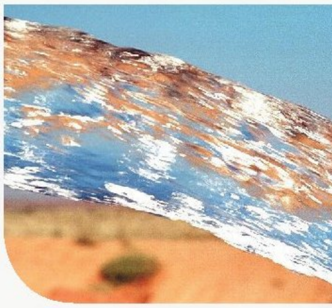
APPENDIX K H3 Hydrogeological Report

H3-LEVEL HYDROGEOLOGICAL ASSESSMENT OF THE HAVIERON PROJECT



REPORT FOR NEWCREST AUSTRALIA

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1 INTRODUCTION

1.1 PROJECT DESCRIPTION

The Havieron Project is a farm-in joint venture between Newcrest Mining Limited (NML) and Greatland Gold Ltd (Greatland). It is located in the Paterson Province, Western Australia, approximately 45 km east of NML's 100%-owned Telfer mine (Figure 1). The Project targets a gold-copper resource within Proterozoic basement rocks. These Proterozoic rocks are overlain by about 410 m of Permian sedimentary cover of the Kidson sub-basin, within the Canning Basin. It is proposed that the Havieron Project will comprise an underground mine, waste rock landform, workshops and road and construction bores along an infrastructure corridor to the Telfer mine.

The Havieron deposit will be mined using sub-level open stoping (SLOS). The mineralised zone will be accessed by a decline which extends through the Permian strata, to the top of the mineralised zone which commences 20 m below the top of the Proterozoic basement rocks (Stage 1). In early 2021 the development of the Havieron mine commenced with the establishment of a boxcut constructed to approximately 20 m depth. Shortly after, the underground decline was established, and it is estimated that this will reach the top of the gold-copper resource at about 430 m depth (about 20 m into Proterozoic basement) by January 2023.

Stage 2 of the mine is planned to commence in early 2023. This will include the development of decline to the base of the mine 4,075 m RL (about 1,185 m depth) over a 70 month period whilst simultaneously developing mine access drives and extracting ore employing SLOS methods. The mine will then continue extracting ore until about February 2034 based on current mineral resources and scheduling.

1.2 PREVIOUS WORK

In 2020, a H3 level hydrogeological assessment for Stage 1 of the project was undertaken (Rockwater, 2020). This work focused on the Permian sediments overlying the Proterozoic basement rocks, which host the ore body. This assessment, which included a numerical groundwater model, was used to support a 5C application for the dewatering required for the construction of the boxcut and decline through the Permian cover (Stage 1), but did not assess potential impacts of the required dewatering for the Proterozoic basement (Stage 2).

1.3 SOURCES OF DATA

Assessments of the geology of the Kidson sub-basin of the Canning Basin were undertaken by the Geological Survey of Western Australia (GSWA) in the 1980's (Towner et al., 1983). The hydrogeological map by Commander (1989) is shown in Figure 2.

The Paterson Province Investigation for the Palaeovalley Groundwater Project undertaken by Geoscience Australia (English et al, 2012) provides information on the targeted Paterson Formation aged sediments. Also on the non-glaciogenic Percival Palaeovalley, of presumed Cenozoic age, which presumably intersect the Paterson Formation in the vicinity of the project. A map showing the outline of the Percival Palaeovalley is provided in Figure 3.

Water bore information and groundwater licence information have been accessed from Department of Water and Environmental Regulation (DWER) databases.

The West Canning Basin groundwater allocation limit report compiled by DWER in 2012 provides a summary of the available data and an assessment of the status of the groundwater resources in the region. However, the targeted Proterozoic-aged Paterson Formation sediments are not discussed in detail. In this report the Paterson Formation is grouped with the *Canning Wallal Aquifer*. For clarity, we suggest that DWER may consider differentiating the (low permeability) non-artesian groundwater resources within the Paterson Formation from the artesian groundwater resources within the Wallal Sandstone further north and (higher permeability) non-artesian groundwater resources within the Triwhite Sandstone to the south (Fig. 2).

New water bore data was acquired by Rockwater during an ongoing field campaign between April 2020 and October 2021 (see Section 6).

Flora and fauna surveys undertaken by Strategen in early 2020 and stygofauna surveys undertaken by Biologic in 2021 are also incorporated in the present study (see Section 2).

1.4 CURRENT ASSESSMENT OBJECTIVE

NML commissioned Rockwater to undertake this H3-level hydrogeological assessment to build on the previously submitted H3-level assessment (Rockwater, 2020). The previous assessment contained only a local scale groundwater model, which was developed to assess the impacts of developing the Havieron through the Permian strata to the top of the mineralisation at 430 m below ground level (bgl) (Stage 1).

The objective of this updated (Stage 2) assessment and modelling is to assess the potential impacts of groundwater extraction for water supply and dewatering over the life of the mine.

The existing groundwater model has been updated to incorporate the latest knowledge of the Permian stratigraphy and underlying Proterozoic basement. The model domain has been extended to allow for a regional scale assessment of mine dewatering for Stage 2 mining approvals.

2 PHYSIOGRAPHY AND CLIMATE

2.1 PHYSIOGRAPHY AND DRAINAGE

The Havieron Project lies about 415 km south of Broome and 440 kilometres southeast of Port Hedland in the Great Sandy Desert (Fig. 1) within an area of Crown Land, and in the land of the Martu people.

Landform and vegetation units in the project area include sandplains and linear sand dunes rising up to 18 m above the inter-dunal corridors. Landforms are predominantly influenced by Cenozoic erosion and deposition events resulting in a series of westerly to north-westerly trending longitudinal dunes (Ferguson et al, 2005). The dunes are fixed by vegetation (Playford, 1964), and were last active about 16,000 to 23,000 years before present (Pieris, 2004). The dunes are many kilometres long and up to 3 km apart. The inter-dunal corridors comprise both weathering products (laterite, silcrete, ferricrete and calcrete) and sediments (aeolian sand, alluvium, and evaporites) (Towner 1977).

Water courses are ephemeral and drain to playa lakes, the closest are numbered Playa Lake #1 to Playa Lake #3 in Figure 4.

A review of the regional topography using the Multi-resolution Valley Bottom Flatness (MrVBF) grids confirmed the key morphological features described above (Fig. 3), particularly the linear westerly trending sand dunes, but also suggests there may be a number of potential non-glaciogenic palaeovalleys of presumed Cenozoic age in the vicinity of the project. The most significant valley near Havieron, the Percival Palaeovalley, is a large NW-SE valley about four to five kilometres west of the project (English et al, 2012) at about 242 m AHD elevation. The valley seems to correlate well with mapped massive calcrete outcrops.

The Havieron Project is at about 250 m AHD elevation and the topography grades to the west towards the Palaeovalley. The Palaeovalley drains to Lake Dora, a Nationally Important Wetland, at about 235 m AHD elevation 40 km SE of Havieron.

2.2 CLIMATE AND RAINFALL

The Havieron Project area has an arid climate with average evaporation exceeding average precipitation during every month of the year (Table 2). Rainfall is seasonal; about 85% of the annual rainfall is received from November to April. Rainfall events are episodic with highly variable amounts resulting from low-pressure cells and cyclonic disturbances, with frequent thunderstorm activity, these high intensity rainfall events are likely to dominate aquifer recharge.

The closest long-term official Bureau of Meteorology (BoM) weather station is Station 01330 at Telfer, which is located about 45 km to the west of Havieron (Fig. 1). Mean monthly rainfall records for the Telfer weather station (BoM Station 013030) and SILO rainfall point data are included in Table 1.

Rainfall at Telfer weather station has been recorded since 1974; the mean annual rainfall is 364.2 mm and the mean annual pan evaporation rate of 3,521.1 mm.

In 29 March 2004, Telfer received almost 200 mm of rainfall from cyclone Fay and in December 1993, 202 mm fell in a 24- hour period. However, Havieron received only 231.5 mm (SILO data) in 2020 demonstrating the inter-annual variability of rainfall. During the 2020 groundwater investigations, it is estimated that Havieron received about 36 mm from ex-cyclone Mangga (SILO data).

The average annual pan evaporation is over an order of magnitude higher than the annual precipitation and the annual rainfall deficit is about 3,290 mm.

The monthly mean temperature maxima range from 28.1°C during June to 45.2oC in December and monthly mean temperature minima range from 6.2°C in July to 22.2°C in December (Table 2).

Table 1: Monthly rainfall and evaporation data

Month	Mean Monthly Evaporation from SILO 2010–2020	Mean Monthly Rainfall at Telfer 1974–2020	Mean Monthly Rainfall from SILO 2010–2020	Actual Monthly Rainfall from SILO 2020
	(mm)	(mm)	(mm)	(mm)
Jan	349.5	63.2	118.6	0.7
Feb	311.9	96.8	83.4	0
Mar	337.1	69.4	40.7	0.7
Apr	278.2	18.1	19.6	0.2
May	220.4	19.0	16.2	0.3
June	156.8	12.7	11.0	0.1
July	190.0	11.7	10.5	23.2
Aug	237.0	4.6	0.3	126.8
Sep	288.9	2.1	2.1	34.5
Oct	365.6	3.0	5.8	0.3
Nov	395.8	15.0	13.6	3.6
Dec	390.0	47.1	43.8	41.1
Total	**3521.1**	**364.2**	**365.5**	**231.5**

Table 2: Mean monthly minimum and maximum air temperatures (Telfer 1974-2020)

Month	Mean Monthly Maximum Temperatures at Telfer 1974–2020	Mean Monthly Minimum Temperatures at Telfer 1974–2020	Mean Monthly Maximum Temperatures from SILO 2010–2020	Mean Monthly Minimum Temperatures from SILO 2010–2020
	(°C)	(°C)	(°C)	(°C)
Jan	40.3	26.1	44.7	21.8
Feb	38.8	25.4	43.4	21.7
Mar	37.6	24.2	42.0	20.2
Apr	34.7	20.8	39.5	15.9
May	29.1	15.4	34.6	9.8
June	25.4	11.9	28.1	6.2
July	25.5	10.7	31.7	6.6
Aug	28.4	12.5	34.3	6.9
Sep	32.9	16.5	38.6	11.5
Oct	37.4	21.2	41.8	16.5
Nov	39.5	23.6	43.7	19.6
Dec	40.4	25.6	45.2	22.2

2.3 VEGETATION SURVEY RESULTS

Vegetation surveys were undertaken by Strategen-JBS&G, both regionally and near the Havieron study area.

The preliminary results of those surveys appear to confirm the BoM's online database (http://www.bom.gov.au/water/groundwater/gde/map.shtml) of potential groundwater dependent ecosystems (GDE). This database does not list any significant vegetation with a high potential for groundwater interaction in the vicinity of the Havieron Project.

Lake Dora is located about 40 km SE of Havieron; the BoM database identifies this surface water feature as having a high potential for groundwater interaction. The vegetation fringing Lake Dora eastern shore 'Succulent steppe with scrub; teatree over salt flats' also has a high potential for groundwater interaction (Fig. 3).

The depth to water in Figure 4 shows that the water table is generally greater than 10 m in the vicinity of Havieron Project. This is consistent with the presumed absence of groundwater dependent vegetation in the vicinity of the project. However, the water table to the west of the project becomes increasingly shallower (up to about 5 m depth) sufficiently shallow to sustain potential groundwater dependent vegetation.

One potential GDE containing scattered *Eucalyptus victrix*, a species associated with increased water availability, was identified by Strategen-JBS&G (Fig. 4). However, Strategen-JBS&G noted that this vegetation community is located within an area of localised water collection, potentially capturing surface water runoff during periods of heavy rainfall. Additionally, no other known groundwater dependant taxa are present within this vegetation type. Based on this advice, *Eucalyptus victrix* is likely to primarily reliant on surface water and as such is unlikely to represent a GDE.

We also note that, possible *Melaleuca* trees are located to the east of the Havieron project, outside of the study area. These trees can have a high potential for groundwater interaction, though in this instance given that the depth to the water table is likely to be around 10 m (Fig. 4), the trees are thought to be associated with low points in the topography that act as a local discharge point for floodwaters.

For details on the vegetation survey the reader should refer to the detailed report by Strategen-JBS&G (2020).

2.4 STYGOFAUNA SURVEY RESULTS

Stygofauna surveys were undertaken by Biologic Environmental Survey (2021) both regionally and near the Havieron study area. A total of 41 holes were sampled within the study area and regionally.

Biologic identified potentially short-range endemic (SRE) species stygofauna in four drill holes within the Havieron Project area, the location of the drill holes are presented in Table 3 and shown in Figure 5. The potentially SRE stygofana species were identified in drill holes which intersect calcrete, weathered mudstone (saprolite) close to the surface, and the upper aquifer at the west of the model domain where it is shallower and subject to more intense weathering.

Under the natural groundwater flow regime the Unconfined and the Upper Confined Aquifers discharge into the overlying calcrete formation in a palaeovalley at the west of the project area, which also has been identified as potential habitat for SRE species.

Table 3: Potentially SRE stygofauna species identified by Biologic (2021)

Site Name	GDA 94 Zone 51		SWL	Aquifer unit (see x-section in Section 3)
	mE	mN	(m bgl)	
HAE009	449441.0	7603059.0	1.49	Calcrete
HAVWB03	461440.2	7598802.0	6.80	Unconfined Aquifer/ Upper Aquifer
HAVWB02	463719.6	7598231.0	10.62	
HAVWB01	463729.1	7598252.0	11.10	
HAE003*	455686.9	7601140.0	1.78	Calcrete

**: additional site without potentially signficant SRE stygofauna added to assess overall imapct at edge of calcrete aquifer*

A preliminary impact assessment is included in Section 6 of this report, which provides model predicted drawdown at locations with SRE stygofauna.

For details on the stygofauna survey the reader should refer to the detailed report by Biologic Environment (2021).

2.5 CULTURAL SIGNIFICANCE

Newcrest acknowledges, recognises and respects Martu as traditional owners and custodians of the landscape on which the company operates. Martu have told Newcrest that their society, spiritual beliefs, cultural identity and traditions are intimately interconnected with their ngurra (lands) and that the Tjukurrpa (creation and law times) operates simultaneously in the past, present and future.

Newcrest recognises it is operating within a cultural landscape and that Martu hold the protection, nurturing and management of this landscape of paramount importance. It is through this understanding, that Newcrest also places the health of the cultural landscape as a priority in everything it does, as both a partner and a guest on Martu ngurra.

3 GEOLOGY

3.1 REGIONAL GEOLOGY

Havieron is located in the Paterson province, to the east of the Archaean Pilbara Craton. Multiple deformed and metamorphosed Palaeo- to Mesoproterozoic sedimentary and igneous rocks of the Rudall Complex form basement in the area (Hickman and Bagas, 1998; Bagas, 2004). These are overlain by sedimentary rocks of the Neoproterozoic Yeneena and northwest Officer basins. These are in turn overlain by Phanerozoic sedimentary rocks of the Canning Basin.

At Havieron, the Canning Basin includes the early Permian Paterson Formation (Fig. 2). The Paterson Formation is laterally equivalent to the Grant Group, plus the Poole Sandstone, and the mid-Permian Triwhite Sandstone (Liveringa Group) which are well exposed elsewhere in parts of the Canning Basin (eg. along the shores of Lake Dora to the SE of Havieron).

Non-glaciogenic palaeovalleys such as the Percival Palaeovalley (Fig. 3) are of presumed Cenozoic age. In places, these river valleys have been incised down to the Permian sediments. Away from the palaeovalley, the surface geology is dominated by Quaternary-aged aeolian sand dunes, characteristic of the Great Sandy Desert.

To the west of Havieron there is a large occurrence of Tertiary or Quaternary age Calcrete, which formed by precipitation in palaeovalleys and around salt lakes. The calcrete is a massive, nodular and vuggy, sandy limestone partly replaced by veins of chalcedony. The thickness of the unit is difficult to estimate because its base is rarely exposed, but in many places exceeds 5 m (Chin, et. al., 1982).

3.2 HAVIERON STRATIGRAPHIC SEQUENCE

At Havieron, the Paterson Formation can be broken down into six major groups defined by major lithological units observed in drill cuttings, core and downhole geophysical logs. Within these six major groups are multiple sub units consistently observed through geological logging. A typical geological sequence encountered at the Havieron Project is provided in Table 4 and the main aquifer units are described in Section 4.1.

Table 4 : Typical geological sequence at the Havieron Project

Age	Geological Formation	Unit	Average Thickness (m)	Average Depth to base of formation (m bgl)	Aquifer
QUATERNARY	SUPERFICIAL	Undifferentiated Cover (aeolian sand, alluvium, and evaporates)	5-15	5-15	Predominantly unsaturated. Where saturated included in the Unconfined/ Perched
QUATERNARY/PERMIAN UNCONFORMITY					
PERMIAN	PATERSON	UM - Upper Mudstone*	95-105	100-110	Aquitard
		PC – Palaeochannel Sands*			Upper Confined
		UT - Upper Tillite*	60	170	
		LSU - Upper Siltstone	85	255	Aquitard
		MS - Middle Sandstone	25	280	Minor Aquifer
		LSL - Lower Siltstone	35	315	Aquitard
		LT - Lower Tillite	95	410	Lower Confined
PERMIAN/PROTEROZOIC UNCONFORMITY					
PROTEROZOIC	UNDIFFERENTIATED	Undifferentiated Basement	N/D	N/D	Proterozoic

*Saprolite forms Unconfined/Perched Aquifer

3.3 LEAPFROG MODEL

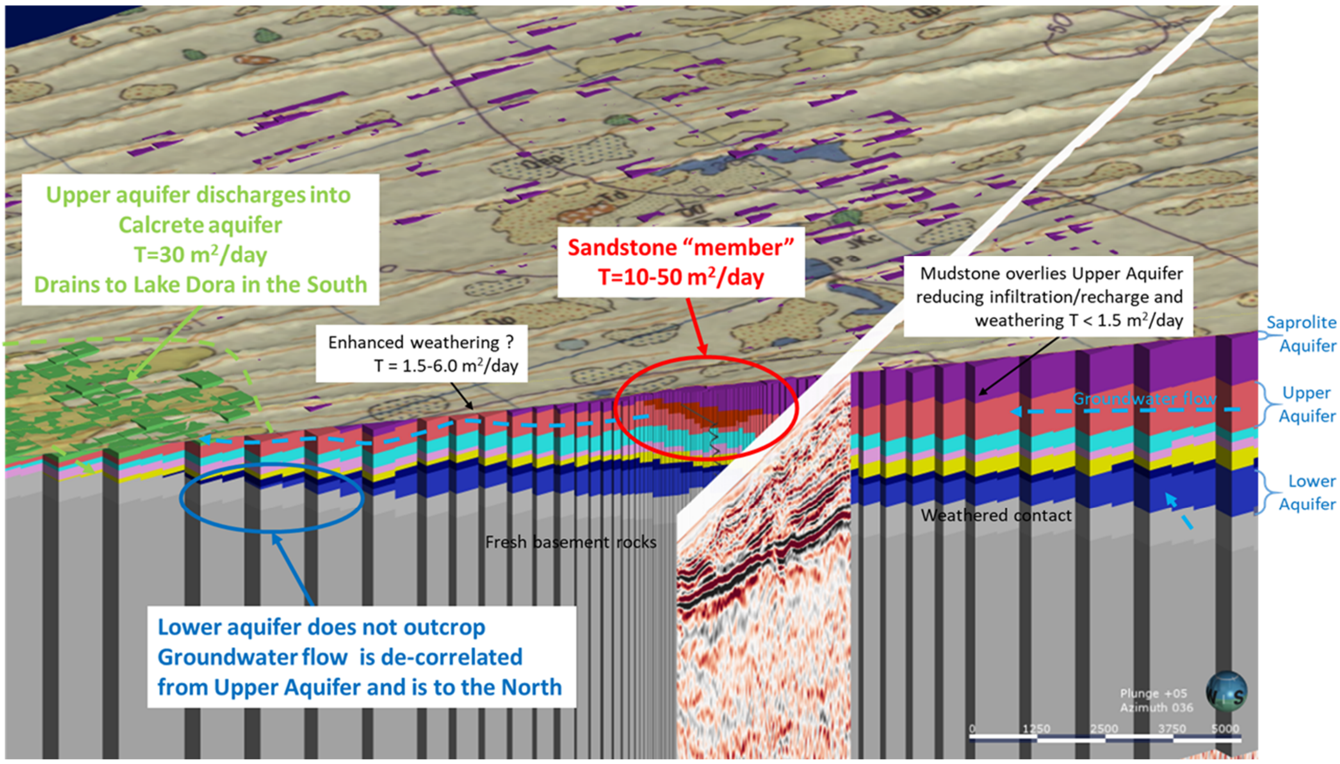
The Leapfrog geological model developed in the previous H3 study (Rockwater, 2020) was extended for numerical modelling to cover an area of ~30 x 30 km around the Havieron deposit. The previous extent of the geological model for Havieron covered an area of ~2.0 x 1.5 km with no geological drilling information available outside this area.

The updated interpretation of the Havieron stratigraphy employed the following data:

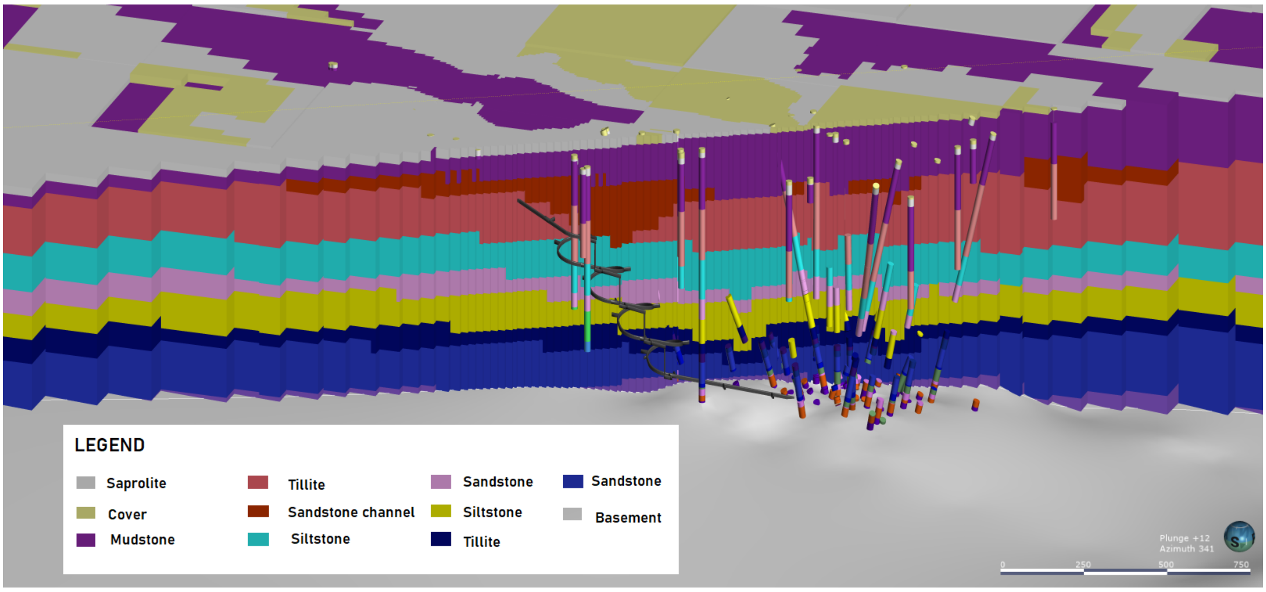
- Detailed Leapfrog modelling of the Permian stratigraphy provided by NML;
- Seismic data to constrain the surfaces away from stratigraphic control in drill holes;
- Re-interpreted data from the HAHY and HAVWB series bores drilled as part of hydrogeological investigations since the previous H3 study were added to the model;
- Surface mapping used to verify outcropping / sub-cropping of the Calcrete to the west of Havieron;
- Geological units were grouped according to their hydraulic characteristics, for example the sandstone members at top of the Upper Confined Aquifer are grouped together and differentiated from other lower permeability sub-units of the Confined Aquifer (i.e the tillite units); and
- Units representing weathered Permian geology and the weathered basement under the unconformity have been added for the purpose of the groundwater modelling.

The calcrete was drilled in HAVWB06 but not observed in the near mine model, was necessary for the groundwater conceptualisation and was added as an additional hydrostratigraphic unit.

Key aspects of the model are presented in two synthetic cross-sections (Cross-Section 1 and 2) and Figure 6. These cross-sections show the key hydrogeological layers included in the MODFLOW groundwater model and relevant to the assessment of drawdown impact for potentially SRE stygofauna species.



Cross-Section 1: Updated stratigraphic interpretation and hydrogeological conceptualisation



Cross-Section 2: The evaluation of the geological model to a MODFLOW grid near decline

4 HYDROGEOLOGY

A conceptual diagram of the hydrogeology at the Havieron Project is presented in Figure 6. The conceptual model considers key hydrogeological processes for the four key aquifer units (informally named):

- The Unconfined / Perched Aquifer;
- The Upper Confined Aquifer (including the palaeochannel aquifer);
- The Lower Confined Aquifer; and
- The Proterozoic Aquifer.

A summary of the above mentioned aquifers characteristics is provided in Table 5. Location of bores drilled in this assessment are shown in Figure 5.

Table 5 : Summary of aquifer characteristics at the Havieron Project

Aquifer	Depth	Primary porosity / Fractured	Salinity	Water Elevation
			(mg/L)	(m AHD)
Unconfined / Perched Aquifer	Within the uppermost 10 m of saturated saprolite	Primary porosity	15,000 - 40,000*	240 - 250
Upper Confined Aquifer	Top of aquifer from 10 m in the west to up to 110 m in the east	Both	2,000 - 20,000**	240 - 247
Lower Confined Aquifer	Typically about 150 m deeper than the Upper Confined Aquifer	Both	55,000	221 - 235
Proterozoic Aquifer	Underlying the Lower Confined Aquifer	Fractured	N/D	N/D

4.1 AQUIFER DESCRIPTIONS

4.1.1 UNCONFINED/PERCHED AQUIFER

The Unconfined/Perched Aquifer is predominantly made up of weathered Permian material and is relatively thin (<10 m thickness); in the east the saprolite overlies fresh mudstone of low permeability and it is hydraulically disconnected from the underlying Upper Confined Aquifer, in the west the mudstone is thin or absent and there is hydraulic connection between the two units. The undifferentiated Quaternary cover is generally unsaturated but is included in this aquifer where the sequence is saturated.

4.1.2 THE UPPER CONFINED AQUIFER:

The Upper Confined Aquifer is made up of glacial tillite and, nearby to the project area, a more permeable palaeochannel sandstone fill which occupies a locally incised glacial valley (Fig. 3). This is the major aquifer at Havieron. It flows from east to west, discharging into the calcrete aquifer to the west. The aquifer is slightly brackish and may be recharged by leakage of fresher groundwater from the younger Triwhite Sandstone where the Numkambah Formation is thin or absent to the east of the model area. Minor rainfall recharge may also occur where the overlying mudstone is thin or absent.

4.1.3 THE LOWER CONFINED AQUIFER:

The lower aquifer is also made up of glacial tillite with a mud matrix to sand matrix. It is separated from the upper aquifer by a thick succession of siltstone. The aquifer is brackish to saline and has a different potentiometric surface from the Upper Confined Aquifer. Based on limited data from deep Permian bores penetrating the aquifer, it appears to flow from south to north in a similar fashion to ther deep formations of the Canning Basin. It is likely that the unit is laterally in connection with the Grant Group which is saline in the area. The Grant Group is likely to provide pressure support and control groundwater flow in this aquifer which does not outcrop in the model area.

4.1.4 THE PROTEROZOIC AQUIFER

The Proterozoic aquifer is comprised of bedded sediments of the Proterozoic Yeneena Basin. The mineralisation is understood to be hosted in the eastern limb of a fault propagated anticlinal fold. The bedded sediments were brecciated by this deformation, cemented and then replaced by sulphide minerals, followed by a dolerite intrusion. The Proterozoic formation has negligible primary porosity and groundwater is only hosted in the weathered contact with the overlying Permian strata or in fractures, which are most notable in the dolerite dike.

There are no bores drilled directly into the Proterozoic aquifer, so there are no water levels or salinity data for this aquifer. However, the water level is likely to be similar to the Lower Confined Aquifer and the salinity is likely to be more saline. There is no recharge to the Proterozoic aquifer in the project area.

4.2 WATER LEVELS

A range of salinities were observed in bores targeting the Unconfined/Perched, Upper Confined and Lower Confined Aquifers at Havieron. To allow for accurate comparison of water levels between each aquifer, and in the case of the Upper Confined Aquifer, across the aquifer, water levels were converted to freshwater heads using the following equation.

Equivalent freshwater head (m) = Measured Head* x Density / 1000
**: measured at top of screened interval*
Density (kg/m^3) = 7.7 x 10^{-4} x Salinity +(-4 x 10^{-3} T^2 - 7 x 10^{-2} T + 1,003)

The potentiometric surface of the Upper Confined Aquifer (Fig. 7) shows groundwater flow to the south - west, towards the palaeovalley from about 261 m AHD to 240 m AHD. The groundwater gradient ranges from 0.002 m/m west of the study area to 0.0003 m/m east of the study area.

There are limited data available to show the groundwater flow direction in the Unconfined / Perched Aquifer. It is likely to follow the general groundwater flow direction in the underlying Upper Confined Aquifer, although locally it will be influenced by areas of recharge and discharge. The head difference with the underlying Upper Confined Aquifer appears to be closely related to the thickness of the UM group and tends to decrease from east to west. Where the UM is relatively thin, thus providing a moderate hydraulic connection, water levels in the Unconfined Aquifer bores appear to be 0.1 m higher than the Upper Confined Aquifer. Where there is the full thickness of the UM, water levels in the Unconfined Aquifer bores are 2.5 m higher than the Upper Confined Aquifer.

Based on this preliminary observations, it appears that the Lower Confined Aquifer behaves similarly to other onshore Canning Basin aquifers, which generally flow toward the centre of the basin to the NW, where they discharge to the ocean (Allen, 1992). The groundwater gradient is estimated to be about 0.001 m/m (Fig. 8).

Water level data for bores in the Lower Confined Aquifer indicate that the potentiometric surface is at about 230 m AHD in the vicinity of Havieron (Fig. 8), which is lower than in the Upper Confined Aquifer which is about 245 m AHD (Fig. 7). The two aquifers do not appear to be in hydraulic connection (consistent with the different salinity values in the two aquifers).

To date there is no dedicated Proterozoic monitoring bore at Havieron. There is oxidation at the contact between Permian and Proterozoic rocks indicating in hydraulic connection the Lower Confined Aquifer, therefore the potentiometric surface is likely to be similar.

4.3 SALINITY

The salinity of the Unconfined/Perched Aquifer is high (18,800 to 39,100 mg/L Total Dissolved Solids (TDS)), probably because of the limited through-flow and evapo-concentration resultant from the relatively slow percolation of groundwater, particularly where the mudstone is present near to the ground surface.

Laws (1990) noted that the Paterson Formation contains generally fresh groundwater near recharge areas but becomes saline with depth and distance down the flow system. This observation is verified in the Upper Confined Aquifer, which has measured bore salinities ranging from 3,000 to 4,000 mg/L TDS where the aquifer is shallow and directly underlies surface sediments (in the west of the study area). The salinity gradually increases with depth and is up to 15,000 to 20,000 mg/L TDS where the aquifer is deeper (in the east of the study area).

The salinity of the Lower Confined Aquifer is up to 55,000 mg/L TDS (in bore HAHY006).

The salinity of the Proterozoic aquifer is unknown, however it is expected to be greater than 55,000 mg/L observed in the overlying Lower Confined Aquifer.

4.4 RECHARGE AND DISCHARGE

4.4.1 RECHARGE

Net recharge to the Unconfined/Perched Aquifer is assumed to negligible where it overlies the UM, as the low permeability results in a very slow rate of infiltration, most rainfall evaporates before it recharges the aquifer. Where this aquifer is directly underlain by the Upper Confined Aquifer, there is more potential for recharge following significant rainfall events. This is consistent with locally lower salinities in the Upper Confined Aquifer to the west of the study area (Section 4.3).

The majority of recharge to the Upper Confined Aquifer is likely to occur away from the study area, where the aquifer outcrops and is more extensive (Fig. 2). Recharge to the Lower Confined Aquifer is likely to minimal and would occur some distance from the study area. Again, possibly to the east where it is in contact with the Triwhite Sandstone.

The Proterozoic aquifer is not recharged within the study area.

4.4.2 DISCHARGE

Discharge from the Unconfined/Perched Aquifer would primarily be via evaporation where the water table is shallower than 10 m (Fig. 4). It may also occur into Calcrete Aquifers within the palaeovalley to the west of the study area and via downward leakage into the underlying Upper Confined Aquifer where the two aquifers are in direct connection (where UM is absent).

Based on the groundwater flow direction it is postulated that the Upper Confined Aquifer (within the groundwater model extent) discharges into the Percival Palaeovalley to the west. This is similar to the way the groundwater seepage from Permian sandstones occurs at springs on the Lake Dora shore near Punmu (Commander, 1985). The through-flow however, is likely to be limited given the relatively low aquifer transmissivity.

Discharge from the Lower Confined Aquifer is likely to be into other onshore Canning Basin aquifers away from the study area, and it is likely to be limited given the relatively low aquifer transmissivity.

4.5 HYDRAULIC PARAMETERS

Values of horizontal hydraulic conductivity (HK) reported from hydraulic testing (BMR logs, pump tests, packer tests and slug tests) and summarised in Table 6. Specific storage (SS) and specific yield (SY) values were estimated during the analysis of pumping data and BMR logs. AQTSOLV was used to determine acceptable ranges for each aquifer; these were redefined and recalibrated as more pumping test and packer test data were integrated into the analyses. The results of testing and associated analyses are presented in Rockwater 2021a and 2021b.

Table 6: Range of hydraulic parameters from hydraulic testing and associated analyses

Model unit	HK min	HK max	VK (assumed)	SY	SS
Cover	1.00E-02	1.00E-01	0.01 x HK	0.15	1.50E-03
Calcrete	1	25	1 x HK	0.2	1.50E-03
Saprolite **Unconfined / Perched Aquifer**	1.00E-02	1.00E-01	0.01 x HK	0.15	1.50E-03
Upper Mudstone	1.00E-04	1.00E-03	0.01 x HK	0.03	1.00E-05
Upper Tillite (Sandstone) **Upper Confined Aquifer**	0.05	0.50	0.1 x HK	0.25	3.00E-05
Upper Tillite	1.00E-03	1.00E-01	0.01 x HK	0.1	3.00E-05
Lower Siltstone (upper)	5.0E-08	5.0E-06	0.01 x HK	0.03	1.00E-05
Middle Sandstone	1.00E-03	5.00E-03	0.1 x HK	0.08	1.50E-05
Lower Siltstone (lower)	5.0E-08	5.0E-06	0.01 x HK	0.03	1.00E-05
Lower Tillite	1.00E-04	1.00E-03	0.01 x HK	0.09	1.50E-05
Lower Tillite (Sandstone) **Lower Confined Aquifer**	1.00E-03	1.00E-02	0.1 x HK	0.09	1.50E-05
Ordovician	5.00E-05	5.00E-04	0.01 x HK	0.01	1.00E-06
Weathered Basement	5.00E-04	5.00E-03	0.01 x HK	0.01	5.00E-06
Basement	1.00E-05	1.00E-04	0.01 x HK	0.01	1.00E-06
Breccia	5.00E-04	5.00E-03	0.01 x HK	0.01	5.00E-06
Dolerite	1.00E-03	1.00E-02	0.01 x HK	0.01	5.00E-06

5 EXISTING AND PLANNED GROUNDWATER USE

5.1 EXISTING GROUNDWATER BORE ABSTRACTION

Water supply demand for the Boxcut construction has been provided by seven groundwater bores:

- HAHY006 (targeting the Lower Confined Aquifer)
- HAHY007, HAVWB07, HAVWB09, HAVWB14, HAD002 and HAVWB13 (targeting the Upper Confined Aquifer)

To date these bores have operated at a total rate of about 3 L/s. It is anticipated that the water supply bores will be limited to this until an additional seven water bores are constructed and equipped in early April 2022 (see Table 7).

5.2 FUTURE GROUNDWATER BORE ABSTRACTION

The average maximum airlift yield of bores at Havieron is 3 L/s while the sustainable pumping yield is much lower at 1 L/s. The actual yield depends on the local hydraulic conductivity and thickness of the encountered Upper Confined Aquifer. The existing seven bores and future additional seven bore when operated at their sustainable yield are likely to deliver about 1 L/s per bore which could ultimately provide up to around 14 L/s (see Table 7), however this may decline over time because of interference drawdown with the dewatering process.

Table 7: Production bore usage (L/s)

Bore #	Bore ID	GDA 94 Zone 51		Aquifer	Extraction Rate (L/s)	
		mE	mN		Year 1	Years 2 - 13
1	HAHY006	463635	7597513	Lower Confined	0.40	1.10
2	HAHY007	464660	7598022	Upper Confined	0.30	0.90
3	HAVWB08	463838	7598078	Upper Confined	-	0.50
4	HAVWB09	464132	7598200	Upper Confined	1.20	1.80
5	HAVWB10	463983	7597786	Upper Confined	-	0.20
6	HAVWB11	463712	7597345	Upper Confined	-	2.00
7	HAVWB12	464487	7597650	Upper Confined	-	0.50
8	HAVWB13	464099	7597214	Upper Confined	-	0.60
9	HAVWB07	460556	7598647	Upper Confined	0.50	1.00
10	HAVWB14	463033	7597248	Upper Confined	0.20	0.00
11	HAVWB04	463700	7597812	Upper Confined	0.20	0.20
12	HAD002	463928	7597746	Upper Confined	0.10	0.50
13	New Bore 1	463753	7597395	Upper Confined	-	1.30
14	New Bore 1	463460	7597470	Upper Confined	-	3.10
				Total	**2.9**	**13.7**

Given that the long-term water requirement is thought to be 24 L/s it will be necessary to utilise some of the dewatering water to meet the mine water requirements. If dewatering water does not suffice, an alternative source of water (ex site) will become necessary to meet the project's requirements.

5.3 DEWATERING REQUIREMENTS

In collaboration with NML, the following dewatering assumptions were adopted:

- Progression of decline construction as per schedule (See Chart 1) up to 01/01/2028.
- Total dewatering extends for 13 years (01/05/2021 to 01/03/2034), in-line with expected Life of Mine (LoM).
- Vent shaft construction in accordance with Table 8. Drives and stopes modelled in accordance with the Deswick mine schedule. Grouting not modelled.

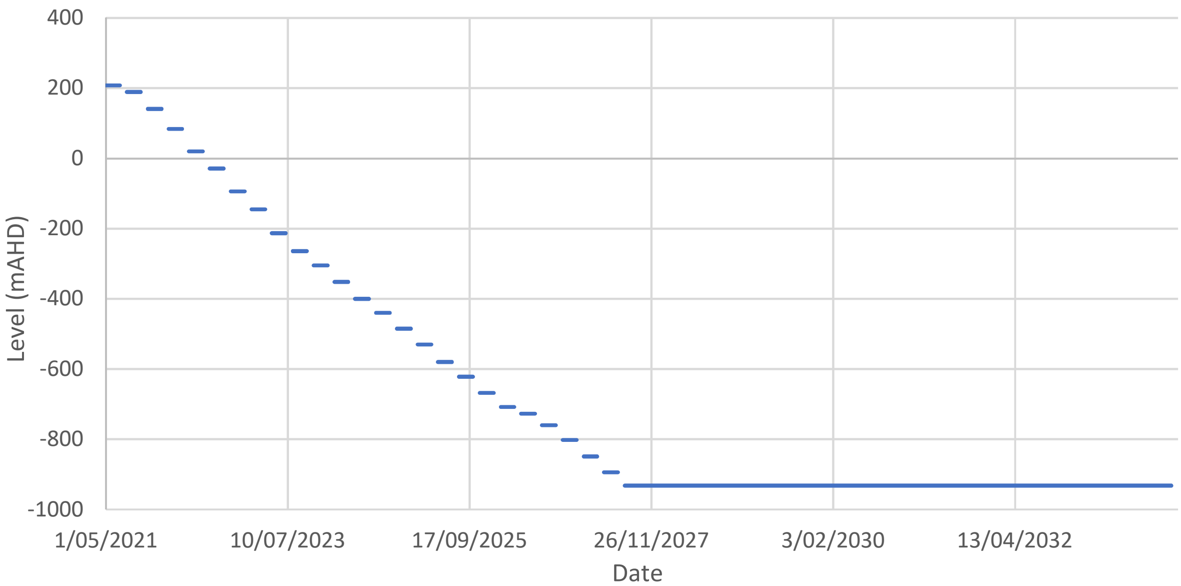


Chart 1: Decline bottom elevation vs time for mine duration.

Table 8: Shaft raise timings within dewatering duration

Vent Shaft	GDA 94 Zone 51		Construction Start	Construction Finish
	mE	mN		
Decline Escapeway Raise 1	463455	7597201	11/12/2021	12/01/2022
Decline Return Air Raise 1	463474	7597184	16/12/2021	15/01/2022
Production Fresh Air Raise 1	463718	7597457	15/11/2022	16/02/2023
Production Fresh Air Raise 2	463667	7597512	21/02/2023	14/05/2023
Production Return Air Raise 1	463843	7597351	19/05/2023	15/09/2023
Production Return Air Raise 2	463888	7597329	22/09/2023	28/12/2023

5.4 LICENCE VOLUME ENTITLEMENT

Based on the predicted dewatering volume and future water bore extraction, it is expected that the cumulative groundwater extraction may peak at around 1.5 GL/a (see Section 8.8.3). Therefore, it is recommended that groundwater licence be obtained for this amount.

6 INVESTIGATIONS

A bore completion report summarising drilling, bore construction and testing to support this hydrogeological investigation is currently in preparation. The following section outlines the hydrogeological work undertaken to date. Table 9 provides a timeline of works and Table 10 a summary of hydrogeological investigation holes. Location of holes are shown in Figure 5.

Table 9: Timeline of hydrogeological investigation holes

Program	Hole ID	Start date	End data
Water supply program	HAVWB07	10/11/2020	13/11/2020
	HAVWB08	13/11/2020	15/11/2020
	HAVWB11	16/11/2020	21/11/2020
	HAVWB13	22/11/2020	25/11/2020
	HAVWB12	26/11/2020	30/11/2020
	HAVWB09	30/11/2020	2/12/2020
	HAVWB10	3/12/2020	6/12/2020
	HAVWB06	7/12/2020	10/12/2020
	HAVWB05	11/12/2020	12/12/2020
	HAVWB14	21/02/2020	24/02/2021
	HAVWB15	24/02/2021	27/02/2021
Proterozoic Investigation	HAGT013	7/12/2020	16/12/2020
	HAD130	13/03/2021	5/04/2021
	HAD132	6/04/2021	23/04/2021
	HAD079	24/04/2021	6/05/2021
Decline Investigation	HAGT016	23/05/2021	30/05/2021
	HAGT017	31/05/2021	6/06/2021
Environmental Monitoring Bore Program	HAHY008	9/06/2021	19/06/2021
	HAHY009	20/06/2021	20/06/2021
	HAHY010	20/06/2021	20/06/2021
	HAHY011	21/06/2021	21/06/2021
	HAHY012	22/06/2021	14/07/2021
	HAHY013	14/07/2021	15/07/2021
	HAHY014	15/07/2021	25/07/2021
	HAHY015	25/07/2021	13/08/2021
	HAHY016	13/08/2021	14/08/2021
	HAHY017	14/08/2021	15/08/2021
	HAHY021	15/08/2021	16/08/2021
	HAHY018	16/08/2021	17/08/2021
	HAHY020	17/08/2021	17/08/2021
	HAHY019	19/08/2021	20/08/2021
	HAHY022	20/08/2021	30/08/2021
	HAHY023	30/08/2021	7/09/2021
	HAHY025	8/09/2021	10/09/2021
	HAHY026	10/09/2021	11/09/2021
Feasibility Study	HAHY028	12/09/2021	15/09/2021
	HAHY030	16/09/2021	21/09/2021
	HAHY034	22/09/2021	03/10/2021
	HAHY031	5/10/2021	In progress

Table 10: Hydrogeological investigation hole summary

Hole ID	GDA 94 Zone 51		mRL	Dip	Azimuth	Drill depth)	Blank Casing Depth	Slotted Interval	Comments
	mE	mN				(m bgl)	(m)	(m)	
HAVWB07	460554.98	7598945.27	247.70	90.00	360.00	97.50	21.9 & 81.9-93.9	21.9 to 81.9	6" uPVC construction
HAVWB08	463836.87	7598075.39	255.73	90.00	360.00	91.50	29.50	29.5 to 89.5	6" uPVC construction
HAVWB11	463711.20	7597343.76	262.17	90.00	360.00	175.00	95.50	103.3 to 169.3	6" SS construction
HAVWB13	464098.49	7597212.23	261.12	90.00	360.00	195.20	105.50	80.9 to 170.9	6" SS construction
HAVWB12	464485.32	7597648.56	258.32	90.00	360.00	199.30	101.5 & 183.3-195.6	99.3 to 183.3	6" SS construction
HAVWB09	464130.61	7598198.83	256.07	90.00	360.00	195.00	72.00	93.4 to 183.4	6" SS construction
HAVWB10	463981.98	7597784.64	256.86	90.00	360.00	195.00	88.5 & 166.5-178.8	88.5 to 166.5	6" SS construction
HAVWB06	446403.75	7603402.51	241.22	90.00	360.00	25.10	12.40	12.4 to 24.4	8" uPVC construction
HAVWB05	430295.33	7608609.26	260.54	90.00	360.00	31.10	13.0 & 25.0-30.0	13.0 to 25.0	8" uPVC construction
HAGT013	463,440.7	7,597,433.7	263.60	90.00	360.00	300	NA	NA	Packer testing
HAVWB14	463033.00	7597242.00	253.77	90.00	360.00	72.00	11.00	11.0 to 70.0	6" uPVC construction
HAVWB15	462949.00	7597256.00	253.66	90.00	360.00	70.00	8.00	8.0 to 66.0	6" uPVC construction
HAD130	463722.79	7598292.77	254.71	-61.04	143.67	1430.60	460.10	NA	VWPs installed
HAD132	464602.38	7597750.13	258.44	-57.89	266.73	950.00	500.00	NA	VWPs installed
HAD079	463612.17	7597738.99	257.62	-56.60	92.48	695.00	486.00	NA	VWPs installed
HAGT016	TBD	TBD	TBD	78.00	4.62	300.00	NA	0.0 to 276.0	Gamma logging only
HAGT017	TBD	TBD	TBD	85.44	3.63	252.00	NA	0.0 to 234.0	Gamma logging only
HAHY008	461831.858	7598267.459	250.397	90.00	360.00	253.40	228.00	228.0 to 240.0	6" uPVC construction
HAHY009	461830.391	7598264.638	250.407	90.00	360.00	24.00	9.00	9.0 to 21.0	2" uPVC construction
HAHY010	462810.335	7598474.469	252.323	90.00	360.00	30.10	24.10	24.1 to 30.1	2" uPVC construction
HAHY011	464277.869	7599002.633	257.169	90.00	360.00	24.50	7.00	7.00 to 19.0	2" uPVC construction
HAHY012	462099.713	7598652.577	250.945	90.00	360.00	253.40	188.00	188.0 to 200.0	6" uPVC construction
HAHY013	462098.199	7598652.239	250.818	90.00	360.00	18.50	6.50	6.5 to 18.5	2" uPVC construction

Hole ID	GDA 94 Zone 51		mRL	Dip	Azimuth	Drill depth)	Blank Casing Depth	Slotted Interval	Comments
	mE	mN				(m bgl)	(m)	(m)	
HAHY014	464483.816	7597227.235	259.891	90.00	360.00	181.40	140 & 152-176	140.0 to 152.0	6” uPVC construction
HAHY015	462452.128	7597599.974	253.393	90.00	360.00	313.40	301.00	301.0 to 313.0	6” uPVC construction
HAHY016	462455.667	7597598.704	253.313	90.00	360.00	30.50	18.00	18.0 to 30.0	2” uPVC construction
HAHY017	461080	7597325	TBC	90.00	360.00	28	16.0	16.0 to 28.0	2” uPVC construction
HAHY021	461917	7596963	TBC	90.00	360.00	30	18.0	18.0 to 30.0	2” uPVC construction
HAHY018	461940	7596963	TBC	90.00	360.00	30	18.0	18.0 to 30.0	2” uPVC construction
HAHY020	462111	7597093	TBC	90.00	360.00	30	16.0	16.0 to 28.0	2” uPVC construction
HAHY019	462120	7597027	TBC	90.00	360.00	30	18.0	18.0 to 30.0	2” uPVC construction
HAHY022	461469	7596912	TBC	90.00	360.00	105	74.0 and 86.0-98.0	75.0 to 86.0	4” uPVC construction
HAHY023	461473	7596919	TBC	90.00	360.00	272	252.0 & 264-270	252.0 to 264.0	6” uPVC construction
HAHY025	460720	7598696	TBC	90.00	360.00	141	124.0	124.0 to 136.0	4” uPVC construction
HAHY026	460720	7598696	TBC	90.00	360.00	30	17.5	17.5 to 29.5	4” uPVC construction
HAHY028	463409.6	7597222.8	TBC	90.00	360.00	381	11.7	NA	Left for re-entry/VWP install
HAHY030	463884.9	7597349	TBC	90.00	360.00	370	11.7	NA	Left for re-entry/VWP install
HAHY034	463460	7597470	TBC	90.00	360.00	182	11.7	NA	Left for re-entry/VWP install
HAHY031	463752.7	7597395	TBC	90.00	360.00	NA	11.7	NA	Left for re-entry/VWP install

6.1 PRODUCTION BORE INSTALLATION

NML commissioned Rockwater to supervise Silver City Drilling in undertaking the drilling, construction and development of eleven production bores designated HAVWB05 to HAVWB15 (Fig. 5). The bores were to: provide a water supply in the upcoming mining area; and supply water along the Havieron Northern Access Road (NAR). Pumping tests were conducted on HAVWB07, HAVWB09 and HAVWB13 to determine maximum sustainable yields over a 3-5 year period. Further details of these bores are provided in the submitted Form 2 and production bore completion report (in-progress) (Rockwater, 2021a).

6.2 PACKER TESTING

NML engaged Rockwater to conduct packer injection tests in three diamond drill holes (HAD132, HAD130 and HAD079) with the purpose of determining the permeability of the upper, weathered section of the Proterozoic basement. Vibrating wire piezometers (VWPs) were subsequently installed in three diamond drill holes. Packer testing was also undertaken at In HAGT013 progressively-increasing depths to assess the permeability of poorly consolidated palaeochannel sands present in the upper tillite at 112.9–122.9 m depth. Further details of this testing are presented in Rockwater, 2021b.

6.3 ENVIRONMENTAL MONITORING BORES

NML commissioned the drilling, construction and development of 18 monitoring bores constructed with screens targeting the three main Permian aquifer intervals to provide a network of monitoring bores as part of NML's Havieron Water Management Plan.

6.3.1 SUPERFICIAL AQUIFER MONITORING BORES

A network of four bores, HAHY009, HAHY010, HAHY011 and HAHY013 were drilled and constructed to allow for regional monitoring of the Unconfined Aquifer. An additional five monitoring bores, designated HAHY017-21, were positioned around the waste rock landform and evaporation ponds to allow for monitoring of potential impacts of groundwater infiltration at features on the Unconfined Aquifer. Monitoring bore HAHY026 is drilled to monitor the superficial aquifer nearby to the accommodation village.

6.3.2 UPPER CONFINED MONITORING BORES

Seven bores HAHY008, HAHY012, HAHY014, HAHY015, HAHY022, HAHY023 and HAHY025 were drilled to allow for regional monitoring of the Upper Confined Aquifer. Further details of these bores are provided in the Havieron monitoring bore completion report (in-progress) (Rockwater, 2021c).

6.3.3 LOWER CONFINED MONITORING BORES

A single Lower Confined Aquifer monitoring bore (HAHY015) has been constructed at Havieron. HAHY015 is drilled to 313 m depth with slotted casing set from 301 to 313 m depth. Further construction details of provided in the Havieron monitoring bore completion report (in-progress) (Rockwater, 2021c).

6.4 FEASIBILITY STUDY PROGRAM

NML commissioned is presently installing a network of vibrating wire piezometers to provide water levels data in the Unconfined, Upper Confined and Lower Confined aquifers close to the mine decline. At the time of completing this report four of the eight proposed bores (HAHY028, HAHY030, HAHY031, and HAHY034) have been drilled but the installation of the instrumentation has not been completed. It is also planned to install two additional production bores at the most prospective of the sites identified in this programme.

7 GROUNDWATER CHEMISTRY

Water samples were collected by Rockwater on 29 and 30 May 2020 and 1, 2 and 4 of June 2020 during airlifting and test pumping. Water pH, salinities and temperatures were measured in the field with calibrated instruments. All samples were chilled before being transported to ALS, a NATA-accredited laboratory, for analyses. The results of the analyses for the Unconfined/Perched Aquifer are presented in Table 11, for the Upper Confined Aquifer in Table 12 and the Lower Confined Aquifer in Table 14.

These results were presented as a Piper plot in the previous hydrogeological assessment (Rockwater, 2020 - Fig 15). This showed that the groundwater is sodium chloride type for all aquifers. However, there appears to be a mixing line between Unconfined/Perched Aquifer HAE series bores and Upper Confined Aquifer bores in the west of the study area where the mudstone is absent (HAWB002) and the Lower Confined Aquifer bore (HAHY006). This is consistent with the progressive increased distance from the recharge zone for those bores and the associated increase in sodium chloride ions in the groundwater because the groundwater had more time to equilibrate with the host aquifer rock and for cationic exchange with clays and mudstones that are present within the Paterson Formation.

Table 11: Laboratory analysed water chemistry – unconfined/perched aquifer

Analyte	Units	LOR	HAE 013	HAE 014
Sample Date			**30/5/20**	**30/5/20**
Field pH	*pH*	-	7.2	7.25
Field EC	*µS/cm*	-	28200	52100
pH	*pH Unit*	*0.01*	7.52	7.54
Electrical Conductivity @ 25°C	*µS/cm*	*1*	25900	51100
Total Dissolved Solids @180°C	*mg/L*	*10*	18800	39100
Total Hardness as $CaCO_3$	*mg/L*	*1*	4530	7720
Hydroxide Alkalinity as $CaCO_3$	*mg/L*	*1*	<1	<1
Carbonate Alkalinity as $CaCO_3$	*mg/L*	*1*	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	*mg/L*	*1*	238	224
Total Alkalinity as $CaCO_3$	*mg/L*	*1*	238	224
Sulphate as $SO4^{2-}$	*mg/L*	*1*	4490	8260
Chloride	*mg/L*	*1*	7050	15000
Calcium	*mg/L*	*1*	763	865
Magnesium	*mg/L*	*1*	638	1350
Sodium	*mg/L*	*1*	4660	11100
Potassium	*mg/L*	*1*	172	388
Dissolved Aluminium	*mg/L*	*0.01*	<0.01	<0.05
Dissolved Manganese	*mg/L*	*0.001*	15.4	4.46
Dissolved Iron	*mg/L*	*0.05*	1.05	<0.25
Reactive Silica	*mg/L*	*0.05*	36.0	13.9
Free Cyanide	*mg/L*	*0.004*	<0.004	<0.040
Weak Acid Dissociable Cyanide	*mg/L*	*0.004*	<0.004	<0.040
Ammonia as N	*mg/L*	*0.01*	0.95	1.18
Nitrite as N	*mg/L*	*0.01*	0.16	0.62
Nitrate as N	*mg/L*	*0.01*	6.16	2.65
Nitrite + Nitrate as N	*mg/L*	*0.01*	6.32	3.27
Reactive Phosphorus as P	*mg/L*	*0.01*	0.01	0.01
Total Anions	*meq/L*	*0.01*	297.0	600.0
Total Cations	*meq/L*	*0.01*	298.0	647.0
Ionic Balance	*%*	*0.01*	0.10	3.80

The results indicate that the groundwater from the Unconfined/Perched Aquifer has the following characteristics:

- The groundwater is slightly alkaline, with a pH of about 7.7;
- It is of a sodium-chloride type with elevated concentrations of sulphate (~2300 mg/L);
- It is saline with salinities ranging from 18,800 to 39,100 mg/L Total Dissolved Solids (TDS); and
- The dissolved iron concentrations are about 0.45 mg/L.

Table 12: Laboratory analysed water chemistry – upper confined aquifer

Analyte	Units	LOR	HAGT 001	HAGT 002	HAGT 005	HAHY 001	HAHY 002	HAHY 003	HAHY 004	HAHY 007
Sample Date			30/5/20	30/5/20	30/5/20	4/6/20	30/5/20	30/5/20	1/6/20	2/6/20
Field pH	*pH*	-	7.52	-	-	-	7.5	7.44	-	-
Field EC	*µS/cm*	-	7950	-	-	-	7640	12150	-	-
pH	*pH Unit*	*0.01*	7.58	7.88	7.9	7.96	7.72	7.70	7.81	7.77
Electrical Conductivity @ 25°C	*µS/cm*	*1*	6870	7340	5780	7890	6590	11500	27200	21400
Total Dissolved Solids @180°C	*mg/L*	*10*	4030	4520	3460	4830	3760	7210	19600	14800
Total Hardness as $CaCO_3$	*mg/L*	*1*	488	683	460	842	451	1270	3890	2500
Hydroxide Alkalinity as $CaCO_3$	*mg/L*	*1*	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as $CaCO_3$	*mg/L*	*1*	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as aCO_3	*mg/L*	*1*	121	126	113	123	126	161	171	96
Total Alkalinity as $CaCO_3$	*mg/L*	*1*	121	126	113	123	126	161	171	96
Sulphate as $SO4^{2-}$	*mg/L*	*1*	682	774	608	858	670	1440	3270	2360
Chloride	*mg/L*	*1*	1640	1790	1270	1760	1560	3020	7990	6440
Calcium	*mg/L*	*1*	85	122	82	154	80	212	658	441
Magnesium	*mg/L*	*1*	67	92	62	111	61	180	545	341
Sodium	*mg/L*	*1*	1280	1270	1030	1320	1200	1910	5250	3850
Potassium	*mg/L*	*1*	51	46	42	54	55	67	97	69
Dissolved Aluminium	*mg/L*	*0.01*	<0.01	0.03	<0.01	0.15	<0.01	0.02	<0.05	<0.01
Dissolved Manganese	*mg/L*	*0.001*	0.931	2.01	1.48	0.816	0.306	1.34	3.21	2.08
Dissolved Iron	*mg/L*	*0.05*	0.78	0.06	<0.05	0.40	<0.05	0.14	1.24	0.54
Reactive Silica	*mg/L*	*0.05*	56.4	31.4	51.5	34.3	53.9	19.9	13.7	17
Free Cyanide	*mg/L*	*0.004*	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Weak Acid Dissociable cyanide	*mg/L*	*0.004*	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Ammonia as N	*mg/L*	*0.01*	<0.01	1.33	0.06	2.47	0.24	1.88	1.92	0.86
Nitrite as N	*mg/L*	*0.01*	0.01	0.03	0.02	0.03	0.06	0.50	<0.01	<0.01
Nitrate as N	*mg/L*	*0.01*	1.01	0.81	1.31	1.38	1.19	0.09	<0.01	<0.01
Nitrite + Nitrate as N	*mg/L*	*0.01*	1.02	0.84	1.33	1.41	1.25	0.59	<0.01	<0.01
Reactive Phosphorus as P	*mg/L*	*0.01*	<0.01	<0.01	0.28	<0.01	0.03	0.02	<0.01	<0.01
Total Anions	*meq/L*	*0.01*	62.9	69.1	50.7	70.0	60.5	118	297	233
Total Cations	*meq/L*	*0.01*	66.7	70.1	55.1	75.6	62.6	110	308	219
Ionic Balance	*%*	*0.01*	2.98	0.68	4.09	3.88	1.74	3.59	1.92	2.97

The results indicate that the groundwater from the Upper Confined aquifer has the following characteristics:

- The groundwater is slightly alkaline, with a pH of about 7.8;
- It is of a sodium-chloride type with elevated concentrations of sulphate (~2,400 mg/L);
- It is brackish to saline with salinities ranging from 3,460 to 19,600 mg/L TDS; and
- The dissolved iron concentrations are about 0.64 mg/L.

Table 13: Laboratory analysed water chemistry – Camp Bore and lower confined aquifer bore

Analyte	Units	LOR	HAWB 002	HAWB 004	Lower Confined Aquifer Bore	LOR	HAHY 006
Sample Date			**6/10/19**	**6/10/19**			**29/5/20**
Field pH	*pH*	-	-	-	Lower Confined Aquifer Bore	-	7.07
Field EC	*µS/cm*	-	-	-		-	93130
pH	*pH Unit*	*0.1*	7.81	8.05		*0.01*	7.29
Electrical Conductivity @ 25°C	*µS/cm*	*2*	18900	3910		*1*	70000
Total Dissolved Solids @180°C	*mg/L*	*10*	13500	2120		*10*	53000
Total Hardness as $CaCO_3$	*mg/L*	*1*	3640	187		*1*	6840
Hydroxide Alkalinity as $CaCO_3$	*mg/L*	*5*	<1	<1		*1*	<1
Carbonate Alkalinity as $CaCO_3$	*mg/L*	*5*	<1	<1		*1*	<1
Bicarbonate Alkalinity as $CaCO_3$	*mg/L*	*5*	161	113		*1*	110
Total Alkalinity as $CaCO_3$	*mg/L*	*5*	161	113		*1*	110
Sulphate as $SO4^{2-}$	*mg/L*	*1*	3300	352		*1*	7490
Chloride	*mg/L*	*1*	4880	886		*1*	22200
Calcium	*mg/L*	*1*	557	42		*1*	1160
Magnesium	*mg/L*	*1*	545	20		*1*	958
Sodium	*mg/L*	*1*	3490	720		*1*	15700
Potassium	*mg/L*	*1*	124	15		*1*	282
Dissolved Aluminium	*mg/L*	*0.01*	<0.02	0.03		*0.01*	<0.1
Dissolved Manganese	*mg/L*	*0.001*	0.545	0.085		*0.001*	2.74
Dissolved Iron	*mg/L*	*0.05*	<0.05	<0.05		*0.05*	4.84
Reactive Silica	*mg/L*	-	-	-		*0.05*	14.1
Free Cyanide	*mg/L*	-	-	-		*0.004*	<0.040
Weak Acid Dissociable Cyanide	*mg/L*	-	-	-		*0.004*	<0.040
Ammonia as N	*mg/L*	-	-	-		*0.01*	1.67
Nitrite as N	*mg/L*	*0.005*	1.22	<0.01		*0.01*	<0.01
Nitrate as N	*mg/L*	*0.005*	<0.01	1.51		*0.01*	<0.01
Nitrite + Nitrate as N	*mg/L*	*0.005*	1.22	1.51		*0.01*	<0.01
Reactive Phosphorus as P	*mg/L*	-	-	-		*0.01*	<0.01
Total Anions	*meq/L*	*0.01*	210	34.6		*0.01*	784
Total Cations	*meq/L*	*0.01*	228	35.4		*0.01*	827
Ionic Balance	*%*	*0.01*	4.13	1.23		*0.01*	2.64

The results indicate that the groundwater from the Lower Confined Aquifer has the following characteristics:

- The groundwater is slightly circumneutral, with a pH of about 7.3;
- It is of a sodium-chloride type with elevated concentrations of sulphate (~7,500 mg/L);

- It is hypersaline with electrical conductivity @ 25°C of about 70.0 mS/cm, and 53,000 mg/L TDS; and
- The dissolved iron concentrations are about 4.8 mg/L.

8 GROUNDWATER FLOW MODELLING

8.1 MODELLING OBJECTIVES

The objective of this modelling assessment is to:

1. Provide an estimation of the inflow into the decline, vent shafts and drives;
2. Provide an estimation of the likely drawdowns in the various aquifers intercepted by and/or overlying the underground decline.

The study uses the latest mine schedule and water balance for the Havieron project provided by NML. The model was developed using the Murray Darling Basin guidelines (Middlemis, 2000), as required by DWER Operational Policy 5.12 (DoW, 2009), and the Australian groundwater modelling guidelines (Barnett et al. 2012) where appropriate.

8.2 CONCEPTUAL MODEL

The hydrogeological conceptual model on which the numerical model is created is based on the most up to date knowledge of the hydrogeology at Havieron gained from all available data (Section 1.3) and the current water bore drilling program (Section 6). Key aspects are presented in Figure 6 and Cross-Sections 1 and 2.

8.3 MODELLING PACKAGES

The code selected for conducting the modelling of the study area is MODFLOW-NWT, a Newton-Raphson formulation for MODFLOW-2005 developed by the USGS (Niswonger et al., 2011).

A Leapfrog geological model was developed for the study area encompassing the entire model boundary (Refer to Section 3.3). The coupling between Leapfrog and MODFLOW was used to develop the MODFLOW model. Each geological unit zone in the Leapfrog model was transferred and retained in the MODFLOW model as shown in Cross Section 2.

The model was built as a block model with flat layers for numerical stability. The FloPy package (Bakker et al., 2018) was used for creating, running, and post-processing the MODFLOW models.

8.4 MODEL EXTENT, LAYERS AND GRID

The model extent is shown in Figure 9 and is contained within the limits of the Leapfrog model. The regional model area was selected to allow for the assessment of the likely impacts of mine dewatering on the SRE species that were identified during the subterranean fauna assessment (Biologic, 2021).

The model extent encompasses a total area of 675 km^2 (approximately 30 km × 22.5 km). A finite difference grid was designed to provide a high resolution of the numerical solution, while at the same time accommodating the large model area. The finite element cell size was initially set at 500 m x 500 m, but become increasingly refined towards the central part of the model, where the decline is located, to 10 m x 10 m cells (Fig. 9). The resulting grid contains 175 Rows, 241 Columns and 25 Layers or a total of 1,054,375 cells.

The top of the model is represented by the LiDAR data resampled at a 25 m interval and extrapolated to the MODFLOW grid. Regional DEM data was used where a LiDAR dataset was unavailable. However, actual surveyed bore collar elevations were used for analysing borehole depth data.

There are 25 model layers, with the layer thicknesses varied to follow lithological unit distribution specified in the Leapfrog model. Layer 1, representing the Perched / Unconfined Aquifer, is 10 m in thickness. Then there are 20 layers from the base of unconfined aquifer to the basement, followed by one layer for weathered basement, then three layers to the base of the maodel at -1400 m AHD, within the Proterozoic. This allows adequate depth below the modelled decline and drives which extend to -932 m AHD depth.

8.5 GROUNDWATER FLOW BOUNDARY CONDITIONS

8.5.1 EXTERNAL BOUNDARY CONDITIONS

Model-perimeter boundaries are summarised in Table 14.

Table 14: Model-perimeter (external) boundary conditions

Model boundary	Feature	Boundary Condition
Perched / Unconfined Aquifer		
Southern Boundary	Palaeovalley drains to Lake Dora	Dirichlet BC = Fixed Potentiometric Head in Model cells defined as Calcrete Elevation (239 m AHD) fixed to match the recorded water level at HAVWB06 and elevation of Lake Dora.
Upper Confined Aquifer		
Eastern Boundary	Potentiometric head contour. Boundary with Triwhite Sandstone	Dirichlet BC = Fixed Potentiometric Head Potentiometric head interpolated by matching groundwater gradient identified in Upper Tillite (0.75 m/km) and adjusted through calibration
Southern Boundary	Palaeovalley drains to Lake Dora	Dirichlet BC = Fixed Potentiometric Head in Model cells defined as Calcrete Elevation (239 m AHD) fixed to match the recorded water level at HAVWB06 and elevation of Lake Dora.
Lower Confined Aquifer		
Northern Boundary	Potentiometric head contour	Dirichlet BC = Fixed Potentiometric Head Potentiometric head (209 m AHD) interpolated by matching groundwater gradient identified in Upper Confined Aquifer (0.0007 m/m) and adjusted through calibration
Southern Boundary	Potentiometric head contour	Dirichlet BC = Fixed Potentiometric Head (Water is permitted to enter the model at this boundary) Potentiometric head (244 m AHD) interpolated by matching groundwater gradient identified in Lower Confined Aquifer (0.001 m/m) identified from available bores (HAGT008, HAGT011 and HAHY005) and adjusted through calibration

8.5.2 RECHARGE AND EVAPOTRANSPIRATION

The evaporation package was used to simulate evapotranspiration where the depth to groundwater is ≤3 m. An evaporation rate of 2,464 mm/yr was adopted based on evaporation data for Telfer (3,520 mm/yr); this was multiplied by a pan factor of 0.7. This rate was applied from the surface, with a linear decrease to the extinction depth set at 3 m bgl.

Recharge was applied to Layer 1 of the model but only to areas of the model domain where depth to groundwater is >3 m and where UM claystone is absent. This is consistent with the previous model (Rockwater, 2020) that assumed no rainfall recharge occurs in areas where UM claystone is present. Values for recharge were derived through calibration of the model.

The internal boundary conditions are summaries in Table 15.

Table 15: Model internal boundaries (Net Recharge)

Boundary	Zone	Adopted Steady-state recharge rate	Adopted Evapotranspiration rate (mm/yr)	Comments
Rainfall Recharge	UM claystone present	0%	0	Assumption that no rainfall recharge occurs Depth to water >3 m and likely no loss to evaporation
Rainfall Recharge	UM claystone absent* and water level > 3 m bgl	0-1%	0	0 to 1% of average annual rainfall Depth to water >3 m and likely no loss to evaporation
Evapotranspiration	Water level ≤ 3 m bgl	0%	3,520 x 0.7 = 2,464	Assumption because of depth to water ≤3 m and likely losses to evaporation

**: Perched / Unconfined Aquifer directly underlain by Upper Confined Aquifer*

8.6 AQUIFER PARAMETERS

Values of horizontal hydraulic conductivity reported from hydraulic testing (BMR logs, pump tests, packer tests and slug tests) and summarised in Table 6. Specific storage and specific yield values were estimated from test pumping data and BMR logs.

8.7 STEADY-STATE CALIBRATION PROCESS

A steady-state groundwater flow model representing the study area was constructed to simulate the current potentiometric heads within the aquifers. To calibrate the model, rainfall was varied between 0 and 1% of the annual rainfall and the hydraulic conductivities were varied within the range of values obtained from hydraulic testing (Table 6). A set of 1,000 models were then generated by varying the recharge rates and hydraulic conductivities within the range of values in Table 16. The parameters were assumed to follow a double-triangle probability distribution with a median value equal to the Base Case in Table 16.

The simulated head distribution for each model was compared to the measured head distribution and the Scaled Root Mean Square (SRMS) Error was calculated (using the measured range of observed groundwater levels). The SRMS values ranged from 4.70 % to 14.27%. For the purpose of this assessment, all runs that achieved a SRMS of less than 5% (182 runs in total) were considered to have an acceptable calibration and were retained for prediction modelling. This matches the industry accepted guideline of <5% suggested by Barnett, et. al. (2012).

Table 16: Model parameters variations used to achieve calibration

Model Parameter	Unit	Base Case	Min	Max
Recharge Rate	mm/yr	1.0E-01	5.0E-02	2.0E-01
Permeability: Top cover	m/d	2.0E-02	1.0E-02	1.0E-01
Permeability: Calcrete	m/d	5.1	1.0E-01	2.5E+01
Permeability: Saprolite **Unconfined / Perched Aquifer**	m/d	1.0E-02	1.0E-02	1.0E-01
Permeability: Upper Mudstone	m/d	9.2E-04	1.0E-04	1.0E-03
Permeability: Upper Tillite Sandstone **Upper Confined Aquifer**	m/d	1.5E-01	5.0E-02	3.0E-01
Permeability: Upper Tillite (West)	m/d	7.5E-02	4.1E-02	9.1E-02
Permeability: Upper Tillite (East)	m/d	1.2E-02	3.6E-03	1.6E-02
Permeability: Lower Siltstone (Upper)	m/d	3.3E-06	5.0E-08	5.0E-06
Permeability: Middle Sandstone	m/d	3.6E-03	1.00E-03	5.0E-03
Permeability: Lower Siltstone (Lower)	m/d	1.2E-06	5.0E-08	5.0E-06
Permeability: Lower Tillite	m/d	6.8E-04	5.0E-04	1.0E-03
Permeability: Lower Tillite Sandstone **Lower Confined Aquifer**	m/d	4.6E-02	1.0E-03	1.0E-02
Permeability: Ordovician	m/d	6.9E-05	5.0E-05	5.0E-04
Permeability: Weathered Basement	m/d	1.3E-03	5.0E-04	5.0E-03
Permeability: Basement	m/d	7.2E-05	1.0E-05	1.0E-04
Permeability: Breccia	m/d	8.9E-04	5.0E-04	5.0E-03
Permeability: Dolerite	m/d	6.3E-03	1.0E-03	1.0E-02

8.7.1 CALIBRATION RESULTS

The simulated head distribution for each model was compared to the measured head distribution and the Scaled Root Mean Square (SRMS) Error was calculated. The SRMS of the best-calibrated run (Run 747) was 4.70%. A comparison of calibrated versus observed hydraulic heads is shown in Figure 10 with parameters from this run presented in Table 17.

Table 17: Model parameters for calibrated model (Run 747)

Model unit	HK Calibrated	HK min	HK max
	(m/day)	(m/day)	(m/day)
Cover	0.01	1.00E-02	1.00E-01
Calcrete	4.10	1	25
Saprolite **Unconfined / Perched Aquifer**	1.00E-02	1.00E-02	1.00E-01
Upper Mudstone	9.43E-04	1.00E-04	1.00E-03
Upper Tillite (Sandstone) **Upper Confined Aquifer**	1.36E-01	5.00E-02	5.00E-01
Upper Tillite (West)	8.58E-02	4.10E-02	9.10E-02
Upper Tillite (East)	1.27E-02	3.60E-03	1.60E-02
Lower Siltstone (upper)	3.96E-06	1.00E-04	2.00E-04
Middle Sandstone	3.60E-03	1.00E-03	5.00E-03
Lower Siltstone (lower)	7.22E-07	1.00E-04	1.00E-03
Lower Tillite	8.82E-04	1.00E-04	1.00E-03
Lower Tillite (Sandstone) **Lower Confined Aquifer**	4.77E-02	1.00E-03	1.00E-02
Ordovician	1.05E-04	5.00E-05	5.00E-04
Weathered Basement	1.04E-03	5.00E-04	5.00E-03
Basement	4.27E-05	1.00E-05	1.00E-04
Breccia	6.75E-04	5.00E-04	5.00E-03
Dolerite	9.71E-03	1.00E-03	1.00E-02

8.7.2 WATER BALANCE

A water balance (Table 18) from the calibrated model indicates an error of -0.01%, which is compliant with the suggested criteria provided by Barnett, et. al. (2012) of <1 %.

Table 18: Steady state water balance (Run 747)

Component	Inflow	Outflow	Cumulative water balance
	(m^3/d)	(m^3/d)	(m^3/d)
1) Net Recharge	85.1297	0.0000	85.1297
2) Net Evapotranspiration	0.0000	189.1802	-189.1802
3) Regional Through-flow	185.9052	81.8724	104.0328
Total	**271.0349**	**271.0525**	**-0.0176**
		Balance Error (%)	**-0.01%**

8.8 PREDICTIVE MODELLING

Each of the calibrated model runs (i.e. all steady state runs with SRMS < 5.0 %) were used as predictive models to determine the impact of future extraction and inflow into the underground decline.

8.8.1 DEWATERING

The following assumption were adopted for modelling dewatering:

- Progression of the decline construction follows the schedule set out in Chart 1 with 3-monthly time steps.
- Model simulation time of 13 years (01/05/2021 to 01/03/2034), in-line with expected Life of Mine (LoM).
- Vent shaft construction in accordance with Table 8. Drives and stopes modelled in accordance with the Deswick mine schedule.

Inflows into the decline, vertical shafts, stopes and drives were simulated using the drain package in MODFLOW. Drain cells conductance was based on the hydraulic conductivity of each cell that is intersected by the decline. The maximum depth of drain cells over the model duration is shown in Chart 1. This was incorporated into the model through a Python script for each model stress period in FloPy.

Modelled drain cells were refined to 10 m x 10 m. This is relatively close to the decline dimensions of approximately 5 m x 6 m. This drain cell size was chosen to also account for the back break or over blast during the decline construction, which would result in a zone of increased permeability surrounding the mine workings.

8.8.2 PRODUCTION BORE EXTRACTION

NML require a water supply of 24 L/s throughout the life of mine. Water will be sourced from water supply bores constructed in the Upper Confined Aquifer and from mine dewatering.

Bore extraction is modelled using the well package with the rates as specified in Table 19. Production bore locations are shown in Figure 5.

Table 19: Production bore usage (L/s)

Bore #	Bore ID	Aquifer	Extraction Rate (L/s)	
			Year 1	Years 2 - 13
1	HAHY006	Lower Confined	0.40	1.10
2	HAHY007	Upper Confined	0.30	0.90
3	HAVWB08	Upper Confined	-	0.50
4	HAVWB09	Upper Confined	1.20	1.80
5	HAVWB10	Upper Confined	-	0.20
6	HAVWB11	Upper Confined	-	2.00
7	HAVWB12	Upper Confined	-	0.50
8	HAVWB13	Upper Confined	-	0.60
9	HAVWB07	Upper Confined	0.50	1.00
10	HAVWB14	Upper Confined	0.20	0.00
11	HAVWB04	Upper Confined	0.20	0.20
12	HAD002	Upper Confined	0.10	0.50
13	HAHY034	Upper Confined	-	1.30
14	HAHY032	Upper Confined	-	3.10
		Total	**2.9**	**13.7**

8.8.3 PREDICTED EXTRACTION VOLUME

Predicted dewatering inflow versus time for all predictive model runs are shown in Figure 11. The P10 and P90 are highlighted to show the likely range of inflows that could be encountered. Results indicate that dewatering inflows will peak 3 to 4.5 years from the commencement of dewatering, at about 33 L/s and then taper off to about 22 L/s in the longer-term. When incorporated with the borefield supply, this indicates that up to 1.5 GL/a may be required during the peak period of dewatering, with 0.8 to 1.2 GL/a required ongoing (Fig. 12).

These predicted inflows may be conservative, as modelling doesn't incorporate the planned lining with shotcrete. This lining has been shown in previous studies by NML to reduce inflows by 1 to 18% (Piteau, 2018).

8.8.4 PREDICTED AQUIFER DRAWDOWN

As a result of groundwater extraction the water levels in Upper Confined and Lower Confined Aquifers, and to lesser extent the Unconfined/Perched Aquifer will drawdown. Drawdown is the measure of change from the static water level or potentiometric surface resultant from the extraction.

The model predicted drawdowns in the Upper Confined Aquifer at 2027 and 2034 are shown in Figures 13 and 14, respecitvely. Drawdowns for the Lower Confined Aquifer at 2027 and 2034 are shown in Figures 15 and 16, respecitvely.

The predicted zone of impact at 2034 (as defined by the 2 m drawdown contour) is predicted to have dimensions of 10.3 km x 8.0 km in the Upper Confined Aquifer. For the Lower Confined Aquifer, the zone of impact larger and is predicted to range from 16.1 km x 17 km. The variation in the extent of drawdown using the different model runs was negligible.

Model-calculated drawdown for monitoring bore HAHY001, located in close proximity to the mine (Fig. 5) is presented with observed drawdown in Figure 17. These show a close correlation and verify that model predictions are reasonable.

Model predicted drawdowns for selected for monitoring bores locations, based on the stygofauna survey, are shown in Figures 18 to 20 and summarised for 2034 in Table 20. These plots provide an indication of predicted drawdown in the Unconfined and Upper Confined aquifers at each bore location, as well as the upper mudstone (aquitard). They show that there is minor drawdown in the Unconfined Aquifer at HAWB01, and significant drawdown in the upper mudstone and Upper Confined Aquifer at HAVWB01 and HAVWB03. Limited drawdown is predicted at HAE003.

Table 20: Model predicted drawdown for 2034 at Stygofauna survey sites

Aquifer	Model Run		Drawdown at HAVWB01 (m)	Drawdown at HAVWB03 (m)	Drawdown at HAE003 (m)
Unconfined	Calibrated Run		0.95	0.00	0.00
	Range	From	0.12	0.00	0.00
		To	1.00	0.02	0.02
Upper Mudstone	Calibrated Run		16.00	10.00	-
	Range	From	15.50	9.00	-
		To	16.50	11.00	-
Upper Confined	Calibrated Run		56.00	13.00	0.38
	Range	From	55.50	12.20	0.08
		To	54.50	14.90	0.41

At HAVWB01 the potentiometric surface of the Upper Confined Aquifer is about 246.10 m AHD, about 58.35 m above the top of the aquifer, which is present at 187.7 m AHD. Groundwater modelling indicates that potentiometric surface in this aquifer would drawdown up to 56 m, to about 190.05 m AHD, therefore the aquifer would remain confined at this location. In the Unconfined Aquifer about 1 m of drawdown is anticipated.

At HAVWB03 the potentiometric surface of the Upper Confined Aquifer is about 245.43 m AHD, about 47 m above the top of the aquifer, which is present at 198.45 m AHD. Groundwater modelling indicates that potentiometric surface in this aquifer would drawdown up to 15 m, to about 230.45 m AHD, therefore the aquifer would also remain confined at this location. Negligible drawdown is predicted in the Unconfined Aquifer, therefore and no stygofauna habitat is predicted to be lost.

8.8.5 WATER BALANCE

A water balance has been developed using the results of the P90 scenario (Table 21). The water balance error of 0.0006% was obtained which is compliant with the suggested criteria provided by Barnett et. al. 2012 of <1 %.

Table 21: Water balance entire model (2021 to 2034) for Run 811

Component	Inflow (m^3/d)	Outflow (m^3/d)	Cumulative water balance (m^3/d)
Storage Change	3268.7489	22.7352	3246.0136
Constant Heads	307.9381	81.8514	226.0867
Recharge	41.8497	0.0000	41.8497
Evaporation	0.0000	258.8269	-258.8269
Bore extraction	0.0000	1121.2508	-1121.2508
Inflow into Decline/Shafts	0.0000	2133.8496	2133.8496
Total	**3618.5367**	**2598.2011**	**0.0230**
		Balance Error (%)	**+0.0006%**

8.8.6 MODEL CAPABILITIES AND LIMITATIONS

This study used a three-dimensional groundwater flow model to:

1. Provide an estimation of the inflow into the decline;
2. Assess the potential for local groundwater resources to provide construction water; and
3. Provide an estimation of the likely drawdowns in the various aquifers intercepted by and/or overlying the underground decline.

The main uncertainties associated with the model are due to gaps in the available data, particularly the uneven distribution of bores and the limited number of bores in the Lower Confined Aquifer and distal from the decline. As a result, it has been necessary to infer aquifer characteristics for large parts of the model. For instance, the groundwater flow direction in the Lower Confined Aquifer relies only on a few data points.

Good quality temporal water-level measurements, which are needed for transient-model flow calibration, were not available and thus only steady state calibration was possible. However, English et al. (2012) have shown that temporal water level variation in Permian aquifers in the region are generally limited to very large rainfall events (for example cyclone Fay in 1993) which led to surface water ponding and enhanced recharge.

The level of data used in the modelling assessment is nonetheless similar to other models at the project evolution stage whereby data is limited. There also exists an inherent variability in the low permeability, highly heterogeneous, sedimentary aquifers. This inherent variability will remain regardless of number of tests or data collected. Furthermore, storage properties when estimated prior to mining are usually highly uncertain.

Nevertheless, the objective of the modelling was to gain further understanding of the aquifers at Havieron, and to quantify the impact of the required dewatering and groundwater extraction on the groundwater resources. This objective has been achieved, particularly since results of numerous model runs have been presented so that the degree of uncertainty in model predictions can be understood.

9 ASSESSMENT OF POTENTIAL IMPACTS

9.1 STYGOFAUNA

The Unconfined/Perched Aquifer and the Upper Confined Aquifer will be intersected by the proposed mine decline and as a result will require the aquifer to be dewatered proximal to the decline for the duration of the mine. The modelling indicates that this drawdown has the potential to affect SRE stygofauna species in bores HAVWB01 and HAVWB03. The model indicates that at HAE003 drawdown will be minor. See section 8.8.4 for further detail.

The Lower Confined Aquifer, weathered basement rocks, the dolerite dyke and brecciated rocks will also require dewatering. However, these units do not appear to host potentially SRE stygofauna species. This is consistent with the hydrogeological conceptualisation which indicates this deeper aquifer is not in hydraulic connection with shallower aquifers in the study area.

9.2 VEGETATION

Vegetation surveys were undertaken by Strategen-JBS&G both regionally and near the Havieron study area.

The preliminary results of those surveys appear to confirm the Bureau of Meteorology's online database of potential groundwater dependent ecosystems (GDE) which do not list any significant vegetation having a high potential for groundwater interaction in the vicinity of the Havieron project.

Where the Upper Mudstone formation is thin or absent the drawdown in the Upper Confined Aquifer (Fig. 14) may have the potential to impact on the identified vegetation communities (Fig. 4). However, Strategen-JBS&G noted that the *Eucalyptus victrix* vegetation communities are located within an area of localised water collection, potentially capturing surface water runoff during periods of heavy rainfall. Additionally, no other known groundwater dependant taxa are present within this vegetation type. Based on this advice, *Eucalyptus victrix* is likely to primarily reliant on surface water within this vegetation and as such is unlikely to represent a Groundwater Dependant Ecosystem.

For details on the vegetation survey the reader may refer to the detailed report by Strategen-JBS&G.

9.3 REGIONAL GROUNDWATER RESOURCES

The zone of impact (as defined by the 2 m drawdown contour; see Figures 14 and 16) are predicted to have approximate dimensions of 10.3 km x 8.0 km in the Upper Confined Aquifer and 16.1 km x 17 km in the Lower Confined Aquifer. These aquifers have a regional extent beyond this predicted zone of impact. The water balance indicates that the water discharge to the west of the model extent (where there are Calcrete aquifers) is unaffected by the proposed extraction.

10 GROUNDWATER MONITORING

NML has prepared and submitted a Groundwater Management Plan to DWER which details its proposed monitoring regime. NML has established a network of monitoring bores which will be used to measure water levels in each of the Permian aquifer intervals and will be used verify model predicted drawdowns. All groundwater extraction will be recorded using approved calibrated flow meters. NML will provide DWER annual groundwater monitoring summaries and triennial groundwater monitoring reviews which will detail groundwater monitoring and extraction data.

11 CONCLUSIONS

The results of this hydrogeological assessment indicate that the impact of dewatering of the proposed underground decline is likely to be localised to an area close to the mine within the Paterson Formation rather than regionally extensive. The extent of drawdown (taken as the 2 m drawdown contour) is predicted to be about 10 km x 8 km in the Upper Confined Aquifer and from 16 km x 17 km in the Lower Confined Aquifer.

Detailed assessment of potential impact on the vegetation can be found in a separate report by Strategen JBS&G (2021,) while a detailed assessment of potential impact on the stygofauna can be found in a separate report by Biologic (2021,).

Dewatering inflows are calculated by modelling to peak at 3 to 4.5 years from the commencement of dewatering, at about 33 L/s and then taper off to about 22 L/s in the longer-term. Actual dewatering inflows are likely to be somewhat lower because of the impact of shotcrete lining of the decline and grouting of stopes. In addition, pumping from production bores is modelled to be up to 14 L/s from 14 bores for most of the mine life.

Results indicate that with the borefield supply, up to 1.5 GL/a may be required during the peak period of dewatering, with 0.8 to 1.2 GL/a required up to 2034. As a result, it is recommended that a GWL licence be sought for 1.5 GL/a.

We suggest that DWER may consider differentiating the (low permeability) non-artesian groundwater resources within the Paterson Formation from the artesian groundwater resources within the Wallal Sandstone further north when considering this application.

Dated: 13 December 2021 **Rockwater Pty Ltd**

Steve Bolton M.Taylor

Steve Bolton
Principal Hydrogeologist

Miranda Taylor
Principal Hydrogeologist

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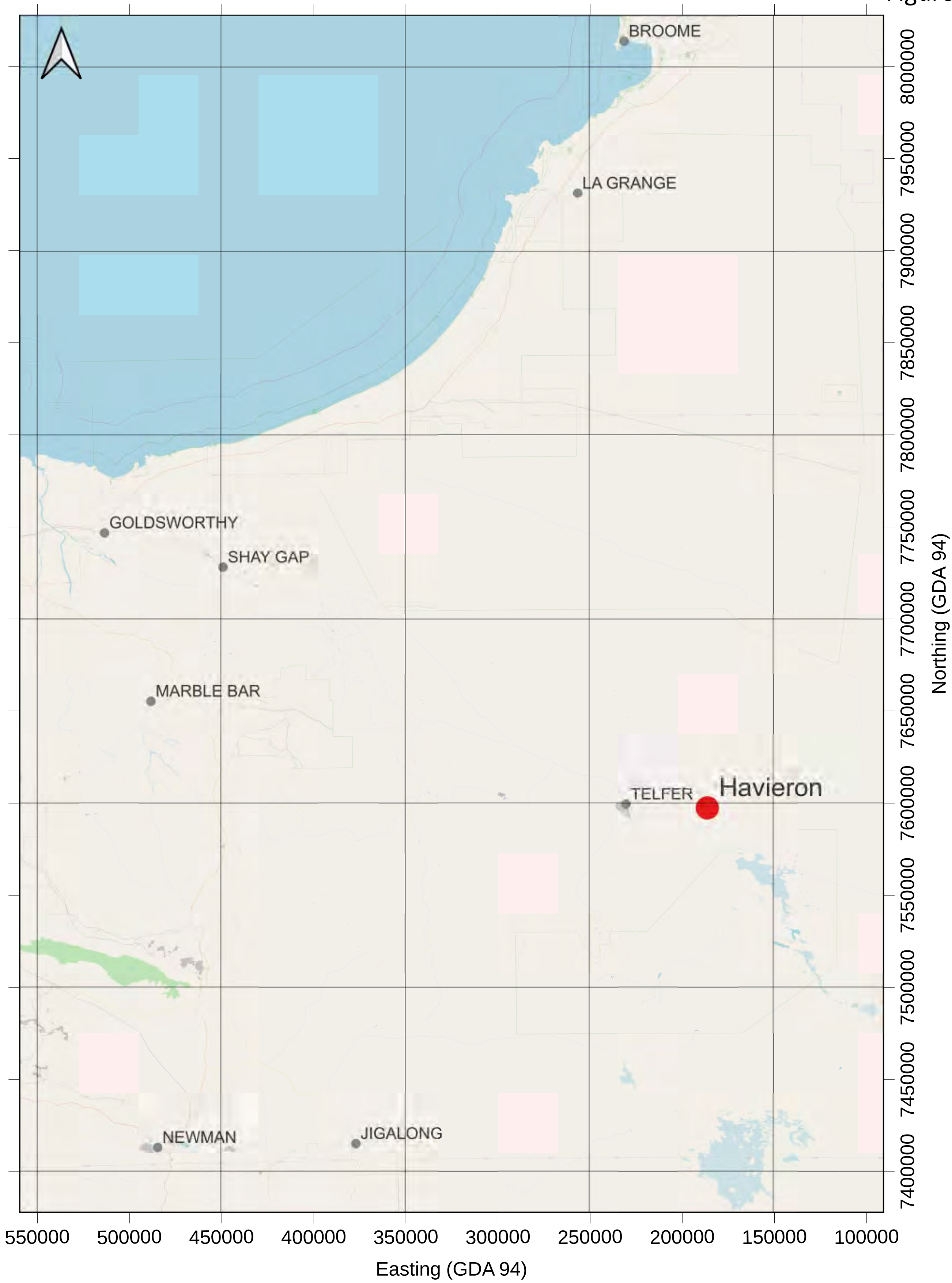
FIGURES

Figure 1



6-3/Surfer/21-05/Fig 1 - Havieron Location and Tenements.srf

Client: Newcrest Australia

Project : H3 Level of Assessment

Date : December 2021

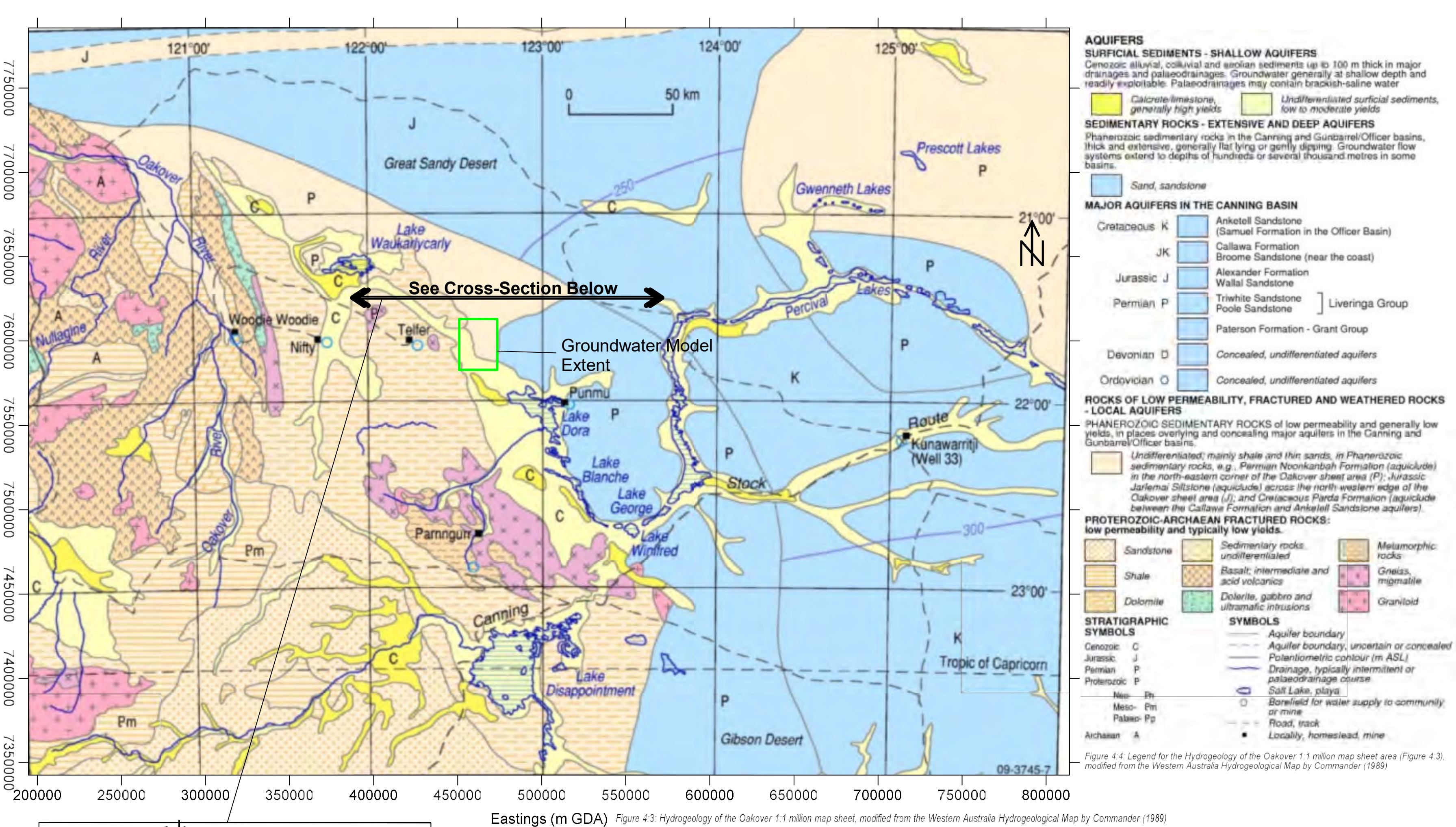
Dwg. No: 6.3/21/5-1

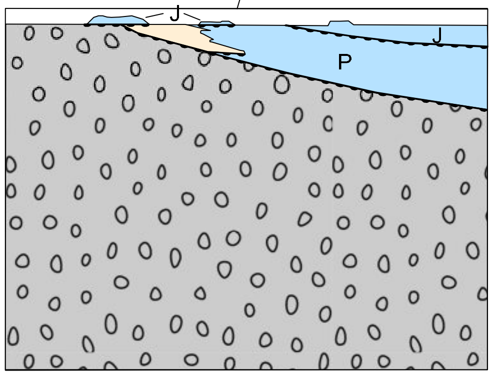
HAVIERON
PROJECT LOCATION

Rockwater PROPRIETARY LIMITED

CLIENT: Newcrest Australia
PROJECT: H3 Level of Assessment
DATE: December 2021
Dwg. No: 6-3/21/5-2

6-3/Surfer/21-05/Figure 2 - Regional Hydrogeology Map.srf





Pre-Cainozoic Schematic Cross Section

- J Jurassic to Early Cretaceous
- P Early Permian
- Paterson Formation - Early Permian
- Protorozoic
- Uncomformity

HYDROGEOLOGY MAP OF THE OAKOVER (COMMANDER (1989))

Figure 2

Rockwater

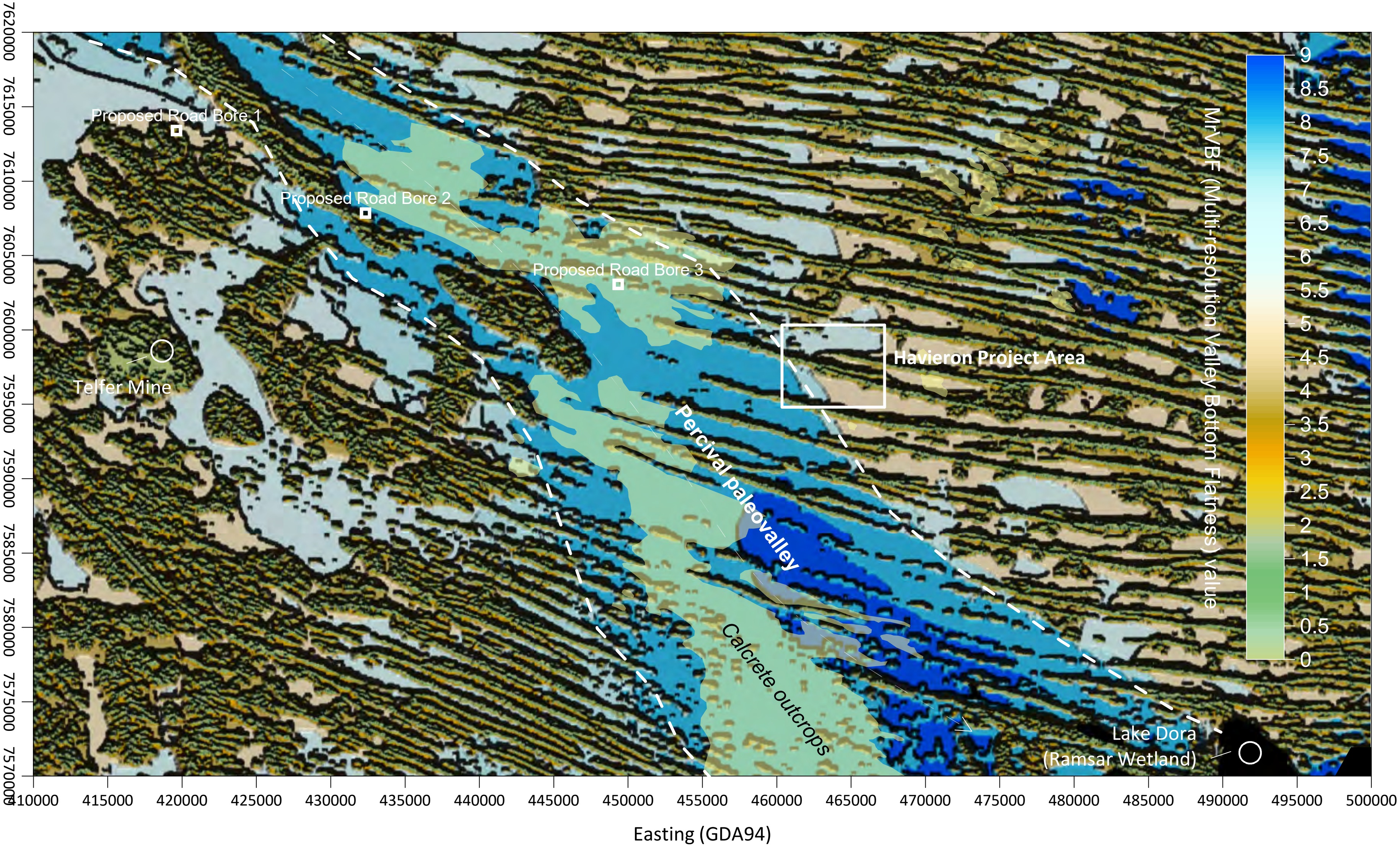


Figure 3

6-3/Surfer/20-02/Figure 4 - Percival Paleovalley Map.srf

Client: Newcrest Australia

Project : H3 Level of Assessment

Date : December 2020

Dwg. No: 6.3/20/2-3

PERCIVAL PALAEOVALLEY MAP

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Client: Newcrest Australia
Project : H3 Level of Assessment
Date : December 2021
Dwg. No: 6.3/21/5-5

6-3/Surfer/21-05/Figure 4 - Depth to Water.srf

HAVIERON
DEPTH TO WATER

Figure 4

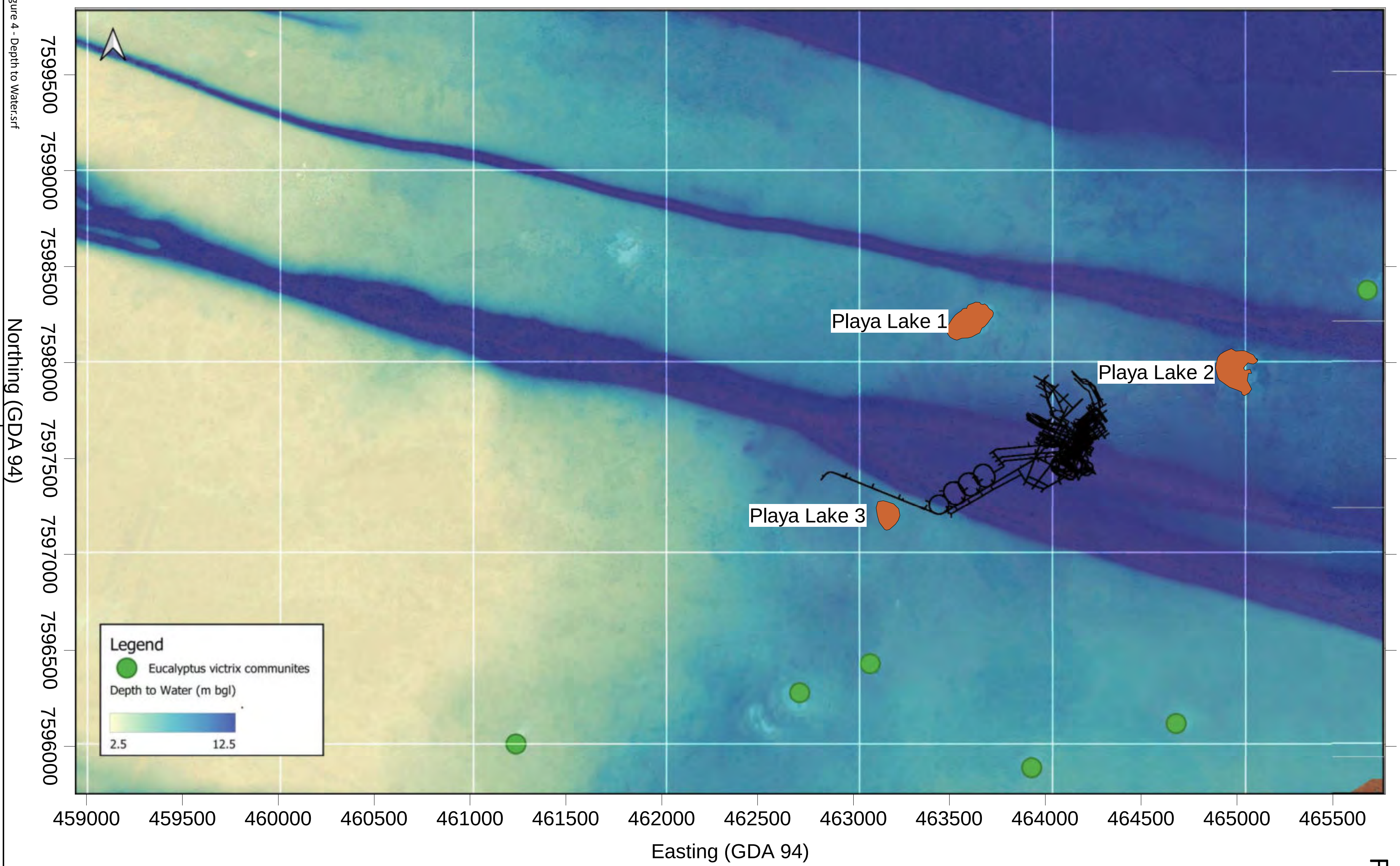

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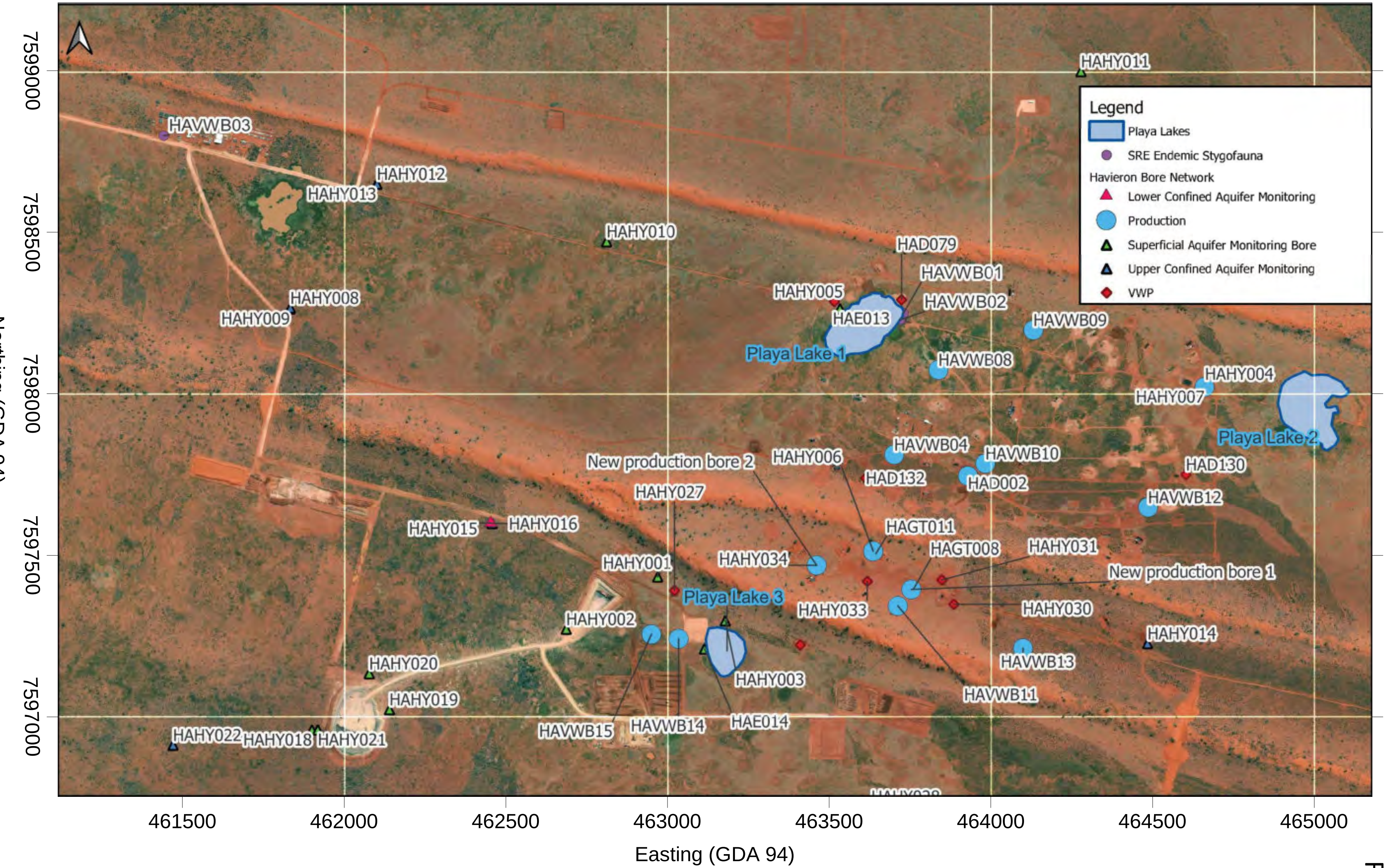
Figure 5



6-3/Surfer/21-05/Figure 5 - Bores.srf

Client: Newcrest Australia
Project : H3 Level of Assessment
Date : December 2021
Dwg. No: 6.3/21/5-5

HAVIERON
WATER BORE SUMMARY

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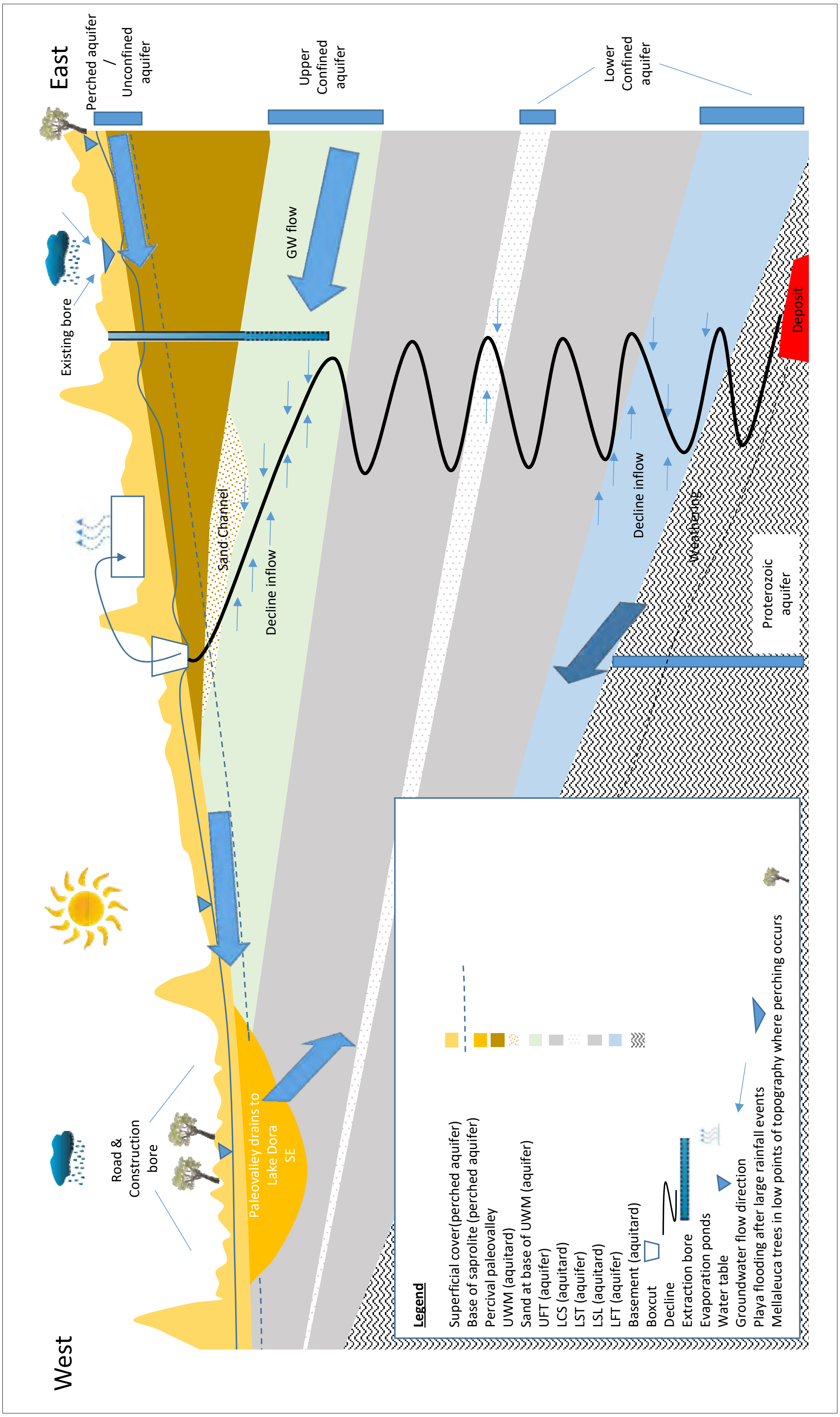
Figure 6

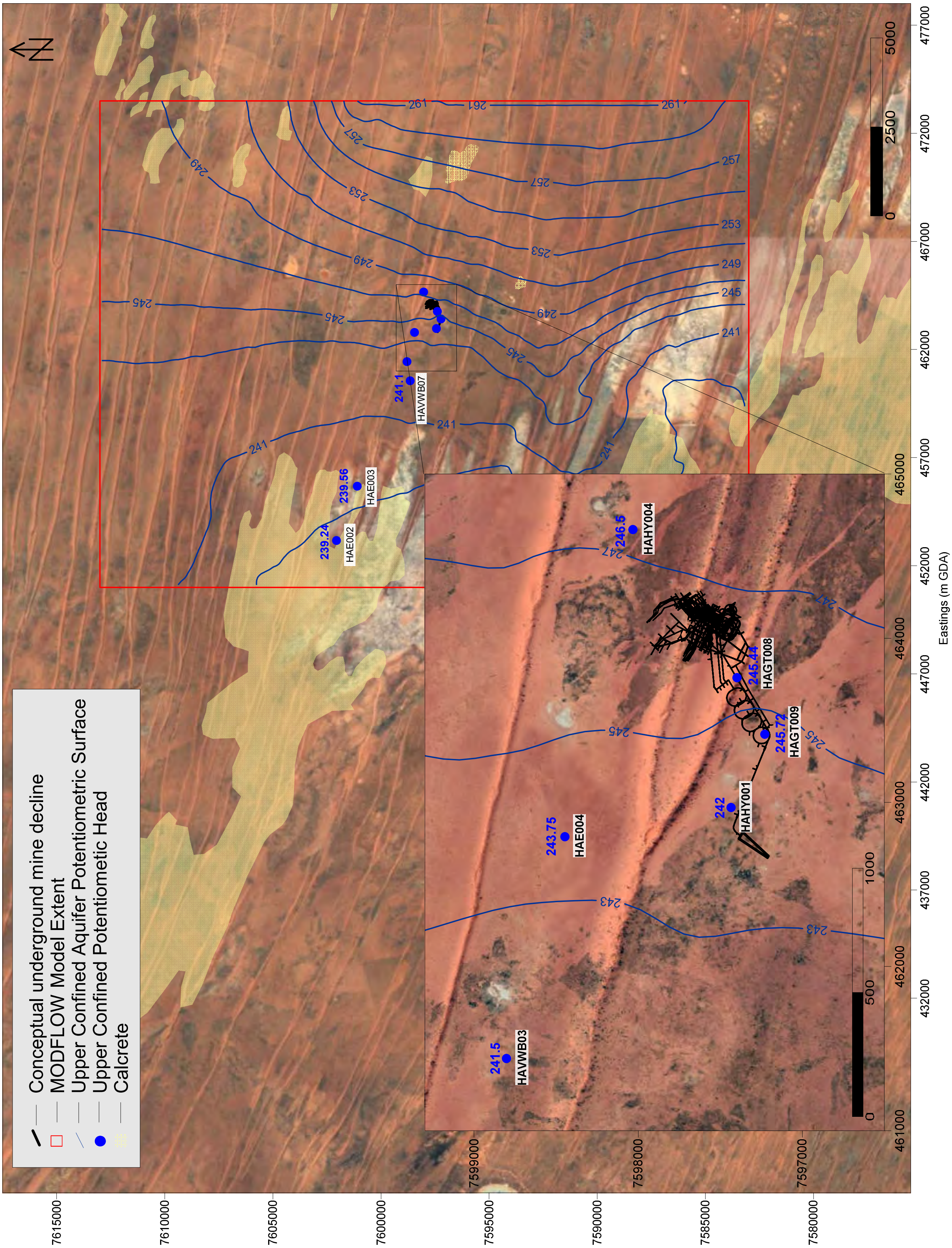


6-3/Surfer/21-05/Figure 6- Conceptual Hydrogeological Diagram.srf

Client:	Newcrest Australia
Project :	H3 Level of Assessment
Date :	December 2021
Dwg. No:	6.3/21/5-6

CONCEPTUAL HYDROGEOLOGICAL DIAGRAM

Figure 7



6-3/Surfer/21-05/Figure 7 - Water Levels.srf

Client: Newcrest Australia

Project : H3 Level of Assessment

Date : December 2021

Dwg. No: 6.3/21/5-7

UPPER CONFINED AQUIFER POTENTIOMETRIC SURFACE

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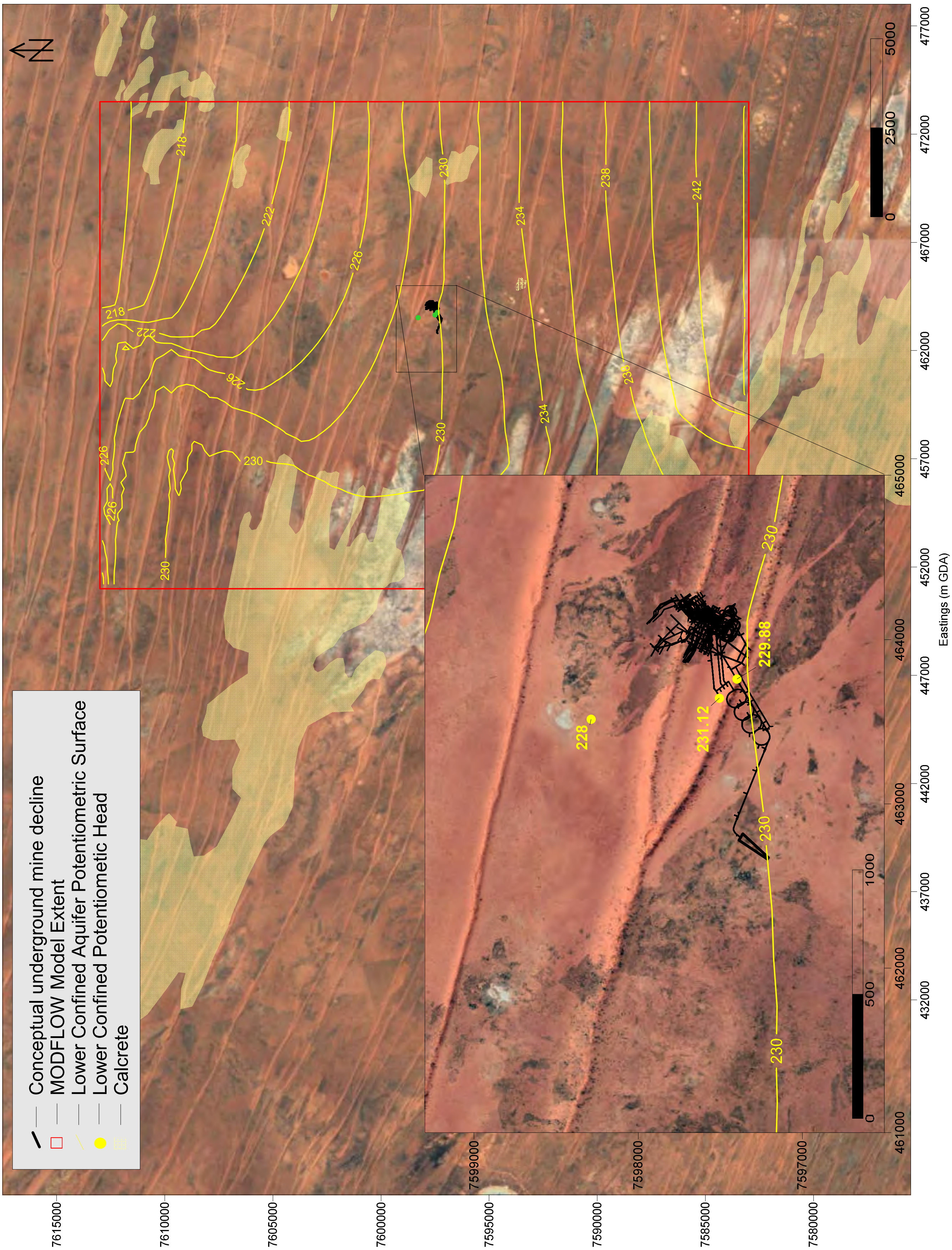
Figure 8



6-3/Surfer/21-05/Figure 8- Water Levels.srf

Client: Newcrest Australia

Project : H3 Level of Assessment

Date : December 2021

Dwg. No: 6.3/21/5-8

LOWER CONFINED AQUIFER POTENTIOMETRIC SURFACE

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Client: Newcrest Australia
Project : H3 Level of Assessment
Date : December 2021
Dwg. No: 6.3/21/5-9

HAVIERON
MODFLOW MODEL GRID AND MEASURED GROUNDWATER LEVELS

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6-3/Surfer/21-05/Figure 9 - Modflow Grid.srf

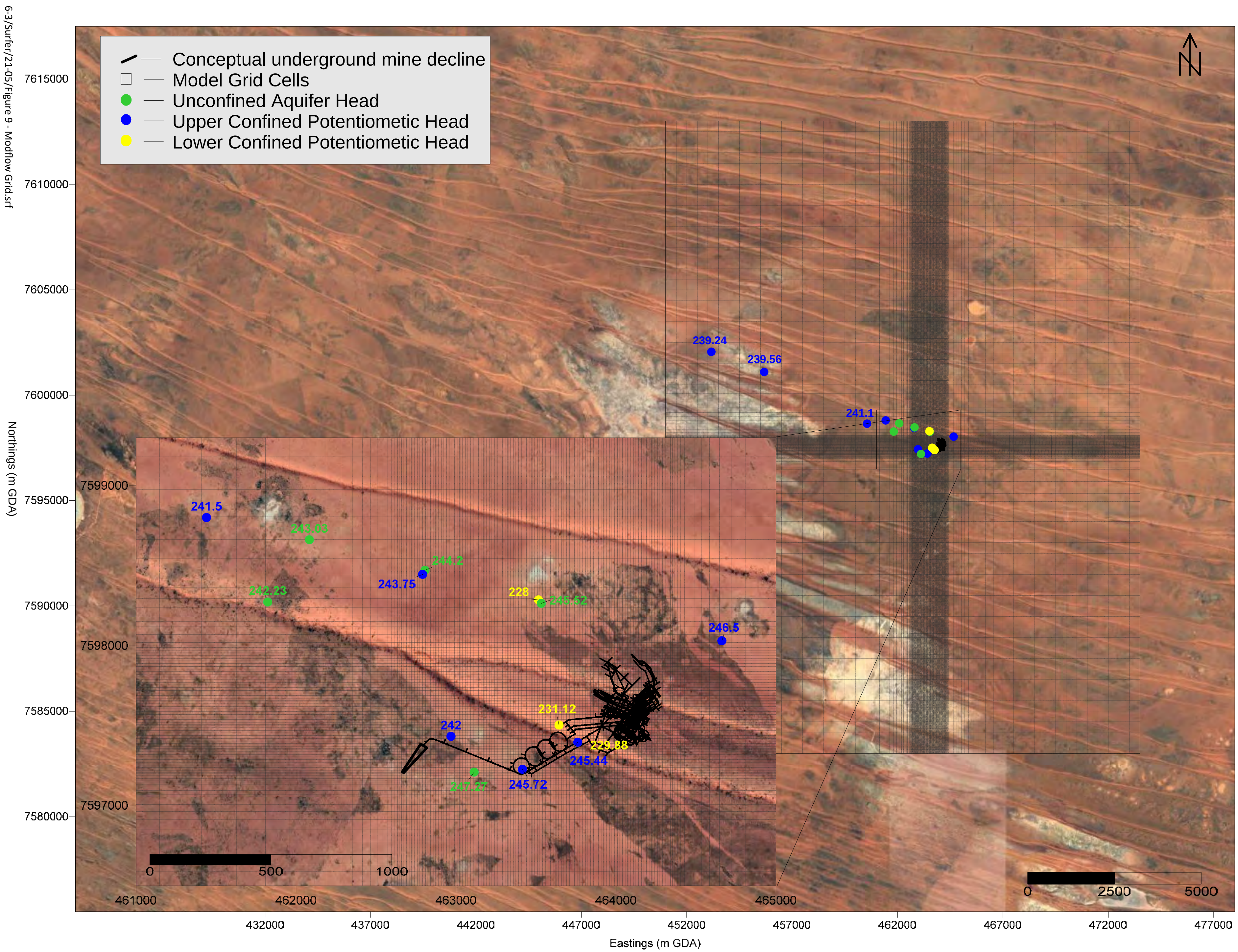
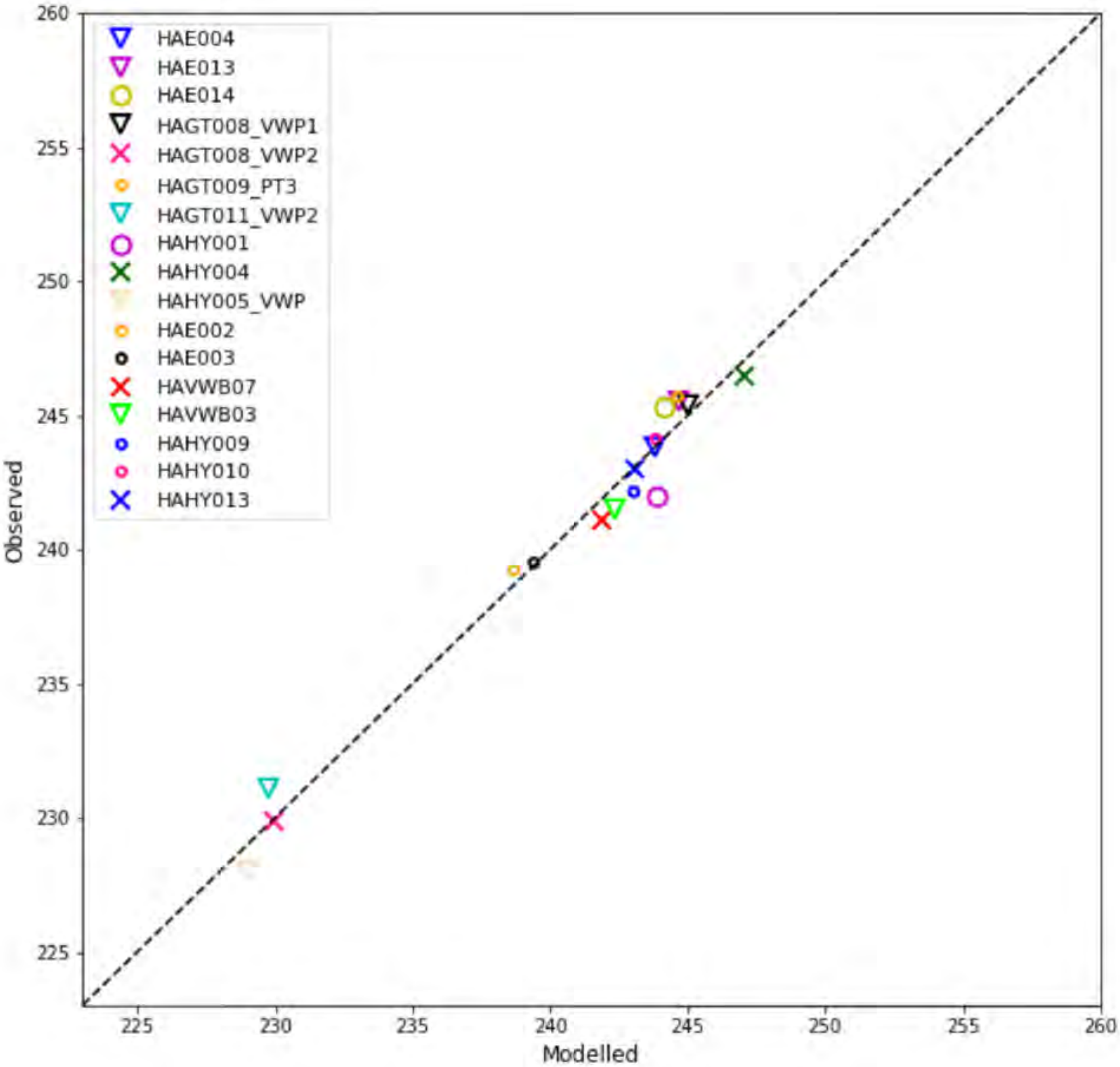


Figure 9

Figure 10



6-3/Surfer/21-05/Figure 10.srf

Client:	Newcrest Australia
Project :	H3 Level of Assessment
Date :	December 2021
Dwg. No:	6.3/21/5-10

STEADY STATE CALIBRATION
OBSERVED VS MODELLED HYDRAULIC HEADS
(RUN 747)

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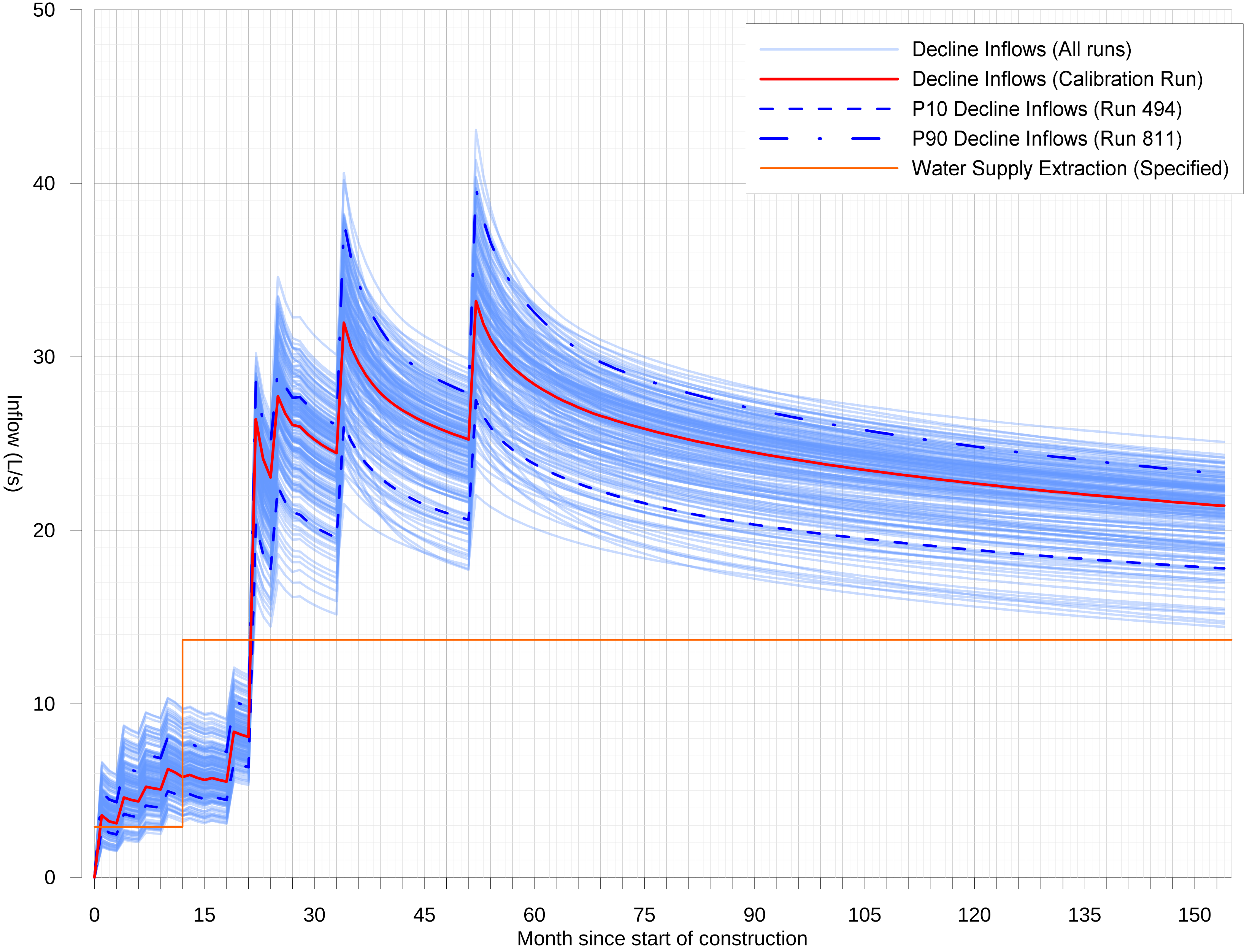
Appendix J H3 Hydrogeological Report
Figures 11-20



6-3/Grapher/Fig 11- Inflow vs time.grf

Client: Newcrest Australia

Project : H3 Level of Assessment

Date : December 2021

Dwg. No: 6-3/21/5-11

MODEL-CALCULATED INFLOWS AND WATER SUPPLY EXTRACTION

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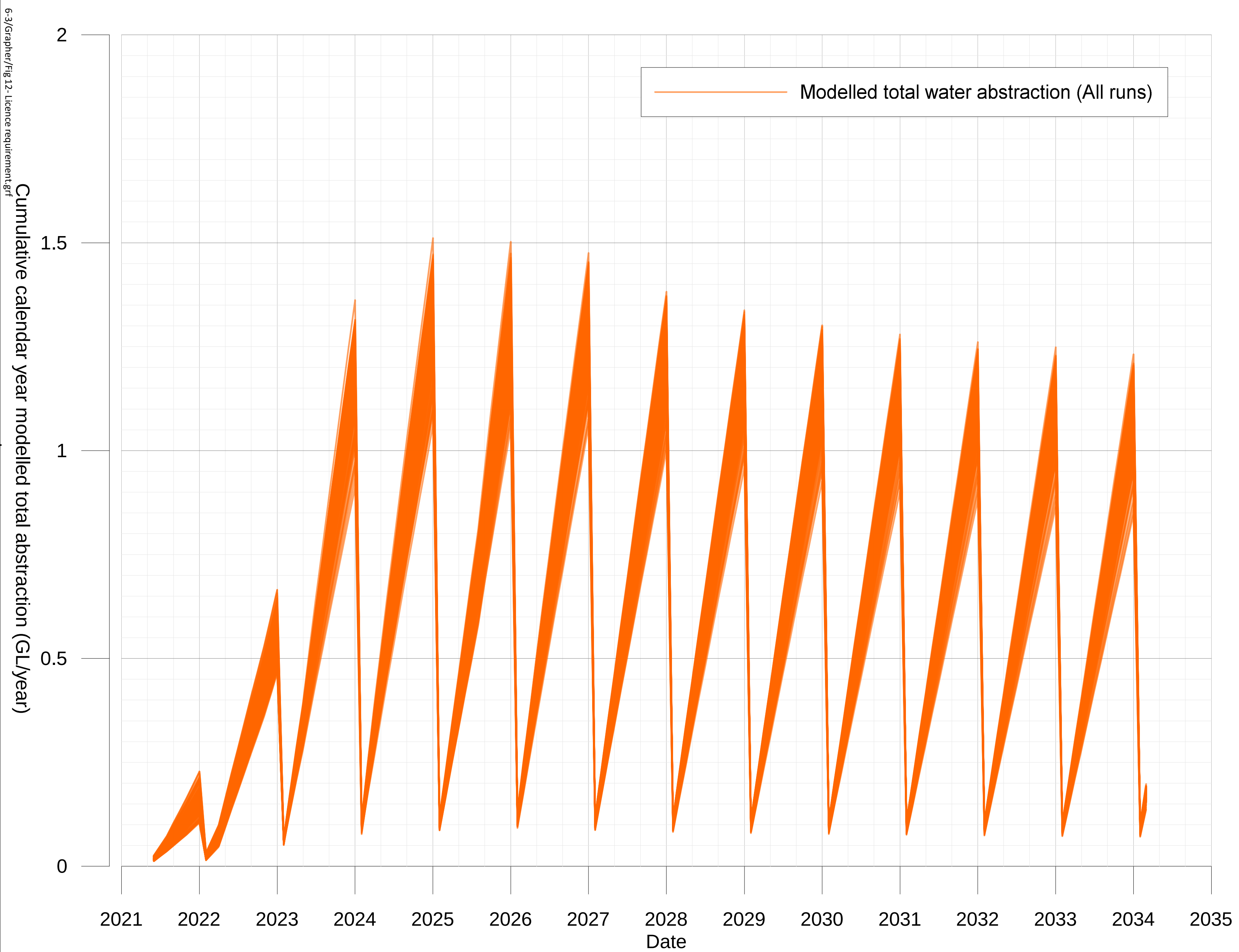
Figure 11



6-3/Grapher/Fig 12- Licence requirement.grf

Client: Newcrest Australia
Project : H3 Level of Assessment
Date : December 2021
Dwg. No: 6-3/21/5-12

MODEL-CALCULATED
TOTAL EXTRACTION

Figure 12

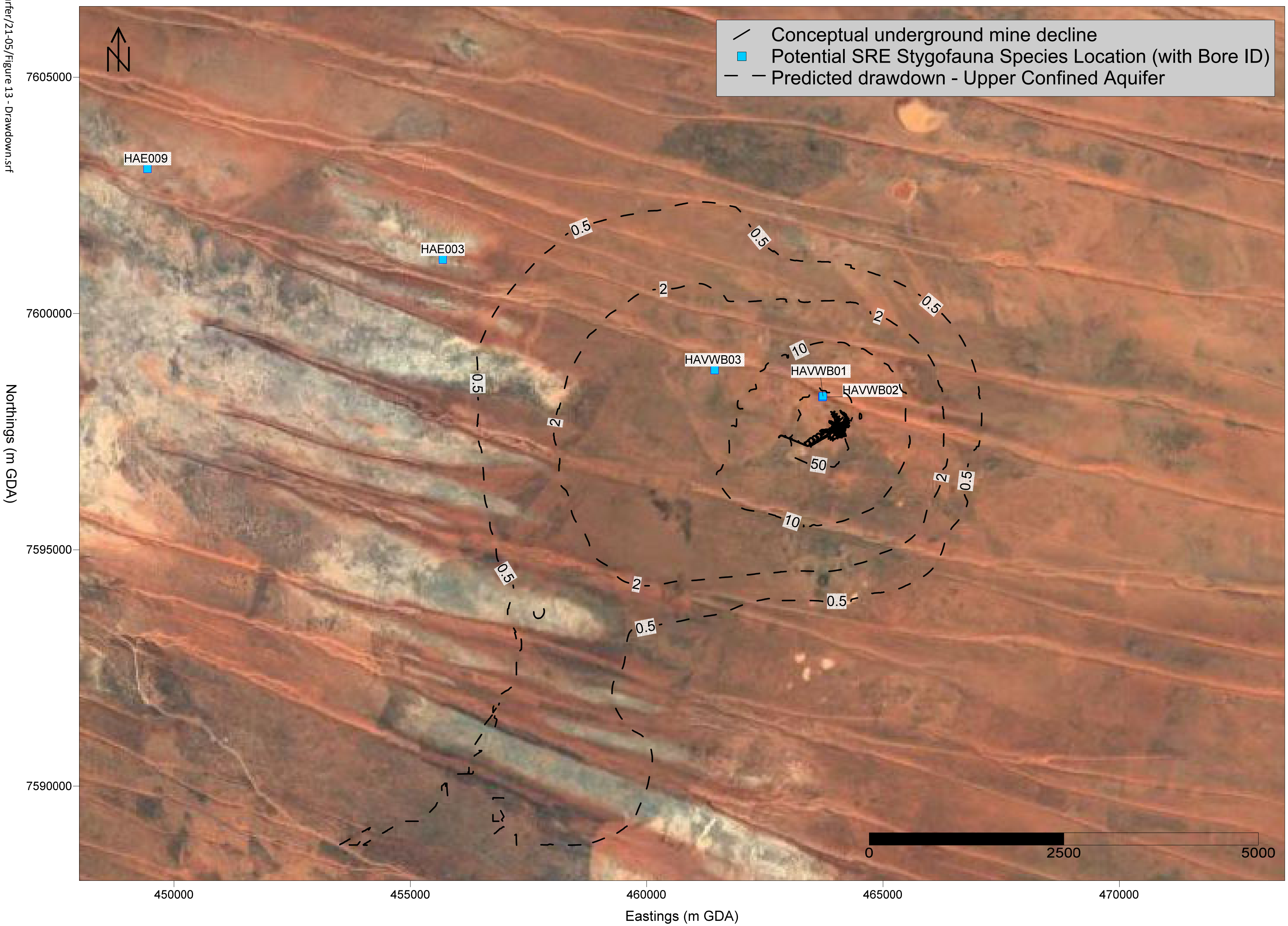


Figure 13

MODEL PREDICTED DRAWDOWN IN UPPER CONFINED AQUIFER 2027

Client: Newcrest Australia
Project: H3 Level of Assessment
Date: December 2021
Dwg. No: 6.3/21/5-13

Rockwater Proprietary Limited

MODEL PREDICTED DRAWDOWN IN UPPER CONFINED AQUIFER END OF MINE (2034)

Client: Newcrest Australia
Project: H3 Level of Assessment
Date: December 2021
Dwg. No: 6.3/21/5-14

6-3/Surfer/21-05/Figure 14- Drawdown.srf

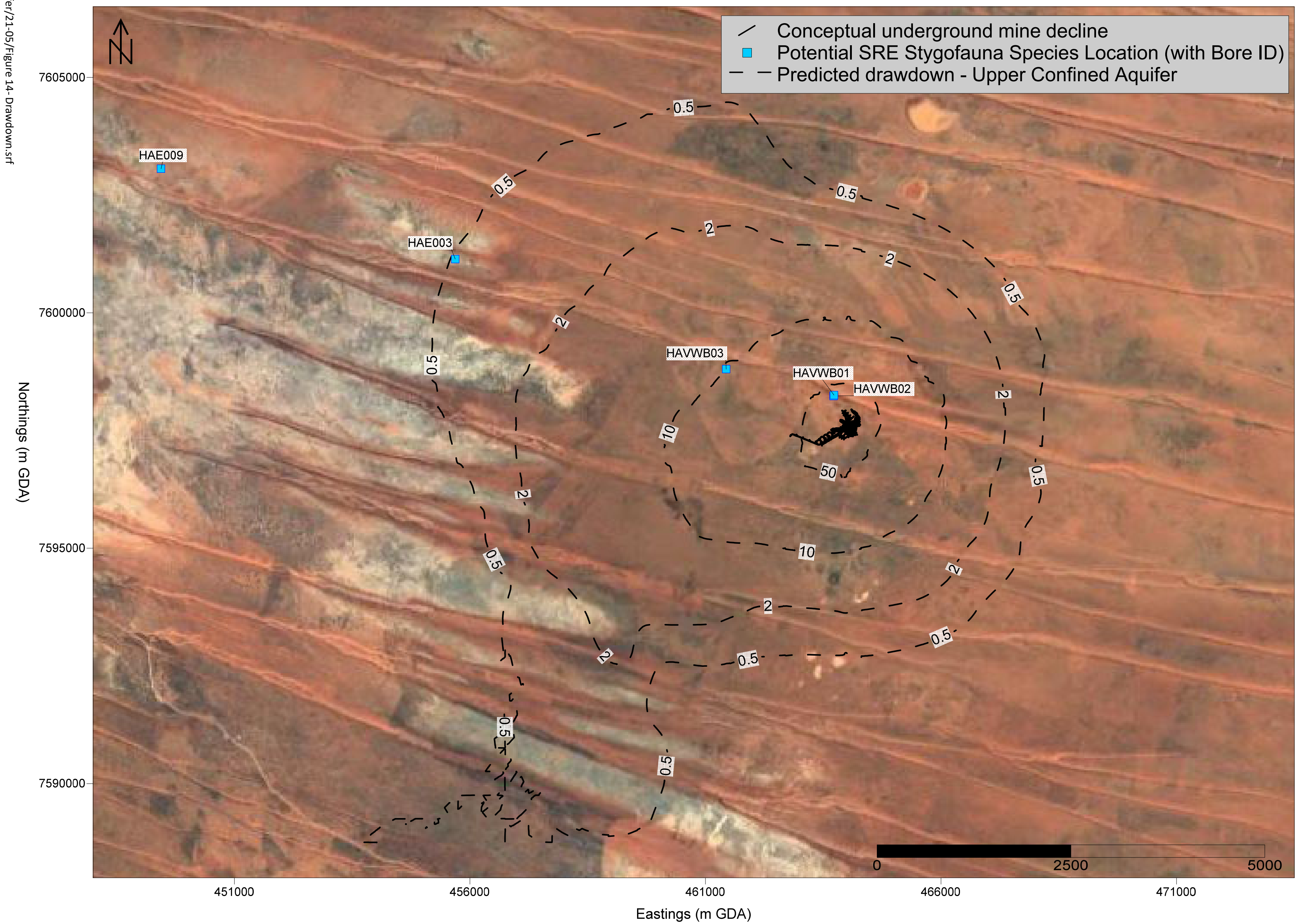
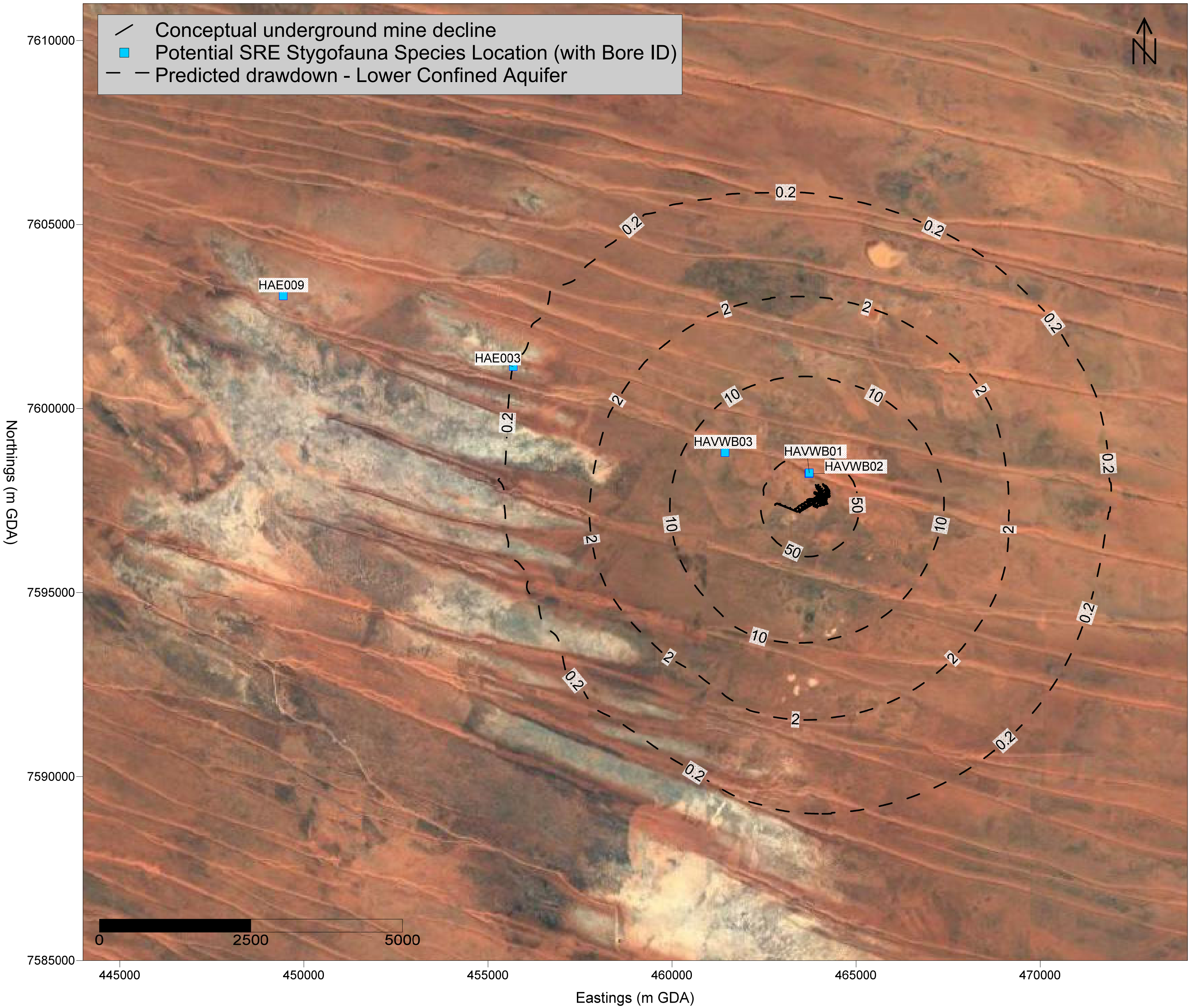


Figure 14

Client: Newcrest Australia
Project : H3 Level of Assessment
Date : December 2021
Dwg. No: 6.3/21/5-15

6-3/Surfer/21-05/Figure 15 - Drawdown.srf



MODEL PREDICTED DRAWDOWN
IN LOWER CONFINED AQUIFER
2027

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Figure 15

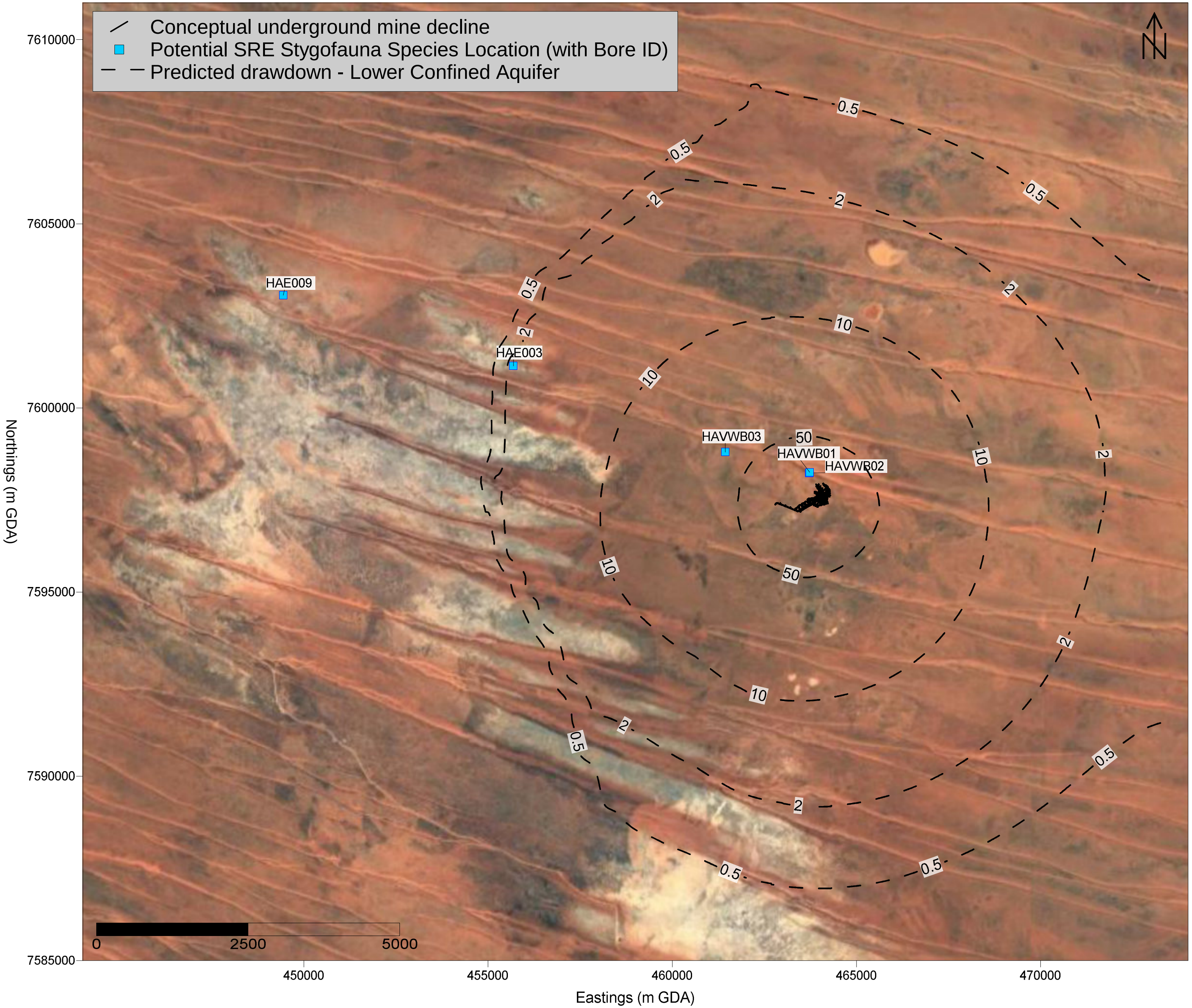

Figure 16

Client: Newcrest Australia
Project: H3 Level of Assessment
Date : December 2021
Dwg. No: 6.3/21/5-16

6-3/Surfer/21-05/Figure 16 - Drawdown.srf

MODEL PREDICTED DRAWDOWN
IN LOWER CONFINED AQUIFER
END OF MINE (2034)

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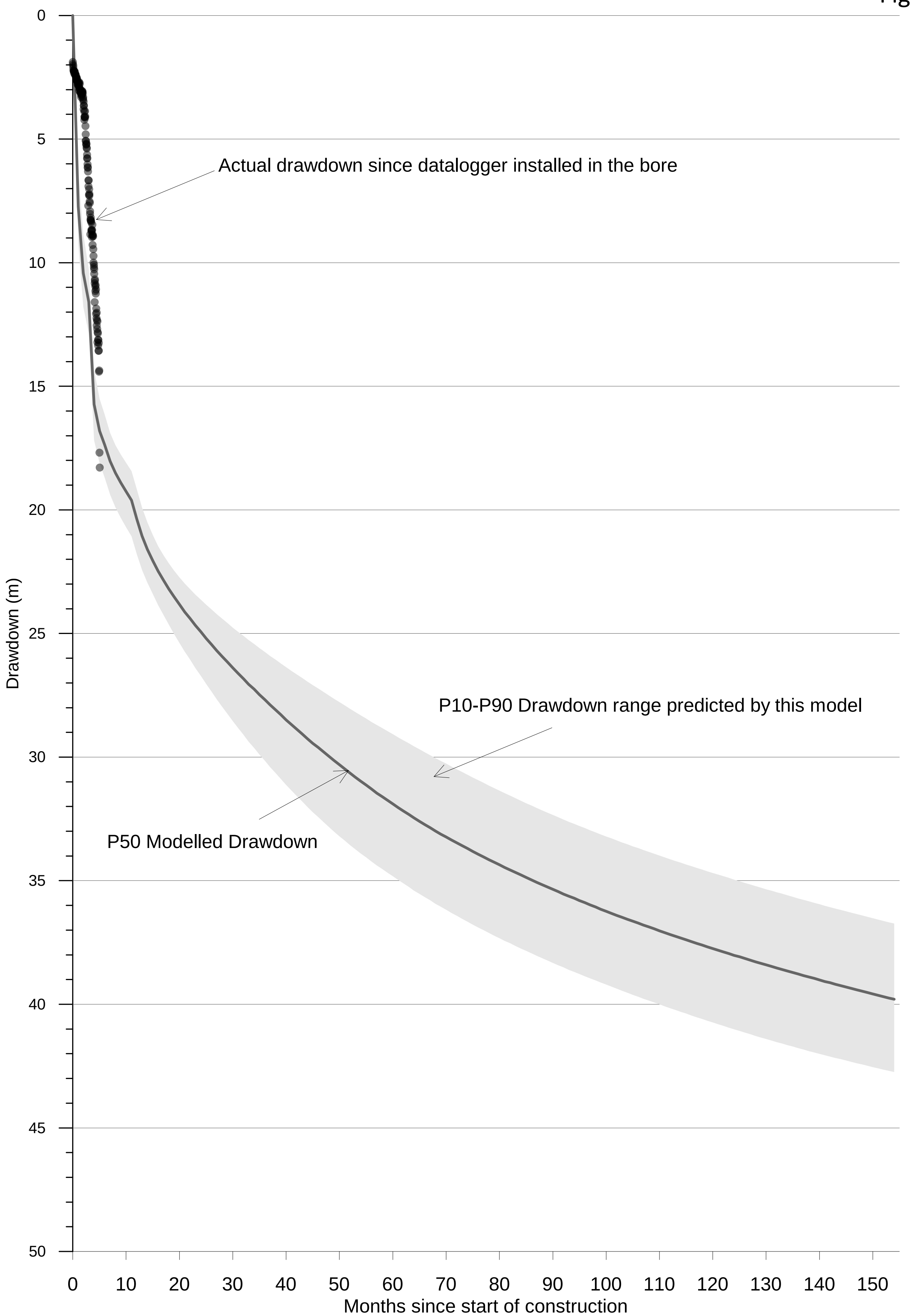
Figure 17



6-3/Grapher/21-05/Figure 17.grf

Client: Newcrest Australia

Project : H3 Level of Assessment

Date : December 2021

Dwg. No: 6-3/21/5-17

DRAWDOWN AT MONITORING BORE HAHY001

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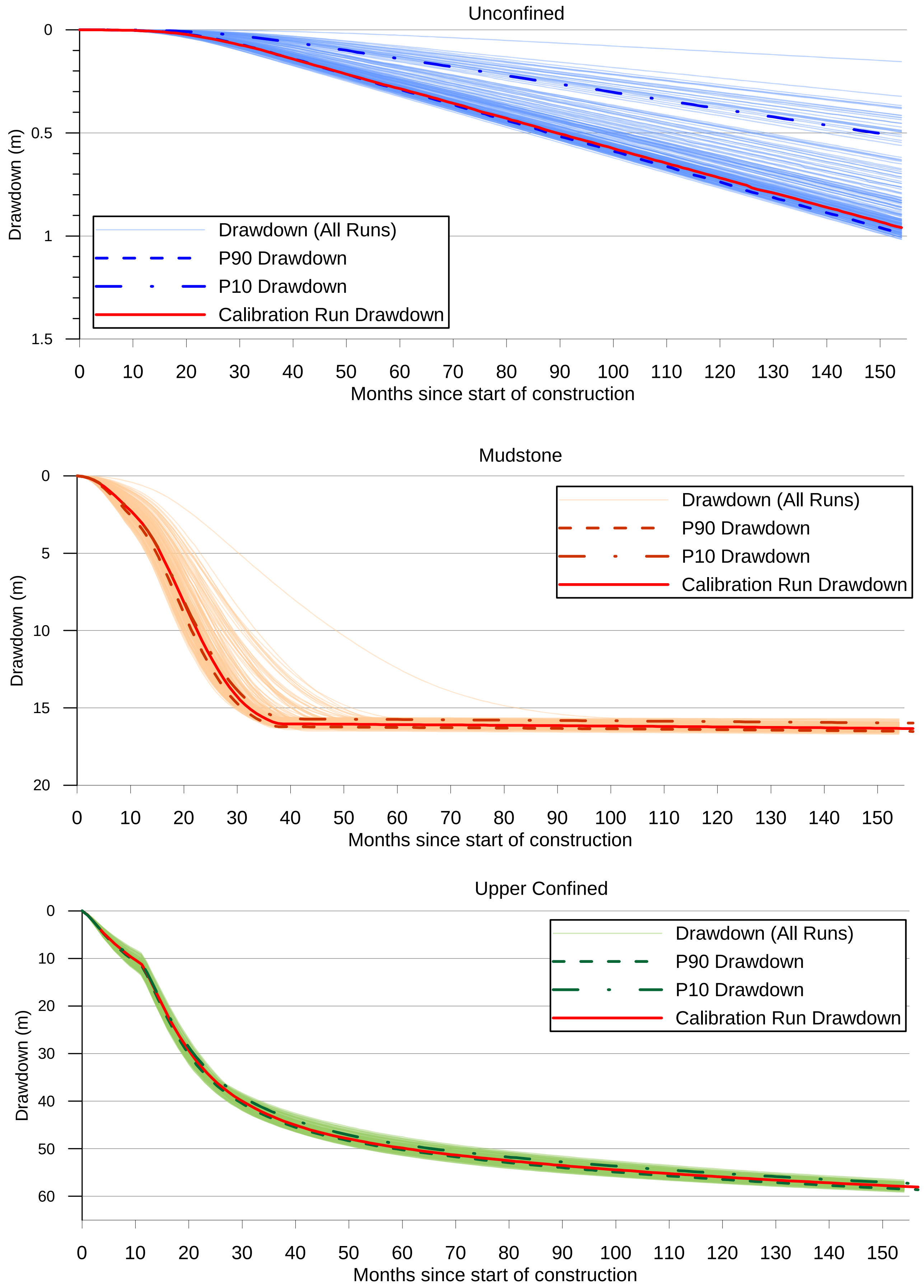
Figure 18



6-3/Grapher/21-05/Figure 18.grf

Client: Newcrest Australia

Project : H3 Level of Assessment

Date : December 2021

Dwg. No: 6-3/21/5-18

MODEL PREDICTED DRAWDOWN
AT MONITORING BORE HAVWB01

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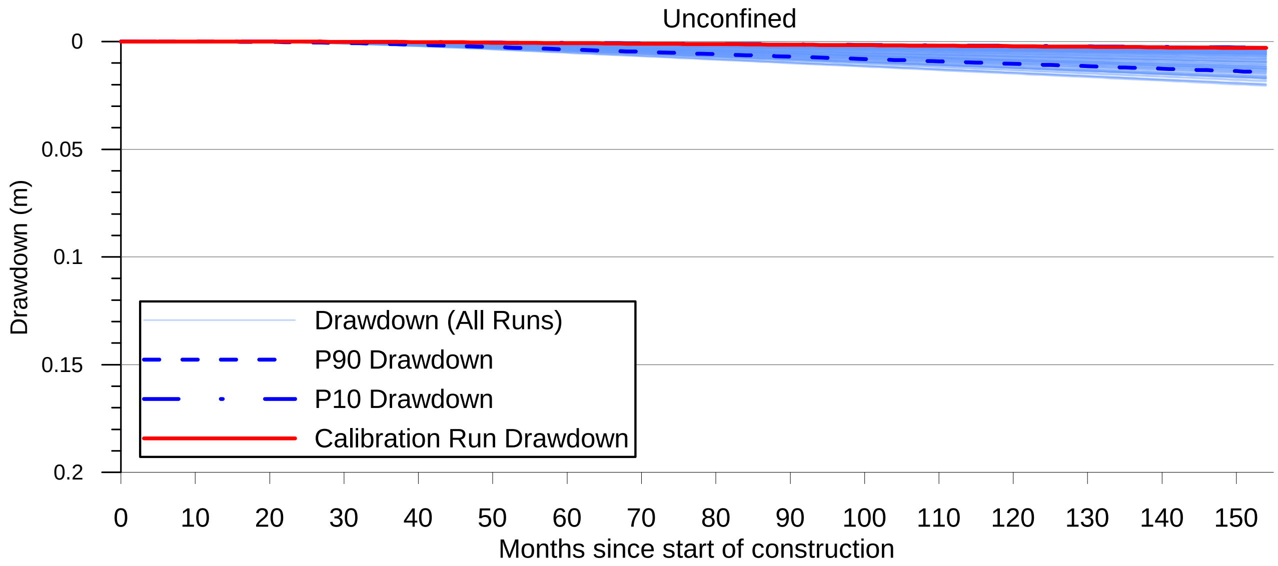
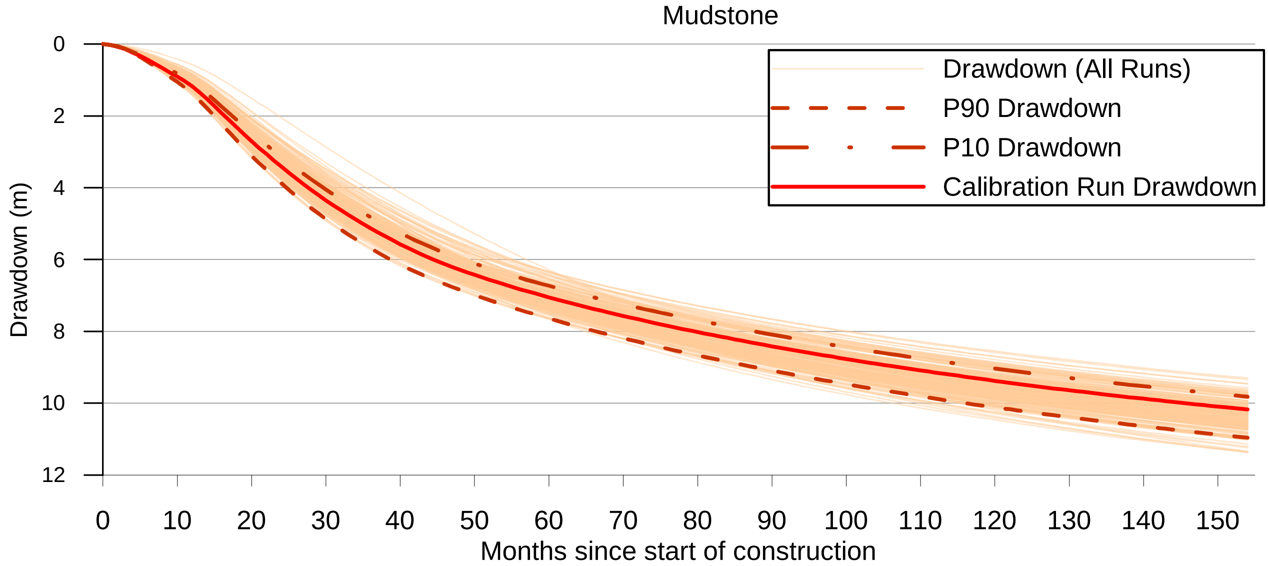
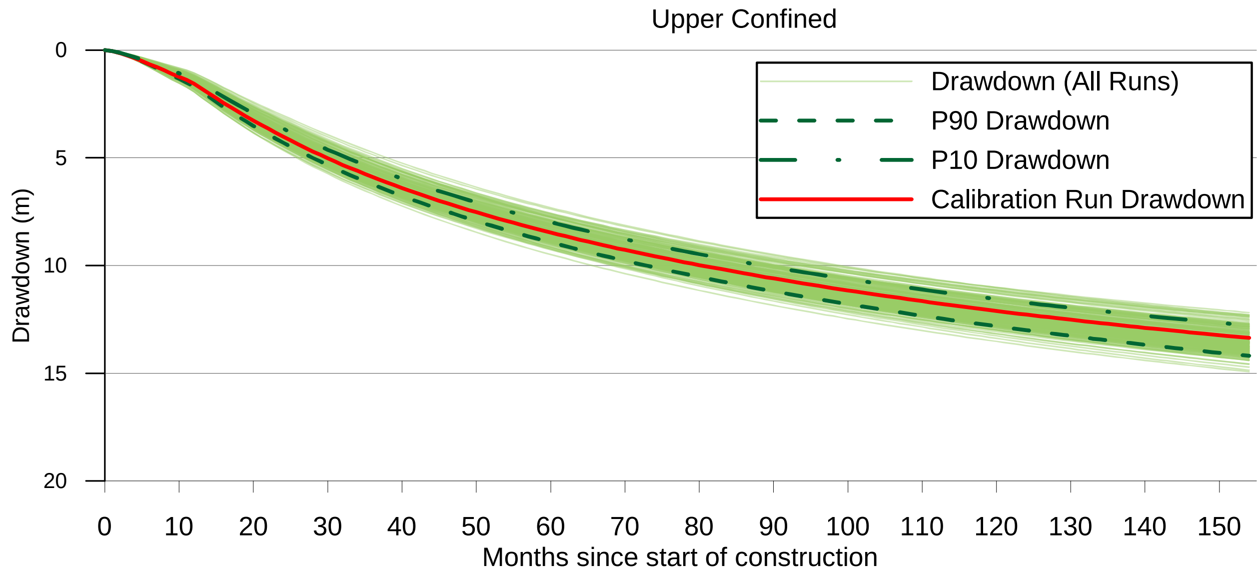
Figure 19



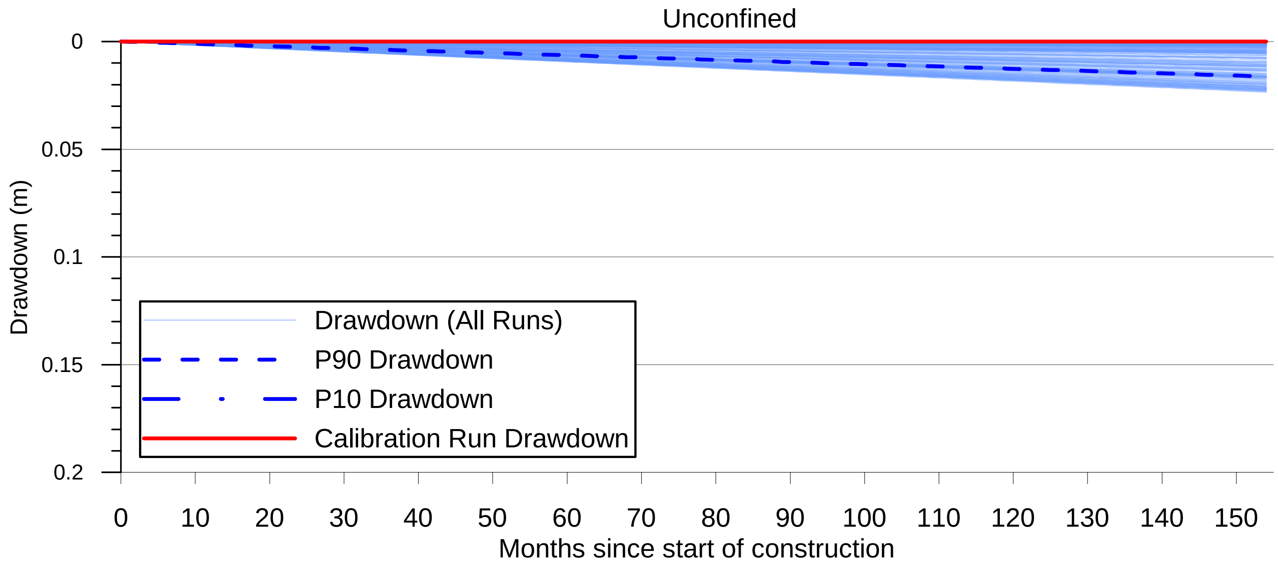




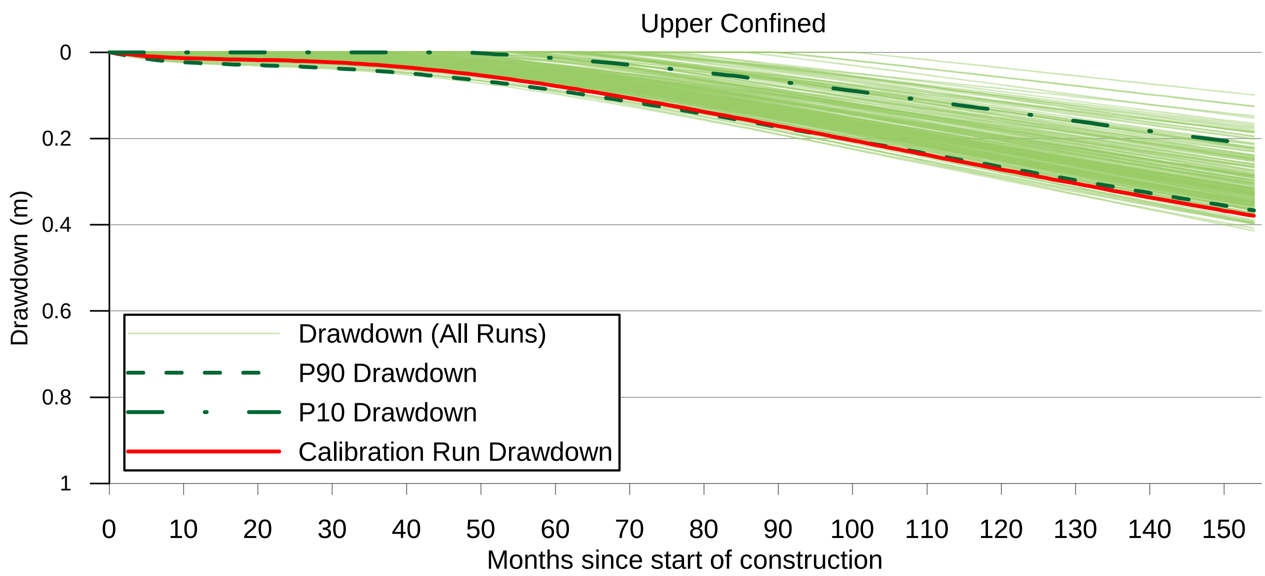
6-3/Grapher/21-05/Figure 19.grf

Client: Newcrest Australia Project : H3 Level of Assessment Date : December 2021 Dwg. No: 6-3/21/5-19	MODEL PREDICTED DRAWDOWN AT MONITORING BORE HAVWB03

Figure 20



Mudstone absent



6-3/Grapher/21-05/Figure 20.grf

Client: Newcrest Australia

Project : H3 Level of Assessment

Date : December 2021

Dwg. No: 6-3/21/5-20

MODEL PREDICTED DRAWDOWN
AT MONITORING BORE HAE003