DRAFT TECHNICAL REPORT

Yallourn: Lake water balance and water quality

Report prepared for

EnergyAustralia Ltd

RGS

MINE WASTE AND
WATER MANAGEMENT

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Executive Summary

RGS Environmental Consultants (RGS) has been commissioned by EnergyAustralia Ltd (EA) to prepare a technical report to assess the lake water balance and water quality for the Yallourn Declared Mines Rehabilitation Project (DMRP).

Executive Summary not included in DRAFT report

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Abbreviations

Term	Definition
AC	Acid Consuming
ADWG	Australian Drinking Water Guidelines
ALS	Australian Laboratory Services
AMD	Acid and metalliferous drainage
ANC	Acid Neutralising Capacity
ANZG	Australian and New Zealand Guidelines
ASS	Acid Sulfate Soils
AWBM	Australian Water Balance Modelling
DMRP	Declared Mines Rehabilitation Plan
EES	Environment Effects Statement
CRS	Chromium Reducible Sulfur
CT	Contaminant Transport
EC	Electrical Conductivity
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EPA	Environment Protection Authority
ERR	Earth Resources Regulator
ERS	Environmental Reference Standard
GED	General Environmental Duty
GWB	Geochemist's Workbench
GL	Gigalitre
HHF	Haunted Hills Formation
KLC	Kinetic leach column
km	Kilometres
m AHD	Metres Australian Height Datum
MNES	Matters of national environmental significance
NAF	Non-Acid Forming
NAF - B	Non-Acid Forming - Barren
NAF - LC	Non-Acid Forming – Low Capacity
NAPP	Net Acid Producing Potential
MPA	Maximum Potential Acidity
MRD	Morwell River Diversion
PAF	Potentially Acid Forming
PAF - LC	Potentially Acid Forming – Low Capacity
PAF - HC	Potentially Acid Forming – High Capacity
RGS	RGS Environnemental Consultants Pty Ltd.
RL	Relative Level
SD	Saline Drainage
TDS	Total Dissolved Solids
TS	Total sulfur
INAP	International Network on Acid Prevention
WB/WQ	Water balance and water quality

Term	Definition
YEF	Yallourn East Field
YTF	Yallourn Township Field

1 Introduction

The Yallourn Coal Mine (YCM) Declared Mines Rehabilitation (DMRP) Project (the project) involves the final rehabilitation of the YCM and Power Station to achieve a safe, stable, sustainable and non-polluting landform capable of supporting productive future land uses. The proposed final landform for the former mine void is a high-level lake(s).

RGS Environmental Consultants (RGS) has been commissioned by EnergyAustralia Pty (EA) to develop a model to assess the lake water balance and water quality (WB/WQ model) for the Yallourn DMRP.

1.1 Purpose of report

The purpose of this report is to assess the potential lake(s) water balance and water quality associated with the project. This includes:

- Estimate the final lake(s) water quality at completion of filling and modelling of how the lake water quality will evolve into the future;
- Modelling the demand for water to fill and maintain the lake(s) level during and beyond creation of the lake(s);
- Assessment of how climate change and climate variability are likely to affect the water balance and water quality of the lake(s); and,
- Comparison of the results for different fill option scenarios.

1.2 RGS scope of work

The RGS scope of work includes:

- Construction of a lake(s) water balance and water quality model which meet the objectives of the project providing results with an ‘inferred’ level of reliability;
- Evaluation of estimated water quality in the lake(s) in relation to applicable water quality standards and guidelines; and,
- Preparation of a standalone technical report for the lake(s) water balance and water quality modelling (i.e. this report).

This report presents the preliminary results of the WB/WQ model which is developed to align with the DMRP and the results are considered to be at an ‘inferred’ level of confidence.

An “Inferred water balance and water quality model" is that part of an environmental and engineering assessment for which quantity and quality can be estimated on the basis of hydrogeological, hydrological, and geochemical ‘evidence’ and reasonably assumed, but not verified, from geological, geochemical and hydro-geological data. The model estimate is based on limited information and sampling gathered through appropriate standard industry practices for sampling and analysis methodology, and conformance to the Australian Groundwater Modelling Guideline.

The results of the inferred model provide an acceptable level of confidence and reliability to forecast likely future environmental outcomes. It is assumed to be suitable for environmental approval level of investigation and suitable for pre-feasibility engineering.

1.3 Lake water balance and water quality context

The YCM open pit is a term used for the excavated area during the mining phase. After mining has ceased and the two open pits are decommissioned, the open pit is termed a mine void. Within the mine void at the YCM there are three overburden dumps and an ash retention area (Former Ash Ponds). When the mine voids are filled with water, a pit lake will develop and inundate the overburden dumps, Former Ash Ponds and a large proportion of the pit walls.

A lake system includes processes influencing pore water quality in the backfilled overburden and ash (i.e. water contained in the pore space of the ash and overburden, respectively) that is inundated by the lake, changes to groundwater as it rebounds towards pre-mine conditions and the resulting water quality in the lake as it evolves over time. The interaction between water and minerals in the local geological environment, and the effect of dissolved minerals on water quality can be studied using hydrogeochemical modelling.

Water balance refers to the accounting of inputs and outputs of water in the lake(s), including precipitation (rainfall entering the lake), streamflow (water potentially entering and leaving the lake), evaporation (loss due to evaporation) and changes in storage (such as through interaction with groundwater, transfer of water between lakes and active filling or top-up from various water sources). There are two types of hydrologic conditions that exist in a lake; flow-through conditions (surface and/ or groundwater flows into and out of this type of lake) and terminal conditions (groundwater flows into the mined void and outflow occurs only as evaporation (and a small amount of groundwater seepage). The latter is referred to herein as the base case scenario, and the terminology for flow-through and terminal conditions is referred to in this report as ‘connected lake’ and ‘unconnected lake’, respectively.

The lake water balance and water quality is important in this context because it may impact water quality of receiving environments (e.g. groundwater and Morwell River in the connected lake scenario). It may also influence the suitability of the lake and surrounding land for future productive land uses once rehabilitation is completed.

2 Project background

The YCM and associated Yallourn Power Station (YPS) is located in Victoria's Latrobe Valley (**Figure 2-1**) and operated by EA. The site is located approximately 150 km south-east of Melbourne on the traditional lands of the Gunaikurnai people. YCM is situated between the townships of Newborough, Morwell and Yallourn North.

Coal mining operations have been part of the Latrobe Valley landscape for over 100 years. Today, EA Yallourn supplies approximately 22% of Victoria's electricity needs and approximately 6% of the national electricity market.

The YPS is scheduled to cease operation in mid-2028, at which point the YCM will also cease production. Following the end of the productive life of the mine, the site will transition to rehabilitation phase and eventually to an anticipated future use beyond mining. The current mining license has been extended to 2051 to incorporate the rehabilitation of the Mine Site.

2.1 Project area

The YCM comprises two adjacent open pits, Township Field and East Field (including Maryvale Field). To the north of the open pits is the Latrobe River which separates the mine from the Yallourn North Open Cut (YNOC) and ash ponds. The two coal open pits (Township and East Field) are separated by a coal dyke with the Morwell River Diversion (MRD) running over this dyke (**Figure 2-2**). YNOC is currently used as the ash storage repository/landfill with no natural connection between YNOC and the mine pit voids.

Pit wall batters comprise both exposed coal, and reshaped and revegetated overburden. Coal exposed in the Township Field batters is heavily weathered relative to the coal exposed in the East Field, with coal in the East Field transitioning toward unweathered at the mining face in the Maryvale Field.

There are three internal overburden dumps at YCM. The Township Field mined void contains the Yallourn Township Field (YTF) Overburden Dump and the Midfield Dump. The East Field mined void contains the operational Yallourn East Field (YEF) Overburden Dump. The Township Field also contains the Former Ash Ponds (FAP) which comprise dumped overburden overlain by layers of coal ash and capped with overburden and soil.

The YTF Overburden Dump is separated into the Northern Overburden (NOB) Dump and Southern Overburden (SOB) Dump. Acid sulfate soils (ASS) were initially identified in one area of the NOB Dump (understood to originate from the excavation of the old Morwell Riverbed and floodplain alignment). Pyrite/marcasite mineralisation has been found within the HHF above the contact with the Yallourn Seam which is likely to have also been placed in the NOB Dump. Since placement of overburden in the NOB Dump, the facility has been generating acidic drainage of approximately pH 3.

Static geochemical testing has confirmed that materials within the NOB Dump are potentially acid forming (PAF) and have also characterised a considerable portion of material placed in the YEF Overburden Dump materials as PAF (RGS, 2024) (**Section 2.6**). YTF SOB and YMF Overburden Dump materials have been generally characterised as non-acid forming (NAF). There is, however, a propensity for the materials placed within the dumps to generate Saline Drainage (SD).

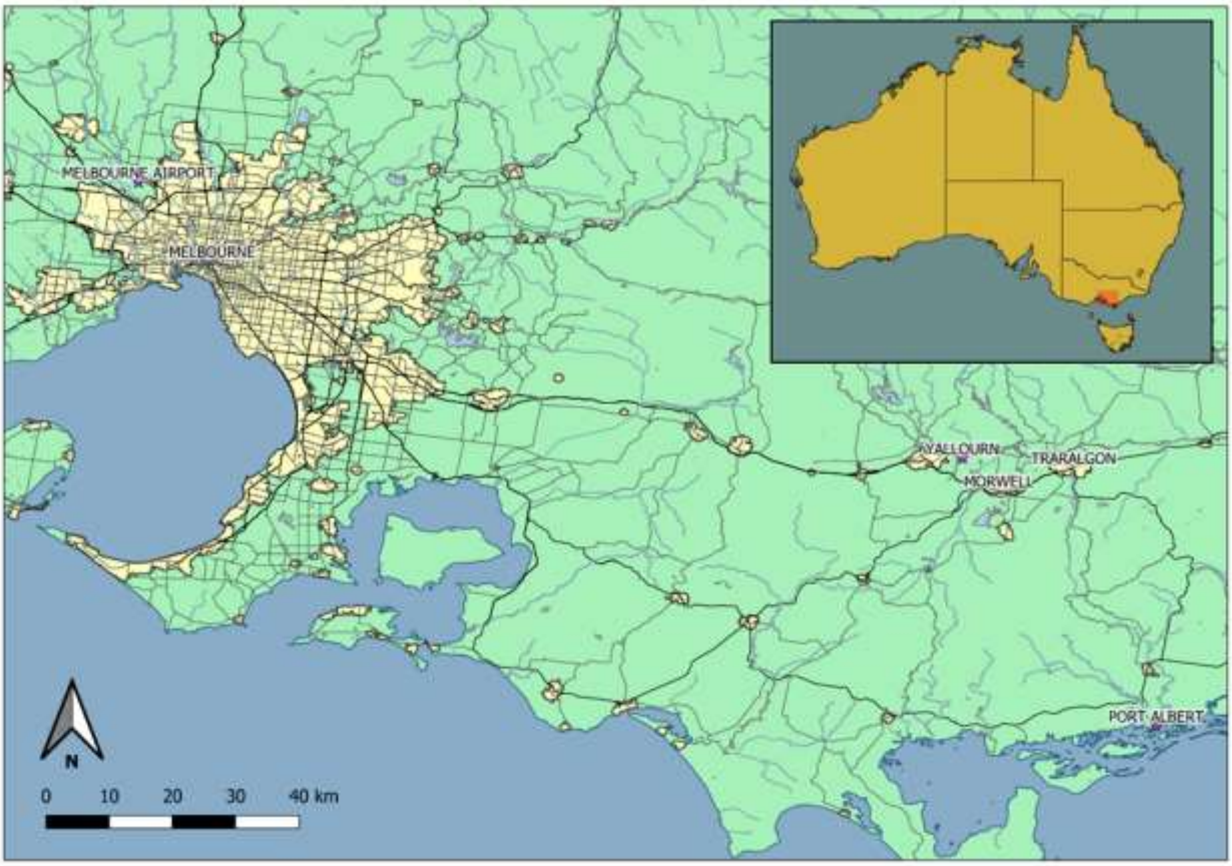

Figure 2-1 Locality map

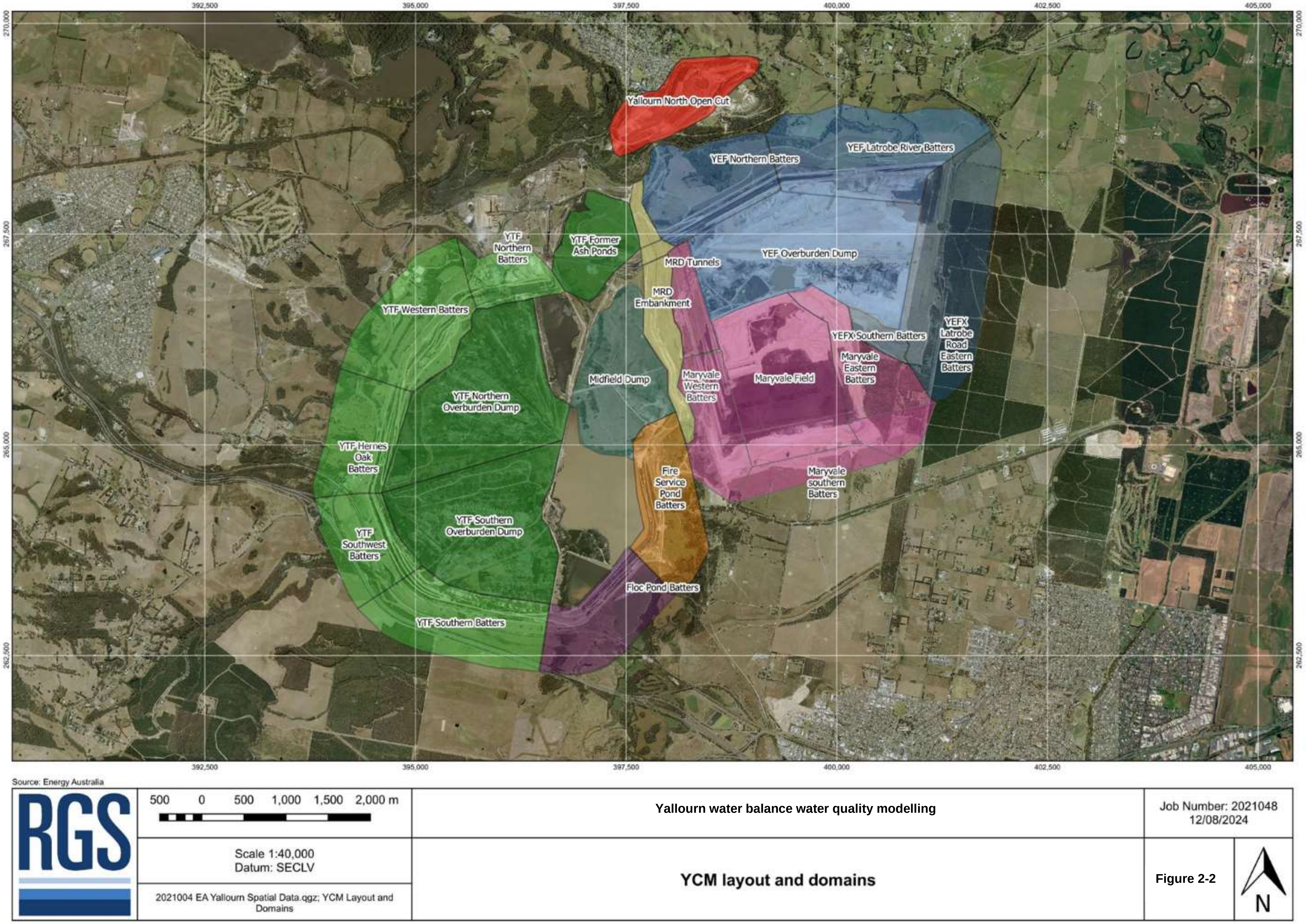

Figure 2-2 Project area

2.2 Project description

The main project components related to the pit lake water balance and water quality assessment include the following:

- Filling the mine voids with water to a relative level (RL) of +37 metres Australian Height Datum (m AHD), using predominately groundwater, surface water and any other approved water sources.
- Earthworks to rehabilitate, stabilise and reshape landforms, primarily upper mine batters where they are above the surface level of the future lake (i.e. laying batters back to design profile), to geotechnically stable landforms with adequate stabilising vegetation and drainage.

The key activity is filling of the mine voids. Several lake scenarios are assessed in the DMRP; however, the two key scenarios include an ‘unconnected lake’ scenario (base case), which does not interact with any other waterways (i.e. terminal conditions), and a ‘connected lake’ scenario (preferred scenario), which would take a portion of peak flows from the Morwell River during flood events via three spillways constructed on the Morwell River Diversion (MRD) and discharge back into the Latrobe River downstream (i.e. flow-through conditions) via a fourth spillway.

It is proposed to fill the mine void using the following primary water sources:

- Bulk water entitlements sourced from the Latrobe River; 24 GL per year (GL/yr)).
- Continued pumping of groundwater obtained under a groundwater licence at a target rate of 1.5 GL/yr to RL 0 m, 1 GL/yr to RL +37 m and then 0 GL from the M1A aquifer.
- Potential surface water entitlements obtained under an agreement with Gippsland Water (Moondarra Reservoir).

A range of other sources are proposed to contribute to filling of the mine, including:

- Flood flows from the Morwell River in a connected lake scenario, subject to approval. Volumes are dependent upon relevant rainfall (flood) incidents and therefore would be occasional and highly variable.

The baseline project scenario provides a baseline against which to compare the preferred project scenario. It generally refers to the continuation of current activities at site which are already approved or are necessary operational works. This includes implementation of approved earthworks, ongoing groundwater pumping to maintain stability, and retention of groundwater and operations water (fire and dust suppression water, natural catchment drainage) within the mine voids.

The preferred project scenario includes continuous filling of the mine voids to an RL +37 m AHD using the same water included in the base case scenario, plus bulk water entitlement and flood flows from the Morwell River. Water will be transferred between lakes via conveyor tunnels to balance lake levels.

2.3 Regional geology

YCM is located within the Latrobe Valley sub-basin which is part of the greater (onshore) Gippsland Sedimentary Basin. The Latrobe Valley contains Victoria's main deposits of brown coal and hosts the Hazelwood, Yallourn and Loy Yang coal mines. The brown coal reserves occur in three Formations (Kinhill, 1981; Schaeffer *et al.*, 2001):

- Yallourn Formation (mid-Miocene Age, 5 to 11 million years ago).
- Morwell Formation (Oligocene and early Miocene Age, 15 to 37 million years ago).
- Traralgon Formation (Eocene Age, 37 to 53 million years ago).

The Yallourn Formation contains the Yallourn Coal Seam, the top-most and youngest coal in the Latrobe Valley (**Figure 2-3**). It consists of a complex unit of thick coal seams and clay-sand sequences, lying conformably on the Morwell Formation, and grades laterally eastward into the barrier sands of the Balook Formation.

Underlying the Yallourn Formation is the fully-developed Morwell 1A Seam. The Yallourn Interseam Clay can be up to 5m thick (Barton, Gloe and Holdgate, 1993) and separates the Yallourn from the Morwell coal seam. The Morwell 1A Seam is up to 80m thick, including interbedded clays, ligneous clay and minor coal bands and is regionally extensive through the Traralgon syncline and from Yallourn to Glengarry. It is mined at Loy Yang and Hazelwood coal mines. West of the Yallourn Monocline the Morwell 1B Seam grades into interbedded sediments, lavas and tuffs of the Thorpdale Volcanics and into Latrobe Coal Seam (Barton, Gloe and Holdgate, 1993; Holdgate, Osborne and Goldie Divko, 2016)

The Yallourn Seam was eroded during the late Miocene. In Traralgon and Latrobe Synclines, the seam is buried by up to 200m of younger Yallourn and Haunted Hill Formation (HHF) clays.

2.4 Stratigraphy

The Yallourn Formation is the youngest and uppermost coal-bearing formation. The stratigraphic units at YCM include (Schaeffer *et al.*, 2001; Holdgate, Osborne and Goldie Divko, 2016) (**Figure 2-3**):

- Overburden (OB): The OB is a clayey silt, approximately 9m to 45m thick.
- Yallourn Coal Seam: Most development of the coal seam occurred in Maryvale East and Yallourn. Within the confines of the operating mine, the seam ranges from 135m in the north to 50m in the south.
- Yallourn Interseam Clay (West): Interbedded clays, ligneous clay and a minor coal band up to 5m thick.
- M1A Interseam Clay (East): Thin clay parting confined only to the east side of the cut. Interseam sands and clays, typically 15m to 25m thick. The upper portion of this stratum consists of a 3m to > 15m layer of silty clay.
- M1A Coal Seam: M2 Coal Seam has a thickness up to 55m.
- M1A and M1B Aquifer: M1A Interseam Clay and Coal Seam underlain by a sandy aquifer of variable thickness and continuity.
- M1B Coal Seam: M1B Coal Seam grades into barrier sands of the Balook Formation, north of the Latrobe River into clays and minor sands, and west of the Yallourn Monocline into interbedded sediments, lavas and tuffs of the Thorpdale Volcanics, up to 165m of thickness.
- Latrobe Coal Seam (M2 Seam): The oldest Morwell 2 Seam, with thickness up to 140m, occurs in area between Yallourn and Glengarry but usually overlain by younger coal-poor Yallourn and Morwell Formation. This is also known locally as Latrobe Seam that includes a limited component of M1B Seam. M2 Interseam has a variable thickness clay stratum containing one or several sand layers near the base of the M2 coal seam.
- M2 Aquifer: Artesian water pressures have been encountered in the sand layers below M2 Coal Seam.
- Basement**:** Mesozoic and Palaeozoic basement

2.5 Hydrogeology

Before mining commenced, groundwater existed within localised aquifers in the overburden strata. YCM dewatered the underlying confined aquifer (M1A) creating a cone of depression. The deeper underlying M2 aquifer is dewatered by the adjacent Hazelwood Mine, which creates a cone of depression to the southeast of Yallourn. Groundwater recharge occurs via percolation of meteoric water through the regolith and coal seams.

The underlying M1A aquifer is divided into four separate sand layers (known as M1AS0, M1AS1, M1ASM & M1ASL in the Yallourn Mine model). The aquifers range from poorly to moderately sorted fine quartz sands to gravels. The upper sand units (A01 to A1) are thin and discontinuous, compared to the A3 which is continuous and considered the main M1 Aquifer unit.

The M2 aquifer is up to 200 m thick beneath YCM (**Figure 2-3**) and consists of six separate sand layers (2A, 2B, 2C, 2D, 2E and 2F). The aquifers range from well sorted, fine to medium gravel. There is intermittent weathered basalt (Thorpdale Volcanics), which act as an aquitard below the 2A sands. The 2A sand is a fine to medium grained sand, while 2B and 2C aquifers are typically fine sands with low permeability. The 2D aquifer has coarse grained sand and gravel and is the main M2 aquifer with the highest yield and transmissivity. The aquifer is > 12 m thick and in isolated areas > 20 m thick. The 2E and 2F sands are generally low permeability.

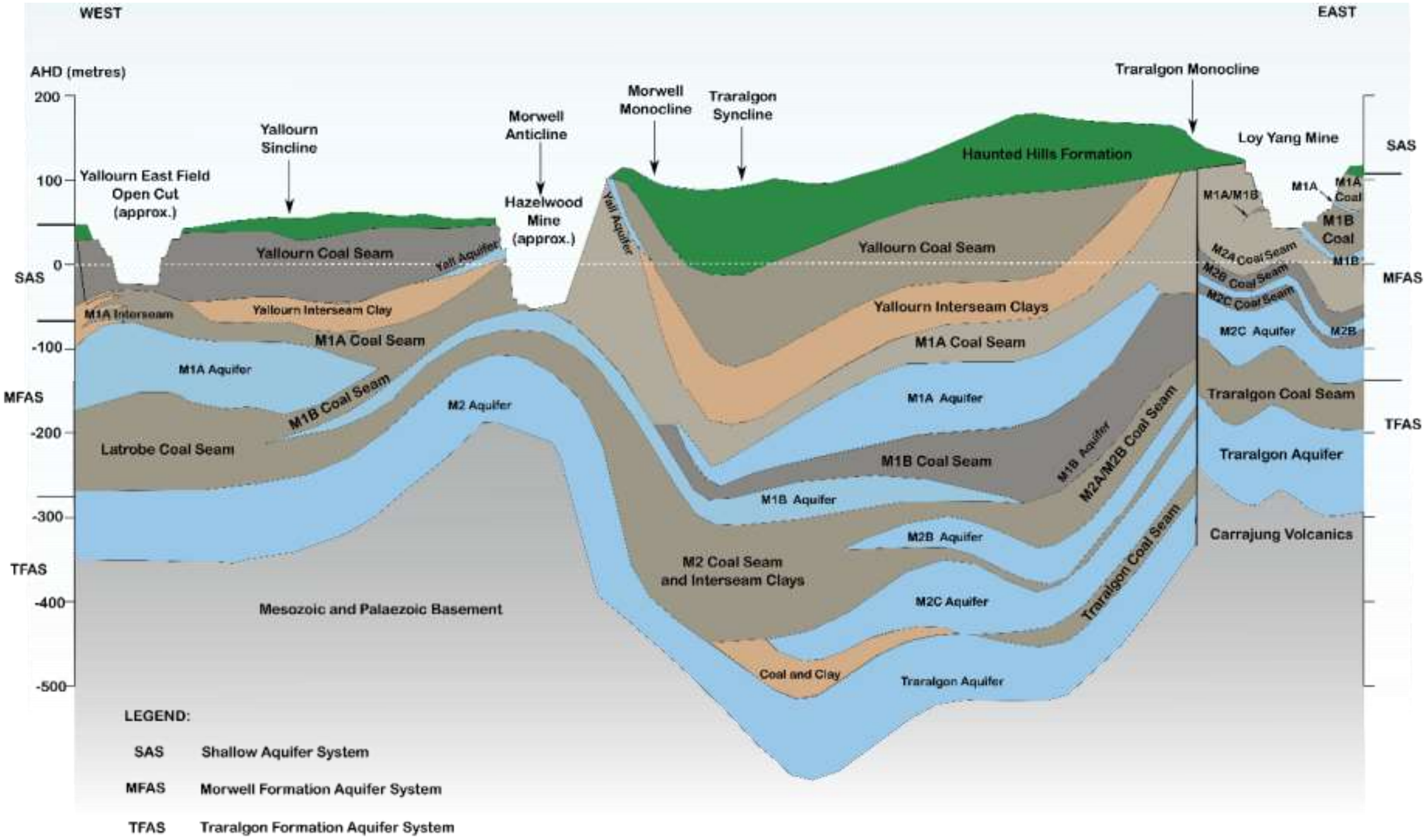

Figure 2-3: Schematic Hydrogeological Section Yallourn - Hazelwood - Loy Yang (Schaeffer et al., 2001)

2.6 Geochemistry

2.6.1 RGS geochemistry testing

Geochemical testing was undertaken to understand the levels of potential contaminants that may be transferred into the water column when various materials (weathered and fresh coal, overburden and ash) come into contact with water.

RGS initially completed a high-level review of relevant available reports and data pertaining to the geochemistry of YCM site and the pit WB/WQ. Based on the outcomes of the high-level geochemistry review, RGS identified the key geochemical data gaps needed to be addressed in order to develop a robust and defensible WB/WQ model and subsequently undertook field sampling and analysis investigations beginning in April 2022. The objective of the field investigation was to characterise the geochemical properties of materials that may affect water quality in the proposed pit water lake(s); therefore, the focus was on in-pit backfilled and in-situ overburden, ash, and pit wall and floor materials as these materials may contribute to the potential for acid to alkaline pH water that may also have the potential to be accompanied by saline and metalliferous drainage.

Over the course of the following year (April 2022 to June 2023), additional coal, ash, and overburden materials were sampled as part of wall washing and in-pit drilling programs (RGS, 2023). Forty-three (43) drill holes were advanced to the target depth across the in-pit overburden dumps and the former ash ponds (41 drill holes), and ex-pit overburden dump above the East Field Northern Batters (2 drill holes). Twelve (12) out of the 43 drill holes were converted to groundwater monitoring wells to enable water quality monitoring within the in-pit dumps and ex-pit dump that can provide source terms for the pit lake WB/WQ model. The field program is summarised in the RGS factual drilling report (RGS, 2023) and is summarised in **Table 2-1**. The water quality monitoring of the groundwater monitoring wells is used to develop geochemical source terms (**Section 4.9.2**).

Table 2-1: Filed drilling program and monitoring wells

Drilling location	No. of drill holes progressed to target depth	No. of drill holes converted to groundwater monitoring wells
Township Field catchment		
Former Ash Ponds (in-pit)	5	3
Midfield Dump/ Midfield Borrow area (in-pit)	9	2
Township Field Northern Overburden dump (in-pit)	7	2
Township Field Southern Overburden dump (in-pit)	7	2
East Field catchment		
East Field Dump (in-pit)	8	2
Maryvale Field Dump (in-pit)	5	0
East Field Northern Batters Overburden Dump (ex-pit)	2	1
Total	**43**	**12**

A total of 1,522 solid grab and drill core samples were included in the programs. These samples were subjected to a series of geochemical screening tests and based on the results, select samples underwent static geochemical testing (RGS, 2024) (**Attachment A**). Based on the static test results, select samples were composited and used for kinetic leach column (KLC) tests (**Attachment B**).

2.6.2 Static geochemistry testing

A summary of the number of samples and material types collected as part of each field program are provided in **Table 2-2**. The results are presented in the static geochemistry assessment technical report for YCM (RGS, 2024) (**Attachment A**).

Table 2-2: Samples subjected to static geochemical testing according to location and material type

Location	Number of Samples	Material Type	Number of Samples
Former Ash Ponds	201	Topsoil	4
Midfield Dump area	341	Overburden	1,259
Township Field North	253	Weathered coal	219
Township Field South	242	Fresh coal	15
East Field	315	Ash	25
Maryvale Field	170		
Total	**1,522**	**Total**	**1,522**

The results of the geochemical data for each of the material types likely to affect or contribute to the final void/ pit lake water quality are summarised in the sections below. The criteria used to classify the potential of the samples to generate acidic drainage are shown in **Table 2-3**. The classification criteria reflect Australian (COA, 2016c) and international (INAP, 2024) guidelines for the classification of mining waste materials.

The NAPP is used as an indicator of materials that may be of concern with respect to acid generation. The NAPP calculation represents the balance between the maximum potential acidity (MPA) of a sample, which is derived from the sulfide sulfur (chromium reducible sulfur; CRS) content, and the acid neutralising capacity (ANC) of the material, which is determined experimentally. By convention, the NAPP result is expressed in units of kg H_2SO_4/t sample. If the capacity of the solids to neutralise acid (ANC) exceeds their capacity to generate acid (MPA), then the NAPP of the material is negative. Conversely, if the MPA exceeds the ANC, the NAPP of the material is positive.

The results of the sulfide sulfur screening tests and geochemical classification criteria are provided in **Figure 2-4** and **Figure 2-5**, respectively, and these results are summarised according to material type is the following sections.

Table 2-3: Classification criteria and sample classifications for samples from the YCM

Classification	S_{CR} (%)	NAPP (kg H_2SO_4/t)
Non-acid Forming (Barren) (NAF-B)	< = 0.1	---
Non-acid Forming (NAF)	> 0.1	< = -10
Uncertain	> 0.1	< = 5
Potentially Acid Forming (Low Capacity) (PAF-LC)	> 0.1	< = 10
Potentially Acid Forming (PAF)	> 0.1	> 10

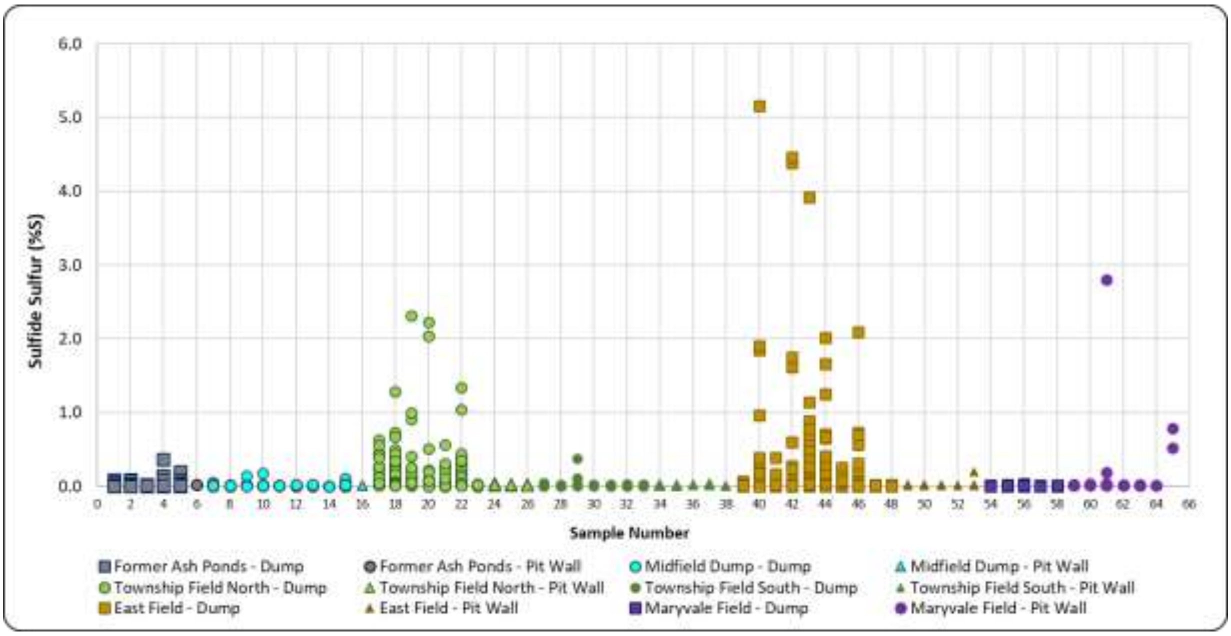

Figure 2-4: Sulfide sulfur (%) for each of the samples according to sampling location at YCM.

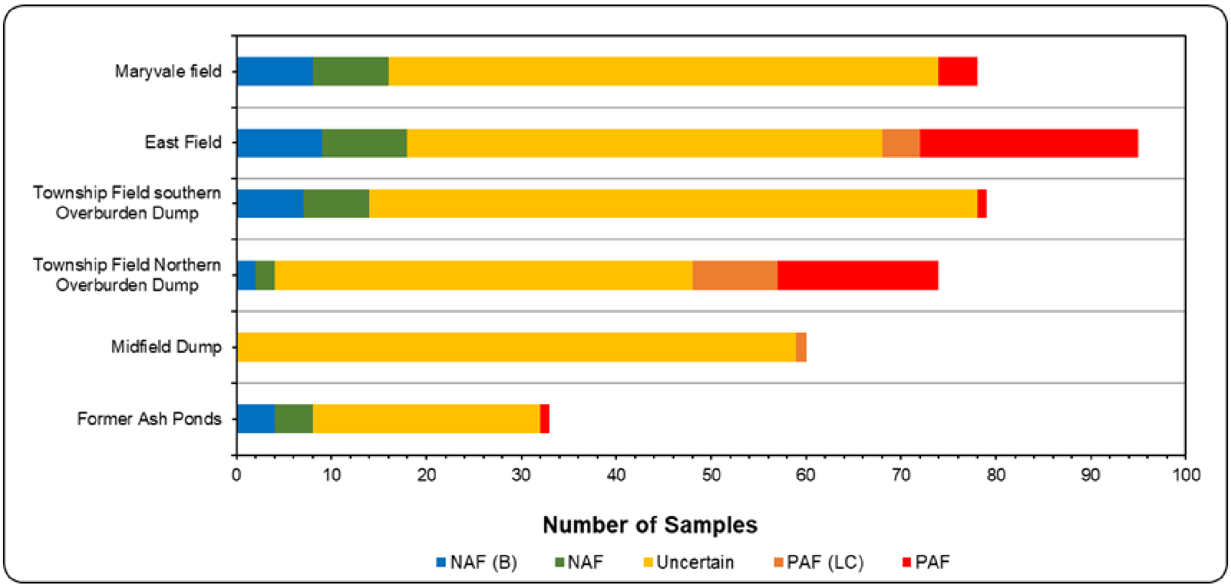

Figure 2-5: Geochemical classification according to sampling location at YCM.

2.6.3 Wall washing experiments

water is collected and analysed for selected chemical parameters. Wall washing provides an indication of runoff quality from an isolated section of in situ coal/overburden after application of a controlled amount of irrigation. The wall washing test is considered to represent a very useful order-of-magnitude estimate of contributions from exposed pit walls (INAP, 2024).

Wall washing was completed at 17 locations across Township Field, East Field, and Maryvale Field (**Table 2-4**). A spray headers manifold was fixed in place adjacent to the pit wall and connected to a potable water supply (**Figure 2-6**). Approximately 20 L/minute of water was sprayed over an area of approximately 2m^2. For 30 minutes, with samples collected at 0 minutes (first flush), 15 minutes and 30 minutes.

The samples collected using wall washing methods allow the filterable fraction (0.45 µm soluble metals) and non-filtered fractions (e.g., suspended sediment and total metals and metalloids) of the water quality to be measured and quantified. Water samples at 0, 15 and 30 minutes were analysed for the filterable fraction, while only samples at 0 minutes were measured for non-filtered fractions.

The results from wall washing are used (together with other data) to develop and verify source terms for pit wall contaminant release (**Section 4.9.2**).

Table 2-4: Wall washing by material type

	Number of wall wash experiments		
Pit wall location	**Weathered coal**	**Fresh coal**	**Topsoil/overburden**
Township Field	5	0	1
East Field	4	0	1
Maryvale Field	3	2	1
Total wall wash experiments	12	2	3
Total water samples collected	36	6	8

Figure 2-6: Wall washing experiments on weathered coal (left) and topsoil/overburden (right) showing spay headers manifold

2.6.4 Coal static geochemistry

Coal materials at YCM occur as both weathered coal in historically mined areas and fresh coal in the YEF and YMF. Minor volumes of coal were also encountered in all the historic dumps.

Weathered coal at YCM has acidic initial pH values that range from pH 3.0 to 5.8, with a median of pH 4.0. Electrical conductivity (EC) values for weathered coal range from 32 to 1,750 µS/cm, with a median value of 179 µS/cm. Sulfide concentration values for weathered coal samples are low relative to the median crustal abundance of sulfur (0.07%)[1], ranging from 0.006% to 1.34% with a median of 0.019%. Samples generally have low acid neutralising capacity (ANC), ranging from below the laboratory limit of reporting (LoR) of 0.5 kg H_2SO_4/t to 38.8 kg H_2SO_4/t with a median value below the LoR.

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[1] Bowen H.J.M (1979) Environmental Chemistry of the Elements, Academic Press, New York, p60-61.

Fresh coal samples are expected to have acidic initial contact water with static pH testing values ranging from pH 3.5 to 4.5 and a median of pH 4.2. Salinity in initial contact water is expected to be less variable than in drainage from weathered coal ranging from 100 to 385 µ/cm, but to generally have similar salinity values from most materials (median 186 µS/cm). Sulfide concentrations in fresh coal are expected to range from 0.015% to 2.80% with a median of 0.22%. As with weathered coal, fresh coal is expected to have very low ANC (ranging from below the LoR to 3.2 kg H_2SO_4/t with a median value below the LoR.

The coal samples, particularly weathered coal are generally classified as NAF with the minority of samples classified as PAF – low capacity (LC) (RGS, 2024). They generally have sufficiently low sulfide sulfur concentrations that the materials can be considered to have a negligible risk of generating additional acidity; however, while these materials have a negligible risk of generating additional acid over time, the $pH_{(1:5)}$ values suggest initial drainage may be acidic, potentially due to the previous weathering of sulfide materials (which have become depleted) or the presence of organic acids withing the materials.

2.6.5 Coal ash static geochemistry

Ash materials generally have alkaline pH values in initial contact water (median pH 8.0, range pH 4.8 to 8.4). Initial contact water salinity values are elevated relative to coal materials ranging from 358 to 1,450 µS/cm with a median of 663 µS/cm. Sulfide concentrations are low relative to the median crustal abundance of sulfur, ranging from 0.005% to 0.199%, with a median of 0.027%. The ANC of ash is elevated relative to other material at YCM ranging from below the LoR to 167 kg H_2SO_4/t with a median of 51.2 kg H_2SO_4/t.

The ash samples are all classified as NAF or NAF-barren (B), with negligible risk of generating additional acidity (RGS, 2024). There is, however, a risk of generating saline drainage.

2.6.6 Overburden static geochemistry

Initial drainage from overburden materials placed on pit walls and within the HHF above the coal seam is expected to be slightly acidic with pH values ranging from pH 4.3 to 6.2 and a median of pH 5.5. Contact water salinity is variable, ranging from 17 to 1,510 µS/cm, but with a median value of 107 µS/cm is expected to generally be similar to coal materials. Sulfide is expected to be present in the materials at negligible concentrations, ranging from 0.009% to 0.033% with a median of 0.013%. ANC of the materials is also expected to be low with static testing results ranging from below the LoR to 5.9 kg H_2SO_4/t and a median of 2.1 kg H_2SO_4/t.

Initial pH values in drainage from YTF SOB and YMF Overburden Dump materials is expected to range from slightly acidic to near-neutral (pH 4.8 to 6.5, median 5.5). Salinity values from static testing range from 19 to 304 µS/cm, with a median of 48. Low sulfide concentrations are expected, with sulfide concentrations in tested materials ranging from below the LoR to 0.061% with a median of 0.010%. The materials are also expected to have very little ANC, with tested materials ranging from below the LoR to 8.6 kg H_2SO_4/t, with a median value below the LoR.

Materials from the YTF NOB and YEF Overburden Dumps are expected to generate acidic to slightly acidic initial drainage. Tested materials have pH values ranging from pH 2.8 to 6.0 and a median of pH 4.6. Salinity values in initial contact water are expected to be higher with static testing results ranging from 12 to 1,660 µS/cm and a median of 324 µS/cm. Sulfide concentrations in materials tested were elevated relative to other overburden materials and range from below the LoR of 0.005% to 5.16% with a median of 0.365%. As with other materials, ANC values are expected to be low with results from tested samples ranging from below the LoR to 38.4 kg H_2SO_4/t with a median of 1.65 kg H_2SO_4/t.

Overburden materials at YCM are expected to generally be NAF, with near-neutral pH values, low total sulfur concentrations and low ANC values. Exceptions are the overburden withing the YTF Northern Overburden Dump and the YEF Overburden Dump which are classified as PAF and generally have excess potential to generate additional acidity relative to the neutralising capacities of these materials and so pose an increased risk of generating acidic drainage.

2.6.7 RGS kinetic geochemical testing

The KLC assessment is summarised in a separate report provided in **Attachment B** (RGS, 2024). KLC composite samples were created based on the site location and material type of the samples (**Table 2-5**). The KLC tests were operated under both saturated and unsaturated (free leaching) conditions (**Figure 2-7**). The primary objectives of the KLC test program were to quantify the concentration and rate at which weathering products (acid, soluble salts and metals and metalloids) are leached from the solid phase materials (ash, coal and overburden) over time, under free leaching unsaturated ('wet-dry') versus saturated conditions. The columns were leached weekly for the first five leaches (to remove readily soluble weathering products) and then monthly thereafter. Filtered leachates were analysed for key parameters and metals and metalloids according to **Table 2-6** in the following sections.

Table 2-5: Summary of KLC sample materials, leach types, material sources, and material classifications

KLC ID	Material	Leach Type	Material Source	Material Classification	Number weeks operated
KLC 01	YTF Overburden	Free Leach	YTF	PAF (LC)	48
KLC 02	Weathered Coal	Free leach	YTF Batters	PAF (LC)	80
KLC 03	Overburden	Free leach	YMF Overheight	NAF	80
KLC 04	Overburden	Saturated	YMF Overheight	NAF	80
KLC 05	Weathered coal	Free leach	YEF	Uncertain	80
KLC 06	Weathered coal	Saturated	YEF	Uncertain	80
KLC 07	Fresh Coal	Free leach	YMF	PAF	48
KLC 08	Fresh Coal	Saturated	YMF	PAF	48
KLC 09	Weathered Coal	Free leach	YTF Northern Batters	Uncertain	49
KLC 10	Weathered Coal	Saturated	YTF Northern Batters	Uncertain	49
KLC 11	Weathered and Fresh Coal	Free leach	YMF Western Batters	Uncertain	49
KLC 12	Weathered and Fresh Coal	Saturated	YMF Western Batters	Uncertain	49
KLC 13	Ash	Free leach	Former Ash Ponds	NAF	56
KLC 14	Ash	Saturated	Former Ash Ponds	NAF	52
KLC 15	Ash	Free leach	Former Ash Ponds	NAF	52
KLC 16	Ash	Saturated	Former Ash Ponds	NAF	52
KLC 17	Drill Hole N7440	Free leach	YEF Overburden Dump	PAF	46
KLC 18	Drill Hole N7440	Saturated	YEF Overburden Dump	PAF	46
KLC 19	Drill Hole N7524	Free leach	YTF NOB Dump	PAF	46
KLC 20	Drill Hole N7524	Saturated	YTF NOB Dump	PAF	46
KLC 21	Drill Hole N75256	Free leach	YTF SOB Dump	Uncertain	46
KLC 22	Drill Hole N75256	Saturated	YTF SOB Dump	Uncertain	46
KLC 23	Drill Hole N7521	Free leach	YMF Overburden Dump	NAF	46
KLC 24	Drill Hole N7521	Saturated	YMF Overburden Dump	NAF	24

Table 2-6: Kinetic testing leachate analysis suite-

Analytes	Laboratory Analysis
Key parameters	pH/ EC and acidity/ alkalinity
Major Ions	Ca, K, Mg, Na, Cl, F, SO_4^{2-}
Metals/ metalloids	Al, As, B, Ba, Be, Bi, Cd, Ce, Cs, Co, Cr, Cu, Dy, Er, Eu, Gd, Ga, Hf, Ho, In, La, Li, Lu, Fe, Hg, Mn, Mo, Nd, Ni, Pr, Pb, Sb, Rb, Sm, Se, Ag, Sr, Te, Tb, Tl, Th, Tm, Ti, Sn, U, V, Yb, Y, Zn, Zr
Nutrients	Total organic carbon

Figure 2-7: Kinetic leach column (KLC) tests for YCM at RGS Laboratory.

The key findings from the KLC testing are summarised below:

- Saturated sample materials transitioned from oxidising to reducing conditions over time except for samples from the YTF Northern and SOB Dumps.
- Across all materials, initial high salinity values, major ion, and metal/metalloid concentrations and high loading rates seen in the leachates are likely due to the initial first flush of readily solubilised reaction products resulting in elevated dissolved concentrations.
- Consistent with the static geochemical testing undertaken on YCM materials (RGS, 2024), most materials are expected to generate slightly acidic to acidic drainage initially, apart from ash which is expected to generate circum-neutral to alkaline drainage.
- The pH of drainage from mine materials is expected to increase as the pit lake fills, materials become saturated, and the oxidation of materials slows or stops. With an increase in pH, leached metals and metalloids typically decrease.
- The salinity of contact water from most materials is expected to be less than that of groundwater encountered during the 2022/2023 drilling program undertaken by RGS (RGS, 2023), with major ions in solution dominated by sodium and sulfate.
- Drainage from most materials is expected to have low dissolved acidity and negligible alkalinity.
- Drainage from ash is expected to have elevated alkalinity relative to other material types.
- Drainage from YEF Overburden and YTF NOB Dump materials is likely to be notably elevated in dissolved acidity relative to drainage from other materials.
- While initial metal concentrations in drainage may be elevated relative to selected water quality guideline values, the loading rates of most metals from most materials are generally expected to decline over time and to further decrease as materials become saturated and increasingly reducing.
- Initial drainage from coal materials may contain concentrations of soluble aluminium, arsenic, and cobalt that are elevated relative to the Livestock Drinking Water guideline values; however, concentrations of these elements in solution are expected to decrease over time.

- Initial contact water from ash materials under oxidising conditions is expected to have higher selenium concentrations relative to drainage from other materials but concentrations are expected to decrease over time and under reducing conditions.
- Under oxidising conditions material from the YTF Northern and YEF Overburden Dumps are expected to generate drainage with lower pH values and increased acidity, salinity, and metal and metalloid loads (notably aluminium, cadmium, cobalt, nickel, and selenium) relative to other materials.
- Under oxidising conditions, pH values in drainage from the YTF Northern and YEF Overburden Dumps is expected to decrease over time while acidity, salinity, and metal and metalloid loading rates are expected to increase.
- The acidity, salinity, and metal loads in drainage from the YTF Northern and YEF Overburden Dumps materials is expected to decrease as the materials become saturated and the ingress of oxygen is limited.

3 Hydrogeochemical conceptual model summary

A hydrogeochemical conceptual model has been developed to inform establishment of the numerical modelling approach. A summary of the conceptual model is provided below.

3.1 Hydrological impact on pit lake(s) quality

The water quality of the pit lake(s) is a result of many factors including but not limited to geology and minerology of the host formations, surface water and groundwater quality entering the mined voids, concentrating effects of evaporation (evapoconcentration), geochemical, biological, and limnological processes with the pit lake(s) and anthropogenic impacts. The key water quality inputs to the final void/

pit lake(s) are summarised in the cross section (

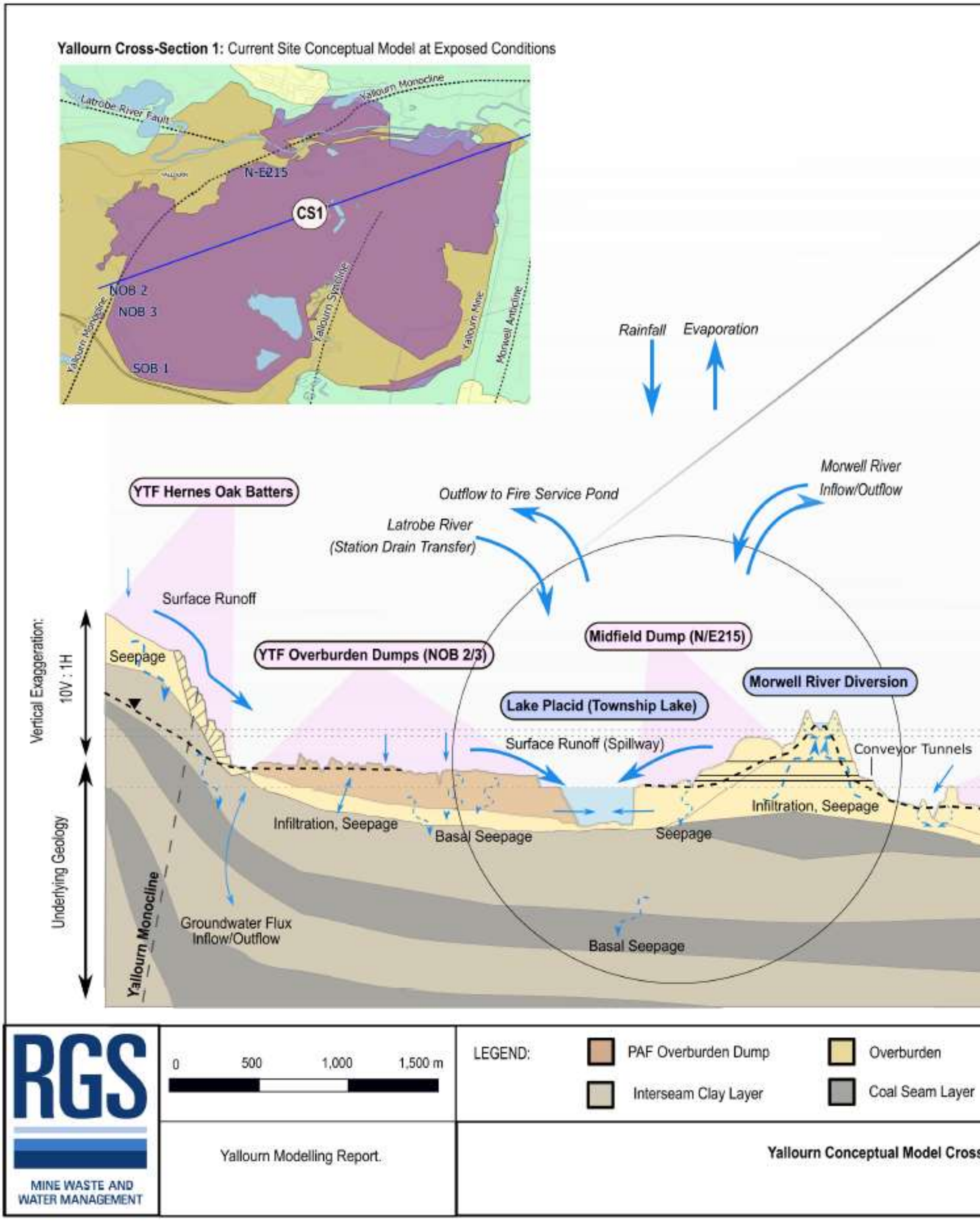

Figure 3-1 and **Figure 3-2**).

The hydrology of the pit lake(s) affects the water quality of the pit lake(s) by changing the chemical mass balance associated with the pit lakes.

General statements regarding the impacts of hydrological processes on water quality can be made and these are applicable to Yallourn:

- Groundwater inflows carry dissolved constituents at background concentrations into the lakes. Natural, upgradient groundwater will have a certain water quality and will contribute to the lakes quality. Inflowing groundwater can also pick-up constituents from weathered coal immediately surrounding the mine void or from recharging meteoric water passing through the dewatered zone.
- Surface water runoff from pit walls and local catchment may transport constituents and sediments that will affect the chemistry of the lakes.
- Flood flows from the Morwell River in a connected lake scenario, will carry dissolved constituents via the three spillways.
- In pit overburden dump (and the Former Ash Ponds) seepage and runoff may carry dissolved constituents into the lakes.
- Direct precipitation generally is a diluting factor on lake water quality although Zn regularly exceeded the freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018).
- Water transferring from lake-to-lake via the conveyor tunnel (as a result of hydraulic head differences) may have a dilution or concentrating effect on the receiving lake.
- Since evaporation removes water and leaves behind any dissolved constituents, evaporation tends to have a concentrating effect on lake water quality (known as evapoconcentration).
- Groundwater and surface water outflows (via the outflow channel) from the lake(s) typically have the effect of removing constituents from the lake(s). However, if the lake(s) is stratified, these outflows may remove water of different quality, which may result in either improved or reduced water quality in the lakes (note: outflows would only reduce the lake water quality if there was a freshwater surface lens that is flowing out).
- Depending on the water quality of the external water sources used to fill and top-up the lake(s), these may result in either improved or reduced water quality in the lake(s).

3.2 Lake – Groundwater interaction

Before mining commenced at YCM the unsaturated (vadose) zone was limited to the shallow regolith above the coal deposit (i.e. HHF). Mining lowered the standing groundwater table through dewatering thereby increasing the extent of the vadose zone, moving (generally) laterally down through the coal seam in a broad cone of depression. As the groundwater table dropped in response to dewatering air was drawn into the coal and this is likely to have led to the (partial) oxidation of the coal, including oxidation of sulfide minerals that may be present within the coal seam (i.e. at the boundary between the coal and HHF and disseminated through the coal). The extent of oxidation and weathering of coal in the cone of depression is uncertain and it is possible that the pore voids in the vadose zone may be dominated by either oxygen or nitrogen.

When the dewatering ceases and the groundwater level rebounds, the rebound could occur ahead, in equilibrium, or lag behind the pit lake(s) level. In each of these situations the soluble weathering products in the pore voids in the vadose zone may be leached out and mobilised to the pit lake or to groundwater. The vadose zone in the coal will also store a large amount of water and this is an aspect to be considered in the numerical model.

Groundwater will seep in and out of the pit lakes through permeable units exposed in the pit walls. A groundwater quality database is available for each of the aquifer systems (HHF, M1 and M2) potentially contributing groundwater flux into the final void/ pit lakes and impacting pit lake(s) water quality composition; this has been used to develop geochemical source terms for groundwater inflow.

The conceptual groundwater model extends beyond the extent of the pit shell and this is being developed by other consultants.

3.3 Surface water inflows

After closure, there will be various potential surface water inflows to the mined void, that will create two pit lakes (i.e. YEF and YTF). Each inflow will need to be accounted for within the numerical model to allow simulation and comparison of different closure scenarios. The conceptual model for the different closure scenarios identified the key surface water flows into the mined void as:

- Runoff from exposed pit walls (weathered and fresh coal, overburden).
- Runoff and seepage from the In-pit Overburden Dumps (YTF and YEF Overburden Dumps and Midfiled Dump).
- Potential runoff and seepage from coal ash facilities (i.e. the Former Ash Ponds; noting YNOC Central and Western Ash Landfills are not included with the closure catchment).
- Direct rainfall onto the mined voids/ pit lakes surface.
- Local runoff from the catchment within the mining lease (various land use types).
- Potential contribution from the external Morwell River upstream catchment for the connected scenarios.

3.4 Conveyor tunnel transfer

Once (if) the rising lake water level reaches the conveyor tunnel, transfer of water and mixing of solutes will occur between lakes. The direction of transfer will depend on the lake that first reaches the conveyor tunnel elevation. With time, lake water level equilibrium is expected to occur; however, lake water quality may always vary between lakes due to the different water inflows (volume and quality) and materials within the pits/lakes (e.g. pit wall material, overburden dumps and ash facility).

3.5 Overburden dump contact water

Sulfide rich material mainly occurs within the Township Field NOB Dump and Eastfield Dump, while the SOB Dump, Midfield Dump and Maryvale Filed is assumed to contain mainly NAF material; for this reason, the focus of this section is largely around the NOB Dump and Eastfield Dump.

Oxidation of sulfide-rich (e.g. pyrite/ marcasite (FeS_2)) materials within the NOB/ Eastfield Dumps are producing seepage water quality that is acidic and elevated in some salts and metals/ metalloids.

During operation, acidic runoff and seepage from the NOB Dump enters Lake Placid. However, the acid is likely to be neutralised by alkalinity from the Latrobe River/ Cooling Tower which is released to Lake Placid via the Station Drain. Similarly, natural bacterial processes may reduce sulfate (i.e. iron sulphide precipitation) and neutralise acid. These processes need to be captured within the numerical model.

Test pits and drillholes placed in the various overburden dumps (Earth Systems, 2011; RGS, 2023) intersected a shallow water table, which is also seen in ponds in geographical lows within the dump. This suggests that a large portion of the dumps would be saturated preventing (or limiting) the oxidation of sulfides below the water table.

Implementation of a full pit lake scenario (RL + 37 m AHD) will impact the hydrogeological processes that currently affect the overburden dumps. During rainfall events, runoff will occur from the various dumps to the pit lake. A fraction of the direct rainfall will infiltrate into and percolate through the dumps, eventually entering into the pit lake(s) as a potentially acidic or saline seep, or potentially containing elevated metals/ metalloids (depending on the dump composition). The amount of runoff versus seepage will be dependent on the closure strategy for the dumps (e.g. clay cap or cover compared to doing nothing). Mixing of dump seepage and runoff water with other pit lake water sources could result in an overall neutral pit lake water; understanding these interactions are a key objective of the numerical modelling.

Groundwater interaction may occur between the perched water table in the dumps and the underlying aquifer(s).

The following conditions would be expected in the full pit lake scenario;

- The various overburden dumps will be submerged (excluding a small portion of the SOB Dump).
- Runoff and seepage will not be the predominant hydrogeological processes affecting the pit lakes once full.
- Groundwater flow directions will be controlled by the rebounding groundwater table and managed discharge to the pits. Flow towards the mined void would be expected with aquifer rebound. If managed discharge rises the pit lake(s) water faster than the aquifer water table rebounds the flow direction may be reversed and towards the adjacent strata.
- Oxidation of sulfides predominantly within the NOB Dump/ Eastfield Dump would be constrained by water saturation and reduced oxygen availability.
- Once the pit walls and overburden dumps are submerged, diffusion will be the dominant process transferring solutes between the pit walls/overburden dumps and lake(s); however, this is expected to be very low.

3.6 Ash landfill

Potential runoff and seepage from the YNOC Central and Western Ash Landfills are not expected to enter the mined void/ pit lake(s) and will therefore not contribute to the overall pit lake(s) water quality. Coal ash deposited within the Former Ash Ponds is within the mine voids/ lake(s) catchment and will therefore generate runoff (from the sandy clay cap) and seepage while above the lake water level.

3.7 Biological processes

Biogeochemical reactions can affect pit lake water quality. Microbial processes can influence the redox conditions present in the pit lake. Concentrations of dissolved metals can be impacted by the precipitation of sulfide minerals and uptake of dissolved metals by microorganisms. Microbial processes can also be responsible for the removal of organic carbon from the pit lake water.

Biological reactions such as photosynthesis and respiration can alter the concentration of dissolved CO_2 and O_2 in the pit lake waters. Stratification in the pit lake can result in the depletion of O_2 at the base of the pit lake, which will affect any organisms present.

Studying the microbial communities in pit lakes is an important part of understanding element cycling. Element cycling occurs from chemical, geological, and biological factors. Microbes can increase chemical reaction rates and water-rock interactions by metabolising both organic and inorganic components in a system. In effect, these interactions affect the speciation of elements in an environment, which can lead to either an increase or reduction of dissolved metals in water. In mine waters, microbes can act as catalysts in redox reactions, alter mineral compositions, sequester or release toxic metals, and change net pH as a product of their metabolism.

The chemical, physical and biological processes that contribute to the production and neutralisation of acid and the presence of salts and metal(loids) particularly in anoxic and reducing water in the pit lake are extremely complex.

The interaction between biota (bacteria) and oxygen, carbon, sulfate, iron and manganese need to be understood as they have a direct effect on element cycling.

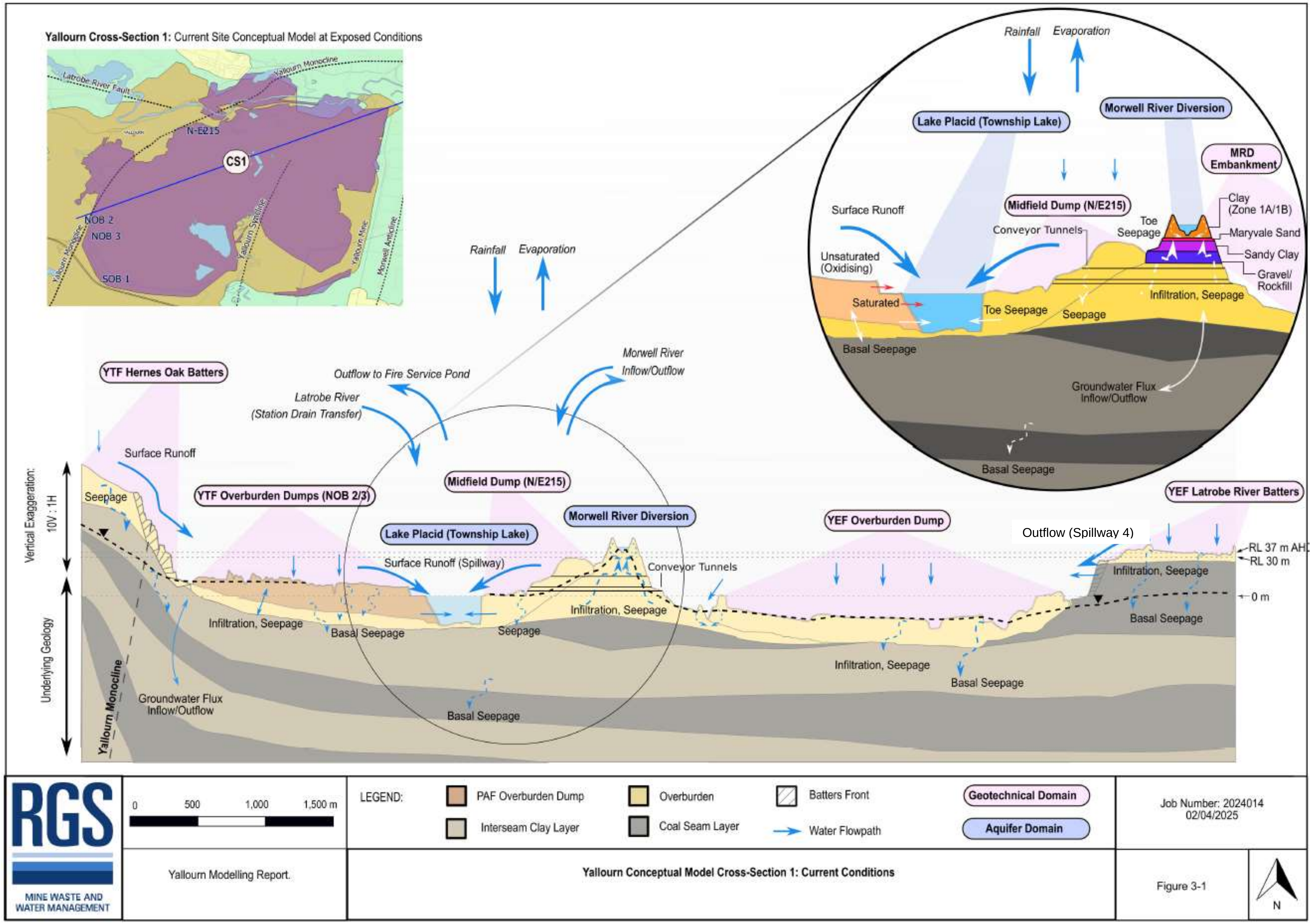

Figure 3-1: Conceptual hydrogeology model (connected to Morwell River; prior to filling)

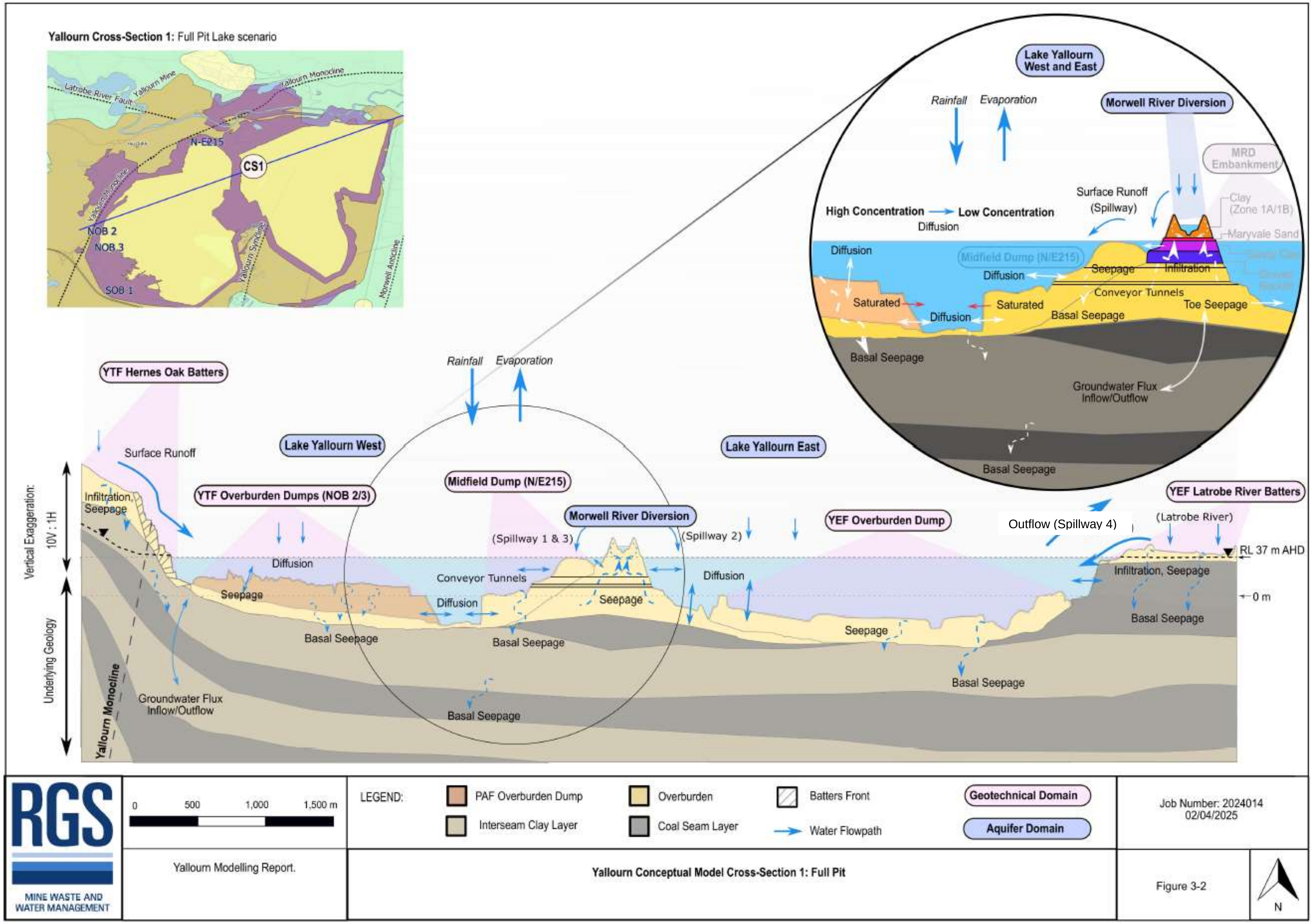

Figure 3-2: **Conceptual hydrogeology model (connected to Morwell River; full lake)**

4 Model Development

The numerical model, including the water balance and water quality components, has been developed using GoldSim Software. The model was developed as a decision support tool for assessing closure options. For this reason, it has been developed with flexibility to allow the user to run a series of different “what-if” scenarios and sensitivity analyses, by varying different inputs and model switches. The model has been developed on a daily time-step, to run probabilistic simulations for periods of up to 100 years (refer to Section 4.4).

The model development is expressed visually in **Figure 4-1**, and depicts the key components of the model, which includes the water balance and water quality. The water balance (direct rainfall, groundwater and surface water contributions to the lake) is controlled by climate (rainfall and evaporation) and external water sources. Each of the key source of water to the lake contributes a water quality (source term) derived from a combination of inferred (e.g. geochemical testing) and measured data.

The sub-sections below describe the numerical model development including input data, model structure and logic, and key assumptions and limitations.

4.1 GoldSim

GoldSim is a dynamic, probabilistic simulation software developed by GoldSim Technology Group. It is a graphical, object-orientated coding platform. This means that it is a flexible platform in which the user can program the software to represent any system (such as a mine site) within a graphical user interface. This makes it user-friendly to lay out equations, code logic and system influences, whilst reducing the risk of errors that might be otherwise hidden in spreadsheets.

GoldSim has been selected for the numerical model development as:

- It is particularly well suited for stochastic or probabilistic simulations with its Monte Carlo simulation framework.
- Its ability to run dynamic simulations of complex systems using a tailored development approach.
- Its ability to simulate both water balance and water quality (using the Contaminant Transport (CT) module).
- It is very well suited to environmental and engineering risk analysis, with applications in the areas of water resource management, mining and water quality assessments.
- Its ability to run a series of different “what-if” scenarios and sensitivity analyses in which input parameters can be varied to understand the impact to the system. This makes it a very useful decision support tool.
- Its dashboard function in which the model can be packaged with a front-end including input and results dashboard. This allows users who are not model developers to run different scenarios in the model to better understand the system and support the decision-making process.

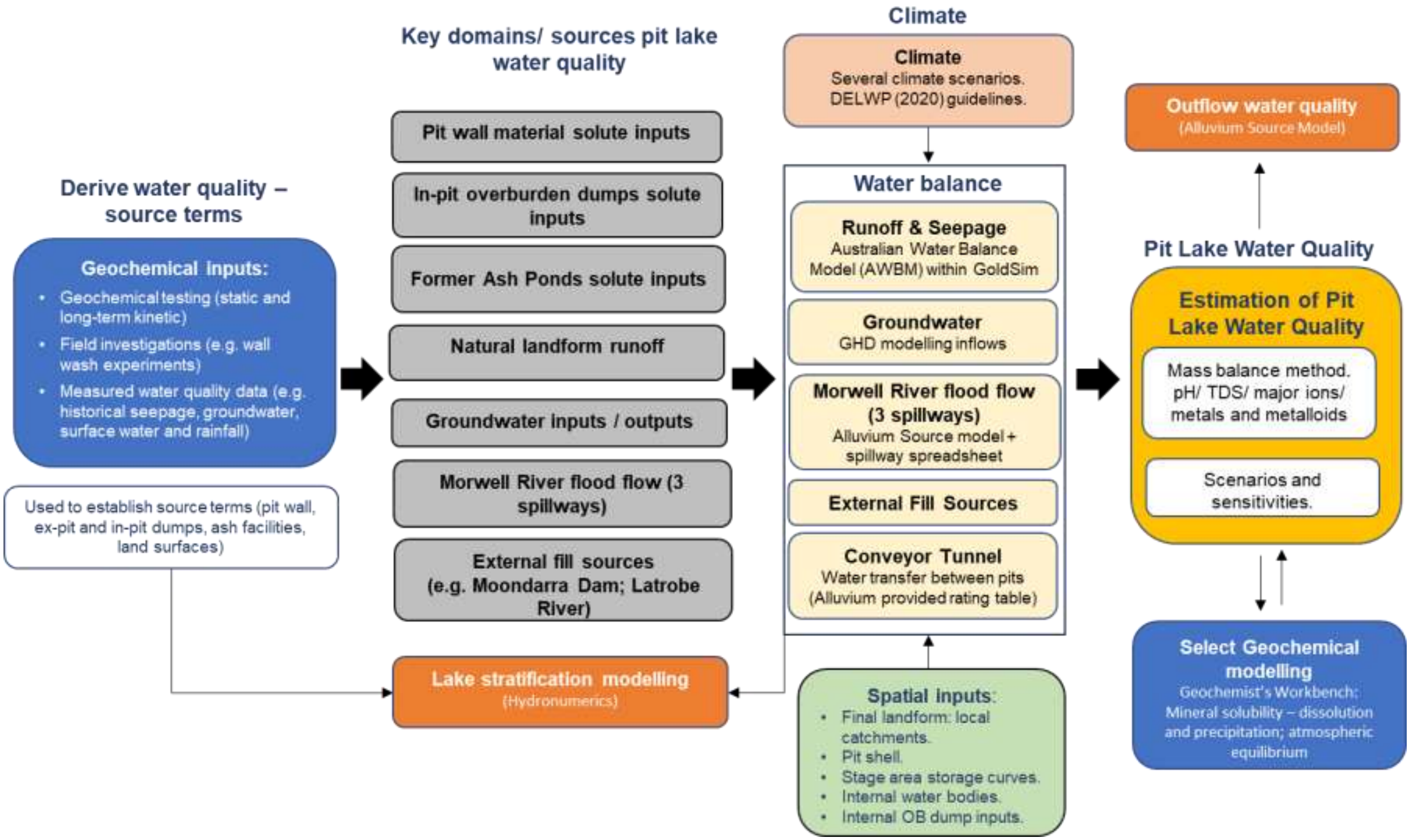

Figure 4-1: Yallourn lake(s) water balance and water quality model development

4.2 Modelling objectives

To evaluate over a 100-year period:

- Lake levels for the proposed YTF and YEF pit lakes.
- Flows between the Morwell River, the proposed pit lake(s) and the Latrobe River.
- The amount of top-up water required to maintain lake levels.
- Lake(s) water quality.
- The influence of climate change and climate variability on the above.

4.2.1 System Boundaries

Plan Boundaries

- Surface water catchments that flow to the YTF and YEF pits/ lakes.
- The MRD as it enters the mine lease.
- The MRD as it exits the mine lease.

Elevation Boundaries

- Lower: the existing surface level of internal and external catchments, plus a conceptual depth to accommodate shallow groundwater water.
- Upper: the existing surface level, or the surface water elevation of water bodies (whichever is higher).

4.2.2 Exogenous (external) influences

- Rainfall and evaporation.
- Groundwater entering the pits (both through pumping and flux).
- River flows.
- Top-up from external sources (e.g. Moondarra Reservoir).

4.2.3 Time Boundaries

From mine closure (01/01/2029) plus 100 years.

4.2.4 Assumptions

- The YEF and YTF lakes will overflow at RL 37. Overflows are unconstrained by spillway capacity and/or tailwater conditions in the MRD.
- All existing in-pit water bodies will be inundated either before or shortly after mine closure, and as such do not need to be explicitly modelled.
- Water will be transferred between YTF and YEF via conveyor tunnels, the capacities of which have been provided by Alluvium (**Section 4.7.3**).
- Witts Gully and Rifle Range Dams will remain operational, however there is currently no modelled demands on these storages (other than evaporation), so they simply overflow to YTF when full.
- The YTF and YEF lakes will be completely mixed.

4.3 Modelling scenarios

The modelling scenarios and sensitivities undertaken as part of the DMRP modelling are outlined in Error! Reference source not found.. The modelling includes the base case scenario (Scenario 1) and several project scenarios (Scenario 2 to 6).

All model simulations commence on 1/01/2029, with a starting water volume of 13.5 gigalitres (GL) in the YTF (i.e. water level at RL -4 m AHD which is the expected final water level of the Fire Service Pond at the end of mine operations) and a starting water volume of 1.0 GL in the YEF (i.e. water level at RL -49 m AHD m).

All scenarios include inflows from direct rainfall, local catchment rainfall runoff, natural groundwater inflow (and outflow) and pumped groundwater. Groundwater from the M1A aquifer is pumped into the YEF at an initial rate of 1.5 GL/year to a lake level of RL 0 m (i.e. up to the point when one of the pumping bores is assumed to be decommissioned and flooded), then 1 GL/year to RL 37 m AHD, and then 0 GL ongoing.

There are no other inflows assumed for the base case scenario (Scenario 1) (i.e. there is no interconnection to the MRD (Morwell River) and no ongoing top-up water to maintain lake water levels. The base case scenario assumes median climate conditions using probabilistic rainfall simulations.

The project modelling includes two ‘pit fill’ scenarios with the Morwell River either connected to the pit(s) in some form (Scenario 2 to 5) or not connected (Scenario 6) (**Table 4-1**). The key fill water sources, others than those mentioned above, include commercial surface water allocations of Latrobe water (24 GL/year [Scenario 2, 4, 5 and 6] or 34 GL/ year [Scenario 3]) and Moondarra Reservoir water (14 GL/year [Scenario 3]). Latrobe water is pumped into YTF while Moondarra Reservoir (Scenario 3 only) is pumped into the YEF.

The Morwell River flood flows (Scenario 2, 3 and 5) are connected via three spillways (Spillway 1 – 3) which are introduced at the start of the model start date (refer to **Section 4.5.1**). Scenario 4 assumes the entire Morwell River is connected to the lake at the completion of filling (i.e. at the completion of filling the MRD is removed forming a single lake and the Morwell River flows into the lake which then overflows to the Latrobe River via Spillway 4).

The fill approach is undertaken as a seamless fill whereby external water is pumped into the YEF until the lake is filled to RL +37 m AHD without pause; this is considered acceptable since EA will likely have access to the majority of water required for fill. After the pit is filled, the ‘top-up’ is triggered if the water level of the lake drops 1 m to RL +36 m AHD (due to evaporation and other losses). Top-up includes pumped Latrobe water with an assumed rate of 0.065 GL/ day, which is based on the annual fill allocation of 24 GL/year (i.e. 24/ 365).

Climate sensitivities for the preferred scenario are modelled for median (Scenario 2) and dry (Scenario 5) climate conditions using probabilistic (rainfall) simulations (refer to **Section 4.5**).

Table 4-1: Yallourn DMRP modelling scenarios-

Scenario ID	Fill Sources (annual until reach RL + 37m AHD)	Morwell River connected?	Top-up water	Climate
Scenario 1	Local catchment flows, natural groundwater & pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing).	No	No	Median
Scenario 2	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing) & 24 GL Latrobe water.	Yes (flood flows only)	Yes	Median
Scenario 3	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing), 34 GL Latrobe water & 14 GL Moondarra water.	Yes (flood flows only)	Yes	Median

Scenario ID	Fill Sources (annual until reach RL + 37m AHD)	Morwell River connected?	Top-up water	Climate
Scenario 4	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing) & 24 GL Latrobe water.	Yes (all)	Yes	Median
Scenario 5	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing) & 24 GL Latrobe water.	Yes (flood flows only)	Yes	Dry
Scenario 6	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing) & 24 GL Latrobe water.	No	Yes	Median

4.4 Assessment period

The model has been developed on a daily time-step to run for a period of 100 years, starting on 1/1/2029.

It should be noted that the longer the model simulation period, the greater the bounds of uncertainty in the modelled WB/WQ results that are likely to be observed. For example:

- the inherent uncertainty of some of the key input parameters such as climate, hydrology and chemistry. When the model run time is extended, these uncertainties are magnified.
- the uncertainty in groundwater inflows (Section 0) especially as related to changes to climate and recharge rates and possible climate induced changes to local and regional water use, as well as possible changes to demand are not currently known
- uncertainty in chemistry and reactions e.g. precipitation of materials as concentration increases which may be compounded with modelled time.
- uncertainty in micro(biological) processes.

The key uncertainties around climate change and climate variability are managed through sensitivity analysis in the model. Water quality inputs use a conservative approach.

4.5 Climate

Numerical models developed for mine water assessments are mathematical representations of complex bio-geo-hydro-physico-chemical systems and will always carry inherent uncertainty.

The primary inputs to a mine water balance are climate inputs: namely rainfall and evaporation. Climate inputs are, however, a primary source of uncertainty in a water balance model.

Changes in climate will affect the individual hydrologic components differently. Generally, surface hydrologic processes are impacted immediately upon a change in climate. Groundwater inflows are generally and ultimately generated from precipitation recharge. The groundwater system tends to buffer short-term climatic changes, but long-term climatic changes will be reflected in groundwater inflows over the long-term.

The Intergovernmental Panel on Climate Change (IPCC, 2023) indicated that there is a strong possibility that temperatures will continue to increase into the future if current conditions affecting atmospheric conditions stay constant. Increased temperatures will affect surface hydrologic processes differently in different parts of the world; some places will become wetter while others become drier, and the rate and duration of precipitation can drastically change.

For lakes, a drier climate will result in lower lake water surface elevations and a wetter climate will result in higher lake elevations and potential changes to the groundwater system can occur. Other broad consequences to pit voids from climate change are difficult to predict as all components of the hydrologic system will be affected. Sensitivity analyses are used in the numerical model to test the effect of climatic changes on water quality and water level, surface and vadose zone water.

The primary uncertainties related to climate modelling which are included in Yallourn GoldSim WB/WQ model include:

- Climate variability
- Future climate change predictions/ assumptions

The approach implemented in the climate module of the WB/WQ model to address future climate uncertainty follows the approach recommended by Department of Environment, Land, Water and Planning (DELWP[2]) presented in "*Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria* (2020)".

4.5.1 External runoff (connected scenarios)

The lake inflows from the Morwell River were modelled by Alluvium. The models use the same 100 realisations of rainfall data supplied by RGS.

More detail provided is provided in **Section 4.7.2**.

4.5.2 Climate variability

Victoria has a highly variable climate, both spatially across the state, and over time. Climate variability is represented by fluctuations in temperature, evapotranspiration, rainfall and other climate variables on sub-daily, daily, seasonal, annual and decadal (long term) time scales. Climate variability can be chaotic or cyclical in nature.

To address uncertainty associated with climate variability, DELWP (2020) recommends an approach in which two historical reference periods are selected:

- A post-1975 historic climate reference period.
- A post-1997 historic climate reference period.

The purpose of the historic climate reference periods is to enable:

- the generation of estimates of historic climate and water availability under historic greenhouse gas concentrations; and,
- the generation of current and future climate scenarios.

These reference periods are simply the historic climate records over the period July 1975 (and/or July 1997) to end of June of the most recent year of available data. The most recent year of available data should ideally extend to the current year.

The post-1975 historic climate reference period incorporates ~49 years of climate variability. Global Climate Models (GCM) derived projections can be applied to the post-1975 historic climate reference period to represent future climate change scenarios.

The DELWP rationale for selecting the post-1975 historic climate reference period is:

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[2] Department of Environment, Land, Water and Planning (DELWP) is now known as Department of Energy, Environment and Climate Action (DEECA).

- It incorporates a wide range of natural climate variability, including the 'Millennium Drought', the 1982–83 drought and several relatively wet years.
- It is long enough to reasonably apply data extension techniques, such as historical data scaling or stochastic data generation, that can incorporate greater natural climate variability.
- It aligns with the reference periods adopted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) 'climate futures' (e.g. Clarke et al., 2011) when estimating the projected changes in temperature, rainfall, potential evaporation and runoff from global climate models.
- The start date is broadly consistent with observed step changes in climate behaviour in the 1970s, particularly temperature, noting, however, that statistically significant step changes have also been detected in the late 1990s.
- It is consistent with recent research by the Bureau of Meteorology (BoM) that has used GCMs to assess the relative contribution of anthropogenic climate change to Victoria's observed cool season rainfall decline since the late 1990s.

The post-1997 historic climate reference period, assumes that the dry conditions experienced since 1997 represent a permanent step-change in climate from that experienced prior to 1997. It allows for the possibility that a step change in climate has already occurred in 1997.

It is therefore arguable whether a historic record spanning 20–25 years (in the case of a post-1997 historic climate reference period) or 45–50 years (in the case of a post-1975 historic climate reference period) contain sufficient climate variability to reasonably assess water availability under a representative range of wet, dry and average conditions. One of the techniques recommended by DELWP to enable the extension of the historic climate reference period to incorporate more climate variability than observed over that period is stochastic data generation.

Stochastic data used in modelling water systems are random numbers that are generated in a way so that they have the same statistical characteristics (in terms of mean, variance, skew, long-term persistency, etc.) as the reference period data on which they are based. Using historical climate data as inputs into hydrological models, provides results that are based on only one realisation of the past climate. Stochastic climate data provide alternative realisations that are equally likely to occur and can therefore be used as inputs into hydrological and ecological models to quantify uncertainty in environmental systems associated with climate variability (Srikanthan et al., 2007).

For the generation of stochastic data consistent with DELWP climate change guidelines, stochastic data generation can be undertaken directly on the post-1997 and post-1975 historic climate reference periods.

When generating stochastic data for use with GCM-based projections, the adjustment of that data for projected peak (if applicable) and average annual historical climate change from 1995 to date can be undertaken either before or after generating the stochastic data. However, due to the level of effort in generating and checking stochastic data, the guidelines suggest that the stochastic data be generated only once (using the post-1975 historic climate reference period). The adjustment for projected historic low, medium and high climate change from 1995 to date can then be applied to the stochastic dataset.

There are at least three tools that are readily available to Australian practitioners for generating stochastic climate data: Stochastic Climate Library (SCL), foreSIGHT and MSSSCAR (in WATHNET5). Within each of these tools, there are several options that are available to generate stochastic data for a system.

SCL has been used by RGS to generate daily stochastic realisations of climate variables.

SCL software was first released in 2005, with a number of updates over the years. SCL was originally produced by the Cooperative Research Centre for Catchment Hydrology and is still available via the eWater toolkit. It contains the following options for stochastic models:

- Annual rainfall — first order autoregressive model with parameter uncertainty.
- Monthly rainfall — modified method of fragments (with annual data generated using the above annual rainfall model).
- Daily rainfall — transition probability matrix (with Boughton's correction).
- Sub-daily rainfall — DRIP model (short to long time scale generator).
- Annual climate — first order autoregressive multivariate model.
- Monthly climate — modified method of fragments.
- Daily climate — first order autoregressive multivariate model conditioned on rainfall state and nested in monthly and annual models.
- Multi-site daily rainfall — multi-site two-part model nested in monthly and annual models.

Full descriptions for each of these models are provided in Srikanthan *et al*. (2007) and the references therein.

The SCL user interface contains tools that allow the user to calibrate a stochastic data generation model and then to generate stochastic replicates. The SCL user interface contains features that allow the key statistics from the underlying (historical) data to be readily compared against the generated replicates, which is a particularly useful feature during model calibration. The multi-site daily rainfall (long to short time scale) generator from SCL has also been implemented in eWater Source (Srikanthan *et al*. (2007)).

4.5.3 Climate change

An example of the uncertainty that is related to climate science includes the future of anthropogenic greenhouse gas and aerosol emissions (and hence their resultant radiative forcing) that is known to be highly uncertain, encompassing substantial unknowns in population and economic growth, technological developments and transfer, and political and social changes.

The climate modelling community has developed Representative Concentration Pathways (RCPs[3]) to explore credible future options. These scenarios span the range of plausible global warming scenarios.

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[3] The RCPs represent a wider set of futures that the previous emissions scenarios used by climate modelling community (Special Report on Emissions scenarios (SRES); IPCC, 2000), and now explicitly include the effect of mitigation strategies. As with SRES, no particular scenario is deemed more likely than the others, however, some require major and rapid change to emissions to be achieved.

There are four RCPS:

RCP8.5 - a future with little curbing of emissions, with a CO_2 concentration continuing to rapidly rise, reaching 940 ppm by year 2100.

RCP6.0 – lower emissions, achieved by application of some mitigation strategies and technologies. CO_2 concentration rising less rapidly (than RCP8.5), but still reaching 660 ppm by year 2100 and total radiative forcing stabilising shortly after year 2100.

RCP4.5 - CO_2 concentrations are slightly above those of RCP6.0 until after mid-century, but emissions peak earlier (around year 2040), and the CO_2 concentration reaches 540 ppm by year 2100.

RCP2.6 - the most ambitious mitigation scenario, with emissions peaking early in the century (around year 2020), then rapidly declining. Such a pathway would require early participation from all emitters, including developing countries, as well as the

They provide a range of options for the world's governments and other institutions for decision making (**Figure 4-2**).

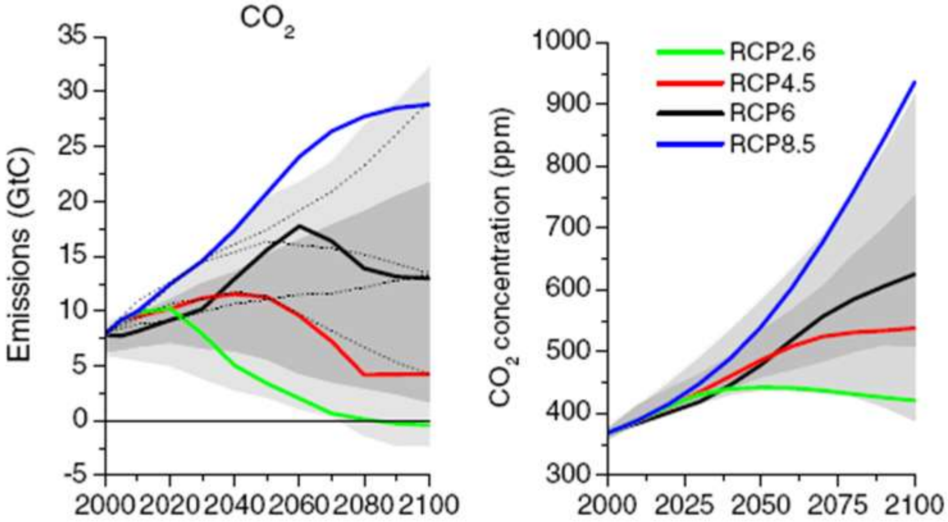

Figure 4-2: Emissions of CO_2 across the RCPs (left), and trends in concentrations of carbon dioxide (right). Grey area indicates the 98th and 90th percentiles (light/dark grey) of the values from the literature. The dotted lines indicate four of the SRES marker scenarios. SOURCE: van Vuuren *et. al*. (2011).

The RCP8.5 scenario is a high emissions scenario that is recommended for water planning applications in Victoria. The RCP8.5 scenario spans a wide range of plausible futures and is consistent with a precautionary approach for water supply impact assessment, which is appropriate in the context of GCM uncertainty and uncertainty around future greenhouse gas emissions and concentrations.

DELWP guidelines recommend the use of the following four climate change scenarios to represent system behaviour under plausible future conditions:

- Low, medium and high climate change scenarios, which are projected from the post-1975 historic climate reference period (with projected changes commencing from 1995). These scenarios make use of climate change projections derived from GCMs.
- Post-1997 step climate change scenario, which is projected as a continuation of the post-1997 historic climate reference period. This scenario is derived independent of global climate modelling. It assumes a continuation of climate and runoff experienced from July 1997 to date.

The guidelines assume that all scenarios are equally plausible. No scenario is recommended in preference to another.

The approach adopted by CSIRO for the guidelines, assumes the 10th, 50th and 90th percentile model outputs as being representative of the range of climate change that could be expected. This provides a wide spread of model results but excludes outlying model results from the wettest (or coolest) and driest (or hottest) 10% of projections.

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application of technologies for actively removing carbon dioxide from the atmosphere. The CO_2 concentration reaches 440 ppm by year 2040 then slowly declines to 420 ppm by year 2100).

It should be noted that there is a tendency to interpret the medium projection as the most likely projection. The medium projection is not the most likely projection, because at the current time, all projections are equally likely. As more information is collected on the global climate response to greenhouse gas emissions over time, it is possible that either the driest projection could be the most likely, or the wettest projection, or any projection in between.

The process for estimating climate under projected low, medium and high climate change involves applying GCM-derived factors to the post-1975 historic climate reference period. Tabulated factors for average annual change in rainfall and potential evapotranspiration for the Latrobe catchment are presented below in **Table 4-2** and **Table 4-3**, respectively.

Table 4-2: Projected change in average annual rainfall (DELWP, 2020)-

River Basin	Projection	Rainfall change relative to 1995 (%)		
		Year 2020	Year 2040	Year 2065
		RCP8.5	RCP8.5	RCP8.5
Latrobe	Low (Wet)	1.80%	3.30%	2.20%
	Medium	-2.20%	-4.00%	-4.50%
	High (Dry)	-6.30%	-11.40%	-16.70%

Table 4-3: Projected change in average annual evaporation (DELWP, 2020)-

River Basin	Projection	Evapotranspiration change relative to 1995 (%)		
		Year 2020	Year 2040	Year 2065
		RCP8.5	RCP8.5	RCP8.5
Latrobe	Low (Wet)	1.40%	2.50%	4.80%
	Medium	2.50%	4.50%	7.60%
	High (Dry)	3.20%	5.80%	11.30%

The post-1997 step climate change scenario is projected from the post-1997 historic climate reference period, but without the use of GCM-derived projections. It assumes that the climate and streamflow experienced post-1997 will continue into the future. This scenario is especially important for near-term applications but is also relevant for long-term planning until such time as the high climate change scenario becomes drier than observed post-1997 conditions. This scenario assumes that:

- Projected climate change has already occurred as a step change in 1997;
- No further climate change has occurred from 1997 to date; and,
- No further climate change will occur into the future.

4.5.4 Climate approach

The climate simulated in the numerical WB/WQ model includes rainfall, evaporation and evapotranspiration. The base climate for the model is derived from *Scientific Information for Land Owners* (SILO) point interpolated data for the location of the Yallourn Township Field (geographic reference: -38.20, 146.35). The SILO data available for the location included daily historic rainfall, evaporation and evapotranspiration data.

Two types of climate data were selected from the available historical record (Base, being the post-1975 reference period, and Drought[4], being the post-1997 reference period, climate types; **Figure 4-3)**. These two types were used to generate stochastic realisations of 100-year long climate records for rainfall and evaporation. Base Climate realisations were then be modified by climate change factors to generate three climate scenarios.

Note: only the Median and Dry climate scenarios were used for the DMRP model runs.

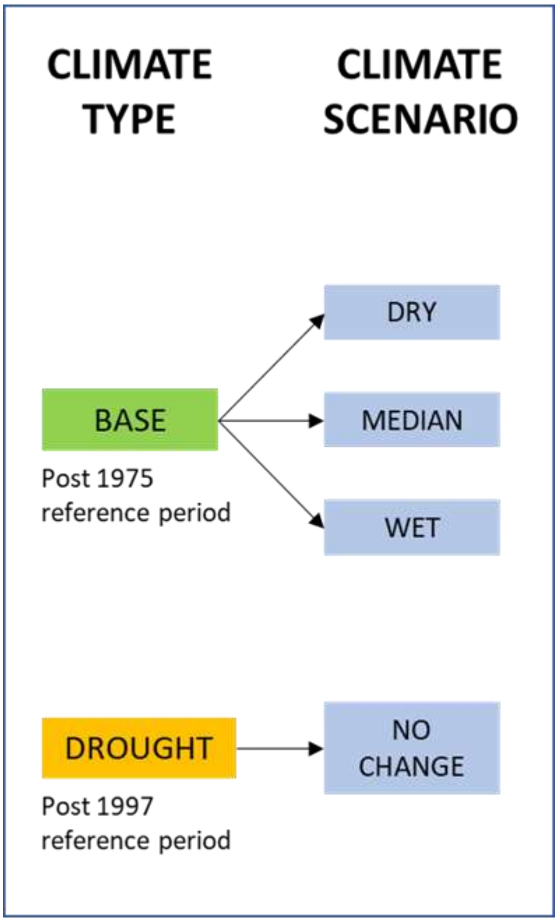

Figure 4-3: Proposed approach to generate climate database

4.5.4.1 *Evaporation*

Two different sets of modelled evaporation datasets are used in the model:

- Morton's Shallow Lake Evaporation (Morton, 1983) is used in the model to represent the evaporation loss from the lake surface. The shallow lake dataset is calculated using Morton's method which converts observed pan evaporation to the evaporation that would likely be observed on a larger body of water. This evaporation dataset will be used to simulate evaporation losses from the lake surface.

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[4] Note: Post 1997 step climate scenarios is less conservative than the high (dry) scenario. The scenario is incorporated in the modelling to remain consistent with DELWP (2020) Guidelines.

1. Morton's Actual Evapotranspiration (Mact) represents the combined loss of water from a given catchment area, by evaporation from the soil surface and by transpiration from plants. The Mact dataset provided in the SILO data is calculated using Morton's method (Morton, 1983) and is an input to the hydrological modelling (Australian Water Balance Model; AWBM), to calculate surface runoff to the pit.

4.5.4.2 *Rainfall*

The base and drought climate datasets (rainfall and evaporation) are based on SILO point data from the location of -38.20 and 146.35 for the prescribed period from 1 Jan 1975 to 31 Dec 2023.

Figure 4-4 shows the average monthly rainfall totals for the base climate type. The average long-term annual rainfall is 754 mm, with the highest rainfall occurring in winter and spring.

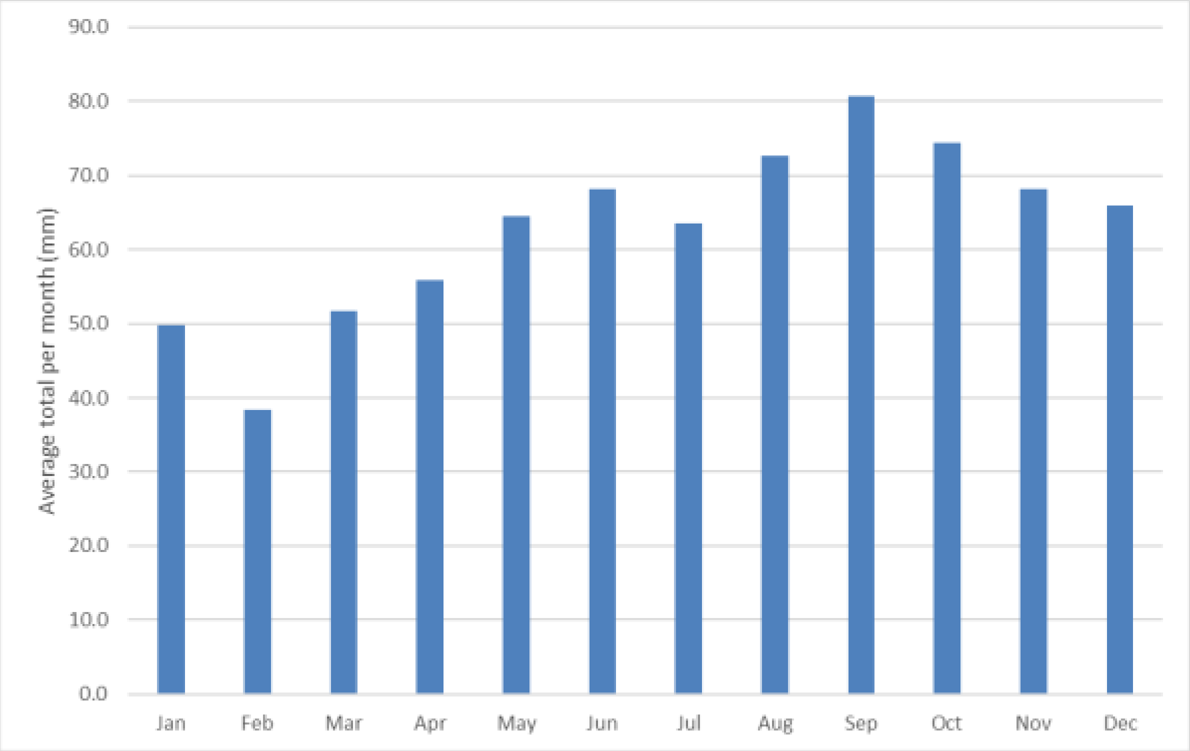

Figure 4-4: Average monthly rainfall totals (base climate: 1 Jan 1975 to 31 Dec 2023)

4.5.4.3 *Probabilistic (stochastic) rainfall*

Each probabilistic dataset was generated using the eWater Stochastic Climate Library Software (SCL), applying the ~49-year daily deterministic sequence as the base climate. Each generated stochastic rainfall dataset is different than the scenario it is based on, but the mean from all generated realisations (100 random realisations, each 100 years long) will have the same statistics as the input dataset. Many of the 100 stochastic rainfall sequences will contain both rainfall events which exceed those experienced in the historical record, and drought periods more extreme than previously experienced. This allows the model to simulate how the pit water balance and water quality may respond to uncertainty in future climate variability.

4.5.4.4 Validation of stochastic rainfall data

Validation of the stochastic rainfall model was undertaken according to Srikanthan and McMahon (2003). The stochastic model validation evaluates how well the generated data preserves key statistics of the measured (interpolated) data (i.e. minimum 2-year, 3-year, 5-year, 7-year and 10-year sums; as well as the mean, variation, skew and auto-correlation) by comparing generated climate statistics to a set of tolerance limits (**Table 4-4)**. The number of average annual parameters from all replicates that are within the tolerance limit is counted according to:

1. *N1 (N2)* is the number of basic model parameters (mean, standard deviation, skewness, lag 1 autocorrelation) that are within Tolerance Limit 1 (Tolerance Limit 2).

2. *M1 (M2)* is the number of the remaining eight validation statistics that are within Tolerance Limit 1 (Tolerance Limit 2).

If *N1* = 4 and *M1* ≥ 6 then the stochastic data is considered a 'good' fit. If *N2* = 4 and *M2* ≥ 6 then the generated data is considered a 'fair' fit. Alternatively, the stochastically generated data is considered a 'poor' fit.

The results of the validation for the generated stochastic rainfall are provided in **Table 4-5**. The validation results indicate that the stochastic model is performing satisfactorily, with the model ranking as 'fair'.

Table 4-4: Tolerance Limits for differences in key statistics (from Srikanthan and McMahon (2003))

	Parameter	Tolerance Limit 1	Tolerance Limit 2
1	Annual mean (%)	5	10
2	Annual standard deviation (%)	5	10
3	Annual coefficient of skewness	0.5	1
4	Annual lag 1 autocorrelation coefficient	0.15	0.25
5	Annual maximum (%)	10	25
6	Annual minimum (%)	10	25
7	Annual adjusted range (%)	10	25
8	Min 2-yr rainfall sum (%)	10	25
9	Min 3-yr rainfall sum (%)	10	25
10	Min 5-yr rainfall sum (%)	10	25
11	Min 7-yr rainfall sum (%)	10	25
12	Min 10-yr rainfall sum (%)	10	25

Table 4-5: Stochastic model assessment (based on Srikanthan and McMahon (2003)) for stochastic rainfall

Parameter	Historical Rainfall	Generated 100 Realisations	Error	Tolerance Limit 1	Tolerance Limit 2
Annual mean (%)	754.271	754.271	0.00%	1	1
Annual standard	119.324	119.324	0.00%	1	1
Annual coefficient of	-0.095	0.25	0.35	1	1
Annual lag 1	0.212	-0.009	-0.22	0	1
Annual minimum (%)	1.366	1.388	1.61%	1	1
Annual maximum (%)	0.628	0.678	7.96%	1	1
Annual adjusted range	1.665	1.204	-27.69%	0	0
Min 2-yr rainfall sum (%)	1.507	1.527	1.33%	1	1
Min 3-yr rainfall sum (%)	2.469	2.444	-1.01%	1	1
Min 5-yr rainfall sum (%)	4.271	4.321	1.17%	1	1
Min 7-yr rainfall sum (%)	6.14	6.249	1.78%	1	1

Parameter	Historical Rainfall	Generated 100 Realisations	Error	Tolerance Limit 1	Tolerance Limit 2
Min 10-yr rainfall sum	8.781	9.178	4.52%	1	1

4.5.4.5 *Evaporation*

Variability of evaporation is significantly less than variability of rainfall (**Table 4-6**). RGS are thus using average daily (per month) evaporation rate based on historical data for pit lake water quality modelling. The values reported below are "base" values that are subsequently adjusted for climate change.

Table 4-6: Evaporation – average daily per month

Month	Evaporation (Lake Surface)(1)	Actual Evaporation (Catchment)(2)
Jan	5.5	4.3
Feb	4.8	3.5
Mar	3.4	2.3
Apr	2	1.2
May	1.1	0.7
Jun	0.7	0.6
Jul	0.8	0.6
Aug	1.4	1.1
Sep	2.4	2.1
Oct	3.5	3.2
Nov	4.5	4.0
Dec	5.3	4.4

Notes

2. Mortons shallow lake evaporation (BoM)
3. Mortons actual evaporation (BoM)

4.5.4.6 *Application of DELWP climate factors*

The order of applying the DELWP climate factors post stochastic rainfall generation is necessary to preserve the projected climate change trends. The SCL works by decomposing the historical rainfall data to generate rainfall statistics (annual, monthly etc.) and then regenerating new, random rainfall records which honour the historical rainfall statistics. In the process, the long-term trends are "bundled" into the overall statistics and are lost from the new generated probabilistic sequences. By applying the climate factors post-rainfall (evapotranspiration) generation process, the forecasted trends in climate change are preserved. As per DELWP guidelines, the factors are applied to the base climate type only, starting from 1995.

The DELWP climate factors have been provided for a period of up to year 2065. To run the model for the proposed 100 years, the additional ~67 years of predicted climate factors are necessary, which are not available at this stage. The DELWP guidelines do however specify that climate factors can be linearly extrapolated from 2040 to 2065 up to the year 2075, leaving ~57 years without climate factors.

The simplest solution to provide the required climate factors is linearly extended the existing factors for the remainder of simulated 100 years forecast (**Figure 4-5** – dotted lines). RGS recognise that straight line extension to the existing climate factor trends, particularly the dry climate scenario, may provide an overly conservative estimate. An alternative approach to extending the DELWP climate factors is reapplying the last provided climate factor in the dataset forward for the remainder of simulated 100 years forecast.

For the purpose of the DMRP WB/WQ modelling, RGS has used a combination of both solutions; to linearly extrapolate from 2040 to 2065 up to the year 2075 (according to DELWP guidelines), and then re-apply the climate factor for 2075 forward for the remainder of simulated 100 years forecast (**Figure 4-6**).

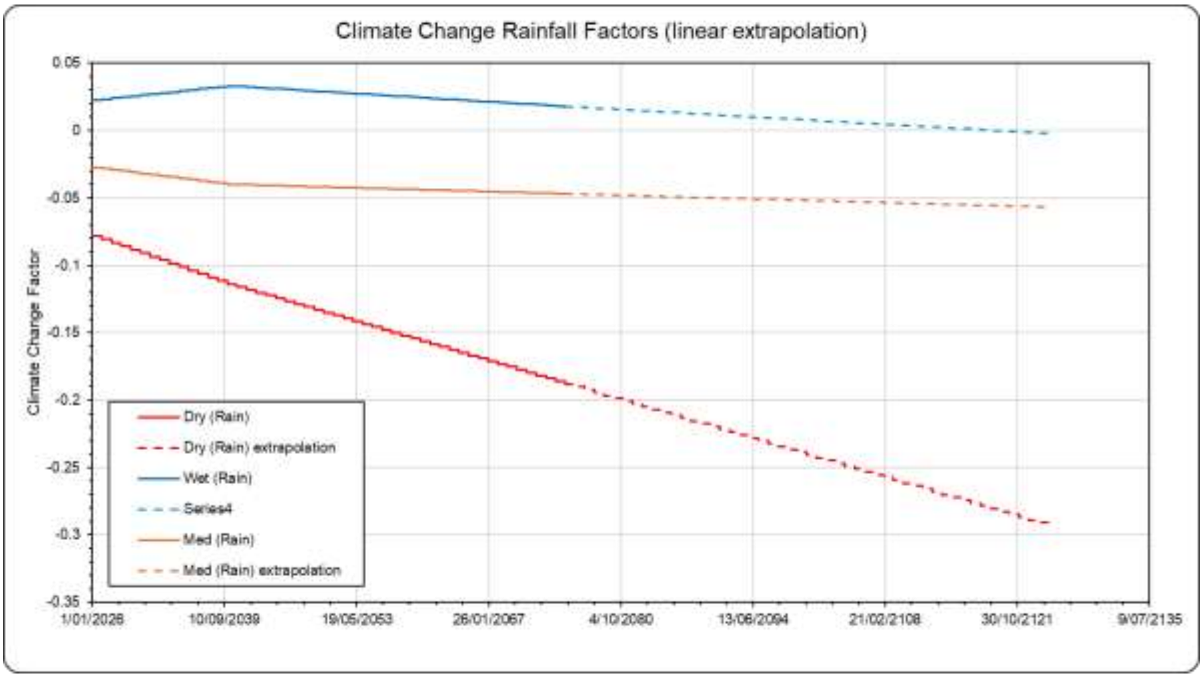

Figure 4-5: Linear extrapolation of DELWP rainfall climate factors.

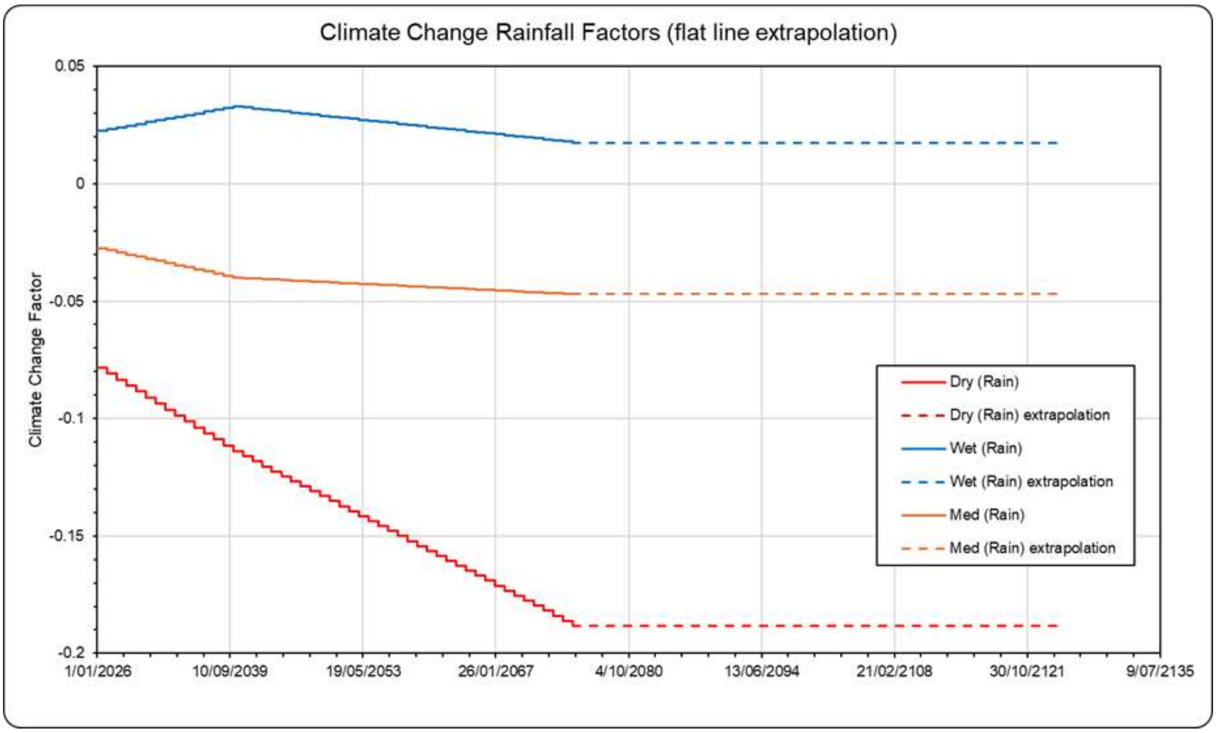

Figure 4-6: Extension of LVRRS rainfall climate factors using last LVRRS value.

4.5.4.7 *Summary of climate approach*

Table 4-7 summarises the proposed approach to climate change modelling in the Yallourn lake WB/WQ model.

Table 4-7: Approach to generating climate data sets for modelling-

Climate Type	Climate Variability	Climate Scenario (Climate Change)
Base Climate Point Climate Data -38.20 146.35 (SILO data) Use data available for years 1975 – 2022	100 stochastic realisations, 100-years long each, using Stochastic Climate Library	High (dry): Modify the realisations using high climate change factors applied after probabilistic sequences generation
		Medium (Median): Modify the realisations using medium climate change factors applied after probabilistic sequences generation
		Low (wet): Modify the realisations using low climate change factors applied after probabilistic sequences generation
Drought Point Climate Data -38.20 146.35 (SILO data) Use data available for years 1997 – 2022	100 stochastic realisations, 100-years long each, using Stochastic Climate Library	No modifications. Use as is.

4.6 Final landform modelling

The “final” landform surface of the pit voids and surrounding catchment area was provided by EA in .dxf format in June, 2022 (**Figure 4-7**).

The final landform surfaces were used in Deswik (geospatial and CAD software) to produce a range of input data to the GoldSim numerical model, including: pit physical characteristics and stage curves and catchment areas. These inputs are described in the sections below.

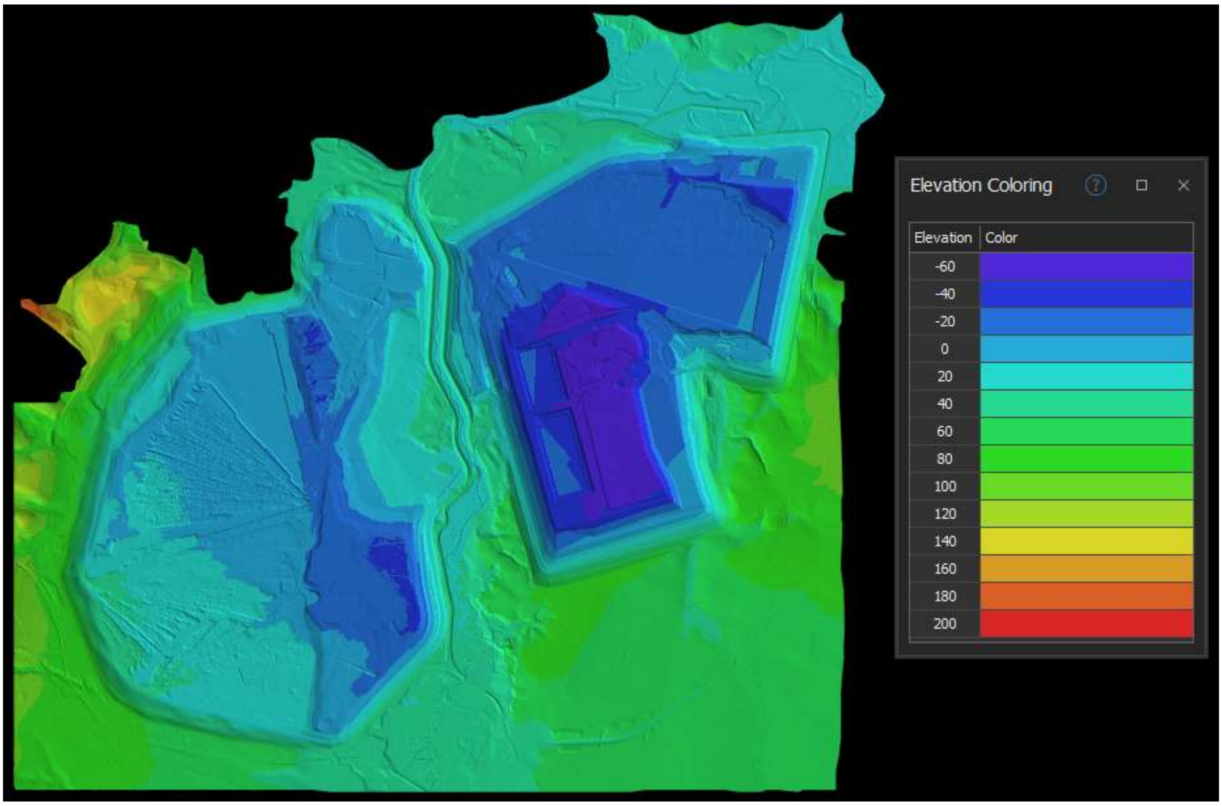

Figure 4-7: Final landform surface for YCM and surrounds

4.6.1 Pit physical characteristics

The numerical model incorporates input data to describe the pit voids geometry and its final landform.

A summary of the pit(s) geometry inputs is provided in **Table 4-8**.

Table 4-8: **Pit Void Geometry Summary-**

Pit Geometry Dataset	Description	Value
Pit maximum elevation	The elevation at which the pits are considered as "full". At this elevation, external pit fill sources will be switched off in the model. The pits will not require top-up at or above this elevation	RL +37 m
Pit maximum volume	Volume corresponding to the pit(s) maximum elevation. This is the volume at which the pits are considered as "full". At this volume, fill sources are switched off in the model and the pit does not require any top-up.	YTF: 249,278 ML YEF: 414,255 ML
Pit freeboard elevation	The elevation at which the pit would spill/ overflow or flow through to the Latrobe River.	RL +37 m

Details of each of the pit void geometry inputs which is incorporated in the model, and their application in the water balance is provided in **Table 4-9**. Each of these geometries was extracted from the final landform surface in Deswik at 1 m intervals.

Table 4-9: **Geometry data and application to water balance in pit water body model-**

No.	Pit Geometry Dataset	Application in Water Balance
1	Storage volume vs water surface area curves	Relates the pit water volume to the pit water surface area at each timestep for each pit. This is used to calculate the evaporation volume loss from and direct rainfall volume into the lakes. In this dataset the pit volume includes the water storage volume within the overburden and ash (assumed porosity of 30% and 40% for coal/ overburden and ash, respectively).
2	Elevation vs volume curves	Relates the pit water volume to the pit water surface elevation at each timestep. Essentially a lookup table which returns the volume for a given elevation for each pit. This is used to calculate the pit water elevation at each timestep as the pits fill. In this dataset the pit volume includes the water storage volume within the overburden and ash (assumed porosity of 30% and 40% for coal/ overburden and ash, respectively).
3	Volume vs Elevation curves	This is the same as the Elevation volume curves but simply in the opposite order. As such, it provides a lookup table to return pit water surface elevation for a given water volume.
4	Elevation vs pit wall area curves	Relates the pit elevation to the pit wall surface area at each timestep. This dataset considers the pit wall surface area which is overburden material only. It should be noted that this curve is different to the volume vs water surface area curve (Item 1) in that the water surface area is the 2-dimensional area measured in plan view of the pit, for each elevation, that would contribute to rainfall & evaporation loss. In contrast, the pit wall area at each elevation is measured as a 3-dimensional surface area, taking into account the vertical pit wall areas which would contribute a chemical load. This is used to calculate the chemical load coming from the exposed pit wall surface area during rain events (runoff/baseflow), and also the submerged pit wall area contributing a diffusive flux (i.e. once the pit walls (and overburden dumps) are submerged, they contribute a chemical load to the lake via diffusion).
5	In pit water elevation vs exposed overburden volume curve	Relates the pit water elevation (calculated from the above elevation vs volume curve) to the exposed overburden volume at each timestep. This is also used to calculate the submerged overburden volume at each timestep.
6	In pit water elevation vs exposed overburden area curve	Relates the pit water elevation (calculated from the above elevation vs volume curve) to the exposed overburden area at each timestep. This is also used to calculate the submerged overburden area at each timestep. This is then used to calculate the contributing surface water runoff from the exposed overburden and subsequently attribute exposed geochemistry source terms to this contributing inflow. Similarly, the inverse is used to determine the submerged surface area contributing to diffusion.

4.6.2 Catchments

The local catchment area draining to the pit was provided by Pells Sullivan Meynink: Geotechnical & Engineering Services (PSM) (**Figure 4-8**).

The catchments were then subdivided based on land use type by identifying different landform features to represent different land types. Separation of sub-catchments based on land use type was important in the model construction for two reasons:

- To align with the geochemistry and source term data. Different catchments were assigned with different source terms in the model and therefore must be separated. Note: the geochemical source terms for each of the catchments within the pit are different, however, the ex-pit catchments all carry the same natural runoff source term.
- Different land use types have different hydrology behaviour and different runoff volumes will be expected.

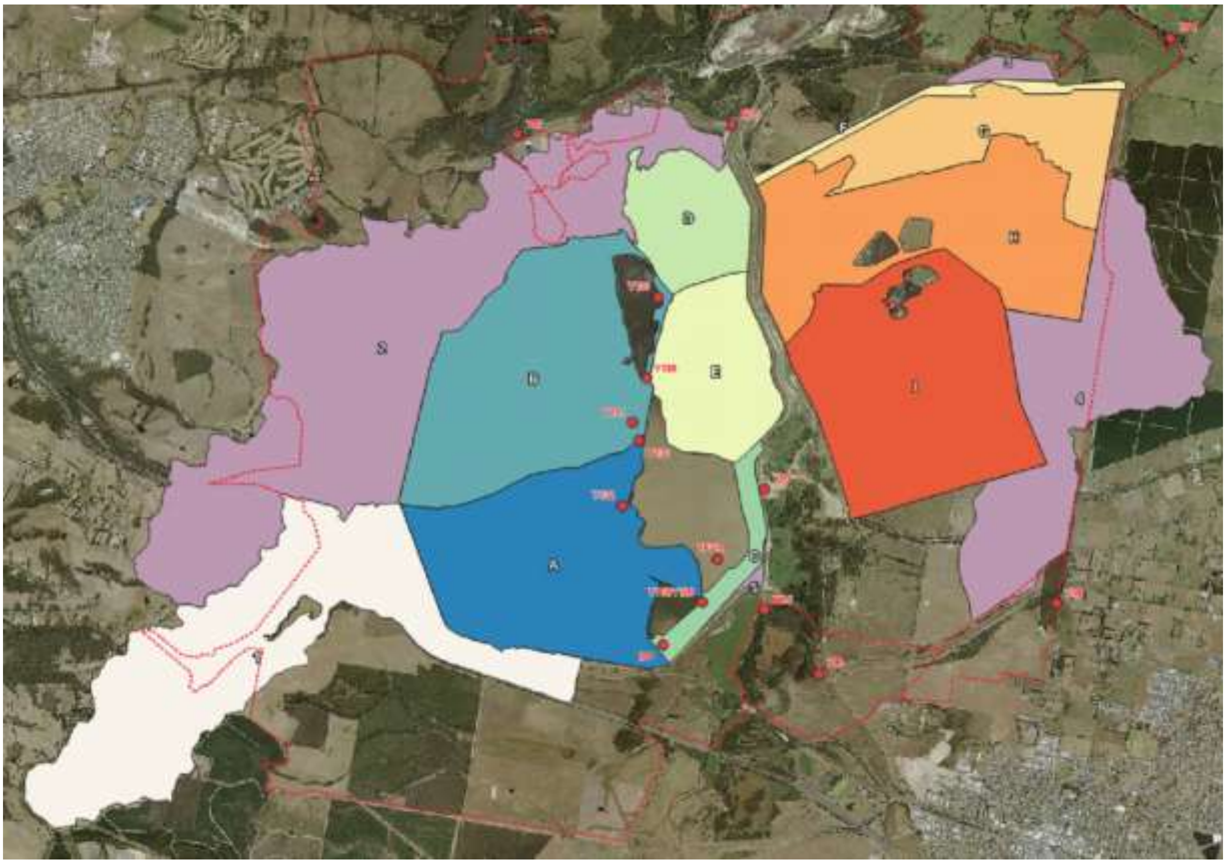

Figure 4-8: **Sub-catchment boundaries draining to pit.**

The different land use types assigned to a particular catchment and the rationale used to categorise each area is provided in **Table 4-10**.

Table 4-10: Sub Catchment Area Descriptions-

Land Use Type	Assigned Catchment	Description
Overburden	A, B, C, D, E, F, G, H, I.	Comprising the internal pit areas (pit floor and walls, up to the top of the batters), noting the majority of the pit floor is/ will be covered with overburden (bare spoil).
Natural undisturbed area	1, 2, 3, 4, 5.	Any area that remains in it’s natural, pre-mining project state and has not been disturbed by the pit or overburden areas. This includes all ex-pit catchments.

Table 4-11 summarises the sub-catchments and their areas determined using Deswik.CAD.

Table 4-11: Sub-catchment Areas

Sub-catchment	Area (km^2)
Catchment 1: Witts Gully	5.1
Catchment 2: Railway Drain, Rife Range Gully and Power Station	7.6
Catchment 3: North of YEF Northern Batters	0.2
Catchment 4: Hancock Victorian Plantations (HVP)/ Maryvale Transfer	3.7
Catchment 5: Above YTF MRD Batters	0.04
Catchment A: YTF Southern Overburden Dump	3.7
Catchment B: YTF Northern Overburden Dump	4.1
Catchment C: YTF MRD Batters	0.4
Catchment D: Midfield North	1.2
Catchment E: Midfield South	1.6
Catchment F: YEF North Batters	0.3
Catchment G: East Field	1.9
Catchment H: YEF Extension	3.4
Catchment I: Maryvale Field	4.1
Total	**37.4**

Catchments 1 and 2 contain water storage (Witts Gully Dam and Rifle Range Dam, respectively). From topographical assessment, the model allocates a proportion of catchment runoff to these water storages, with the balance reporting directly to YTF. The model routes flow through these storages with overflows also reporting to YTF. The allocated splits are:

- Catchment 1: 70% to Witts Gully Dam, 30% to YTF
- Catchment 2: 20% to Rifle Range Dam, 80% to YTF

4.7 Surface Water

After closure, there will be various potential surface water inflows to the pit voids from the catchments as described in **Section 4.6.2** and each of these has been accounted for within the model to allow simulation and comparison of different closure scenarios. This section describes the approach to the surface water and hydrology components in the model development.

The catchments included in the model are both local catchments (within the mine lease itself), as well as external catchments which may contribute flow into the lakes (i.e. Morwell River interconnection). The key surface water flows incorporated in the model are:

- Local rainfall and runoff
    - runoff from pit walls (e.g. Catchment F and C);
    - runoff and seepage from the in-pit overburden dumps (e.g. Catchment A, B, E, G, H and I);
    - runoff and seepage from the Former Ash Ponds (Catchment D);
    - direct rainfall onto the lake surface; and,
    - local runoff from the catchments within the mining lease.
- External runoff
    - external Morwell River upstream catchment. This contributes flow to the pit for a connected scenario (via the three spillways or fully integrated). Flow is allowed to leave the lake via Spillway 4.

Local rainfall and runoff are modelled within GoldSim while external runoff, specifically flows from the upper Morwell River catchment, were modelled by Alluvium Consulting (**Section 4.5.1**) and the outputs provided to RGS used as inputs into the WB/WQ model.

4.7.1 Local rainfall and runoff

All local surface water inflows to the pit (and within the pit) and their hydrological response are simulated within the GoldSim model itself, using the Australian Water Balance Model (AWBM) as an in-built module.

The AWBM is a daily timestep hydrology model which takes in rainfall and evapotranspiration data, then simulates the infiltration, soil storage based on antecedent rainfall conditions, and the hydrological lag response in the catchment and produces runoff as a daily timestep. **Figure 4-9** shows a schematic of the model logic. The model is able to simulate both surface runoff and shallow baseflow runoff, which together make up the total runoff.

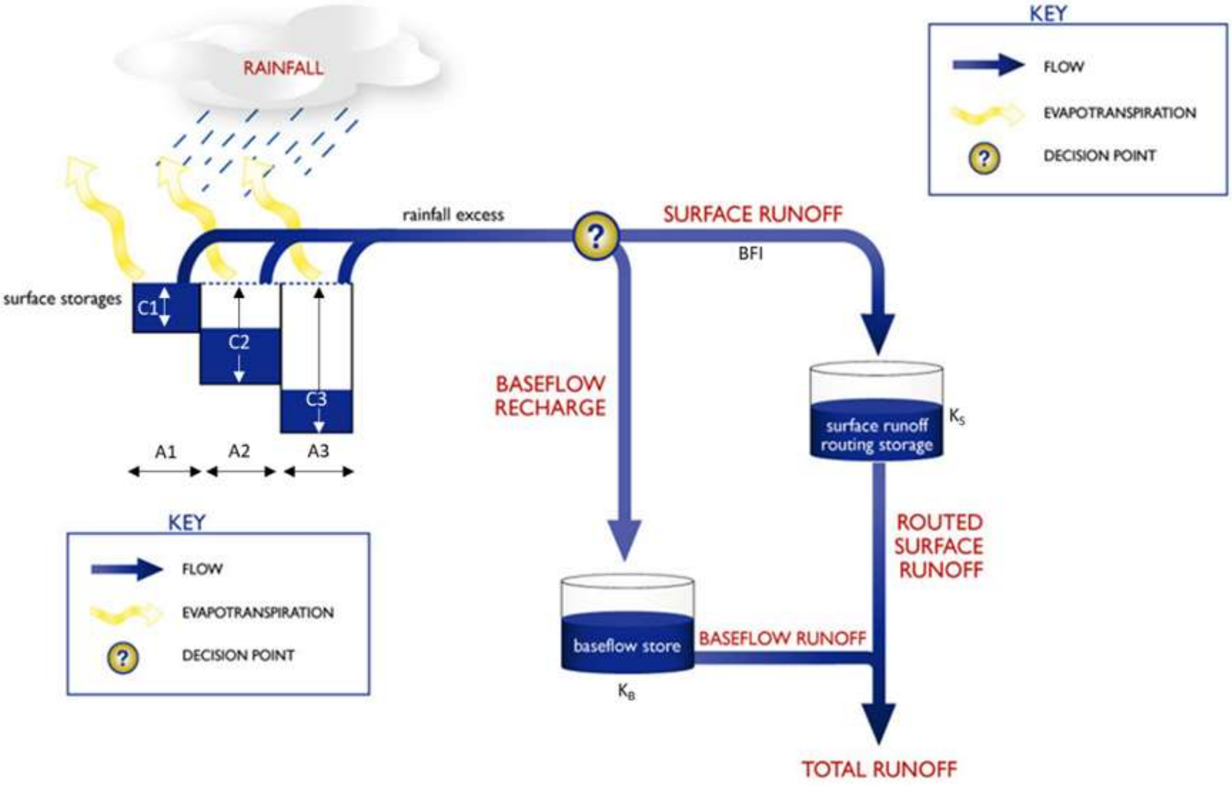

Figure 4-9: Schematic of the Australian Water Balance Model

The parameters in the AWBM model are summarised in **Table 4-12**.

Table 4-12: AWBM parameters

Parameter	Symbol	Description
Surface Area Stores	A_1, A_2, A_3	Proportion of the modelled catchment for each of the surface storages. i.e. storage per square meter of surface area. $A_1 + A_2 + A_3 = 1$
Soil Storage Capacities	C_1, C_2, C_3	Storage capacity for each surface store. Each storage is a depth measured in mm.
Baseflow Index	BFI	Fraction of runoff which reports to baseflow (ranges from 0 to 1)
Surface runoff recession constant	K_s	Fraction of surface runoff recession at each timestep (ranges from 0 to 1)
Baseflow runoff recession constant	K_b	Fraction of baseflow runoff recession at each timestep (ranges from 0 to 1)

A separate hydrology module has been developed for each of the land use types represented in the pit water balance. Each module will produce two hydrology outputs:

- surface runoff; and,
- shallow baseflow.

A summary of the different modules to represent each land-use type, and the proposed hydrology approach is provided in **Table 4-13**.

Table 4-13: Hydrology approach for various Yallourn landforms-

Landform Area	Hydrology module	Simulation approach
Direct rainfall onto the pit(s) water body surface (YTF and YEF)	**Water surface**	The pit water body surface area (for each pit) at each timestep Direct rainfall volumes are calculated at each timestep with the dynamic water surface area and 100% Runoff assumed. i.e. runoff (m^3/day) = rainfall (mm/d) * surface area (ha)
Natural undisturbed surrounding catchments (Catchment 1, 2, 3, 4, 5)	**Natural**	Any area that remains in it's natural, pre-mining project state and has not been disturbed by the pit or overburden areas. The undisturbed AWBM module has been calibrated to river gauging station 226210 Morwell River at Yinnar. This station is situated on the Morwell River approximately 14 km upstream of the YCM. This calibrated module represents land which is not disturbed by mining activities.
In-pit overburden dumps (Catchment A, B, E, G, H and I)	**Overburden**	In the absence of recorded runoff data for overburden land use types or Ash land-use types, the Overburden AWBM module uses parameters adopted from the Australian Coal Association Research Program (ACARP) project C7007 which evaluated water quality and discharge estimates for final void and spoil catchments (ACARP, 2001). Specifically, those parameters adopted were for "bare dragline spoil". Key parameter characteristics are the moderately increased recession coefficients and soil pore storage, to reflect the additional pore storage and lag time of runoff through the overburden which is likely to be observed.
Pit walls and floor (Catchment F and C)		
Former Ash Ponds (Catchment D)		

4.7.1.1 *Undisturbed AWBM Hydrology Module Calibration*

The undisturbed module was calibrated to observed streamflow data for the Morwell River at Yinnar gauge - BOM ID 226210. This gauge is about 14 km upstream of the pit voids. The gauged catchment is 249 km^2.

In the calibration, SILO rainfall and potential evapotranspiration data from the nearby Yinnar rainfall gauge (BOM ID 85100) was used. The model was calibrated within GoldSim using the available data from 1951 to 1960. An optimisation algorithm was used to maximise the Nash Sutcliffe efficiency index (as the objective function). The Nash Sutcliffe efficiency (NSE) index is used to measure fit of hydrology models, with an NSE of 0.65 or greater considered to be good fit. The calibration achieved a Nash Sutcliffe efficiency of 0.71.

Figure 4-10 presents the observed flow timeseries plotted against the calibrated simulated flow timeseries. The figure shows that the calibration achieved a very good fit between the observed and modelled streamflow data. Generally, the AWBM model captured both the baseflow and the peaks quite well.

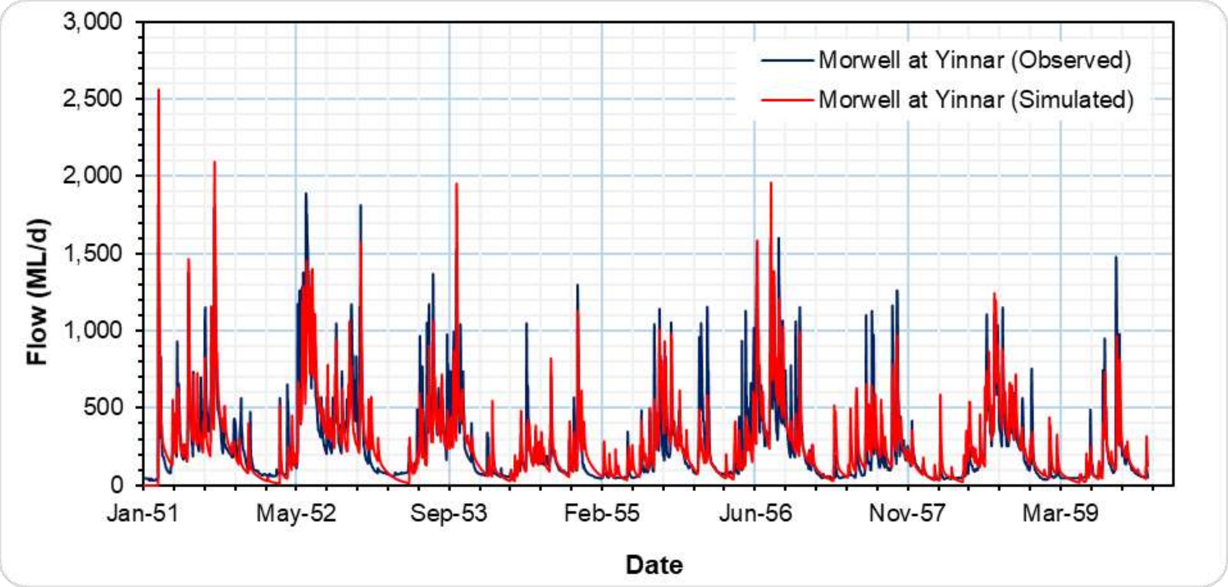

Figure 4-10: Observed versus simulated stream flow data for Morwell at Yinnar

Figure 4-11 shows the flow duration curves for both the observed flow and the simulated flow. This figure demonstrates that the calibration achieved a good representation of the distribution and seasonality of flows, when compared to the observed data.

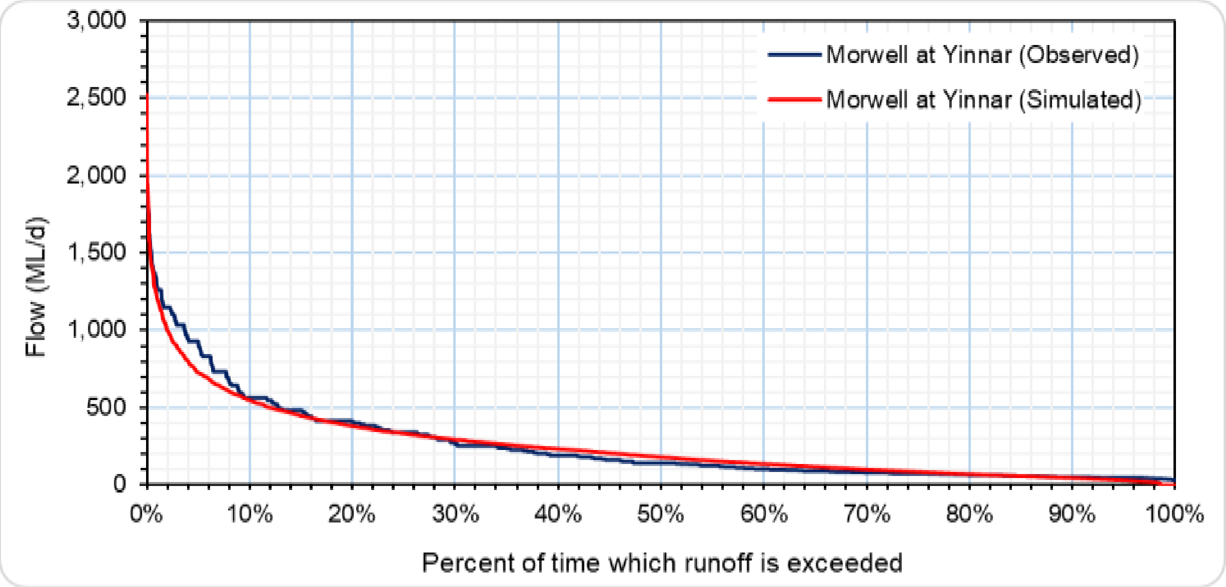

Figure 4-11: Flow duration curves for observed and simulated runoff

In the context of this lake water balance and water quality study, the most important factor for simulated runoff was that the annual and overall volumes were representative of the observed runoff. **Figure 4-12** presents the cumulative volume of the observed flow compared to the simulated flow. The cumulative difference in flow volume over the calibration period was 1.19 %.

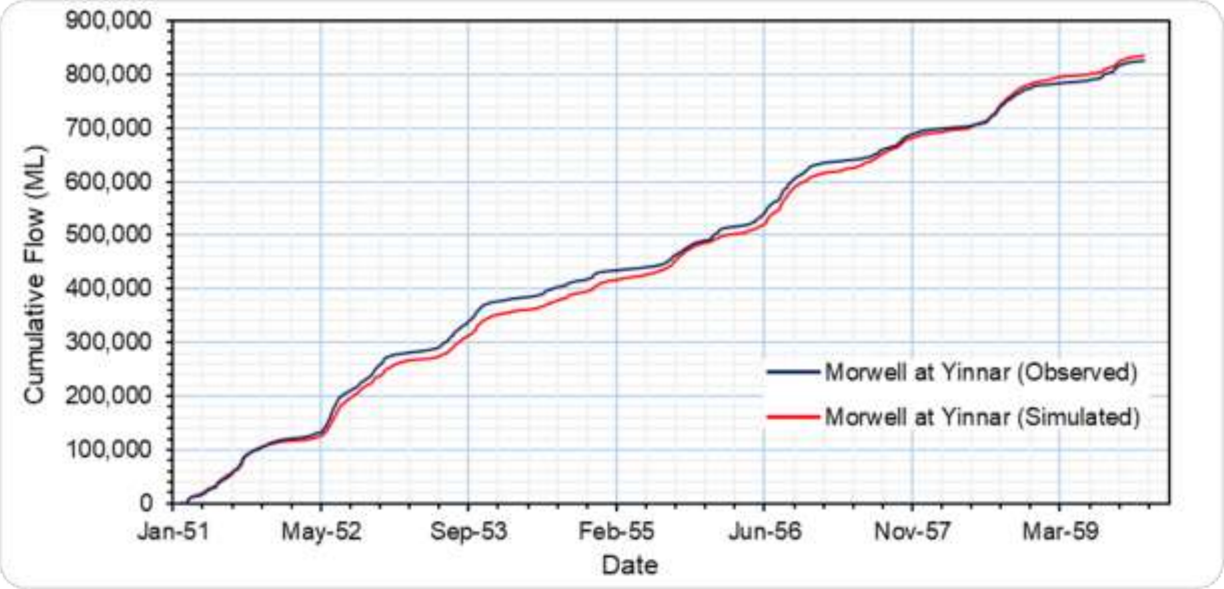

Figure 4-12: Observed versus Modelled (simulated) stream flow data for Morwell at Yinnar

In summary, the calibrated AWBM module for the Morwell catchment was considered a suitable model for use on undisturbed land use types in terms of surface runoff volume estimates. The resultant calibrated parameters for the undisturbed AWBM module are summarised in **Table 4-14**.

Note: EA are in the process of collecting site specific data which can be used in future to update the AWBM calibration.

Table 4-14: Calibrated parameters for natural undisturbed catchments-

Parameter	A_1	A_2	A_3	C_1	C_2	C_3	BFI	K_b	K_s
Calibrated Value	0.4880	0.1755	0.3365	10	100	180	0.3334	0.6915	0.9766

4.7.1.2 *AWBM hydrology modules for overburden modules*

As discussed, for all other areas including overburden, ash (capped with overburden), pit wall and floor (covered with overburden), data was unavailable to calibrate an AWBM model.

These areas have been collectively referred to as the ‘Overburden’ hydrology module. These parameters have been adapted from ACARP project C7007 (ACARP, 2001). It used a Spoil Hydrology Lumped Parameter Model (SHLPM), which is conceptually similar to the AWBM. Given the pits and overburden dumps may not be completely rehabilitated, we have selected the ACARP values for “bare dragline spoil”, presented below in **Table 4-15**.

Table 4-15: Adopted parameters for other land use types-

Parameter	A_1	A_2	A_3	C_1	C_2	C_3	BFI	K_b	K_s
Overburden	0.5	0.3	0.2	70	42.5	5	0.2^	0.95*	0.35*

Notes: ^BFI for dragline spoil (ACARP, 2001) was 0. Since the overburden dumps produce seepage (baseflow), the value has been conservatively updated to 0.2 (i.e. 20% of runoff reports as seepage which carries a different geochemical source term)
*No ACARP parameters were provided for Kb and Ks, so default AWBM values have been adopted.

4.7.2 External: Morwell River inflows

As mentioned above, the water balance of the project site (site water balance; RGS) and the whole catchment (Alluvium) have been simulated using two different hydrological models with different structures and different objectives.

A preliminary spillway design arrangement (**Figure 4-13**) was developed and assessed for the site based on a “Partially Connected Morwell” option and its potential to meet key hydrologic, geomorphic and ecological criteria outlined in *The Latrobe River system: A context statement for EnergyAustralia Yallourn to inform the rehabilitation of the Yallourn Open Cut mine* (Alluvium, 2024).

Daily estimation of flows through each of the spillways has been determined through the use of calibrated flow data from the Regional Hydraulic Modelling Assessment. Using the calibrated flow data, rating curves for each spillway have been determined and used to estimate daily flows over the spillways (for equivalent flow levels in the Morwell and Latrobe Rivers).

Stochastic flows scenarios (101 realisations) for both the dry and medium climate scenarios were run through the spillway rating curves to produce a daily timeseries of flows over the spillways for each model scenario.

These flow series were provided to RGS to use as inputs to the Goldsim model in lake modelling. An example of the data is provided for a single realisation in **Figure 4-14**.

Figure 4-13: Spillway locations.

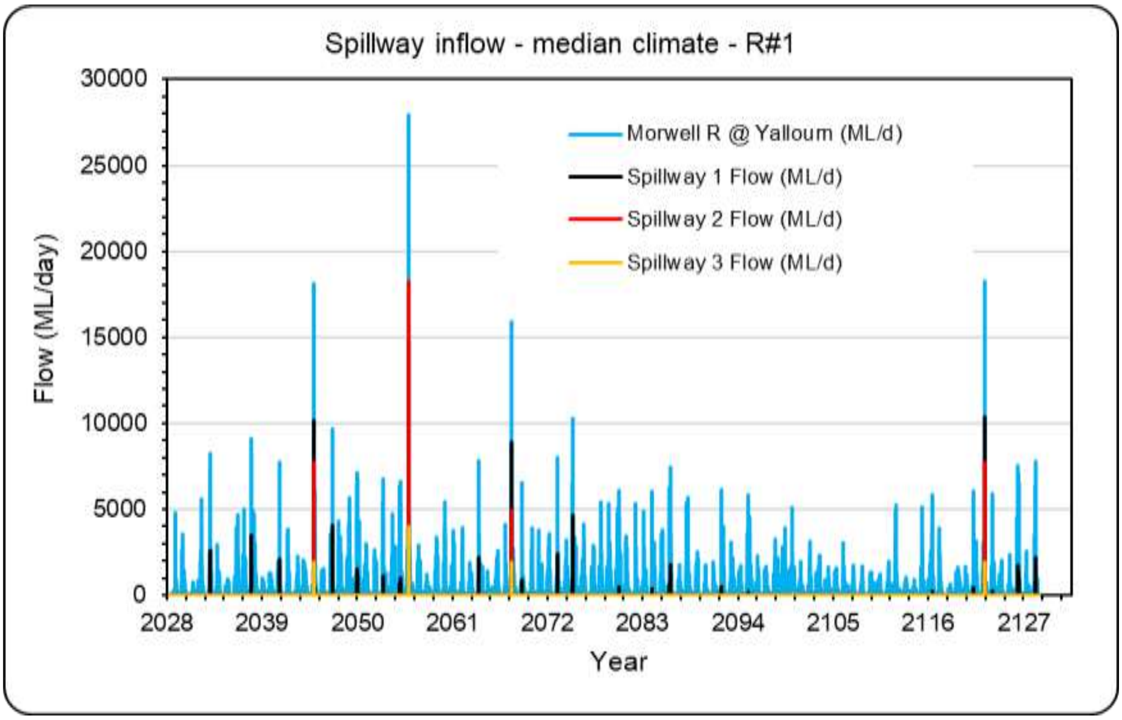

Figure 4-14: Spillway inflow data (Median climate) for Realisation #1 (of 101) (generated by Alluvium).

4.7.3 Tunnel transfer

Existing conveyor tunnels EL210, EL310 and EL410 will be retrofitted with 1.6 m diameter high density polyethylene (HDPE) pipes to transfer water between the YTF and YEF lakes. The balance of the existing cross-sectional area will be backfilled with impermeable material. Transfer will be activated when lake levels reach the conveyor levels shown in **Table 4-16**.

Table 4-16: Tunnel transfer elevations

Conveyor ID	Start transfer RL (mAHD)
EL210	17
EL310	13
EL410	12

Alluvium provided a rating table defining the tunnel flow rate versus lake elevation difference, shown in figures **Figure 4-15** to **Figure 4-17**.

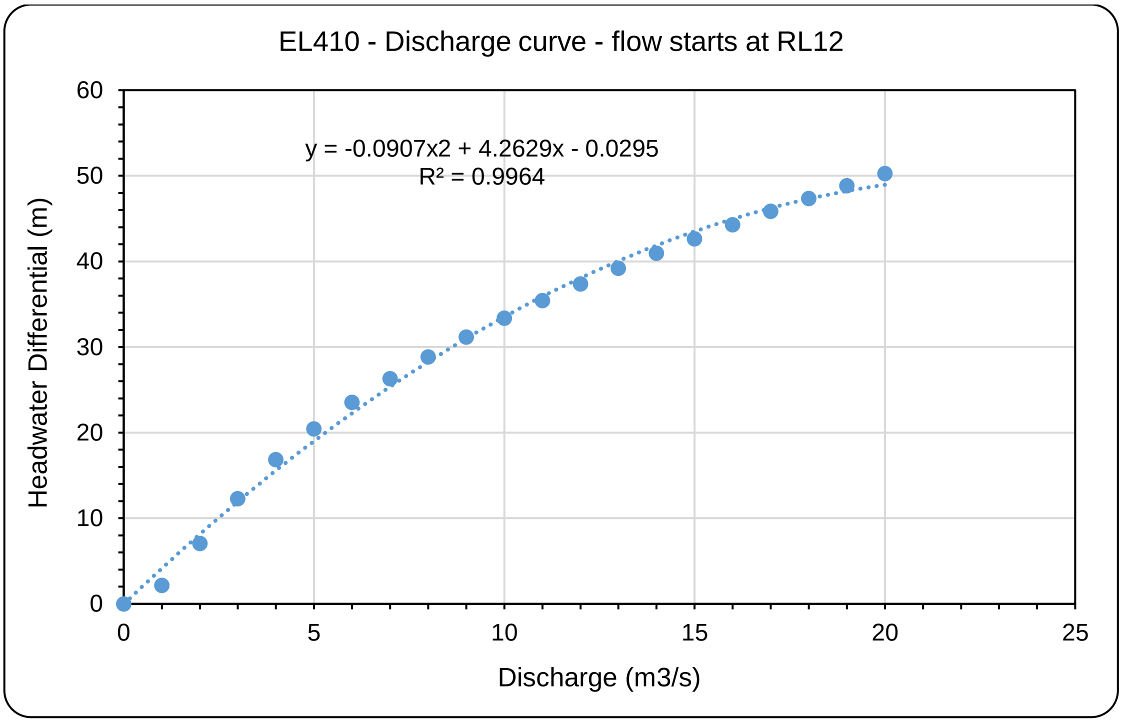

Figure 4-15: Tunnel EL410: Flow rate versus lake elevation

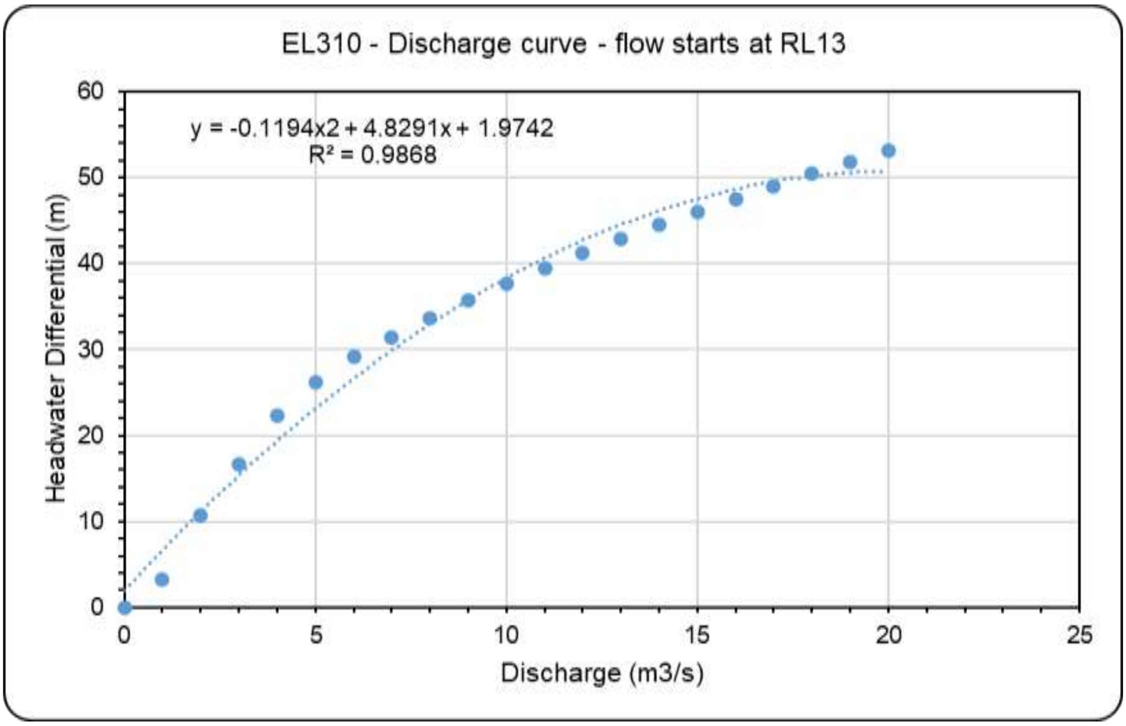

Figure 4-16: Tunnel EL310: Flow rate versus lake elevation

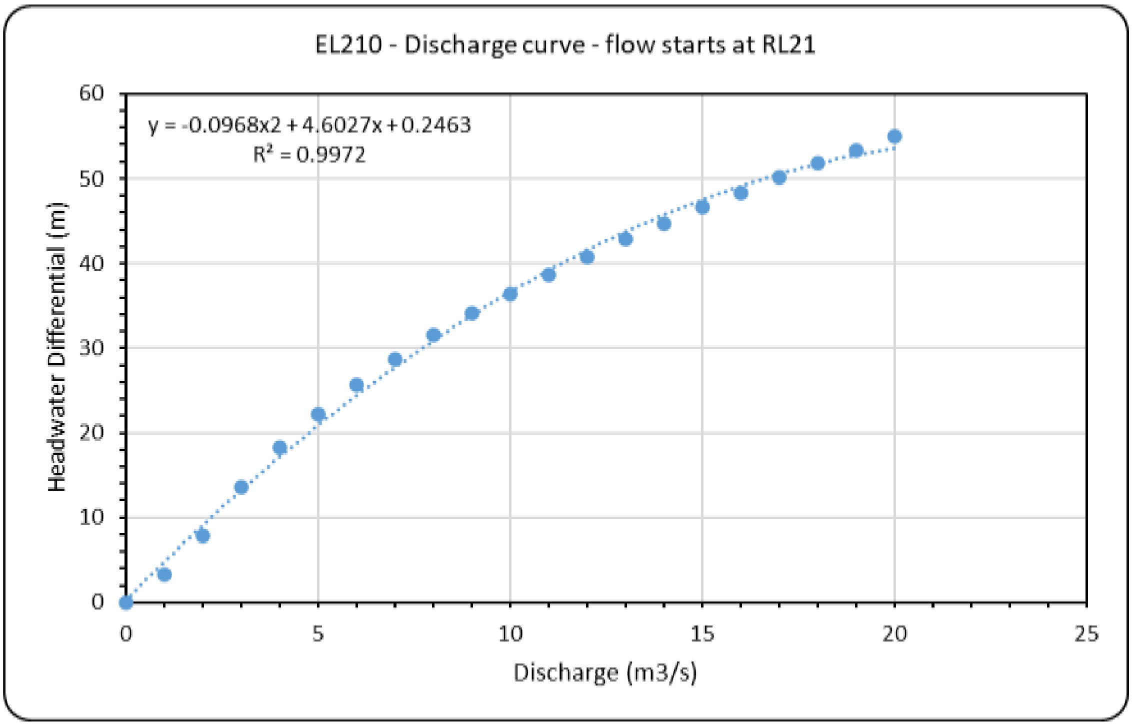

Figure 4-17: Tunnel EL210: Flow rate versus lake elevation

4.8 Groundwater

The conceptual groundwater model extends beyond the extent of the pit shells and is specifically excluded from the RGS scope of work. The conceptual groundwater model outputs were provided by GHD (GHD, 2025).

Groundwater inflow rates into each of the pits were generated and provided to RGS as time series groundwater fluxes generated in the groundwater model under a certain set of hydrodynamic boundary conditions, including complete fill of the lake to +37 m RL. The provided groundwater fluxes into and out of the pits/ lakes were a time series with quarterly timesteps. Fluxes in and out were provided for six different aquifers/geological formations:

- Haunted Hills Formation (L1)
- Yallourn Coal (L2)
- Yallourn Coal (L3)
- Yallourn Coal (L4)
- Yallourn Coal (L5)
- Yallourn Interseam (L6)

The GoldSim model has daily timesteps and so the GHD groundwater inputs needed to be broken down from quarterly fluxes to daily fluxes. The implementation in GoldSim assumed a linear interpolation of the fluxes between the provided 90-day periods.

The groundwater fluxes (inflow and seepage) generated by GHD for the base case scenario are presented for the YTF and TEF in **Figure 4-18** and **Figure 4-19**, respectively.

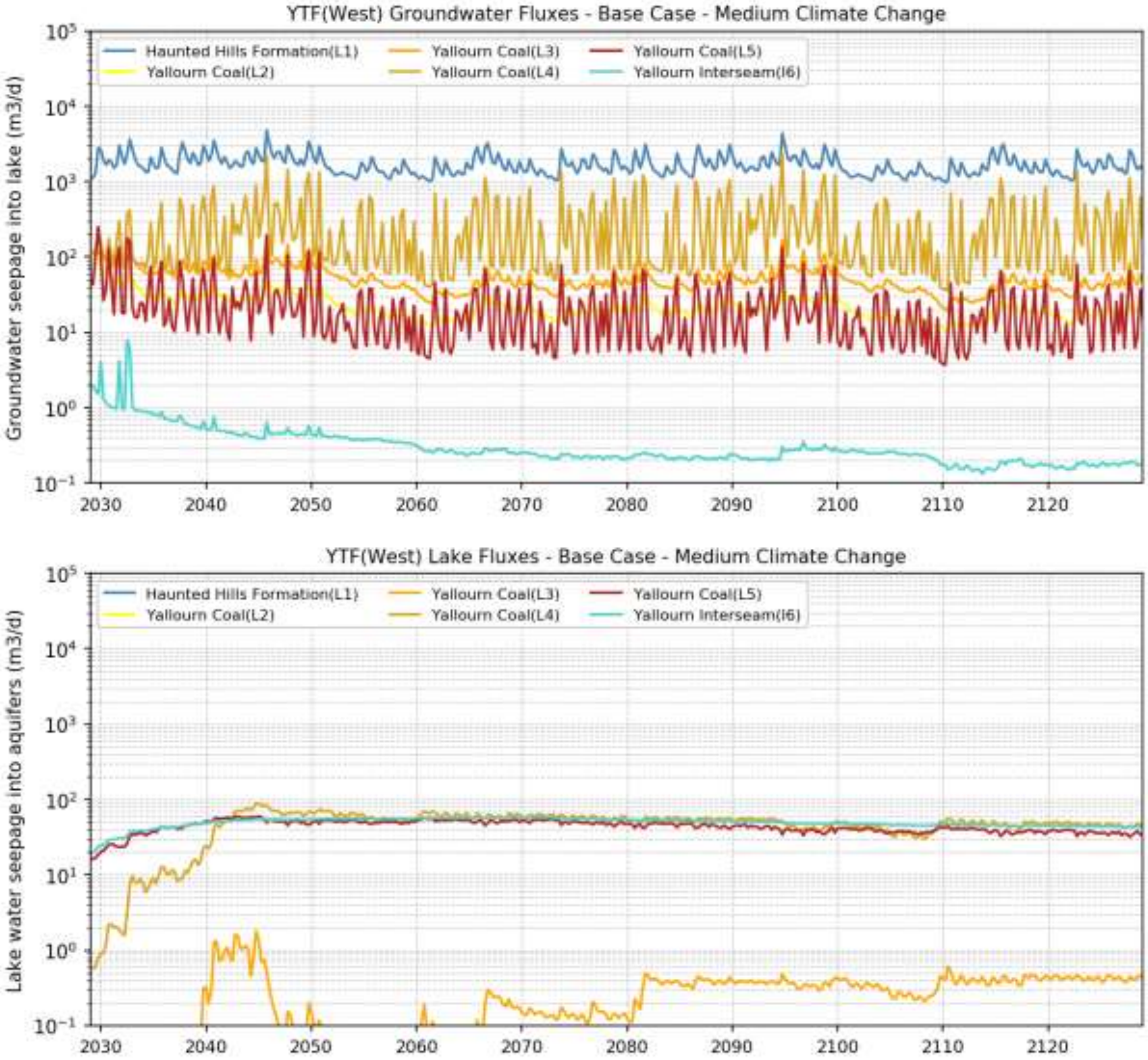

Figure 4-18: Groundwater inflow and outflow (seepage) from YTF base case scenario (from GHD, 2025)

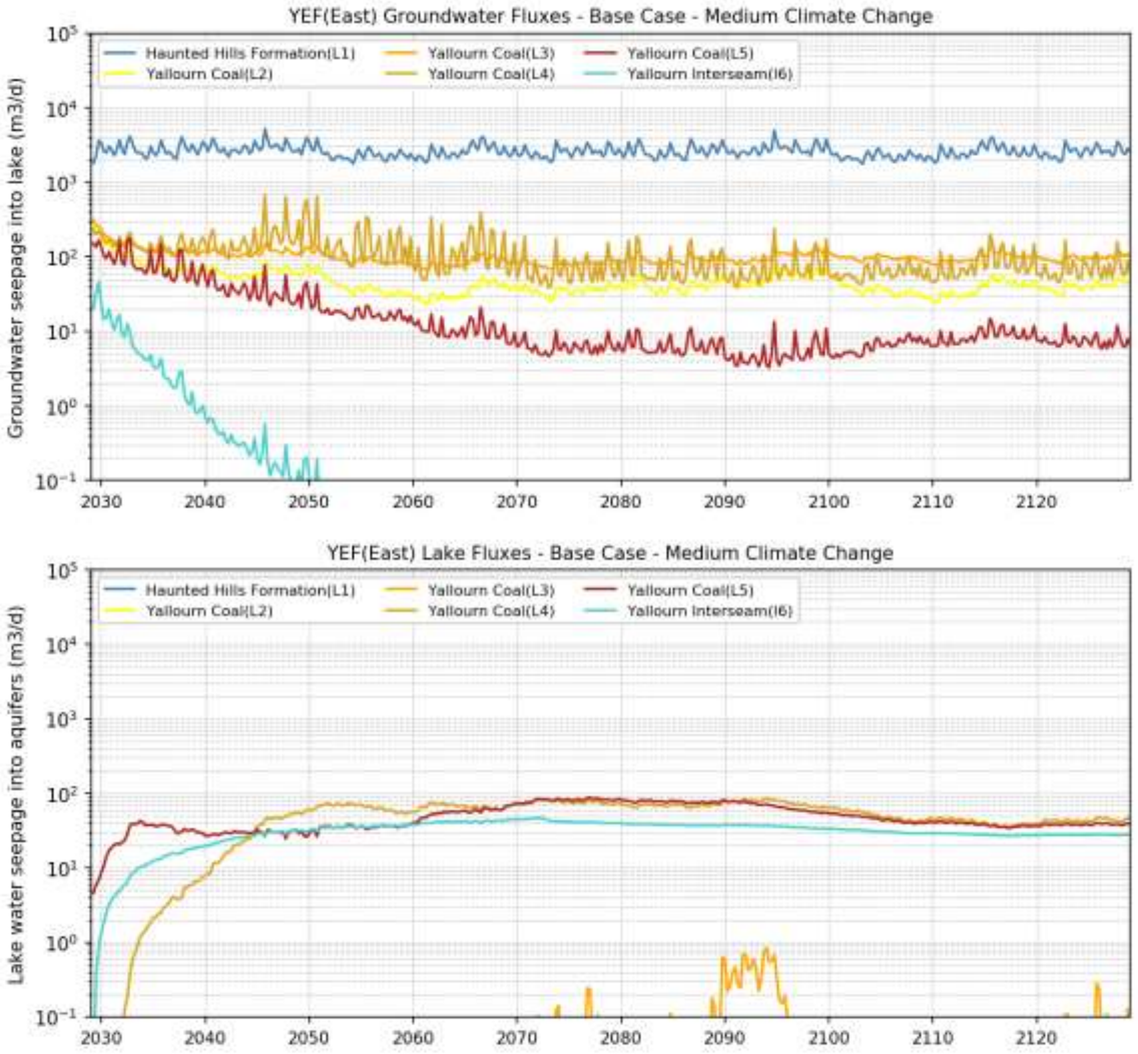

Figure 4-19: Groundwater inflow and outflow (seepage) from YEF base case scenario (from GHD, 2025)

4.9 Water quality components of model

4.9.1 General Approach

The general approach to simulating water quality within the model for each scenario includes:

- Determination of the exposed/ saturated pit wall, overburden dump and water volumes in each (daily) time step of the simulation;
- Addition of dissolved loads added to the system through direct rainfall, groundwater inflows, surface water runoff (including pit wall runoff) and ash/ overburden dump reactions;
- Addition of mass load from the MRD spillways (for select scenarios);
- Mixing of loads and volumes to determine mass balance concentrations;
- Calculation of water losses via evaporation, groundwater, outflow and other losses with distributed dissolved mass loss; subsequent mass additions and water balance considerations;

- Recalculation of lake(s) quality progressively (daily) over the duration of model simulation (100 years); and,
- Selectively apply geochemical controls (e.g. mineral solubility, atmospheric equilibrium).

4.9.2 Geochemical Source Terms

The source terms (geochemical inputs) are used in the WB/WQ model to estimate how the lake(s) water quality may evolve over time. The source terms have been generated from a combination of inferred, assumed and measured data. The general data used to derive the source terms is provided in **Table 4-17**.

Surface water and groundwater quality source terms were generally developed from historical site monitoring data. Seepage water quality for each of the overburden dumps and the Former Ash Ponds was inferred from measured groundwater data collected from bores installed in each of the dumps/ ash pond. Pit wall and overburden dump runoff water quality was inferred from wall washing experiments conducted on site (**Section 2.6.3**) (RGS, 2024).

When water quality data was below instrumental detection limits, concentrations equal to half the detection limit were applied to the source terms. As part of the quality assurance and quality control (QA/ QC) process unit errors were corrected, and in some cases spurious results were deleted.

Median water quality data was applied to the model; however, the option of applying the 95th percentile is included in case of sensitivity analysis.

Some metals and metalloids may become significantly diluted in flood waters during high-rainfall (flood) events, while nutrients tend to be higher (**Figure 4-20)**. For the Morwell River flood flow input, the median value was conservatively used in the model.

The historical groundwater measurements are missing sodium (Na) from the analysis suite, so a value 2/3 of the chloride concentration is applied in the model, this can be updated in future iterations of modelling.

Since pH is on a logarithmic scale, pH was converted to H^+ so that median and 95th percentile could be calculated for source term inputs.

The source terms for natural land runoff were conservatively inferred using median Rifle Range Gully data and Latrobe River water (Location Y97).

Table 4-17: Geochemical data to derive source terms-

Type	Water Quality Input	Type	Description
Direct Precipitation	Rainfall	Measured water quality	Measured site rainfall measurements 14/06/2022 and 12/10/2022.
Pit fill and top-up potential waters	Latrobe Water (fill and top-up)	Measured (routine monitoring)	L'trobe River @ old Yall Pumphouse.
	Moondarra Reservoir (Gippsland Water)	Measured	Moondarra Offtake (1 – 4) & Pipeline. Measured tap water (Gippsland water) and Moondarra Reservoir.
	Pumped Groundwater (fill and top-up)	Measured (routine monitoring)	M1A aquifer (sampling bores N5056 and N6899).
Surface Water	Morwell River (flood flows)	Measured (routine monitoring)	Morwell River @ Pump House.

Type	Water Quality Input	Type	Description
	Natural catchments (Catchment 1, 2, 3, 4 and 5)	Inferred (routine monitoring)	Combination Rifle Range Gully and Yallourn River water (sampling location Y97).
	Lake (starting water quality)	Measured (routine monitoring)	Combination of Fire Service Pond, Floc Pond and Lake Placid.
Groundwater (flux)	Haunted Hill Formation (HHF) groundwater	Measured (routine monitoring)	HHF shallow aquifer (YTF): monitoring bores - (N6904, N7156, (N5207, N6656). HHF shallow aquifer (YEF): monitoring bores - (N7043, N5207, N6656).
	Yallourn Coal	Measured (routine monitoring)	Yallourn Coal (YTF): monitoring bores - (N6904, N7156). Yallourn Coal (YEF): monitoring bores - (N7043).
	Yallourn Interseam	Measured (routine monitoring)	Yallourn Interseam (YTF): monitoring bores - (N6713, N6722, N6904, N7156). Yallourn Interseam (YEF): monitoring bores - (N6815).
Seepage/ runoff water quality	Seepage Catchment A: SOB Dump	Measured (routine monitoring)	Shallow groundwater bores: (N7430, N7428).
	Seepage Catchment B: NOB Dump	Measured (routine monitoring)	Shallow groundwater bores: (N7426, N7425).
	Seepage Catchment D: Former Ash Ponds	Measured (routine monitoring)	Shallow groundwater bores: (N7450, N7452, N7449).
	Seepage Catchment E: Midfield Dump	Measured (routine monitoring)	Shallow groundwater bores: (N7431, N7433).
	Catchment G and H: Eastfield Dump	Measured (routine monitoring)	Shallow groundwater bores: (N7442, N7438).
	Runoff/ baseflow Catchment C: Fire Service Pond & Floc Pond batters	Inferred pit wall experiments	Wall wash experiment data for three sites (2 weathered coal wall & 1 overburden wall; fire service pond & floc pond batters).
	Runoff Catchment A, B, D & E (overburden dumps)	Inferred pit wall experiments	Wall wash experiment data (overburden wall); Southern overburden batters.
	Runoff/ baseflow Catchment F: Latrobe River and Northern batters	Inferred pit wall experiments	Wall wash experiment data for two sites (2 weathered coal); Latrobe River and Northern batters.
	Runoff/ baseflow Catchment I: Maryvale Field	Inferred pit wall experiments	Wall wash experiment data for two sites (1 weathered coal; 1 fresh coal); Maryvale field floor.

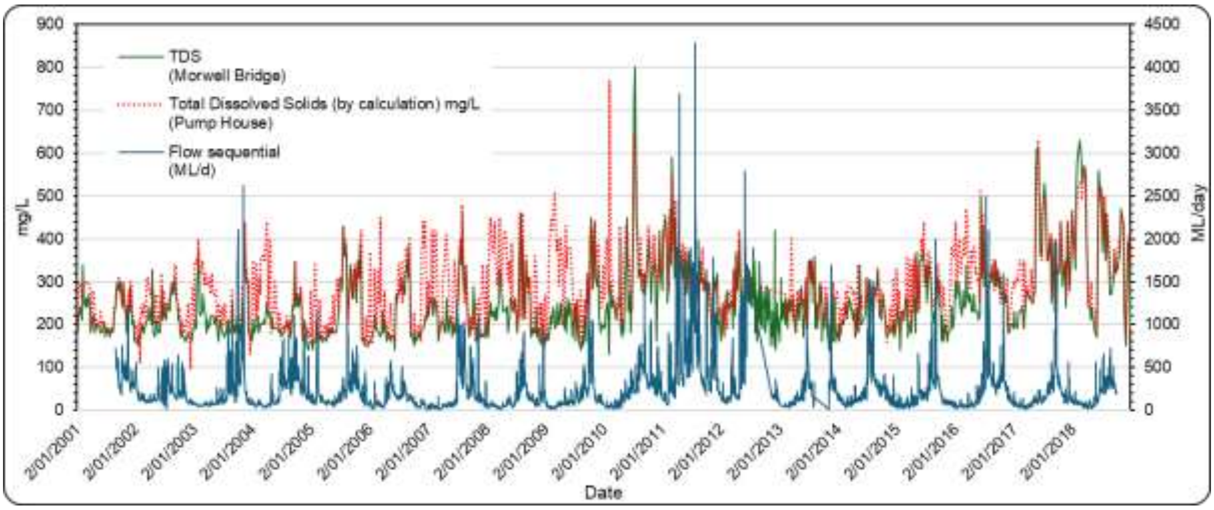

Figure 4-20: Morwell River flow (Yallourn) versus measured TDS (mg/L)

4.9.3 Key water quality inputs

The median hydro-chemistry values of the key water inputs are provided in **Table 4-18** against the assessment criteria (i.e. the revised Australian and New Zealand Guidelines for fresh and marine water quality guidelines – freshwater aquatic ecosystem (95% species protection) and livestock drinking water guidelines (ANZG, 2018), as well as the Australian Drinking Water Guidelines (ADWG) (NRMMC, 2011)) (refer to assessment criteria in **Section 5**).

Comparison of the key water quality inputs against the assessment criteria highlights that a number of the parameters exceed the fresh and marine water quality guidelines – freshwater aquatic ecosystem (95% species protection) (namely median Al, Cu, pH, Ni and Zn), while median Pb and Mn exceed the ADWG guidelines for some of the runoff and seepage qualities (not shown). One input (catchment A, B, D & E runoff) exceeds the livestock drinking water guidelines for Al.

Table 4-18: Median key water quality inputs against assessment criteria

Parameter	Assessment Criteria				Fill & top-up	Fill & top-up	Spillways	Groundwater					
	ADWG	Aquatic Ecosystem (95% species protection)	Livestock Drinking Water Guideline	Rainfall	Latrobe River	Moondarra Reservoir	Morwell River	HHF (YTF)	YCoal (YTF)	Yintsm (YTF)	HHF (YEF)	Ycoal (YEF)	Yintsm (YEF)
Aluminium (mg/L)	-	0.055	5	0.005	0.27	0.17	0.26	0.068	0.13	0.07	0.25	0.5	0.46
Arsenic (mg/L)	0.01	0.024	0.5	0.0005	0.0005	0.0005	-	0.00025	0.00025	0.00025	0.00025	0.00025	0.0005
Barium (mg/L)	2	-	-	0.002	0.0435	0.019	-	0.17	0.026	0.065	0.2	0.07	0.087
Boron (mg/L)	4	0.37	5	0.15	0.0155	0.025	-	0.0105	0.0085	0.006	0.01425	0.016	0.014
Cadmium (mg/L)	0.002	0.0002	0.01	0.00005	0.00005	0.00007	0.00005	0.00002	0.00002	0.00002	0.00003	0.00005	0.000025
Calcium (mg/L)	-	-	1000	0.5	4.6	1.7	11	7.04	0.58	1.68	7.8	2.2	2.5
Chloride (mg/L)	-	-	-	4	39	11	85	90	50	71.5	135	140	110
Chromium (mg/L)	0.05	0.001*	1	0.001	0.0005	0.0007	0.0005	0.00025	0.00025	0.00025	0.00052	0.0008	0.0007
Copper (mg/L)	2	0.0014	1	0.0005	0.001	0.0005	0.002	0.003	0.006	0.003	0.0005	0.0005	0.002
Fluoride (mg/L)	1.5	-	2	0.05	0.05	0.41	0.1	0.1	0.05	0.05	0.1	0.05	0.1
Iron (mg/L)	-	-	-	0.025	0.51	0.42	0.4	3.18	0.04	0.08	3.24	0.16	4.1
Lead (mg/L)	0.01	0.0034	0.1	0.0005	0.0005	0.0005	0.0005	0.0003	0.0005	0.0004	0.0002	0.0003	0.0002
Magnesium (mg/L)	-	-	-	0.5	4.6	1.45	11	12.4	3.95	6.2	13.2	5.4	5.7
Manganese (mg/L)	0.5	1.9	-	0.0005	0.025	0.011	0.013	0.28	0.005	0.02	0.29	0.03	0.16
Mercury (mg/L)	0.001	0.0006	0.002	0.00005	0.00005	<0.0001	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005
Molybdenum (mg/L)	0.05	-	0.15	0.001	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Nickel (mg/L)	0.02	0.011	1	0.0005	0.001	0.0005	0.001	0.002	0.003	0.0036	0.0012	0.0013	0.0014
pH	-	6 to 9	-	5.3	7.1	6.6	7.3	5.4	4.7	4.9	5.7	5.2	5.3
Potassium (mg/L)	-			0.5	2.2	0.7	3.7	1.0275	0.255	0.5	1.5	1.2	1.2
Selenium (mg/L)	0.01	0.011	0.02	0.005	0.0005	0.0025	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Sodium (mg/L)	-	-	-	2.5	19.5	11.9	53	59.4	33	47.1	89.1	92.4	72.6
Sulfate (mg/L)	-	-	1000	0.75	5	2.5	31	7	7.5	9	10.25	14	39
Total Alkalinity as $CaCO_3$ (mg/L)	-	-	-	1.75	22	9	43	168	7	14	176	23.5	26
TDS (mg/L)	-	-	4000	28.4	110	35	270	332	159	225	435	365	352
Zinc (mg/L)	-	0.008	20	0.044	0.0025	0.002	0.0025	0.036	0.039	0.075	0.029	0.025	0.035

*Note: chromium guideline applicable to Cr^{6+} species and applied in the table to total (i.e. Cr^{6+} and Cr^{3+}).

Note: Mercury is included in the table but not modelled because it is below instrumental detection limits. Mercury was not included in the analysis suite for rainfall and wall washing.

4.9.4 Contaminant transport module

The water quality components of the model are simulated using the contaminant transport module in GoldSim. For each water source (including local rainfall and runoff sources, external fill sources and groundwater flux sources), a cell pathway was used to simulate the loading rates. All Cell pathways were constructed as vectors referencing the array of chemical species. This means that for each input source, one cell pathway element was used to simulate the transport of all modelled species.

Loading rates in the Cell pathways were calculated as follows:

Source terms (Vector of 32 species) [mg/l] x inflow rate [kg/d] = loading rate (kg/d)

4.9.5 Geochemistry inputs

The model has the capacity to simulate 32 species which are defined within the materials container of the model, in the species element. The list of species which has been programmed into the GoldSim model is in **Table 4-19**.

Geochemistry source term data for each of these species is then imported into the model directly from a spreadsheet file *WQ inputs.xlsx.* This file must be located with the same folder directory as the GoldSim model file in order for the model to run. This means that the geochemistry source terms can be easily updated in subsequent stages of work and read straight into the model whilst minimising additional programming within the GoldSim model.

Source terms are read into a spreadsheet element in the GoldSim model, which translates the data into a GoldSim element. A number of selectors are then used to determine which source term datasets will be used based on which geochemistry scenarios have been selected (i.e. average or 95th percentile).

Table 4-19: List of water quality species simulated in GoldSim model

Array number	Parameter
1	Acidity as $CaCO_3$
2	Aluminium
3	Arsenic
4	Barium
5	Placeholder
6	Boron
7	Cadmium
8	Calcium
9	Placeholder
10	Chloride
11	Chromium
12	Cobalt
13	Copper
14	Fluoride
15	H+
16	Placeholder
17	Iron
18	Lead
19	Magnesium
20	Manganese
21	Molybdenum
22	Nickel
23	Placeholder
24	Potassium

Array number	Parameter
25	Selenium
26	Sodium
27	Strontium
28	Sulfate
29	TDS
30	Placeholder
31	Total Alkalinity as $CaCO_3$
32	Zinc

4.9.6 Thermodynamic constraints and atmospheric equilibrium

Consideration of thermodynamic constraints (mineral solubility) and atmospheric equilibrium are incorporated in the WB/WQ modelling results. The median (50th percentile) mass balance water quality outputs from the GoldSim model were used as input to PHREEQC (Parkhurst and Appelo, 2013).

PHREEQC allows for the inclusion of equilibrium reactions based on the lake quality and mineralogy (**Figure 4-21**); the interaction of water and material (e.g. pit wall) may involve dissolution and precipitation of minerals (based on mineral solubilities), which is influenced by factors such as pH and pe (redox) variations.

The PHREEQC model compares modelled pit water body data with theoretical solubility limits of a number of minerals (within the *minteq.v4.dat* database[5]) under different conditions (e.g. variations in pH, redox and temperature). The saturation index (SI) of a mineral is calculated, under these conditions. The SI value of a particular mineral is indicative of whether a mineral will tend to precipitate or dissolve. If the SI value is negative, then the mineral is undersaturated in solution and therefore may dissolve, or if already in solution, remain dissolved. However, if the SI of a mineral is positive, then the mineral is supersaturated and likely to precipitate out of solution (i.e. in the lake); these dissolution/precipitation reactions will affect concentrations of elements in the lake and will become particularly important if the effects of evapo-concentration in the lake are significant enough to concentrate elements to saturation state.

PHREEQC modelling can also be used to equilibrate the lake with atmospheric conditions ($pCO_2 = 10^{-3}$ atm). For example, groundwater pCO_2 is orders of magnitude higher than atmospheric air values; therefore, when groundwater mixes with the lake and is exposed to surface conditions, the water will release CO_2 gas to the atmosphere. This results in the pH of water rising due to loss of carbonic acid.

PHREEQC allows for adsorption of aqueous chemical species to iron (oxy)hydroxide based on a diffuse double layer surface complexation model (Dzombak & Morel, 1990). This can be linked to modelled precipitation of the mineral phase ferrihydrite ($Fe(OH)_3$) from solution.

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[5] Mo and Cd species are not part of this database; however, the concentration of these species is low and not likely to be mineralogically constrained. This is conservative as in reality they may be mildly constrained and/or adsorbed to iron (oxy)hydroxides.

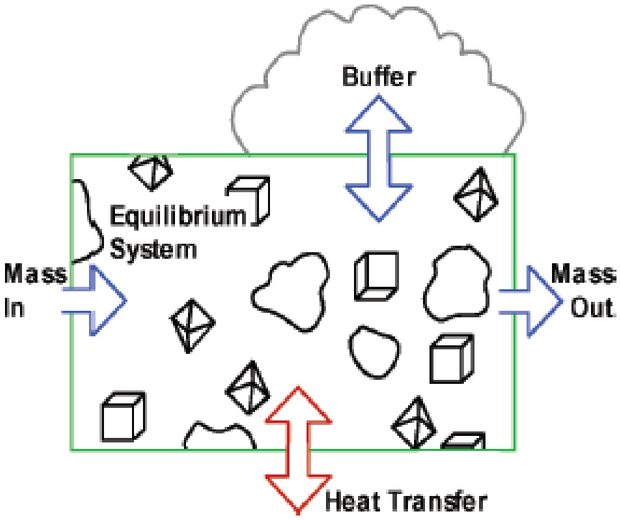

Figure 4-21: Conceptualisation of the geochemical processes considered in PHREEQC

4.9.7 Diffusion modelling

Diffusive mass transport between the submerged features (overburden and ash dumps, pit walls and floor) and lake(s) were modelled in the GoldSim WB/WQ model.

Diffusive mass flux links are used to transport mass through a stagnant or slowly moving fluid via the process of molecular diffusion. Diffusive mass transport is driven by (in fact, proportional to) a concentration difference, with mass diffusing from high concentration to low concentration. The constant of proportionality is referred to as the *diffusive conductance*:

Diffusive Mass Rate = (Diffusive Conductance) x (Concentration Difference)

In this equation, the Diffusive Mass Rate has dimensions of mass/ time, the Diffusive Conductance has dimensions of volume/ time, and the Concentration Difference has dimensions of mass/ volume.

The diffusive conductance is a function of the properties of the species and fluids involved, and the geometry of the diffusive process.

Assuming that the species are diffusing through a single fluid (water), the Diffusive Conductance term is computed in GoldSim as follows:

D = (Ad t n r) / L

where:

D is the Diffusive Conductance (L3/T);

A is the diffusive area (L2);

d is the diffusivity in the fluid (L2/T);

n is the porosity of the porous medium;

t is the tortuosity of the porous medium;

r is a reduction factor to account for the degree of saturation (1 if saturated);

L is the diffusive length (L).

The key assumptions made in the diffusion models include the following:

4. The diffusive area between the in pit feature (i.e. pit walls/ overburden dumps/ Former Ash Pond cap) and the lake is equal to the submerged surface of the feature, which is calculated in daily time-steps. In general, for the modelled scenarios involving a full lake (water level at or around RL+ 37 m AHD), the majority of the in-pit features (excluding the SOB Dump) is always completely saturated past the initial pit filling time. During the pit filling time, the diffusive area increases as lake level rise (i.e. diffusion will only occur through the saturated zone).
    - The diffusivity of the fluid (water) was set to default water self-diffusion coefficient of $1e^{-9}$ m^2/s
    - The porosity of overburden and coal materials was set to 30% (Durie, 1991) for both diffusivity conductance calculations and calculations of saturated pore volume of overburden or coal subject to diffusion. Coal ash material porosity was set to 40% (Mudd, 2000).
    - Bulk density of overburden use default values for sandy clay, while ash use 0.5 g/cm^3 (Mudd, 2000) and coal 1.5 g/cm^3 (Durie, 1991).
    - The tortuosity quantifies the degree to which diffusion is slowed down due to the tortuous path that a diffusing species must travel as it moves through the pore space. The tortuosity of the in-pit features (pit walls, overburden dump and Former Ash Pond cap) pore space was set to 1, which is a conservative assumption (the value can be specified as a value from > 0 to 1).
    - Only the submerged portion of the in-pit features takes account in the diffusivity calculations hence the “r” variable was set to 1. The non-submerged portion of the in-pit features, during the pit filling process contributes runoff and seepage to the lakes (refer to Section 4.7.1).
    - The diffusive length L of the in-pit features is assumed to be ten-centimetres (cm) (i.e. the distance between the feature pore water (of constant concentrations) and the lake water). This is considered conservative, since, in reality, it would be expected that the diffusion zone would be much greater than 10 cm due to a contact zone “mixing” and hence the concentration gradient between these two fluids will be significantly smaller. Similarly, it is conservatively assumed that there is no depletion of porewater concentrations.
    - For the Former Ash Ponds, the diffusive length L was assumed to represent a thickness of the cap cover (i.e. 1 m). It should be noted that no attenuation of the constituents diffusing from the Former Ash Pond to the lake (or vice versa) was modelled within the cap material, which should be considered as a conservative assumption.
5. The volume of water within the saturated in-pit features is calculated in the model as a product of feature porosity and the in-pit feature volume based on its geometry and the relationship to lake water level. The quality of water within the saturated in-pit features is set to the respective seepage/ baseflow quality and it remains constant throughout the simulation.

4.10 Lake stratification

Lake stratification was assessed separately by Hydronumerics (2025). The technical report is provided in **Attachment C** and summarised in **Section 6.2.6**.

4.11 Limitations, uncertainties and assumptions

All models estimate future conditions (e.g., physicochemical parameters) by reducing complex systems to a limited number of significant, often simplified, processes. Predicting the water qualities of complex systems requires many assumptions. Even a rigorous sampling and analysis programme cannot precisely determine all the physical, chemical, and geological characteristics of the system. Nor can they precisely indicate how these characteristics might change over time. Even though assumptions are informed by data they include an inherent level of uncertainty. As geochemical models become more sophisticated, the most important thing that gets lost is an understanding of the uncertainties associated with the predictions (Drever, 2011). While these uncertainties are generally hard to quantify, they can be recognised.

The following limitations, uncertainties and assumptions apply to this assessment:

- It should be recognised that the climate forecasting into the future will always have an associated uncertainty. However, the method adopted by RGS attempts to capture the full extent of climatic variability or uncertainty (i.e. through wet, dry and drought scenarios and stochastic modelling).
- There is uncertainty in climate change predictions, which increases the further into the future the predictions are made. However, RGS has modelled the range in potential water qualities using climate factors (linearly and straight line extrapolated past the available dataset) and stochastic modelling. The lack of climate factors beyond year 2065 is a limitation.
- Some of the AWBM modelling has been limited to the use of parameters adopted based on experience from similar assessments and literature.
- Bio-geochemical processes (e.g. nutrient cycle) and stratification are not considered as part of the RGS modelling; however, stratification is being addressed as part of a supporting assessment (Hydronumerics, 2025) (**Attachment C**).
- The groundwater flux inputs provided by GHD were limited to quarterly timesteps which were averaged into daily timesteps. The updated groundwater influx rates were calculated based on the data provided.
- This water balance water quality model was not coupled with the groundwater model for an iterative simulation (i.e. results were not passed between each model dynamically at each timestep). This means that the simulation of the water body elevation and hydrology was undertaken separately in both the WB/WQ model and the Groundwater model. This represented some duplication and overlap of a key driver of the pit water body groundwater flux estimates. Whilst best efforts were undertaken by RGS and GHD to align hydrology estimates and pit fill estimates, it is acknowledged that the model does not integrate with the groundwater modelling dynamically and iterate calculations and this may have impacted the groundwater flux estimates as well as the direct rainfall and evaporation estimates.
- Geochemical source terms are constant median values in the model. There is rarely sufficient data to identify how source terms may vary over time and whether the variation is systematic or random. This limitation is managed by assuming most source terms are constant. For declining source terms, this is a conservative assumption.
- The quality of water sources, such as groundwater, surface water, and rainwater, are the results of other complex systems (aquifer, catchment, atmosphere). While water composition can be determined in the laboratory with some accuracy, it requires a statistically relevant number of samples to establish inherent variability due to factors such as seasons, sediment movement, changes in gradient, etc. The required number of samples is only rarely obtained in practice.
- The technical feasibility of the filling and top-up was not considered by RGS.

5 Assessment criteria

Assessment criteria are used to assess the significance of an impact. For the lake water balance and water quality assessment, the key impact of concern is reduced water quality. A significant impact could eventuate if discharges from the lake (YEF) resulted in a change to the environmental values of surface water in the region. Accordingly, levels of various parameters estimated using modelling will be evaluated against criteria specified in relevant legislation and guidelines as outlined below.

The legislation and guidelines vary depending on a specified land use. Since there is currently no specified Post Mining Land Use (PMLU) for YCM. The results of the modelling will be compared to a range of water quality guidelines which will then be used to guide the PMLU.

The *Guidelines for Managing Risk in Recreational Water* have been developed by the National Health and Medical Research Council (NHMRC, 2008), with the primary aim of protecting the health of humans from threats posed by the recreational use of coastal, estuarine and fresh waters (NHMRC, 2008). For the assessment of chemical hazards, the guidelines have adopted the *Australian Drinking Water Guidelines* (ADWG) (NRMMC, 2004) to provide a point of reference for exposure through ingestion. The guidelines have since been updated in 2011 (NRMMC, 2011) and are used as one of the lake water quality assessment criteria.

The *Environment Reference Standard* (ERS) (2021) pursuant to the *Environment Protection Act 2017* outline the water quality indicators and objectives for the Victorian Central Foothills and Coastal Plains, which includes the Latrobe River basin (Table 5-1.). The ERS also references ADWG, and the revised *Australian and New Zealand Guidelines* for fresh and marine water quality guidelines – freshwater aquatic ecosystem (95% species protection; i.e. the concentration at which it is expected that 95% of species will be protected) and the recommended guidelines for livestock drinking water (ANZG, 2018). These are presented in Table 5-2.

Table 5-1 Water quality indicator and objectives for the receiving waterways as defined in the ERS (2021).

Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Dissolved Oxygen (% saturation)		Turbidity (NTU)	Electrical Conductivity (µS/cm@ 25°C)	pH (pH units)		Toxicants (Water)
75th Percentile	75th Percentile	25th Percentile	Maximum	75th Percentile	75th Percentile	25th Percentile	75th Percentile	% Protection
≤55	≤1,100	≥75	130	≤25	≤250	≥6.7	≤7.7	95

The fresh and marine water quality guidelines provide authoritative guidance on the management of water quality for natural and semi-natural water resources in Australia and New Zealand. They are therefore considered highly conservative for a pit lake assessment, but included for comparison.

The Livestock drinking water guidelines provide recommended values for biological, chemical and radiological substances that may occur in livestock drinking water. If levels of the substance in drinking water are below these values, there should be little risk of harmful effects on animal health (ANZG, 2018).

The ADWG provide a basis for determining the quality of water to be supplied to consumers in all parts of Australia; they are intended to provide a framework for good management of drinking water supplies.

These water quality guidelines are collectively used as the assessment criteria for lake water balance and water quality.

Table 5-2 Summary of key water quality trigger levels for freshwater aquatic ecosystems (95% species protection), livestock drinking water guidelines (ANZG, 2018) and Australian Drinking Water Guidelines (NRMMC, 2011).

Parameter	Unit	Australian Drinking Water Guidelines		Aquatic Ecosystem (95% species protection) Guideline	Livestock Drinking Water Guideline
		Health	Aesthetic		
Electrical conductivity	µS/cm	-		<1,000[#]	3,580[^]
Chlorophyll	mg/L			0.005	
Chloride	mg/L		250		
Sulfate	mg/L	-	250	-	1000
pH	-	6.5 to 8.5		6 to 9	-
Fluoride	mg/L	1.5		-	2
Nitrate	mg/L	-		0.7	400
TDS	mg/L	-		-	4000
Aluminium	mg/L	-		0.055	5
Arsenic	mg/L	0.01		0.024	0.5
Barium	mg/L	2		-	-
Boron	mg/L	4		0.37	5
Cadmium	mg/L	0.002		0.0002	0.01
Calcium	mg/L	-		-	1000
Chromium (III+VI)	mg/L	0.05		0.001	1
Cobalt	mg/L	-		-	1
Copper	mg/L	2	1	0.0014	1
Mercury	mg/L	0.001		0.0006	0.002
Molybdenum	mg/L	0.05		-	0.15
Lead	mg/L	0.01		0.0034	0.1
Manganese	mg/L	0.5	0.1	1.9	-
Nickel	mg/L	0.02		0.011	1
Total Nitrogen	mg/L			0.35	
Nitrate Nitrogen	mg/L			0.1	
Ammonium	mg/L			0.01	
Total Phosphorous	mg/L			0.01	
Filterable Reactive Phosphorous	mg/L			0.005	
Selenium	mg/L	0.01		0.011	0.02
Zinc	mg/L	-		0.008	20

for still water bodies only, moving rivers at low flow rates should not exceed 2,200µS/cm.

^ Calculated based on total dissolved solids (TDS) conversion rate of 0.67% of EC. TDS is an approximate measure of inorganic dissolved salts and should not exceed 2,400mg/L for livestock drinking water.

6 Modelling results

The following section reports the key findings for the scenarios (i.e. Scenario 1 to Run 6) (**Table 6-1**). These results are of an indicated level of reliability.

Table 6-1: Yallourn project scenarios and sensitivities

Scenario ID	Fill Sources (annual until reach RL + 37m AHD)	Morwell River connected?	Top-up water	Climate
Scenario 1	Local catchment flows, natural groundwater & pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing).	No	No	Median
Scenario 2	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing) & 24 GL Latrobe water.	Yes (flood flows only)	Yes	Median
Scenario 3	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing), 34 GL Latrobe water & 14 GL Moondarra water.	Yes (flood flows only)	Yes	Median
Scenario 4	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing) & 24 GL Latrobe water.	Yes (all)	Yes	Median
Scenario 5	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing) & 24 GL Latrobe water.	Yes (flood flows only)	Yes	Dry
Scenario 6	Local catchment flows, natural groundwater, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing) & 24 GL Latrobe water.	No	Yes	Median

6.1 Water balance

The water balance results are discussed below in terms of the time it takes to fill the lake(s) to the target water level (RL +37 m AHD) and the top-up volume required to maintain the lakes level. The sensitivity of the water balance to climate is also discussed.

A full summary of the modelled water balance results for each of the key contributing inflows and outflows (annual) is provided in **Attachment D**.

The greatest contributors to the lake water balance can be separated according to the ‘fill phase’ and ‘post fill phase’. The indicative annual pit inflows and outflows (minimum, maximum and median) during fill and post filling are presented in **Table 6-2** and **Table 6-3**, respectively. Note that Morwell River inflows for the connected scenarios and Latrobe water top-up is not an annual event so annual pit inflow statistics for these inputs can be misleading.

The dominant water balance inputs during the fill phase for the majority of scenarios are (in approximate order of largest volume to smallest):

- Pumped Latrobe water fill (excluding for Scenario 1).
- Morwell River flood flows (connected scenarios if these events occur during the fill phase).
- For the YEF, tunnel transfer from the YTF.
- Direct rainfall (noting this increases with time during fill as the lake surface area increases).

- Moondarra Reservoir water (Scenario 3 only).
- External catchment runoff.
- Internal catchment runoff (particularly for Scenario 1 since more features (overburden dumps, pit walls, etc.) in the pits are exposed for longer).
- Pumped groundwater.
- Groundwater (natural) inflow which is very small.

The only outflows during the fill phase occur via lake surface evaporation followed by groundwater seepage which is very small. The exchange of water from YTF to YEF is the dominant outflow for the YTF pit for all scenarios.

The dominant water balance inputs post filling for the majority of scenarios are (in approximate order of largest volume to smallest):

- Morwell River (only for Scenario 4 where the lake is fully integrated to Morwell River).
- Morwell River flood flows (connected scenarios only when these events occur)
- Conveyor tunnel transfer from YTF to YEF (note: the tunnel transfers for Scenario 4 reflect the complete mixing of the lakes after filling. This was achieved by setting a very high conveyor transfer rate between the lakes).
- Latrobe top-up water (particularly for the dry Scenario 5 and excluding for Scenario 1 which does not reach fill capacity over the simulation period; **Section 6.1.1**).
- Direct rainfall.
- External catchment runoff.
- Groundwater (natural) and internal catchment runoff is very small.

The dominant outflow post filling is evaporation, except during those years when overflow occurs via Spillway 4; this is particularly evident for Scenario 4 where the lake is fully integrated with the Morwell River so is a flow through system, with flow in approximately equalling flow out. The exchange of water between YTF to YEF is also a dominant outflow for YTF.

Groundwater outflow (seepage) is generally very small relative to the other outflows.

Table 6-2: Indicative annual pit inflows and outflows during filling

Scenario		**1**			**2**			**3**			**4**			**5**			**6**		
Statistic		**Min**	**P50**	**Max**	**Min**	**P50**	**Max**	**Min**	**P50**	**Max**	**Min**	**P50**	**Max**	**Min**	**P50**	**Max**	**Min**	**P50**	**Max**
Fill time		**NA**	**NA**	**NA**	**22.3**	**24.5**	**26.5**	**11.9**	**12.7**	**13.4**	**22.3**	**24.5**	**26.5**	**24.8**	**27.5**	**29.5**	**23.4**	**25.3**	**26.6**
Indicative annual pit lake inflows (GL)																			
Direct rainfall	YTF	0.72	2.98	5.44	1.59	5.57	10.55	1.63	4.60	10.24	1.59	4.47	11.76	1.50	4.28	9.84	1.59	4.51	11.47
	YEF	0.50	4.50	8.54	0.59	5.50	9.34	1.25	5.28	8.91	0.59	5.22	9.95	0.53	4.81	8.48	0.57	5.22	9.70
Internal catchments	YTF	0.11	1.32	4.56	0.08	0.70	3.50	0.08	1.15	3.36	0.08	0.95	3.50	0.06	0.77	3.04	0.08	0.94	3.50
	YEF	0.06	0.70	3.48	0.05	0.52	3.37	0.07	0.66	2.77	0.05	0.58	3.37	0.05	0.46	3.06	0.06	0.59	3.37
External catchments	YTF	0.14	1.63	6.55	0.31	1.70	5.84	0.39	1.82	5.08	0.31	1.76	5.84	0.25	1.30	4.76	0.31	1.75	5.84
	YEF	0.06	0.51	2.01	0.11	0.53	1.79	0.13	0.57	1.56	0.11	0.55	1.79	0.09	0.41	1.47	0.11	0.55	1.79
Groundwater inflow	YTF	0.44	0.74	1.42	0.65	0.80	1.42	0.65	0.88	1.15	0.65	0.89	1.42	0.55	0.86	1.42	0.65	0.88	1.42
	YEF	0.80	1.03	1.46	1.03	1.11	1.46	1.03	1.19	1.39	1.03	1.18	1.46	0.88	1.18	1.46	1.01	1.18	1.46
Groundwater pumped	YTF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	YEF	1.00	1.00	1.50	1.00	1.00	1.50	1.00	1.00	1.50	1.00	1.00	1.50	1.00	1.00	1.50	1.00	1.00	1.50
Conveyer transfer in	YTF	0.00	0.00	0.14	0.00	0.00	0.23	0.00	0.00	0.49	0.00	0.00	6.01	0.00	0.00	1.01	0.00	0.00	0.00
	YEF	0.00	0.83	10.74	8.01	11.93	49.57	8.07	12.62	60.61	8.01	13.22	49.57	6.03	12.73	42.81	7.57	13.03	35.44
MRD spillways	YTF	0.00	0.00	0.00	0.00	0.00	19.11	0.00	0.00	19.11	0.00	0.00	19.11	0.00	0.00	18.30	0.00	0.00	0.00
	YEF	0.00	0.00	0.00	0.00	0.00	15.59	0.00	0.00	15.59	0.00	0.00	15.59	0.00	0.00	15.24	0.00	0.00	0.00
Latrobe pumped in to first fill	YTF	0.00	0.00	0.00	23.98	23.98	24.05	33.98	33.98	34.07	23.98	23.98	24.05	23.98	23.98	24.05	23.98	23.98	24.05
Moondarra pumped in	YTF	0.00	0.00	0.00	0.00	0.00	0.00	13.99	13.99	14.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indicative annual pit lake outflows (GL)																			
Evaporation	YTF	1.68	5.22	6.78	4.39	9.50	12.16	4.85	7.36	11.95	4.39	7.62	12.17	4.41	7.92	12.54	4.38	7.71	12.15
	YEF	1.13	7.92	8.79	1.26	9.28	10.29	2.72	8.60	10.12	1.26	8.73	10.30	1.22	8.93	10.62	1.22	8.76	10.28
Groundwater seepage	YTF	0.02	0.05	0.08	0.02	0.06	0.08	0.02	0.04	0.06	0.02	0.06	0.08	0.02	0.06	0.08	0.02	0.06	0.08
	YEF	0.01	0.07	0.10	0.01	0.06	0.08	0.01	0.02	0.03	0.01	0.03	0.08	0.01	0.04	0.08	0.01	0.04	0.08
Conveyor transfer out	YTF	0.00	0.83	10.74	8.01	11.93	49.57	8.08	12.62	60.76	8.01	13.22	49.57	6.03	12.72	42.81	7.57	13.02	35.44
	YEF	0.00	0.00	0.14	0.00	0.00	0.23	0.00	0.00	0.49	0.00	0.00	6.03	0.00	0.00	1.01	0.00	0.00	0.00

Notes: *Morwell River flood inflows and outflows are not an annual event.

Table 6-3: Indicative annual pit inflows and outflows once full for each scenario

Scenario		2			3			4			5			6		
Statistic		Min	0.5	Max	Min	0.5	Max	Min	0.5	Max	Min	0.5	Max	Min	0.5	Max
Fill time		22.3	24.5	26.5	11.9	12.7	13.4	22.3	24.5	26.5	24.8	27.5	29.5	23.4	25.3	26.6
Pit lake inflows																
Direct rainfall	YTF	3.26	7.03	12.68	3.25	7.04	12.68	3.48	7.58	13.56	2.79	6.02	11.03	3.25	7.03	12.68
	YEF	2.77	5.97	10.78	2.76	5.97	10.78	2.95	6.41	11.47	2.37	5.12	9.37	2.76	5.96	10.78
Internal catchments	YTF	0.03	0.35	1.22	0.03	0.35	1.22	0.03	0.40	1.33	0.01	0.21	0.90	0.03	0.36	1.23
	YEF	0.03	0.39	1.37	0.03	0.39	1.37	0.03	0.45	1.49	0.01	0.23	1.00	0.03	0.39	1.37
External catchments	YTF	0.14	1.60	6.54	0.14	1.60	6.54	0.25	1.92	7.22	0.03	0.95	4.65	0.14	1.60	6.57
	YEF	0.06	0.50	2.01	0.06	0.50	2.01	0.10	0.60	2.21	0.02	0.31	1.43	0.06	0.50	2.01
Groundwater inflow	YTF	0.44	0.71	1.32	0.44	0.72	1.42	0.44	0.71	1.32	0.44	0.71	1.32	0.44	0.71	1.32
	YEF	0.80	1.00	1.35	0.80	1.01	1.46	0.80	1.00	1.35	0.80	1.00	1.35	0.80	1.00	1.35
Conveyer transfer in	YTF	0.00	0.00	1.12	0.00	0.00	1.13	0.00	4.58	7.73	0.00	0.06	1.22	0.00	0.00	1.13
	YEF	0.00	0.38	30.33	0.00	0.41	30.34	3.91	5.44	7.42	0.00	0.13	15.20	0.00	0.32	9.52
MRD spillways (not annual event)	YTF	0.00	0.00	30.43	0.00	0.00	30.43	0.00	0.00	0.00	0.00	0.00	15.73	0.00	0.00	0.00
	YEF	0.00	0.00	21.70	0.00	0.00	21.70	0.00	114.80	421.70	0.00	0.00	13.90	0.00	0.00	0.00
Latrobe topup after first fill (not annual event)	YTF	0.00	0.00	13.41	0.00	0.00	13.89	0.00	0.00	0.00	0.00	0.21	13.72	0.00	0.00	13.44
Pit lake outflows																
Evaporation	YTF	11.11	12.34	12.49	11.79	12.34	12.49	11.11	12.45	12.51	11.17	12.86	12.99	11.33	12.34	12.48
	YEF	9.81	10.48	10.57	10.05	10.48	10.57	9.81	10.53	10.58	9.96	10.93	11.01	9.88	10.48	10.57
Groundwater	YTF	0.04	0.05	0.07	0.04	0.06	0.08	0.04	0.05	0.07	0.04	0.05	0.07	0.04	0.05	0.07
	YEF	0.06	0.07	0.10	0.04	0.07	0.10	0.06	0.07	0.10	0.06	0.08	0.10	0.06	0.07	0.10
Conveyor transfer out	YTF	0.00	0.38	30.33	0.00	0.42	30.34	3.91	5.44	7.41	0.00	0.13	15.20	0.00	0.32	9.49
	YEF	0.00	0.00	1.12	0.00	0.00	1.12	0.00	4.59	7.74	0.00	0.06	1.22	0.00	0.00	1.13
Overflow	YEF	0.00	0.00	48.21	0.00	0.00	49.10	0.00	111.95	413.65	0.00	0.00	28.51	0.00	0.00	12.52

Notes: *Morwell River flood inflows and outflows are not an annual event.
^Latrobe top-up not an annual event
Scenario 1 (base case) not shown because it doesn't reach fill height.

6.1.1 Pit fill time

The results in **Table 6-4** show the time required to fill the lake to an elevation of RL +37 m AHD, while **Table 6-5** shows the volume of pumped water required to achieve first fill. The key results for each of the scenarios are summarised in the following points.

- Scenario 1 did not fill over the simulation period. The maximum lake elevation reached is +15.5 m AHD for both the YTF and YEF lakes (**Figure 6-1** and **Figure 6-2**).
- Scenario 2 fills between 23 and 27.4 years (mean probability 25.3 years). Scenario 5, the equivalent of Scenario 2 with dry climate, fills between 25.7 and 30 years (mean probability 28.1 years). The dry climate change sensitivity adds an additional 2.8 years (mean probability) to fill time.
- Scenario 3 fills between 12.3 and 13.5 years (mean probability 12.9 years). The faster fill time relative to Scenario 2 is due to the additional 10 GL/year Latrobe water and 14 GL/year Moondarra Reservoir water.
- Scenario 4 is essentially the same as Scenario 2 during the fil phase so fills between 23 and 27.4 years (mean probability 25.3 years).
- Scenario 6 fills between 24.4 and 27.5 years (mean probability 25.9 years). The exclusion of the Morwell River flood flows during the filling period (unlike Scenario 2) adds an additional 0.6 years (mean probability) to fill time. Noting that a large Morwell River flood event during the fill phase will affect the fill time significantly.

Table 6-4: Timeframes required to achieve the desired water level for each scenario

Scenario	Time to fill (years)					
	Mean	Min	P5	P50	P95	Max
1^	NA	NA	NA	NA	NA	NA
2	25.3	23.0	23.6	25.5	26.6	27.4
3	12.9	12.3	12.4	12.9	13.5	13.5
4	25.3	23.0	23.6	25.5	26.6	27.4
5	28.1	25.7	26.6	28.4	29.5	30.0
6	25.9	24.4	24.6	25.7	26.8	27.5

^Scenario 1 did not reach full lake elevation.

Table 6-5: Volume of pumped water to achieve first fill for each scenario

Scenario	Volume pumped water to achieve first fill (GL)					
	Mean	Min	P5	P50	P95	Max
1^	0.0	0.0	0.0	0.0	0.0	0.0
2	606.4	551.8	567.0	610.9	637.5	658.1
3	620.7	588.1	595.9	616.9	646.0	650.2
4	606.4	551.8	567.0	610.9	637.5	658.1
5	674.8	616.0	637.3	681.0	707.1	720.0
6	621.7	585.3	591.6	617.6	642.1	660.9

^Scenario 1 did not reach full lake elevation.

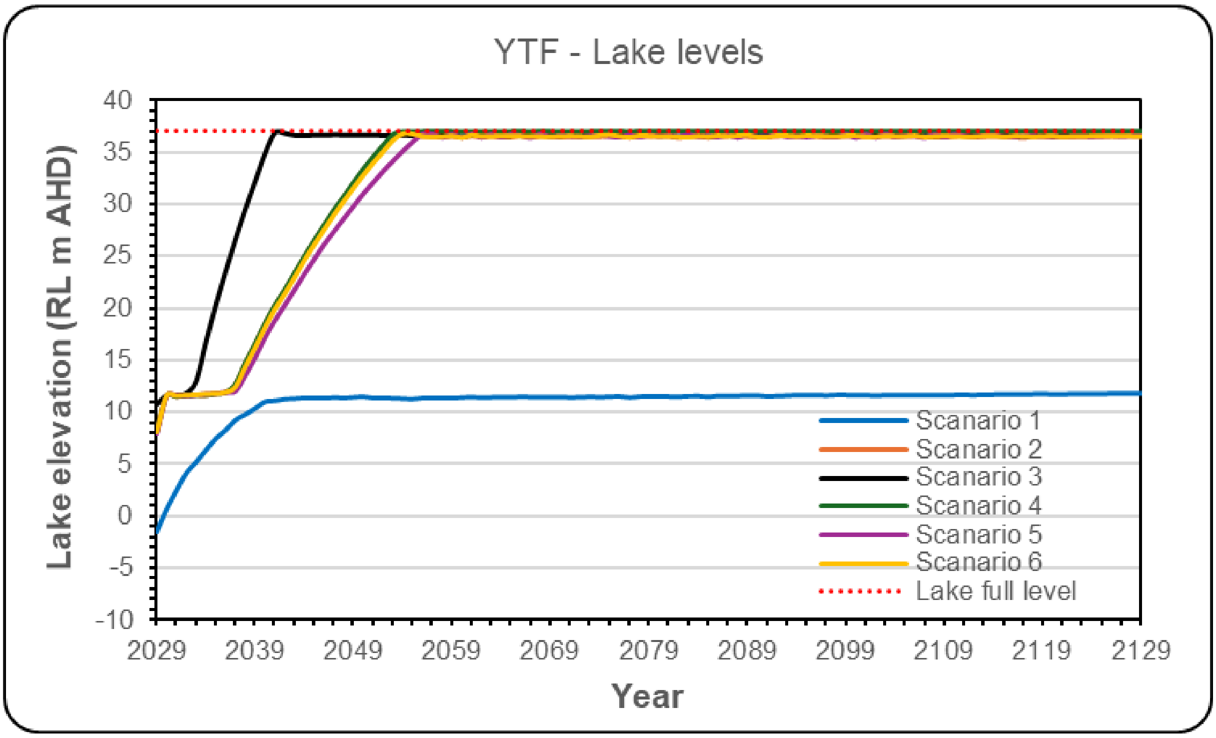

Figure 6-1: Pit lake water level for YTF (50th percentile)

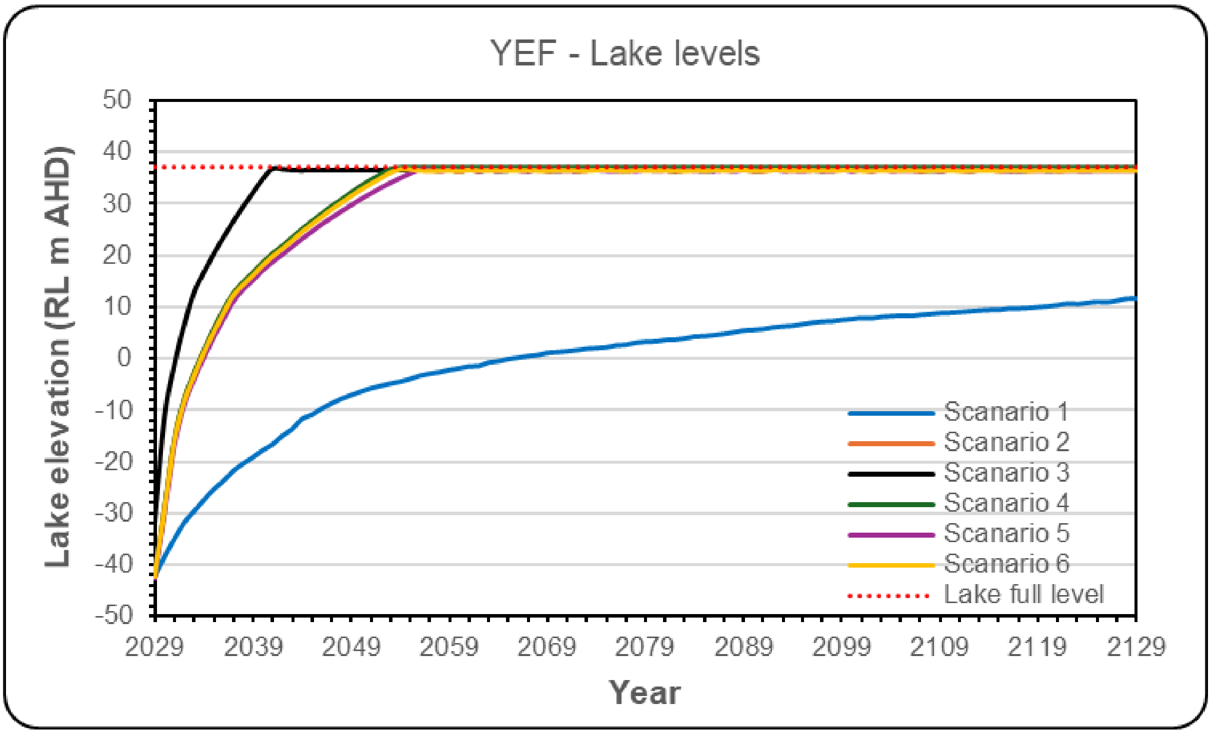

Figure 6-2: Pit lake water level for YEF (50th percentile)

6.1.2 Pit top-up volume

Pit top-up volumes are defined as the ‘on going’ inflow volumes from Latrobe water required to maintain the lake elevation at around RL +37m AHD. For all scenarios, except Scenario 1 (base case) which does not reach fill height, the top-up takes place when the pit water level falls below minimum elevation of RL +36 m and it stops when the lake reaches the maximum elevation of RL +37 m (at +37.1 m outflow to Latrobe River would occur via Spillway 4).

Table 6-6 shows the annual volume of top-up required once the pit is filled for each scenario. The frequency for top-up is not a fixed event (**Figure 6-3**), therefore **Table 6-6** can be misleading since top-up is not triggered annually (i.e. when lake level drops to RL +36 m). **Table 6-7** shows the total top-up volume required over the simulation for each scenario.

The probability of top-up results is influenced by the relatively narrow band of lake elevation within which the top-up requirement is triggered (i.e. 1 m), resulting in the need to periodically top-up the pit from external water sources. Additionally, decrease in rainfall over time, especially for the dry climate scenario, results in potential increase in annual top-up volume over time.

The only exception is Scenario 4 which is fully integrated with the Morwell River (once full) so does not require top-up over the simulation period. A further benefit of Scenario 4 is that lake levels, once full, only ever drop to a minimum of +36.5 m AHD i.e. a smaller range of lake levels compared to other post-fill scenarios.

For those scenarios that require top-up, the mean annual top-up volume varies from 2.1 to 5.1 GL/year. The climate sensitivity analysis for the preferred scenario (Scenario 2 and Scenario 5) show substantial differences for top-up requirements. For example, the mean annual top-up required in dry climate (Scenario 5), is approximately 45% more than required for the median scenario (Scenario 2) (**Table 6-6** and **Table 6-7**).

It should be noted that the requirement for top-up increases with time and reflects the expected climate change over time with predicted increased evaporation and decreased rainfall.

There is an opportunity to decrease top-up volumes by operating the top-up functionality differently. For example, allowing a freeboard would mean less water is lost via Spillway 4 if a Morwell River flood event occurs soon after a top-up event. Similarly, the top-up pumping rate will affect top-up volumes in the long term.

Table 6-6: Indicative annual pit top-up for each scenario

Scenario	Indicative annual top-up (GL) over simulation period					
	Mean	Min	P5	P50	P95	Max
1	0.00	0.00	0.00	0.00	0.00	0.00
2	2.61	2.10	2.23	2.62	2.96	3.17
3	2.73	2.34	2.41	2.71	3.05	3.14
4	0.00	0.00	0.00	0.00	0.00	0.00
5	4.66	4.13	4.35	4.66	5.00	5.10
6	2.80	2.26	2.49	2.83	3.09	3.21

Note: Scenario 1 (base case) does not reach ‘full’ elevation, so no top-up required. Scenario 4 has no provision for external top-up, relying entirely on Morwell River inflows to maintain lake level.

Table 6-7: Volume of pumped water to maintain lake water levels (post initial fill)

Scenario	Indicative top-up volume over simulation period (GL)					
	Mean	Min	P5	P50	P95	Max
1	NA	NA	NA	NA	NA	NA
2	195.0	161.6	170.6	195.5	217.4	229.9
3	237.4	205.1	211.5	236.1	263.6	271.3
4	0.0	0.0	0.0	0.0	0.0	0.0
5	334.7	307.0	319.4	333.9	352.8	357.0
6	207.7	170.8	187.8	209.9	226.2	232.4

Note: Scenario 1 (base case) does not reach 'full' elevation, so no top-up required. Scenario 4 has no provision for external top-up, relying entirely on Morwell River inflows to maintain lake level.

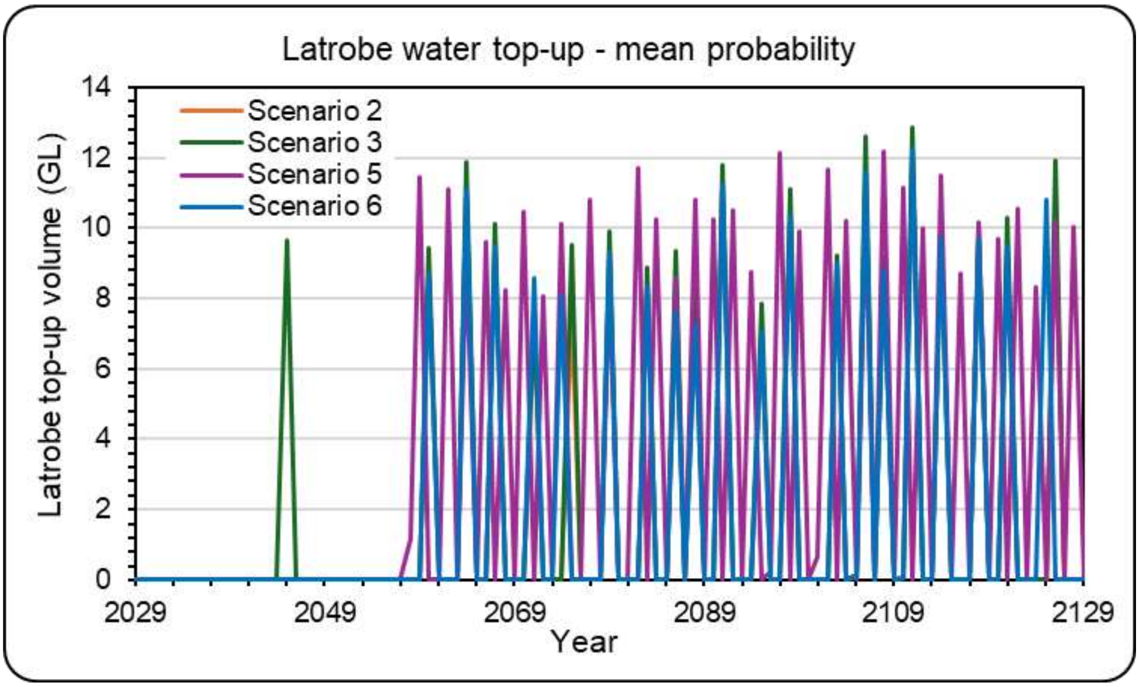

Figure 6-3: Indicative top-up required post fill for each scenario (mean probability realisation 1). Scenario 1 and Scenario 4 not shown because no top-up required.

6.1.3 Climate influence

The probabilistic scenarios applied 100 stochastic climate timeseries replicates over 100 realisations (model runs) to understand how the lake responded under climatic uncertainty, and these were run for median (Scenario 2) and dry (Scenario 5) climate sensitivities.

The probabilistic results for the pit filling timeframes and top-up volumes are presented in **Table 6-4** and **Table 6-7.** Overall, the results show that the pit fill times were sensitive to climatic uncertainty (e.g. **Figure 6-4** and **Figure 6-5** for Scenario 2). The main reason for the variation in the time to fill the pit for the probabilistic simulations is largely driven by the large contribution of Morwell River flood flows, direct rainfall and catchment runoff to the water balance which are all climate dependent. The YTF was more sensitive to climate uncertainty earlier in the model simulation (e.g. **Figure 6-4**), since the YTF lake was initially isolated from the YEF lake which was receiving Latrobe fill water. Once the lake reached the conveyor tunnel elevation and received transfer of water from YEF, the effects of climate uncertainty were smoothed.

Similarly, the required top-up volumes are also sensitive to climatic uncertainty. The required top-up volume is driven mainly by the balance between the inputs from net rainfall and runoff that the lake receives and loses from evaporation, with Morwell River flood flows affecting the balance.

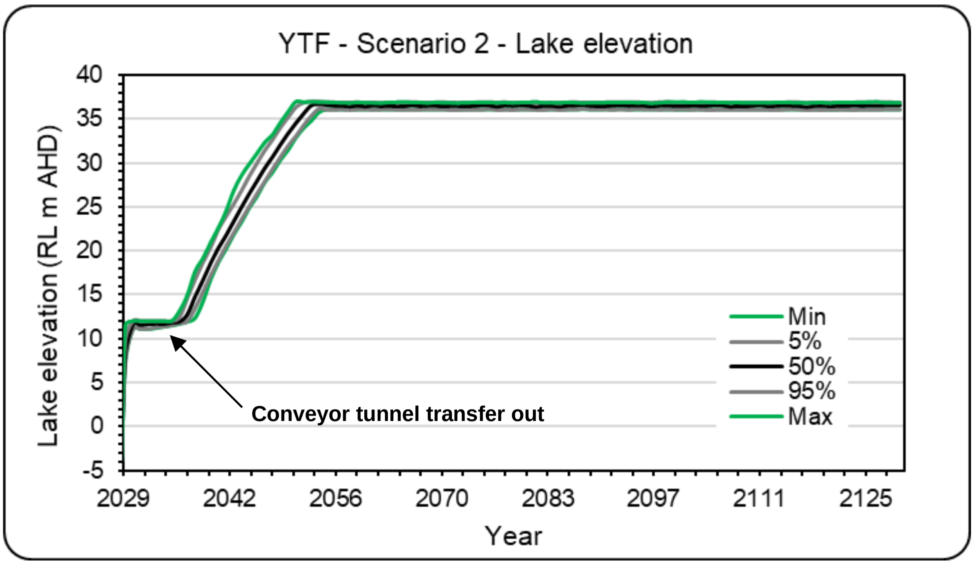

Figure 6-4: YTF modelled probabilistic lake elevations.

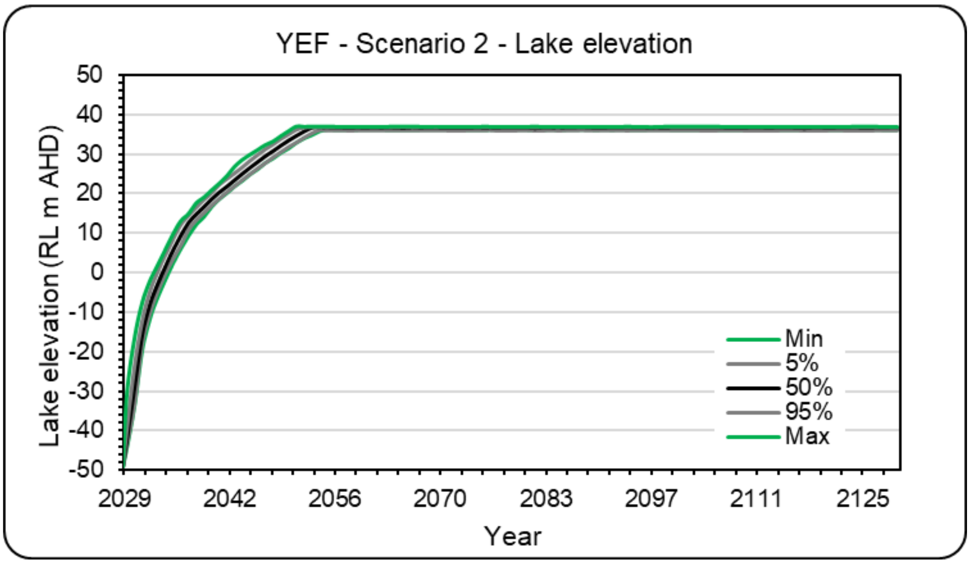

Figure 6-5: YEF modelled probabilistic lake elevations.

6.2 Water Quality

Hydrogeochemical modelling of the lakes water quality is an iterative process similar to the water balance modelling, with results for daily time steps available for the scenarios. Key results were exported from the model to summarise the key water quality results.

A full summary of the water quality results for each of the modelled deterministic scenarios and sensitivities for select years (years 5, 10, 25, 50, 75 and 100) are shown in **Attachment E**. Corresponding water quality versus time graphs are shown for each of the scenarios for each modelled water quality parameter in **Attachment F**.

The modelled concentrations presented in this and following sections are all dissolved, and total concentrations are likely to be significantly higher (due to the contributions from particulates) especially for runoff from surrounding landforms. It also needs to be highlighted that the mass balance approach does not include mineral(s) precipitation (which would reduce dissolved concentrations in the lake for chemical species associated with the precipitated mineral), so the modelled results are considered conservative.

The modelled lake water qualities are compared to the revised Australian and New Zealand Guidelines for fresh and marine water quality guidelines – freshwater aquatic ecosystem (95% species protection) and livestock drinking water guidelines (ANZG, 2018), as well as the Australian Drinking Water Guidelines (NRMMC, 2011) (refer to **Section 5**).

6.2.1 General lake water quality trend

The general water quality trends for the lakes varies for different modelled parameters and reflect the dominant water balance inputs and geochemical source terms during the fill phase (Latrobe water fill [scenario 2-6], direct rainfall, catchment runoff and Morwell River flood flows (connected only)) and post fill phases (direct rainfall, catchment runoff, Latrobe water top-up (if required) and Morwell River flood flows (connected only)).

The estimated water qualities for each of the lakes (YTF and YEF) are different even through there is water transfer via the conveyor tunnels (e.g. **Figure 6-6**). Generally, the water quality of the YEF is marginally better for most modelled parameters than YTF, due a combination of the following points:

- The poorer seepage water quality associated with internal overburden dumps (NOB Dump, SOB Dump) and the Former Ash Ponds.
- The effects of evapoconcentration are greater for YTF lake due to its greater surface area and shallower depth.
- Solutes are generally released from YEF during flood events via Spillway 4 (once full).

The only exception is for Scenario 4 where the Morwell River is completely integrated into the lakes post filling, meaning that there is a single mixed lake with near identical water qualities (**Figure 6-6**).

The conveyor tunnels influence the water qualities of the lakes, particularly earlier on in the simulation (< 5 years) (e.g. **Figure 6-7**). Once the conveyor tunnel elevations are reached, there is a transfer of water from YTF to YEF, resulting in a plateau of water quality concentration (represented as TDS) in the YTF and either an increase (concentration) or decrease (dilution) of water quality concentrations in the YEF. Once the lake levels equilibrate, then there is generally an increase in concentration in the YTF (since there is no longer transfer (removal) of solutes from YTF to YEF) and a plateau in YEF (e.g. **Figure 6-7**). As the lake level in the YTF progressively inundates overburden dumps (NOB, SOB and Midfield Dumps) and the Former Ash Ponds there is a decrease in concentration in YEF (due to a decrease in seepage and runoff contributions to the lake). Once the lake(s) reach 'full' (except for Scenario 1) there is a slight adjustment in YTF and YEF water quality before reaching steady state.

The water quality results for pH, salinity, metals and metalloids are summarised in the below sections. A summary of potential for stratification is provided from Hydronumerics (2025).

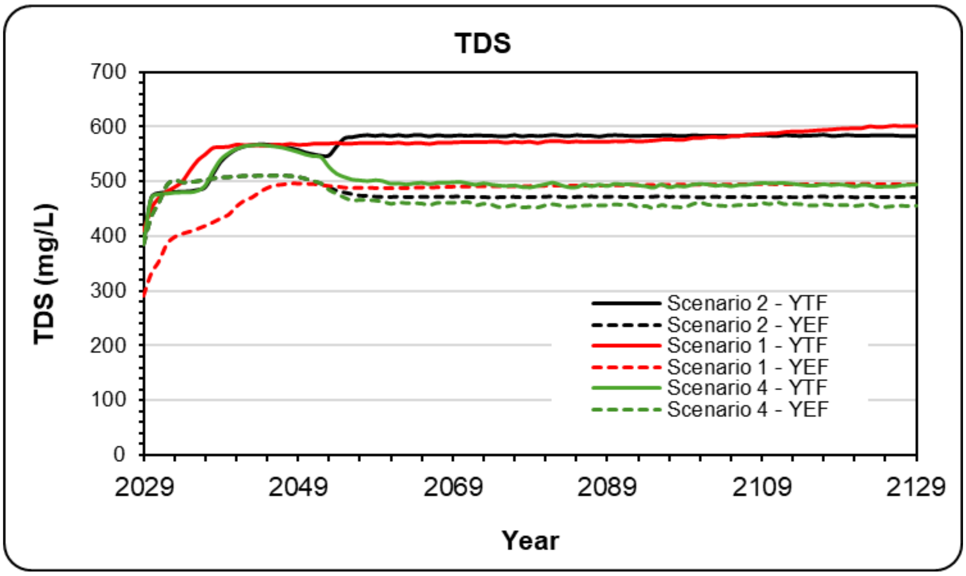

Figure 6-6: Median probability TDS (mg/L) for YEF and YTF highlighting concentration difference between lakes.

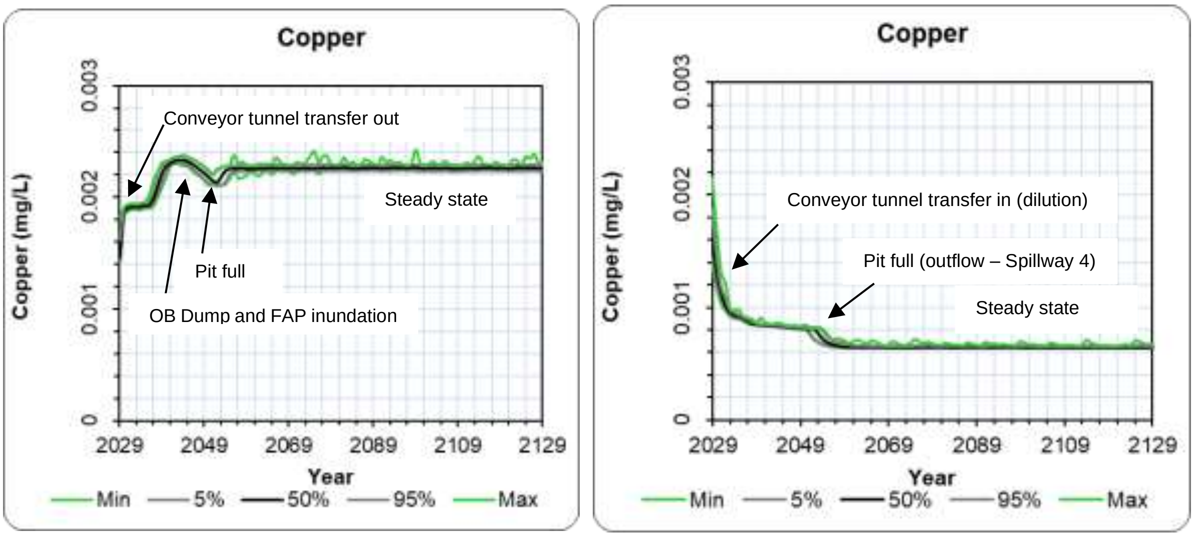

Figure 6-7: Estimated Copper (mg/L) concentration for Scenario 2. YTF left, and YEF right.

6.2.2 Lake pH

The results for each of the modelled scenarios indicate that (mass balance) pH is slightly acidic to neutral over the simulation period, with a pH range of ~ pH 4.11 to pH 6.65 (**atmospheric equilibration** of natural and pumped groundwater inflows to the lake may alter pH. For example, as the pumped groundwater in the lake equilibrates with atmospheric concentrations of carbon dioxide ($CO_{2(g)}$) and oxygen ($O_{2(g)}$), excess dissolved carbon dioxide from groundwater is vented to the atmosphere and diffusion of atmospheric oxygen into the lake. The loss of carbon dioxide results in a slight increase in pH due to a decrease in carbonic acid.

The effect of thermodynamic constraints and atmospheric equilibrium are discussed for the lake in **Section 6.2.5**. The PHREEQC model predicted pH which incorporates atmospheric equilibrium is ~pH 7 and pH 7.6 for the YTF and YEF, respectively, over the 100-year modelling period. This is consistent with the water quality of the existing water bodies within the mined voids which include: Lake Placid (median pH = 6.6), Floc Pond (median pH = 7) and Fire Service Pond (median pH = 6.7). However, incorporation of thermodynamic constraints (i.e. precipitation of ion (oxy)hydroxides)) results in generation of acidity, consumption of alkalinity and a change in lake pH to 4.5 and 7.5, in the YTF and YEF, respectively. There are limitations to this modelling discussed in **Section 6.2.5**.

Table 6-8). The pH of the YTF is approximately a 0.5 pH unit less than the modelled YEF pH. The pH of the lake trends towards the key water balance inputs which are generally dominated by Latrobe water (median = pH 7.1), direct rainfall (median pH = 5.3), Morwell River flood flows (median pH = 7.3), external catchments (median pH = 7), internal catchments (seepage and runoff) (median pH = 3.91 to 5.7) and pumped and natural groundwater (median pH = 4.7 to 5.7). Similarly, the influence of acidic drainage, mainly associated with NOB Dump, Eastfield Dump and some pit walls, contributes to the lakes slightly acid/ acid pH; however, this is expected to become less evident with time as the influence of seepage from the internal overburden dumps and pit wall runoff is less prevalent when the pit is full (i.e. diffusion becomes the dominant process by which acidity enters the lake which is orders of magnitude lower than the contributions from seepage/ runoff).

The mass balance approach of modelling pH excludes key geochemical reaction including the potential acid buffering effects of some materials in the pit (coal ash and some overburden materials), and dissolved alkalinity associated with some of the key water balance inputs (e.g. Latrobe water). Furthermore, atmospheric equilibration of natural and pumped groundwater inflows to the lake may alter pH. For example, as the pumped groundwater in the lake equilibrates with atmospheric concentrations of carbon dioxide ($CO_{2(g)}$) and oxygen ($O_{2(g)}$), excess dissolved carbon dioxide from groundwater is vented to the atmosphere and diffusion of atmospheric oxygen into the lake. The loss of carbon dioxide results in a slight increase in pH due to a decrease in carbonic acid.

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Table 6-8: Estimated pH values for YTF and YEF over time using mass balance approach

Parameter		pH											
Scenario		1		2		3		4		5		6	
Statistic	Year	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
YTF	5	5.08	5.22	4.25	4.45	4.11	4.33	4.25	4.45	4.24	4.40	4.24	4.38
	10	5.06	5.15	4.35	4.58	4.40	4.54	4.35	4.58	4.31	4.48	4.34	4.50
	25	5.06	5.18	4.65	5.15	4.96	5.15	4.65	6.20	4.62	4.96	4.65	5.07
	50	5.06	5.14	4.95	5.19	4.96	5.19	5.61	6.09	4.93	5.07	4.95	5.10
	75	5.05	5.15	4.95	5.18	4.95	5.22	5.55	6.14	4.93	5.11	4.94	5.13
	100	5.05	5.13	4.95	5.27	4.96	5.28	5.56	6.09	4.92	5.07	4.95	5.12
YEF	5	5.37	5.41	6.23	6.42	6.58	6.65	6.23	6.42	6.26	6.47	6.23	6.38
	10	5.47	5.60	6.29	6.33	5.56	5.77	6.29	6.33	6.30	6.33	6.29	6.32
	25	5.56	5.62	5.56	6.23	5.41	5.55	5.39	6.23	5.89	6.28	5.68	6.23

	50	5.59	5.61	5.42	5.58	5.41	5.55	5.38	5.84	5.40	5.54	5.42	5.54
	75	5.59	5.61	5.42	5.54	5.42	5.54	5.34	5.96	5.40	5.52	5.42	5.54
	100	5.60	5.61	5.42	5.56	5.41	5.56	5.38	5.93	5.40	5.54	5.42	5.54

6.2.3 Lake salinity and major ions

The estimated water qualities for the lakes are dominated by the major ions sulfate (SO_4), chloride (Cl), sodium (Na), with lesser magnesium (Mg), calcium (Ca) and potassium (K). Iron, not a major ion, is also a dominant contributor to the lakes water quality; however, this is likely overly conservative due to the mass balance approach of modelling and the potential overestimation of iron concentrations due to colloids passing through filtration (refer to **Section 6.2.5**).

The estimated TDS concentrations for the lakes vary slightly depending on the scenario (**Figure 6-8** and **Figure 6-9**); however, at the end of the simulation period (100 years), there is only a relatively tight range in TDS values between modelled scenarios (e.g. the mean probability TDS range at the end of the simulation for Scenario 2, 3, 5 and 6 is 575 mg/L (minimum) to 591 mg/L (maximum) for YTF lake and 465 mg/L (minimum) to 476 mg/L (maximum) for YEF lake) (**Figure 6-8**). The tight range in estimated TDS values is due to the fill and top-up water qualities dominating the lake water balance regardless of scenario.

The estimated YTF lake TDS concentrations for Scenario 4 are lower (~100 mg/L lower) than for the other scenarios due to the influence of being fully integrated with the Morwell River (after filled) which acts to both dilute lake concentrations and release solutes to Latrobe River via Spillway 4 (**Figure 6-8**).

The estimated YEF lake TDS concentrations for Scenario 1 (base case) are marginally higher (~25 mg/L) than the other scenarios (**Figure 6-8** and **Figure 6-8**) due to a combination of the following points:

- the effects of evapoconcentration with inflows exceeding outflows (excluding evaporation which leaves solute mass in the lake).
- No large dilution inflows are received from the Morwell River like other connected scenarios.
- Seepage and runoff from pit walls and overburden dumps continue to release solutes to the lake due to these features being exposed above the lake surface.

Generally, the TDS results show that during the fill phase for all scenarios, the same general trend occurs (refer to **Section 6.2.1**). For YTF lake, there is an initial increase in TDS with time due to the dominant water balance inputs during the fill phase, but also, to a lesser extent, the minor water balance inputs that contribute a greater mass load to the pit (e.g. seepage water quality from the NOB Dump, Former Ash Ponds and pit walls). After the initial increase, once the lake level reaches the conveyor tunnels, there is a plateau as solutes are removed from the lake to YEF. As the lake water levels equilibrate, the transfer of water from YTF to YEF is significantly reduced so TDS increases. The TDS concentration then plateaus or decreases reflecting the inundation of the overburden dumps, Former Ash Ponds and pit walls, before reaching a steady state post filling (e.g. **Figure 6-8** and **Figure 6-10**). The contribution of mass load from key features within the YTF pit is less pronounced with time as they become inundated (e.g. the NOB Dump becomes inundated at ~ RL 25 m). When the NOB Dump, Former Ash Ponds and pit walls (etc.) become inundated, the contribution of solutes to the lake from these sources is no longer controlled by runoff and seepage but is controlled by diffusive flux which is significantly slower.

The estimated TDS concentrations of the YEF also show a general increase in TDS during the fill phase. There is generally a sharp increase for the first 2- 5 years followed by a plateau (**Figure 6-11**). The increase in estimated TDS concentration reflects the dominant water balance inputs during the fill phase such as conveyor tunnel inflow from the YTF. Once the lakes levels are equilibrated, and the inflows from YTF are significantly reduced, there is a plateau in TDS. There is a release of solutes from YEF to YTF, leading to a plateau in TDS until the lake is full.

During the post fill phase, the lake TDS concentrations tend to diverge between scenarios depending on if the Morwell River is fully integrated (Scenario 4) or not. For Scenario 1 (base case) where the Morwell River is not connected and there is no top-up, the TDS concentration increases slightly with time in both lakes due to evaporation (i.e. evapoconcentration). Since Scenario 1 model simulates a ‘terminal sink’, the only means for removal of solutes (in the model) is via groundwater seepage, which is relatively low/ negligible. Conversely, for the other scenarios where the Morwell River is connected to the lake (whether it be fully integrated or receiving flood flows via the three spillways), there are TDS concentration decreases during Morwell River flood flow events. The connection of the Morwell River acts to dilute lake water quality during flood events, while also removing solutes via Spillway 4. Similarly, the inflows from lake top-up water acts to buffer the effects of climate change and variability. This is why, for all scenarios (excluding Scenario 1 which receives no top-up), the TDS concentrations are relatively consistent post filling (i.e. a steady state is reached).

The TDS and major ion concentration probabilities (maximum and minimum) at 5, 10, 25, 50, 75 and 100 years were compared with the assessment criteria (**Section 5**; **Table 5-2**). TDS, sulfate and calcium is well below the guideline (2,400 mg/L, 1,000 mg/L and 1,000 mg/L, respectively) for each of the scenarios (**Table 6-10**).

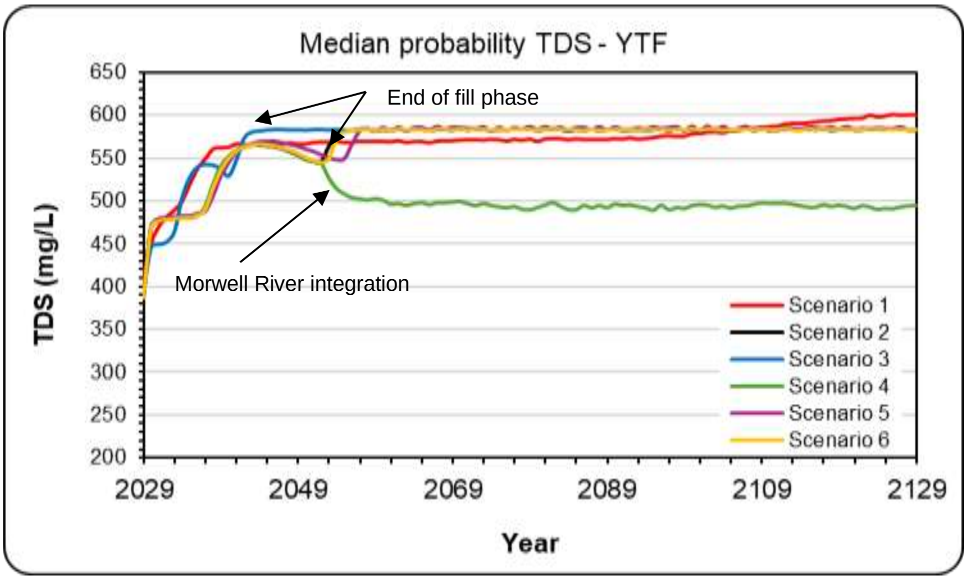

Figure 6-8: YTF median probability TDS versus time for each of the scenarios (annual time steps).

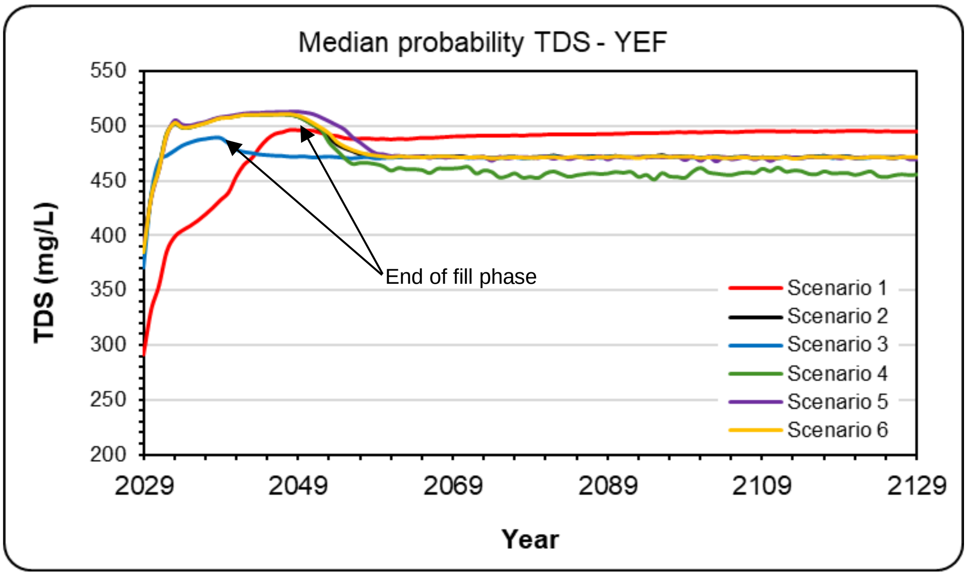

Figure 6-9: YEF median probability TDS versus time for each of the scenarios (annual time steps).

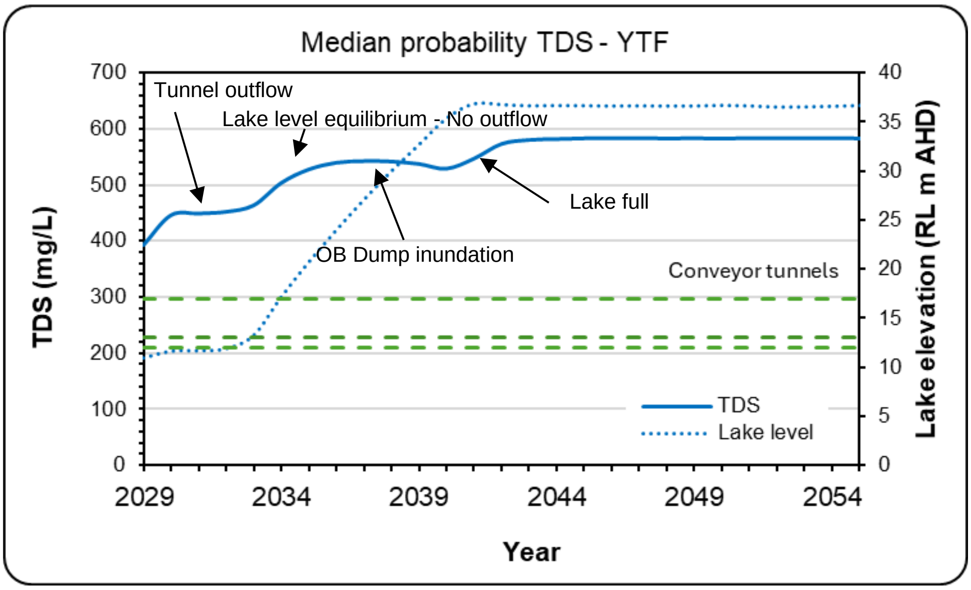

Figure 6-10: YTF median probability TDS for Scenario 3 (annual time steps) during fill with median lake water level.

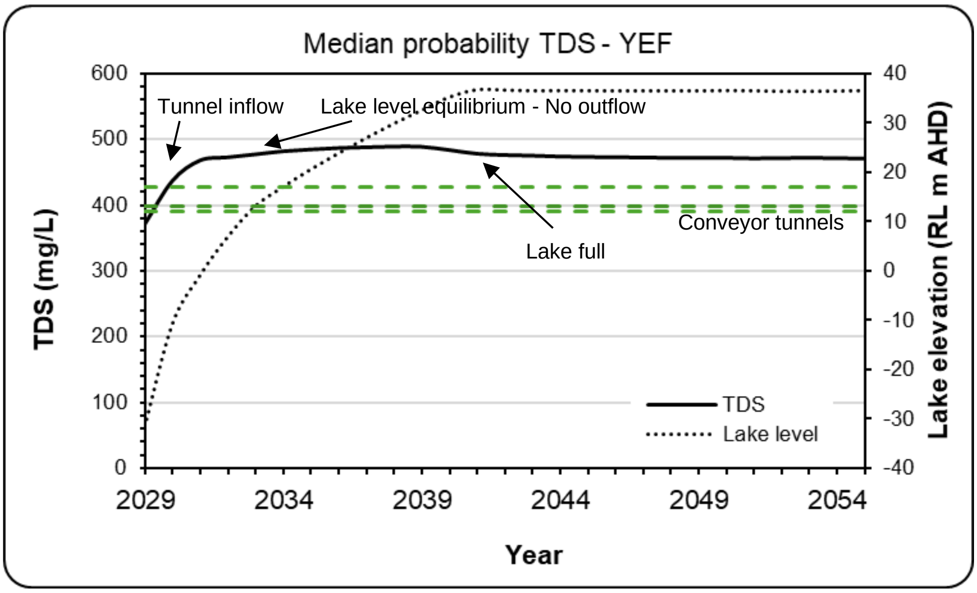

Figure 6-11: YEF median probability TDS for Scenario 3 (annual time steps) during fill with median lake water level.

Table 6-9: Summary of model estimated TDS and major ion water qualities for each of the project scenarios at select years.

Guideline			TDS (mg/L)		Calcium (mg/L)		Chloride (mg/L)		Magnesium (mg/L)		Potassium (mg/L)		Sodium (mg/L)		Sulfate (mg/L)	
ADWG (NRMC, 2011)			-		-		-		-		-		-		-	
Freshwater aquatic ecosystem (ANZG, 2018)			-		-		-		-		-		-		-	
Livestock Drinking Water (ANZG, 2018)			-		1000		-		-		-		-		1000	
Scenario	Pit	Year	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
1	**YTF**	**5**	465	542	5.57	6.86	139	147	26	32	1.28	1.51	90	97	149	196
		10	506	579	6.03	7.50	143	150	29	35	1.36	1.57	93	99	172	218
		25	539	582	7.21	7.55	143	151	33	36	1.48	1.61	93	99	199	221
		50	559	587	7.38	7.84	146	151	34	36	1.49	1.59	96	99	209	224
		75	562	626	7.42	8.41	147	156	35	40	1.49	1.64	96	103	211	247
		100	568	632	7.49	8.53	148	156	35	40	1.51	1.62	97	103	214	250
	YEF	**5**	391	412	4.51	4.58	274	291	26	27	2.67	2.76	195	206	56	57
		10	450	501	4.54	4.83	303	343	28	29	2.41	2.57	211	236	57	72
		25	480	503	4.54	4.68	321	350	28	29	2.42	2.50	221	240	58	66
		50	486	497	4.54	4.62	333	346	29	29	2.44	2.48	230	239	58	63
		75	489	500	4.54	4.59	336	349	28	29	2.44	2.47	232	240	59	62
		100	489	499	4.54	4.58	338	348	28	29	2.44	2.48	233	240	59	61
2	**YTF**	**5**	467	489	6.21	6.53	123	127	29	30	1.25	1.37	80	84	173	185
		10	514	558	6.81	7.60	130	138	32	35	1.33	1.48	86	91	198	221
		25	544	588	6.87	7.46	144	156	33	36	1.35	1.50	95	103	200	216
		50	575	591	7.25	7.56	153	156	35	36	1.44	1.52	101	103	211	217
		75	575	591	7.24	7.61	153	156	35	36	1.43	1.53	101	103	211	217
		100	575	591	7.25	7.66	152	157	35	36	1.43	1.55	101	104	211	217
	YEF	**5**	493	510	5.29	5.50	305	323	29	30	2.55	2.63	209	222	74	79
		10	504	515	5.19	5.35	331	341	29	30	2.61	2.65	227	234	68	70
		25	471	497	4.49	5.09	327	333	28	29	2.48	2.67	227	231	59	66
		50	466	478	4.38	4.58	325	333	28	29	2.45	2.51	226	231	57	59
		75	464	476	4.38	4.50	324	332	28	28	2.45	2.50	225	231	57	59
		100	465	476	4.38	4.55	325	332	28	28	2.45	2.50	226	231	57	59
3	**YTF**	**5**	482	527	6.47	7.11	123	130	30	33	1.27	1.39	80	86	185	208
		10	524	545	6.89	7.25	135	138	32	34	1.35	1.40	89	91	197	212
		25	573	591	7.24	7.48	152	156	35	36	1.43	1.50	100	103	210	217
		50	576	591	7.26	7.56	153	156	35	36	1.44	1.52	101	103	211	217
		75	576	591	7.25	7.67	153	156	35	36	1.43	1.54	101	103	211	217
		100	575	591	7.26	7.67	153	157	35	36	1.44	1.55	101	104	211	217
	YEF	**5**	478	487	5.33	5.45	305	315	28	28	2.64	2.69	208	216	65	68
		10	464	478	4.48	4.67	321	331	28	28	2.48	2.55	222	230	57	60
		25	465	477	4.38	4.51	325	333	28	28	2.45	2.50	226	231	57	59
		50	464	477	4.38	4.58	325	333	28	29	2.45	2.50	226	231	57	59
		75	463	476	4.37	4.50	324	332	28	28	2.45	2.50	225	231	57	59
		100	465	476	4.38	4.55	325	332	28	28	2.45	2.50	226	231	57	59
4	**YTF**	**5**	467	489	6.21	6.53	123	127	29	30	1.25	1.37	80	84	173	185
		10	514	558	6.81	7.60	130	138	32	35	1.33	1.48	86	91	198	221
		25	481	588	6.16	7.85	144	252	28	36	1.35	2.31	95	172	121	216
		50	462	522	6.94	7.84	185	217	27	31	2.05	2.25	124	147	119	141
		75	446	533	6.74	8.13	176	220	26	32	2.02	2.29	117	149	111	143
		100	461	520	6.83	7.91	183	217	27	31	2.03	2.25	122	147	117	140
	YEF	**5**	493	510	5.29	5.50	305	323	29	30	2.55	2.63	209	222	74	79
		10	504	515	5.19	5.35	331	341	29	30	2.61	2.65	227	234	68	70
		25	409	503	4.62	7.26	183	333	23	30	2.04	2.67	123	231	60	120
		50	426	481	6.38	7.35	186	215	24	29	2.03	2.23	125	146	98	120

Guideline			TDS (mg/L)		Calcium (mg/L)		Chloride (mg/L)		Magnesium (mg/L)		Potassium (mg/L)		Sodium (mg/L)		Sulfate (mg/L)	
ADWG (NRMC, 2011)			-		-		-		-		-		-		-	
Freshwater aquatic ecosystem (ANZG, 2018)			-		-		-		-		-		-		-	
Livestock Drinking Water (ANZG, 2018)			-		1000		-		-		-		-		1000	
Scenario	Pit	Year	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
		75	406	491	6.28	7.73	174	220	23	29	2.01	2.29	116	150	90	124
		100	418	484	6.42	7.55	180	217	24	29	2.03	2.26	121	147	95	121
5	**YTF**	**5**	470	489	6.22	6.46	124	127	29	30	1.25	1.34	81	84	175	186
		10	503	545	6.64	7.39	129	136	31	34	1.30	1.42	84	90	192	214
		25	537	579	6.85	7.30	141	154	33	35	1.35	1.44	93	101	199	213
		50	577	591	7.26	7.46	153	157	35	36	1.43	1.48	101	103	212	218
		75	577	591	7.26	7.44	153	157	35	36	1.43	1.48	101	103	212	218
		100	576	591	7.26	7.44	153	157	35	36	1.43	1.47	101	103	211	218
	YEF	**5**	495	517	5.31	5.53	307	324	29	30	2.55	2.65	210	222	74	80
		10	508	517	5.21	5.29	334	342	29	30	2.62	2.65	229	234	69	69
		25	486	509	4.79	5.15	329	340	29	30	2.59	2.68	228	234	62	67
		50	466	476	4.38	4.53	326	333	28	28	2.45	2.50	227	231	57	59
		75	466	475	4.38	4.47	326	332	28	28	2.45	2.49	226	231	57	58
		100	465	475	4.37	4.49	325	332	28	28	2.45	2.50	226	231	57	59
6	**YTF**	**5**	467	488	6.21	6.34	123	127	29	30	1.25	1.35	80	83	174	185
		10	510	553	6.78	7.47	130	137	32	35	1.33	1.45	85	90	196	218
		25	540	588	6.85	7.39	142	156	33	36	1.35	1.46	94	103	199	216
		50	577	591	7.26	7.44	153	156	35	36	1.43	1.47	101	103	211	217
		75	576	591	7.25	7.43	153	156	35	36	1.43	1.48	101	103	211	217
		100	577	591	7.25	7.43	153	157	35	36	1.43	1.47	101	103	211	217
	YEF	**5**	493	508	5.30	5.42	307	323	29	29	2.55	2.63	210	221	74	77
		10	505	515	5.18	5.25	332	341	29	30	2.62	2.65	228	234	68	69
		25	475	498	4.57	5.09	328	334	28	29	2.52	2.67	227	231	60	66
		50	465	476	4.38	4.48	325	333	28	28	2.45	2.50	226	231	57	59
		75	463	476	4.38	4.48	324	332	28	28	2.45	2.50	225	231	57	59
		100	465	475	4.38	4.48	325	332	28	28	2.45	2.50	226	231	57	59

6.2.4 Lake metals and metalloids

The estimated metal and metalloid probabilistic modelling results for each of the project scenarios and sensitivities are provided in **Attachment E** (for years 5, 10, 25, 50, 75 and 100) and concentration versus time graphs for each modelled parameter are provided in **Attachment F**. The minimum and maximum statistics (at 5, 10, 25, 50, 75 and 100 years) are summarised against water quality guidelines (assessment criteria) in **Table 6-10**.

The minimum and maximum probabilities are compared with the revised Australian and New Zealand Guidelines for fresh and marine water quality guidelines – freshwater aquatic ecosystem (95% species protection) and livestock drinking water guidelines (ANZG, 2018), as well as the Australian Drinking Water Guidelines (NRMMC, 2011) (**Table 6-10**). These guidelines are provided for context only as the modelling excludes key biogeochemical processes which may affect solute concentration results. For example, some minerals may become supersaturated (beyond saturation point) and are therefore likely to precipitate out of the lake (forming minerals) which would reduce the estimated modelled concentrations for the associated chemical species. Similarly, some metals and metalloids may co-precipitate with the mineral(s) or adsorb to the surface of mineral(s) reducing their dissolved concentrations in the lake. The mass balance approach to modelling metal and metalloid concentrations is therefore considered conservative.

The guideline comparison is summarised in the following points:

- Aluminium exceeds the freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018) (0.055 mg/L) for all scenarios for all probabilities. Aluminium was well below livestock drinking water guidelines (5 mg/L), and no trigger level exists for ADWG. The cause of the aluminium exceedance, relative to freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018), is due to several source term inputs which also show exceedance: Latrobe water (median = 0.27 mg/L), Morwell River (median = 0.26 mg/L), groundwater (median = 0.07 to 0.4 mg/L) and Latrobe top-up (median = 0.17 mg/L) (amongst other sources). It is common for colloidal aluminium (and iron) to pass through size 45 µm filter paper resulting in an overestimation of the dissolved concentration.
- Copper exceeds the freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018) (0.0014 mg/L) for all scenarios in the YTF; noting copper concentrations are below guidelines in the YEF except for Scenario 4 where the large Morwell River inflow causes an exceedance in copper concentration after 25 years. Copper is well below livestock drinking water guidelines (1 mg/L), and ADWG (2 mg/L). The cause of the copper exceedance, relative to freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018), is mainly due to Latrobe water (median =0.001 mg/L), Morwell River (median =0.002 mg/L), groundwater (median =0.002 to 0.003 mg/L) and local rainfall quality (median = 0.005 mg/L).
- Zinc exceeds the freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018) (0.008 mg/L) for all scenarios and all probabilities. Zinc was well below livestock drinking water guidelines (20 mg/L), and no trigger level exists for ADWG. The cause of the zinc exceedance, relative to freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018), is due to multiple sources, including rainfall (median =0.044 mg/L) and groundwater (median =0.025 to 0.039 mg/L) (amongst other sources).
- Lead exceeds the freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018) (0.0034 mg/L) in the YEF. Lead in the YTF is below the same guideline, except for Scenario 4 where some probabilities exceed from years ~25 (due to mixing with YEF which also results in a dilution of the lead concentrations in YEF). Lead briefly exceeded ADWG (0.01 mg/L) for Scenario 1 and was well below the livestock drinking water guidelines (0.1 mg/L. The cause of the lead exceedance, relative to freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018), is due to seepage and runoff water quality source terms associated with the pit walls and floor.

- Manganese marginally exceeds the ADWG (0.5 mg/L) for all scenarios in the YTF lake; noting that there are no exceedances for manganese in the YEF lake. Manganese generally exceeds the ADWG guideline after 10 to 25 years. The full integration of Morwell River into the lake (Scenario 4) reduces the estimated manganese concentration below ADWG. The cause of the manganese exceedance, relative to ADWG, is due mainly to seepage from the Former Ash Ponds and NOB Dump.

Copper and zinc levels are elevated relative to freshwater aquatic ecosystem (95% species protection) guideline throughout the Morwell and Latrobe catchments and are present in rainfall at concentrations of approx. 50 µg/L, likely due to burning of coal at power stations throughout the Latrobe Valley. It is expected that a reduction in the burning of coal in the Latrobe Valley will reduce the supply of copper and zinc to the system and thus reduce the modelled lake concentrations for these parameters. Similarly, the presence of lead in the pit walls and floor is likely associated with power stations in the Latrobe Valley. Over time, as the power stations are decommissioned, it is expected that the lead concentrations to the system will also decrease. The modelled results reflect the static nature of the source terms used in the model.

For Scenario 1 and Scenario 6 (unconnected scenarios), the modelled metal and metalloid concentrations are likely to increase with time beyond the simulation period, since lake solutes can only be removed via groundwater seepage which is low. Furthermore, the increase in dry conditions (low rainfall and high evaporation) will result in greater evapoconcentration.

Table 6-10: Summary of estimated metal and metalloid concentrations at select years for various project scenarios and sensitivities

Guideline			Aluminium (mg/L)		Arsenic (mg/L)		Cadmium (mg/L)		Chromium (mg/L)		Copper (mg/L)		Lead (mg/L)		Manganese (mg/L)		Molybdenum (mg/L)		Nickel (mg/L)		Selenium (mg/L)		Zinc (mg/L)	
ADWG (NRMC, 2011)			-		0.01		0.002		0.05		2		0.01		0.5		0.05		0.02		0.01		-	
Freshwater aquatic ecosystem (ANZG, 2018)			0.055		0.024		0.0002		0.001*		0.0014		0.0034		1.9		-		0.011		0.011		0.008	
Livestock Drinking Water (ANZG, 2018)			5		0.5		0.01		1		1		0.1		-		0.15		0.02		0.02		20	
Scenario	**Pit**	**Year**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
1	**YTF**	**5**	0.141	0.173	0.0020	0.0028	0.00003	0.00004	0.00032	0.00040	0.0017	0.0021	0.0010	0.0015	0.40	0.49	0.00053	0.00054	0.0066	0.0074	0.0007	0.0009	0.090	0.103
		10	0.153	0.180	0.0026	0.0029	0.00003	0.00004	0.00036	0.00040	0.0019	0.0023	0.0013	0.0017	0.45	0.59	0.00053	0.00054	0.0071	0.0078	0.0008	0.0009	0.095	0.105
		25	0.172	0.183	0.0028	0.0030	0.00003	0.00004	0.00037	0.00042	0.0022	0.0023	0.0016	0.0017	0.55	0.60	0.00053	0.00054	0.0072	0.0078	0.0008	0.0010	0.103	0.106
		50	0.173	0.183	0.0029	0.0030	0.00003	0.00003	0.00038	0.00040	0.0023	0.0024	0.0016	0.0017	0.58	0.62	0.00053	0.00054	0.0075	0.0078	0.0008	0.0009	0.104	0.106
		75	0.173	0.188	0.0028	0.0030	0.00003	0.00004	0.00037	0.00041	0.0023	0.0026	0.0016	0.0017	0.58	0.68	0.00053	0.00054	0.0075	0.0082	0.0007	0.0009	0.103	0.107
		100	0.176	0.187	0.0028	0.0030	0.00003	0.00003	0.00037	0.00040	0.0023	0.0026	0.0016	0.0017	0.59	0.69	0.00053	0.00054	0.0076	0.0082	0.0008	0.0009	0.104	0.108
	YEF	**5**	0.347	0.372	0.0021	0.0022	0.00009	0.00009	0.00053	0.00056	0.0007	0.0007	0.0098	0.0111	0.15	0.16	0.00052	0.00053	0.0078	0.0084	0.0023	0.0025	0.358	0.383
		10	0.234	0.298	0.0019	0.0021	0.00007	0.00008	0.00044	0.00050	0.0006	0.0008	0.0078	0.0096	0.16	0.21	0.00053	0.00054	0.0090	0.0102	0.0018	0.0021	0.236	0.303
		25	0.233	0.254	0.0019	0.0020	0.00007	0.00007	0.00044	0.00047	0.0006	0.0007	0.0063	0.0070	0.17	0.19	0.00053	0.00054	0.0097	0.0104	0.0018	0.0019	0.237	0.260
		50	0.243	0.253	0.0020	0.0020	0.00007	0.00007	0.00045	0.00046	0.0006	0.0007	0.0066	0.0070	0.17	0.18	0.00053	0.00054	0.0100	0.0103	0.0018	0.0019	0.247	0.258
		75	0.240	0.248	0.0020	0.0020	0.00007	0.00007	0.00045	0.00046	0.0006	0.0007	0.0065	0.0068	0.17	0.18	0.00053	0.00054	0.0100	0.0104	0.0018	0.0019	0.245	0.253
		100	0.240	0.246	0.0020	0.0020	0.00007	0.00007	0.00045	0.00046	0.0006	0.0007	0.0066	0.0068	0.17	0.18	0.00053	0.00054	0.0101	0.0103	0.0018	0.0019	0.245	0.251
2	**YTF**	**5**	0.145	0.164	0.0023	0.0025	0.00003	0.00003	0.00032	0.00035	0.0019	0.0019	0.0014	0.0014	0.47	0.50	0.00045	0.00046	0.0062	0.0066	0.0006	0.0008	0.084	0.090
		10	0.154	0.175	0.0024	0.0025	0.00003	0.00003	0.00032	0.00034	0.0021	0.0023	0.0013	0.0014	0.54	0.61	0.00046	0.00048	0.0068	0.0073	0.0007	0.0008	0.090	0.095
		25	0.160	0.179	0.0027	0.0030	0.00003	0.00003	0.00035	0.00040	0.0021	0.0023	0.0015	0.0017	0.55	0.59	0.00049	0.00054	0.0074	0.0080	0.0007	0.0009	0.096	0.104
		50	0.170	0.182	0.0029	0.0030	0.00003	0.00003	0.00037	0.00039	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00054	0.0078	0.0080	0.0008	0.0008	0.102	0.104
		75	0.169	0.185	0.0029	0.0030	0.00003	0.00003	0.00037	0.00040	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00054	0.0078	0.0080	0.0008	0.0009	0.102	0.104
		100	0.170	0.187	0.0029	0.0030	0.00003	0.00003	0.00037	0.00040	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00055	0.0078	0.0080	0.0008	0.0008	0.102	0.104
	YEF	**5**	0.267	0.274	0.0020	0.0021	0.00007	0.00007	0.00050	0.00051	0.0009	0.0010	0.0058	0.0062	0.21	0.23	0.00058	0.00060	0.0094	0.0099	0.0017	0.0018	0.224	0.238
		10	0.265	0.271	0.0020	0.0020	0.00007	0.00007	0.00049	0.00050	0.0008	0.0009	0.0061	0.0063	0.20	0.20	0.00058	0.00059	0.0100	0.0103	0.0018	0.0018	0.232	0.239
		25	0.298	0.310	0.0020	0.0021	0.00007	0.00007	0.00050	0.00053	0.0007	0.0008	0.0069	0.0076	0.17	0.19	0.00053	0.00058	0.0097	0.0100	0.0019	0.0020	0.263	0.282
		50	0.296	0.306	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0073	0.0077	0.16	0.17	0.00052	0.00054	0.0097	0.0099	0.0019	0.0020	0.278	0.284
		75	0.296	0.304	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0074	0.0077	0.16	0.17	0.00052	0.00054	0.0096	0.0099	0.0019	0.0020	0.278	0.284
		100	0.296	0.305	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0074	0.0077	0.16	0.17	0.00052	0.00054	0.0097	0.0099	0.0019	0.0020	0.278	0.284
3	**YTF**	**5**	0.147	0.165	0.0023	0.0024	0.00002	0.00003	0.00030	0.00033	0.0020	0.0022	0.0013	0.0013	0.51	0.58	0.00043	0.00045	0.0063	0.0069	0.0006	0.0007	0.085	0.090
		10	0.157	0.166	0.0024	0.0025	0.00003	0.00003	0.00032	0.00034	0.0021	0.0022	0.0014	0.0014	0.54	0.59	0.00047	0.00048	0.0069	0.0072	0.0007	0.0007	0.090	0.093
		25	0.170	0.179	0.0029	0.0030	0.00003	0.00003	0.00037	0.00040	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00054	0.0078	0.0080	0.0008	0.0009	0.102	0.104
		50	0.170	0.182	0.0029	0.0030	0.00003	0.00003	0.00037	0.00039	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00054	0.0078	0.0080	0.0008	0.0008	0.102	0.104
		75	0.169	0.186	0.0029	0.0030	0.00003	0.00003	0.00037	0.00040	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00054	0.0078	0.0080	0.0008	0.0009	0.102	0.104
		100	0.170	0.187	0.0029	0.0030	0.00003	0.00003	0.00037	0.00040	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00055	0.0078	0.0080	0.0008	0.0008	0.102	0.104
	YEF	**5**	0.276	0.280	0.0019	0.0020	0.00007	0.00007	0.00051	0.00052	0.0009	0.0009	0.0056	0.0058	0.19	0.20	0.00059	0.00060	0.0093	0.0095	0.0017	0.0018	0.216	0.221
		10	0.297	0.305	0.0019	0.0020	0.00007	0.00007	0.00049	0.00052	0.0007	0.0007	0.0060	0.0061	0.16	0.17	0.00053	0.00055	0.0095	0.0098	0.0019	0.0020	0.269	0.280
		25	0.296	0.305	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0074	0.0077	0.16	0.17	0.00052	0.00054	0.0097	0.0099	0.0019	0.0020	0.278	0.284
		50	0.296	0.306	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0072	0.0077	0.16	0.17	0.00052	0.00054	0.0096	0.0099	0.0019	0.0020	0.278	0.284
		75	0.296	0.304	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0074	0.0077	0.16	0.17	0.00052	0.00054	0.0096	0.0099	0.0019	0.0020	0.279	0.284
		100	0.296	0.305	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0074	0.0077	0.16	0.17	0.00052	0.00054	0.0096	0.0099	0.0019	0.0020	0.278	0.284
4	**YTF**	**5**	0.145	0.164	0.0023	0.0025	0.00003	0.00003	0.00032	0.00035	0.0019	0.0019	0.0014	0.0014	0.47	0.50	0.00045	0.00046	0.0062	0.0066	0.0006	0.0008	0.084	0.090
		10	0.154	0.175	0.0024	0.0025	0.00003	0.00003	0.00032	0.00034	0.0021	0.0023	0.0013	0.0014	0.54	0.61	0.00046	0.00048	0.0068	0.0073	0.0007	0.0008	0.090	0.095
		25	0.160	0.304	0.0020	0.0030	0.00003	0.00005	0.00035	0.00048	0.0015	0.0023	0.0015	0.0045	0.33	0.59	0.00049	0.00057	0.0072	0.0091	0.0007	0.0014	0.096	0.193
		50	0.261	0.298	0.0019	0.0024	0.00005	0.00005	0.00045	0.00047	0.0017	0.0018	0.0029	0.0038	0.32	0.38	0.00053	0.00056	0.0067	0.0081	0.0011	0.0013	0.129	0.164
		75	0.253	0.312	0.0018	0.0024	0.00005	0.00005	0.00044	0.00048	0.0017	0.0018	0.0031	0.0037	0.29	0.39	0.00053	0.00058	0.0062	0.0082	0.0010	0.0013	0.117	0.165
		100	0.258	0.302	0.0019	0.0024	0.00005	0.00005	0.00044	0.00048	0.0017	0.0018	0.0029	0.0037	0.31	0.38	0.00053	0.00056	0.0066	0.0081	0.0011	0.0012	0.126	0.163
	YEF	**5**	0.267	0.274	0.0020	0.0021	0.00007	0.00007	0.00050	0.00051	0.0009	0.0010	0.0058	0.0062	0.21	0.23	0.00058	0.00060	0.0094	0.0099	0.0017	0.0018	0.224	0.238
		10	0.265	0.271	0.0020	0.0020	0.00007	0.00007	0.00049	0.00050	0.0008	0.0009	0.0061	0.0063	0.20	0.20	0.00058	0.00059	0.0100	0.0103	0.0018	0.0018	0.232	0.239
		25	0.253	0.307	0.0016	0.0023	0.00005	0.00007	0.00044	0.00053	0.0007	0.0016	0.0037	0.0072	0.17	0.32	0.00050	0.00058	0.0061	0.0100	0.0011	0.0020	0.128	0.279
		50	0.257	0.300	0.0017	0.0021	0.00005	0.00005	0.00044	0.00046	0.0015	0.0016	0.0031	0.0041	0.26	0.33	0.00051	0.00053	0.0063	0.0077	0.0011	0.0013	0.131	0.164
		75	0.253	0.315	0.0015	0.0022	0.00005	0.00005	0.00043	0.00046	0.0015	0.0016	0.0033	0.0041	0.24	0.34	0.00050	0.00053	0.0058	0.0079	0.0010	0.0013	0.117	0.170
		100	0.258	0.308	0.0016	0.0022	0.00005	0.00005	0.00043	0.00046	0.0015	0.0016	0.0032	0.0041	0.25	0.33	0.00050	0.00053	0.0061	0.0078	0.0011	0.0013	0.125	0.166

Guideline			Aluminium (mg/L)		Arsenic (mg/L)		Cadmium (mg/L)		Chromium (mg/L)		Copper (mg/L)		Lead (mg/L)		Manganese (mg/L)		Molybdenum (mg/L)		Nickel (mg/L)		Selenium (mg/L)		Zinc (mg/L)	
ADWG (NRMC, 2011)			-		0.01		0.002		0.05		2		0.01		0.5		0.05		0.02		0.01		-	
Freshwater aquatic ecosystem (ANZG, 2018)			0.055		0.024		0.0002		0.001*		0.0014		0.0034		1.9		-		0.011		0.011		0.008	
Livestock Drinking Water (ANZG, 2018)			5		0.5		0.01		1		1		0.1		-		0.15		0.02		0.02		20	
Scenario	**Pit**	**Year**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
5	**YTF**	**5**	0.145	0.159	0.0024	0.0025	0.00002	0.00003	0.00031	0.00034	0.0019	0.0019	0.0014	0.0014	0.48	0.50	0.00044	0.00046	0.0063	0.0066	0.0006	0.0008	0.085	0.089
		10	0.151	0.164	0.0025	0.0025	0.00003	0.00003	0.00032	0.00034	0.0020	0.0022	0.0014	0.0014	0.53	0.59	0.00045	0.00047	0.0067	0.0071	0.0006	0.0007	0.089	0.094
		25	0.160	0.171	0.0027	0.0029	0.00003	0.00003	0.00034	0.00038	0.0021	0.0022	0.0015	0.0016	0.54	0.58	0.00049	0.00052	0.0072	0.0079	0.0007	0.0008	0.095	0.102
		50	0.170	0.176	0.0029	0.0030	0.00003	0.00003	0.00037	0.00039	0.0022	0.0023	0.0017	0.0017	0.58	0.59	0.00052	0.00054	0.0078	0.0080	0.0007	0.0008	0.102	0.104
		75	0.169	0.175	0.0029	0.0030	0.00003	0.00003	0.00037	0.00039	0.0022	0.0023	0.0016	0.0017	0.58	0.59	0.00052	0.00054	0.0078	0.0080	0.0007	0.0008	0.102	0.104
		100	0.169	0.174	0.0029	0.0030	0.00003	0.00003	0.00037	0.00039	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00054	0.0078	0.0080	0.0007	0.0008	0.102	0.104
	YEF	**5**	0.265	0.275	0.0021	0.0021	0.00007	0.00007	0.00050	0.00051	0.0009	0.0010	0.0058	0.0062	0.21	0.23	0.00058	0.00060	0.0095	0.0100	0.0017	0.0018	0.225	0.236
		10	0.266	0.268	0.0020	0.0021	0.00007	0.00007	0.00049	0.00050	0.0008	0.0009	0.0061	0.0063	0.20	0.20	0.00058	0.00059	0.0101	0.0103	0.0018	0.0018	0.236	0.239
		25	0.276	0.307	0.0020	0.0021	0.00007	0.00007	0.00050	0.00053	0.0007	0.0008	0.0065	0.0072	0.18	0.19	0.00056	0.00059	0.0099	0.0102	0.0018	0.0020	0.248	0.275
		50	0.296	0.303	0.0020	0.0020	0.00007	0.00007	0.00048	0.00050	0.0006	0.0007	0.0075	0.0077	0.16	0.17	0.00052	0.00053	0.0097	0.0099	0.0019	0.0020	0.278	0.284
		75	0.296	0.301	0.0020	0.0020	0.00007	0.00007	0.00049	0.00050	0.0006	0.0007	0.0075	0.0077	0.16	0.17	0.00052	0.00053	0.0097	0.0099	0.0019	0.0020	0.278	0.283
		100	0.296	0.302	0.0020	0.0020	0.00007	0.00007	0.00049	0.00050	0.0006	0.0007	0.0075	0.0077	0.16	0.17	0.00052	0.00053	0.0097	0.0099	0.0019	0.0020	0.278	0.283
6	**YTF**	**5**	0.145	0.154	0.0024	0.0025	0.00003	0.00003	0.00032	0.00035	0.0019	0.0019	0.0014	0.0014	0.48	0.50	0.00045	0.00046	0.0062	0.0065	0.0006	0.0008	0.087	0.090
		10	0.154	0.166	0.0025	0.0025	0.00003	0.00003	0.00032	0.00034	0.0021	0.0023	0.0014	0.0014	0.54	0.60	0.00046	0.00048	0.0067	0.0072	0.0007	0.0008	0.091	0.095
		25	0.160	0.173	0.0027	0.0030	0.00003	0.00003	0.00035	0.00039	0.0021	0.0023	0.0015	0.0017	0.54	0.59	0.00049	0.00054	0.0073	0.0080	0.0007	0.0009	0.095	0.104
		50	0.170	0.174	0.0029	0.0030	0.00003	0.00003	0.00037	0.00039	0.0022	0.0023	0.0016	0.0017	0.58	0.59	0.00052	0.00054	0.0078	0.0080	0.0008	0.0008	0.102	0.104
		75	0.169	0.175	0.0029	0.0030	0.00003	0.00003	0.00037	0.00040	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00054	0.0078	0.0080	0.0008	0.0009	0.102	0.104
		100	0.170	0.174	0.0029	0.0030	0.00003	0.00003	0.00037	0.00040	0.0022	0.0023	0.0016	0.0017	0.57	0.59	0.00052	0.00054	0.0078	0.0080	0.0008	0.0008	0.102	0.104
	YEF	**5**	0.267	0.273	0.0021	0.0021	0.00007	0.00007	0.00050	0.00051	0.0009	0.0010	0.0058	0.0062	0.21	0.22	0.00058	0.00059	0.0095	0.0099	0.0017	0.0018	0.227	0.237
		10	0.265	0.267	0.0020	0.0020	0.00007	0.00007	0.00049	0.00050	0.0008	0.0008	0.0062	0.0063	0.20	0.20	0.00058	0.00059	0.0101	0.0103	0.0018	0.0018	0.237	0.239
		25	0.298	0.309	0.0020	0.0021	0.00007	0.00007	0.00051	0.00053	0.0007	0.0008	0.0069	0.0075	0.17	0.19	0.00055	0.00058	0.0098	0.0100	0.0019	0.0020	0.262	0.281
		50	0.296	0.304	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0075	0.0077	0.16	0.17	0.00052	0.00054	0.0097	0.0099	0.0019	0.0020	0.278	0.284
		75	0.296	0.303	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0075	0.0077	0.16	0.17	0.00052	0.00054	0.0096	0.0099	0.0019	0.0020	0.278	0.284
		100	0.296	0.303	0.0020	0.0020	0.00007	0.00007	0.00049	0.00051	0.0006	0.0007	0.0075	0.0077	0.16	0.17	0.00052	0.00054	0.0097	0.0099	0.0019	0.0020	0.278	0.284

6.2.5 Thermodynamic modelling

Consideration of thermodynamic constraints (mineral solubility) and atmospheric equilibrium was undertaken on the GoldSim generated average mass balance results for Scenario 1 and Scenario 2, Years 2029 to 2129.

The thermodynamic modelling was undertaken in three steps, including the following.

- The mass balance water quality results were equilibrated to atmospheric conditions. This assumed $pCO_2 = -3$, considered generally consistent with pit lake water in which groundwater is a component and interaction with the atmosphere is somewhat limited through the top surface of the pit lake water body. Oxygen was allowed to enter the pit lake water body sufficient to maintain oxic pit lake conditions.
- The equilibration indicated mineral saturation indices > 0, i.e., supersaturated minerals with the potential to precipitate based on the theoretical solubility limits of these minerals within the *minteq.v4.dat* database. By default, all minerals were initially suppressed (prevented from precipitating). Selected minerals were allowed to precipitate based on the equilibration results and RGS's technical experience on similar systems. This was undertaken stepwise for selected minerals to observe the effects on element concentrations and key chemical parameters (e.g. pH, TDS).
- Sorption of trace elements from solution, including copper and zinc, was associated with precipitating iron (oxy)hydroxides.

The results, including Scenarios 1 and 2 are discussed by pit in the following sections.

6.2.5.1 *YTF pit*

During equilibration with atmospheric conditions, CO_2 is vented to the atmosphere and diffusion of atmospheric oxygen into the lake results in significant changes to pH and alkalinity (**Figure 6-12**).

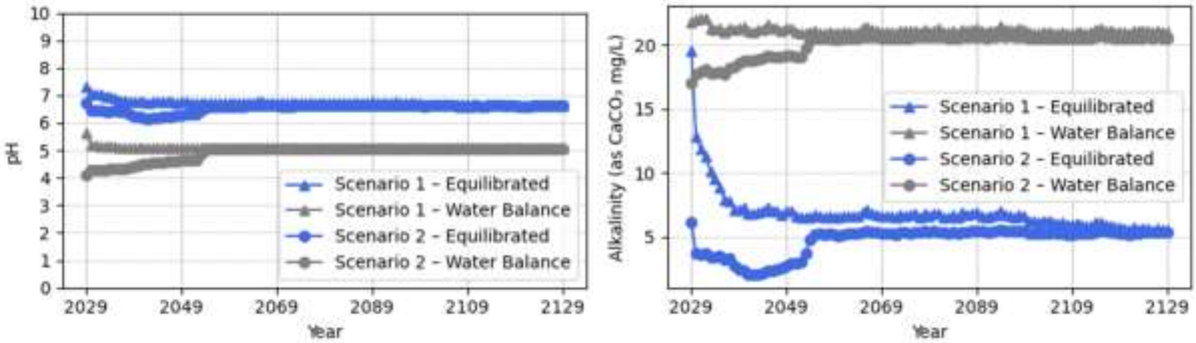

Figure 6-12: Modelled YTF pH and alkalinity after equilibration with atmosphere

The loss of CO_2 shifts the equilibrium and results in a reduction in the amount of carbonic acid, observed as an increased pH relative to the water balance results. The thermodynamic model simulation shows pH in the YTF lake increasing from ~pH 5 to ~pH 7 and alkalinity decreases significantly from ~20 mg/L to ~5 mg/L as $CaCO_3$. Significant changes in pH and alkalinity are limited to the first ~25 years of the simulation after which approximate steady state conditions are reached.

The alkalinity results indicate the YTF pit lake will have limited neutralisation capacity. There are modest differences between Scenario 1 and Scenario 2 although the trends are similar.

The thermodynamic modelling suggests that mineralogical controls on the YTF lake water quality include iron (oxy)hydroxides (e.g. goethite/ hematite) and, to a minor extent, sulfates (e.g. barite). Aluminium (oxy)hydroxides (e.g. gibbsite) are in approximate equilibrium with the pit lake water (-0.5 < SI <0.5).

When allowed to precipitate, iron (oxy)hydroxides remove dissolved iron from the pit water significantly reducing dissolved iron concentration from ~20 mg/L to ~5 mg/L. The iron precipitation releases acidity which neutralises alkalinity in the pit water causing the pH to fall to ~pH 4.5 while the alkalinity decreases to below zero[6] (**Figure 6-13**).

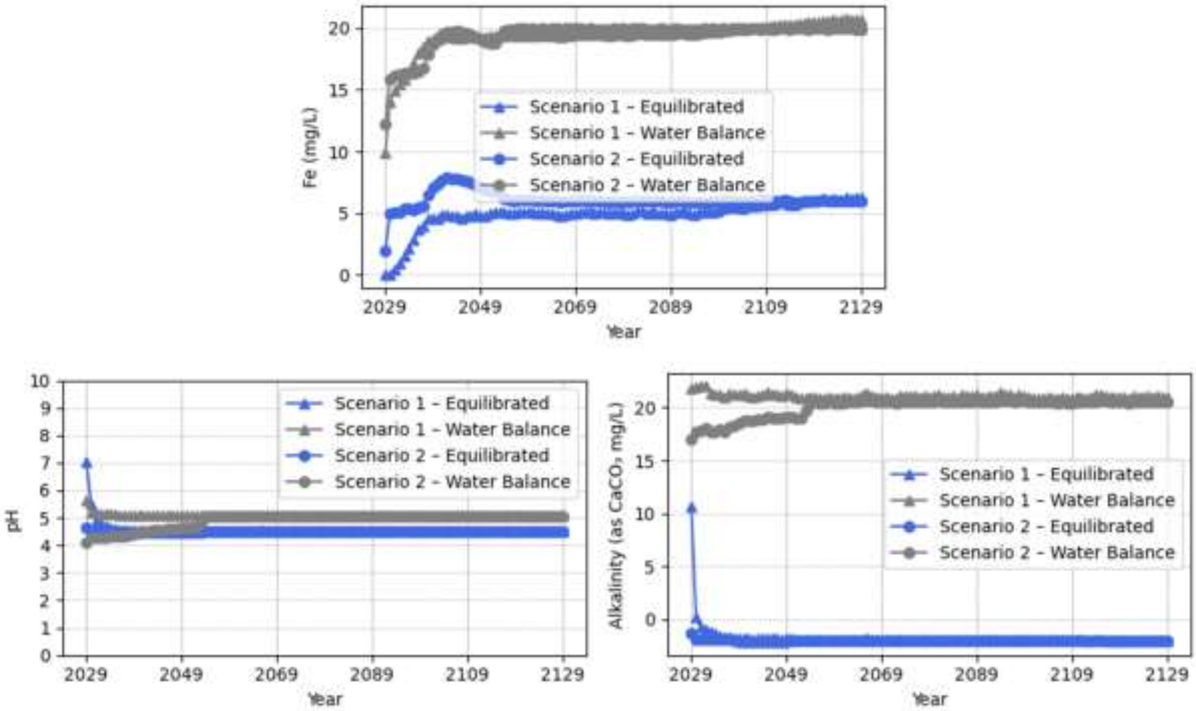

Figure 6-13: Modelled YTF iron, pH and alkalinity after atmospheric equilibration and mineral precipitation

The thermodynamic modelling results indicate the YTF pit lake water quality lacks significant acid buffering capacity. Iron (oxy)hydroxide precipitation combined with other acidity sources (e.g. acid seepage from waste rock or pit walls) will likely consume available alkalinity resulting in acid pH conditions.

Note that the iron inputs from the WB/WQ modelling may be significantly overestimated due to colloids passing through 45 μm filters, as applied to characterise source terms from field water samples. If this is the case, iron (oxy)hydroxide precipitation may not release enough acidity to neutralise the available alkalinity in the YTF pit water. Similarly, groundwater inflows from the HHF may oxidise prior to entering the lake; this would also result in a decrease in the iron inputs. Further detailed thermodynamic modelling of source terms and pit lake water may be required to resolve this.

The thermodynamic modelling had little influence on the mass balance results for aluminium, manganese, copper and zinc because of the low pH conditions. These increase metal solubility and keep the metals in solution in the modelled YTF pit water (**Figure 6-14**). Results for both scenarios were generally similar except for increasing metal concentrations in the last ~30 years of Scenario 1 due to evapoconcentration (Scenario 1 is isolated from the Morwell River, while flood flows are considered in Scenario 2).

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[6] A negative alkalinity value in PHREEQC, or in any water chemistry context, signifies that the solution has more H^+ ions than proton-consuming species, leading to an acidic condition.

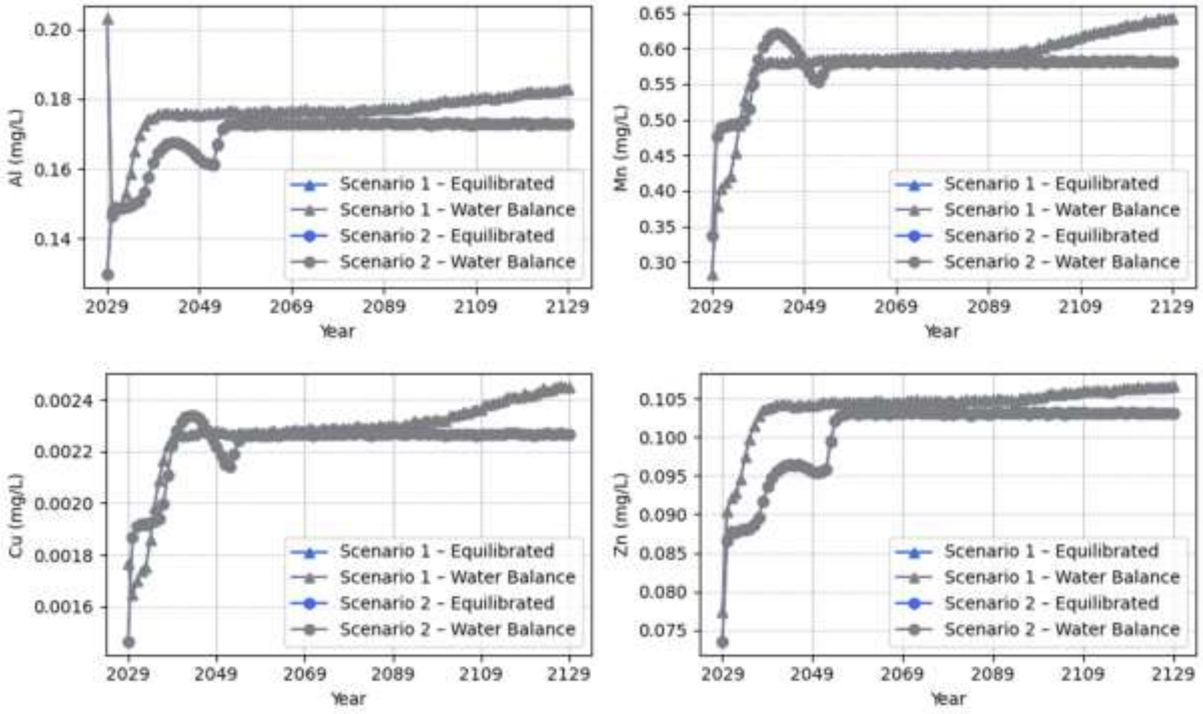

Figure 6-14: Modelled YTF aluminium, manganese, copper and zinc after atmospheric equilibration and mineral precipitation

Similarly, there is no significant sorption of metals on precipitating iron (oxy)hydroxide surfaces due to the low pH.

6.2.5.2 *YEF pit*

Like the YTF pit, during modelled equilibration with atmospheric conditions, CO_2 is vented to the atmosphere from the YEF pit water body, resulting in significant changes to pH and alkalinity (**Figure 6-15**).

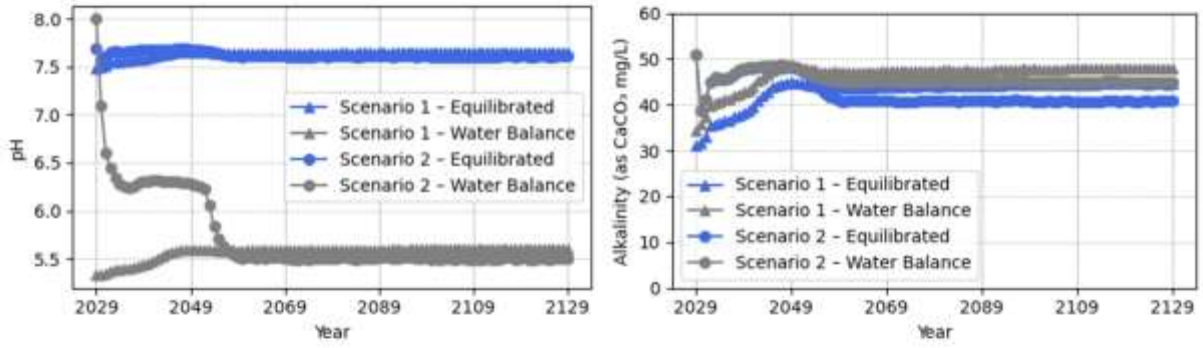

Figure 6-15: Modelled YEF pH and alkalinity after equilibration with atmosphere

The loss of CO_2 increased pH relative to the water balance results from ~pH 5.5 to ~pH 7.6 for both scenarios. Alkalinity decreased in both scenarios and generally remained ~40 mg/L as $CaCO_3$. Significant changes are limited to the first ~25 years of the simulation after which approximate steady state conditions are reached.

The alkalinity results indicate the YEF pit lake will have higher neutralisation capacity than the YTF pit lake. There are modest differences between Scenario 1 and Scenario 2, particularly in the first three years of simulation, although the general trends are similar.

The thermodynamic modelling suggests that mineralogical controls on the YEF lake water quality include iron (oxy)hydroxides (e.g. goethite/ hematite), aluminium (oxy)hydroxides (e.g. gibbsite) and, to a minor extent, sulfates (e.g. barite). Manganese oxides (e.g. birnessite) are not likely controls on manganese concentrations.

When allowed to precipitate, iron (oxy)hydroxides remove dissolved iron from the pit water significantly reducing dissolved iron concentration from ~12 mg/L to <0.001 mg/L. Similarly, allowing aluminium (oxy)hydroxides to precipitate reduces aluminium concentration from ~0.3 mg/L to <0.005 mg/L. The iron and aluminium precipitation both release acidity which neutralises alkalinity in the pit water causing the pH to fall slightly to ~pH 7.5 while the alkalinity decreases and generally remains ~30 mg/L as $CaCO_3$ (**Figure 6-16**).

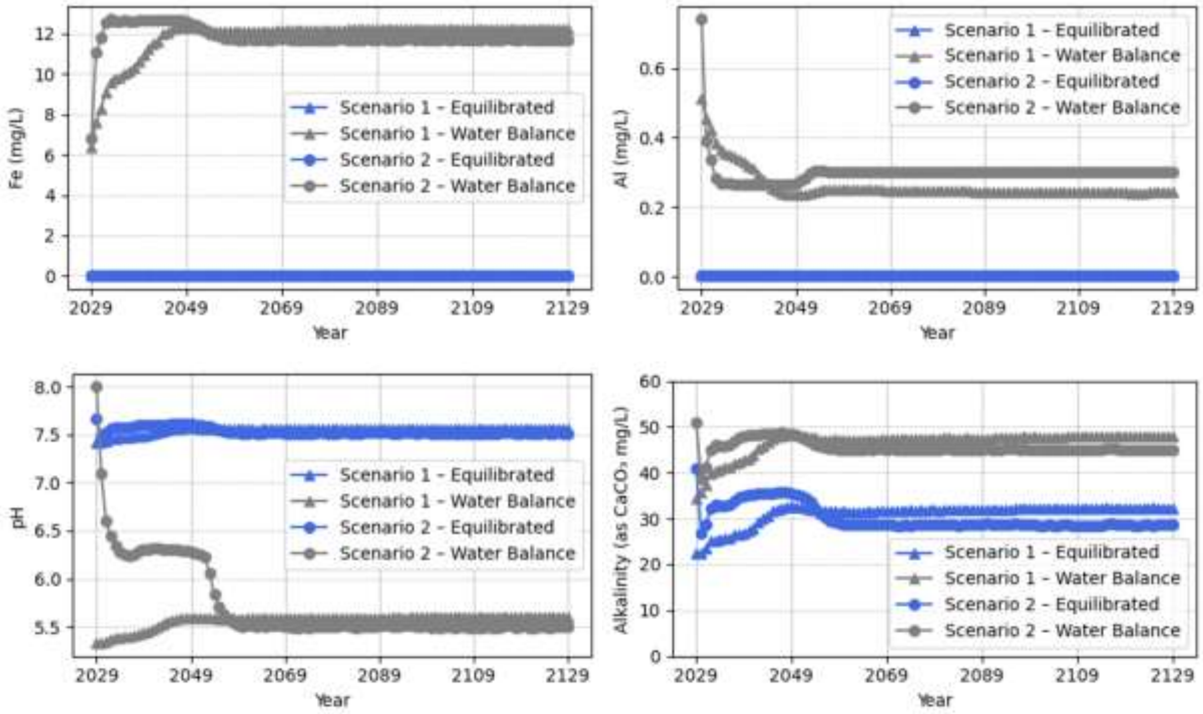

Figure 6-16: Modelled YEF iron, aluminium, pH and alkalinity after atmospheric equilibration and mineral precipitation

The thermodynamic modelling had little influence on the mass balance results for manganese, since the YEF pit lake water was unsaturated with respect to likely manganese minerals. However, sorption of copper and zinc ions on precipitating iron (oxy)hydroxides resulted in notable concentration decreases (**Figure 6-17**). Mass balance copper was already below the freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018) of 0.0014 mg/L and decreased to <0.0001 mg/L on thermodynamic modelling. Mass balance zinc decreased significantly but still exceeded the freshwater aquatic ecosystem (95% species protection) guideline of 0.008 mg/L.

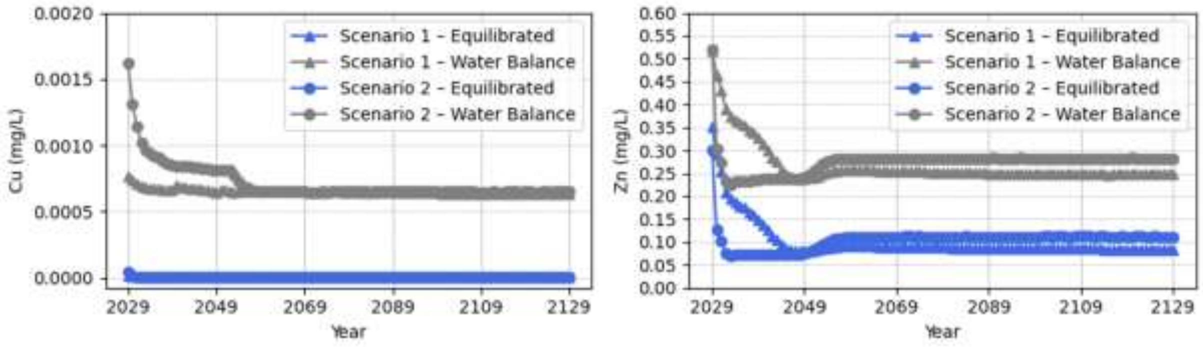

Figure 6-17: Modelled YEF copper and zinc after atmospheric equilibration, mineral precipitation and sorption on iron (oxy)hydroxides

6.2.5.3 *Summary pit water quality*

Table 6-11 presents YTF and YEF pit water quality in terms of key chemical parameters. This compares the water balance results of Scenario 2 with the thermodynamic model results 50 years into the 100-year modelling period (Year 2079).

Table 6-11: Summary of model estimated water qualities for the YTF and YEF pits for Scenario 2 after application of solubility controls and atmospheric equilibrium.

Chemical Para-meter	unit	YTF pit (Year 2079)			YEF pit (Year 2079)		
		Water balance (50th perc.)	Equilibrated with atmosphere	With mineral precipitation and sorption	Water balance (50th perc.)	Equilibrated with atmosphere	With mineral precipitation and sorption
pH	pH unit	5.09	6.62	4.50	5.50	7.61	7.51
Alkalinity	mg/L as $CaCO_3$	25	5.33	<0	55	40.8	28.3
TDS	mg/L	584	540	522	471	720	690
Ca	mg/L	7.37	7.37	7.37	4.45	4.45	4.45
Mg	mg/L	35	35.5	35.5	28	28.2	28.1
Na	mg/L	102	102	102	229	229	229
K	mg/L	1.46	1.46	1.46	2.48	2.49	2.49
SO_4	mg/L	214	214	214	58	58	58
Cl	mg/L	155	155	155	329	330	330
F	mg/L	0.114	0.114	0.114	0.055	0.0549	0.0549
Al	mg/L	0.173	0.173	0.173	0.301	0.301	0.00405
Fe	mg/L	19.9	19.94	5.98	11.7	11.7	0.00010
Mn	mg/L	0.58	0.582	0.582	0.166	0.166	0.166
As	mg/L	0.0030	0.0030	0.0030	0.0020	0.0020	<0.00001
Cd	mg/L	0.00003	0.00003	0.00003	0.00007	0.00007	<0.00001
Cr	mg/L	0.0004	0.0004	0.0004	0.0005	0.0005	<0.00001
Cu	mg/L	0.0023	0.0023	0.0023	0.0007	0.0007	<0.00001
Ni	mg/L	0.0079	0.0079	0.0079	0.0098	0.0098	0.00682
Pb	mg/L	0.0017	0.0017	0.0017	0.0002	0.0002	<0.00001
Zn	mg/L	0.103	0.103	0.103	0.282	0.282	0.112

6.2.6 Lake stratification

Lake stratification was assessed separately by Hydronumerics (2025). The technical report is provided in **Attachment C** A and summarised below.

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6.2.7 Climate influence

Climate sensitivity and the impacts of climate change are assessed for the preferred scenario (Scenario 2) using climate factors (i.e. dry and medium climate change factors applied to post 1975 reference period; **Section 4.5**) under probabilistic climate (100 replicates of stochastic climate datasets applied in 100 simulations or model runs; results are presented as probability distributions). As mentioned in **Section 6.1.3**, the lake water balance is sensitive to climate through Morwell River flood flows (connected lakes only), external catchment runoff, direct rainfall, and evaporation. However, during the fill and post filling phases (excluding Scenario 1), the lake inflows are not entirely climate dependent with the inflows being dominated by Latrobe water (fill or top-up). The impacts of climate change post fill are supressed largely by the top-up water (when required) and Morwell River inflows (when these occur). The impacts of climate change and the effect on lake water quality is highlighted by the median probabilistic TDS results for Scenario 2 (median climate) and Scenario 5 (dry climate) (**Figure 6-18**) and the probabilistic TDS results for Scenario 2 (**Figure 6-19**); there is negligible difference in median TDS at the end of the simulation between Scenario 2 and Scenario 5.

Overall, the influence of climate change and climate variability on the lake water quality is limited, due to the availability of Latrobe top-up water and Morwell River flood flows (for connected lake).

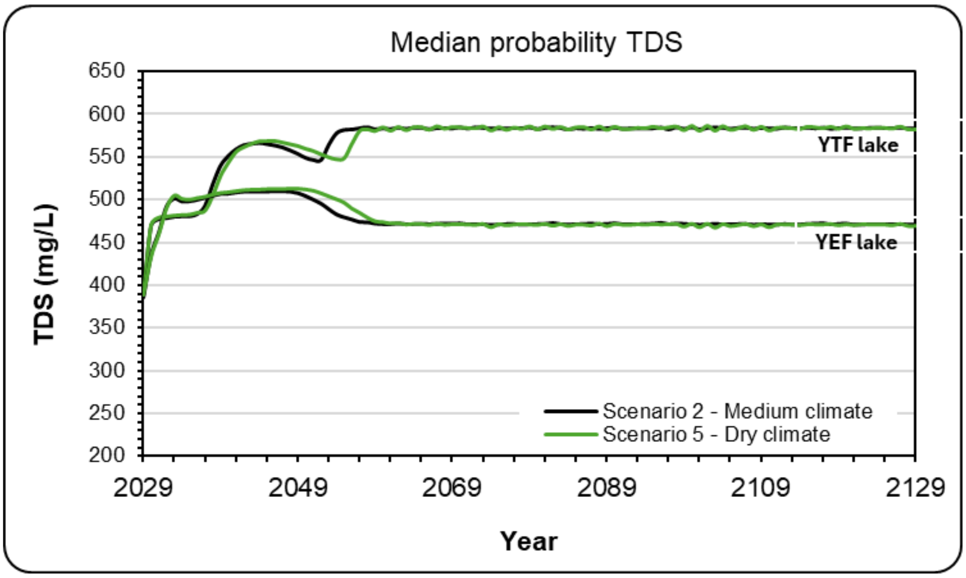

Figure 6-18: Medium probability TDS versus time for Scenario 2 (medium climate) and Scenario 5 (Dry climate).

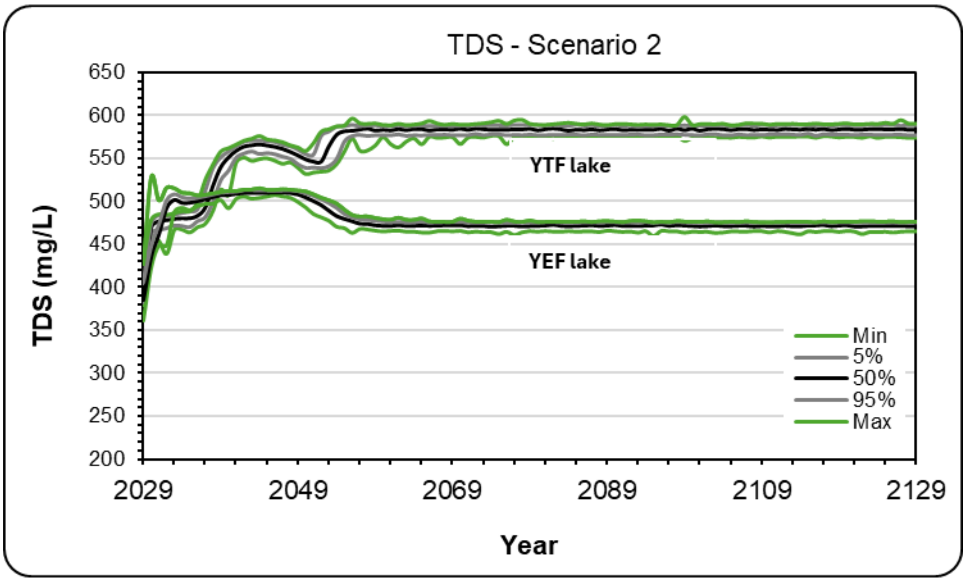

Figure 6-19: Modelling results for TDS probabilities for Scenario 2 (annual time steps).

7 Conclusions

The purpose of this report is to assess the potential lake(s) water balance and water quality associated with the project to inform the preparation of the DMRP. To assess the potential lake water balance and water quality, a numerical GoldSim WB/WQ model was developed with the following objectives:

1. Estimate the final lake(s) water quality at completion of filling and modelling of how the lake water quality will evolve into the future;
2. Modelling the demand for water to fill and maintain the lake(s) level during and beyond creation of the lake(s);
3. Assessment of how climate change and climate variability are likely to affect the water balance and water quality of the lake(s); and,
4. Comparison of the results for different fill option scenarios.

The key conclusions of the modelling for each of the scenarios are summarised in the following points.

The results discussed in this report are considered to be at an ‘inferred’ level of confidence. The key conclusions from the water balance are summarised in and in the following points:

- Scenario 1 (base case) did not reach fill elevation (+37 m AHD) over the simulation period (100-years); the maximum lake elevation reached is +15.5 m AHD for both the YTF and YEF lakes.
- For the other scenarios (Scenario 2 to Scenario 6), the modelling showed that the pit filled to RL +37 m AHD within 12.3 to 30 years with the mean values being 12.9 to 28.1 years (**Table 7-1**), depending on which fill scenario was modelled, climate variability/ uncertainty and if the Morwell River is connected.
- The climate change sensitivity analysis showed that the pit fill timeframes were sensitive to climate (medium versus dry showed a +2.8-year (mean probability) increase in fill time). The main reason for the variation in the time to fill the pit for the probabilistic simulations is largely driven by the large contribution of Morwell River flood flows, direct rainfall and catchment runoff to the water balance which are all climate dependent.
- The requirement for the top-up occurs when the evaporation from the lake surface (and groundwater seepage) exceeds the lake inflow volumes. The annual top-up, for those scenarios that require top-up (Scenarios 2, 3 and 6), varies between a mean of approximately 2.61 and 4.66 GL/year depending on the particular scenario (**Table 7-1**). There is an opportunity to reduce the top-up volumes by allowing a freeboard in the lake which would reduce the water loss via Spillway 4 (particularly if a flood event occurs shortly after top-up).

Table 7-1: Summary of water balance results

Scenario	Additional fill sources (annual)*	Morwell River connected?	Top-up?	Climate	Mean years (volume [GL]^) to fill	Mean annual top-up (GL/year)	Mean top-up volume (GL) over simulation
1	None	No	No	Median	NA	NA	NA
2	24 GL Latrobe water.	Yes (flood flows only)	Yes	Median	25.3 (606)	2.61	194
3	38 GL Latrobe water & 14 GL Moondarra water.	Yes (flood flows only)	Yes	Median	12.9 (620)	2.73	237
4	24 GL Latrobe water.	Yes (all)	Yes	Median	25.3 (606)	0.00	0
5	24 GL Latrobe water.	Yes (flood flows only)	Yes	Dry	28.1 (674)	4.66	334
6	24 GL Latrobe water.	No	Yes	Median	25.9 (621)	2.80	207

*Additional fill sources include those sources of fill that are not common to all scenarios (i.e. local catchment flow, natural groundwater, direct rainfall, pumped groundwater (1.5 GL to RL 0; 1 GL to RL 37; 0 GL ongoing) are consistent for all modelled scenarios.

^Volume pumped water to achieve first fill (+37 m AHD).

The key conclusions from the water quality modelling are summarised in the following points.

- The PHREEQC model predicted pH incorporating atmospheric equilibrium is ~pH 7 and pH 7.6 for the YTF and YEF, respectively. However, incorporation of thermodynamic constraints (i.e. precipitation of ion (oxy)hydroxides)) results in generation of acidity, consumption of alkalinity and a change in lake pH to 4.5 and 7.5, in the YTF and YEF, respectively.
- The modelled acidic pH in YTF is likely due to the iron concentration inputs in the WB/WQ model which may be significantly overestimated due to colloids passing through 45 µm filter for field water samples. If this is the case, iron (oxy)hydroxide precipitation may not release enough acidity to neutralise the available alkalinity in the YTF pit water. Similarly, groundwater inflows from the HHF may oxidise prior to entering the lake; this would also result in a decrease in the iron inputs. Further detailed thermodynamic modelling of source terms and pit lake water may be required to resolve this.
- The general water quality trends for the lake varies for different modelled parameters and reflect the water balance inputs and geochemical source terms during the fill (Latrobe water fill [scenario 2-6], direct rainfall, catchment runoff and Morwell River flood flows (connected only)) and post fill phases (direct rainfall, catchment runoff, Latrobe water top-up (if required) and Morwell River flood flows (connected only)).
- Although the trends differ between scenarios, there is only a relatively tight range in salts and metal and metalloid values between modelled scenarios (e.g. the mean probability TDS range at the end of the simulation for Scenario 2, 3, 5 and 6 is 575 mg/L (minimum) to 591 mg/L (maximum) for YTF lake and 465 mg/L (minimum) to 476 mg/L (maximum) for YEF lake). The tight range in modelled lake water quality values is due to the fill and top-up water qualities dominating the lake water balance regardless of scenario.
- The water qualities for each of the scenarios and sensitivities for all scenarios are dominated by the major ions (namely sulfate, chloride and sodium), with metal and metalloid concentrations relatively low in comparison.
- Comparison of the modelled lake water qualities to the assessment criteria is used to determine potential reduced lake water quality. As mentioned above, the assessment criteria includes the revised *Australian and New Zealand Guidelines* for freshwater aquatic ecosystem (95% species protection) and the recommended guidelines for livestock drinking water (ANZG, 2018) as well as the *Australian Drinking Water Guidelines* (NRMMC, 2011). As mentioned previously, the ANZG freshwater aquatic ecosystem water quality guidelines are considered highly conservative for a pit lake assessment, since they are typically applied in the context of the management of natural and semi-natural water resources. Comparison of the modelled mass balance metals and metalloids to these guidelines indicate that:
  - all modelled parameters are below the livestock drinking water guidelines (ANZG, 2018) for all probabilities and scenarios.
  - Aluminium and zinc exceed the freshwater aquatic ecosystem (95% species protection) guideline (ANZG, 2018) in the YTF and YEF for each of the scenarios over the simulation period.
  - The cause of the aluminium exceedance is due to several source term inputs which also show exceedance: Latrobe water, Morwell River, groundwater and Latrobe top-up (amongst other sources). It is common for colloidal aluminium (and iron) to pass through size 45 µm filter paper resulting in an overestimation of the dissolved concentration. Thermodynamic modelling indicated that some aluminium may precipitate out of the lake as gibbsite (or aluminium (oxy)hydroxide) resulting in corrected concentrations below the guideline (see below).
  - The cause of the zinc exceedance is due to multiple sources, including rainfall and groundwater (natural and pumped).

  - Copper exceeds the freshwater aquatic ecosystem (95% species protection) guideline in the YTF for each of the scenarios over the simulation period. However, copper concentrations are below guidelines in the YEF except for Scenario 4 where the large Morwell River inflow causes an exceedance in copper concentration after 25 years (shortly after being fully integrated with Morwell River).
  - The cause of the copper exceedance (where noted above) is mainly due to Latrobe water, Morwell River, groundwater (natural and pumped) and local rainfall quality.
  - Lead exceeds the freshwater aquatic ecosystem (95% species protection) guideline in the YEF for each of the scenarios over the simulation period. However, lead concentrations are below guidelines in the YEF except for Scenario 4 where the YEF and YTF are mixed, resulting in a large increase in lead concertation in the YTF and a decrease in lead concertation in the YEF after 25 years (shortly after being fully integrated with Morwell River).
  - As highlighted above, copper and zinc levels are elevated relative to freshwater aquatic ecosystem (95% species protection) guideline throughout the Morwell and Latrobe catchments. Copper and zinc levels are present in rainfall at concentrations of approx. 50 µg/L, possibly due to burning of coal at power stations throughout the Latrobe Valley. It is expected that a reduction in the burning of coal in the Latrobe Valley will reduce the supply of copper and zinc to the system and thus reduce the modelled lake concentrations for these parameters.
  - Similarly, the elevated lead concentrations in the YEF, relative to freshwater aquatic ecosystem (95% species protection) guidelines, are associated with runoff and seepage from the pit walls and floor, which is also likely due to burning of coal at power stations throughout the Latrobe Valley. As the burning of coal in the Latrobe Valley is reduce the supply of lead to the system is also expected to decrease and so will the modelled lake lead concentrations.
  - Manganese slightly exceeds the ADWG for all scenarios in the YTF lake after ~10 to 25 years; noting that there are no exceedances for manganese in the YEF lake. The full integration of Morwell River into the lake (Scenario 4) reduces the estimated manganese concentration below ADWG. The cause of the manganese exceedance, relative to ADWG, is due mainly to seepage from the Former Ash Ponds and NOB Dump.
  - Some of the elevations likely reflect the static nature of the geochemical source terms used in the model. As above, some source term qualities may improve with time improving the modelled lake water qualities.
  - For the YEF, the thermodynamic modelling showed that when allowed to precipitate, iron (oxy)hydroxides remove dissolved aluminium from the pit water significantly reducing dissolved aluminium concentration from ~0.3 mg/L to <0.005 mg/L (i.e. below guideline value). Similarly, sorption of copper and zinc ions on precipitating iron (oxy)hydroxides resulted in notable concentration decreases. Mass balance copper decreased to <0.0001 mg/L on thermodynamic modelling. Mass balance zinc decreased significantly but still exceeded the freshwater aquatic ecosystem (95% species protection) guideline.
  - For the YTF, the thermodynamic modelling had little influence on the mass balance results for aluminium, manganese, copper and zinc because of the low modelled pH conditions which increase metal solubility keeping metals in solution. However, as mentioned above, if the modelled acidic pH in YTF is due to overestimated iron concentration inputs in the WB/WQ model, then correction/ update could result in neutral pH conditions and decreased solubility which would decrease modelled concentrations similar to the values modelled
- Lake stratification was assessed separately by Hydronumerics (2025). The simulations indicate...Hydronumerics to update

- Climate sensitivity and the impacts of climate change on the lake water quality is limited, due to the dominance of fill inputs, and the availability of Latrobe top-up water and Morwell River flood flows (for connected lake).

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