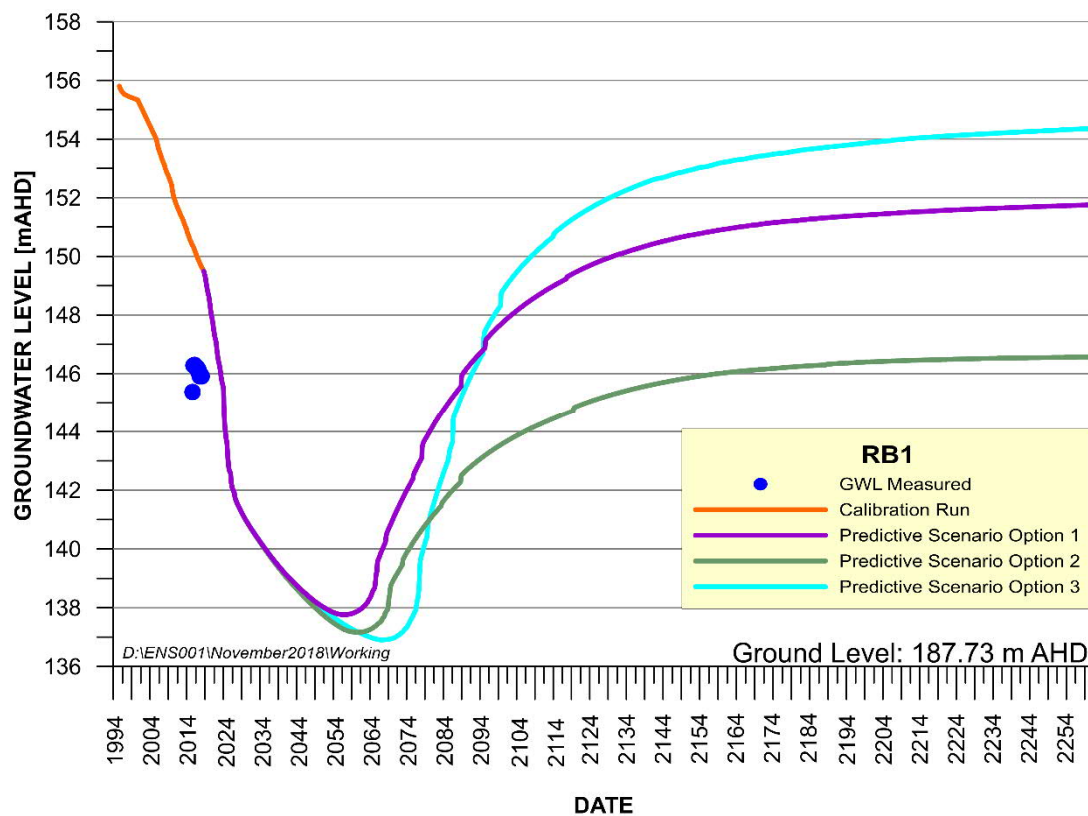


Figure C- 5: RB1

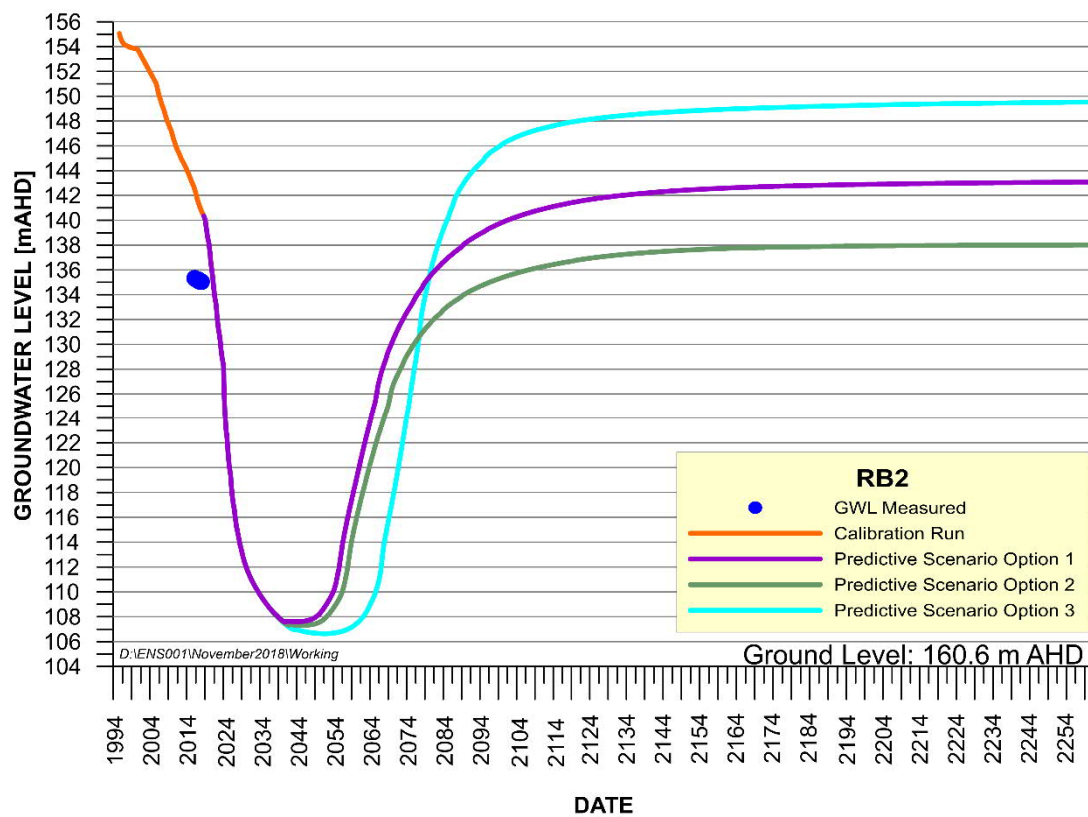


Figure C- 6: RB2

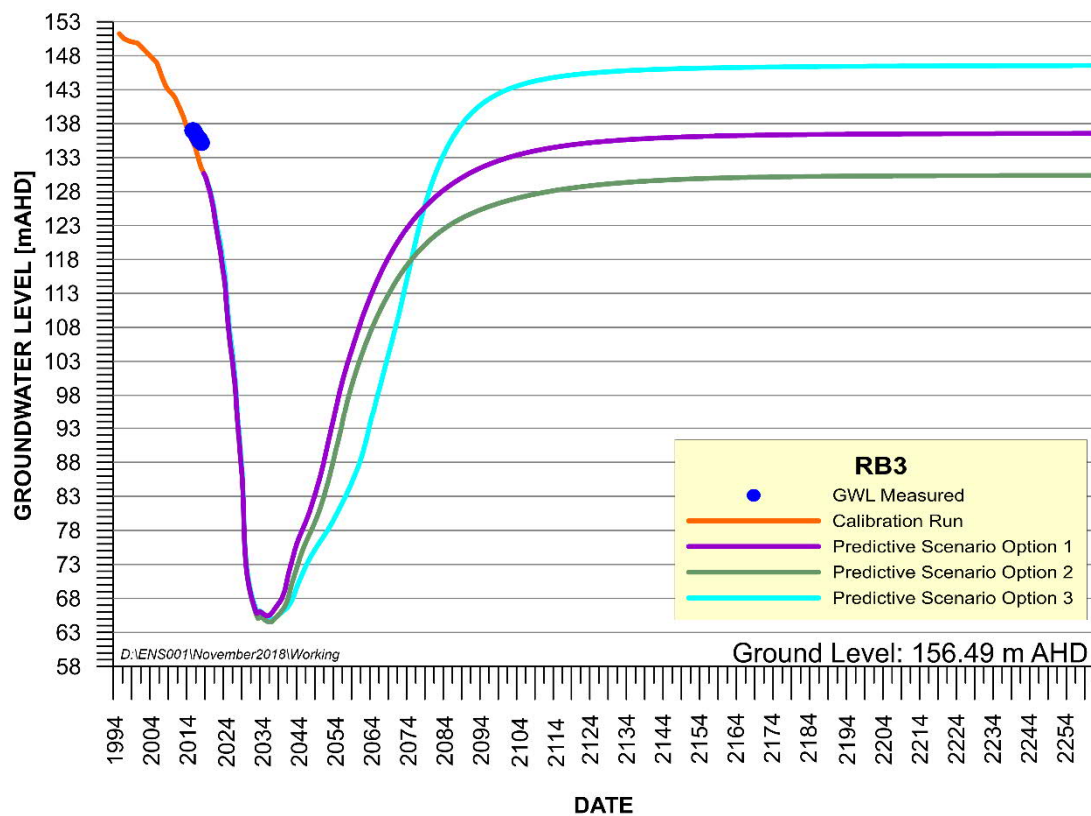


Figure C- 7: RB3

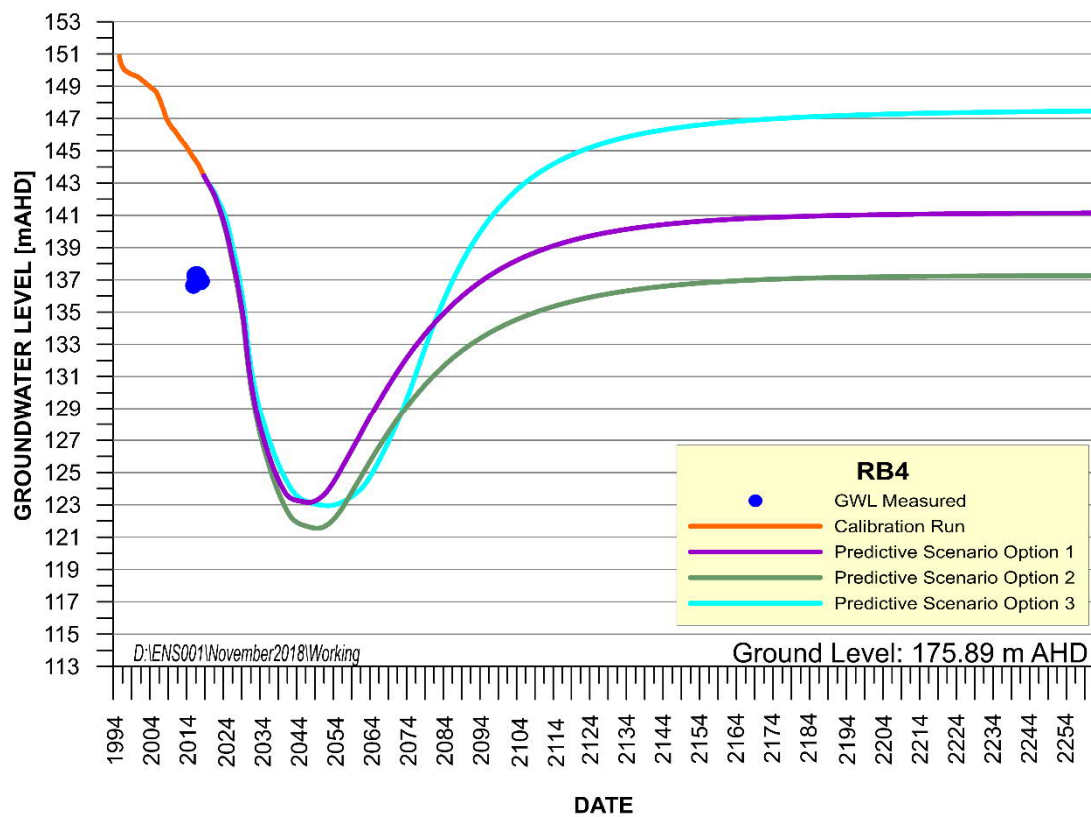


Figure C- 8: RB4

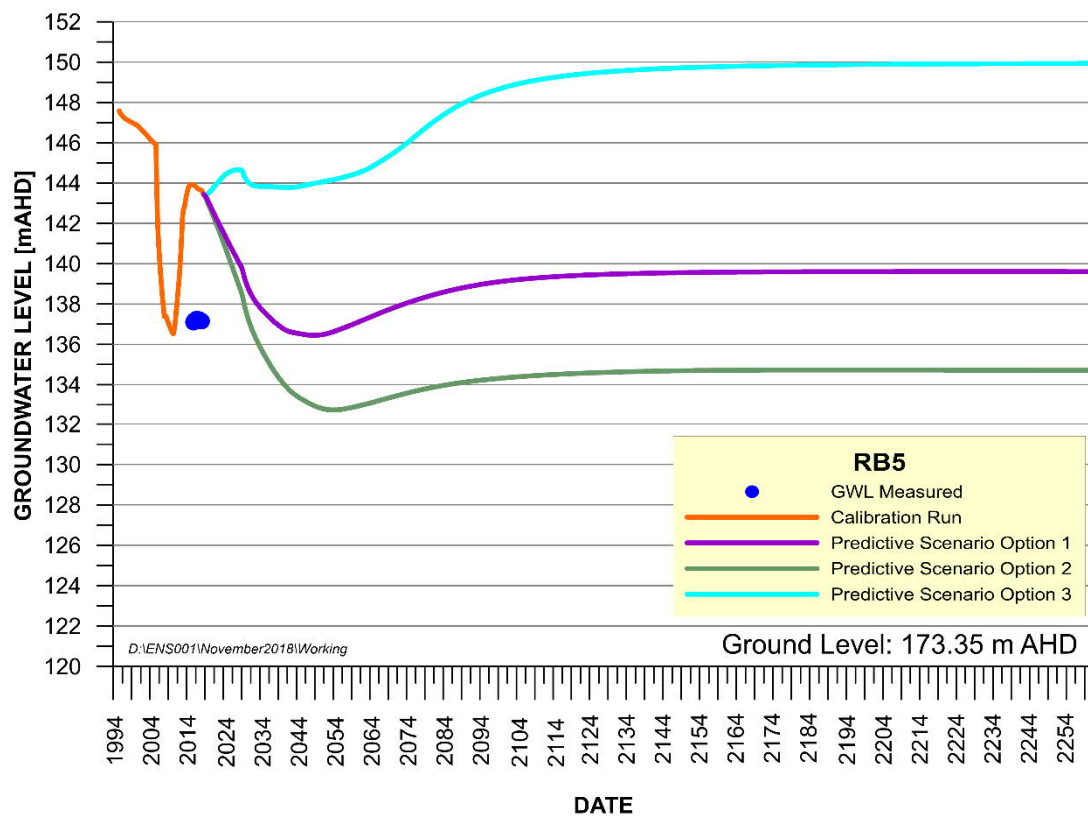


Figure C- 9: RB5

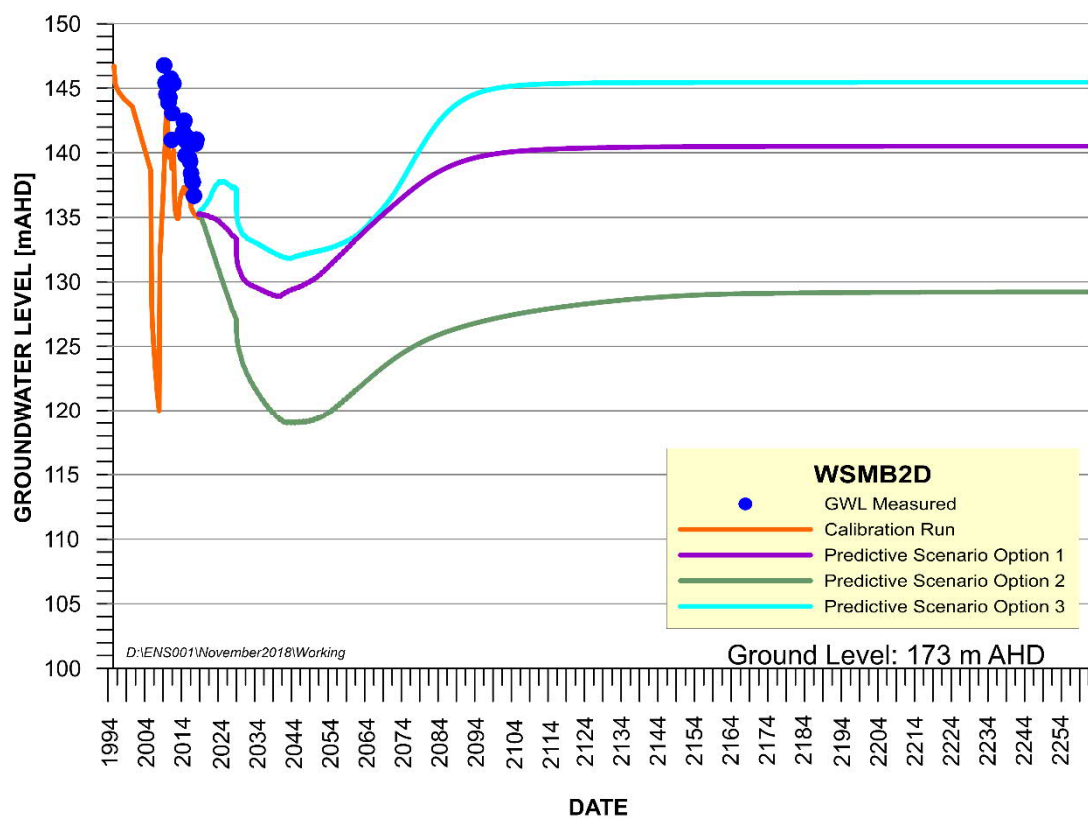


Figure C- 10: WSMB2D

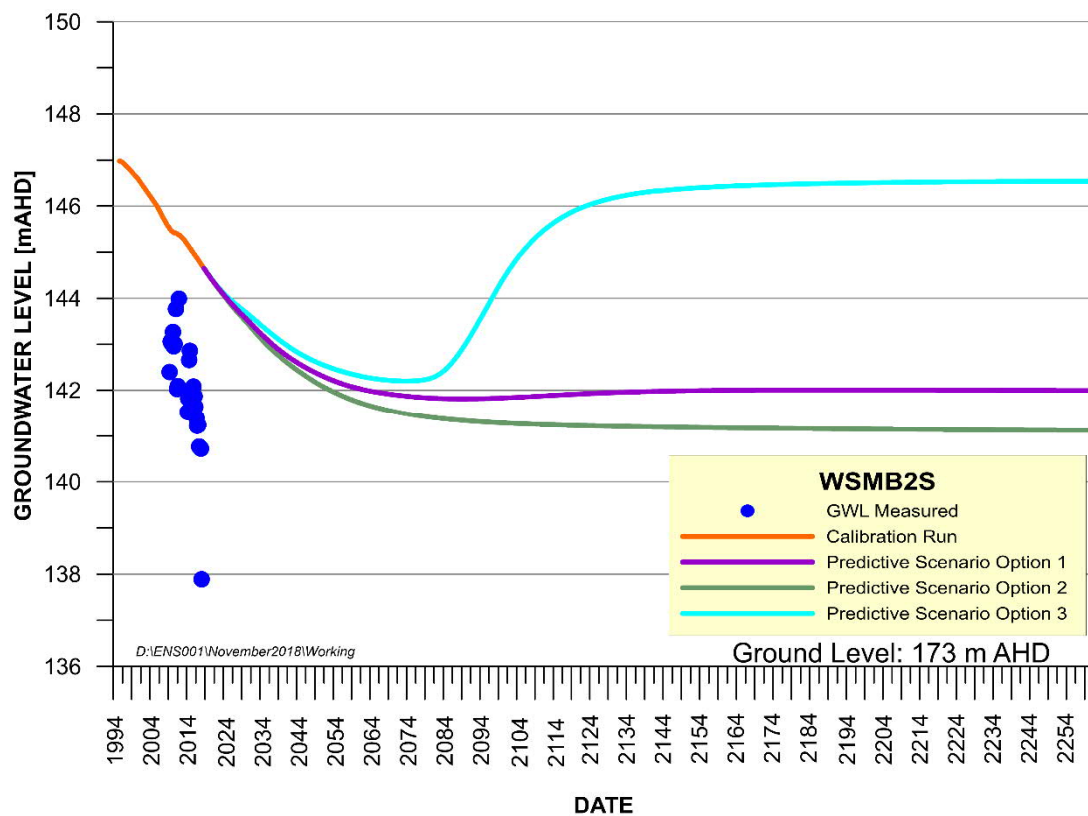


Figure C- 11: WSMB2S

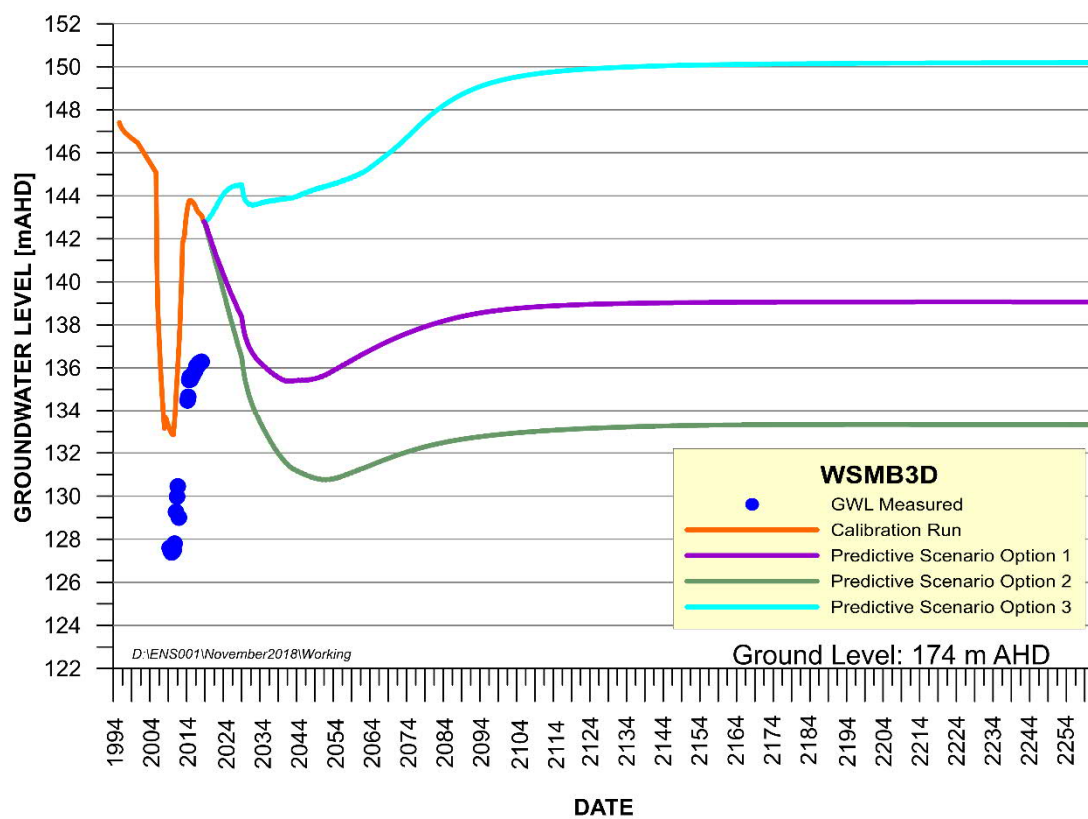


Figure C- 12: WSMB3D

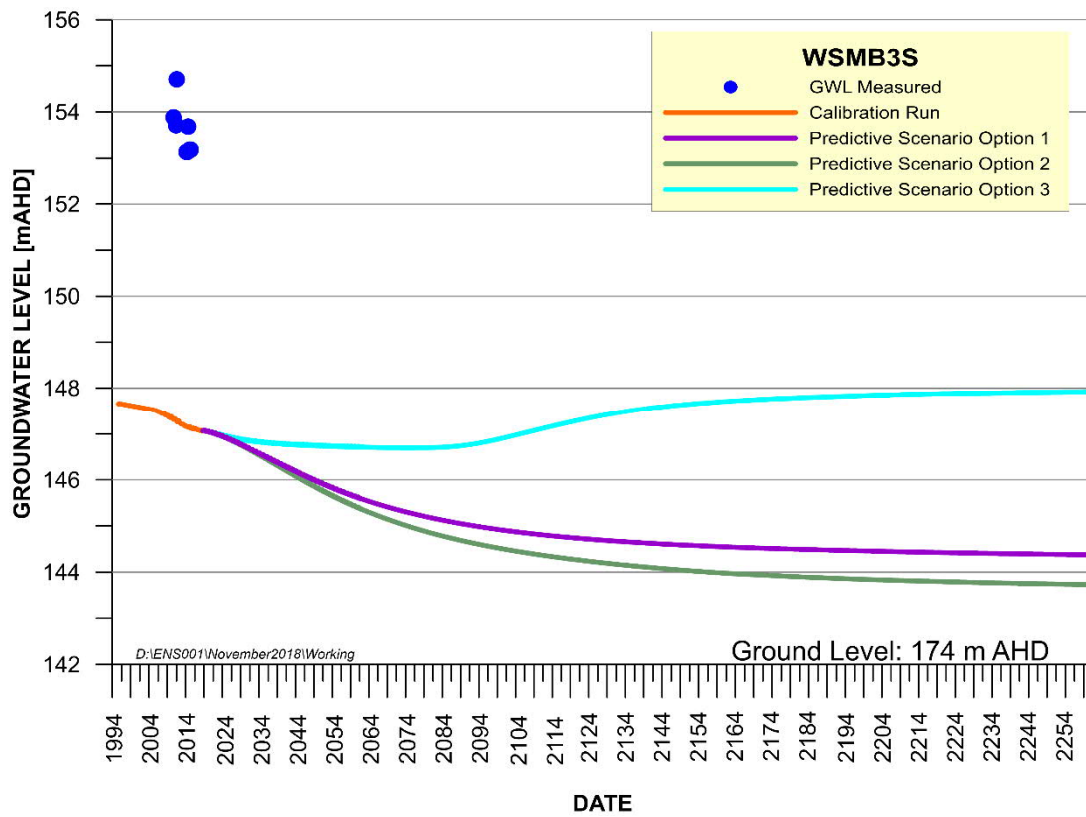


Figure C- 13: WSMB3S

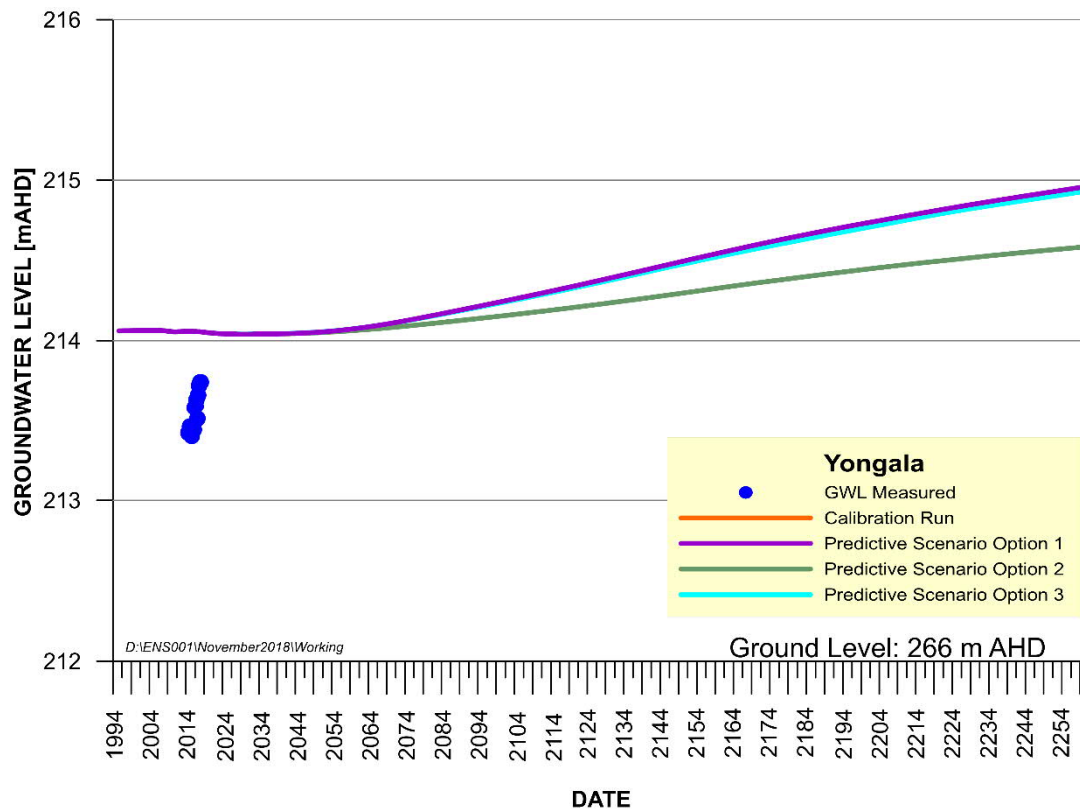
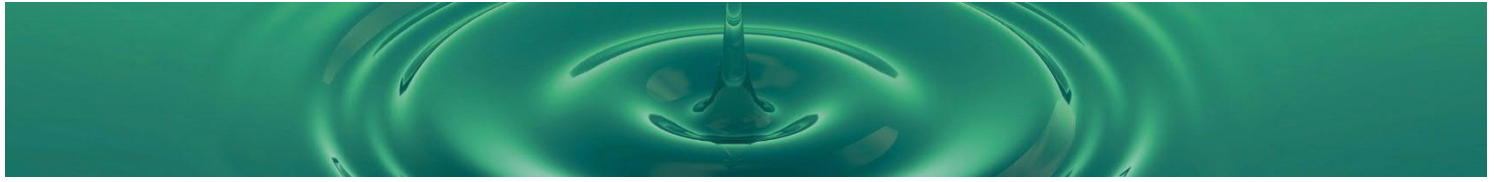


Figure C- 14: Yongala Bore



APPENDIX D

Prediction and Recovery Mine Void Inflows/Outflows

Options 1 and 2

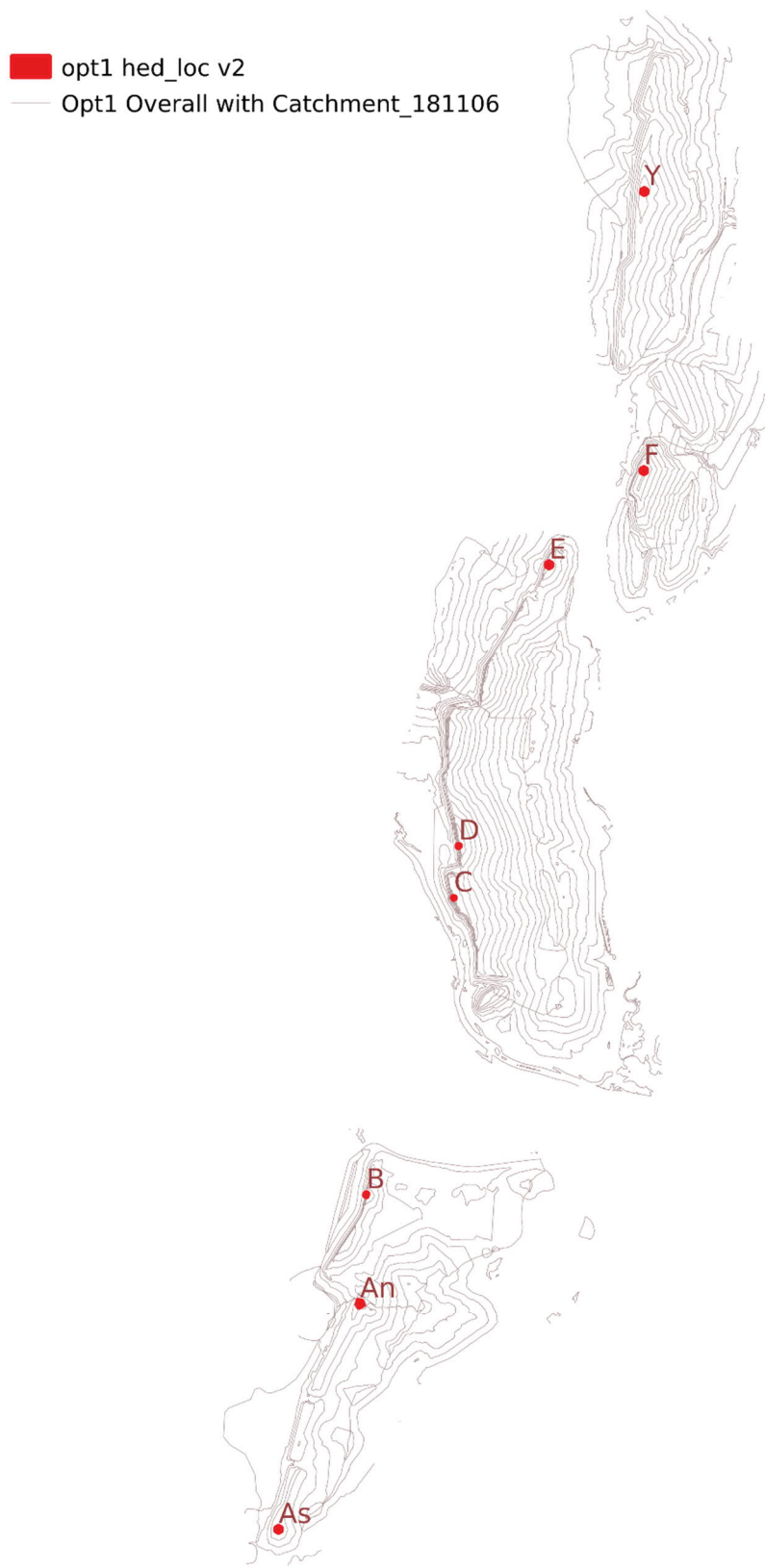


Figure D- 1: Option 1 Head Extraction Point locations



Figure D- 2: Option 2 Head Extraction Point locations

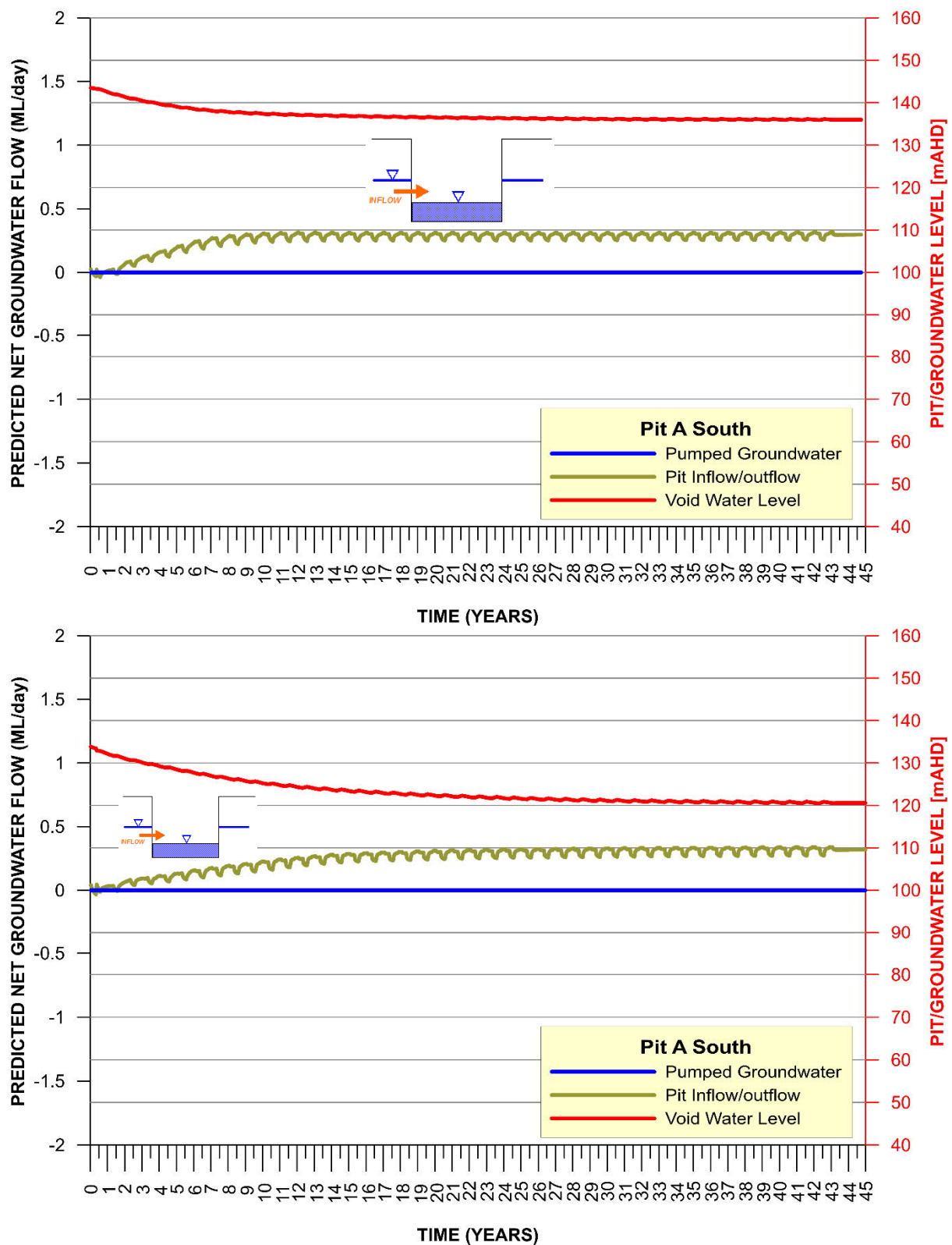


Figure D- 3: Predicted Water Levels and Flows - Pit A South - a) Option 1 b) Option 2

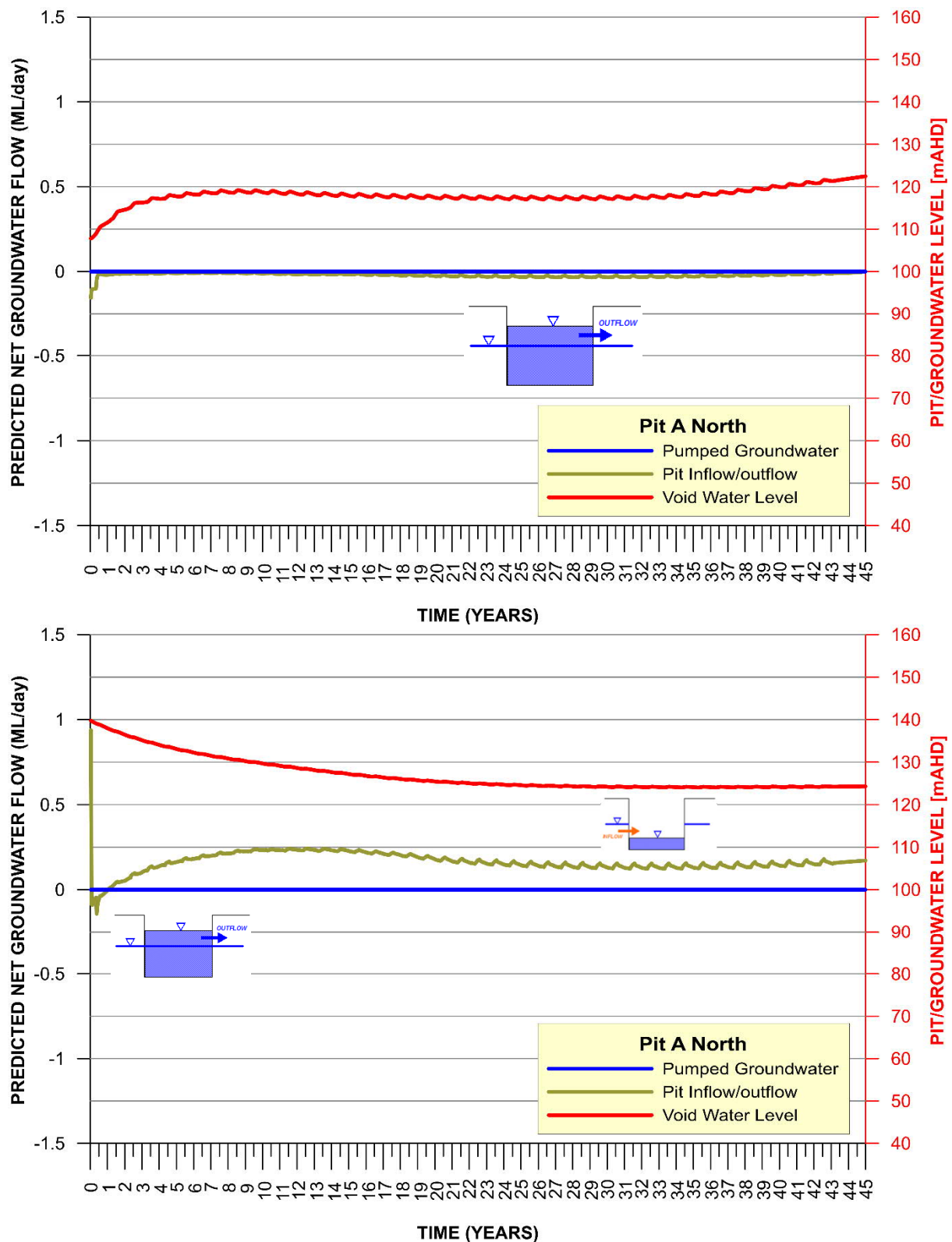


Figure D- 4: Predicted Water Levels and Flows - Pit A North - a) Option 1 b) Option 2

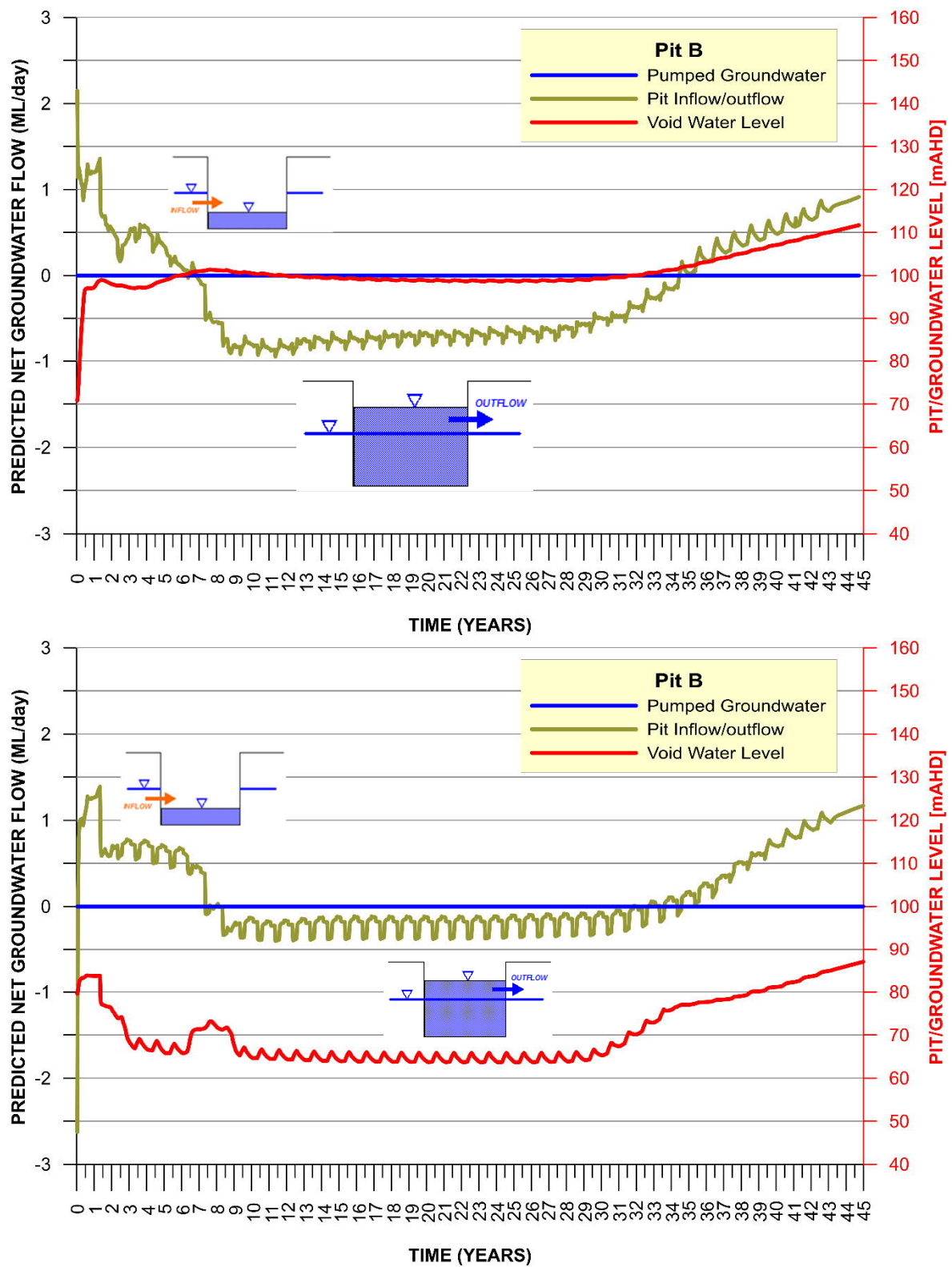


Figure D- 5: Predicted Water Levels and Flows - Pit B - a) Option 1 b) Option 2

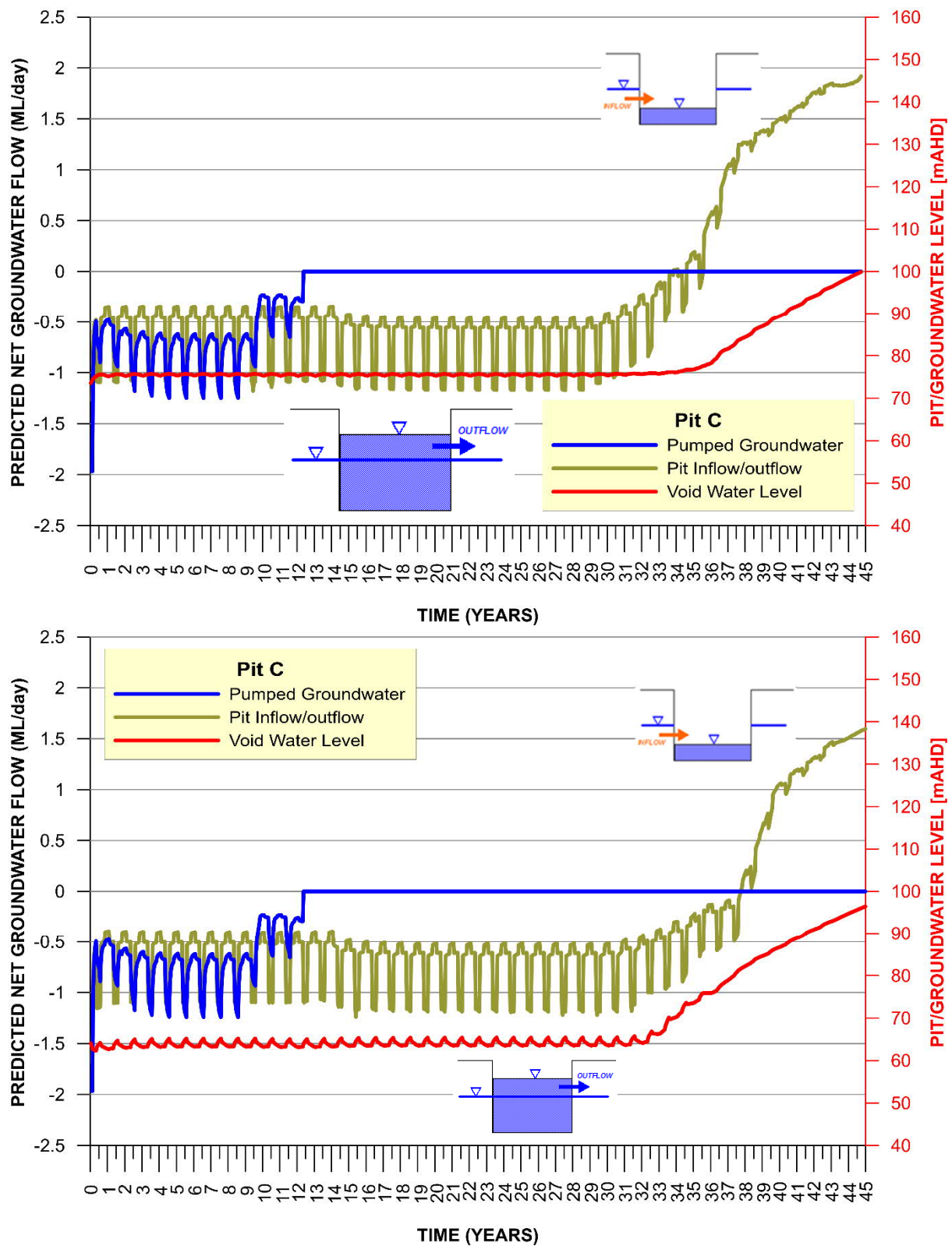


Figure D- 6: Predicted Water Levels and Flows - Pit C - a) Option 1 b) Option 2

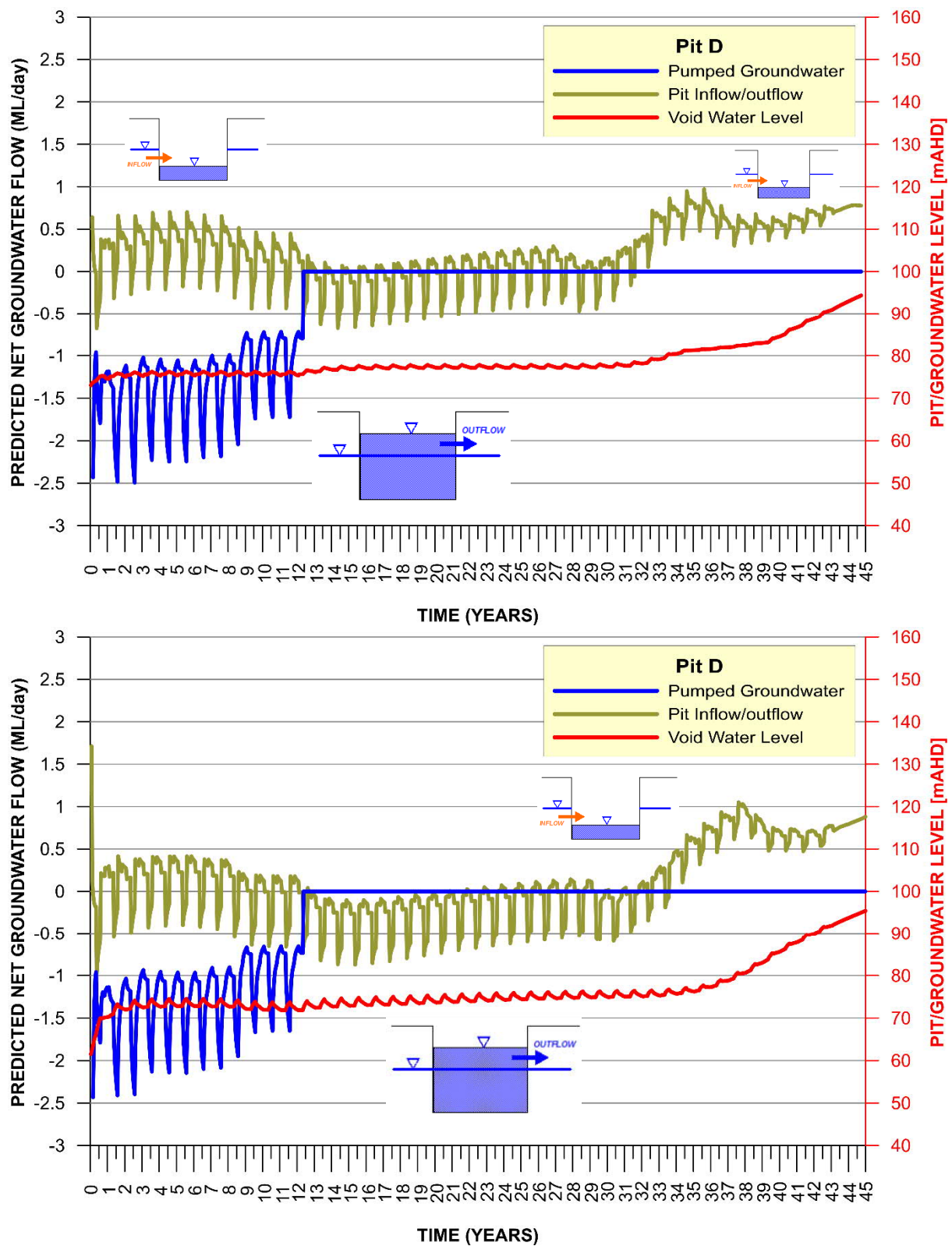


Figure D- 7: Predicted Water Levels and Flows - Pit D - a) Option 1 b) Option 2

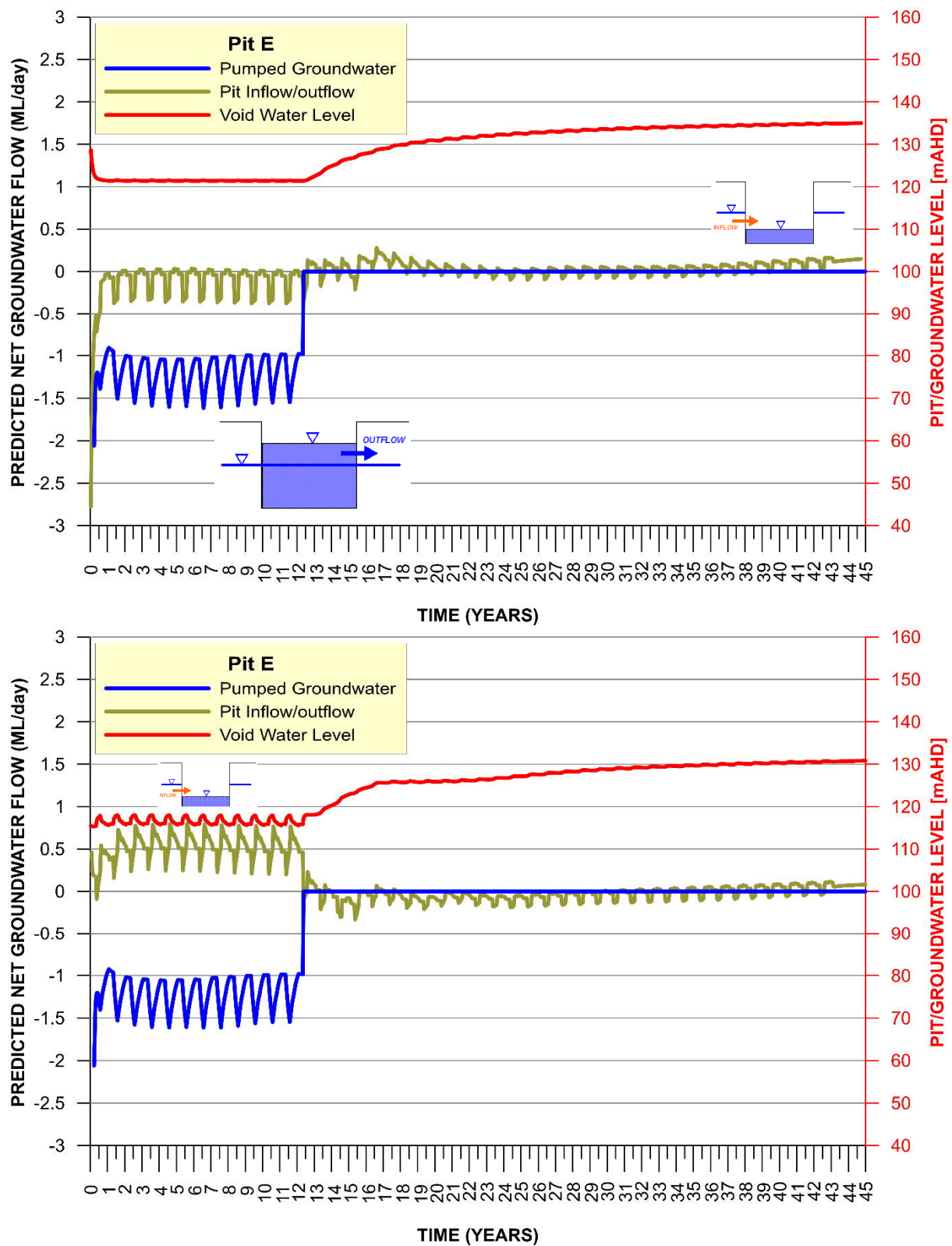


Figure D- 8: Predicted Water Levels and Flows - Pit E - a) Option 1 b) Option 2

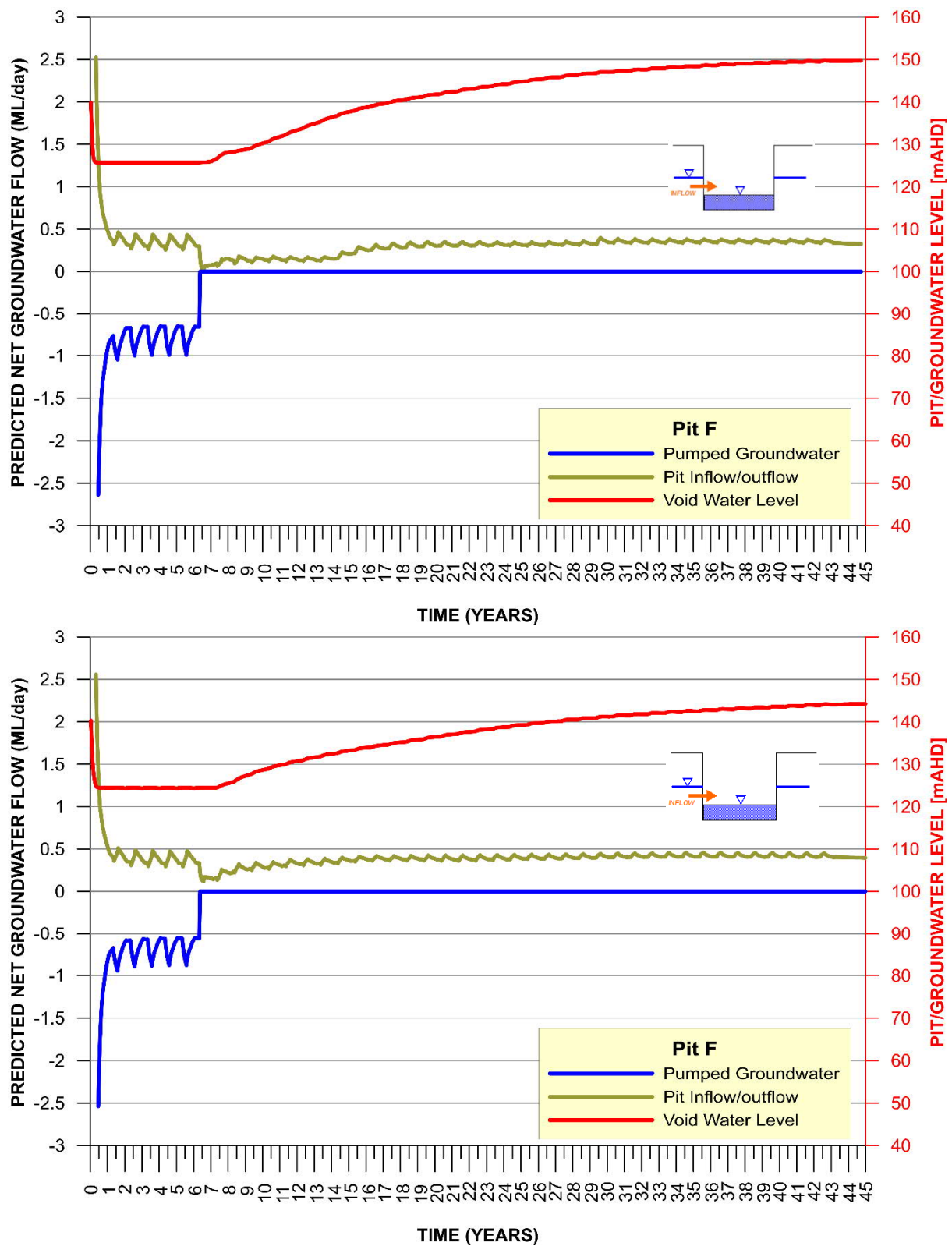
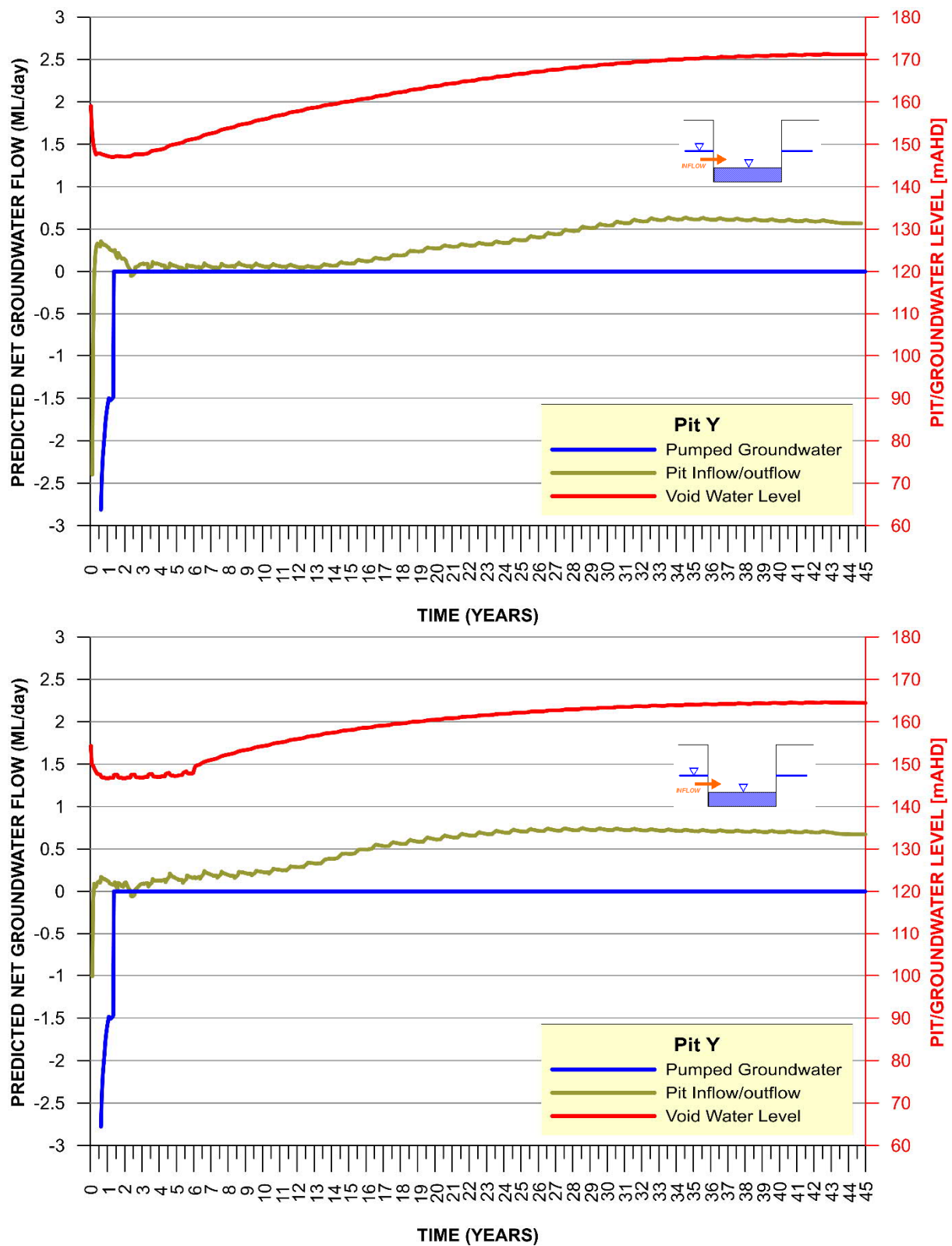


Figure D- 9: Predicted Water Levels and Flows - Pit F - a) Option 1 b) Option 2



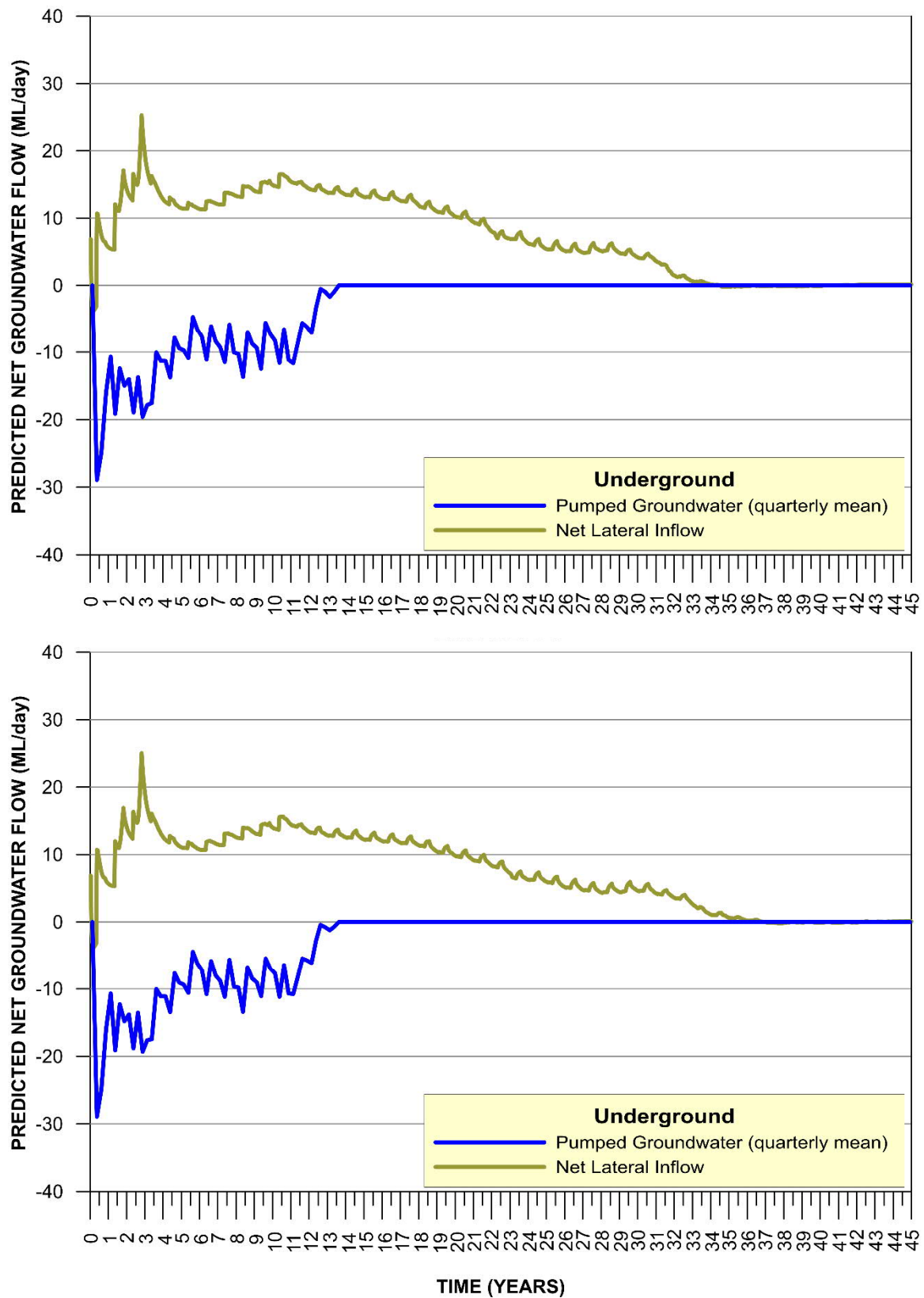


Figure D- 11: Predicted Underground Mine Inflow - a) Option 1 b) Option 2

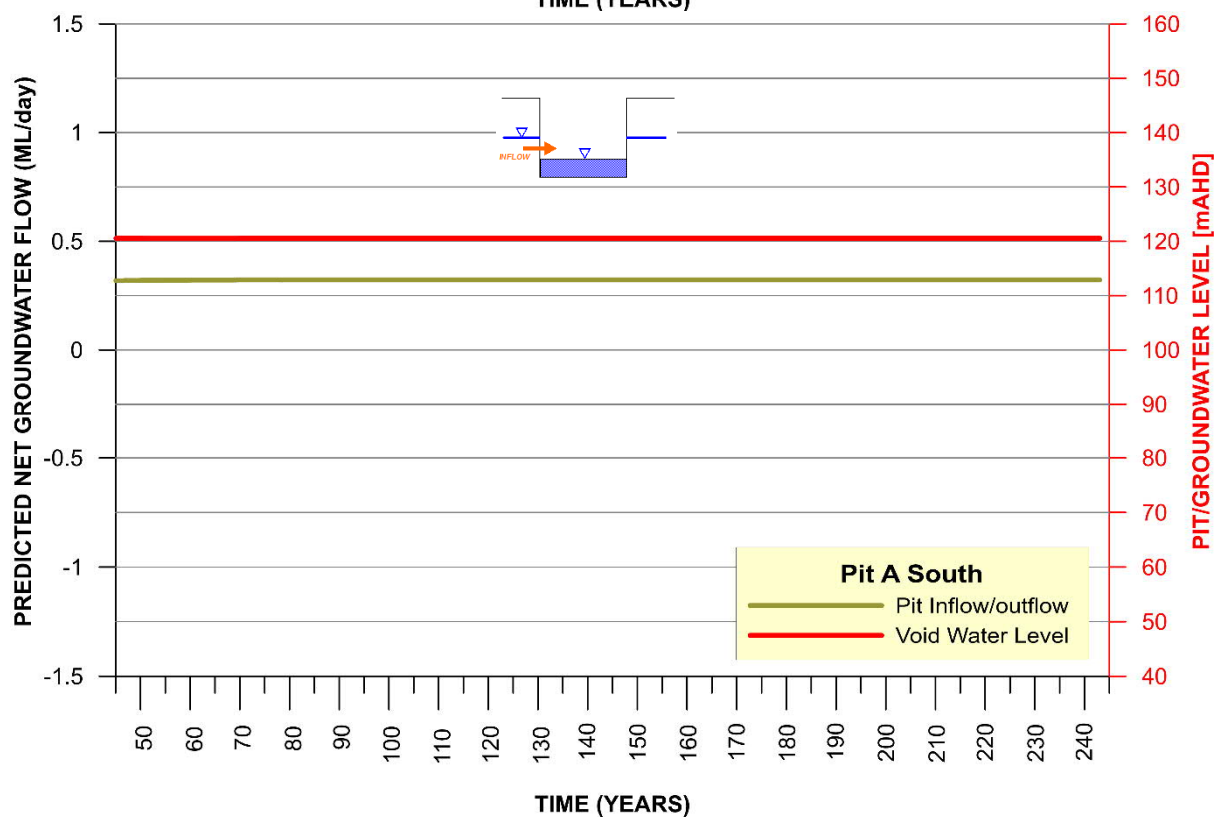
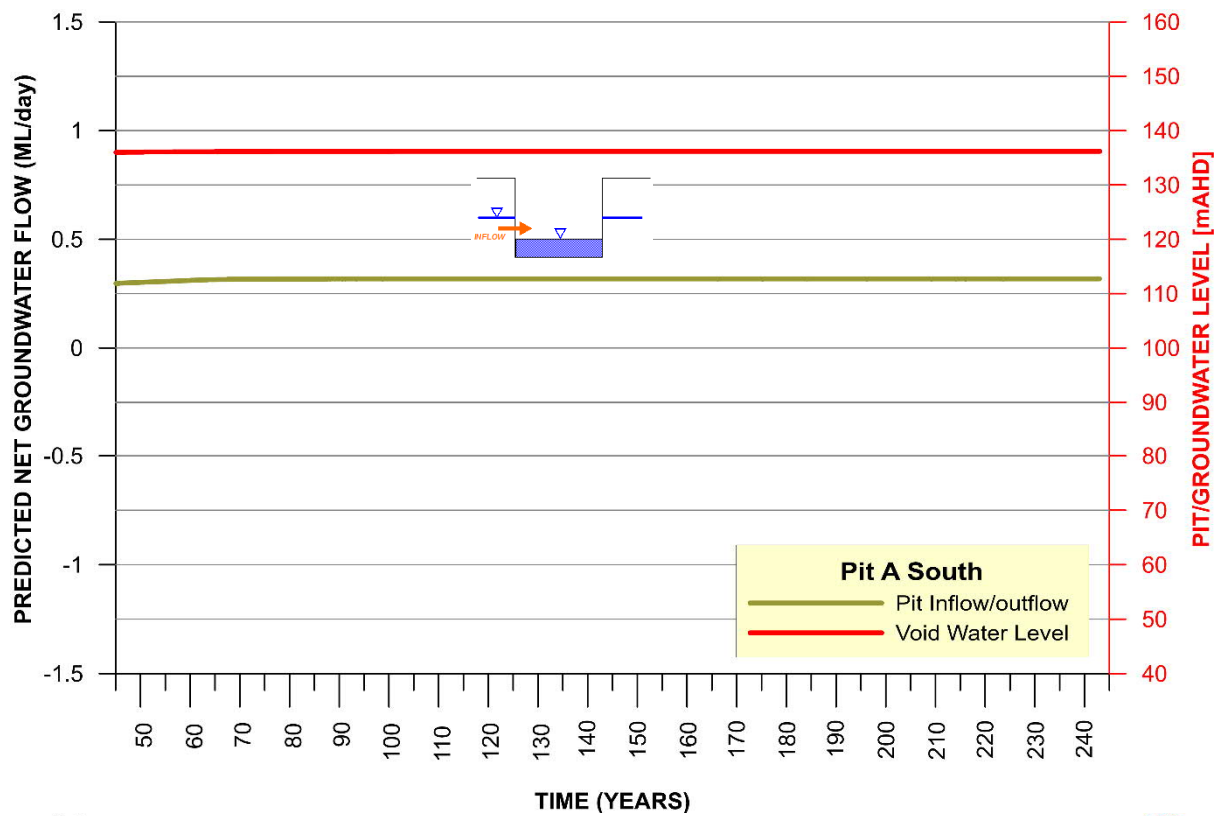


Figure D- 12: Predicted Long-term Water Levels and Flows - Pit A South - a) Option 1 b) Option 2

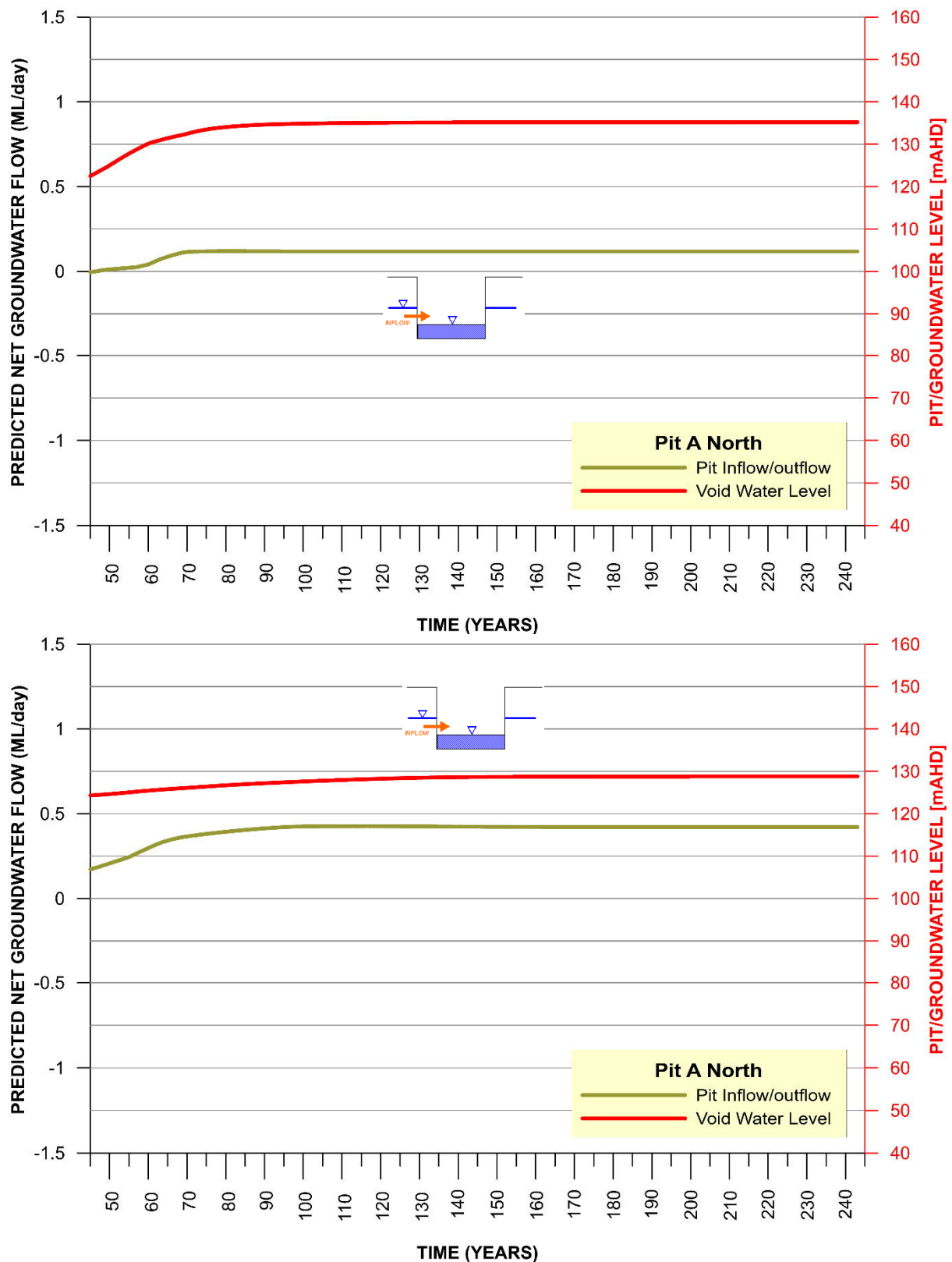


Figure D- 13: Predicted Long-term Water Levels and Flows - Pit A North - a) Option 1 b) Option 2

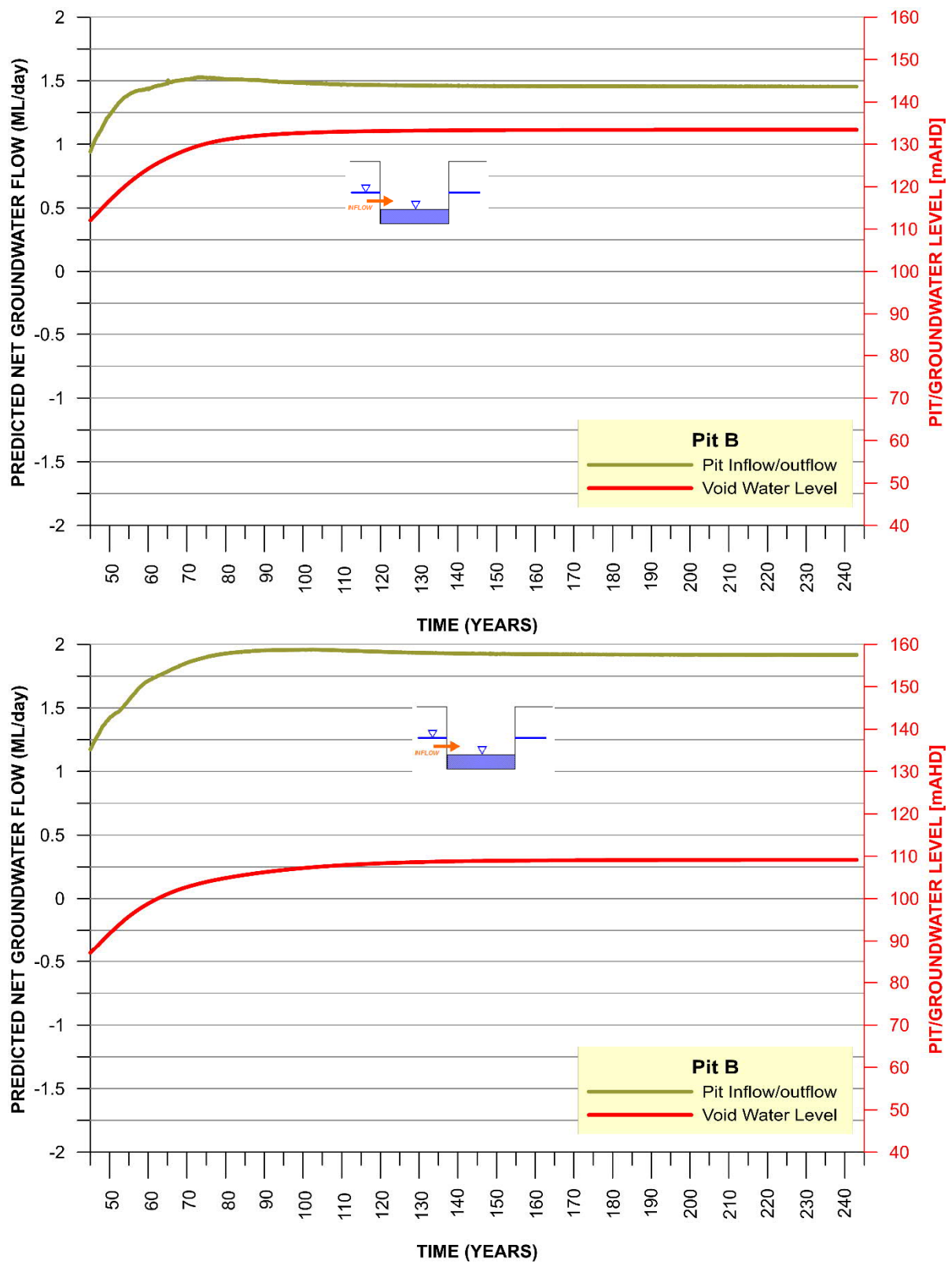


Figure D- 14: Predicted Long-term Water Levels and Flows - Pit B - a) Option 1 b) Option 2

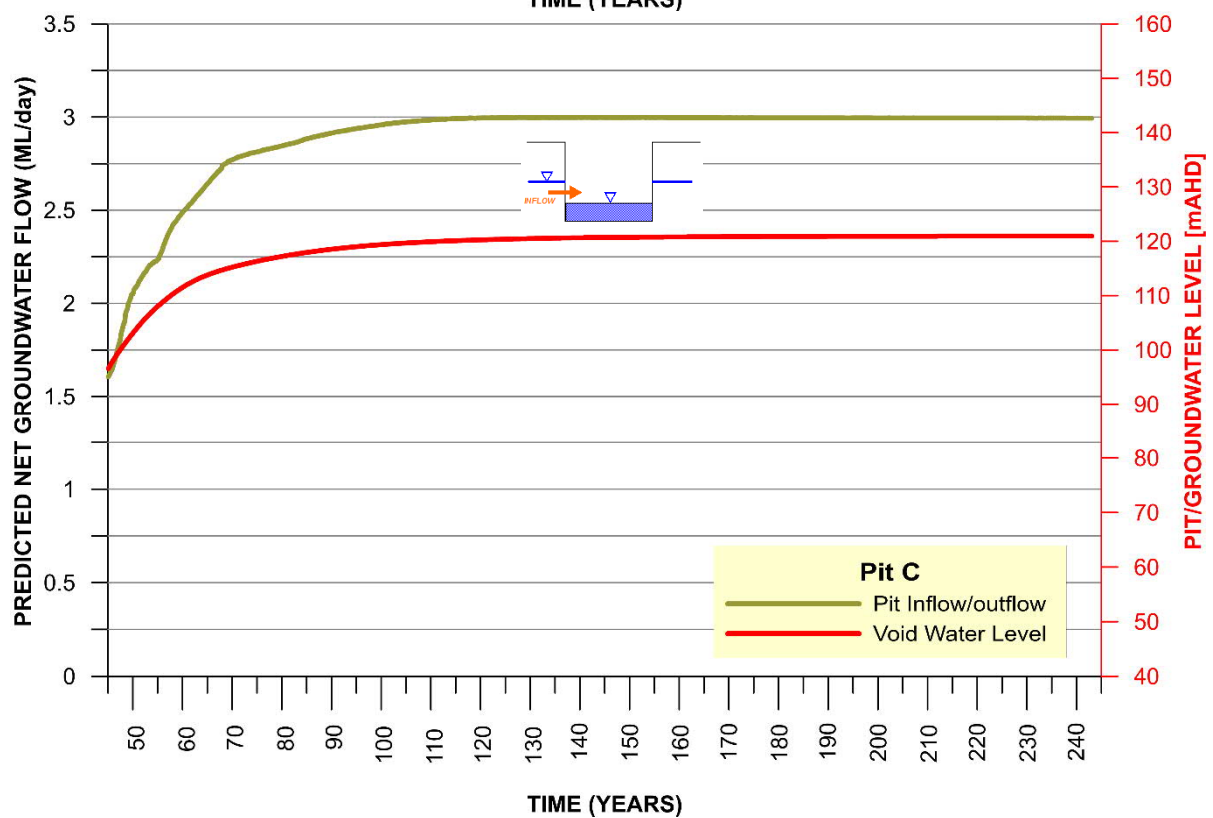
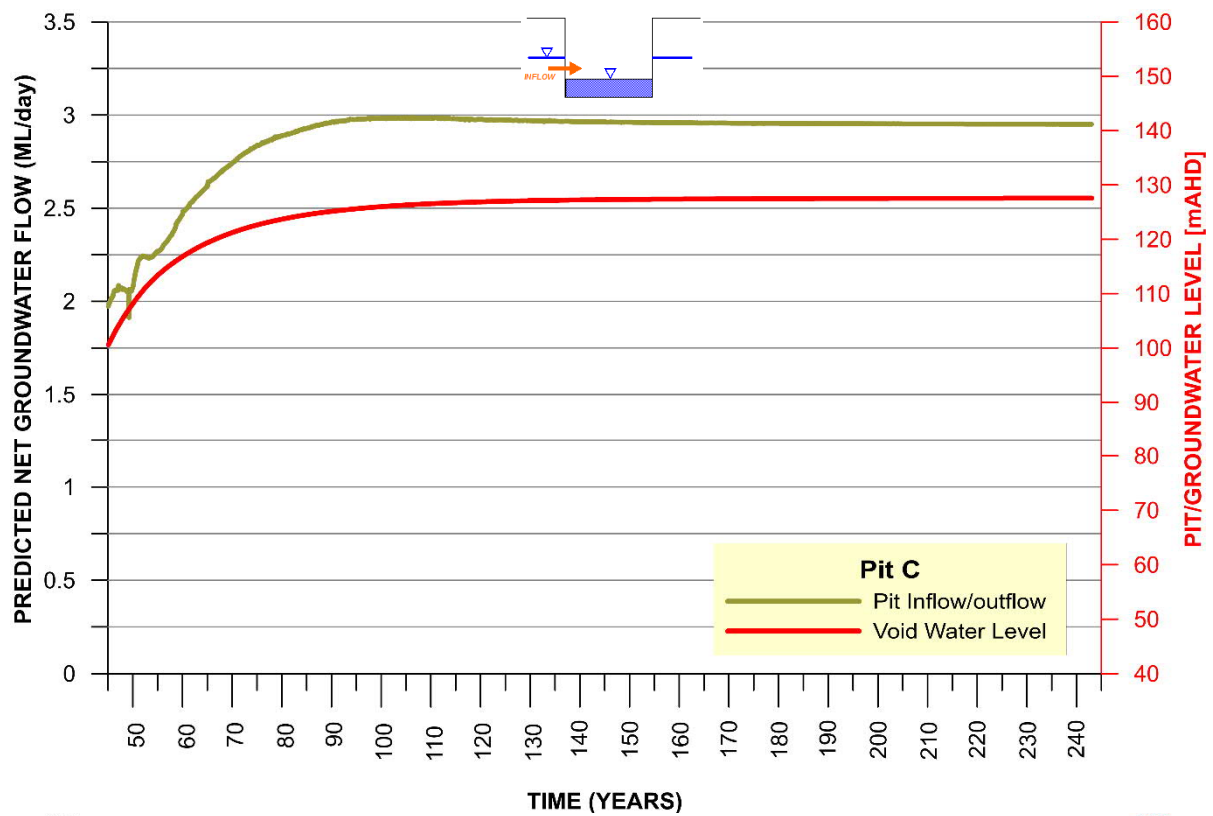


Figure D- 15: Predicted Long-term Water Levels and Flows - Pit C - a) Option 1 b) Option 2

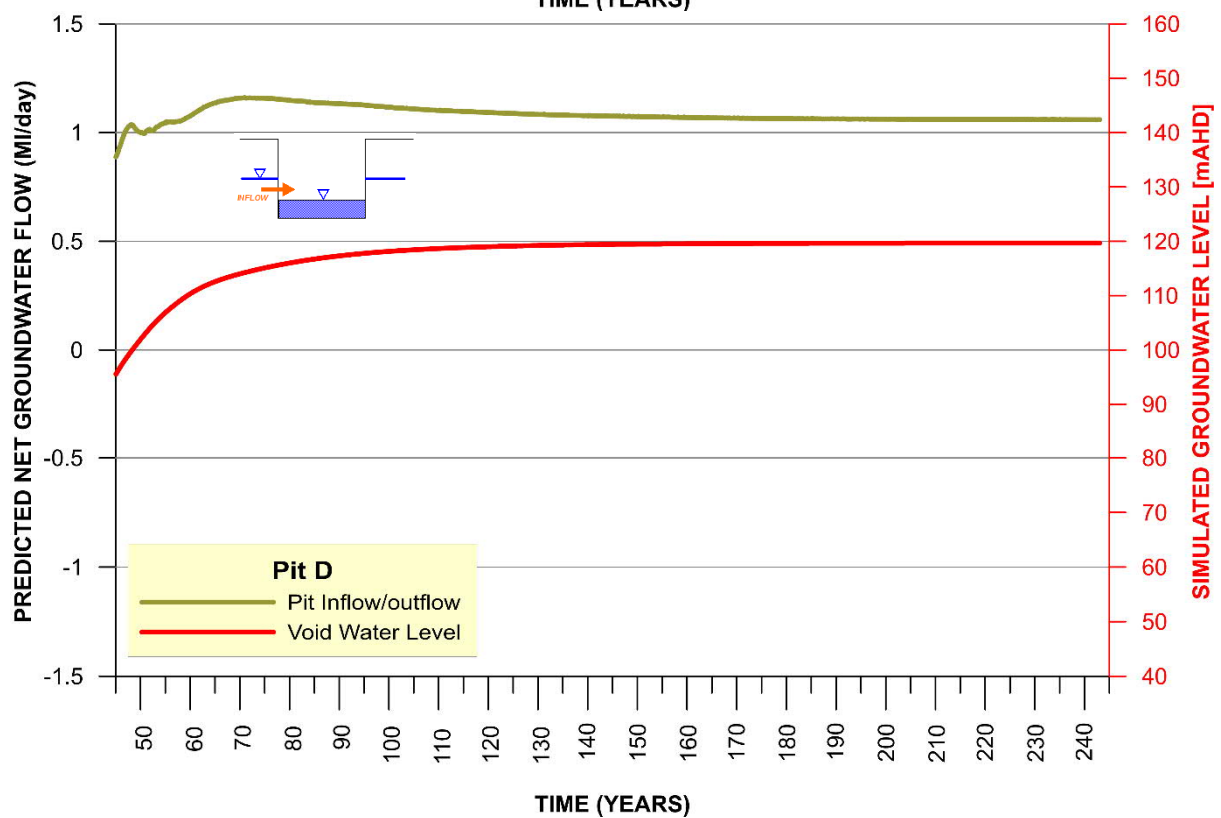
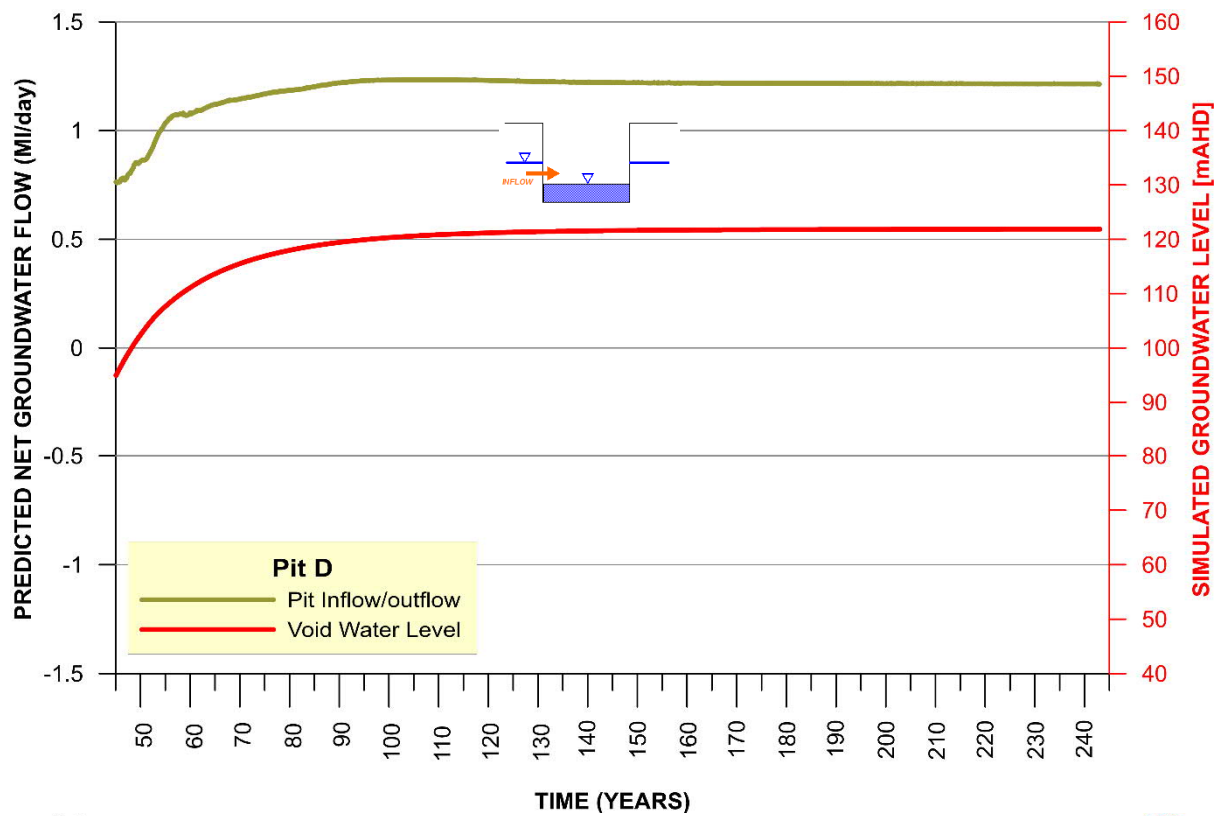


Figure D- 16: Predicted Long-term Water Levels and Flows - Pit D - a) Option 1 b) Option 2

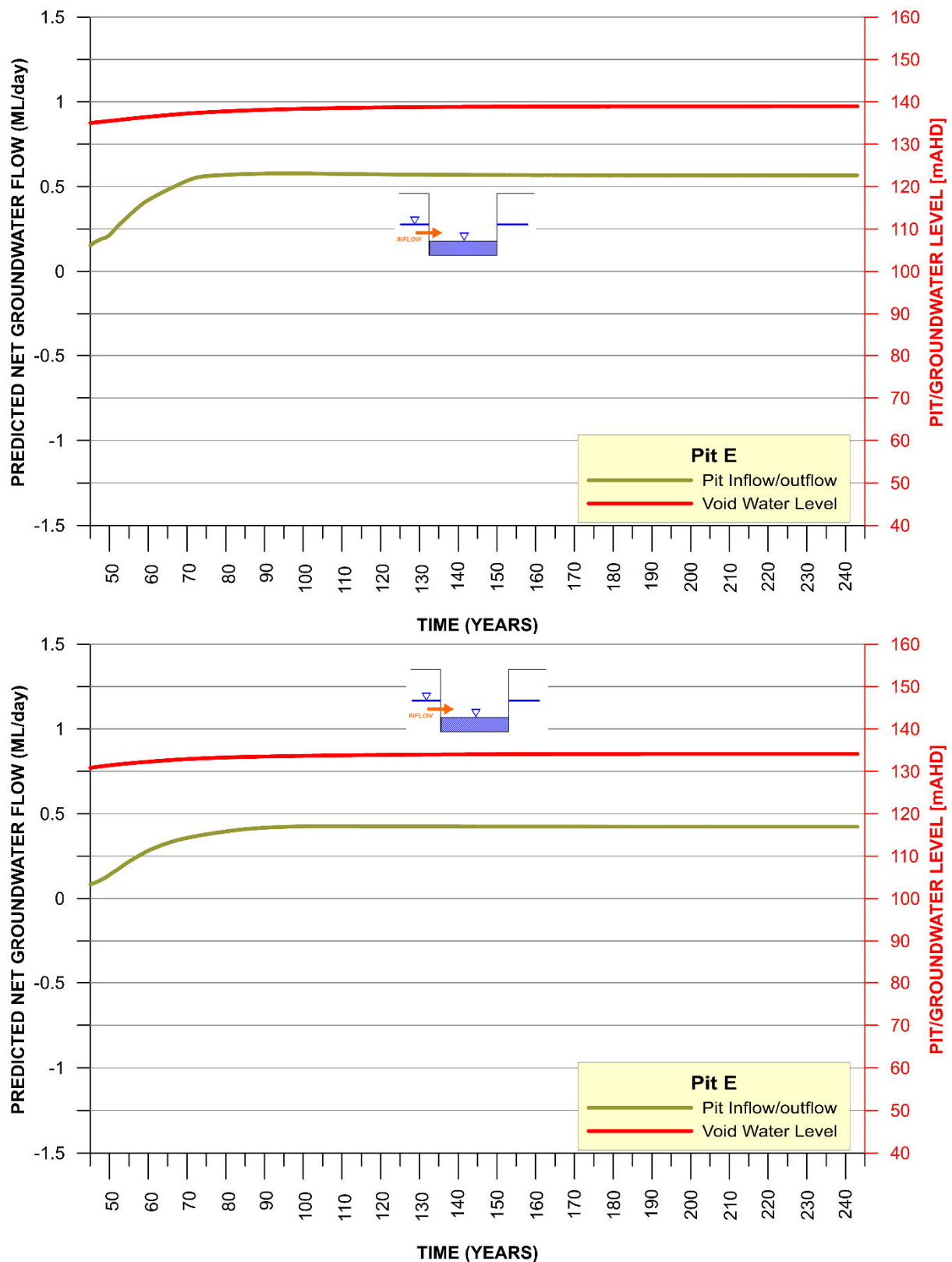


Figure D- 17: Predicted Long-term Water Levels and Flows - Pit E - a) Option 1 b) Option 2

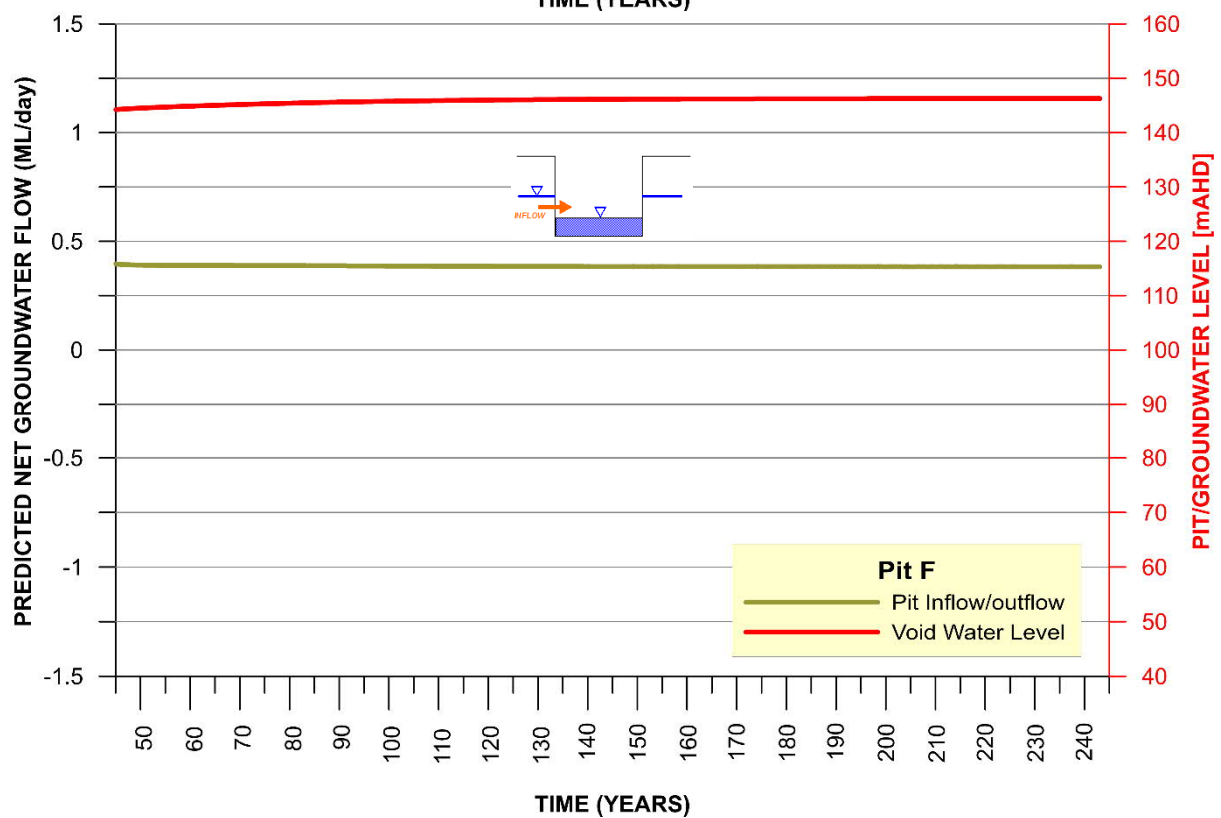
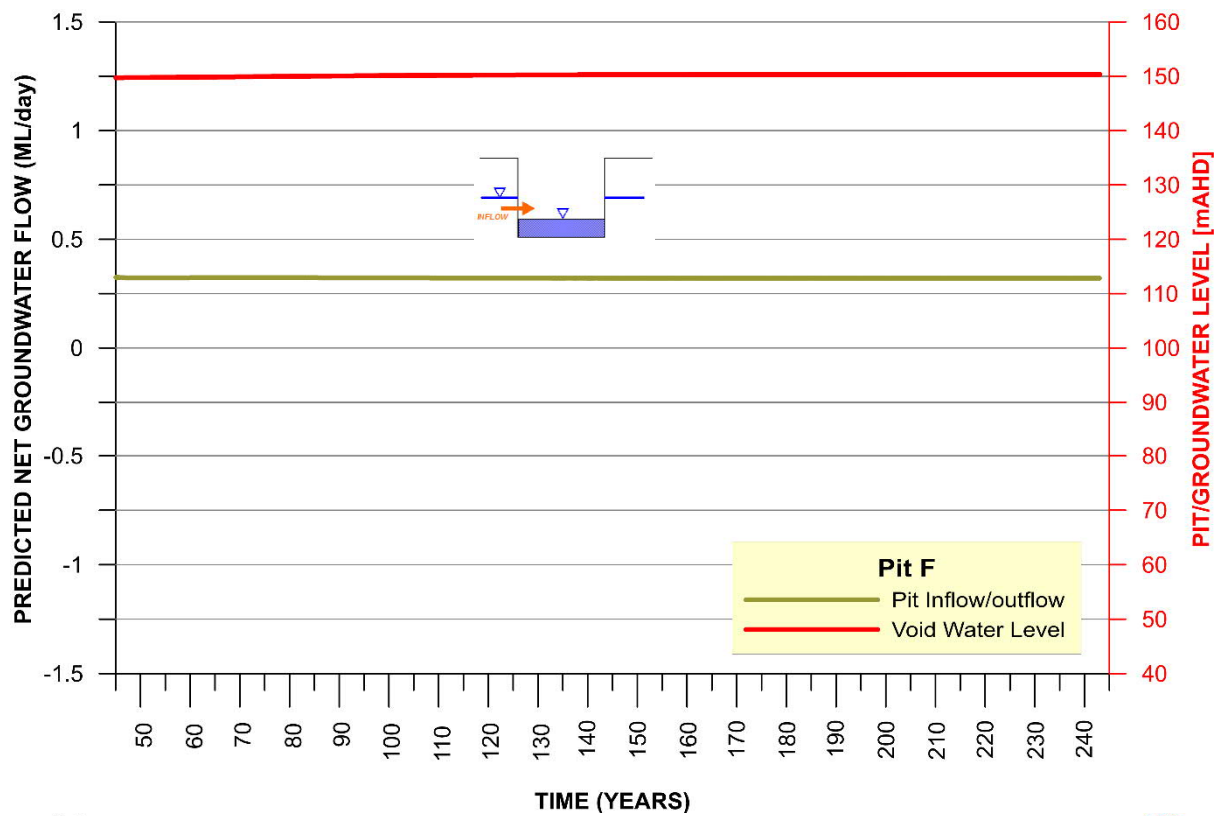


Figure D- 18: Predicted Long-term Water Levels and Flows - Pit F - a) Option 1 b) Option 2

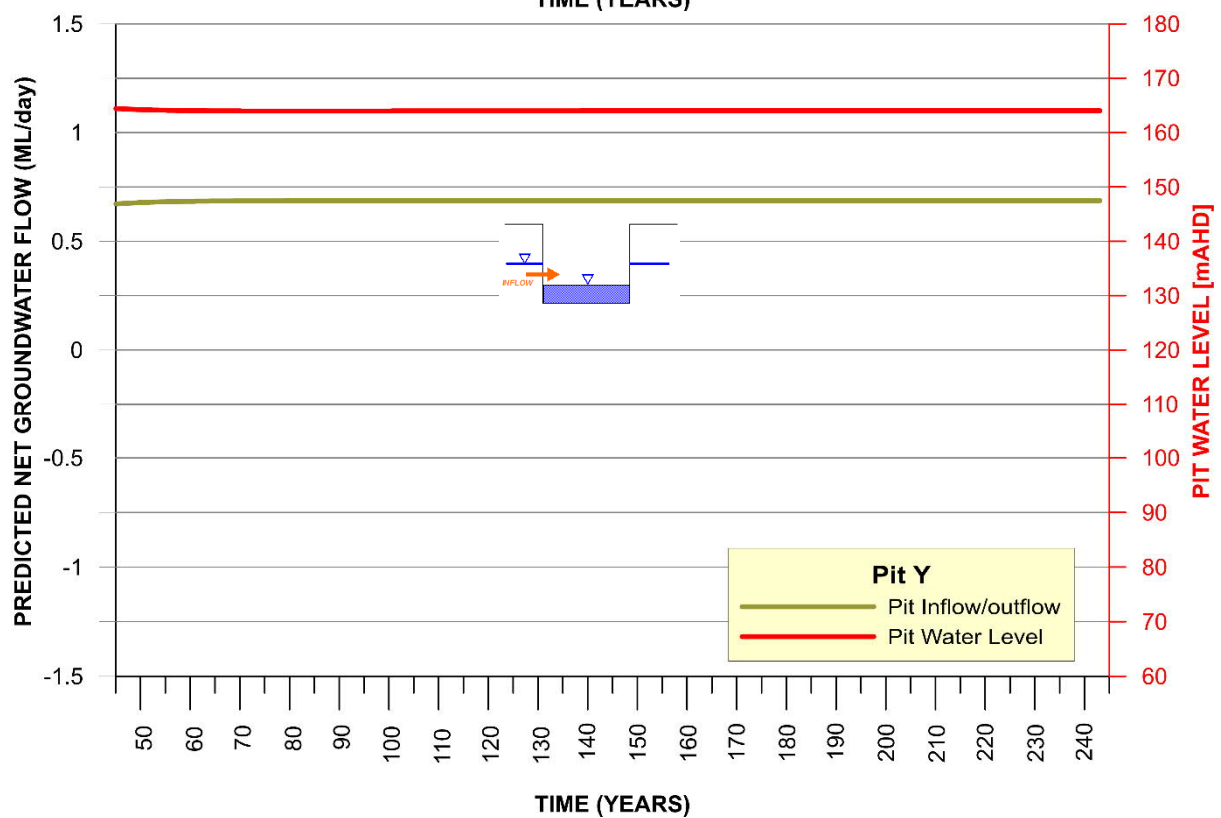
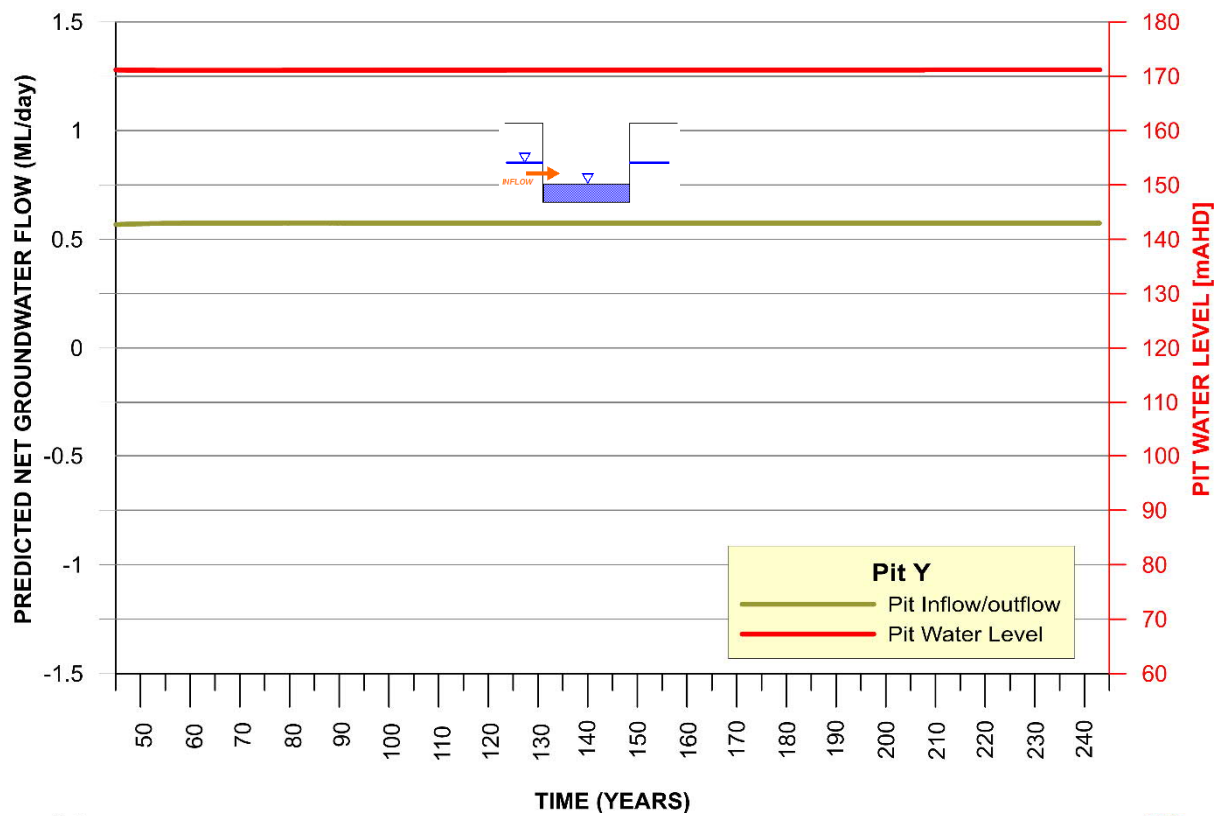


Figure D- 19: Predicted Long-term Water Levels and Flows - Pit Y - a) Option 1 b) Option 2

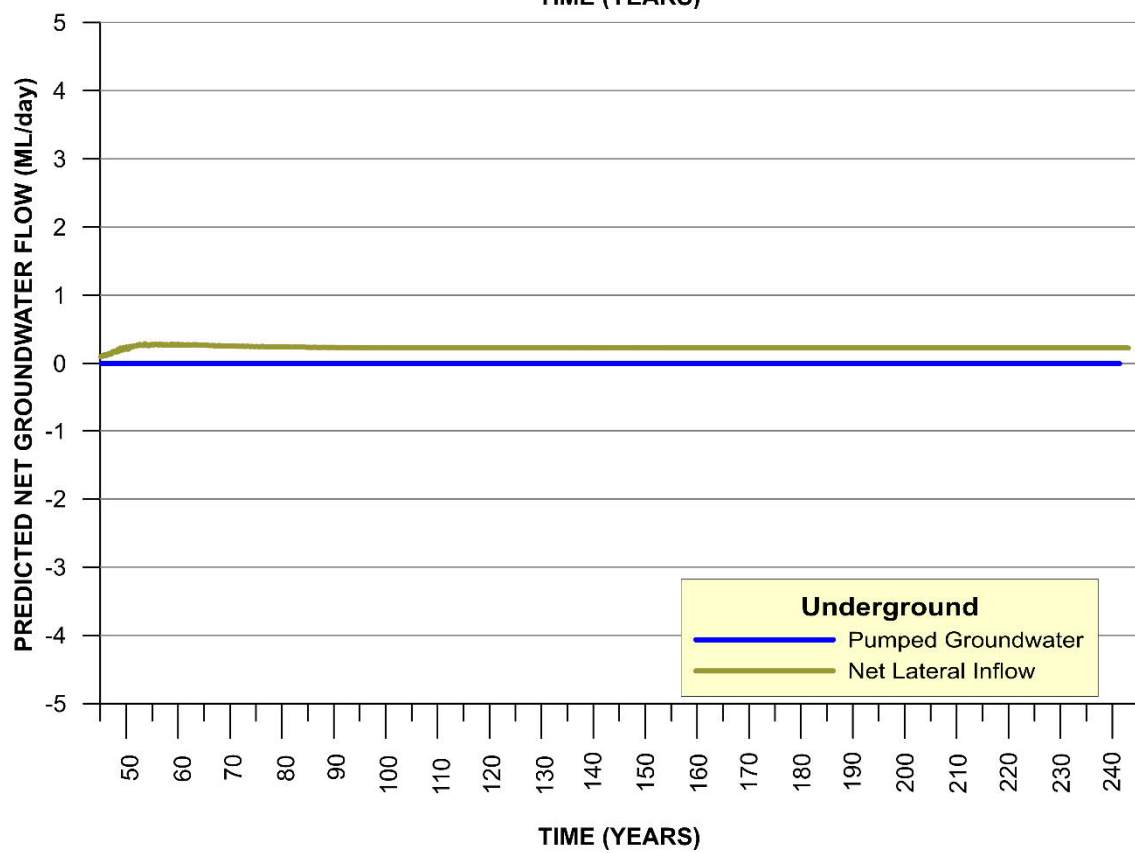
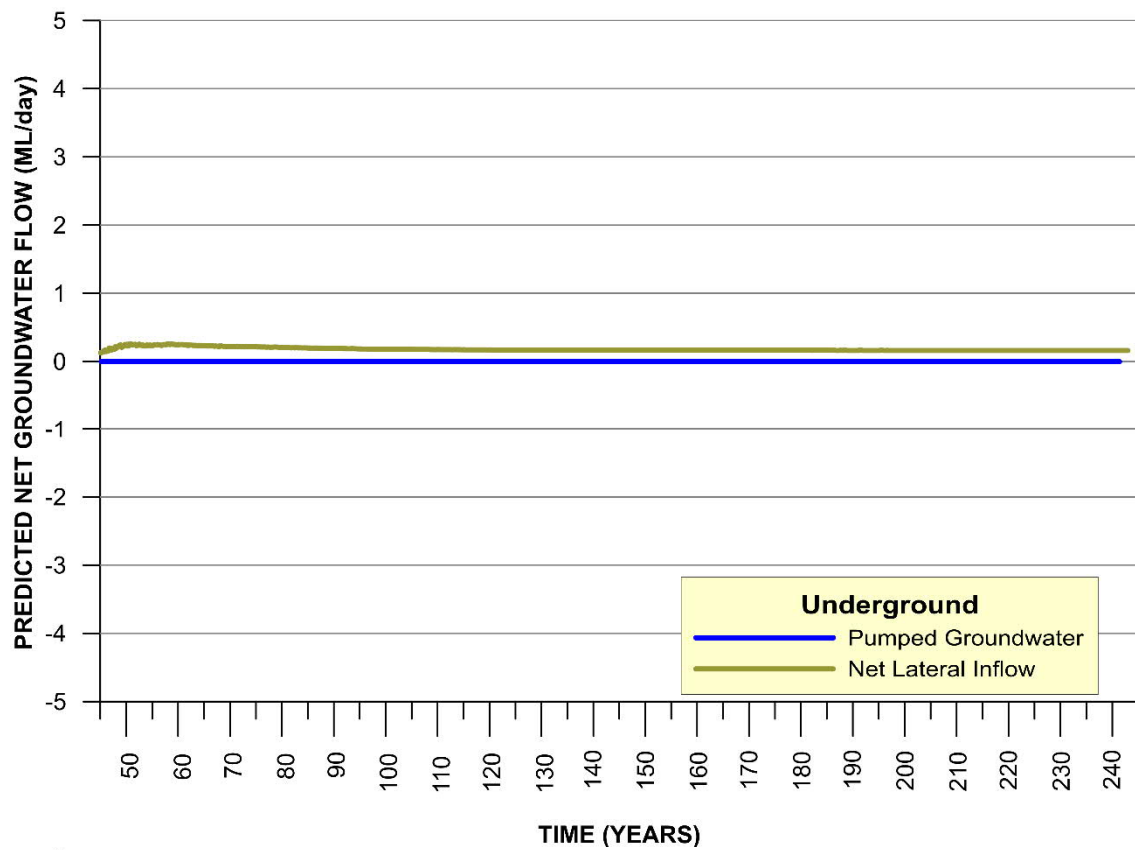


Figure D- 20: Predicted Long-term Underground Mine Inflow - a) Option 1 b) Option 2

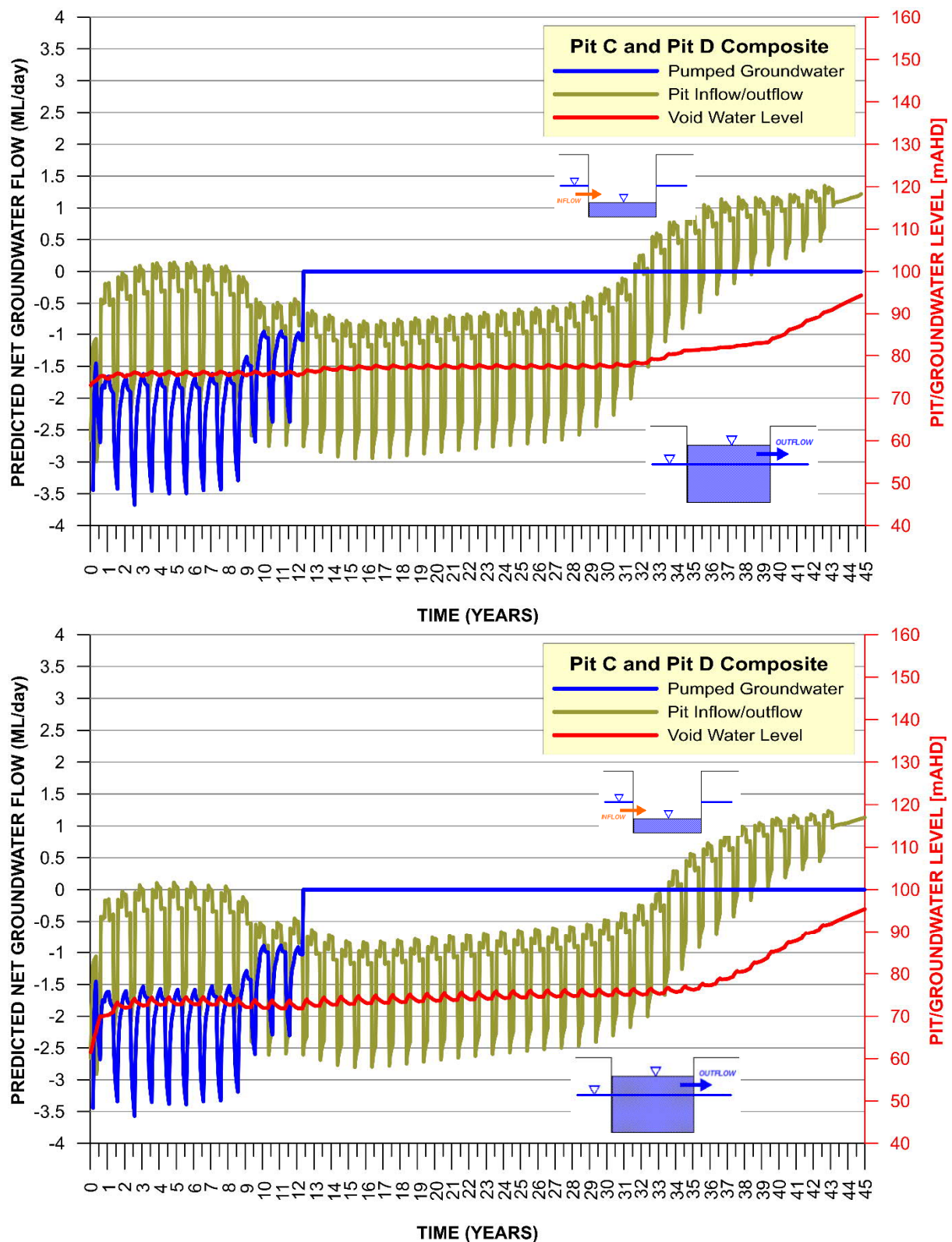


Figure D- 21: Predicted Water Flows Pit C and Pit D Composite and Water Level Pit D - a) Option 1 b) Option 2

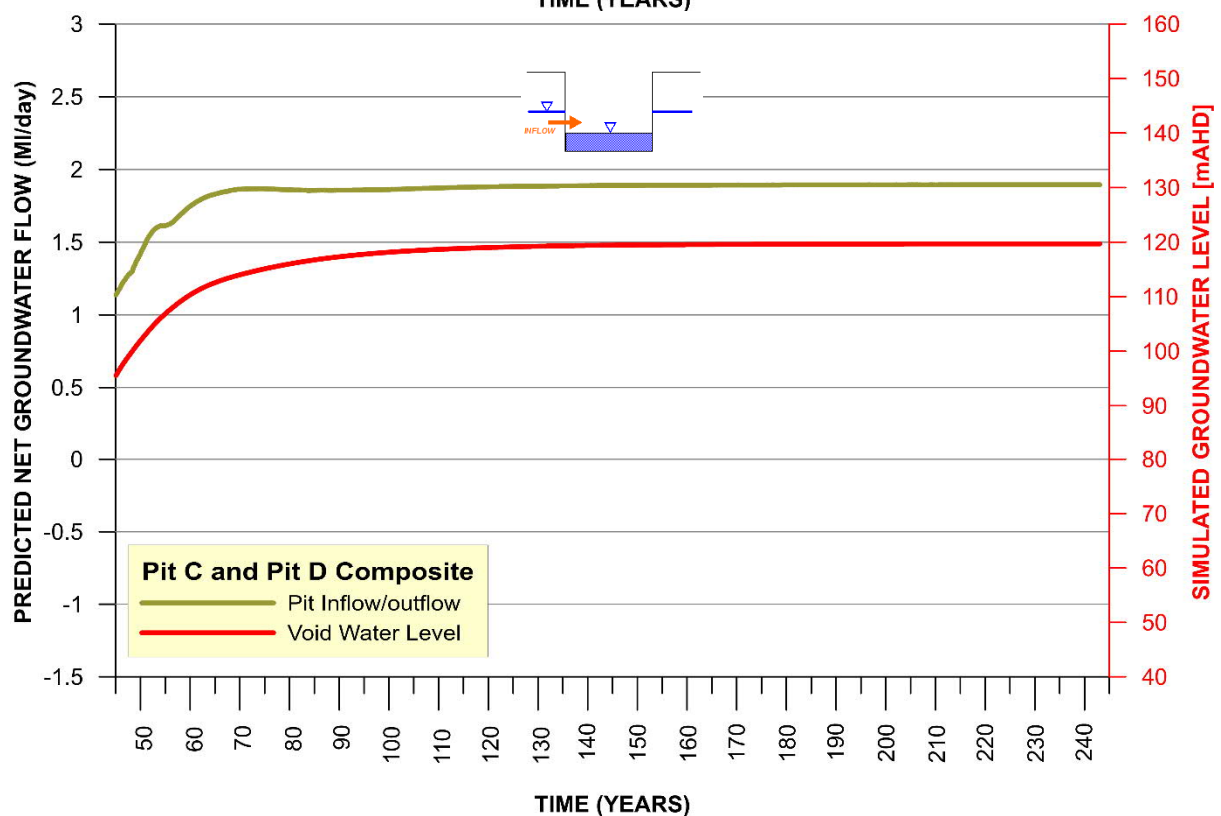
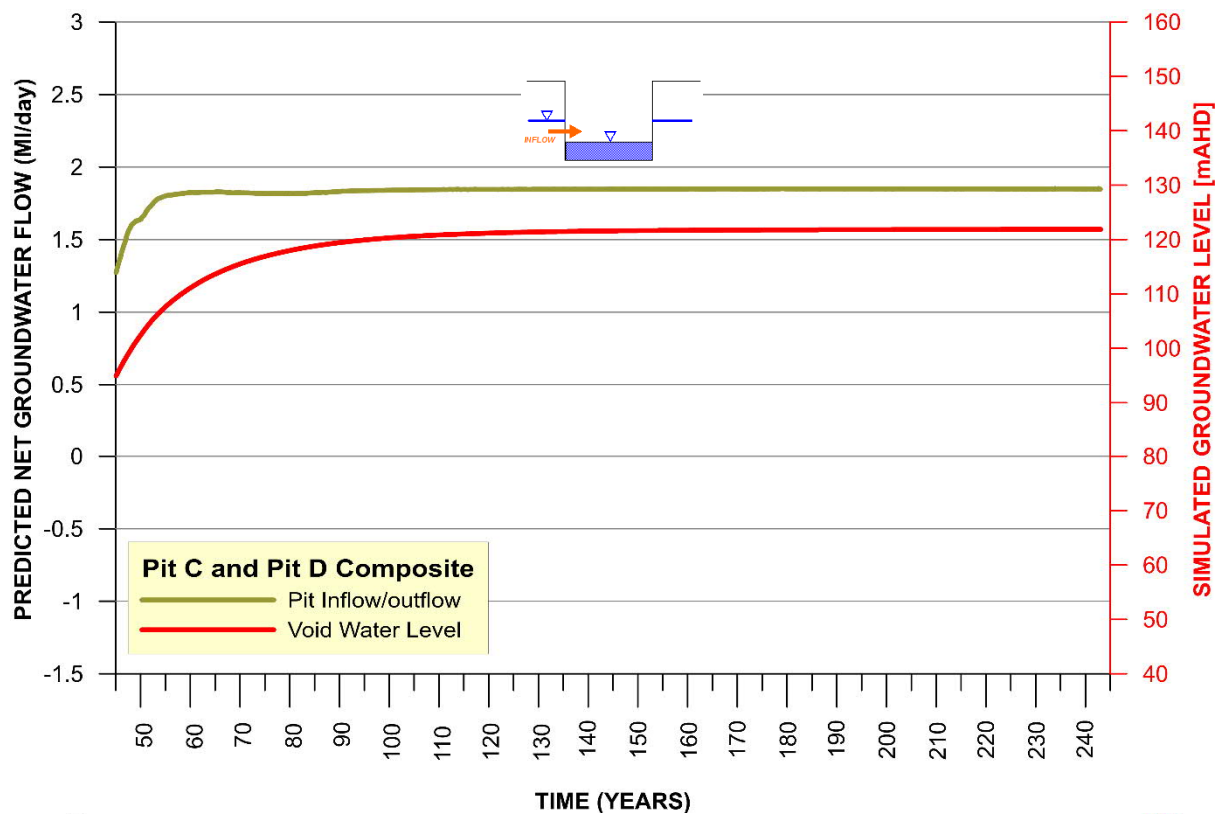
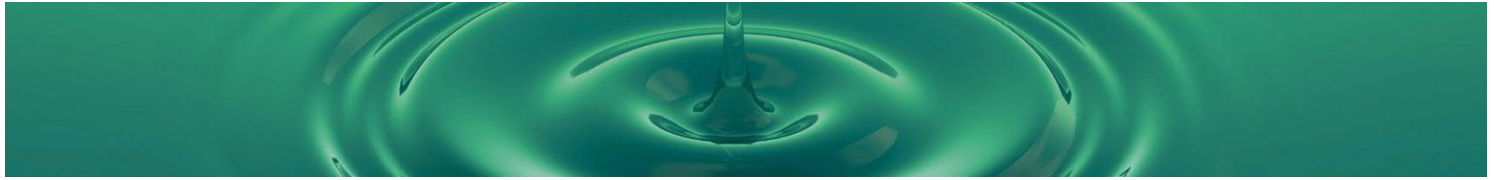


Figure D- 22: Predicted Long-term Water Flows Pit C and Pit D Composite and Water Level Pit D - a)
Option 1 b) Option 2



APPENDIX E

Prediction and Recovery Mine Void Inflows/Outflows

Options 1 and 3

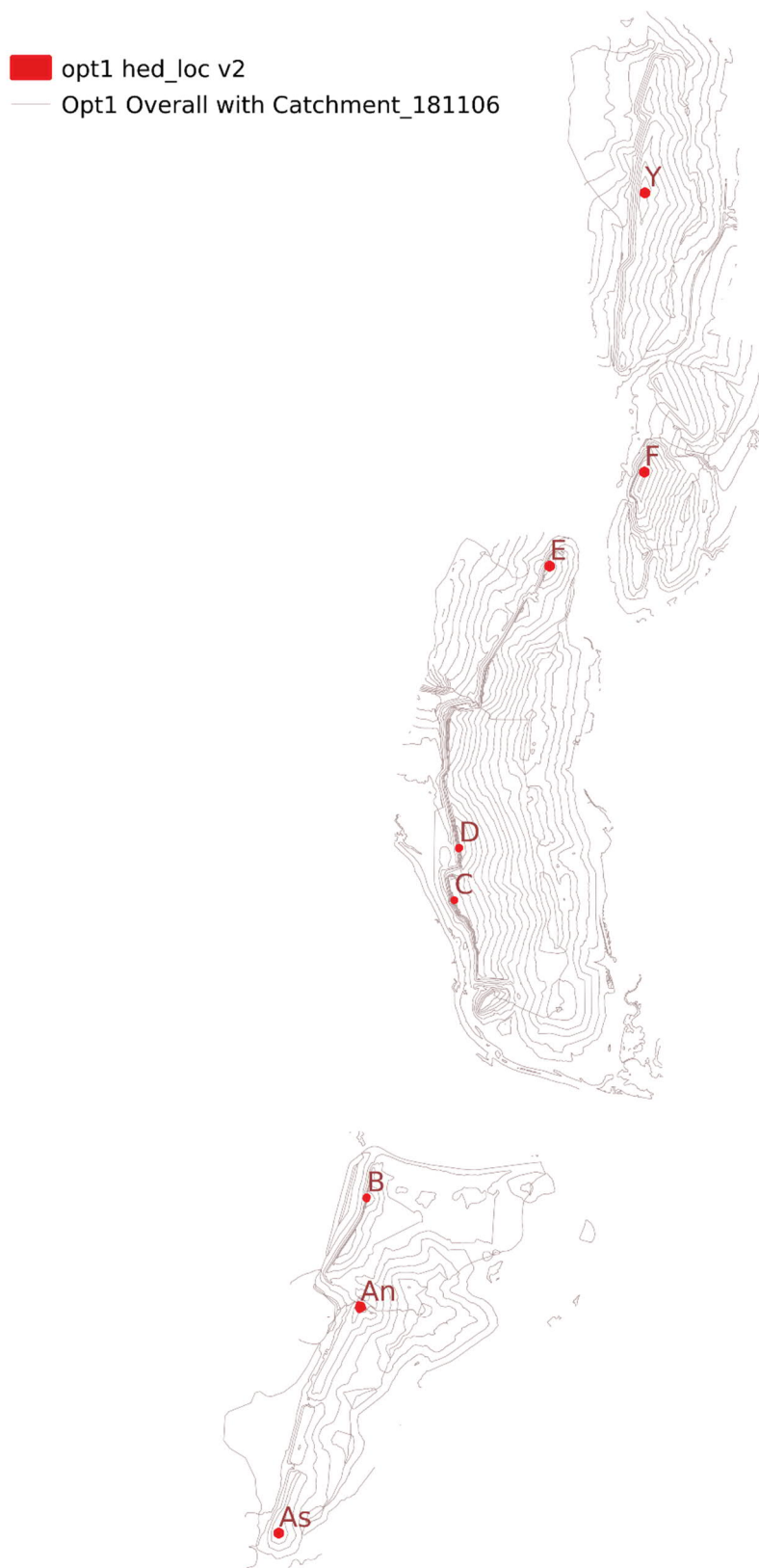


Figure E-23: Option 1 Head Extraction Point locations



Figure E-24: Option 3 Head Extraction Point locations

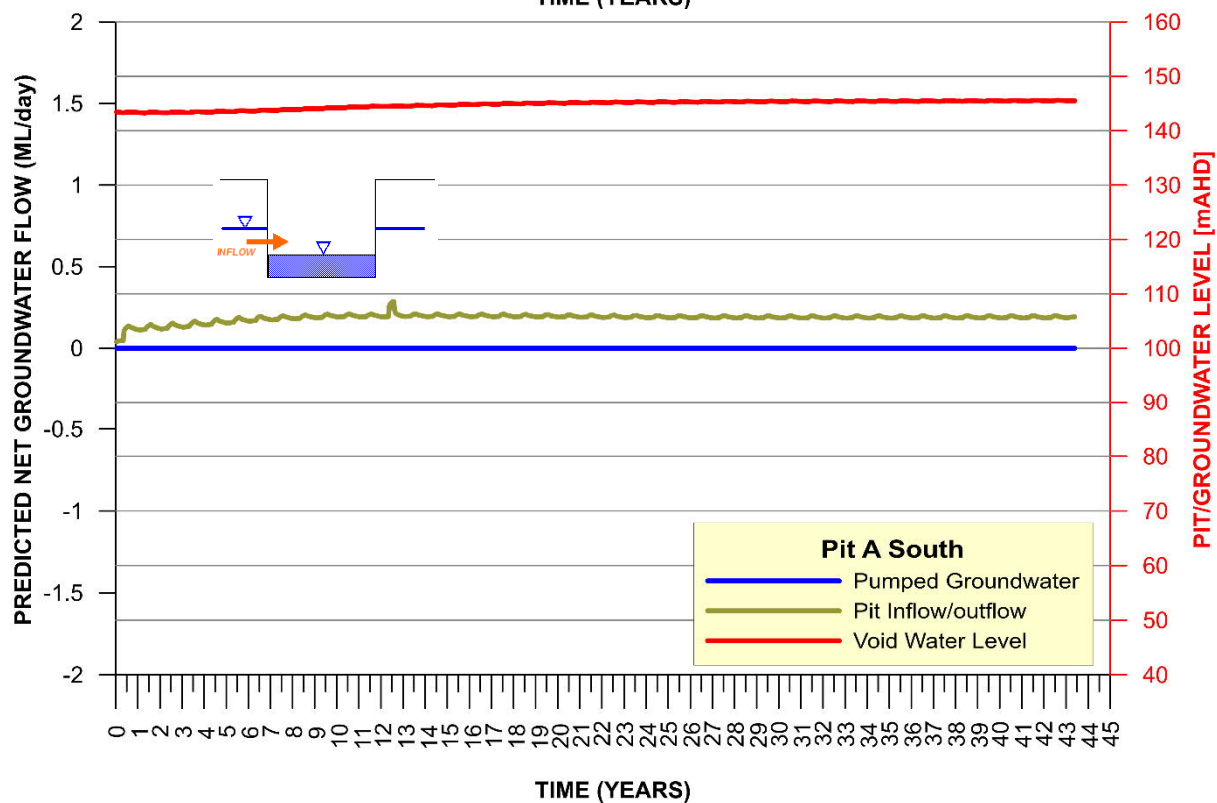
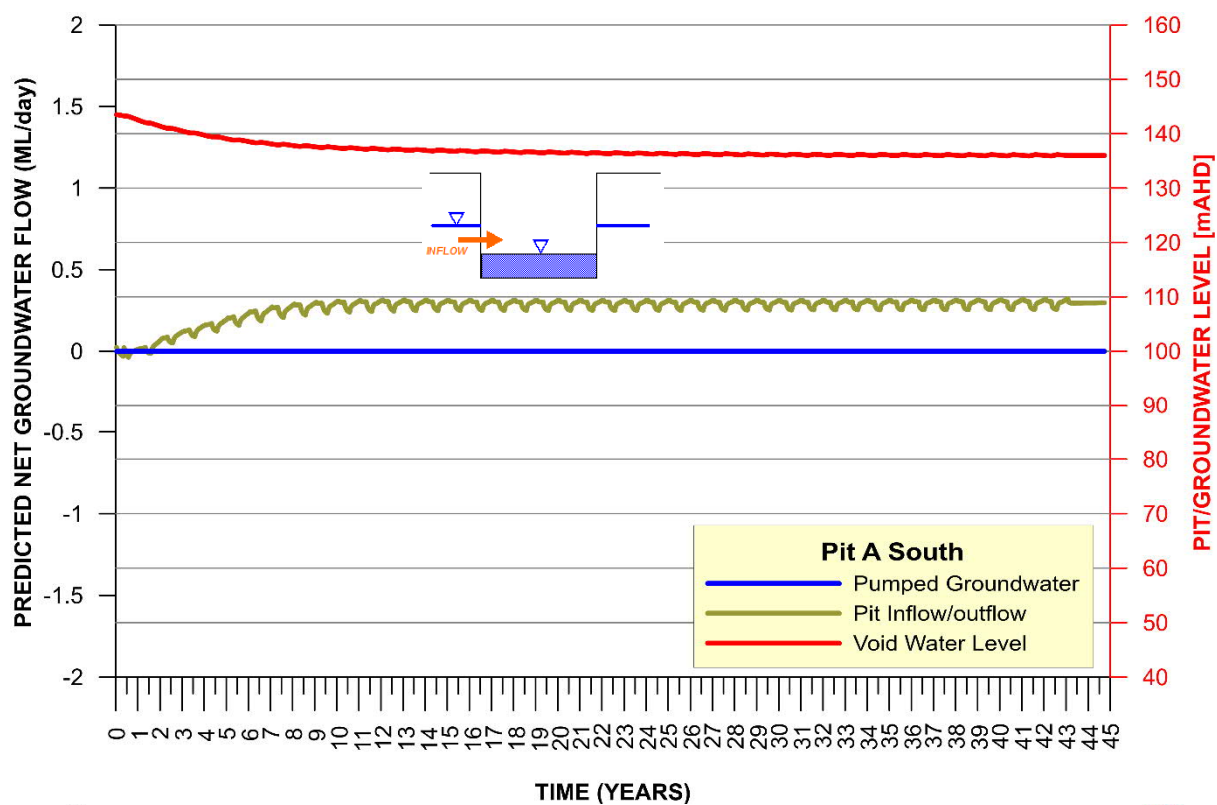


Figure E-25: Predicted Water Levels and Flows - Pit A South - a) Option 1 b) Option 3

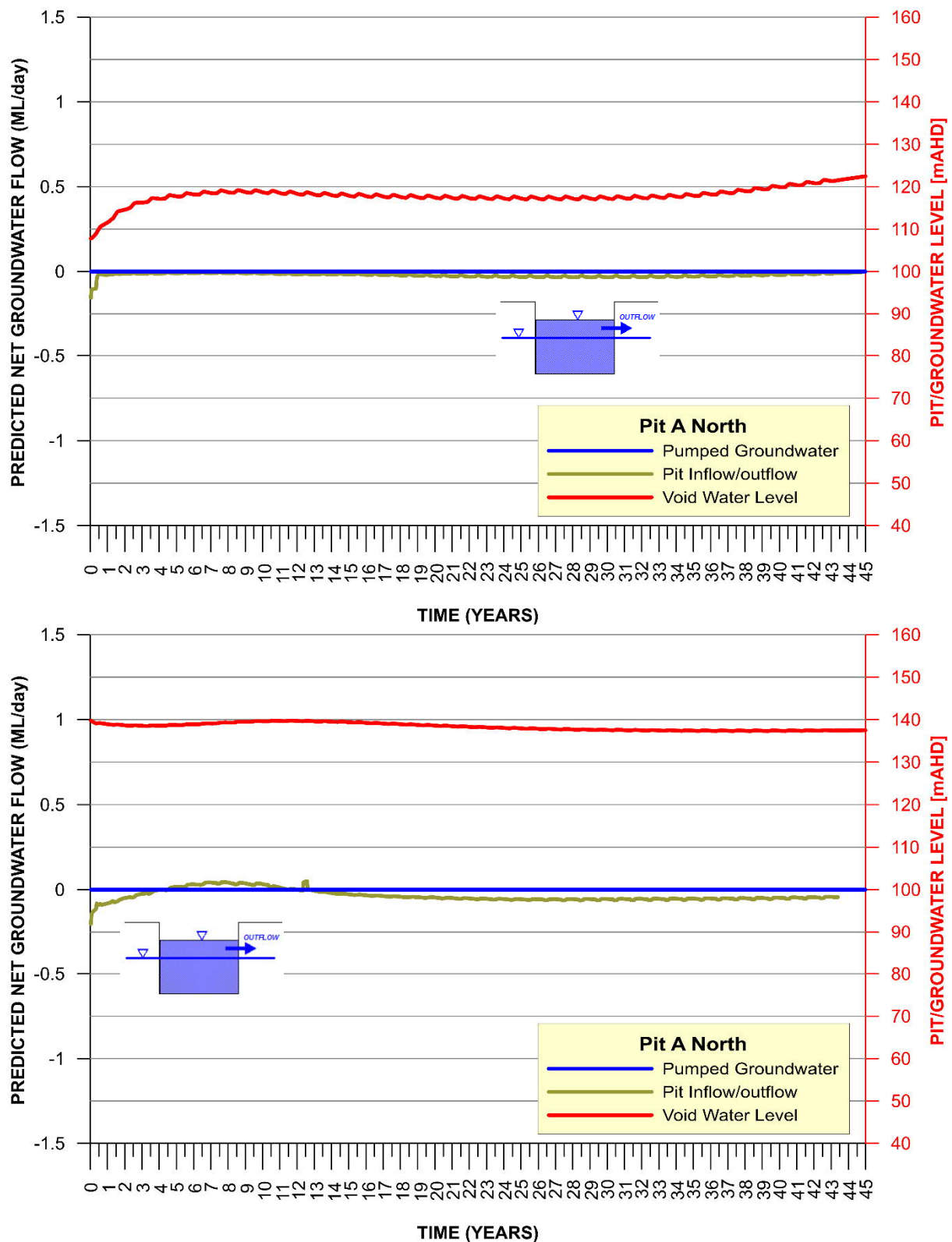


Figure E-26: Predicted Water Levels and Flows - Pit A North - a) Option 1 b) Option 3

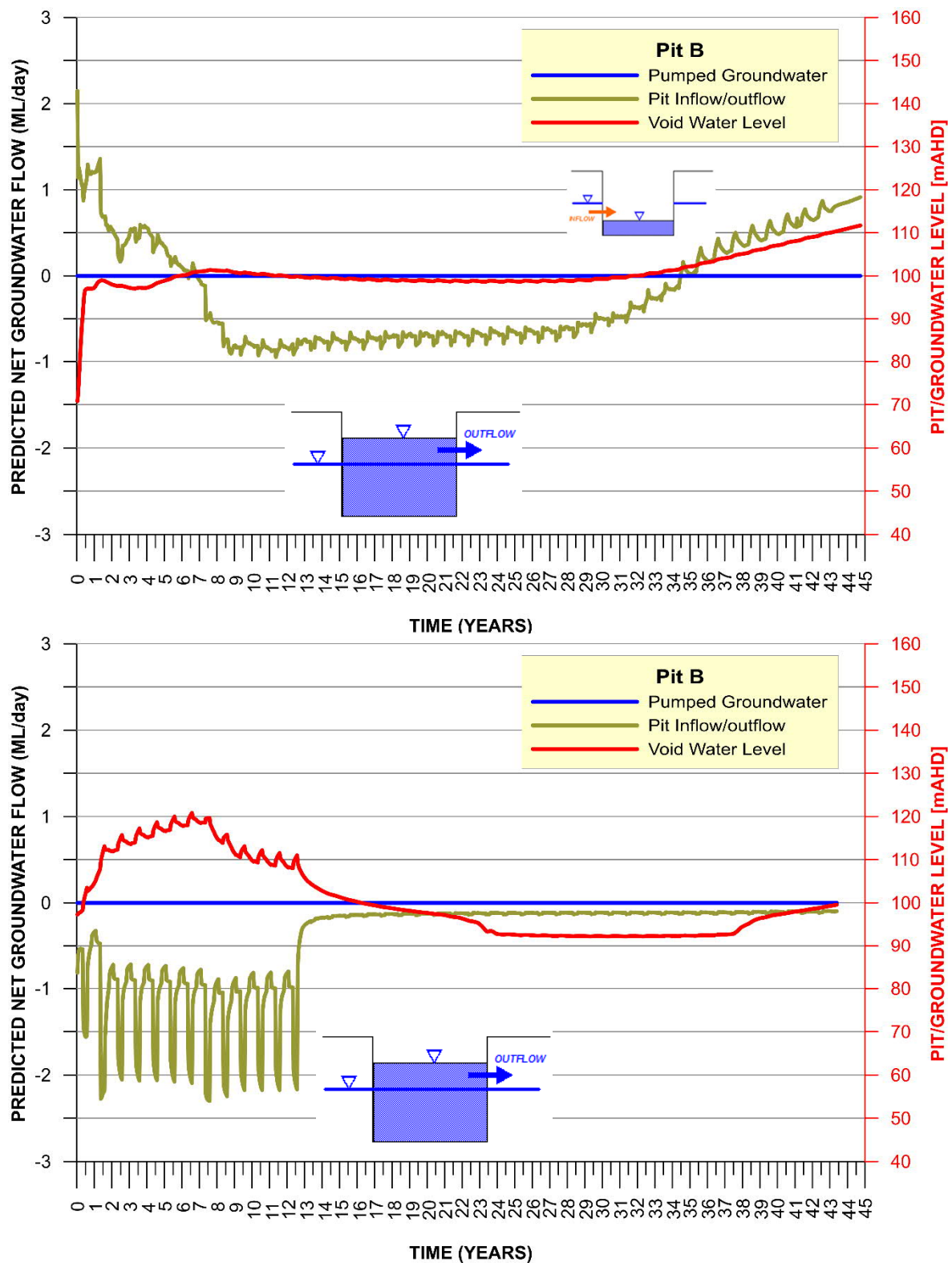


Figure E-27: Predicted Water Levels and Flows - Pit B - a) Option 1 b) Option 3

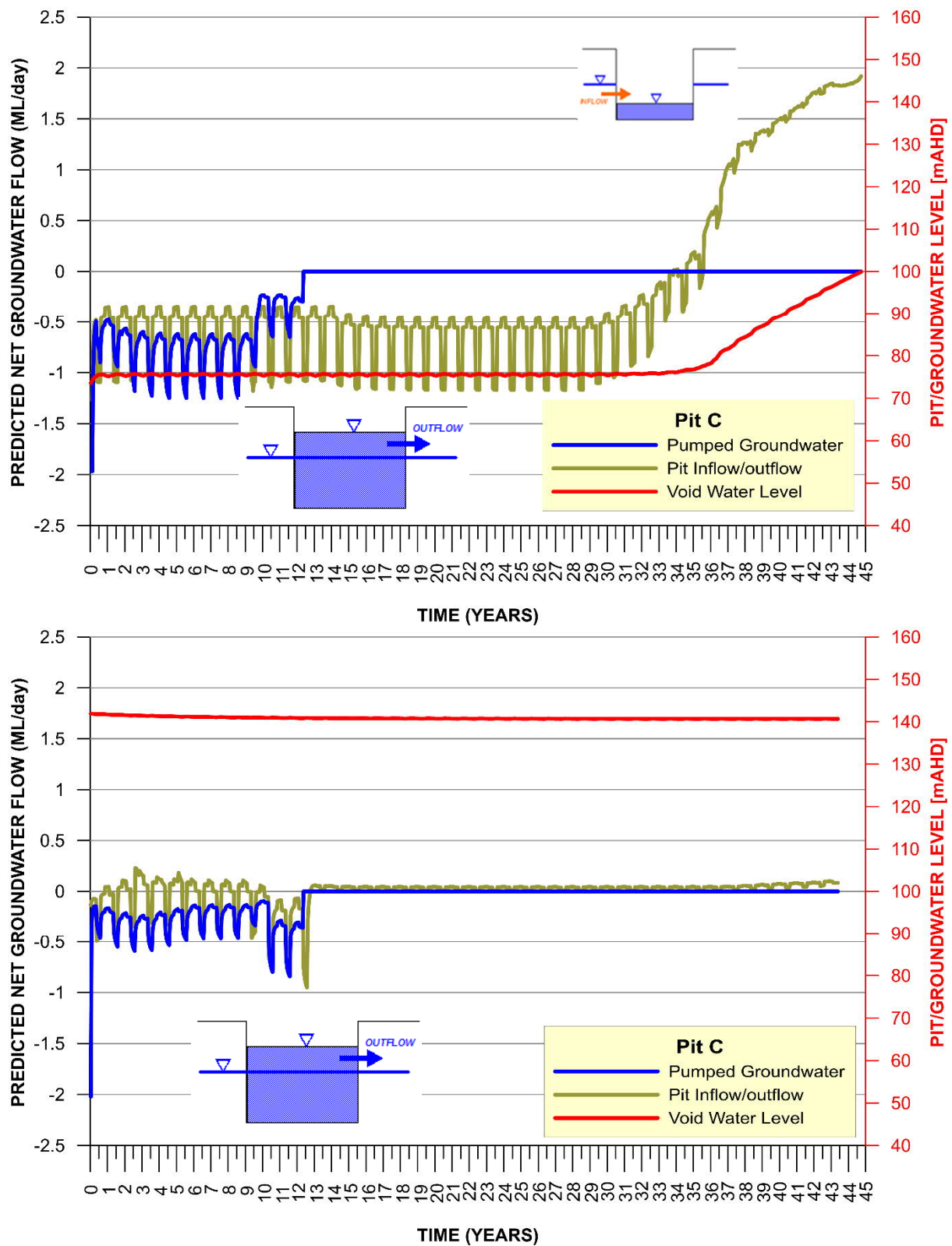


Figure E-28: Predicted Water Levels and Flows - Pit C - a) Option 1 b) Option 3

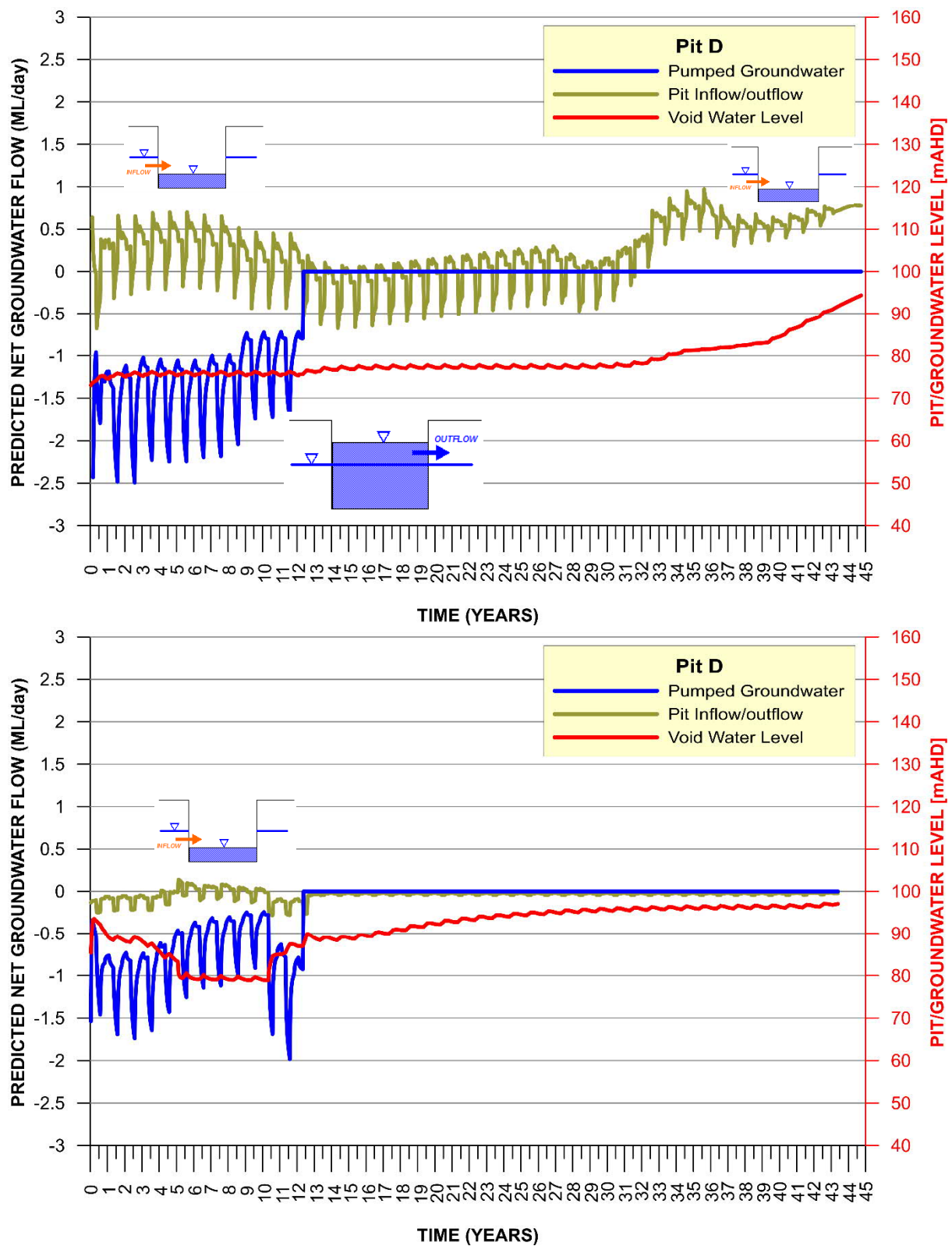
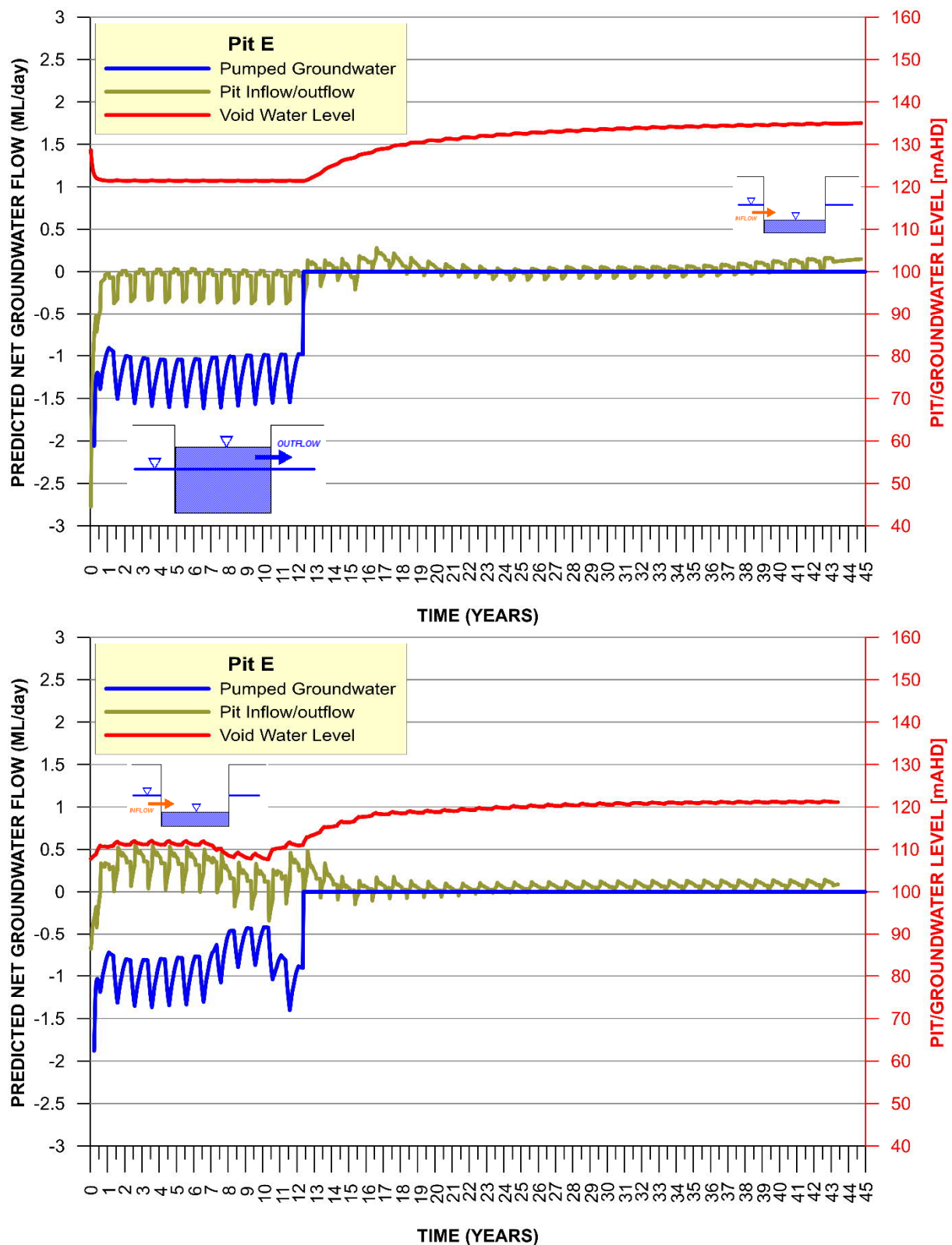


Figure E-29: Predicted Water Levels and Flows - Pit D - a) Option 1 b) Option 3



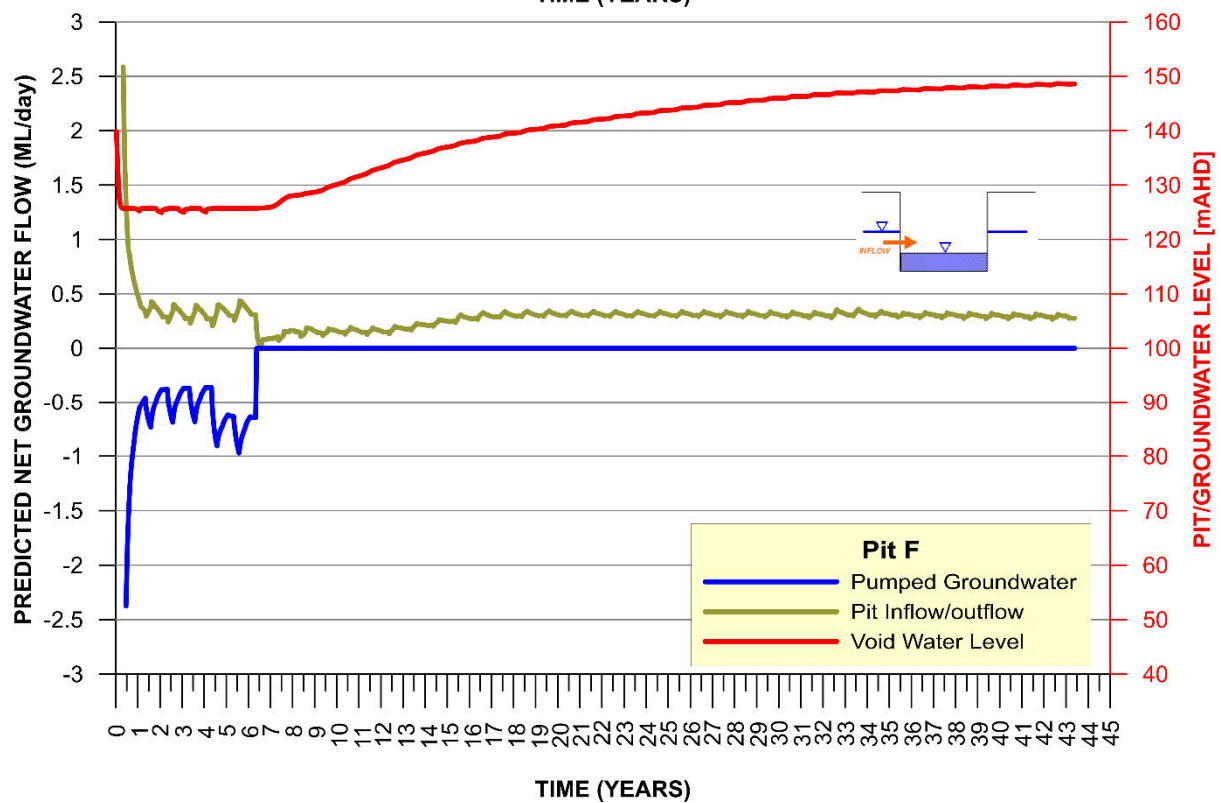
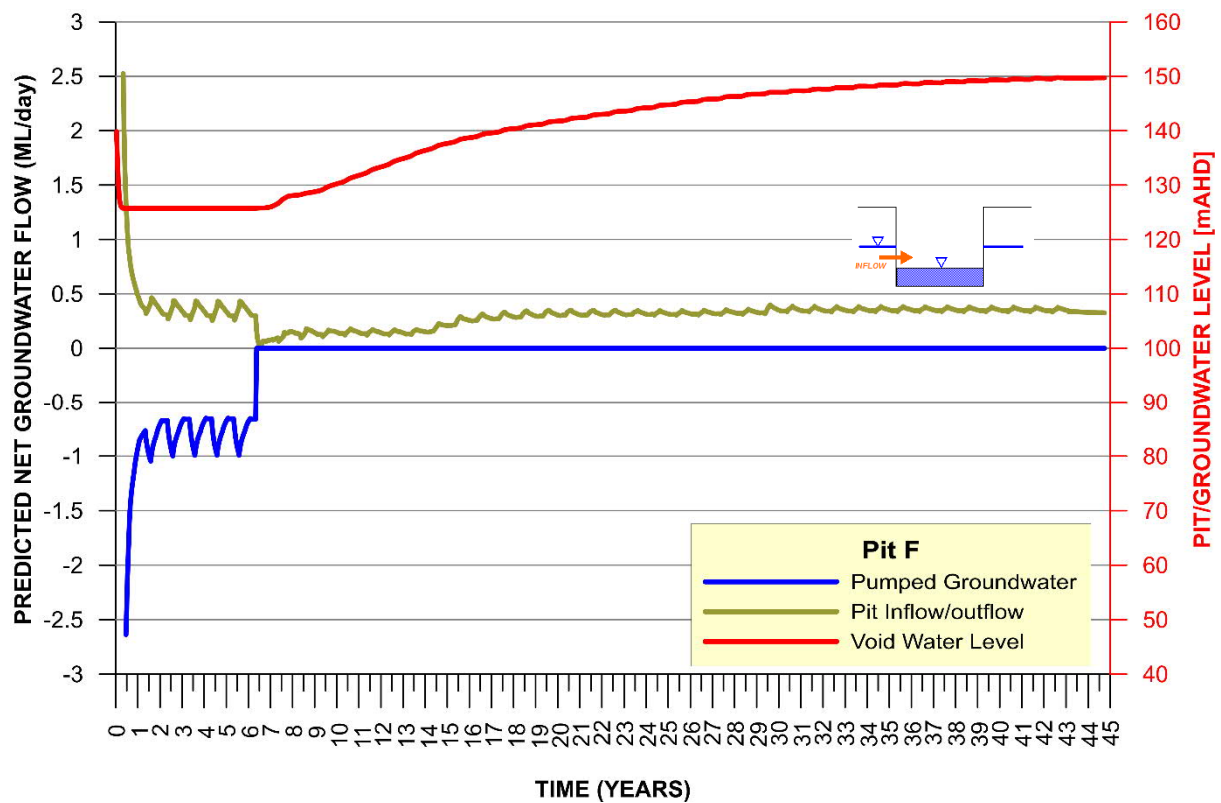


Figure E-31: Predicted Water Levels and Flows - Pit F - a) Option 1 b) Option 3

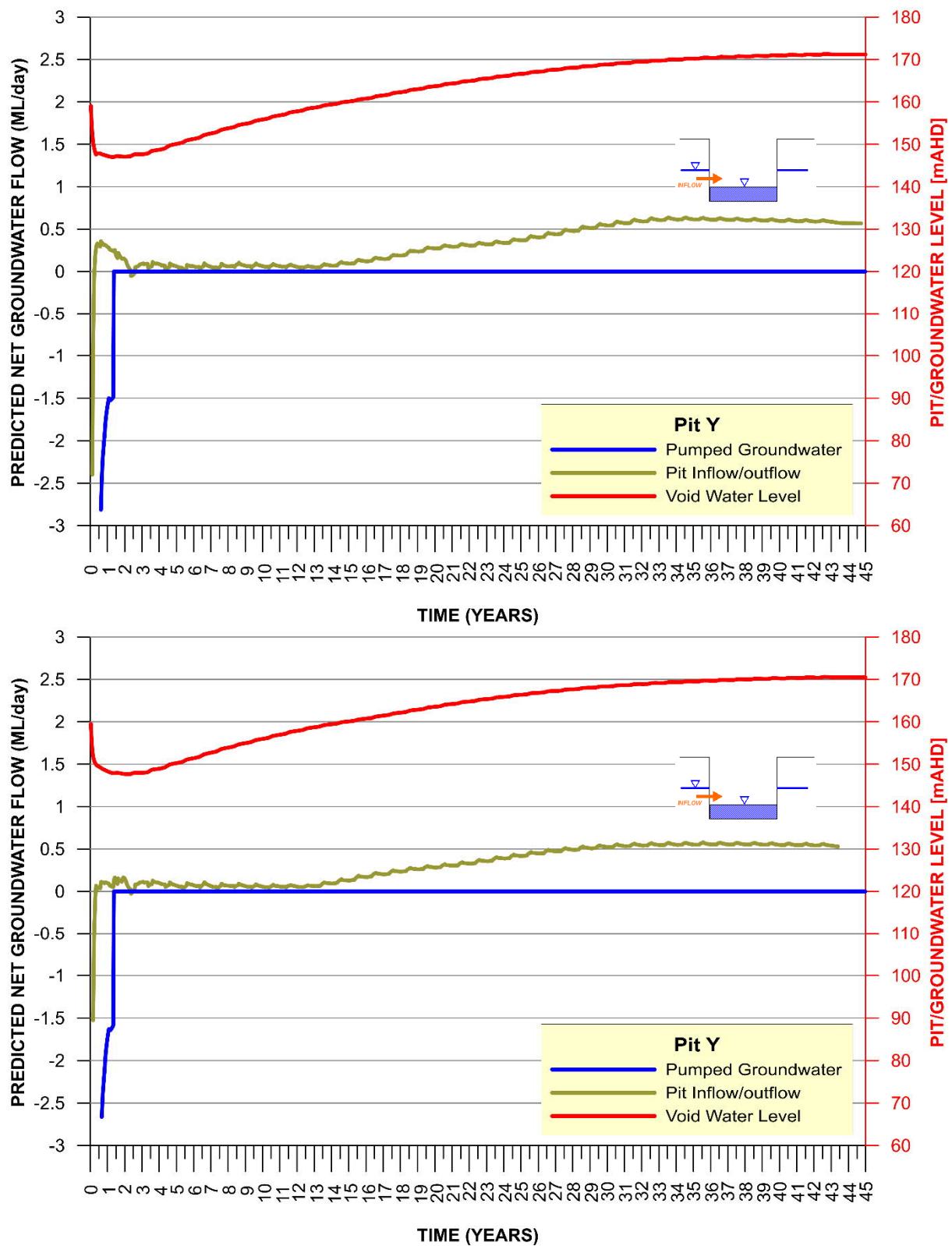


Figure E-32: Predicted Water Levels and Flows - Pit Y - a) Option 1 b) Option 3

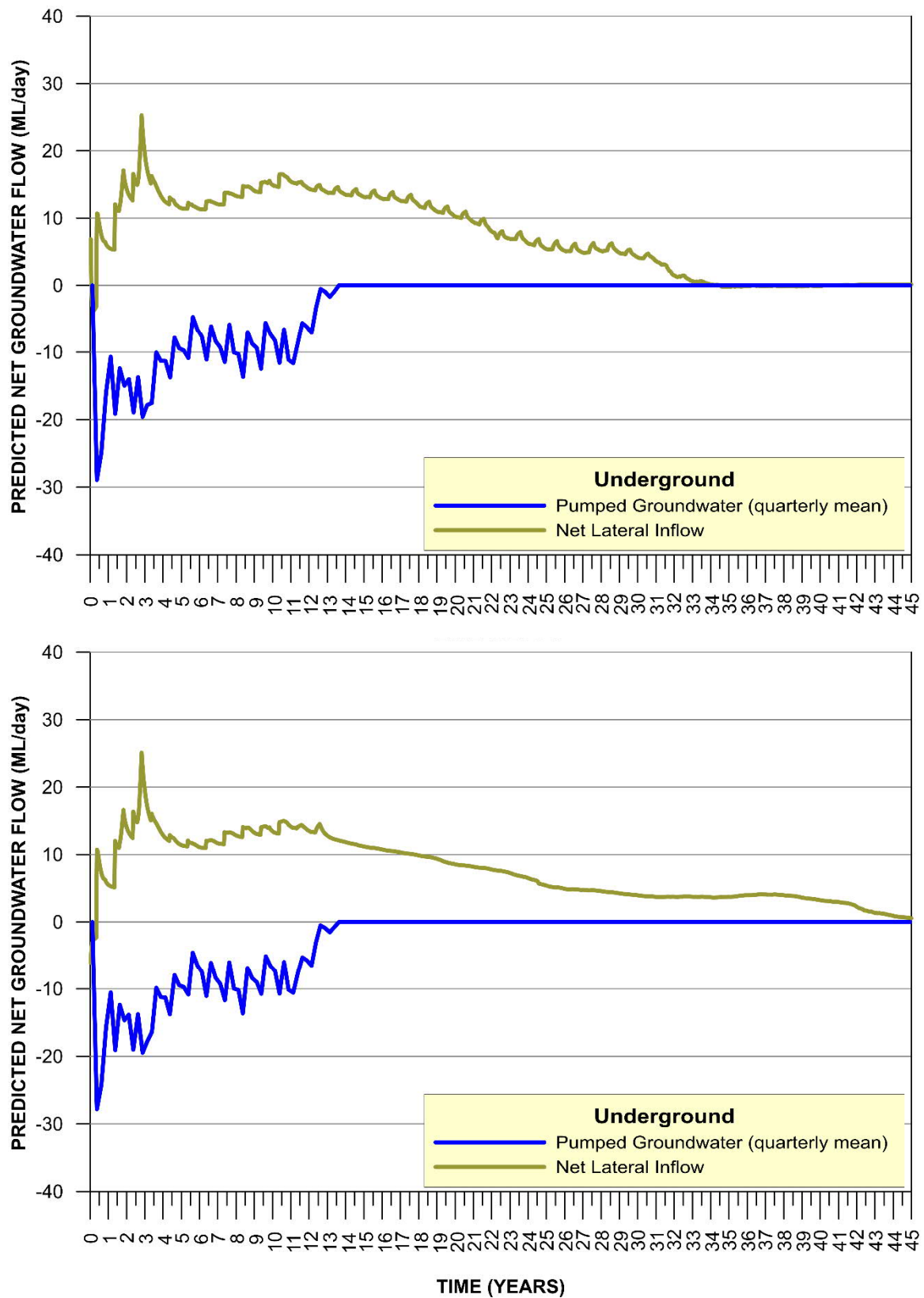


Figure E-33: Predicted Underground Mine Inflow - a) Option 1 b) Option 3

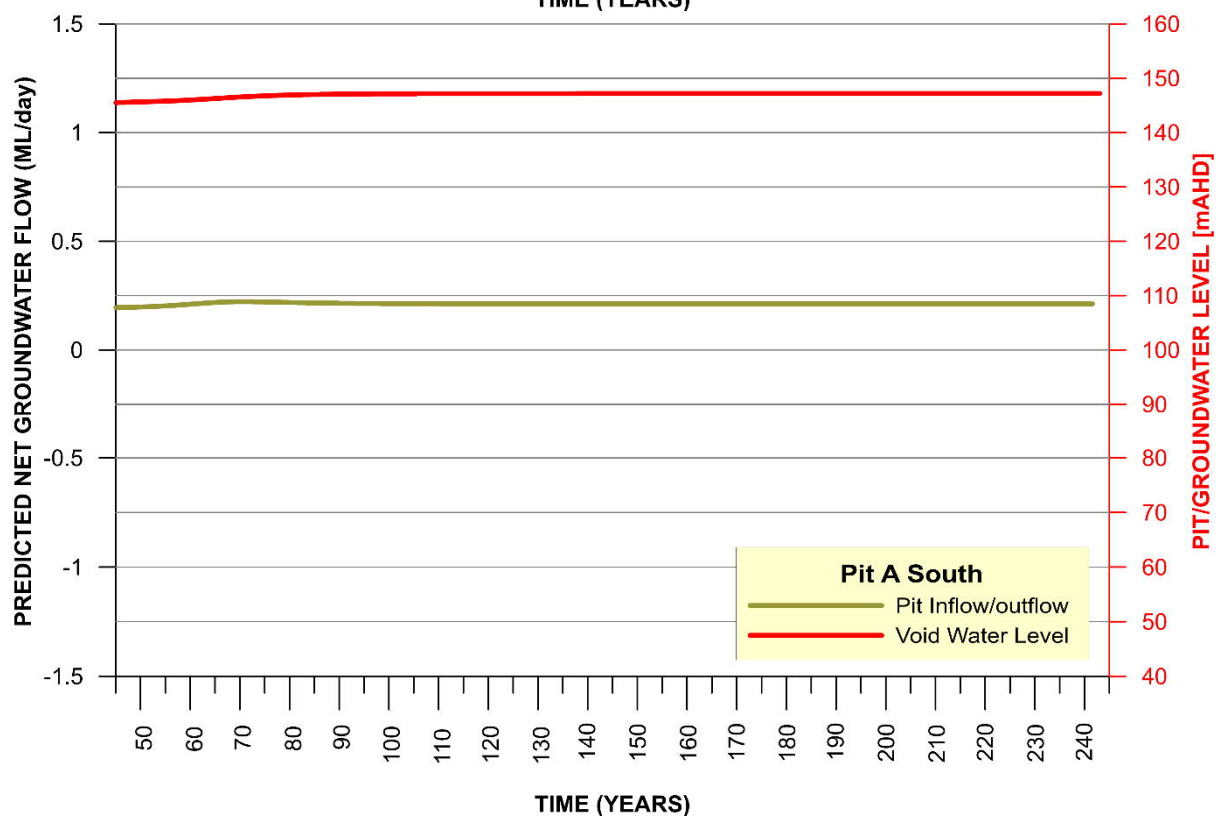
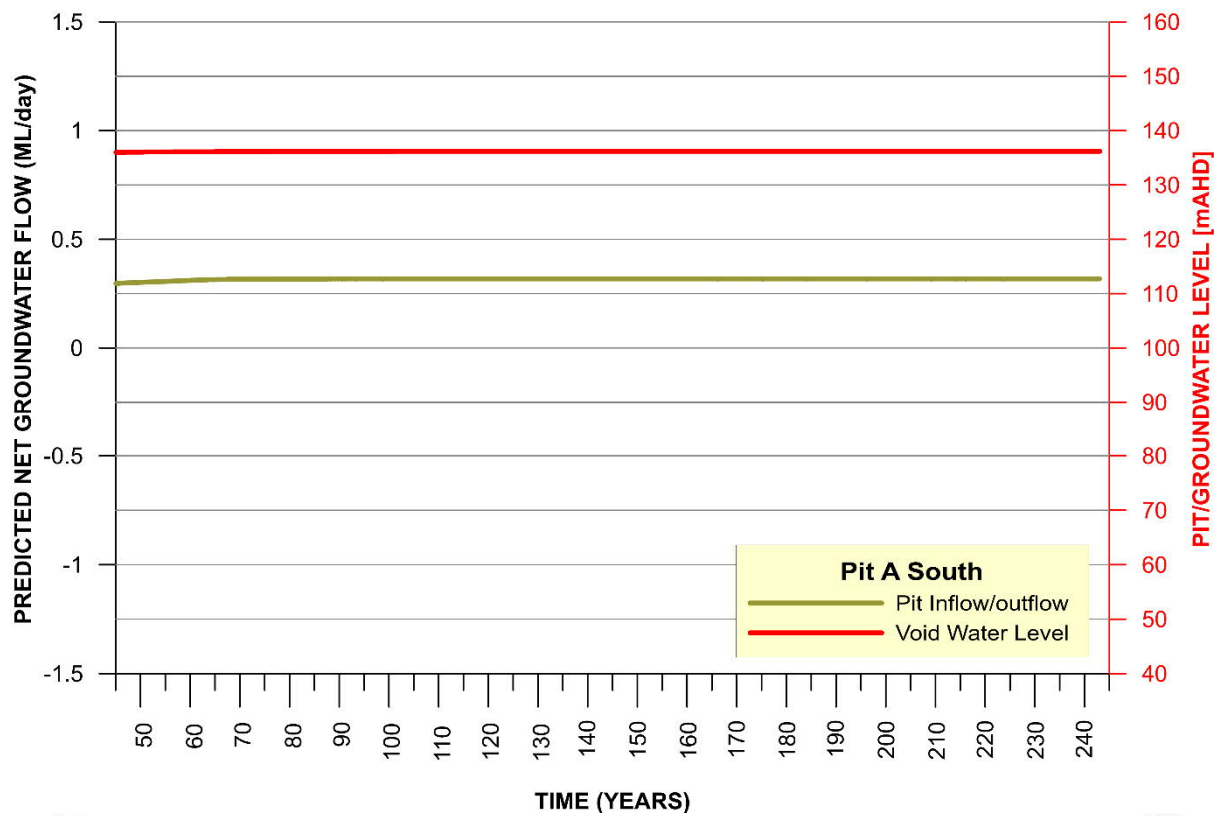


Figure E-34: Predicted Long-term Water Levels and Flows - Pit A South - a) Option 1 b) Option 3

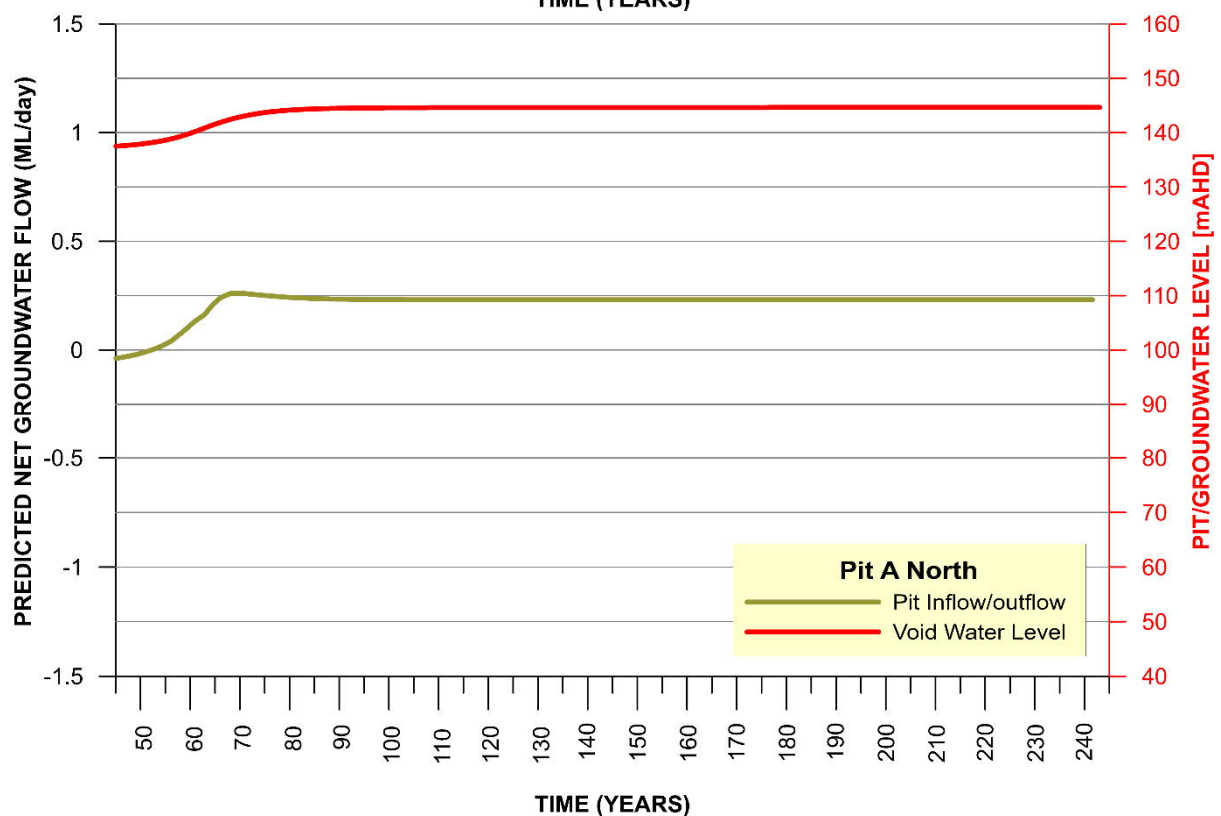
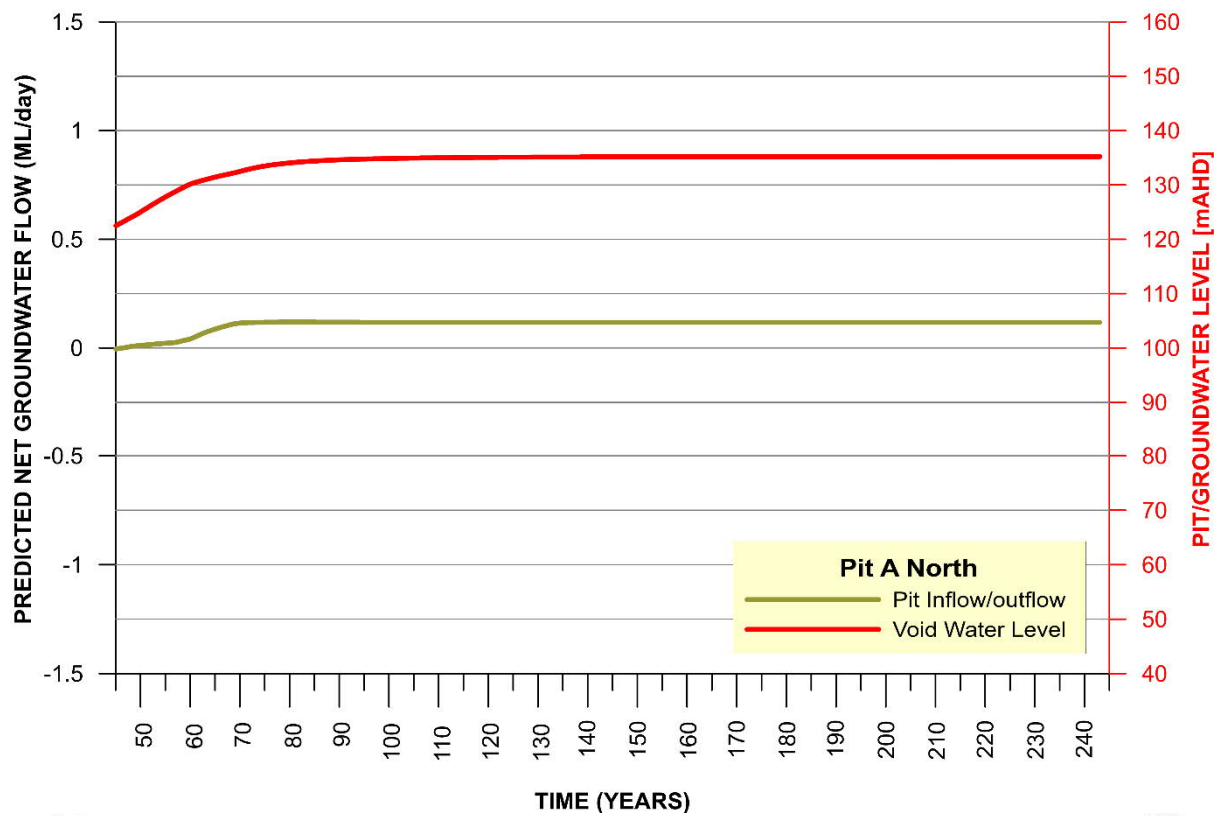


Figure E-35: Predicted Long-term Water Levels and Flows - Pit A North - a) Option 1 b) Option 3

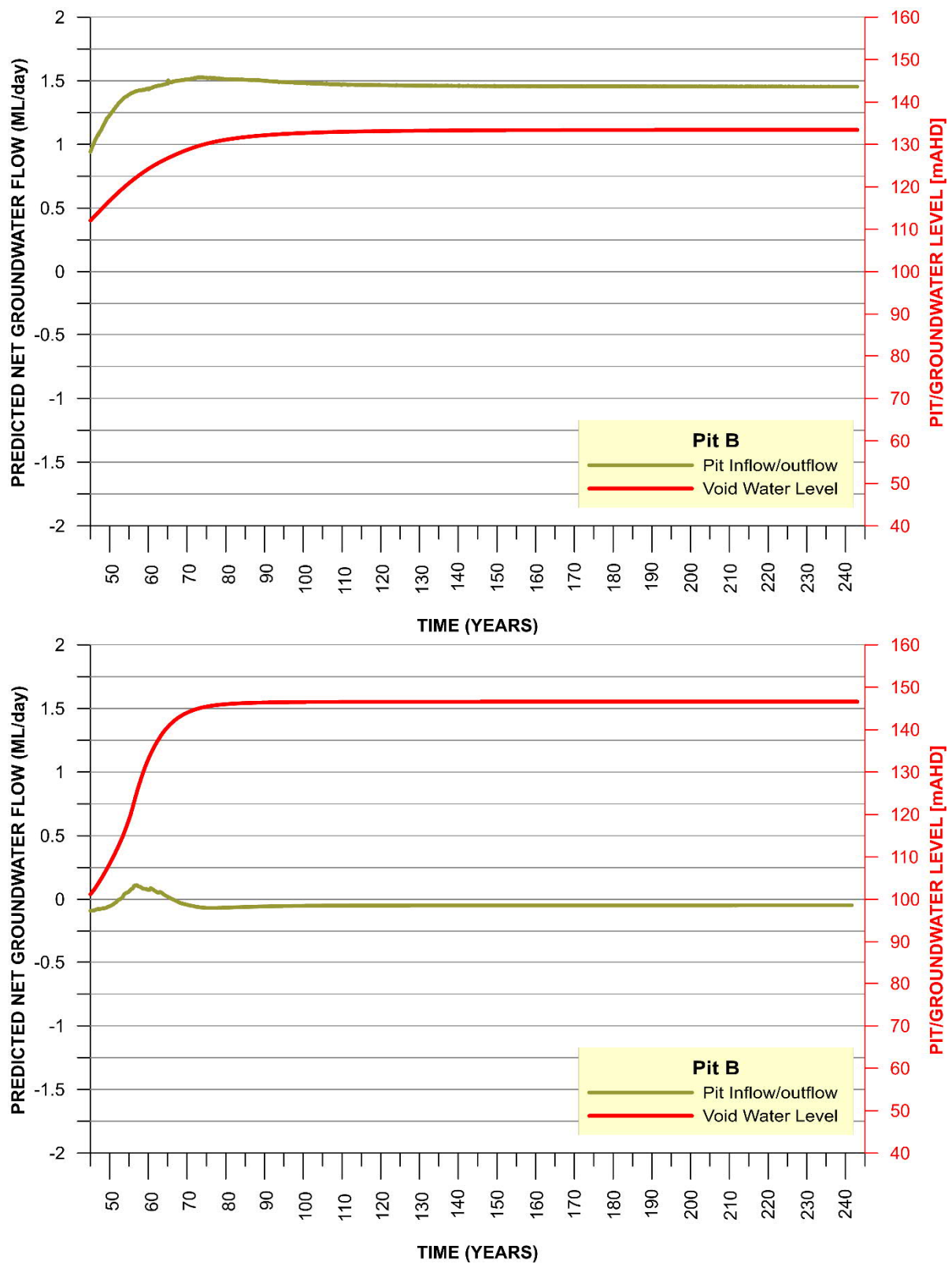


Figure E-36: Predicted Long-term Water Levels and Flows - Pit B - a) Option 1 b) Option 3

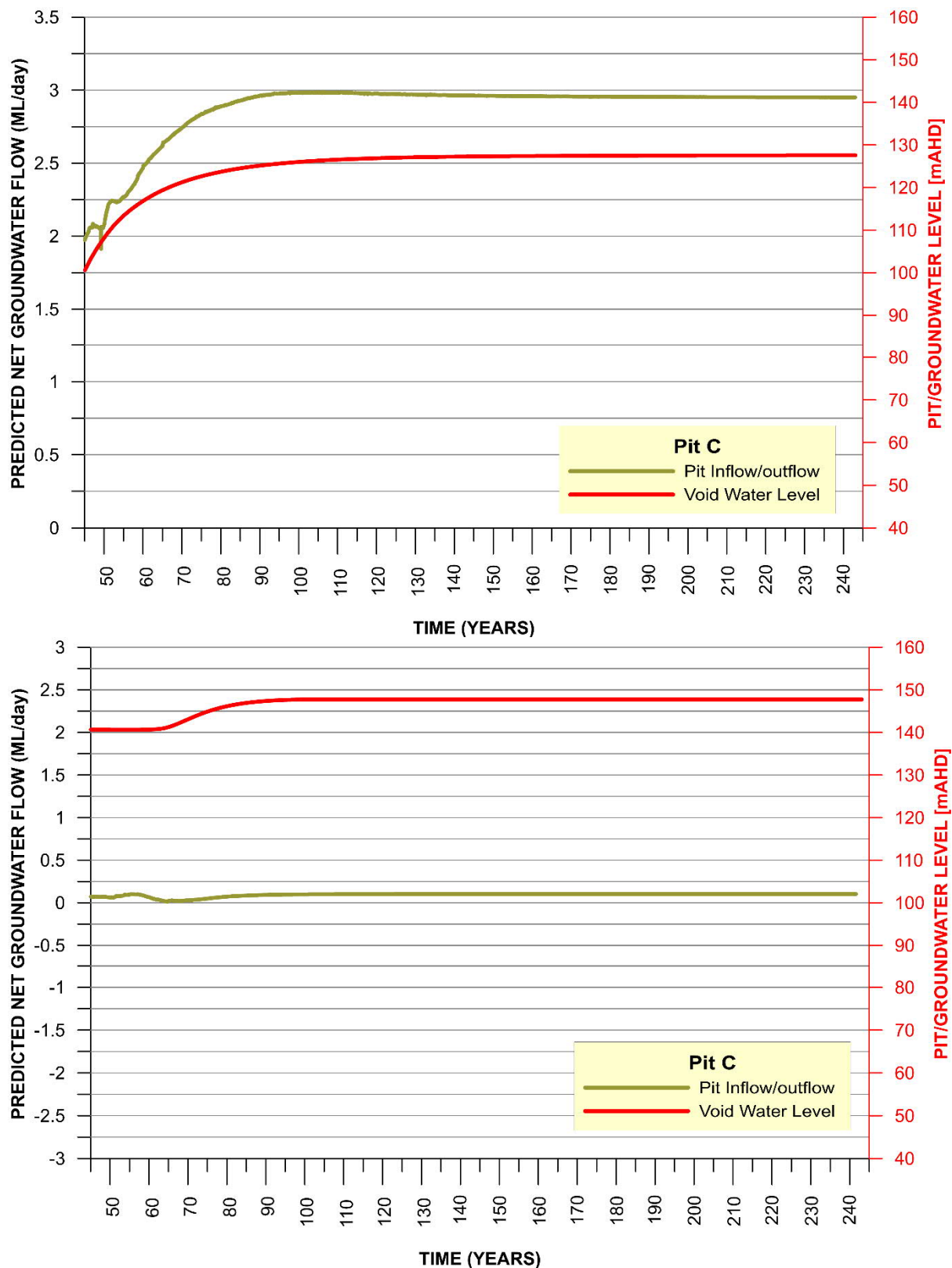


Figure E-37: Predicted Long-term Water Levels and Flows - Pit C - a) Option 1 b) Option 3

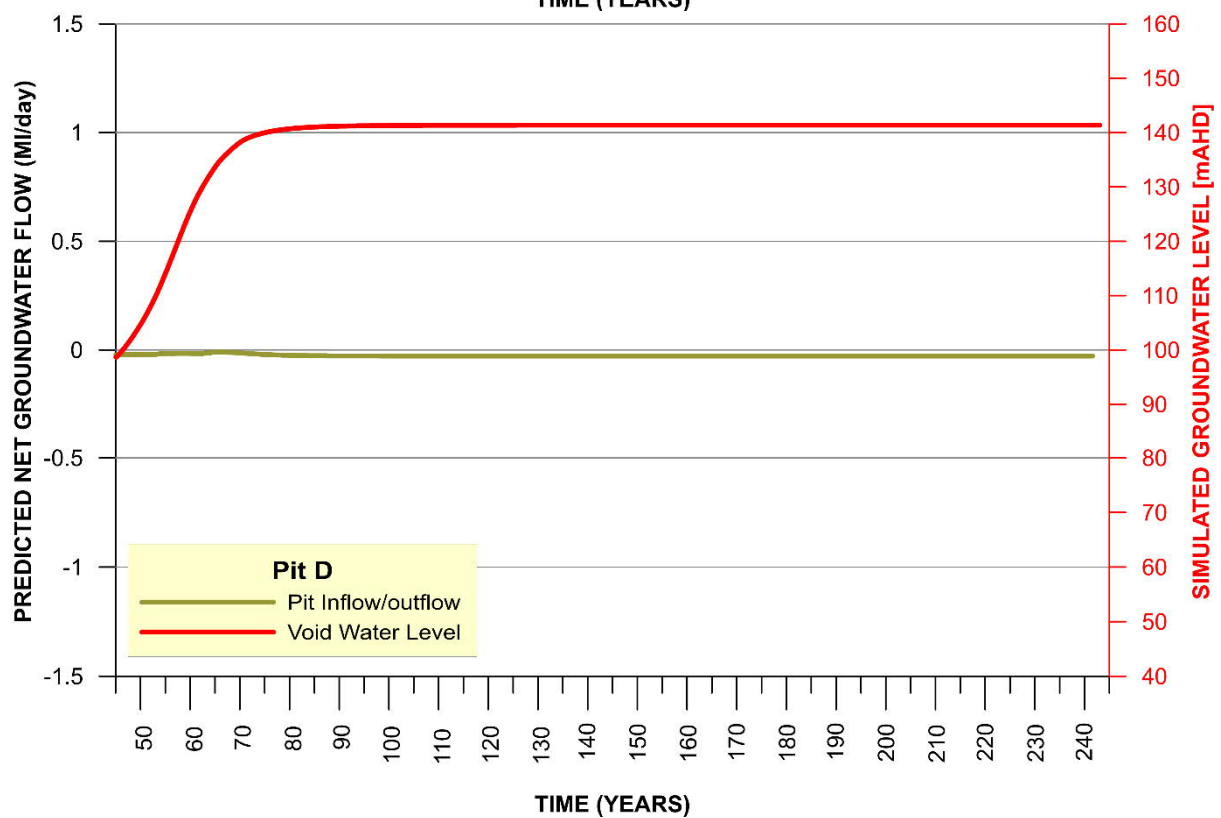
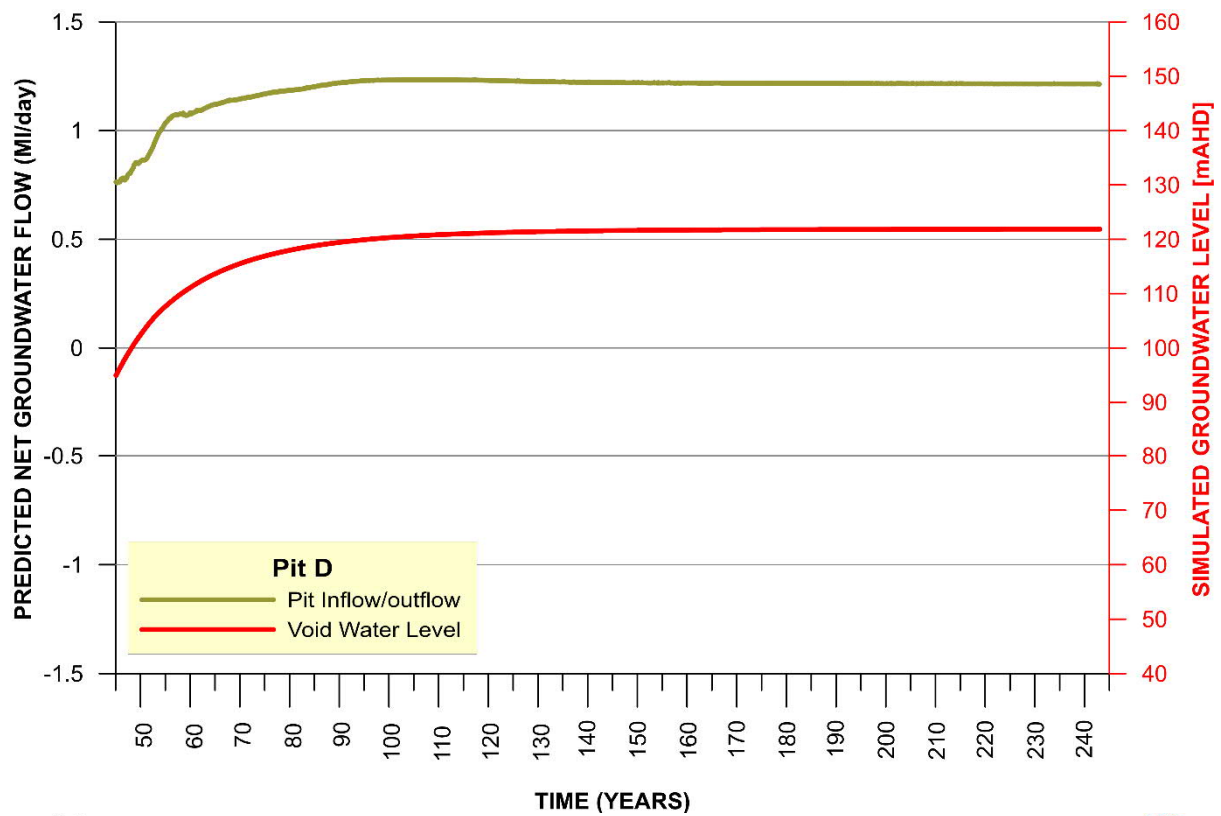


Figure E-38: Predicted Long-term Water Levels and Flows - Pit D - a) Option 1 b) Option 3

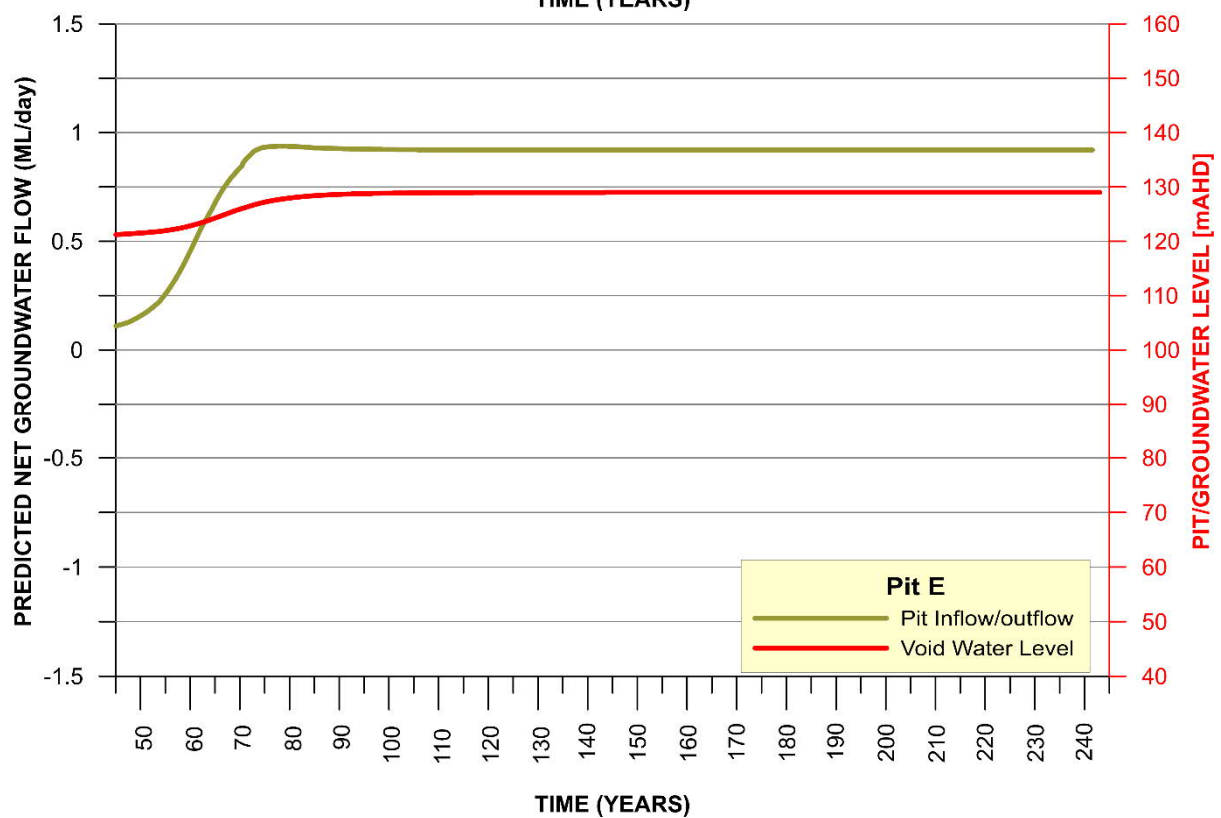
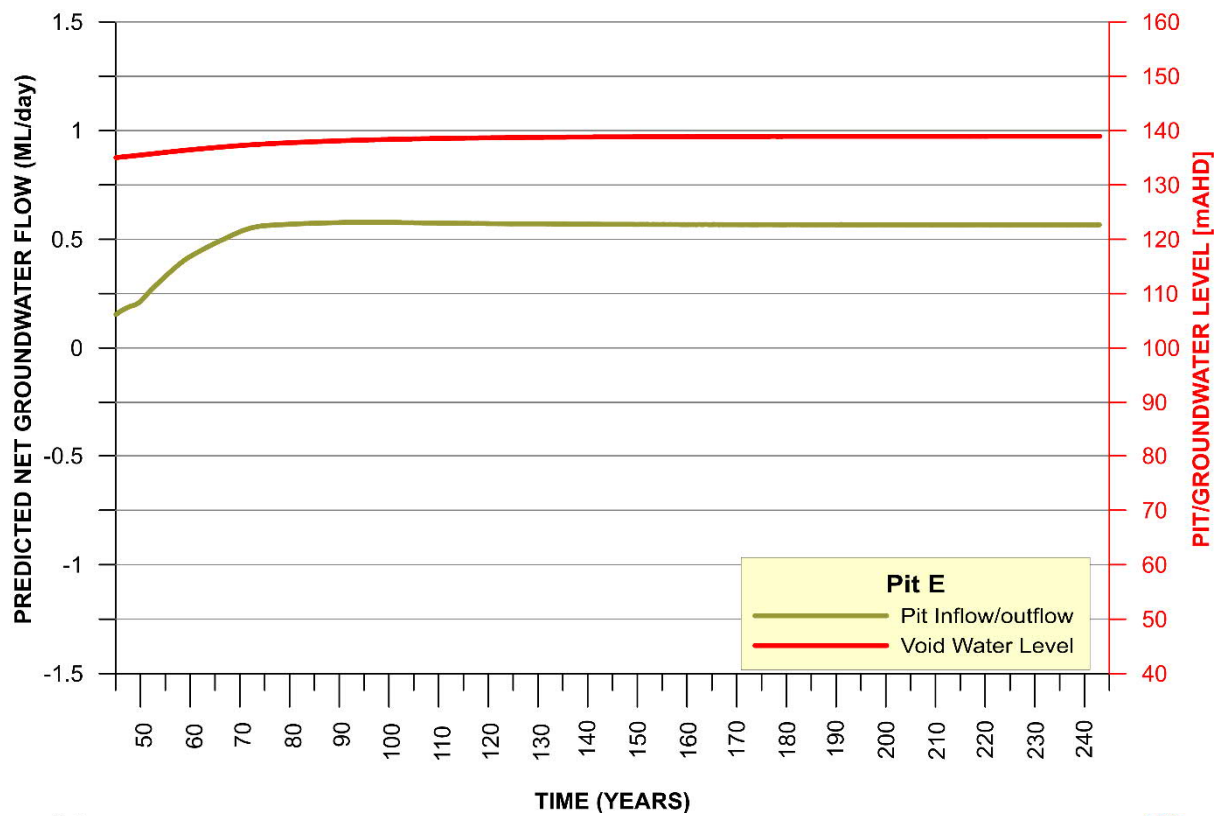


Figure E-39: Predicted Long-term Water Levels and Flows - Pit E - a) Option 1 b) Option 3

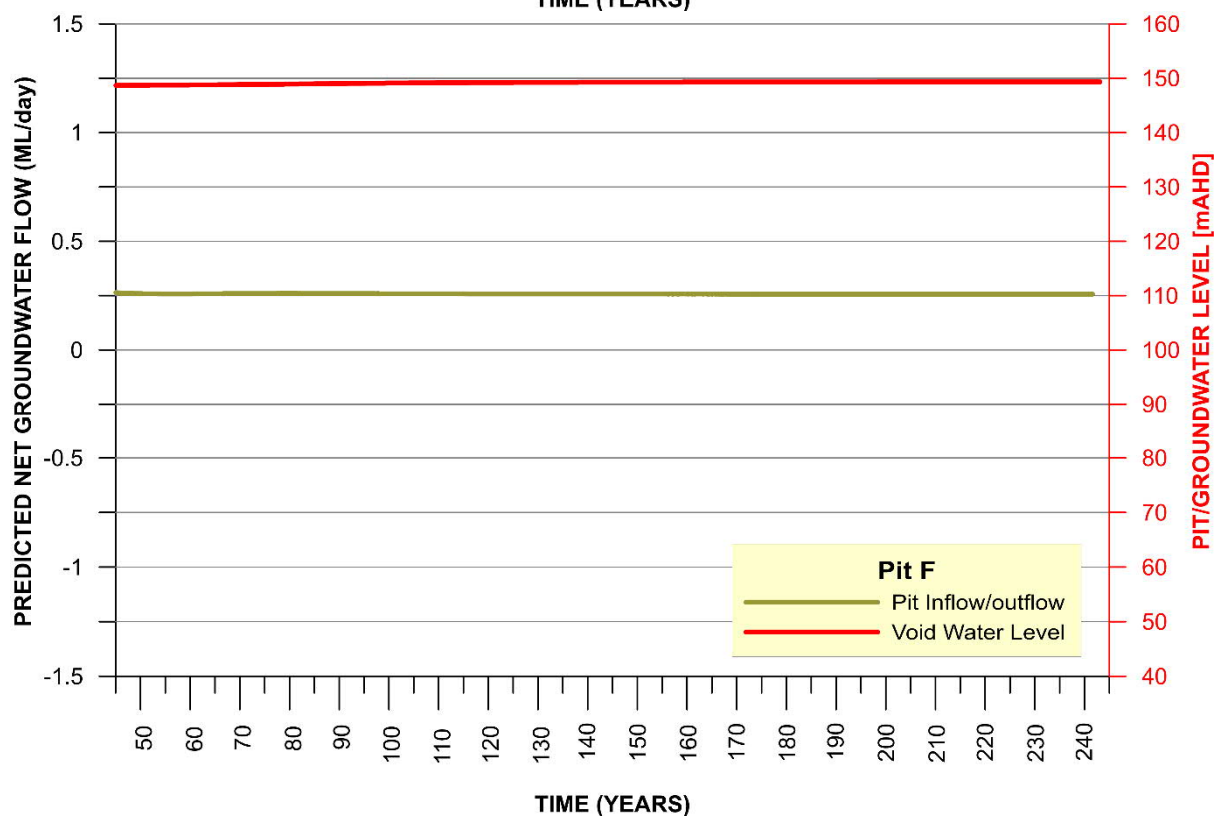
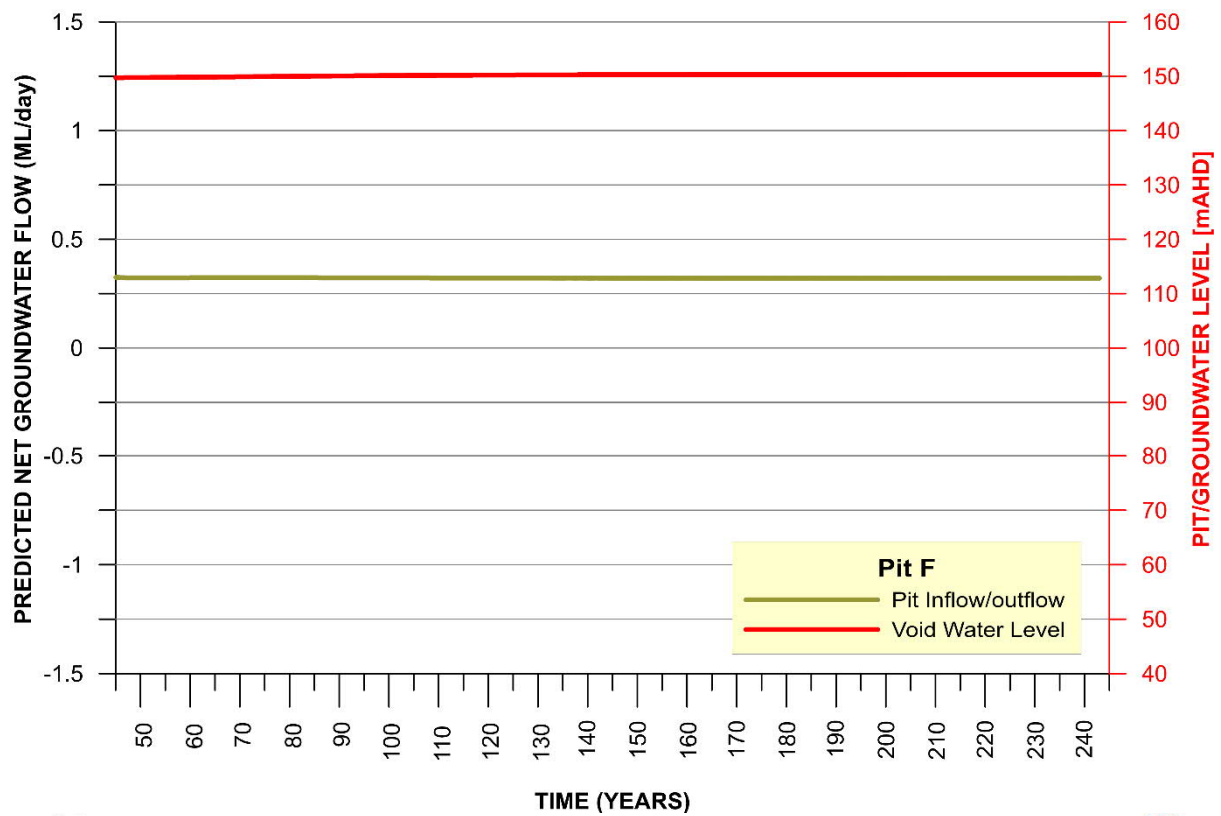


Figure E-40: Predicted Long-term Water Levels and Flows - Pit F - a) Option 1 b) Option 3

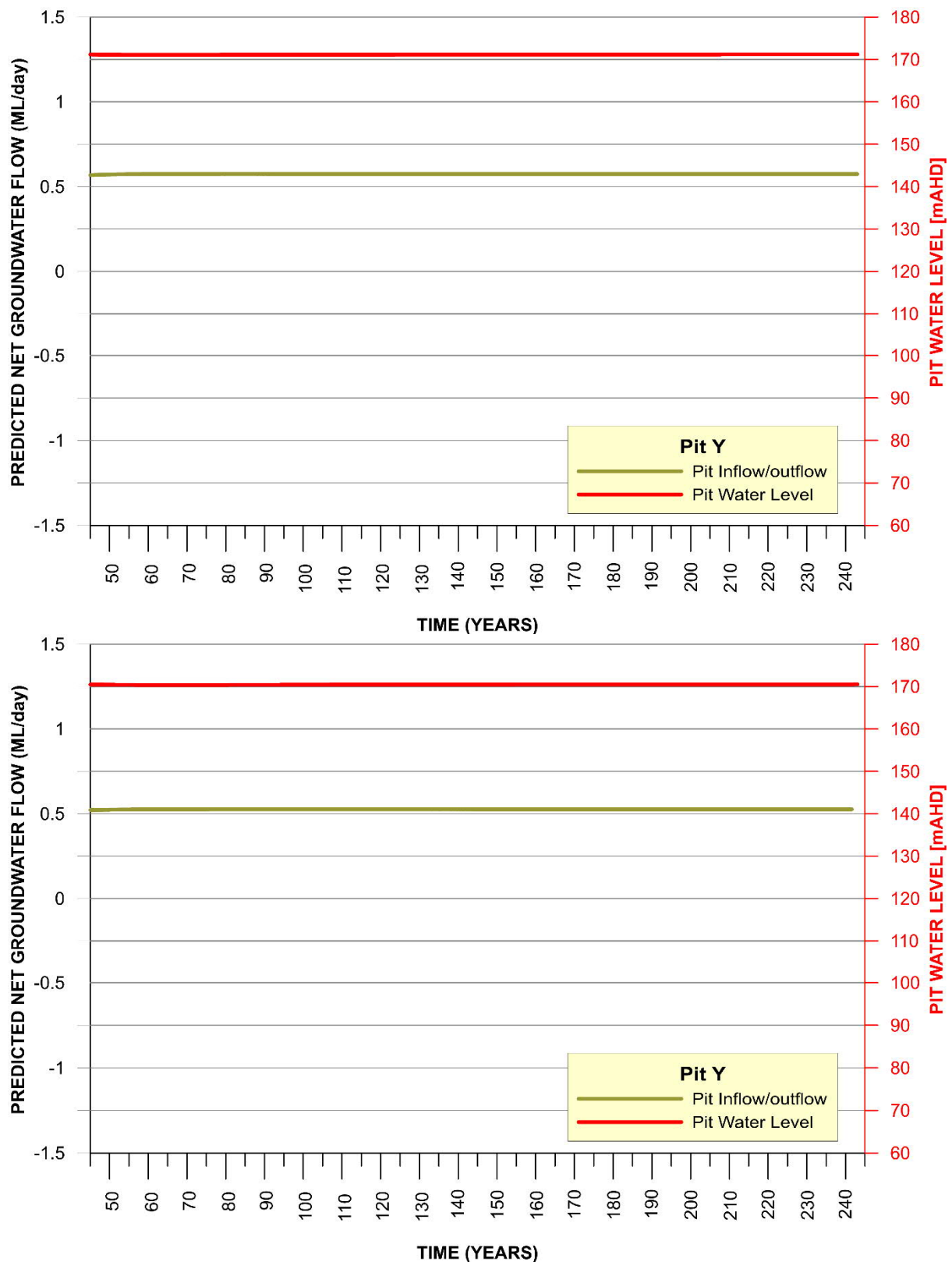


Figure E-41: Predicted Long-term Water Levels and Flows - Pit Y - a) Option 1 b) Option 3

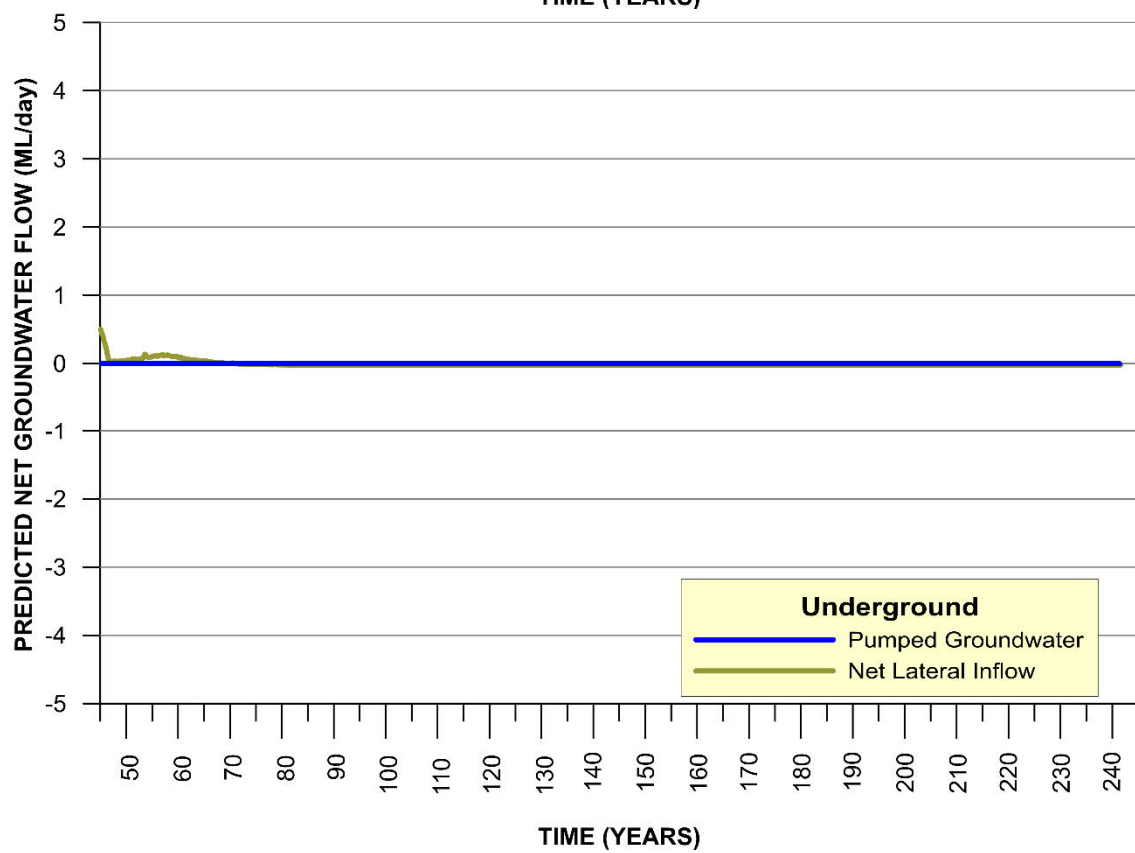
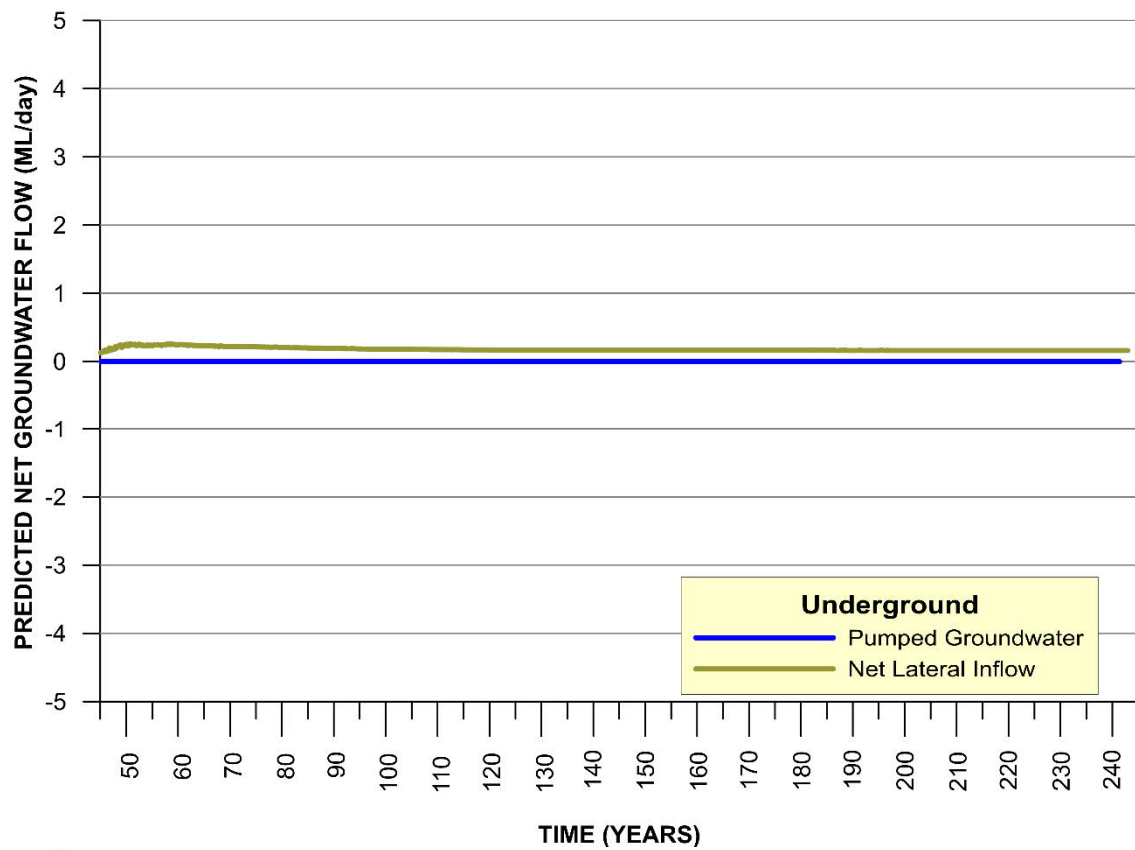


Figure E-42: Predicted Long-term Underground Mine Inflow - a) Option 1 b) Option 3

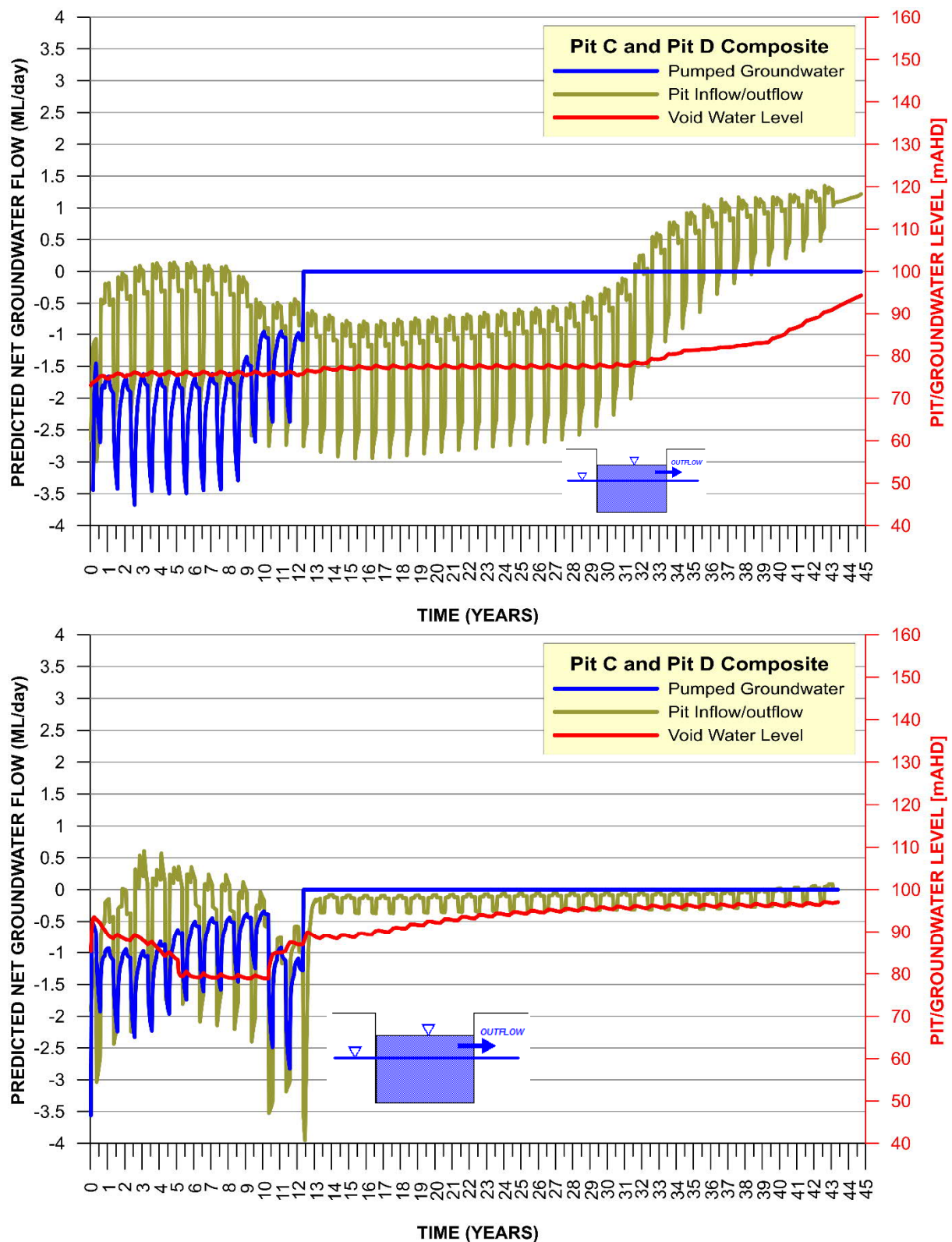


Figure E-43: Predicted Water Flows Pit C and Pit D Composite and Water Level Pit D - a) Option 1 b) Option 3

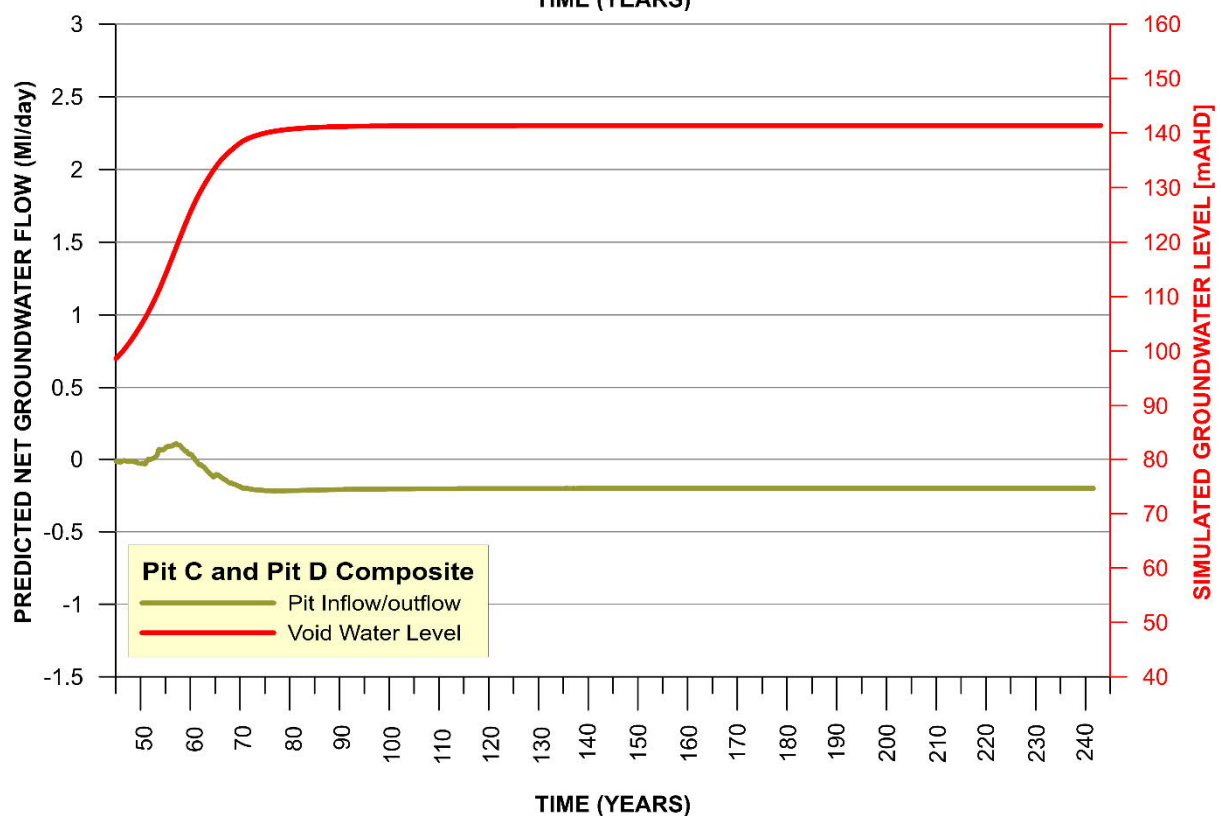
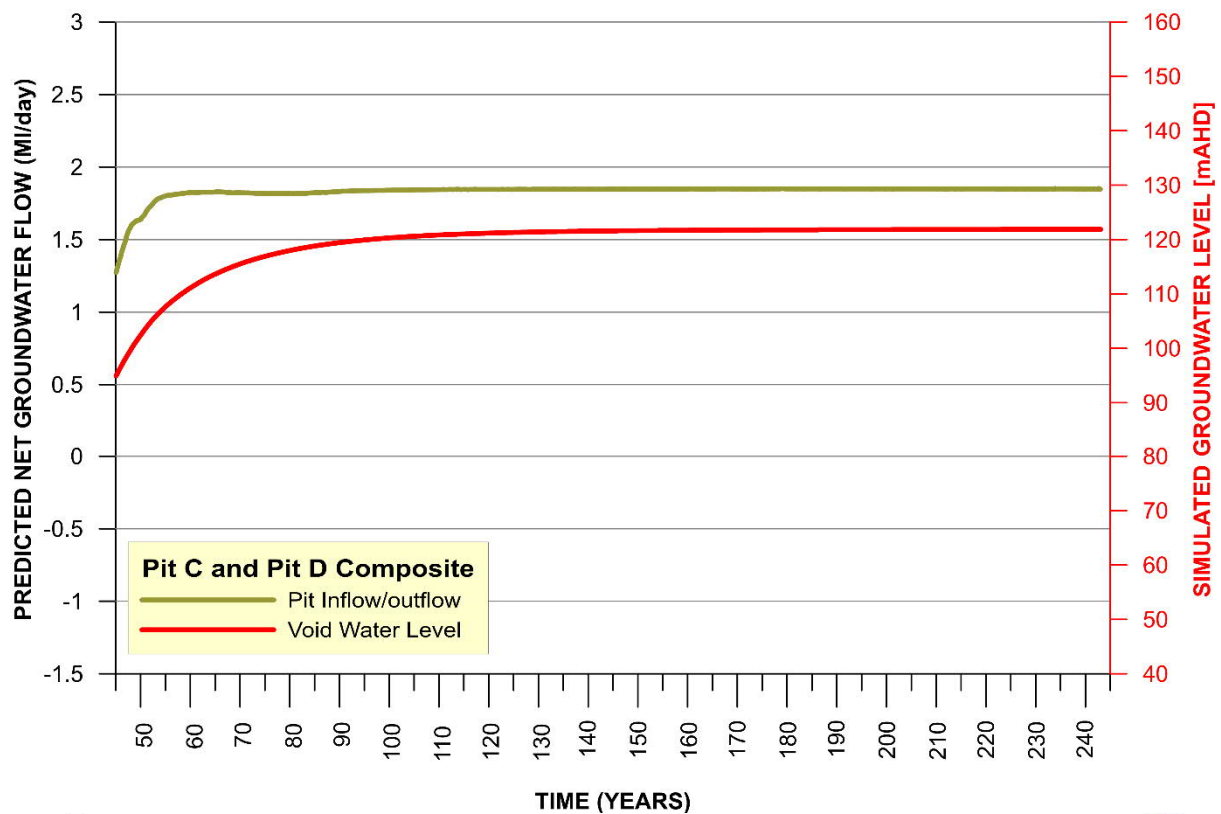
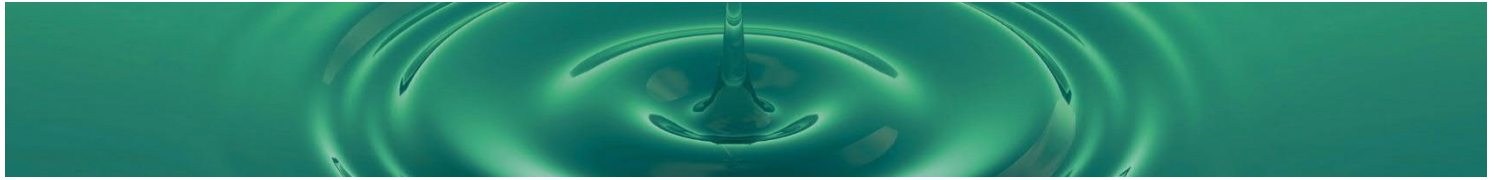


Figure E-44: Predicted Long-term Water Flows Pit C and Pit D Composite and Water Level Pit D - a)
Option 1 b) Option 3



APPENDIX F

Discharge-Stage Curves

v3: valid early time (before final landform)

v4: valid late time (after landform change)

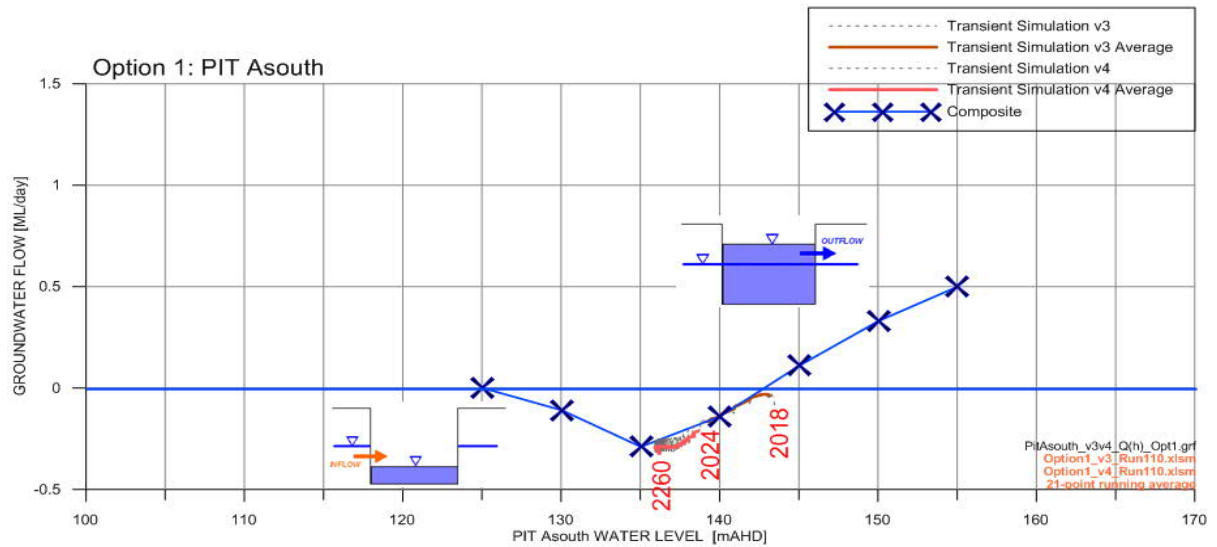


Figure F-1: Option 1 Pit Asouth discharge-stage curve

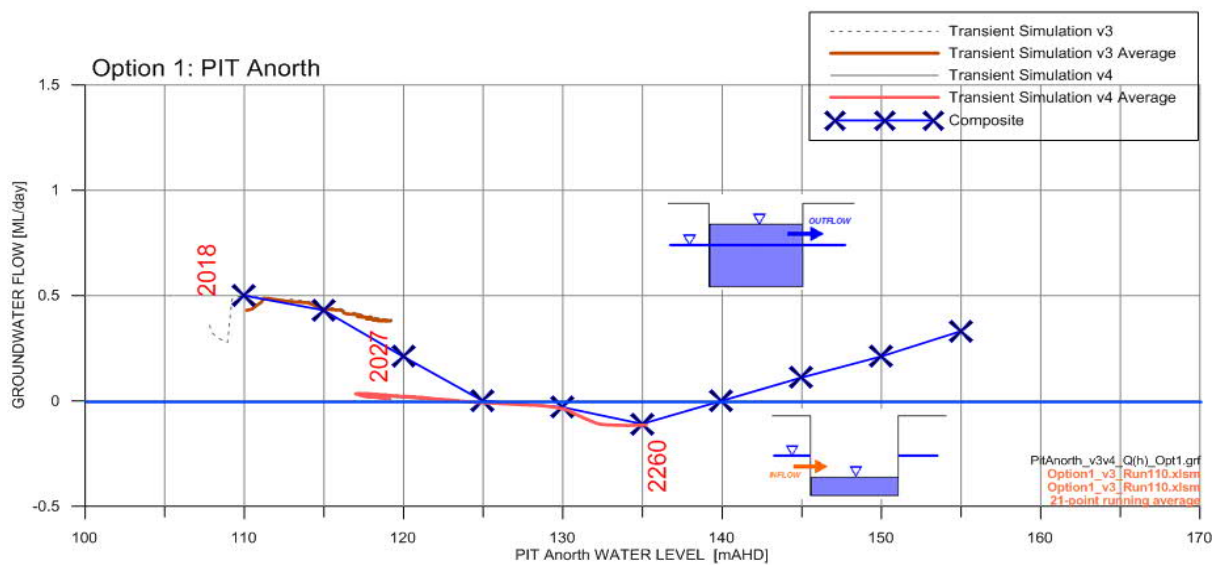


Figure F-2: **Option 1** Pit Anorth discharge-stage curve

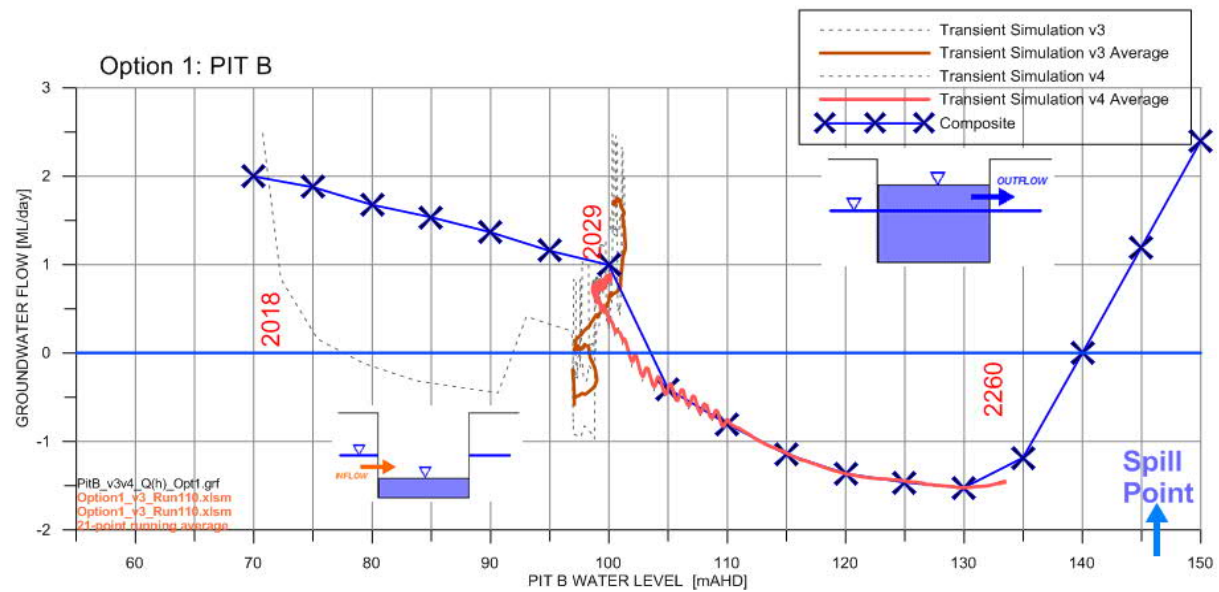


Figure F-3: **Option 1** Pit B discharge-stage curve

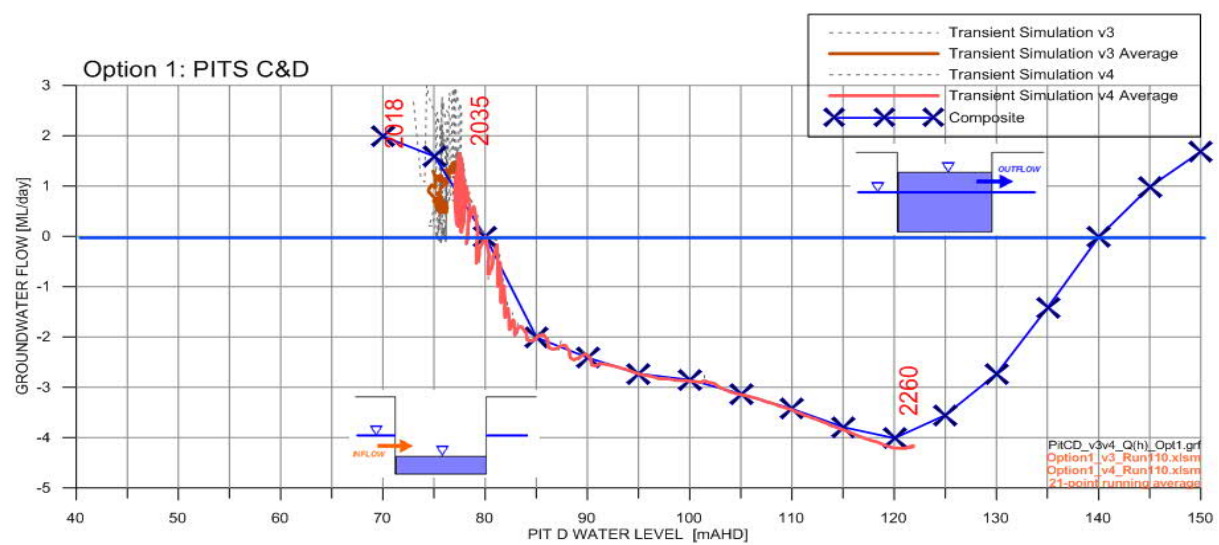


Figure F-4: **Option 1** Pits C&D discharge-stage curve

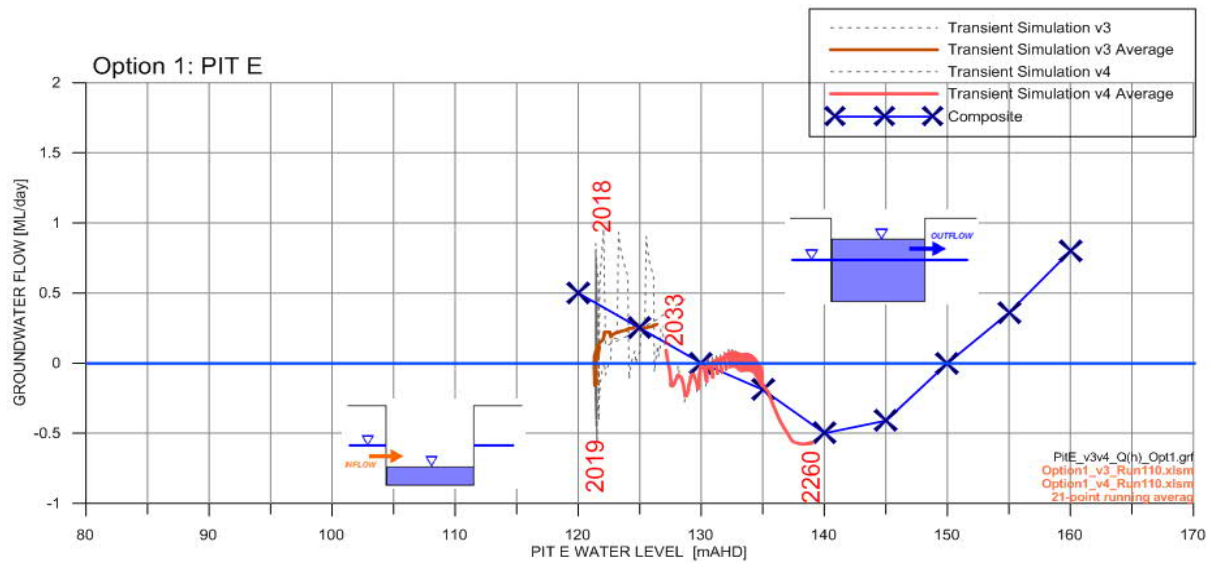


Figure F-5: Option 1 Pit E discharge-stage curve

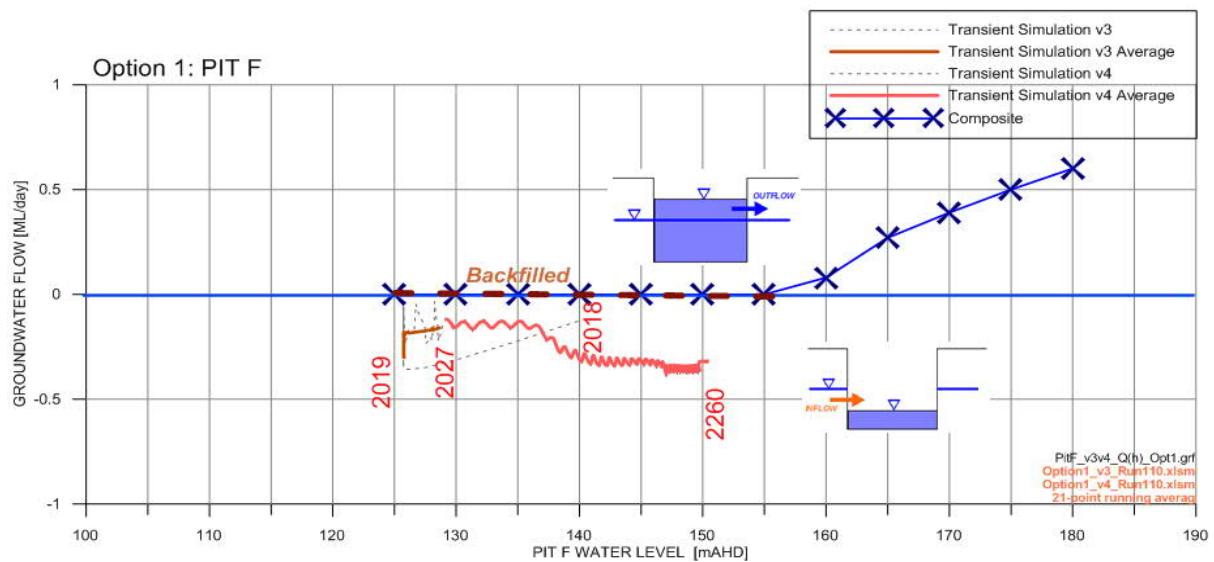


Figure F-6: Option 1 Pit F discharge-stage curve
[composite curve assumes backfill to 5m above water rest level]

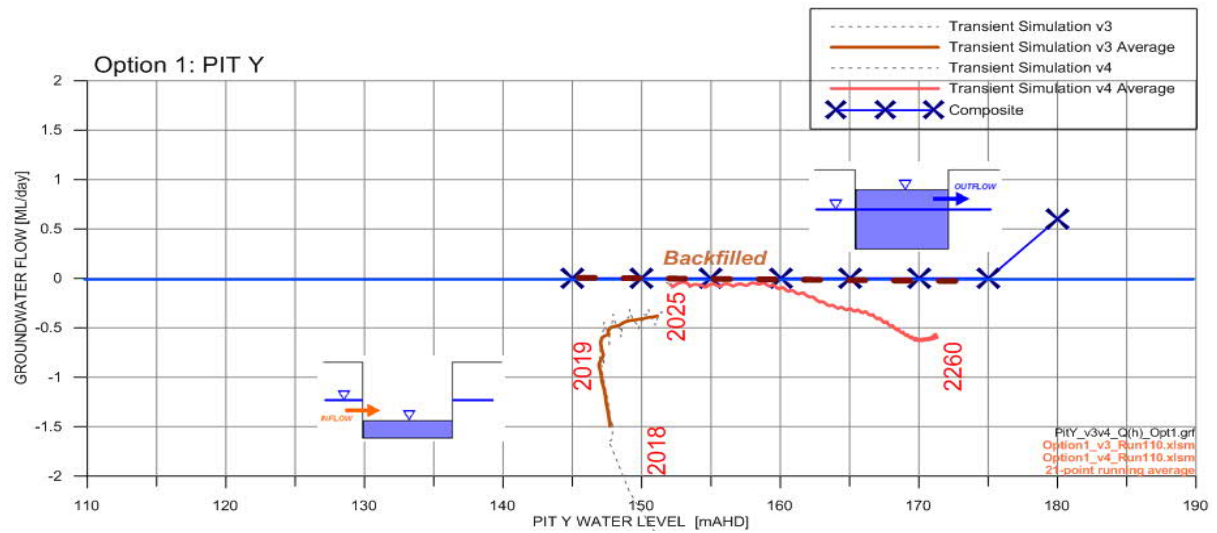


Figure F-7: Option 1 Pit Y discharge-stage curve
[composite curve assumes backfill to 5m above water rest level]

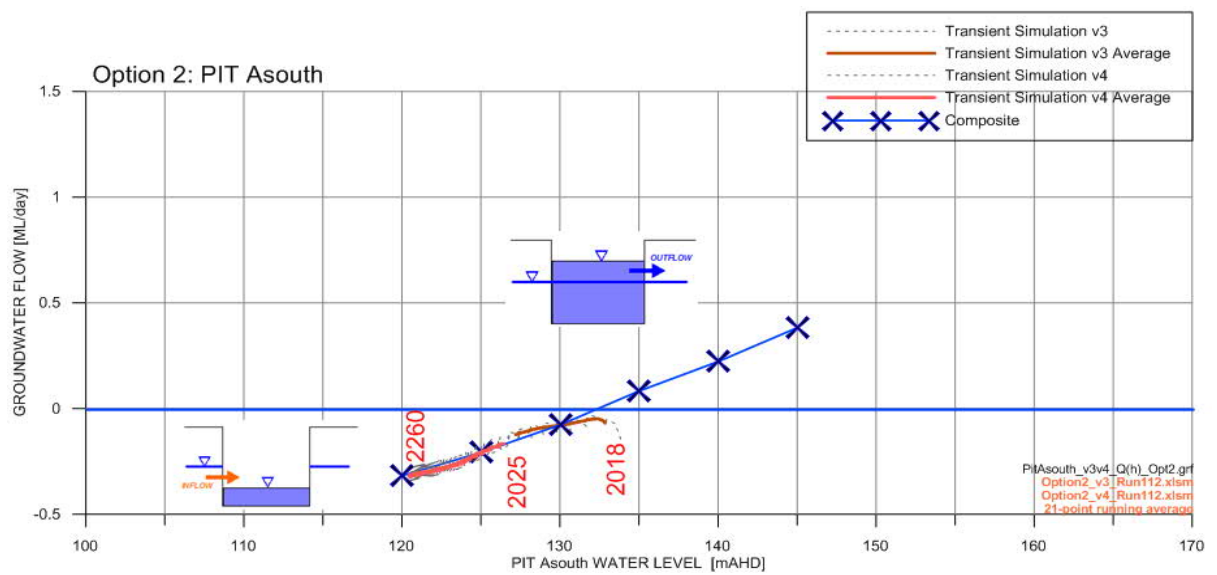


Figure F-8: Option 2 Pit Asouth discharge-stage curve

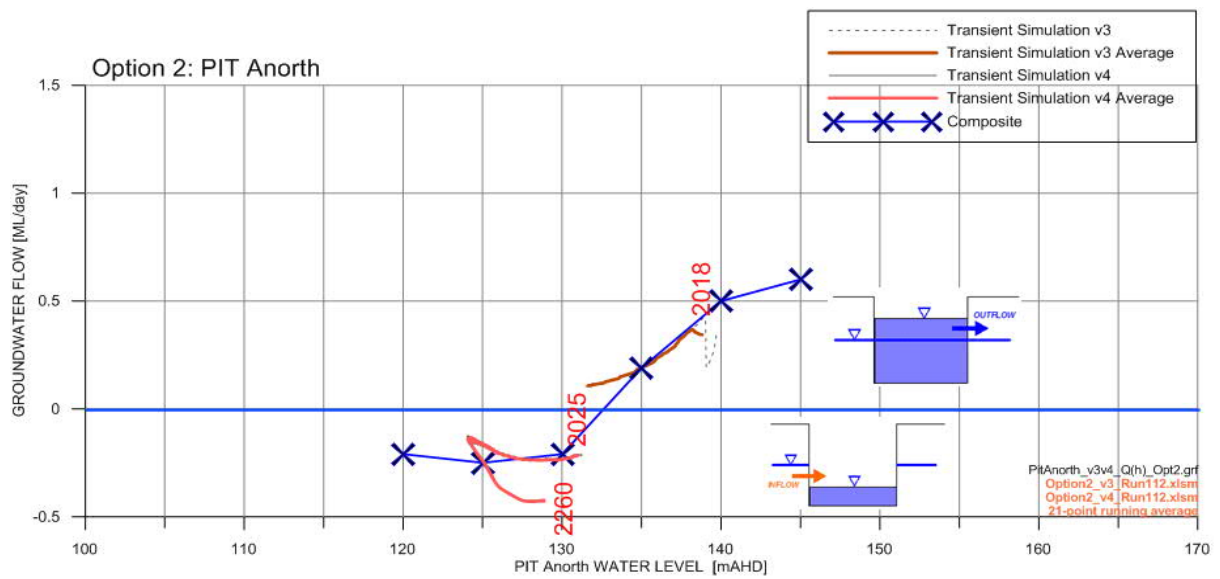


Figure F-9: Option 2 Pit Anorth discharge-stage curve

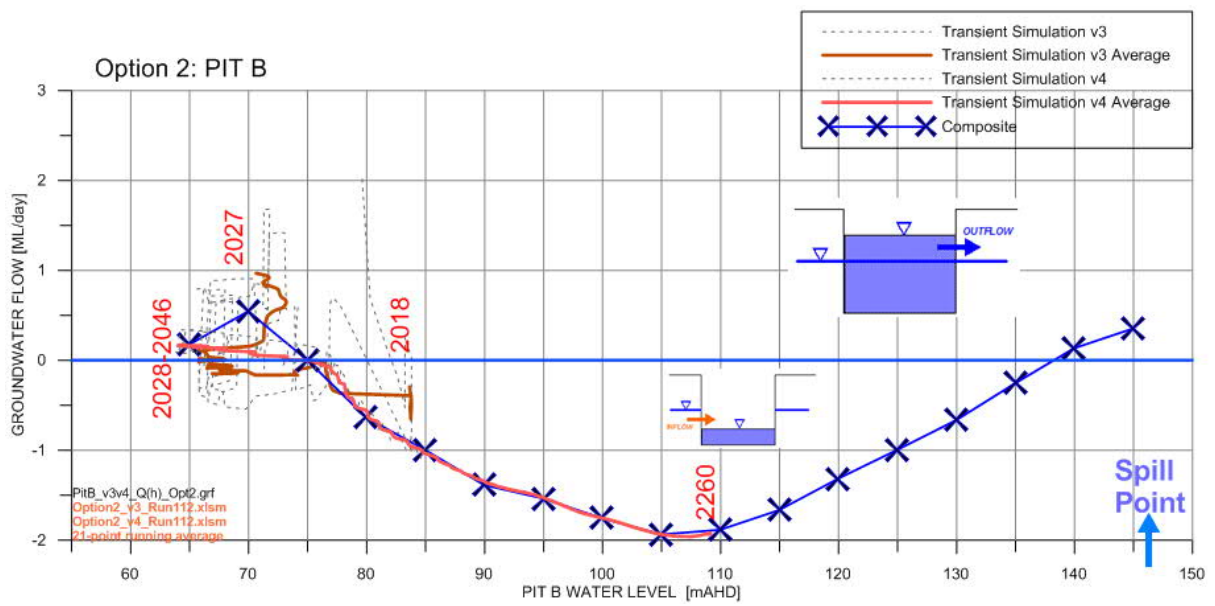


Figure F-10: Option 2 Pit B discharge-stage curve

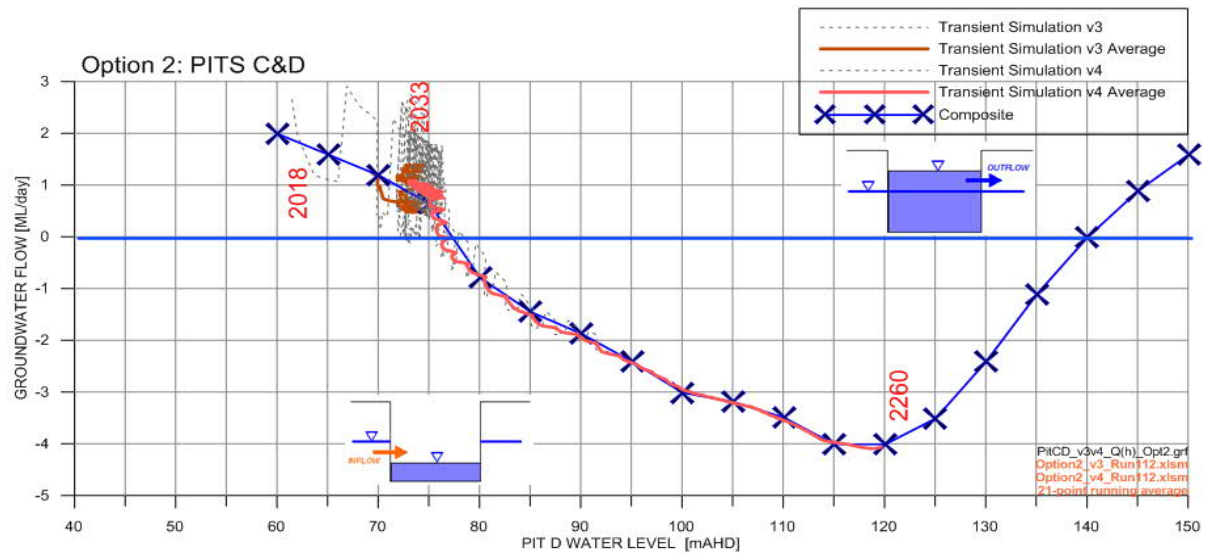


Figure F-11: Option 2 Pits C&D discharge-stage curve

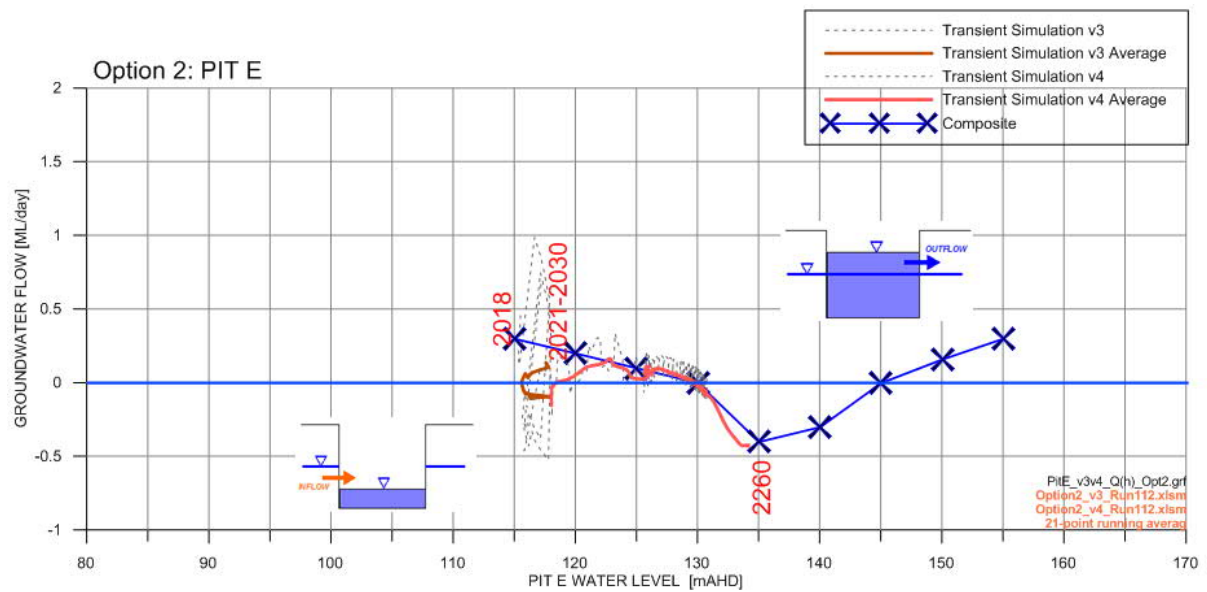


Figure F-12: Option 2 Pit E discharge-stage curve

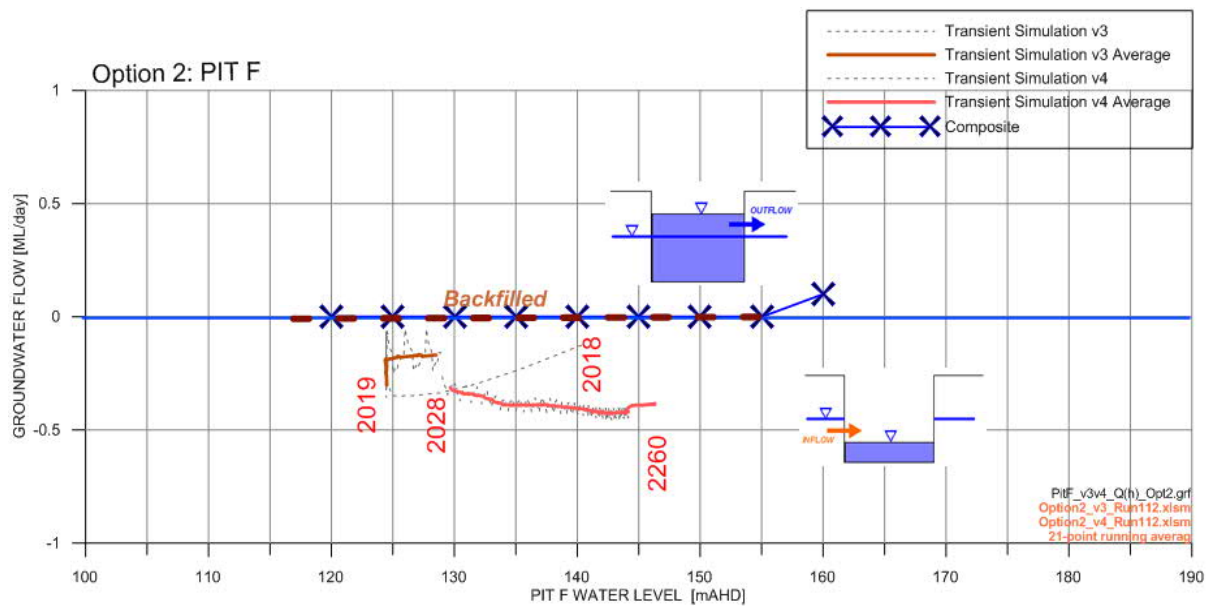


Figure F-13: Option 2 Pit F discharge-stage curve
[composite curve assumes backfill to 5m above water rest level]

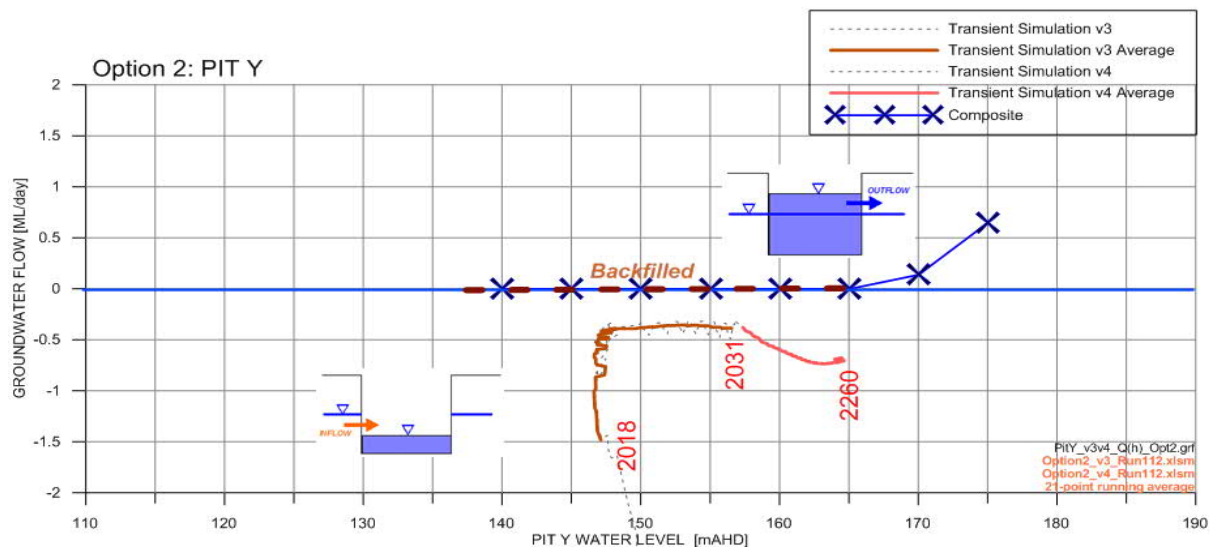


Figure F-14: Option 2 Pit Y discharge-stage curve
[composite curve assumes backfill to 5m above water rest level]

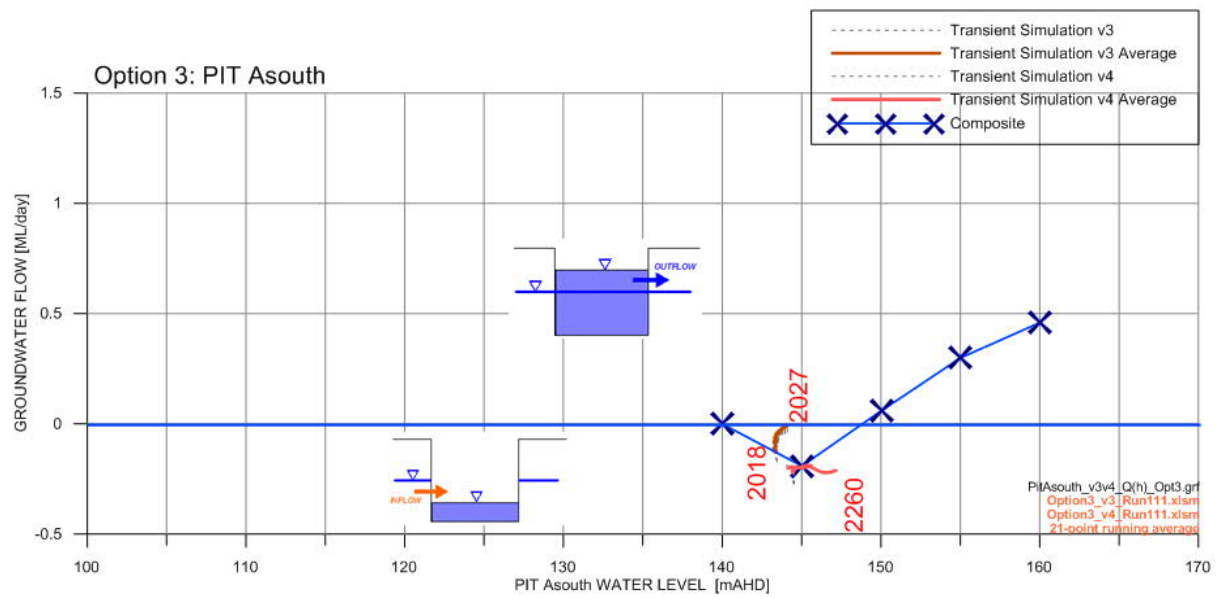


Figure F-15: Option 3 Pit Asouth discharge-stage curve

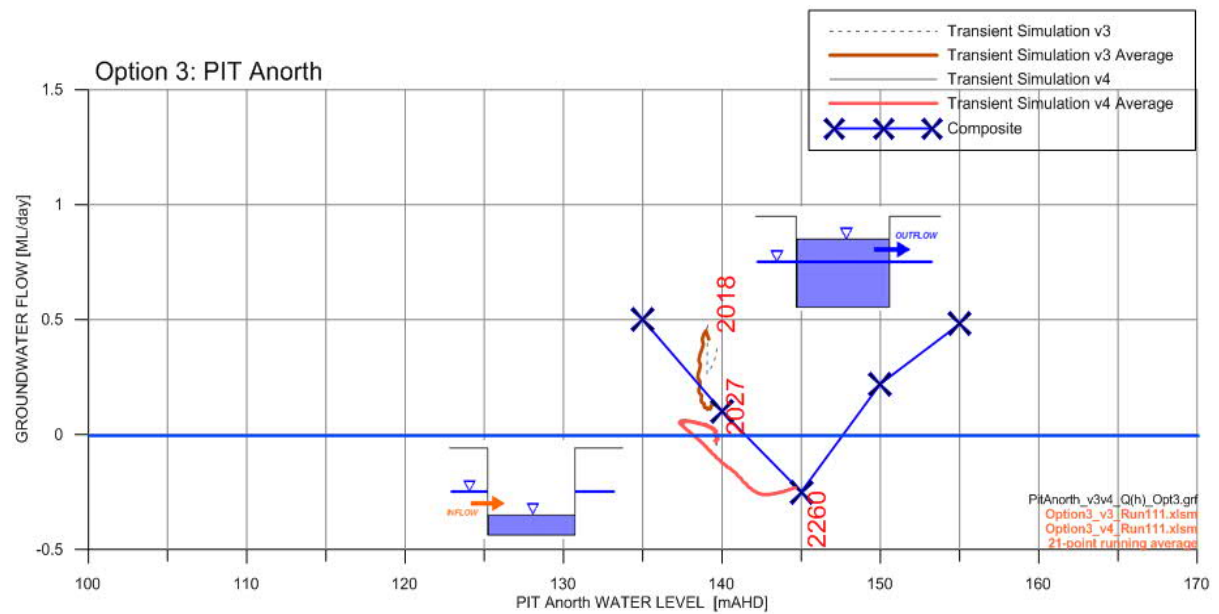


Figure F-16: Option 3 Pit Anorth discharge-stage curve

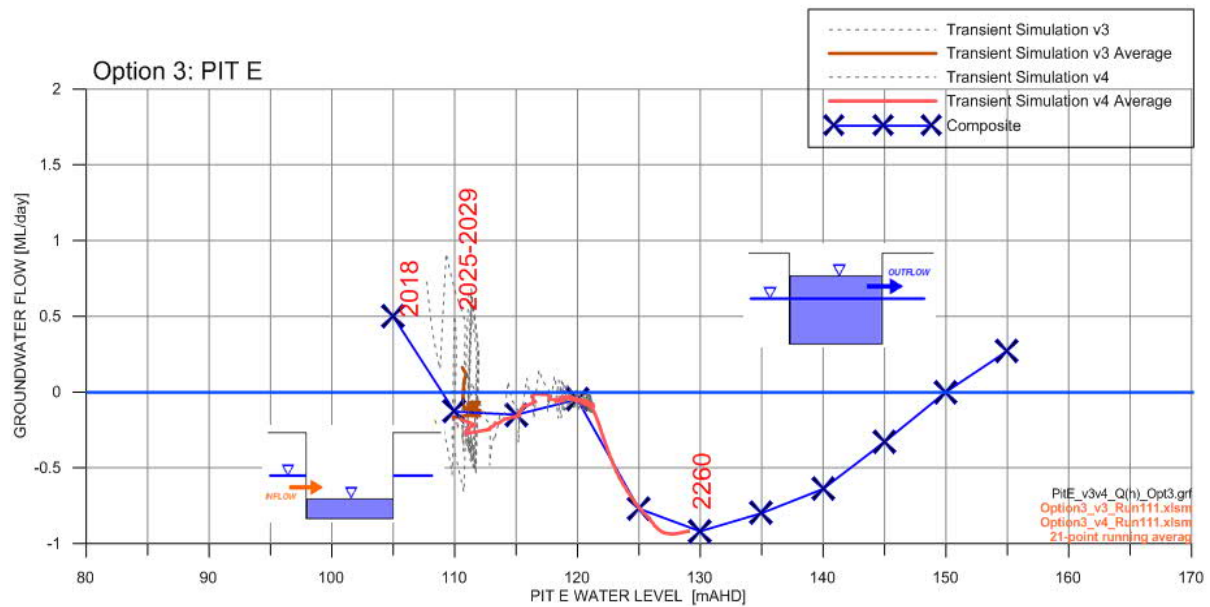


Figure F-17: Option 3 Pit E discharge-stage curve

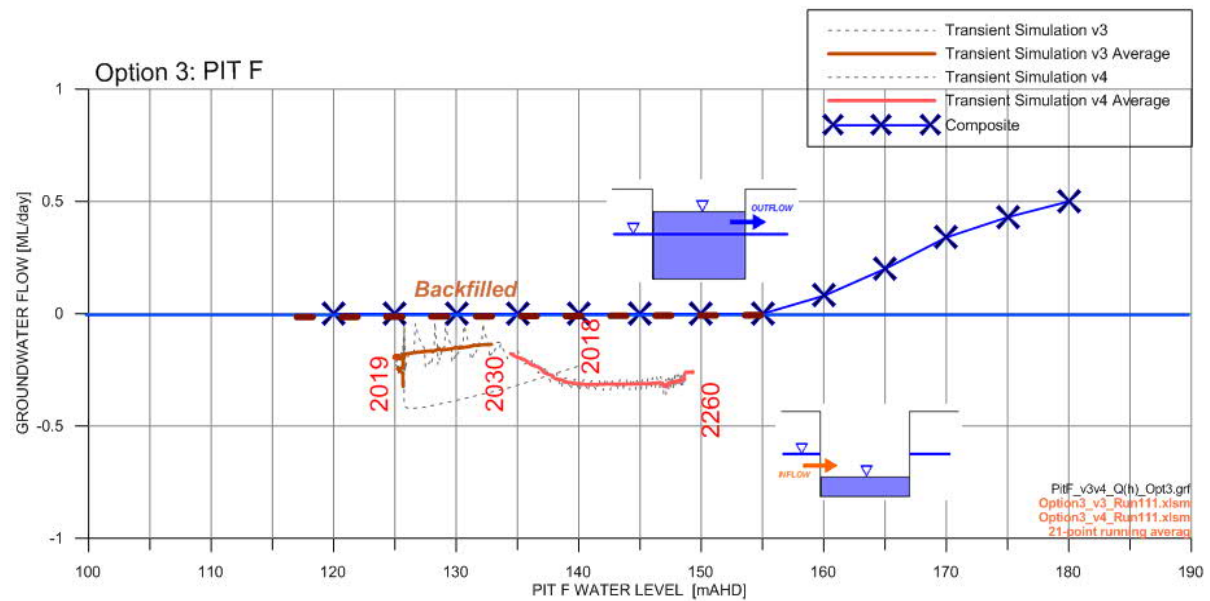


Figure F-18: Option 3 Pit F discharge-stage curve

[composite curve assumes backfill to 5m above water rest level]

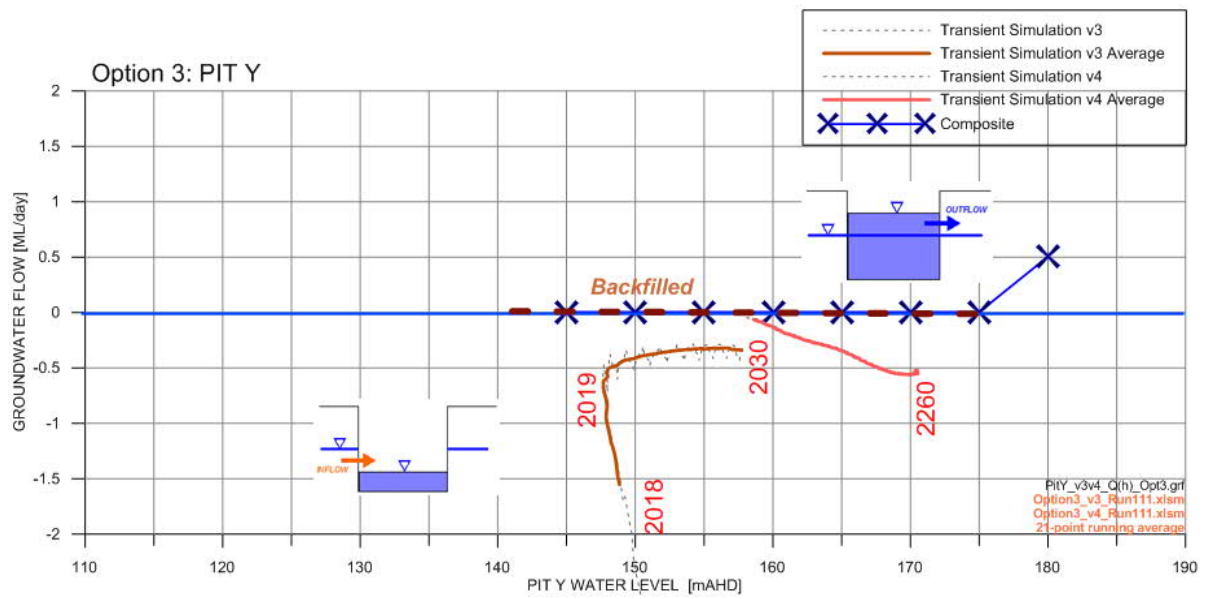
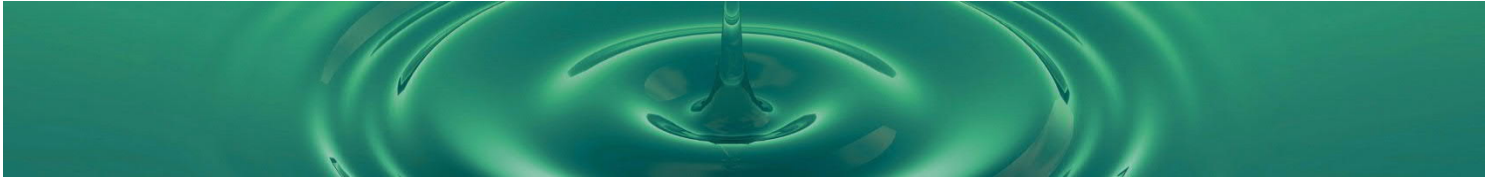


Figure F-19: Option 3 Pit Y discharge-stage curve
 [composite curve assumes backfill to 5m above water rest level]



APPENDIX G

Amended Model Parameter Fields

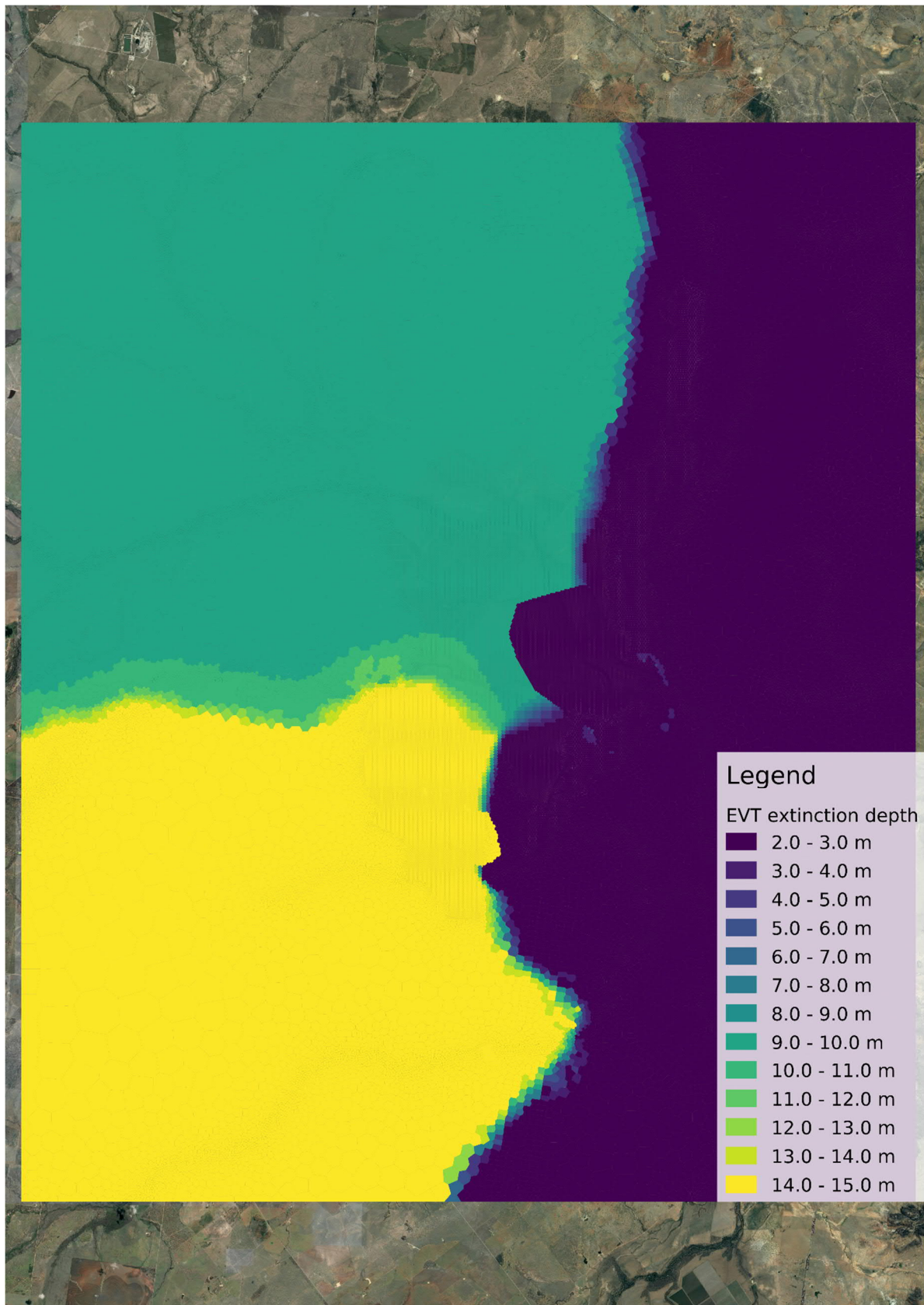


Figure G-1: Post-calibration evapotranspiration extinction depth

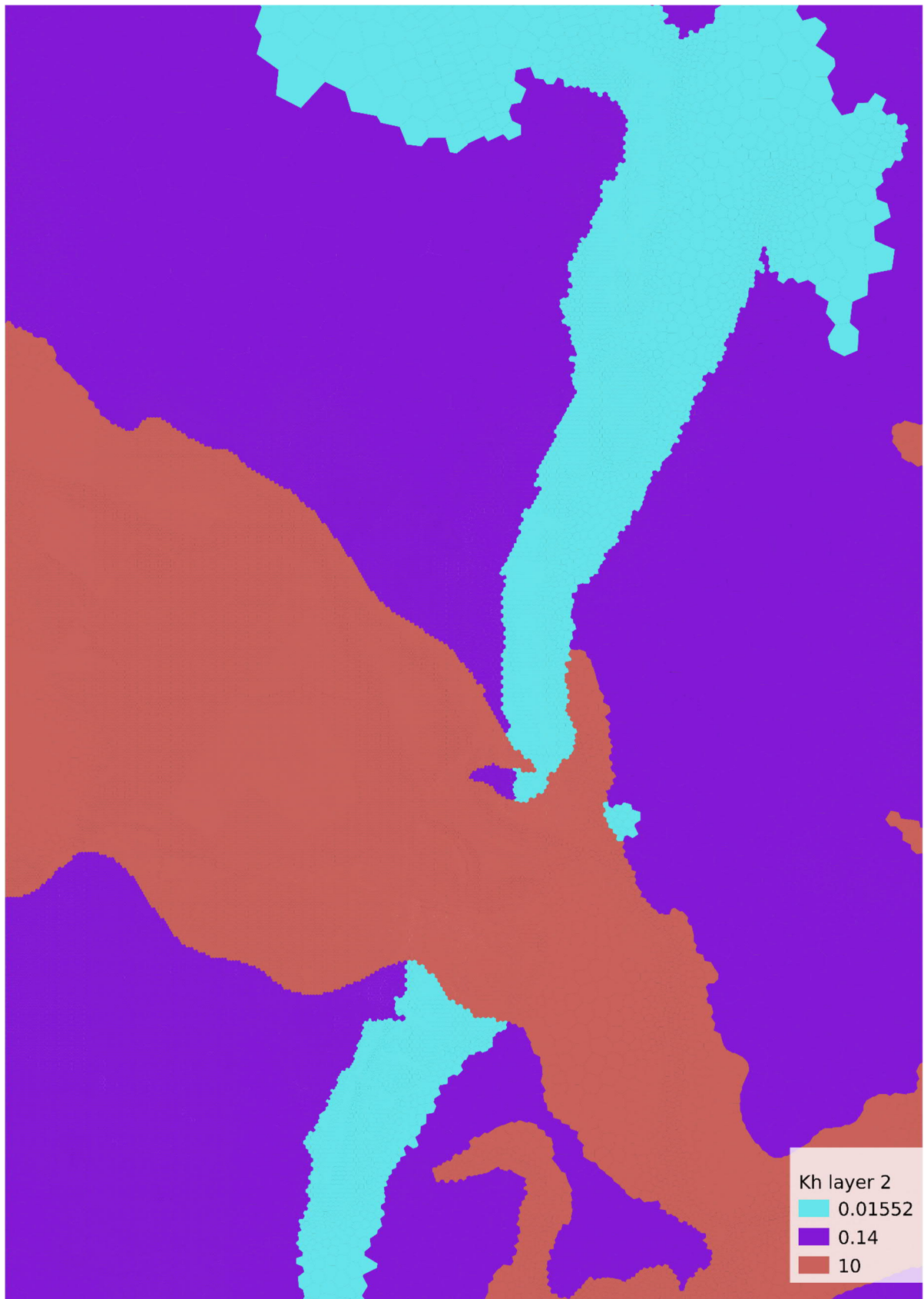


Figure G-2: Pre-calibration Kh layer 2 [m/day]



Figure G-3: Post-calibration Kh layer 2 [m/day]

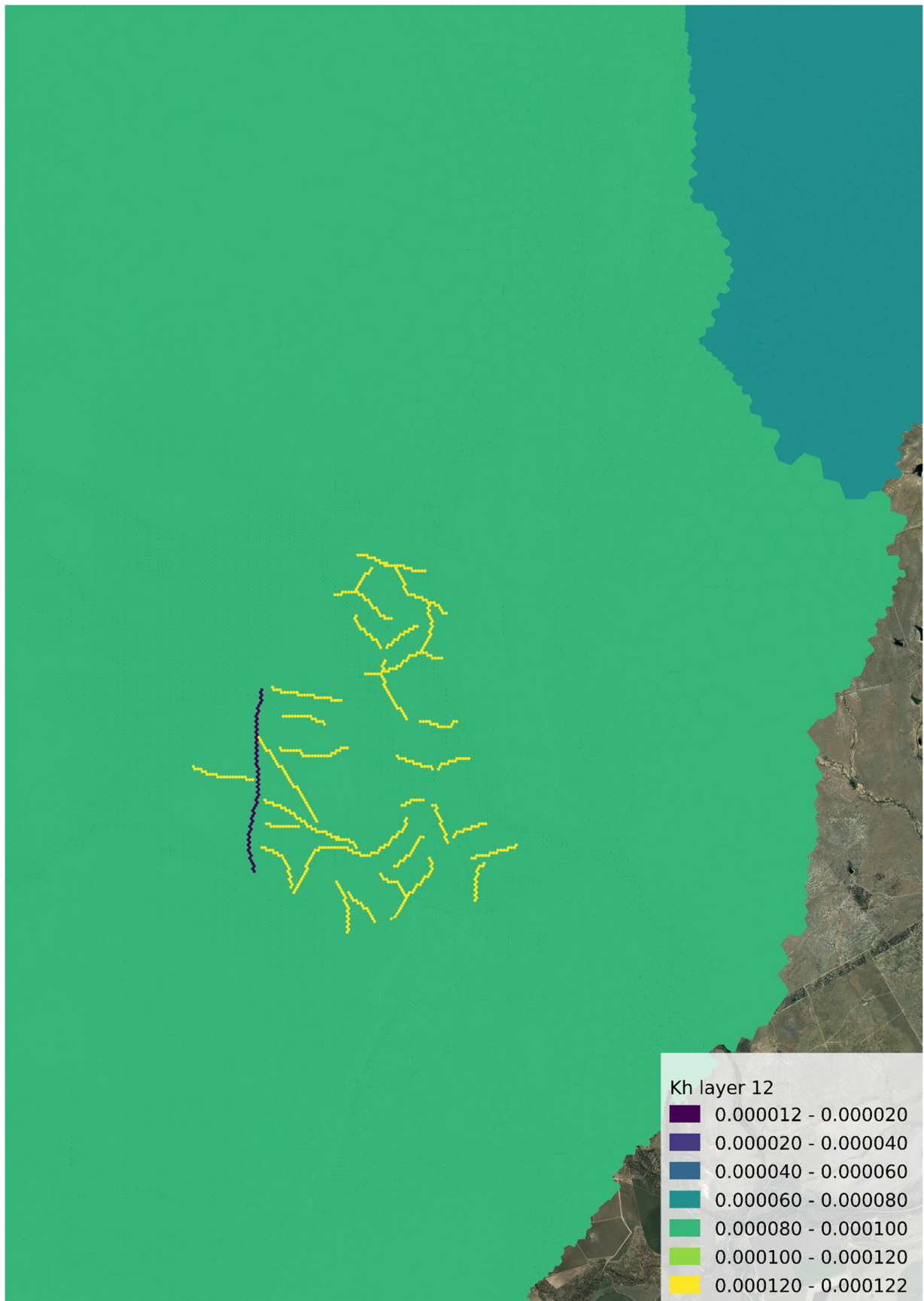
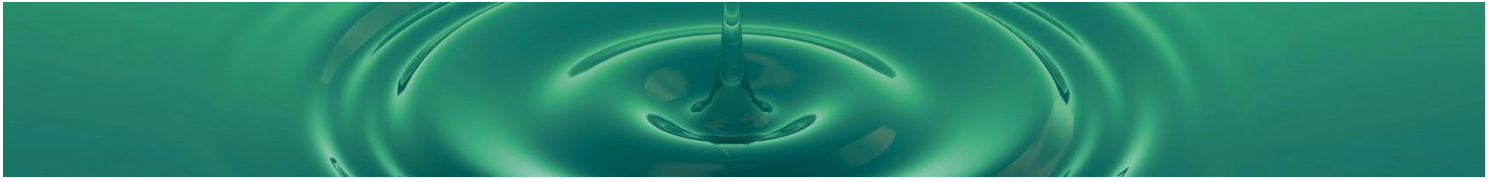


Figure G-4: Pre-calibration Kh layer 12 [m/day]



Figure G-5: Post-calibration Kh layer 12 [m/day]



APPENDIX H

Final Landforms

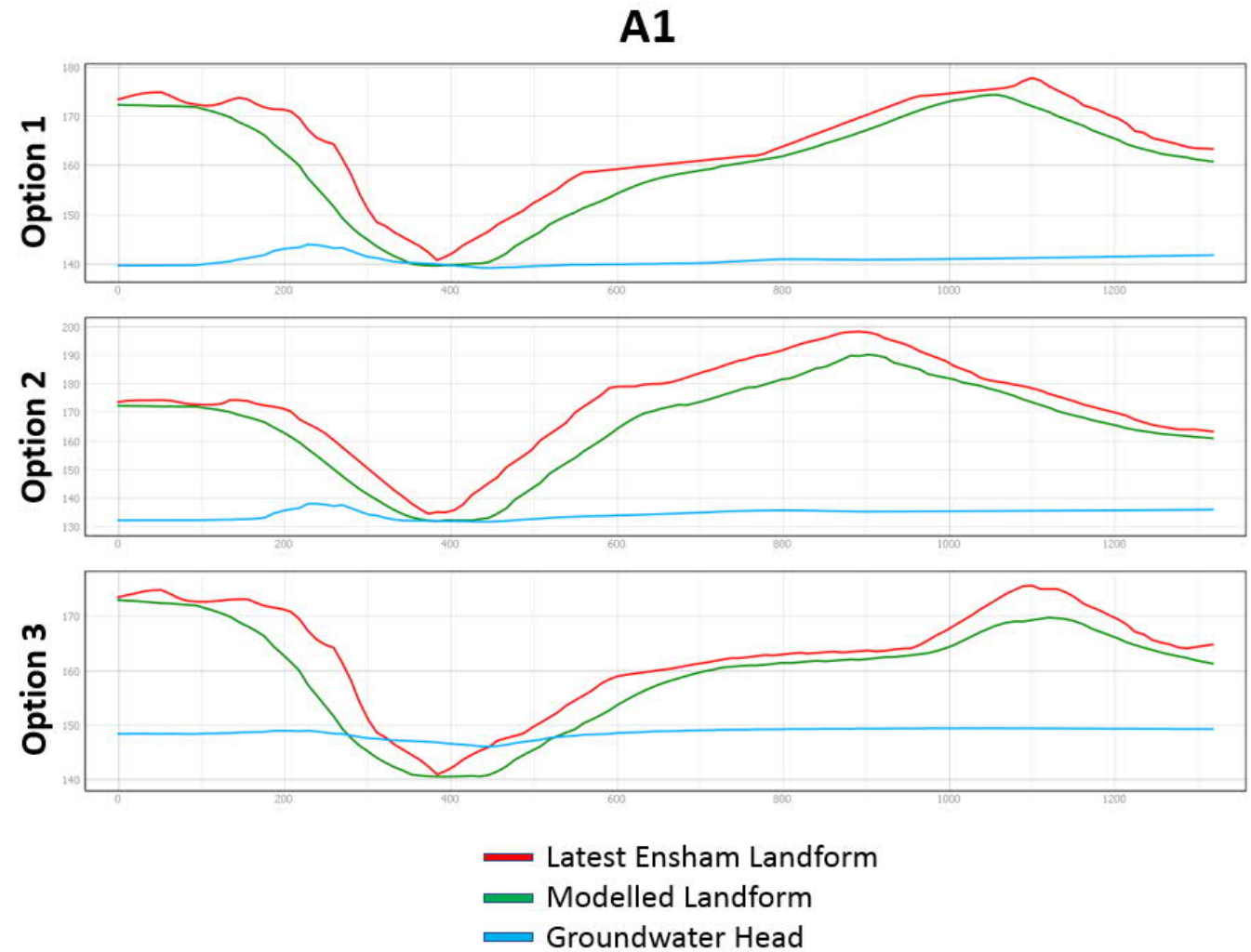
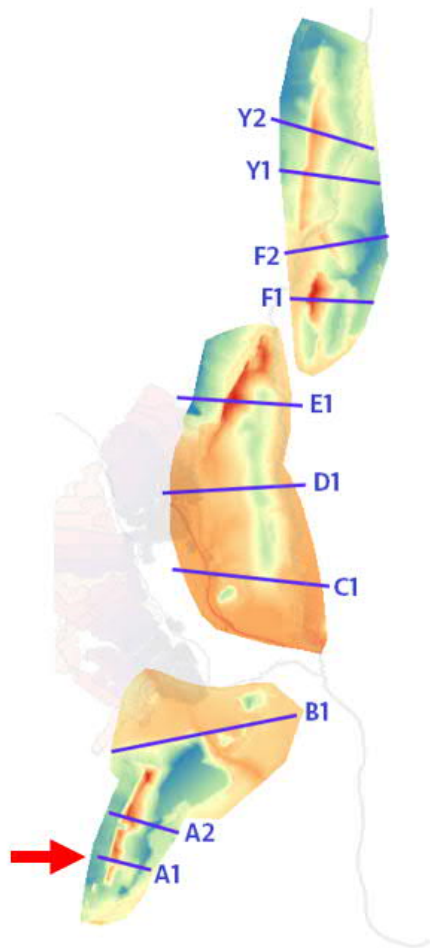


Figure H-1: Pit A South Section A1 Final Landforms

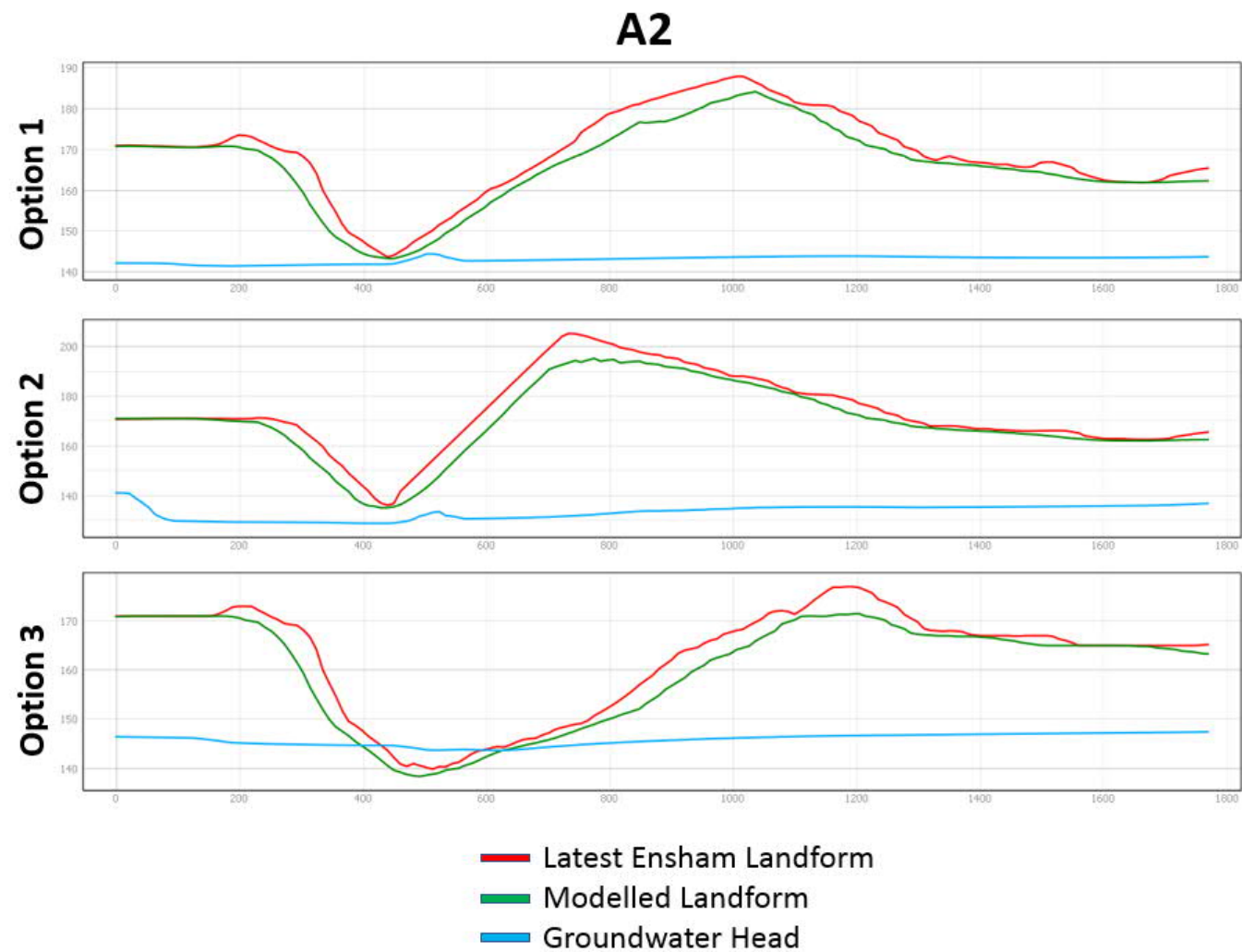
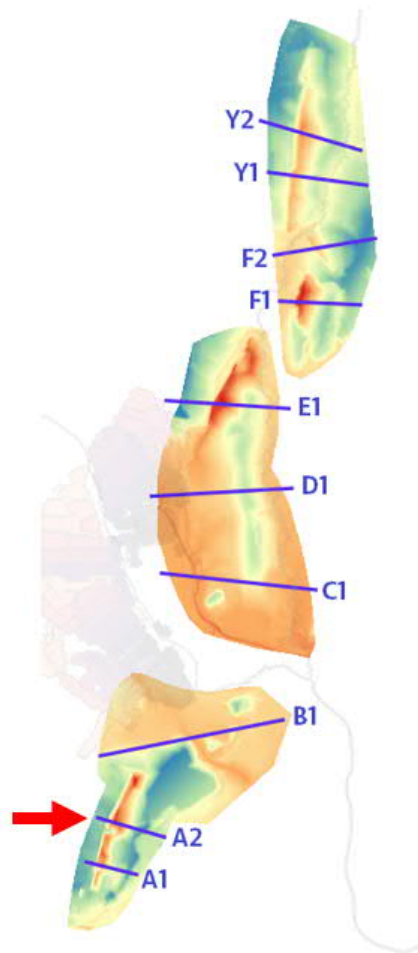


Figure H-2: Pit A North Section A2 Final Landforms

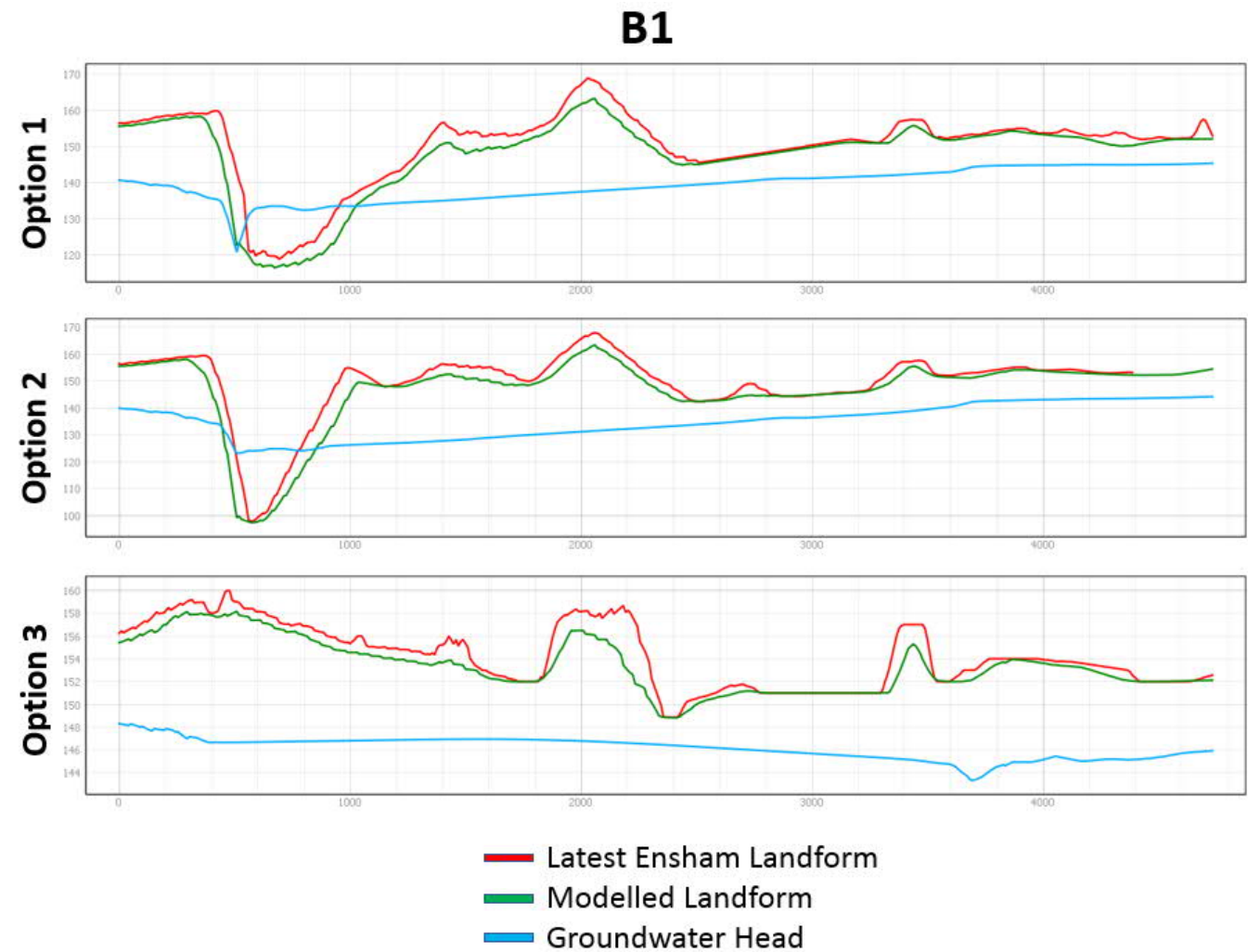
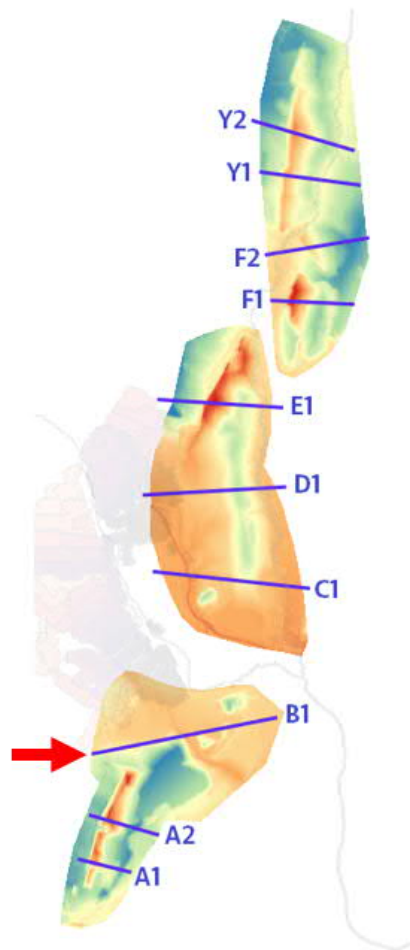


Figure H-3: Pit B Section B1 Final Landforms

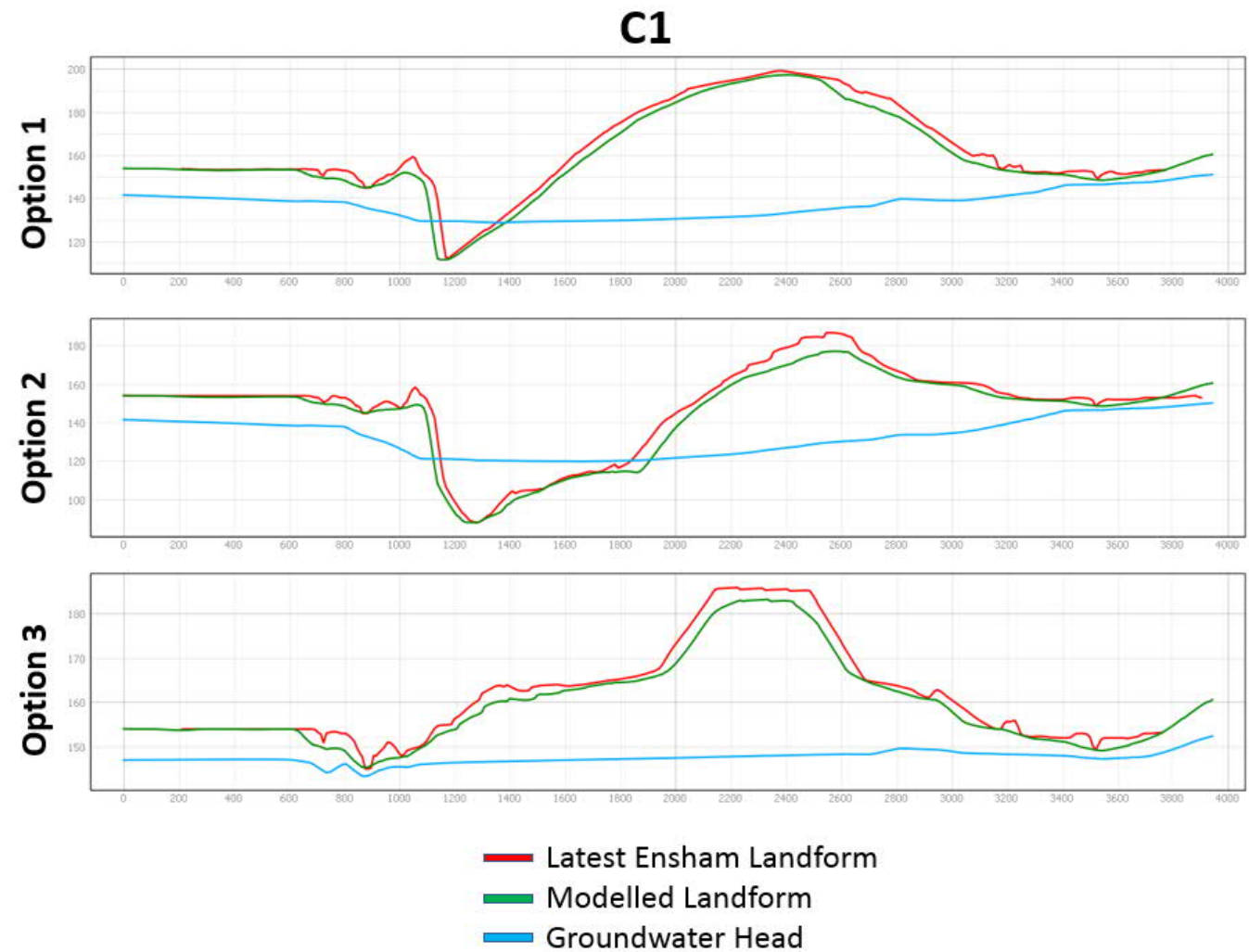
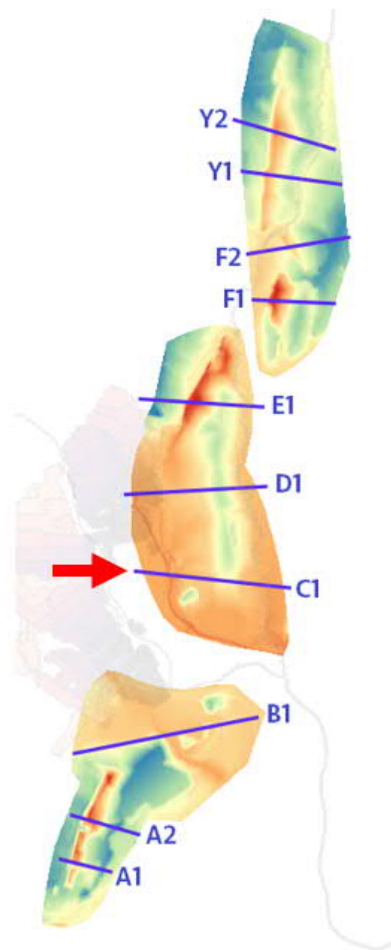


Figure H-4: Pit C Section C1 Final Landforms

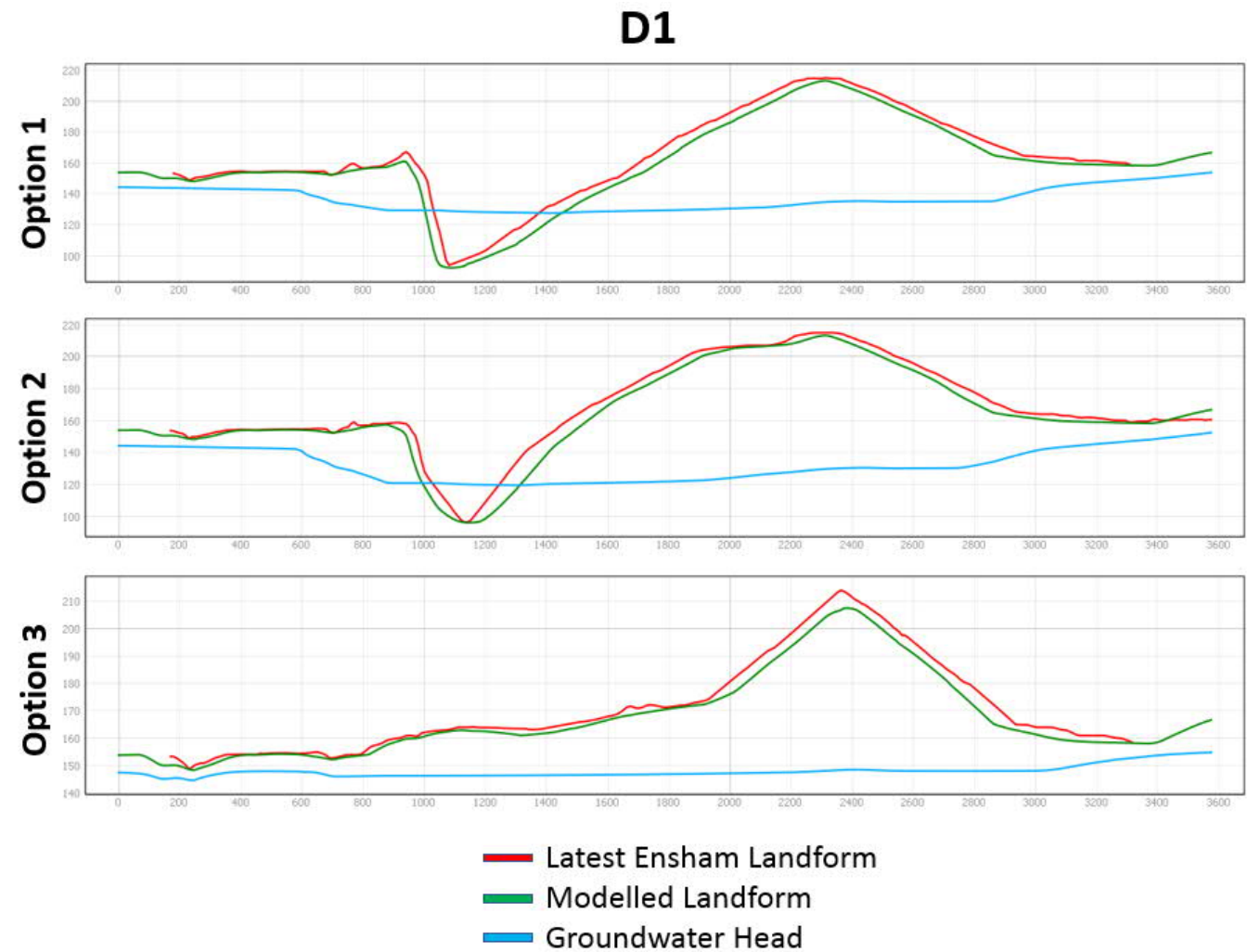
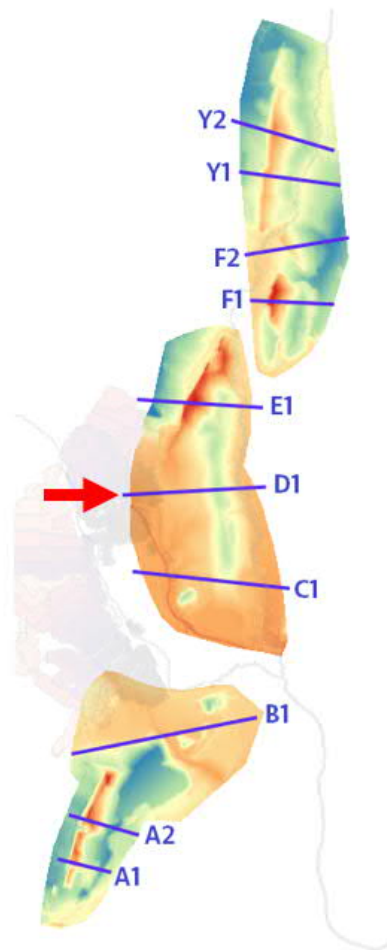


Figure H-5: Pit D Section D1 Final Landforms

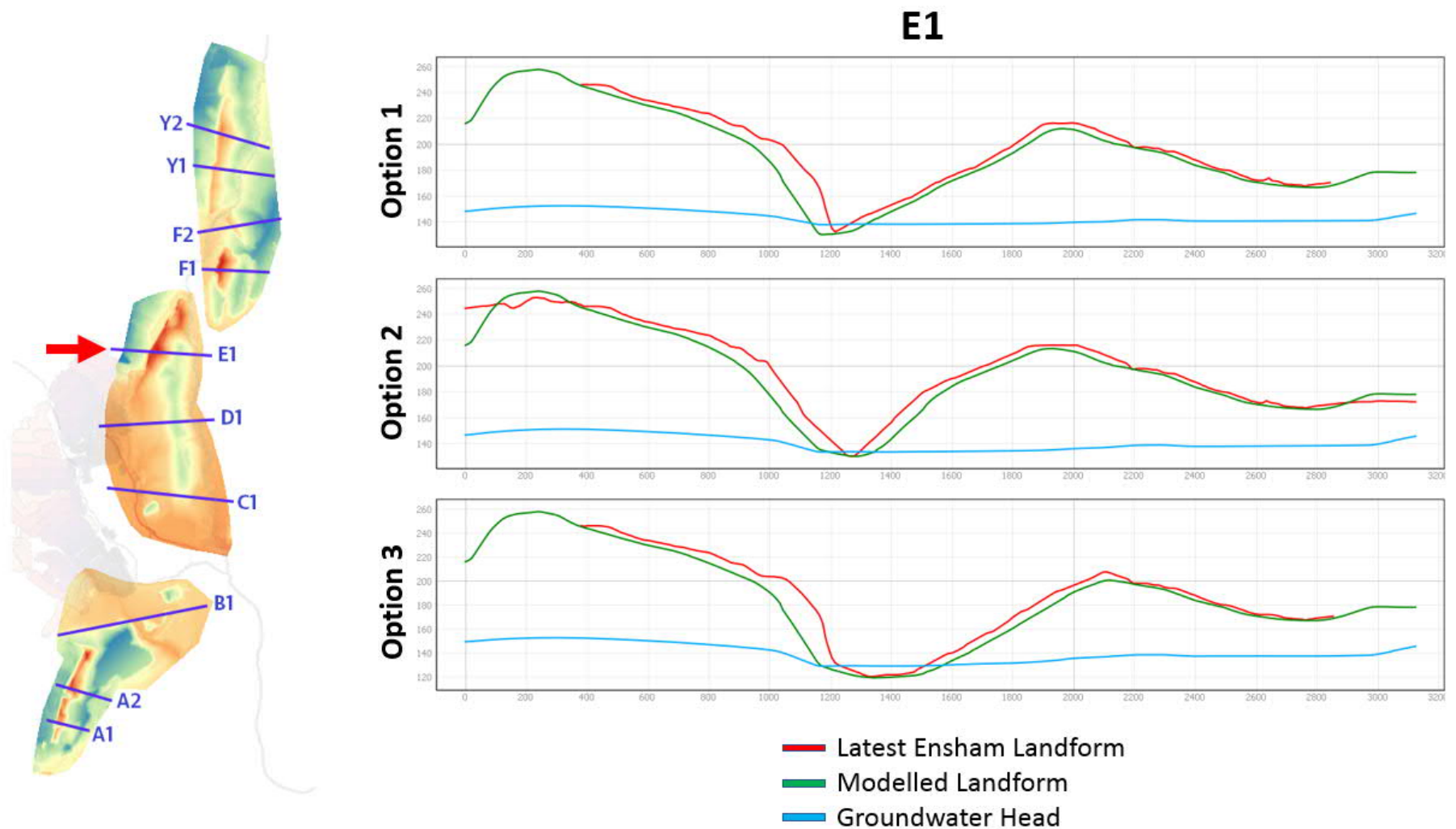


Figure H-6: Pit E Section E1 Final Landforms

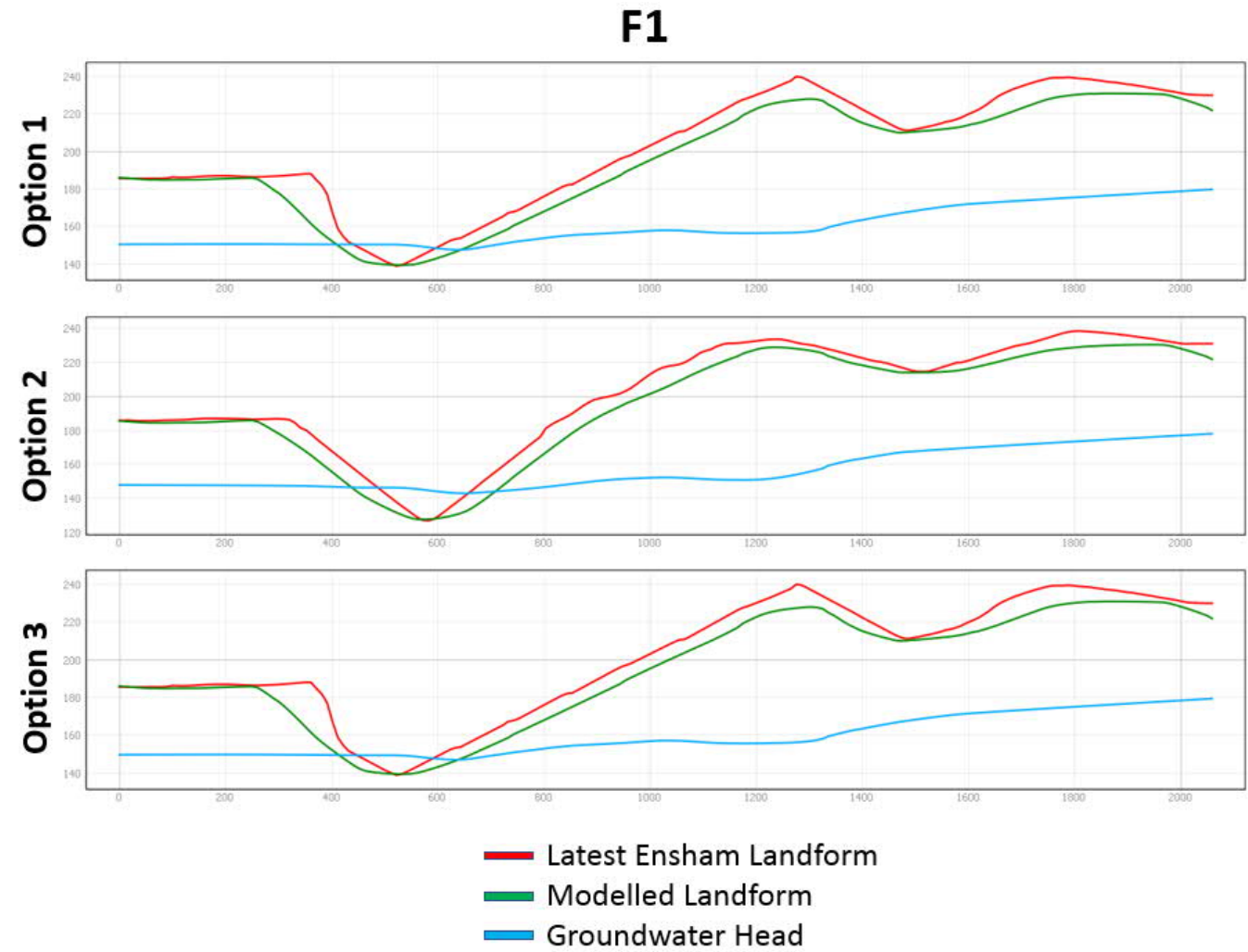
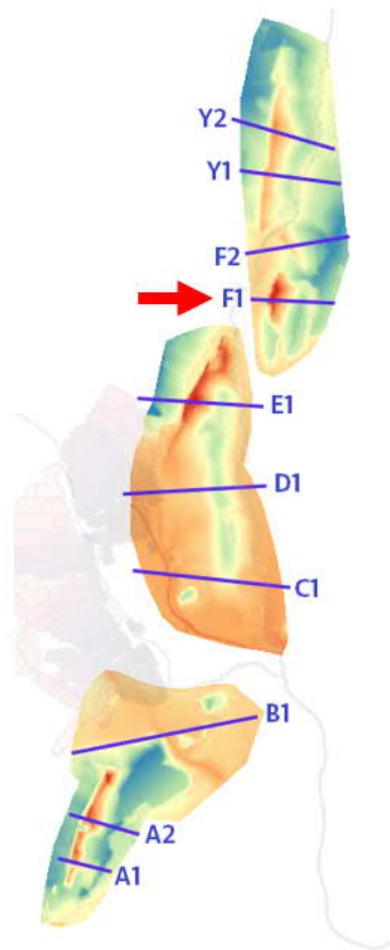


Figure H-7: Pit F Section F1 Final Landforms

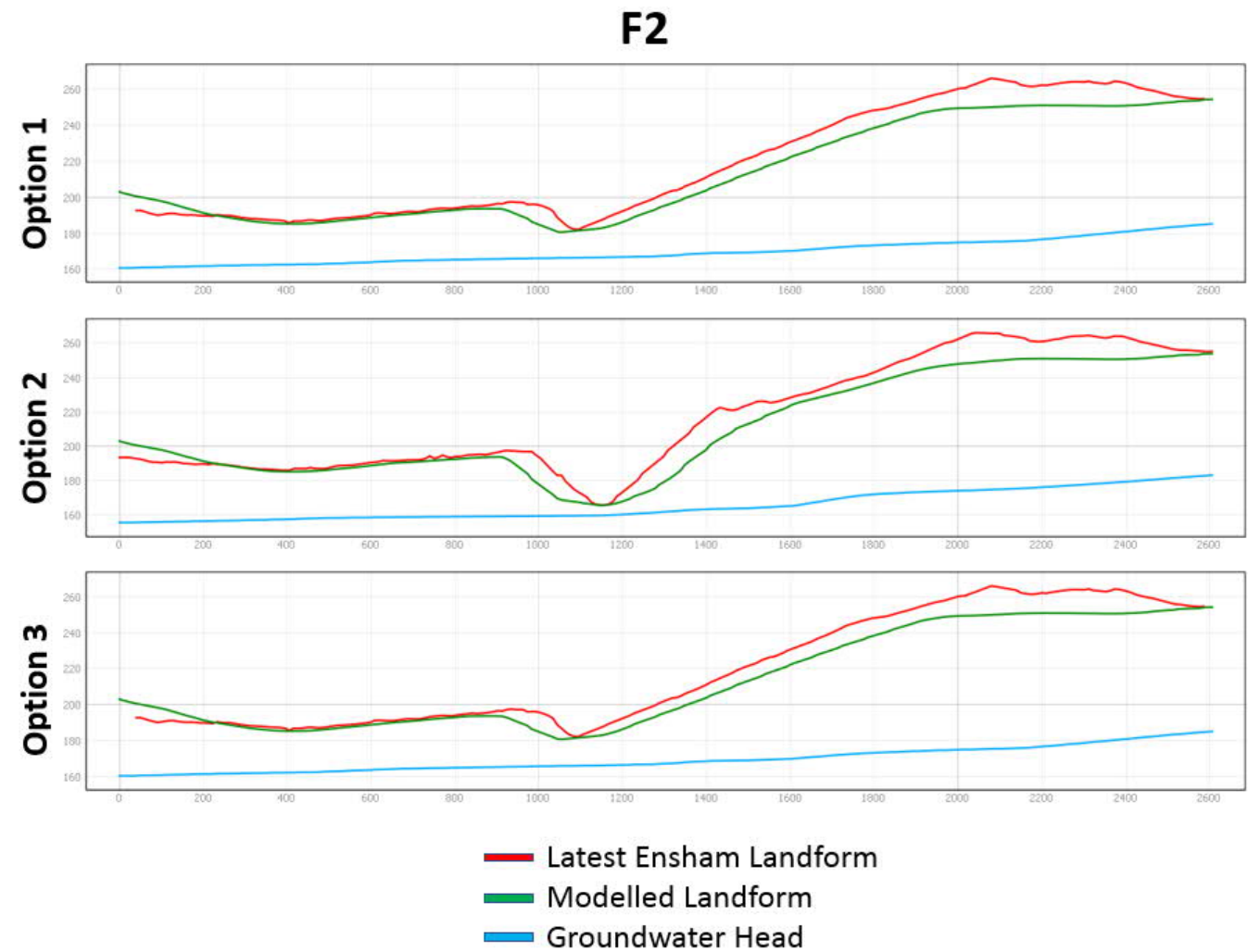
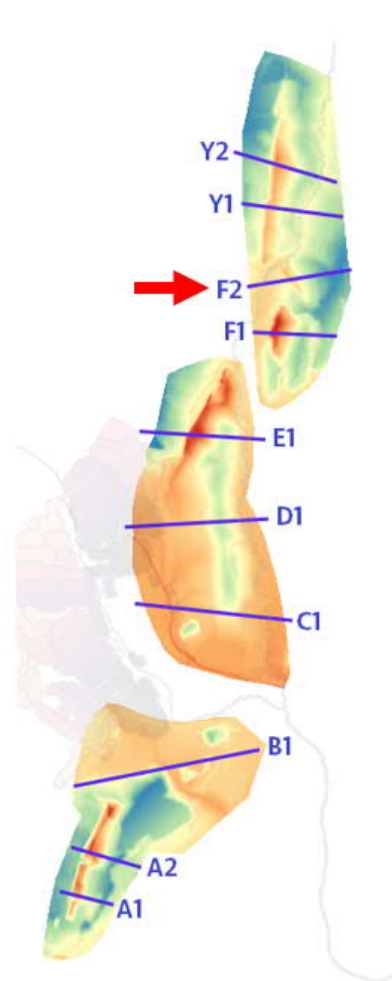


Figure H-8: Pit F Section F2 Final Landforms

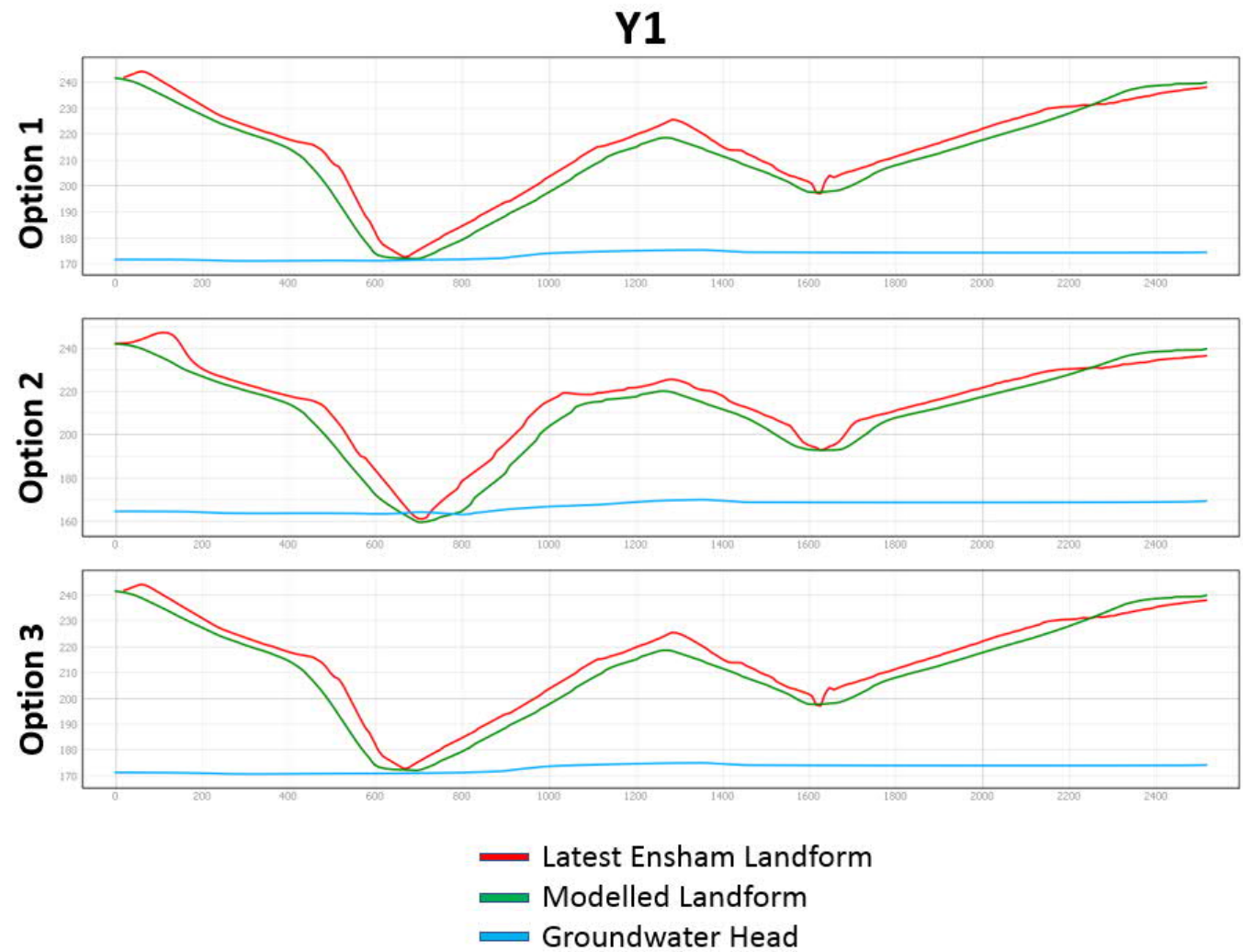
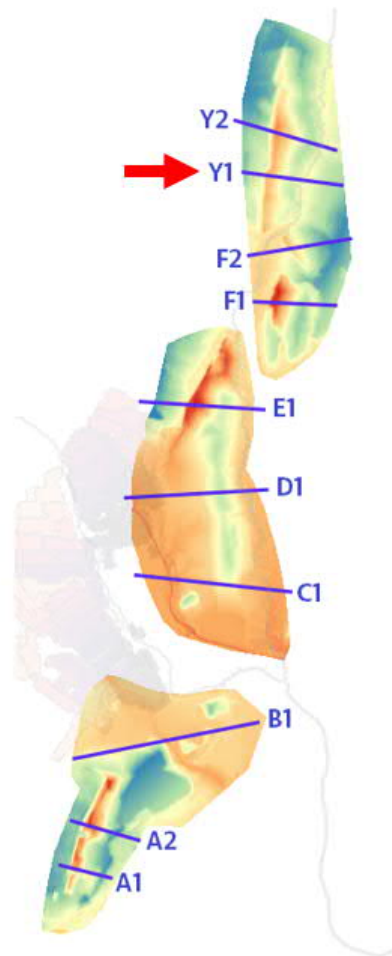


Figure H-9: Pit Y Section Y1 Final Landforms

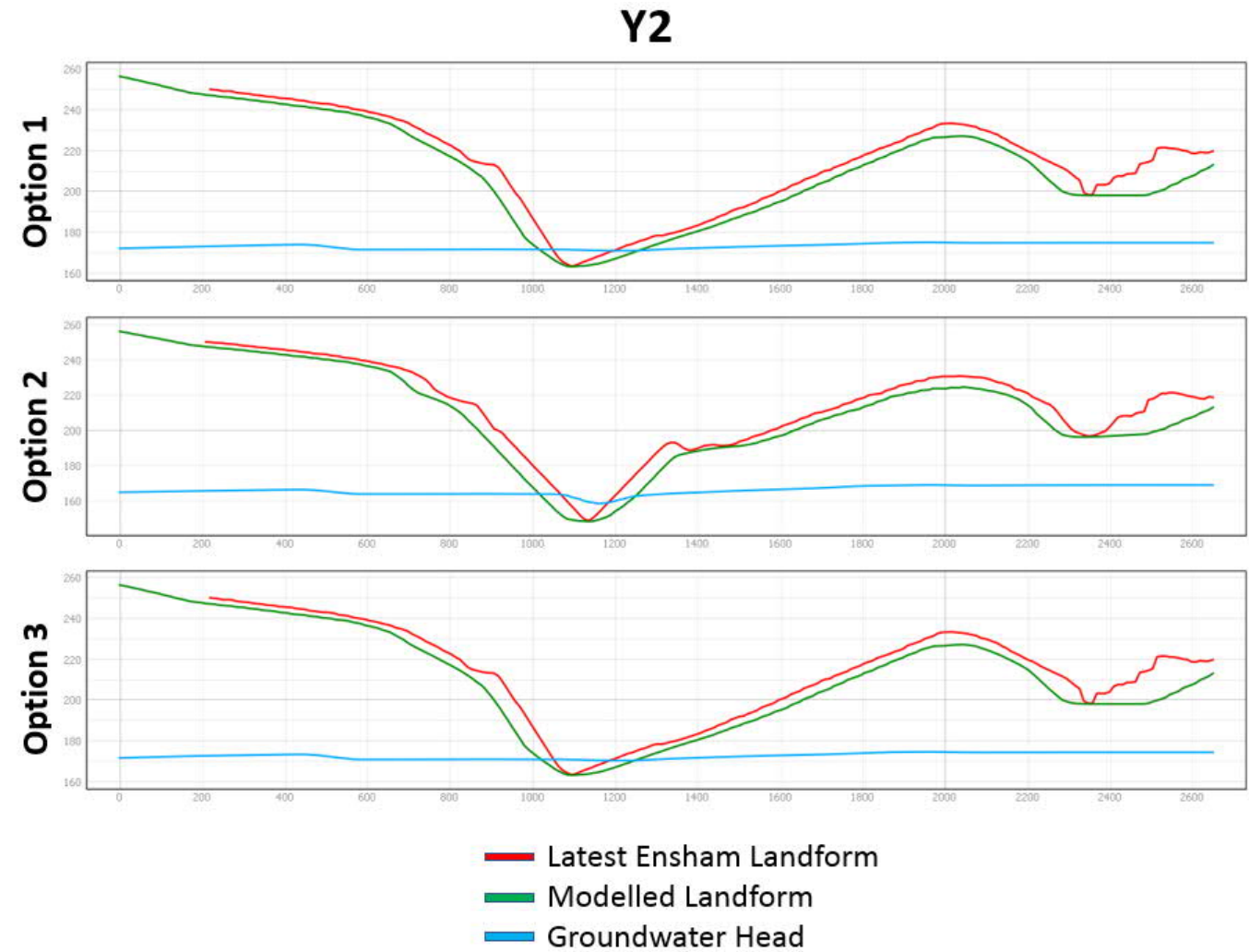
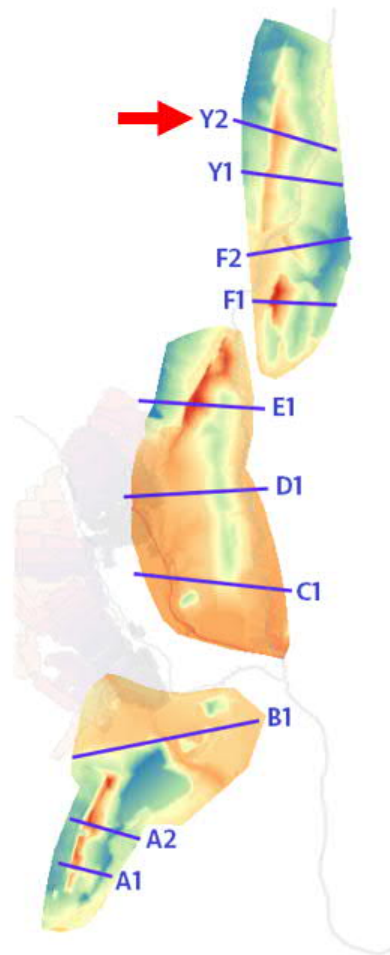


Figure H-10: Pit Y Section Y2 Final Landforms