ERIAS Group

Fountain Head Gold Project – Groundwater Model Update for Supplementary EIS Response 2022

7 July 2022

Table of Contents

Figures

Tables

Appendices

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Section 1 Introduction

1.1 Background

CDM Smith Australia Pty Ltd (CDM Smith) has been engaged by ERIAS Group Pty Ltd (ERIAS) to undertake water-related assessments to support environmental approvals for the proposed Fountain Head Gold Project (FHGP) operated by PNX Metals Limited (PNX). The Project is located approximately 170 km south of Darwin (Figure 1-1) within the Pine Creek region of the Northern Territory.

The FHGP proposes brownfield development of the Fountain Head deposit, where gold mining and exploration dates back to the late-1800's. Mining at Fountain Head was most recently undertaken from 2007 to 2009 by GBS Gold. PNX acquired the tenements in 2018 and following further exploration completed a mining scoping study in 2019. Recent exploration drilling intersected notable gold mineralisation in the vicinity of the existing open (but flooded) pit, prompting a renewed focus on the Fountain Head site. PNX proposes to use open pit mining methods and a carbon in pulp plant (CIP) at the Project site including the following activities:

- Dewatering of the existing pit and expansion of the existing open pit.
- Expansion of the waste rock storage (WRS) as an integrated waste landform (IWL).
- Construction of processing related areas, crushing facility and gold processing plant.
- Construction of supporting infrastructure and expansion of the existing Evaporation Dam to an Evaporation Pond (EP) for water storage.

1.2 Project Status

On 6 January 2022, PNX were issued a direction (the Direction) to provide additional information for the draft environmental impact statement (EIS) (clause 14(2)(a) of the Environmental Assessment Administrative Procedures 1984). The direction follows the preparation and submission of a supplementary EIS (SEIS) in November 2021 from which further comments relating to the FHGP were raised. Of relevance to surface and / or groundwater, the following summarises the key concerns and comments made by the Northern Territory Environmental Protection Agency (NT EPA) in the Direction:

- Water quality
  - Elevated contaminant concentrations within the Evaporation Pond (EP) and pit during and post mining.
  - Potential impacts to the downstream environment as a result of storing potentially acid forming (PAF) material within the Fountain Head pit.
  - Passive or uncontrolled discharge of contaminants and impacts from the sources of contamination (EP and Fountain Head Pit).
  - Lack of broader predictions of contaminants relating to water quality evolution post mining.
- Groundwater model (MODFLOW model)
  - Model calibration requires improvement by means of lowering the scaled root mean square (SRMS) error and addition of further groundwater level data.
  - Model parameterisation does not align with literature and NT EPAs observations within the Project area / broader region. Furthermore, the model lacks field derived aquifer properties to inform the parameterisation.
  - Reduction in model uncertainty is suggested by means of expanding the current monitoring (groundwater and surface water) network.

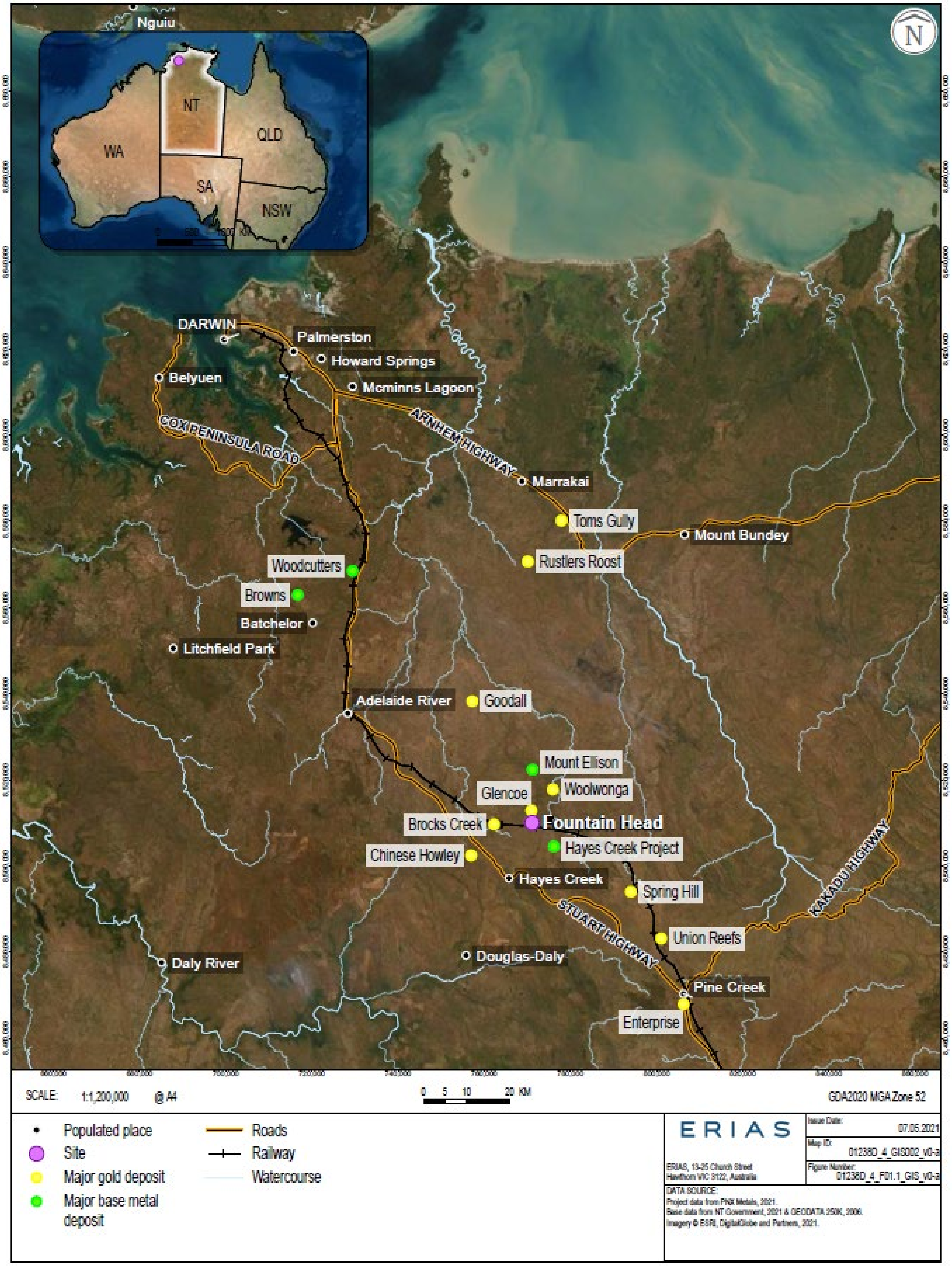

Figure 1-1 Project location map (source: ERIAS Group, 2021)

- Groundwater dependent ecosystems (GDEs)
  - The distribution and current condition of GDEs within the Project area is not adequately understood.
  - Conceptual understanding of GDEs and their interaction with alluvial and fractured rock aquifers should be improved.
  - Impacts of mining (drawdown and groundwater quality) on GDEs should be better understood to demonstrate an unacceptable impact will not occur on these receptors.
  - The GDE risk assessment should be revised.

1.3 Objectives

The overarching objective of this report is to address the comments made by the NT EPA in the Direction relating to the FHGP groundwater (MODFLOW) model. Specifically, the work completed will seek to:

- Improve the model calibration (using existing data) to be better constrained (i.e. by additional water level measurements and reduction in scaled root mean square (SRMS) error).
- Refining the model parameterisation to more closely align with observed field data and literature.
- Reducing and describing in greater detail the model uncertainty (using existing data).
- Understand the extent and scale of the groundwater drawdown in response to mine-related water affecting activities with regard to the location of identified environmental values (EVs) reliant to some extent on groundwater.
- Provide predictions of groundwater flow to determine the degree of potential impact on downstream environmental receptors.
- Benchmark the groundwater fluxes predicted by the Goldsim water balance model (WBM) to provide improved confidence of the dewatering requirements.

Section 2 Physical Setting

2.1 Climate

Two distinct seasons are experienced in the Project area - a wet season typically occurring from November to April and a dry season typically occurring from May to October. The wet season is characterised by warm to hot temperatures with high humidity and rainfall. The dry season is characterised by cooler temperatures, lower humidity and little to no rainfall (see Figure 2-1). The majority of rainfall typically occurs between November and March. Average annual rainfall is around 1200 mm (Douglas River).

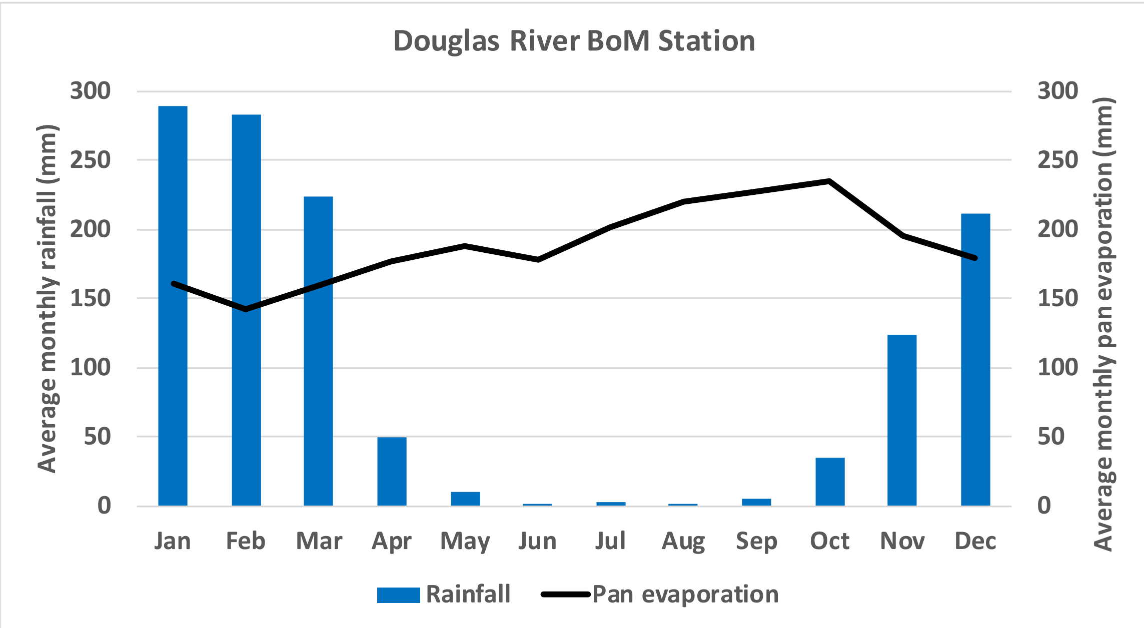

Figure 2-1 Mean monthly rainfall and daily pan evaporation at Douglas River (BOM station 14901)

Potential evapotranspiration (PET) (shown here as the pan evaporation rate) remains high throughout the year, peaking in the build-up to the wet season before humidity increases with net yearly evaporation exceeding net yearly rainfall (Figure 2-1).

2.2 Hydrology

The Margaret River and its tributaries within the Project area are shown in Figure 2-2. Anecdotally and from previous field observations, there have been end-of dry season pools along some watercourse reaches. Their presence in the dry season is likely dependent on the previous wet season's rainfall and runoff, and subsequent evaporation.

The nearest surface water gauge on the Margaret River is at Bobs Hill (G8170240; Figure 2-2) some 50 km downstream of the Fountain Head site. Figure 2-3 shows the measured flow regime at this location with an incomplete data record from 1967 to 1986 after which there are no data. The flow regime is ephemeral and flow duration is typically between three and six months.

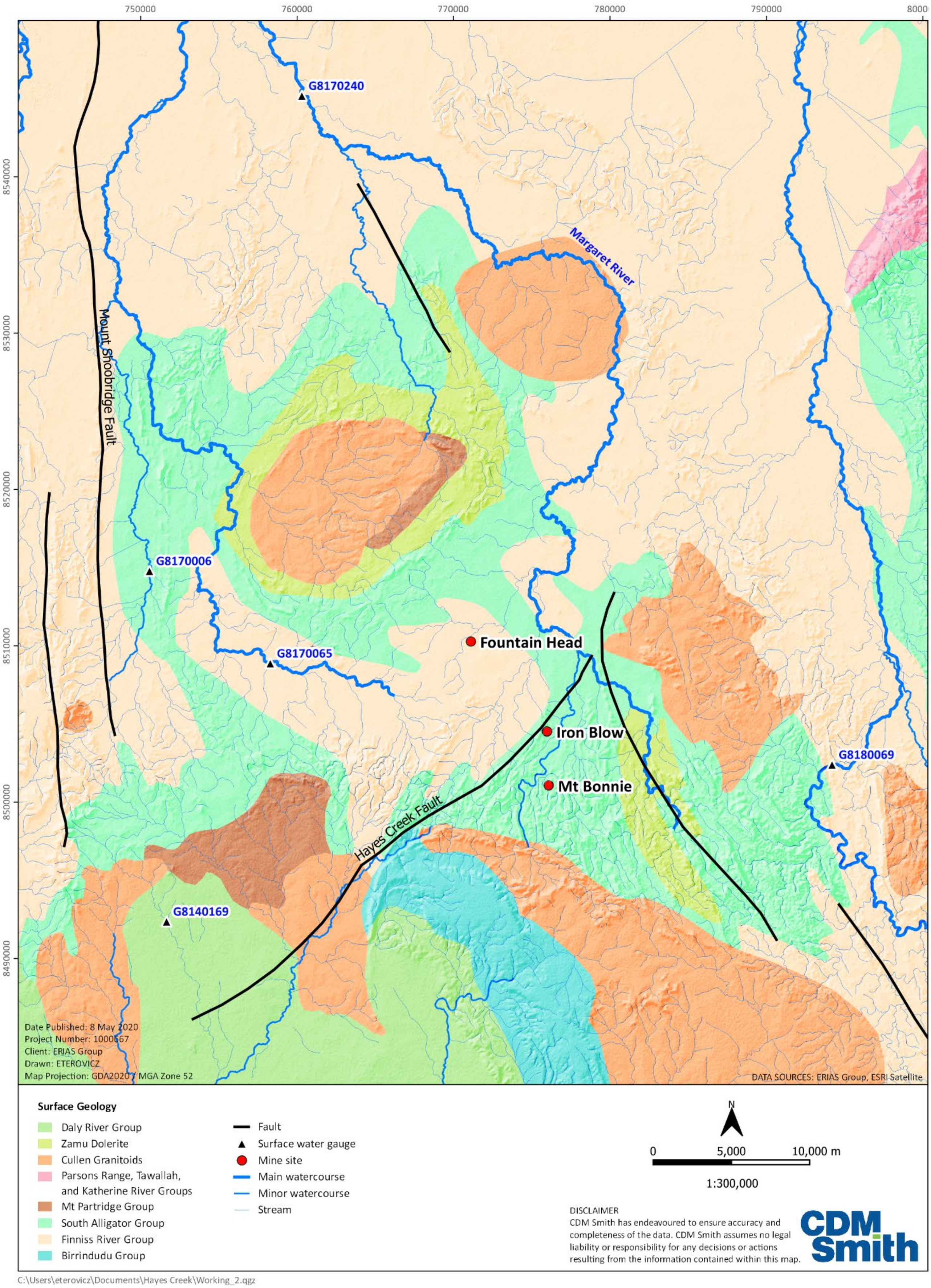

Figure 2-2 Surface water and regional geology in the vicinity of Fountain Head

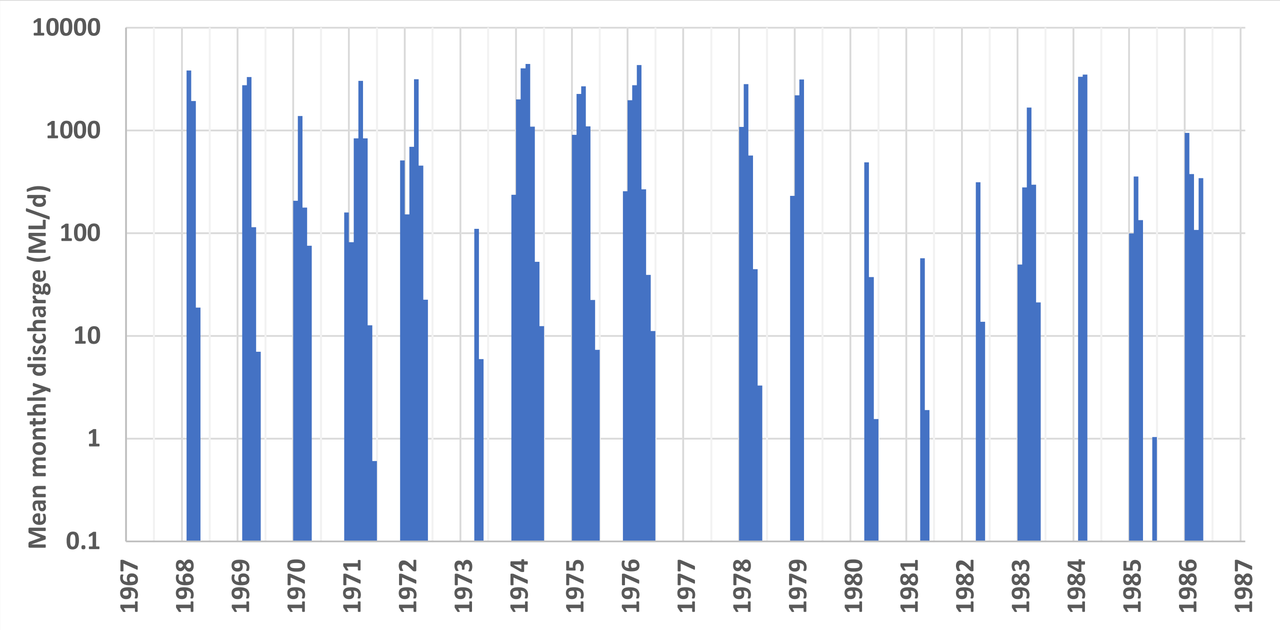

Figure 2-3 Daily discharge per month from Margaret River at Bobs Hill (G8170240)

2.3 Hydrogeology

2.3.1 Hydrostratigraphy

The Project is located within the Pine Creek Geosyncline geological province, within which McGowan (1989) has identified four Proterozoic hydrostratigraphic units (HSUs) within the South Alligator Group and Finniss River Group in the Project area:

- Alluvial sediments – alluvial aquifer where saturated
  - Variably weathered mudstone with poorly sorted sandstone, gravel and cobbles containing pyritic veining; comprised of remnant fragments of the Mt Bonnie Formation.
  - Forms the alluvial cover of the Margaret River floodplain and tributaries.
  - Groundwater flow and storage controlled by primary porosity.
- Burrell Creek Formation – fractured rock aquifer
  - A fine to course-grained feldspathic meta-greywacke consisting of minor slate/phyllite, mudstone, schist and lenses of volcanilithic pebble conglomerate.
- Mt Bonnie Formation – fractured rock aquifer
  - An interbedded carbonaceous unit consisting of pyritic and/or chloritic slate, feldspathic metagreywacke and ferruginous phyllite (metasiltstone) with chert lenses and nodules.
  - Conformably overlies the Gerowie Tuff.
- Gerowie Tuff – fractured rock aquifer
  - A combination of cherty/feldspathic crystal tuff, lithic tuff with minor felsic ignimbrite, volcaniclastic shale and siliceous siltstone.

Figure 2-4 presents the stratigraphic relationships. The sub-regional geology in the vicinity of Fountain Head is bounded by the Hayes Creek Fault to the south, the Pine Creek Shear Zone to the east and the Shoobridge Fault to the west (Figure 2-2). The original geometry of these sedimentary units has undergone significant distortion while surface geology at Fountain Head is dominated by weathering products of the Burrell Creek Formation.

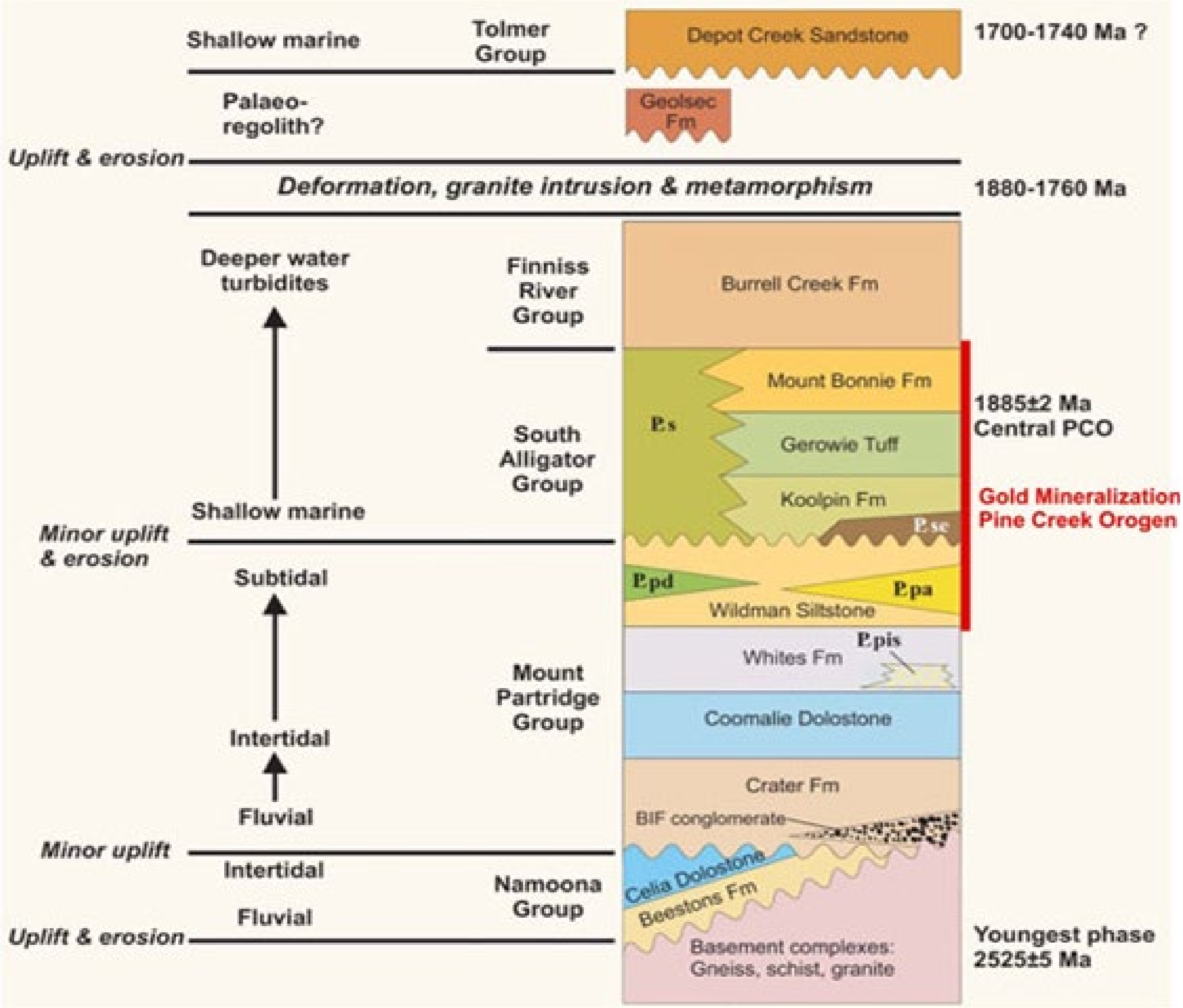

Figure 2-4 Stratigraphy of the Adelaide River – Pine Creek area (Coffey, 2012)

2.3.2 Groundwater Levels and Flow Direction

Groundwater level monitoring and sampling was conducted by CDM Smith from 15 July to 19 July 2019. The results of this field work are summarised in CDM Smith (2020a) and have been used where relevant in this report along with historical information and data (groundwater levels, water quality data, spatial data, site details) provided by ERIAS. Figure 2-5 shows the July 2019 the Fountain Head site. Given the uncertainty associated with screened/open intervals and reference elevations of some bores, combined with a near-flat hydraulic gradient, it is difficult to infer a clear groundwater flow direction from the site data or vertical head gradients within the HSUs. Partly this is due to the uncertainty of the elevation (m AHD) of each monitoring point, and it is also possible the water table surface is quite flat in this area of relatively low relief (i.e. hydraulic gradients may be quite low). However, groundwater levels measured from monitoring bores to the northeast and outside the Project area suggest groundwater flow is likely from the southwest to the northeast.

PNX staff collected refined reference elevations using a Differential Global Positioning System (DGPS) for eight groundwater bores in early 2021, and these have been used where relevant to improve the accuracy of groundwater level data from the bores surveyed. At the time of project delivery, 14 regional monitoring bores have not been

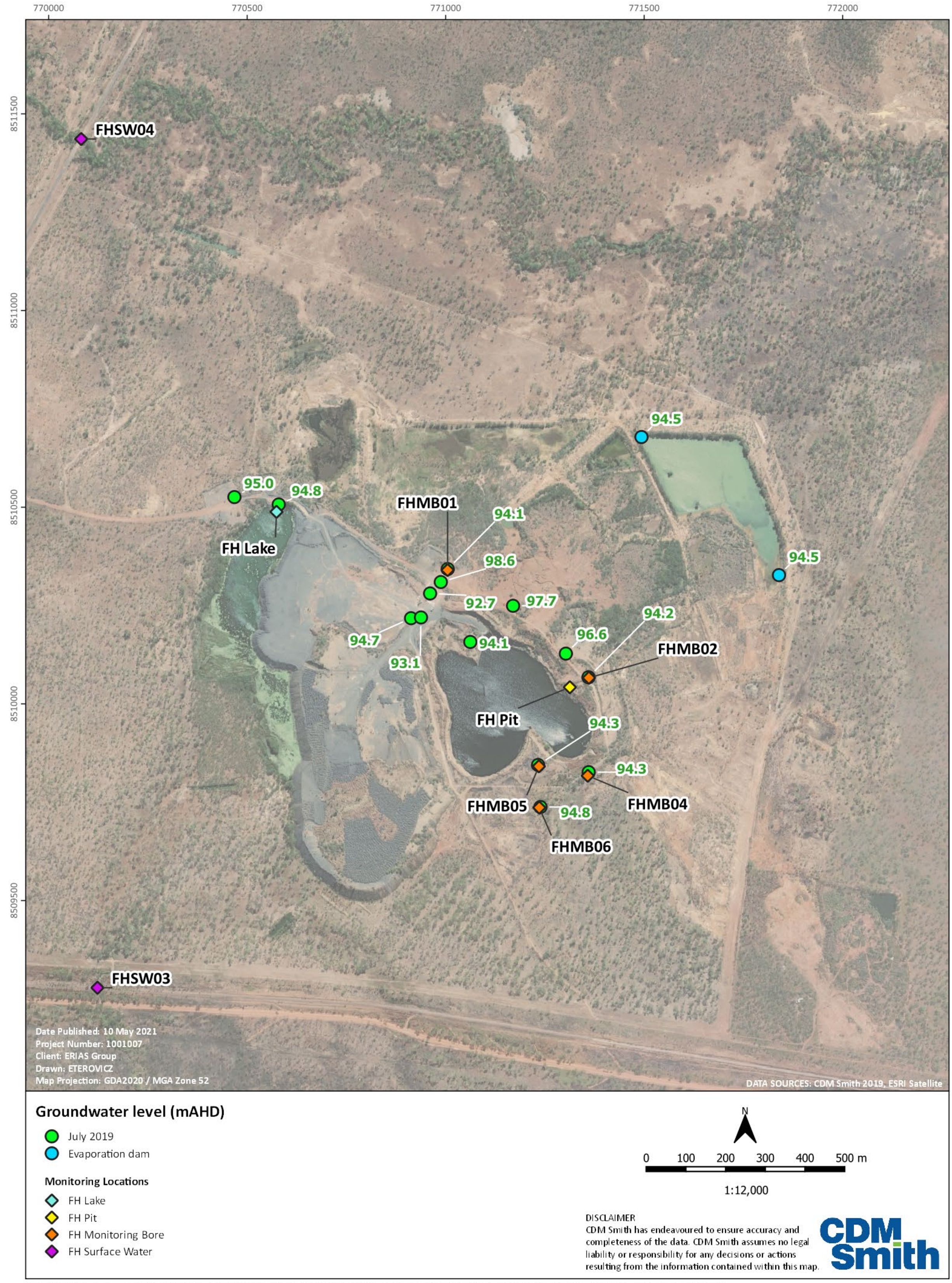

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Figure 2-5 July 2019 groundwater levels (reference elevations estimated from recent DEM and DGPS for some locations) and monitoring sites

surveyed using differential global positioning system (DGPS). Accurate reference elevations from all monitoring bores (which as described in Section 3.2.2 total 22), and additional time-series water level data (groundwater and surface water) would assist in further reducing uncertainty related to groundwater flow direction and potential connection between the shallow groundwater and surface water features (i.e. Fountain Head Lake and the EP), in addition to an expansion of groundwater monitoring at greater distances away from the Pit Lake.

Conceptually, the Fountain Head Pit is likely to be acting as a local groundwater discharge zone with minor throughflow due to the overall deficit between evaporation and rainfall (i.e. pit water levels may decline when evaporation exceeds rainfall, causing groundwater to flow from the aquifer into the pit). Given the Pit Lake is likely to have now fully recovered after previously being dewatered (CDM Smith, 2019), it is possible for there to be a throughflow component from the pit Other on-site surface water features, including the Fountain Head Lake (to the west of the WRS) and the EP have at least some of their extent permanently inundated based on historical satellite imagery (Figure 2-5). This implies they may be fed by groundwater discharge and their bed levels could be intersected by the water table. Regional groundwater flow is assumed, based on topography and water levels outside of the Project area, to be in a north-easterly direction while site data does not resolve a clear flow direction given its proximity to the Pit Lake.

2.3.3 Groundwater System Hydraulic Properties

Hydrogeological investigations by CDM Smith have been undertaken previously at the nearby Mt Bonnie and Iron Blow sites (Figure 2-2) (CDM Smith, 2018), where estimates of hydraulic conductivity derived for the Mt Bonnie Formation range from less than 0.5 m/d up to around 33 m/d (geometric mean of around 4 m/d), and estimates derived for storativity values of around $7x10^{-5}$.

Field work by CDM Smith in early-2021 (CDM Smith, 2021a), completed infiltration testing using Talsma Permeameters within the extent of the proposed EP area. This data supersedes existing data collected by WANT Geotechnics (2020) due to an improved methodology. Collecting water level measurements every 30 seconds until the infiltration rate became constant. Four tests were completed at each of two sites (western and southwestern segments) and intersected variable soils from silty clays with a median vertical hydraulic conductivity of $1.5x10^{-2}$ m/d with three tests indicating values < $1x10^{-3}$ m/d. Three tests in silty sands and clayey silts with minor sand, had a median of 1.2 m/d but are not considered representative of the bulk characteristics of the proposed EP. It is clear from these tests that the vertical hydraulic conductivity of the soils within the proposed EP are highly variable, and larger scale infiltration tests may be needed to make more reliable estimates of potential infiltration rates. More detail on these and other sites can be found in CDM Smith (2021a).

Fountain Head water balance modelling completed by CDM Smith (2019) used an analytical solution to match groundwater inflow rates to the pit as it has recovered over time since last being dewatered. Through calibration to the historical pit water level (recovery) data, a fractured rock aquifer hydraulic conductivity value of 0.2 m/d produced a good fit to the observations, which is similar to the lower end of the range observed for the Mt Bonnie Formation around Mt Bonnie and Iron Blow. This hydraulic conductivity value is considered to be representative of bulk hydraulic conductivity of the aquifer hosting the Fountain Head Pit and is consistent with the calibrated parameters presented in Section 3.3.7.

2.4 Groundwater Dependent Ecosystems

A conceptualisation and review of the FHGP GDEs has been completed in response to the Direction and is presented in Appendix A. The following summarises the key conclusions of this review while Figure 2-6 presents a locality plan of the identified GDEs using the GDE Atlas (BOM, 2022):

- The dominant species associated with the FHGP (i.e. Melaleuca *leucadendra* & M. *viridiflora*) exist across many Australian environments being well adapted and resilient to relatively extreme conditions within riparian settings with respect to the timing of water availability.

- Seasonal rainfall at the potential GDEs is thought to be the primary driver of vegetation condition supplemented by episodic surface water flood events.
- The water table is considered to be deeper than the drainage lines. This is based upon the fact that there is no groundwater discharge into the creek line (unnamed creek) as they are ephemeral and during no-flow periods have no surface water present. During no flow periods, the creek line acts as a recharge zone to the water table.
- Photographs of the potential GDEs demonstrate that the riparian vegetation is a similar size to non-riparian vegetation suggesting a significant additional source of water (i.e. groundwater) is not present to enable the presence of large height and girth riparian vegetation.
- This does not discount the idea that there may be some groundwater use among riparian trees, however, the current eco-physical explanation is that these trees are resilient and adaptive to changes in water sources. The trees dominant water source will be from direct rainfall and bank storage after surface flow events. A minor component may be derived from groundwater; however, this is expected to be a minor component of the trees environmental water requirements.
- The current condition of the potential GDEs are already affected by a number of processes (e.g. bank erosion and grazing from current pastoral land use) that reduce the condition of the vegetation. The condition and resilience of this vegetation can be improved by appropriate land management practices.
- A GDE assessment has been undertaken by Aquatic Ecology Services Pty Ltd to further characterise the potential GDE's in the vicinity of the FHGP. The outcomes of this assessment will be incorporated into the Project Water Management Plan (WMP) and will include update to any mitigation and management measures if required.

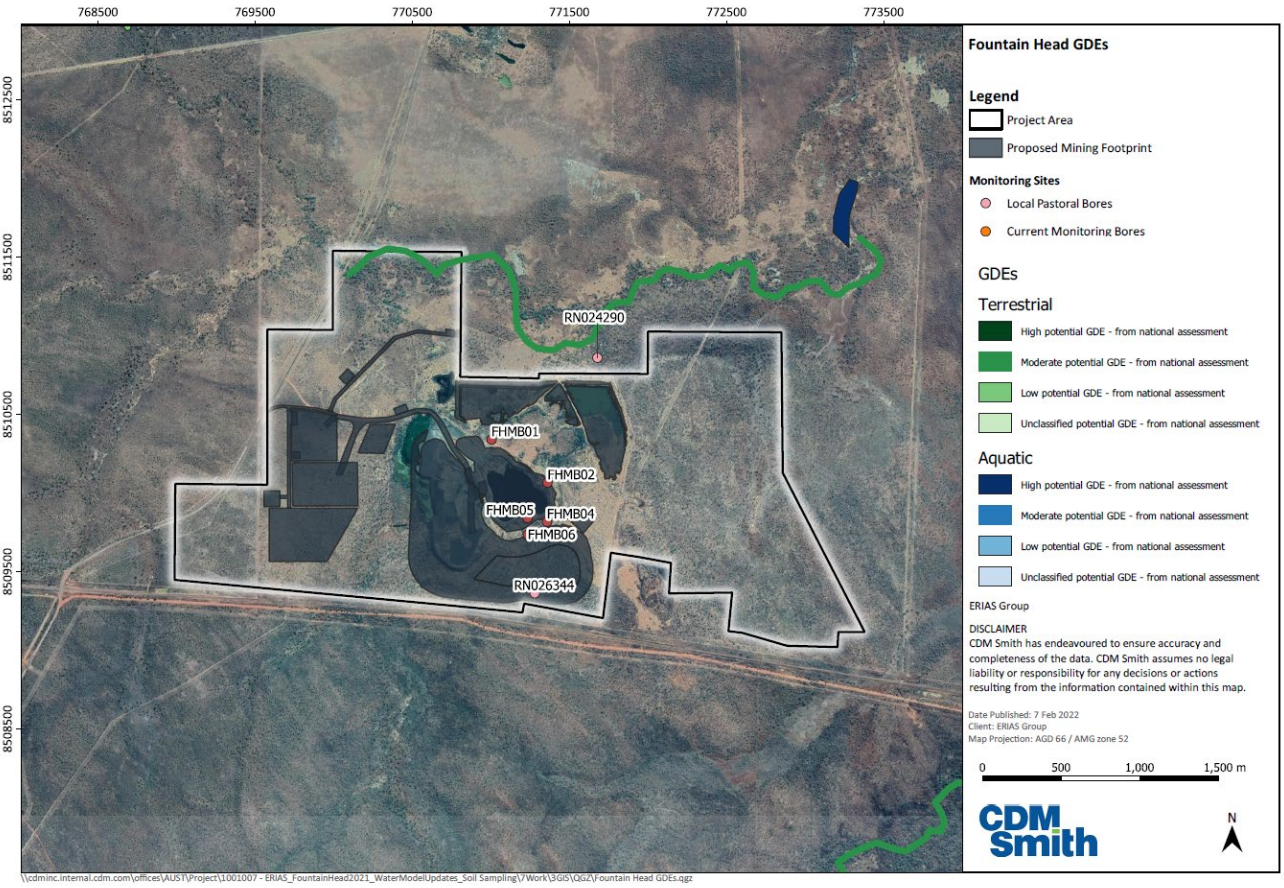


Figure 2-6 Fountain Head GDE locality map

2.5 Hydrogeological Conceptualisation

The water table surface is likely to follow a subdued form of the topography and also be structurally controlled due to the nature of fractured rock aquifers (i.e. flow through networks of connected fractures). Groundwater discharge is expected along ephemeral creek lines as groundwater evapotranspiration from riparian vegetation. An unnamed ephemeral creek is located approximately 1 km north of the Fountain Head Pit and flows approximately 5 km towards the northeast before joining the Margaret River, consistent with the inferred groundwater flow field. These smaller undefined water ways are considered to connect to the groundwater system and may act as episodic recharge zones (losing streams) (Appendix A). As stated, the conceptualisation of these waterways should be updated by identifying the groundwater levels within proximity of the drainages which host terrestrial GDEs to the north of the FHGP. It is understood the FHGP WMP proposes such a scope.

An indicative conceptual cross-section from the top of the surface water catchment (south of the site) through the Fountain Head Pit and to the Margaret River is shown in Figure 2-7.

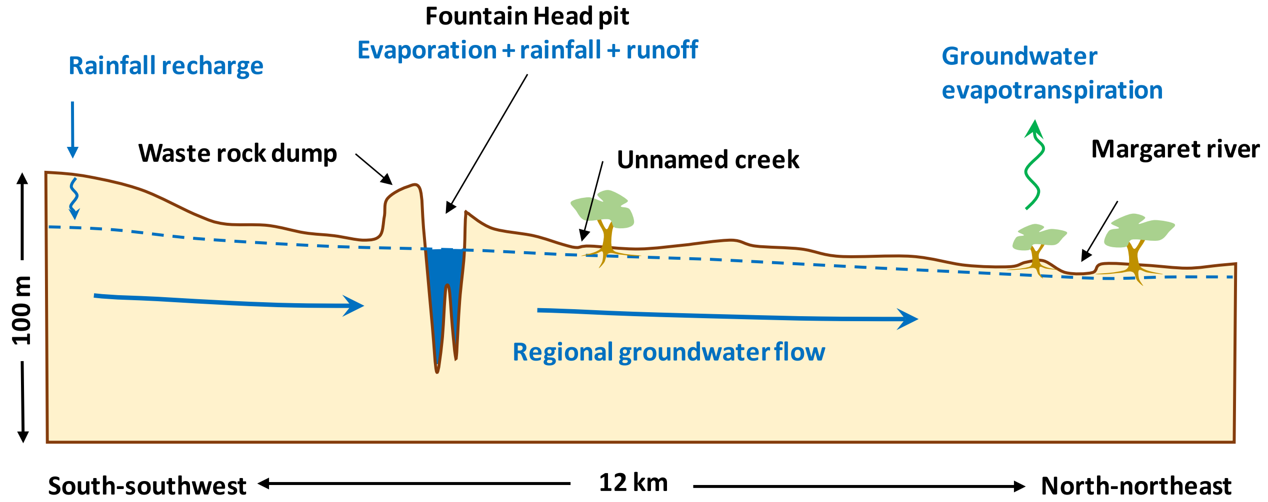


Figure 2-7 Simplified hydrogeological conceptual model

Section 3 Groundwater dynamics

3.1 Overview

In May 2021, a numerical groundwater model was developed using the USGS MODFLOW code (NWT) (herein referred to as the 2021 MODFLOW model) to interface with the GoldSim water balance model (WBM) generated to predict the dewatering requirements, movement of water and solute chemistry related to the FHGP (CDM Smith 2021b). The objective of the 2021 MODFLOW model was to generate water table surfaces that can be used to interpret flow patterns and the extent and scale of the groundwater drawdown in response to mine-related water affecting activities.

Following receipt of review comments relating to the Direction, the 2021 MODFLOW model has been updated to address the requested changes made by the NT EPA in order to improve the existing model and confidence in assessing the results. The following provides a summary of the updates made which are further detailed in the ensuing subsections:

- Incorporation of additional transient water level data (2010 to 2021) from localised monitoring wells and recovering pit water levels surrounding the Fountain Head pit and inclusion in the transient calibration.
- Incorporation of additional regional wells (i.e. wells not previously used) as calibration targets.
- Review and revision of aquifer parameterisation including adjustment of recharge to be consistent with seasonal rainfall cycles.
- Addition of spatial heterogeneity throughout the model domain.
- Stochastic model calibration and prediction.
- Completion of an uncertainty analysis to better describe and understand the confidence level in which the model results can be relied upon.

3.2 Data and Information Review

A review of all publicly available data used to inform the 2021 MODFLOW model has been completed as a preliminary step to further model refinement. The objectives of the review were to search for additional data that could be included in the model refinement (i.e. additional monitoring bores, water levels or literature to inform aquifer parametrisation) as well as screen the quality of the existing data which informed the 2021 MODFLOW model. The review included the following steps:

- Step 1 - An additional search for regional groundwater levels sourced from the Northern Territory Government's publicly available website, NR Maps (DEPWS, 2022).
- Step 2 - Review of existing water level database collected by PNX for the FHGP.
- Step 3 - Review of aquifer parameterisation which informed the 2021 MODFLOW model including further literature search and revisit of previous aquifer test results taken within the region.

Results of the review are detailed in the following subsections.

3.2.1 Step 1 - Regional Groundwater Data (NR Maps)

A search area spanning approximately 196 km^2 (14 km by 14 km), an area slightly larger than and overlaying the 2021 MODFLOW model domain, returned a total of 68 groundwater bores for consideration as calibration targets. The bore logs and metadata from NR Maps were screened for water level data and lithological information which could further inform and/or validate the existing hydrogeological conceptualisation. The review found:

- Lithologies and hydrogeological setting are consistent with what was previously reported by CDM Smith (2021b), i.e. lithology is likely to be Mt Bonnie Formation hosting fractured rock aquifers.
- Majority of the groundwater bores identified within the search area had been excluded from consideration in the 2021 MODFLOW model revision due to data quality issues at the time including:
  - Bores located outside the 2021 MODFLOW model domain.
  - No water level information being ascribed to the bore logs.
  - Suspicious or untrustworthy coordinates (i.e. bores estimated from maps and lacking GPS coordinates or bores with duplicate coordinates).
  - Misalignment of water levels when compared against measurements taken from nearby wells (i.e. water level outliers).
  - Water levels which coincided with periods of mining. Such bores have been removed as they are considered to be affected by mining activities that are unable to be replicated by the model.
- An additional six (6) groundwater bores to those used to inform the 2021 MODFLOW model have been identified as suitable calibration targets for the 2022 model.
- A total of 22 groundwater bores comprising of 10 unregistered bores surrounding the Fountain Head pit (in the form of RC exploration holes) and 12 registered bores are suitable as calibration targets to inform further model refinement. A map of the calibration targets considered in the model refinement is presented in Figure 3-1.

3.2.2 Step 2 - Review of Existing Data

Monitoring of groundwater and surface water levels at the FHGP site has been ongoing since previous operations under GBS Gold ceased in 2009. At the time of the 2021 MODFLOW model construction, numerous data capturing the seasonal variation and subsequent groundwater recovery between 2010 and 2019 existed including:

- Six monitoring bores (FHMB01 – FHMB06) surrounding the Fountain Head pit measured on an *ad hoc* basis ranging from monthly to yearly between 2010 and 2019.
- Recovering pit water levels measured daily by a pressure sensor installed within the Fountain Head pit between 2014 and 2017.

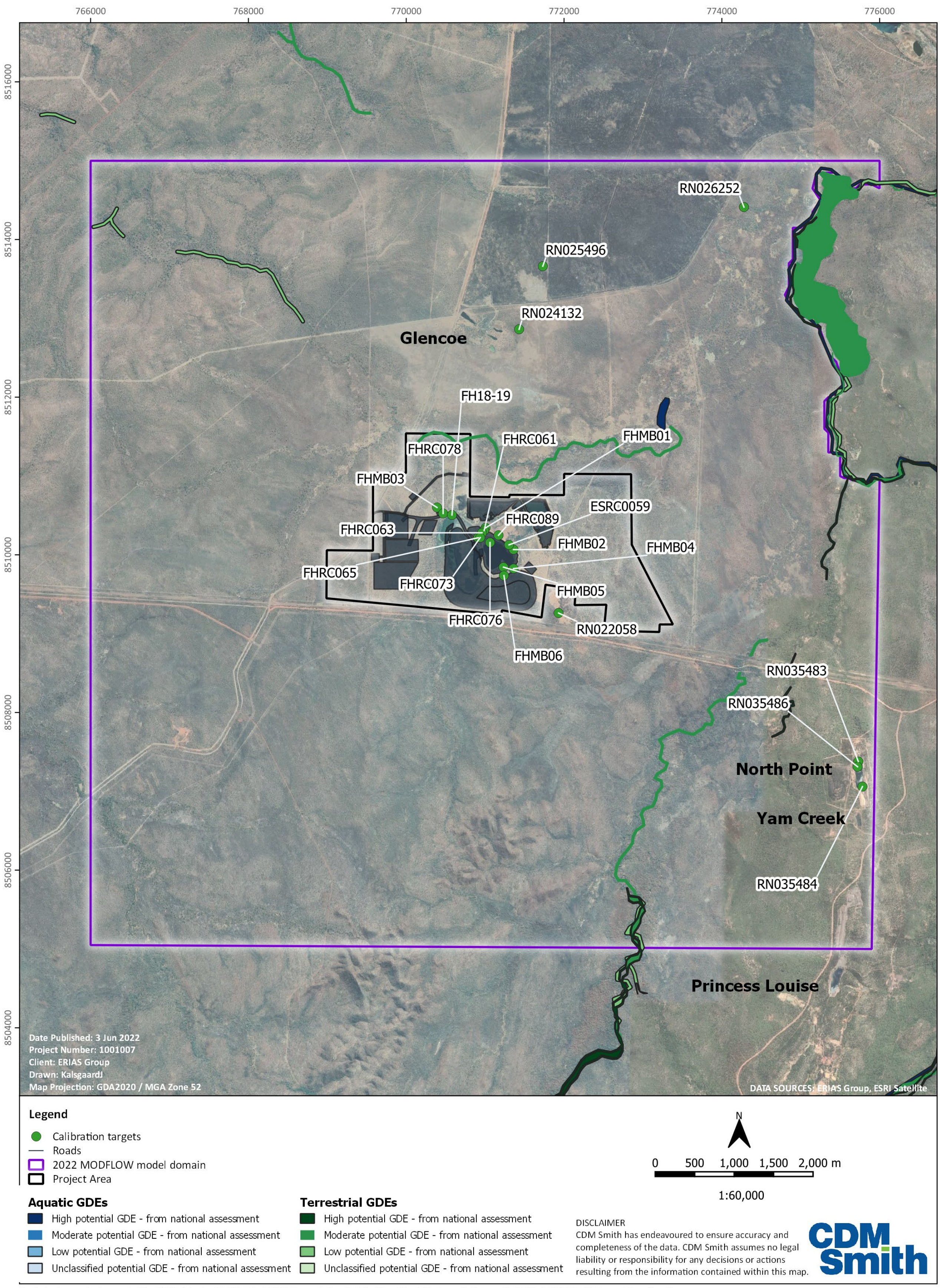
Since the development of the 2021 MODFLOW model, further data have been collected including additional monitoring bore water levels measured in 2021 and further recovering pit water levels estimated from satellite imagery. The total data set at present includes 245 water levels taken from 22 groundwater wells and 1,211 pit water level measurements. A timeseries plot showing the full dataset is presented in Figure 3-2.

3.2.3 Step 3 - Review of Aquifer Parameterisation

The Direction listed a number of deficiencies regarding the 2021 MODFLOW model parameterisation including:

- Hydraulic conductivity and specific yield are thought to be too low considering regional knowledge of the aquifers, with 2021 calibrated properties of 0.053 m/d and 0.0083 respectively in the 2021 model.
- Rainfall recharge thought to be too low, with a 2021 calibrated value of 31 mm/y or 2.6% when assuming an annual rainfall of 1,200 mm/y (BOM station 14901).

A review of literature was completed to consider whether an update to the parameter constraints was warranted for further re-calibration of the MODFLOW model. Hydrogeological investigations by CDM Smith undertaken previously at the nearby Mt Bonnie and Iron Blow sites (Figure 2-2) (CDM Smith, 2018), estimated hydraulic conductivity derived for the Mt Bonnie Formation range from around 0.2 m/d up to around 33 m/d (geometric mean of around 4 m/d), and estimates derived for storativity is around 7×10^{-5}. These results provide further evidence to suggest the region is dominated by highly heterogeneous aquifers, reflective of the anisotropic nature of fractured rock systems.



\\cdminc.internal.cdm.com\offices\AUST\Project\1001007 - ERIAS_FountainHead2021_WaterModelUpdates_Soil Sampling\7Work\3GIS\QGZ\Figure3-1_calibration targets.qgz

Figure 3-1 Fountain Head Gold Project groundwater model calibration targets locality plan

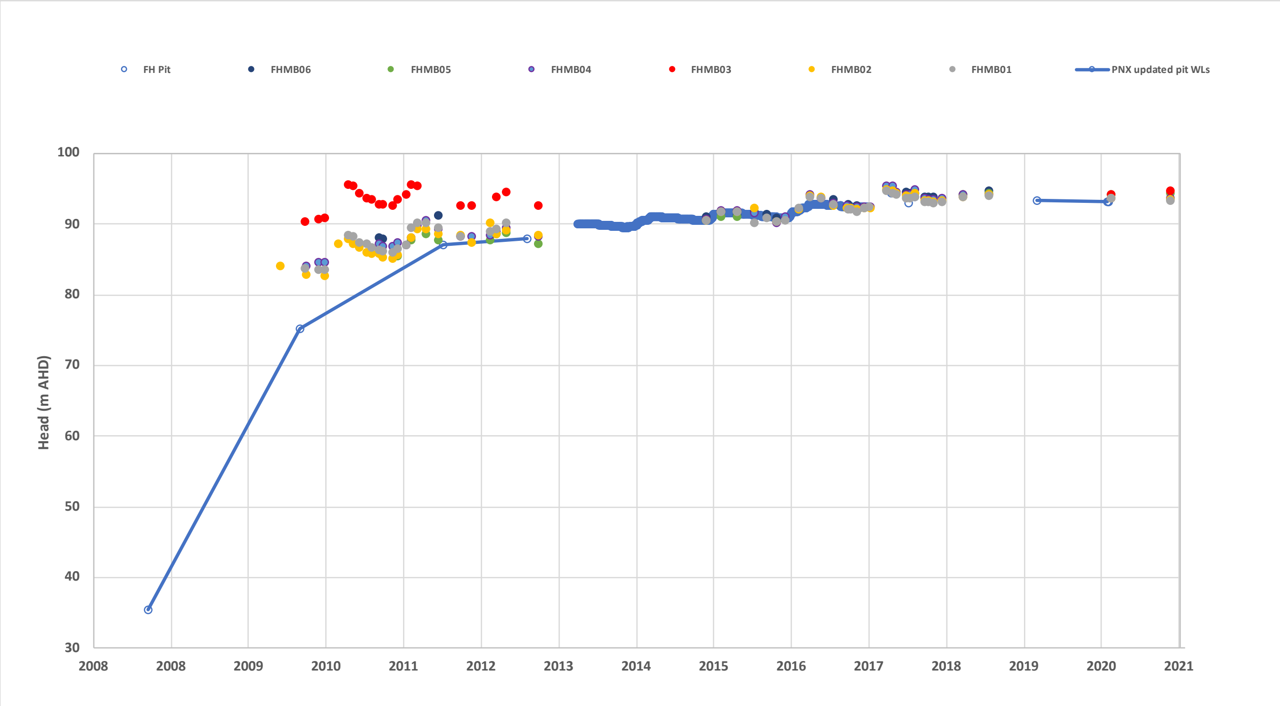


Figure 3-2 Fountain Head water levels

Furthermore, the results are consistent with the Goldsim WBM, which assumes a hydraulic conductivity of 0.2 m/d, suggesting the hydraulic conductivity of the 2021 MODFLOW model may have been underpredicted. Similarly, Duffield (2019) estimates specific yield for unconsolidated sandstone is around 6% whereas a value of 0.09% could be applied to Granite. By this logic, it would be reasonable to assume specific yield for siltstone (the primary constituent of the Mt Bonnie formation and lithology at Fountain Head) is likely within this range, which again, suggests the calibrated value for specific yield in the 2021 MODFLOW model is too low at 0.0083.

Groundwater recharge estimates for the Daly region of the Northern Territory range considerably. Crosbie (2010) states recharge can vary between 11 and 200 mm/y, although further evidence suggests the recharge rate is closer to 90 mm/y. This is generally consistent with the Australian landscape water balance website (BOM, 2022) which estimates recharge within the region to range between around 82 and 120 mm/y. In addition to these studies, a representative rainfall chloride concentration for the FHGP has been estimated, full details of which are provided in Appendix B. The results suggest the recharge rate for the Project area is around 200 mm/y (approximately 16% of annual rainfall) assuming the bulk of recharge occurs during a 1% AEP 72hr storm event and using the geometric mean of the dataset. These results remain consistent with the recharge ranges presented by the reviewed literature of which the 2021 MODFLOW model results (31 mm/y) are on the lower end of this scale.

3.3 Numerical model

3.3.1 Model Objectives

A three-dimensional numerical groundwater model (the model) has been developed to support the environmental approvals by informing the following:

- Groundwater levels at the current condition (i.e. pre-mining), end of mining and 50 years post mining commencement (i.e. new long-term equilibrium).
- Groundwater drawdown induced by dewatering for the proposed mining activities at the end of mining and 50 years post mining commencement.

- The fate of contaminants from the EP, especially on whether the contaminant would be transported through the groundwater system to sensitive receptors including GDEs.

3.3.2 Numerical Code

The model was constructed using the numerical code MODFLOW-NWT (Niswonger et al. 2011). This code is part of the MODFLOW suite, which is the industry standard for groundwater modelling. MODFLOW-NWT was selected due to its ability to overcome the dry cell issue, which is often encountered when simulating the dewatering of mine pits. Groundwater Vistas version 8 and Python were used for the pre- and post-processing of model results.

3.3.3 Model Domain and Grid

The model domain was designed to be of sufficient size to capture the key stresses imposed on the groundwater system and their area of influence without incurring significant boundary effects. Figure 3-3 presents the outer boundary conditions of the model domain, which is approximately 10 km by 10 km and centred on the Fountain Head Pit. The model origin is located at Easting 766000 Northing 8505000 (MGA 1994 Zone 52).

Figure 3-4 shows the structured model grid with a cell size of 25 by 25 m in the vicinity of the Pit Lake and 50 by 50 m elsewhere. The model has 257 rows and 258 columns and four model layers, resulting in a total 265,224 cells. As the Margaret River is conceptualised as a groundwater discharge zone, the part of the model domain to the eastern side of Margaret River has been set to be a no-flow boundary, reducing the number of active cells to 260,264.

3.3.4 Model Layers and Elevations

The model simulates the fractured rock aquifer as a single HSU with four model layers used to provide adequate vertical resolution. Each layer has a thickness of approximately 15 m, except for the top layer that has a thickness of approximately 140 m to accommodate the time-varying pit water level that can drop down to approximately -27 m AHD.

The model surface (Figure 3-3), representing the ground surface, has been sourced from high resolution survey data (provided by PNX), and a 25 by 25 m digital elevation model (ELVIS data) outside the high-resolution survey area. The model base is set at -80 m AHD, which is approximately 50 m below the pit bottom at the final mining stage.

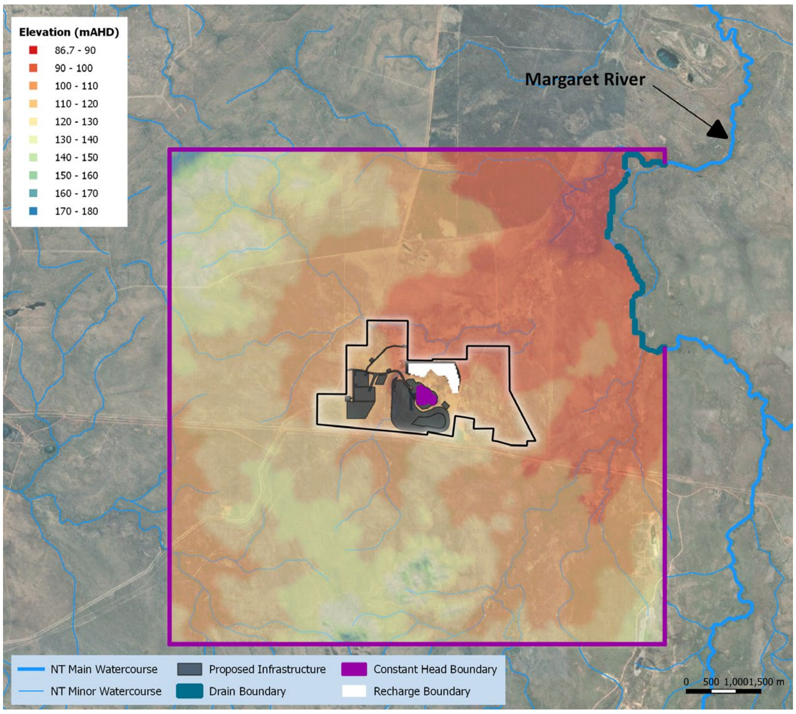
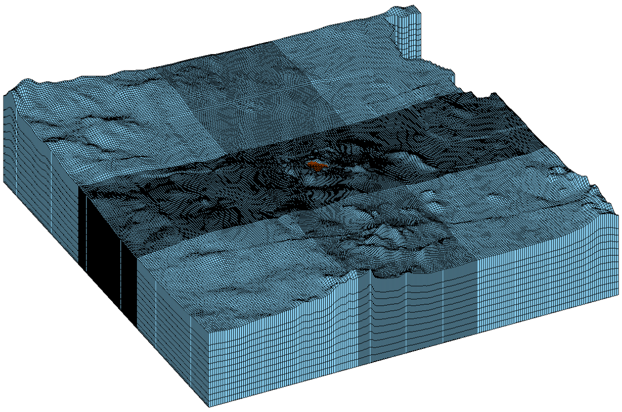


Figure 3-3 Groundwater model domain with surface elevation

(a)



(b)

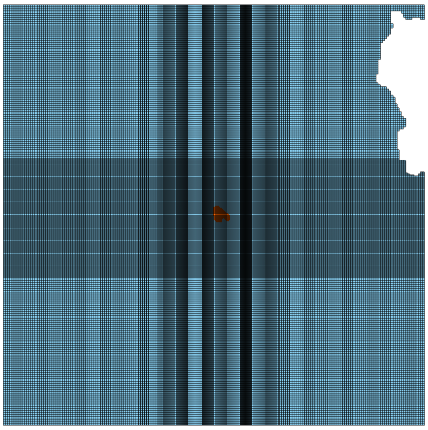


Figure 3-4 3D model view (a) and spatial discretization (b)

3.3.5 Boundary Conditions

Boundary conditions are used to represent the key physical processes of a given groundwater system that are relevant for the model objectives. The key physical processes for this work include (i) regional groundwater inflows and outflows, (ii) groundwater discharge through surface water features, (iii) groundwater recharge from rainfall and EP, (iv) evapotranspiration (ET) discharge of shallow groundwater and (iv) groundwater discharge to the pit. These processes are discussed in the following sub-sections.

3.3.5.1 Regional Groundwater Flows

Regional groundwater inflows and outflows across the model domain edges are simulated using constant head boundaries (Figure 3-3). The head values have been derived from the correlation between topography and measured groundwater elevations. The same constant head cells have been applied to all the model layers.

3.3.5.2 Surface Water-Groundwater Interactions

The Margaret River located in the north-eastern part of the model domain is the only considerable surface water feature that is simulated in the model (Figure 3-3). This river is ephemeral in nature and conceptualised to be a groundwater discharge feature either through groundwater Evapotranspiration (ET) or as baseflow during episodic high flow events. The Margaret River is represented in the model using drain cells with the stage specified as the surface elevation and a conductance value of 10 m^2/d. Other surface water features (including Fountain Head Lake) are not explicitly represented in the model , although the evapotranspiration feature results in discharge from some low-lying parts of the landscape, such as the riparian zones around creeks and rivers. Smaller undefined water ways are considered to connect to the groundwater system and may act as episodic recharge zones (losing streams) (Appendix A).

3.3.5.3 Groundwater Recharge

Rainfall can percolate through the soil and eventually reach the water table as groundwater recharge. Rainfall records (with an annual mean of approximately 1,200 mm/y) from the Douglas River Research Farm weather station (14901) have been imported into the model as recharge multipliers that are applied to the whole model (excluding the EP area) separately for each stress period to ensure the temporal trend in rainfall is properly represented. The average of the last 5 years (2018 – 2022) has been used to represent future predictions. This is to ensure the climate of future period is similar to that of recent period, without biasing towards low-rainfall years (e.g. 812 mm in 2019) or high rainfall years (e.g. 1439 mm in 2018). This setup is also justified based on the observation that there is little seasonal variation in groundwater levels.

The recharge-to-rainfall ratio, which represents the portion of rainfall that becomes recharge, was estimated through model calibration. This ratio is assumed to represent the intrinsic infiltration properties of the surficial sediments that do not change over time.

To assess the impact of climate change on the model prediction, different future recharge realisations were derived from the 2018-2022 average rainfall using different recharge-to-rainfall ratios from the 100 calibrated model realisations (Section 3.3.7). This provides insights into how variations in future recharge influence the model prediction. More information regarding the model's application to variable climate is provided in Section 3.3.7.3.

During mine dewatering, the pit water is discharged to the EP, enhancing infiltration and hence groundwater recharge. Groundwater recharge rates under the EP were estimated using the GoldSim WBM and used as an input to the updated MODFLOW model. The recharge multipliers described above have not been applied to the EP area.

3.3.5.4 Groundwater Evapotranspiration

Shallow groundwater can be lost to the atmosphere through a combination of soil evaporation and vegetation transpiration, which is known as groundwater ET. The model requires two inputs for groundwater ET, including potential ET rate and extinction depth.

Potential ET rate is the rate of ET that would occur if the water table was at the land surface. Weather data from the Douglas River Research Farm station (14901) has been used to inform this input to the model. Pan evaporation is considered too high to be used as it assumes unlimited water availability. Instead, FAO56 (with an annual mean of approximately 1800 mm/y) which estimates ET using a combination of temperature, relative humidity, wind speed and solar radiation (Allen et al. 2005) is considered more representative and has been used to inform the potential ET rate in the model. The average of the last 5 years (2018 – 2022) has been used to represent future predictions.

Extinction depth is the depth below which groundwater ET ceases to occur. The extinction depth has been set to the conventional value of 2 m in the model. Both the potential ET rate and extinction depth are spatially uniform across the model domain.

3.3.5.5 Pit Dewatering

The process of pit dewatering is simulated in the model using constant head cells at the pit (Figure 3-3). The time-varying water levels are based on the measurements provided by PNX for the historical calibration period. The GoldSim water level estimates have been used for the future period where the proposed mining activities are simulated.

The predicted Fountain Head pit water levels are presented in Figure 3-6, and show a reduction from approximately 94 m AHD (pre-mining) to -27 m AHD during mining occurs before water levels gradually recover to around 94 m AHD in the post-mining period.

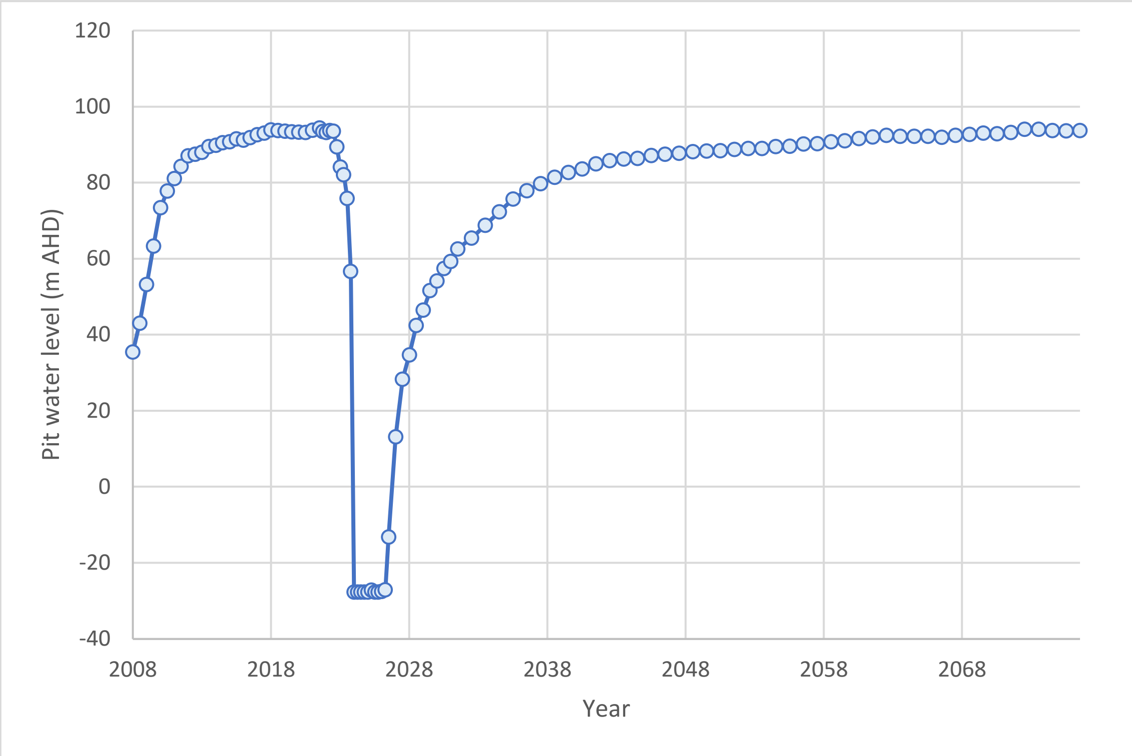


Figure 3-5 Modelled pit water level

3.3.6 Temporal Discretisation

The model simulation period spans from 2008 to 50 years after mining commencement, with a total of 103 stress periods. The starting year of 2008 was selected based on the availability of pit water level measurements provided by PNX which are presented in Figure 3-2 and discussed in Section 3.2.

The historical calibration period consists of a steady-state (warm-up) period and 27 half-yearly transient stress periods, covering the time between 2008 and 2022, during groundwater recovery following previous mining from the Fountain Head pit. The first steady state stress period represents the steady state period for model equilibration to the specified boundary conditions and parameters to provide the initial conditions for the subsequent transient simulation.

The future prediction period consists of 75 transient stress periods with varying lengths. The stress period length ranges in duration from 3-monthly during mining, and gradually increases to yearly for the post-mining period. To accommodate any potential future changes in the mine schedule, for reporting purposes these stress periods use the commencement of mining as the reference point (i.e. 1 year after mining commencement). The future period extends for 50 years following mining commencement.

3.3.7 Model Calibration

Model calibration refers to the process of adjusting model input parameters such that the model outputs match the field observations. However, this process is non-unique in that there are numerous combinations of parameters that can achieve a reasonable fit to field observations. Traditionally groundwater modelling is undertaken in a deterministic manner where only a single model is developed and used for prediction.

To better address the issue of non-uniqueness, model calibration has been undertaken in a stochastic manner where multiple model realisations (a realisation is a unique combination of parameters) have been developed and calibrated. The calibrated model realisations were then used for prediction, enabling a more robust non-linear uncertainty analysis that is not subject to any linear assumptions between model inputs and outputs. This technique is robust in that it literally samples the posterior (i.e. post calibration) prediction space that is generally, if using other methods, computationally intensive to generate.

The stochastic modelling was undertaken using the iterative ensemble smoother (IES) method through PESTPP-IES (White 2018), a member of the PEST++ suite that is the industry standard for model calibration and uncertainty analysis. It is worth noting that currently there is no guidance on how many model realisations are considered adequate. Therefore, based on the model complexity and project timeframe, 105 model realisations have been developed and calibrated, 5 of which are considered “spare” to account for potential failures. The best performing 100 model realisations (i.e. smallest misfit) were selected for post-processing and prediction.

Although PESTPP-IES is not specifically designed for testing extreme conditions, this stochastic technique may have a better chance of discovering potential risks (as demonstrated in our particle tracking results) compared to the traditional deterministic approach where only a single model is used.

3.3.7.1 Hydraulic Parameters

Compared to traditional PEST, PESTPP-IES has an efficiency advantage where its run time is only dependent on the number of realisations to be calibrated but not dependent on the number of calibration parameters. This advantage enables the use of highly parameterised modelling (i.e. calibrating a very high number of parameters) through the use of pilot points, a parameterisation technique where parameters are estimated at discrete locations and then interpolated to the model domain (Doherty et al. 2010).

In this work, a total of 7,866 pilot points were used to calibrate horizontal hydraulic conductivity, vertical anisotropy (i.e. Kh / Kv), specific storage, specific yield and the recharge-to-rainfall ratio. The pilot points have a nominal separation distance of approximately 250 m.

Table 3-1 shows the hydraulic parameter settings for calibration based on Section 3.2. Parameter values for the 105 model realisations were randomly drawn (constrained by a semi-variogram) between the lower and upper bounds, assuming a log-normal distribution that is centred at the initial value.

Table 3-1 Hydraulic parameter settings for calibration

Parameter	Initial value	Lower bound	Upper bound
Horizontal hydraulic conductivity (m/d)	0.5	0.01	35
Vertical anisotropy (Kh / Kv)	10	1	100
Specific storage (m^{-1})	3×10^{-5}	1×10^{-5}	1×10^{-4}
Specific yield (-)	0.007	0.001	0.05
Recharge-to-rainfall ratio (Recharge / Rainfall)	0.1	0.05	0.25

3.3.7.2 Calibration Targets

It is generally a good modelling practice to use multiple types of calibration targets to provide a greater constraints on the model. Two types of targets have been used for calibration; groundwater level targets and flux targets. These data are described in Section 3.2 and further below:

1. Observation wells – 22 observation wells have been used for calibration, with a total of 245 time-series records of groundwater level measurements. These measurements were averaged in accordance with the stress period setup (Section 3.3.6) and a weight of 1 was applied to all groundwater level targets. The observation well locations are shown in Figure 3-1.
2. Groundwater flux targets - 75 time-series groundwater flux targets have been used for the calibration. These estimates of groundwater flux to the pit were sourced from the GoldSim WBM which were in turn estimated from recovering pit water level data. Given the uncertainty in these estimates (i.e. they are not field measurements), a lower weight of 0.1 was applied to these flux targets. The selection of weight value is often

iterative in nature and for this particular model the value of 0.1 was found to be adequate for achieving a good fit to both the head and flux targets. The aim of including the flux targets is to ensure the modelled flux to the pit is in the right order of magnitude that is consistent with our site knowledge (i.e. hard matching these flux estimates is not intended).

3.3.7.3 Calibration Performance

Figure 3-6 compares the observed and modelled groundwater levels. The blue point and error bar represent the mean and range of modelled water levels from the 100 calibrated model realisations respectively. The diagonal 1:1 reference line represents the ideal situation where the simulated water levels fit the observations perfectly. Therefore, points that are closer to the reference line indicate a better calibration performance. Figure 3-5 shows that the point cluster is mostly centred around the reference line, suggesting an overall good calibration performance. Some discrepancies may be attributed to errors in reference elevation, accuracy of stand-pipe measurements and long open hole screen intervals.

There are three outliers with a short range of modelled water levels at approximately 93 m AHD. These outliers represent the 2019 measurements from observation wells ESRC0059, FHRC061 and FHRC089 that are located near the pit (Figure 3-1). Given the proximity of these wells to the pit, the modelled water levels at these wells are largely driven by the constant head cells, which explains the short range of modelled water levels for these wells in Figure 3-6. The misfits for these measurements are likely attributed to the sparse pit water level data during this time period (Figure 3-2), causing the constant head cells to lack the transient details that may be required to fit these measurements.

In contrast, measurements between 83 and 86 m AHD show a relatively large spread of modelled water levels. These measurements are from observation wells FHMB01, FHMB02, FHMB04 and FHMB05 between 2010 and 2012, during which the pit water level was rising considerably (Figure 3-2). The relatively large spread of modelled water levels for these measurements possibly reflects the uncertainty associated with how the groundwater system may respond differently to the rising pit water level across the 100 model realisations. This uncertainty in the transient behaviour of the groundwater system is accounted for in the model prediction by using all the 100 calibrated model realisations for the prediction.

The calibration results report a root mean square error (RMSE) of 1.5 to 1.9 m with a mean of 1.7 m, which translates to a scaled root mean square (SRMS) error of 5.0 to 6.3% with a mean of around 5.6%, consistent with modelling guideline criteria (Barnett et al. 2012). These statistics suggest each of the 100 calibrated model realisations has achieved a reasonable fit to the groundwater level observations.

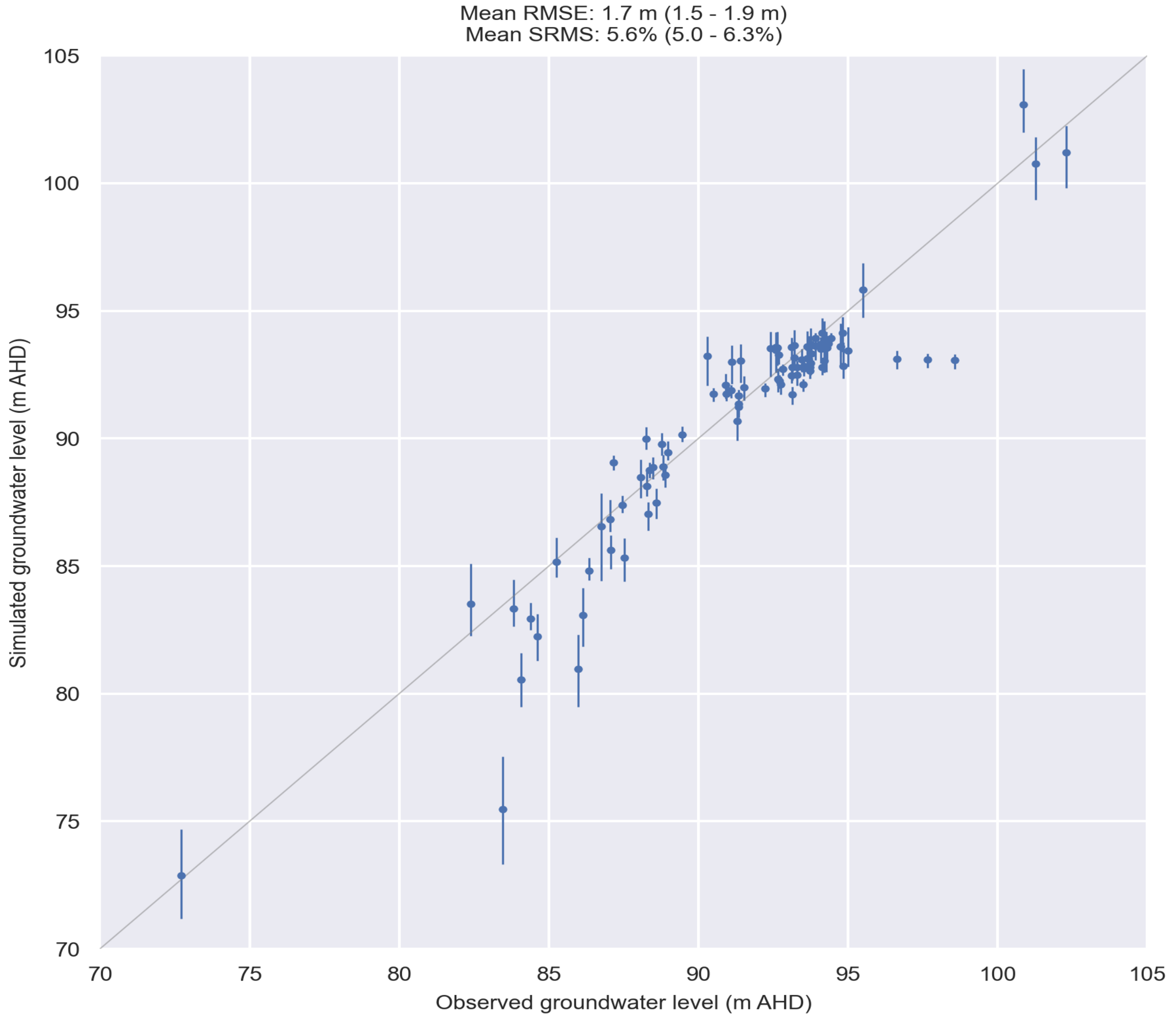


Figure 3-6 Comparison of observed and simulated groundwater levels

Figure 3-7 compares the target and modelled groundwater flux to the pit. Given the uncertainty in the flux targets (i.e. a hard match is not intended), the comparison shows a satisfactory match. The results report a RMSE of 178 to 187 kL/d with a mean of 182 kL/d, and a SRMS of 5.8 to 6.1% with a mean of 6.0%. These statistics suggest that the modelled groundwater flux from each of the 100 calibrated model realisations is consistent with our site knowledge (i.e. GoldSim WBM dewatering estimates).

To maintain the readability of this report, hydrographs with observed and simulated groundwater levels are shown in Appendix C. In general, the hydrographs suggest a reasonable match between the observed and modelled groundwater levels and pit lake water levels, thus providing validation of the Goldsim WBM estimates of groundwater flux to the Fountain Head pit.

The hydrographs generally show a rapid re-equilibration from the initial steady-state conditions to the transient calibration up to 2022, when recharge is based on actual rainfall. This is followed by further re-equilibration to the future prediction conditions when recharge is based on average rainfall between 2018 and 2022. This demonstrates the model performs well under a range of different climatic assumptions.

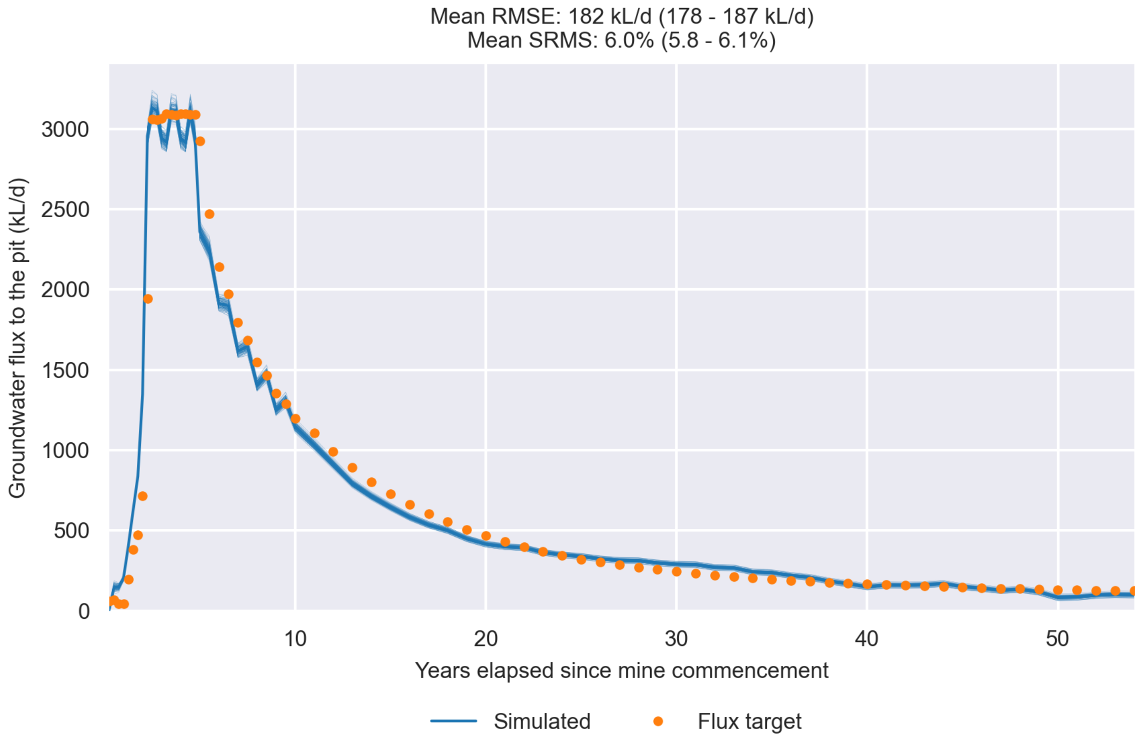


Figure 3-7 Comparison of groundwater flux to the pit - GoldSim (orange) and 2022 MODFLOW model (blue)

3.3.7.4 Calibrated Parameters

Table 3-2 presents a summary of the calibrated model parameters and show good agreement with the data review (Section 3.2). A model-wide geometric mean has been calculated for each parameter for each of the 100 calibrated model realisations. These values are further aggregated into geometric mean, minimum and maximum in Table 3-2 to represent the full range of realisation parameters. Assuming the parameters are log-normally distributed, the geometric mean represents the most likely value.

The spatial distribution of the calibrated parameters is shown in Figure 3-8 through to Figure 3-11, with the distribution likely reflecting the natural variability of parameters within the fractured rock system. In particular, the calibrated specific storage values are in the same order of magnitude as suggested by Rau et al. (2018), who investigated the physical upper limit of specific storage.

To assess the impact of climate change on the model prediction, different future recharge realisations have been derived from the 2018-2022 average rainfall using different recharge-to-rainfall ratios from the 100 calibrated model realisations. Table 3-2 shows that the recharge-to-rainfall ratios can range from 44% above the geometric mean to 22% below the geometric mean. This range is relatively large and considered adequate to provide insights into how different future recharge influences the model prediction.

Table 3-2 Summary of calibrated model parameters

Parameter	Geometric Mean	Minimum	Maximum
Horizontal hydraulic conductivity (m/d)	0.4	0.2	0.9
Vertical anisotropy ratio (Kh / Kv)	11.8	4.5	33.1
Specific storage (m^{-1})	3.2E-05	2.2E-05	5.3E-05
Specific yield (-)	0.005	0.003	0.011
Recharge-to-rainfall ratio (Recharge / Rainfall)	0.09	0.07	0.13

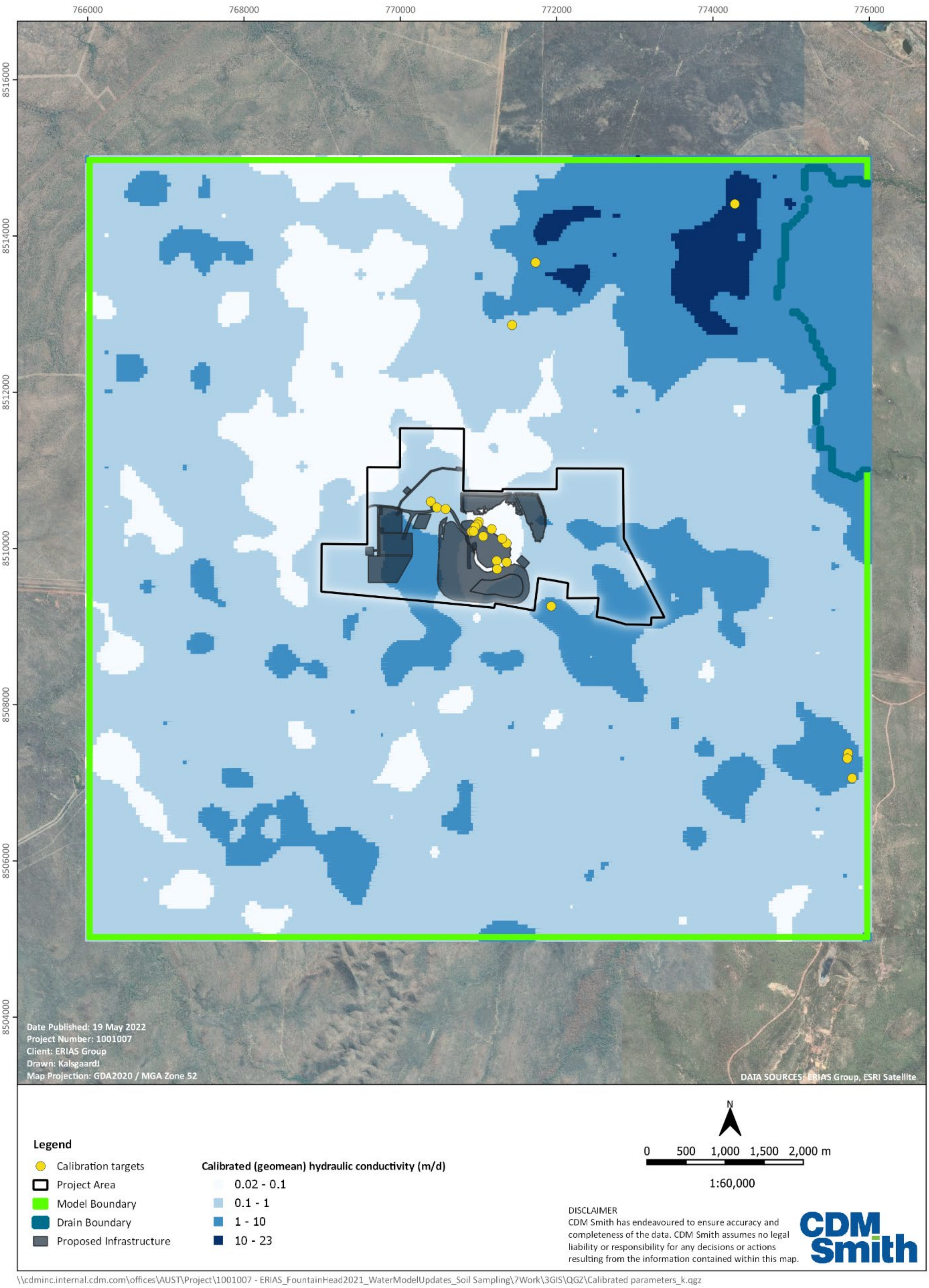


Figure 3-8 Calibrated (geomean) hydraulic conductivity

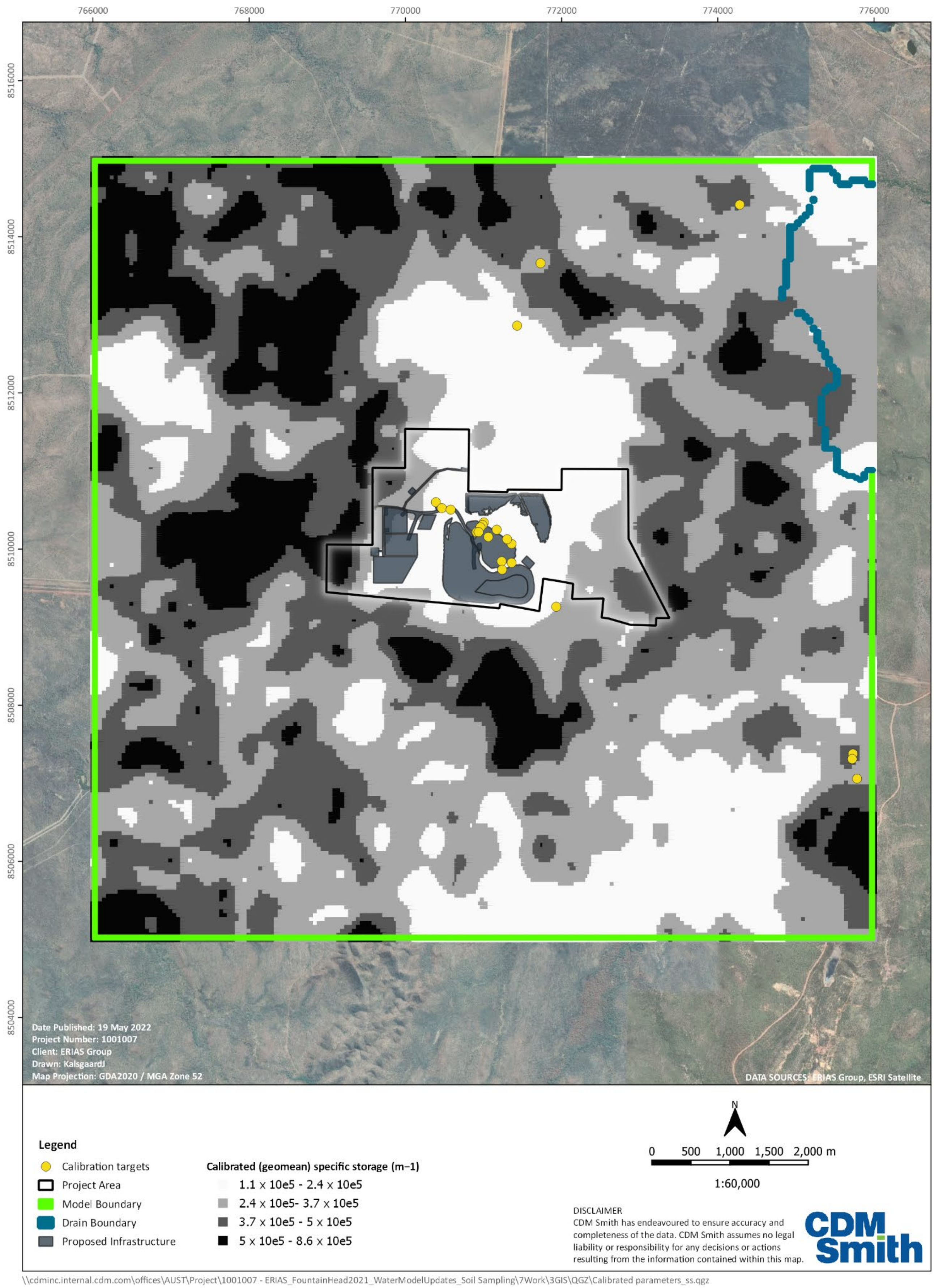


Figure 3-9 Calibrated (geomean) specific storage

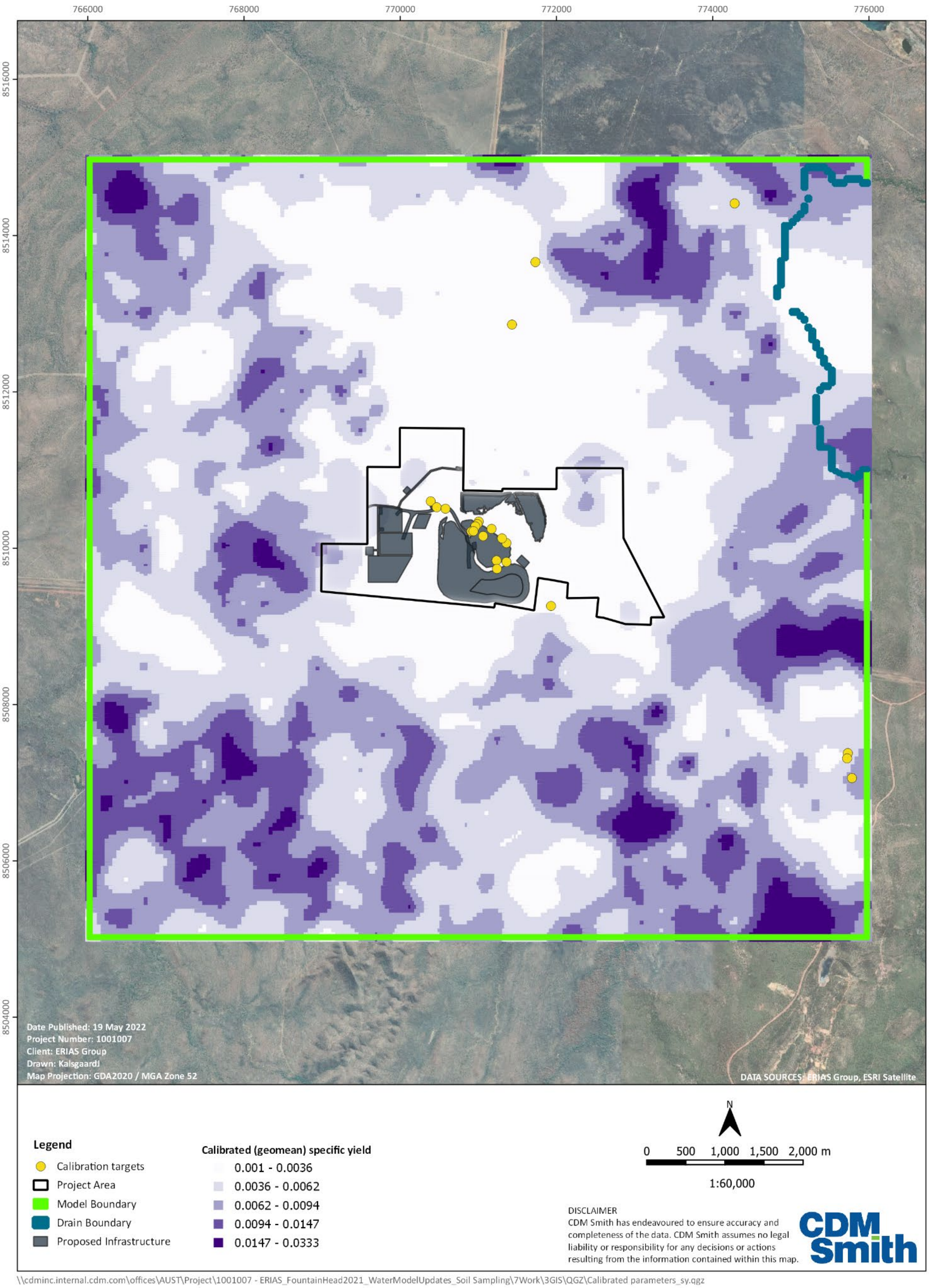


Figure 3-10 Calibrated (geomean) specific yield

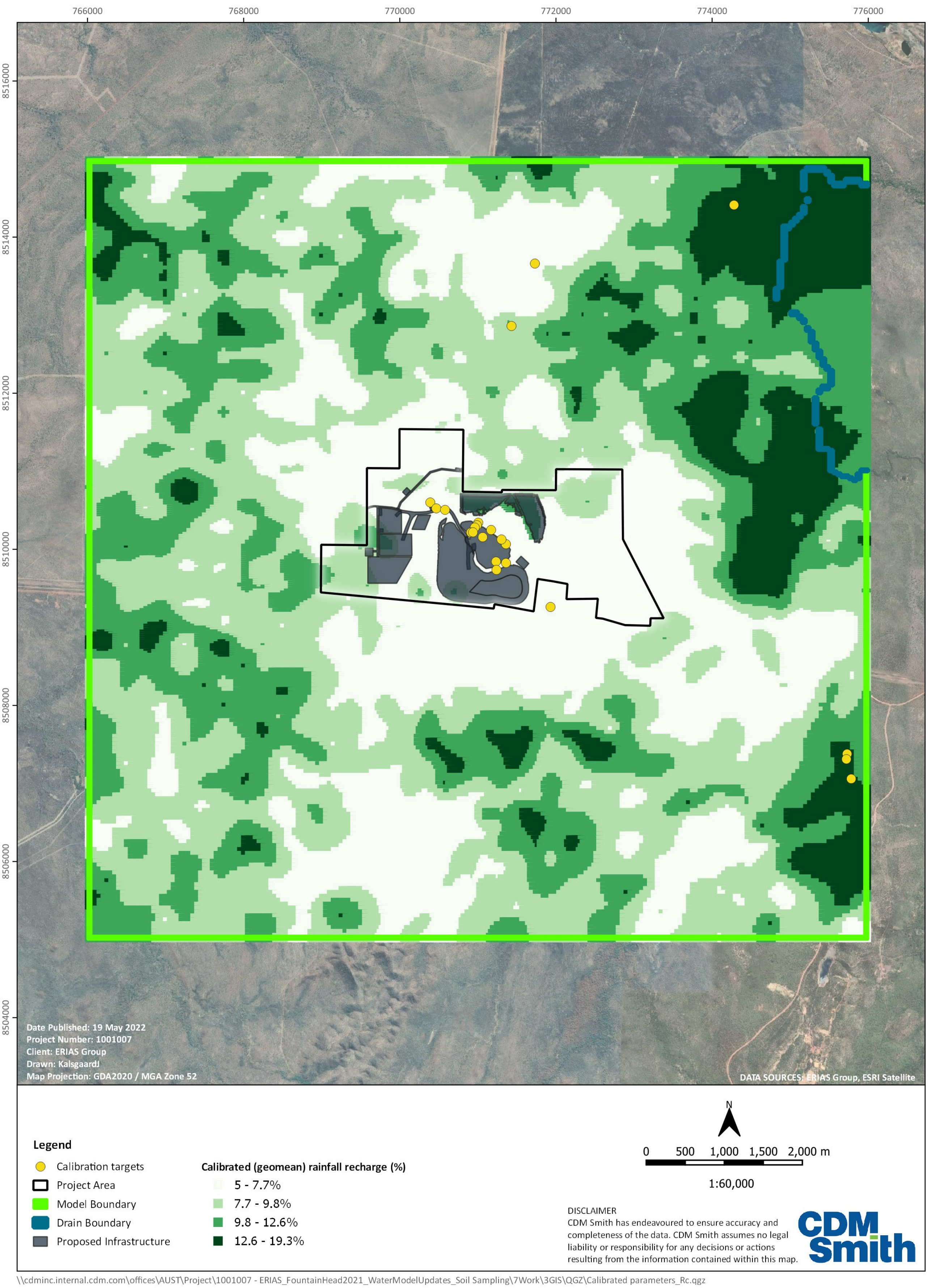


Figure 3-11 Calibrated (geomean) rainfall recharge

3.3.7.5 Calibrated Mass Balance

Model mass balance provides insights into whether the water balance components are represented appropriately in the model. In addition, the difference between total inflows and outflows should be small (< 1%) to ensure the model is numerically stable (Barnett et al. 2012).

Table 3-3 shows the mean of mass balance across the 100 calibrated model realisations for the steady-state period (representing the average between 1900 and 2008) and the end of calibration period (representing the average between Nov 2021 and Apr 2022). Note these two periods represent the pre-mining conditions, as the proposed mining activities are simulated in the future period (potential groundwater fluxes to the pit are discussed in Section 3.3.7.3). Note also that the 2021 mass balance represents much lower recharge due to low rainfall conditions (i.e. dry season) than the long-term average to 2008, and the other mass balance components change accordingly.

The results show regional groundwater flow is the major inflow component while groundwater discharge to the pit lake (via drainage to the constant head cells, which represents evaporation from the pit lake) is the major outflow component. The climate components, including rainfall recharge and groundwater ET, have a smaller role in the water balance, albeit still considerable.

The percent discrepancy is 0.01% for both periods, which is substantially lower than the 1% requirement in the National Groundwater Modelling Guidelines (Barnett et al. 2012), indicating the model is numerically stable.

Table 3-3 Calibrated Mass Balance (Mean of the 100 calibrated realisations)

Water Balance Component	Steady-state (Average between 1900 and 2008)	End of Calibration Period (Nov 2021 – Apr 2022)
Storage IN	0	1
Constant Head IN	65,588	70,857
Recharge IN	29,698	5,361
Total IN	**95,286**	**76,219**
Storage OUT	0	11,21
Constant Head OUT	75,590	65,793
Drains OUT	11	0
ET OUT	19,692	9,309
Total OUT	**95,293**	**76,224**
IN - OUT	-7	-5
Percent discrepancy	**-0.01%**	**-0.01%**

3.3.7.6 Sensitivity Analysis

Due to the stochastic approach adopted in this study, the sensitivity analysis needs to be undertaken in a different manner using the concept of relative uncertainty reduction of parameters (Manewell and Doherty, 2021), which is defined as follows:

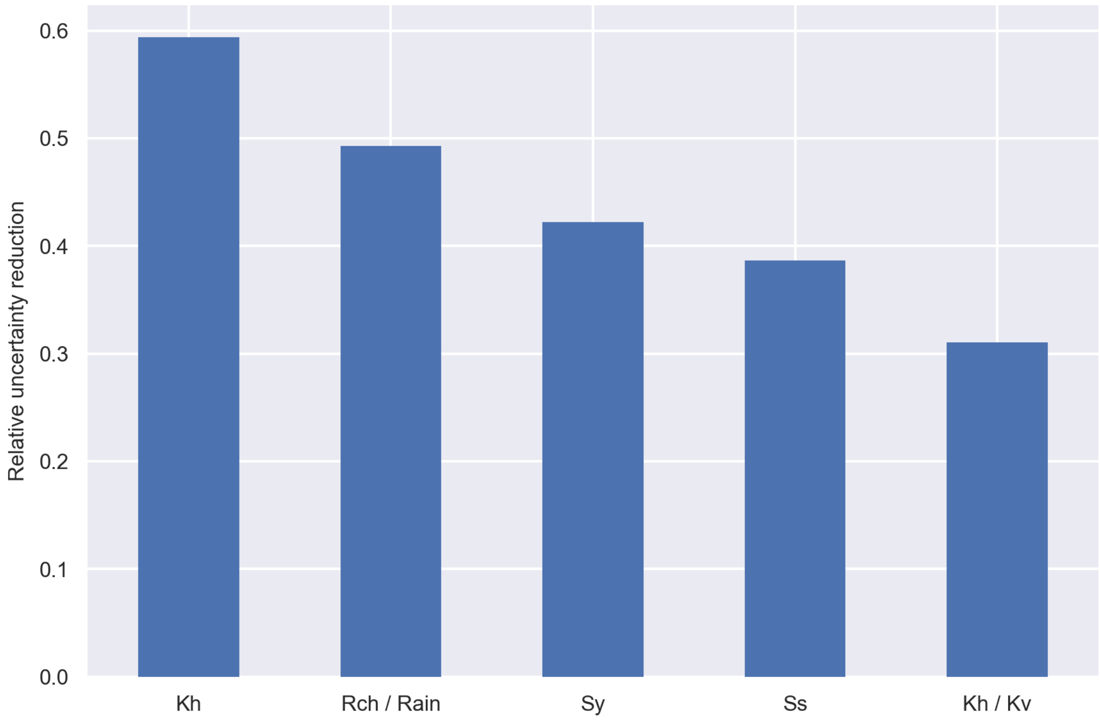
$$r_i = 1 - \frac{\sigma_i^{post}}{\sigma_i^{prior}}$$

Where:

- r_i is the relative uncertainty reduction of parameter i.
- σ_i^{prior} is the prior uncertainty of parameter i (i.e. the standard deviation of parameter i across the 100 realisations before calibration).
- σ_i^{post} is the posterior uncertainty of parameter i (i.e. the standard deviation of parameter i across the 100 realisations after calibration).

This approach is based on the rationale that the uncertainty (i.e. the standard deviation across the 100 realisations) of a more sensitive parameter would be reduced more by the calibration, and vice versa.

Figure 3-12 presents the results of the parameter sensitivity analysis. The results show that hydraulic conductivity is the most sensitive parameter, followed by recharge-to-rainfall ratio and specific yield. The latter is expected given that this work is mostly for an unconfined aquifer setting. Specific storage and the vertical anisotropy of hydraulic conductivity were found to be the least sensitive.



Kh = Horizontal hydraulic conductivity, Rch/Rain = recharge-to-rainfall ratio, Ss = specific storage, Sy = specific yield, Kh/Kv = Vertical anisotropy of hydraulic conductivity

Figure 3-11 Parameter sensitivity analysis

3.3.8 Model Prediction and Uncertainty Analysis

3.3.8.1 Overview

The groundwater model consists of a historical calibration period ranging between 2008 and 2022, and a future prediction period which spans 50 years after mining commencement (Section 3.3.6). The proposed mining activities are represented through changes in pit water levels (Section 3.3.5.5) and EP seepage recharge (Section 3.3.5.3), as informed by the GoldSim WBM.

The key prediction results are listed in Section 3.3.1 and presented below:

- Groundwater level contours at the current condition (i.e. pre-mining), end of mining and 50 years post mining commencement (i.e. new long-term equilibrium).
- Groundwater drawdown contours induced by dewatering for the proposed mining activities at the end of mining and 50 years post mining commencement.
  - Due to the rapid recovery of pit water level (Figure 3-5), the end of mining was found to represent the conditions when the cone of depression is the deepest and the spatial extent of drawdown is the largest.
- The transport and fate of contaminant seepage from the EP, especially on whether the contaminant would be transported through the groundwater system to the surrounding GDEs.

Consistent with best practice, the predictions and uncertainty have been presented together so that readers viewing the prediction results can also gain an appreciation of the associated uncertainty.

The Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Large Coal Mining Development (the theory of which also applies to generic groundwater modelling) consolidates the approaches for uncertainty analysis into three broad types (Middlemis & Peeters 2018). Our uncertainty analysis approach belongs to IESC Type-3 (Stochastic Modelling with Bayesian Probability Quantification) that is mathematically the most complex in that (i) it is non-linear in nature, which does not require any linear assumptions between model inputs and outputs, and (ii) it involves sampling the posterior prediction space that is generally, if using other methods, computationally intensive to generate. This seemingly complex concept, however, can be understood by using all the 100 calibrated model realisations for prediction, and then analysing the similarities and differences (i.e. the range) between the 100 sets of prediction results.

Uncertainty analyses should be project-specific and based on the model objectives and tailor-made for risk management purposes. In-line with the FHGP objectives, two key threats have been considered for further interrogation regarding their predictive uncertainty:

1. Groundwater Drawdown, i.e. what the worst-case drawdown impact is that is supported by the field data.
2. Contaminant transport, i.e. whether any situations exist that enable the leachate from the EP to be transported off-site.

To address the first potential risk, the 95th percentile of drawdown impact from the 100 calibrated model realisations has been used to describe the drawdown predictions that are very unlikely to be exceeded (after the schema presented in Table 2 of Middlemis and Peeters, 2018).

To address the second potential risk, all the 100 calibrated model realisations have been used for particle tracking and interrogated further to understand the uncertainty in predicting groundwater flow.

The model prediction results presented in this section implicitly incorporate the impact of climate change through using different calibrated recharge-to-rainfall ratios from the 100 model realisations. As shown in Table 3-2, the recharge-to-rainfall ratios can range from 44% above the geometric mean to 22% below the geometric mean. This range is relatively large and considered adequate to provide insights into how different future recharge influences the model prediction.

3.3.8.2 Predicted Groundwater Levels and Drawdowns

Predicted groundwater levels at the current condition (i.e. pre-mining), end of mining and 50 years post mining commencement (i.e. new long term equilibrium) are presented in Figure 3-11, 3-12 and 3-13 respectively. As it is visually challenging to present groundwater level contours from the 100 calibrated model realisations, the figures have been simplified to show the mean groundwater levels across the 100 realisations. Assuming a normal distribution (a standard assumption that is often used in groundwater modelling based on the Central Limit Theorem), the mean water level represents the most likely outcome.

Figure 3-11 shows that the groundwater flow direction is generally towards the north-east at the current pre-mining condition, aligning with the current hydrogeological conceptualisation. Figure 3-12 indicates that the pit water level is at approximately -27 m AHD at the end of mining and considerable drawdown occurs in the immediate vicinity of the pit. Figure 3-13 shows that 50 years after mining commencement, the groundwater level contours are similar to the current condition, with subtle differences that are likely to be caused by the EP seepage recharge.

Drawdown has been predicted for the end of mining (EoM) period and is shown in Figure 3-15. Drawdown of greater than 100 m (around 120 m) is predicted at the EoM, however, gradients are relatively steep with the cone of depression largely restricted to the near vicinity of the Fountain Head pit and EP. The groundwater drawdown extent of 1 m or greater, representing the average of 100 model realisations, is predicted to extend to 750 m to 1,600 m from the pit, with the drawdown extending farthest to the west and southeast of the pit, where the hydraulic conductivity values are highest. It is likely this will capture much of the water that infiltrates across the site with exception to infrastructure that is designed to prevent leakage such as the IWL and as seepage from the EP (also residing within the drawdown extent) while groundwater recovery takes place.

Groundwater drawdown is expected to have a negligible impact on GDEs with up to 1 m drawdown predicted at the un-named creek directly north of the site (potential terrestrial GDE) and around 0.1 m at the west and eastern edges of the creek. Seepage from the EP is helping to constrain the extent of drawdown to the north. These mapped GDEs are not Type 1 (reliant on groundwater discharge to the land surface), however, are likely to be Type 3 (reliant on the sub surface presence of groundwater) (Richardson et al. 2011). The updated conceptualisation of the Type 3 GDEs (Appendix A), suggests the vegetation will be resilient to minor changes in groundwater levels predicted by the model. No drawdown has been predicted within the vicinity of aquatic GDE, with the perennial billabong located to the site's northeast residing outside of the zone of influence and therefore not impacted by the project activities.

Post mining predictions reveal a residual drawdown of around 0.1 m to greater than 5 m exists around the pit and EP at 10 years post mining, with groundwater levels predicted to fully recover within 40 years following mining (Figure 3-16). Groundwater levels beneath the EP are expected to begin to recover from around five years post mining and are presented in Figure 3-17 showing the predicted mean groundwater levels beneath the north-eastern corner of the EP (annotated with a red dot on this figure). The model suggests temporary mounding of groundwater levels beneath the EP might occur during the beginning of mining as the Fountain Head pit is dewatered and mine water discharged to the EP. The mounding, however, is expected to be encompassed by the greater drawdown extent (Figure 3-15) and therefore, would flow downgradient towards the Fountain Head pit during dewatering until operations cease and groundwater levels under the EP recover. Recovery of groundwater levels under this facility are expected to be gradual, occurring first from the northeast corner of the EP at 5 years post mining (Figure 3-17) and progressively reducing before full recovery is reached within 40 years end of mine (Figure 3-16). Therefore, the flow of seepage from the EP from five years following mining will likely occur both towards the pit (where a downward gradient exists) as well as to the northeast until full recovery is reached and quasi-steady state flow conditions to the northeast resume.

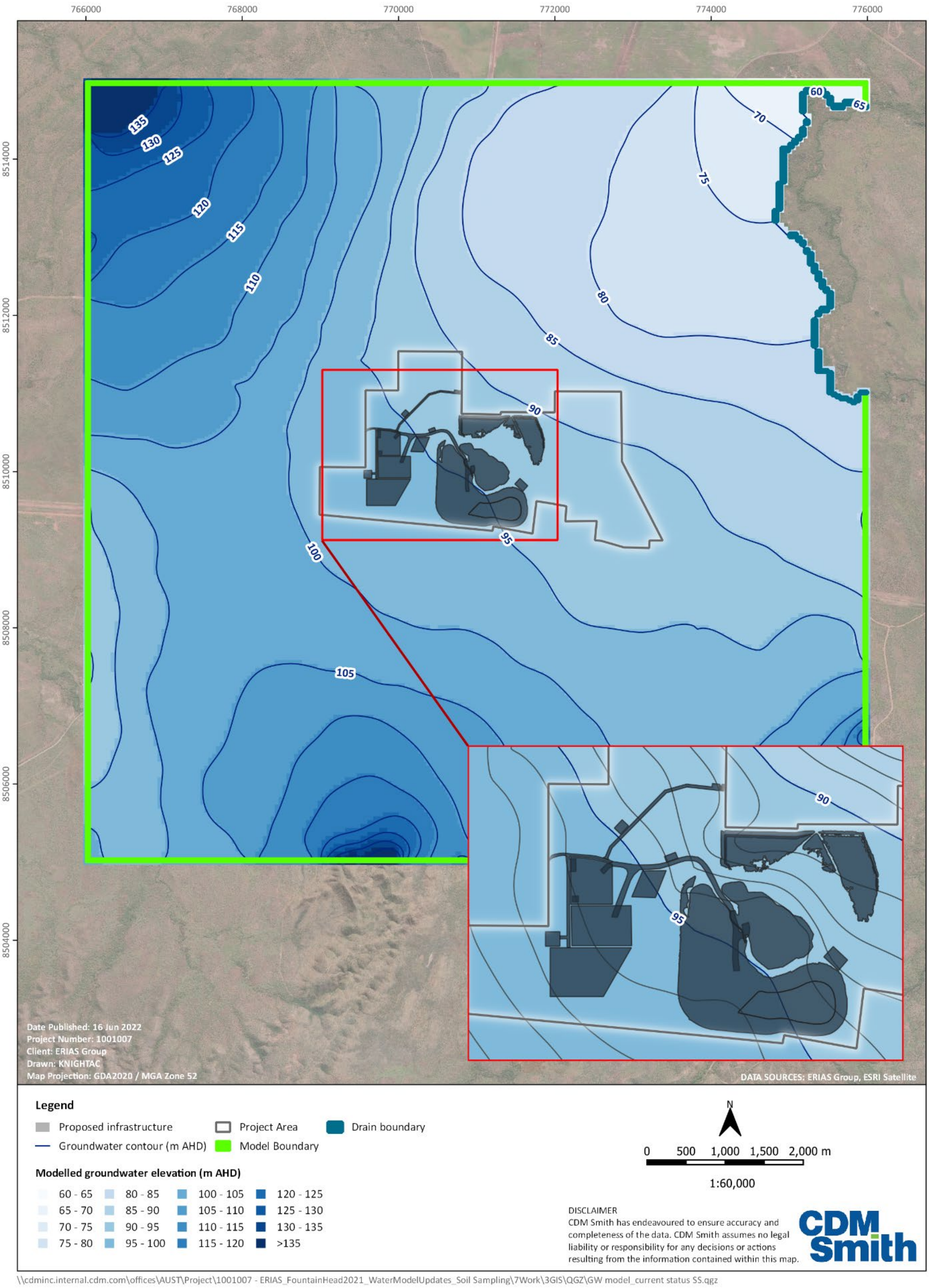


Figure 3-12 Predicted mean groundwater elevation – current condition 2021 (m AHD)

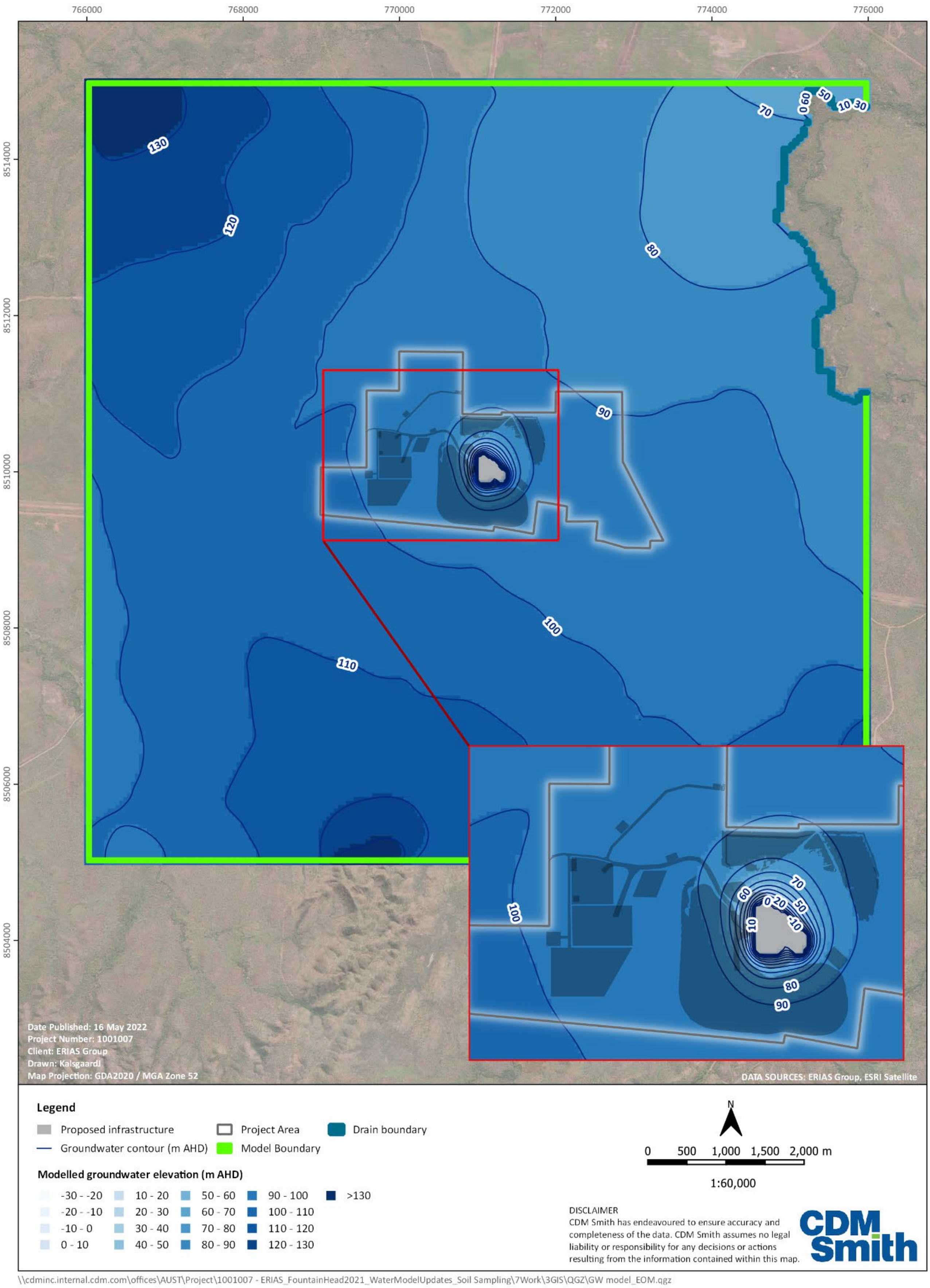


Figure 3-13 Predicted mean groundwater elevation at end of mining (m AHD)

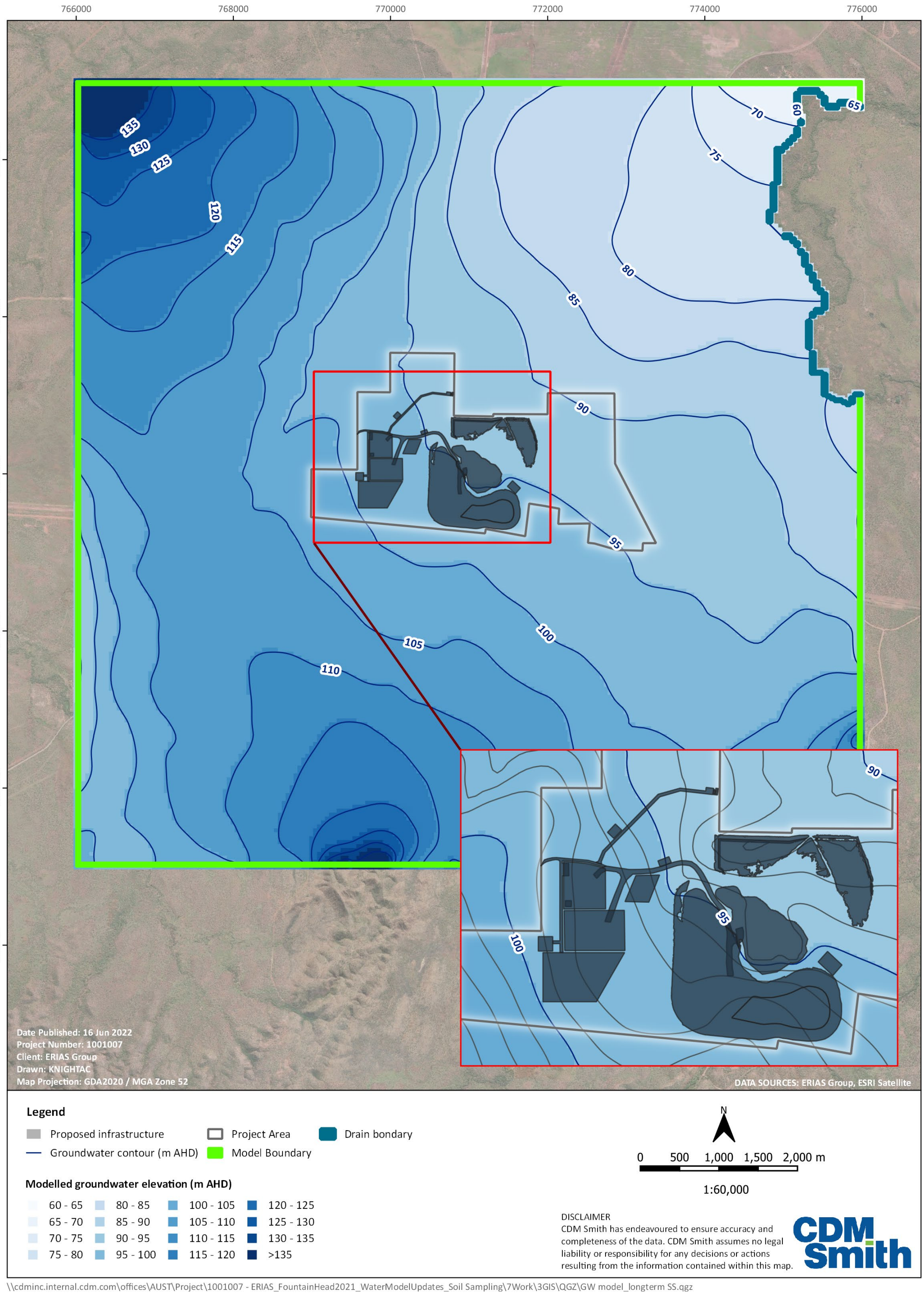


Figure 3-14 Predicted mean groundwater elevation 50 years post-mining commencement (m AHD)

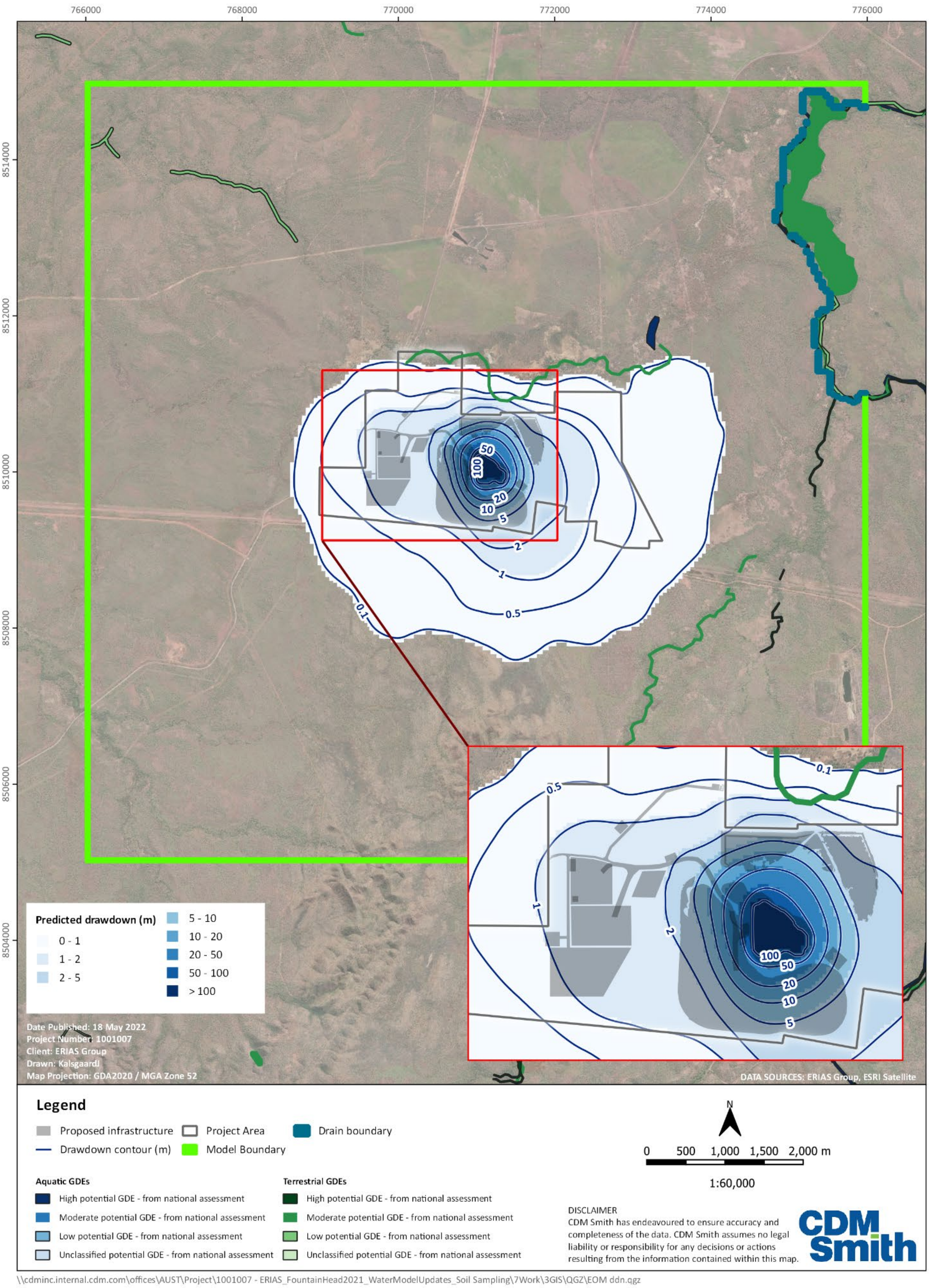


Figure 3-15 Predicted mean drawdown at end of mining (m)

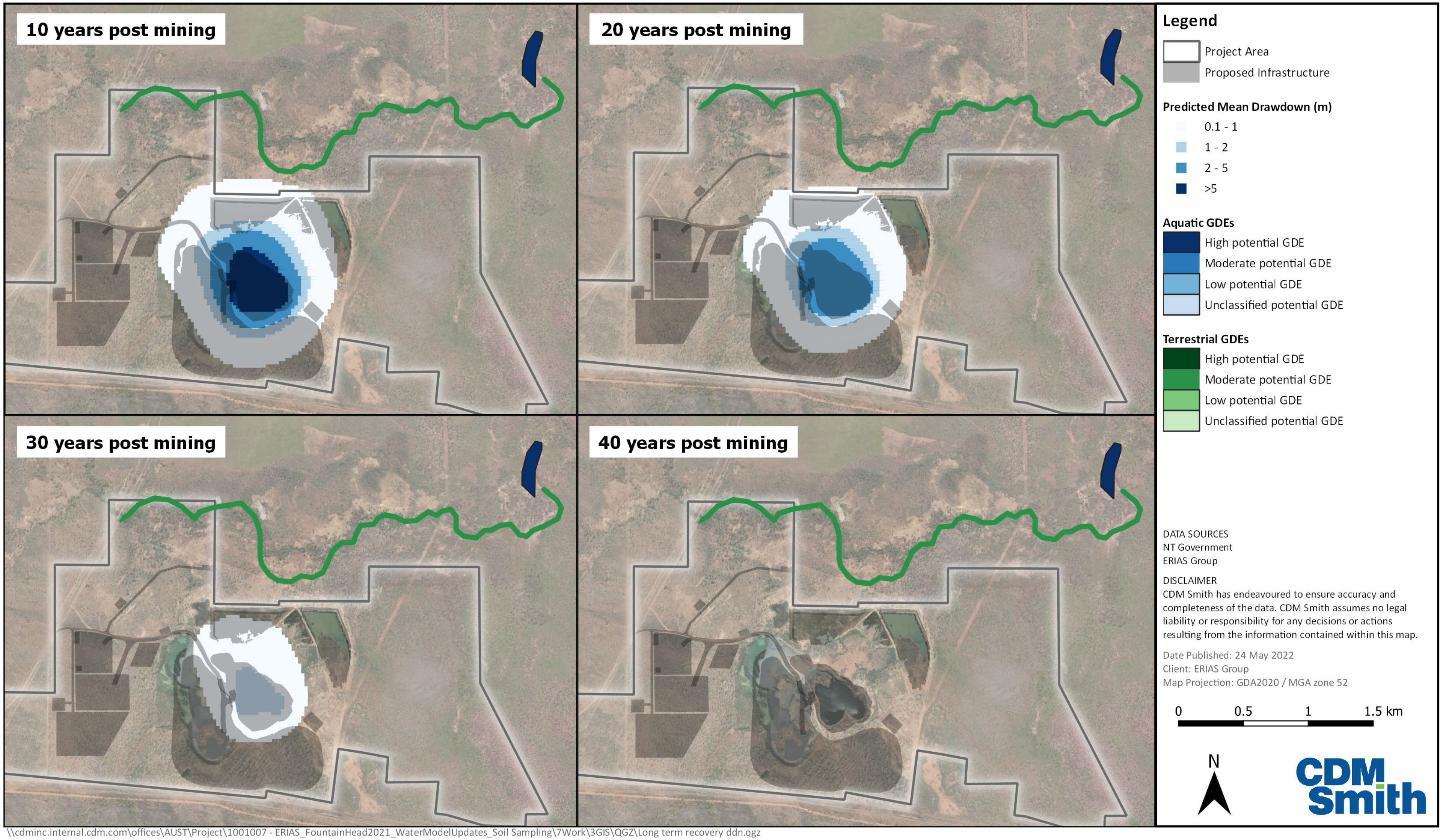


Figure 3-16 Predicted mean drawdown post-mining (m)

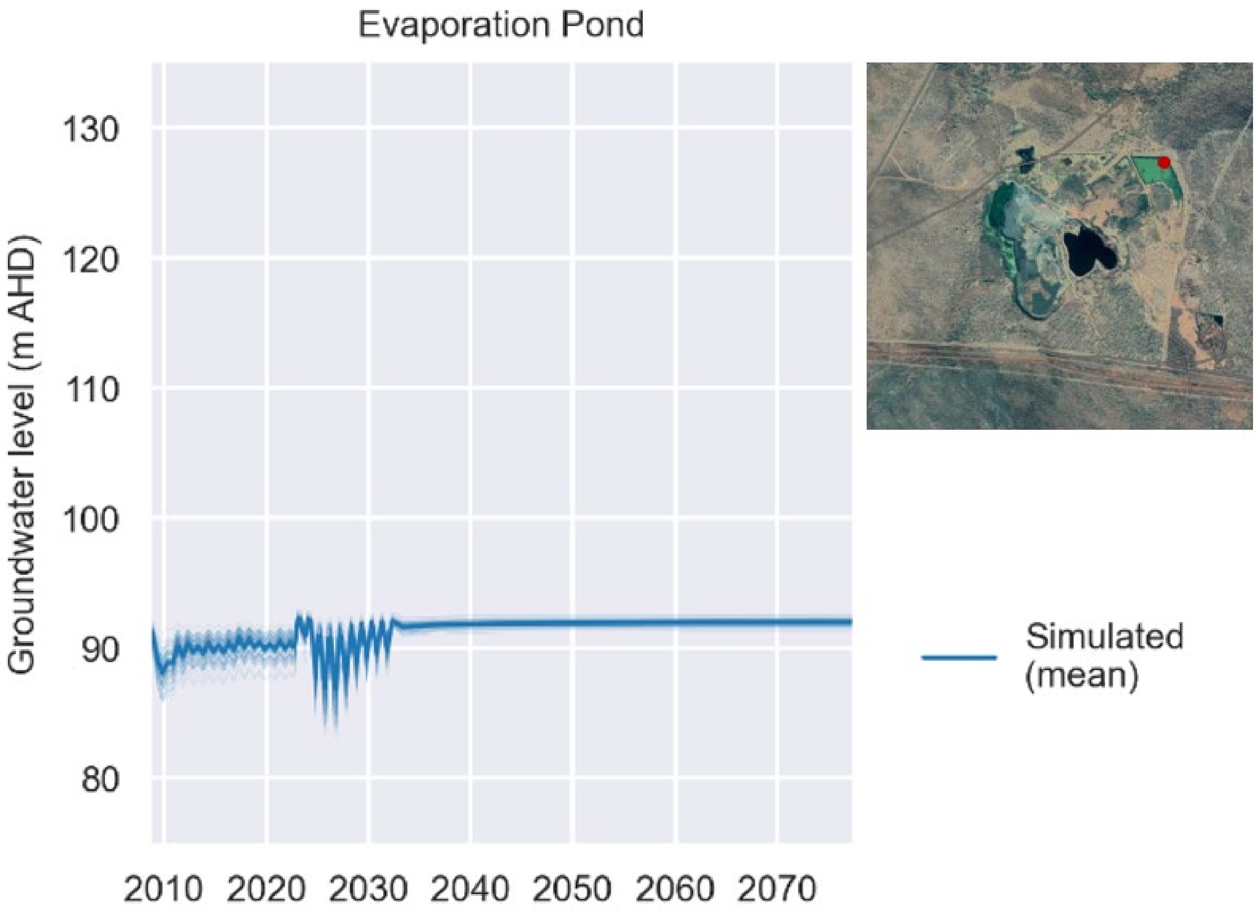


Figure 3-17 Timeseries groundwater elevation under the northeast corner of the evaporation pond

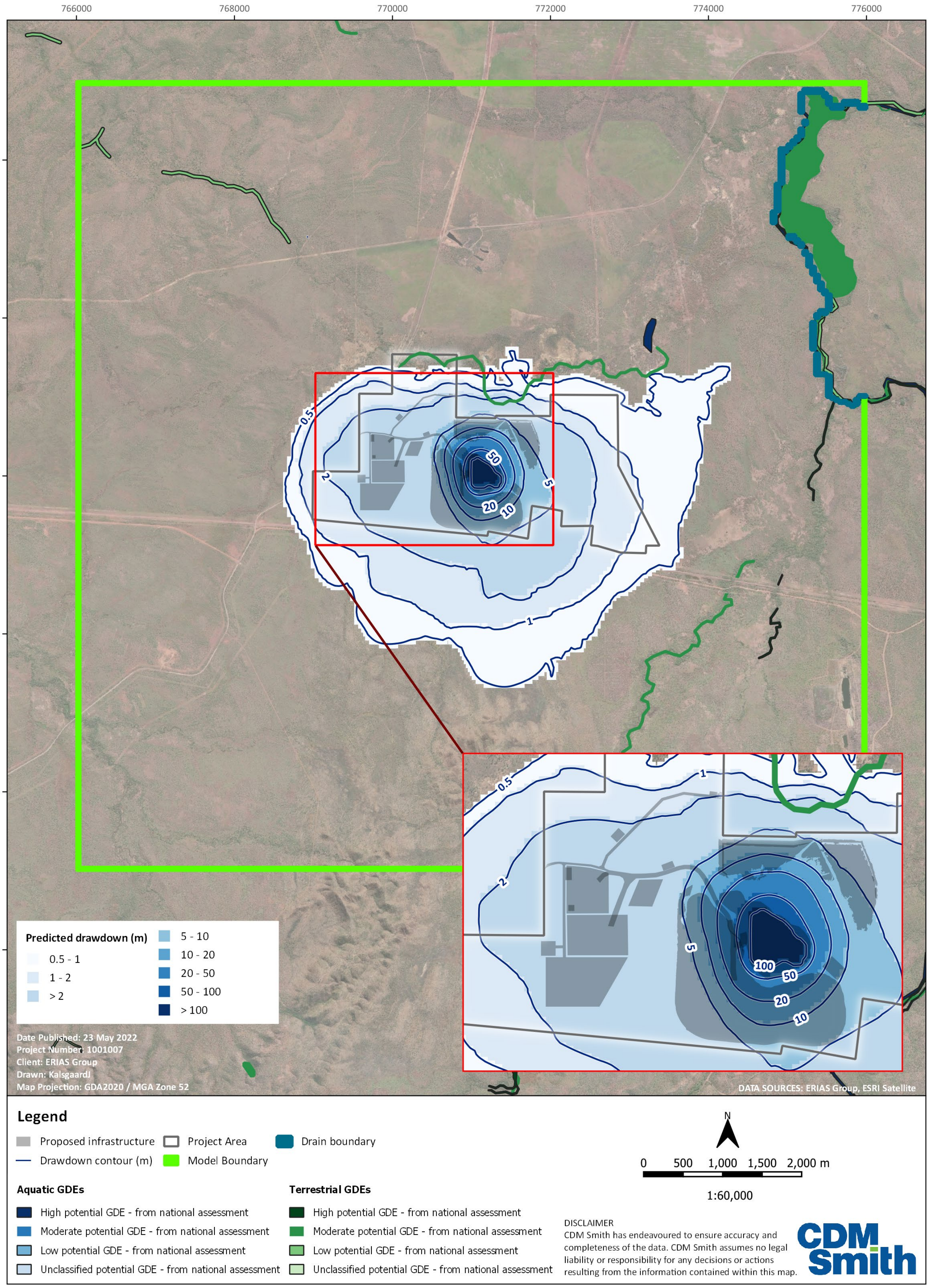


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Figure 3-18 Predicted 95th percentile drawdown at end of mining (m)

Figure 3-19 shows the modelled groundwater fluxes across the constant head cells that represent the pit. This figure is similar to Figure 3-7 but with the addition of inflows from the constant head cells (i.e. leakages from the pit). The 100 model realisations show very similar results, possibly due to the constraints exerted by the flux targets.

The model results show that groundwater discharge to the pit rises rapidly as mining commences and falls exponentially after the cessation of mining. In comparison, leakages from the pit are negligible throughout the prediction period. This suggests the pit acts as a groundwater sink throughout the prediction period, albeit becoming more local-scale over time as groundwater discharge to the pit reduces.

This is supported by Figure 3-14 where at 50 years post mining commencement, the pit is surrounded by the 94 mAHD groundwater level contour, while the pit water level is at around 93.7 mAHD (Figure 3-5), suggesting the influence of the pit acting as a groundwater sink decreases over time. Therefore, it is likely that sometime in the future (beyond the modelling timeframe) that the regional groundwater will force a throughflow situation. However, as the pit water quality is predicted to be better than the current pit lake water quality (CDM Smith, 2022) this is not considered a risk.

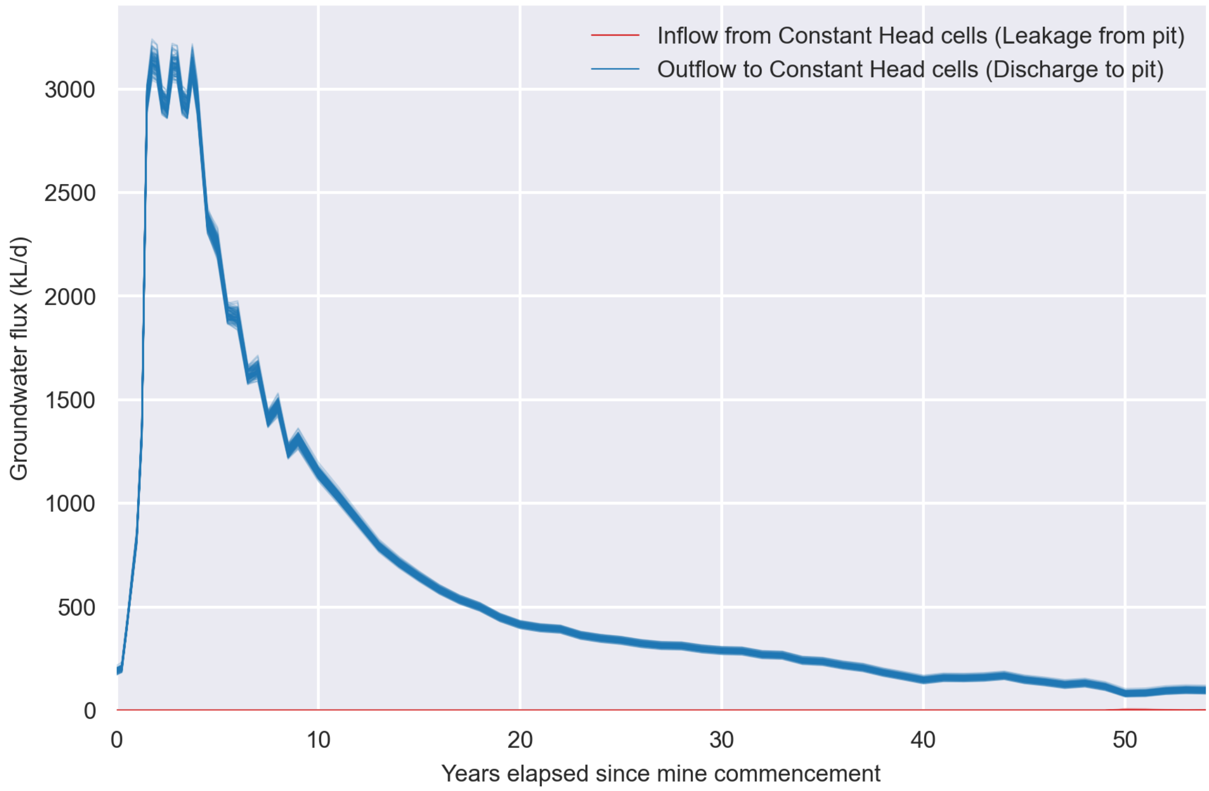

Figure 3-19 Groundwater fluxes across the constant head cells representing the pit

3.3.8.3 Particle Tracking

Particle tracking using the MODPATH software code (Pollock, 1994) has been undertaken to simulate the potential fate (conservatively assuming advective transport only) of any leachate that may enter the water table from beneath the proposed EP and the Fountain Head pit. Particles have been set up for each model cell within the EP area and released at year 0 (i.e. beginning of mining) and at year 40 (from mining start) over a 50 year prediction period. Porosity is assumed to be 1% uniformly.

The traditional deterministic approach where only a single model is used has a relatively large probability to miss the potential risks associated with the predictions (in this instance, groundwater flow path). In comparison, the stochastic approach comprising all 100 of the calibrated model realisations for particle tracking enables a more comprehensive predictive uncertainty analysis, with a larger chance to capture the potential risks and a much greater understanding of what conditions may lead to these potential risks.

A high-level view of the particle tracking results is presented in Figure 3-20, using the maximum particle travel distance[1] over the 50-year prediction period as the metric. Despite all the 100 model realisations being similarly calibrated (Section 3.3.7.3), the particle tracking results are notably different in that the maximum travel distance can range from less than 1 km to beyond 6 km, demonstrating the impact of non-uniqueness on model prediction.

The results are presented in Figure 3-20 as exceedance probability, which describes the probability of the maximum particle travel distance exceeding a given value, the concept of which is further illustrated in the figure annotations (blue caption). This can also be interpreted as a function of the number of model realisations, where an exceedance probability of 60% as shown in Figure 3-20 suggests 40 of the 100 model realisations have a result greater than a given value, in this instance ~900 m. Adopting this approach, results from the 100 calibrated model realisations can be broadly split into two clusters, where 80% of the models (referred to as the 80% cluster) suggest the maximum distance could be less than ~3,500 m, while 20% of the models (referred to as the 20% cluster) indicate the maximum distance can be greater than ~3,500 m. None of the 100 models fall into the range between 3,500 and 5,400 m, which acts as a clear divide between the two clusters and can be observed in Figure 3-20 as a plateau at the 20% exceedance probability. Note that the use of only 100 model realisations means that the probability calculation is not intended to be precise but an approximation.

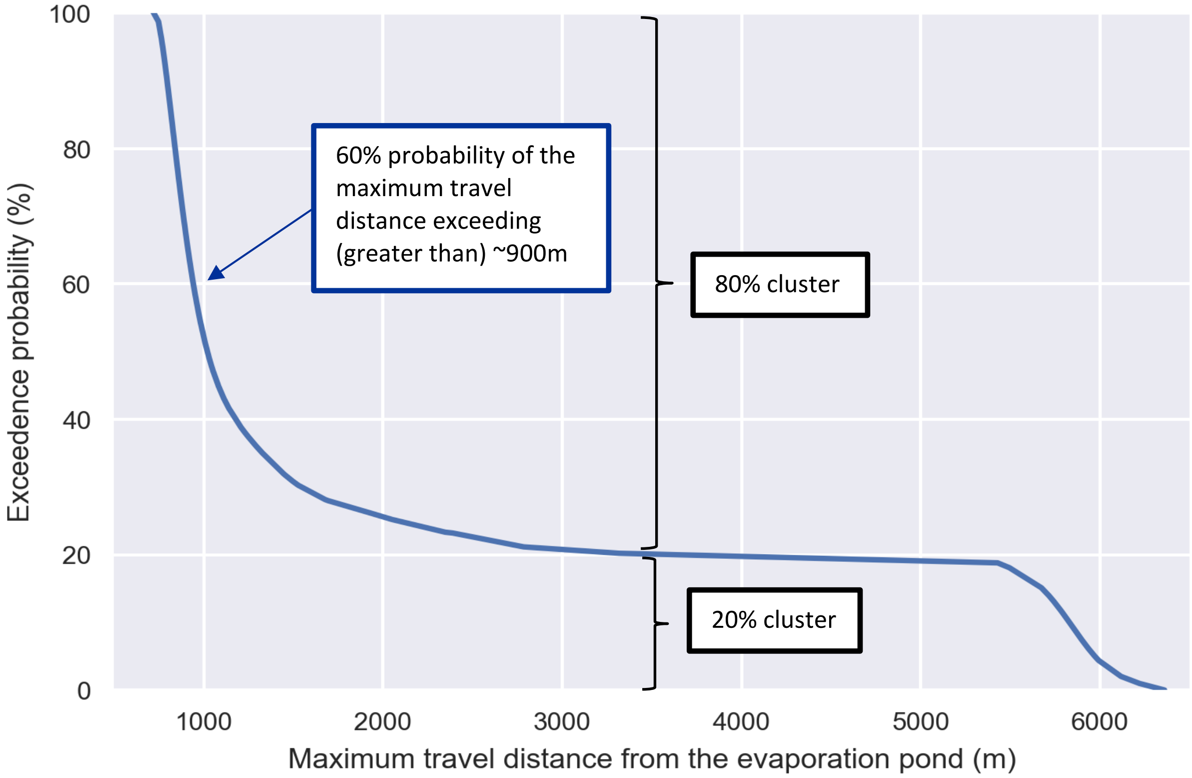

Figure 3-20 Predicted maximum particle travel distance exceedance probability (0 – 50 years mining commencement)

The predicted particle flow paths for 0 to 50 years post mining commencement are shown in Figure 3-21 and Figure 3-22 and suggest particles from the EP will likely be captured by the Fountain Head pit during mining activities when hydraulic heads are lowered as a result of dewatering, however, following recovery of groundwater levels post mining, particles may be transported from the EP to the northeast following the regional groundwater flow field. The figures present the particle tracking results in two slightly different ways, where Figure 3-21 presents all 100 realisations

[1] Maximum travel distances of all groundwater flow paths for each model realisation. Note these flow paths may not travel in a single direction.

arranged into groups of 20 (i.e. 20% probability) in ascending order from shortest to longest maximum travel distances. Figure 3-22 presents the results in terms of exceedance probability (i.e. the probability that particles exceed the flow paths shown).

The results show the 80% cluster (realisations 0 to 80 in Figure 3-21 and C in Figure 3-22 predicts the particles will not travel far from the EP within a 50-year period, less than 3,500 m, and 1,100 m when considering a 60% cluster (realisations 0 to 60 in Figure 3-21 and B in Figure 3-22). The results suggest there is a 40% probability of groundwater flow paths intersecting the un-named creek immediately north of the site within a 50-year period. In comparison, the 20% cluster (realisations 80-100 in Figure 3-21 and C in Figure 3-22) predicts the particles may travel all the way to the north-eastern model edge within a 50-year period. However, no direct interaction of groundwater flow paths and aquatic GDEs (i.e. the perennial billabong to the sites northeast) is predicted.

For risk management purposes, it is critical to better understand the 20% cluster, especially the parameters of these model realisations that lead to the longer particle paths as well as the potential threat posed to downstream receptors. Groundwater flow alone to these receptors should not be construed as an adverse effect, as disruption of the GDEs would partly be a function of solute concentrations within the Fountain Head pit and EP and the degree to which they become diluted along the pathway. Water quality modelling by CDM Smith (2022) predicts the future pit lake will have lower contaminant concentrations than present, while arsenic in the EP peaks at around 4.3 mg/L during mining and declines to less than stock water guideline (0.5 mg/L) (ANZECC,2000) by early 2026 and less than background groundwater concentrations (0.056 mg/L) by early 2027. Given seepage from the EP will be captured by the pit drawdown during this time and the pit lake solute concentrations are no greater than present, seepage water from these facilities is unlikely to pose a threat to downstream receptors even under scenarios where the farthest particle travel distances are predicted.

The predicted particle flow paths for 40 to 50 years post mining commencement are shown in Figure 3-23, representing the period after groundwater levels are predicted to have recovered. Under this scenario, the particles do not become captured by the pit with only minor flow to the south of the EP and majority of flow occurring towards the northeast. Maximum particle travel distances are less than the 0 to 50 years scenario and are not predicted to exceed around 2,600 m (E in Figure 3-23) for any of the 100 realisations. Conceptually this observation is sound as the prediction period for this scenario is only 10 years as opposed to 50. These results confirm the flow direction of seepage from the EP will be dictated by the groundwater gradient resulting from pit dewatering.

To address the predictive uncertainty associated with the groundwater flow paths, further analysis has been made regarding the parameterisation of the model realisations. The results of the analysis are presented in Figure 3-24 and show the averaged spatial distribution of the calibrated hydraulic conductivity (geometric mean) for the 80% and 20% clusters. The comparison clearly shows hydraulic conductivity to the northeast of the EP is lower for the 80% cluster and higher for the 20% cluster. This finding is logical in that the higher hydraulic conductivity of the 20% cluster would facilitate the escape of particles from the EP.

This predictive uncertainty analysis shows (i) the hydraulic conductivity of aquifers to the northeast of the EP is critical for the particle tracking assessment, with the predictions sensitive to small changes in hydraulic conductivity, and (ii) the current calibration targets do not provide enough constraint on the hydraulic properties in this area. To improve the confidence in future predictions, further hydraulic tests (e.g. pumping tests and/or rising/falling head tests) would need to be completed in the areas northeast of the FHGP. Environmental monitoring in these areas during and post operations is also recommended. However, given seepage from the Fountain Head pit and EP are unlikely to pose a threat to downstream receptors, the current predictive uncertainty regarding solute transport is considered adequate.

PNX has committed to collecting further site-specific data which will entail hydraulic tests (e.g. pumping tests and/or rising/falling head tests) and will include several monitoring bores in the areas northeast of the FHGP. Should the results of the site-specific data be materially different to those used in the current model, the model will be updated and re-run accordingly. If the values are representative of the previous data used, model updates will not be required. Environmental monitoring will also take place during, and post operations as outlined in the FHGP WMP.

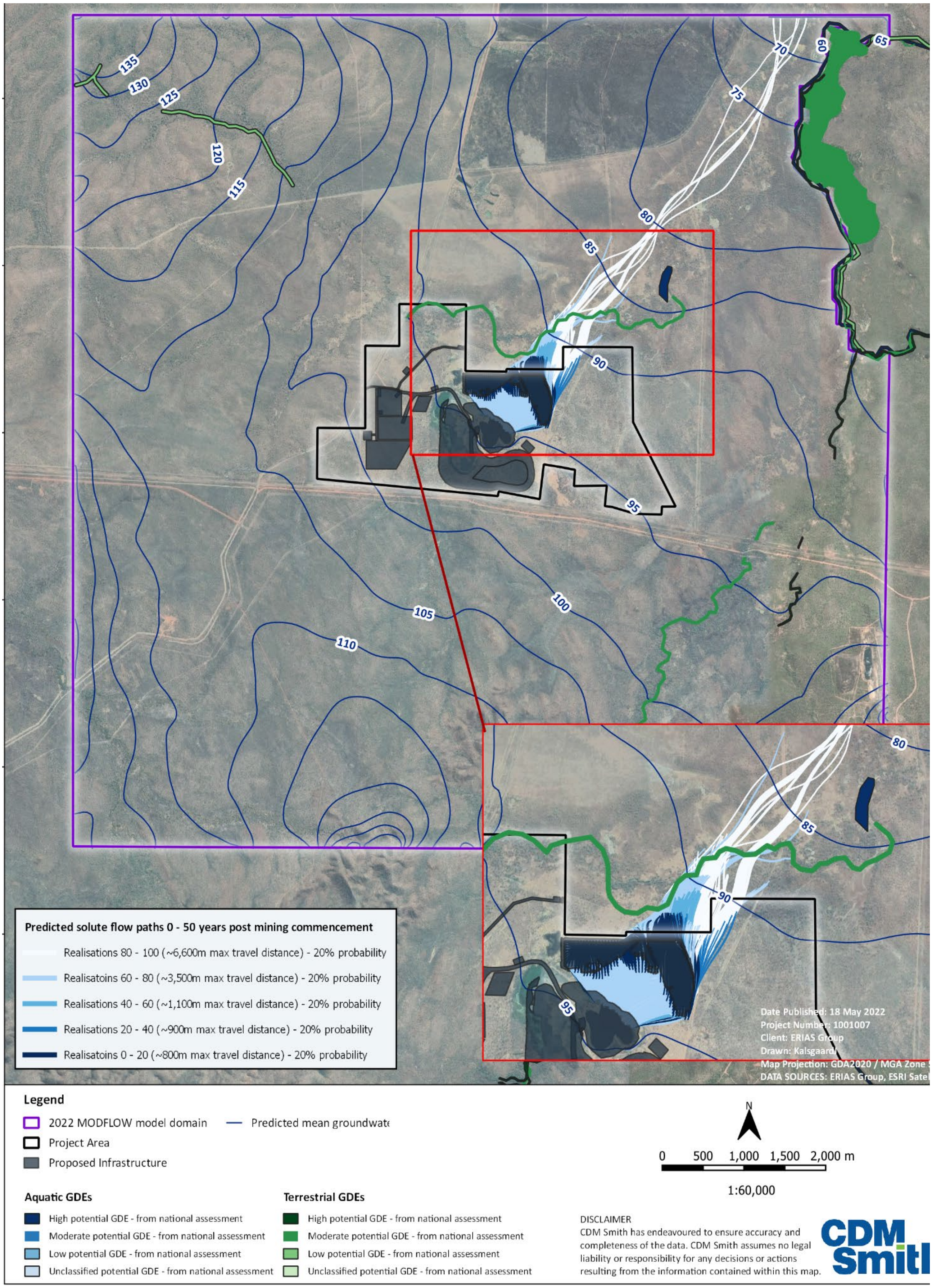

Figure 3-21 Predicted solute flow paths 0 – 50 years post mining commencement

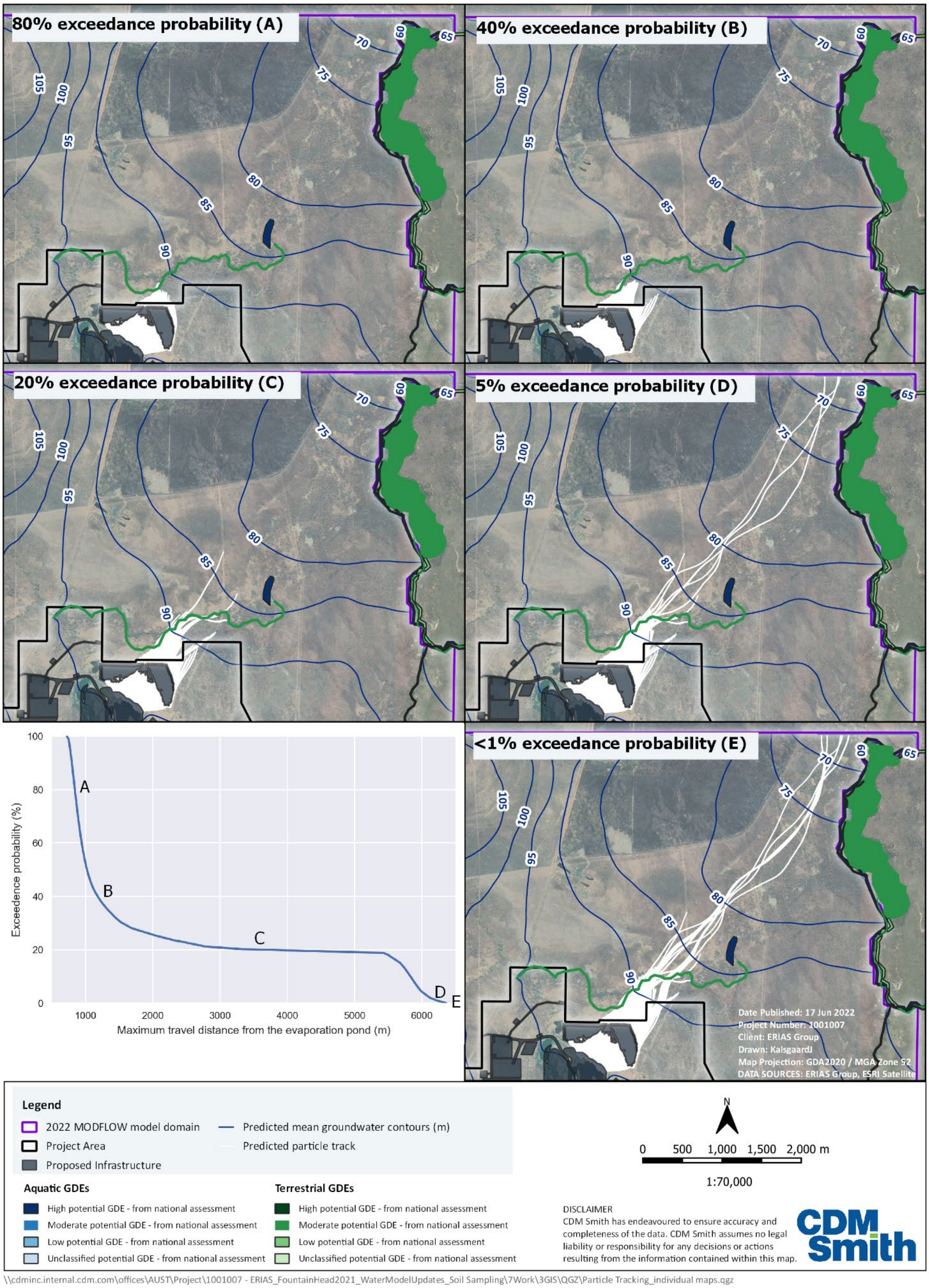

Figure 3-22 Predicted solute flow paths 0 – 50 years post mining commencement

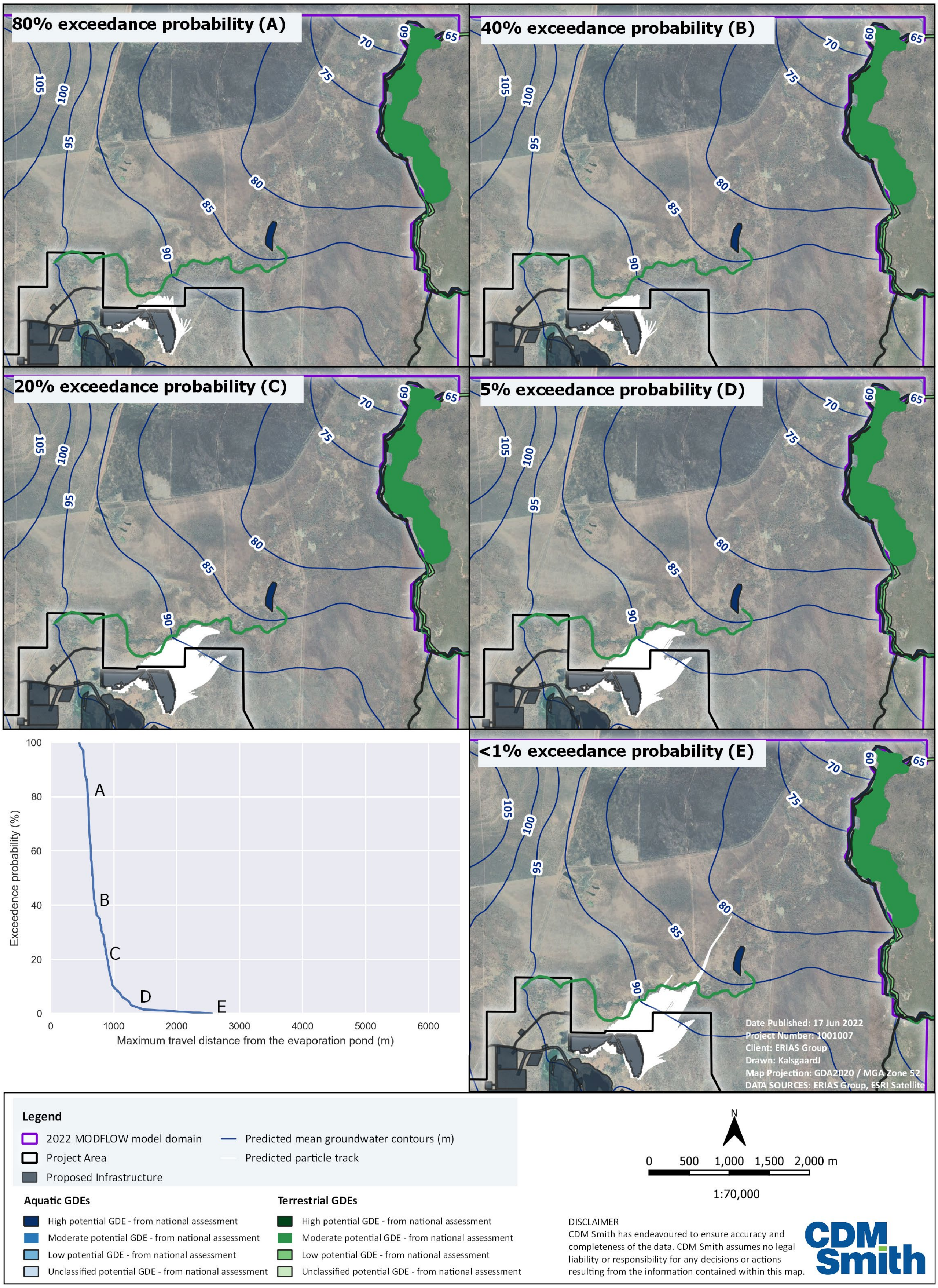

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Figure 3-23 Predicted solute flow paths 40 - 50 years post mining commencement

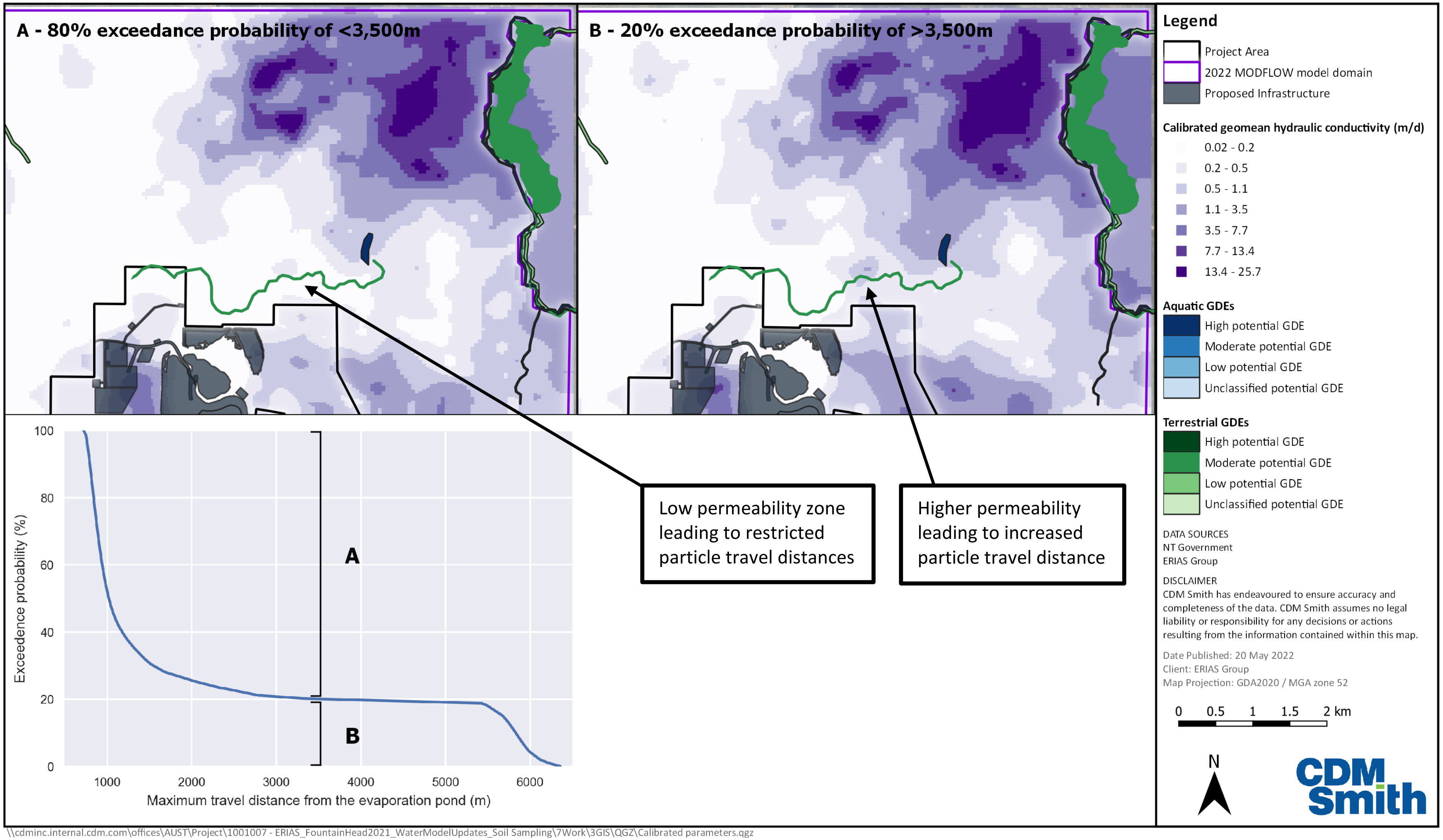

Figure 3-24 Spatial distribution of hydraulic conductivity for 80% (left) and 20% (right) of model realisations

3.3.9 Model Capability Statements

Most, if not all, groundwater models are subject to simplifying assumptions and limitations. The groundwater model developed in this work is subject to the following assumptions and limitations:

- The study site is cut by a series of faults (URS 2006 and PNX 2020), due to a lack of information on the orientation and dimensions of the fault zones, it is difficult to characterise the effects of the faults in the groundwater model. Hence the fault zones are not considered in this assessment. This limitation, however, is expected to be addressed to some extent through the use of pilot points, which introduces spatial heterogeneities into the model that are supported by the field observations.
- Given the nature of fractured rock aquifers and the nominal pilot point separation distance of 250 m, and the fairly sparse monitoring bore network, the model is unlikely to capture all the local scale heterogeneities, some of which may have considerable control on local groundwater flow dynamics as they may act as recharge or discharge boundaries.
- Two key model inputs, including pit water levels and evaporation seepage recharge rates, are informed by the GoldSim WBM. Therefore, the predictive capability of the groundwater model is largely dependent on the quality of the WBM estimates.
- Only the major water courses are considered in this study, noting that they are largely ephemeral.
- The model does not directly consider the influence of the unsaturated zone on recharge timing or other spatial variability.
- The model does not consider the influence to recharge rates from site infrastructure other than the EP and Fountain Head pit.
- The impact of climate change on the model prediction was assessed where future groundwater recharge was varied by using different calibrated recharge-to-rainfall ratios from the 100 model realisations.

Section 4 Conclusions and Recommendations

4.1 Conclusions

Further groundwater flow modelling has been completed to update the previous 2021 MODFLOW model and improve the model confidence. The update included incorporation of additional publicly available data as well as additional transient monitoring site data to better constrain the calibration. Further improvements to the calibration were made by incorporating spatial heterogeneity over the model domain and adjustment of hydraulic parameterisation. The following conclusions have been made regarding the updated 2022 MODFLOW model results:

- The groundwater model results for the current and long-term recovery conditions suggest the Fountain Head pit lake acts as an evaporative sink with a minor groundwater throughflow component, where regional groundwater flows from the southwest towards the northeast.
- During active dewatering, the mean groundwater drawdown extent of 1 m or more, based on the average of 100 model realisations, is predicted to range from 750 m to 1,600 m from the pit. It is likely the drawdown will capture much of the water that infiltrates through site infrastructure and beneath the EP as seepage to the water table while groundwater recovery takes place up until throughflow conditions are restored.
- Groundwater drawdown is expected to have a negligible impact on GDEs, with up to 1 m drawdown predicted at the potential terrestrial GDEs located in the un-named creek directly north of the site and around 0.1 m to the west and eastern edges of the creek. No drawdown has been predicted within the vicinity of aquatic GDEs with the perennial billabong located to the site’s northeast residing outside of the zone of influence.
- Post mining predictions reveal a residual drawdown of around 0.1 m to greater than 5 m exists around the pit and EP at 10 years post mining with groundwater levels predicted to fully recover within 40 years following operations.
- Particle tracking results (i.e. the potential fate of any leachate that may enter the water table from beneath the proposed EP and the Fountain Head pit) suggest the probability of any groundwater flow path maximum travel distance exceeding 3,500 m is low (20%) with the majority of realisations (80%) predicting a maximum travel distance less than 3,500 m in a northeast direction, downgradient of the FHGP.
- No direct interaction of groundwater flow paths and aquatic GDEs is predicted, however, there is a 40% probability of groundwater flow paths intersecting potential terrestrial GDEs located in the un-named creek immediately north of the site within a 50-year period. However, groundwater flow to these receptors should not be construed as an adverse effect, as disruption of the GDEs would partly be a function of solute concentrations within the Fountain Head pit and the degree to which they become diluted along the pathway.
- A degree of uncertainty exists in the model predictions and most notably to the northeast of the Fountain Head pit which is observed by the large range in predictions for both groundwater drawdown and maximum particle tracking distances.
- The predictive uncertainty can best be explained by differences in hydraulic conductivity between the 100 model realisations to the northeast of the EP, where a higher permeability exists over this area in realisations with the farthest maximum travel distances of particles. This suggests the current calibration data does not provide enough constraint on the hydraulic properties in this area.
- However, noting the impact to receptors associated with groundwater drawdown and pit lake and EP water quality are predicted to be negligible, the current level of predictive uncertainty is considered adequate for predicting and assessing the impacts of the Project on the receiving environment.

4.2 Recommendations

Based on the current state of knowledge, the areas of greatest uncertainty with regards to the risk posed by the Project resides within understanding the nature of the groundwater system to the site's northeast and how this system interacts with potential GDEs. The modelling results demonstrate the current level of uncertainty is sufficient to determine these risks, which, as discussed are considered acceptable (low). The recommendations, therefore, are focused on enabling greater monitoring of the environment to the northeast of the FHGP.

The following recommendations have been made:

- Six monitoring bores have been recommended for installation by CDM Smith (2021c) to inform future groundwater monitoring. The preliminary locations are presented in Figure 4-1.
- The proposed locations of these monitoring bores should be reviewed with respect to the recent modelling to enable validation of model predictions and ongoing environmental monitoring.
- Testing of these bores to derive further site-specific hydraulic properties and water quality sampling.
- Continue existing environmental monitoring (i.e. groundwater / surface water gauging and water quality sampling) at the FHGP, especially in areas north and northeast of the site during mining and post operations as per PNX's commitments in the FHGP WMP.
- Update of the conceptual site model (if drilling indicates vastly different results) and further refinement on the understanding of potential terrestrial GDEs and how these are likely to be connected, or not connected to the groundwater system.
- Updates to the hydrogeochemical and groundwater modelling should be considered upon further development of the FHGP and additional field-based data is collected, E.g., one year after completion of the future works program. This may simply involve consideration of whether the additional data changes the risk profile of the Project and/or modelled predictions.

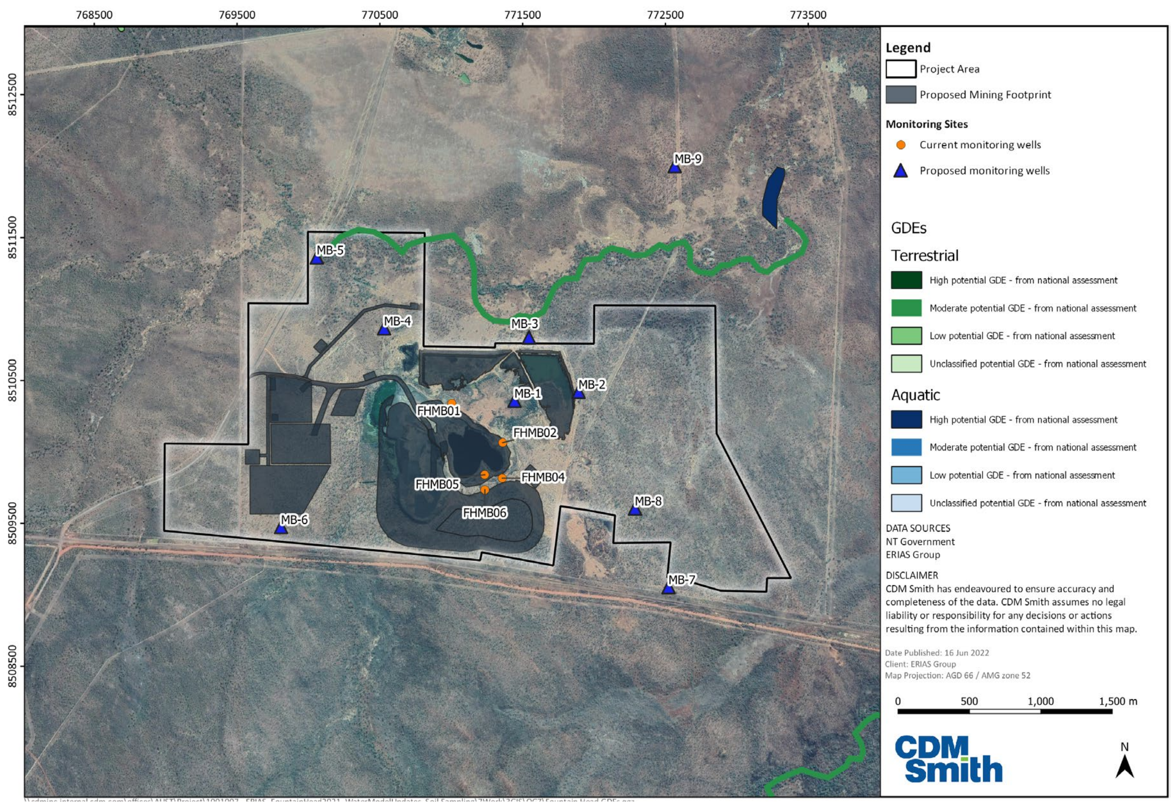

Figure 4-1 Proposed monitoring wells (preliminary) (CDM Smith, 2021c)

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Appendix A Groundwater Dependent Ecosystem Conceptualisation

A.1 Introduction

Regulatory comments submitted to PNX in response to the Supplementary EIS requested a revised assessment of the risk to groundwater dependent ecosystems (GDEs) be undertaken in light of identified “moderate” likelihood GDEs being identified within the study area. The Fountain Head Gold Project (FHGP) supplementary EIS, submitted in late 2021 identified three broad vegetation types as being present within the study area:

1. Melaleuca woodland (Veg unit No. 316).
2. Eucalyptus woodland (Veg unit No. 572).
3. Pastoral/horticultural roads (Veg unit No. 1064), i.e. Acacia holesericea, Calytrix sp., Gamba grass, (Andropogongayanus), hyptis (Hyptissuaveolens), mission grass (Cenchrus pedicellatus).

It is probable these vegetation classes will occur within the moderate likelihood GDE areas in the study area, which was identified using the national assessment methodology of the GDE Atlas (BOM, 2022), which reside within riparian areas to the north of the mining lease in and around the unamed creek (Figure 1). Riparian GDEs such as Eucalyptus and Melaleuca woodland are likely to have the ability to access and use groundwater (i.e. they may be phreatophytes), and are therefore the focus of this response. A high potential aquatic GDE (located northeast in Figure A1) identified by ERIAS as a perennial billabong and culturally signficant site, resides outside the predicted drawdown extent and therefore is not included in this discussion.

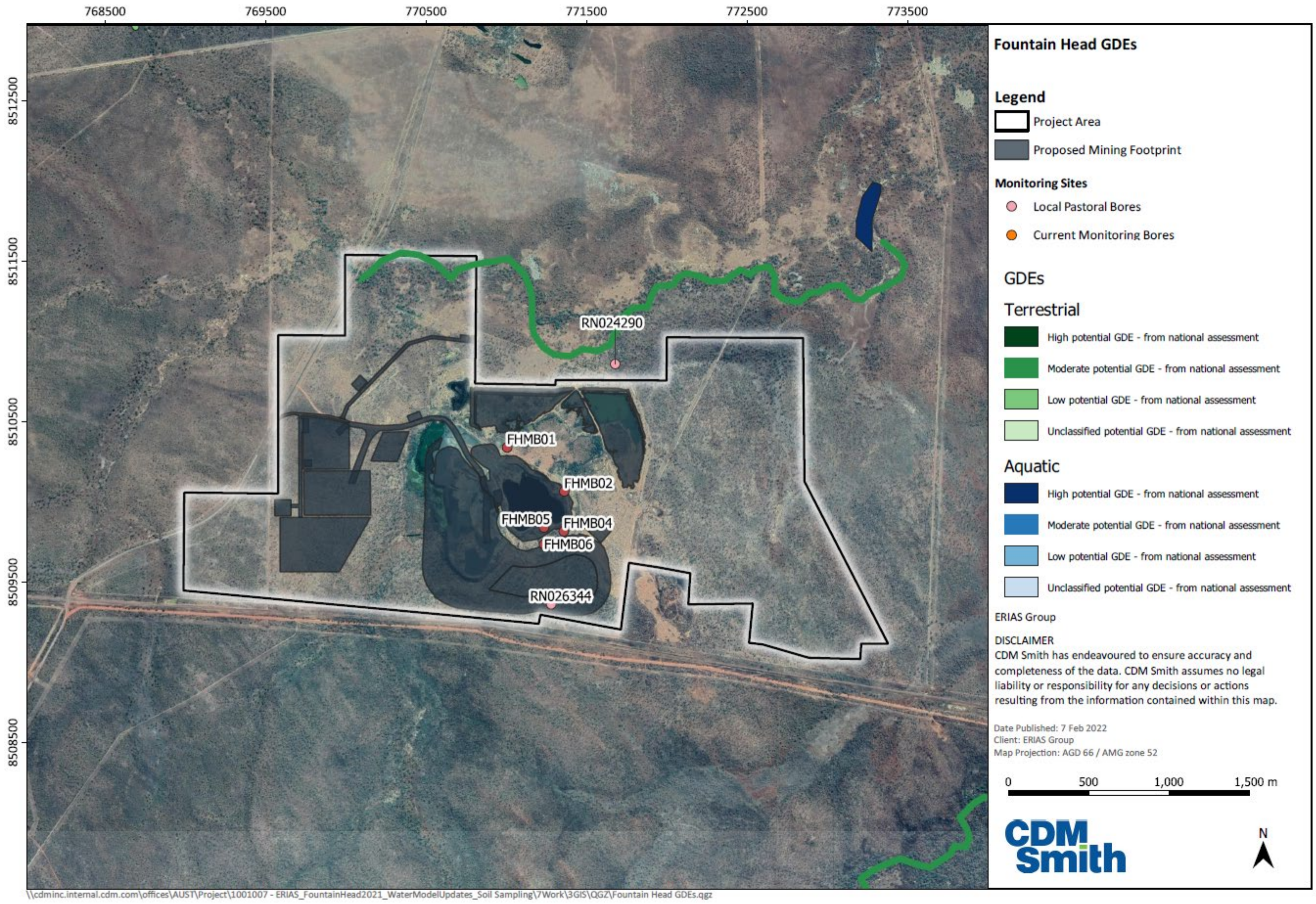


Figure A-1 Fountain Head GDE Likelihood Locality Map

A.2 Root structure and phenology of riparian vegetation

The dominant species associated with the identified GDEs (i.e. Melaleuca leucadendra & M. viridiflora) exist across many Australian environments and are found to occur in a wide range of geological settings. Typically, they are well adapted and resilient to relatively extreme conditions within riparian settings with respect to the timing of water availability. They have the ability to access multiple sources of soil moisture because of their dimorphic root structures (i.e. two distinct root structures – shallow and deep) as shown in Figure A2.

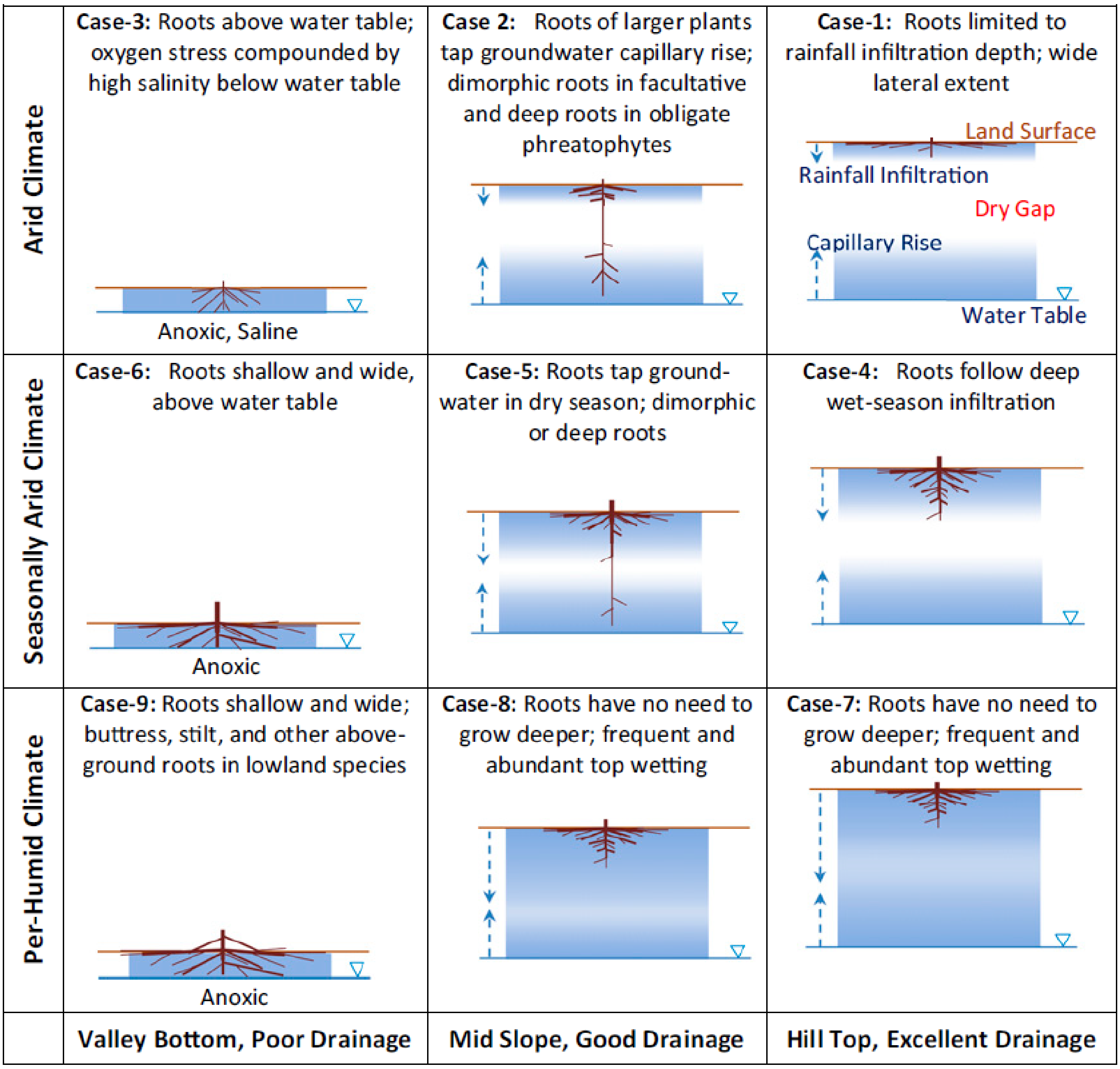


Figure A-2 Hydrologic framework for rooting depths along climate and depth to water gradients (Fan et al, 2017)

The dimorphic root structure is shown in Figure A3 (C) along with photos of riparian vegetation taken in two different environments (A) and (B) in the vicinity of ephemeral creeks overlying bedrock aquifers (Fawcett pers comm., 2021 and Cranswick pers comm., 2021 respectively). The mature trees shown in (A) and (B) have considerable root mass extending laterally, in addition to tap roots directed vertically. Although the vertical extent of the tap roots remain unsighted, depth to groundwater is expected to be on the order of many metres given the nature of creek flow (ephemeral), position in the landscape and a semi-arid climate.

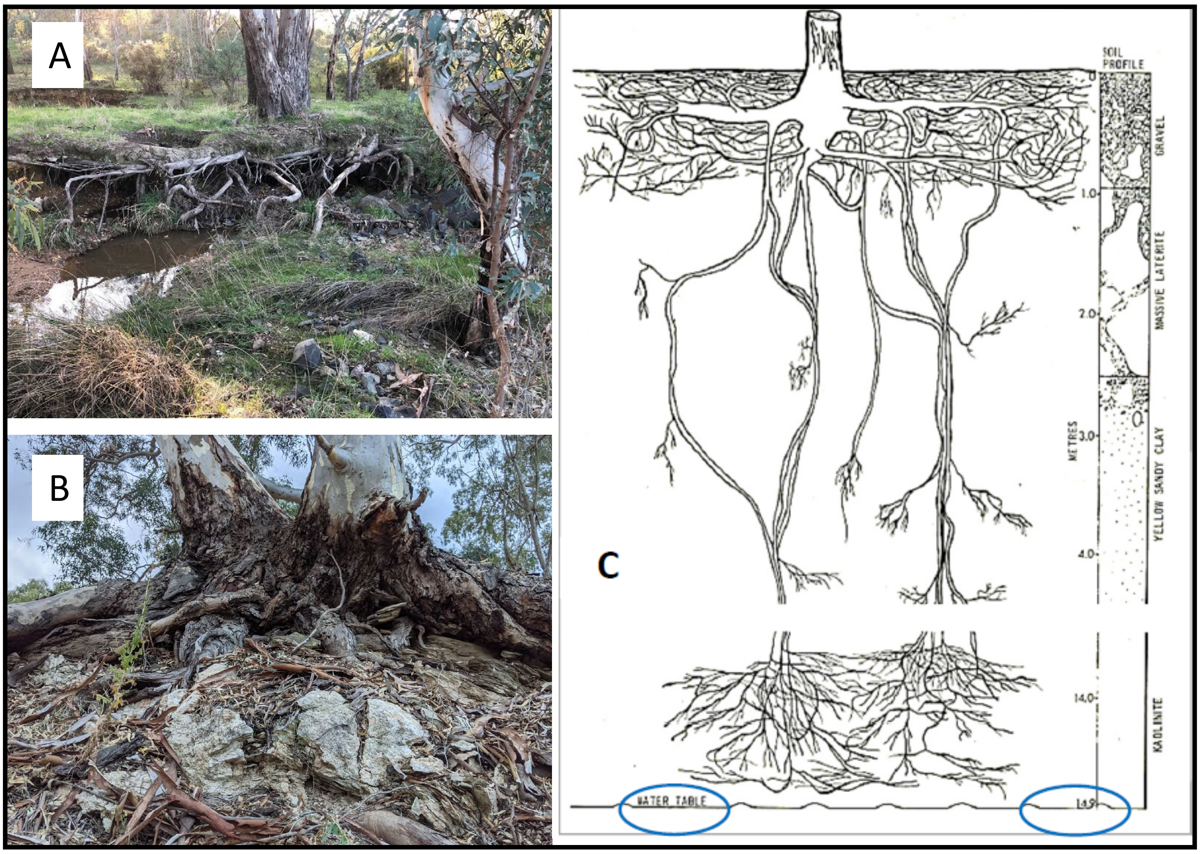


Figure A-3 Root structures of RRGs (*Eucalyptus camaldulensis*) (A) Castlemaine Victoria, (B) Adelaide South Australia, and (C) dimorphic root structure of Jarrah (*Eucalyptus marginata*) in Western Australia (Kimber 1974)

One of the most well-known citations related to maximum rooting depth is a global meta-analysis by Canadell et al. (1996). Of relevance to the FHGP are the grouping of data from sclerophyllous trees (data comprised partly from Eucalypt species), having an average maximum rooting depth of 12.6 m (n = 11). Fan et al. (2017) reports a mean maximum rooting depth for Eucalypts of 8.71 m (n = 45). Eucalypts in Australia have been shown to use groundwater from a range of depths for example: >13 m (Salient Solutions, 2007) and up to 16 m (Salama et al., 1994). As discussed by Zolfaghar et al. (2014; 2015) there may be differences in the nature of and ability of trees to use groundwater when comparing vegetation with relatively shallow to deep groundwater sources. It should also be noted, that phreatophytes access the capillary fringe above the water table (rather than the saturated groundwater itself) and have maximum rooting depths that are generally correlated with the depth just above the watertable (Fan et al., 2017).

In addition to having both shallow and deep root systems, Eucalypts have shown physiological responses allowing them to adapt to water stress (i.e. drought and flood). Doody et al. (2015) found that trees reduce sapwood area and water use to minimise plant stress and damage to leaves when water is scarce, and then respond with increased transpiration and sapwood growth when water becomes available again. In periods of greater water stress, stomata in leaves will close to maintain xylem pressure and prevent leaf death. As dry conditions continue, leaf shedding occurs to regulate water loss. The authors describe this as a rapid readjustment of transpiration and leaf area, that followed a period where increased shallow root density had taken advantage of shallow water availability through flooding the previous winter.

Hydraulic redistribution is a process where a root systems of plants move water through root xylem from areas of higher to lower water availability. Bleby et al. (2010) show that during periods of drought, deep roots (up to 20 m bgs) contributed up to five times more water to transpiration and hydraulic redistribution than shallow roots. Meanwhile following periods of rainfall shallow roots redistributed water to other shallow roots while the deep root system was inactive (Bleby et al., 2010).

A.3 Conceptual model of riparian vegetation water sources

The use of remote sensing data to monitor the condition of riparian vegetation has been undertaken previously by CDM Smith on separate projects to characterise the vegetation responsiveness to rainfall. This approach utilises NDVI (normalised difference vegetation index) to infer the vegetation response. Figure A4 presents an example timeseries NDVI dataset from which the following points describe the key attributes of three vegetation types derived from the example NDVI data:

- **Dense riparian forest** shows seasonal variability in NDVI in response to wet season rainfall (i.e. with median NDVI ranging from around 0.4 to 0.8) suggesting vegetation has access to multiple water sources independent of seasonal rainfall and has an extended growing period, classified as ‘Slow Drying’.
- **Open riparian forest** shows similar seasonal variability in response to rainfall (i.e. more than doubling in NDVI following the 2019/20 wet season rainfall from a median NDVI of around 0.25 to 0.7) and a slightly wider range of NDVI values than the open riparian forest at some sites, suggesting a reliance on both shallow and deeper sources of soil moisture, classified as a combination of ‘Slow and Fast Drying’.
- **Grassland** shows very large seasonal variability in response to rainfall (i.e. NDVI rises rapidly from around 0.2 to almost 0.9 in response to 2019/20 wet season rainfall before declining back to a value of around 0.2) and has a relatively narrow NDVI distribution, suggesting a reliance on shallow soil moisture availability and dependence on seasonal rainfall with a limited growing period, classified as ‘Fast Drying’.

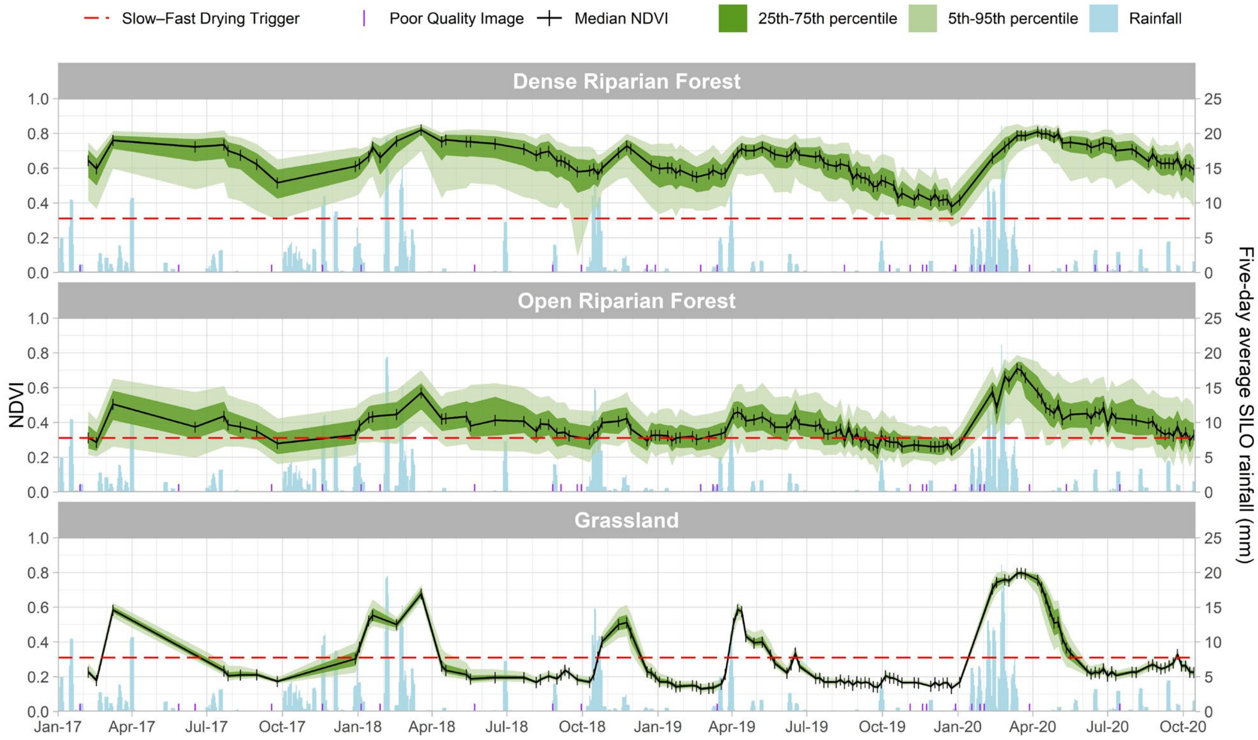


Figure A-4 Example of Sentinel-2 NDVI analysis for vegetation patches at RS5 (note: red dashed line is the NDVI trigger, vertical tick red marks indicate poor quality images) (CDM Smith 2020a)

The NDVI analysis shows vegetation responds positively with an increase in NDVI following rain events which is driven primarily by seasonal rainfall. Of note is the similar response across each vegetation class (i.e. dense riparian forest, open riparian forest and grassland) where despite differences in access to water sources across the vegetation classes, and the resulting variability of the NDVI, the vegetation classes generally follow the same trend in response to rainfall.

This demonstrates that these riparian vegetation ensembles are fundamentally driven by rainfall rather than access to groundwater.

Though this dataset does not reflect the riparian vegetation within the FHGP study area, it is conceptualised that the vegetation response will be similar. This can be further demonstrated by comparison against seasonal rainfall at the FHGP (Figure A5), where clear wet and dry seasons are observed. Similar to the example provided, seasonal rainfall at FHGP is thought to be the primary driver of vegetation condition where vegetation growth follows periods of sustained rainfall.

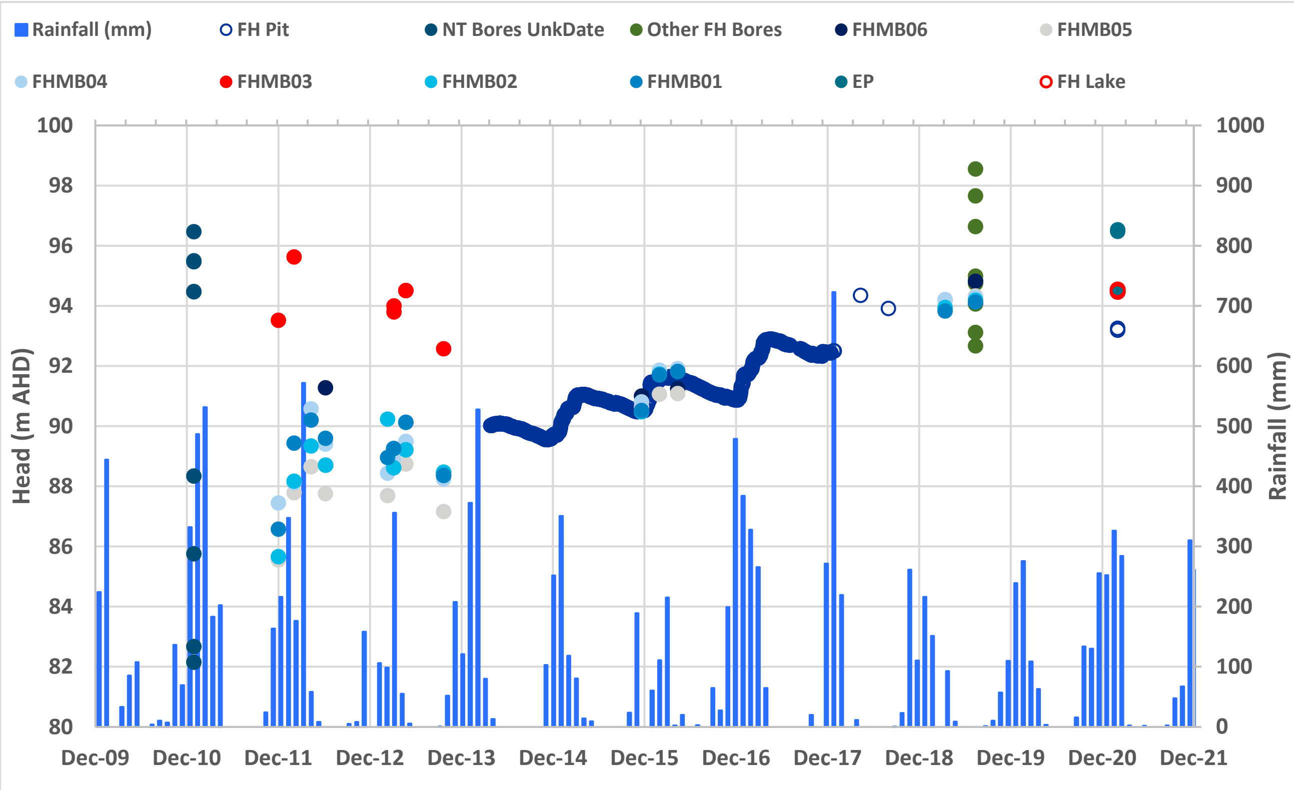


Figure A-5 Fountain Head Groundwater Monitoring and Rainfall

Our understanding of the riparian vegetation response to rainfall is further conceptualised in Figure A6. This model shows how semi-arid flood plain ecosystems respond to wetting and drying phases in terms of biomass. The concept proposed by Colloff and Baldwin (2010) is that the resilience of the system is a function of how the transition between wet and dry phases occurs, which may have a cycle frequency of many years. Consistent with the NDVI data shown in Figure A4, the model suggests biomass increases and is sustained by significant rain events for years following these events. It is thought the riparian vegetation surrounding the FHGP exist according to similar drying and wetting phases. For the majority of the time, they will be existing within a drying phase before being disturbed by an episodic wet phase. Through this cycle they have developed a resilience to these associated changes in water availability over longer time periods (as demonstrated by their existence and the distribution of rainfall at FHGP).

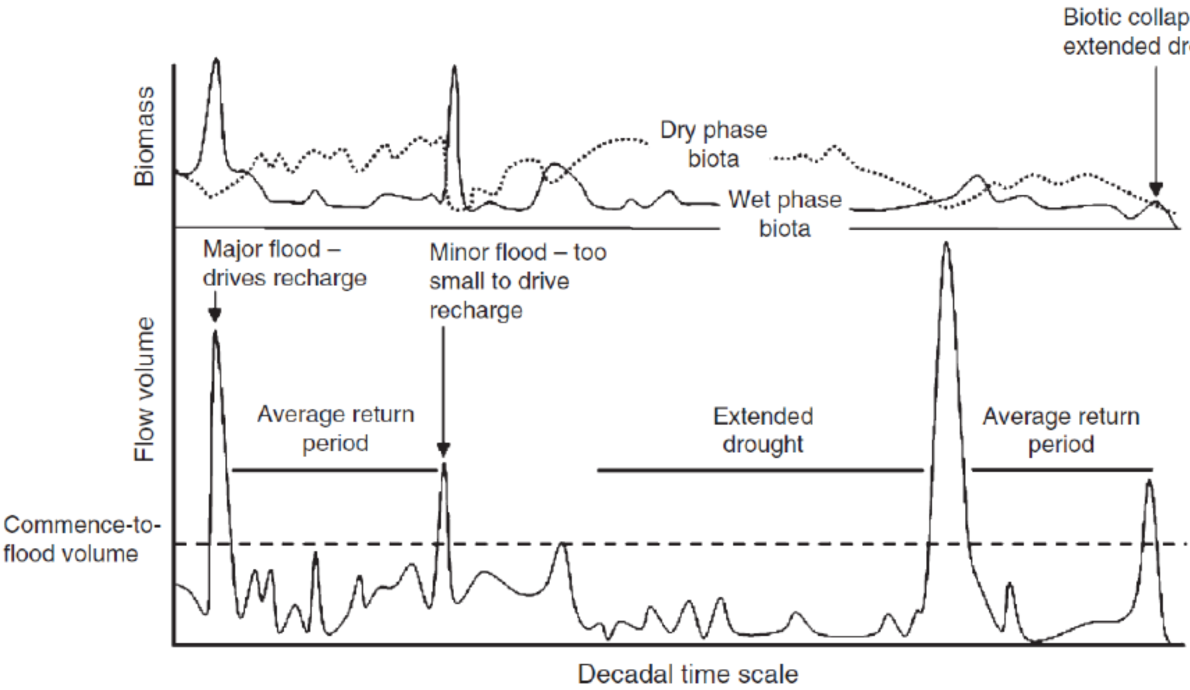


Figure A-6 **Conceptual Model of Wet and Dry Phase Biomass Production (Colloff and Baldwin, 2010)**

A.4 Site vegetation observations

Photographs of the riparian vegetation from an ephemeral creek at the Fountain Head site are provided in Plate A1. As can be seen, the vegetation is relatively uniform with little variation in size in terms of height and tree girth. Based on these observations, there is no evidence to suggest groundwater contributes to streams due to the riparian vegetation being non-significantly larger than trees across the woodland areas and the absence of mesic species within the drainages. If the riparian trees have an additional source of water (i.e. groundwater) they would be distinctly larger than the woodland trees (taller, larger girth). In addition, the girth of the trees does not suggest a consistent third source of water, as they are relatively narrow. It is more likely growth is controlled by rainfall patterns as opposed to a permanent source of water that is stable and not impacted by seasonal rainfall (i.e. groundwater).

Plate A-1 **Fountain Head Riparian Vegetation**

These observations are mirrored by additional site photographs presented in Plate A2 which shows several surface water sampling locations at the FHGP (Figure A1), noting the absence of mesic species and lacking tree girth. Due to the drainages being ephemeral and observations suggesting a lack of groundwater dependent vegetation, it is likely the streams are that of 'losing' streams, i.e. lose water to the underlying water table.

It should also be noted it is likely the condition of the FHGP riparian zone is affected by a number of processes (i.e. bank erosion, surface water flows etc) that are likely to have a larger impact on the local vegetation than the presence of underlying groundwater.

Plate A-2 ERIAS Aquatic Sampling Locations (S6 left, S7 right)

A.5 Conclusions

The following conclusions are made with regard to the riparian vegetation at the FHGP:

- The dominant species associated with the FHGP (i.e. Melaleuca leucadendra & M. viridiflora) exist across many Australian environments being well adapted and resilient to relatively extreme conditions within riparian settings with respect to the timing of water availability.
- Seasonal rainfall at the potential GDEs is thought to be the primary driver of vegetation condition supplemented by episodic surface water flood events.
- The water table is considered to be deeper than the drainage lines. This is based upon the fact that there is no groundwater discharge into the creek line (unnamed creek) as they are ephemeral and during no-flow periods have no surface water present. During no flow periods, the creek line acts as a recharge zone to the water table.
- Photographs of the potential GDEs demonstrate that the riparian vegetation is a similar size to non-riparian vegetation suggesting a significant additional source of water (i.e. groundwater) is not present to enable the presence of large height and girth riparian vegetation.
- This does not discount the idea that there may be some groundwater use among riparian trees, however, the current eco-physical explanation is that these trees are resilient and adaptive to changes in water sources. The trees dominant water source will be from direct rainfall and bank storage after surface flow events. A minor component may be derived from groundwater; however, this is expected to be a minor component of the trees environmental water requirements.
- The current condition of the potential GDEs are already affected by a number of processes (e.g. bank erosion and grazing from current pastoral land use) that reduce the condition of the vegetation. The condition and resilience of this vegetation can be improved by appropriate land management practices.

Appendix B Chloride Mass Balance

Groundwater recharge will occur predominantly via rainfall infiltration to underlying sediments and, through groundwater recharge in ephemeral water courses within the region. The rate of recharge will be constrained by evapotranspirative losses from the upper soil and sediment layers. Furthermore, it is likely only higher intensity/duration rainfall events that result in surface ponding or ephemeral flow will result in significant recharge, with rainfall from lesser events evaporating prior to or soon after infiltration.

Recharge has been calculated using the chloride mass balance (CMB) method (Eq. 1; Wood, 1999), which assumes:

- Chloride in groundwater originates only from precipitation.
- Chloride is conservative in the system.
- The chloride mass flux is constant over time and there is no recycling or concentration of chloride within the aquifer.

$$q = \frac{P.Cl_p}{Cl_{gw}} \qquad \text{Eq.1}$$

where: $q = groundwater\ recharge\ rate\ (LT^{-1})$
$P = average\ rate\ of\ precipitation\ (LT^{-1})$
$Cl_p = average\ concentration\ of\ chloride\ in\ precipitation\ (ML^{-3})$
$Cl_{gw} = average\ concentration\ of\ chloride\ in\ groundwater\ (ML^{-3})$

A representative rainfall chloride concentration for the FHGP has been determined using the mean chloride concentration reported for Darwin rainfall samples (Crosbie, 2012). Combining these data with the annual average rainfall from Douglas River Research Farm (BOM station 14901) (1,200 mm/y), the recharge rate for the project area has been estimated to be around 200 mm/y (approximately 16% of annual rainfall) for a 1% AEP 72hr storm event and using the geometric mean of the dataset. Table A-1 lists the estimated recharge based on the reported groundwater chloride concentrations of the FHGP groundwater monitoring wells.

Table A-1 Calculated groundwater recharge using chloride mass balance method

Sample ID	Groundwater Chloride (mg/L)	Rainfall Chloride (mg/L) [1]	Average Rainfall (mm/yr)	Recharge %	Recharge (mm/yr)	Rainfall 1%AEP 72hr (mm)	Recharge mm/72hr
FHMB01	6	1.9	1200	31.67%	380.00	439	139.02
FHMB01	6	1.9	1200	31.67%	380.00	439	139.02
FHMB01	3	1.9	1200	63.33%	760.00	439	278.03
FHMB01	6	1.9	1200	31.67%	380.00	439	139.02
FHMB01	6	1.9	1200	31.67%	380.00	439	139.02
FHMB01	7	1.9	1200	27.14%	325.71	439	119.16
FHMB01	7	1.9	1200	27.14%	325.71	439	119.16
FHMB01	6	1.9	1200	31.67%	380.00	439	139.02
FHMB01	6	1.9	1200	31.67%	380.00	439	139.02
FHMB01	6	1.9	1200	31.67%	380.00	439	139.02
FHMB01	5	1.9	1200	38.00%	456.00	439	166.82
FHMB01	8	1.9	1200	23.75%	285.00	439	104.26
FHMB01	4	1.9	1200	47.50%	570.00	439	208.53
FHMB01	7	1.9	1200	27.14%	325.71	439	119.16
FHMB01	7	1.9	1200	27.14%	325.71	439	119.16

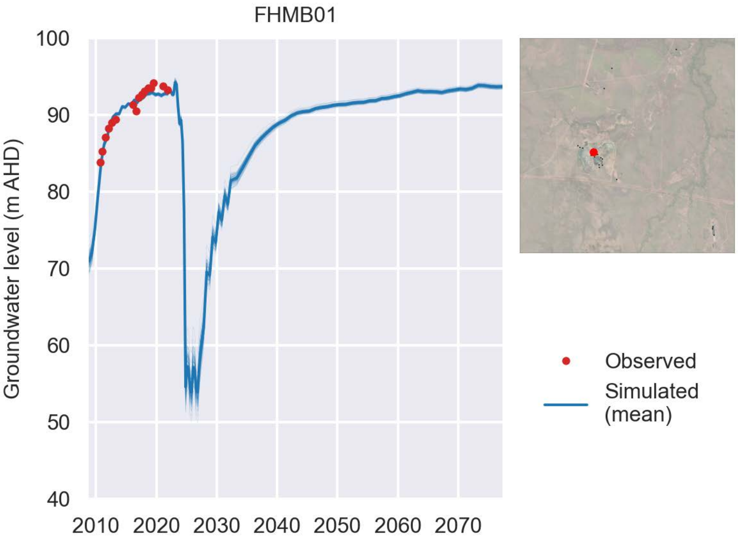
Sample ID	Groundwater Chloride (mg/L)	Rainfall Chloride (mg/L) [1]	Average Rainfall (mm/yr)	Recharge %	Recharge (mm/yr)	Rainfall 1%AEP 72hr (mm)	Recharge mm/72hr
FHMB01	4	1.9	1200	47.50%	570.00	439	208.53
FHMB02	5	1.9	1200	38.00%	456.00	439	166.82
FHMB02	5	1.9	1200	38.00%	456.00	439	166.82
FHMB02	4	1.9	1200	47.50%	570.00	439	208.53
FHMB02	5	1.9	1200	38.00%	456.00	439	166.82
FHMB02	5	1.9	1200	38.00%	456.00	439	166.82
FHMB02	5	1.9	1200	38.00%	456.00	439	166.82
FHMB02	5	1.9	1200	38.00%	456.00	439	166.82
FHMB02	5	1.9	1200	38.00%	456.00	439	166.82
FHMB02	5	1.9	1200	38.00%	456.00	439	166.82
FHMB02	6	1.9	1200	31.67%	380.00	439	139.02
FHMB02	4	1.9	1200	47.50%	570.00	439	208.53
FHMB02	6	1.9	1200	31.67%	380.00	439	139.02
FHMB02	7	1.9	1200	27.14%	325.71	439	119.16
FHMB02	6	1.9	1200	31.67%	380.00	439	139.02
FHMB03	3	1.9	1200	63.33%	760.00	439	278.03
FHMB03	2	1.9	1200	95.00%	1140.00	439	417.05
FHMB03	2	1.9	1200	95.00%	1140.00	439	417.05
FHMB03	4	1.9	1200	47.50%	570.00	439	208.53
FHMB03	2	1.9	1200	95.00%	1140.00	439	417.05
FHMB03	4	1.9	1200	47.50%	570.00	439	208.53
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	6	1.9	1200	31.67%	380.00	439	139.02
FHMB04	5	1.9	1200	38.00%	456.00	439	166.82
FHMB04	6	1.9	1200	31.67%	380.00	439	139.02
FHMB04	6	1.9	1200	31.67%	380.00	439	139.02
FHMB05	2	1.9	1200	95.00%	1140.00	439	417.05
FHMB05	2	1.9	1200	95.00%	1140.00	439	417.05

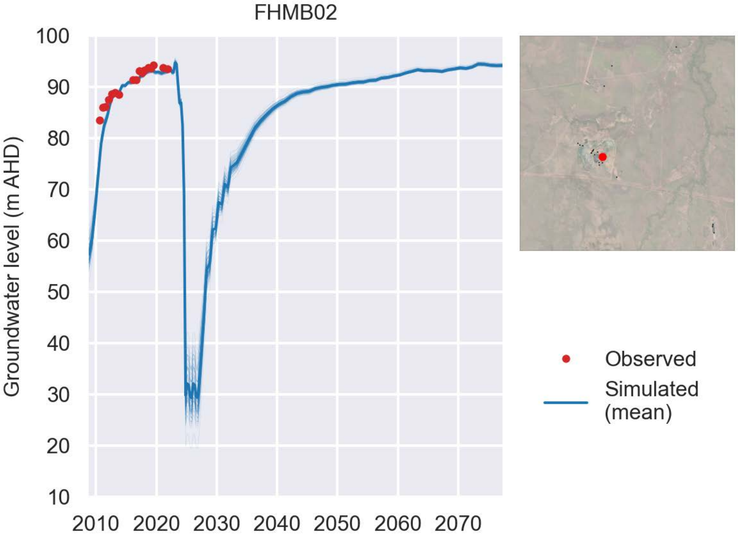
Sample ID	Groundwater Chloride (mg/L)	Rainfall Chloride (mg/L) [1]	Average Rainfall (mm/yr)	Recharge %	Recharge (mm/yr)	Rainfall 1%AEP 72hr (mm)	Recharge mm/72hr
FHMB05	2	1.9	1200	95.00%	1140.00	439	417.05
FHMB05	3	1.9	1200	63.33%	760.00	439	278.03
FHMB05	3	1.9	1200	63.33%	760.00	439	278.03
FHMB05	3	1.9	1200	63.33%	760.00	439	278.03
FHMB05	3	1.9	1200	63.33%	760.00	439	278.03
FHMB05	3	1.9	1200	63.33%	760.00	439	278.03
FHMB05	3	1.9	1200	63.33%	760.00	439	278.03
FHMB05	3	1.9	1200	63.33%	760.00	439	278.03
FHMB05	3	1.9	1200	63.33%	760.00	439	278.03
FHMB05	4	1.9	1200	47.50%	570.00	439	208.53
FHMB05	5	1.9	1200	38.00%	456.00	439	166.82
FHMB05	16	1.9	1200	11.88%	142.50	439	52.13
FHMB06	1	1.9	1200	190.00%	2280.00	439	834.10
FHMB06	7	1.9	1200	27.14%	325.71	439	119.16
FHMB06	2	1.9	1200	95.00%	1140.00	439	417.05
FHMB06	2	1.9	1200	95.00%	1140.00	439	417.05
FHMB06	1	1.9	1200	190.00%	2280.00	439	834.10
FHMB06	1	1.9	1200	190.00%	2280.00	439	834.10

Average	**52.91%**	**634.97**		**232.29**
Geomean	**45.63%**	**547.55**		**200.31**

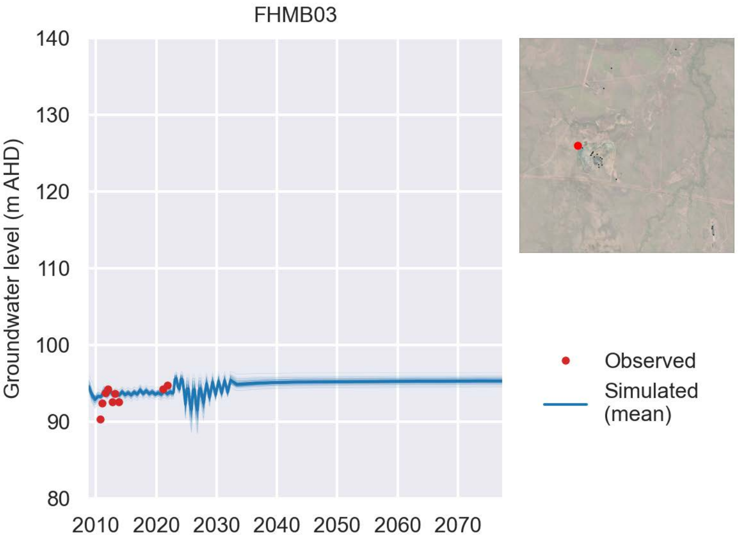
Notes: 1. Darwin rainfall chloride concentrations (Crosbie, 2012)

Appendix C Calibration Hydrographs

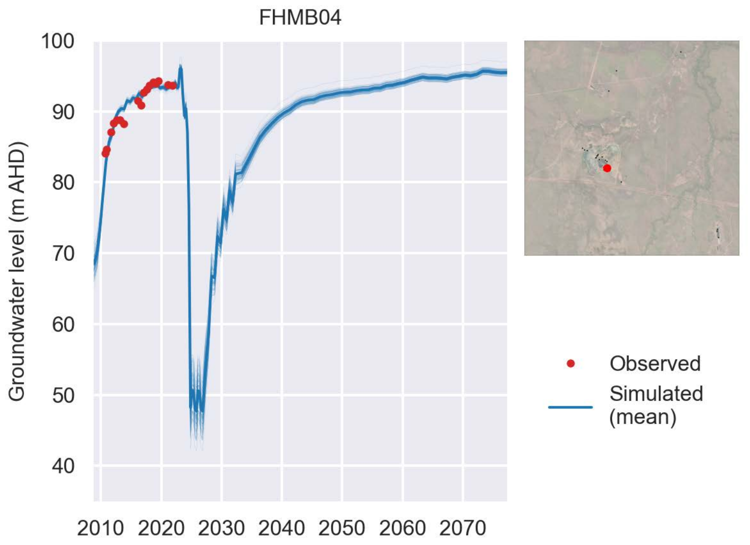

FHMB01
Groundwater level (m AHD)
100
90
80
70
60
50
40
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated (mean)

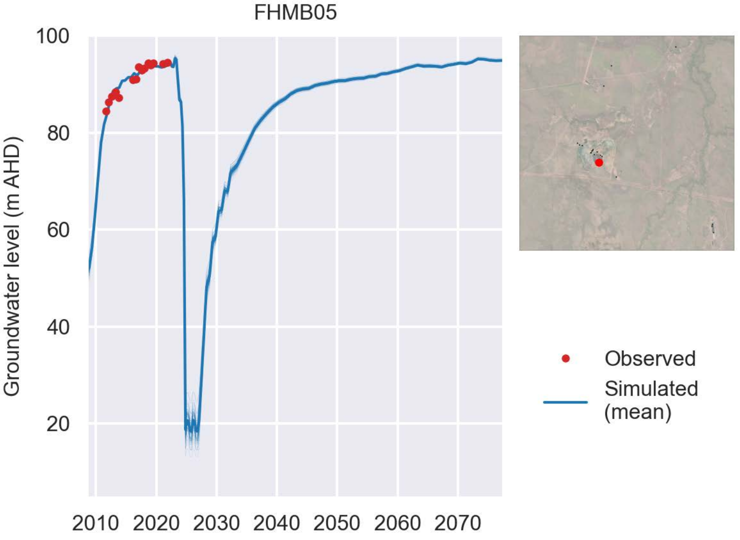


FHMB02
Groundwater level (m AHD)
100
90
80
70
60
50
40
30
20
10
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

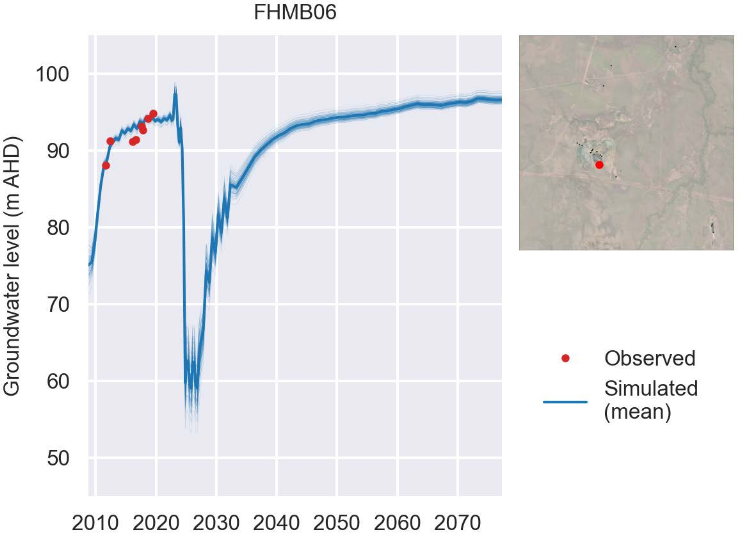


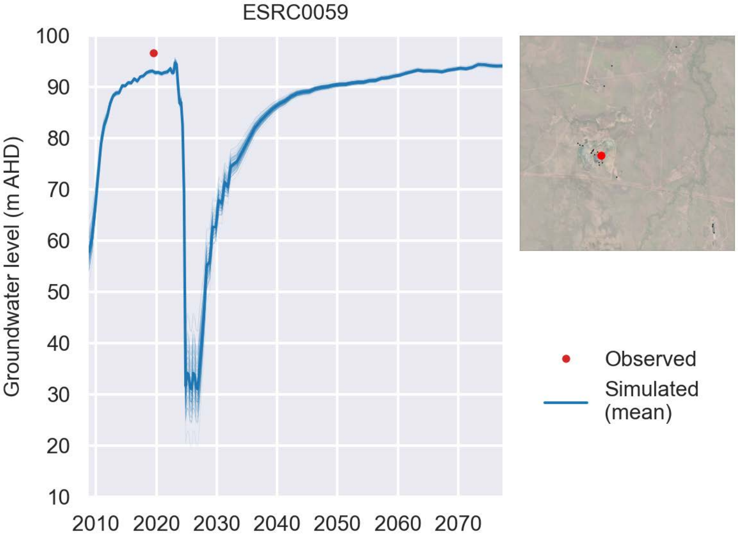
FHMB03
140
130
120
110
100
90
80
Groundwater level (m AHD)
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)


FHMB04
Groundwater level (m AHD)
100
90
80
70
60
50
40
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

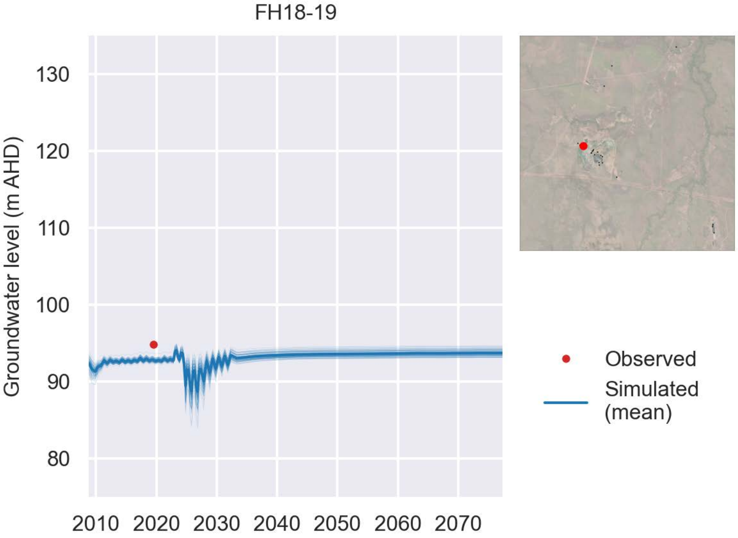


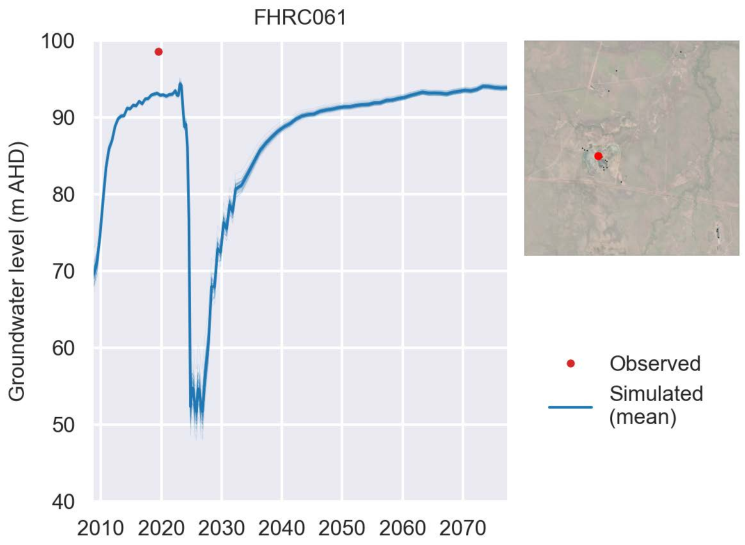
FHMB05
Groundwater level (m AHD)
100
80
60
40
20
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

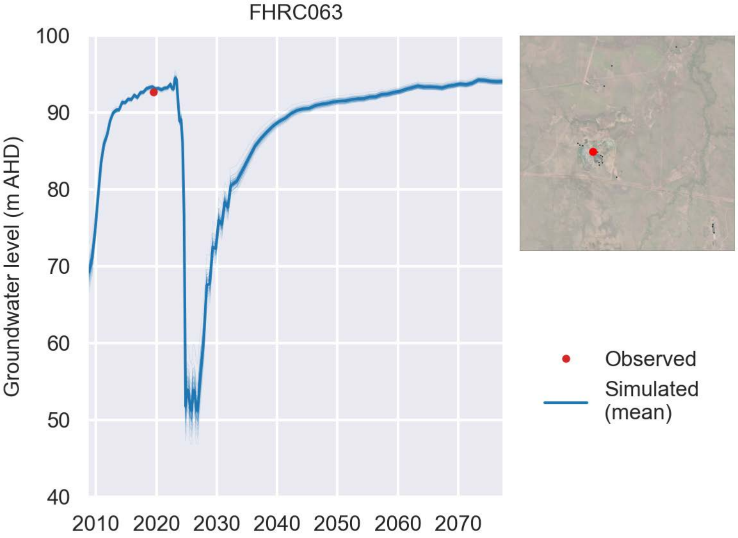

FHMB06
Groundwater level (m AHD)
100
90
80
70
60
50
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

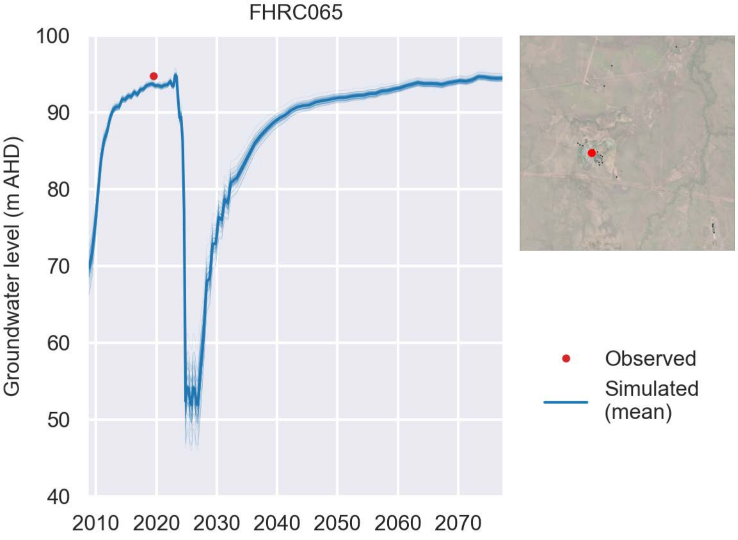


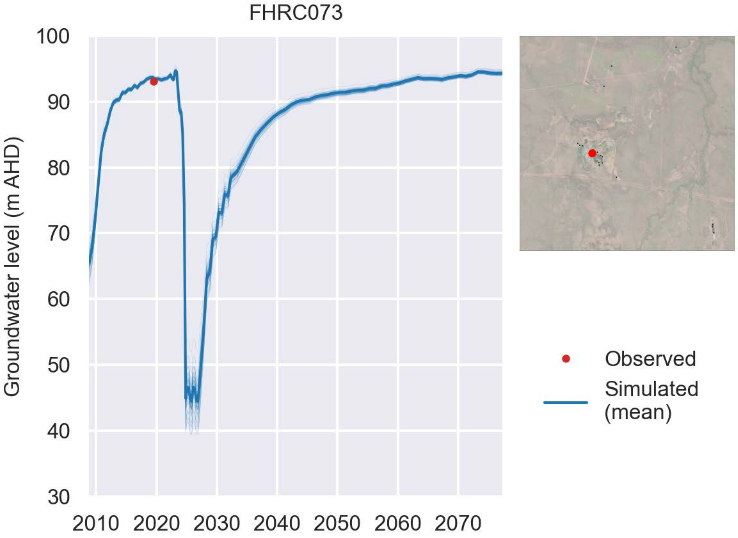
ESRC0059
Groundwater level (m AHD)
100
90
80
70
60
50
40
30
20
10
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated (mean)

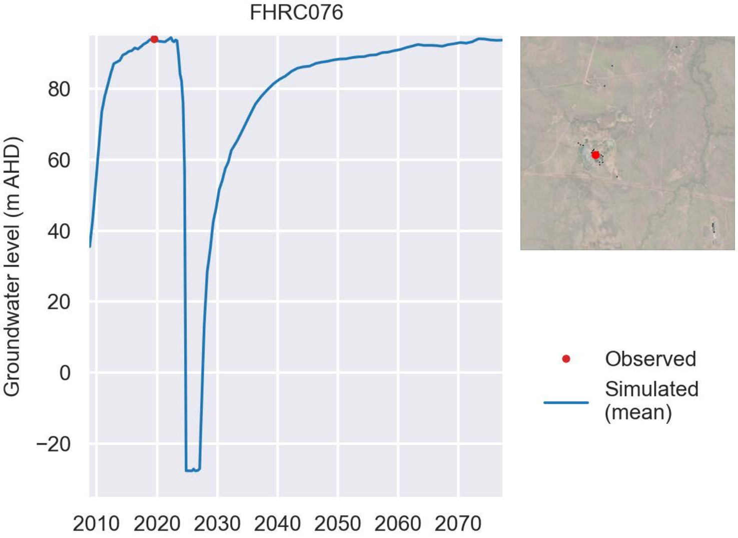

FH18-19
Groundwater level (m AHD)
130
120
110
100
90
80
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

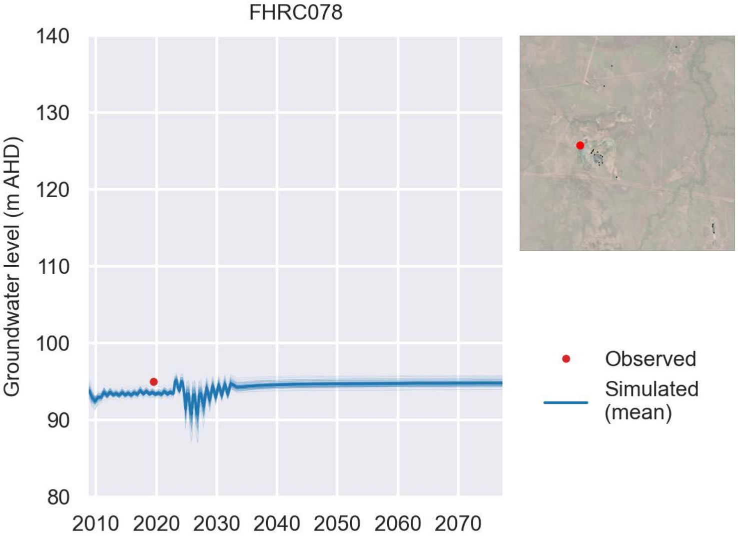

FHRC061
Groundwater level (m AHD)
100
90
80
70
60
50
40
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)


FHRC063
Groundwater level (m AHD)
100
90
80
70
60
50
40
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

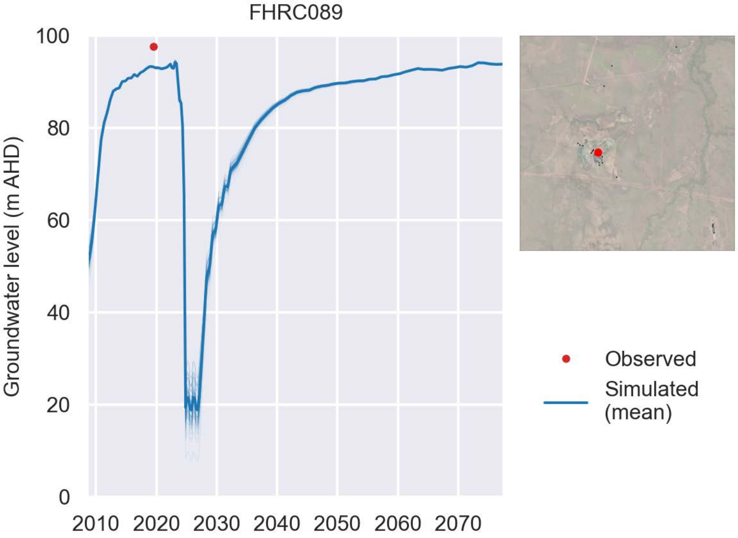

FHRC065
Groundwater level (m AHD)
100
90
80
70
60
50
40
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)


FHRC073
Groundwater level (m AHD)
100
90
80
70
60
50
40
30
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

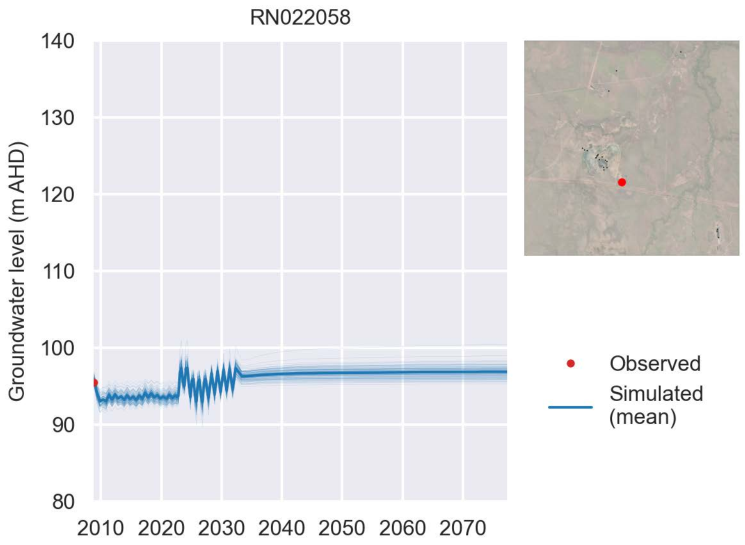

FHRC076
Groundwater level (m AHD)
80
60
40
20
0
−20
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

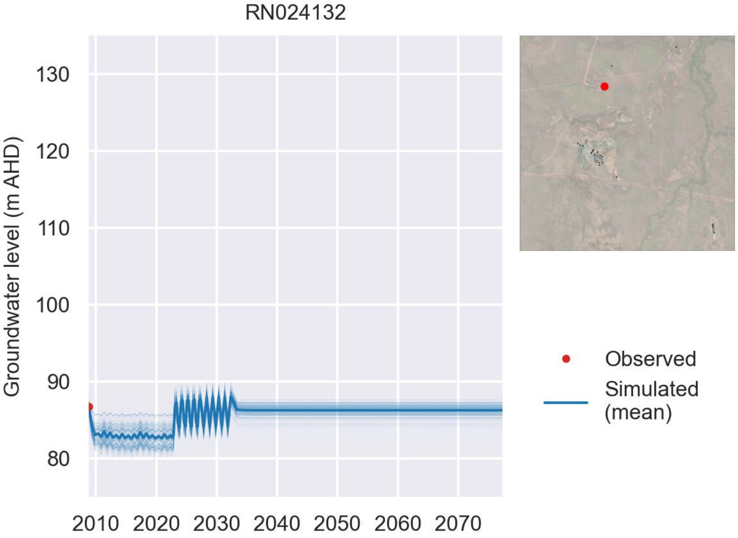


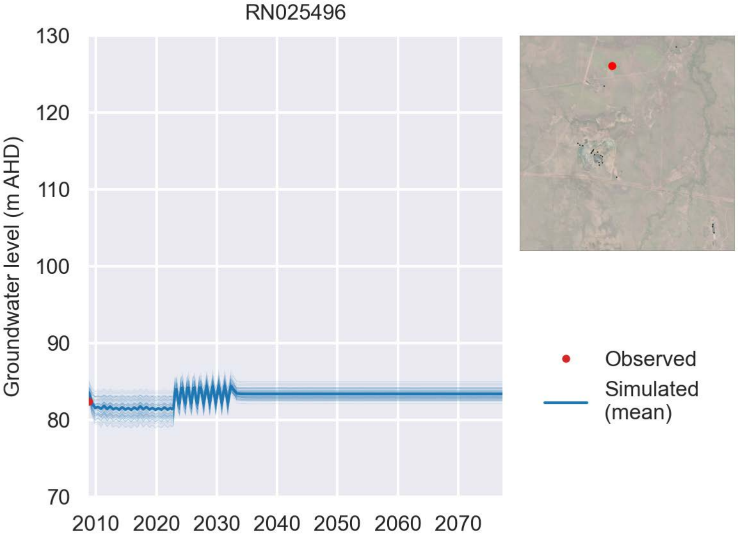
FHRC078
Groundwater level (m AHD)
140
130
120
110
100
90
80
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated (mean)

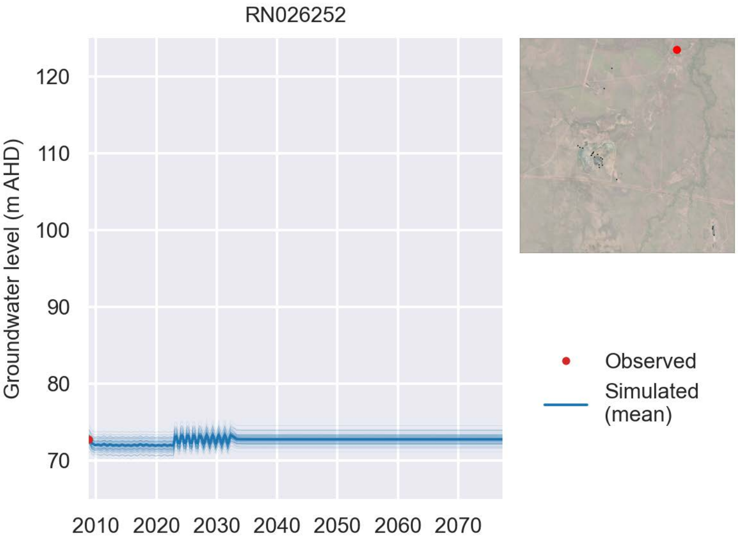


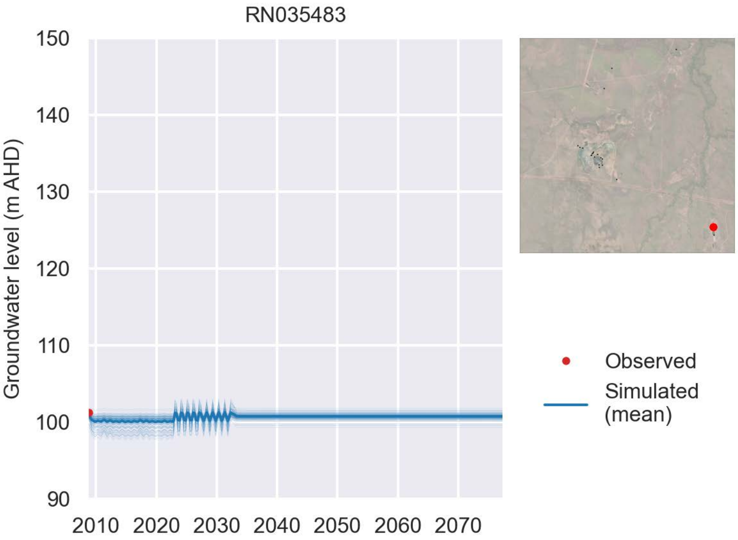
FHRC089
Groundwater level (m AHD)
100
80
60
40
20
0
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

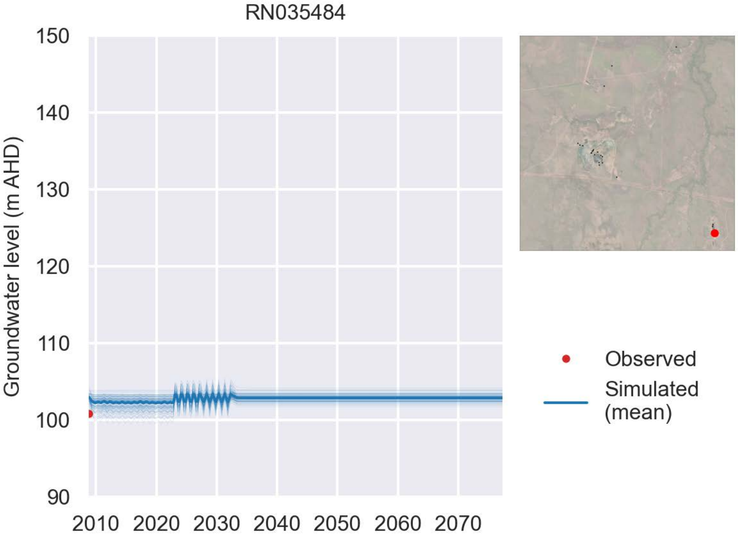

RN022058
Groundwater level (m AHD)
140
130
120
110
100
90
80
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated (mean)


RN024132
Groundwater level (m AHD)
130
120
110
100
90
80
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)

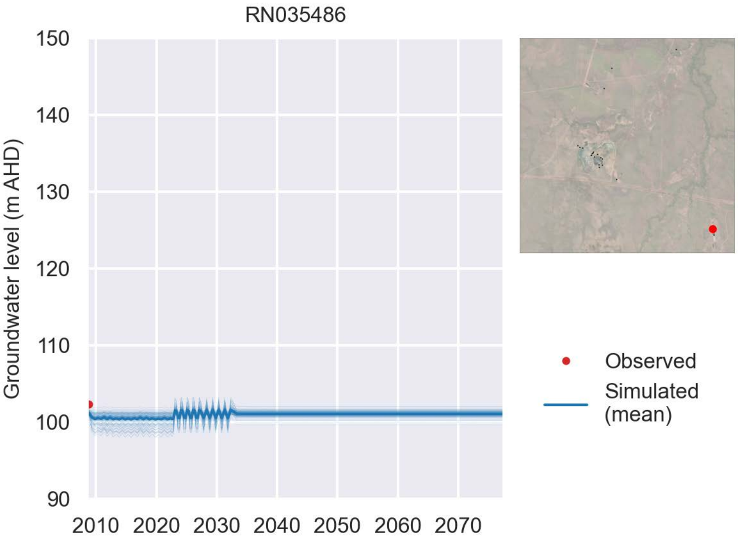

RN025496
130
120
110
100
90
80
70
Groundwater level (m AHD)
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated (mean)


RN026252
Groundwater level (m AHD)
120
110
100
90
80
70
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)


RN035483
150
140
130
120
110
100
90
Groundwater level (m AHD)
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated (mean)



RN035484
Groundwater level (m AHD)
150
140
130
120
110
100
90
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)


RN035486
Groundwater level (m AHD)
150
140
130
120
110
100
90
2010
2020
2030
2040
2050
2060
2070
Observed
Simulated
(mean)