Sustainable Minerals Institute
18 May 2020

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

ENSHAM Residual Void Project

Summary of Water Studies

Contact Person
Dr Claire Côte, Sustainable Minerals Institute | The University of Queensland
Phone: +61 7 3346 4061 | Email: c.cote@uq.edu.au

Summary

Ensham Mine has undertaken detailed technical studies to assess various options for the rehabilitation of the open cut mining areas near the Nogoa River and up in the escarpment country. These studies led to the selection of the Submitted Option, which consists of a landform either side of the floodplain that excludes the rehabilitated open cut mining areas on both sides of the Nogoa River from the floodplain. This requires a detailed assessment of any potential interactions between water retained in these landforms and the receiving environment.

For the purpose of this report, the following definitions are used:

Landform refers to the area comprising the existing levee and improvements that will exclude the rehabilitated open cut mining areas from the floodplain.

The Rehabilitated open cut mining areas are the partially backfilled voids left by open cut mining. They include the following rehabilitation domains:

- Native Bushland Corridor,
- Self-sustaining vegetative cover, and
- Grazing and Water Habitat.

To predict how much water would be collected by the rehabilitated open cut mining areas and whether any of this water would be transferred to the receiving environment, a water balance model was developed to simulate all flows in and out of the rehabilitated open cut mining areas, including interactions with groundwater and prediction of water quality. Information related to groundwater was generated by a groundwater assessment and associated model. Information related to geochemistry and solute transport, which is required to predict water quality, was derived from laboratory experiments on spoil material (leaching tests) and application of a standard methodology. Rainfall, runoff and evaporation were calculated with climate data derived using standard practices. The model simulated the water quantity and quality in the water body on a daily basis and included an analysis of the sensitivity of the predicted results to climate change, evaporation calculation methodology and initial water levels in the pits.

Model results show that:

- For the rehabilitated open cut mining areas that will maintain a permanent water body in the long term, the water level will fluctuate around an average equilibrium level in response to climate variations; this equilibrium level is not overly sensitive to assumptions related to climate scenarios, evaporation calculations and initial water storage volume.
- water retained in the rehabilitated open cut mining areas does not reach levels that result in overflow to the environment via surface pathways. As such, there is no risk of water being exported to surrounding creeks and rivers.
- water in the rehabilitated open cut mining areas (including under climate change scenarios) remains beneath the regional groundwater levels: there is no flow to the regional groundwater system.
- concentrations in salt and metals increase but given that there is no export of water to surface water or groundwater, this does not pose a threat to the receiving environment.
- water retained in the rehabilitated open cut mining areas does not pose any concern to the landform structure and function as it does not come into contact with the landform.

Based on the above dot points, the rehabilitated open cut mining areas are predicted to be non-polluting.

In addition, the post-mining water balance is such that there are no predicted changes to the Nogoa River stream losses and negligible effect on the interactions between the river and aquifers.

1. Introduction

The Ensham Mine (Ensham) is an open cut and underground bord and pillar coal mine in the Bowen Basin, located 35 km east of Emerald along the Nogoa River in Central Queensland. In accordance with its Environmental Authority, Ensham has undertaken a Residual Void Project (RVP) to assess options for the rehabilitation of final open cut mining areas.

Initially, three Preferred Options were considered:

1. Landform Levee
   Create a landform along the existing levee alignment to provide flood immunity up to the 0.1% (1 in 1,000) Annual Exceedance Probability (AEP) flood event plus 0.5m.
2. Flood Mitigation and Beneficial Use
   Incorporate engineered intake structures into the existing flood levees to capture a proportion of high flow flood water, using the rehabilitated open cut mining areas as water storages with the potential to supply the stored water for beneficial use.
3. Backfill to PMF
   Backfill the open cut mining areas located within the pre-mining floodplain up to the elevation of the original floodplain within the lateral extent of the pre-mining Probable Maximum Flood (PMF) level.

These options were analysed in detail in previous studies, as summarised in the report prepared by HEC (HEC, 2020). Based on feedback received from DES and DNRME in January 2019, Option 2 was revised and no longer considers actively storing water in the rehabilitated open cut mining areas for beneficial reuse. The predominant land use will be grazing, with some rehabilitated open cut mining areas holding a permanent water body fed by surface runoff and groundwater inflows. This revised option is called the Submitted Option. It has the same rehabilitated open cut mining area treatments as Option 2 but without the engineered structures to harvest water from the Nogoa River. A South and E rehabilitated open cut mining areas will be partially backfilled so that these areas do not retain water. The existing flood levees are incorporated into the landform design and will provide protection against floods with an AEP of 0.1% plus 0.5m. The term “landform” is used to refer to the area comprising the existing levee and these improvements. The Submitted Option and its potential impacts on water resources were assessed. This report addresses this additional investigation.

Detailed technical studies were undertaken to predict:

- water levels in the rehabilitated open cut mining areas that will maintain a water body in the long term, and the time required for the water level to reach long-term equilibrium conditions;
- the interactions of the water with the surrounding surface and groundwater systems;
- whether during prolonged or extreme wet periods, water in the rehabilitated open cut mining areas is expected to reach levels that would result in ponding against the inward facing toe of the landform or overflow to the receiving environment via surface pathways;
- changes in water quality, with a focus on total dissolved solids (salinity), calcium, chloride, magnesium, potassium, sodium, sulfate, arsenic, molybdenum and selenium.

2. Overview of Methodology

For simplicity, the water assessments refer to the rehabilitated open cut mining areas as "pits", conceptually representing the depressions that will contain the water.

A water balance model was developed to simulate all flows in and out of the pits, including interactions with groundwater and prediction of water quality (HEC, 2020). Information related to groundwater was generated by a groundwater model (Hydrosimulations, 2020). Information related to geochemistry, which is required to predict water quality, was provided by SRK with data collection by RGS (RGS, 2018; SRK, 2020).

A conceptual representation of the water balance model (HEC, 2020) is provided below.

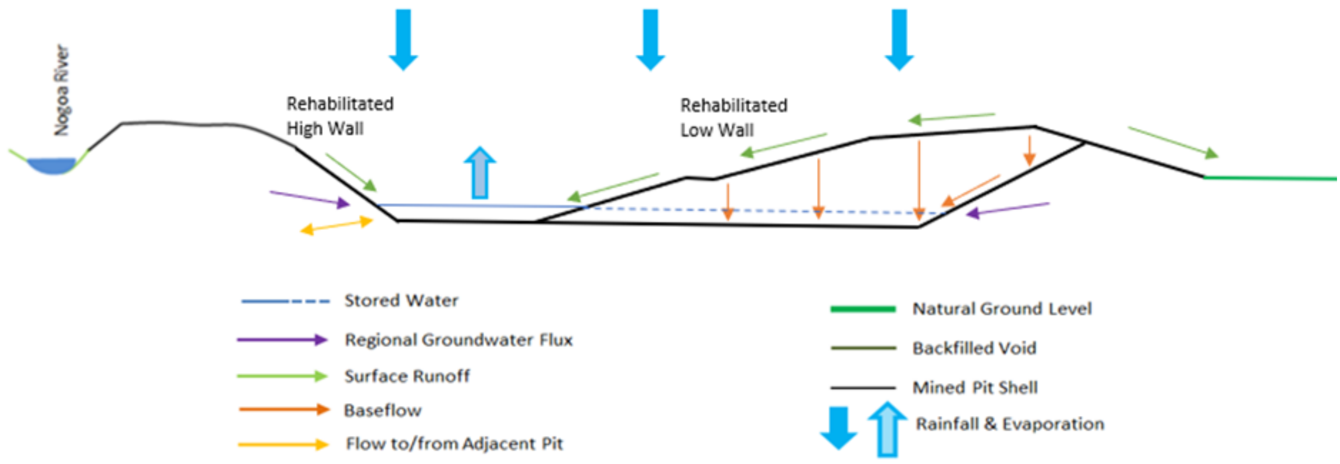


Figure 1: Conceptual Model of Pit Water Balance

This diagram shows that the inputs of water are rainfall and runoff, baseflow[1] (infiltration through the spoil pile that eventually drains to the base of the rehabilitated open cut mining areas) and groundwater flow. The outputs of water are evaporation, potential flow to the regional groundwater system and potential spill to the receiving environment. With the option that is the focus of this summary, there is no input of water from the Nogoa River and there is no water extraction from the rehabilitated open cut mining areas.

The water and salt balance model was developed using the GoldSim® simulation package. Rainfall, runoff and evaporation are calculated using a water balance model (AWBM) with climate data derived using standard practices (HEC, 2020). Final design of the rehabilitated open cut mining area topography was supplied by Ensham and was used to derive catchment areas, spoil volumes and pit geometry. The relationships between water level, stored water volume and surface area were calculated using pit shell geometry, spoil volumes and porosity data.

The model simulated the water quantity and quality in the rehabilitated open cut mining areas on a daily basis with the timestep being reduced to 1 hour during periods of high transfer (such as a spill between pits).

Modelling has included sensitivity analysis to assess the potential impact of:

[1] In hydrology, baseflow refers to the portion of streamflow that is sustained between precipitation events, usually fed from bedrock water storage in riparian zones. The flow of water through spoil piles is a flow through a porous medium that behaves similarly as it can lead to water input into the pits in dry periods.

- Climate change: a conservatively high emissions scenario was selected, which predicts for 2050 an increase in annual evapotranspiration combined with lower annual rainfall.
- Uncertainty of evaporation calculations: evaporative losses are calculated with a simple approach that combines average monthly pan evaporation rates and a pan factor. There is uncertainty associated with the selection of the pan factor and the impact of a different values was assessed.
- Initial water level in the rehabilitated open cut mining areas.

3. Interaction with Groundwater

For the purpose of predicting final water levels in the rehabilitated open cut mining areas and analysing the potential interactions between the rehabilitated open cut mining areas and groundwater, a detailed hydrogeological assessment was undertaken (Hydrosimulations, 2020), which comprised description and modelling of water flow through:

- The two main groundwater bearing units: the alluvium (quaternary sediments) and the Permian Rangal coal measures. The alluvium is an unconfined system recharged by rainfall and irrigation practices. Its water is saline and unsuitable for uses such as stock watering or irrigation. The alluvium is not well connected with the Nogoa River. The most permeable lithological units are the coal seams, which form aquifers with low transmissivities that are confined by overlying and underlying shales and mudstones. Groundwater in the coal seams is also saline and not suitable for stock water supply or irrigation. These groundwater bearing units are referred to as the “regional groundwater system”.
- The underground workings: groundwater flow direction in the Rangal Coal Measures is not well defined but data indicates that groundwater from the seams flows primarily towards underground workings. When underground workings are in close proximity to rehabilitated open cut mining areas, there can also be pathways with relatively high hydraulic conductivity that convey water from the rehabilitated open cut mining areas to the underground workings. This will impact on the water levels in the rehabilitated open cut mining areas, which will only stabilise once the underground workings have filled with water. Groundwater levels in the regional system are always higher than the underground workings so there cannot be flow from the underground workings to the regional groundwater system. There can only be flow between the rehabilitated open cut mining areas and the underground workings.
- Waste material: as open-cut operations progress, pits are backfilled with waste material. This creates a porous medium through which water can flow. This water is treated as groundwater. Similar to an aquifer, the waste material is assigned hydraulic properties to simulate the interaction with water in the pit.

A groundwater model was used to simulate these flow components and is described in the Hydrosimulations Groundwater Assessment report (2020). It provided estimates of:

- the potential drawdown in the regional groundwater system as a function of time and the level at which the groundwater table will stabilise after mining activities has ceased. This level is referred to as “recovery” level.
- For each individual rehabilitated open cut mining area, the groundwater fluxes through the waste material, which can be from one pit to another or to the underground mining area. There is waste material between the A rehabilitated open cut mining area and the B rehabilitated open cut mining area so A and B are hydraulically connected. Similarly, there is waste material between the CD rehabilitated open cut mining area and the E rehabilitated open cut mining area so CD and E are hydraulically connected.
- For each individual rehabilitated open cut mining area, the relationship between the water level in the rehabilitated open cut mining area and the net groundwater flow into or out of the rehabilitated open cut

mining area. In the Hydrosimulations Assessment report (2020), these relationships are referred to as Stage-Discharge Tables, where “stage” refers to the water level in the rehabilitated open cut mining area and “discharge” refers to the net groundwater flow. If the net groundwater flow is positive, the rehabilitated open cut mining area loses water to the groundwater system. If the net groundwater flow is negative, the rehabilitated open cut mining area gains water from the groundwater system. The groundwater system is the combination of regional groundwater system (mainly coal measures) and waste material. Net groundwater flow is used because the model results are too complex to split the flow into individual components.

The Stage-Discharge tables were incorporated into the surface water balance model to calculate groundwater flow. As such, the model incorporates two types of flow through waste material:

- Rain infiltrates into the waste piles, which creates a baseflow through the material that drains to the pit. This is effectively a surface water component that is treated independently from the groundwater system;
- Water stored in the rehabilitated open cut mining areas can flow into surrounding waste material and be conveyed to underground workings or can flow from one rehabilitated open cut mining area to another. This is the case for the A and B rehabilitated open cut mining areas, which are “connected” by flow through porous material. This component is incorporated into the net groundwater flow derived from the groundwater model.

The hydraulic connections between the rehabilitated open cut mining areas add complexities to the detailed calculations but do not impact on overall site water balance and long-term average final water levels. It does pose challenges to the prediction of water quality, as discussed in the next section.

In the previous version of the water balance model, the calculation of flows due to hydraulic connections between rehabilitated mining areas had been included twice: in the GoldSim® model itself but also in the Groundwater Stage-Discharge tables. This duplication was identified and the calculation of these flows was removed from the GoldSim® model. With the duplication removed, predictions of water levels in the rehabilitated mining areas are lower than those in the previously submitted reports, and always below regional groundwater levels as provided in the Void Water Quantity and Quality Balance Report (HEC, 2020).

Beyond the prediction of final water levels in rehabilitated open cut mining areas, the post-mining water balance is such that there are no predicted changes to the Nogoa River stream losses and negligible effect on the interactions between the river and aquifers.

4. Prediction of water quality

Water infiltrating through the spoil material will trigger a range of chemical reactions that will lead to various solutes or metals being exported to the rehabilitated open cut mining areas and will contribute to final water quality. There are many geochemical processes that can impact on water quality and the geochemical characteristics of the spoil determine which processes are likely to be the most prevalent. These cannot be represented in detail as they are too complex. A simplified approach was adopted, based on a methodology provided by SRK (2020) supported by some test results (RGS, 2018)

Samples of spoils were analysed by RGS and the results indicated that the key geochemical processes are dissolution and transport of salts (total dissolved solids, calcium, chloride, magnesium, potassium and sodium) and oxidation of sulfide minerals that will release sulfate and associated metals and metalloids, primarily Arsenic, Molybdenum and Selenium.

Salts are immediately soluble and will be mobilised by water flow. Leaching tests performed by RGS showed that salt concentrations in the leachate from the spoil material declines over time, with a solute concentration reduction of about 50% for each pore water volume displacement. A decay curve predicting the likely evolution of salt concentration in the flow from the spoils was derived based on these results.

Oxidation of sulfide minerals will depend on the rate of oxygen ingress into the spoil, which was calculated to provide an estimate of the depth of oxygen ingress. It was estimated that sulfide minerals would be fully oxidised in a 20 m high spoil pile after about 130 years. After this time, no additional solutes would be generated but the accumulated solutes would continue to be flushed from the spoil in a process similar to that defined for salts. This analysis provided the evolution of Arsenic, Molybdenum and Selenium concentrations in the flow from the spoils and produced decay curves for these elements.

Water quality in the rehabilitated open cut mining areas will also be influenced by flows from the regional groundwater system, which are captured in the water and solute balance model as a net groundwater flow (the combination of flow from the regional groundwater system and flow through waste material). This poses a challenge as solute concentration in the regional groundwater system may not be the same as that in the waste material. This limitation is not significant in the context of the geochemical simplifications that had to be adopted to produce water quality estimates.

5. Results

Modelling results show that some of the rehabilitated open cut mining areas will maintain a permanent water body with a water level that will fluctuate around a steady-state ‘equilibrium’ level in response to climate variations. Equilibrium level is predicted to be reached after 50 years for the A rehabilitated open cut mining area, 100 years for the B rehabilitated open cut mining area, 150 years for the CD rehabilitated open cut mining area and 75 years for the E rehabilitated open cut mining area. The modelling results are shown in Figures 142 to 145 of the Void Water Quantity and Quality Balance Report (HEC, 2020).

The schematics below in Figure 2 shows the predicted long-term average water level in each rehabilitated open cut mining area. It also shows the volume occupied by free water (in blue) and the volume of water stored in the spoil piles (in grey). As all rehabilitated open cut mining areas contain backfilled spoil at the lowest points, water is stored in spoil below the level of visible water.

As seen in Figure 2, all predicted long-term average water levels are below the external “spill” level (the level at which water would overflow out of the rehabilitated open cut mining area). There will be no export of water from the rehabilitated open cut mining areas to surface water in the receiving environment. Predicted water levels in the rehabilitated open cut mining areas were compared with the recovery level of the groundwater table in the regional system: for the Submitted Option, all predicted water levels within the rehabilitated open cut mining areas are beneath the regional groundwater levels, as shown in Figure 2 of this report and Figures 163 to 166 of the Void Water Quantity and Quality Balance Report (HEC, 2020). Groundwater will flow from the regional system to the rehabilitated open cut mining areas. There will be no flow from the rehabilitated open cut mining areas to the regional groundwater system.

There is some sensitivity of the water levels within the rehabilitated open cut mining areas to climate change and evaporation calculations, which reflect the scenario assumption (for instance, with the climate change scenario, a lower level is predicted as the climate data set has lower annual rainfall). These variations are not significant as seen in Figure 3 below. Detailed results are provided in Figure 163 to 166 of the Void Water Quantity and Quality Balance Report (HEC, 2020). This does not influence the key results: the model does not predict any export of water from the rehabilitated open cut mining areas to surface water or regional groundwater.

The Void Water Quantity and Quality Balance Report also includes predicted concentrations of total dissolved solids, major ions and trace elements for the simulation period, shown in Figure 152 to Figure 162 (HEC, 2020). In the water quality modelling, the leaching behaviour of all modelled solutes is based on that of salts (as explained in Section 4 above). As such, the predicted concentrations of total dissolved solids provide a good overview of water quality predictions and they are reproduced here in Figure 4. In rehabilitated open-cut mining area A, concentrations reach an equilibrium after about 20 years. This is because there is flow through the porous medium from area A to B. There is a balance between the inputs and outputs of solutes so that concentrations remain around a stable value. For rehabilitated open-cut mining areas B, CD and E, concentrations are predicted to keep increasing. This is because the only outflow from these areas is via evaporation, which does not contain solutes. There is no output of solutes and concentrations increase with time. Given that the water held in the rehabilitated open cut mining areas does not reach levels that result in overflow to surface water or groundwater, this does not pose a threat to the receiving environment. In addition, it is not proposed to use the water for any purpose.

Based on these results, all rehabilitated open cut mining areas are predicted to be non-polluting.

Opportunities to further reduce groundwater daylighting in the final rehabilitated open cut mining areas have been assessed post lodgement of the Submitted Option. It is proposed that the rehabilitated open cut mining areas A South and E will be partially back-filled such that groundwater will not daylight in either of these rehabilitated open cut mining areas. In addition, the land barrier separating the E rehabilitated open cut mining area from the CD rehabilitated open cut mining area will be removed. Surface water runoff produced during rain events will drain to the CD rehabilitated open cut mining area.

Where groundwater does daylight in the rehabilitated mining areas in the long term, access to water in the rehabilitated open cut mining areas will be prevented by installing fences. The water is not intended for use in agriculture (irrigation and stock use), for drinking or recreation. As such the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) Guidelines for these water types are not applicable.

The prediction of groundwater recovery levels for the submitted option as shown in Table 15 of the groundwater assessment (Hydrosimulations, 2020) will be used for the engineering design of backfilling requirements.

Predicted levels were also used to assess potential interactions between these water bodies and the landform. The water retained in the rehabilitated open cut mining areas does not pose any concern to the levee structure and function as it does not come into contact with the landform (Ensham, 2020). The history of the current levees and the performance of these levees is covered in more detail in the Landform Report. The report also includes a detailed description of the proposed landform for the Submitted Option.

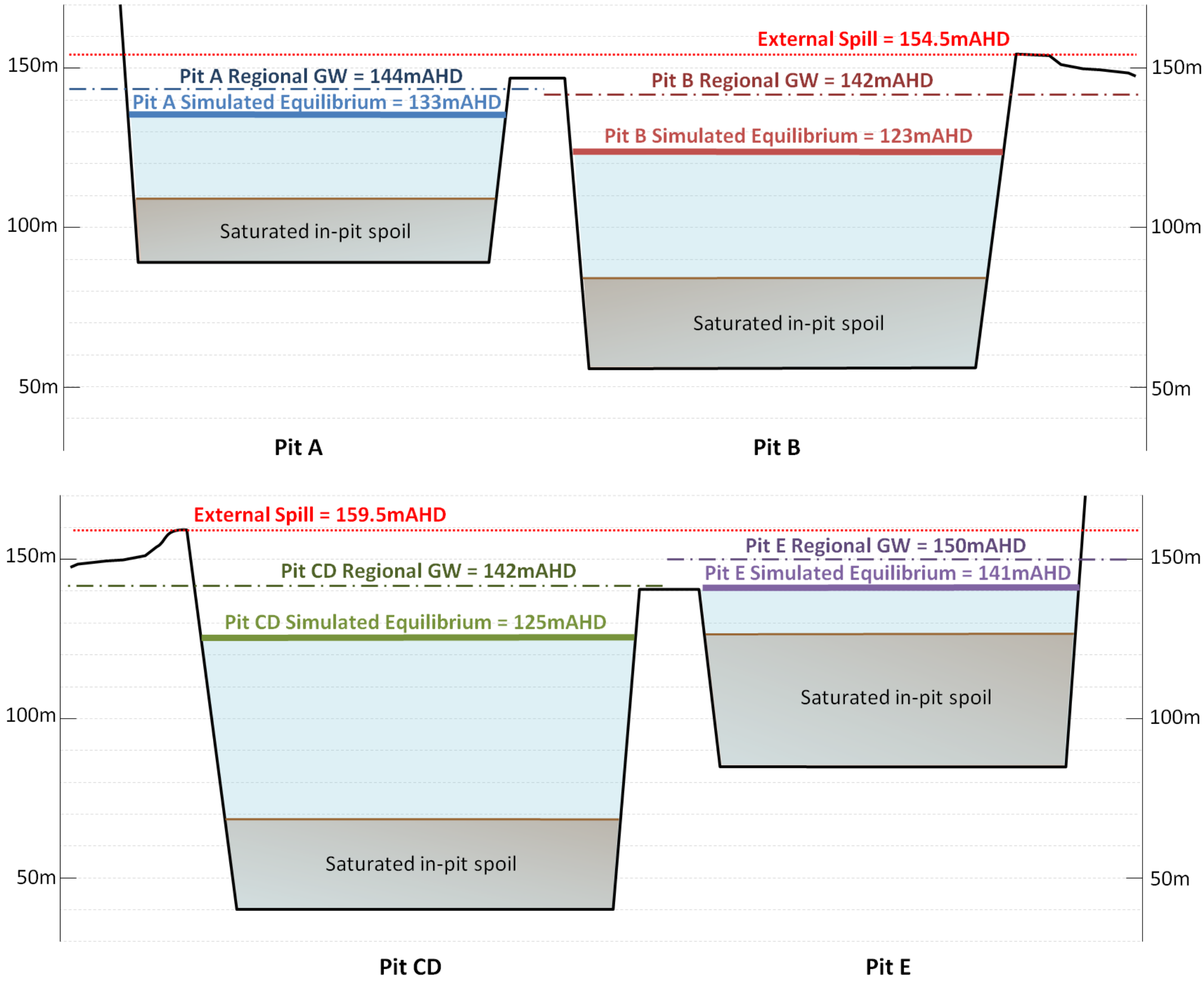


Figure 2: Predicted water levels (from HEC, 2020)

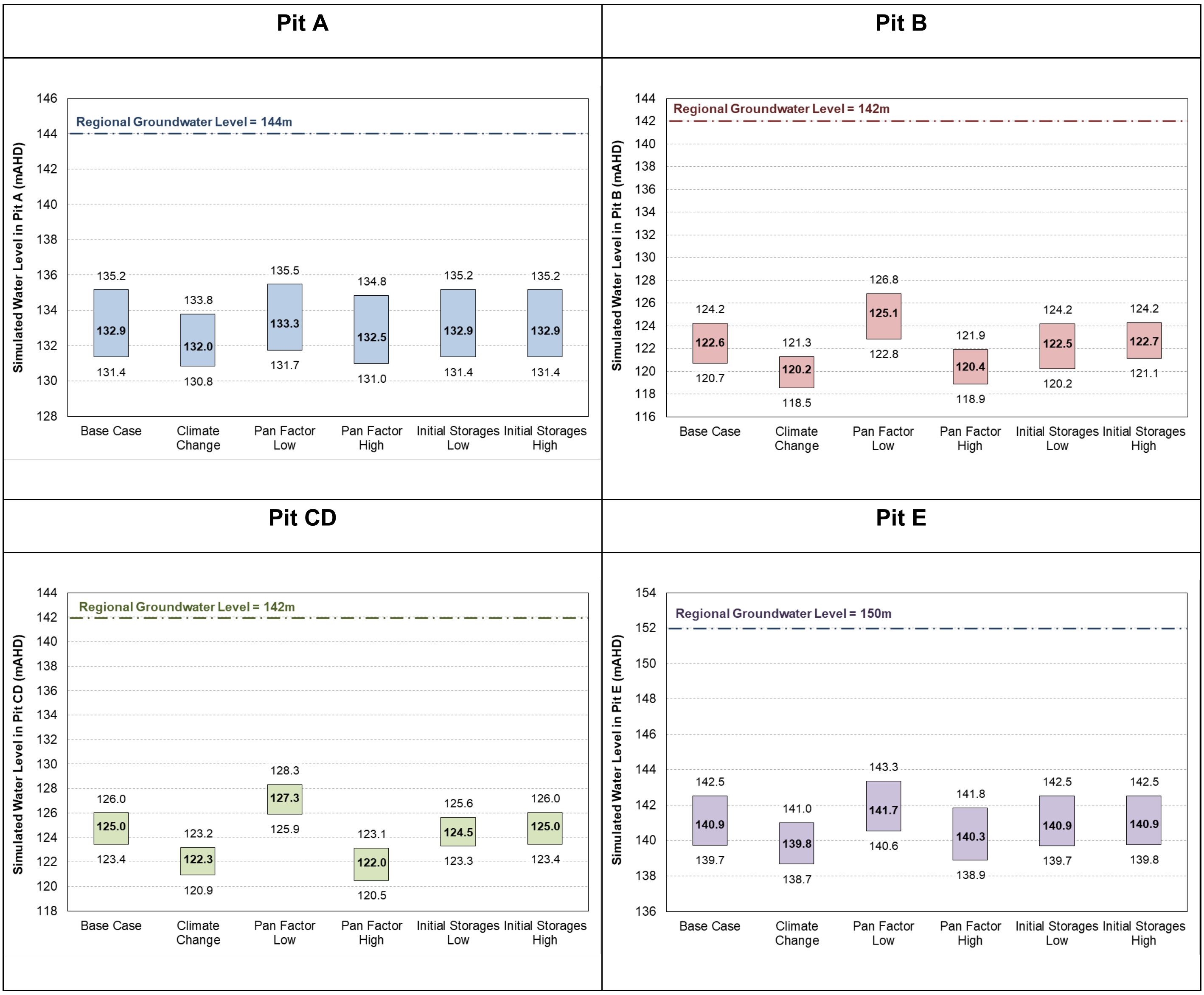
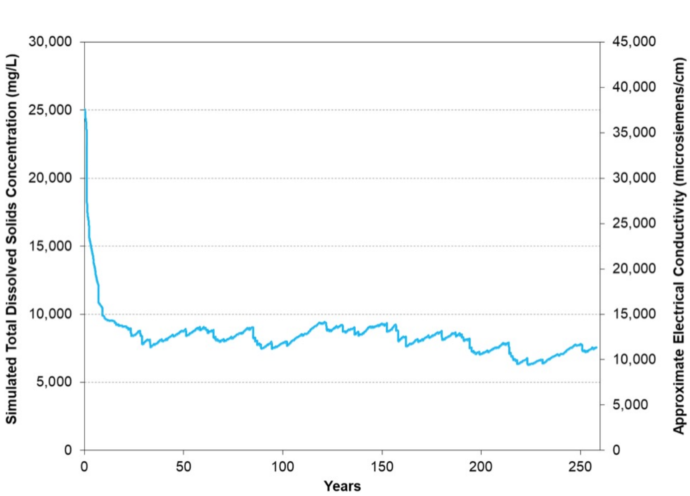
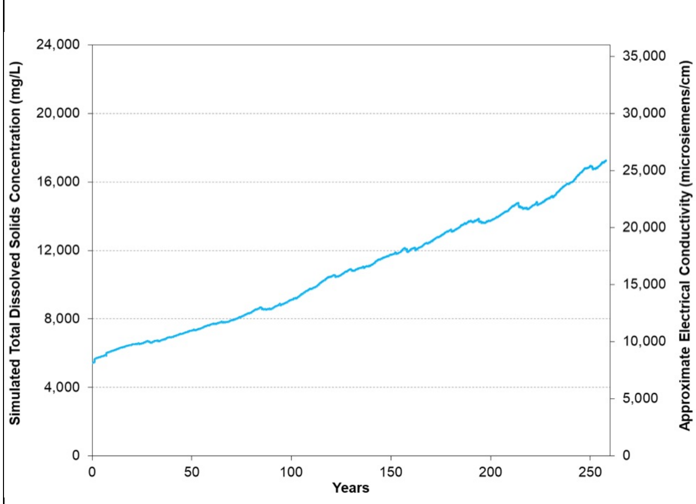


Figure 3: Sensitivity of Predicted Water Levels (from HEC,2020)

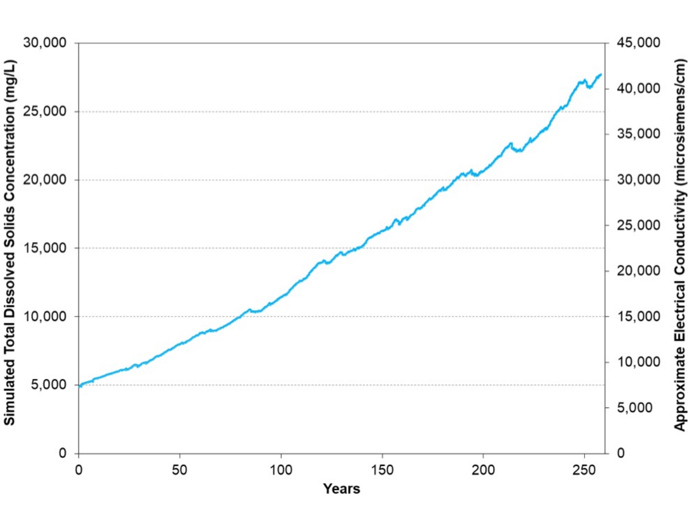
Pit A



Pit B



Pit CD



Pit E

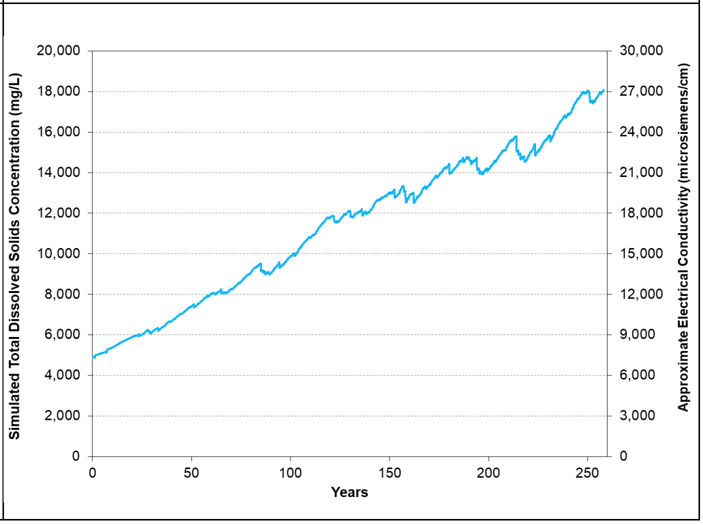


Figure 4: Predicted Total Dissolved Solids concentrations (from HEC,2020)

6. Conclusions

Predictions from the detailed technical studies that were undertaken to predict post-mining water balance and water quality and included a detailed analysis of the interactions between surface water and groundwater, are that:

- some final rehabilitated open cut mining areas will maintain a water body with a water level that fluctuates around an average equilibrium level in response to climate variations; this equilibrium level is not overly sensitive to assumptions related to climate scenarios, evaporation calculations and initial water storage volume.
- water in the rehabilitated open cut mining areas does not reach levels that result in overflow to the environment via surface pathways. As such, there is no risk of water being exported to surrounding creeks and rivers.
- water levels in the rehabilitated open cut mining areas (including under climate change scenarios) remains beneath the regional groundwater levels: there is no flow to the regional groundwater system.
- concentrations in salt and metals are predicted to increase in areas B and CD (given that E rehabilitated area is proposed to be backfilled above the groundwater rest level as an additional treatment post stage 3, as described in the Landform Report (Ensham 2020)) but since there is no export of water to surface water or regional groundwater, this does not pose a threat to the receiving environment.
- all rehabilitated open cut mining areas are predicted to be non-polluting.
- Access to water in the rehabilitated open cut mining areas will be prevented by installing fences. The water is not intended for use in agriculture (irrigation and stock use), for drinking or recreation. As such the ANZG 2018 Guidelines for these water types are not applicable.
- water retained in the rehabilitated open cut mining areas does not pose any concern to the landform structure and function as it does not come into contact with the landform.
- In addition, the post-mining water balance is such that there are no predicted changes to the Nogoa River stream losses and negligible effect on the interactions between the river and aquifers.

7. References

ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality.

HEC - Hydro Engineering & Consulting Pty Ltd. 2020. Ensham Coal Mine Residual Void Project. Submitted Option: Void Water Quantity and Quality Balance Modelling. Prepared for Ensham Resourced Ltd.

Hydrosimulations. 2020. Residual Void Project: Groundwater Assessment Stage 3. Prepared for Ensham Resourced Ltd.

RGS. 2018. Technical Report: Material Characterisation and source term development for the Ensham Coal Mine Final Void Plan. Prepared for Ensham Resources Pty Ltd.

SRK. 2020. Project Memorandum: Sulphide and Metal/Metalloid Source Depletion Estimates. Prepared for Ensham Resources Pty Ltd.

Ensham. 2020. Ensham Final Landform Design, Stage 3 Technical Report, prepared for Ensham Resources Pty Ltd.