HYDRO ENGINEERING & CONSULTING PTY LTD

FINAL REPORT

Ensham Coal Mine
Residual Void Project: Stage 3
Void Water Quantity and Quality Balance Modelling

Prepared for: Ensham Resources Pty Limited

This document should not be distributed, nor any reference to it made, to any person or organisation not directly involved in making decisions on the subject matter of this document.

Revision	Description	Author	Reviewer	Approved	Date
s	Final	DNB	TSM	TSM	19/05/2020

CONFIDENTIAL

38a Nash Street
Rosalie QLD 4064
p (07) 3367 2388

PO Box 1575
Carindale QLD 4152
www.hecons.com
ABN 11 247 282 058

EXECUTIVE SUMMARY

Ensham Resources Pty Ltd (Ensham) is considering options for the management of final open cut mine voids located near the Nogoa River – Pits A and B are located on the southern side and Pits C, D, E, F and Y are located on the northern side of the Nogoa River. A Residual Void Project (RVP) is being undertaken in accordance with Ensham Coal Mine's Environmental Authority. Stage 3 of the RVP comprises detailed design of the preferred options. The three preferred options considered and the Submitted Option are:

Option 1: Landform Levee – landform along the existing levee alignment that provides flood immunity for the 0.1% (1 in 1,000) Annual Exceedance Probability (AEP) flood event. The existing levees will be incorporated into the landform design with overburden emplacement areas behind the levees being reshaped in a manner that achieves the minimum stable landform slope requirements.

Option 2: Flood Mitigation and Beneficial Use – with existing flood levees modified to incorporate engineered intake structures allowing flow into the voids to utilise the post-mining voids as water storages to capture a proportion of high flow flood water and store this water for potential beneficial use.

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

Submitted Option:

Following feedback from the Department of Environment and Science and the Department of Natural Resources Mines and Energy, Option 2 was revised and no longer has a water reservoir as a post mining land use, but now has a predominantly grazing land use. The revised option is called the Submitted Option. This option has the same design criteria as preferred option 2 for the rehabilitation of the open cut mining areas but excludes the engineered intake structures which allow water capture from the Nogoa River. It is also proposed to incorporate the existing levees into the landform design, with overburden emplacement areas behind the levee being reshaped in a manner that achieves a stable landform. This landform would possess 0.1% AEP flood protection.

The Stage 3 water balance has been built on the work undertaken for Stage 2 and included:

- initial model calibration;
- updating model assumptions (landforms, groundwater flux and geochemistry) for all three preferred options and the Submitted Option;
- simulating all three preferred options and the Submitted Option producing updated result graphs and tables;
- simulating a sensitivity analysis for climate change for all preferred options;
- initial filling geochemistry sensitivity for Preferred Option 2;
- simulating scenario modelling for two irrigation demand cases for Preferred Option 2; and
- producing updated result graphs and tables and updating the report accordingly.

The water balance model accounts for the various water inflows, such as rainfall, runoff and groundwater inflows, as well as outflows including evaporation. Model results indicate the following for the ten model runs:

1. Model Run 1 – Preferred Option 1 base case:
    a. Simulated water levels in all voids are below the external spill level.

b. Simulated outflows from voids comprise evaporation only hence solute concentrations trend upwards over the simulation period.

2. Model Run 2 – Preferred Option 1 with climate change:
   a. Simulated water levels are lower in all voids than for Model Run 1.
   b. As for Model Run 1, simulated outflows from voids comprise evaporation only hence solute concentrations trend upwards over the simulation period.
   c. Reducing rainfall and increasing evaporation reduces inflows (volume and solutes) to the voids but increases outflows (volume only) via evaporation. Hence major ions and salinity concentrations are simulated to be higher in Model Run 2 compared to Model Run 1.
3. Model Run 3 – First stage of Preferred Option 2 development using only southern voids:
   a. Simulated water levels in Pit A and Pit B rise mainly due to inflows from the Nogoa River. Water levels in Pit A are drawn down in line with Pit B due to the hydraulic connection between the pits.
   b. Simulated outflow from Pit B is dominated by irrigation and post-flood return flow to the Nogoa River which includes volume and solutes outflows. This differs to Model Runs 1 and 2 where evaporation was the sole outflow and thus, there is no outflow of solute.
   c. Simulated water quality in Pit B is improved by the regular inflows from the Nogoa River which has the dual effects of:
      i. topping up the void such that there is sufficient water available to pump to irrigation; and
      ii. diluting solute concentrations, particularly salinity such that the salinity in the void remains below the salinity threshold for suitability for irrigation, therefore the water from the void remains suitable to supply the irrigation demand.

      Simulated solute concentrations in Pit A are higher than Pit B but, due to the hydraulic connection modelled, are also improved by the interaction with the Nogoa River.
   d. On average, Pit B can supply 7.9 GL/year to the irrigation demand of 8 GL/year.
   e. A comparison of cumulative flow in the Nogoa River downstream of the voids shows an average decrease in the river flow volume of 1.8% with the development of the first stage of Preferred Option 2.
   f. Dilution calculations for backflow from the voids to the river immediately after the peak of a flood event show that for 97% of the time backflow is occurring, the estimated Nogoa River TDS downstream of the voids would be equal to the adopted background TDS of 115 mg/L.
4. Model Run 4 – Full development of Preferred Option 2 using all floodplain voids:
   a. Simulated water levels in all voids rise mainly due to inflows from the Nogoa River to Pit B and Pit CD. Water levels in Pit E are drawn down in line with Pit CD due to the hydraulic connection between the pits.
   b. Simulated outflow from Pit B and Pit CD is dominated by irrigation and post-flood return flow to the Nogoa River which includes both volume and solute outflows. This is similar to Model Run 3.
   c. Simulated water quality in Pit B and Pit CD is improved by the regular inflows from the Nogoa River which has the dual effects of:
      i. topping up the voids such that there is sufficient water available to pump to irrigation; and

ii. diluting solute concentrations, particularly salinity such that the salinity in the void remains below the salinity threshold for suitability for irrigation, therefore the water from the voids remains suitable to supply the irrigation demand.

Simulated solute concentrations are higher in Pit A than Pit B however the modelled hydraulic connection between the pits is such that the Pit A solute concentrations are diluted by interaction with Pit B. Similarly, simulated solute concentrations are higher in Pit E than Pit CD however the modelled hydraulic connection between the pits is such that the Pit E solute concentrations are diluted by interaction with Pit CD.

d. On average, Pit B can supply 7.9 GL/year to the irrigation demand of 8 GL/year while Pit CD can supply 11.9 GL/year to the irrigation demand of 12 GL/year.

e. A comparison of cumulative flow in the Nogoa River downstream of the voids shows an average decrease in the river flow volume of 3.3% with the full development of Preferred Option 2.

f. Dilution calculations for backflow from the voids to the river immediately after the peak of a flood event show that for 95% of the time, the estimated Nogoa River TDS downstream of the voids would be equal to the adopted background TDS of 115 mg/L.

5. Model Run 4a – Full development of Preferred Option 2 using all floodplain voids with climate change:

   a. Simulated water levels are generally higher in all voids in Model Run 4a when compared to Model Run 4 due to the decreased total irrigation demand of 10 GL/year compared to the total demand in Model Run 4 of 20 GL/year.

   b. Simulated solute concentrations are comparable to those in Model Run 4 mainly due to the dominant interaction with the Nogoa River but also due to the balancing effect of:

      i. inflow solutes decreasing due to decreased rainfall;

      ii. outflow solutes decreasing due to less pumping to irrigation;

      iii. outflow volume increasing due to increased evaporation; and

      iv. more water stored to dilute the solutes.

   c. A comparison of cumulative flow in the Nogoa River downstream of the voids shows an average decrease in the river flow volume of 2.2% with the full development of Preferred Option 2 with climate change.

6. Model Run 5 – Preferred Option 2 assessment of potential elevated salinity during initial filling and drawdown:

   a. Simulated solute concentrations in Pit B and Pit CD are higher than simulated in Model Run 4. Following the initial fill with water from the Nogoa River, salinity in Pit B does exceed the irrigation salinity upper limit of 2,000 mg/L while salinity in Pit CD remains below the trigger. However, following the initial few fill cycles, due to the dilution effects of the Nogoa River inflows this impact is expected to be negligible to the long term viability of water supply from Pit B and Pit CD to meet the irrigation demand.

7. Model Run 6 – Preferred Option 2 rehabilitated open cut mining areas after cessation of beneficial use:

   a. All voids are filled by inflows from the Nogoa River.

   b. Simulated water quality in Pit B and Pit CD is improved by the regular inflows from the Nogoa River.

   c. A comparison of cumulative flow in the Nogoa River downstream of the voids shows an average decrease in the river flow volume of 0.9% with Preferred Option 2 after cessation of beneficial use.

8. Model Run 7 – Preferred Option 3 base case:
   a. Simulated water levels in Pit A and Pit E are well below the external spill level
   b. Simulated outflows from Pit A and Pit E comprise evaporation only hence solute concentrations trend upwards over the simulation period.
9. Model Run 7a – Preferred Option 3 base case with climate change:
   a. Simulated water levels are lower in Pit A and Pit E than for Model Run 7.
   b. As for Model Run 7, simulated outflows from Pit A and Pit E comprise evaporation only hence solute concentrations trend upwards over the simulation period.
   c. Reducing rainfall and increasing evaporation reduces inflows (volume and solutes) to the voids but increases outflows (volume only) for those pits dominated by evaporation hence solute concentrations are simulated to be higher in Model Run 7a compared to Model Run 7.
10. Model Run 8 (Submitted Option) – Preferred Option 2 for the rehabilitation of the open cut mining areas but does not include the installation of intake structures, thereby removing the ability to harvest water from or release water to the river. It is also proposed to incorporate the existing levees into the landform design, with overburden emplacement areas behind the levee being reshaped in a manner that achieves a stable landform:
    a. Simulated water levels in all voids for all model runs undertaken are below the external spill level and the regional groundwater level.
    b. Simulated outflows from voids comprise evaporation or transfer to adjacent voids hence, solute concentrations trend upwards over the simulation period. However, as there is no outflow from the pits to the receiving environment, solutes are contained and the pits are non-polluting.

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

The EVs related to the water aspect are irrigation use, farm supply, stock use, aquaculture, human consumption, primary recreation, secondary recreation and industrial use. Potential impacts on these EVs were assessed by selecting three criteria: downstream river quality, water availability and void water quality. A qualitative approach has been undertaken for this assessment. Preferred Options 1 and 3 and the Submitted Option result in no impact for any of the criteria nominated while Preferred Option 2 resulted in either no impact, minor impact or medium benefit.

Environmental Values Ranking – Water Balance Assessment Summary

Aspect	Value	Criterion	Preferred Option 1	Preferred Option 2	Preferred Option 3	Submitted Option
Land	Agricultural potential	Downstream river quality	0	-1	0	0
		Water availability	0	-1	0	0
Water	Irrigation use	Void water quality	0	2	0	0
		Downstream river quality	0	-1	0	0
	Farm supply	Void water quality	0	2	0	0
		Downstream river quality	0	-1	0	0
	Stock use	Void water quality	0	2	0	0
		Downstream river quality	0	-1	0	0
	Aquaculture	Downstream river quality	0	-1	0	0
		Void water quality	0	0	0	0
	Human consumption	Downstream river quality	0	-1	0	0
	Primary recreation	Void water quality	0	0	0	0
	Secondary recreation	Void water quality	0	0	0	0
	Industrial use	Void water quality	0	0	0	0
Flooding	Changes in flooding and runoff characteristics	Impact on local runoff volumes to river	0	0	0	0
Waste	Waste generation and environmental dispersal	Evaporative concentration on salinity with the voids	-1	-1	-1	-1

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

1.1 PROJECT CONTEXT

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

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

a) Terms of Reference;

b) Residual Void Study;

c) Progress Reports; and

d) Rehabilitation success criteria for voids.

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

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

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

Stage 1 - Project definition and options identification

Stage 2 - Preferred Options technical studies

Stage 3 - Preferred Options detailed design

Stage 4 - Most Preferred Option Identification

Stage 5 - Regulatory Documentation.

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

The Options Analysis workshop held in Stage 1 of the RVP identified two options for the floodplain voids (i.e. Pits A, B, C, D and E):

Option 1: Landform Levee.

Option 2: Flood Mitigation and Beneficial Use.

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

All three options have been advanced through Stage 2 and into Stage 3 of the RVP and are referred to herein as the 'preferred options'. Following feedback from DES and DNRME in January 2019, Option 2 was revised and no longer has a water reservoir as a post mining land use, but has a predominantly grazing land use. The revised option was called the Submitted Option. This option has the same design criteria for the rehabilitation of the open cut mining areas as Option 2 but excludes the engineered intake structures which allow water capture from the Nogoa River. It is also proposed to incorporate the existing levees into the landform design, with overburden emplacement areas behind the levee being reshaped in a manner that achieves a stable landform. This landform would possess 0.1% AEP flood protection.

More detailed descriptions of the three preferred options and the Submitted Option are contained in Section 2.0.

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

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

- the long-term stability of the final rehabilitation of the open cut mining areas;
- safety of access to the site; and
- the short, medium and long-term risks associated with each preferred option.

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

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

1.2 PURPOSE OF THIS REPORT

As part of the RVP, Hydro Engineering & Consulting Pty Ltd (HEC) was commissioned to undertake void water quantity and quality balance modelling. A previous (Stage 2) study was completed in April 2018 (HEC, 2018a).

This report summarises the water quantity and quality balance modelling of voids conducted to support the RVP. It builds on the modelling conducted by Gilbert & Associates Pty Ltd (G&A, now HEC) in 2012, HEC in early 2016 and early 2018 (refer Section 3.0). The water balance modelling relies on topographic data including spoil volumes supplied by Ensham as well as groundwater modelling conducted by HydroSimulations (2018b) and geochemistry information provided by RGS (2018) and SRK (2020) (refer Section 4.0).

The objective of the Stage 3 water quantity and quality balance modelling is to quantify the long-term water quantity and quality balance of the final voids including: i) likely filling rates, ii) concentrations in key solutes of interest (calcium, chloride, magnesium, potassium, sodium, sulphate, arsenic, molybdenum, selenium, and total dissolved solids [TDS]) and iii) likely nature and significance of interactions with the surrounding surface and groundwater systems. The modelling has also investigated potential opportunities for using the floodplain voids as supplementary storages to supply water for beneficial use (refer Section 2.2). Modelling of Preferred Option 2 has included simulation of inflow to the final voids via engineered intake structures. A parallel hydrologic and hydraulic modelling study was undertaken by HEC and is reported under separate cover (HEC, 2018c).

2.0 PREFERRED REHABILITATION AND SUBMITTED OPTIONS DESCRIPTION

This section contains an extended description of each of the three preferred options and the Submitted Option as well as the rationale behind their development which has been provided by Ensham.

2.1 PREFERRED OPTION 1: LANDFORM LEVEE

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

Figure 1 Option 1 – Landform Levee

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

- Eliminates afflux impacts for upstream landholders during flood events with AEP lower than 0.1%;
- Eliminates any potential increased impacts on downstream landholders associated with widening the river floodplain;
- Eliminates the need to realign the Nogoa anabranch.

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

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

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

2.2 PREFERRED OPTION 2: FLOOD MITIGATION AND BENEFICIAL USE

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

Figure 2 Option 2 – Flood Mitigation and Beneficial Use

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

The design of rehabilitation should comply with the current site Rehabilitation Management Plan and preferred option 2 design criteria for the rehabilitation of the open cut mining areas to optimise water capacity. Overburden emplacement areas located adjacent to the water storage voids are to be reshaped in a manner that achieves stable rehabilitated slopes without resulting in significant void backfilling. Low wall areas are to be reshaped in-pit to achieve minimum stable slope requirements to ensure safe access and stability of exposed slope surfaces.

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

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

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

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

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

Figure 3 Conceptual Plan of the Weemah Virtual Channel to Irrigation and Yamala Inland Port (red) and the Mine Internal Pump System (blue)

Preferred Option 2 proposes that pontoon-based pumping stations would be sited at each pit to transfer water as required. The Weemah channel coming into the mining lease would be configured to deliver water initially to Pit A. Similarly, pumping from the mine to the Weemah Channel would be undertaken from Pit A.

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

The intakes from the Nogoa River to Pits B and C would allow temporary storage of peak flood flows during flood events. As the river rises during a flood event, it would reach the overflow level of the inlet structures constructed in the levee (the intakes) and flow into the residual voids. The water would rise in the voids to reflect the height of the flood. As flood levels recede, water would ebb back into the river floodplain through the intakes to the base level of the intakes leaving the voids at full level. The intake level for Pits B and C has been considered as part of Stage 3 (refer Section 4.14).

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

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

Residual voids that are not within the floodplain, for example Pits E, F and Y, would be rehabilitated to achieve minimum stable slope requirements and comply with the currently approved site Rehabilitation Management Plan and preferred option 2 design criteria for the rehabilitated mining areas.

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

2.3 PREFERRED OPTION 3: BACKFILL TO PMF

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

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

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

Figure 4 Preferred Option 3 – Backfill to PMF

Virgin rock typically exhibits an increase in volume when excavated - this is referred to as 'bulking'. The degree of bulking will vary with the geo-mechanical properties and size distribution of the excavated rocks and the methods used in excavation and transport. Furthermore, it is likely to vary both along the linear extent of the open cut mine and within different parts of spoil tips created through the extraction of rock dominated by lithologies characterising the local stratigraphy. Spoil which is re-excavated spoil and re-emplaced within voids within the modelled PMF extent will again exhibit bulking. Whether subjected to dynamic compaction or allowed to settle with subsequent loading by overlying backfill, the spoil within the voids will inevitably exhibit uncontrolled settlement.

This will lead to the development of low areas within the PMF extent which, though shallow, lie below the original level of the floodplain. These low areas will not necessarily be connected and are likely to collect surface water runoff but be subject to intense evaporation and surface accumulation of evaporative salts which would be flushed clean by fluvial flood events.

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

Beyond the modelled extent of the PMF, residual voids would be rehabilitated in accordance with the submitted option design criteria.

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

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

2.4 SUBMITTED OPTION DESCRIPTION

The Submitted Option involves partial backfilling of the residual voids to create rehabilitated mining areas consistent with the regional topography protected by permanent landforms. These landforms have been designed and independently peer reviewed by RPEQ certified engineers and would be along the existing levee alignment to provide flood immunity and exclude the rehabilitated areas from flood interactions up to and including a 0.1% Annual Exceedance Probability (AEP) event.

It is proposed to incorporate the existing levees into the landform design, with overburden emplacement areas behind the levee being reshaped in a manner that achieves a stable landform. All slopes have been designed to exceed a Factor of Safety (FoS) of 1.5. In doing so the design of the Submitted Option delivers long-term safe and stable slopes with Post Mining Land Uses (PMLUs) of:

- Sustainable Grazing/ Water Body
- Self-Sustaining Vegetated Cover
- Native Bushland Corridor
- Mining Infrastructure Retained, and
- Boggy Creek Diversion.

The inward facing slopes of the rehabilitated void would be at a maximum of 25% and would likely include rock mulching or other suitable treatment to further reduce erosion risk potential. Overburden slope grades remain as currently approved in the Ensham Environmental Authority and as such do not require approval as part of this application. The PMLU for the low wall rehabilitated areas would remain as grazing, which is the current approved PMLU for this area.

The existing 0.1% AEP levees adjoining A, B, C and D pits will be upgraded to 0.1% AEP landforms that exceed a FoS of 1.5 to ensure that these areas safe and stable into perpetuity.

A native bushland corridor will be developed along the western (highwall) side of the rehabilitated Pits A and B to provide connectivity between Corkscrew Creek and the Nogoa River floodplain. A native bushland corridor will also be provided adjacent to the Pit CD highwall to provide improved connectivity between the Nogoa River and the escarpment area.

3.0 SUMMARY OF PREVIOUS FINAL VOID STUDIES

In 2012, G&A (now HEC) investigated the likely difference between retaining the flood levees to separate the floodplain voids (i.e. Pits A, B, C, D and E) from interaction with the Nogoa River compared to removing them and allowing interaction with the Nogoa River. Groundwater flux information was provided by AGEC (specialist groundwater consultants) while flood estimates for the Nogoa River were provided by KBR (2012) and geochemistry information provided by URS (2006).

Results of that modelling indicated that with the flood levees in place, the voids took approximately 50 years to reach an equilibrium level, while without flood levees, the floodplain void water levels were estimated to stabilise within 15 years. In the "no levees" case, void inflows were dominated by river inflows which meant the rate of filling was faster (being dependent of the timing of the first few significant flood inflow events) and the equilibrium water levels were higher than the "with levees" case. The water level in the "no levees" case was high enough to cause a number of spills from the floodplain voids to the Nogoa River. This interaction between the Nogoa River and the floodplain voids caused the salt concentrations in voids to be much lower relative to the "with levees" case. Modelling was also carried out for the non-floodplain void Pit Y with results suggesting spill would occur to the environment. The water balance for Pit Y was driven by rainfall runoff with the pit acting as a water source for regional groundwater. As a result, the long-term salinity in Pit Y was lower than that predicted for the floodplain voids "with levees" case with TDS concentrations near 1,000 mg/L as opposed to 5,000 mg/L to 25,000 mg/L in the other voids.

An update to the 2012 study was undertaken by HEC in 2016 using the same geochemical (URS, 2006) information with revised and updated groundwater flux (AGEC, 2015) and floodplain modelling conducted by KBR in 2013. Modelling of the final voids confirmed that the water balance and the likely salt concentrations that would occur in the final voids for the "no levees" case would be still dominated by interaction with the Nogoa River during significant flood events. Based on the available flow record at the Duck Ponds gauging station (GS 130219A) there were three flood events which would have resulted in significant inflows to the Pit B and Pit C voids in the period of recorded flows (May 1993 to September 2015). Assuming a similar frequency and magnitude of flooding occurs post-closure, it was predicted that the salt concentration in the floodplain voids (once they had reached a pseudo steady state) would be below 1,000 mg/L during spill events. Spills from the floodplain voids to the Nogoa River (without levees) were expected to occur during significant flood events and would have relatively little effect on downstream salinity in the Nogoa River. Water levels in the floodplain voids would tend to decline slowly between flood events. Modelling was also carried out for the non-floodplain void Pit F with results suggesting water level equilibrium would be reached within 100 years and would be approximately 20 m below the spill level. Pit F void salinity results showed a gradual increase in salinity over the simulation period. Pit Y was split into three parts (North, Central and South) with the Central part simulated to spill to the North which in turn spilled externally often. Simulated salinity in Pit Y North was highly variable due to spill received from Pit Y Central and external spill while Pit Y Central showed a gradual increase in salinity over the simulation period. Pit Y South was independent of the North and Central parts with the water level equilibrating approximately 40 m below spill and a gradual increase in salinity over the simulation period.

In the early 2018 revision (HEC, 2018a) only the floodplain voids were evaluated. Pits A and B were modelled as one storage (Pit AB) and Pits C and D were modelled as one storage (Pit CD). Results of modelling demonstrated that the overall behaviour of both sets of floodplain voids would be similar under similar assumptions and inputs. Modelling confirmed the advantages to void water quality of rapidly filling them through offtake of flow from the Nogoa River during periods of elevated flow. Modelling also demonstrated the significance of the currently predicted groundwater outflows from the void at elevated void water levels on salt concentration. The simulations indicated that with management of inflow and outflow, salt concentrations in the voids should be able to be maintained at levels consistent with water quality guidelines for irrigation.

Table 1 summarises each of the previous final void studies to date and compares key assumptions with the current study.

Table 1 Summary of Final Void Studies to Date

	HEC (2012)	HEC (2016)	HEC (2018a) (Stage 2)	Current Study (Stage 3)
Groundwater	AGE	AGE (2015)	HydroSimulations (2018a)	HydroSimulations (2018b) & SLR [1] (2020)
River Flows	KBR (2012)	KBR (2013)	Intake structures with link to hydraulic model (HEC 2018b)	Refined intake structures and link to hydraulic model (HEC 2018c)
Geochemistry	URS (2006)	URS (2006)	URS (2006) and preliminary advice from RGS	RGS (2018) and SRK (2018; 2020)
Water Quality Parameters	TDS only	TDS only	TDS only	Calcium, chloride, magnesium, potassium, sodium, sulphate, selenium, TDS, arsenic, molybdenum and selenium.
Spoil Storage	No	No	Yes, 20% porosity	Yes, 30% porosity
Voids Included	A, B, C, D, E & Y	A, B, C, D, E, F & Y (North, Central and South)	AB & CD	A, B, CD, and E
Options Simulated	With and without levees	With and without levees	Preferred Option 2 (refer Section 2.0) & Scenarios*	Preferred Options 1, 2 & 3 (refer Section 2.0) and the Submitted Option

* Scenarios included variation in hydraulic connection to the Nogoa River, groundwater flux, salinity assumptions and release from voids.

[1] Note that SLR recently acquired HydroSimulations.

4.0 MODEL ASSUMPTIONS

4.1 WATER QUANTITY AND QUALITY MODEL

4.1.1 Conceptual Representation

A conceptual representation of the hydrological processes simulated in the model is depicted in Figure 5.

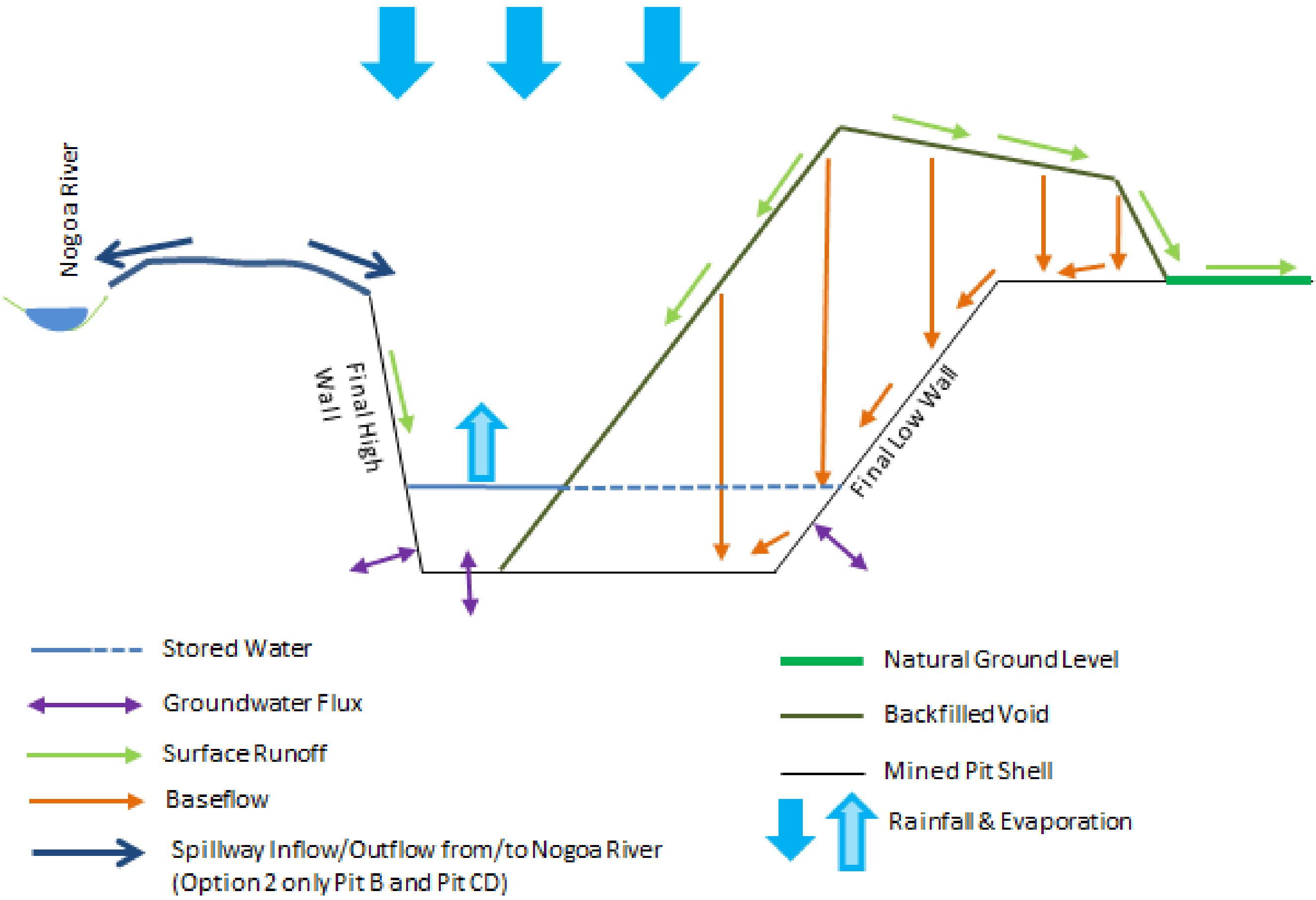

Figure 5 Conceptual Model of Floodplain Void

During the filling phase water would accumulate in the void as a result of rainfall runoff and baseflow (i.e. from infiltration through spoil overburden) from the void catchment. The void catchments comprise mostly rehabilitated overburden areas within and adjacent to the void and other rehabilitated areas adjacent to the void. The void highwall area comprises exposed rock with relatively high runoff potential. If the water level in the pit remained below the regional groundwater level, then groundwater would flow from the regional groundwater system to the void. Evaporation would occur from the void water surface.

The water quality characteristics of the void will depend on a number of inputs to, and losses from, void waterbodies. Salt is typically associated with most coal mining operations in the Bowen Basin. Elevated salt concentrations are often found in groundwater associated with Permian coal measures. Mining and placement of overburden within voids provide another source of salt which is leached out of the overburden and transported to the void. Naturally high infiltration rates associated with un-rehabilitated overburden stockpiles can be reduced by effective rehabilitation practices which promote evapotranspiration through surface covering and revegetation and a decrease in the infiltration capacity of the rehabilitated surface. Other water quality parameters are also modelled and discussed further in Section 4.10.

Mine voids can become permanent groundwater sinks when the equilibrium water level is below the regional groundwater level. If the only outflow from the void is evaporation, and solutes cannot flow out with evaporation, then it is understood that solutes are left to concentrate in the void.

In response to ongoing refinement of the groundwater modelling and design criteria of rehabilitated mining areas, the planned floor levels of Pit F South, Pit F North and Pit Y have been raised to be approximately 5 m above the simulated long-term groundwater level. Consequently, groundwater would not contribute inflow and only a negligible volume of seepage is likely to enter the pit. Other inflows will comprise surface runoff, baseflow and direct rainfall, whereas outflows will comprise discharge to groundwater and evaporation. Only surface water runoff will report to the lowest point in the rehabilitated mining areas and from there will drain through the backfill material to the groundwater table. For this reason, these pits are not expected to hold water for extended periods and modelling of the water quality and balance in these voids was accordingly not undertaken.

4.1.2 Water Balance Schematic

A water and salt balance model of the voids was developed using the GoldSim® simulation package to simulate future conditions. GoldSim is a graphically based model simulation system which enables probabilistic modelling of hydrological systems. The model simulated the water quantity and quality of each void on a daily basis using the balance components summarised in Table 2. The daily timestep was reduced to 1 hour during periods of high transfer (e.g. spill between voids). Inflows to the voids comprised direct rainfall over the void water surface, surface runoff and baseflow from the void catchment area, groundwater inflow and intake structure inflow from the Nogoa River (applies to Preferred Option 2 only). Outflows comprised evaporation, groundwater outflow, external spill, pumped outflow to irrigation (applies to Preferred Option 2 only) and intake structure outflow to the Nogoa River (applies to Preferred Option 2 only). In addition, contained water could be transferred between the voids via internal seepage and spills to adjacent voids (applies to/from Pit A and Pit B and to/from Pit CD and Pit E).

The difference between inflows and outflows represents the change (increase or decrease) in water contained within the void. The void water balance modelling has been undertaken assuming saturation of the backfilled material up to the void water surface level. The model accounts for the total storage as a single volume (i.e. storage is equal to the combined water stored in the spoils and free water in the lake).

Figure 6, Figure 7, Figure 8 and Figure 9 show a schematic representation of these voids and their inter-linkages for Preferred Options 1, 2, 3 and the Submitted Option respectively. The GoldSim water balance model is based on these water management schematics.

Table 2 Void Water Balance Components

Void Inflows	Void Outflows
Direct rainfall on void water surface	Evaporation from void water surface
Surface runoff from void catchment	Groundwater outflows
Baseflow from infiltration through spoil overburden	External spill
Regional groundwater inflows	Pumped outflow to irrigation (Preferred Option 2 only)
Intake structure inflow from the Nogoa River (Preferred Option 2 only)	Intake structure outflow to the Nogoa River (Preferred Option 2 only)
Flow from adjacent voids (applies to/from Pit A and Pit B and to/from Pit CD and Pit E).	Flow to adjacent voids (applies to/from Pit A and Pit B and to/from Pit CD and Pit E).
Supplemented water allocation to pits	

4.2 MODEL RUNS

Ten (10) model runs were simulated with the governing assumptions for each run summarised in Table 3. These governing assumptions are detailed further in the sections to follow.

Modelling for Preferred Option 1 simulated a base case (Model Run 1) and a case applying climate change factors to rainfall and evaporation (Model Run 2). Similarly, modelling for Preferred Option 3 simulated a base case (Model Run 7) and a case applying climate change factors to rainfall and evaporation (Model Run 7a).

In contrast to Preferred Options 1 and 3, water will periodically be pumped from Pit B and Pit CD for irrigation in Preferred Option 2 and water levels will rise and fall as a result. Modelling for Preferred Option 2 considered a number of model runs in order to explore the effects of irrigation demand being sourced from Pit B only (Model Run 3) compared to being sourced from Pit B and Pit CD (Model Run 4), compared to no water being sourced from either Pit B or Pit CD in a post-use scenario (Model Run 6). The effect of applying climate change factors to rainfall and evaporation on Model Run 4 was also simulated (Model Run 4a). Model Run 5 was included to assess short-term impact of salt leaching from the in-pit overburden dumps and wall rocks on water quality in the voids due to filling and drawdown periods (refer Section 4.11). The resulting impacts of salt leaching on salinity are assumed to be short-term, as solutes will be removed from the pits during repeated pumping events. Once flushed, longer term salinity results in Model Runs 3, 4, 4a and 6 should not be impacted. In this way, assumptions regarding salt leaching for Model Runs 3, 4, 4a and 6 are equivalent to assuming modelling commences after the short-term impacts of salt leaching have occurred. A final model run for Preferred Option 2 was carried out and this is the Submitted Option (Model Run 8).

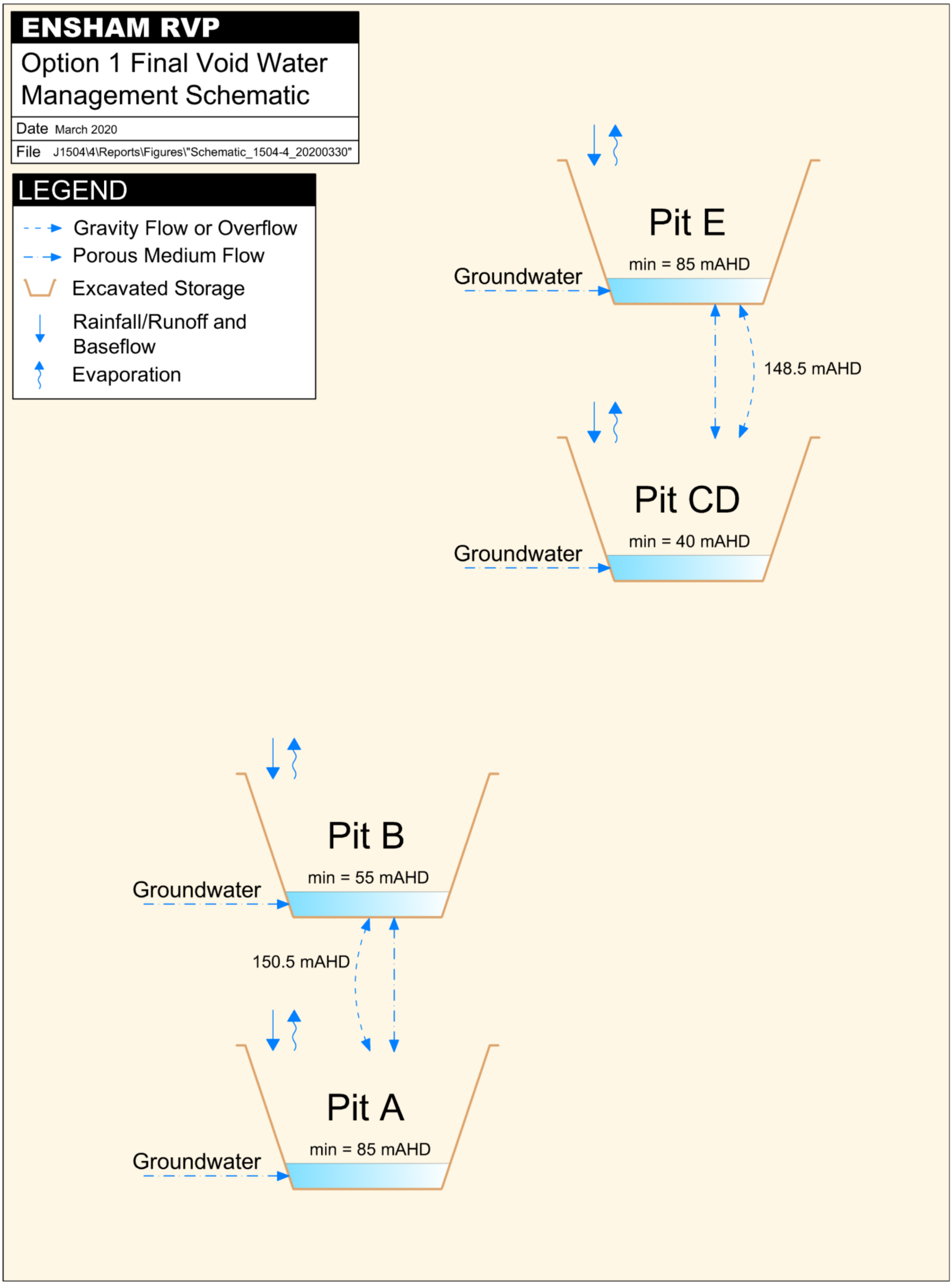

Figure 6 Water Management Schematic – Preferred Option 1

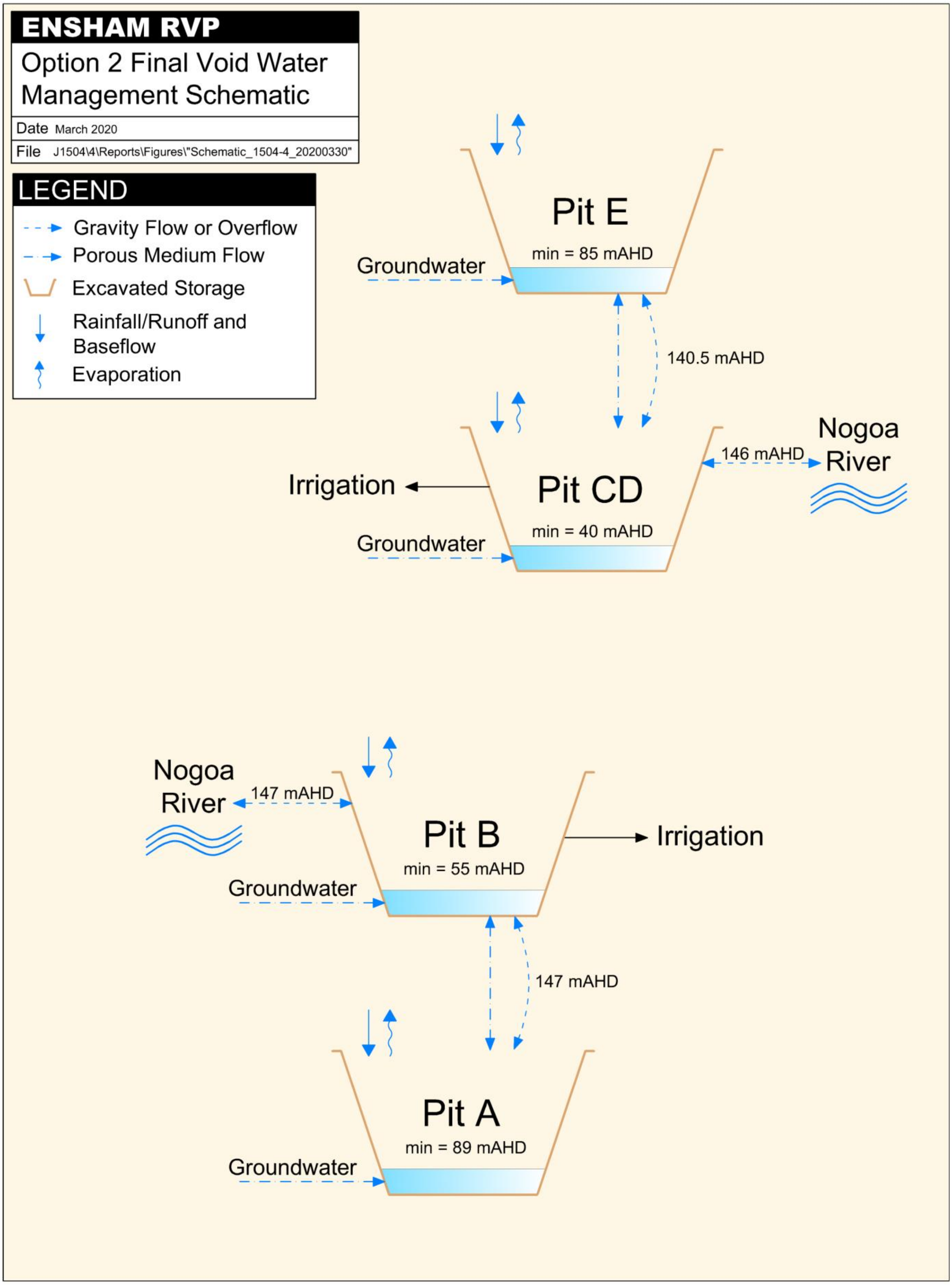

Figure 7 Water Management Schematic – Preferred Option 2

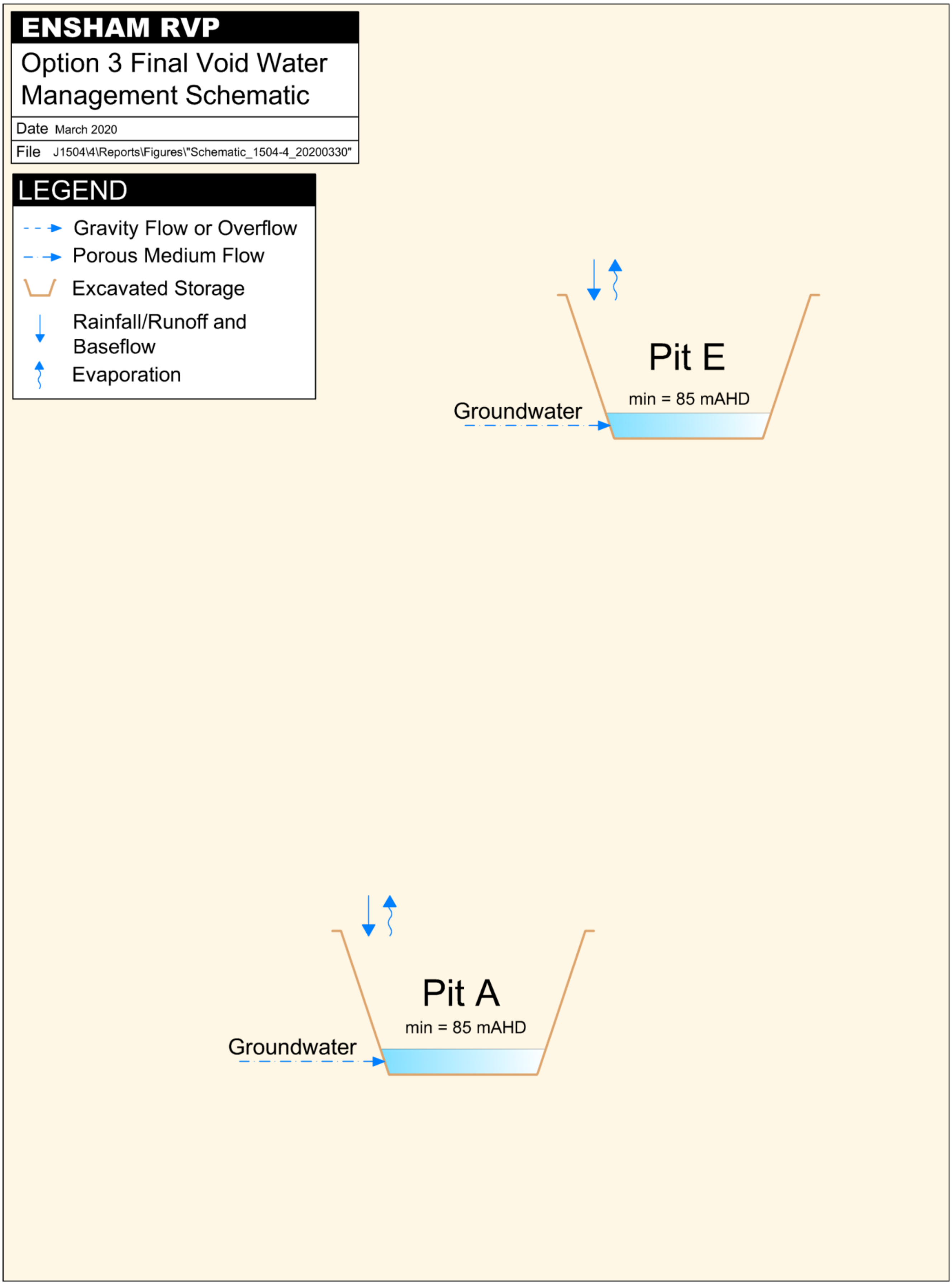

Figure 8 Water Management Schematic – Preferred Option 3

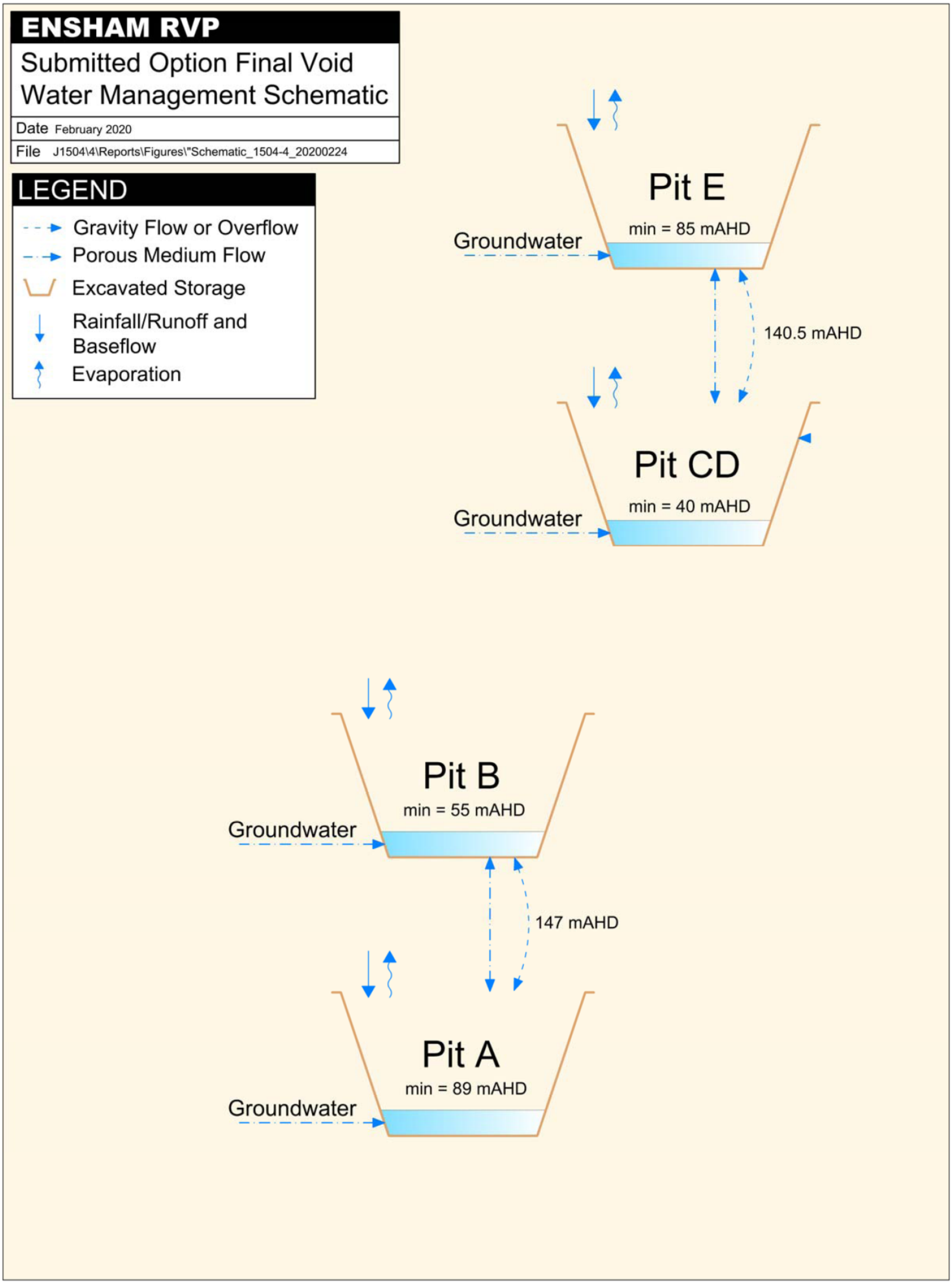

Figure 9 Water Management Schematic – Submitted Option

Table 3 Summary of Model Runs

Run Number	1	2	3	4	4a	5	6	7	7a	8
Preferred Option	1	1	2	2	2	2	2	3	3	2
Pits Modelled	Pit A, Pit B, Pit CD and Pit E	Pit A, Pit B, Pit CD and Pit E	Pit A and Pit B	Pit A, Pit B, Pit CD and Pit E	Pit A, Pit B, Pit CD and Pit E	Pit A, Pit B, Pit CD and Pit E	Pit A, Pit B, Pit CD and Pit E	Pit A, Pit B, Pit CD and Pit E	Pit A, Pit B, Pit CD and Pit E	Pit A, Pit B, Pit CD and Pit E
Description	Base Case	Climate Change	Irrigation from Pit B only	Irrigation from Pit B and Pit CD	Irrigation from Pit B and Pit CD & Climate Change	Initial Filling & Drawdown	Post Use[2]	Base Case	Climate Change	Base Case
Run Duration (years)	258	258	129	129	129	27	258	258	258	258
Water Quality	Best estimate	Best estimate	Best estimate	Best estimate	Best estimate	Load-based TDS	Best estimate	Best estimate	Best estimate	Best estimate
Climate	Historical (repeated)	Historical (repeated) with climate change factors	Historical	Historical	Historical with climate change factors	Historical (1889-1915)	Historical (repeated)	Historical (repeated)	Historical (repeated) with climate change factors	Historical (repeated)
Irrigation Demand (GL/year)	0	0	Pit B = 8	Pit B = 8 Pit CD = 12	Pit B = 4 Pit CD = 6	Pit B = 8 Pit CD = 12	0	0	0	0
Supplemented Water Allocation (GL/year)	0	0	1.5	1.5	1.5	1.5	0	0	0	0

[2] after cessation of beneficial use period.

4.3 RAINFALL AND EVAPORATION

A record of 129 years of rainfall data (1889-2017 inclusive) was obtained for the site from the SILO Data Drill[3] for a location near to the Ensham Mine. The data set was repeated to simulate 258 years to provide a climate sequence long enough to reach an equilibrium water level in the voids. Rainfall was included in the model as direct rainfall into the void and as an input to the catchment runoff model.

A 129-year pan evaporation data set for the site was also obtained from the SILO Data Drill. Storage volumes calculated by the model are used to calculate storage surface area (i.e. water area) based on storage volume-area-level relationships for each final void. Evaporation from storages is calculated in the model by multiplying storage surface area by daily pan evaporation rate and by a pan factor. At near empty, evaporation rates from the void would be lower than occurs in "normal" shallow exposed water surfaces due to the shading effects within voids. It is expected that potential evaporation rates would increase as the void water levels rise and become increasingly exposed to surface climatic conditions. Therefore, a pan factor of 0.6 was used to convert pan evaporation rates to open water evaporation rates when the void was near empty. This pan factor was linearly increased to 0.85 based on a proportion full calculation for each void (i.e. 0.6 at empty and 0.85 at capacity). The effect of evapotranspiration from the catchment surface is simulated in the AWBM rainfall runoff model (refer Section 4.5).

4.4 CLIMATE CHANGE

To test sensitivity of model results to assumed rainfall and evaporation, climate change factors were calculated using the Climate Change in Australia website (https://www.climatechangeinaustralia.gov.au/en/). Assessments of likely future concurrent rainfall and evapotranspiration changes have been undertaken using the online Climate Futures Tool (CSIRO and BoM, 2015). Projected changes from all available climate models are classified into broad categories of future change defined by these two variables, which are the most relevant available parameters affecting rainfall runoff. The Climate Futures Tool excludes global climate models which were not found to perform satisfactorily over the Australian region. The assessments assumed a conservatively high emissions scenario – Representative Concentration Pathway (RCP) 8.5 (representing a future with little curbing of emissions, with a carbon dioxide level continuing to rapidly rise to the end of the century). The assessment was performed for 2050 (consistent with hydrological modelling by OD Hydrology [2018]) for the east coast (north) region of the continent. Table 4 presents predicted mean annual changes for these two climate variables.

Table 4 Predicted Mean Change in Annual Rainfall and Evapotranspiration

Climate Variable	Mean Change To 2050
Annual Rainfall	-8%
Annual Evapotranspiration	+7%

The most likely climate future in 2050 for the given emissions scenario is for an "increase" in annual evapotranspiration combined with a "drier" rainfall scenario or little change. These effects are likely to, in the longer term, lead to reductions in rainfall runoff and increased evaporation from the voids resulting in lower average water levels in the voids. The climate change factors were conservatively applied to the full record of rainfall and evaporation in Model Runs 2, 4a and 7a (refer Section 4.2) to simulate the impact on model results.

[3] The Data Drill is a system which provides synthetic data sets for a specified point in Australia by interpolation between surrounding point records held by the Bureau of Meteorology (refer https://legacy.longpaddock.qld.gov.au/silo/datadrill/)

4.5 RAINFALL RUNOFF

The water balance model includes a simulation of daily rainfall-runoff from rainfall and evaporation data (refer Section 4.3). For final void storage surface areas (i.e. water), rainfall was assumed to add directly to the storage volume with no losses. For other sub-catchments, rainfall runoff was simulated using the Australian Water Balance Model (AWBM) – Boughton (2004). The AWBM is a catchment-scale water balance model that estimates streamflow from rainfall and evaporation. Different AWBM parameters were used for each sub-catchment type. AWBM parameters were set based on reported values and experience with a calibrated AWBM for a coal mine in the Bowen Basin.

The rainfall runoff component of the GoldSim water balance model was checked against available site data for Pit B and Pit Y but limited pumping data for both pits meant that a comprehensive calibration could not be undertaken (refer Section 5.1). Estimates of surface runoff and infiltration/percolation were generated for each catchment reporting to the void. The parameters used in the AWBM are summarised in Table 5.

Table 5 Assumed AWBM Parameters

Parameter	Sub-Catchment Type			
	Natural	Rehabilitated Spoil	Active Spoil	Highwall (Open Cut Pit)
C1 (mm)	15	25	15	5
C2 (mm)	100	140	75	70
C3 (mm)	400	400	150	0
A1	0.013	0.05	0.1	0.1
A2	0.444	0.3	0.3	0.9
A3	0.543	0.65	0.6	0
BFI	0.21	0.85	1	0
k_b	0.850	0.950	0.985	-
k_s	0	0.3	0.5	0.1

4.6 CATCHMENT AREAS

The layout and extent of modelled catchments for each Preferred Option are shown on Figure 10, Figure 11 and Figure 12 with totals summarised in Table 6. Sub-surface areas are simulated as contributing seepage from mine rehabilitated areas only (simulated as baseflow in the AWBM) with surface runoff from these areas assumed directed away from the voids.

Table 6 Assumed Surface and Sub-Surface Catchment Areas

Void	Catchment Type	Catchment Area (ha)		
		Preferred Option 1	Preferred Option 2 and Submitted Option	Preferred Option 3
Pit A	Surface*	454.6	432.6	403.6
	Sub-surface**	85.4	127.0	128.2
Pit B	Surface	506.6	659.9	0
	Sub-surface	285.1	130.9	0
Pit CD	Surface	627.5	727.7	0
	Sub-surface	440.0	291.5	0
Pit E	Surface	402.5	414.8	557.7
	Sub-surface	84.9	135.4	84.9

* Surface runoff and baseflow
** Baseflow only

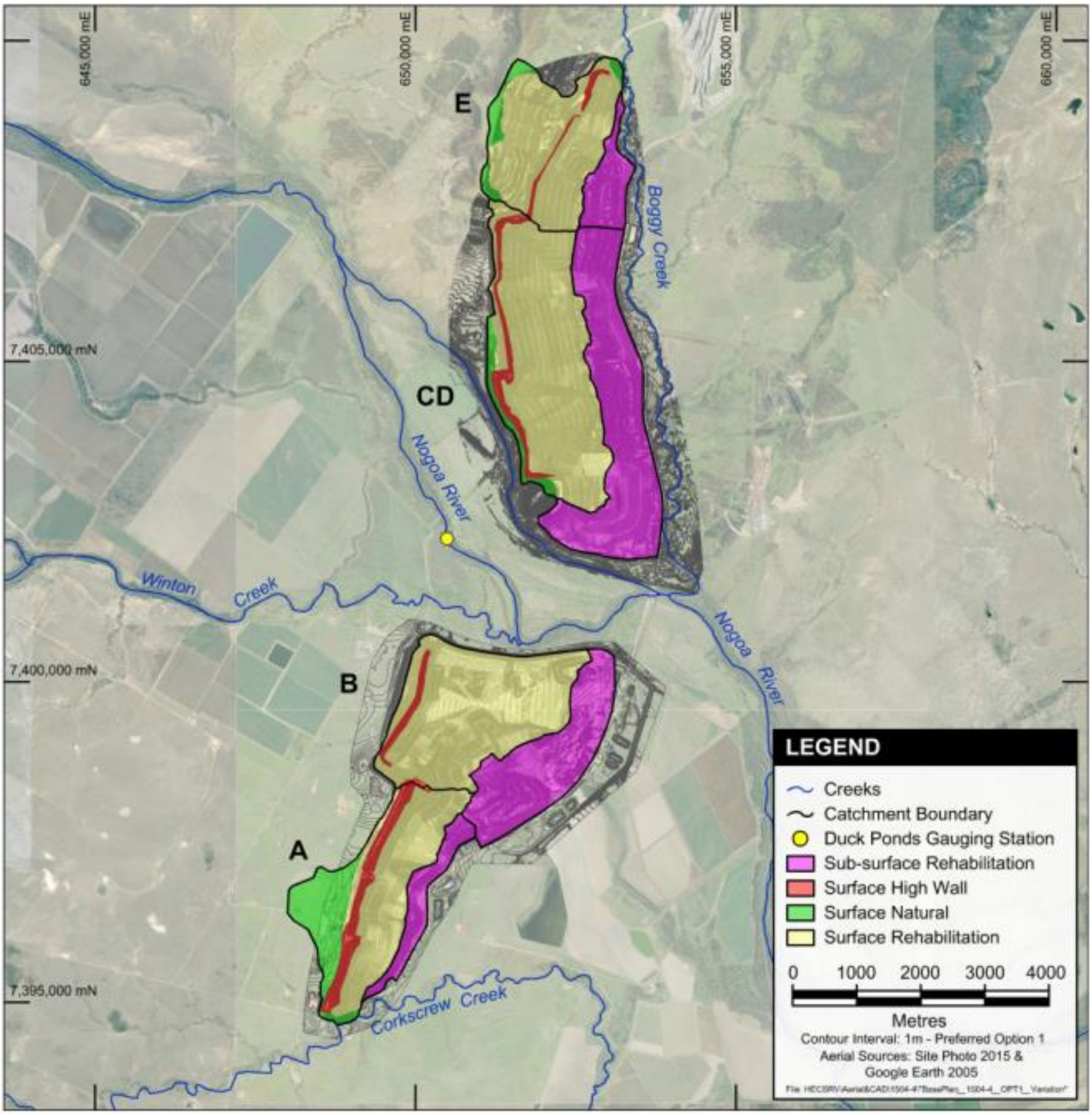

Figure 10 Assumed Catchment Areas – Preferred Option 1

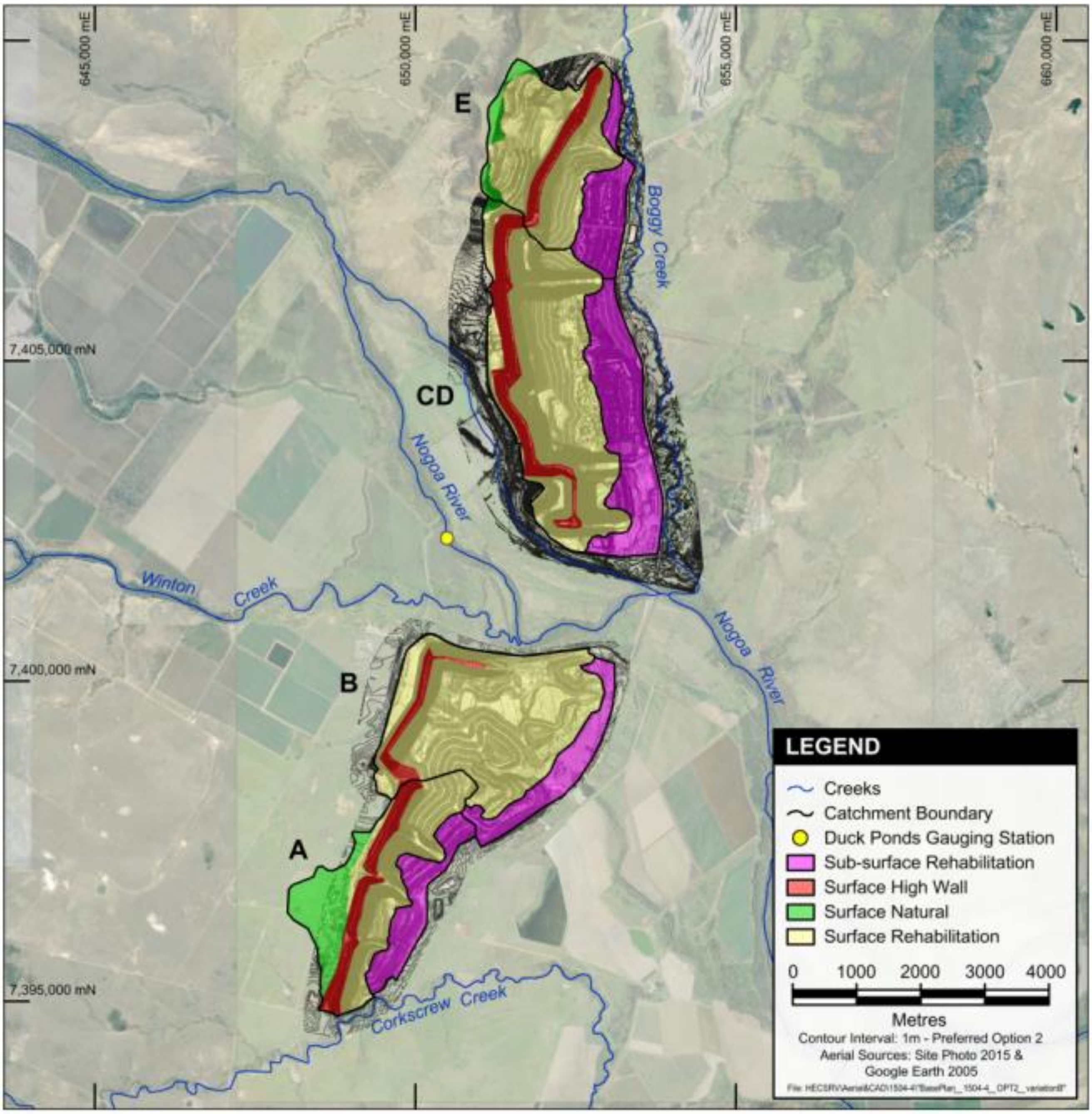

Figure 11 Assumed Catchment Areas – Preferred Option 2 and Submitted Option

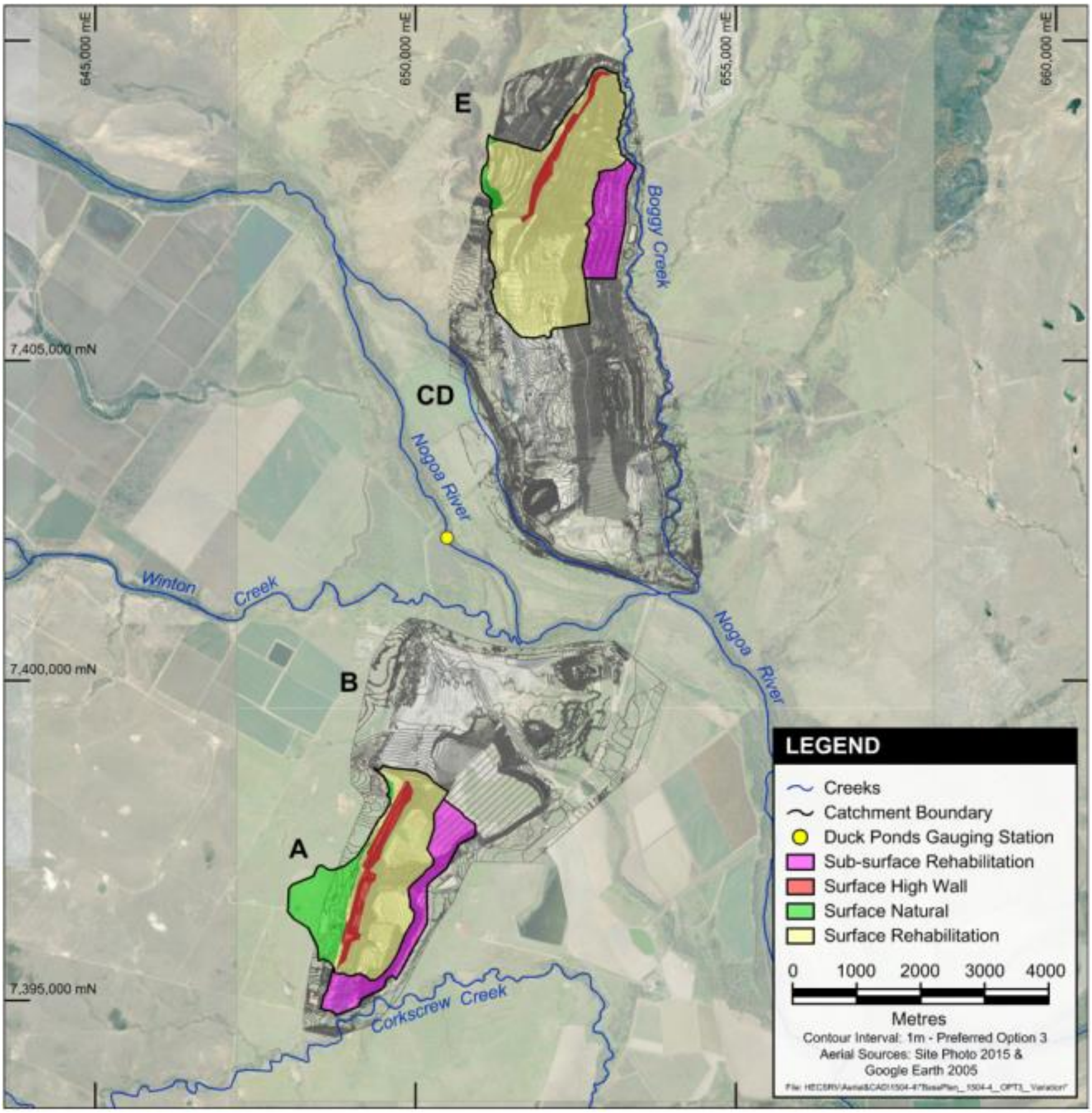

Figure 12 Assumed Catchment Areas – Preferred Option 3

4.7 REGIONAL GROUNDWATER LEVELS AND NET GROUNDWATER FLUX

Regional groundwater levels for each of the Preferred Options and the Submitted Option have been provided by SLR (2020) as shown in Table 7.

Table 7 Regional Groundwater Levels (SLR, 2020)

Void	Regional Groundwater Level (mAHD)			
	Preferred Option 1	Preferred Option 2	Preferred Option 3	Submitted Option
Pit A	144	144	148	144
Pit B	142	142	-	142
Pit CD	142	142	-	142
Pit E	152	150	152	150

For the purpose of predicting final pit water levels and analysing the potential interactions between the pits and groundwater, a detailed hydrogeological assessment was undertaken (Hydrosimulations, 2020). This assessment comprised description and modelling of water flow through the main groundwater bearing units (alluvium and Permian Rangal coal measures), representing the regional groundwater system; the underground workings; and the waste material, which creates a porous medium through which water can flow between Pit A and Pit B, and between Pit CD and Pit E.

Estimates of net groundwater flux into and out of each of the pits as a function of water level were provided by HydroSimulations (2018b) for post-closure conditions for each of the Preferred Options, as stage-discharge tables, where "stage" refers to the water level in the pit and "discharge" refers to the net groundwater flux. The net groundwater flux represents the balance of all groundwater flow components (through the regional groundwater system, through the porous medium and to the underground workings). Net groundwater flux is used because the model results are too complex to split the flow into individual components. A negative net groundwater flux represents a net flow out of the void while a positive net groundwater flux represents a net flow into the void.

The simulated net groundwater fluxes as a function of water level for the voids for Preferred Options 1, 2 (and the Submitted Option) and 3 are shown in Table 8, Table 9 and Table 10 respectively.

Table 8 Net Groundwater Flux – Preferred Option 1 (HydroSimulations, 2018b)

Pit A		Pit B		Pit CD		Pit E	
Level (mAHD)	Net Flux (ML/d)	Level (mAHD)	Net Flux (ML/d)	Level (mAHD)	Net Flux (ML/d)	Level (mAHD)	Net Flux (ML/d)
		70	-2.00	70	-2.00		
		75	-1.88	75	-1.60		
		80	-1.68	80	0.00		
		85	-1.54	85	2.00		
		90	-1.37	90	2.40		
		95	-1.16	95	2.72		
		100	-1.00	100	2.84		
		105	0.40	105	3.12		
110	-0.50	110	0.80	110	3.42		
115	-0.43	115	1.14	115	3.78		
120	-0.21	120	1.36	120	4.00	120	-0.50
125	0.00	125	1.46	125	3.54	125	-0.25
130	0.14	130	1.52	130	2.72	130	0.00
135	0.40	135	1.18	135	1.40	135	0.19
140	0.14	140	0.00	140	0.00	140	0.50
145	-0.22	145	-1.20	145	-1.00	145	0.41
150	-0.54	150	-2.40	150	-1.70	150	0.00
155	-0.83					155	-0.36
						160	-0.8

Table 9 Net Groundwater Flux – Preferred Option 2 (HydroSimulations, 2018b)

Pit A		Pit B		Pit CD		Pit E	
Level (mAHD)	Net Flux (ML/d)	Level (mAHD)	Net Flux (ML/d)	Level (mAHD)	Net Flux (ML/d)	Level (mAHD)	Net Flux (ML/d)
				60	-2.00		
		65	-0.17	65	-1.60		
		70	-0.54	70	-1.20		
		75	0.00	75	-0.65		
		80	0.64	80	0.78		
		85	1.00	85	1.44		
		90	1.39	90	1.86		
		95	1.54	95	2.40		
		100	1.76	100	3.00		
		105	1.94	105	3.18		
110	0.00	110	1.89	110	3.48		
115	0.20	115	1.67	115	4.00	115	-0.30
120	0.53	120	1.32	120	4.00	120	-0.20
125	0.46	125	1.00	125	3.50	125	-0.10
130	0.29	130	0.67	130	2.40	130	0.00
135	-0.27	135	0.26	135	1.10	135	0.40
140	-0.72	140	-0.13	140	0.00	140	0.30
145	-0.98	145	-0.35	145	-0.90	145	0.00
				150	-1.60	150	-0.16
						155	-0.30

Table 10 Net Groundwater Flux – Preferred Option 3 (HydroSimulations, 2018b)

Pit A		Pit B		Pit CD		Pit E	
Level (mAHD)	Net Flux (ML/d)	Level (mAHD)	Net Flux (ML/d)	Level (mAHD)	Net Flux (ML/d)	Level (mAHD)	Net Flux (ML/d)
						105	-0.50
						110	0.13
						115	0.15
						120	0.05
						125	0.77
						130	0.92
135	-0.50					135	0.80
140	-0.10					140	0.64
145	0.44					145	0.33
150	-0.28					150	0.00
155	-0.78					155	-0.27
160	-0.46						

Individual flux estimates for Pit A South and Pit A North were provided for these pits however the void water balance model assumes Pit A is one continuous void. The total groundwater flux for Pit A was obtained by adding the fluxes for Pit A South and Pit A North together – this methodology was confirmed as suitable by HydroSimulations.

Where a negative net groundwater flux is predicted at a level below the regional groundwater level, SLR (2020) indicated that this flux would be a flow through the porous medium between pits. It cannot be a flow to the regional system as the water level in the pit is below the regional groundwater level.

While net groundwater flux estimates provide suitable assumptions for the void water quantity balance modelling, they present limitations for the void water quality modelling, 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.

4.8 PIT GEOMETRY

The relationships between stored water volume (ML), water level (mAHD) and surface area (ha) for each void for each preferred option were calculated using a combination of supplied spoil volumes (MEC 2018) and an assumed spoil porosity of 30% (provided by Ensham). Note that for all pits, the pit shell contains backfilled spoil at the lowest points, hence water can be stored in the spoil below the level of visible water. A summary of pit geometry for each preferred option is provided in Table 11. Table 12, Table 13 and Table 14 provide the adopted level-volume-area relationships for Preferred Options 1, 2 and 3 respectively.

Table 11 Summary of Pit Geometry

Preferred Option	Void	Pit Shell Minimum Level (mAHD)	Internal Spill Level (mAHD)	External Spill Level (mAHD)	Capacity at External Spill Level (ML)	Surface Area at External Spill Level (ha)
1	A	85.0	150.5	-	29,121*	95.0*
	B	55.0	150.5	154.5	128,784	376.9
	CD	40.0	148.5	159.5	188,016	301.2
	E	85.0	148.5	-	26,947[α]	52.6[α]
2	A	89.0	147.0	-	18,887*	58.7*
	B	55.0	147.0	147.0	107,716	195.9
	CD	40.0	140.5	146.0	141,618	226.7
	E	85.0	140.5	-	16,149[α]	25.2[α]
3	A	80.0	-	163.5	20,968	164.8
	B	Backfilled				
	CD	Backfilled				
	E	80.0	-	163.0	44,804	190.2

* External spill occurs via Pit B hence value shown here is at the Pit B external spill level.

[α] External spill occurs via Pit CD hence value shown here is at the Pit CD external spill level.

Table 12 Preferred Option 1 Level-Volume-Area Relationship For Pits A, B, CD and E

Level (mAHD)	Pit A		Pit B		Pit CD		Pit E	
	Total Storage Volume (ML)	Open Water Area (ha)	Total Storage Volume (ML)	Open Water Area (ha)	Total Storage Volume (ML)	Open Water Area (ha)	Total Storage Volume (ML)	Open Water Area (ha)
40					0	0.0		
45					2	0.0		
50					60	0.0		
55			0	0.0	238	0.0		
60			54	0.0	722	0.0		
65			409	0.0	1,582	0.0		
70			1,121	0.0	2,964	0.0		
75			2,282	0.0	4,959	0.0		
80			3,941	0.0	7,523	0.8		
85	0	0.0	6,114	0.0	10,721	4.7	0	0.0
90	6	0.0	9,009	0.0	14,708	10.5	9	0.0
95	46	0.0	12,799	0.0	19,640	18.3	102	0.0
100	155	0.0	17,484	0.0	25,523	27.6	324	0.0
105	357	0.0	22,821	0.8	32,412	38.7	689	0.0
110	703	0.0	28,871	5.1	40,437	52.7	1,258	0.0
115	1,264	0.0	35,549	10.9	49,659	70.3	2,142	0.0
120	2,163	0.0	42,890	18.1	60,142	90.6	3,386	0.0
125	3,499	0.0	51,000	26.9	71,912	111.1	5,015	0.0
130	5,245	0.4	59,889	36.9	84,979	132.4	6,965	1.1
135	7,444	2.8	69,769	60.4	99,265	154.6	9,254	5.4
140	10,246	12.0	80,888	88.2	114,737	177.2	11,961	11.3
145	15,284	39.0	93,833	152.3	131,518	206.8	15,127	19.0
150	22,011	71.2	110,211	270.5	149,698	237.9	18,733	28.1
155	29,911	97.7	130,847	388.7	-	-	-	-
160					190,032	304.5	27,379	53.9

Note: levels provided for spoil volumes were in 5 m increments and the highest level provided does not necessarily match the assumed external spill level (Table 11). Where an external or internal spill level lies between the 5 m increments shown, the corresponding volume or area was linearly interpolated.

Table 13 Preferred Option 2 and Submitted Option Level-Volume-Area Relationship For Pits A, B, CD and E

Level (mAHD)	Pit A		Pit B		Pit CD		Pit E	
	Total Storage Volume (ML)	Open Water Area (ha)	Total Storage Volume (ML)	Open Water Area (ha)	Total Storage Volume (ML)	Open Water Area (ha)	Total Storage Volume (ML)	Open Water Area (ha)
40					0	0.0		
45					2	0.0		
50					60	0.0		
55			0	0.0	238	0.0		
60			54	0.0	722	0.0		
65			409	0.0	1,582	0.0		
70			1,121	0.0	2,964	0.1		
75			2,282	0.0	4,976	0.8		
80			3,941	0.0	7,583	1.9		
85	0	0.0	5,676	0.5	10,782	3.9	0	0.0
90	6	0.0	9,091	4.6	14,742	10.3	9	0.0
95	46	0.0	13,141	10.2	19,723	22.2	102	0.0
100	155	0.0	18,284	16.2	25,868	39.3	324	0.0
105	357	0.0	24,277	21.6	33,284	56.8	689	0.0
110	703	0.0	31,085	27.3	42,007	73.9	1,258	0.0
115	1,258	0.0	38,563	34.4	52,025	93.6	2,142	0.0
120	2,146	0.8	46,767	43.8	63,301	112.0	3,386	0.0
125	3,505	3.2	55,783	52.5	75,759	129.2	5,015	0.0
130	5,360	7.1	65,569	62.6	89,417	147.9	6,965	1.5
135	7,694	11.2	76,219	75.8	104,178	166.0	9,300	6.8
140	10,820	26.9	87,873	98.9	120,306	197.7	12,092	14.0
145	16,113	47.5	101,268	159.4	137,870	221.4	15,406	23.8
150	23,048	75.5	117,387	250.6	156,607	247.9	19,121	30.9
155	31,077	95.9	137,230	371.9	176,806	288.6	23,147	39.7
165	50,806	158.6	191,706	614.6	225,997	444.9	32,565	64.2

Note: levels provided for spoil volumes were in 5 m increments and the highest level provided does not necessarily match the assumed external spill level (Table 11). Where an external or internal spill level lies between the 5 m increments shown, the corresponding volume or area was linearly interpolated.

Table 14 Preferred Option 3 Level-Volume-Area Relationship For Pits A, B, CD and E

Level (mAHD)	Pit A		Pit B		Pit CD		Pit E	
	Total Storage Volume (ML)	Open Water Area (ha)	Total Storage Volume (ML)	Open Water Area (ha)	Total Storage Volume (ML)	Open Water Area (ha)	Total Storage Volume (ML)	Open Water Area (ha)
40								
45								
50								
55								
60								
65								
70								
75								
80								
85	0	0.0					0	0.0
90	6	0.0					9	0.0
95	46	0.0					102	0.0
100	155	0.0					324	0.0
105	357	0.0					689	0.0
110	703	0.0					1,258	0.0
115	1,264	0.0					2,142	0.0
120	2,163	0.0					3,392	0.8
125	3,499	0.0					5,117	5.0
130	5,243	0.0					7,386	14.6
135	7,394	0.0					10,292	27.0
140	10,155	8.9					13,907	41.7
145	14,740	14.6					18,276	57.4
150	20,592	50.6					23,490	79.6
155	27,776	80.4					30,049	117.2
160	36,307	119.1					38,468	161.0
165	46,760	184.4					49,027	209.6

Note: levels provided for spoil volumes were in 5 m increments and the highest level provided does not necessarily match the assumed external spill level (Table 11). Where an external or internal spill level lies between the 5 m increments shown, the corresponding volume or area was linearly interpolated.

4.9 INITIAL STORED WATER VOLUMES

The volume of water initially stored in each void was calculated differently for Preferred Options 1 and 3 and the Submitted Option compared to Preferred Option 2. This is because pits in Preferred Options 1 and 3 and the Submitted Option will respond relatively slowly to the various water inflows and outflows as groundwater levels recover over time. Water storage in Preferred Option 2 will change quickly at the time of the first inflow from the river. For Preferred Options 1 and 3 and the Submitted Option, the initial water level was assumed to be the maximum of:

- the minimum final rehabilitated mining area floor level; and
- one metre above the lower zero groundwater flux level predicted by HydroSimulations (2018b).

For Preferred Option 2, the initial water level was assumed to be equal to the HydroSimulations (2018b) predicted groundwater level as at the year 2030 which reflects the average timeframe for completion of the rehabilitated mining areas. Table 15 summarises the resulting initial stored water volumes.

Table 15 Summary of Assumed Initial Stored Water Volumes

Option	Void	Initial Stored Water Level (mAHD)			Initial Stored Water Volume (ML)
		Minimum Final Rehabilitated Area Floor Level	1 m Above Zero Flux Boundary	Adopted Initial Level	
Preferred Option 1	A	127.0	126.0	127.0	4,196
	B	100.0	104.6	104.6	22,363
	CD	77.0	81.0	81.0	8,163
	E	127.0	131.0	131.0	7,418
Preferred Option 2	A	-	-	126.0	3,876
	B	-	-	66.0	551
	CD	-	-	69.0	2,688
	E	-	-	117.0	2,640
Preferred Option 3	A	136.0	141.9	141.9	11,921
	B	-	-	-	-
	CD	-	-	-	-
	E	116.0	110.0	116.0	2,390
Submitted Option	A	109.0	111.0	111.0	814
	B	84.0	76.0	84.0	5,676
	CD	68.0	78.3	78.3	6,683
	E	127.0	131.0	131.0	7,432

4.10 WATER QUALITY

Surface runoff, groundwater and river inflows were assumed to supplying solutes to the void at a constant concentration representative of each source. The solute concentrations adopted in the modelling were based on information supplied by RGS (2018) and are summarised in Table 16.

Table 16 Summary of Assumed Water Quality Source Concentrations

Parameter	Assumed Concentration (mg/L)					
	Sub-Catchment Surface Runoff			Other Sources		
	Natural	Rehabilitated Spoil	Highwall (Open Cut Pit)	Groundwater	Nogoa River	Baseflow
Calcium	17	14	30	360	17	400
Chloride	18	140	86	3,200	18	6,400
Magnesium	6	18	111	320	6	640
Potassium	5	8	5	18	5	36
Sodium	56	100	3	1,580	56	3,160
Sulphate as SO_4	13	68	38	480	13	1,056
Arsenic	0.0022	0.002	0.0064	0.002	0.0022	0.1
Molybdenum	0.00175	0.00175	0.0051	0.006	0.00175	0.34
Selenium	0.0005	0.0005	0.0147	0.0025	0.0005	0.23
TDS	115	348	273	5,958	115	11,692

The baseflow source term for all salt parameters (i.e. calcium, chloride, magnesium, potassium, sodium and TDS) in Table 16 would be conservatively high if these values were assumed to remain constant for the duration of the simulation. The results of leach column tests (RGS, 2018) show that salt from the spoil material declines over time. To include the effects of decline in salts over time, a source decay relationship was developed for baseflow in consultation with Ensham and SRK (2020). This relationship has been applied to the parameters for Preferred Options 1 and 3 as shown in Table 17 as well as to Preferred Option 2 and the Submitted Option as shown in Table 18. These relationships were estimated from unsaturated leach column tests that indicated a solute concentration reduction of about 50% for each pore water volume displacement. The 50 year term is based on an average recharge rate (baseflow) of 10% of mean annual precipitation as indicated by the AWBM modelling results and an average spoil height of about 20 m above the maximum water level. A starting year of 2000 was adopted by RGS (2018) based on an average establishment time for the in-pit spoil. Adopting this as the starting time for the decay relationship reflects the partial displacement of salt which has already occurred since the spoil was emplaced. Decay factors were linearly interpolated in between simulation years given in Table 17 and Table 18.

The adopted start date for the water balance simulation of Preferred Options 1 and 3 has been taken as 2057 based on the assumed initial stored water levels (refer Section 4.9) and the resulting date which the groundwater model predicted those levels would be reached (HydroSimulations, 2018b). Preferred Option 2 and the Submitted Option were started in 2030 based on the assumed initial stored water levels (refer Section 4.9).

Table 17 Decay Factors for Solute Concentrations in Baseflow: Preferred Options 1 and 3 (SRK, 2020)

Year	Decay Factor									
	Ca	Cl	Mg	K	Na	SO_4	TDS	As	Mo	Se
0	0.5	0.5	0.5	0.5	0.5	1	0.5	1	1	1
43	0.5	0.5	0.5	0.5	0.5	1	0.5	1	1	1
44	0.25	0.25	0.25	0.25	0.25	1	0.25	1	1	1
93	0.25	0.25	0.25	0.25	0.25	1	0.25	1	1	1
94	0.125	0.125	0.125	0.125	0.125	1	0.125	1	1	1
143	0.125	0.125	0.125	0.125	0.125	1	0.125	1	1	1
144	0.125	0.125	0.125	0.125	0.125	0.5	0.125	0.5	0.5	0.5
158	0.125	0.125	0.125	0.125	0.125	0.5	0.125	0.5	0.5	0.5
159	0.0625	0.0625	0.0625	0.0625	0.0625	0.5	0.0625	0.5	0.5	0.5
193	0.0625	0.0625	0.0625	0.0625	0.0625	0.5	0.0625	0.5	0.5	0.5
194	0.0625	0.0625	0.0625	0.0625	0.0625	0.25	0.0625	0.25	0.25	0.25
208	0.0625	0.0625	0.0625	0.0625	0.0625	0.25	0.0625	0.25	0.25	0.25
209	0.03125	0.03125	0.03125	0.03125	0.03125	0.25	0.03125	0.25	0.25	0.25
243	0.03125	0.03125	0.03125	0.03125	0.03125	0.25	0.03125	0.25	0.25	0.25
244	0.03125	0.03125	0.03125	0.03125	0.03125	0.125	0.03125	0.125	0.125	0.125
258	0.03125	0.03125	0.03125	0.03125	0.03125	0.125	0.03125	0.125	0.125	0.125
259	0.015625	0.015625	0.015625	0.015625	0.015625	0.0625	0.015625	0.0625	0.0625	0.0625
293	0.015625	0.015625	0.015625	0.015625	0.015625	0.0625	0.015625	0.0625	0.0625	0.0625

Table 18 Decay Factors for Solute Concentrations in Baseflow: Preferred Option 2 and Submitted Option (SRK, 2020)

Year	Decay Factor									
	Ca	Cl	Mg	K	Na	SO_4	TDS	As	Mo	Se
0	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1	1	1
21	0.5	0.5	0.5	0.5	0.5	1	0.5	1	1	1
70	0.5	0.5	0.5	0.5	0.5	1	0.5	1	1	1
71	0.25	0.25	0.25	0.25	0.25	1	0.25	1	1	1
120	0.25	0.25	0.25	0.25	0.25	1	0.25	1	1	1
121	0.125	0.125	0.125	0.125	0.125	1	0.125	1	1	1
135	0.125	0.125	0.125	0.125	0.125	1	0.125	1	1	1
136	0.125	0.125	0.125	0.125	0.125	0.5	0.125	0.5	0.5	0.5
170	0.125	0.125	0.125	0.125	0.125	0.5	0.125	0.5	0.5	0.5
171	0.0625	0.0625	0.0625	0.0625	0.0625	0.5	0.0625	0.5	0.5	0.5
185	0.0625	0.0625	0.0625	0.0625	0.0625	0.5	0.0625	0.5	0.5	0.5
186	0.0625	0.0625	0.0625	0.0625	0.0625	0.25	0.0625	0.25	0.25	0.25
220	0.0625	0.0625	0.0625	0.0625	0.0625	0.25	0.0625	0.25	0.25	0.25
221	0.03125	0.03125	0.03125	0.03125	0.03125	0.25	0.03125	0.25	0.25	0.25
235	0.03125	0.03125	0.03125	0.03125	0.03125	0.25	0.03125	0.25	0.25	0.25
236	0.03125	0.03125	0.03125	0.03125	0.03125	0.125	0.03125	0.125	0.125	0.125
270	0.03125	0.03125	0.03125	0.03125	0.03125	0.125	0.03125	0.125	0.125	0.125

Final void water quality concentrations have been simulated under simplifying assumptions of conservation of mass and fully-mixed behaviour for the waterbodies. The concentration of various parameters in void outflows was assumed to be equal to the fully mixed concentration of the waterbody in the void at the time the outflows were simulated, other than evaporation for which concentrations were assumed equal to zero.

The solute concentrations of the water initially stored in the voids were provided by RGS (2018) and are summarised in Table 19.

Table 19 Summary of Assumed Initial Solute Concentrations

Parameter	Assumed Concentration (mg/L)			
	Pit A	Pit B	Pit CD	Pit E
Calcium	68	275	148	*
Chloride	2,560	3,120	2,600	
Magnesium	198	147	242	
Potassium	16	18	17	
Sodium	1,393	1,513	1,409	
Sulphate as SO_4	630	347	465	
Arsenic	0.001	0.002	0.001	
Molybdenum	0.006	0.004	0.004	
Selenium	0.0005	0.0005	0.0005	
TDS	4,864	5,420	4,881	

* No data available, assumed the same as Pit CD.

For ease of viewing results for TDS, a conversion factor to electrical conductivity (EC) of one divided by 0.67 has been applied as agreed with SRK.

4.11 POTENTIAL SHORT-TERM IMPACT OF SALT LEACHING (RUN 5)

The results of the geochemical assessment (RGS, 2018) indicate the potential for elevated short-term salinity release associated with an initial leaching of salt from in-pit spoil under Preferred Option 2, prior to leachate concentrations stabilising to a much lower level in the longer term. The potential short-term impacts on void water salinity (i.e. TDS) for Preferred Option 2 were investigated in Model Run 5 using a different methodology for salt release to the water bodies.

In addition to the constant long-term salt release rates, Model Run 5 included the initial leaching of salt from both the pit highwall and in-pit spoil which could occur during the initial few fill cycles of the voids, with water inflow from the river and subsequent drawdown for beneficial use.

The additional salt input terms were developed by RGS (2018) in consultation with SRK (2018). The average salt load from the in-pit spoil to the open water body was estimated to be 100 tonnes/kilometre length of pit-spoil interface/metre fall in water level (RGS, 2018). The salt load from the highwall was assumed to be 70 tonnes/hectare (RGS, 2018) and implemented to be proportional to the change in surface area inundated during each water level rise event. Based on the configuration of the rehabilitated mining areas, the proportion of spoil drainage increases as water levels are drawn down and the proportion of highwall drainage increases as water levels increase. Since the water balance combines the spoil storage and the open water body as a single storage, this was represented by a correction factor for the spoil salt load for each pit as derived by SRK (2018) to account for the difference between the source derivation and the model implementation.

The actual behaviour of the voids during the initial filling and drawdown will be affected by the magnitude and sequence of wet and dry periods following completion of construction. To illustrate the potential effects of the initial filling and drawdown, a period that included several fills and drawdowns was selected from the historical climate record. The adopted period was a 27 year period from 1889 to 1916, which is the first 27 years of the climate data series (i.e. the same starting data as were used for all other runs).

4.12 INTERNAL SPILL BETWEEN FLOODPLAIN VOIDS

Internal spill was assumed to occur between Pit A and Pit B as well as Pit CD and Pit E in Preferred Options 1 and 2 when water levels in each void exceeded the adjacent pit water level and the internal spill level specified in Table 11. Internal spill was assumed (by HEC) to occur at a rate of 500 ML/d. This adopted rate provided a representation of the likely pumped transfer of water to Pits A and E in the weeks immediately following a flood event that generated significant inflow to Pits B and CD.

4.13 MANAGEMENT OF VOID WATER QUALITY WITH SUPPLEMENTED WATER ALLOCATION (PREFERRED OPTION 2 ONLY)

Ensham has an existing supplemented allocation of 1,500 ML per annum from Fairbairn Dam which could potentially be used to maintain improved water quality in the Ensham voids. It was assumed that the existing allocation up to 1,500 ML per year would be pumped to Pit B and Pit CD at a maximum rate of 50 L/s (total to both pits) for Preferred Option 2 if the water level in the voids fell more than 1 m below the spill level to the Nogoa River.

4.14 INTAKE STRUCTURE FLOW TO/FROM NOGOA RIVER (PREFERRED OPTION 2 ONLY)

Preferred Option 2 comprises the existing levees but with channels linking the Pit B and Pit CD final voids with the Nogoa River and culverts located within the channels (coincident with the levees) to regulate the rate of flow exchange between the Nogoa River and the final voids.

In order to simulate inflows from and outflows to the Nogoa River via the proposed intake structures at Pit B and Pit CD in Preferred Option 2, a flow sequence for the Nogoa River was required. This data was supplied by Ensham. It is understood that this flow sequence comprised daily flow rate data generated using the Integrated Quantity and Quality Model (IQQM) for the Nogoa River at the Duck Ponds gauging station (GS 130219A) from the Fitzroy Basin Resource Operations Plan (ROP) model. The location of the Duck Ponds gauging station is shown on Figure 10, Figure 11 and Figure 12. It is further understood that the model is based on the historical climate sequence with the water supply scheme operating under the ROP assumptions. This means that the simulated flow sequence will not exactly match historical flows because the simulated sequence includes infrastructure (such as Fairbairn Dam) and demands that would not have been in place over the full historical climate sequence. Figure 13 shows peak annual flows recorded at the Duck Ponds gauging station and the values predicted from the flood frequency analysis by HEC (2018c).

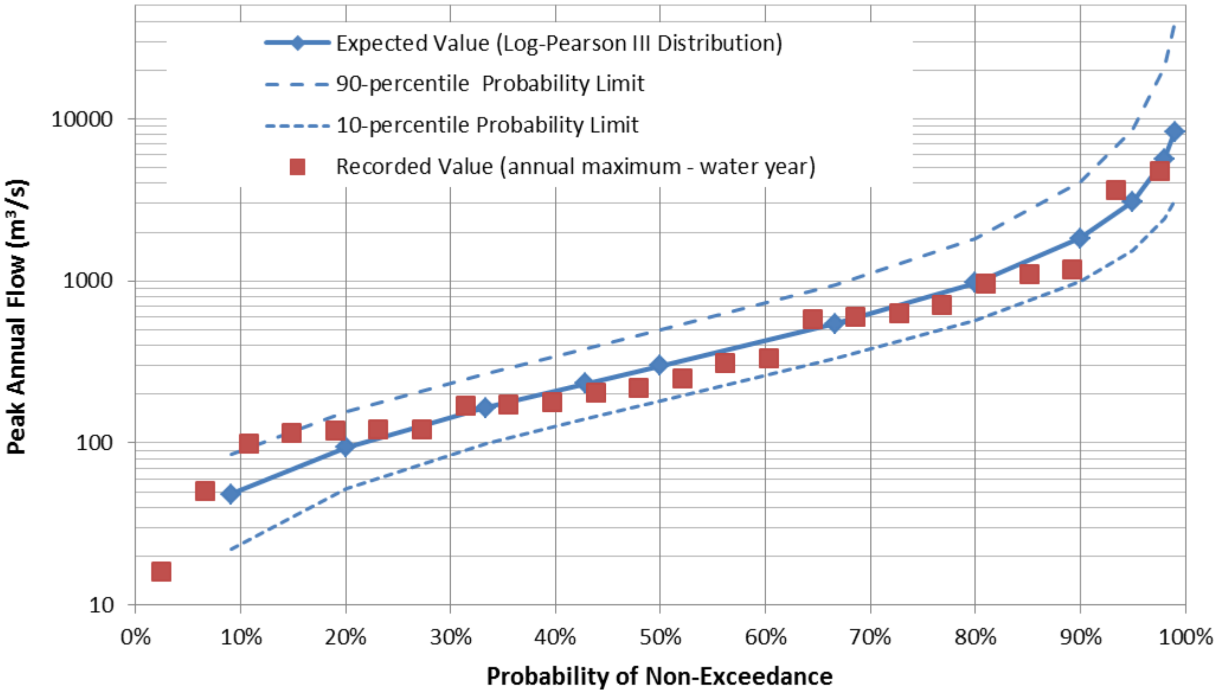

Figure 13 Peak Annual Flow Frequency Analysis – Duck Ponds Gauging Station

The modelled flow sequence was provided from 1889 to 2007 inclusive. However, when recorded flow data was available for the Duck Ponds gauging station (i.e. from April 1993 to end of 2017) this recorded data was used preferentially to the IQQM flow sequence. The resulting composite flow sequence is plotted in Figure 14. Also shown in Figure 14 is the assumed daily Nogoa River flow sequence for the climate change scenario provided by OD Hydrology (2018).

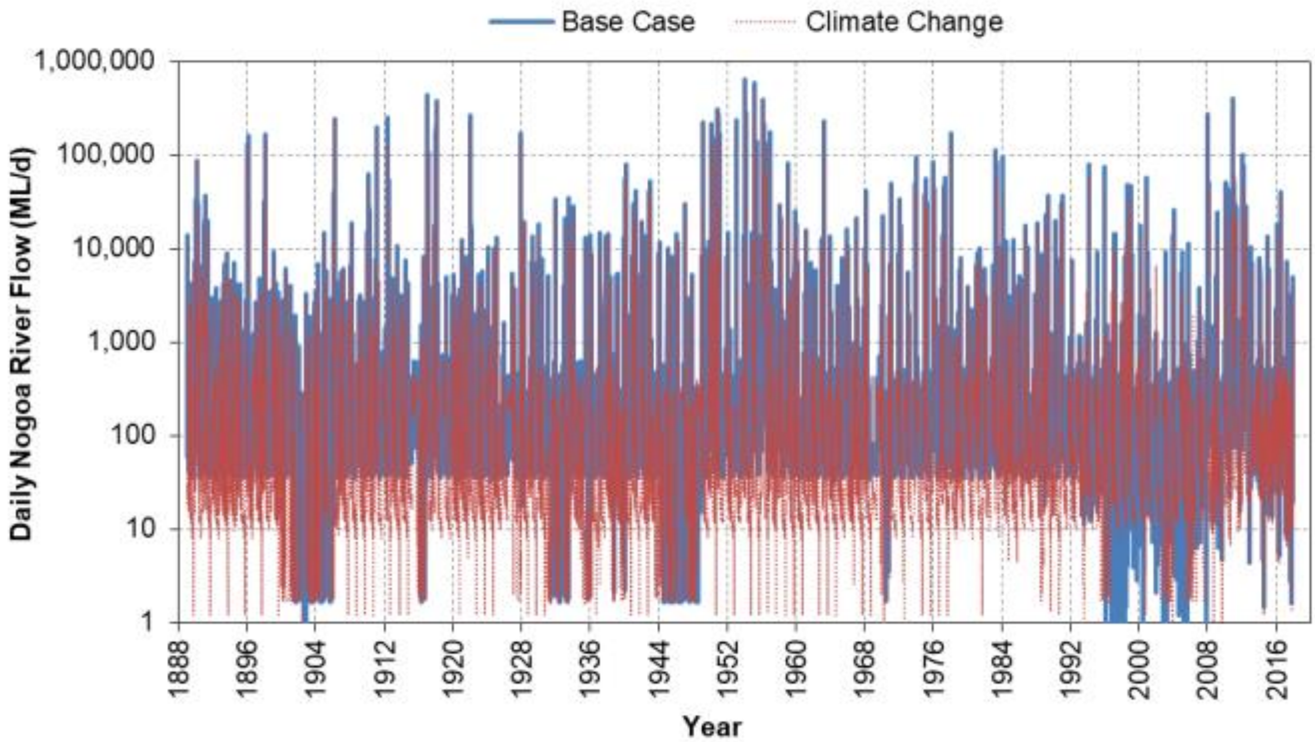

Figure 14 Assumed Daily Nogoa River Flow at Duck Ponds Gauging Station

This flow record was repeated in the model in the same way as the rainfall and evaporation data (refer Section 4.3).

It was assumed (by HEC) that the flow rate at the Duck Ponds gauging station was equal to the flow rate at both the Pit B and Pit CD intake structures. The hydraulic (flood) model (HEC 2018c) was used to convert the flow rate in the Nogoa River to a water level at each intake structure via the generation of two separate rating curves at the intake structure locations. Details of the hydraulic modelling are outlined in the HEC (2018c) report.

Once the water level in the Nogoa River at each intake structure was calculated, this water level was converted to a flow rate through the intake structures based on rating curves provided by WSP (2018) as summarised in Figure 15.

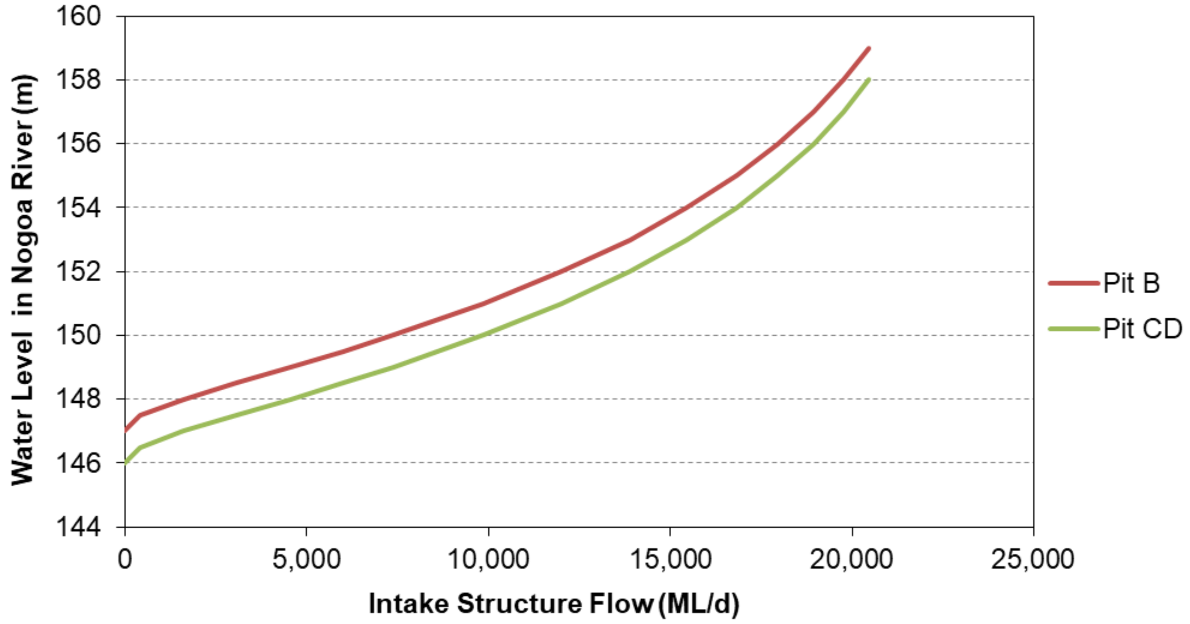

Figure 15 Intake Structure Rating Curves (WSP, 2018)

Given the relatively flat slope on each of the intake structures, it was assumed (by HEC) that the relationship for Nogoa River to void flow would also apply to void to Nogoa River flow in an equal and opposite fashion. Tailwater effects for each intake structure caused by rising water levels within the voids were calculated, used to modify the flow relationships in Figure 15 and included in the GoldSim model.

4.15 IRRIGATION FROM PIT B AND PIT CD (PREFERRED OPTION 2 ONLY)

For Preferred Option 2 to be viable, a reliable water supply to irrigation and industrial users should be demonstrated by the void water balance model. As noted in Section 2.2, this water supply would be delivered via a series of pipes to the Weemah Channel and Yamala inland port. Irrigation demand was provided by OD Hydrology (2018) for three options:

- Pit B only (i.e. Stage 1) – 8 GL/year;
- Pit B and CD (i.e. Stage 2) – 20 GL/year; and
- Pit B and CD with climate change (i.e. Stage 2 with climate change) – 10 GL/year.

The values were provided as monthly demands for one year as summarised in Table 20. This annual demand sequence was applied to all simulated years as advised by OD Hydrology.

Table 20 Assumed Irrigation Demand (OD Hydrology, 2018)

Month	Daily Irrigation Demand (ML/d)		
	Pit B only	Pit B and CD	Pit B and CD with climate change
January	37.4	93.5	46.7
February	33.0	82.5	41.2
March	30.0	74.9	37.5
April	9.5	23.8	11.9
May	9.0	22.4	11.2
June	8.4	21.0	10.5
July	13.3	33.2	16.6
August	15.1	37.7	18.8
September	16.0	39.9	19.9
October	27.9	69.8	34.9
November	31.0	77.4	38.7
December	31.9	79.7	39.8

Note that a dead storage level was assumed for each void based on contours (supplied by Ensham) below which water is stored in spoils and cannot be pumped. A salinity limit of 2,000 mg/L was applied to pumping to irrigation such that if the simulated salinity in Pit B or Pit CD rose above the limit, pumping to supply irrigation would cease.

The proposed pumping system linking the water storage pits for Preferred Option 2 would be subject to detailed assessment and optimisation in future studies to support engineering design. The system will have complex pumping rules and will be adaptively managed to maximise water availability and quality which will be affected by the frequency and volume of river inflows and demands. The overflow rate from Pit B to Pit A was increased to simulate potential inter-storage transfer of water to replenish Pit A during a significant inflow event to Pit B, as noted in Section 4.12. Water for irrigation use was assumed to be drawn from Pit B and Pit CD only because these pits represent the vast majority of available water storage and will provide the best representation of water quality to be used for irrigation.

4.16 SENSITIVITY RUNS

In addition to the Submitted Option base case described in Section 2.4, six additional (6) model runs were simulated and are summarised in the sections below.

4.16.1 Climate Change

To test sensitivity of model results to changes in rainfall and evaporation, climate change factors were calculated using the Climate Change in Australia website (refer Section 4.4).

4.16.2 Pan Factor Low

Pan factors are an assumed parameter in the model hence the sensitivity of model results to this parameter has been tested. The base case model run assumes a pan factor of 0.6 when the voids are empty and 0.85 at capacity. For the "pan factor low" model run, the pan factors have been reduced to 0.5 when the voids are empty and 0.75 at capacity.

4.16.3 Pan Factor High

For the "pan factor high" model run, the pan factors have been increased to 0.7 when the voids are empty and 0.95 at capacity.

4.16.4 Initial Storages Low

In order to understand the impact of the adopted initial stored water levels/volumes in each pit on the overall results, the initial storage levels were reduced by 10 m.

4.16.5 Initial Storages High

For the "initial storages high" model run, the initial stored water levels in each pit were increased by 10 m.

5.0 RESULTS AND ANALYSIS

5.1 RAINFALL RUNOFF MODEL CALIBRATION

The rainfall runoff component of the GoldSim water balance model was checked against available site data for Pit B and Pit Y. The limited pumping data for both pits meant that a comprehensive calibration could not be undertaken.

Anecdotal site information (provided by Ensham) suggests that water is pumped into and out of Pit Y however there are no volumetric records available. Figure 16 shows plots of the predicted volumes (red) and site recorded (green) data for Pit Y from the start of 2016 to April 2018 assuming no pumping. The fit between the recorded and modelled volumes is poor, however pump in volumes are inferred to have occurred in the first half of 2016 while dewatering appears to have occurred since. By making reasonable assumptions regarding pumping volumes, Figure 17 shows that a reasonable fit to recorded volumes can be achieved for Pit Y.

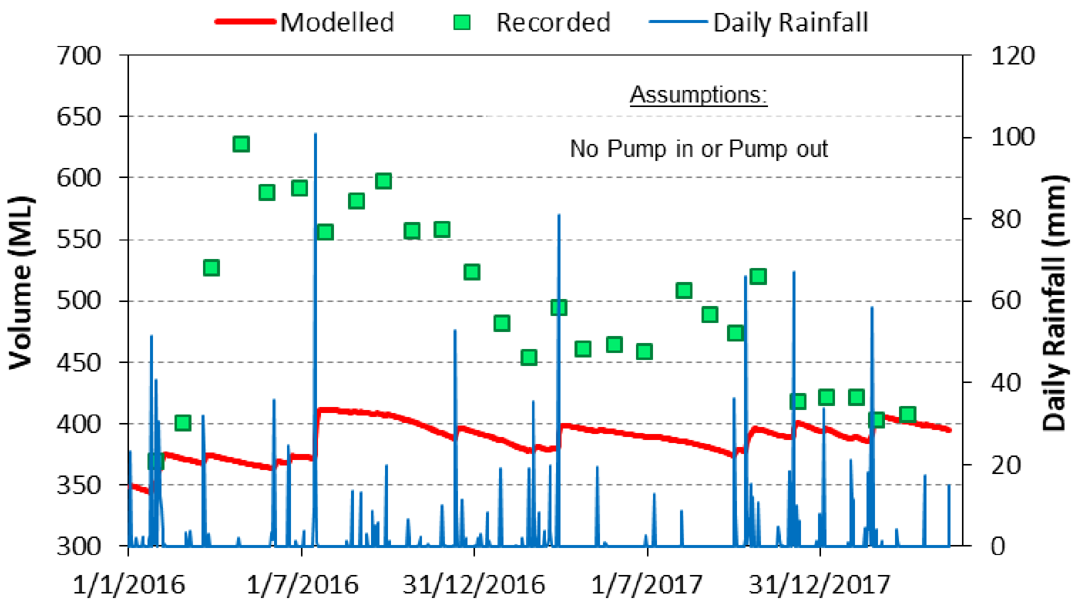

Figure 16 Calibration: Pit Y, No Pumping In or Out

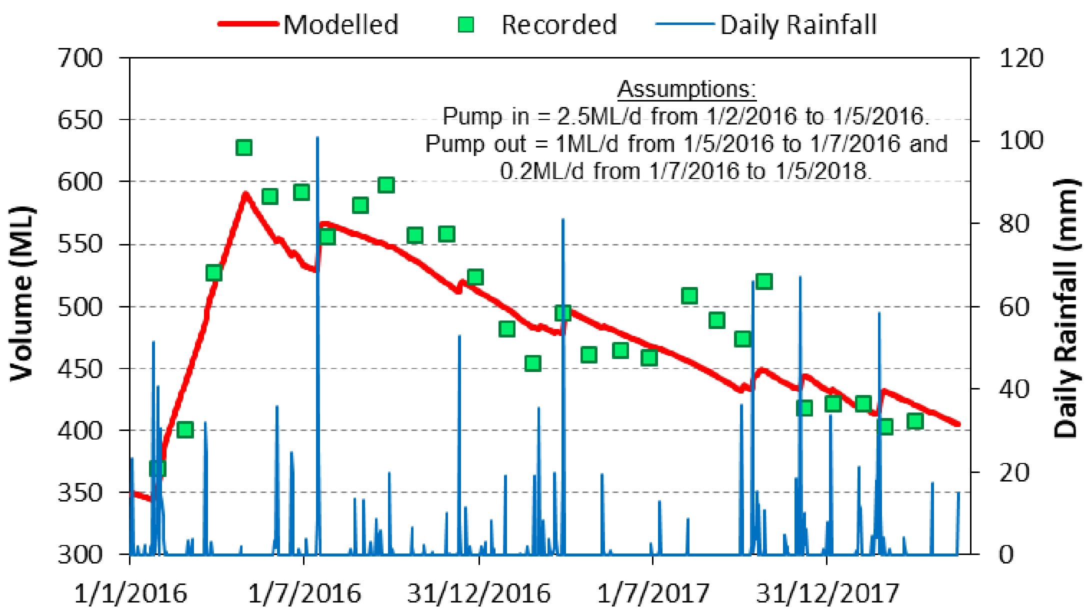

Figure 17 Calibration: Pit Y, Assumed Pumping In or Out

Without pumping data, comprehensive calibration of the rainfall runoff component of the GoldSim water balance model is not possible at this stage.

5.2 MODEL RUN 1 RESULTS (PREFERRED OPTION 1: BASE CASE)

The objective of Model Run 1 is to predict the water levels, volumes and quality results for the base case of Preferred Option 1. Results for each void for Model Run 1 are summarised in the sections to follow.

5.2.1 Water Levels

Figure 18 to Figure 21 show forecast water levels over the 258 year simulation period for each of the voids in Model Run 1.

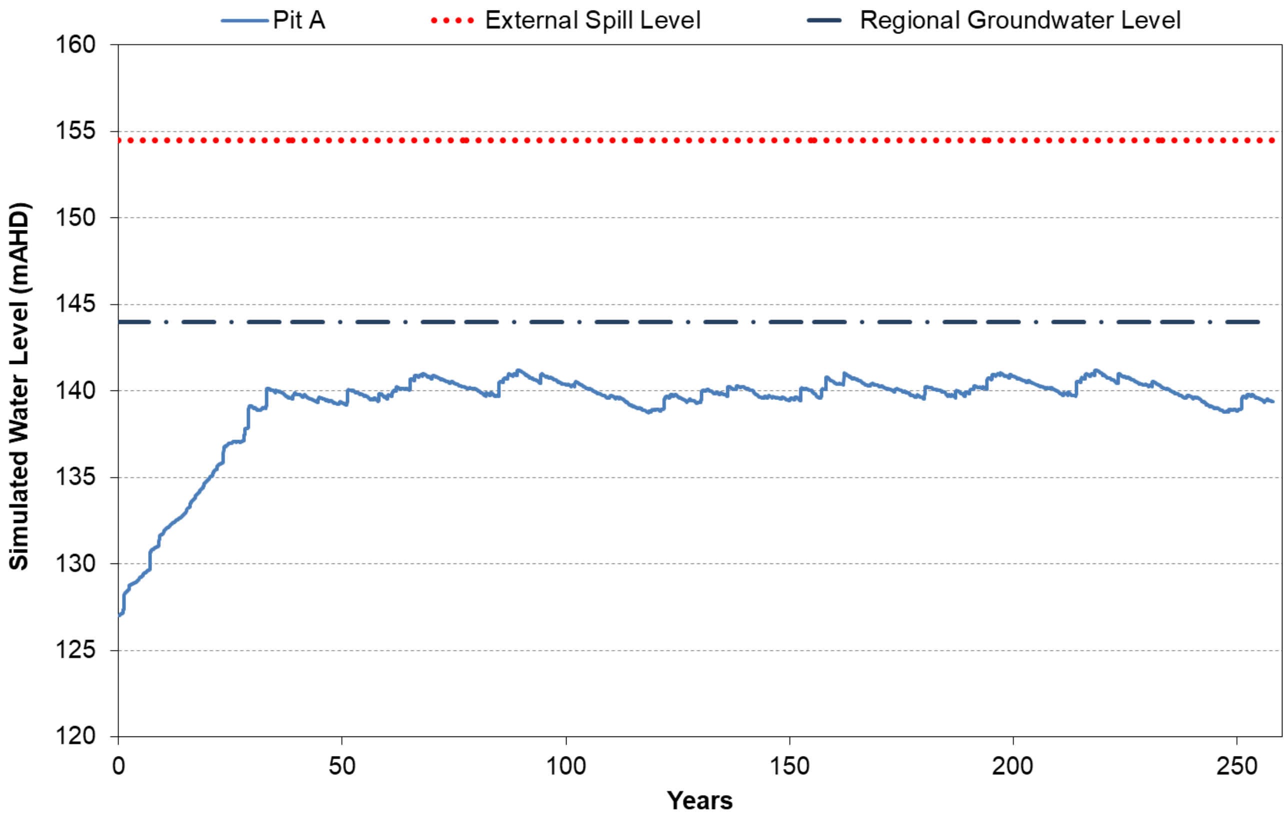

Figure 18 Water Level Results: Model Run 1, Pit A

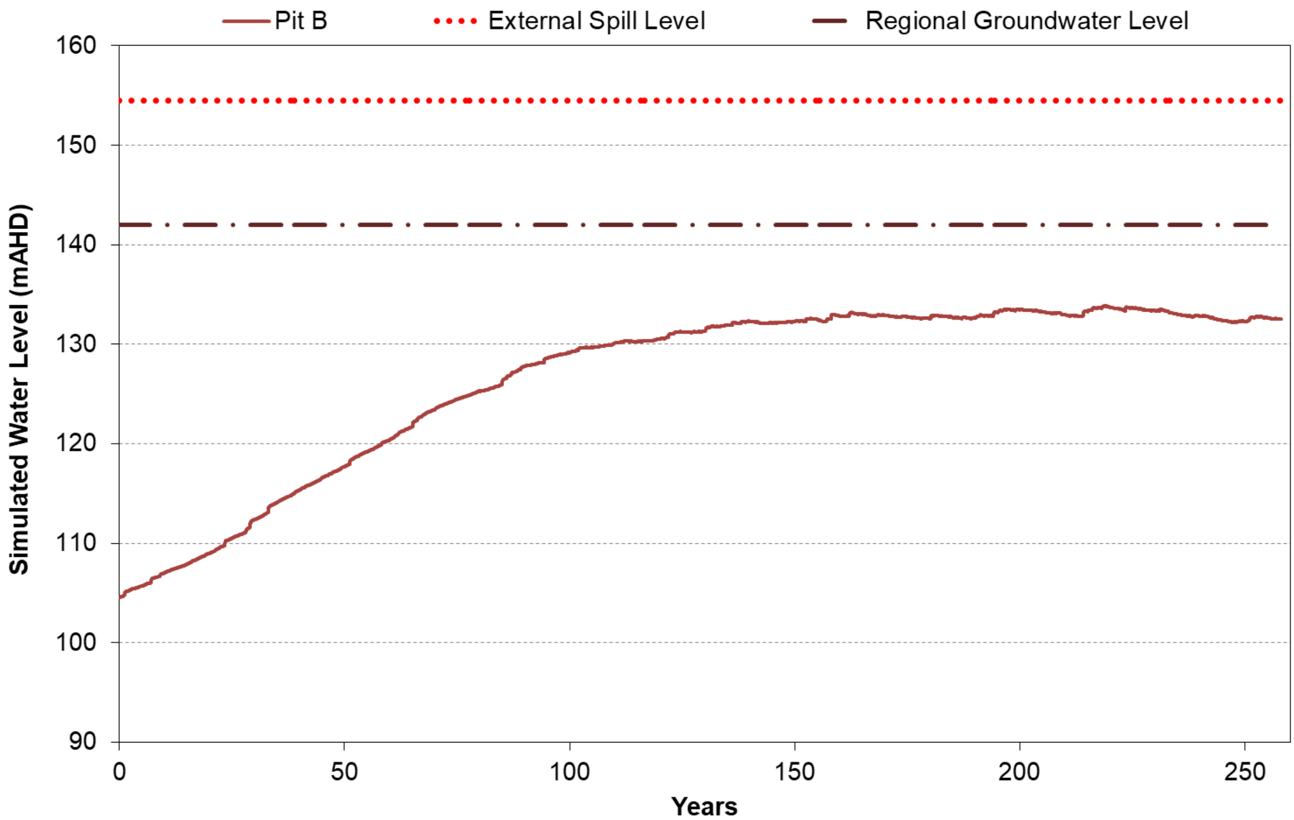

Figure 19 Water Level Results: Model Run 1, Pit B

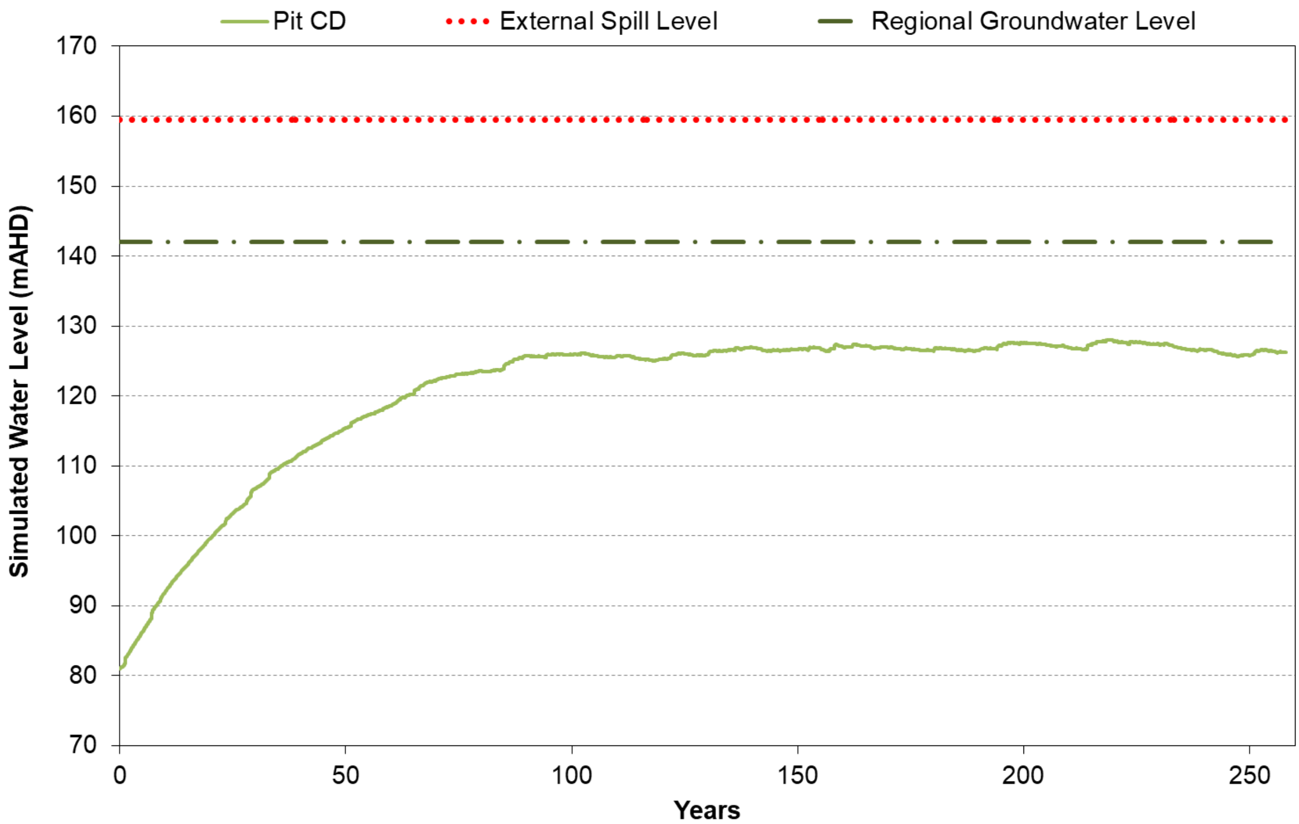

Figure 20 Water Level Results: Model Run 1, Pit CD

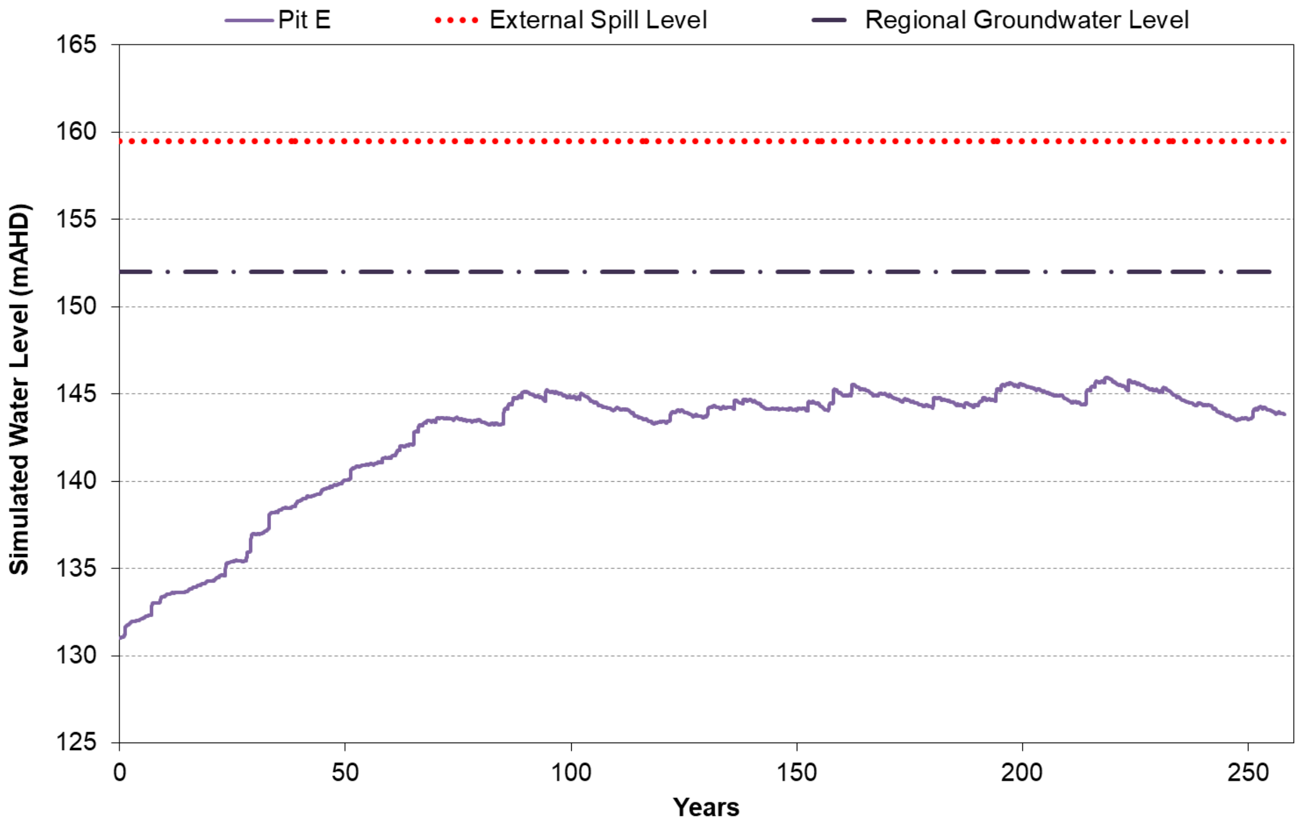

Figure 21 Water Level Results: Model Run 1, Pit E

Figure 18 shows that Pit A reaches equilibrium water level after around 50 years at approximately 140 mAHD or 14.5 m below the external spill level (154.5 mAHD) and approximately 4 m below the regional groundwater level (144 mAHD).

Figure 19 shows that Pit B reaches equilibrium water level after around 150 years at approximately 133 mAHD or 21.5 m below the external spill level (154.5 mAHD) and approximately 9 m below the regional groundwater level (142 mAHD).

Figure 20 shows that Pit CD reaches equilibrium after around 125 years at approximately 127 mAHD or 32.5 m below the external spill level (159.5 mAHD) and approximately 15 m below the regional groundwater level (142 mAHD).

Figure 21 shows that Pit E reaches equilibrium after around 100 years at approximately 144.5 mAHD or 15 m below the external spill level and approximately 7.5 m below the regional groundwater level (152 mAHD).

5.2.2 Water Volumes

Figure 22 shows the simulated water volume results over the 258 year simulation period for each of the voids in Model Run 1.

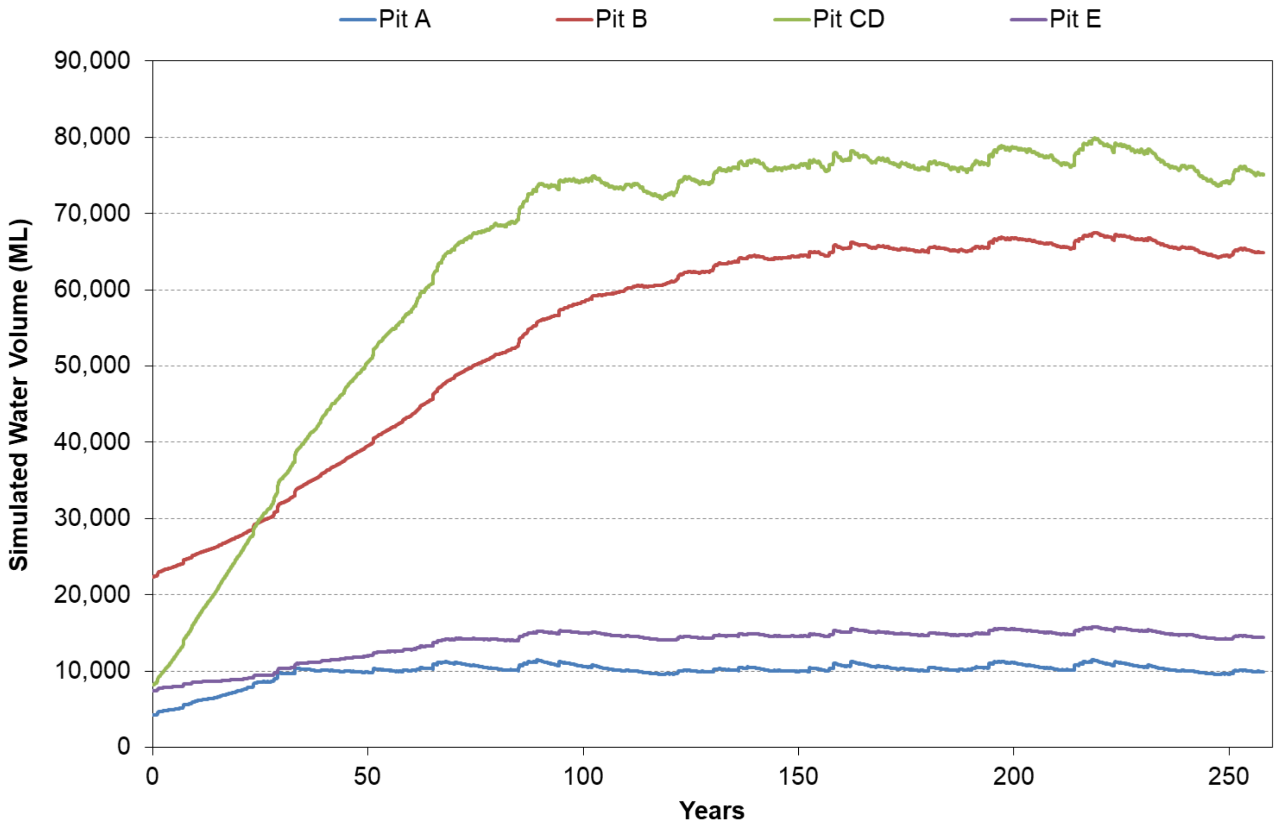

Figure 22 Water Volume Results: Model Run 1

Figure 22 shows that simulated water volume in Pit CD (approximately 75 GL after 250 years) is the highest followed by Pit B (approximately 65 GL after 250 years). Pit A and Pit E are both simulated to store less than 20 GL over the simulation period.

5.2.3 Water Quality

Figure 23 to Figure 34 show water quality results (major ions, trace elements and salinity) over the 258 year simulation period for each of the voids in Model Run 1.

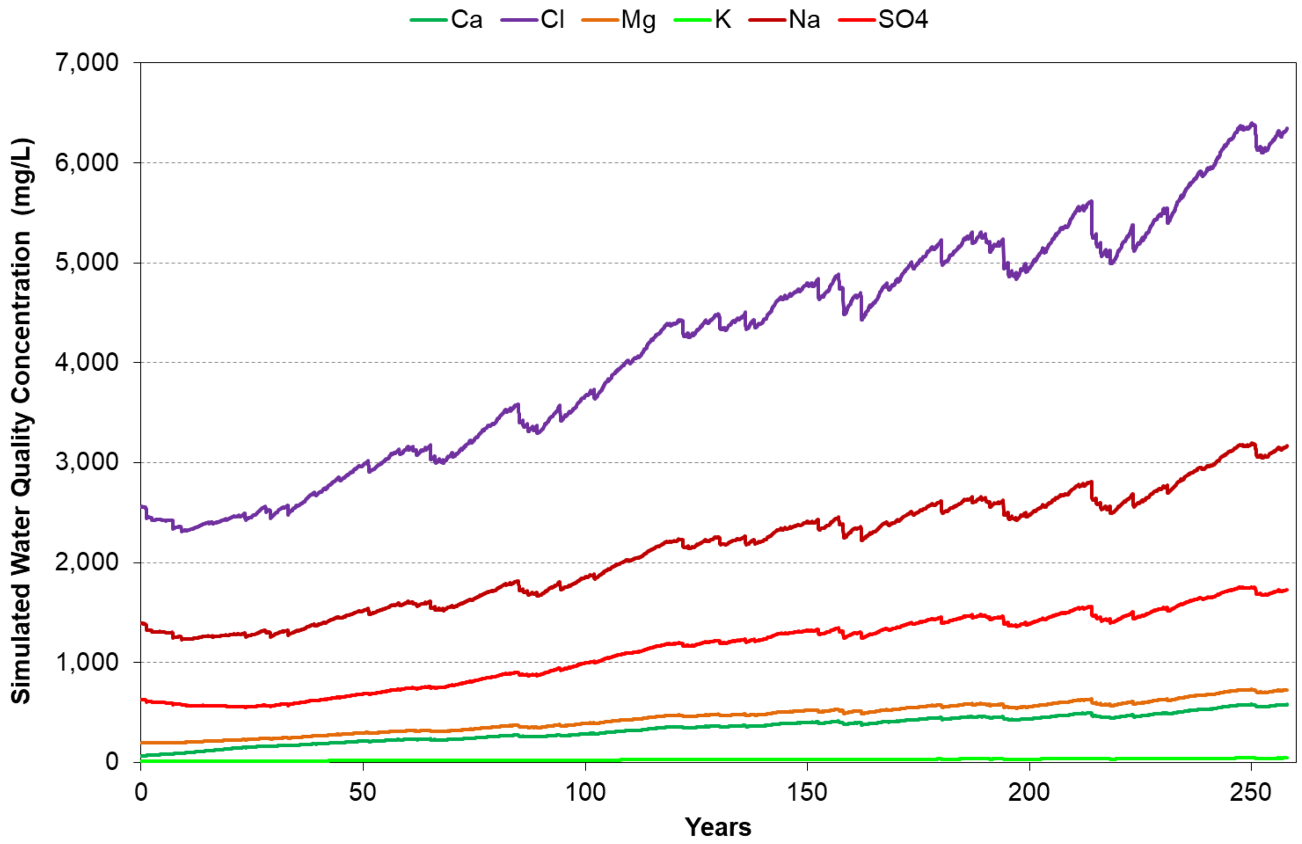

Figure 23 Water Quality Results: Model Run 1, Pit A – Major Ions

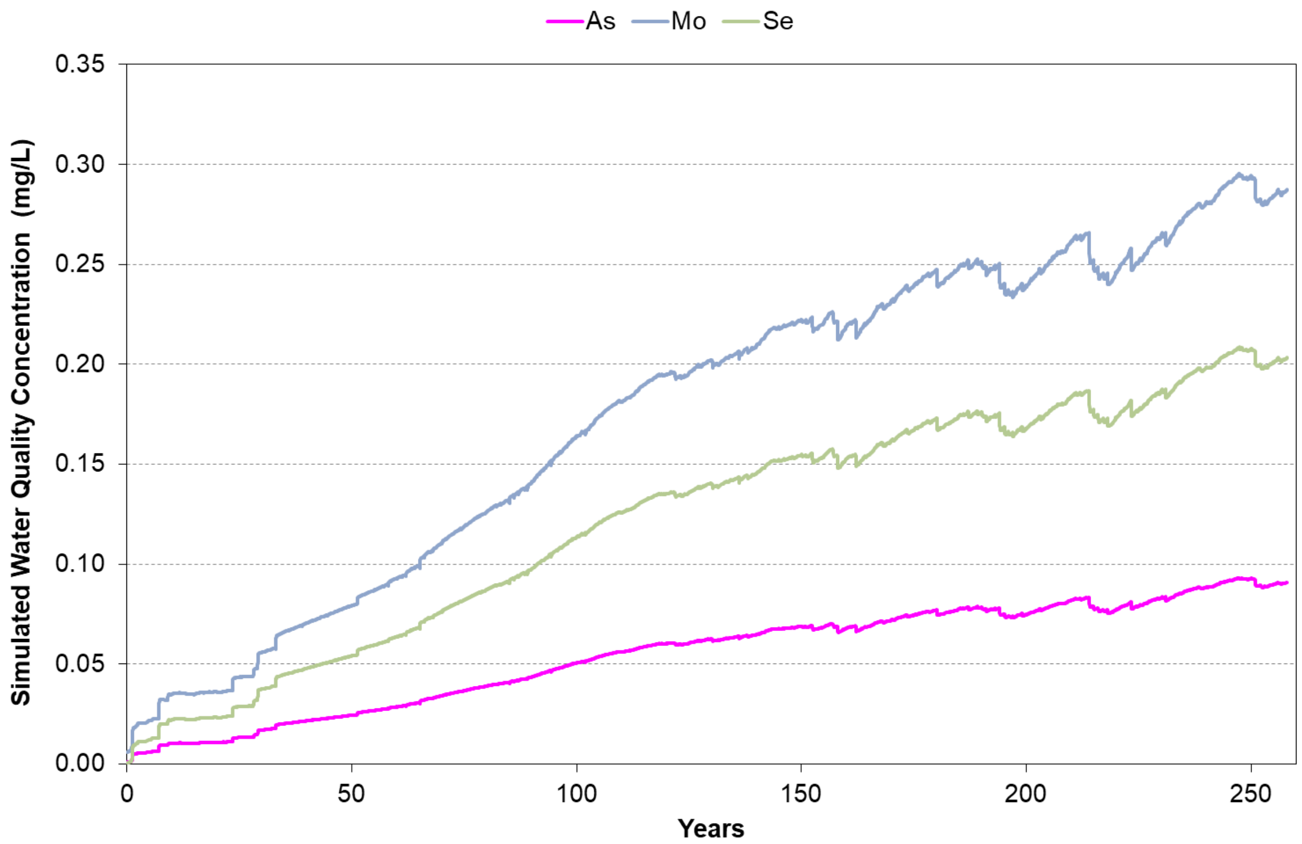

Figure 24 Water Quality Results: Model Run 1, Pit A – Trace Elements

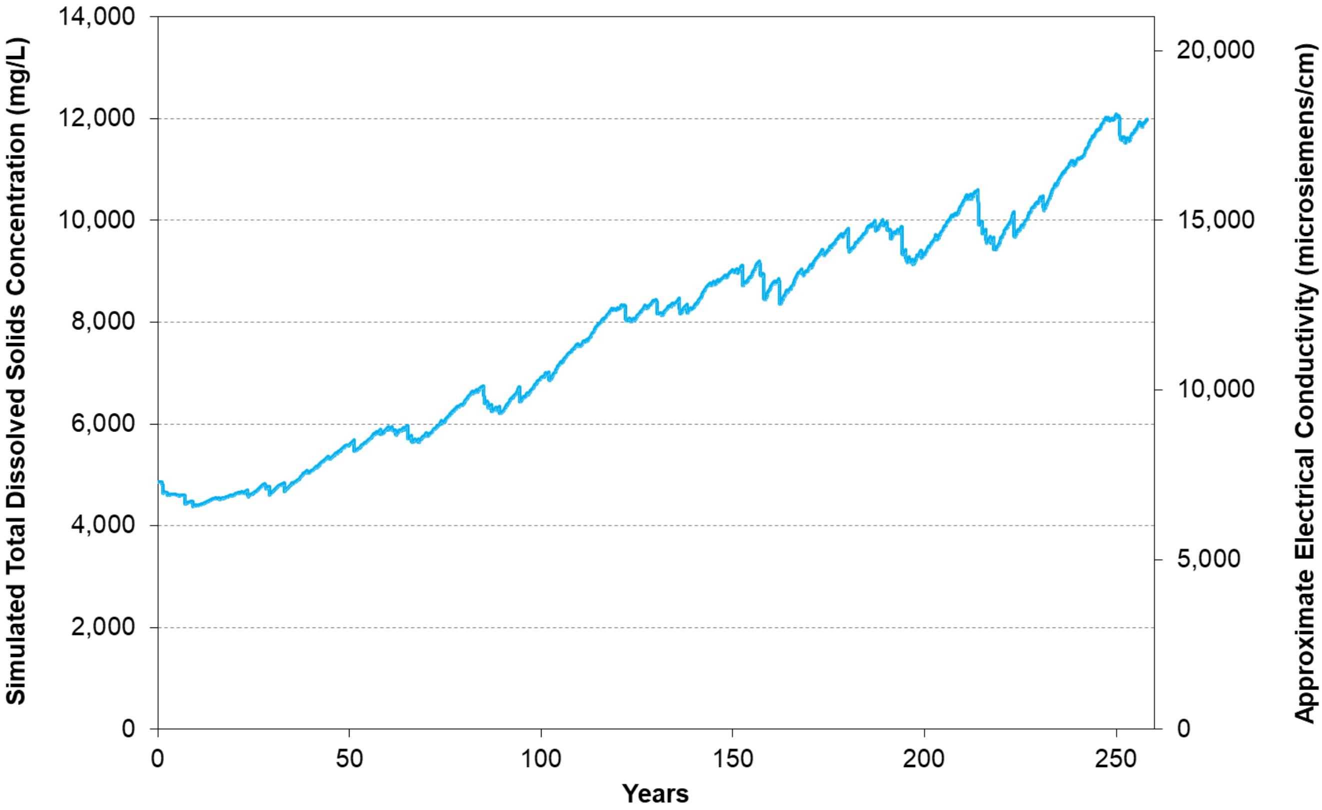

Figure 25 Water Quality Results: Model Run 1, Pit A – Salinity

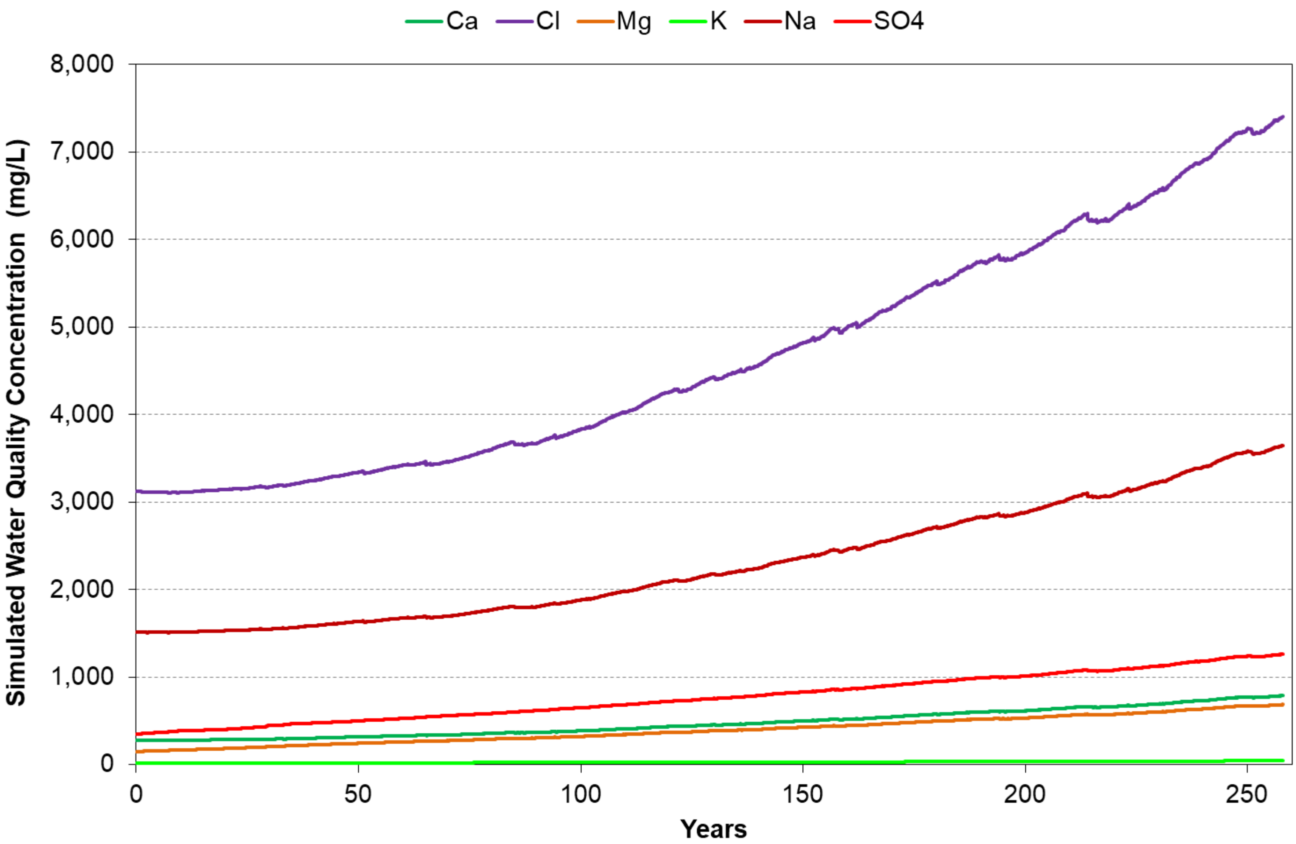

Figure 26 Water Quality Results: Model Run 1, Pit B – Major Ions

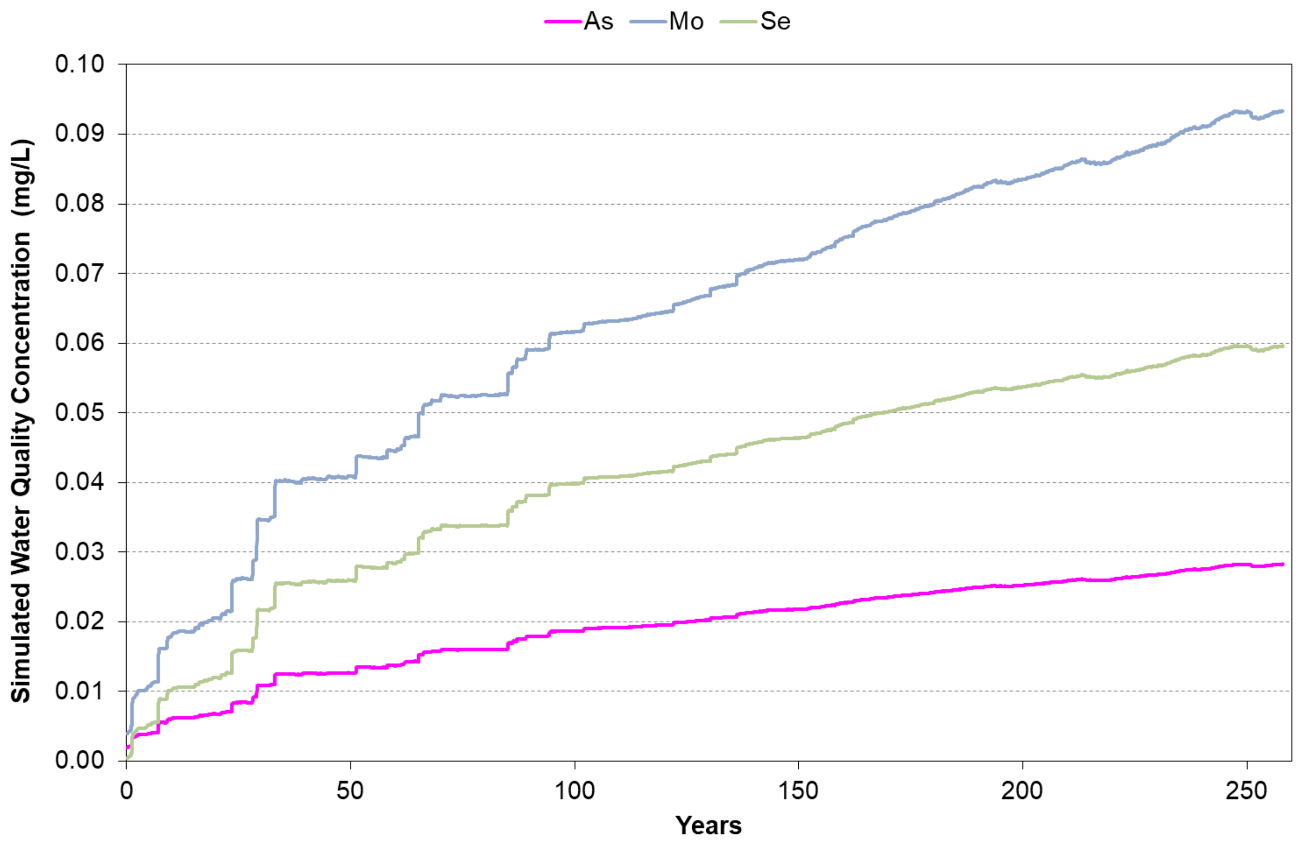

Figure 27 Water Quality Results: Model Run 1, Pit B – Trace Elements

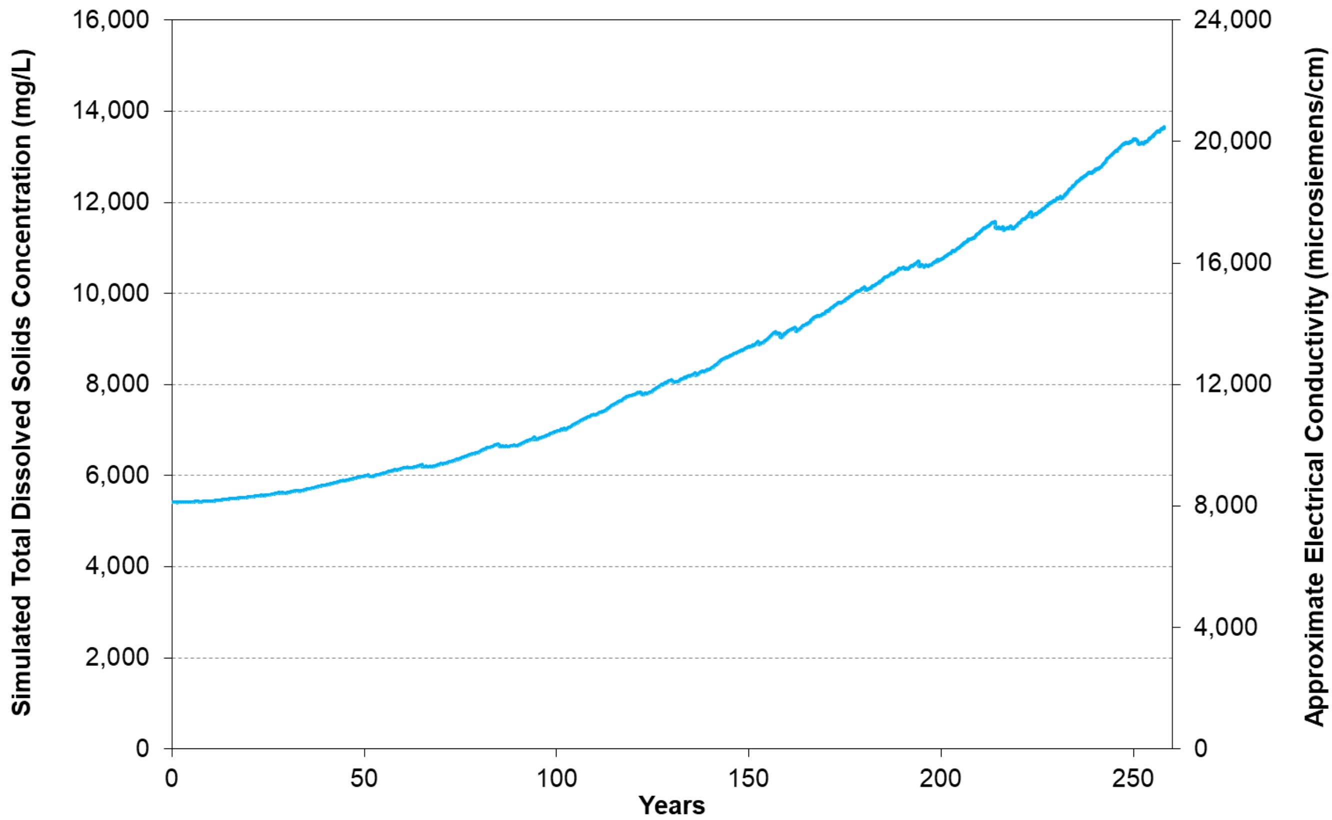

Figure 28 Water Quality Results: Model Run 1, Pit B – Salinity

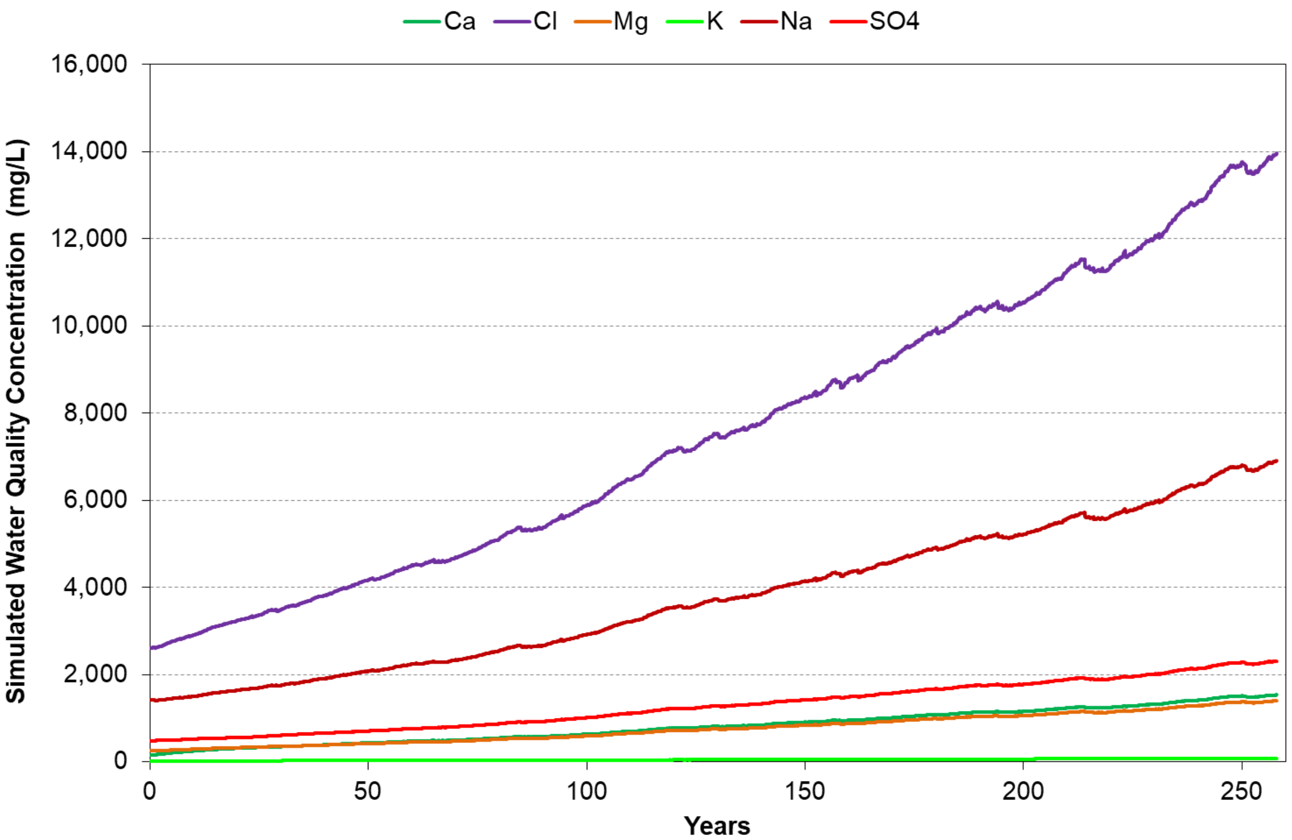

Figure 29 Water Quality Results: Model Run 1, Pit CD – Major Ions

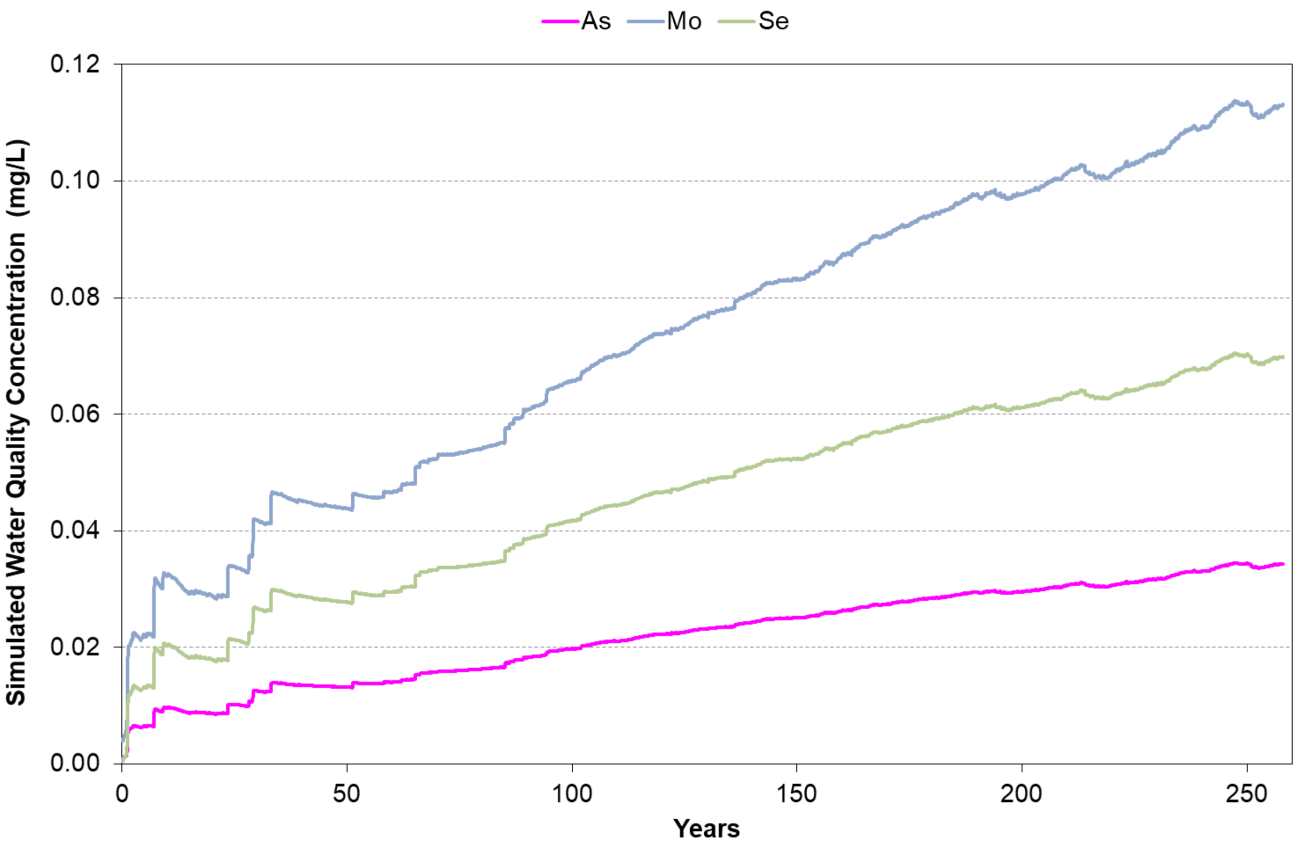

Figure 30 Water Quality Results: Model Run 1, Pit CD – Trace Elements

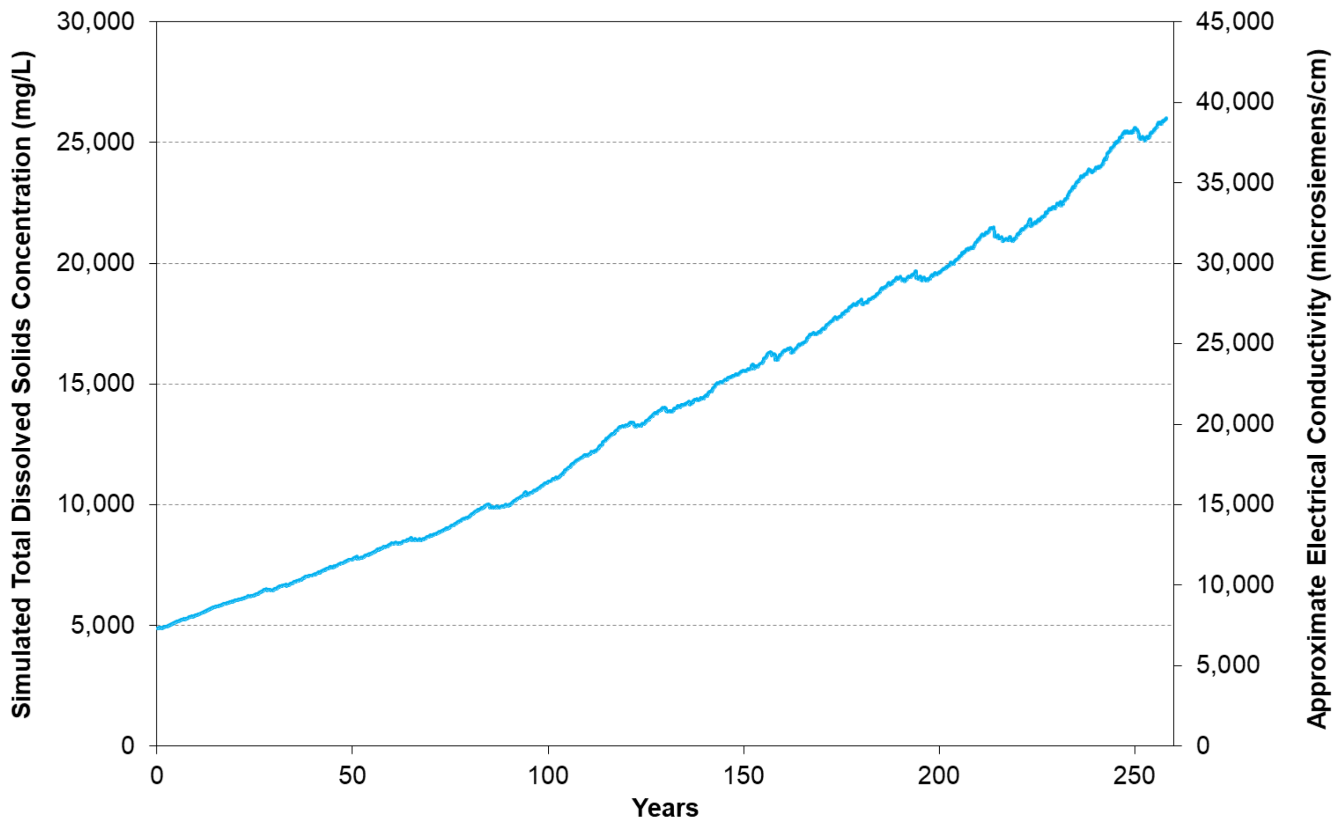

Figure 31 Water Quality Results: Model Run 1, Pit CD – Salinity

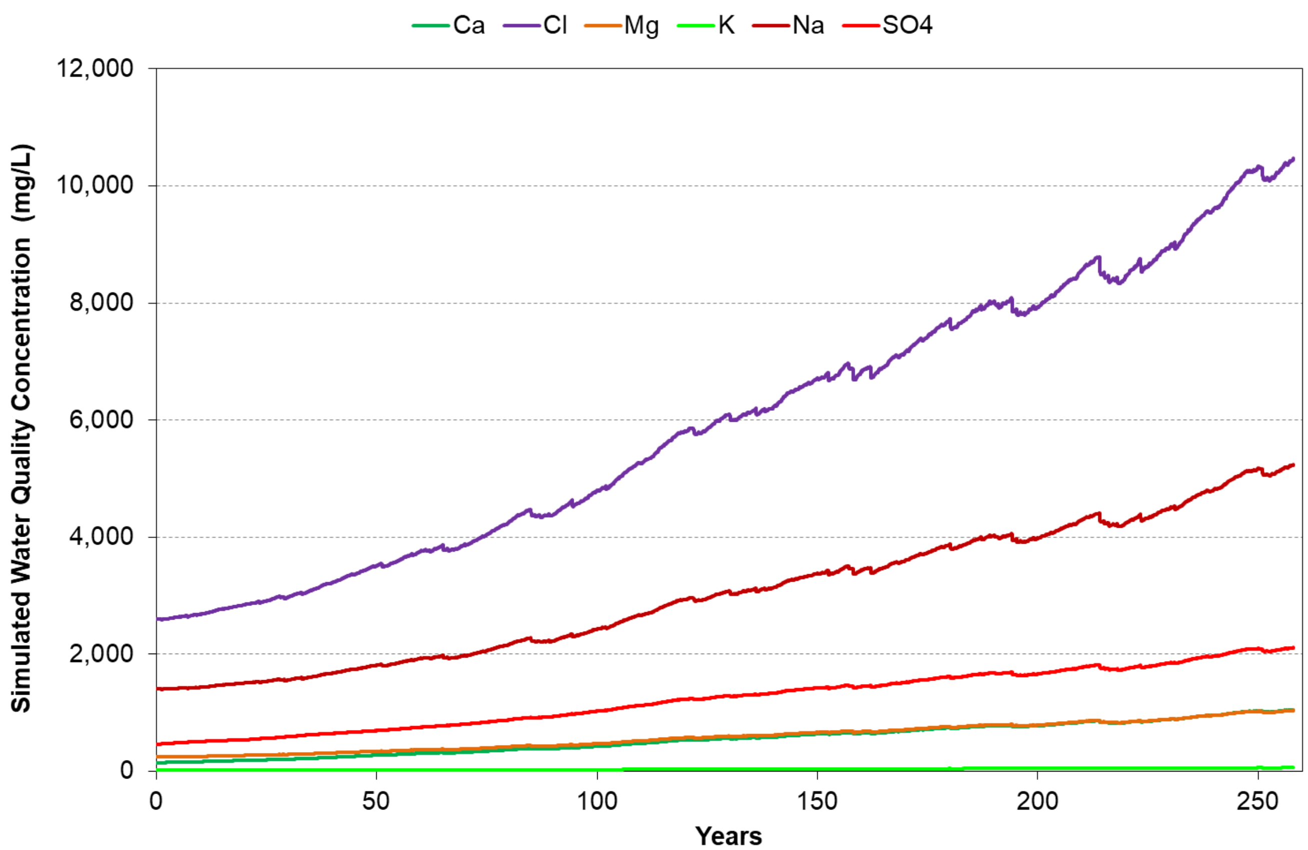

Figure 32 Water Quality Results: Model Run 1, Pit E – Major Ions

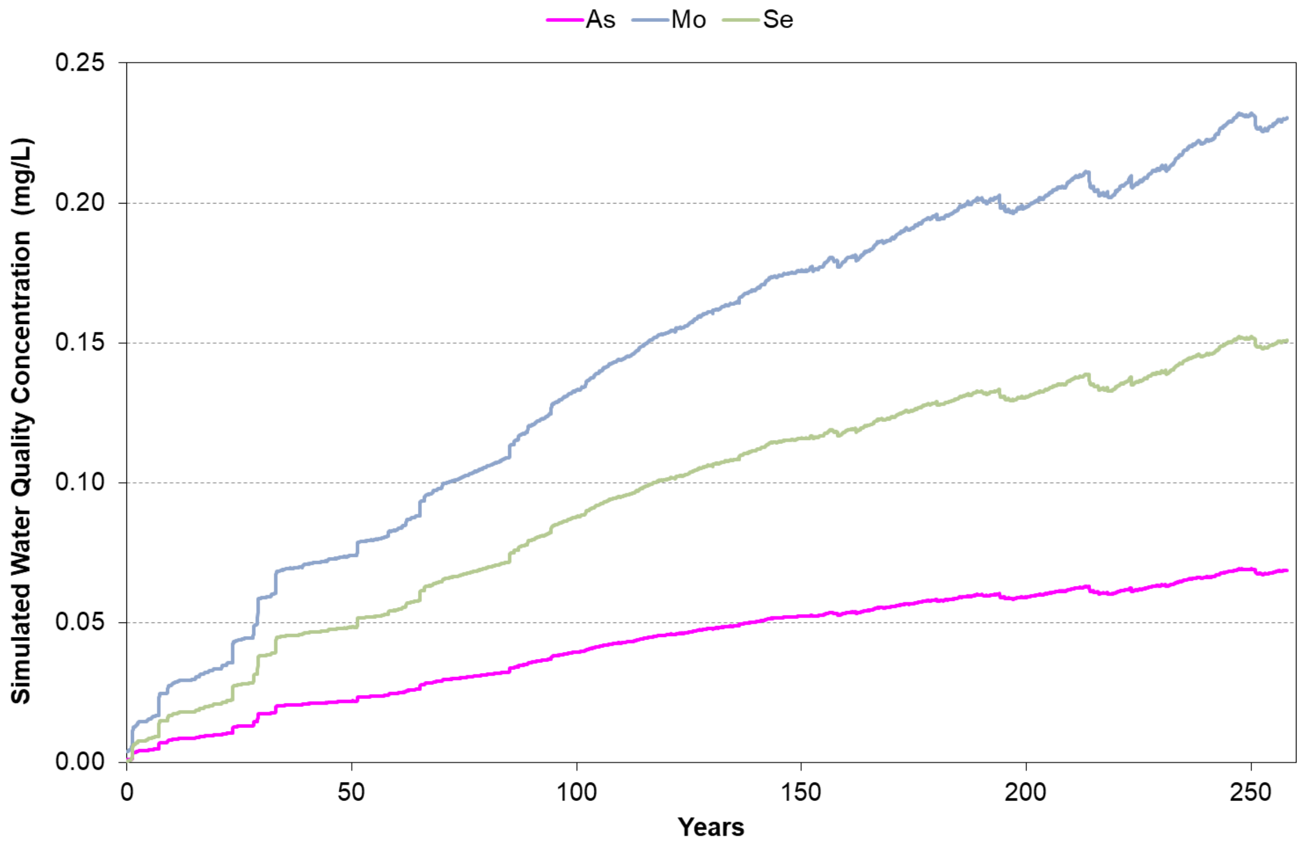

Figure 33 Water Quality Results: Model Run 1, Pit E – Trace Elements

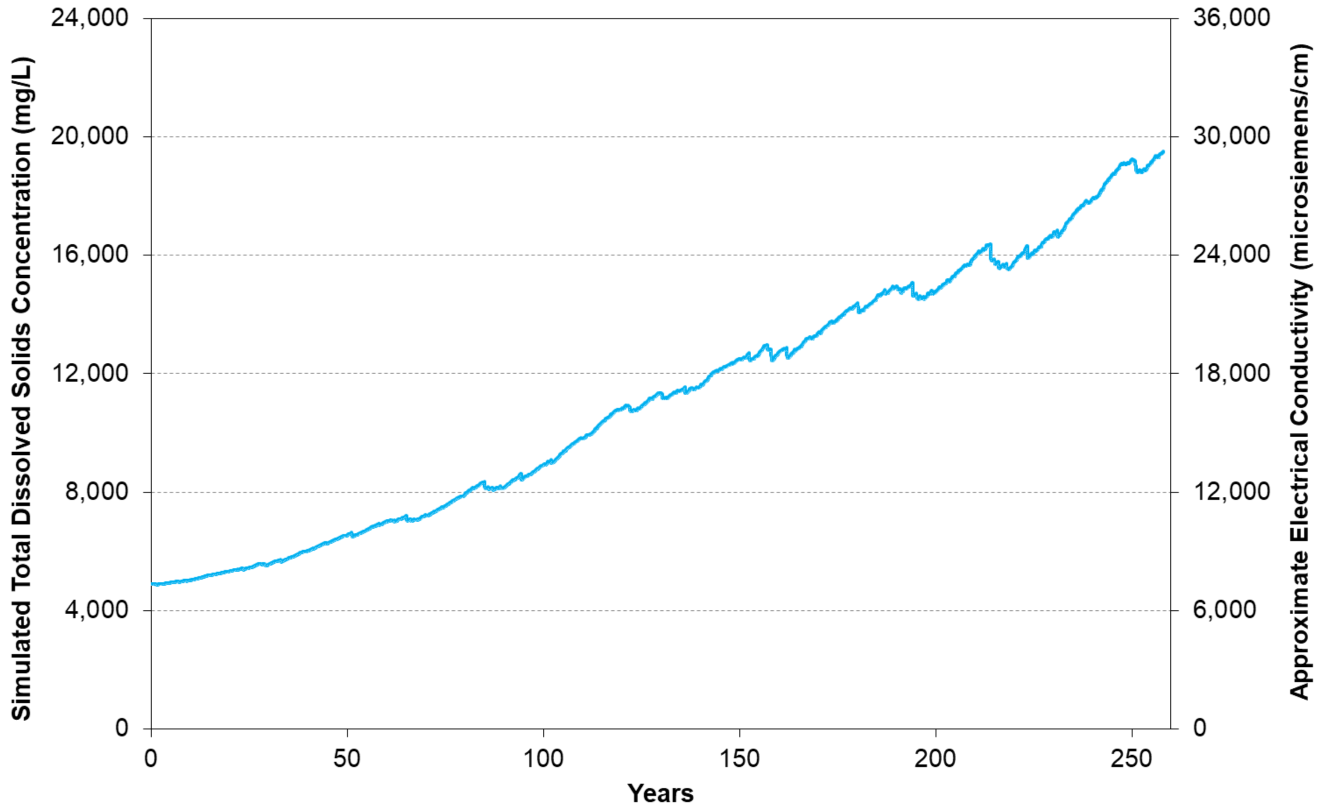

Figure 34 Water Quality Results: Model Run 1, Pit E – Salinity

Figure 23 to Figure 34 show that simulated concentrations of solutes in Pit A, Pit B, Pit CD and Pit E are all predicted to trend upward during the simulation due to the only simulated outflow comprising evaporation via which no solutes can flow out of the voids.

5.3 MODEL RUN 2 RESULTS (PREFERRED OPTION 1: CLIMATE CHANGE)

The objective of Model Run 2 is to predict the water levels, volumes and quality results for Preferred Option 1 with climate change factors applied. Results for each void for Model Run 2 are summarised in the sections to follow.

5.3.1 Water Levels

Figure 35 to Figure 38 show forecast water levels over the 258 year simulation period for each of the voids in Model Run 2.

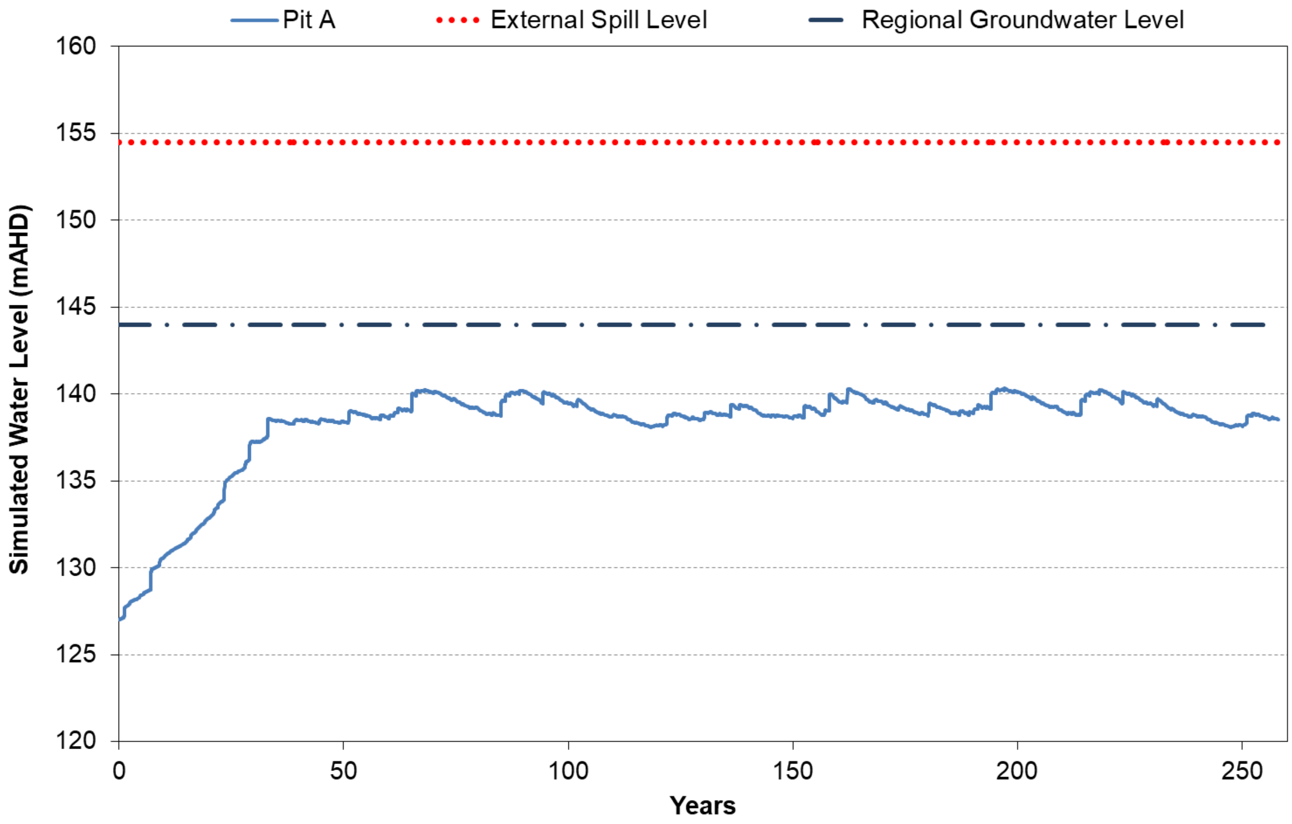

Figure 35 Water Level Results: Model Run 2, Pit A

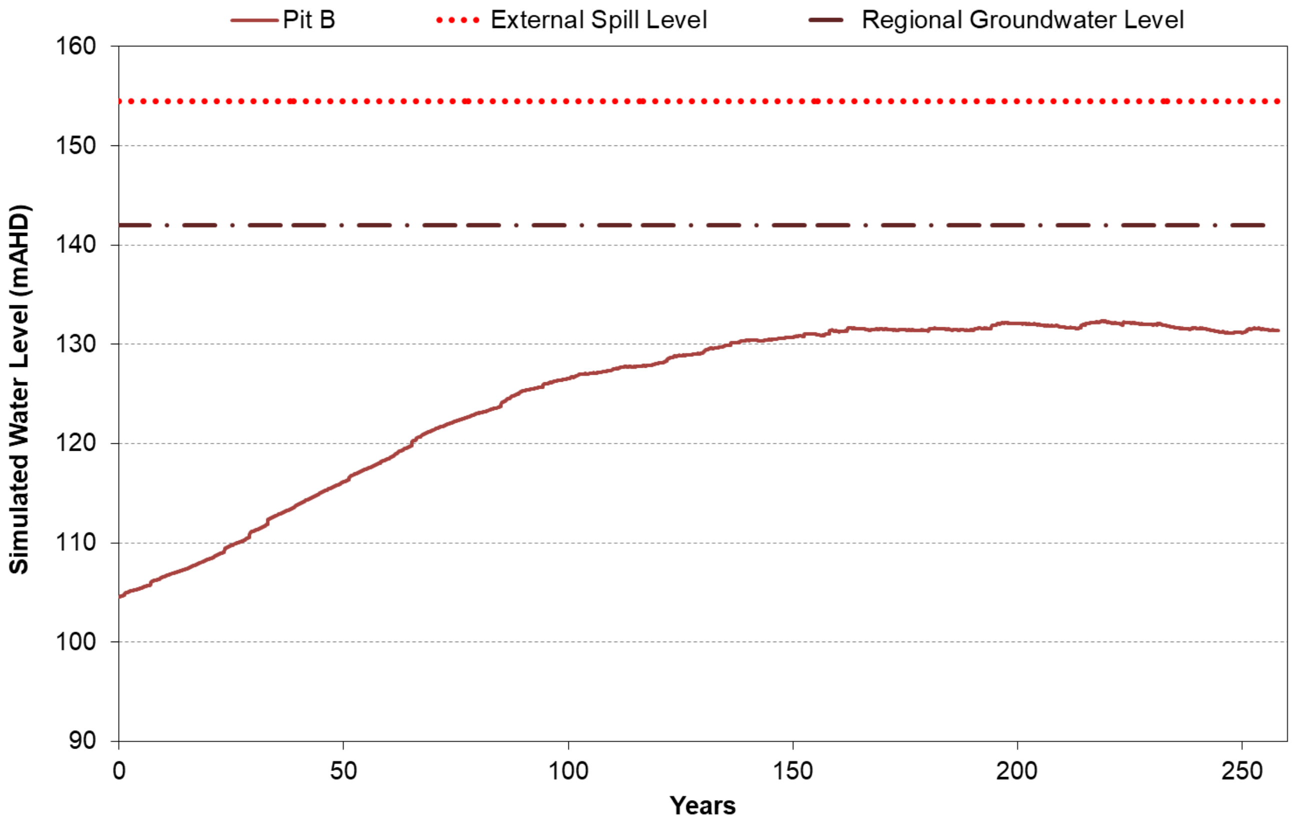

Figure 36 Water Level Results: Model Run 2, Pit B

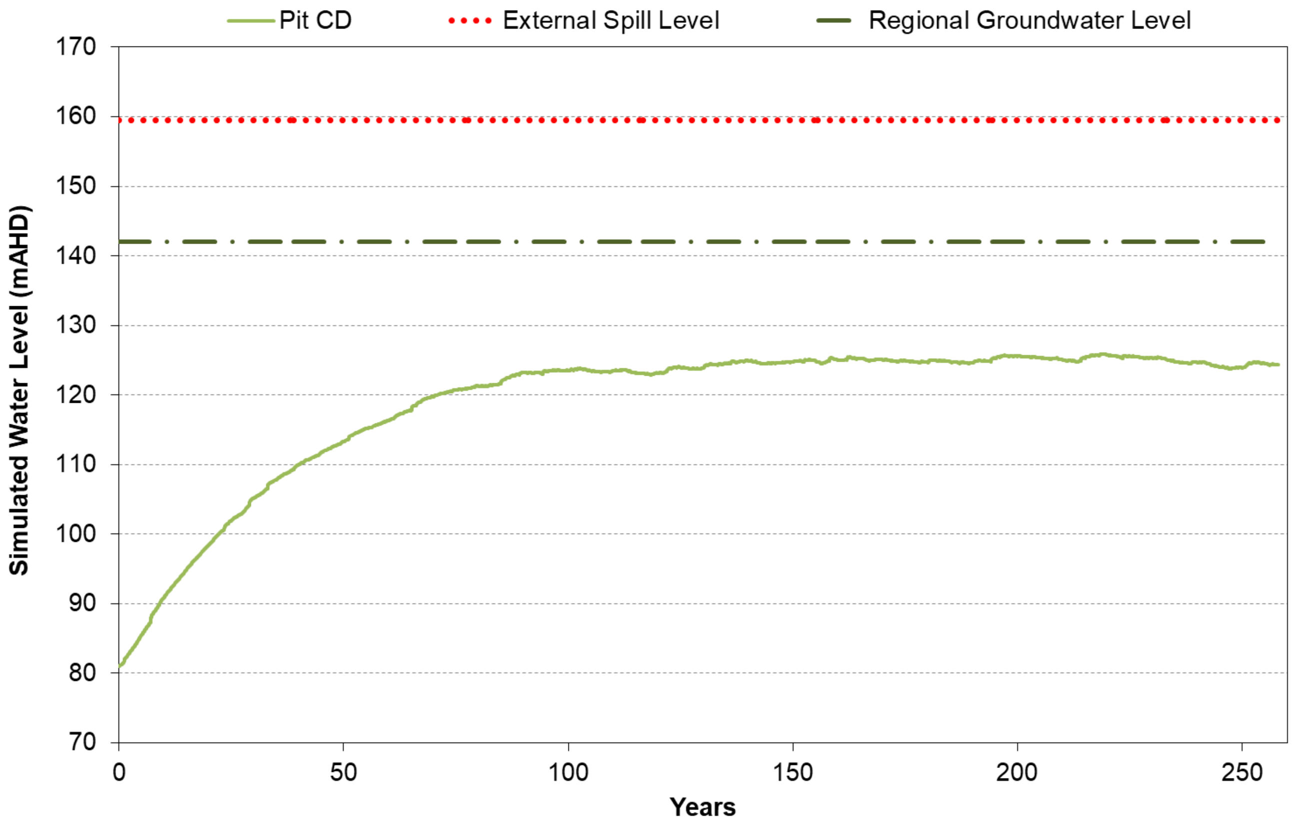

Figure 37 Water Level Results: Model Run 2, Pit CD

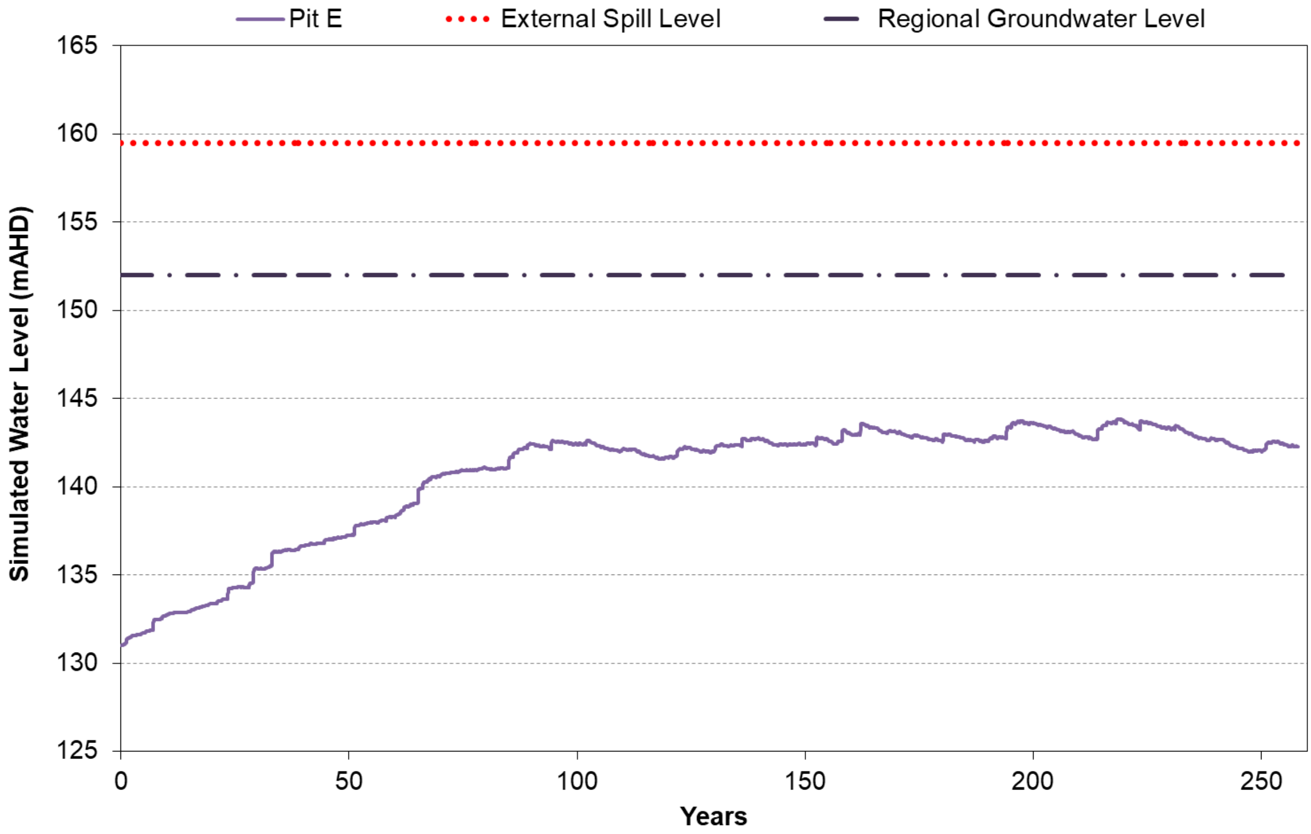

Figure 38 Water Level Results: Model Run 2, Pit E

Figure 35 shows that Pit A reaches equilibrium water level after around 75 years at approximately 139 mAHD or 15.5 m below the external spill level (154.5 mAHD) and approximately 5 m below the regional groundwater level (144 mAHD).

Figure 36 shows that Pit B reaches equilibrium water level after around 175 years at approximately 131.5 mAHD or 23 m below the external spill level (154.5 mAHD) and approximately 10.5 m below the regional groundwater level (142 mAHD).

Figure 37 shows that Pit CD reaches equilibrium water level after around 125 years at approximately 125 mAHD or 34.5 m below the external spill level (159.5 mAHD) and approximately 17 m below the regional groundwater level (142 mAHD).

Figure 38 shows that Pit E reaches equilibrium water level after around 100 years at approximately 142.5 mAHD or 17 m below the external spill level (159.5 mAHD) and approximately 9.5 m below the regional groundwater level (152 mAHD).

5.3.2 Water Volumes

Figure 39 shows the simulated water volume results over the 258 year simulation period for each of the voids in Model Run 2.

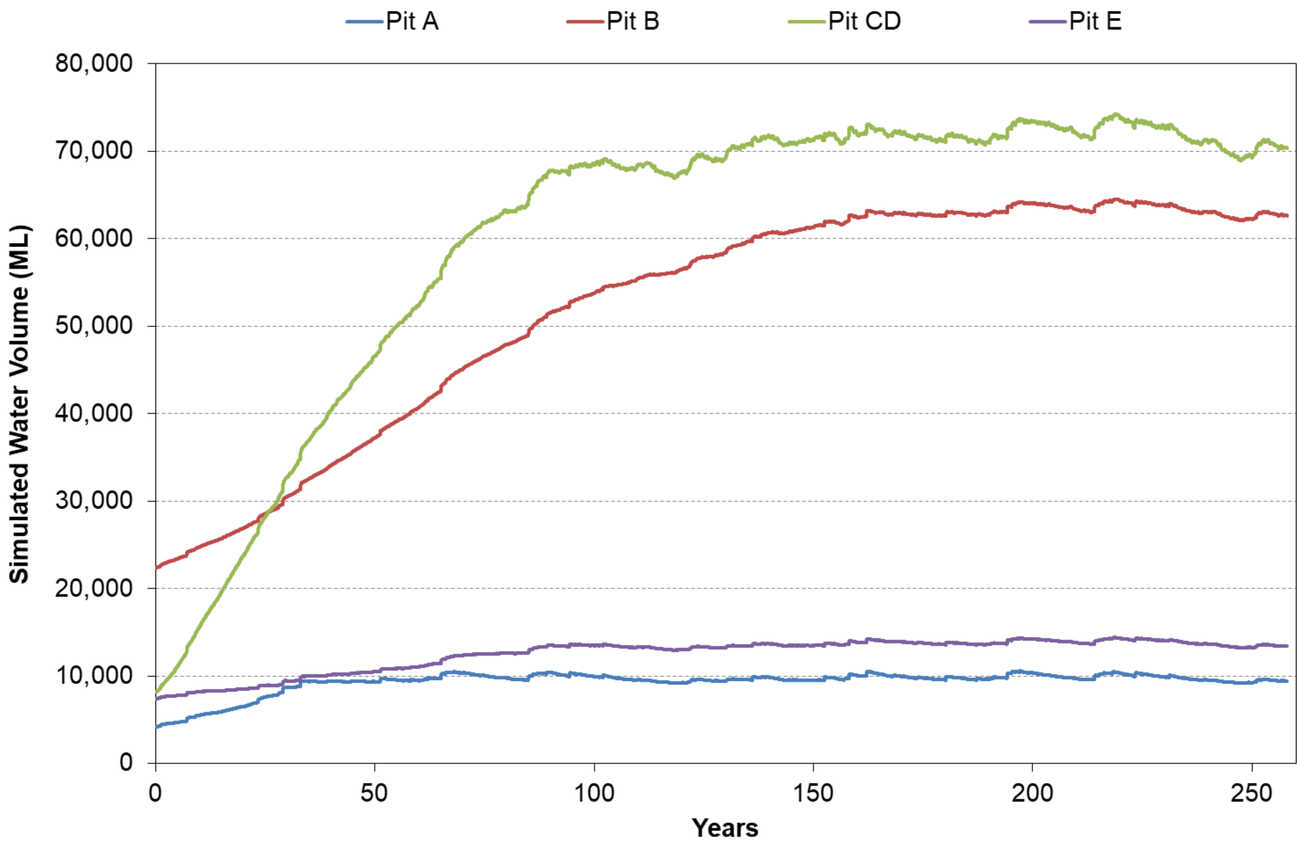

Figure 39 Water Volume Results: Model Run 2

Figure 39 shows that simulated water volumes in Pit CD (approximately 70 GL after 250 years) are the highest followed by Pit B (approximately 63 GL after 250 years). Pit A and Pit E are both simulated to store less 20 GL over the simulation period.

5.3.3 Water Quality

Figure 40 to Figure 51 show water quality results (major ions, trace elements and salinity) over the 258 year simulation period for each of the voids in Model Run 2.

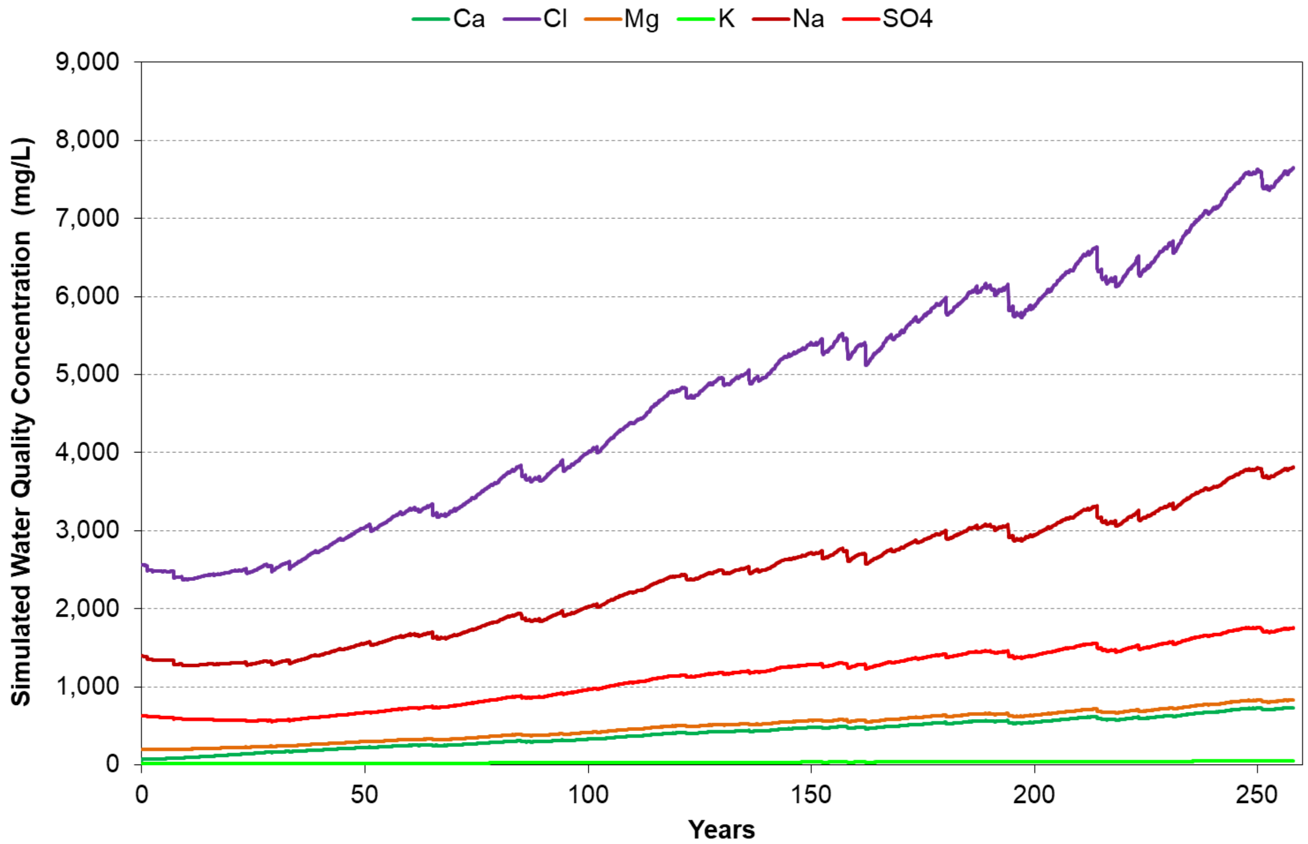

Figure 40 Water Quality Results: Model Run 2, Pit A – Major Ions

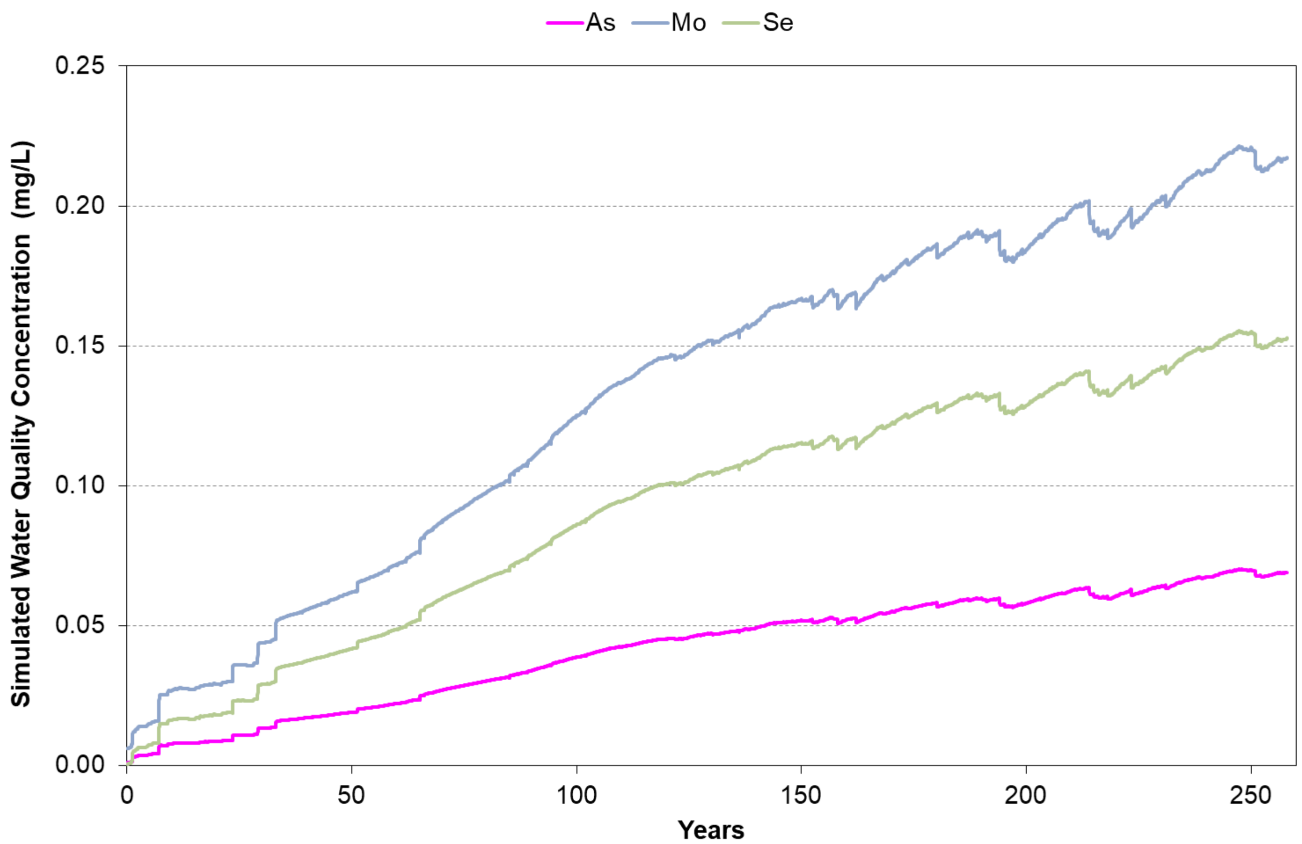

Figure 41 Water Quality Results: Model Run 2, Pit A – Trace Elements

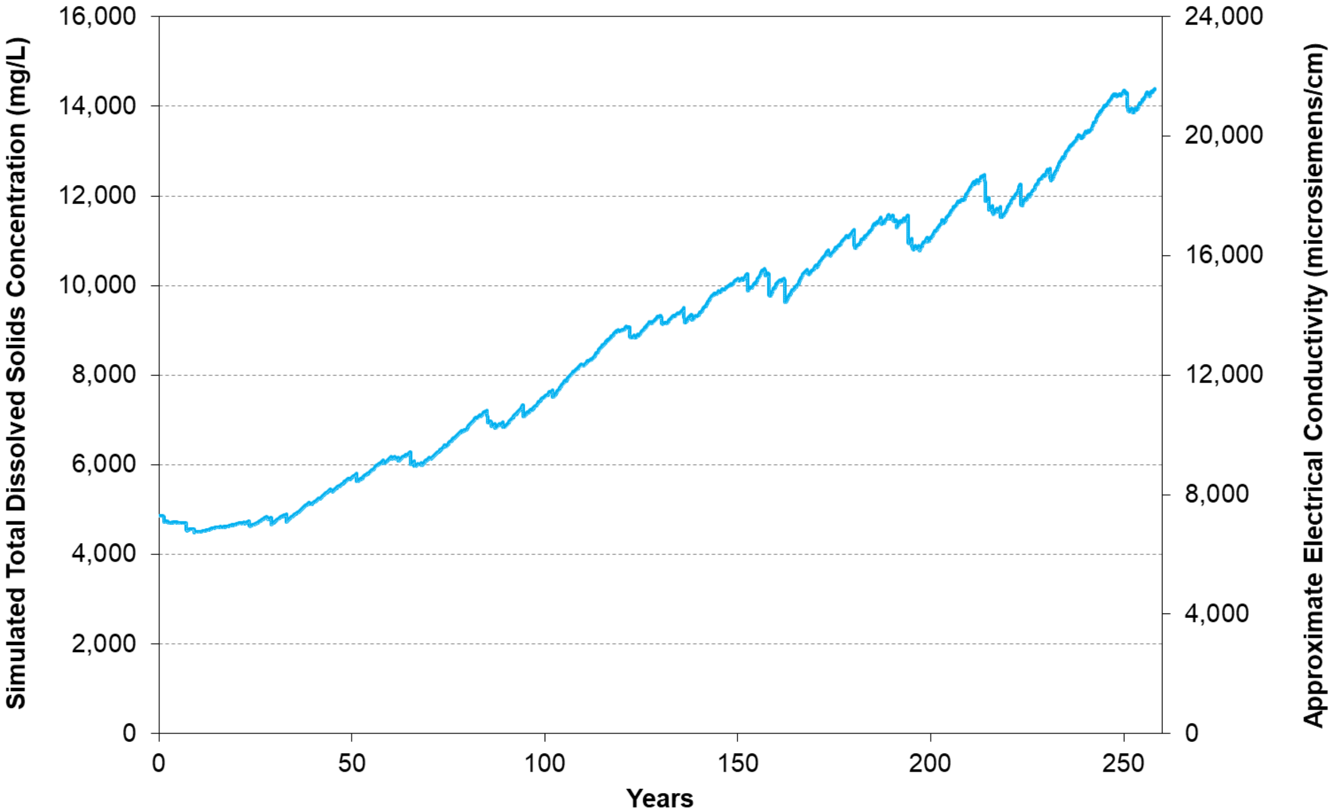

Figure 42 Water Quality Results: Model Run 2, Pit A – Salinity

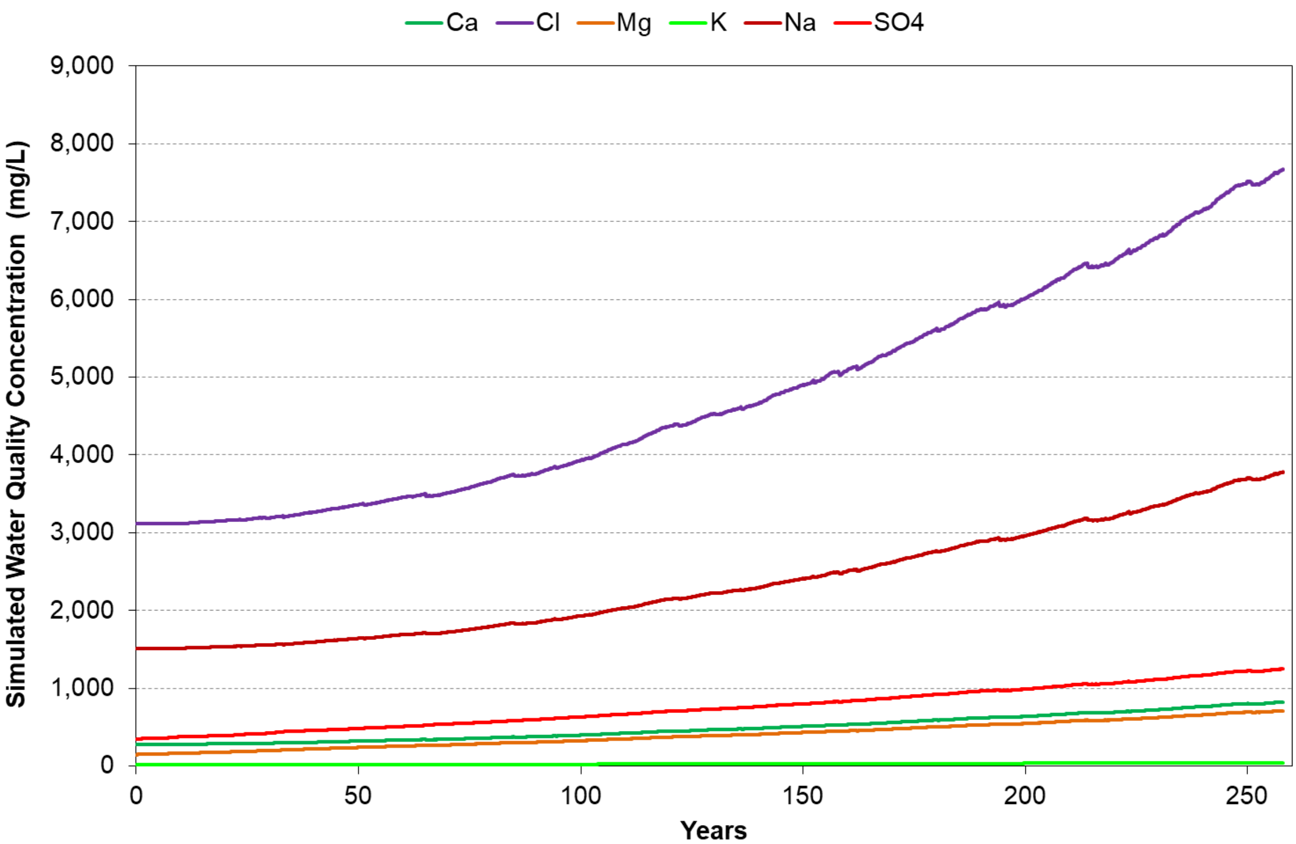

Figure 43 Water Quality Results: Model Run 2, Pit B – Major Ions

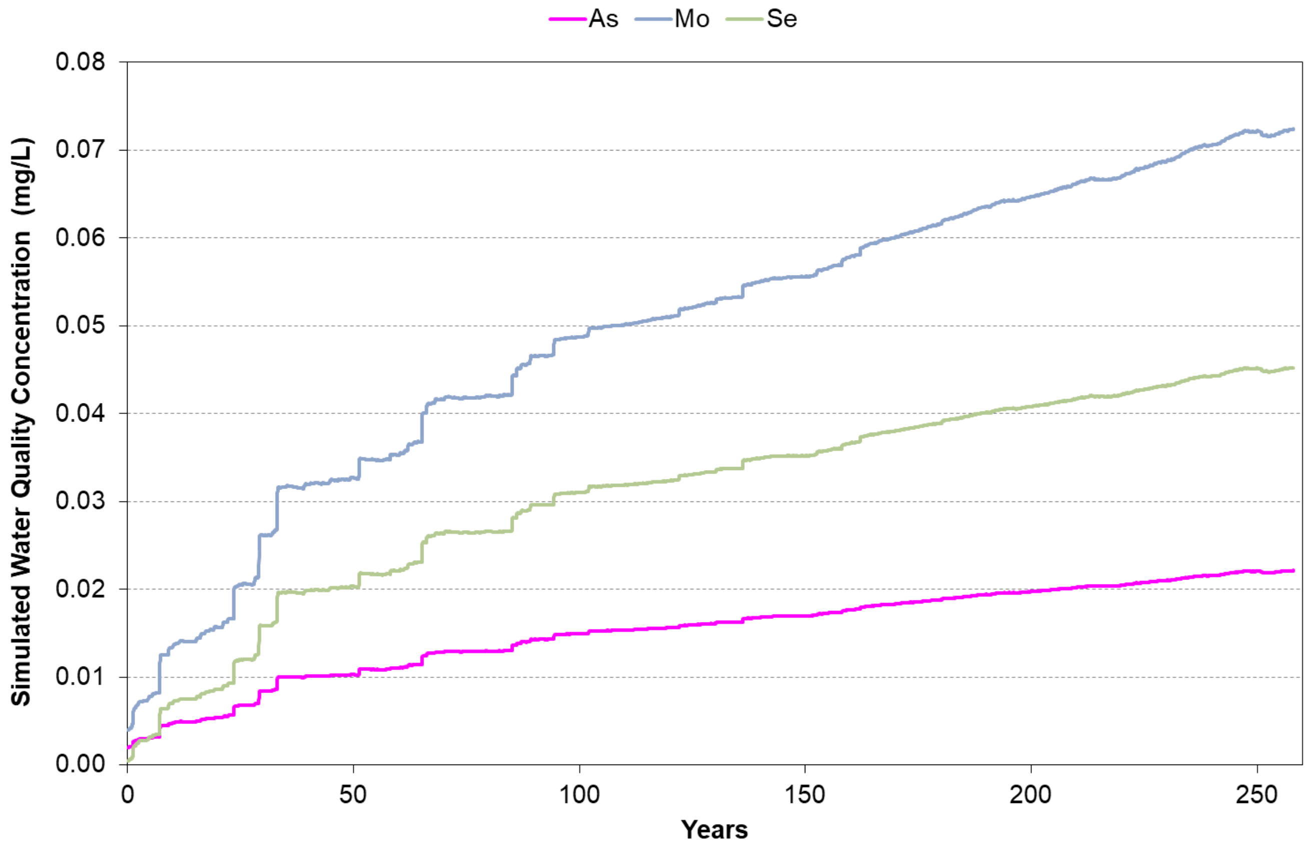

Figure 44 Water Quality Results: Model Run 2, Pit B – Trace Elements

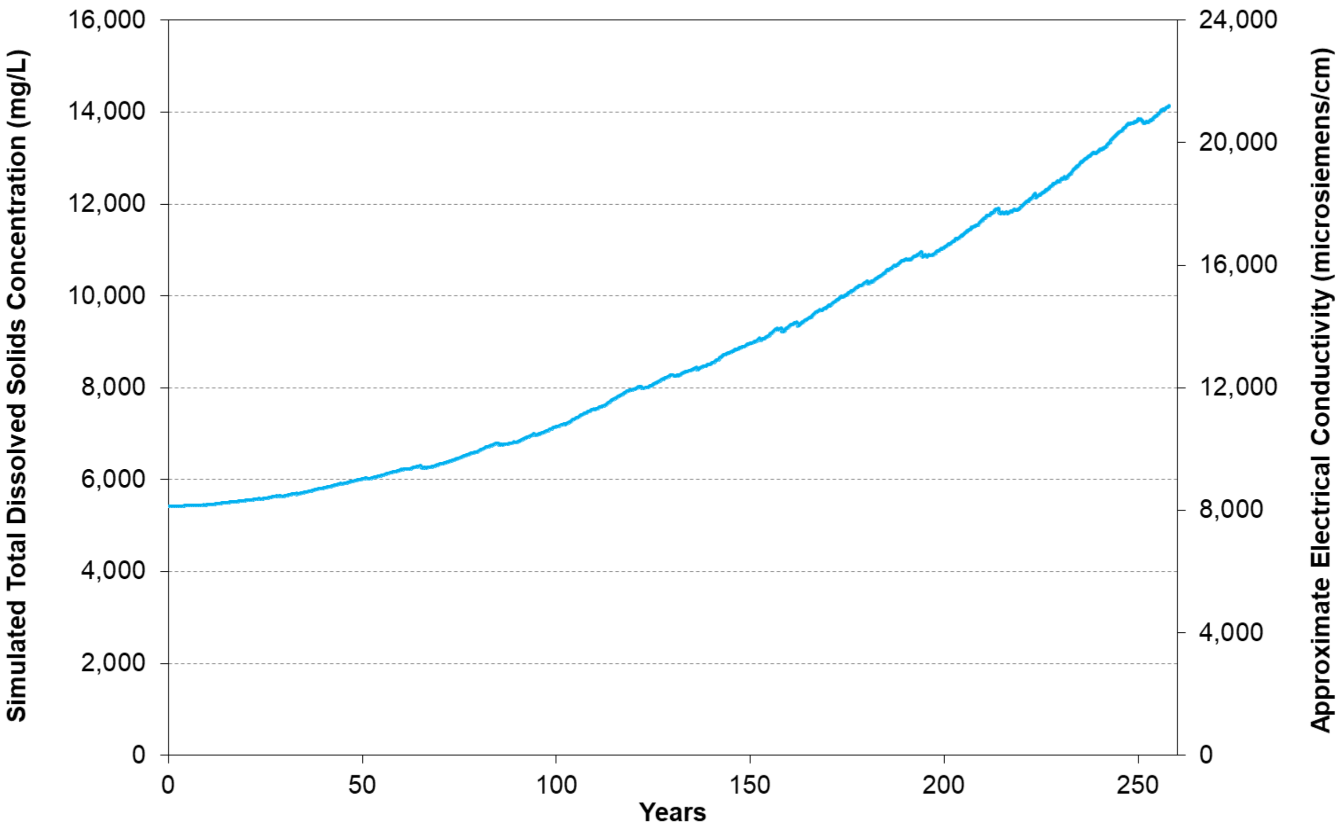

Figure 45 Water Quality Results: Model Run 2, Pit B – Salinity

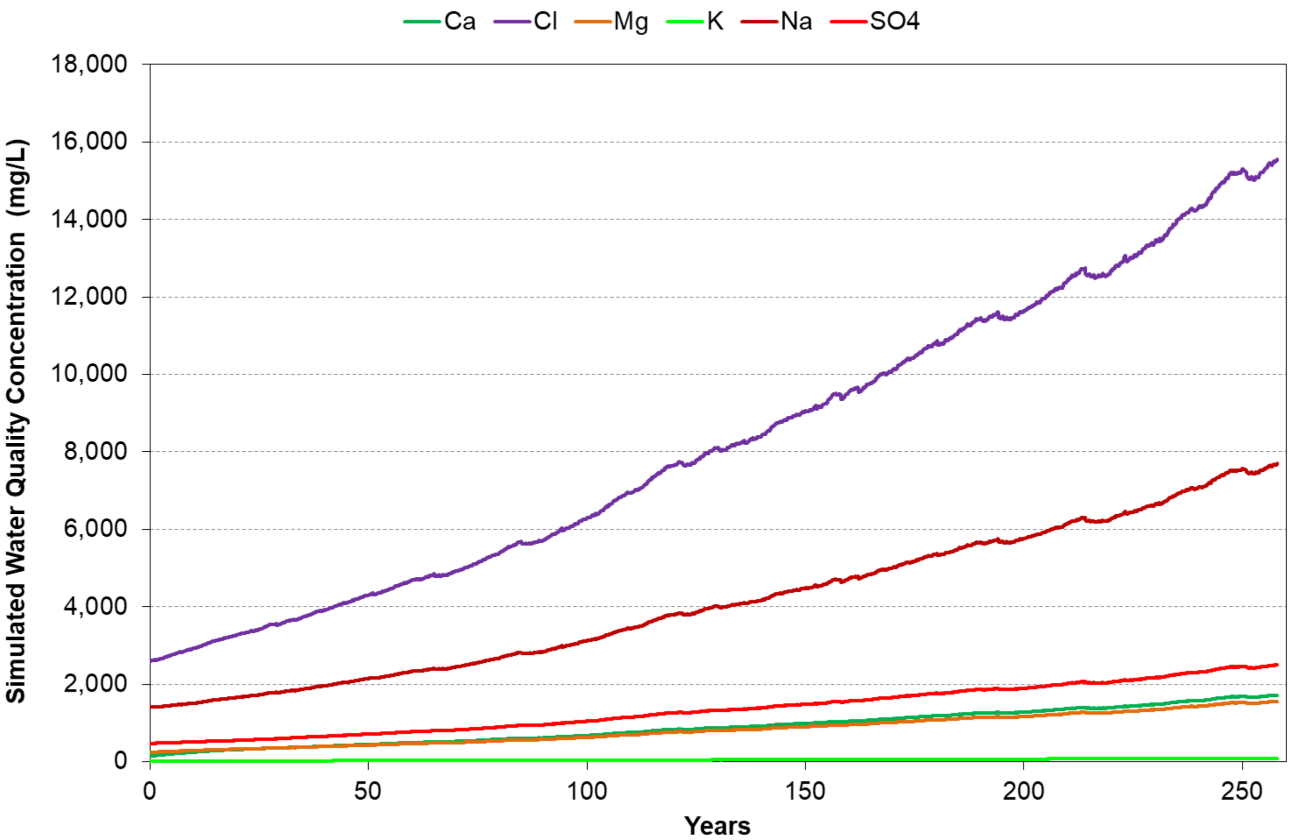

Figure 46 Water Quality Results: Model Run 2, Pit CD – Major Ions

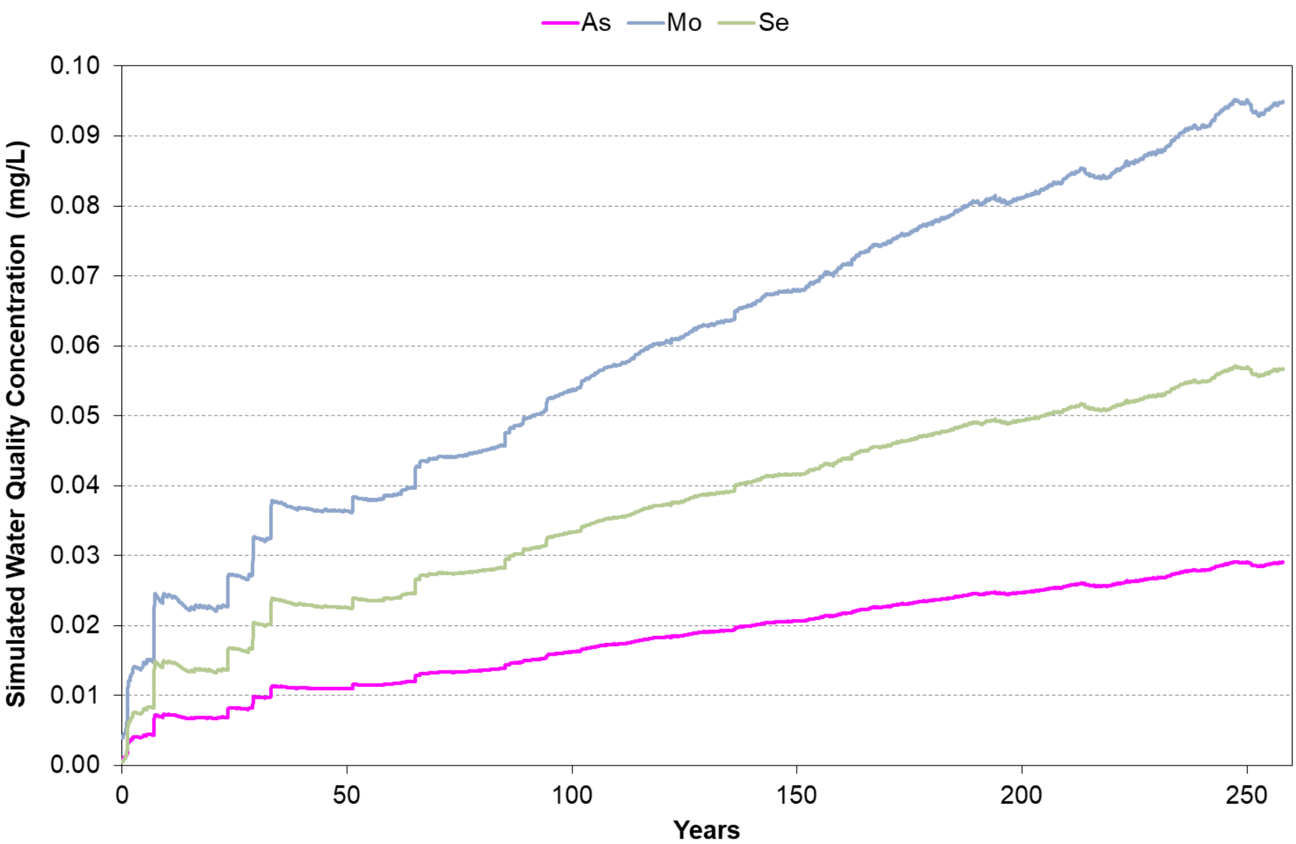

Figure 47 Water Quality Results: Model Run 2, Pit CD – Trace Elements

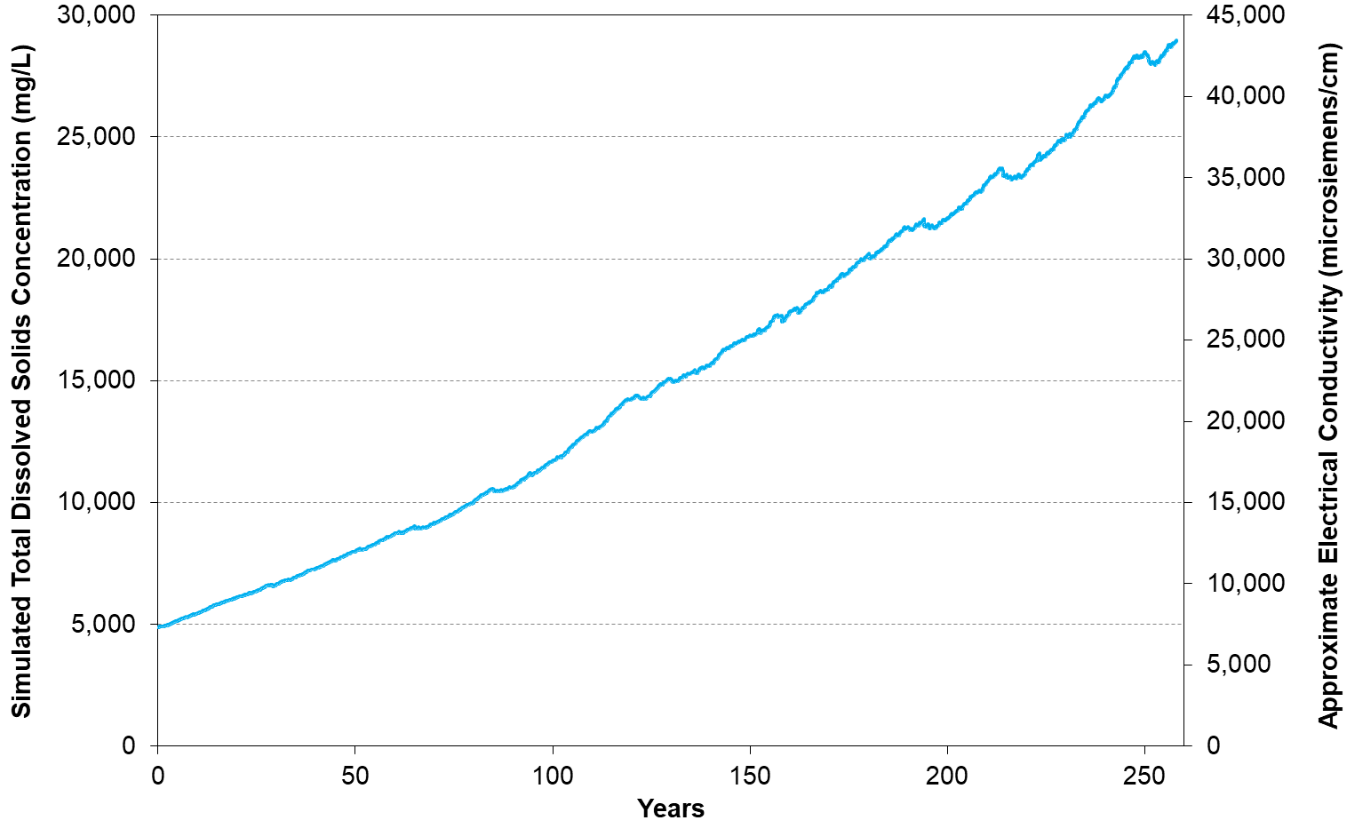

Figure 48 Water Quality Results: Model Run 2, Pit CD – Salinity

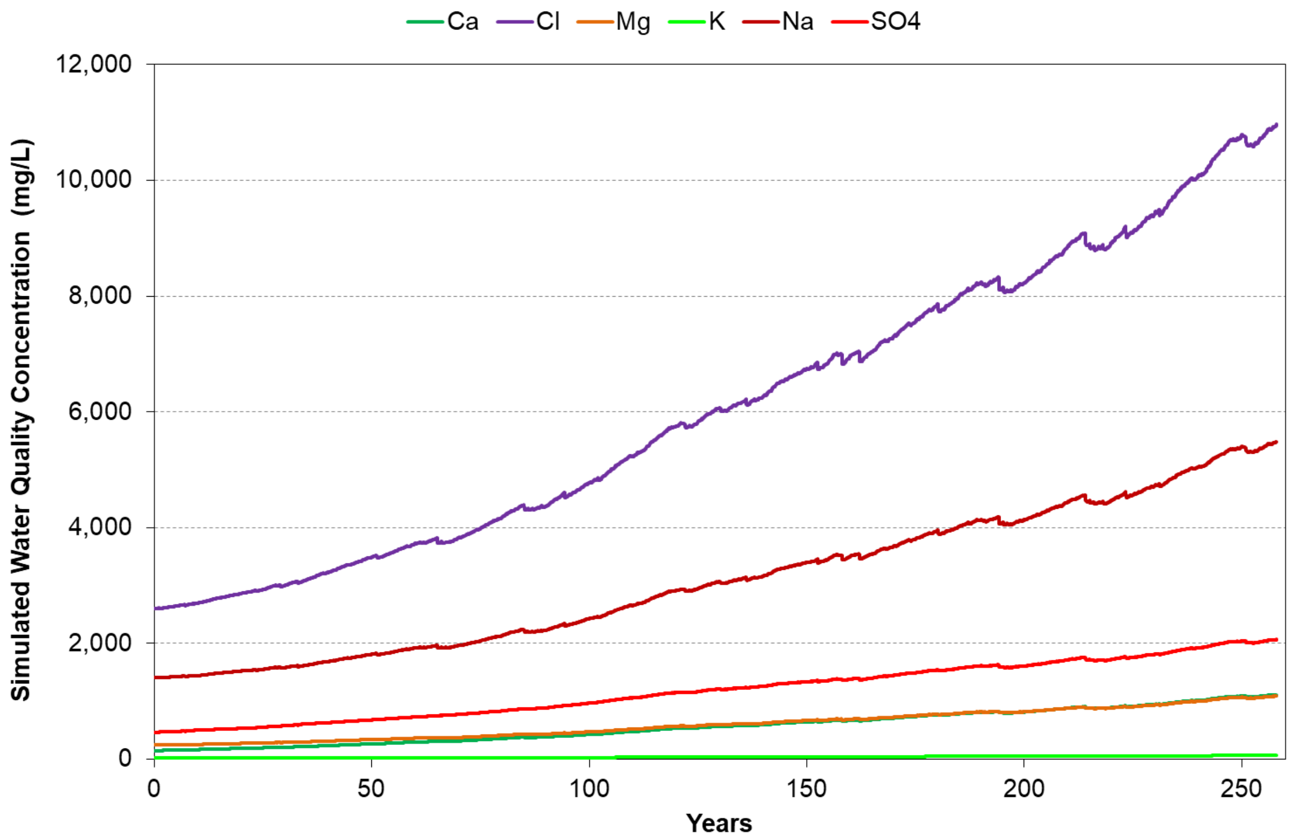

Figure 49 Water Quality Results: Model Run 2, Pit E – Major Ions

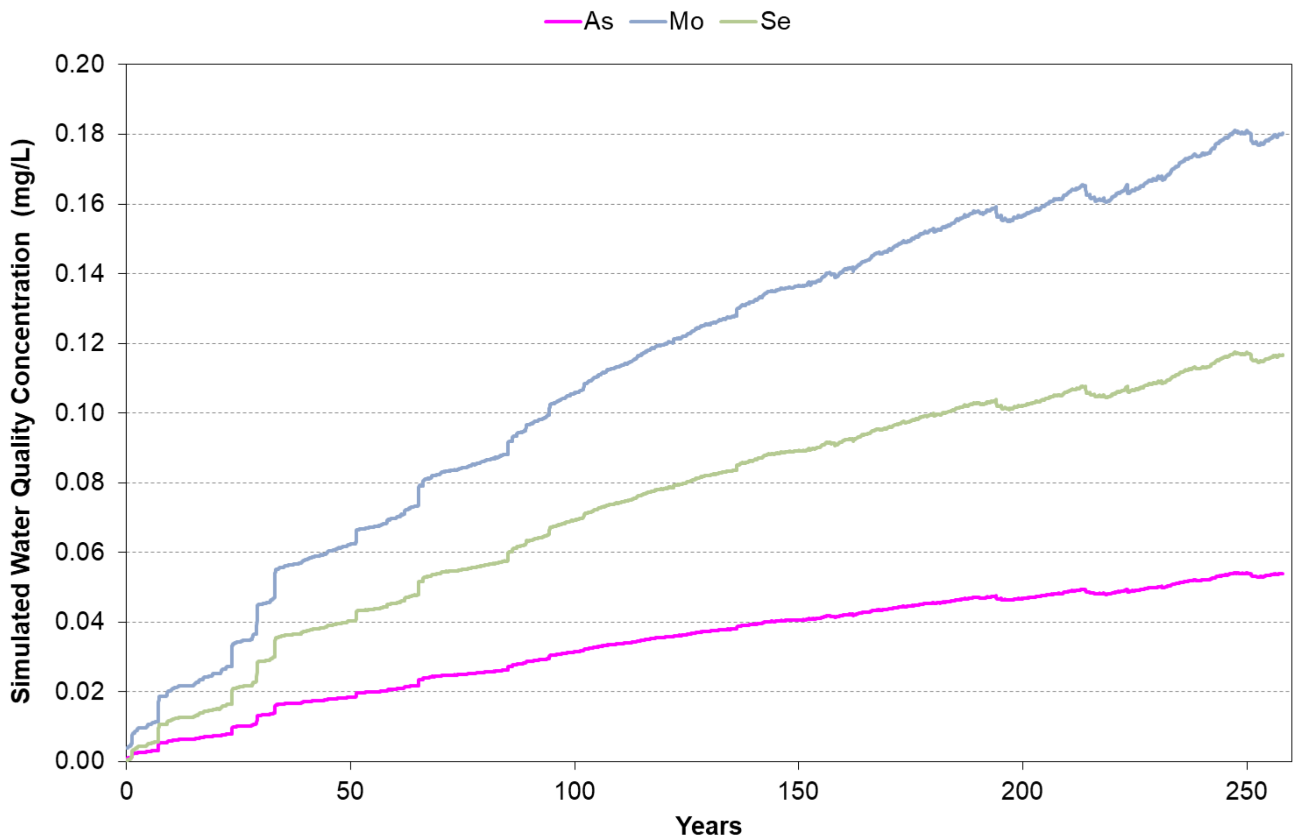

Figure 50 Water Quality Results: Model Run 2, Pit E – Trace Elements

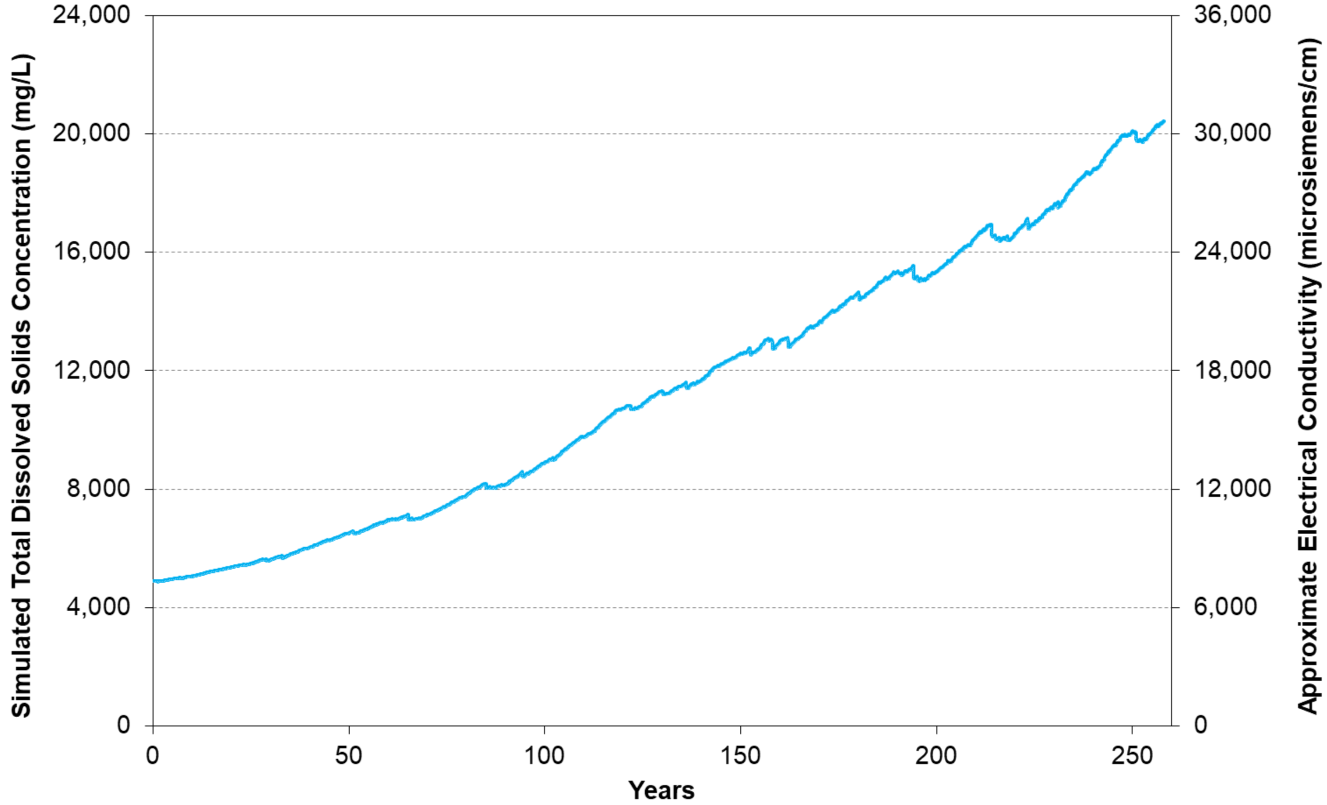

Figure 51 Water Quality Results: Model Run 2, Pit E – Salinity

Figure 40 to Figure 51 show that simulated concentrations of solutes in Pit A, Pit B and Pit CD are all predicted to trend upward during the simulation due to the only simulated outflow comprising evaporation via which no solutes can flow out of the voids.

5.4 MODEL RUN 3 RESULTS (PREFERRED OPTION 2: IRRIGATION FROM PIT B ONLY)

The objective of Model Run 3 is to predict the water levels, volumes and quality results for Preferred Option 2 with irrigation from Pit B only (i.e. development of the southern voids only). Results for Pit A and Pit B for Model Run 3 are summarised in the sections to follow. No results are presented for Pit CD and Pit E, because the final rehabilitated mining areas for these pits would still be under construction when the initial stage of Option 2 (Pits A and B) are completed.

On average, 7.9 GL/year was simulated as pumped from Pit B to irrigation demand.

5.4.1 Water Levels

Figure 52 and Figure 53 shows forecast water levels over the 129 year simulation period for Pit A and Pit B in Model Run 3.

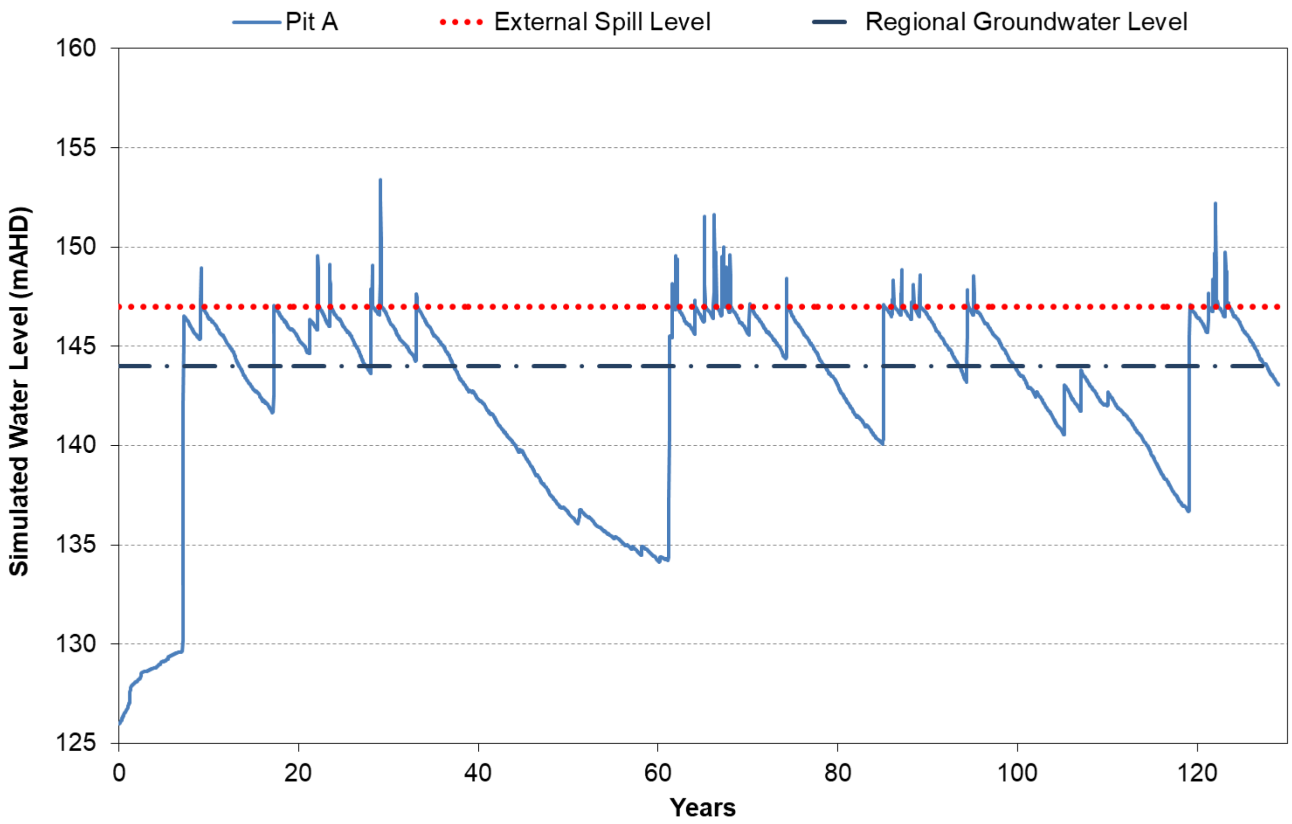

Figure 52 Water Level Results: Model Run 3, Pit A

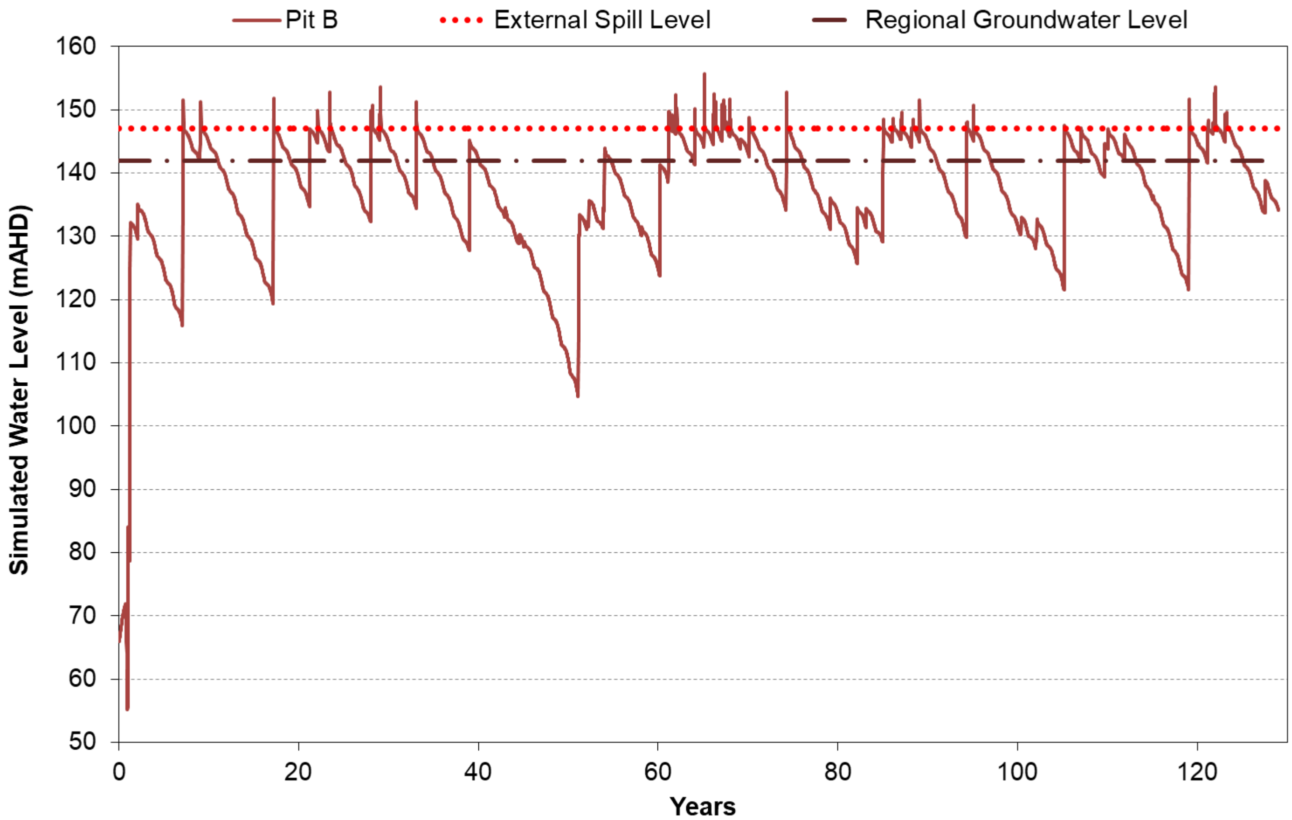

Figure 53 Water Level Results: Model Run 3, Pit B

Figure 52 and Figure 53 show that there are notable variations in the water levels in Pit A and Pit B due to the simulated Nogoa River inflows to Pit B, irrigation demand pumped from Pit B and the hydraulic link (i.e. spill/seepage) between Pit A and Pit B. The water levels in both Pit A and Pit B rise above the external spill level to the Nogoa River during river flood events. Water levels in Pit A and Pit B both rise above the respective regional groundwater levels and regional groundwater outflow from both pits is simulated during these periods.

5.4.2 Water Volumes

Figure 54 shows the simulated water volume results over the 129 year simulation period for Pit A and Pit B in Model Run 3.

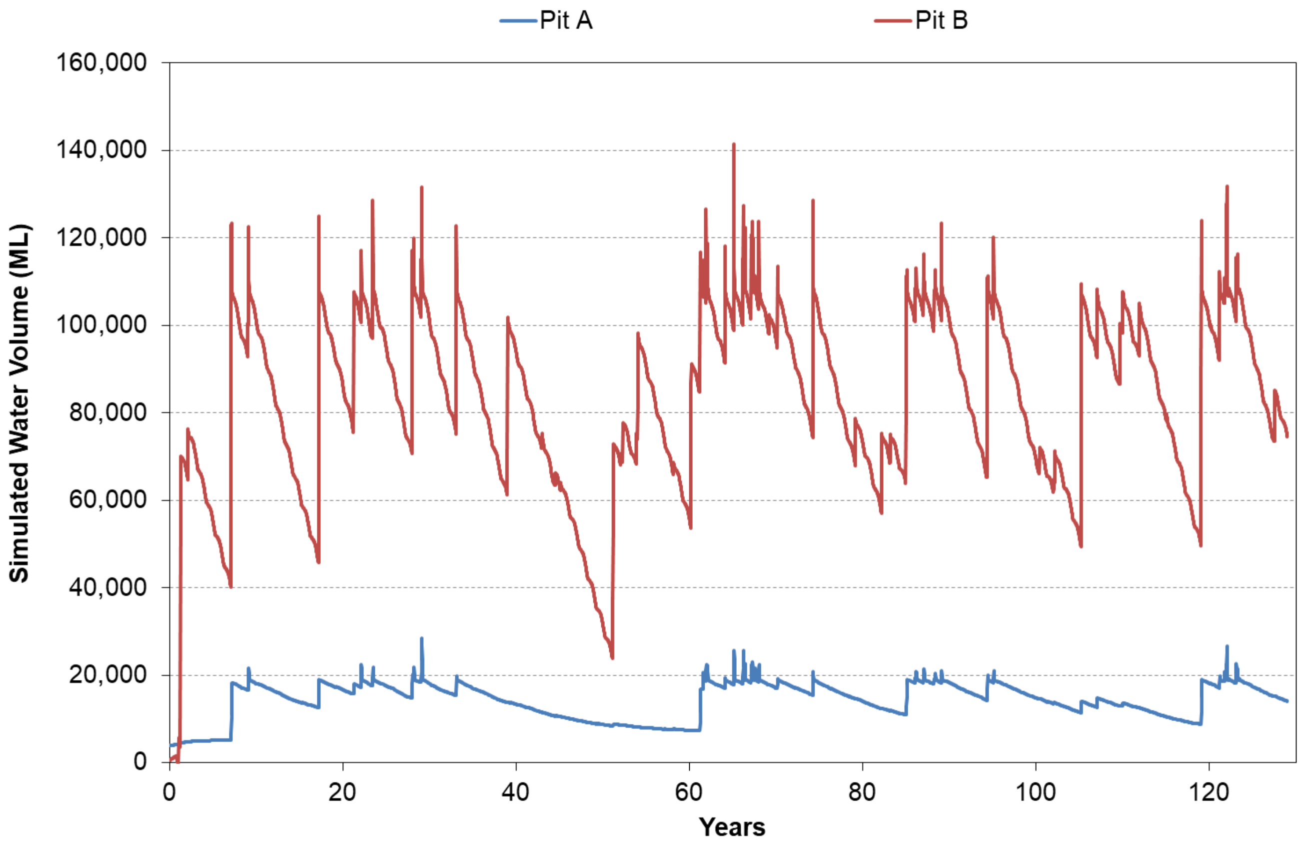

Figure 54 Water Volume Results: Model Run 3

Figure 54 shows that simulated water volumes in Pit B are notably higher than Pit A and the volume stored in Pit B fluctuates more than the volume stored in Pit A.

5.4.3 Water Quality

Figure 55 to Figure 60 show water quality results (major ions, trace elements and salinity) over the 129 year simulation period for Pit A and Pit B in Model Run 3. Note that the simulated water quality concentration for solutes in Pit B provides an indication of the quality of water supplied to irrigation.

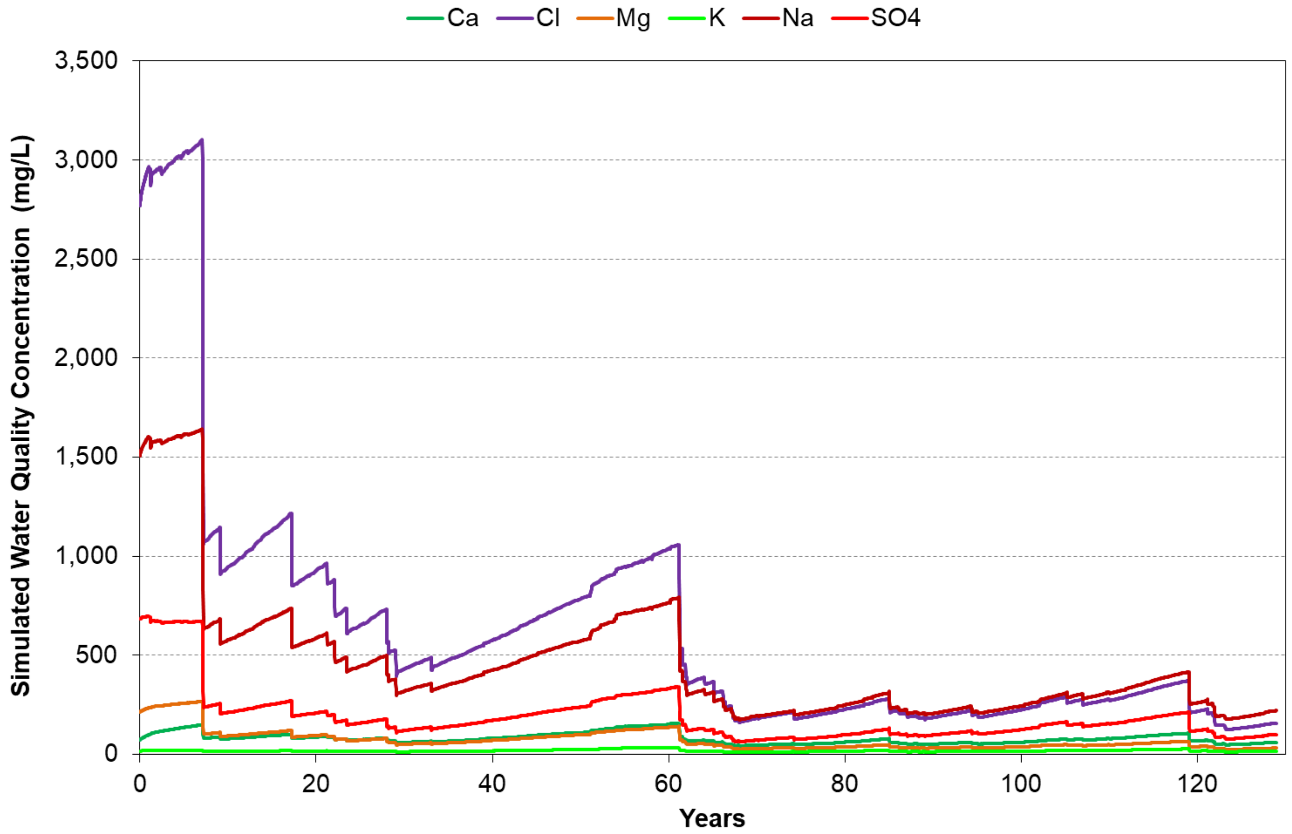

Figure 55 Water Quality Results: Model Run 3, Pit A – Major Ions

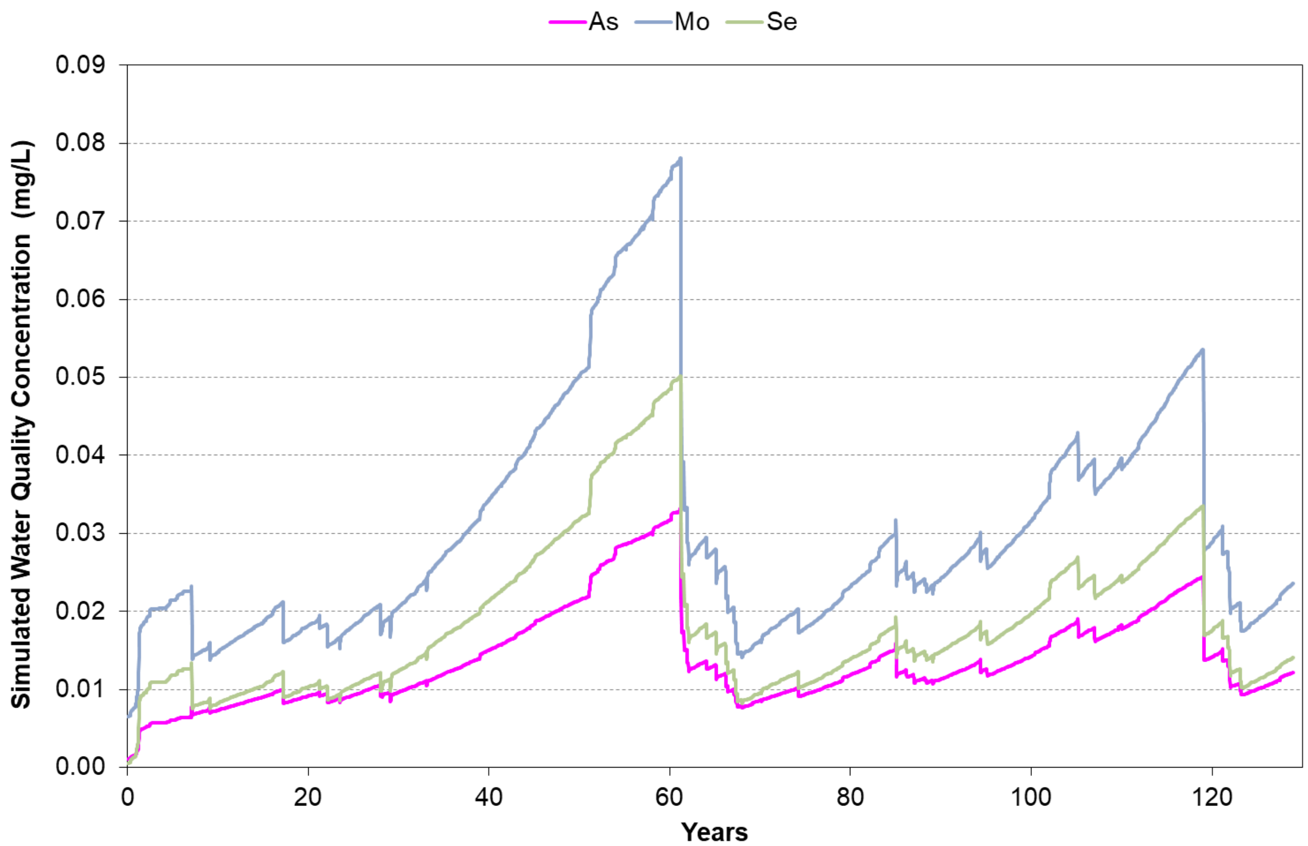

Figure 56 Water Quality Results: Model Run 3, Pit A – Trace Elements

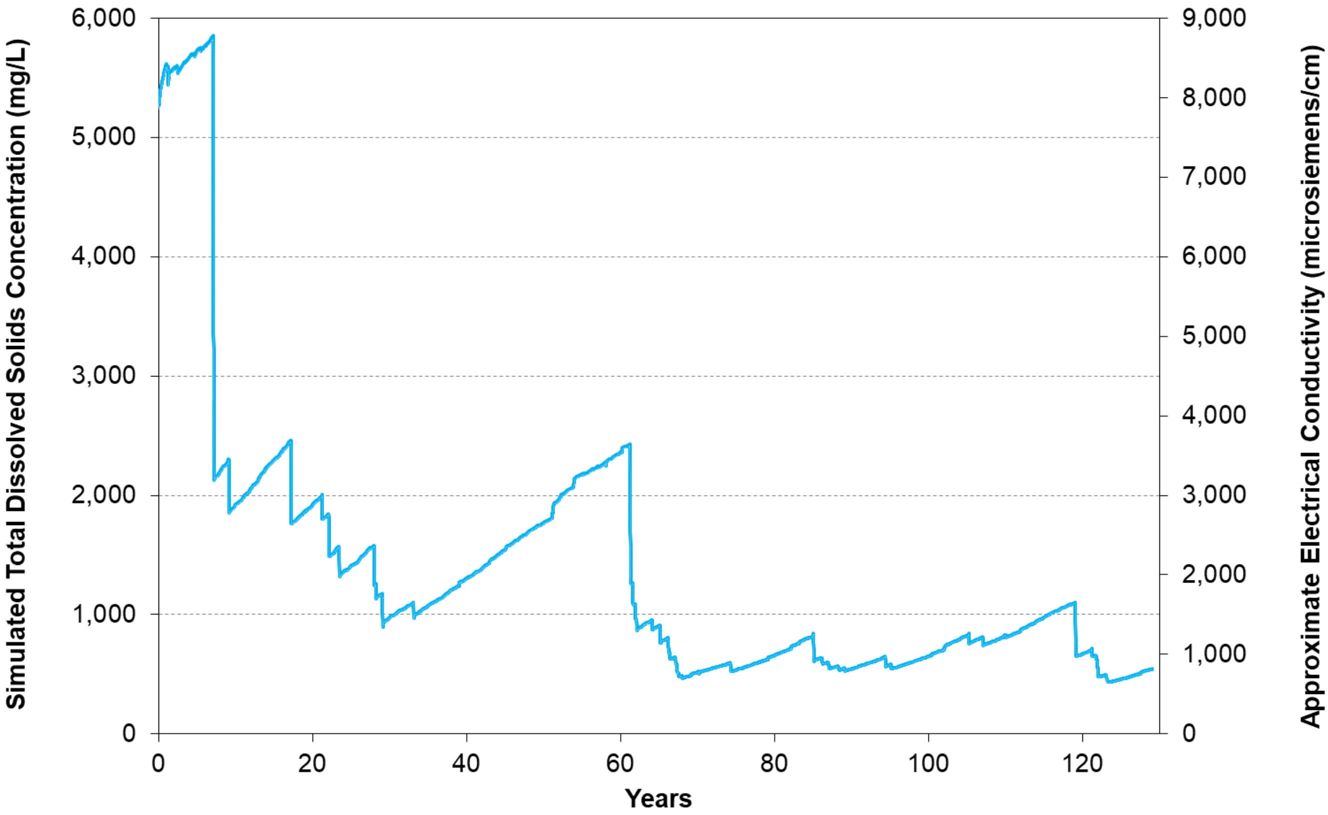

Figure 57 Water Quality Results: Model Run 3, Pit A – Salinity

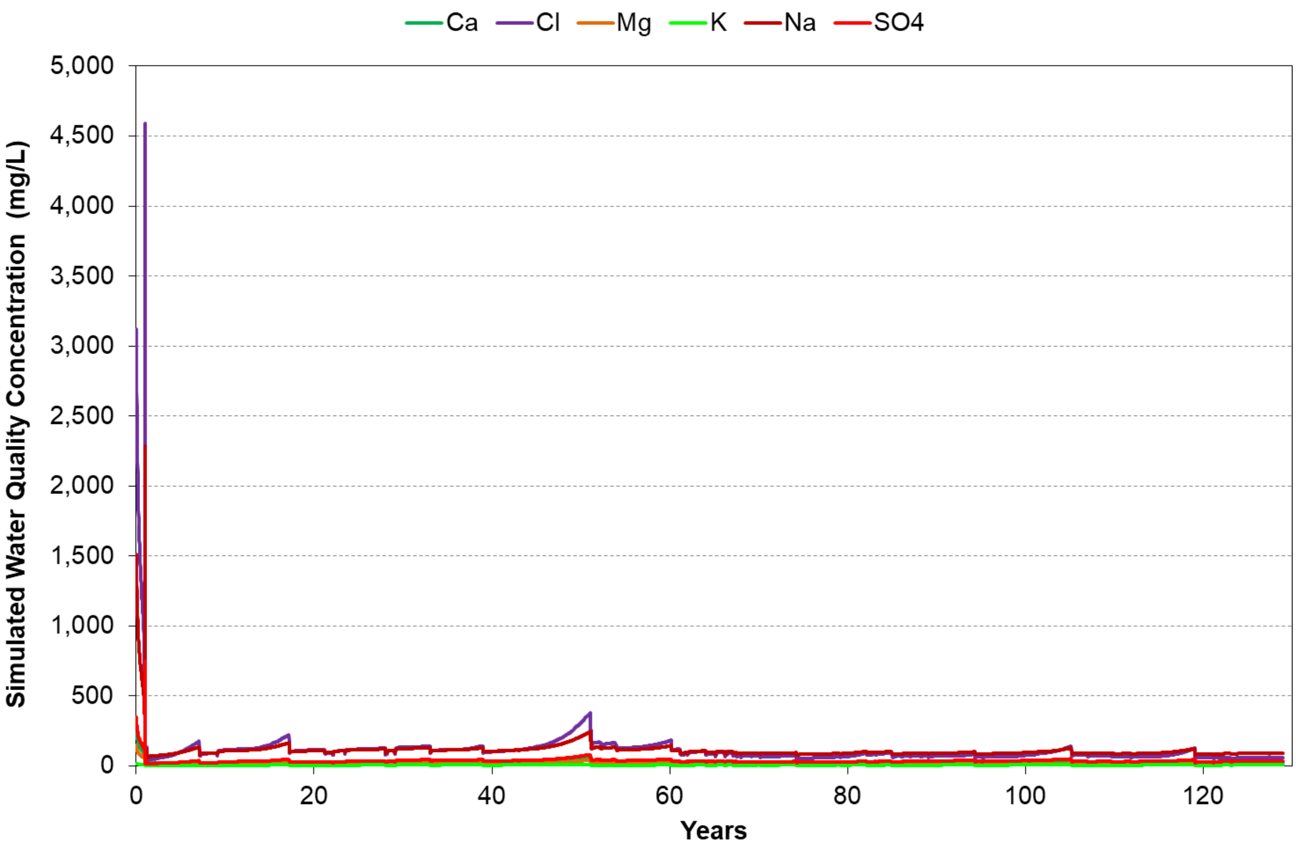

Figure 58 Water Quality Results: Model Run 3, Pit B – Major Ions

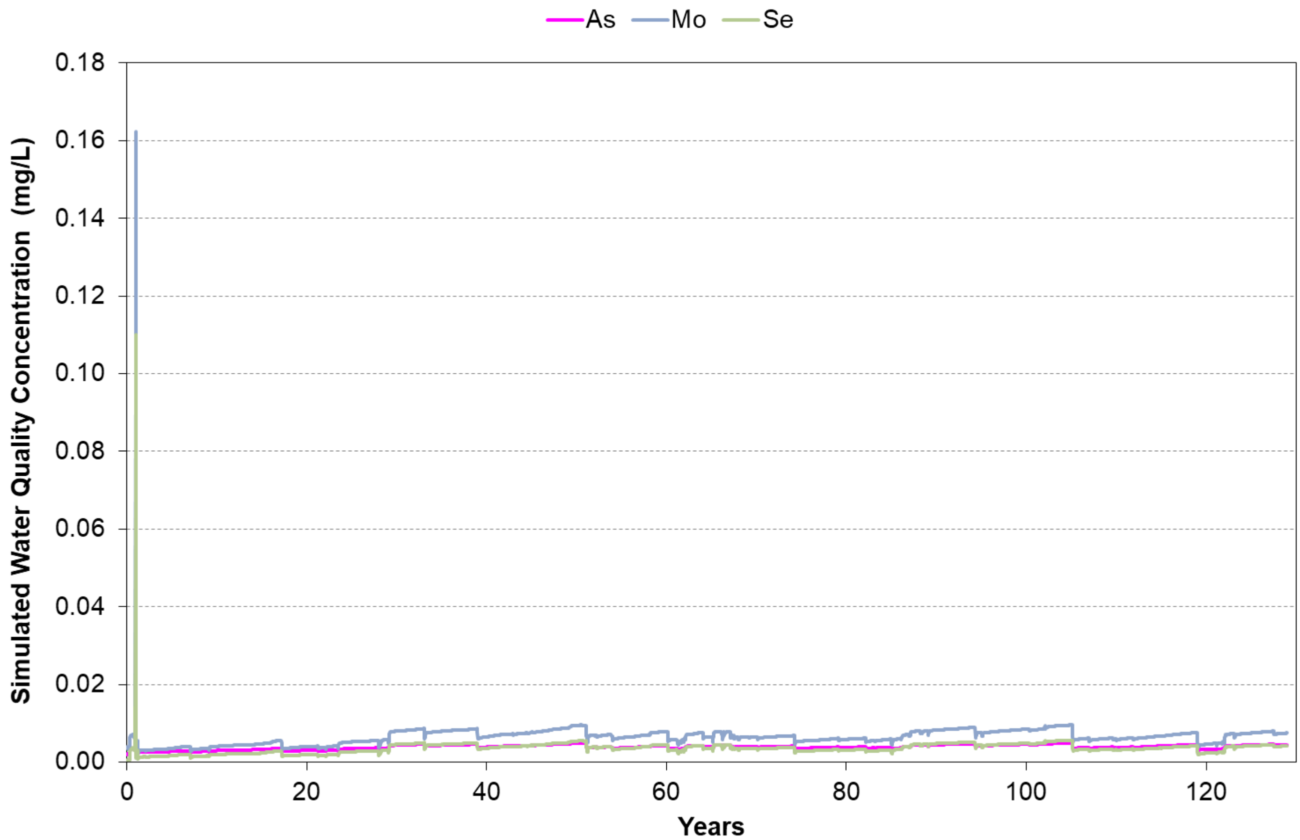

Figure 59 Water Quality Results: Model Run 3, Pit B – Trace Elements

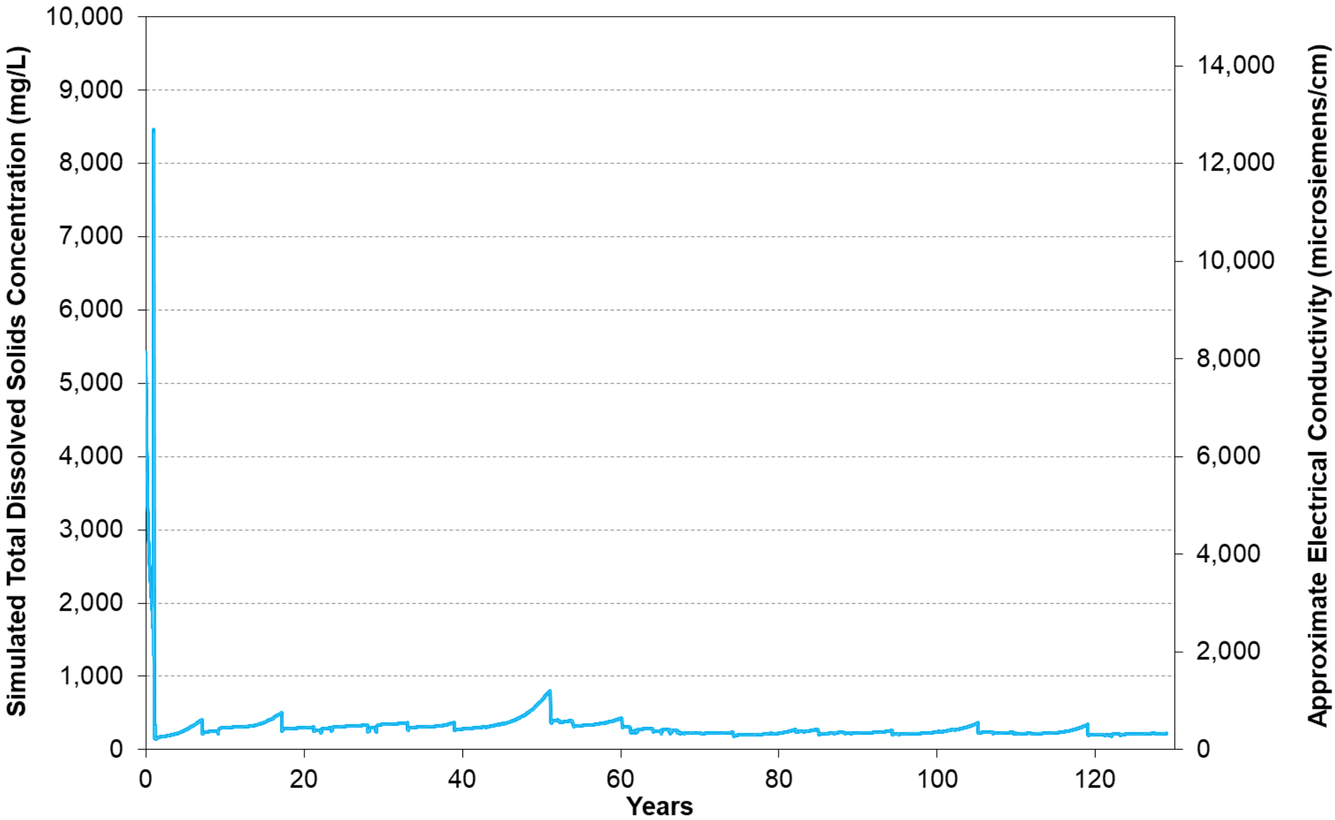

Figure 60 Water Quality Results: Model Run 3, Pit B – Salinity

Figure 55 and Figure 57 show that due to the link to Pit B and the effects of Nogoa River inflows/outflows, simulated concentrations of major ions and salinity in Pit A are predicted to decrease notably as a result of dilution due to the first inflow event. Figure 56 shows that simulated concentrations of trace elements are all predicted to increase/decrease cyclically in Pit A.

Figure 58, Figure 59 and Figure 60 show that due to the effects of Nogoa River inflows/outflows, simulated concentrations of major ions and salinity in Pit B are predicted to decrease notably as a result of dilution due to the first inflow event and reach a concentration similar to those assumed for Nogoa River water (refer Table 16).

5.4.4 Nogoa River Cumulative Flow Comparison

Due to the notable volumes of water simulated as spilling in from and out to the Nogoa River from Pit B for Model Run 3, there is a potential impact on net flow in the Nogoa River downstream of the voids. Figure 61 shows a comparison of cumulative Nogoa River flows without and with Preferred Option 2 with irrigation from Pit B over the 129 year simulation period. The difference between the total flows at the end of the simulation period is approximately 1,603 GL or an average of 12.6 GL/year. This represents an average decrease in the river flow volume of 1.8%.

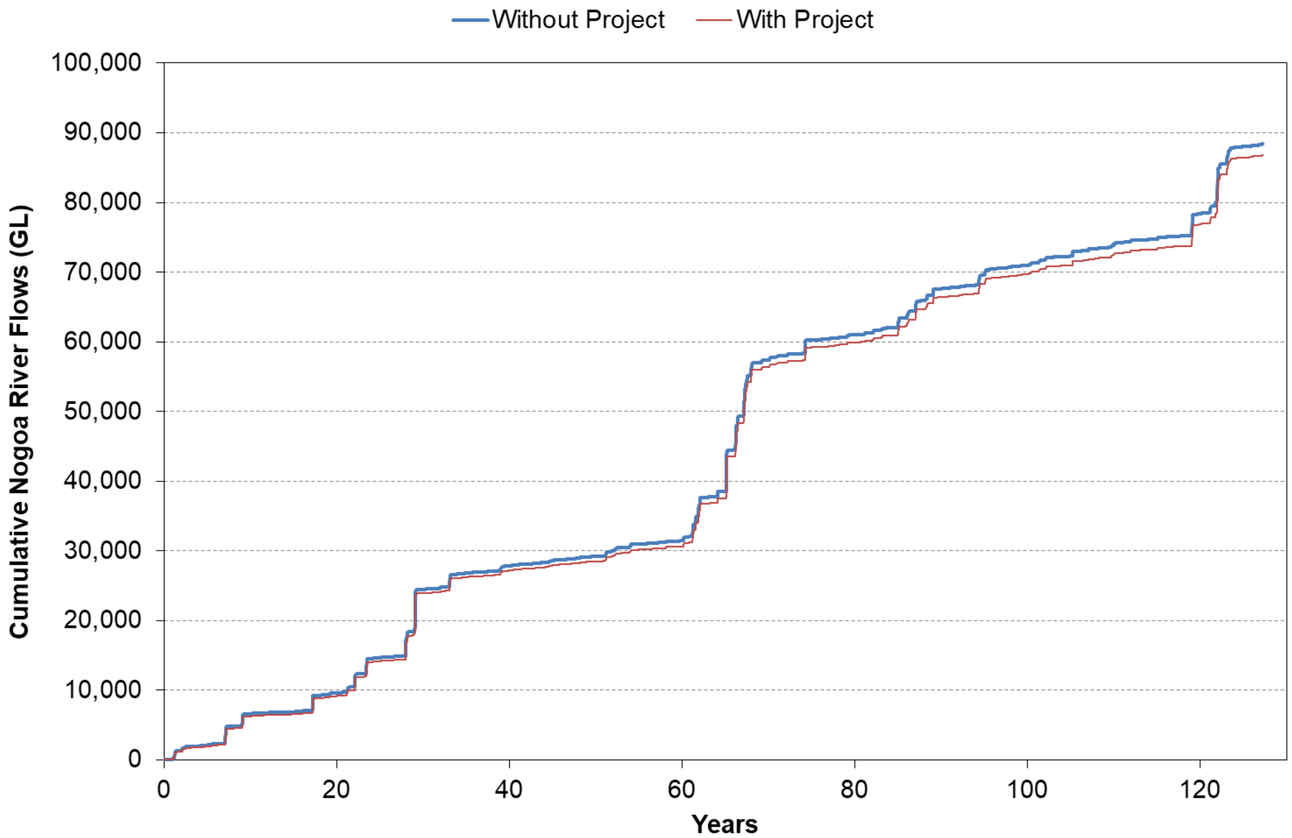

Figure 61 Nogoa River Flow Comparison: Model Run 3

5.4.5 Nogoa River Dilution Calculations

In order to gain an understanding of the change in water quality in the Nogoa River in Run 3, the ratio of the Nogoa River flow volume to the pit outflow volume to the Nogoa River has been calculated and is summarised as a probability plot in Figure 62.

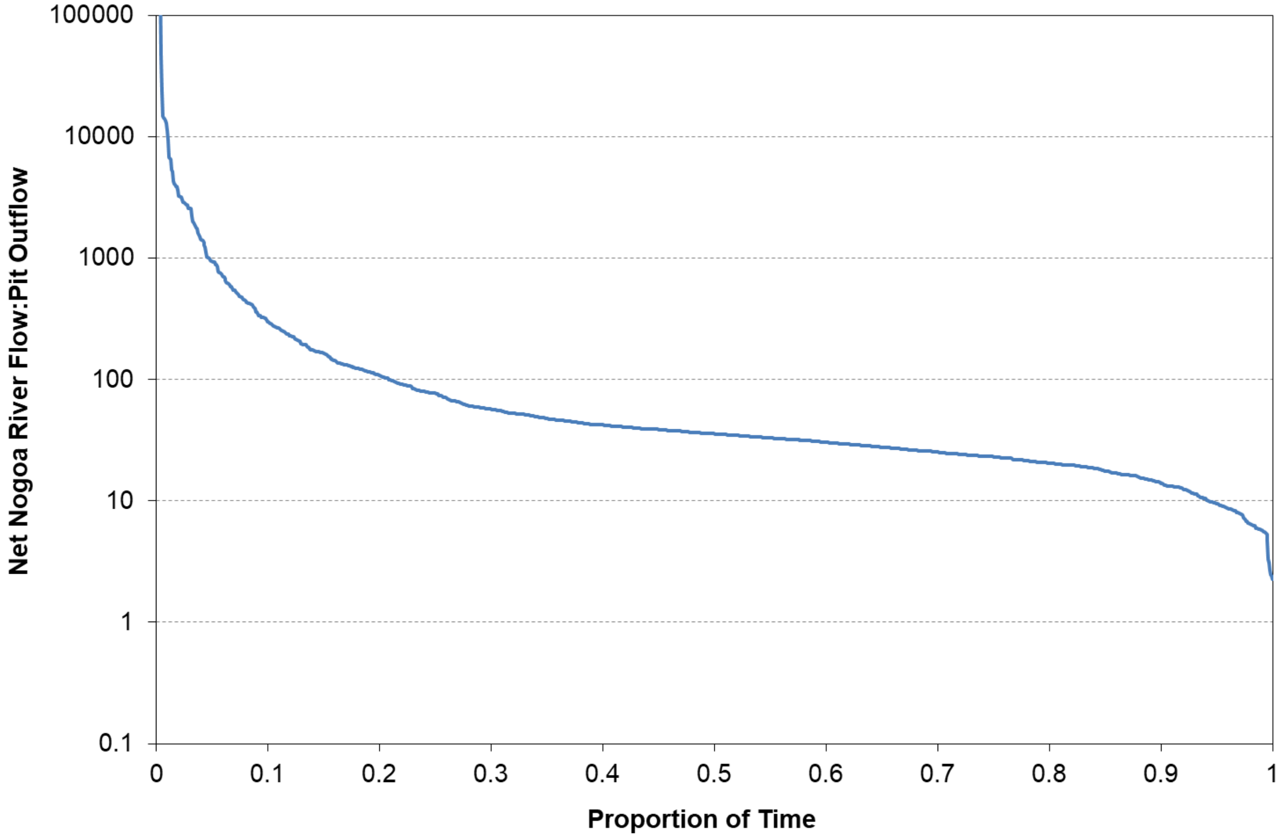

Figure 62 Pit B Outflow Dilution by Nogoa River: Model Run 3

Figure 62 shows that 100% of the time that outflow is occurring, the ratio of Nogoa River volume to pit outflow volume is greater than 1 (i.e. Nogoa River flow is greater than pit outflow, 100% of the time). Figure 62 also shows that 50% of the time, the Nogoa River flow volume is approximately 35 times that of the outflow from Pit B (when outflow is occurring).

A TDS probability plot is provided in Figure 63 which shows that for 97% of the time that outflow is occurring, the estimated Nogoa River TDS downstream of the voids would be equal to the adopted background TDS of 115 mg/L.

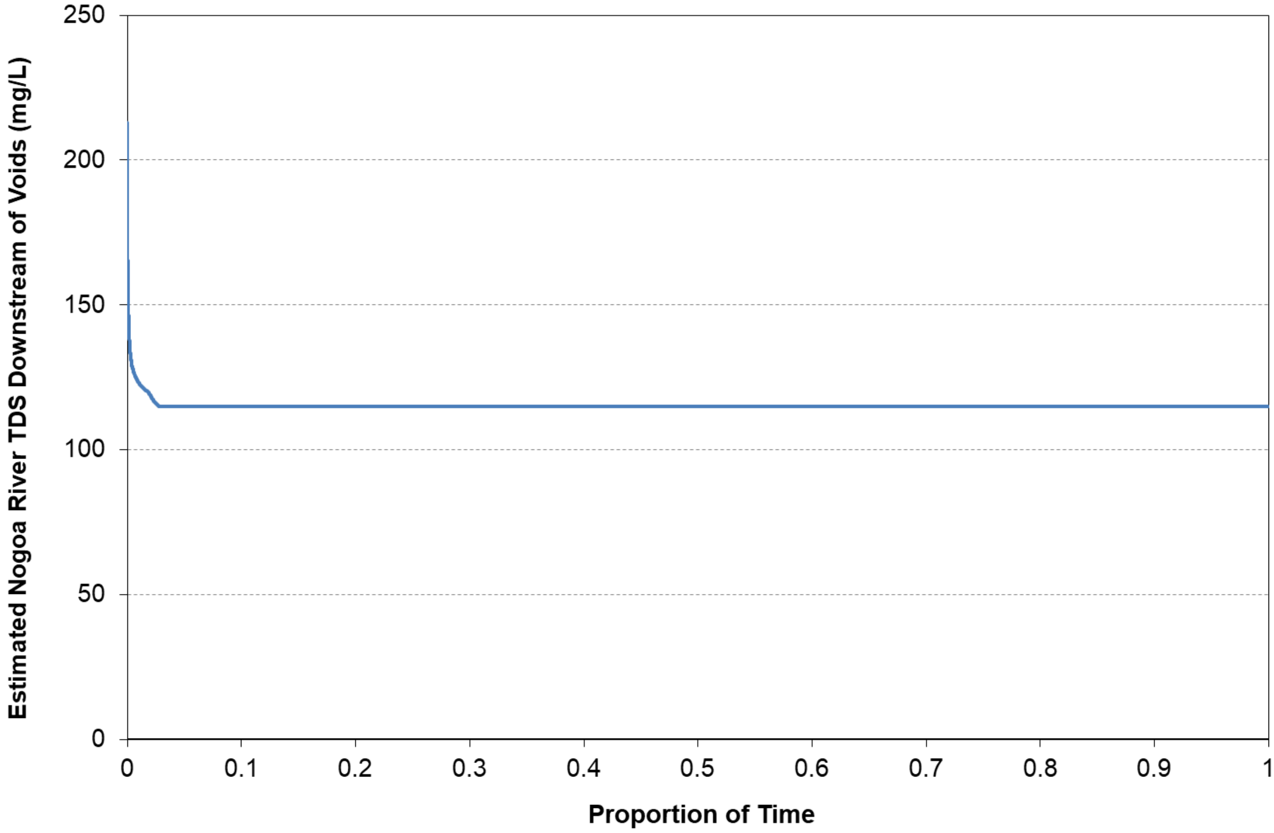

Figure 63 Estimated Nogoa River TDS Downstream of Voids during outflow from Pit B: Model Run 3

5.5 MODEL RUN 4 RESULTS (PREFERRED OPTION 2: IRRIGATION FROM PIT B AND PIT CD)

The objective of Model Run 4 is to predict the water levels, volumes and quality results for Preferred Option 2 with irrigation from Pit B and Pit CD (i.e. full development of both the southern and northern voids). Results for the voids for Model Run 4 are summarised in the sections to follow.

On average, 7.9 GL/year was simulated pumped from Pit B to irrigation demand while 11.9 GL/year was pumped from Pit CD to irrigation demand.

5.5.1 Water Levels

Figure 64 to Figure 67 show forecast water levels over the 129 year simulation period for each of the floodplain voids in Model Run 4.

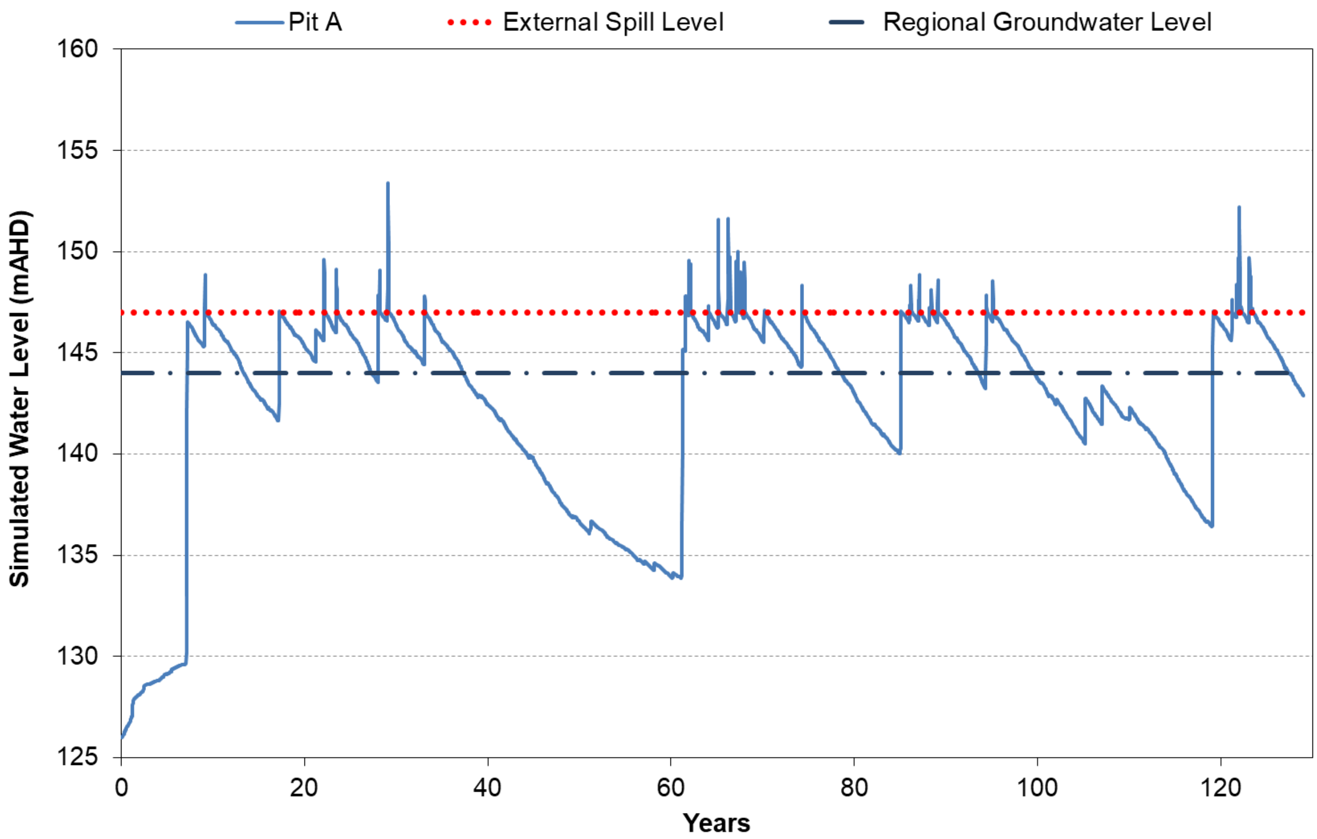

Figure 64 Water Level Results: Model Run 4, Pit A

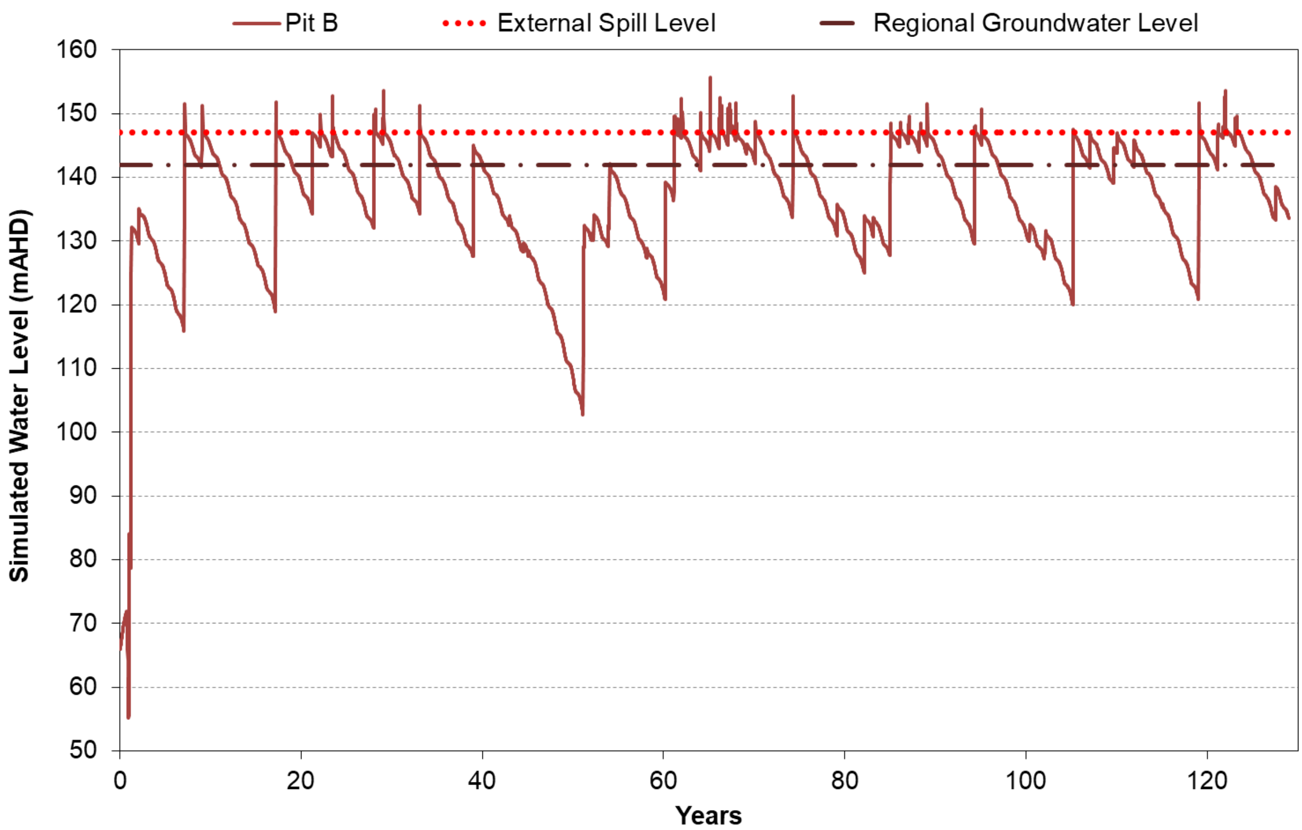

Figure 65 Water Level Results: Model Run 4, Pit B

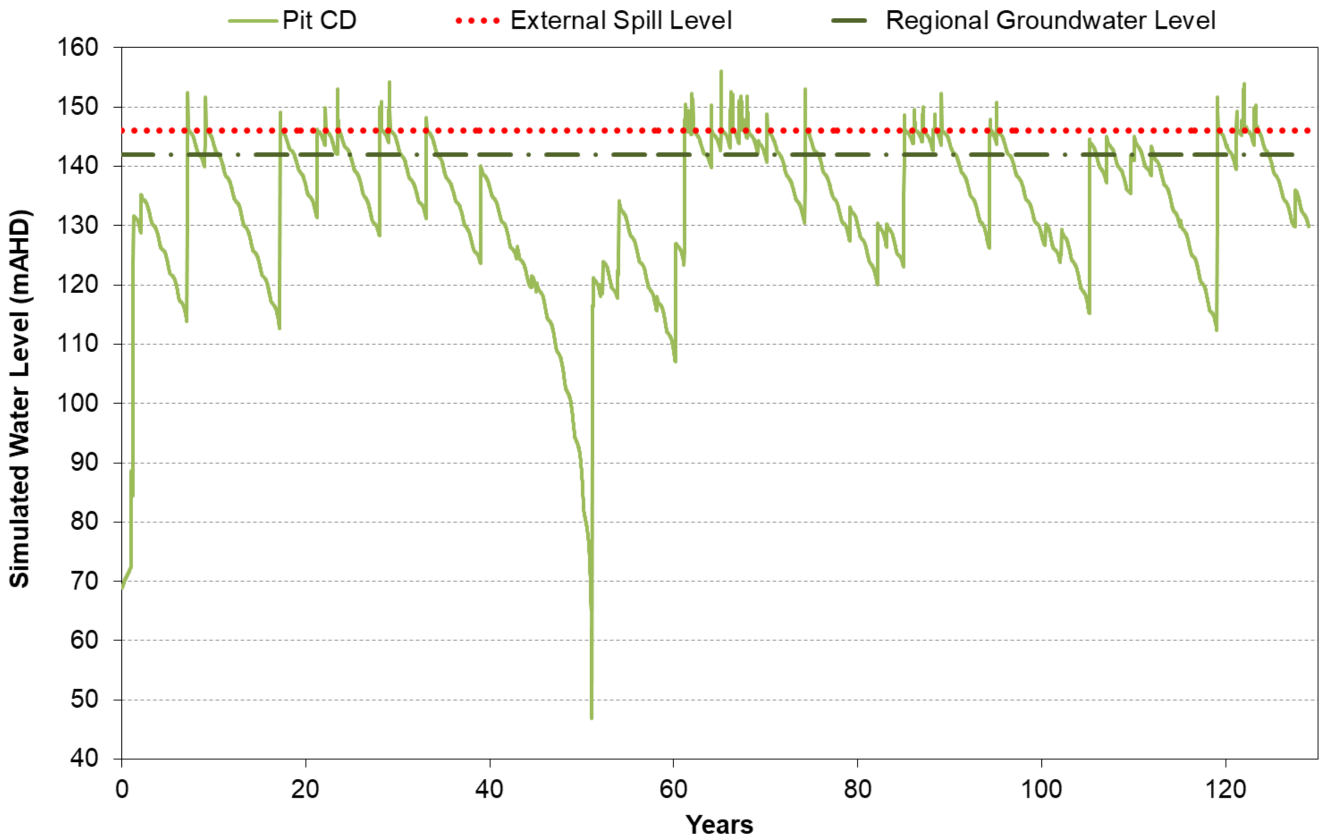

Figure 66 Water Level Results: Model Run 4, Pit CD

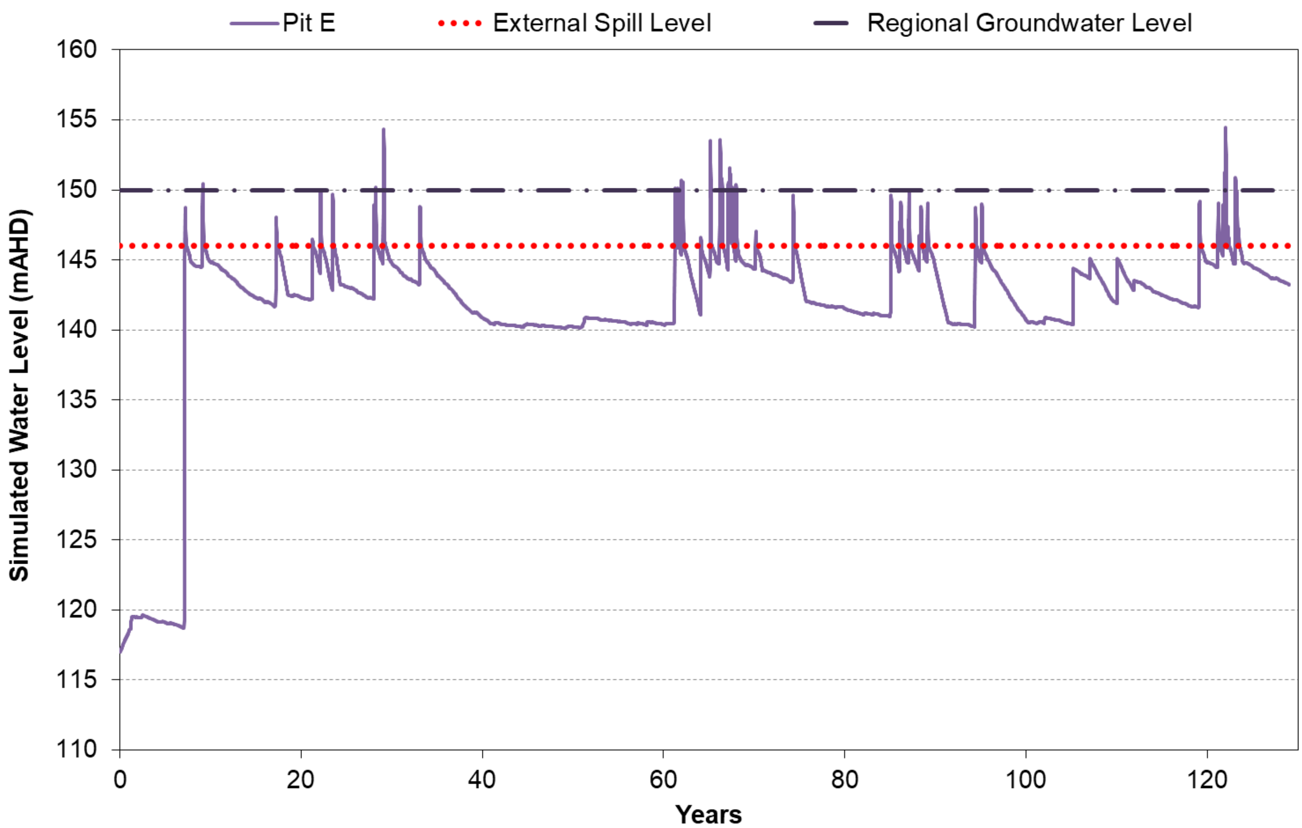

Figure 67 Water Level Results: Model Run 4, Pit E

Figure 64 and Figure 65 show notable variations in the water levels in Pit A and Pit B due to the simulated Nogoa River inflows to Pit B, irrigation demand pumped from Pit B and the hydraulic link (i.e. spill/seepage) between Pit B and Pit A. The water levels in both Pit A and Pit B rise above the external spill level to the Nogoa River during river flood events. Water levels in Pit A and Pit B both rise above the respective regional groundwater levels and regional groundwater outflow from both pits is simulated during these periods.

Figure 66 and Figure 67 show notable variations in the water levels in Pit CD and Pit E due to the simulated Nogoa River inflows to Pit CD, irrigation demand pumped from Pit CD and the hydraulic link between Pit CD and Pit E. The water level in both Pit CD and Pit E rise above the external spill level to the Nogoa River during river flood events. Water levels in Pit CD and Pit E both rise above the respective regional groundwater levels and regional groundwater outflow from both pits is simulated during these periods.

5.5.2 Water Volumes

Figure 54 shows the simulated water volume results over the 129 year simulation period for each of the floodplain voids in Model Run 4.

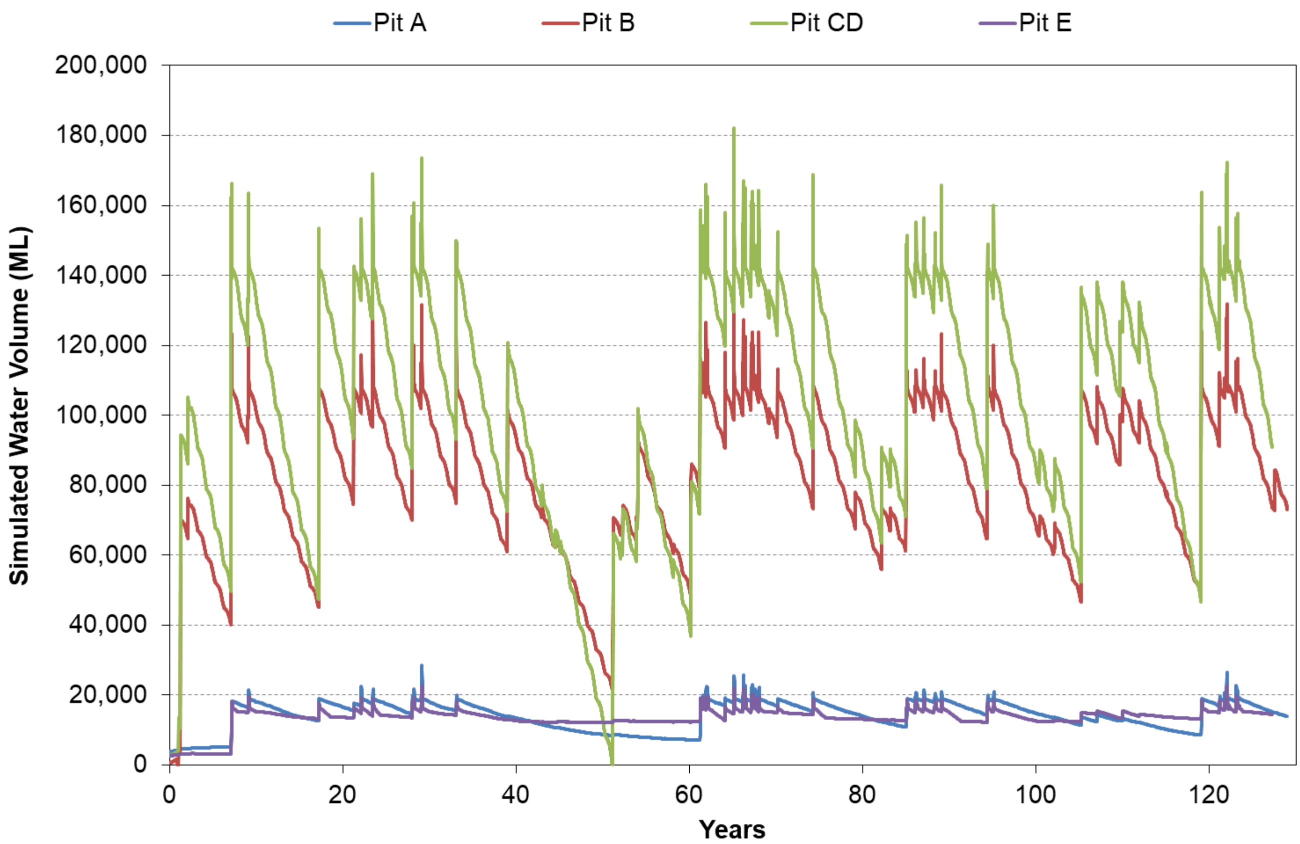

Figure 68 Water Volume Results: Model Run 4

Figure 54 shows that simulated water volumes in Pit B and Pit CD are notably higher than Pit A and Pit E with Pit CD holding slightly more water that Pit B on average. The water volumes stored in Pit B and Pit CD fluctuate more than the water volumes stored in Pit A and Pit E.

5.5.3 Water Quality

Figure 69 to Figure 80 show water quality results (major ions, trace elements and salinity) over the 129 year simulation period for each of the floodplain voids in Model Run 4. Note that the simulated water quality concentration for solutes in Pit B and Pit CD provides an indication of the quality of water supplied to irrigation.

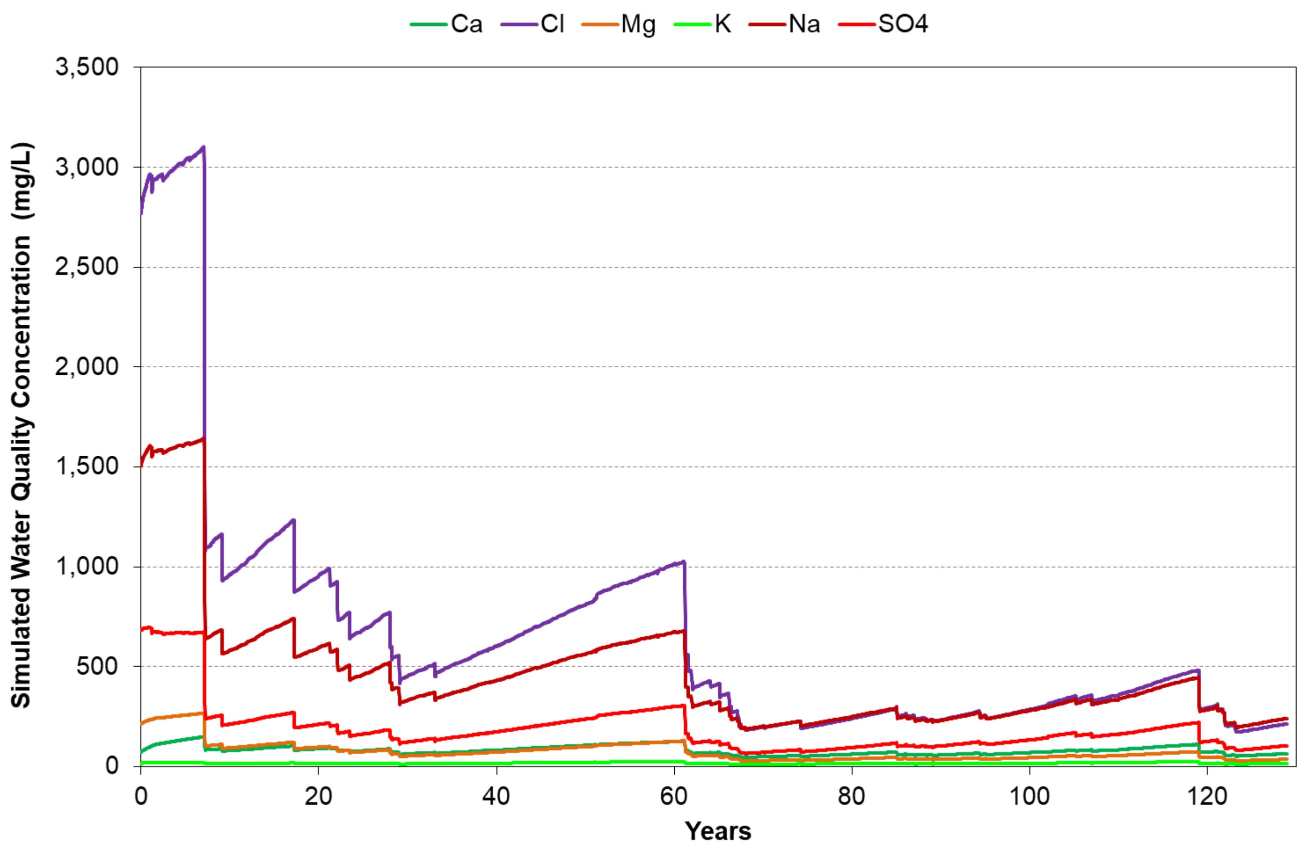

Figure 69 Water Quality Results: Model Run 4, Pit A – Major Ions

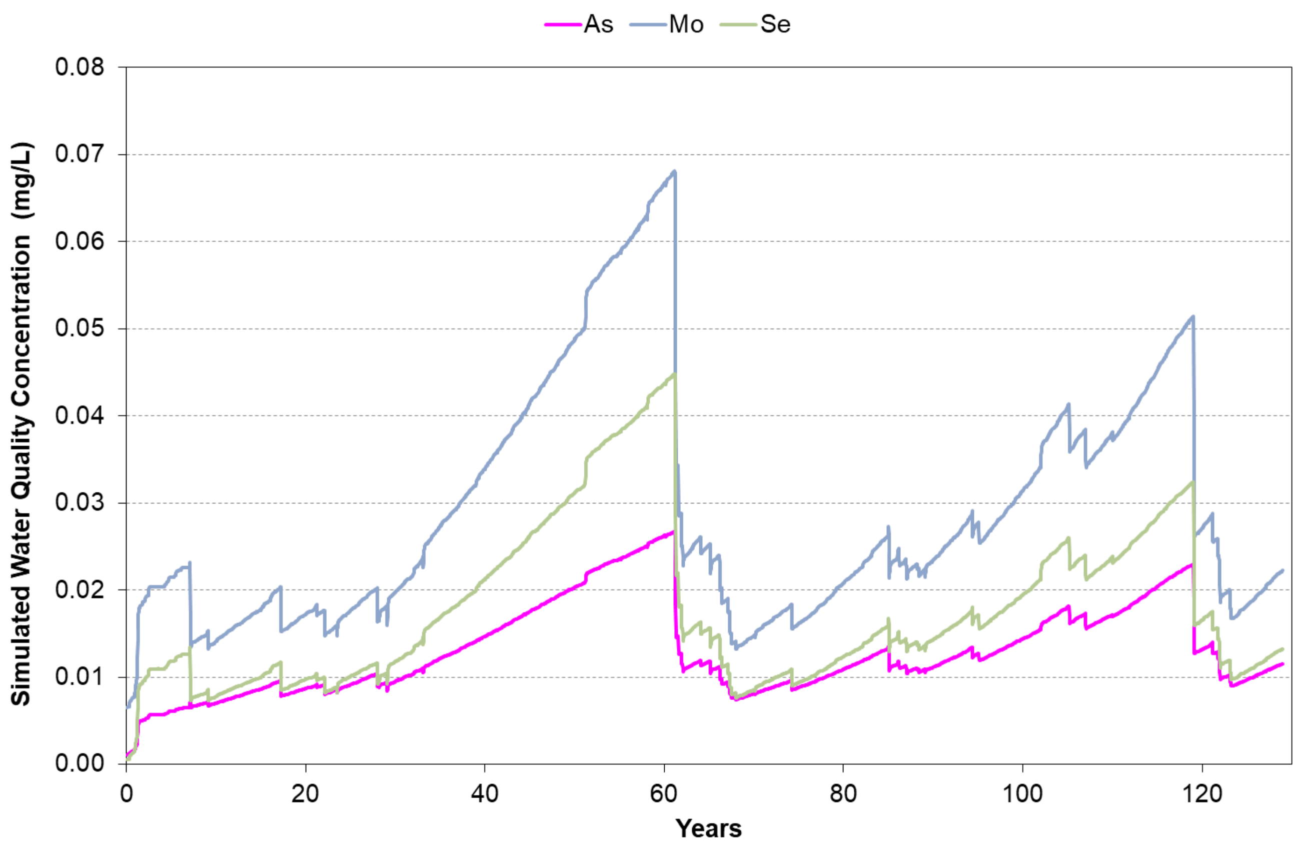

Figure 70 Water Quality Results: Model Run 4, Pit A – Trace Elements

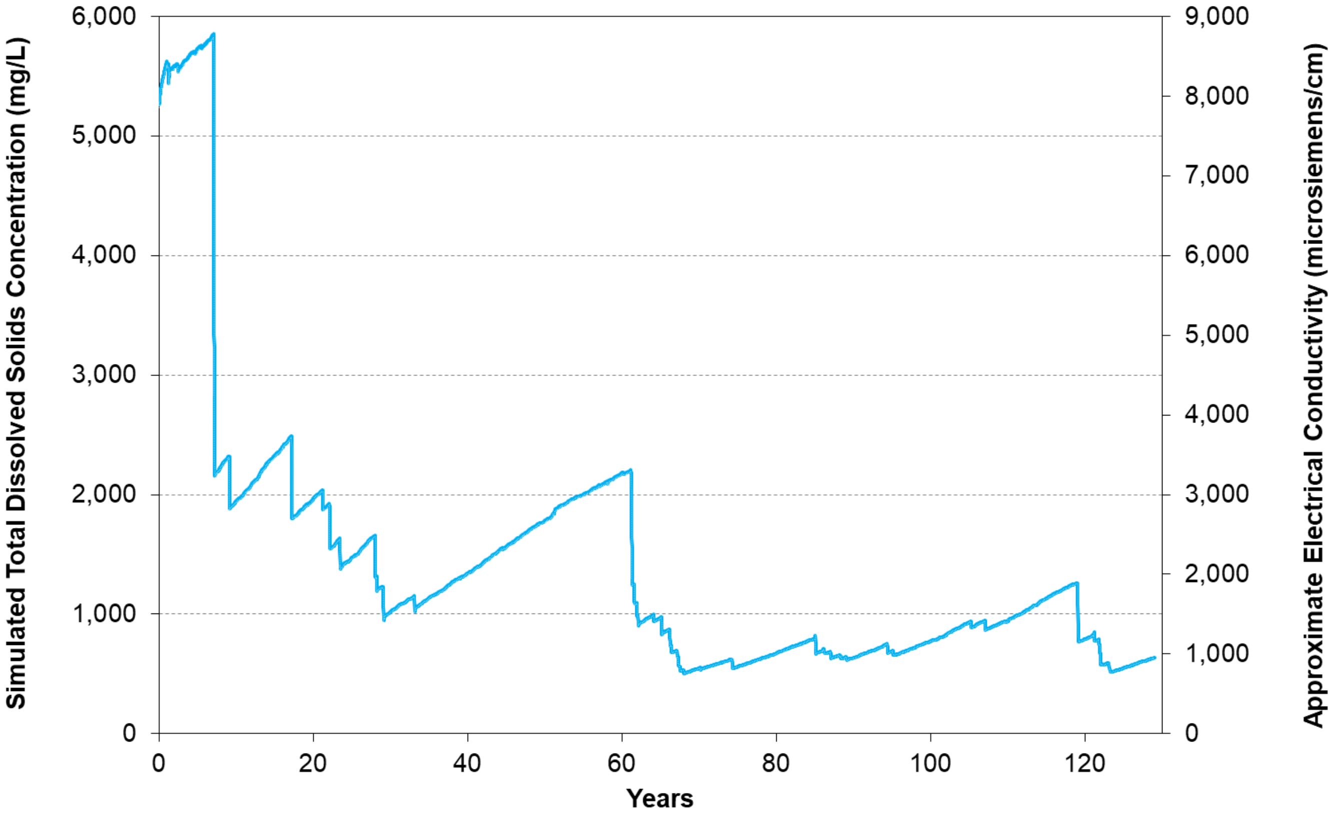

Figure 71 Water Quality Results: Model Run 4, Pit A – Salinity

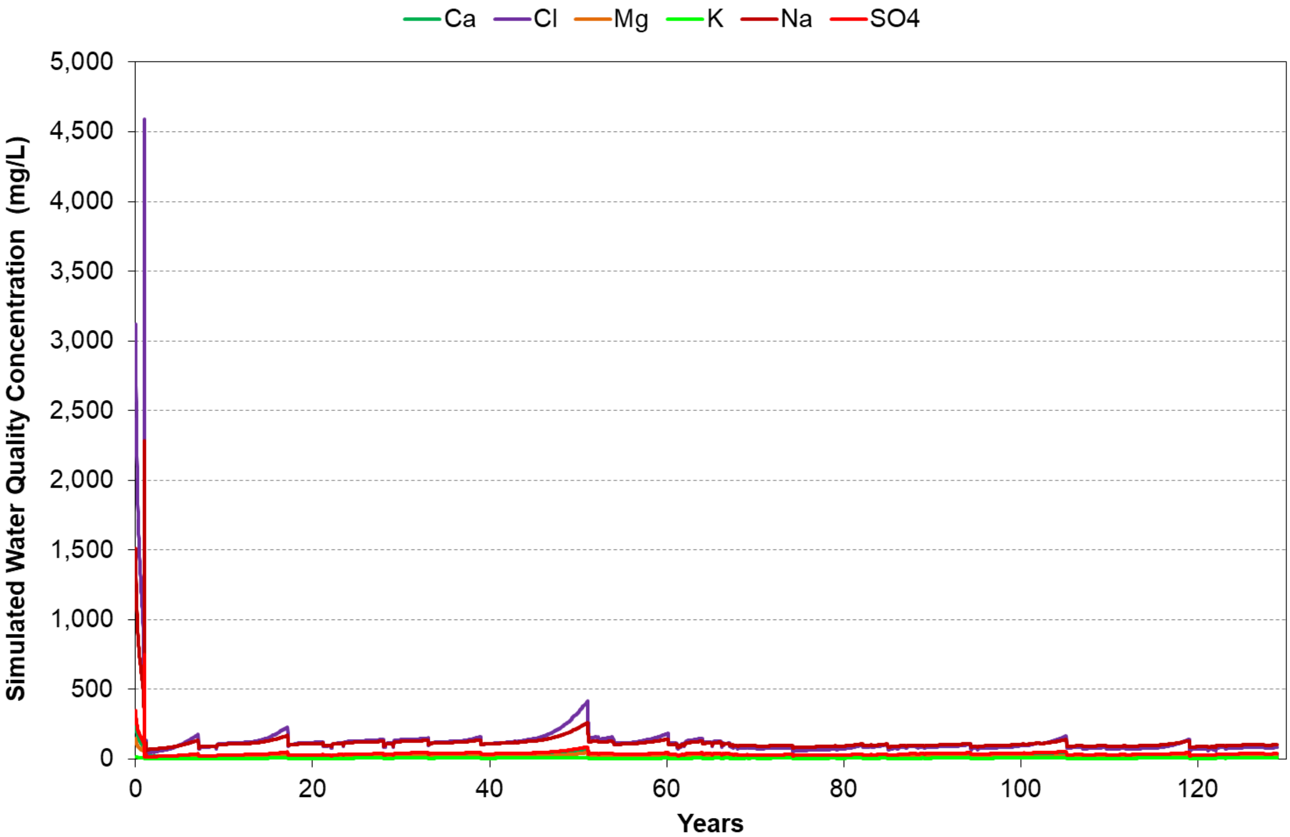

Figure 72 Water Quality Results: Model Run 4, Pit B – Major Ions

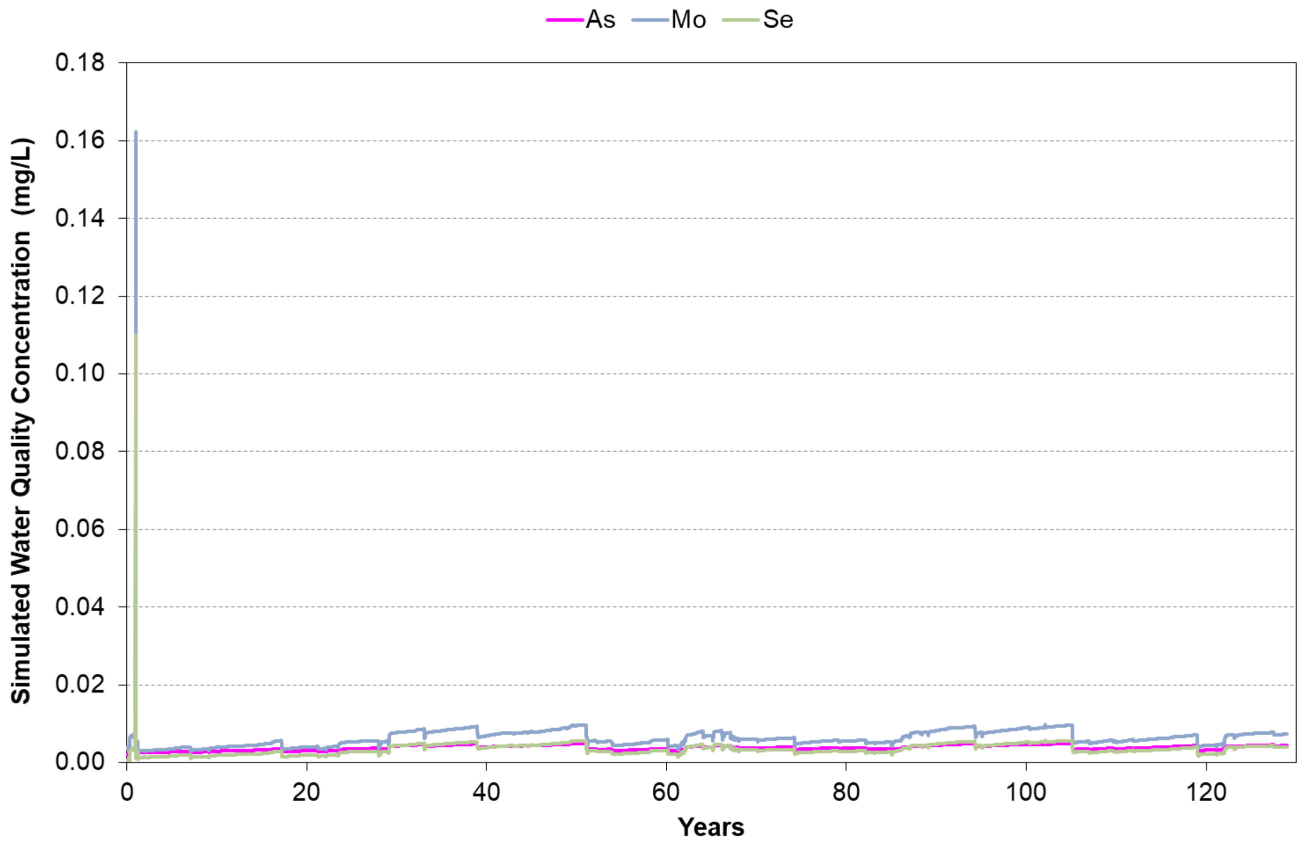

Figure 73 Water Quality Results: Model Run 4, Pit B – Trace Elements

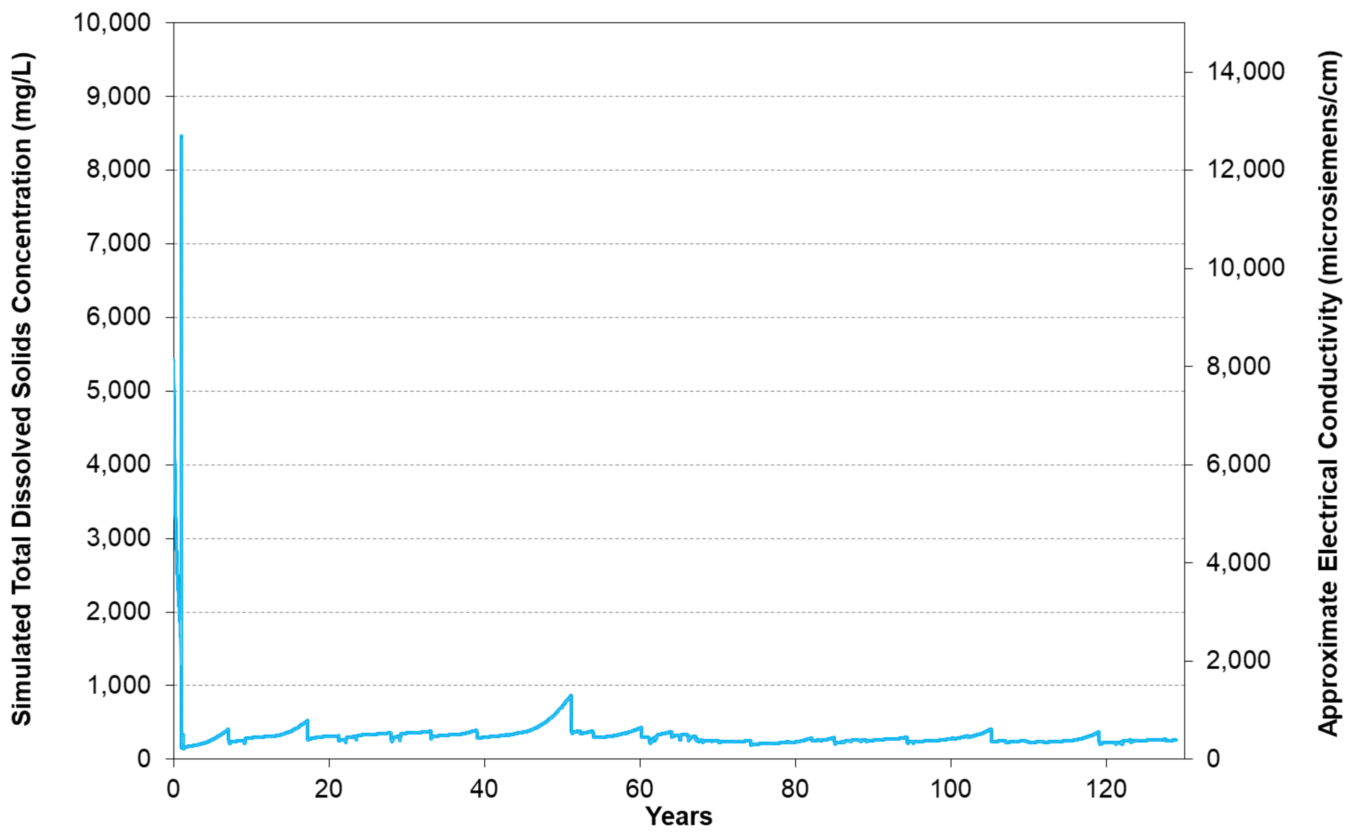

Figure 74 Water Quality Results: Model Run 4, Pit B – Salinity

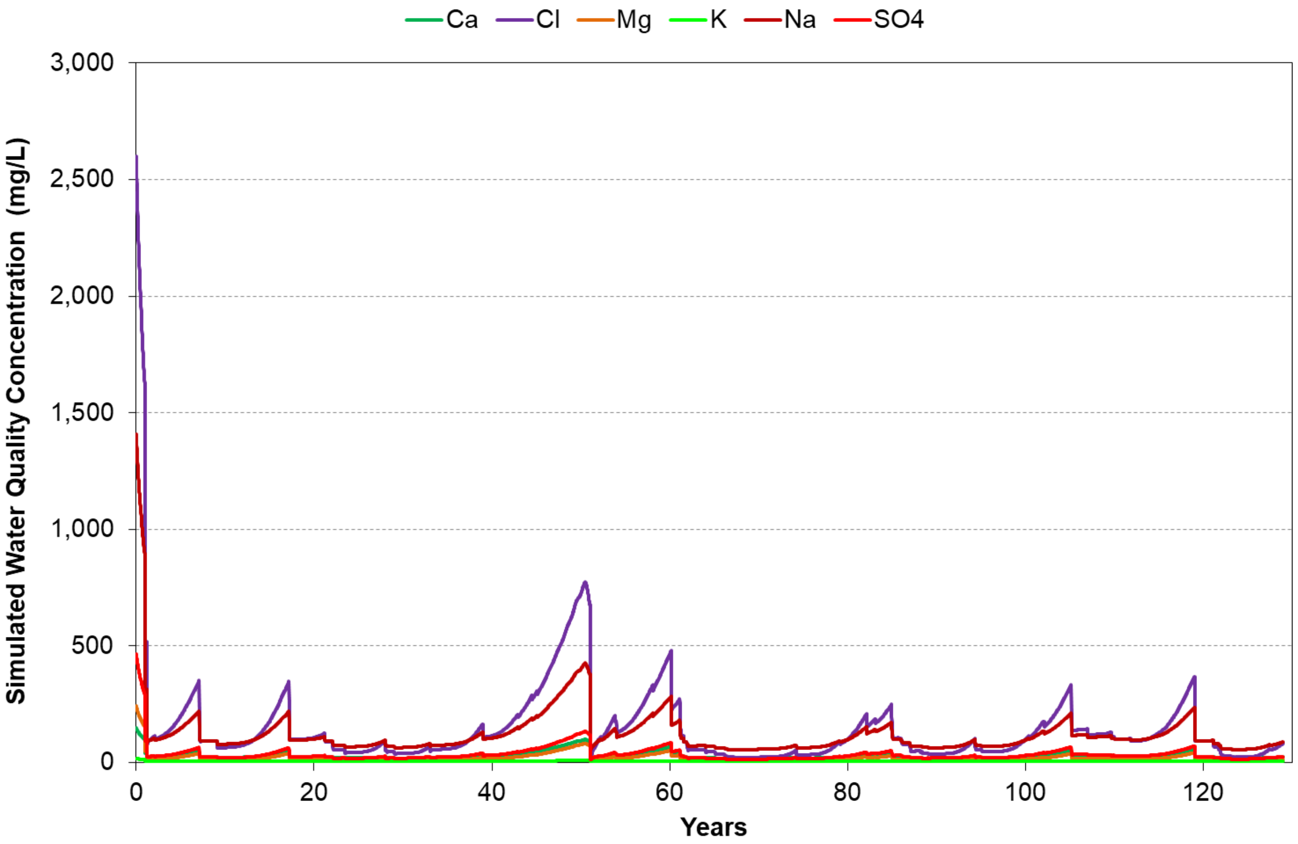

Figure 75 Water Quality Results: Model Run 4, Pit CD – Major Ions

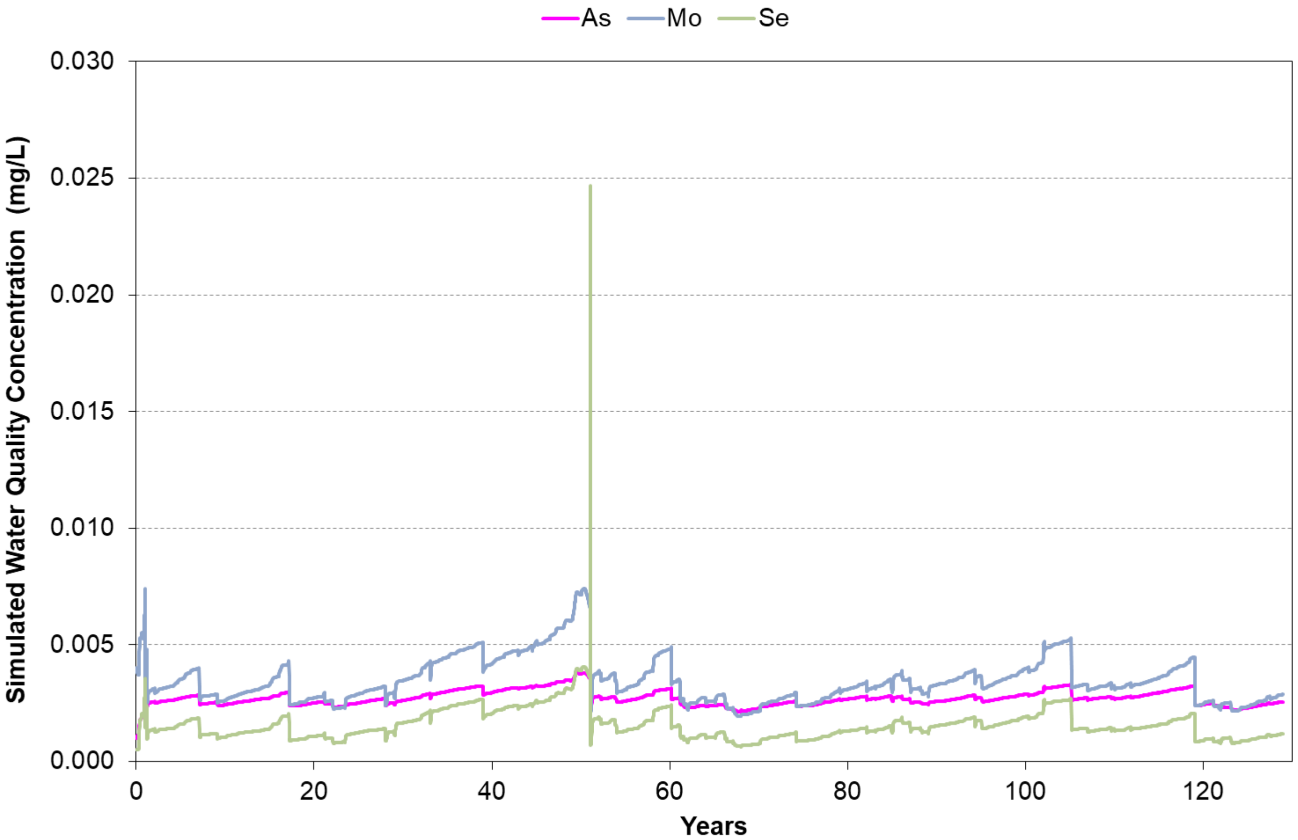

Figure 76 Water Quality Results: Model Run 4, Pit CD – Trace Elements

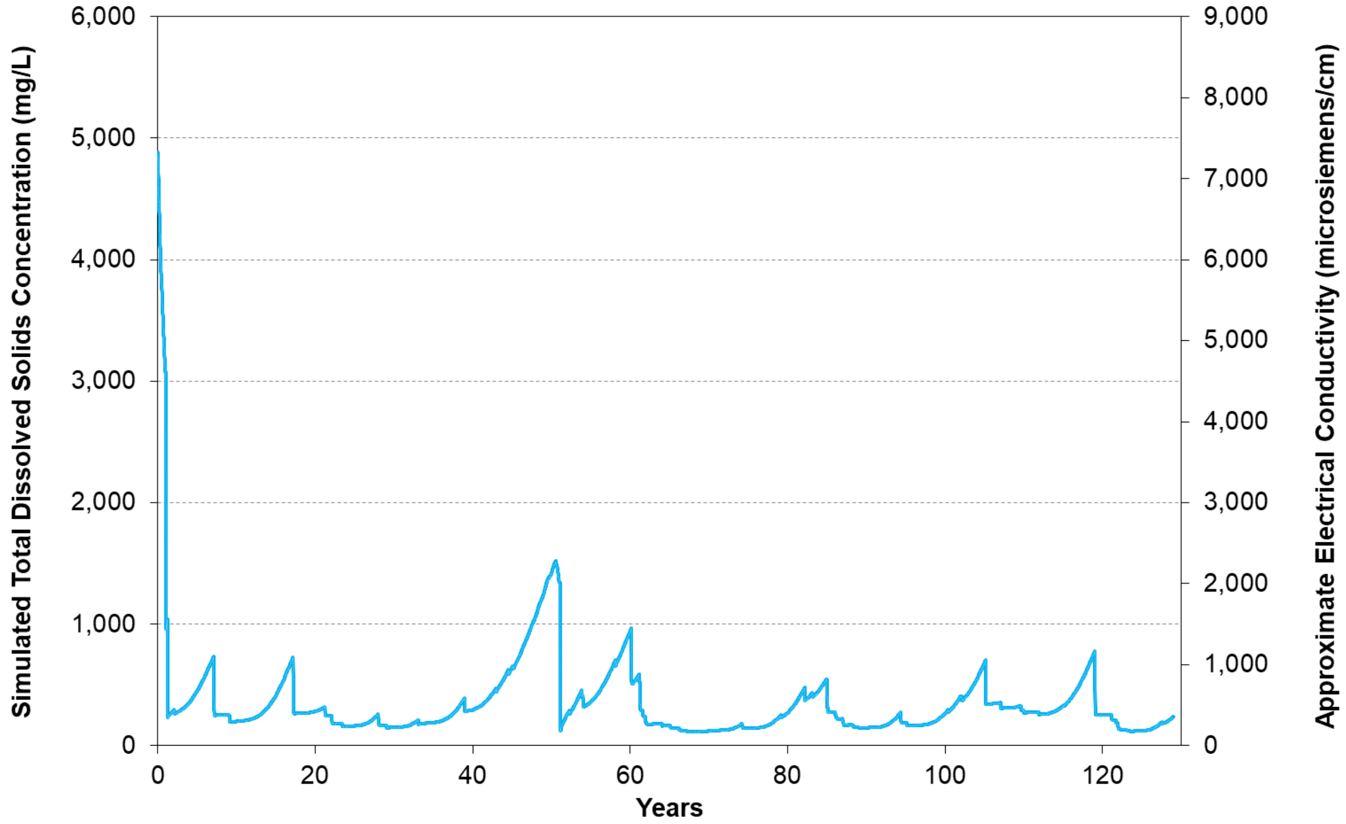

Figure 77 Water Quality Results: Model Run 4, Pit CD – Salinity

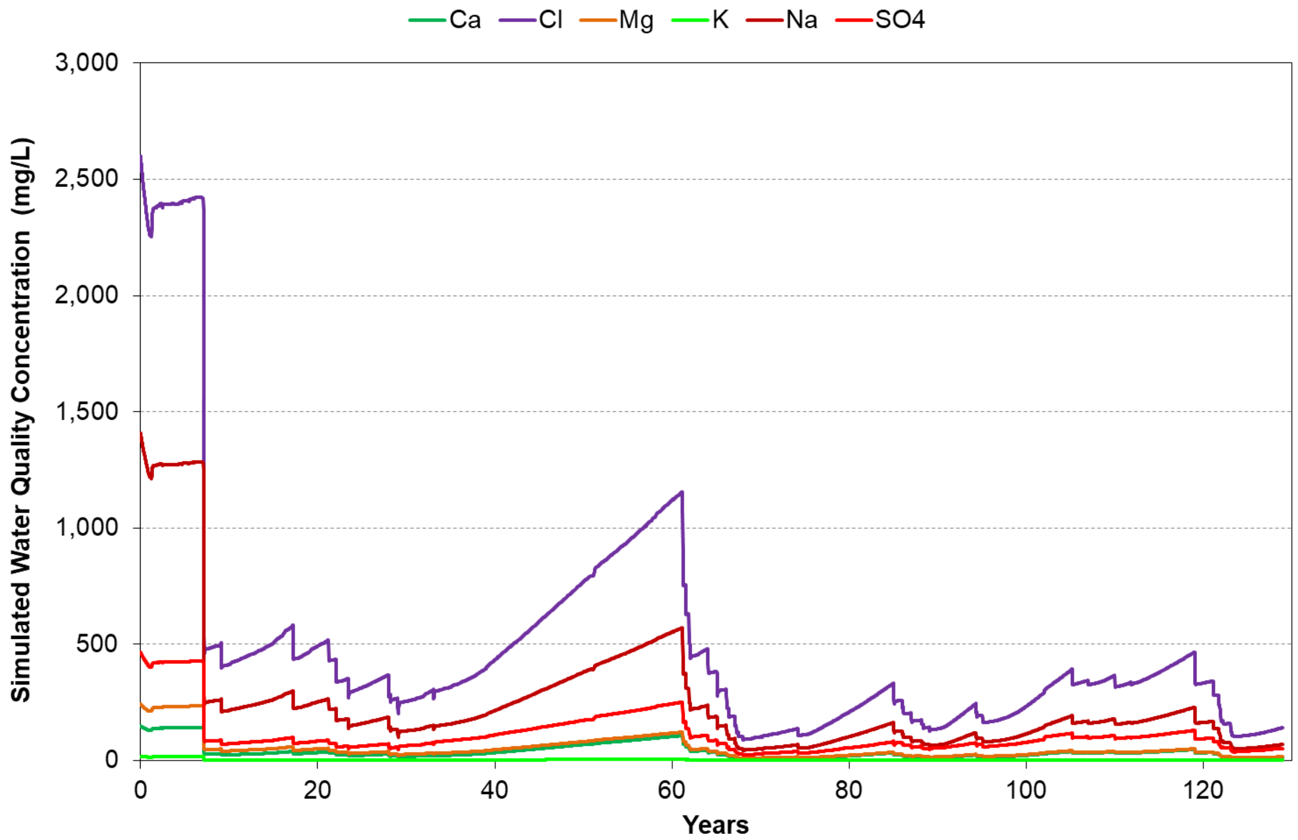

Figure 78 Water Quality Results: Model Run 4, Pit E – Major Ions

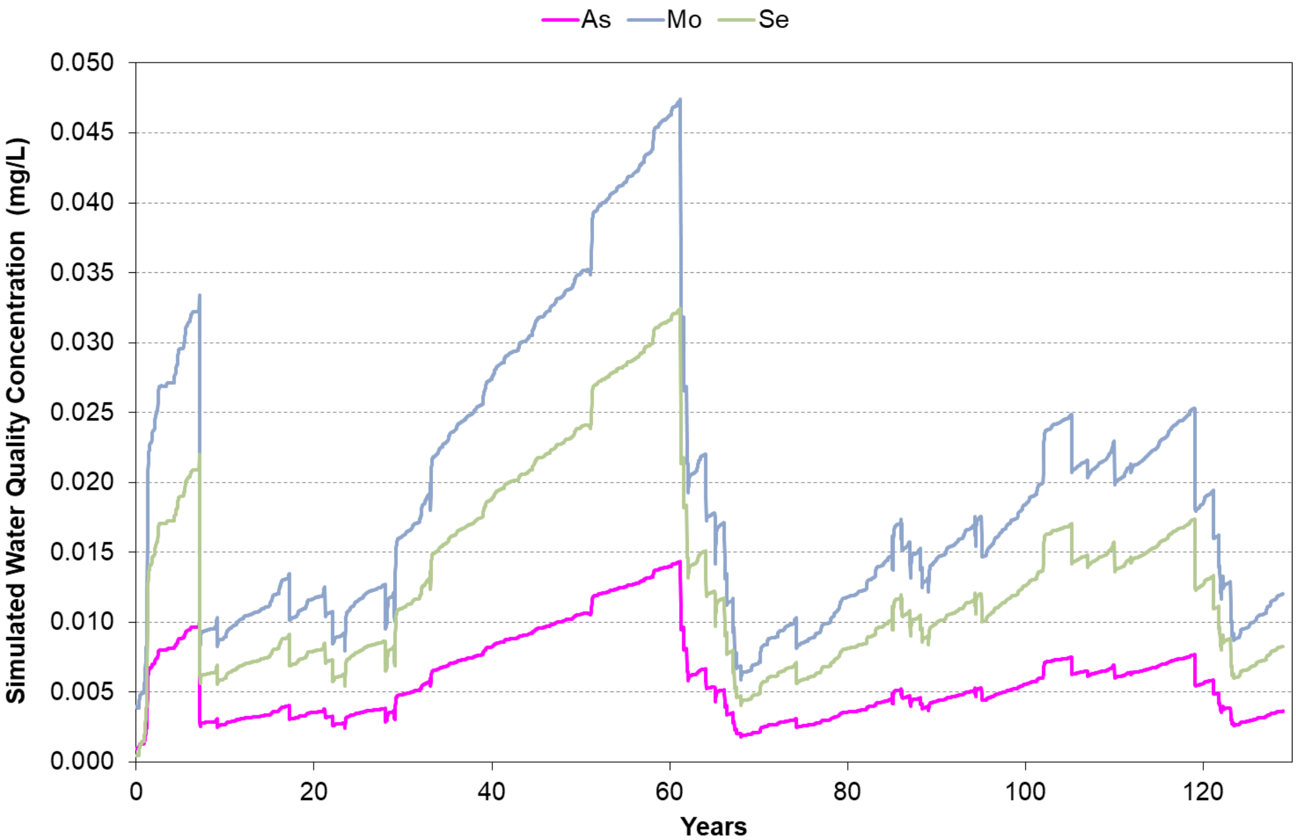

Figure 79 Water Quality Results: Model Run 4, Pit E – Trace Elements

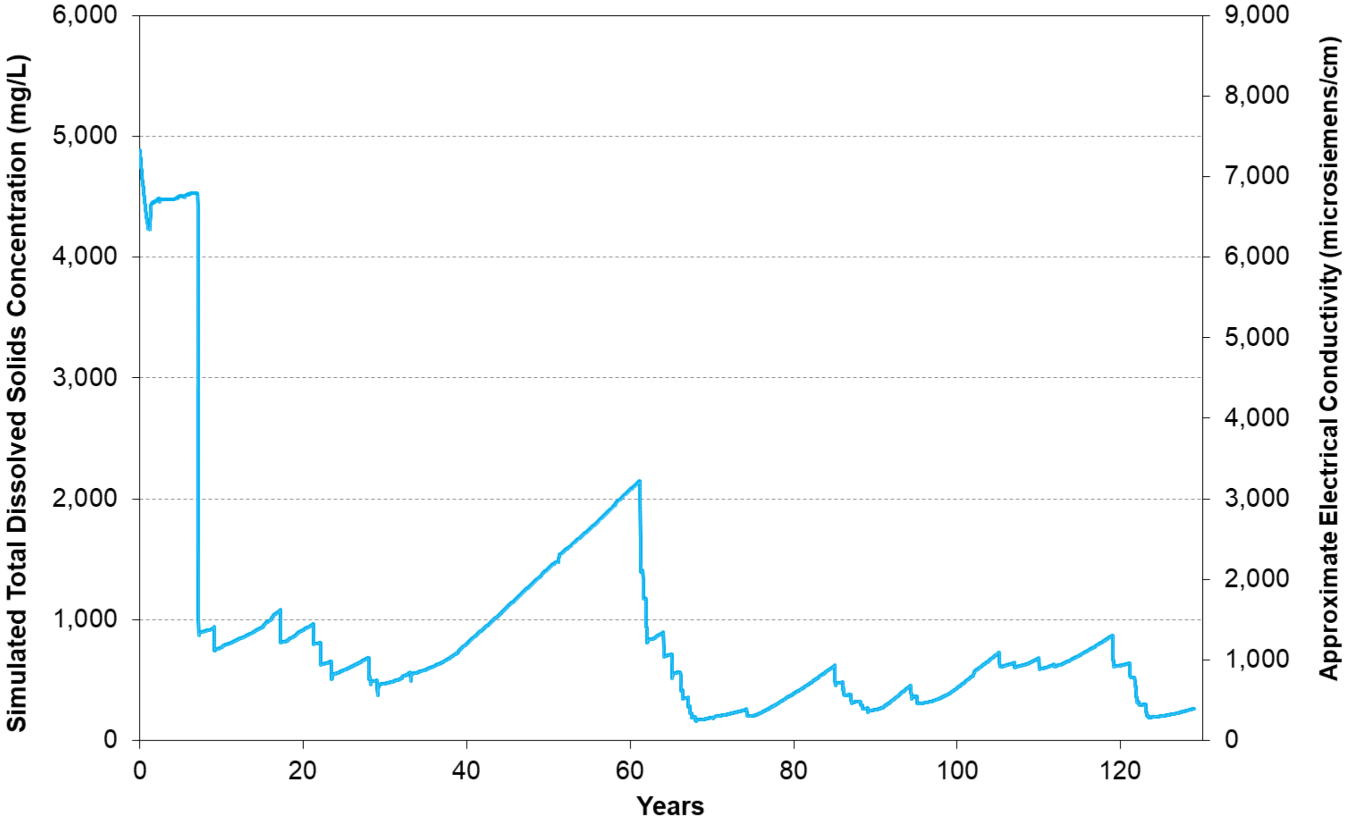

Figure 80 Water Quality Results: Model Run 4, Pit E – Salinity

Figure 69 and Figure 71 show that due to the effects of Nogoa River inflows/outflows (via Pit B), simulated concentrations of major ions and salinity in Pit A are predicted to decrease as a result of dilution due to the first inflow event. Figure 70 shows that simulated trace element concentrations are predicted to increase/decrease cyclically in Pit A over the simulation period.

Figure 72, Figure 73 and Figure 74 show that simulated concentrations of solutes are all predicted to increase/decrease cyclically in Pit B due to interaction with the Nogoa River.

Figure 75, Figure 76 and Figure 77 show that simulated concentrations of solutes are all predicted to increase/decrease cyclically in Pit CD due to interaction with the Nogoa River.

Figure 78 and Figure 80 show that due to the effects of Nogoa River inflows/outflows (via Pit CD), simulated concentrations of major ions and salinity in Pit E are predicted to decrease as a result of dilution due to the first inflow event and reach a concentration similar to those assumed for Nogoa River water (refer Table 16). Figure 79 shows that simulated trace element concentrations are predicted to increase/decrease cyclically in Pit E over the simulation period.

5.5.4 Nogoa River Cumulative Flow Comparison

Due to the notable volumes of water simulated as spilling in from and out to the Nogoa River from Pit B and Pit CD for Model Run 4, there is a potential impact on net flow in the Nogoa River downstream of the voids. Figure 81 shows a comparison of cumulative Nogoa River flows without and with Preferred Option 2 with irrigation from Pit B and Pit CD over the 129 year simulation period. The difference between the total flows at the end of the simulation period is approximately 2,874 GL or an average of 22.6 GL/year. This represents an average decrease in the river flow volume of 3.3%.

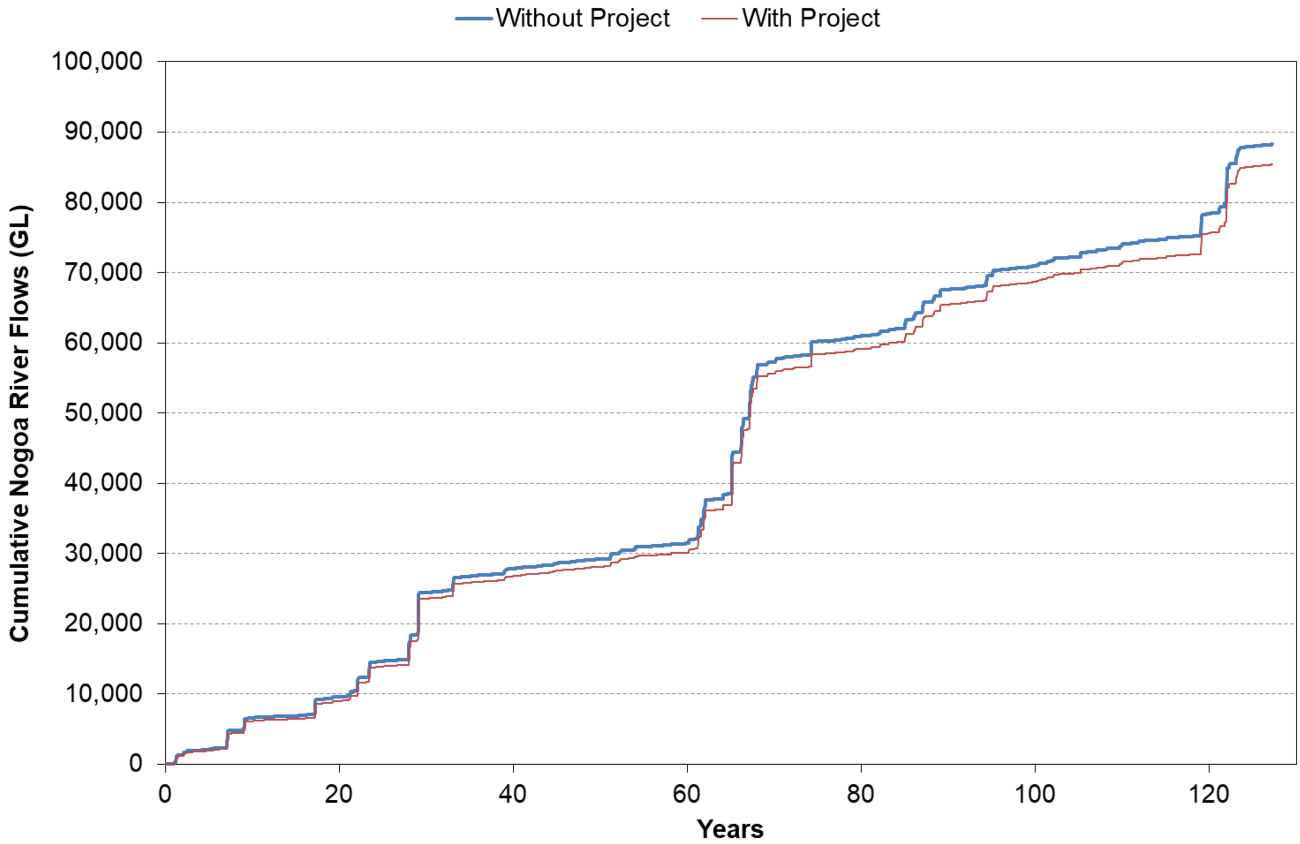

Figure 81 Nogoa River Flow Comparison: Model Run 4

5.5.5 *Nogoa River Dilution Calculations*

In order to gain an understanding of the change in water quality in the Nogoa River in Run 4, the ratio of the Nogoa River flow volume to the pit outflow volume to the Nogoa River has been calculated and is summarised as a probability plot in Figure 82.

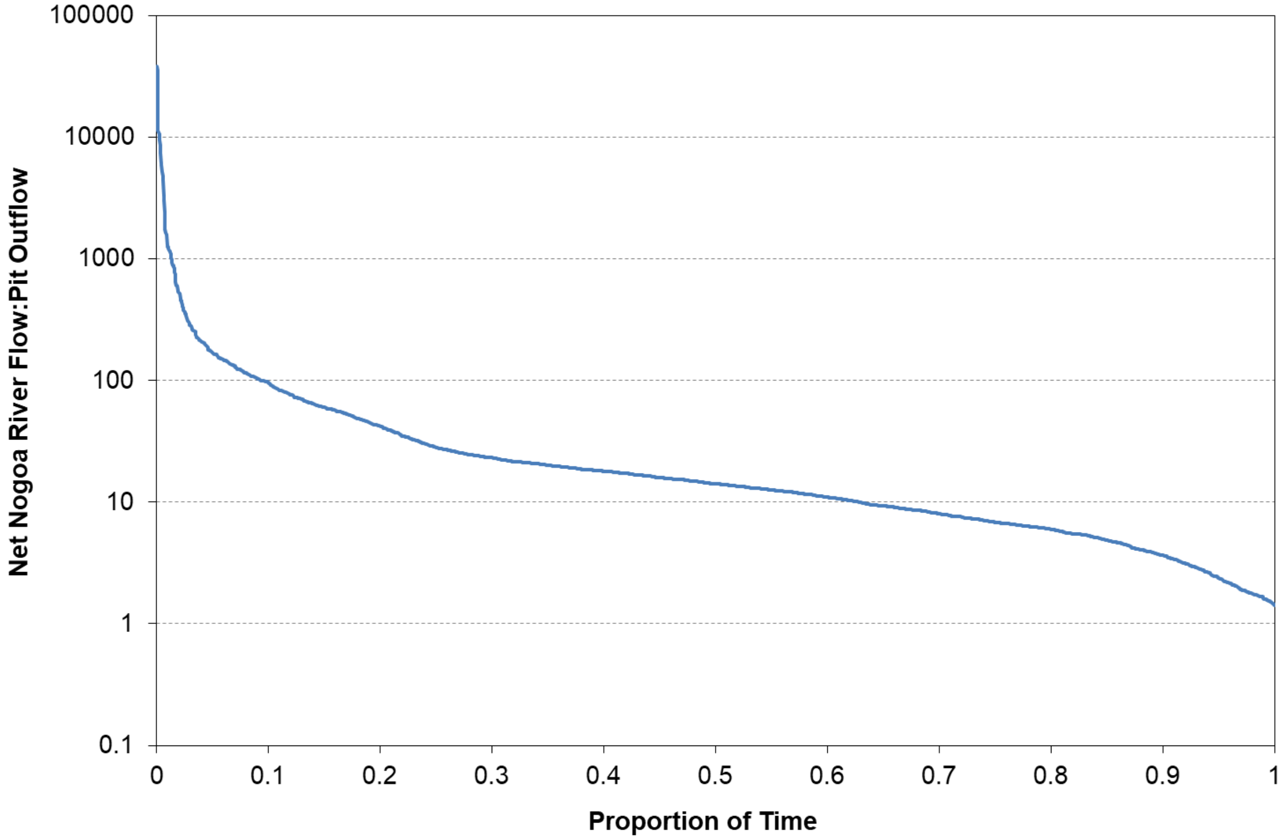

Figure 82 Pit B and Pit CD Dilution by Nogoa River: Model Run 4

Figure 82 shows that 100% of the time that outflow is occurring, the ratio of Nogoa River volume to pit outflow volume is greater than 1 (i.e. Nogoa River flow is greater than pit outflow, 100% of the time). Figure 82 also shows that 50% of the time, the Nogoa River flow volume is approximately 14 times that of the outflow from Pit B and Pit CD (when outflow is occurring).

A TDS probability plot is provided in Figure 83 which shows that for 95% of the time that outflow from the pits is occurring, the estimated Nogoa River TDS downstream of the voids would be equal to the adopted background TDS of 115 mg/L.

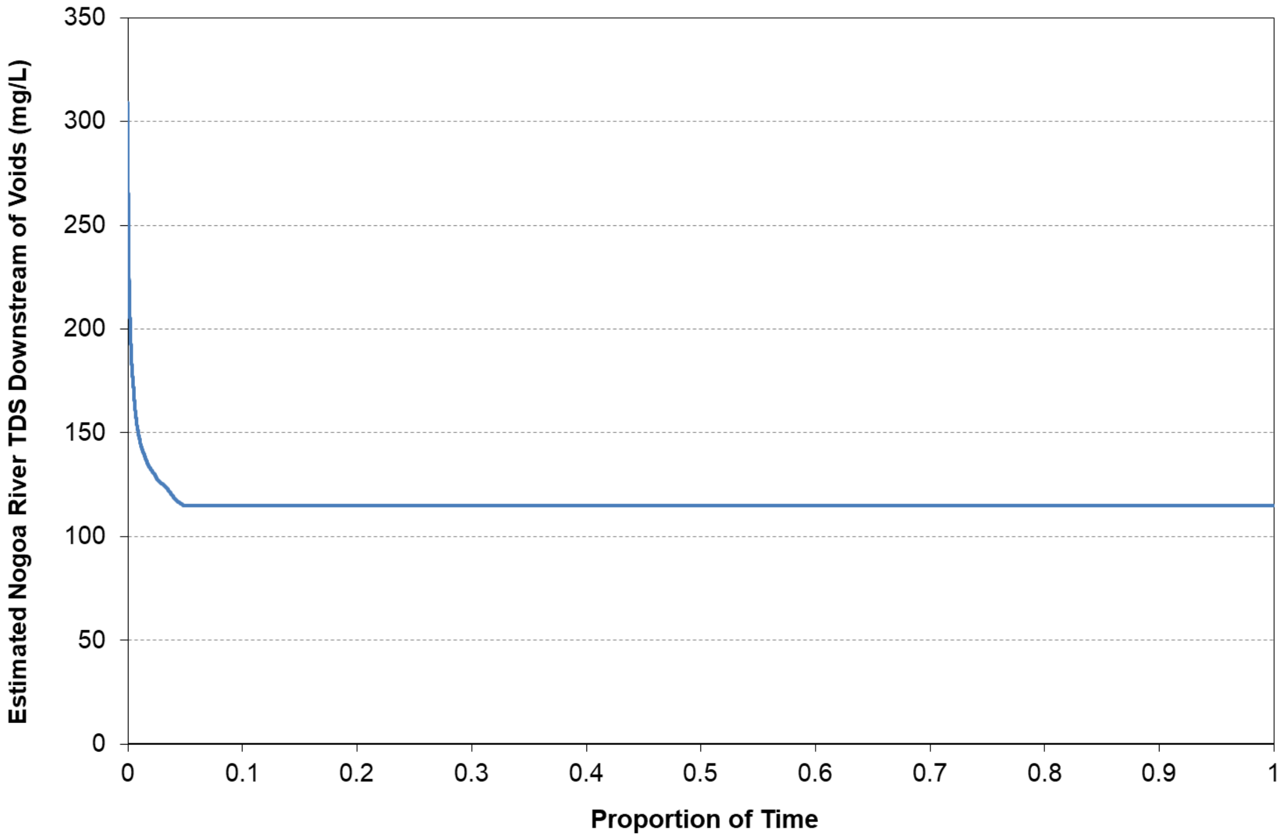

Figure 83 Estimated Nogoa River TDS Downstream of Voids during outflow from Pit B and Pit CD: Model Run 4

5.6 MODEL RUN 4A RESULTS (PREFERRED OPTION 2: IRRIGATION FROM PIT B AND PIT CD, CLIMATE CHANGE)

The objective of Model Run 4a is to predict the water levels, volumes and quality results for Preferred Option 2 with irrigation from Pit B and Pit CD (i.e. full development of both the southern and northern voids) with climate change factors applied. Results for each void for Model Run 4a are summarised in the sections to follow.

5.6.1 Water Levels

Figure 84 to Figure 87 show forecast water levels over the 129 year simulation period for each of the voids in Model Run 4a.

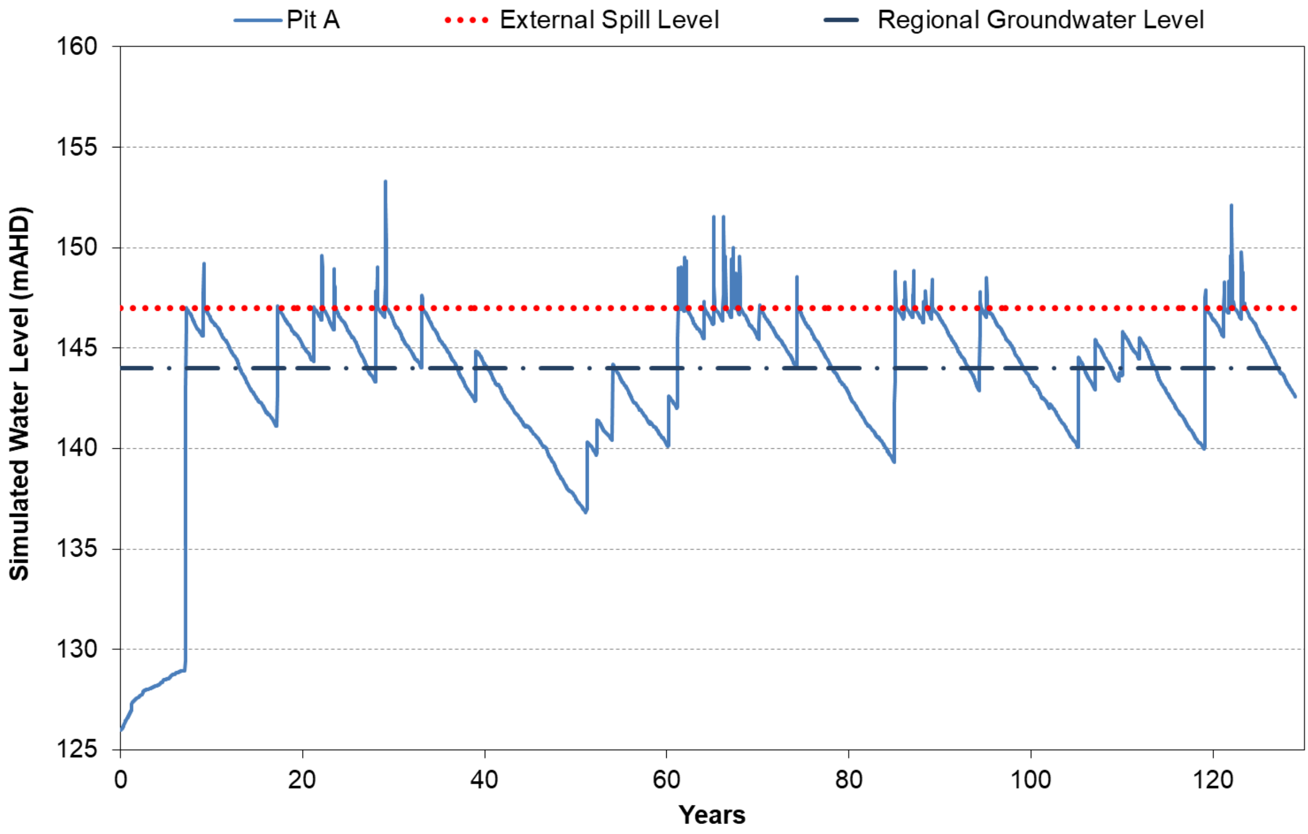

Figure 84 Water Level Results: Model Run 4a, Pit A

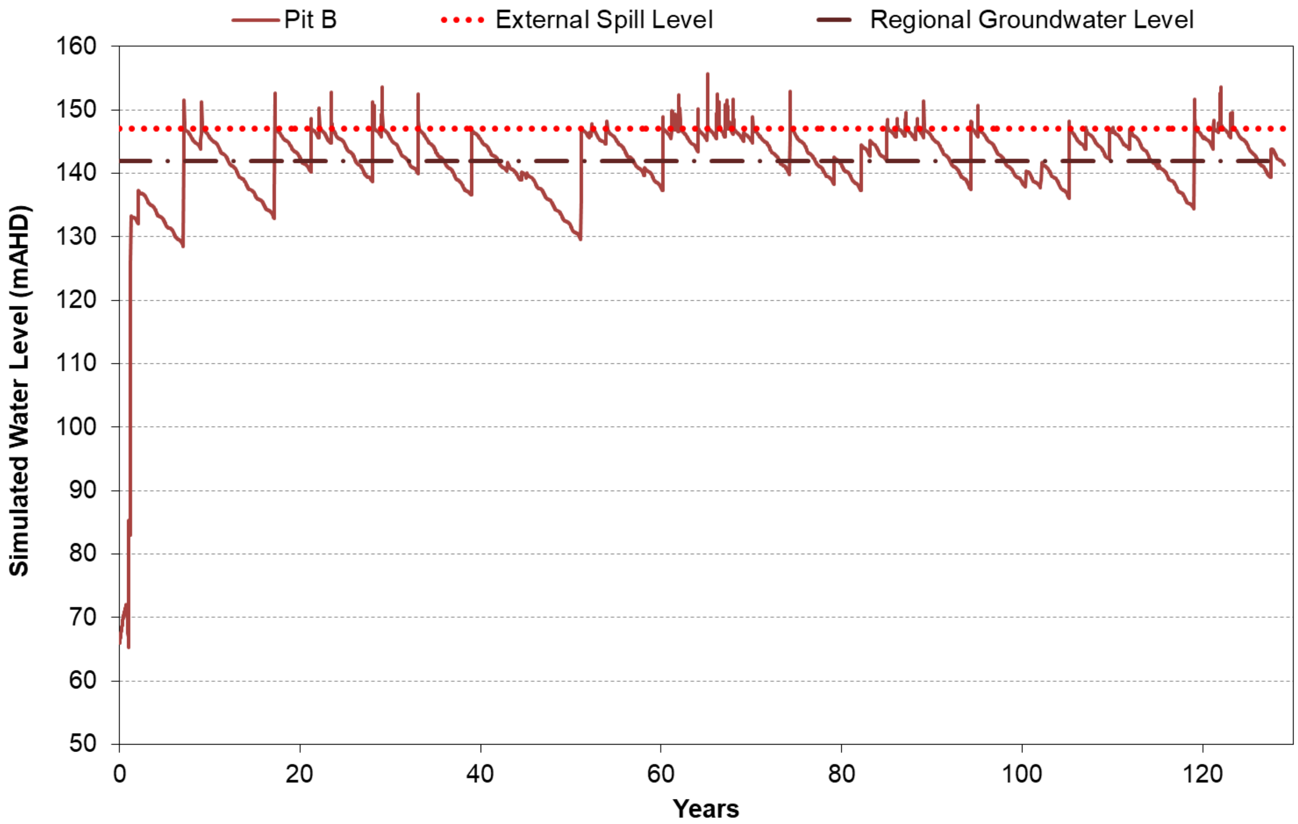

Figure 85 Water Level Results: Model Run 4a, Pit B

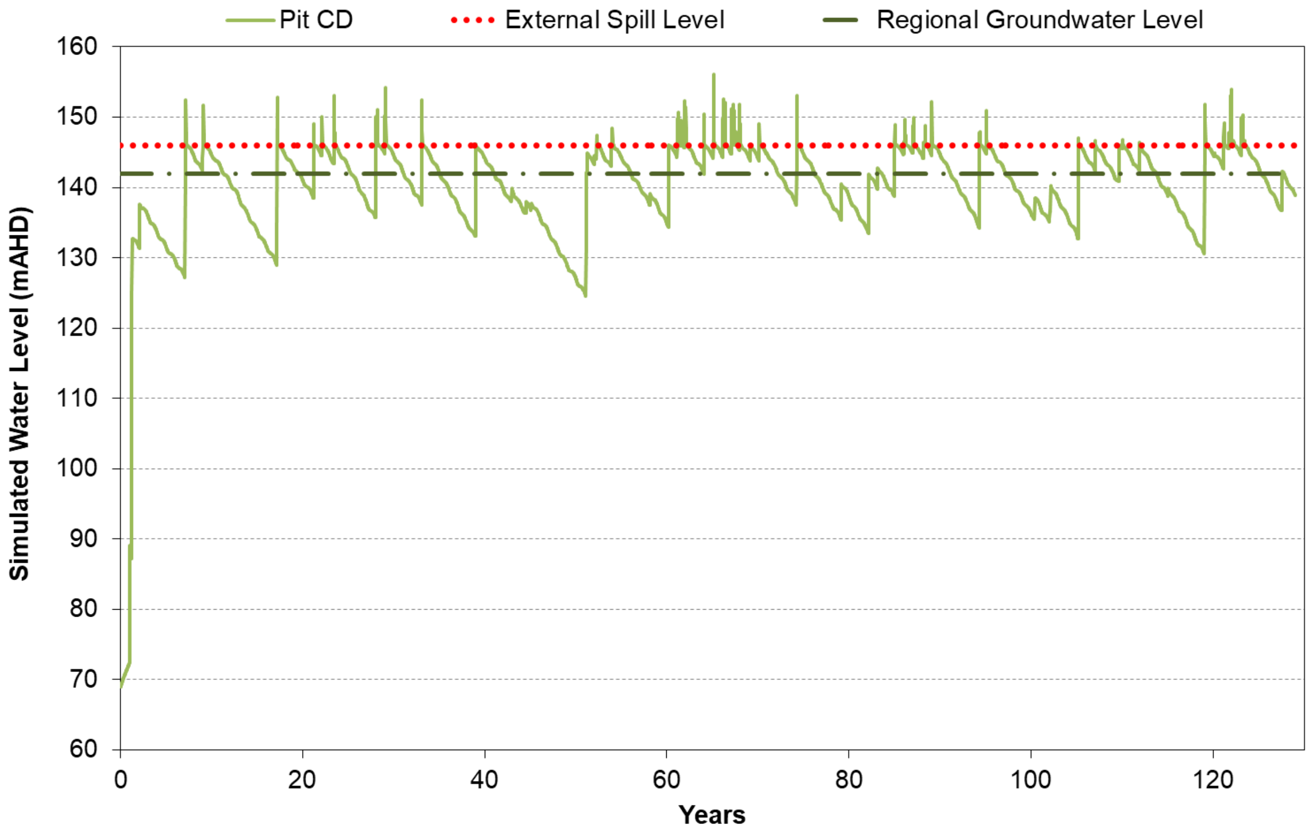

Figure 86 Water Level Results: Model Run 4a, Pit CD

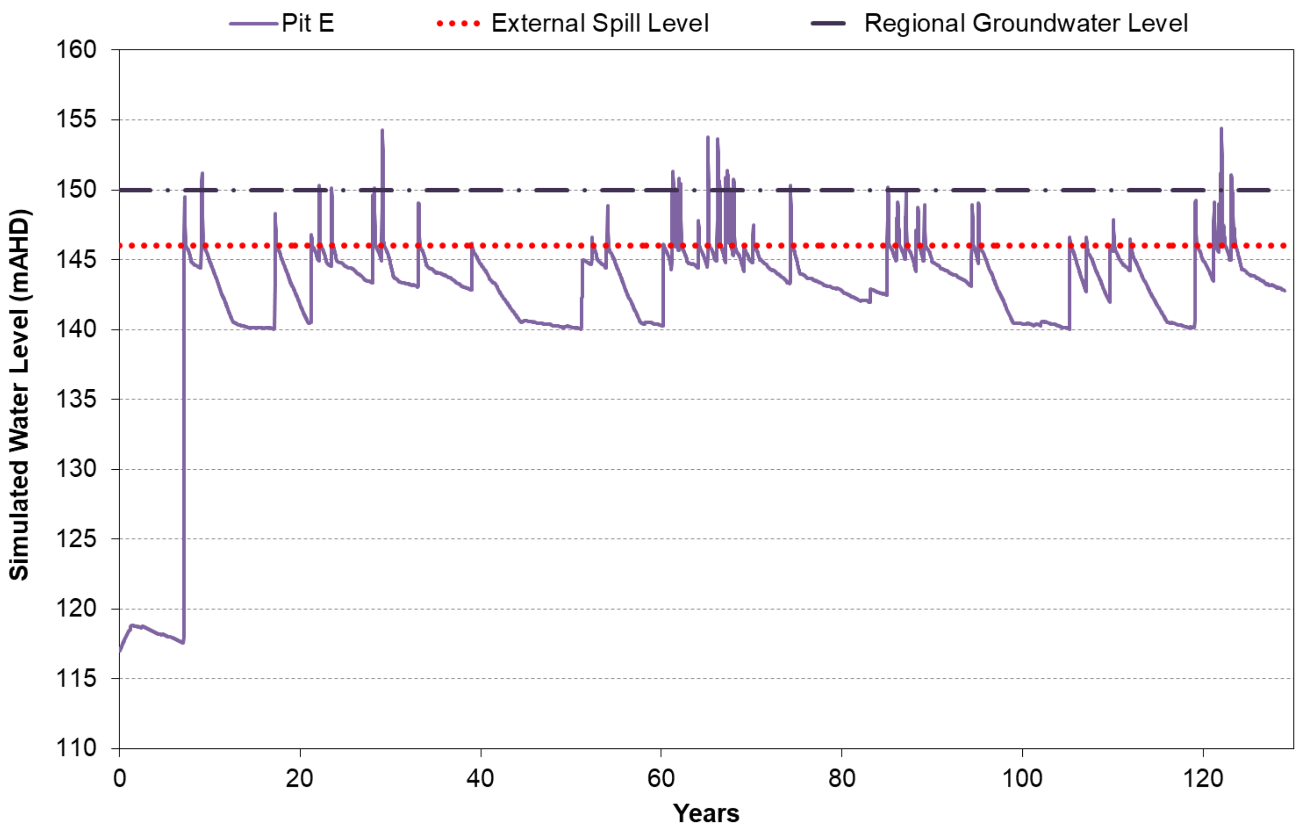

Figure 87 Water Level Results: Model Run 4a, Pit E

Figure 84 and Figure 85 show notable variations in the water levels in Pit A and Pit B due to the simulated Nogoa River inflows to Pit B, irrigation demand pumped from Pit B and the hydraulic link (i.e. spill/seepage) between Pit B and Pit A. The water levels in both Pit A and Pit B rise above the external spill level to the Nogoa River during river flood events. Water levels in Pit A and Pit B both rise above the respective regional groundwater levels and regional groundwater outflow from both pits is simulated during these periods.

Figure 86 and Figure 87 show notable variations in the water levels in Pit CD and Pit E due to the simulated Nogoa River inflows to Pit CD, irrigation demand pumped from Pit CD and the hydraulic link between Pit CD and Pit E. The water levels in both Pit CD and Pit E rise above the external spill level to the Nogoa River during river flood events. Water levels in Pit CD and Pit E both rise above the respective regional groundwater levels and regional groundwater outflow from both pits is simulated during these periods.

5.6.2 Water Volumes

Figure 88 shows the simulated water volume results over the 129 year simulation period for each of the voids in Model Run 4a.

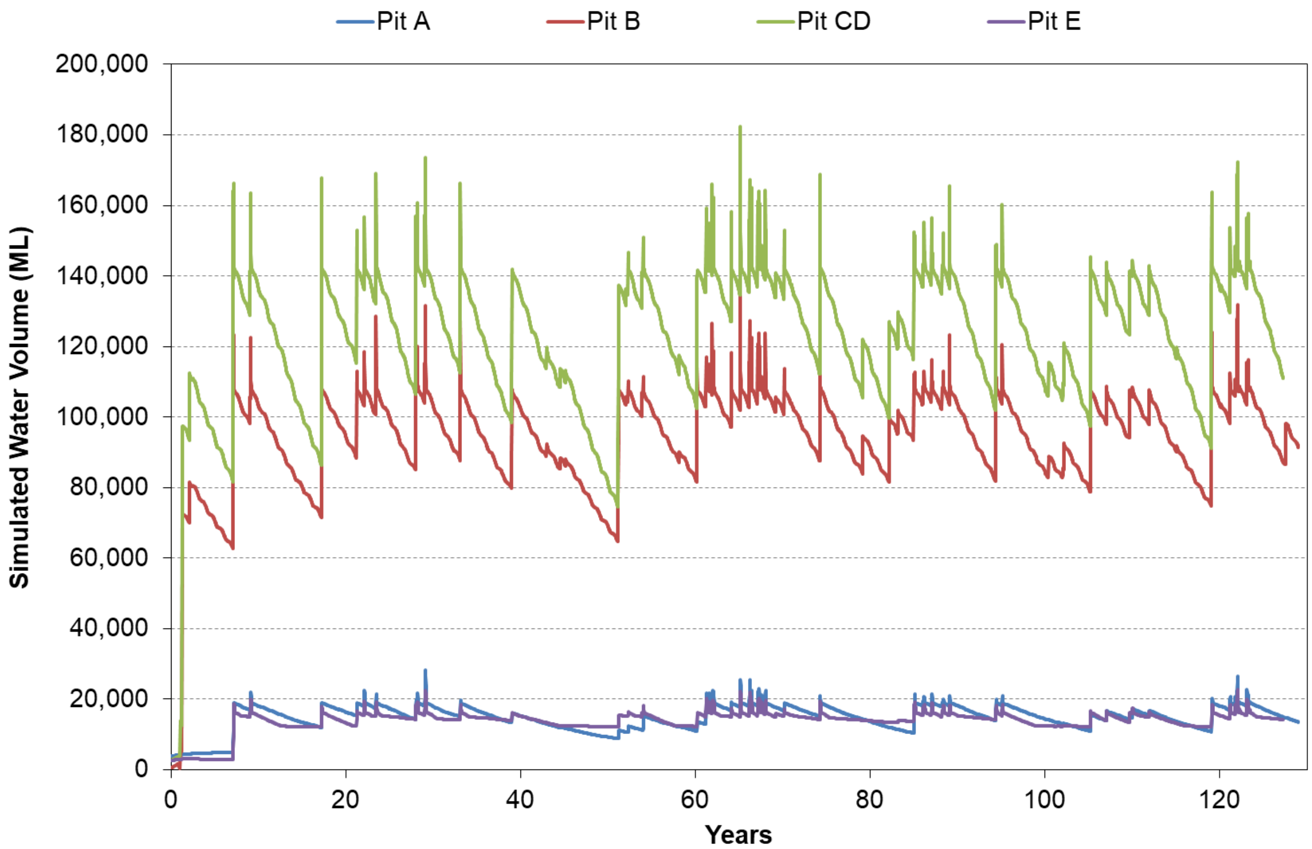

Figure 88 Water Volume Results: Model Run 4a

Figure 88 shows that simulated water volumes in Pit B and Pit CD are notably higher than Pit A and Pit E with Pit CD holding more water that Pit B on average. The water volumes stored in Pit B and Pit CD fluctuate more than the water volumes stored in Pit A and Pit E.

5.6.3 Water Quality

Figure 89 to Figure 100 show water quality results (major ions, trace elements and salinity) over the 129 year simulation period for each of the voids in Model Run 4a. Note that the simulated water quality concentration for solutes in Pit B and Pit CD provides an indication of the quality of water supplied to irrigation.

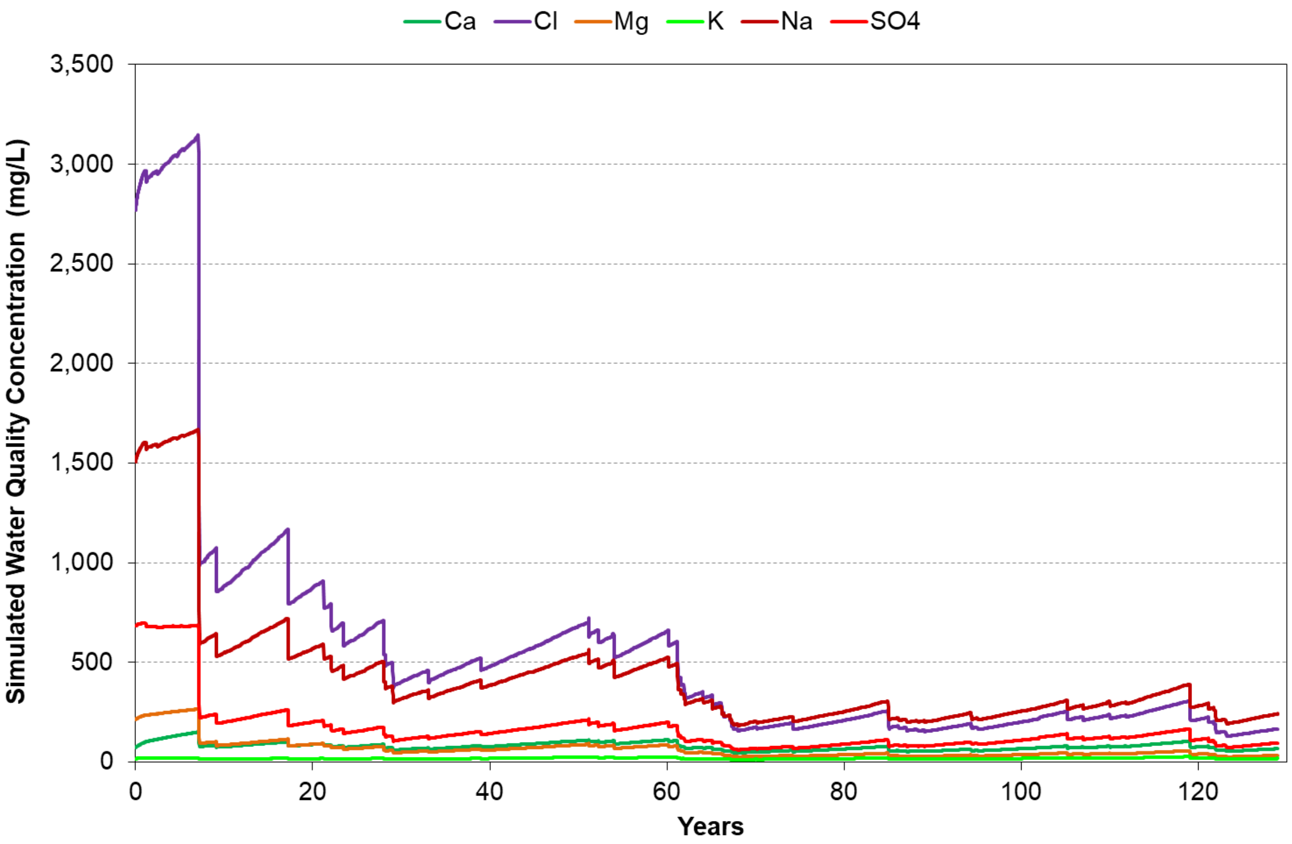

Figure 89 Water Quality Results: Model Run 4a, Pit A – Major Ions

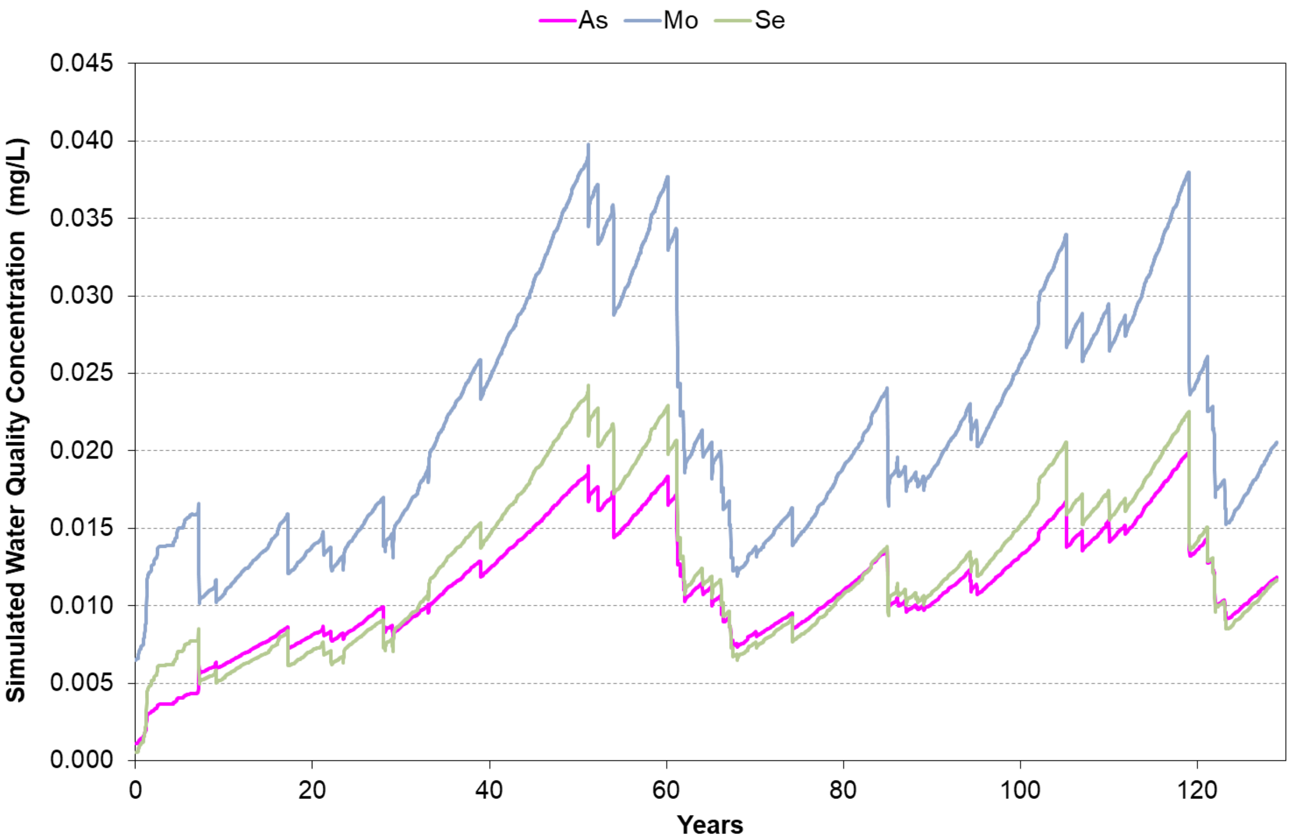

Figure 90 Water Quality Results: Model Run 4a, Pit A – Trace Elements

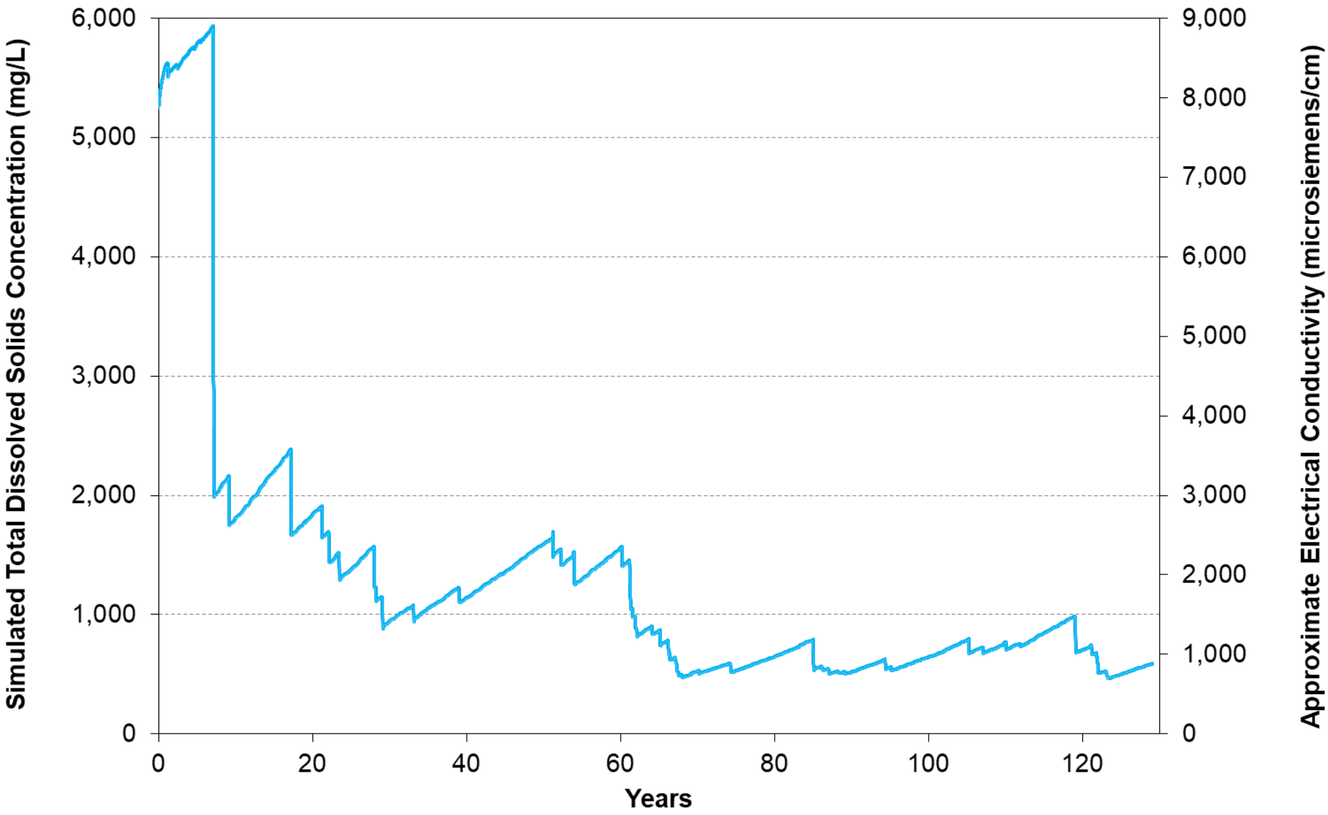

Figure 91 Water Quality Results: Model Run 4a, Pit A – Salinity

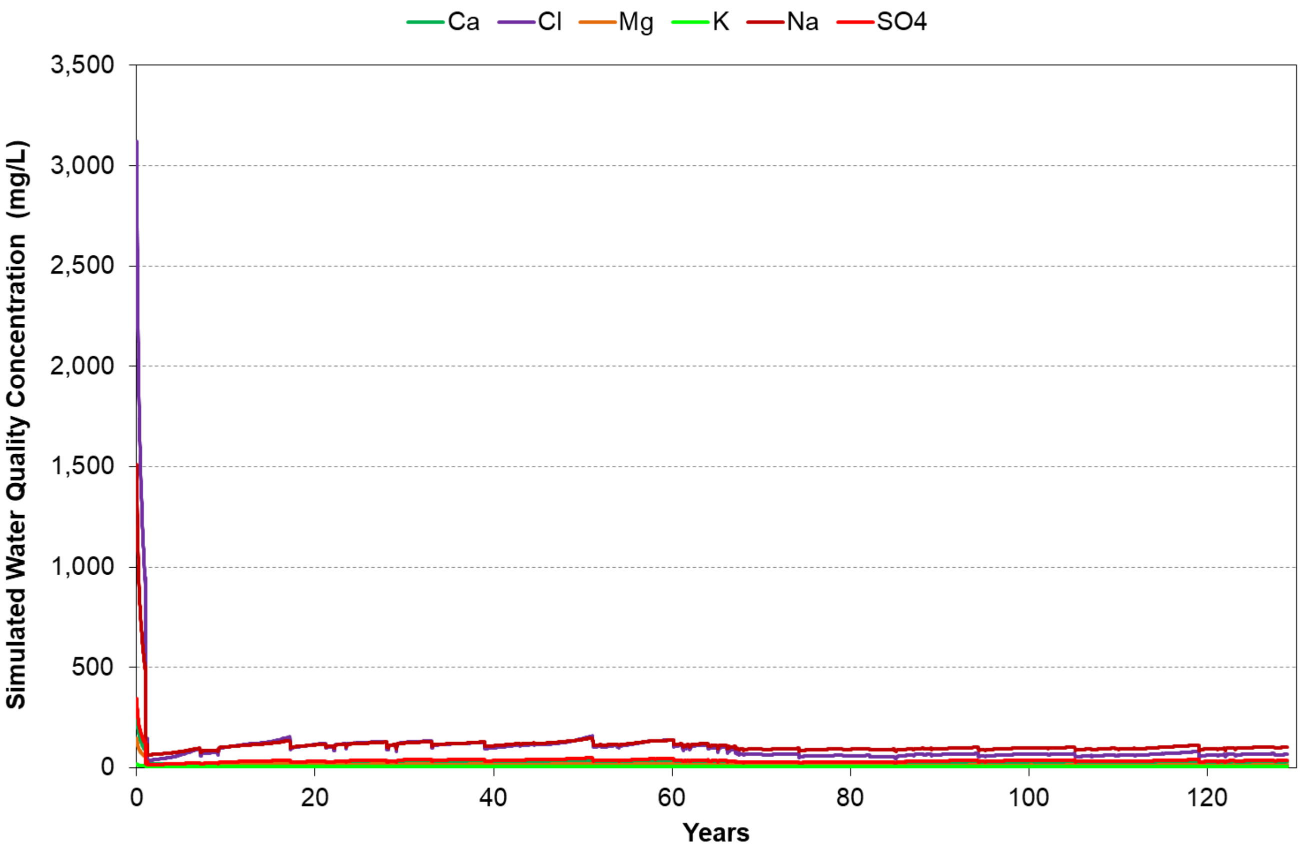

Figure 92 Water Quality Results: Model Run 4a, Pit B – Major Ions

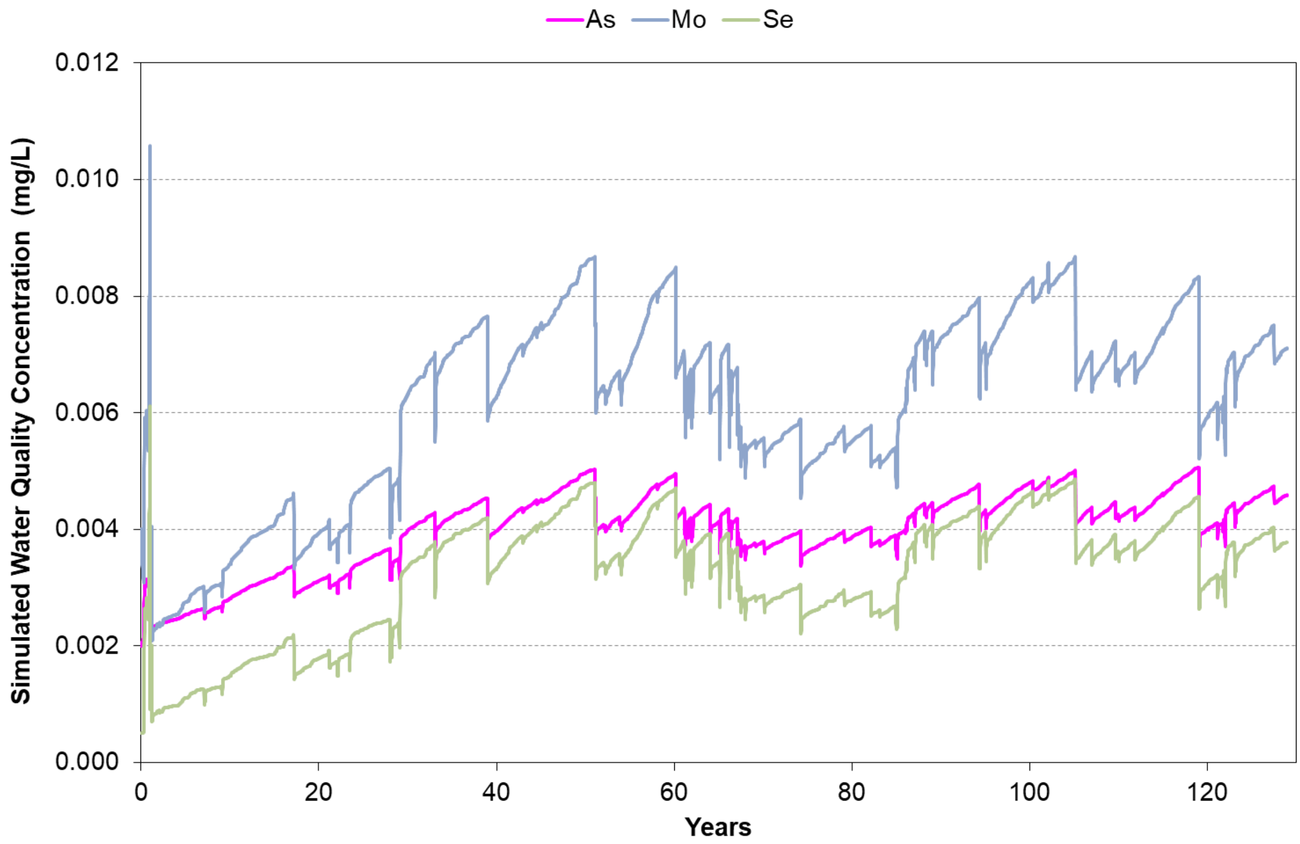

Figure 93 Water Quality Results: Model Run 4a, Pit B – Trace Elements

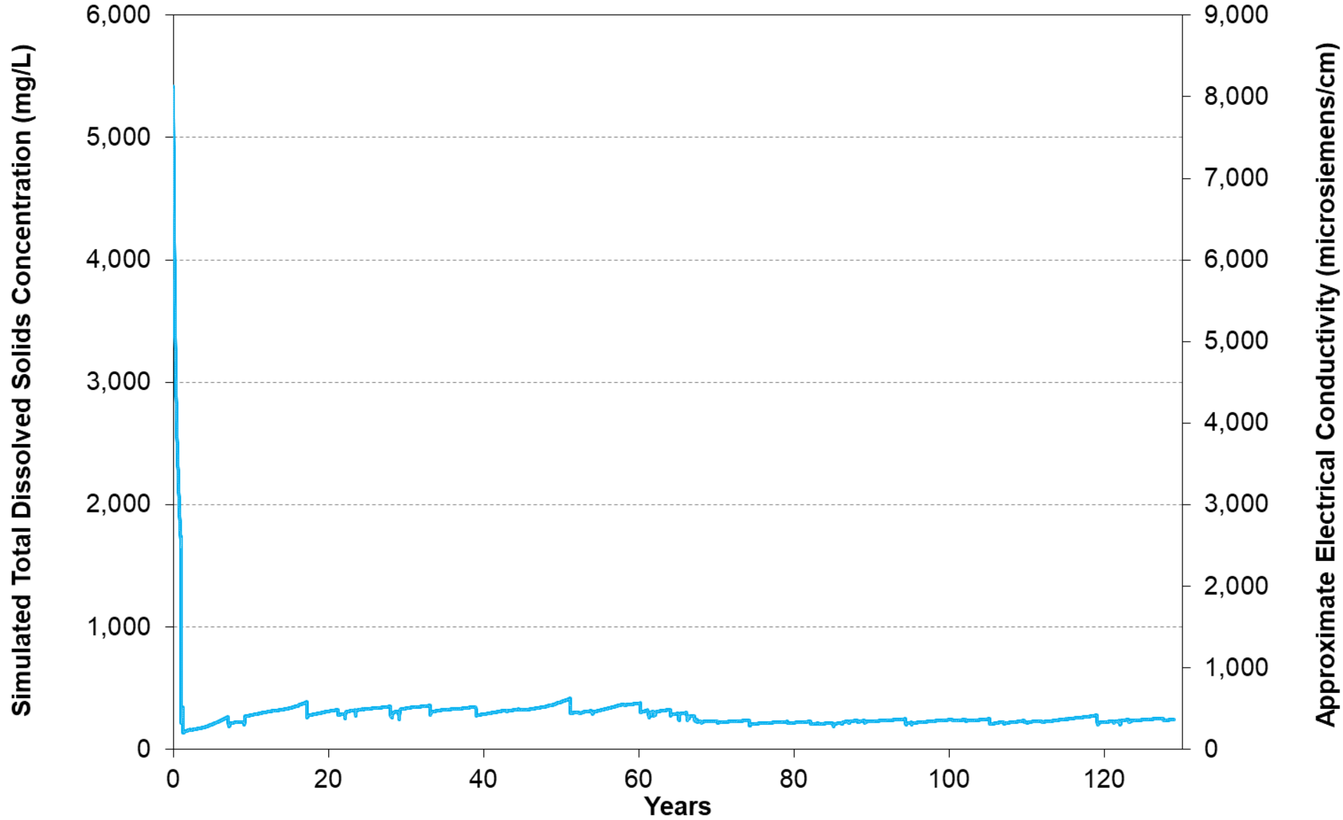

Figure 94 Water Quality Results: Model Run 4a, Pit B – Salinity

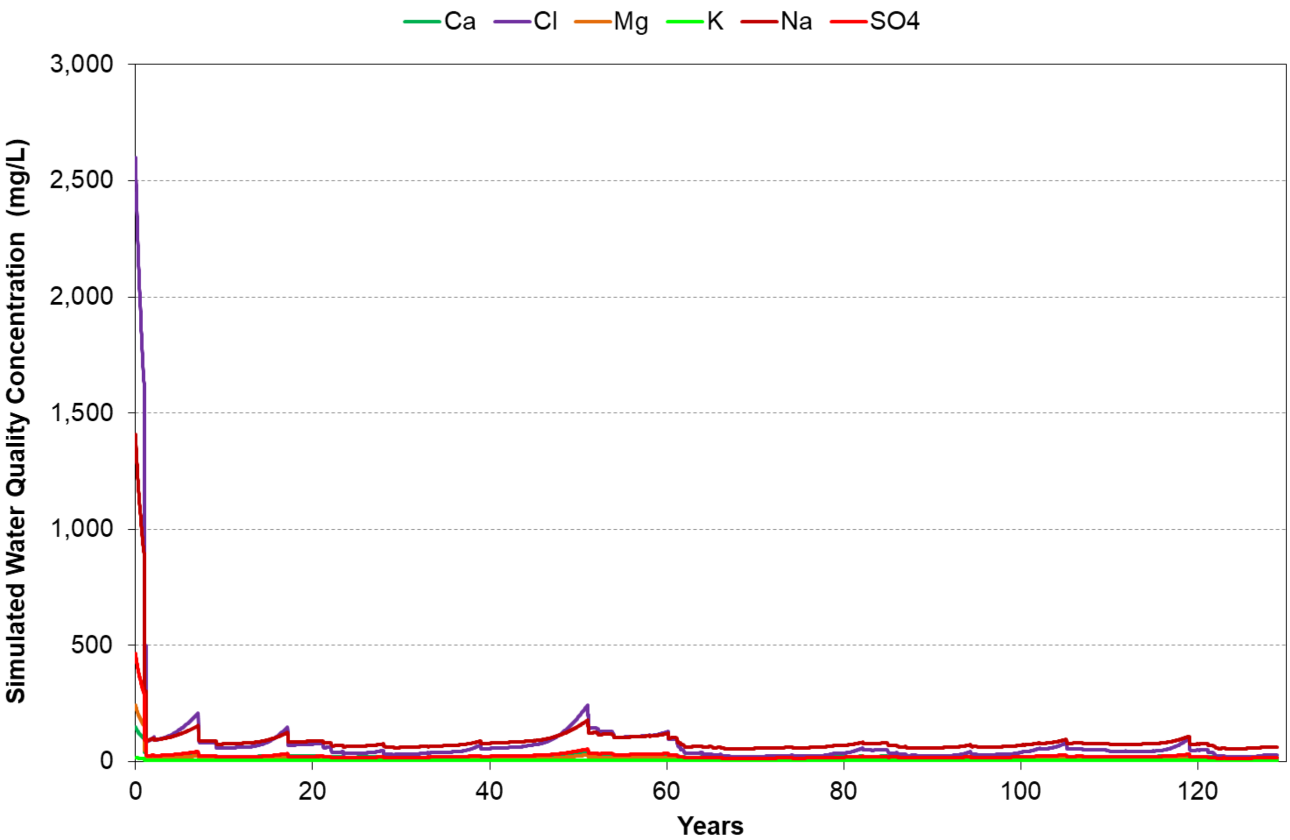

Figure 95 Water Quality Results: Model Run 4a, Pit CD – Major Ions

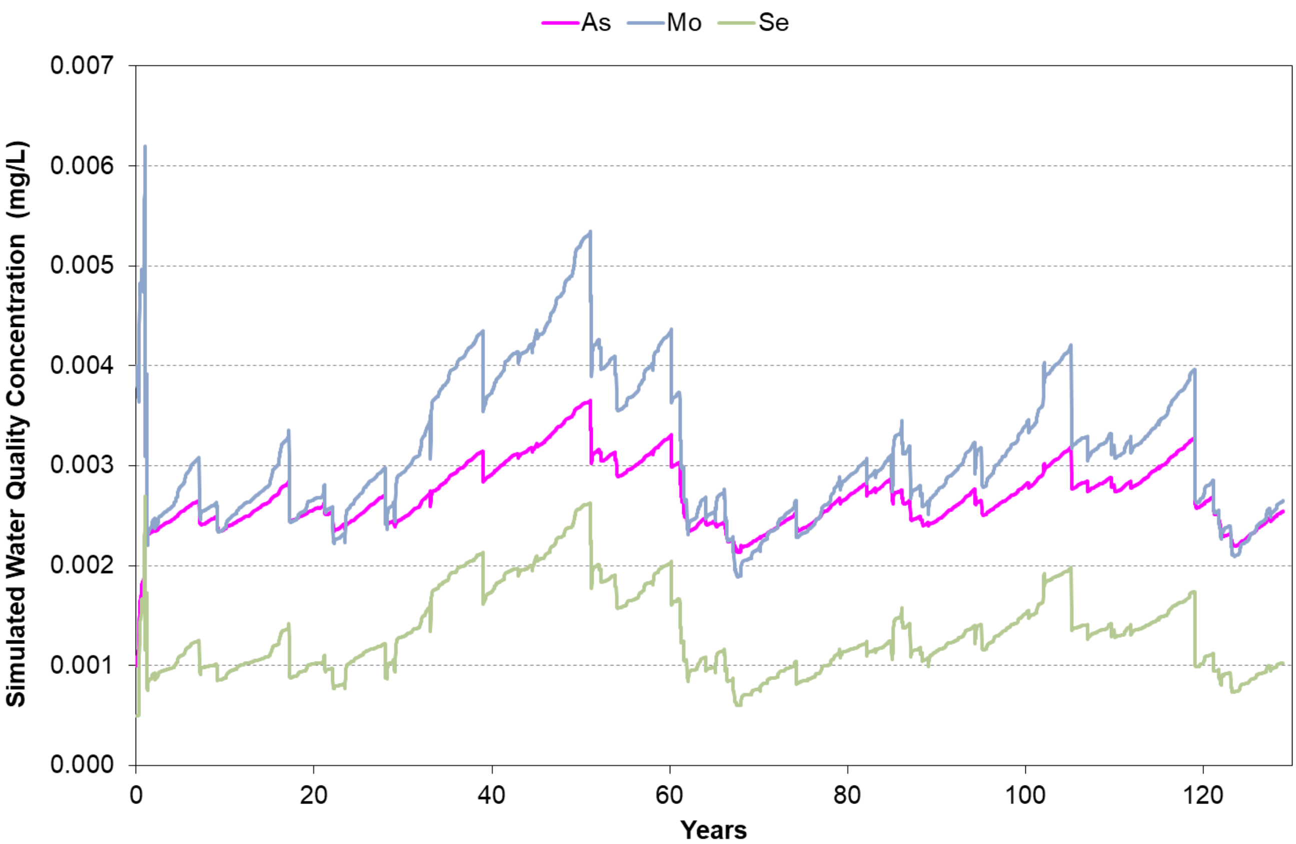

Figure 96 Water Quality Results: Model Run 4a, Pit CD – Trace Elements

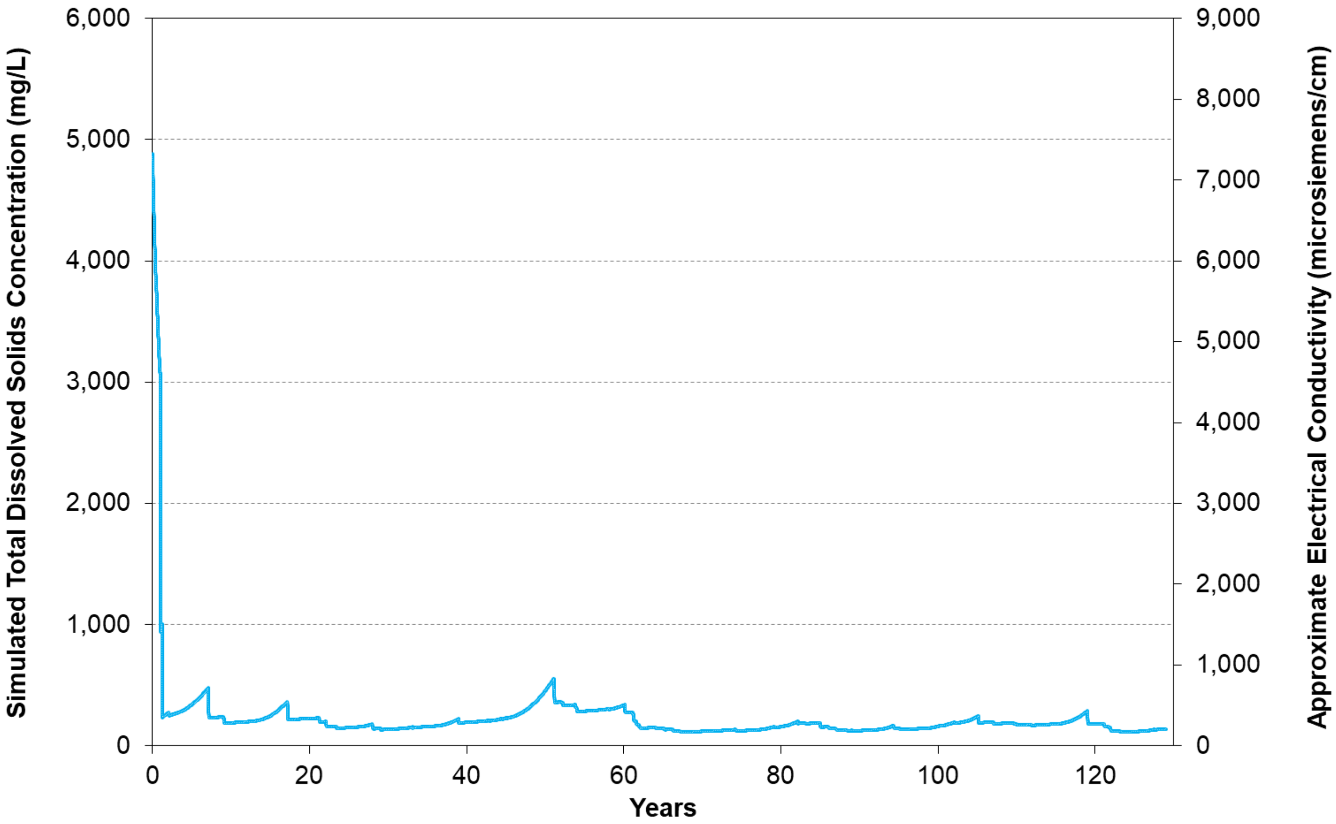

Figure 97 Water Quality Results: Model Run 4a, Pit CD – Salinity

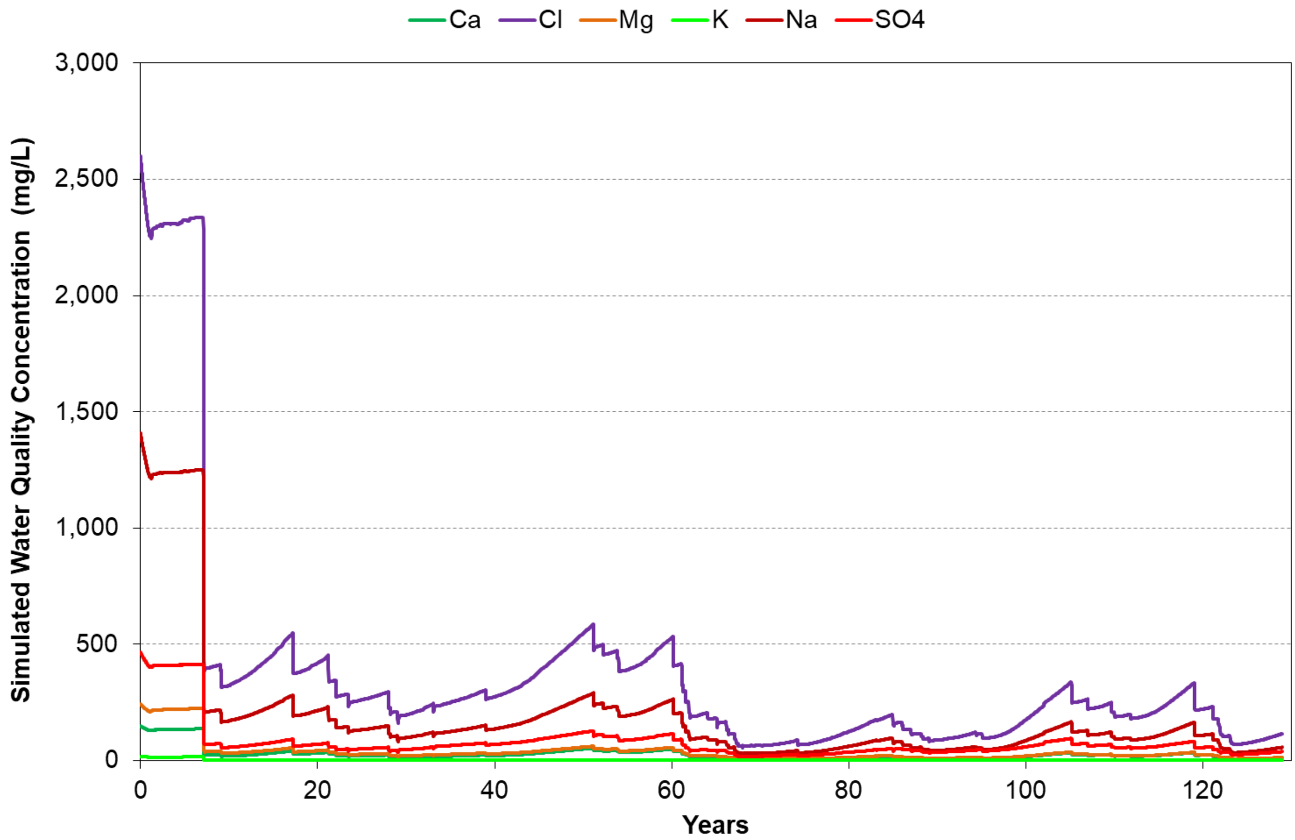

Figure 98 Water Quality Results: Model Run 4a, Pit E – Major Ions

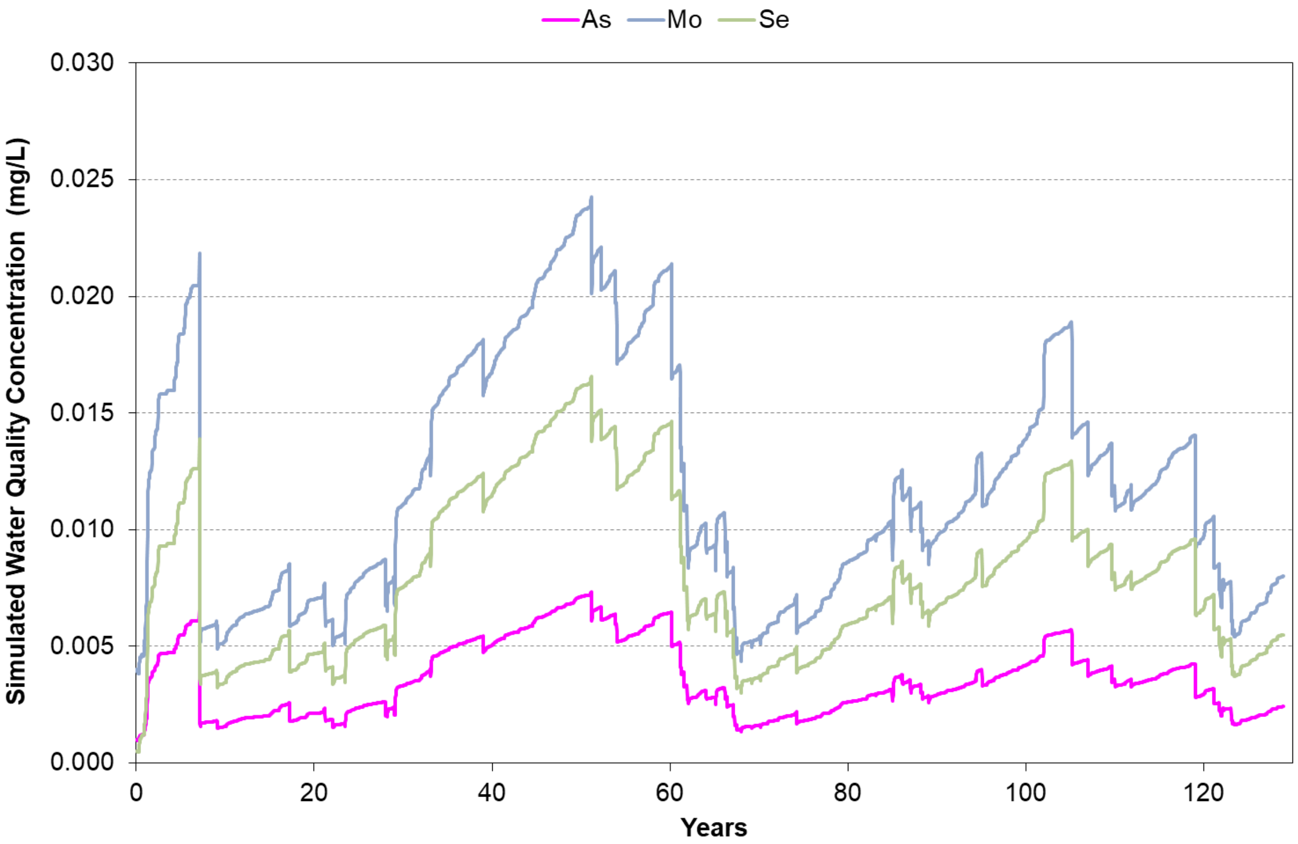

Figure 99 Water Quality Results: Model Run 4a, Pit E – Trace Elements

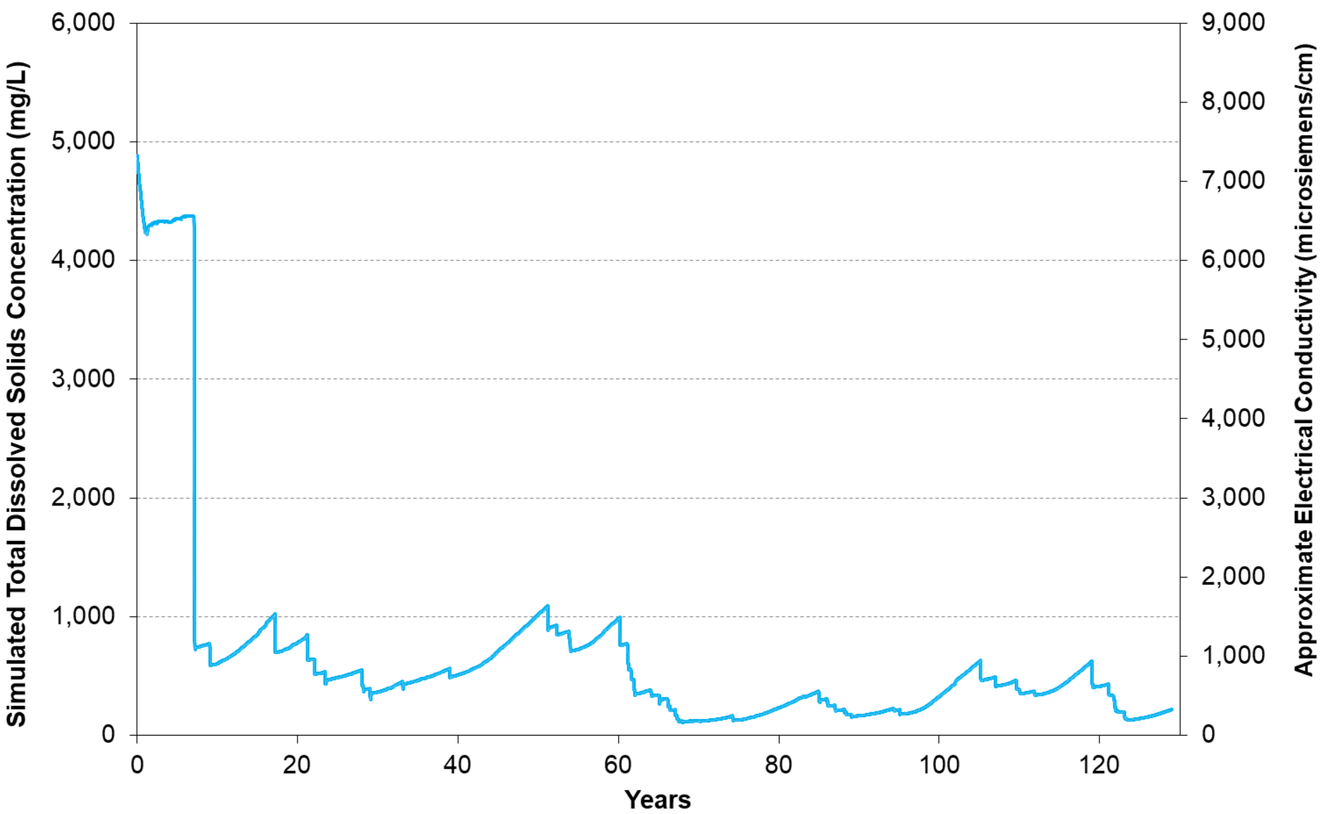

Figure 100 Water Quality Results: Model Run 4a, Pit E – Salinity

Figure 89 and Figure 91 show that due to the effects of Nogoa River inflows/outflows (via Pit B), simulated concentrations of major ions and salinity in Pit A are predicted to decrease as a result of dilution due to the first inflow event. Figure 90 shows that simulated trace element concentrations are predicted to increase/decrease cyclically in Pit A over the simulation period. Generally, the water quality concentration results for Model Run 4a are lower than for Model Run 4 due to the lower irrigation demand for the climate change scenario (refer Section 4.15).

Figure 92, Figure 93 and Figure 94 show that simulated concentrations of solutes are all predicted to increase/decrease cyclically in Pit B due to interaction with the Nogoa River.

Figure 95, Figure 96 and Figure 97 show that simulated concentrations of solutes are all predicted to increase/decrease cyclically in Pit CD due to interaction with the Nogoa River.

Figure 98 and Figure 100 show that due to the effects of Nogoa River inflows/outflows (via Pit CD), simulated concentrations of major ions and salinity in Pit E are predicted to decrease as a result of dilution due to the first inflow event and reach a concentration similar to those assumed for Nogoa River water (refer Table 16). Figure 99 shows that simulated trace element concentrations are predicted to increase/decrease cyclically in Pit E over the simulation period.

5.6.4 Nogoa River Cumulative Flow Comparison

Due to the notable volumes of water simulated as spilling in from and out to the Nogoa River from Pit B for Model Run 4a, there is a potential impact on net flow in the Nogoa River downstream of the voids. Figure 101 shows a comparison of cumulative Nogoa River flows without and with Preferred Option 2 with irrigation from Pit B and CD including climate change over the 129 year simulation period. The difference between the total flows at the end of the simulation period is approximately 1,921 GL or an average of 15.1 GL/year. This represents an average decrease in the river flow volume of 2.2%.

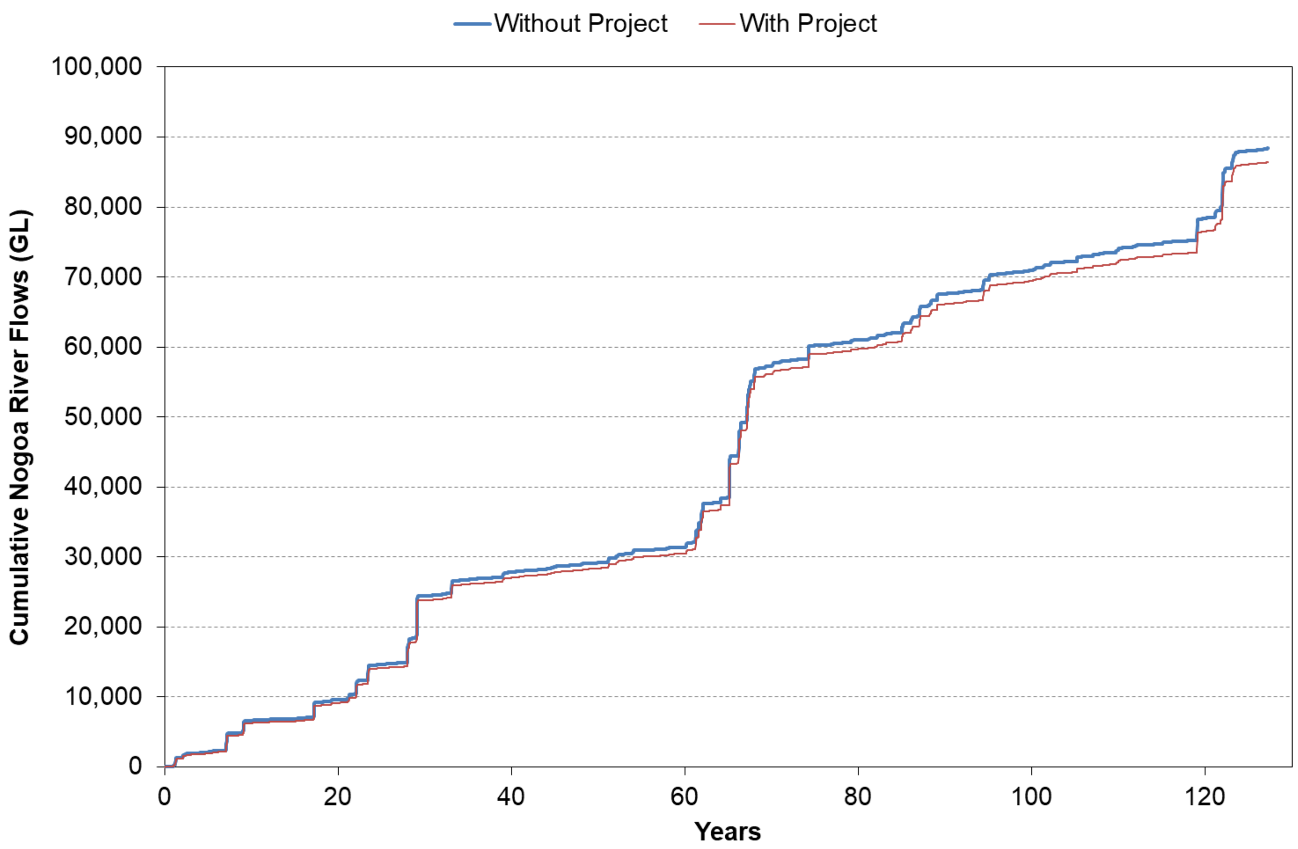

Figure 101 Nogoa River Flow Comparison: Model Run 4a

5.7 MODEL RUN 5 RESULTS (PREFERRED OPTION 2: INITIAL FILLING)

The aim of Model Run 5 is to simulate the impact of salt flushing assumptions (refer Section 4.11) on simulated salinity in each of the floodplain voids. Figure 102 to Figure 105 show salinity results over the 27 year simulation period for each of the floodplain voids in Model Run 5.

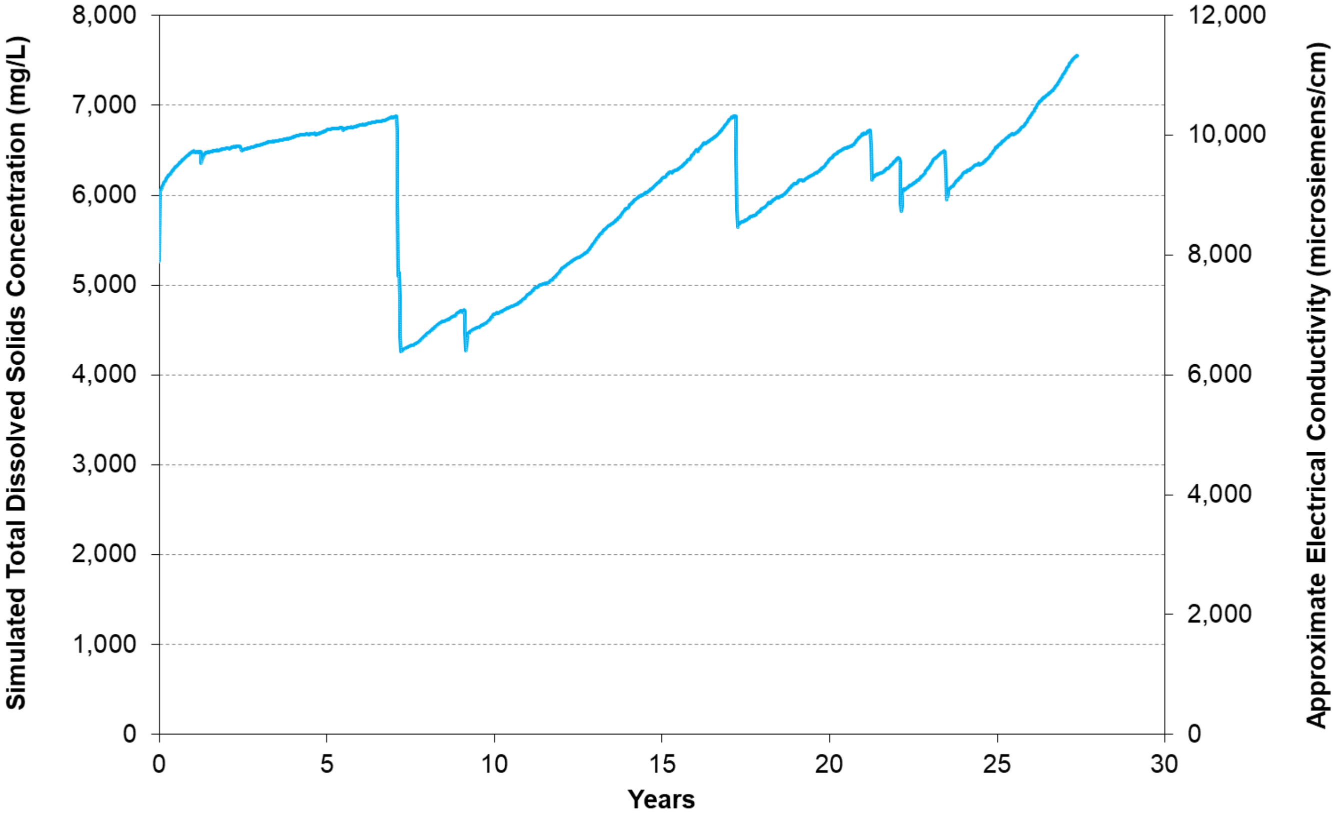

Figure 102 Water Quality Results: Model Run 5, Pit A – Salinity

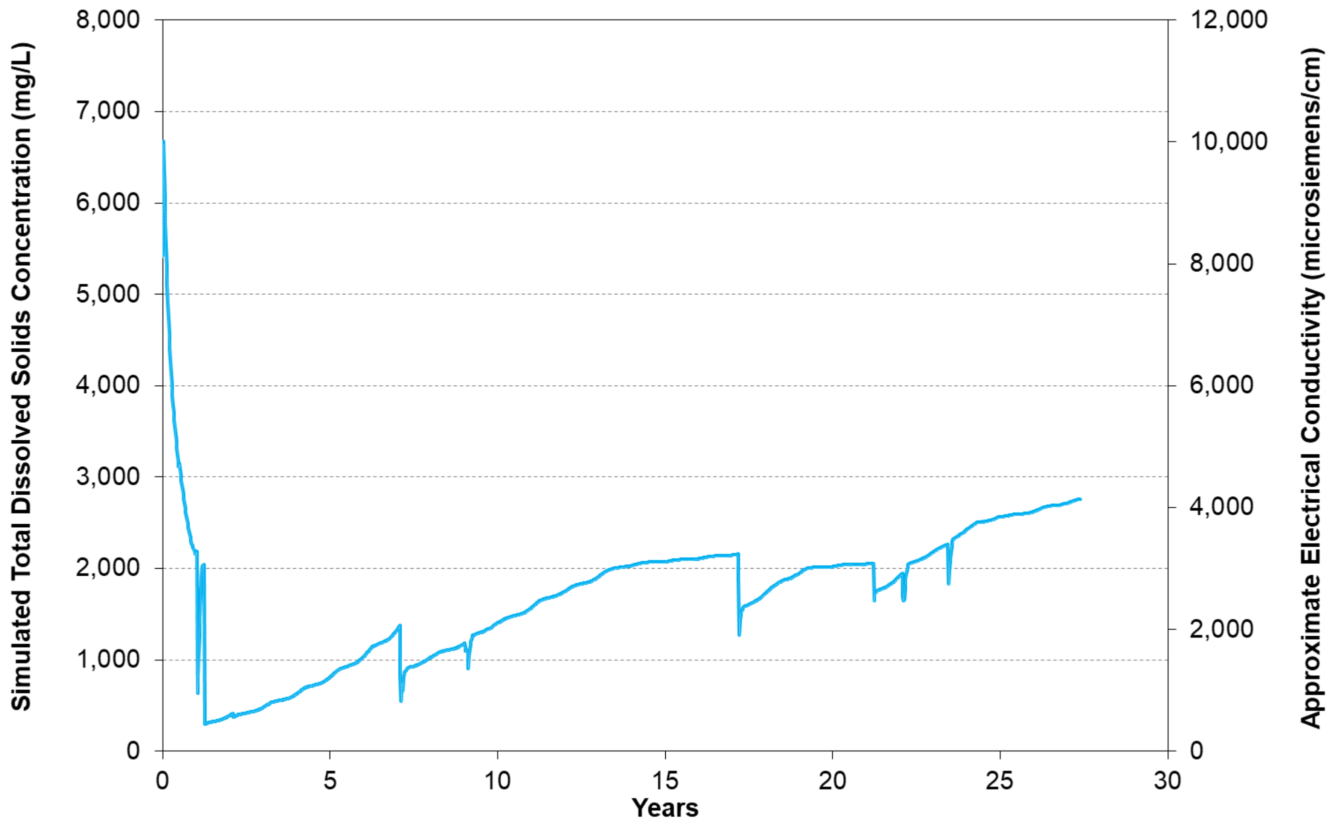

Figure 103 Water Quality Results: Model Run 5, Pit B – Salinity

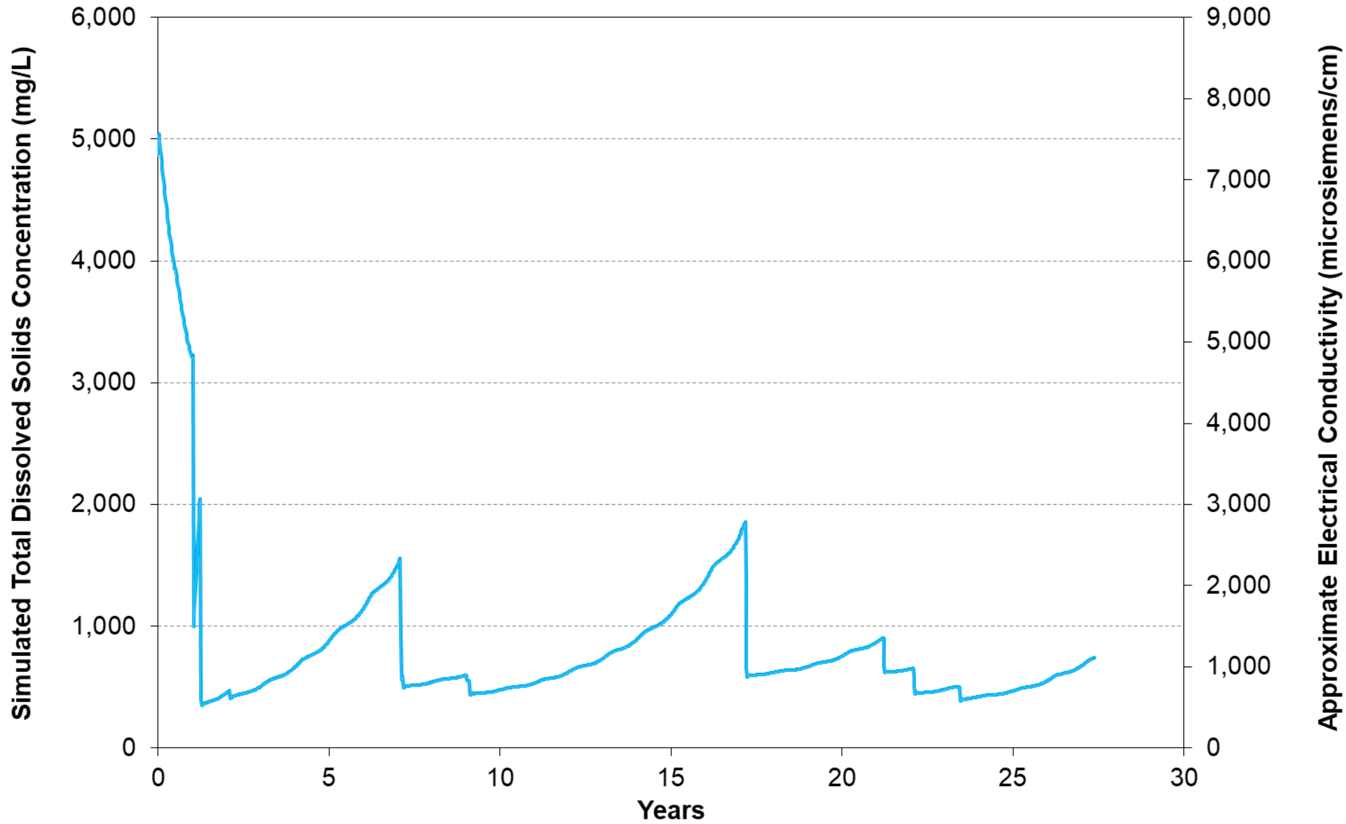

Figure 104 Water Quality Results: Model Run 5, Pit CD – Salinity

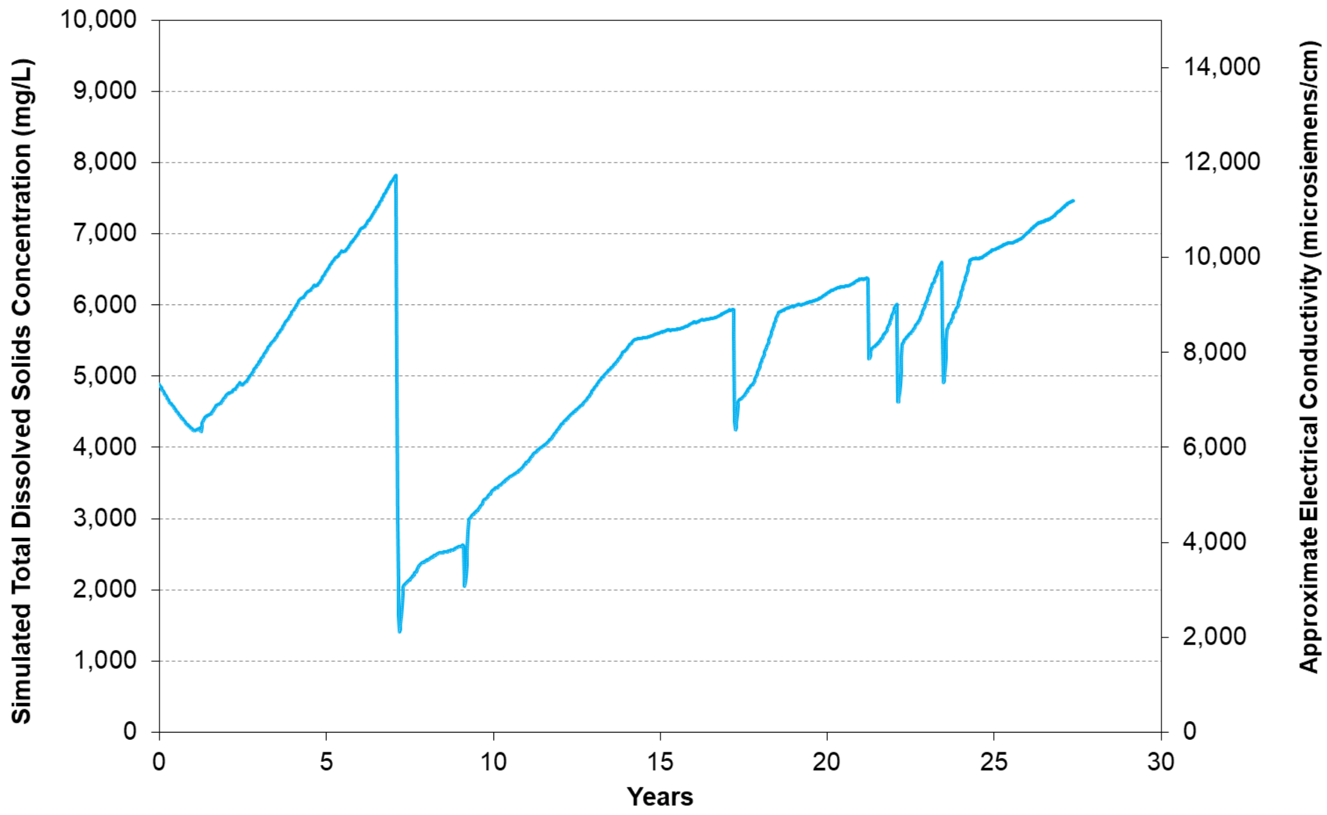

Figure 105 Water Quality Results: Model Run 5, Pit E – Salinity

Figure 104 shows that following the initial fill with water from the Nogoa River, salinity in Pit CD does not exceed the irrigation salinity upper limit of 2,000 mg/L. Figure 103 shows that salinity in Pit B remains close to the irrigation salinity trigger. Initial salt flushing from the highwall and backfilled spoil emplacement does impact the quality of water stored in Pit B and Pit CD which may limit the irrigation supply from Pit B and Pit CD in the short term. For example, in the 27 year simulation for Model Run 5, the average annual volume supplied to irrigation from Pit B was 4.5 GL/year compared to 7.9 GL/year simulated in Model Run 4. Similarly, the average annual volume supplied to irrigation from Pit CD was 11.5 GL/year compared to 11.9 GL/year simulated in Model Run 4. However, following the initial few fill cycles, due to the dilution effects of the Nogoa River inflows (refer Section 5.5) this impact is expected to be negligible to the long term viability of water supply from Pit B and Pit CD to meet the irrigation demand.

5.8 MODEL RUN 6 RESULTS (PREFERRED OPTION 2: POST USE)

The objective of Model Run 6 is to predict the water levels, volumes and quality results for the base case of Preferred Option 2. Results for each void for Model Run 6 are summarised in the sections to follow.

5.8.1 Water Levels

Figure 106 to Figure 109 show forecast water levels over the 258 year simulation period for each of the voids in Model Run 6.

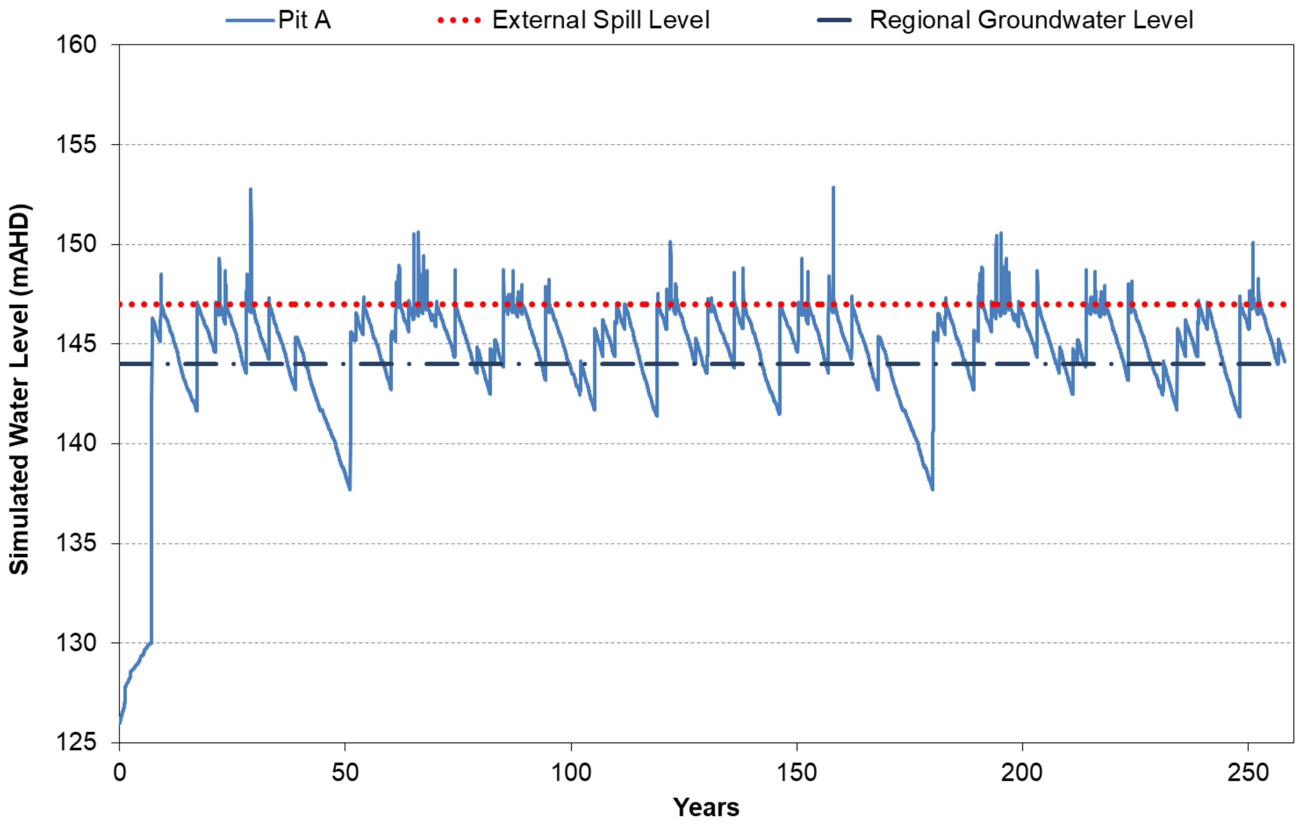

Figure 106 Water Level Results: Model Run 6, Pit A

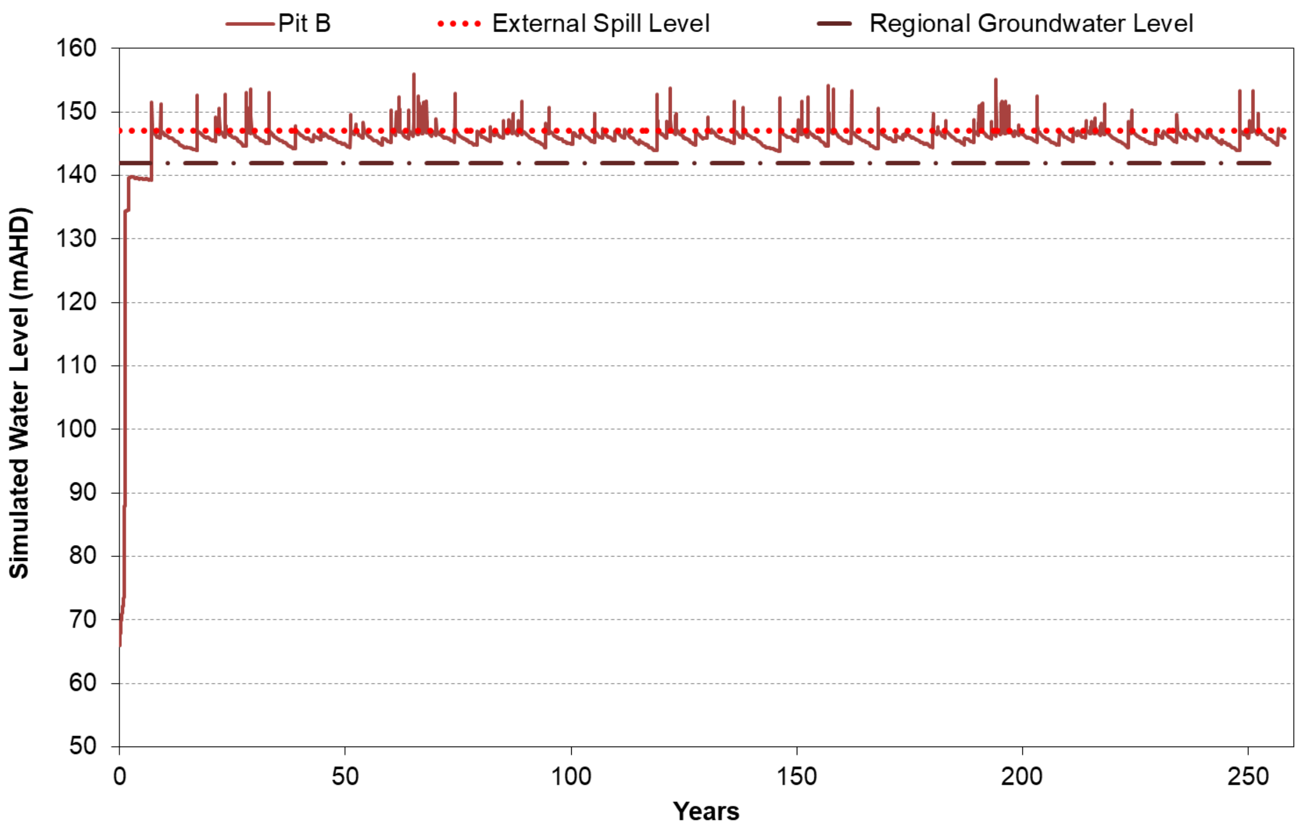

Figure 107 Water Level Results: Model Run 6, Pit B

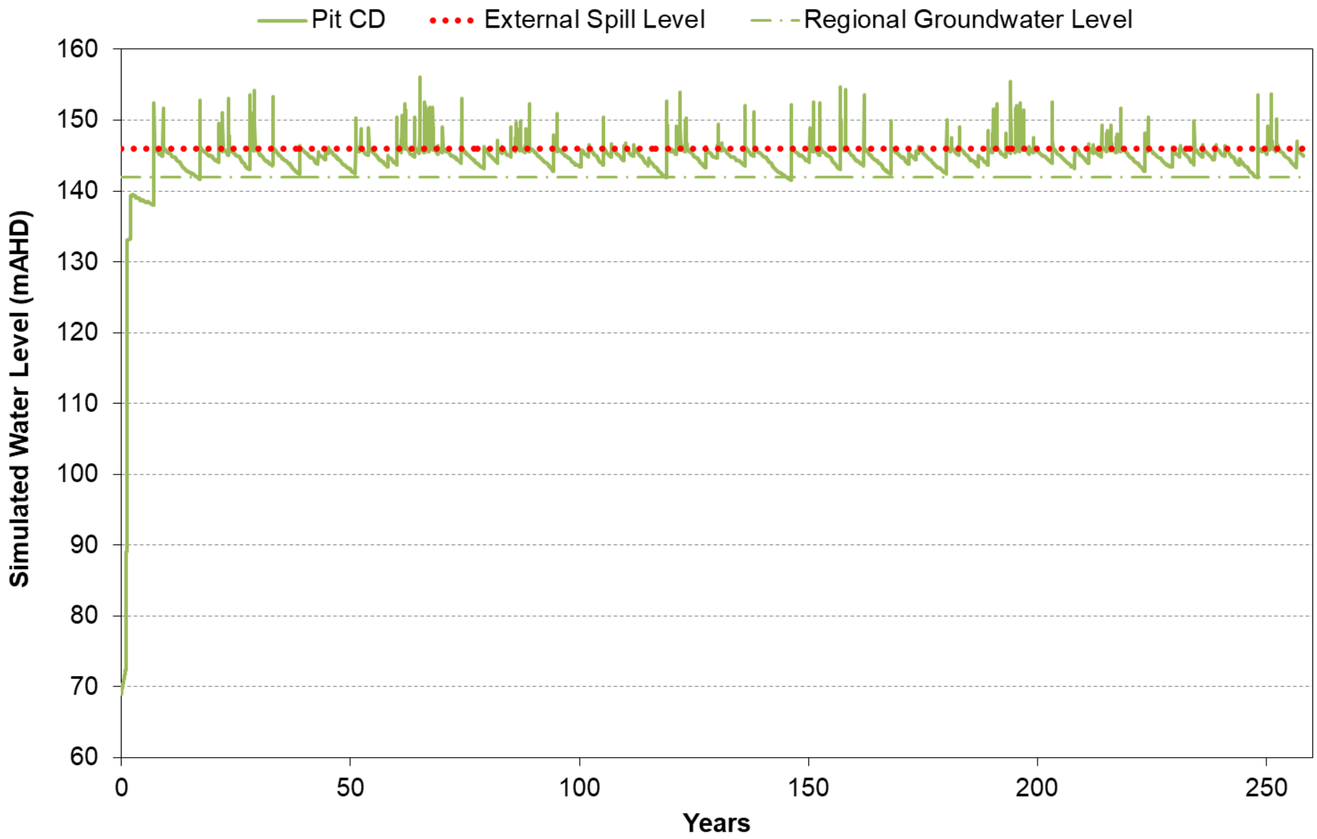

Figure 108 Water Level Results: Model Run 6, Pit CD

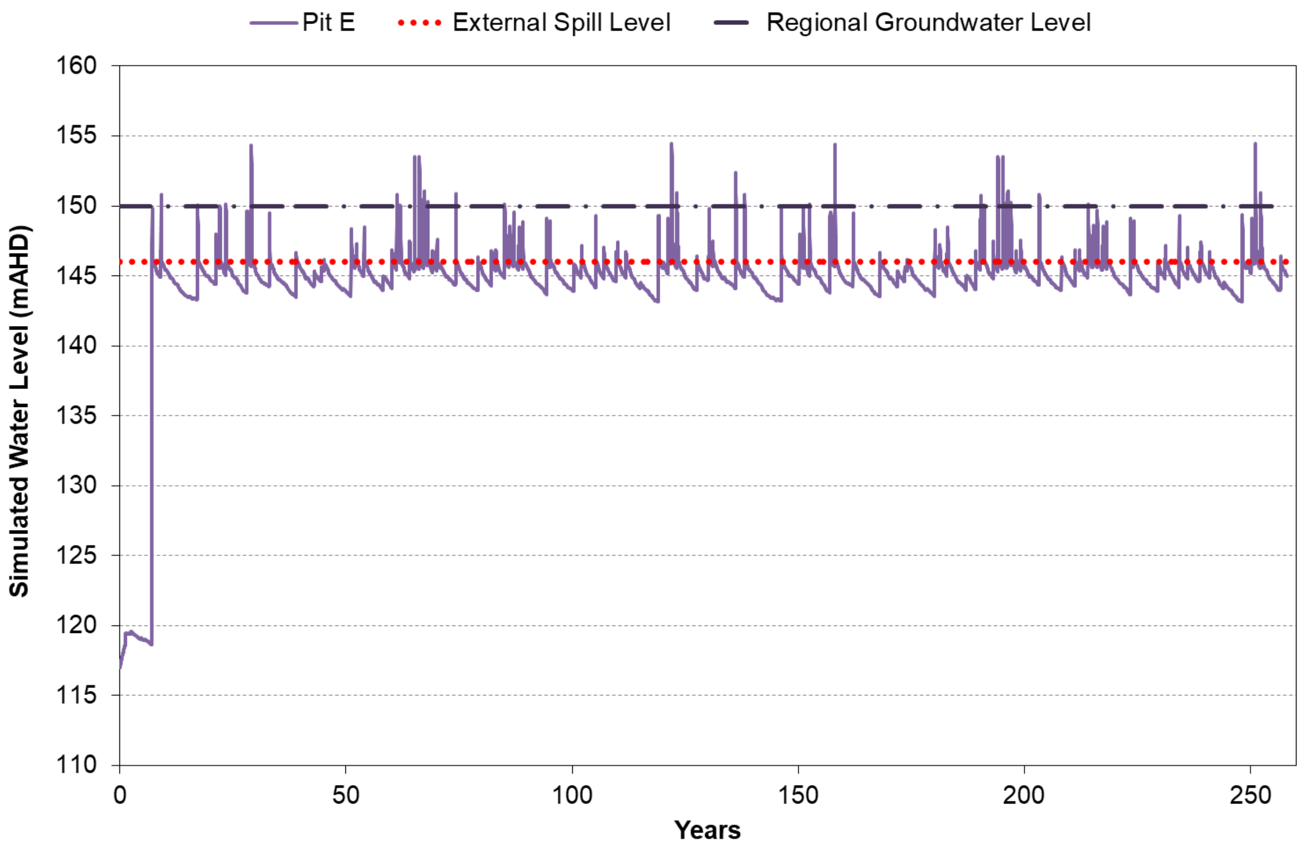

Figure 109 Water Level Results: Model Run 6, Pit E

Figure 106 and Figure 107 show notable variations in the water levels in Pit A and Pit B due to the simulated Nogoa River inflows to Pit B and the hydraulic link (i.e. spill/seepage) between Pit B and Pit A. The water levels in both Pit A and Pit B rise above the external spill level to the Nogoa River during river flood events. Water levels in Pit A and Pit B both rise above the respective regional groundwater levels and regional groundwater outflow from both pits is simulated during these periods.

Figure 108 and Figure 109 show notable variations in the water levels in Pit CD and Pit E due to the simulated Nogoa River inflows to Pit CD and the hydraulic link (i.e. spill/seepage) between Pit CD and Pit E. The water levels in both Pit CD and Pit E rise above the external spill level to the Nogoa River during river flood events. Water levels in Pit CD and Pit E both rise above the respective regional groundwater levels and regional groundwater outflow from both pits is simulated during these periods.

5.8.2 Water Volumes

Figure 110 shows the simulated water volume results over the 258 year simulation period for each of the voids in Model Run 6.

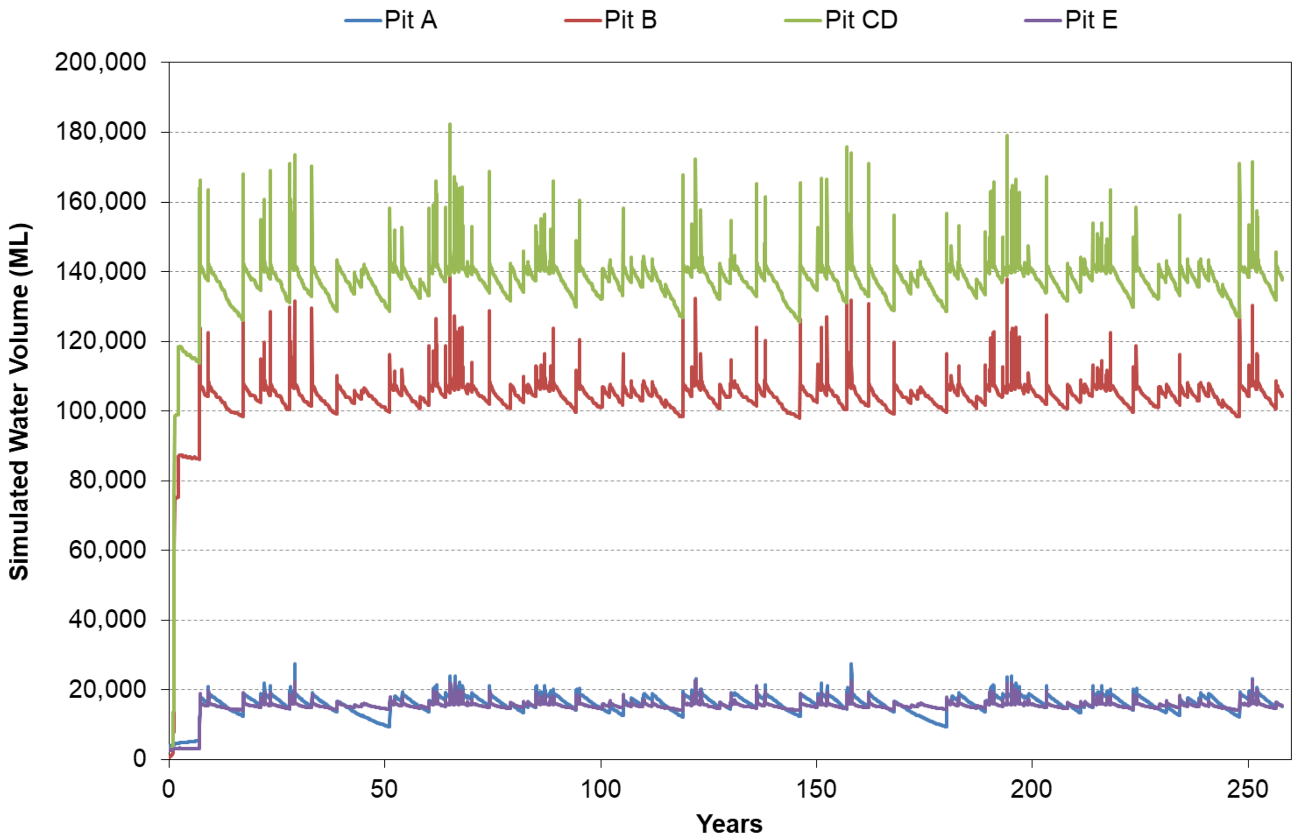

Figure 110 Water Volume Results: Model Run 6

Figure 110 shows that simulated water volumes in in Pit CD (approximately 140 GL after 129 years) are the highest followed by Pit B (approximately 105 GL after 129 years). The water volumes stored in Pit B and Pit CD fluctuate more than the water volumes stored in the remaining pits. Pit A and Pit E are all simulated to store approximately 20 GL or less over the simulation period.

5.8.3 Water Quality

Figure 111 to Figure 122 show water quality results (major ions, trace elements and salinity) over the 258 year simulation period for each of the voids in Model Run 6.

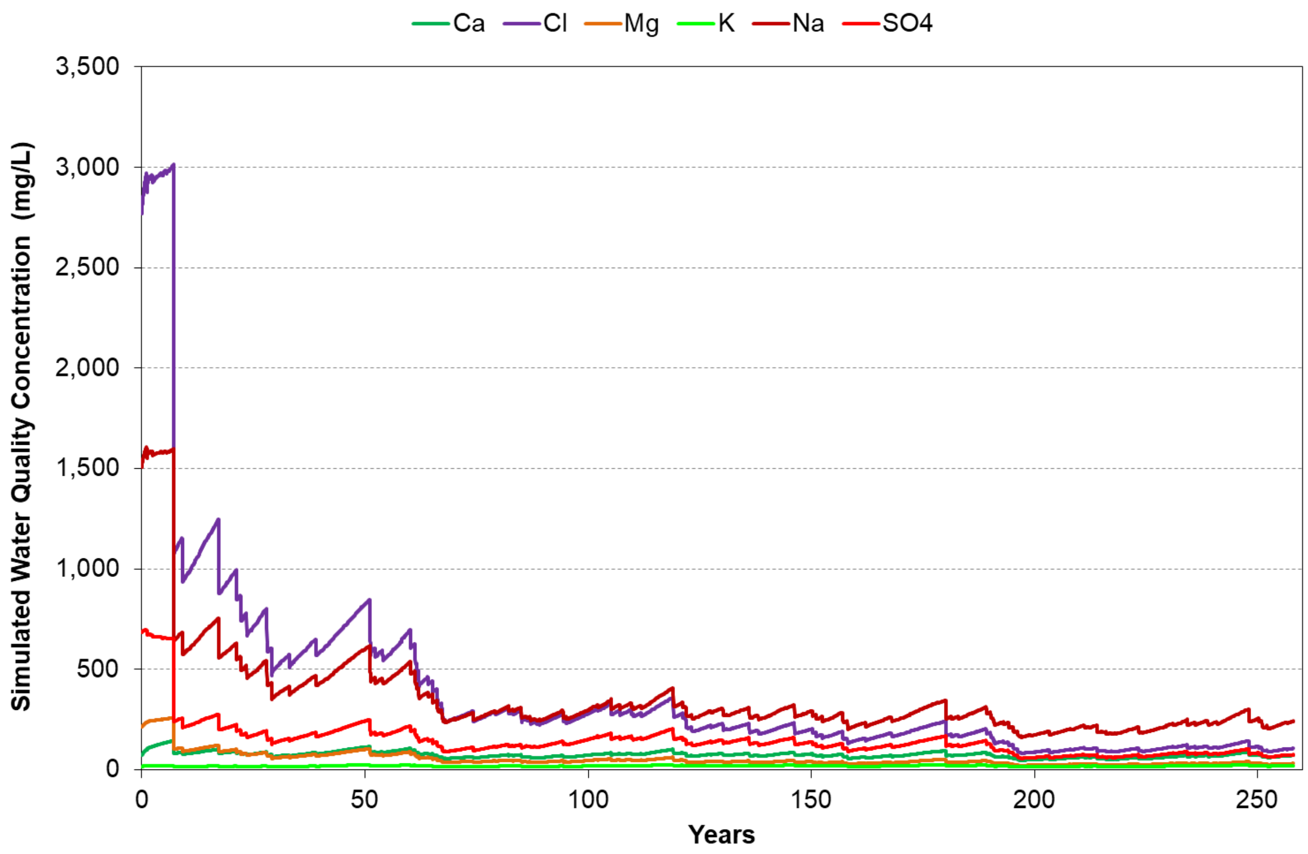

Figure 111 Water Quality Results: Model Run 6, Pit A – Major Ions

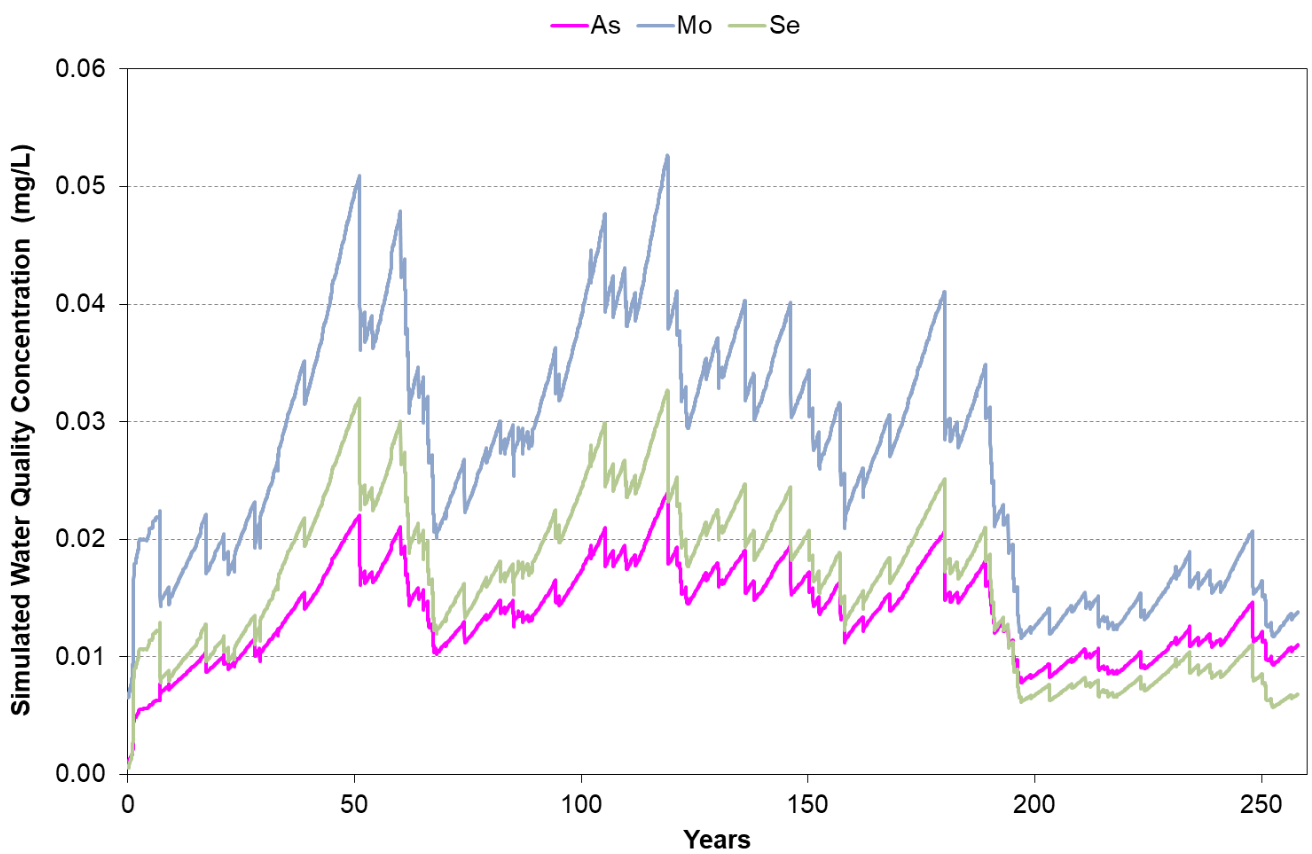

Figure 112 Water Quality Results: Model Run 6, Pit A – Trace Elements

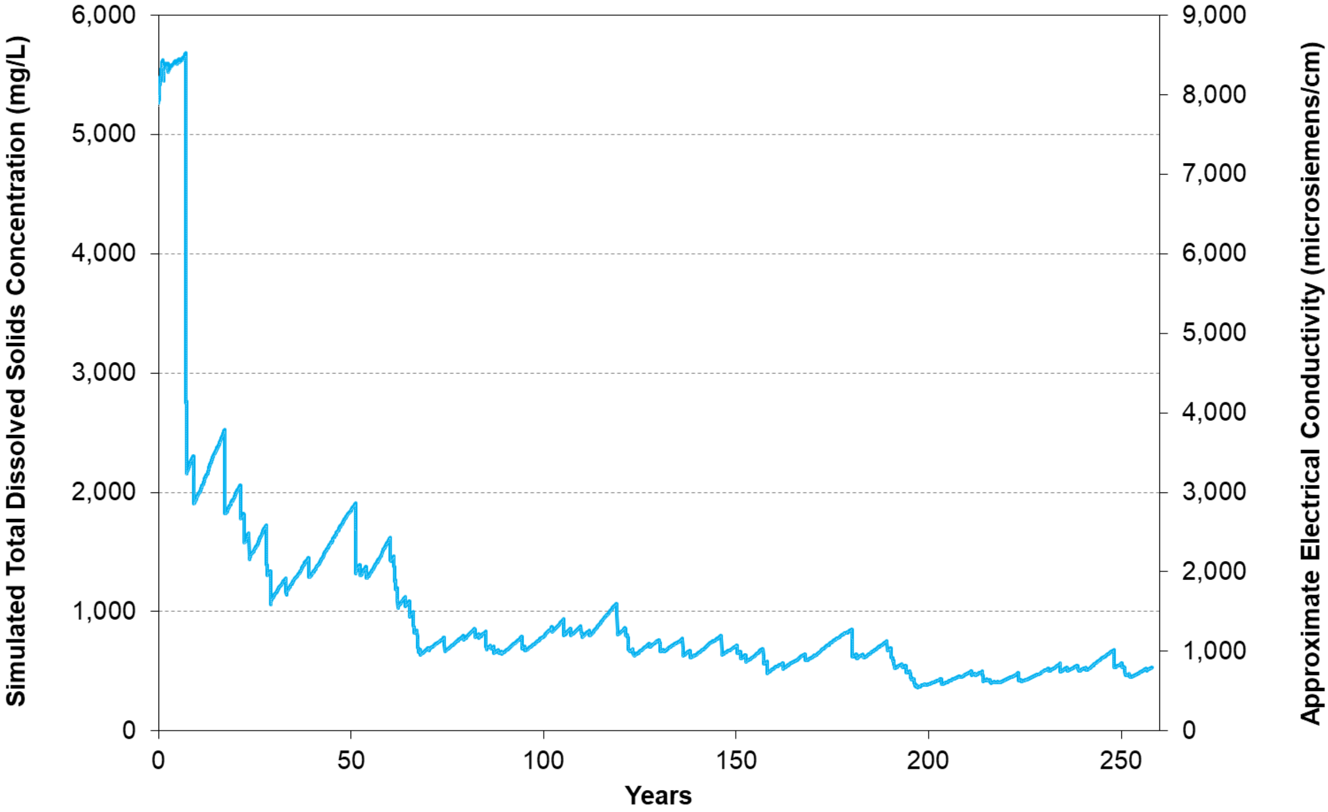

Figure 113 Water Quality Results: Model Run 6, Pit A – Salinity

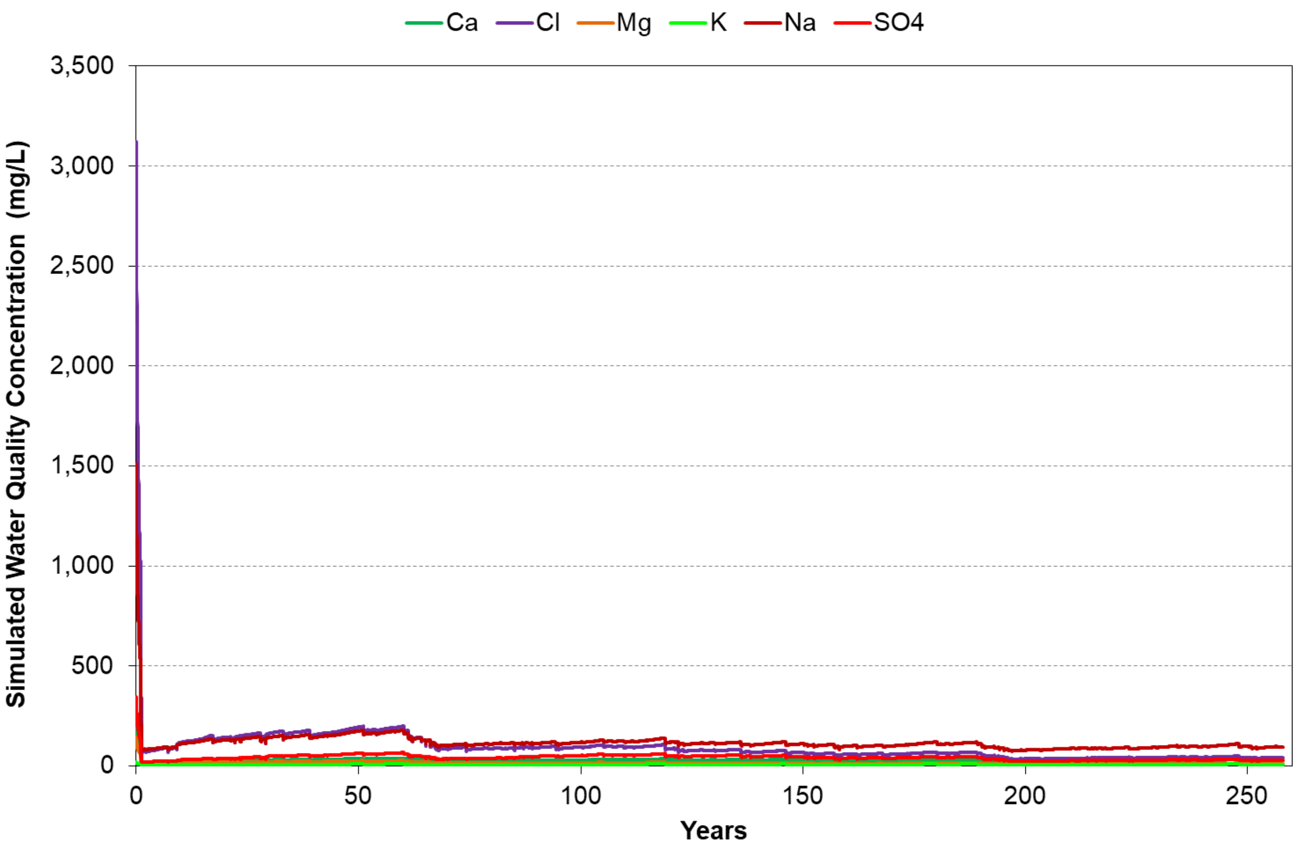

Figure 114 Water Quality Results: Model Run 6, Pit B – Major Ions

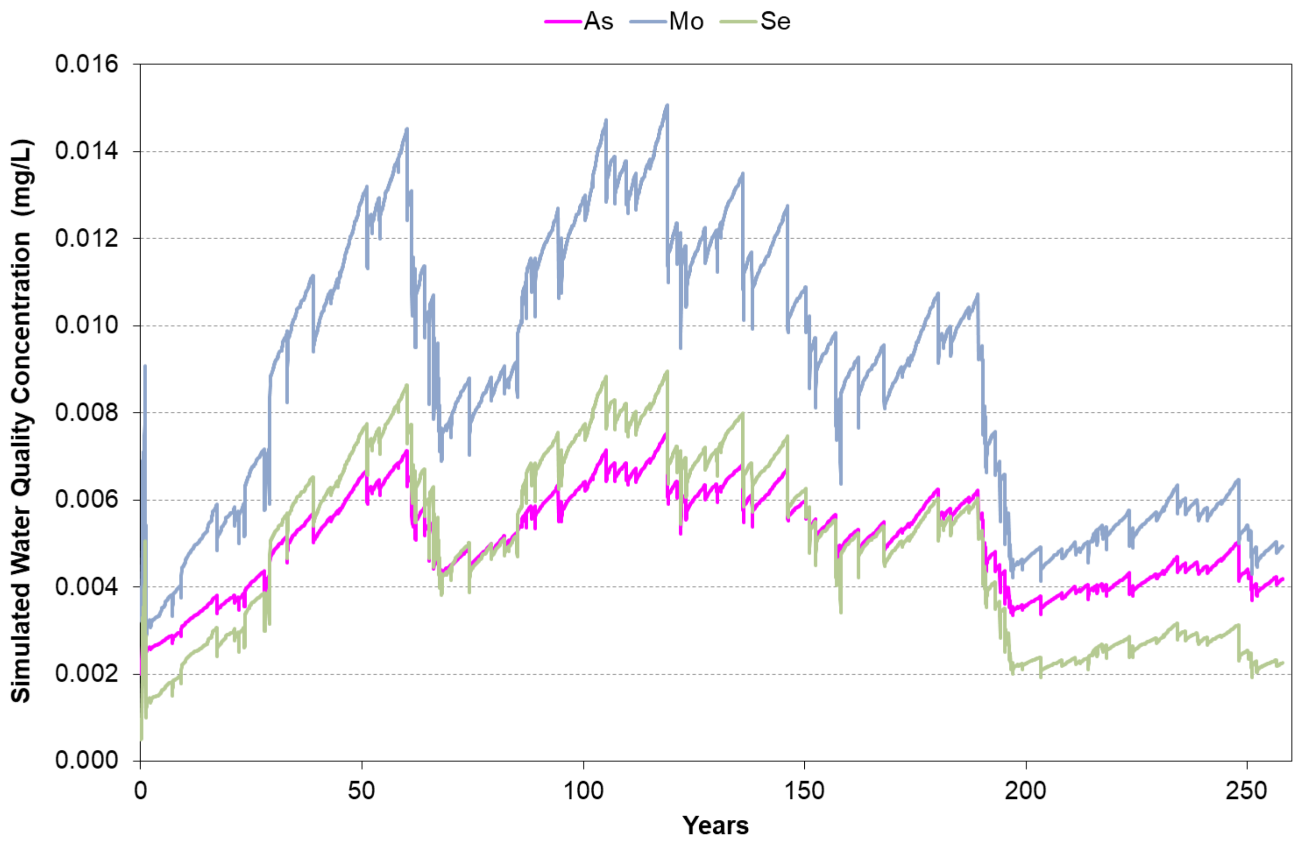

Figure 115 Water Quality Results: Model Run 6, Pit B – Trace Elements

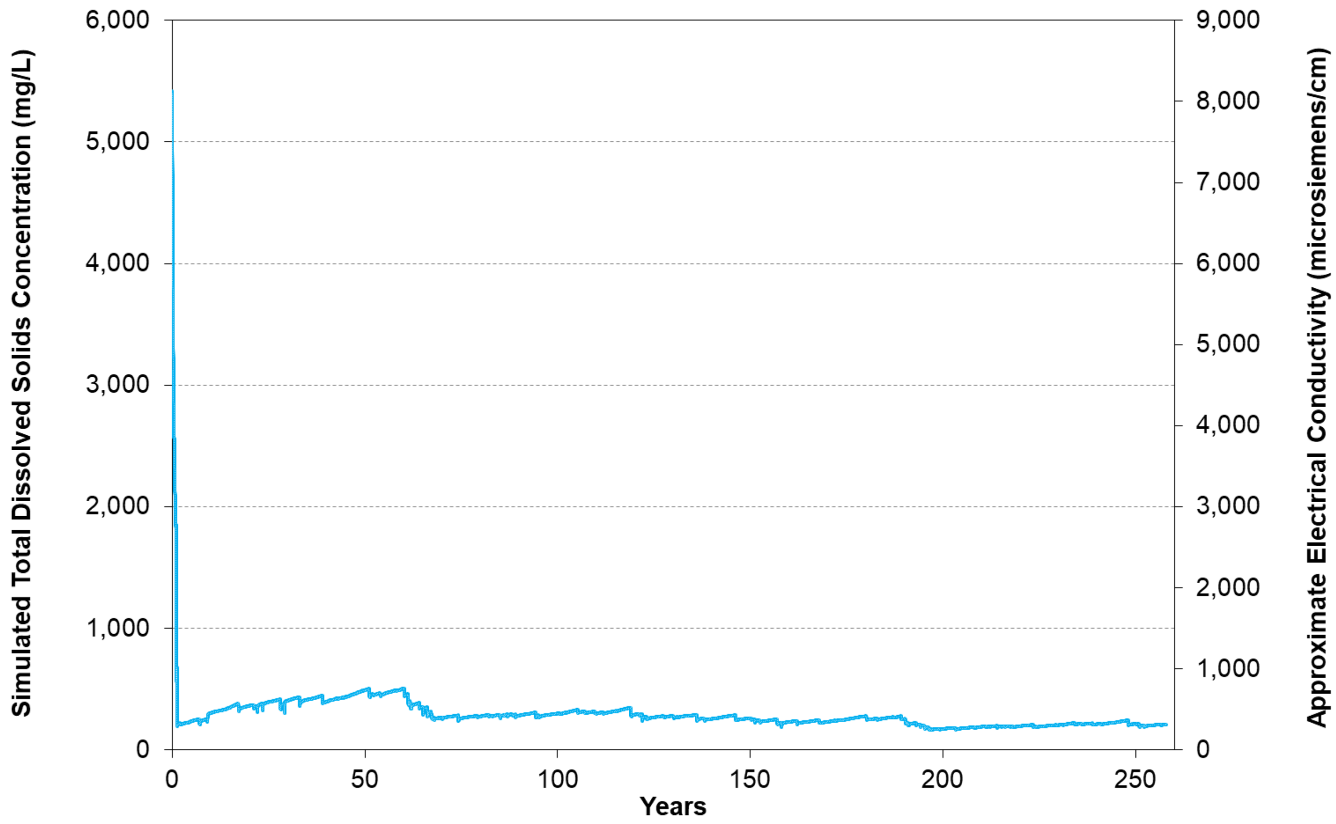

Figure 116 Water Quality Results: Model Run 6, Pit B – Salinity

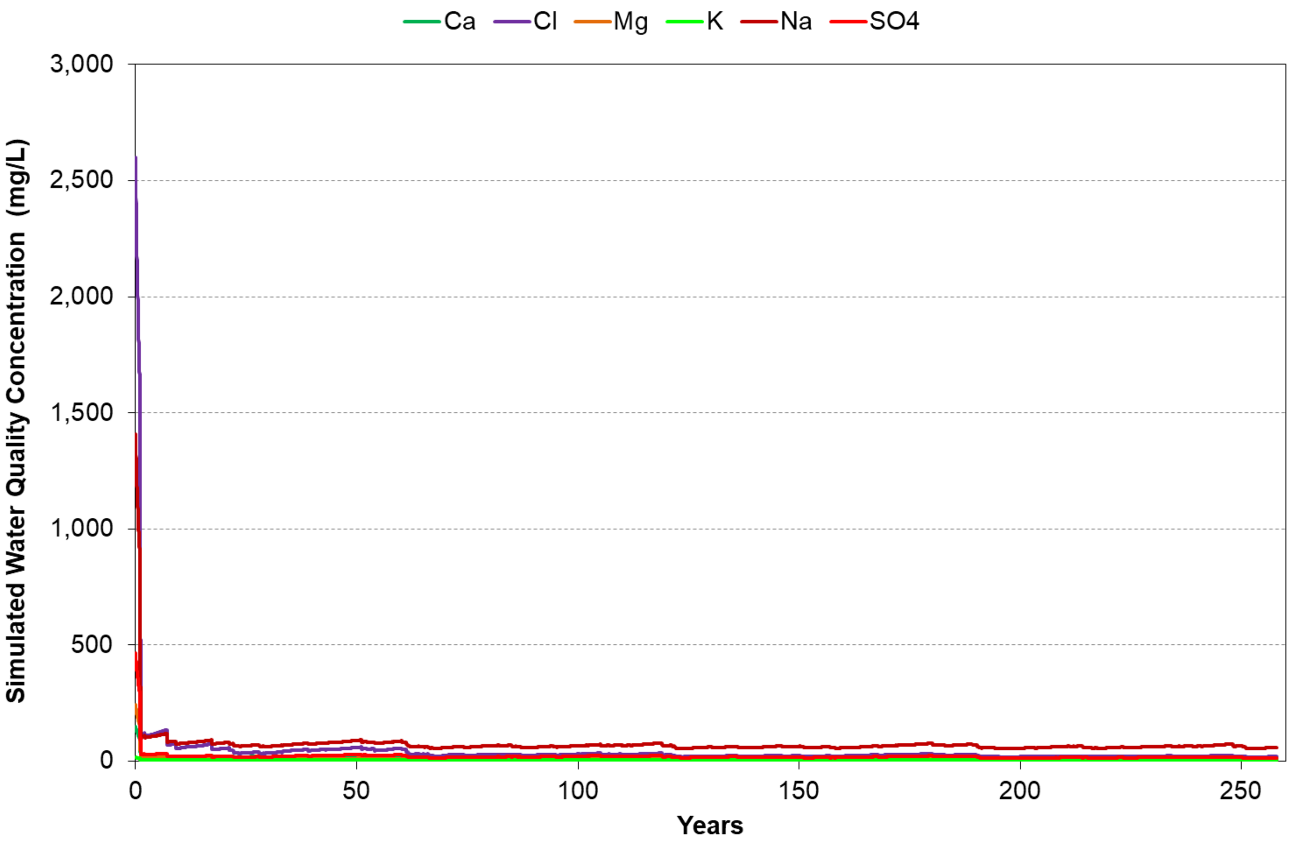

Figure 117 Water Quality Results: Model Run 6, Pit CD – Major Ions

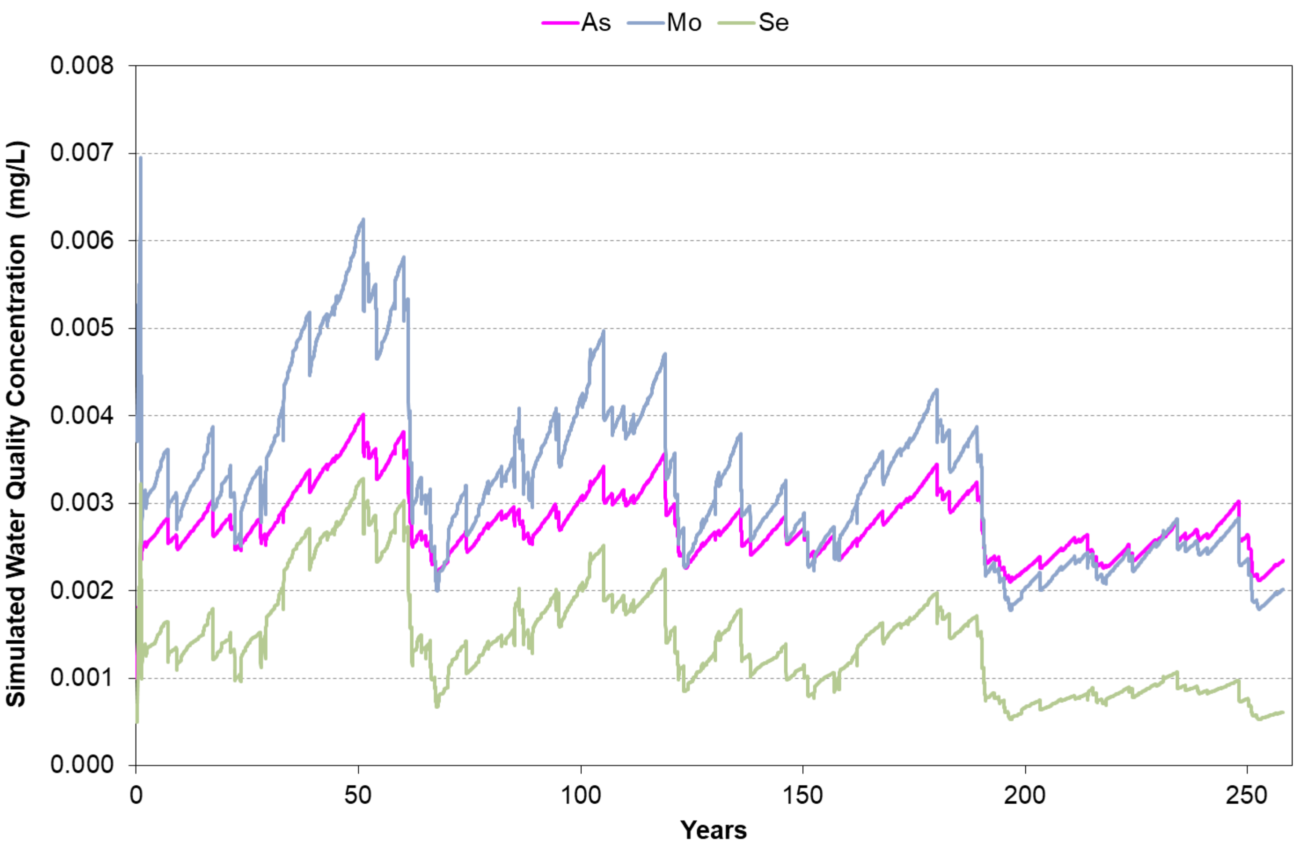

Figure 118 Water Quality Results: Model Run 6, Pit CD – Trace Elements

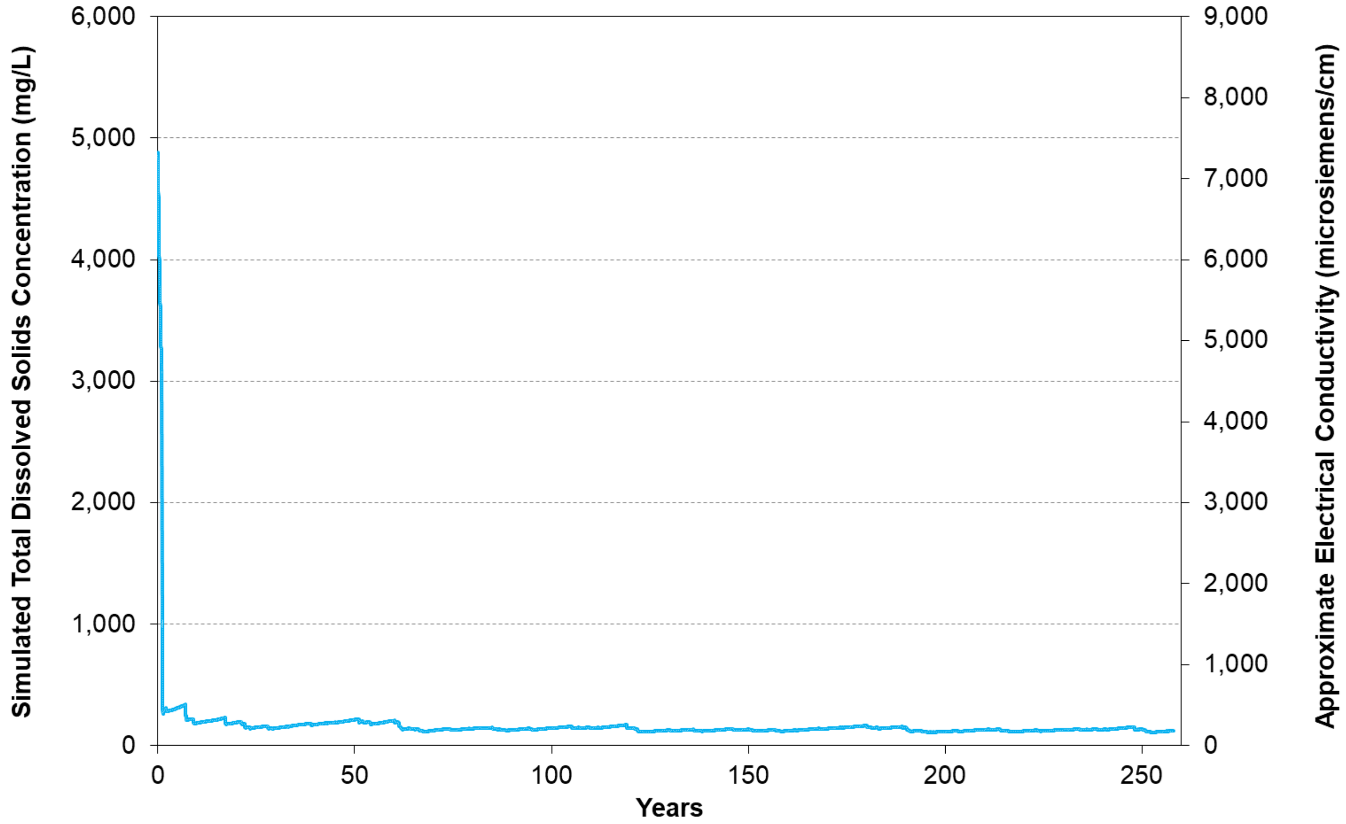

Figure 119 Water Quality Results: Model Run 6, Pit CD – Salinity

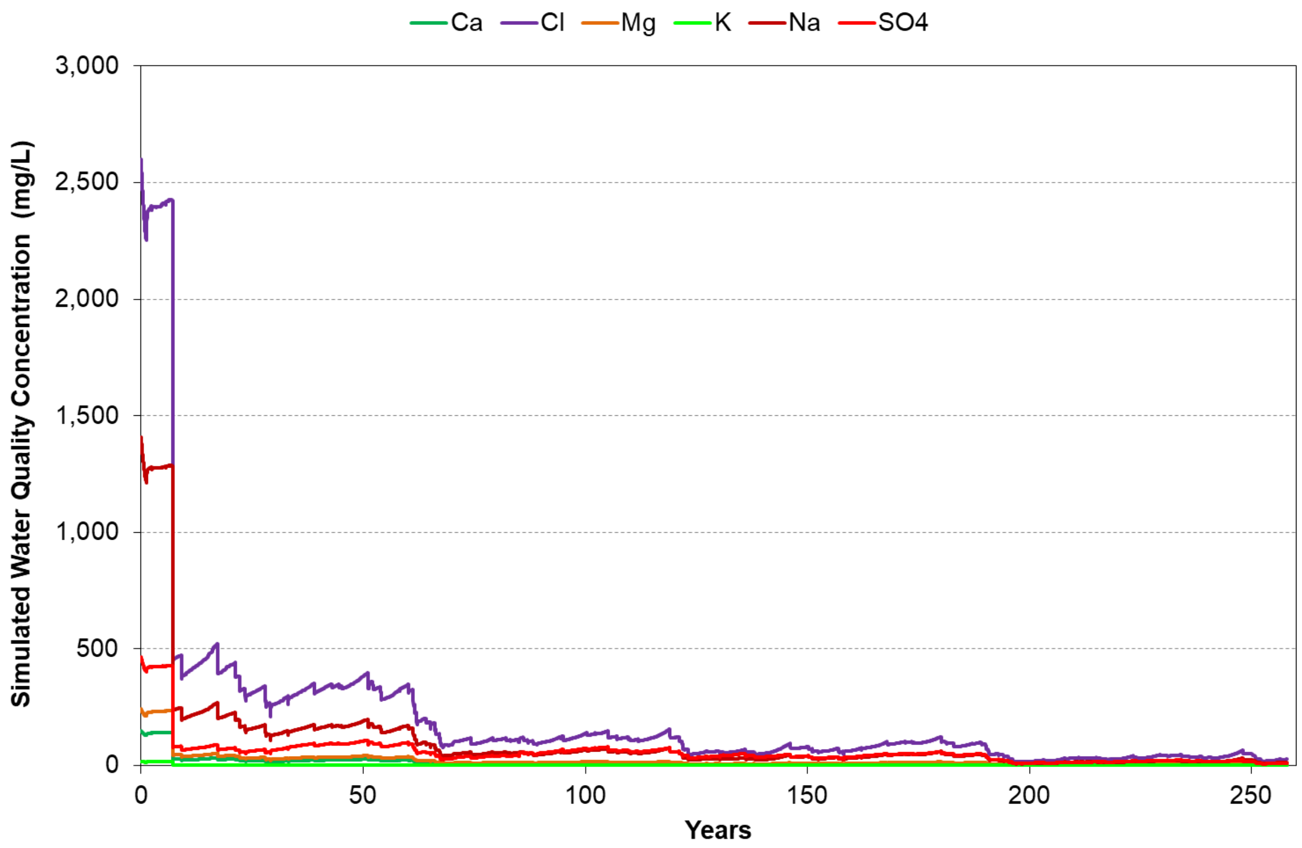

Figure 120 Water Quality Results: Model Run 6, Pit E – Major Ions

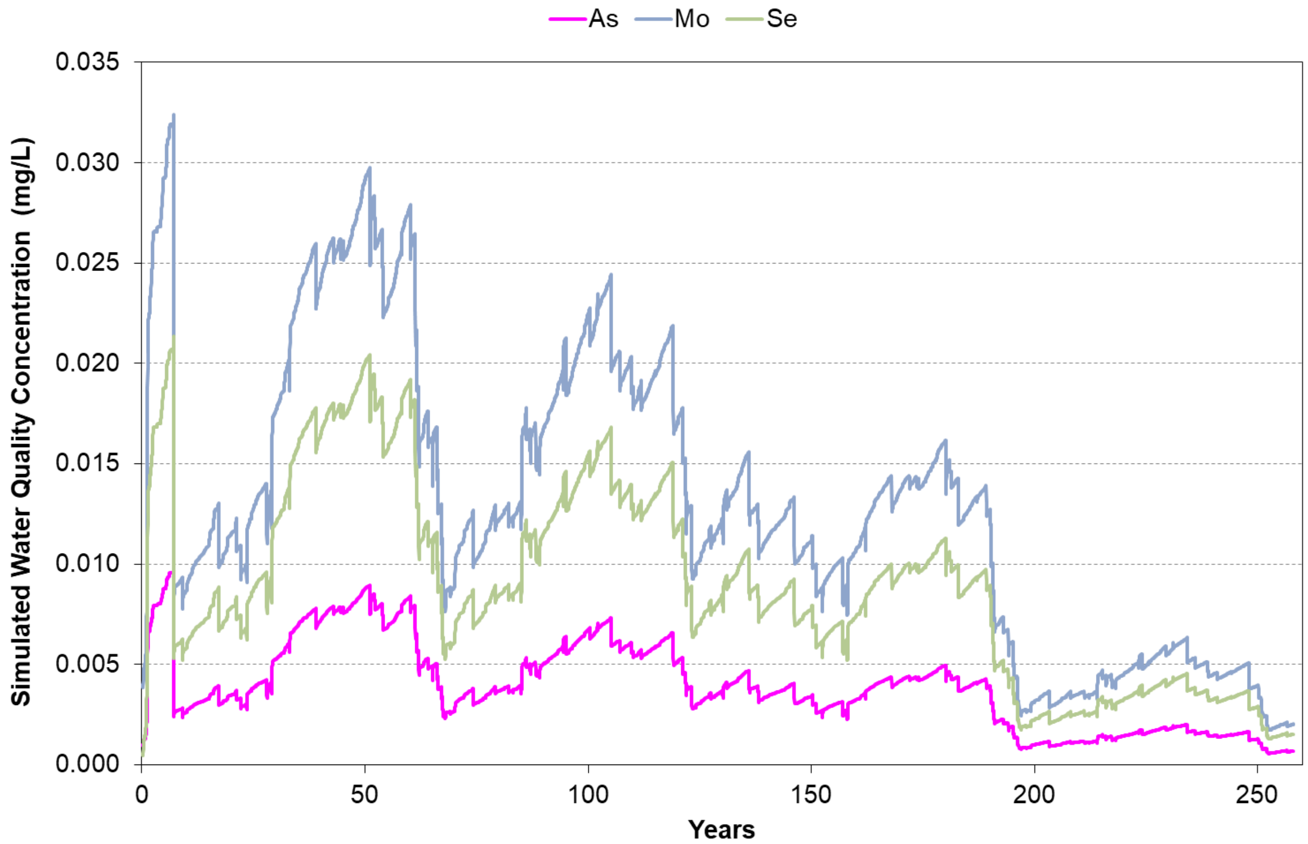

Figure 121 Water Quality Results: Model Run 6, Pit E – Trace Elements

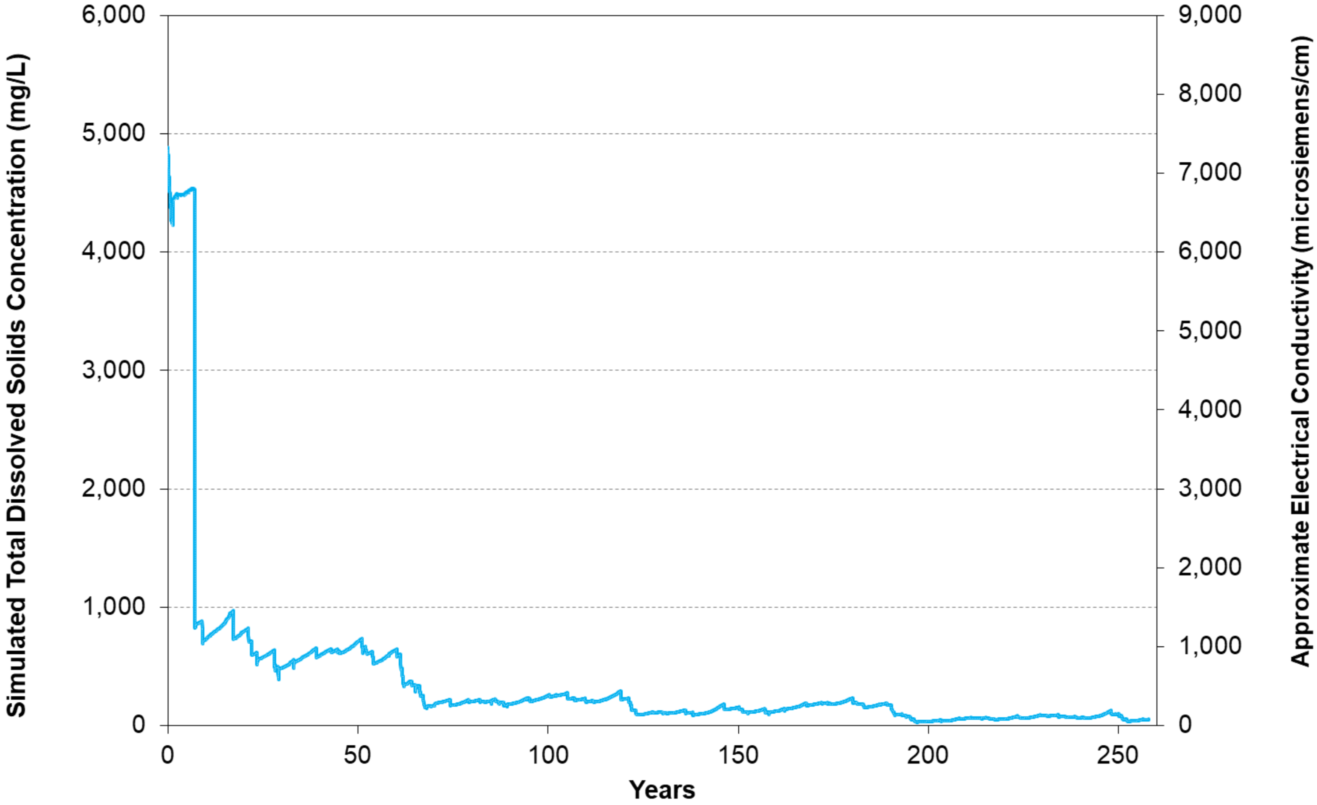

Figure 122 Water Quality Results: Model Run 6, Pit E – Salinity

Figure 111 and Figure 113 show that due to the effects of Nogoa River inflows/outflows (via Pit B), simulated concentrations of major ions and salinity in Pit A are predicted to decrease as a result of dilution due to the first inflow event. Figure 112 shows that simulated trace element concentrations are predicted to increase/decrease cyclically in Pit A over the simulation period.

Figure 114 and Figure 116 show that due to the effects of Nogoa River inflows/outflows, simulated concentrations of major ions and salinity in Pit B are predicted to decrease as a result of dilution due to the first inflow event and reach an equilibrium concentration similar to those assumed for Nogoa River water (refer Table 16). Figure 115 shows that simulated trace element concentrations are predicted to increase/decrease cyclically in Pit B over the simulation period.

Figure 117 and Figure 119 show that due to the effects of Nogoa River inflows/outflows, simulated concentrations of major ions and salinity in Pit CD are predicted to decrease as a result of dilution due to the first inflow event and reach an equilibrium concentration similar to those assumed for Nogoa River water (refer Table 16). Figure 118 shows that trace element concentrations are predicted to increase/decrease cyclically in Pit CD over the simulation period.

Figure 120 and Figure 122 show that due to the effects of Nogoa River inflows/outflows (via Pit CD), simulated concentrations of major ions and salinity in Pit E are predicted to decrease as a result of dilution due to the first inflow event and reach a concentration similar to those assumed for Nogoa River water (refer Table 16). Figure 121 shows that simulated trace element concentrations are predicted to increase/decrease cyclically in Pit E over the simulation period.

5.8.4 Nogoa River Cumulative Flow Comparison

Due to the notable volumes of water simulated as spilling in from and out to the Nogoa River from Pit B and Pit CD for Model Run 6, there is a potential impact on net flow in the Nogoa River downstream of the voids. Figure 123 shows a comparison of cumulative Nogoa River flows without and with interaction with Pit B and Pit CD over the 129 year simulation period. The difference between the total flows at the end of the simulation period is approximately 811 GL or an average of 3.1 GL/year. This represents an average decrease in the river flow volume of 0.9%.

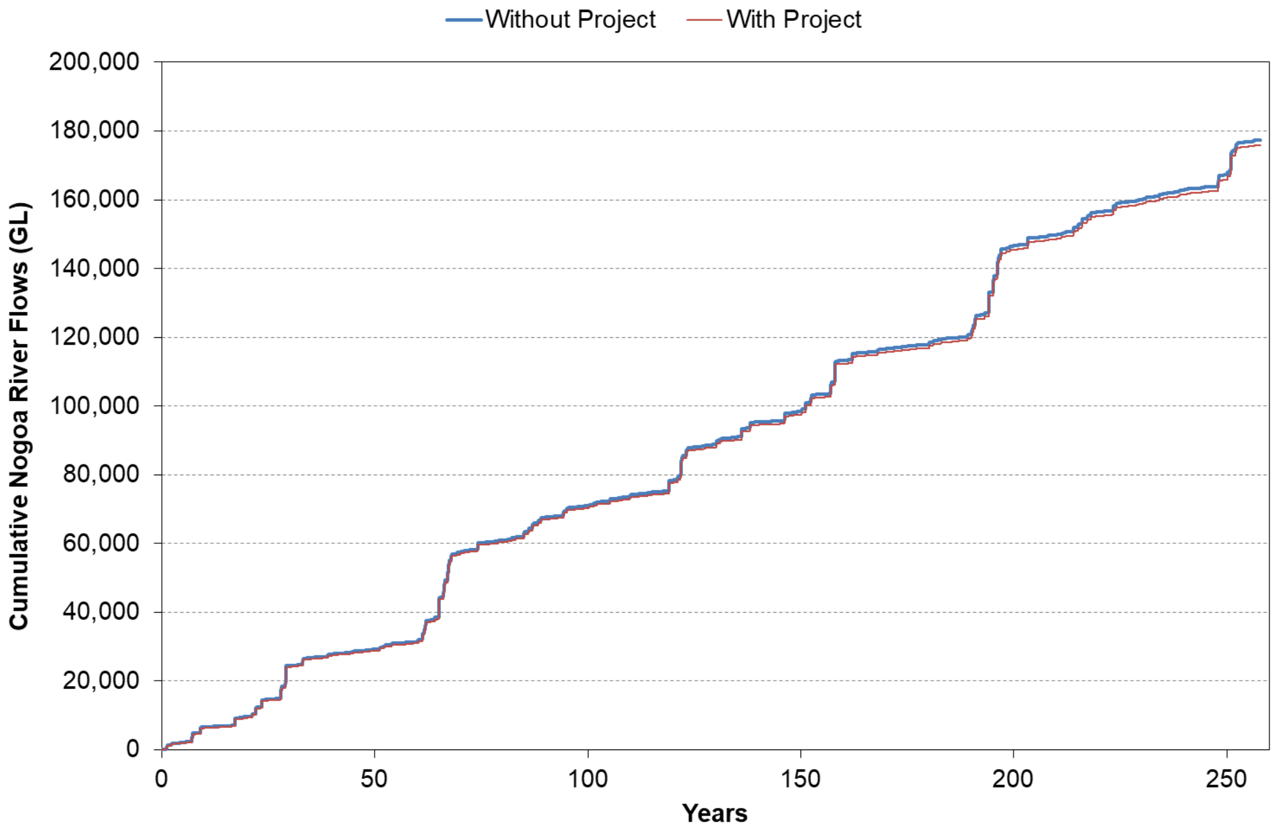

Figure 123 Nogoa River Flow Comparison: Model Run 6

5.9 MODEL RUN 7 RESULTS (PREFERRED OPTION 3: BASE CASE)

The objective of Model Run 7 is to predict the water levels, volumes and quality results for the base case of Preferred Option 3. Results for each void for Model Run 7 are summarised in the sections to follow. Note that no results are presented for Pit B and Pit CD as these pits are backfilled in Preferred Option 3.

5.9.1 Water Levels

Figure 124 and Figure 125 show forecast water levels over the 258 year simulation period for both of the voids in Model Run 7.

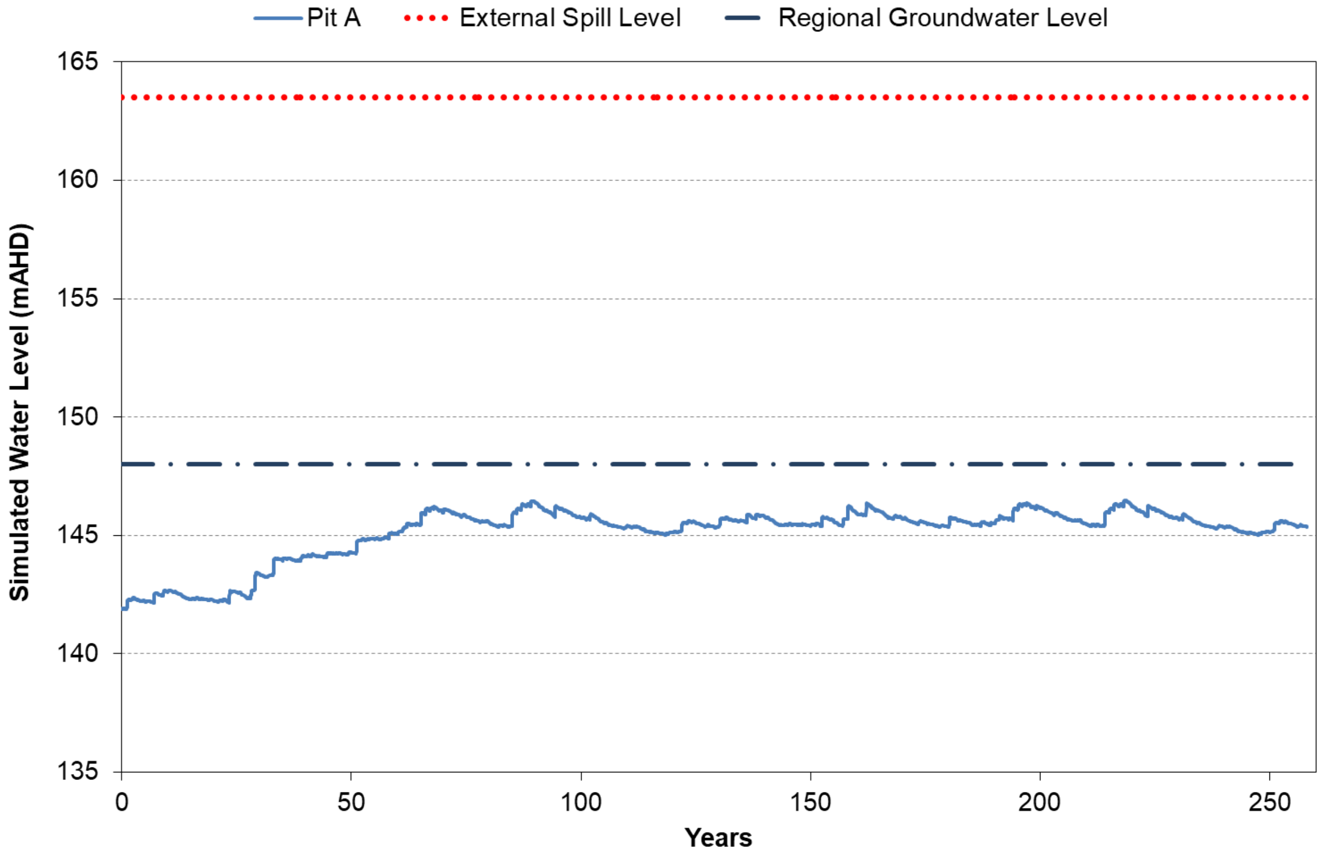

Figure 124 Water Level Results: Model Run 7, Pit A

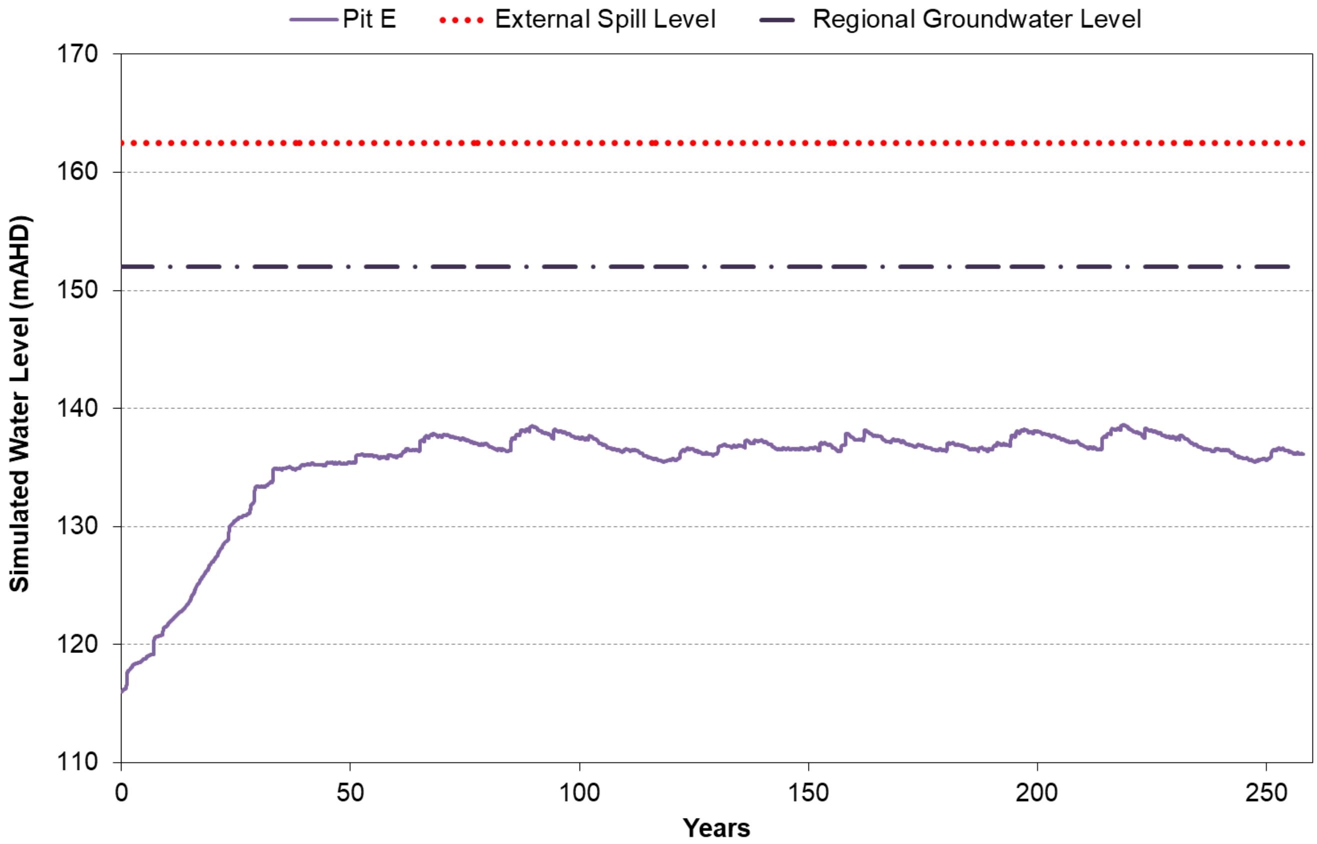

Figure 125 Water Level Results: Model Run 7, Pit E

Figure 124 shows that Pit A reaches equilibrium water level after around 75 years at approximately 145.5 mAHD or 18 m below the spill level (163.5 mAHD) and approximately 2.5 m below the regional groundwater level (148 mAHD).

Figure 125 shows that Pit E reaches equilibrium water level after around 75 years at approximately 137 mAHD or 25.5 m below the spill level (162.5 mAHD) and approximately 15 m below the regional groundwater level (152 mAHD).

5.9.2 Water Volumes

Figure 126 shows the simulated water volume results over the 258 year simulation period for both of the voids in Model Run 7.

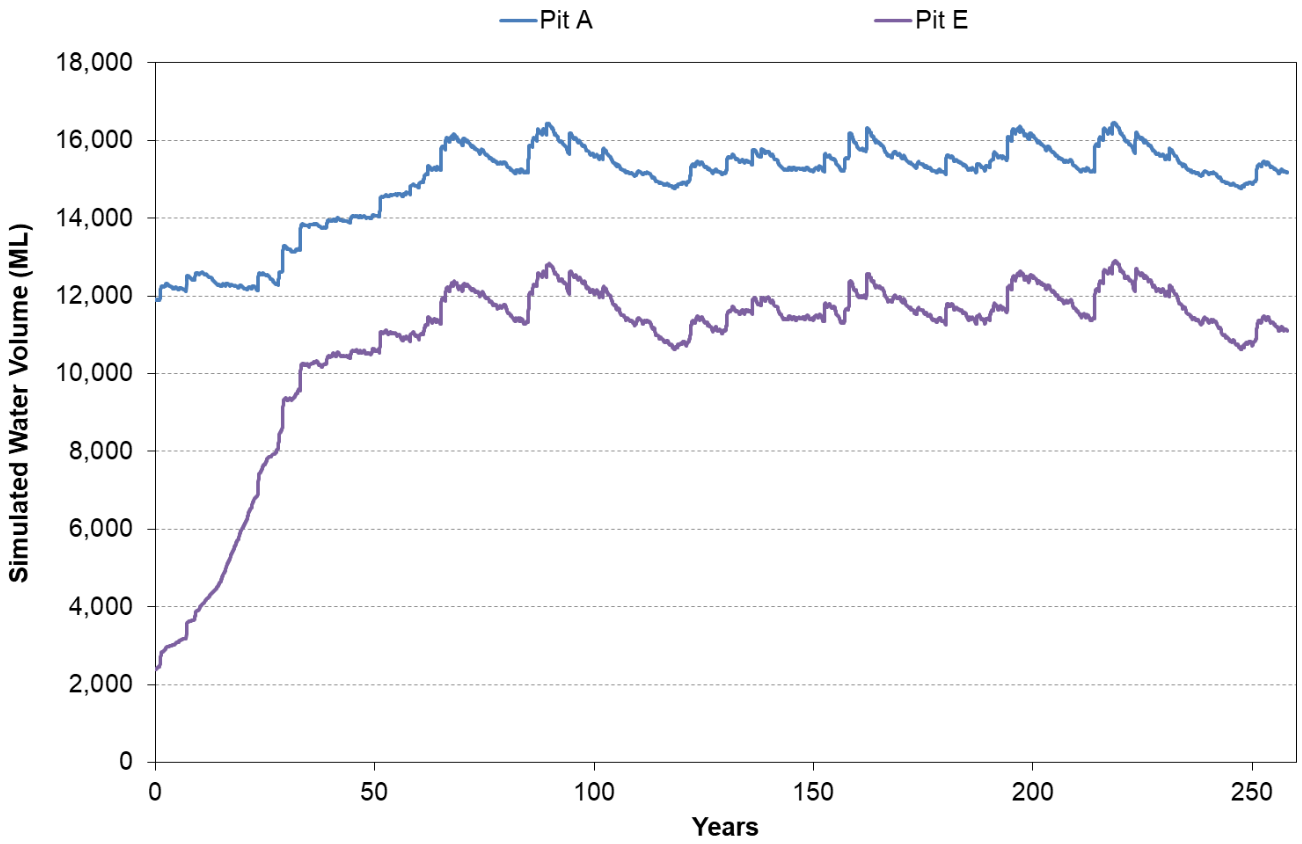

Figure 126 Water Volume Results: Model Run 7

Figure 126 shows that simulated water volumes in Pit A (approximately 15 GL after 250 years) are higher than Pit E (approximately 11 GL after 250 years).

5.9.3 Water Quality

Figure 127 to Figure 132 show water quality results (major ions, trace elements and salinity) over the 258 year simulation period for both of the voids in Model Run 7.

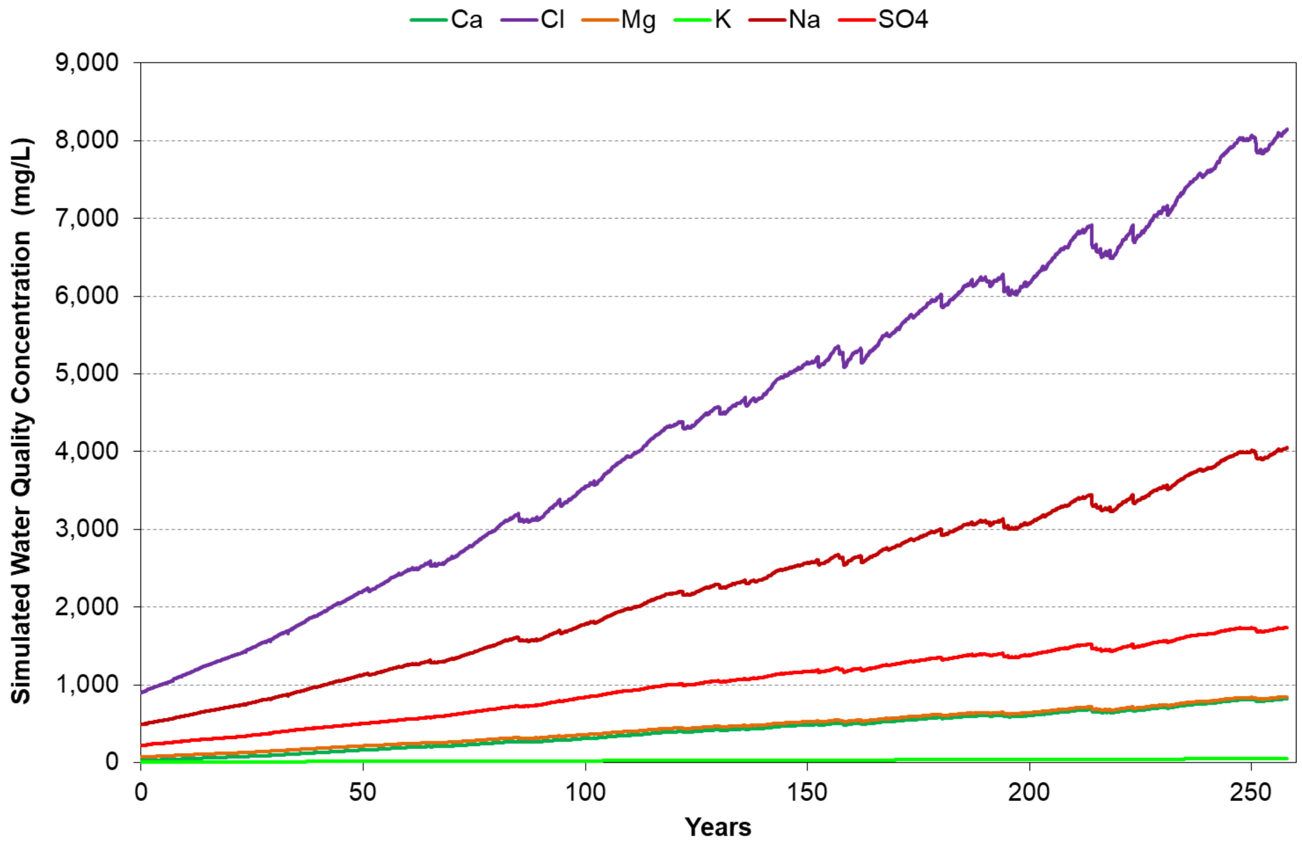

Figure 127 Water Quality Results: Model Run 7, Pit A – Major Ions

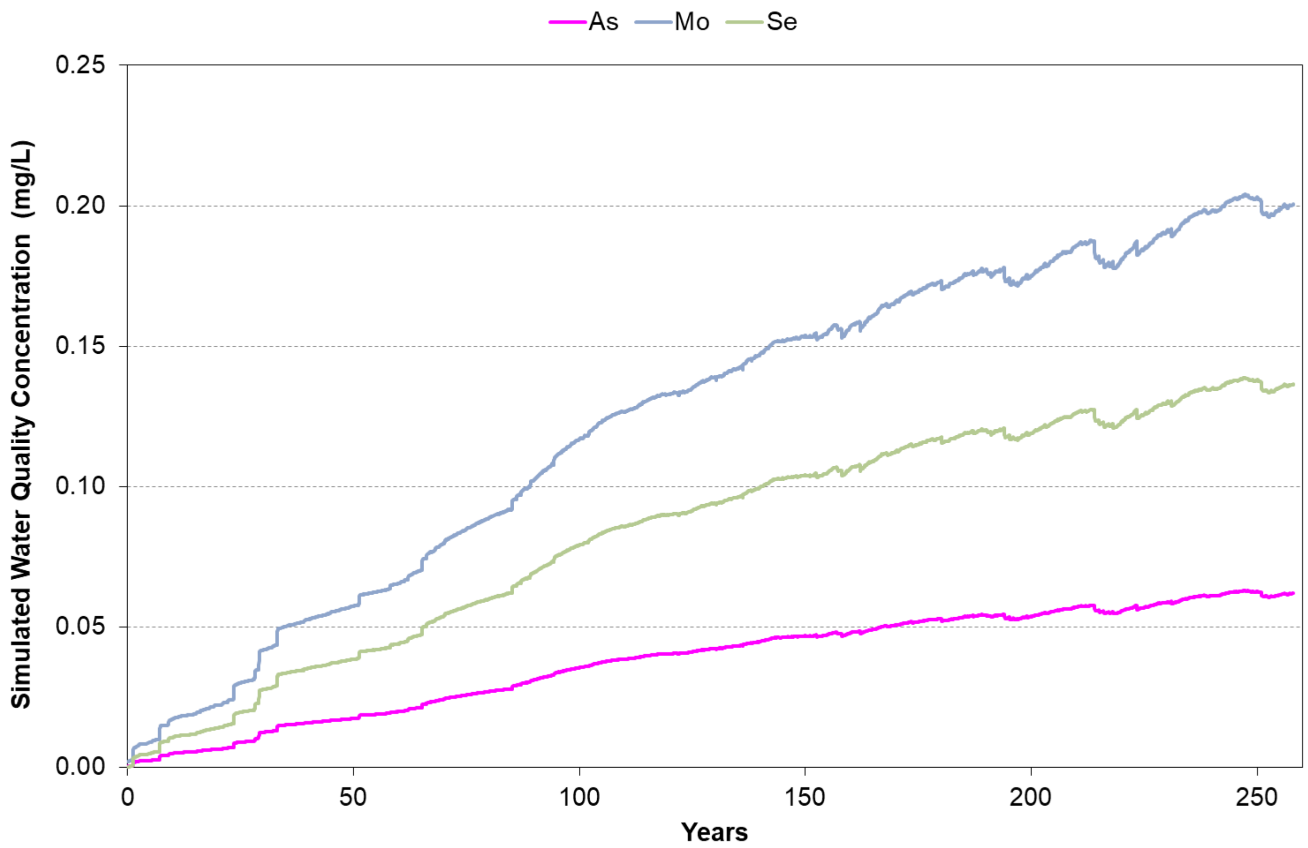

Figure 128 Water Quality Results: Model Run 7, Pit A – Trace Elements

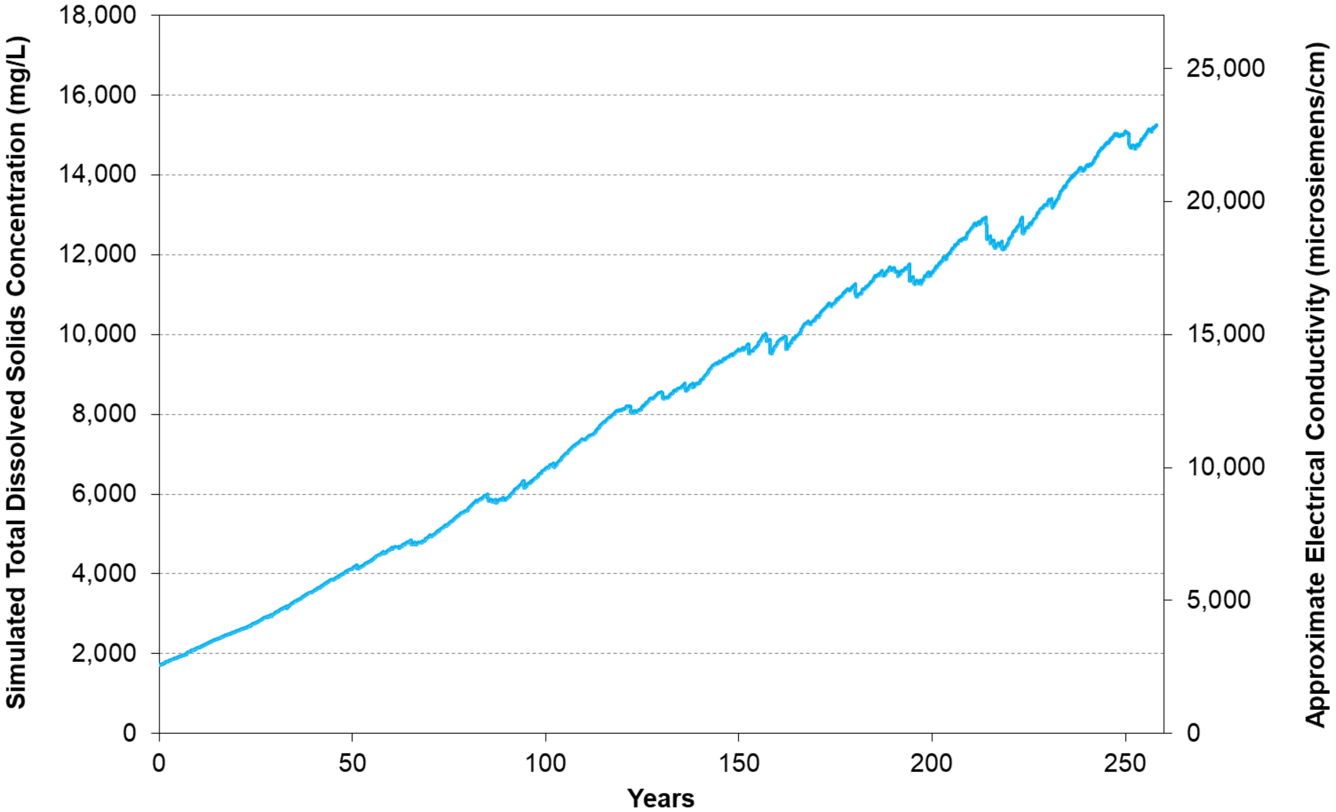

Figure 129 Water Quality Results: Model Run 7, Pit A – Salinity

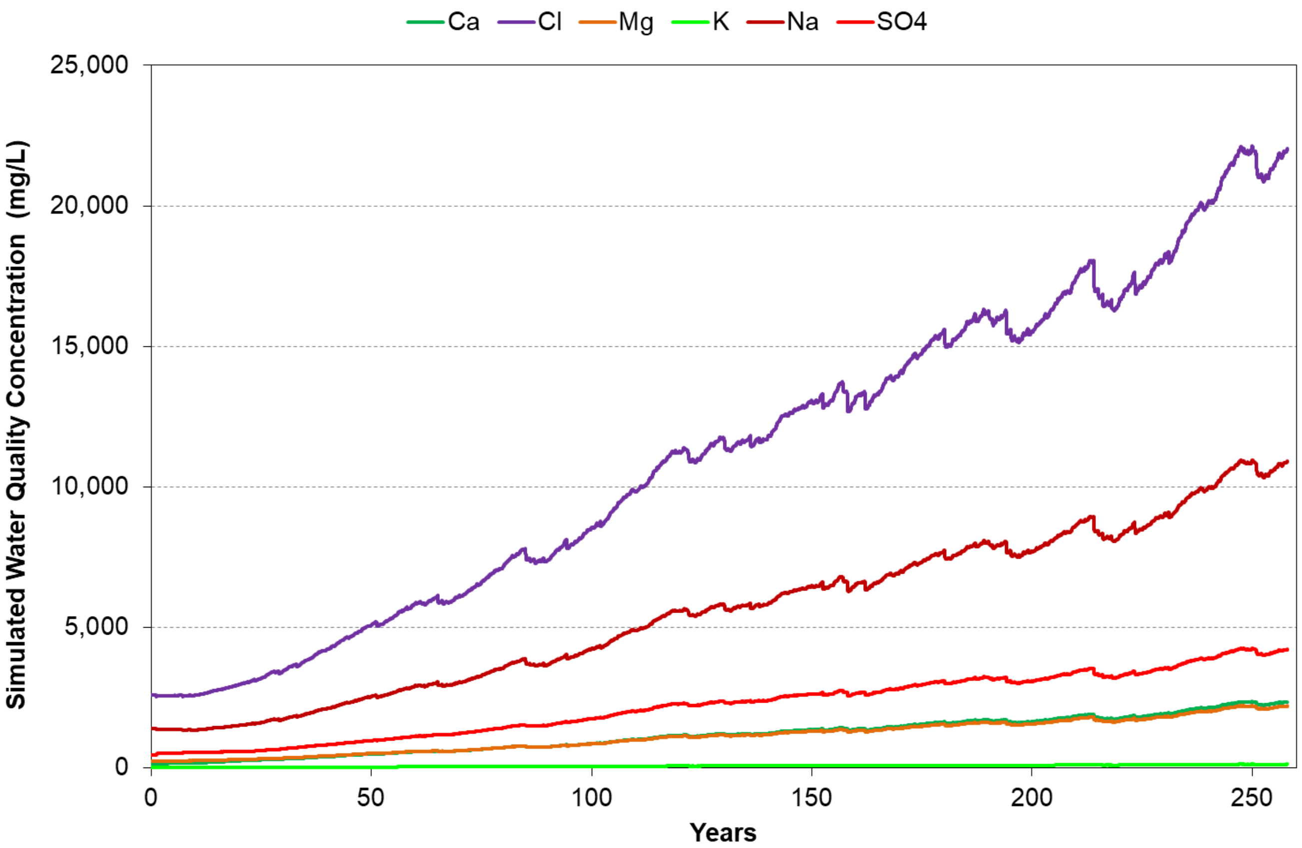

Figure 130 Water Quality Results: Model Run 7, Pit E – Major Ions

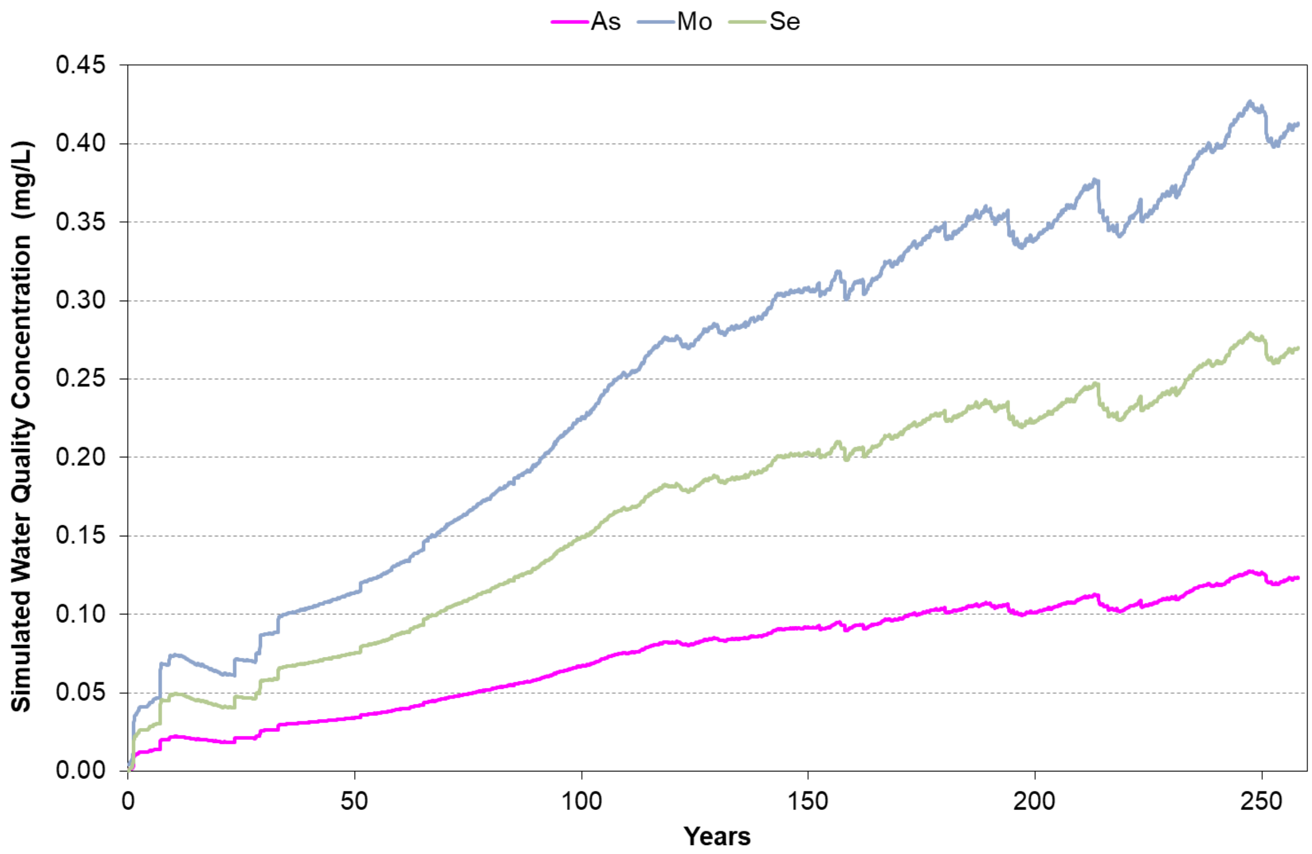

Figure 131 Water Quality Results: Model Run 7, Pit E – Trace Elements

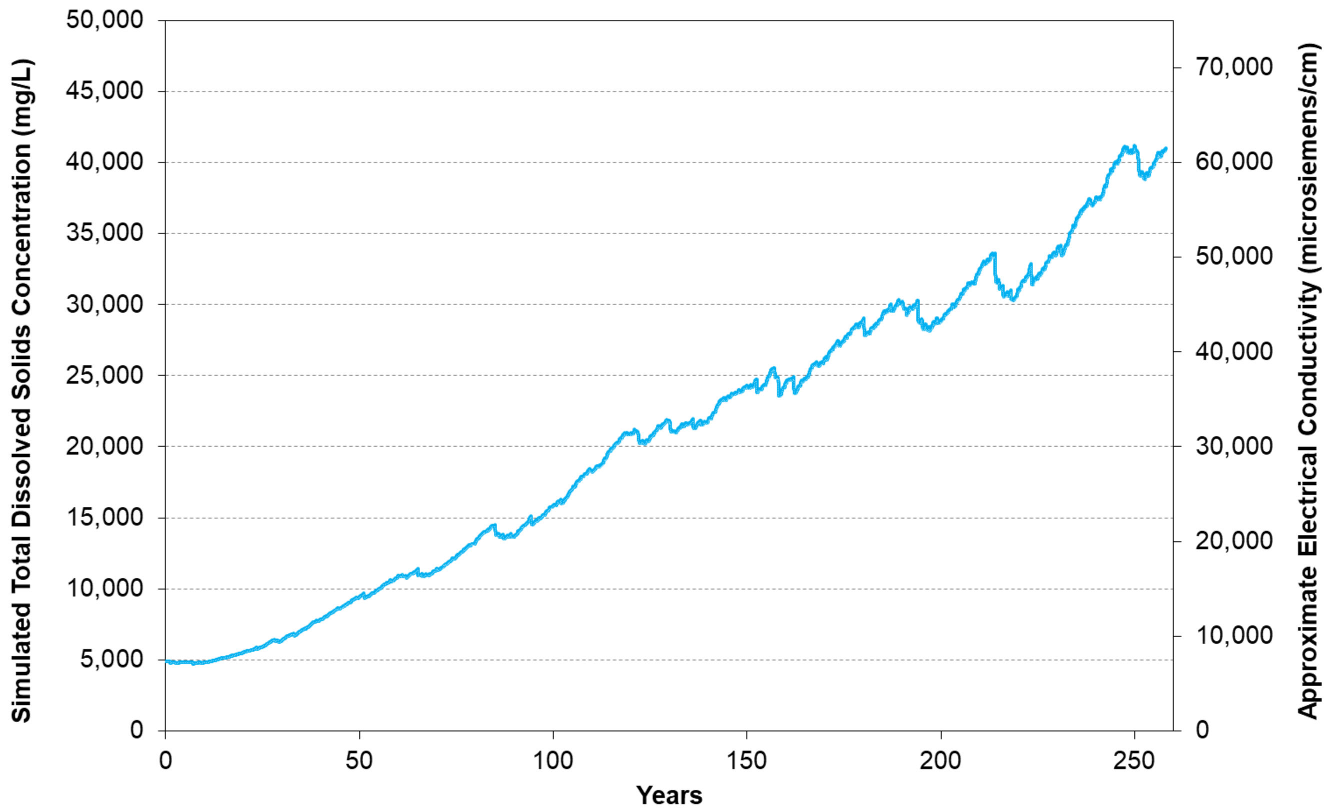

Figure 132 Water Quality Results: Model Run 7, Pit E – Salinity

Figure 127 to Figure 132 show that simulated concentrations of solutes are all predicted to increase in Pit A and Pit E over the simulation period due to the only simulated outflow comprising evaporation via which no solutes can flow out of the voids.

5.10 MODEL RUN 7A RESULTS (PREFERRED OPTION 3: BASE CASE WITH CLIMATE CHANGE)

The objective of Model Run 7a is to predict the water levels, volumes and quality results for the base case of Preferred Option 3 with climate change factors applied. Results for each void for Model Run 7a are summarised in the sections to follow. Note that no results are presented for Pit B and Pit CD as these pits are backfilled in Preferred Option 3.

5.10.1 Water Levels

Figure 133 and Figure 134 show forecast water levels over the 258 year simulation period for both of the voids in Model Run 7a.

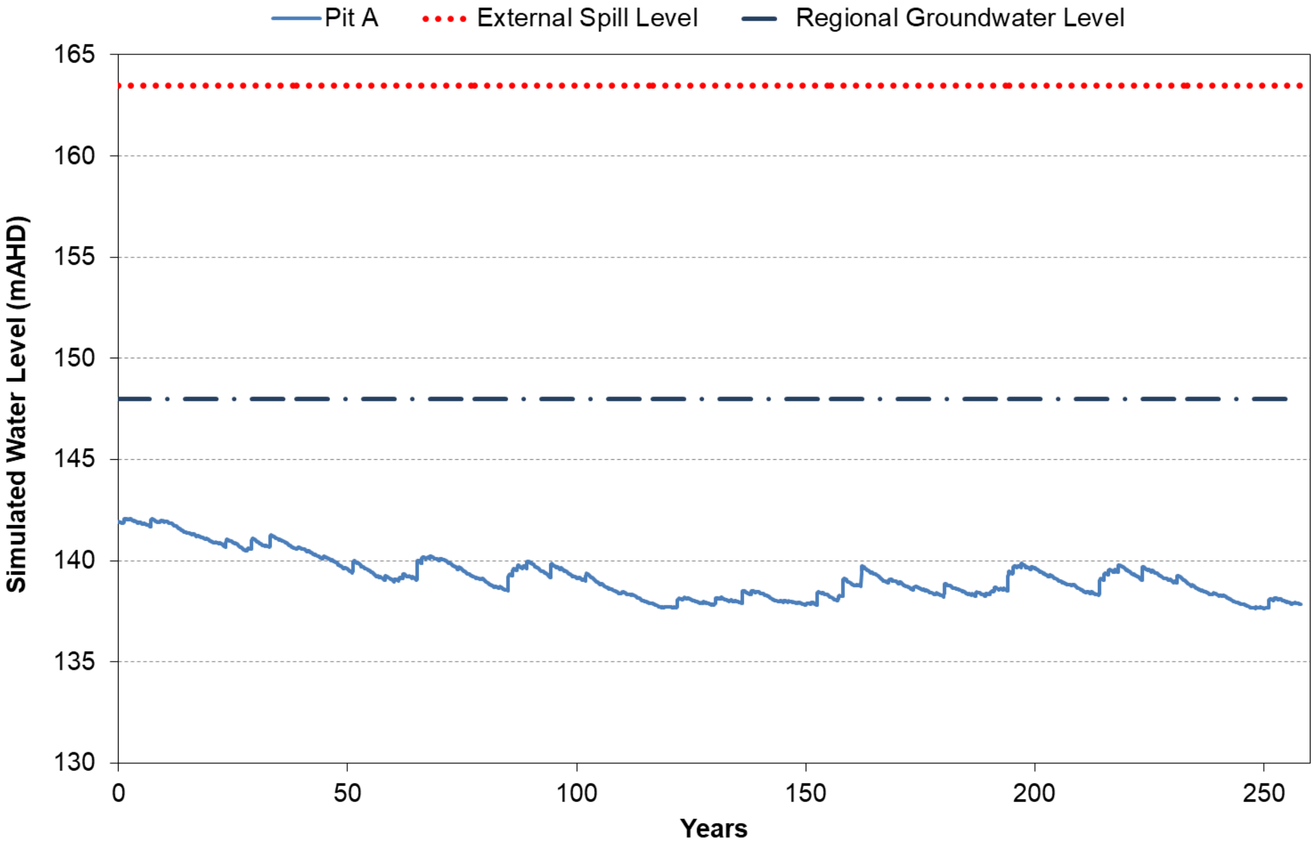

Figure 133 Water Level Results: Model Run 7a, Pit A

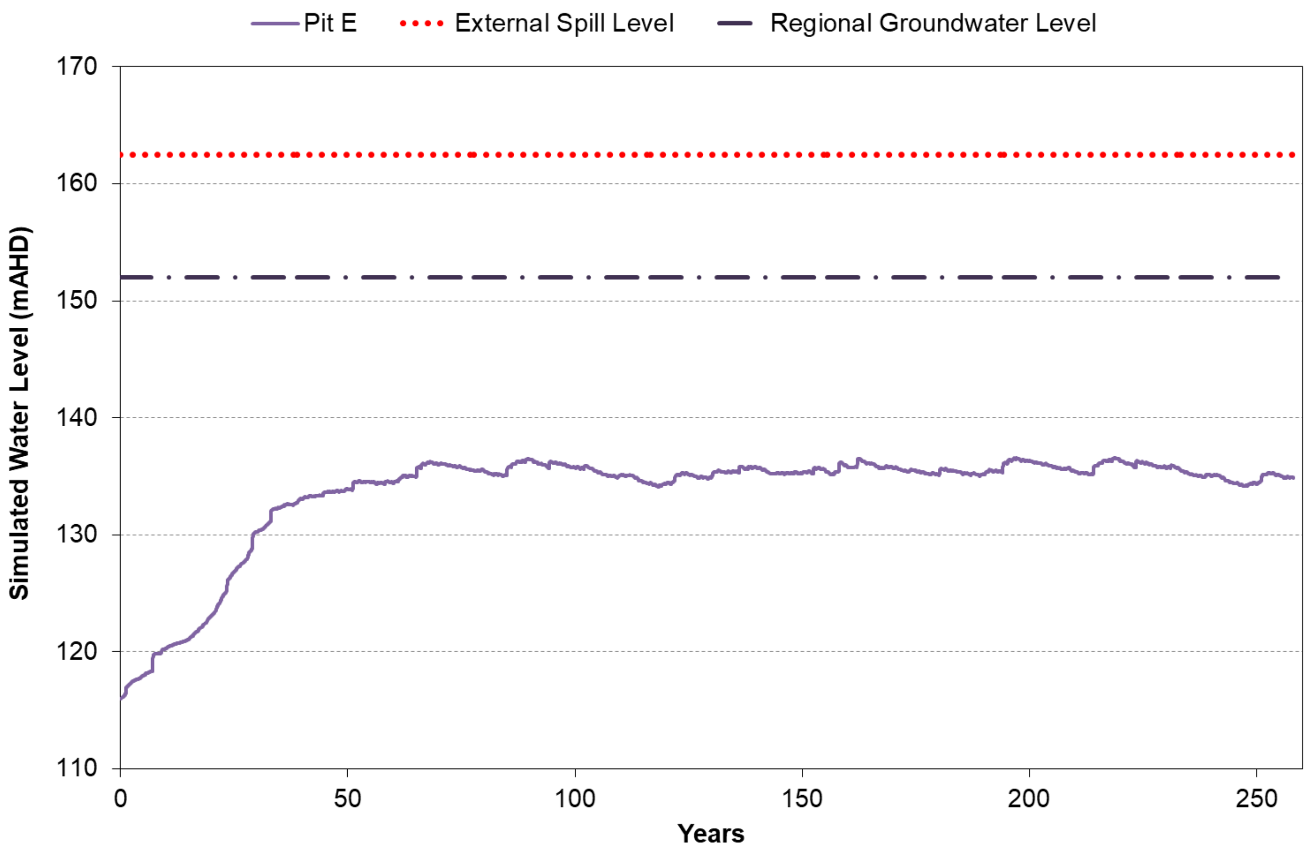

Figure 134 Water Level Results: Model Run 7a, Pit E

Figure 133 shows that Pit A reaches equilibrium water level after around 75 years at approximately 138.5 mAHD or 25 m below the spill level (163.5 mAHD) and approximately 9.5 m below the regional groundwater level (148 mAHD).

Figure 134 shows that Pit E reaches equilibrium water level after around 75 years at approximately 135.5 mAHD or 27 m below the spill level (162.5 mAHD) and approximately 16.5 m below the regional groundwater level (152 mAHD).

5.10.2 Water Volumes

Figure 135 shows the simulated water volume results over the 258 year simulation period for both of the voids in Model Run 7a.

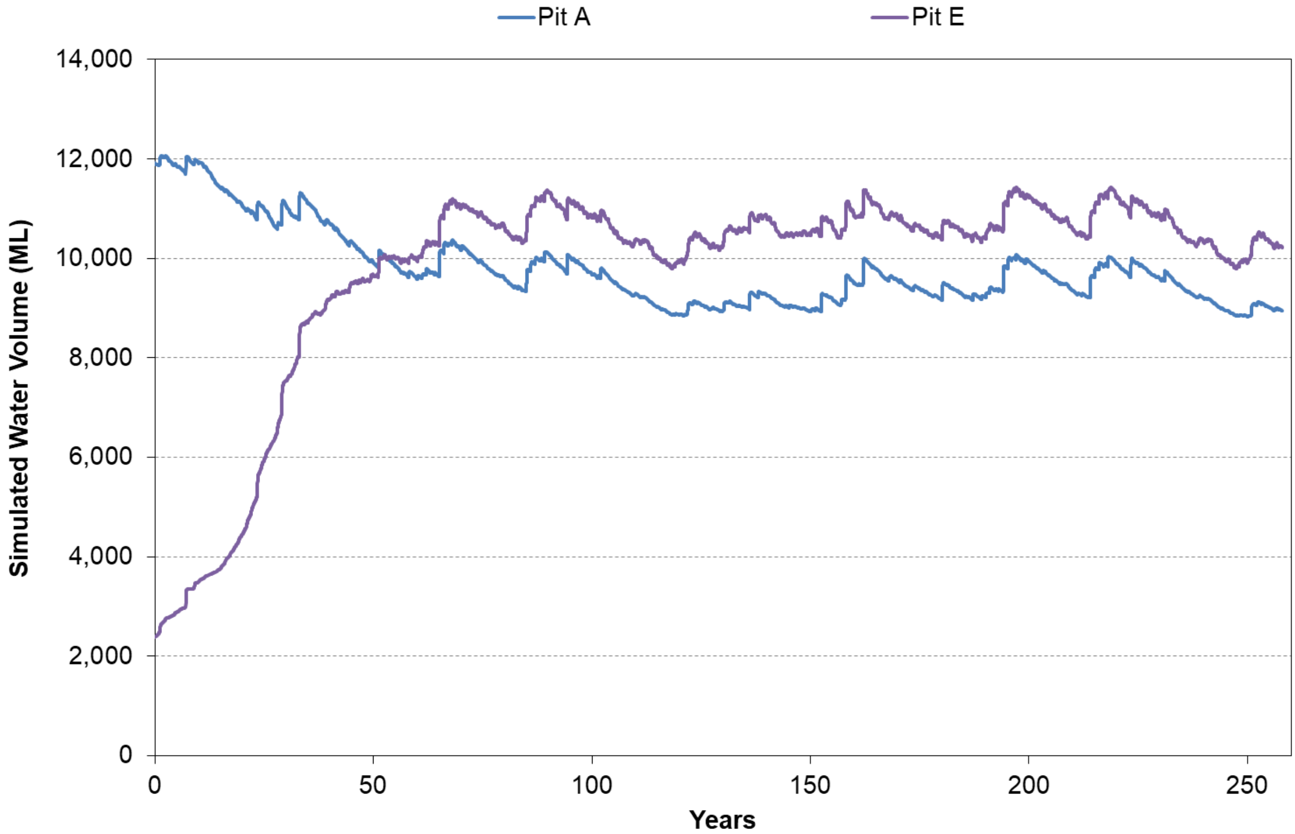

Figure 135 Water Volume Results: Model Run 7

Figure 135 shows that simulated water volumes in Pit A (approximately 9 GL after 250 years) are lower than Pit E (approximately 10 GL after 250 years).

5.10.3 Water Quality

Figure 136 to Figure 141 show water quality results (major ions, trace elements and salinity) over the 258 year simulation period for both of the voids in Model Run 7a.

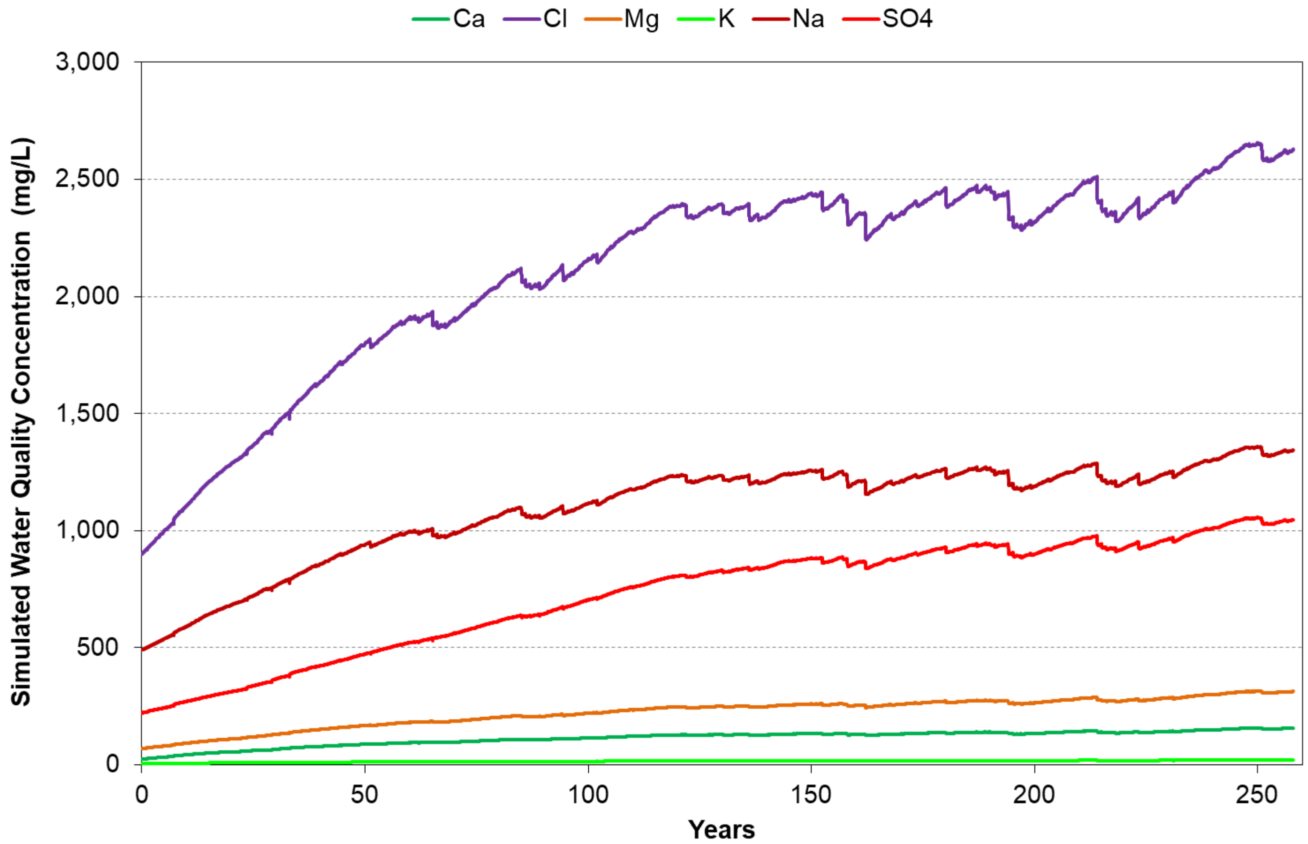

Figure 136 Water Quality Results: Model Run 7a, Pit A – Major Ions

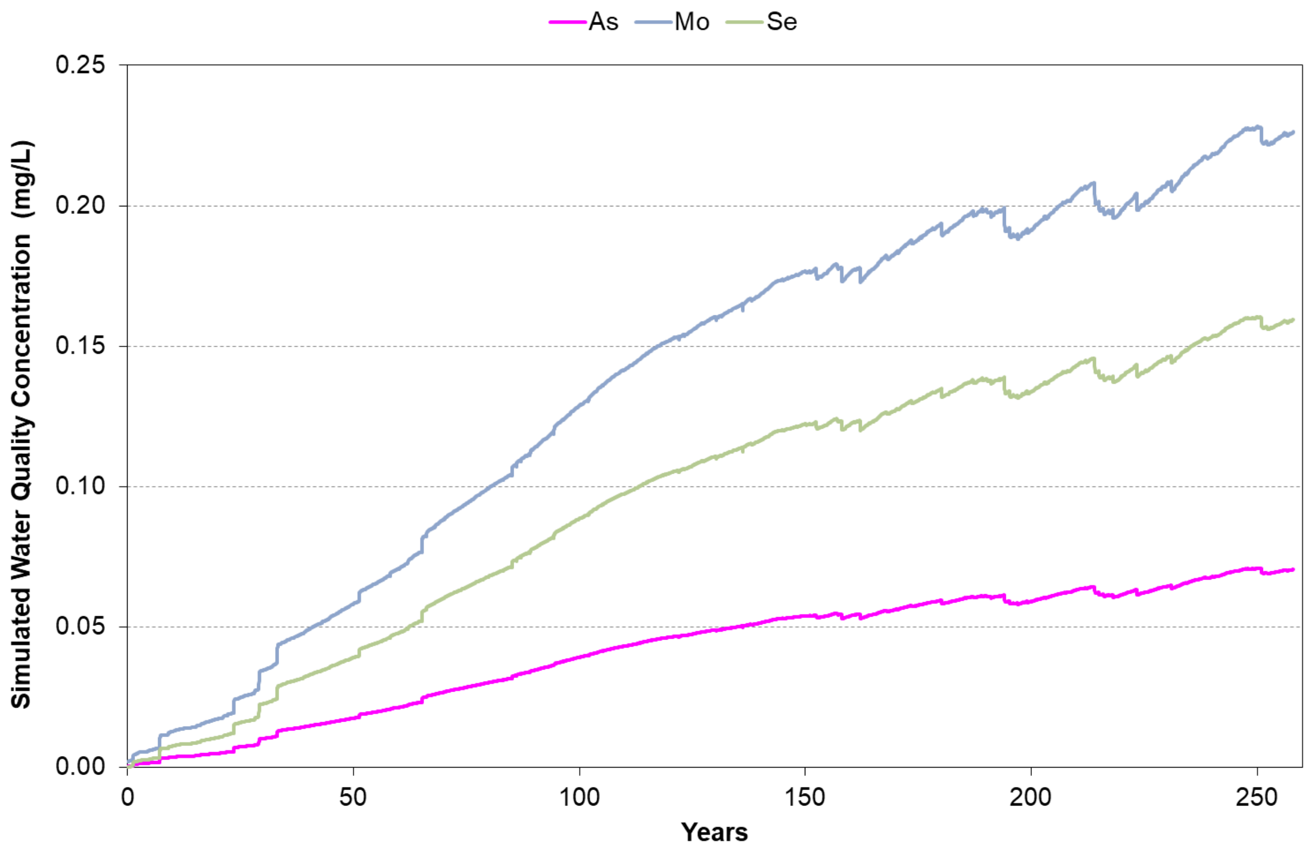

Figure 137 Water Quality Results: Model Run 7a, Pit A – Trace Elements

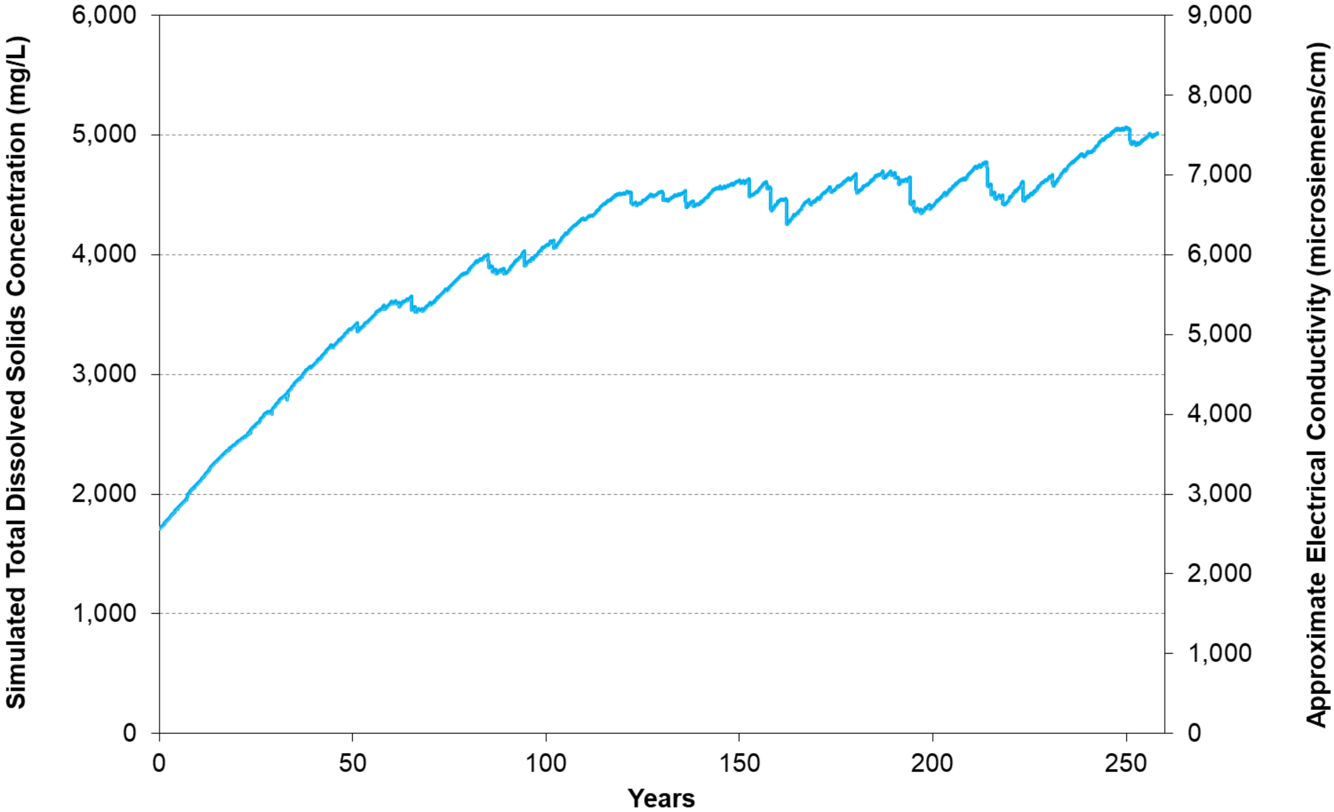

Figure 138 Water Quality Results: Model Run 7a, Pit A – Salinity

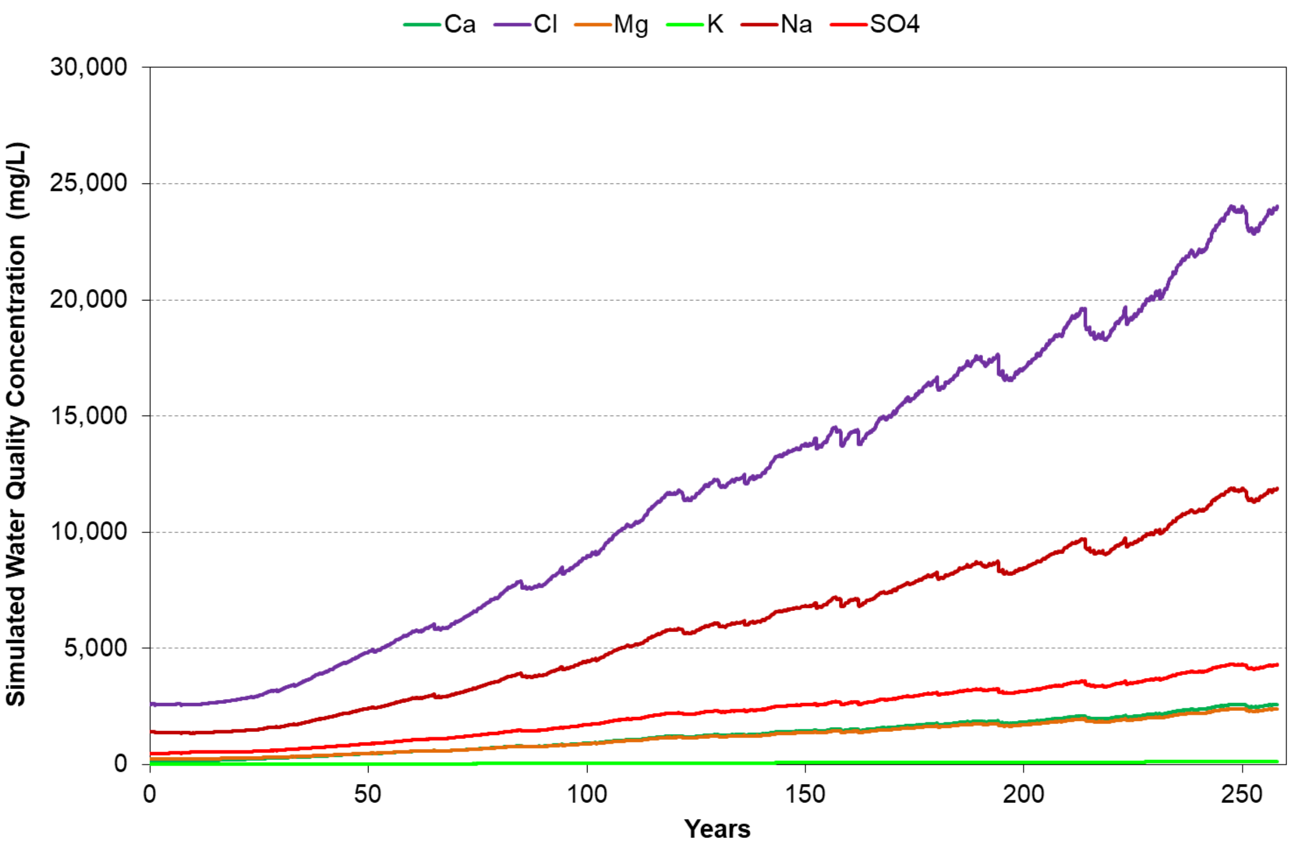

Figure 139 Water Quality Results: Model Run 7a, Pit E – Major Ions

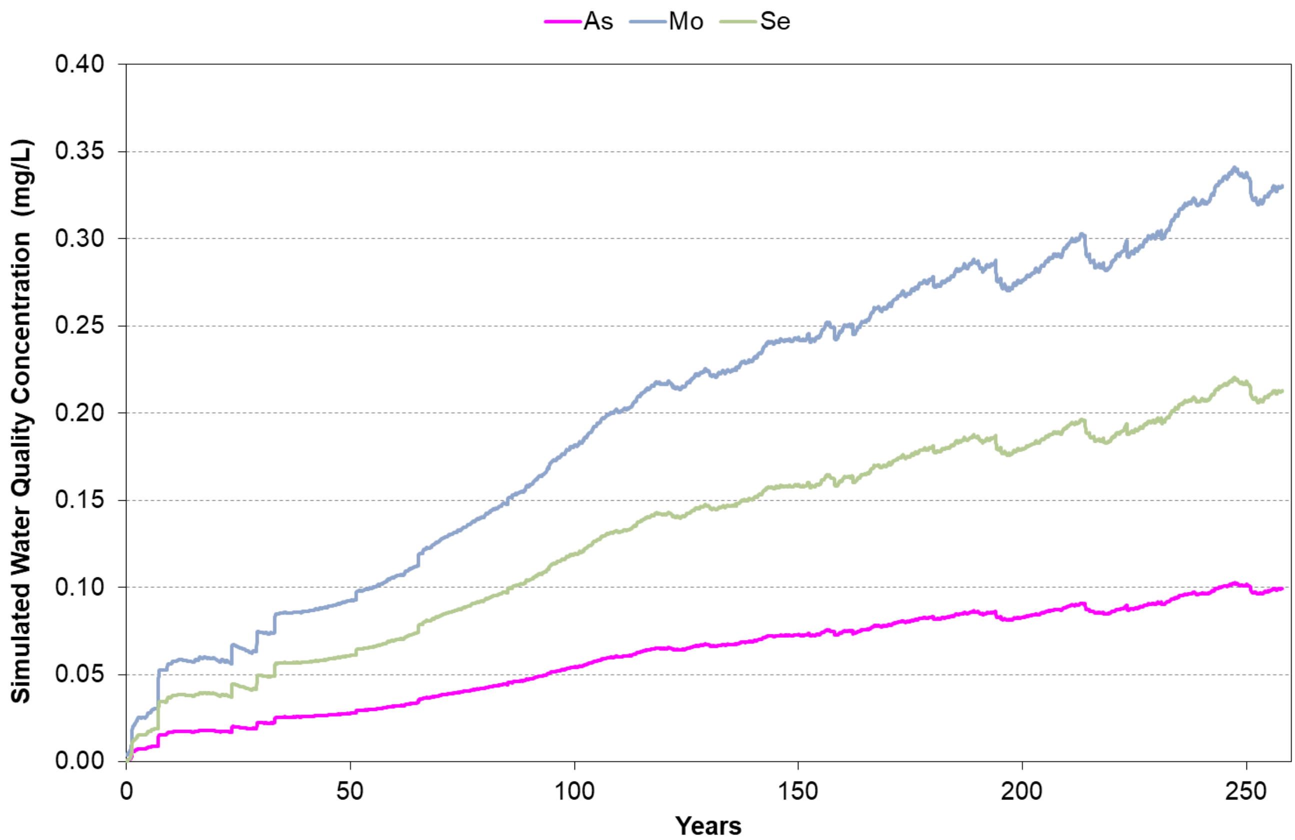

Figure 140 Water Quality Results: Model Run 7a, Pit E – Trace Elements

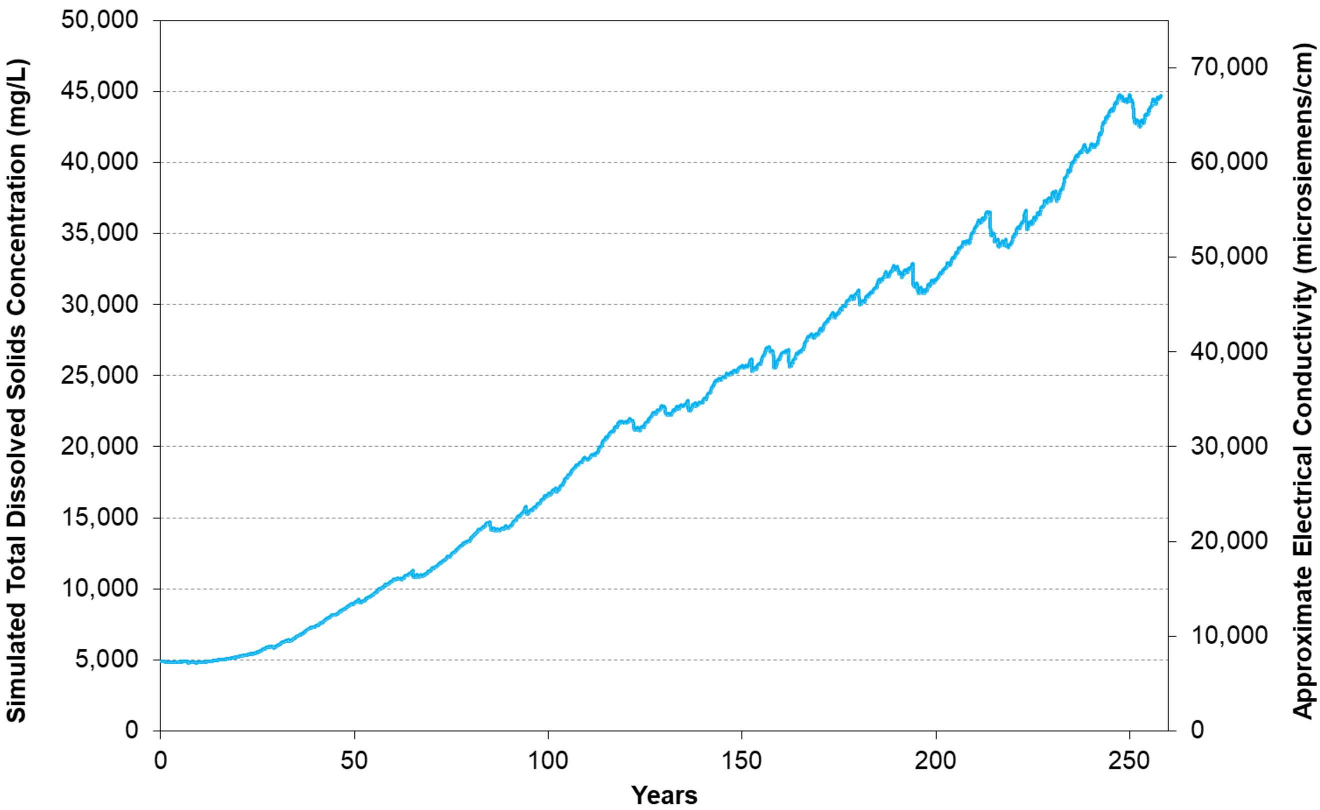

Figure 141 Water Quality Results: Model Run 7a, Pit E – Salinity

Figure 136 to Figure 141 show that simulated concentrations of solutes are all predicted to increase in Pit A and Pit E over the simulation period due to the only simulated outflow comprising evaporation via which no solutes can flow out of the voids.

5.11 MODEL RUN 8 RESULTS (SUBMITTED OPTION)

The objective of Model Run 8 is to predict the water levels, volumes and quality results for the Submitted Option. Results for each void for the base case Submitted Option are summarised in the sections that follow.

5.11.1 Water Levels

Figure 142 to Figure 145 show the simulated water levels over the 258 year simulation period for each of the voids in the Submitted Option base case.

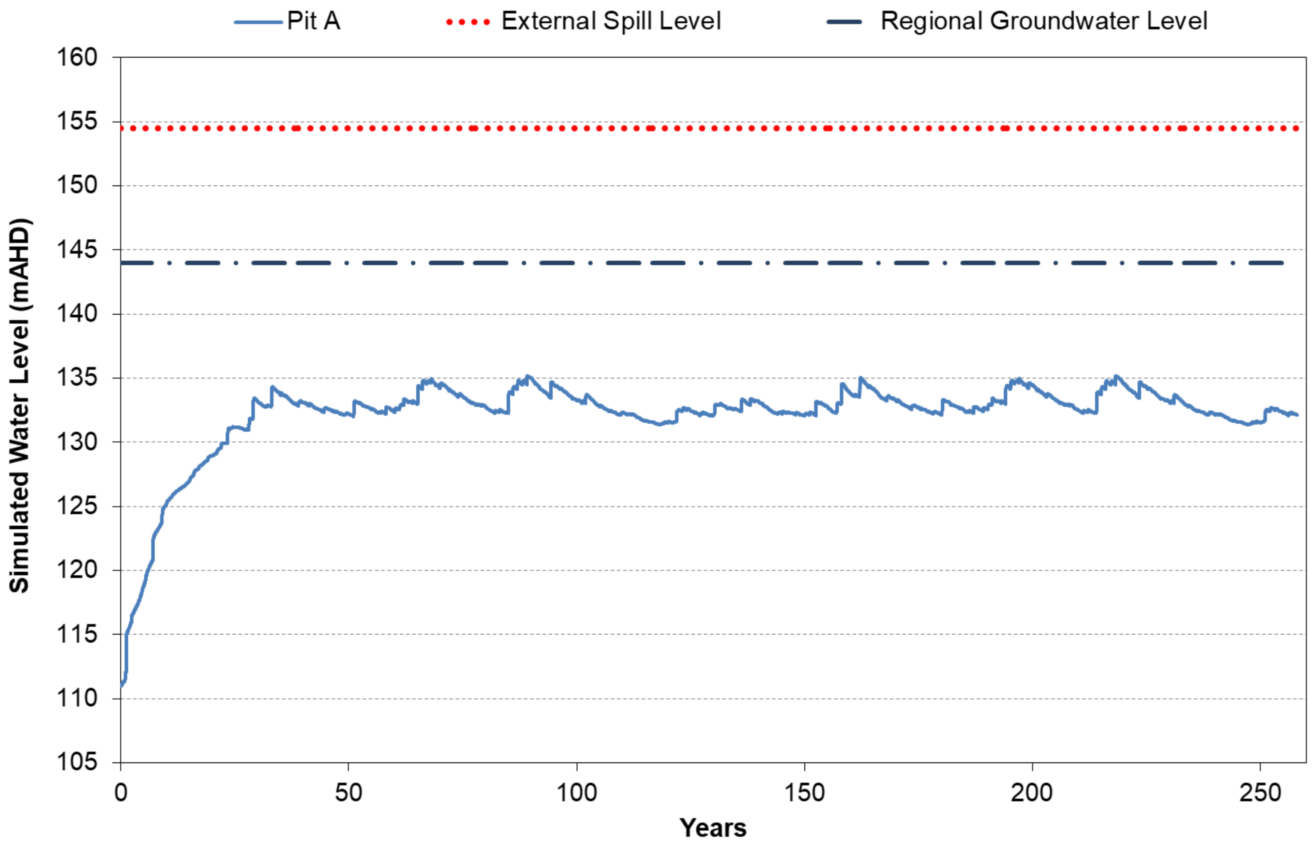

Figure 142 Water Level Results: Submitted Option Base Case, Pit A

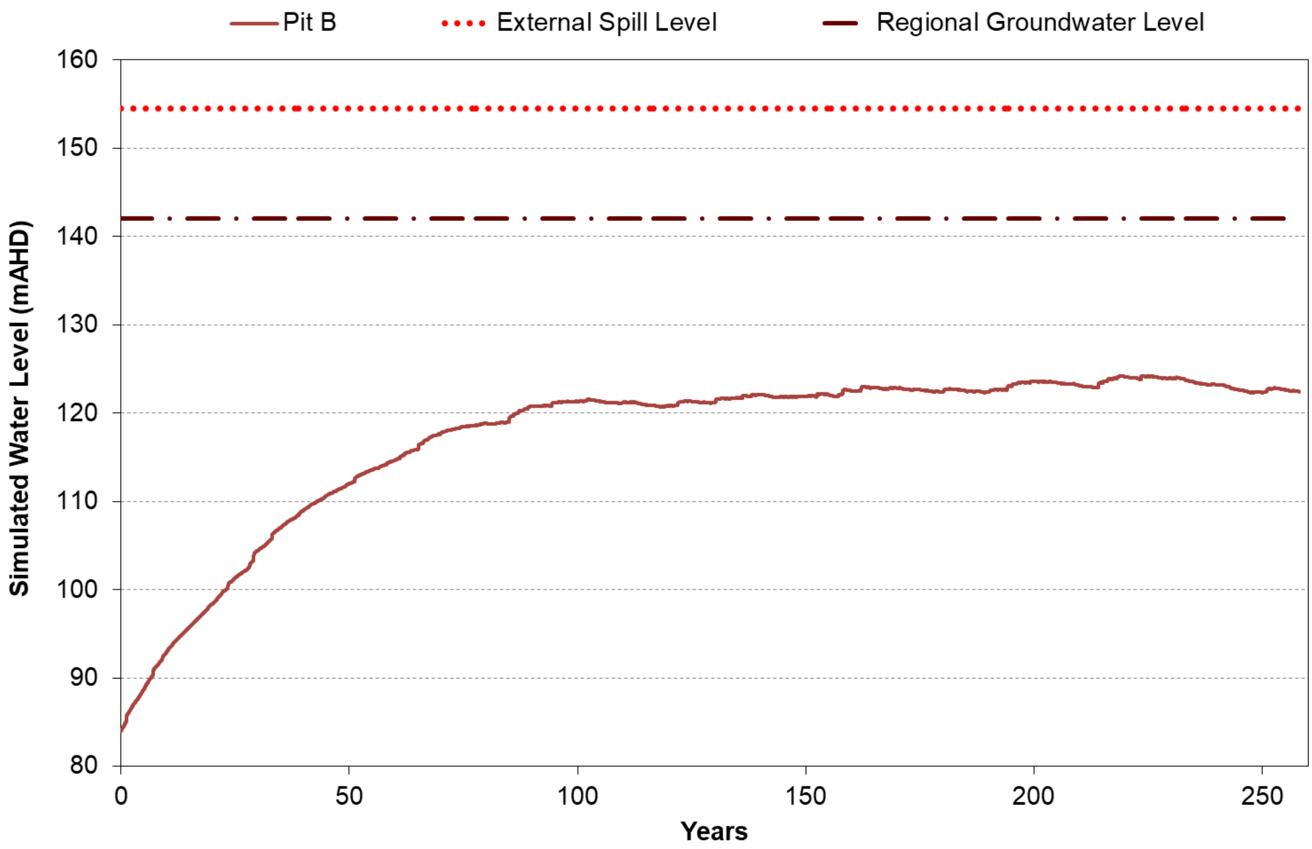

Figure 143 Water Level Results: Submitted Option Base Case, Pit B

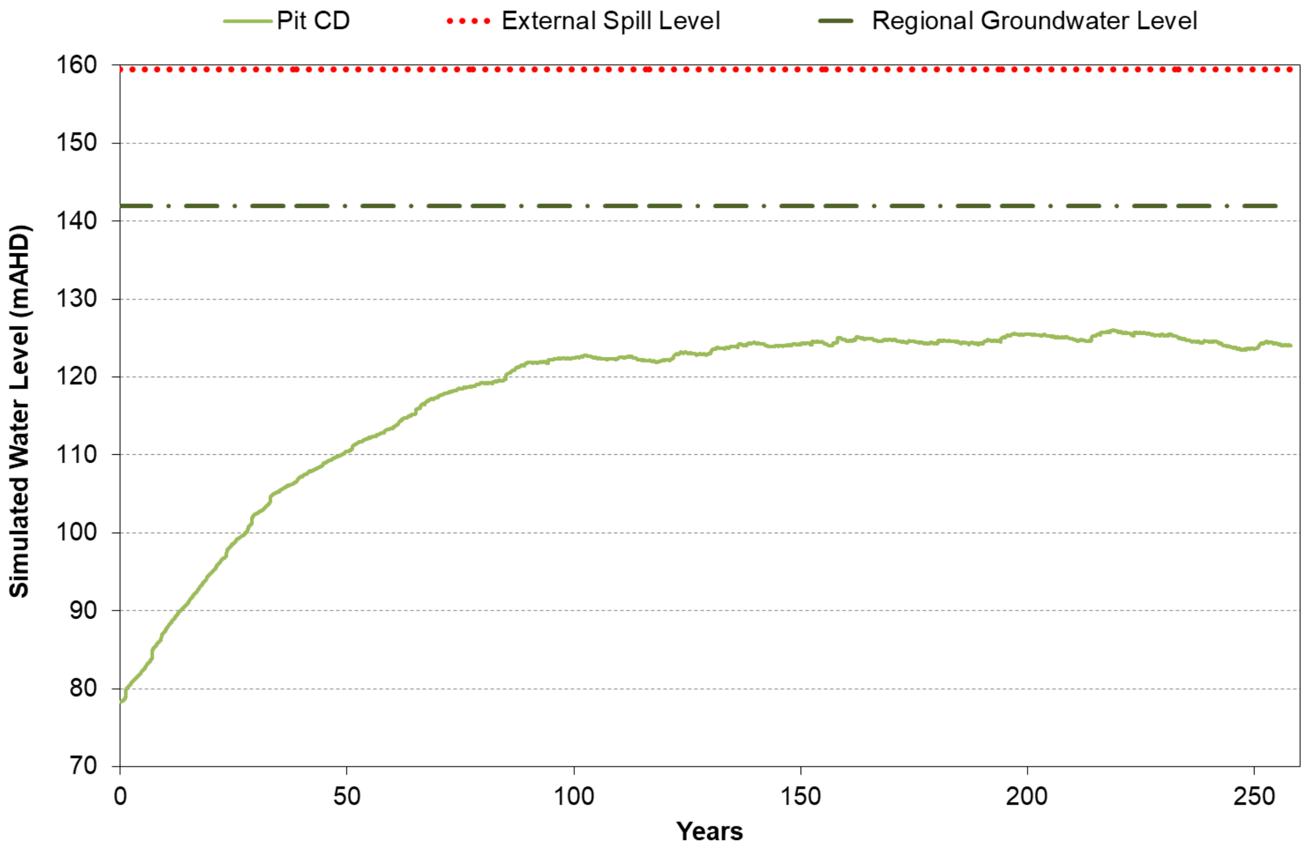

Figure 144 Water Level Results: Submitted Option Base Case, Pit CD

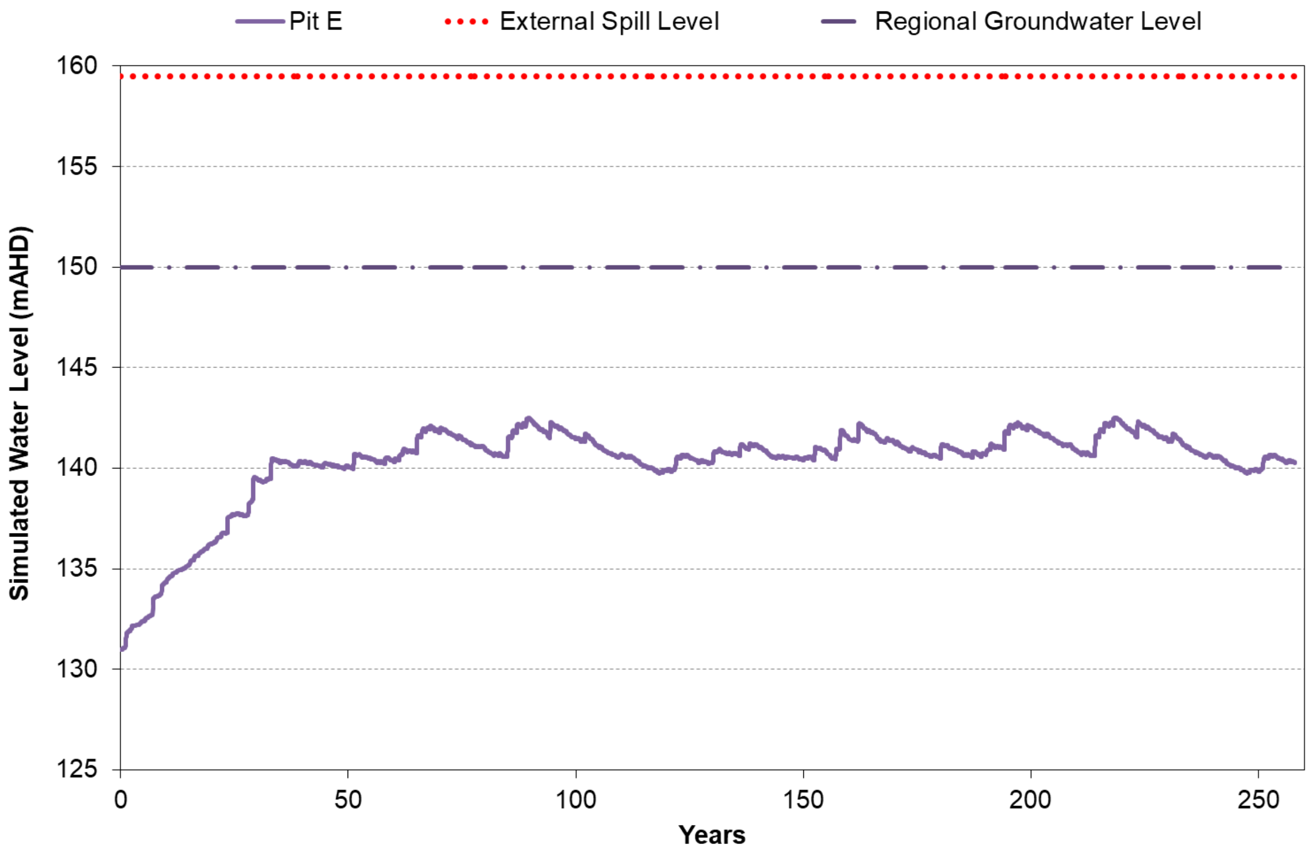

Figure 145 Water Level Results: Submitted Option Base Case, Pit E

Figure 142 shows that Pit A reaches equilibrium water level after around 50 years at approximately 133 mAHD or 21.5 m below the external spill level (154.5 mAHD) and approximately 11 m below the regional groundwater level (144 mAHD).

Figure 143 shows that Pit B reaches equilibrium water level after around 150 years at approximately 123 mAHD or 31.5 m below the external spill level (154.5 mAHD) and approximately 19 m below the regional groundwater level (142 mAHD).

Figure 144 shows that Pit CD reaches equilibrium after around 150 years at approximately 125 mAHD or 34.5 m below the external spill level (159.5 mAHD) and approximately 17 m below the regional groundwater level (142 mAHD).

Figure 145 shows that Pit E reaches equilibrium after around 75 years at approximately 141 mAHD or 18.5 m below the external spill level (159.5 mAHD) and approximately 9 m below the regional groundwater level (150m AHD).

Figure 146 provides a conceptual representation of the results for the Submitted Option base case for all four pits simulated. It shows the predicted long-term average water level in each pit, with the volume occupied by free water in blue and the volume stored in the spoil piles in grey. As all pit shells contain backfilled spoil at the lowest points, water is stored in spoil below the level of visible water. All predicted long-term average water levels are below the external "spill" level (i.e. the level at which water would overflow out of the pit). There will be no export of water from the pits to surface water in the receiving environment. Predicted water levels in the pits are also compared with the regional groundwater levels: all pit water levels are beneath the regional groundwater levels. Groundwater will flow from the regional system to the pits. There will be no flow from the pits to the regional groundwater system.

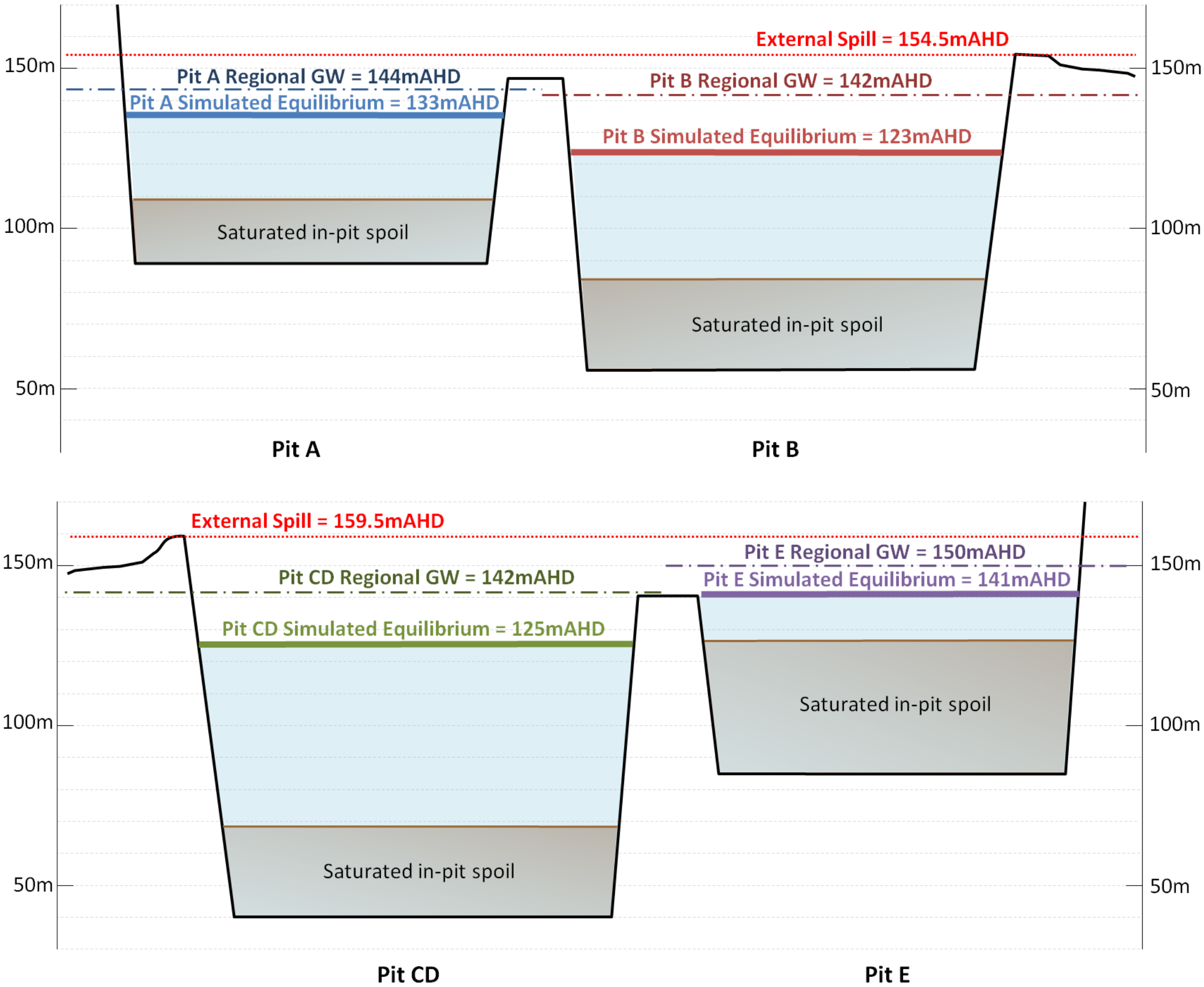

Figure 146 Conceptual Representation of Submitted Option Base Case Results

5.11.1 Water Volumes

Figure 147 shows the simulated water volume results over the 258 year simulation period for each of the voids in the base case.

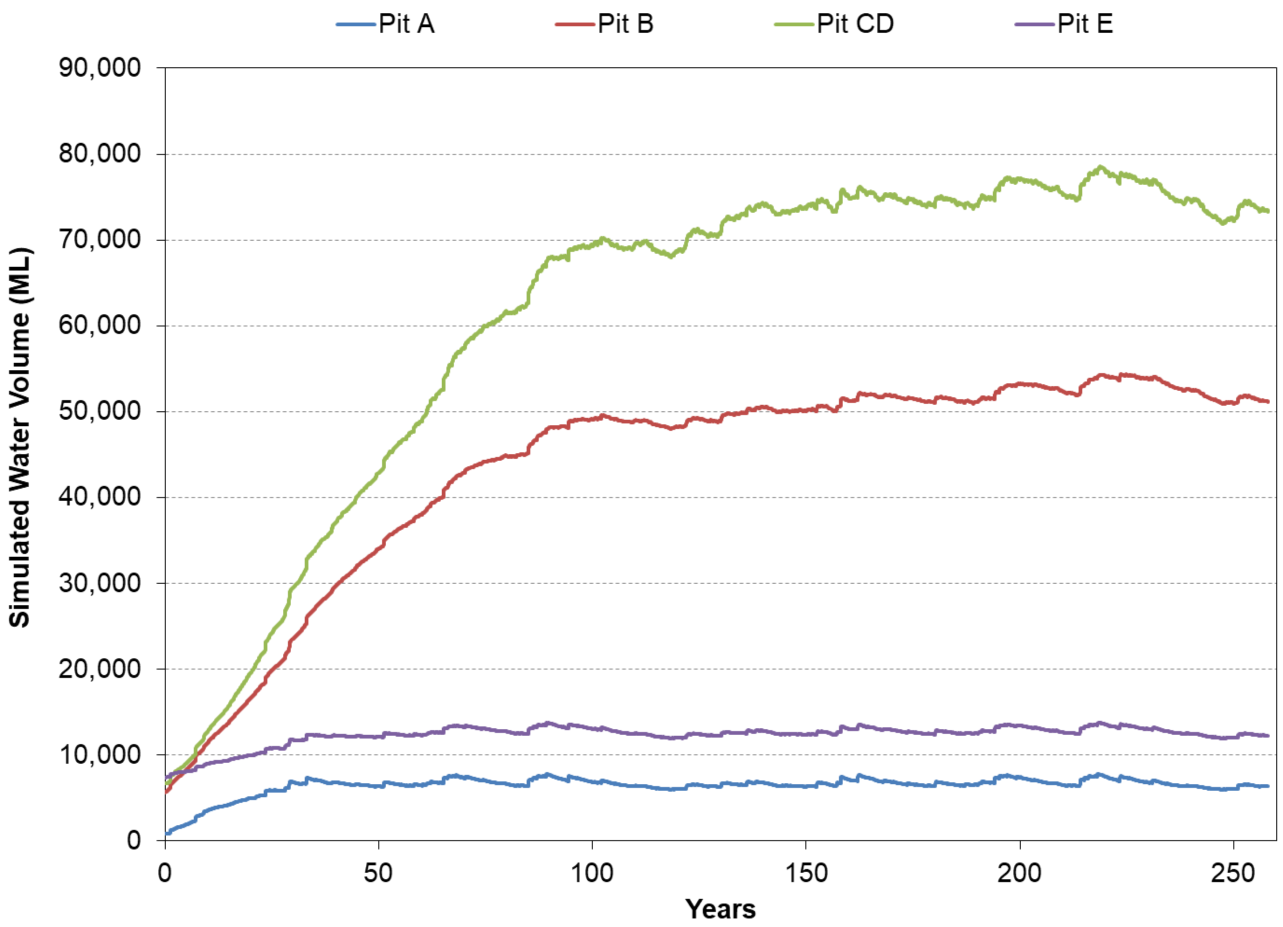

Figure 147 Water Volume Results: Submitted Option Base Case

Figure 147 shows that the simulated water volume in Pit CD (approximately 73 GL after 250 years) is the highest followed by Pit B (approximately 51 GL after 250 years). Pit A and Pit E are both simulated to store less than 20 GL over the simulation period.

5.11.2 Water Quality

Figure 148 to Figure 159 show water quality results (major ions, trace elements and salinity) over the 258 year simulation period for each of the voids in the Submitted Option base case.

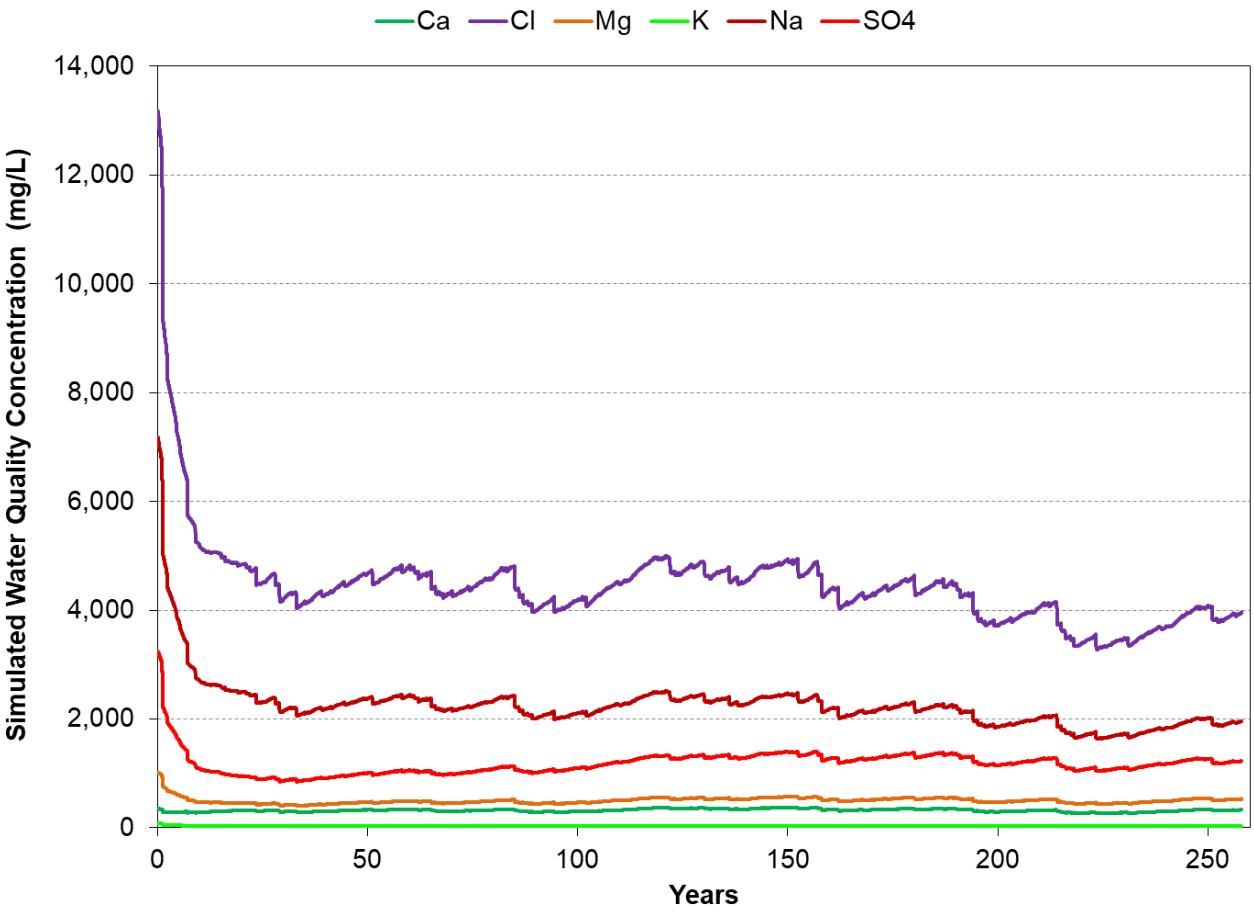

Figure 148 Water Quality Results: Submitted Option Base Case, Pit A – Major Ions

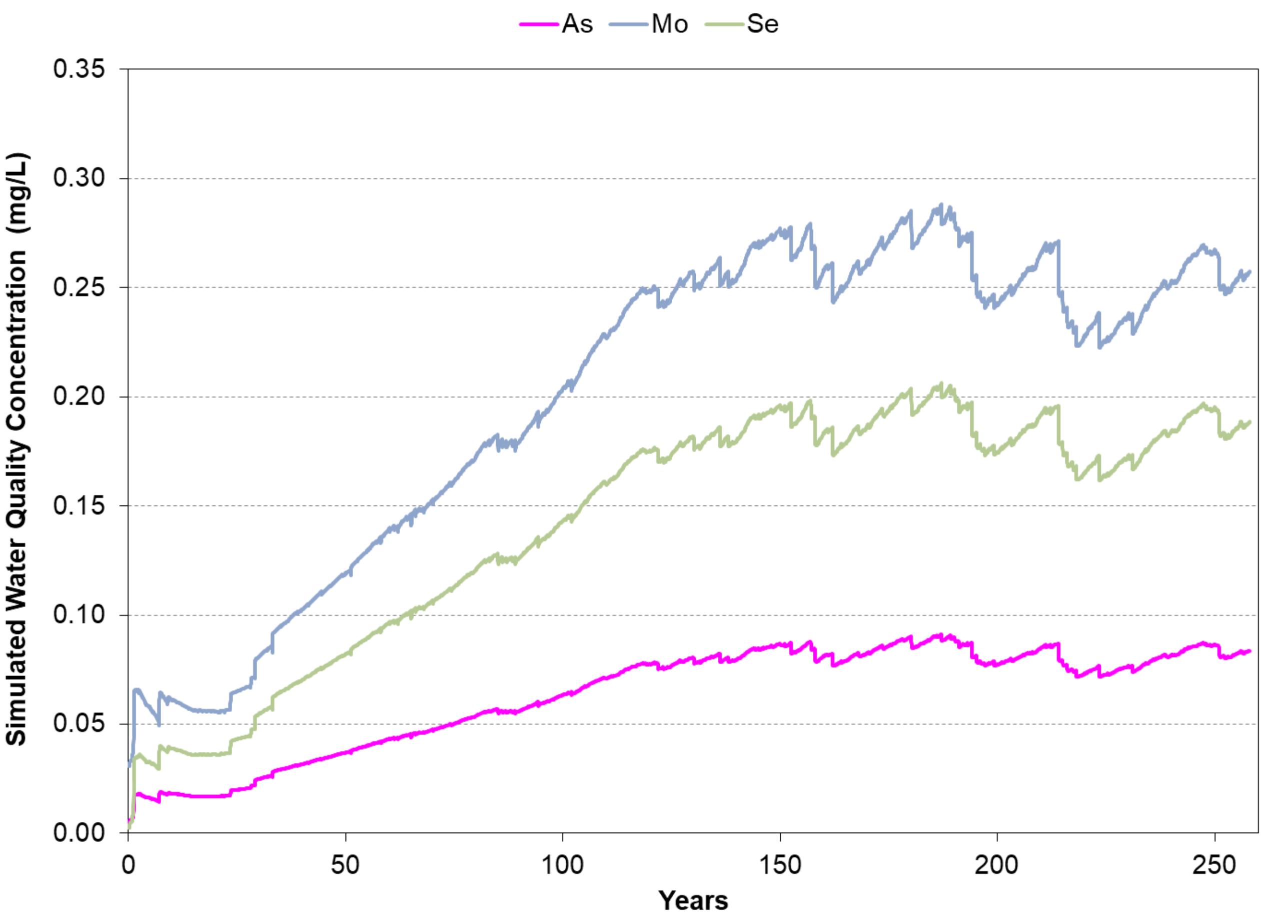

Figure 149 Water Quality Results: Submitted Option Base Case, Pit A – Trace Elements

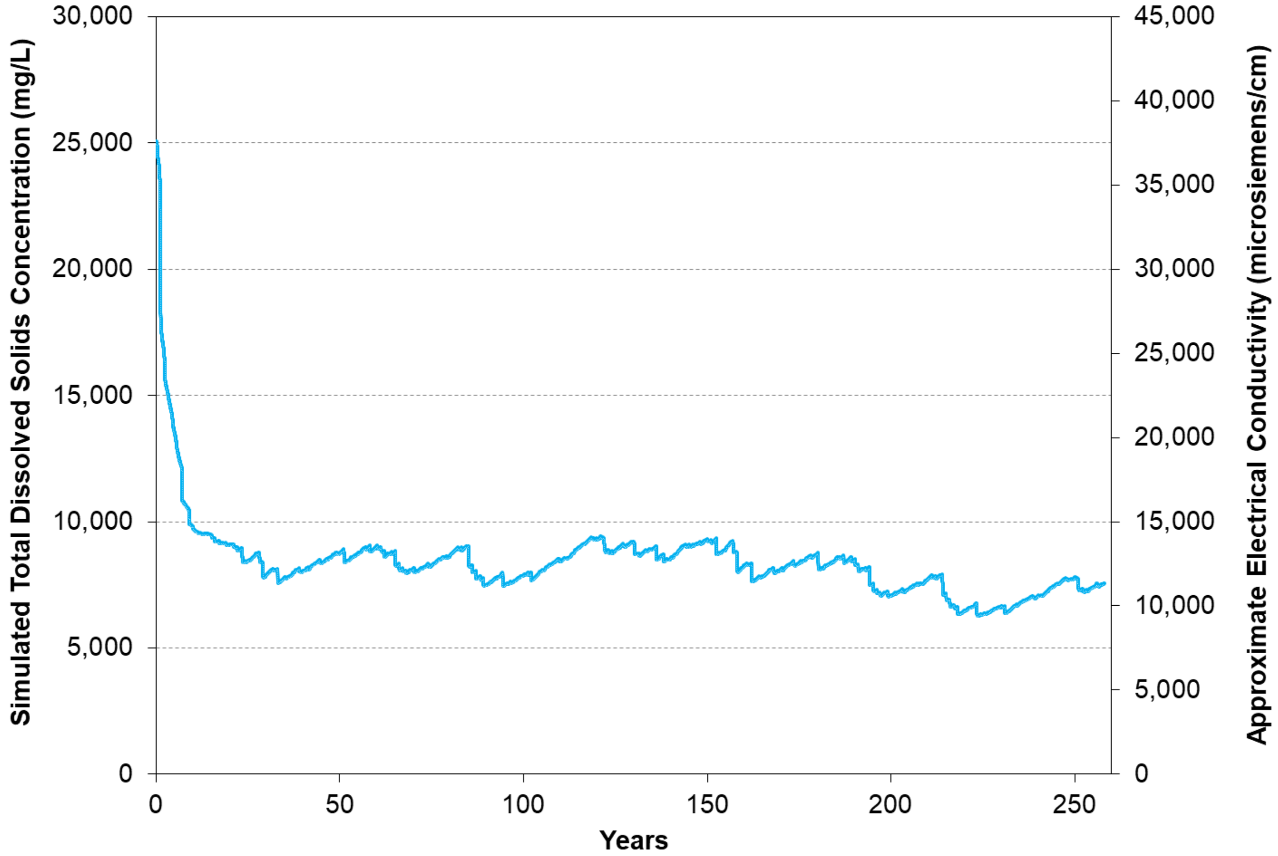

Figure 150 Water Quality Results: Submitted Option Base Case, Pit A – Salinity

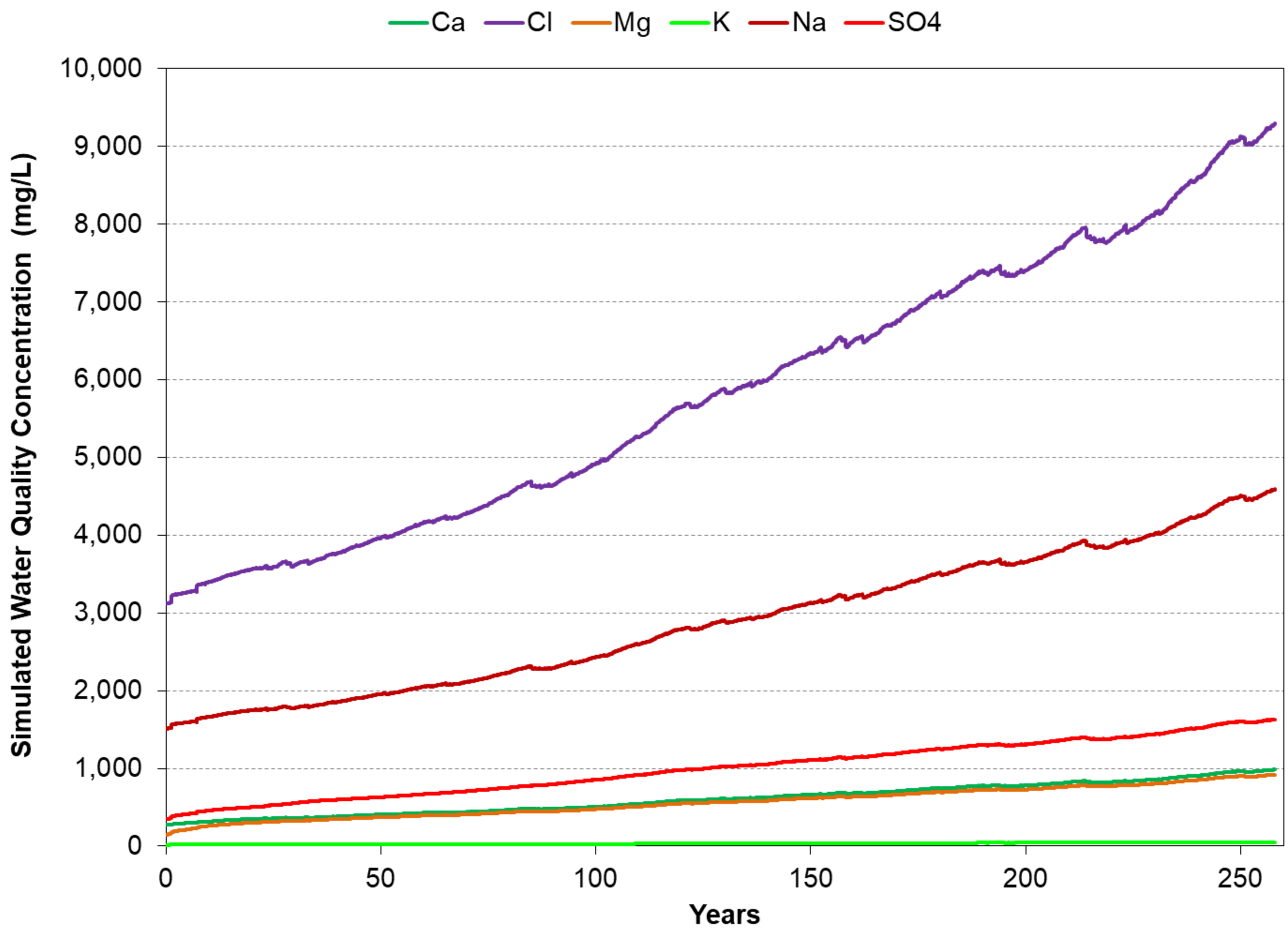

Figure 151 Water Quality Results: Submitted Option Base Case, Pit B – Major Ions

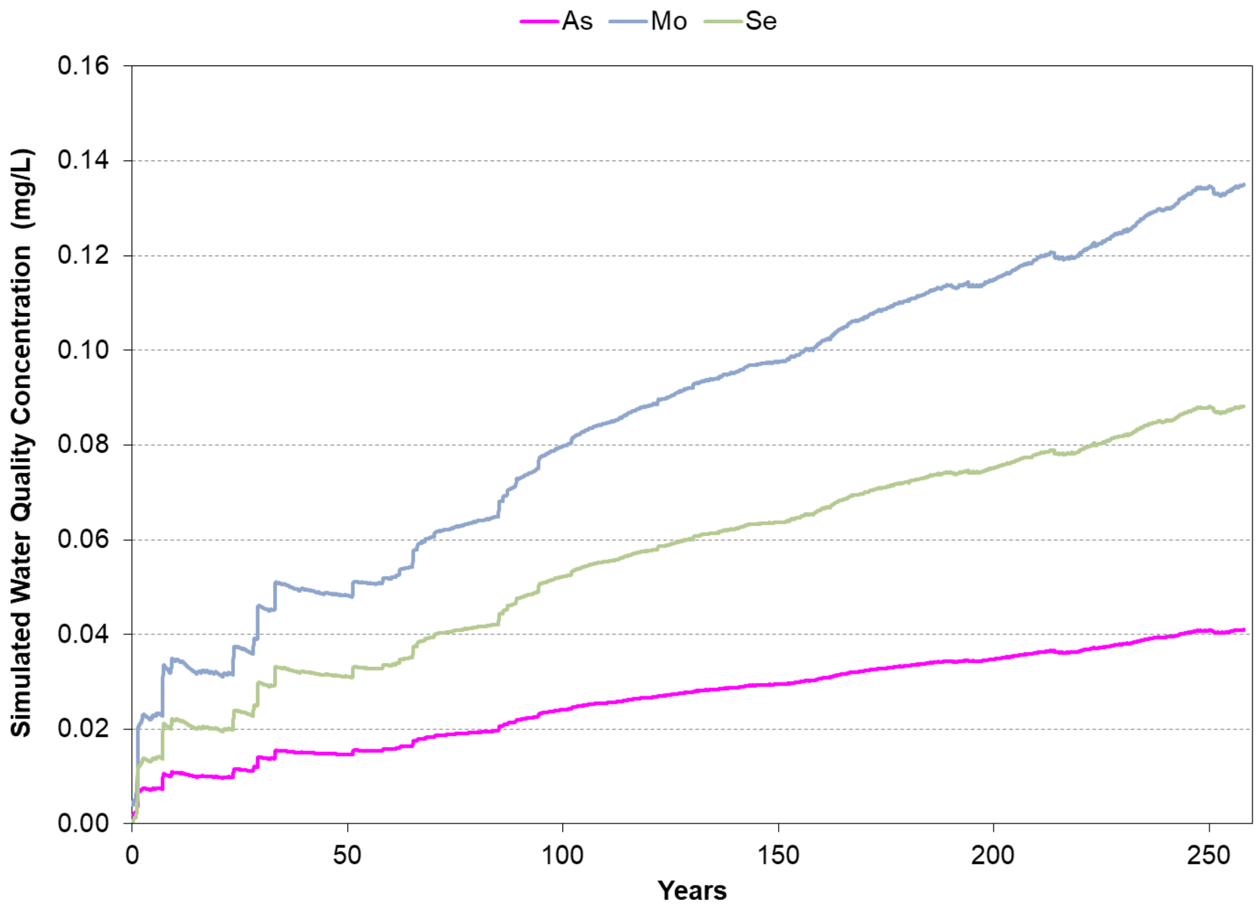

Figure 152 Water Quality Results: Submitted Option Base Case, Pit B – Trace Elements

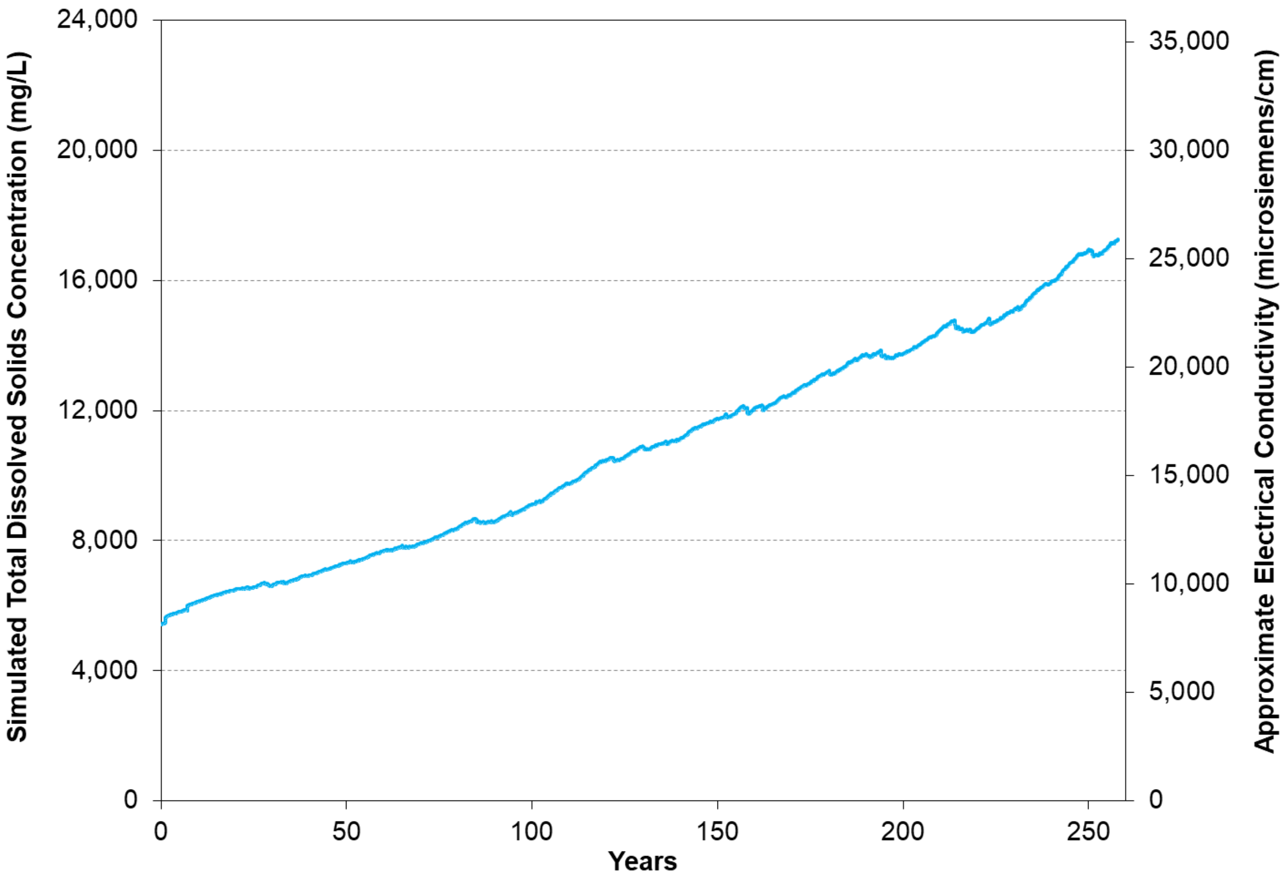

Figure 153 Water Quality Results: Submitted Option Base Case, Pit B – Salinity

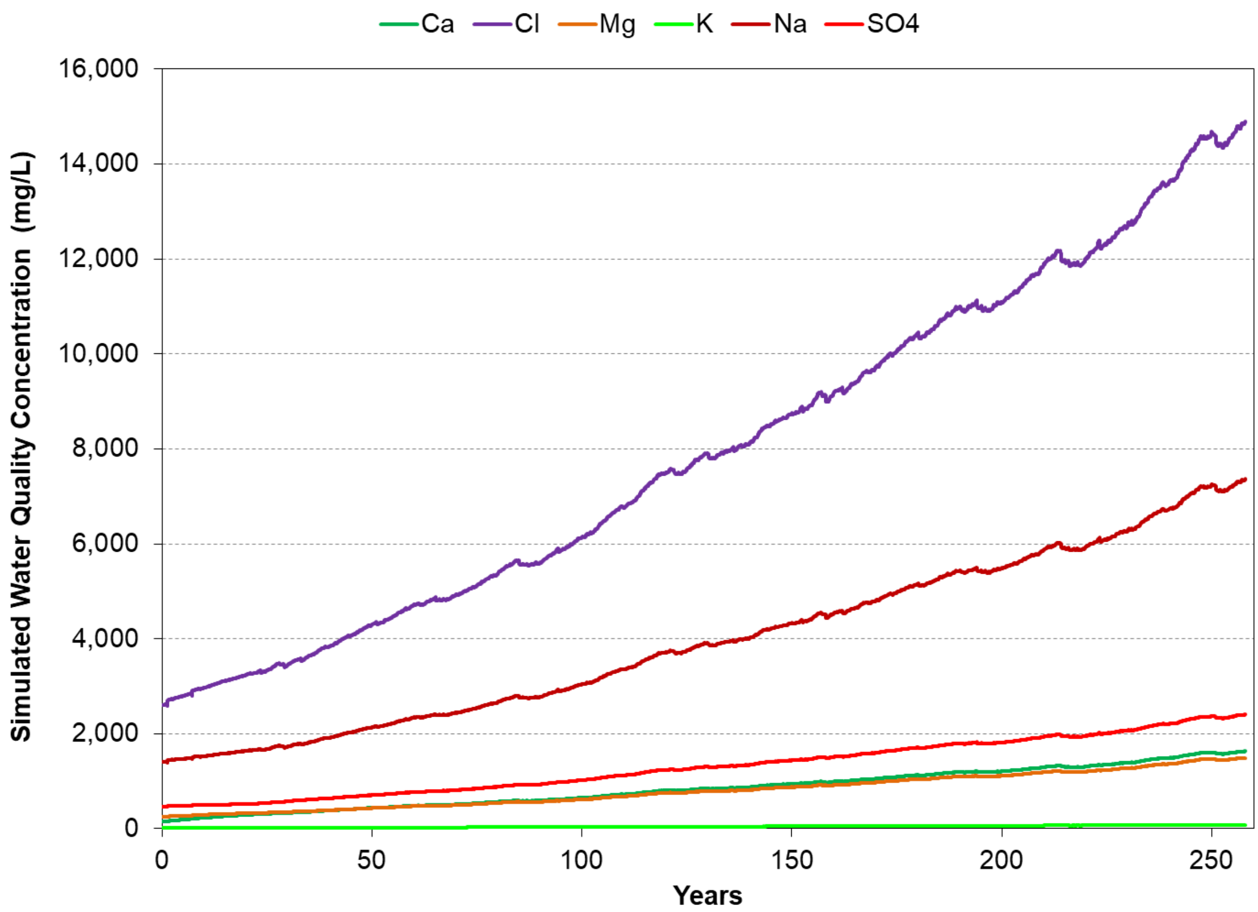

Figure 154 Water Quality Results: Submitted Option Base Case, Pit CD – Major Ions

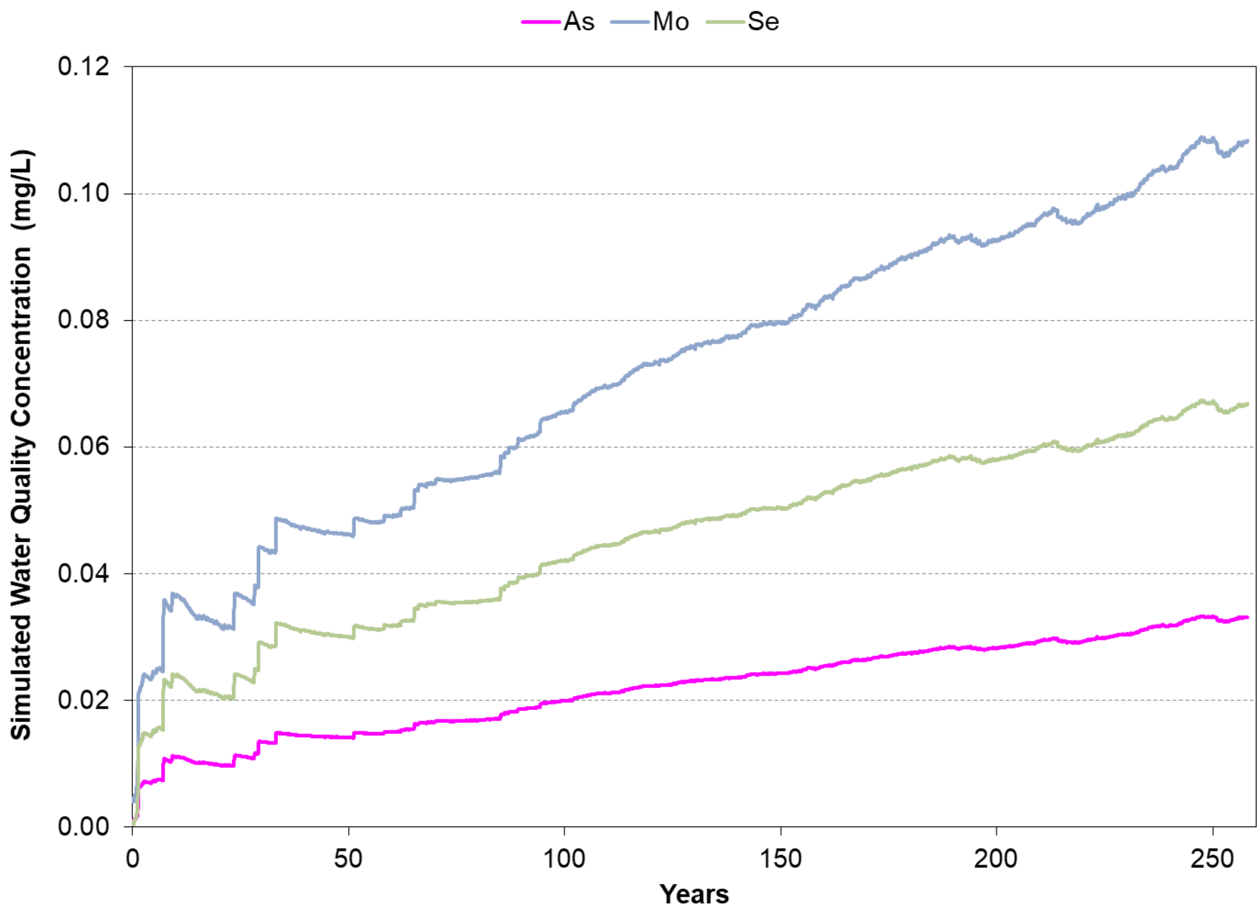

Figure 155 Water Quality Results: Submitted Option Base Case, Pit CD – Trace Elements

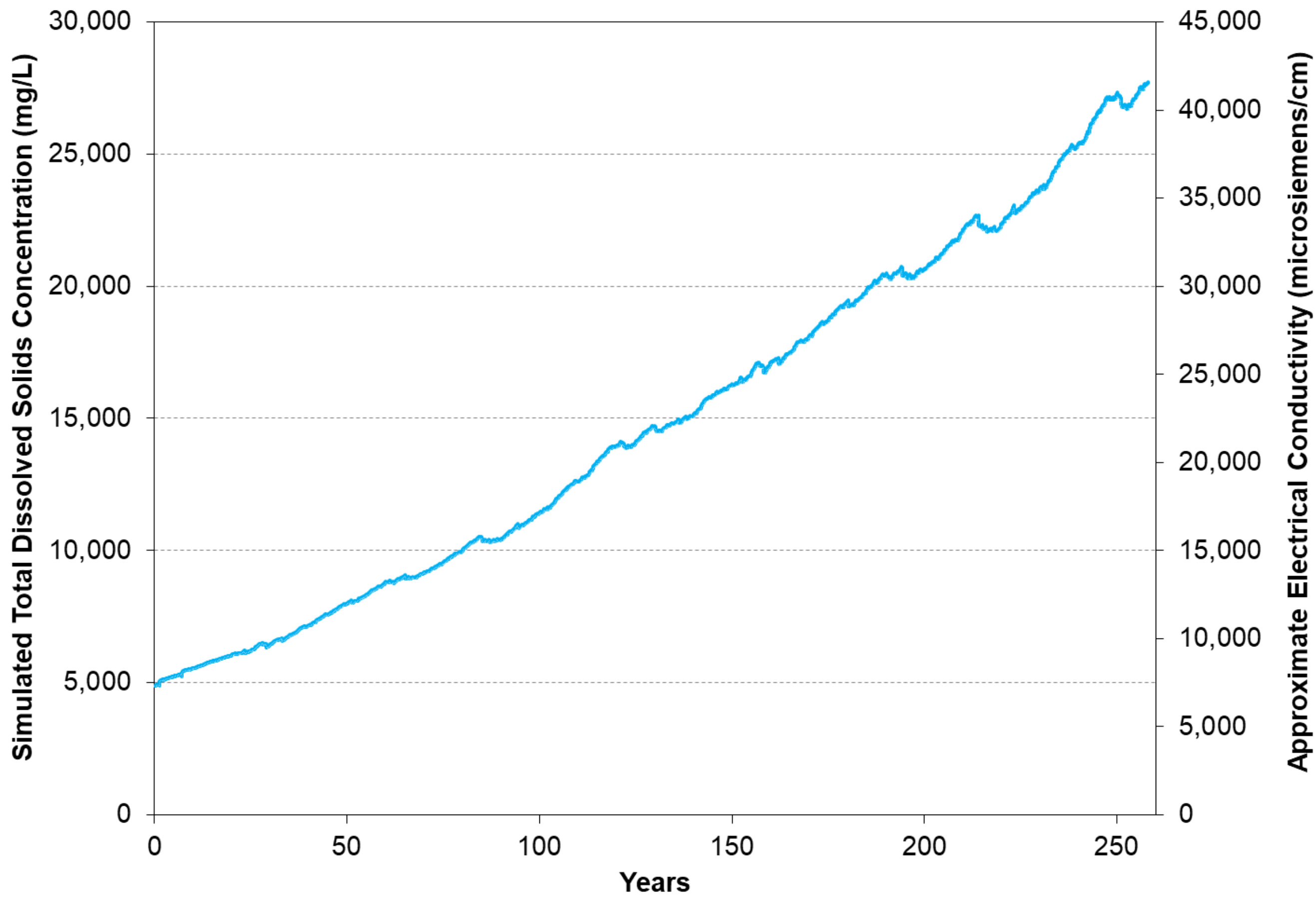

Figure 156 Water Quality Results: Submitted Option Base Case, Pit CD – Salinity

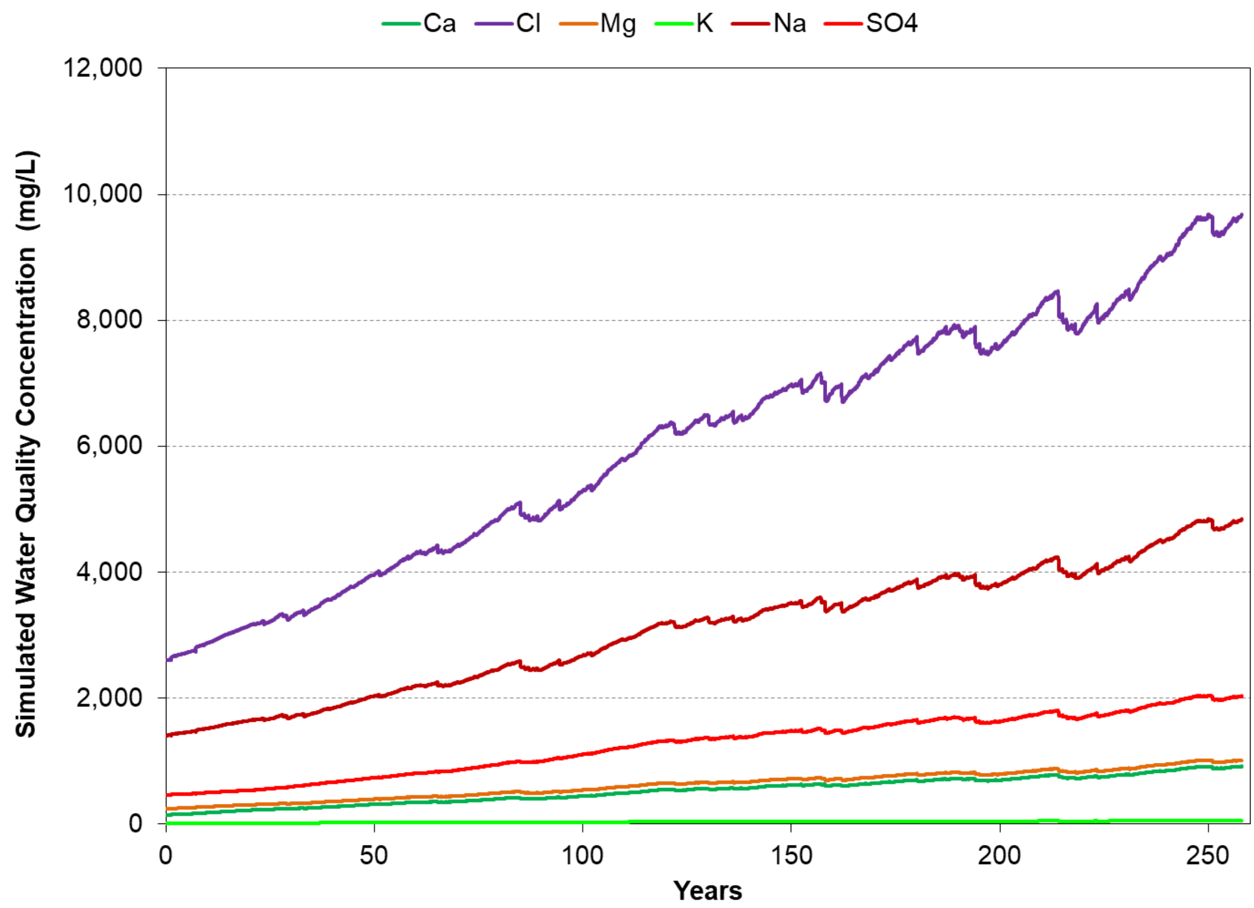

Figure 157 Water Quality Results: Submitted Option Base Case, Pit E – Major Ions

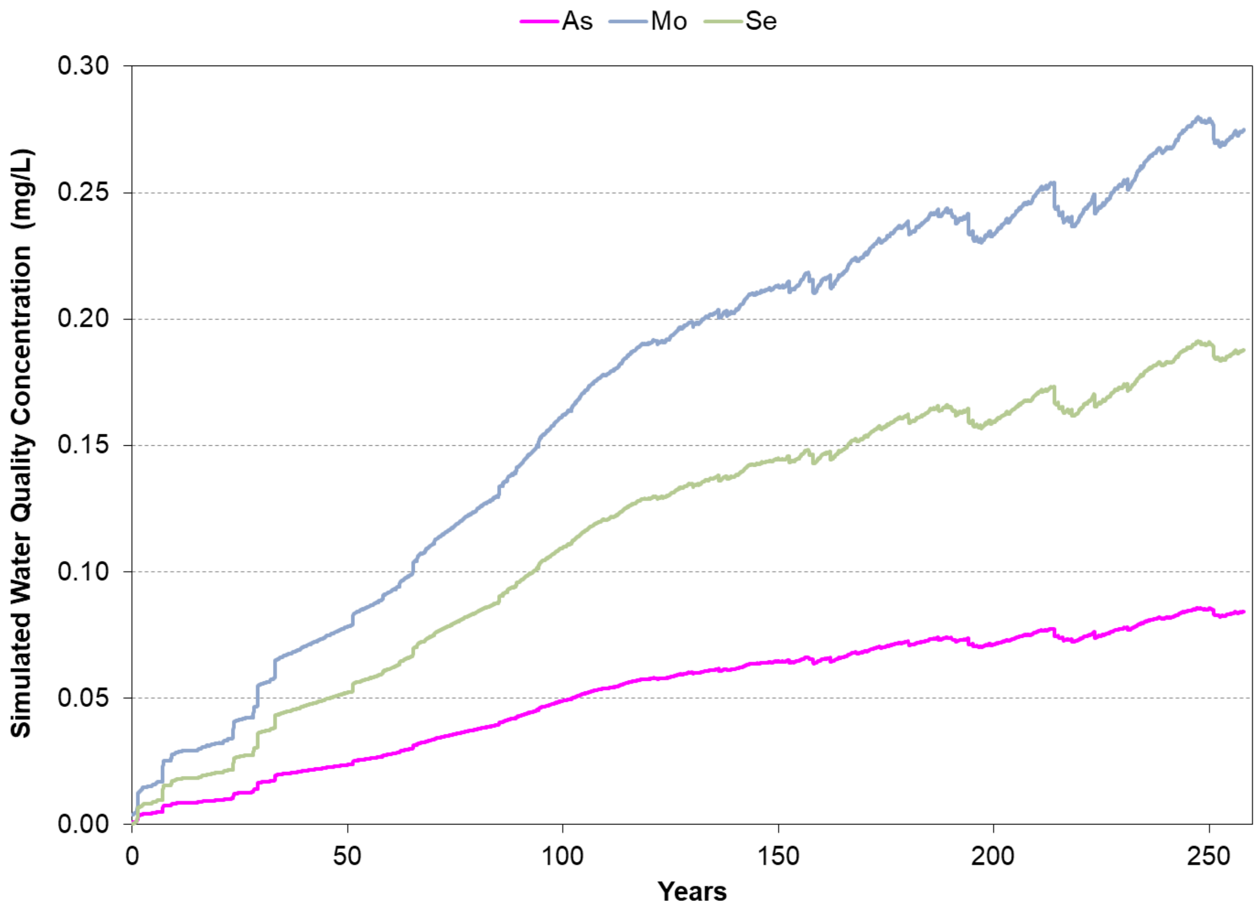

Figure 158 Water Quality Results: Submitted Option Base Case, Pit E – Trace Elements

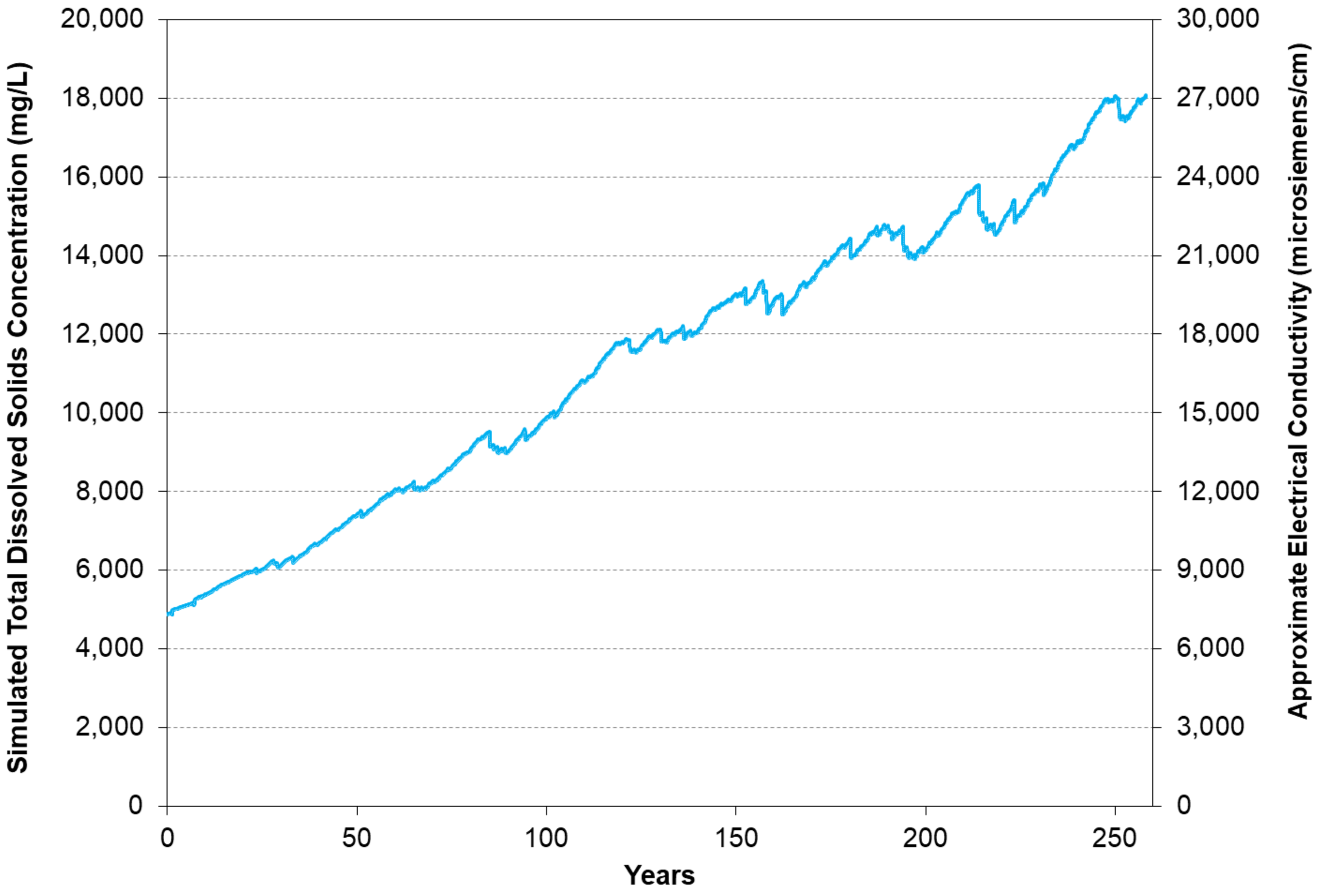

Figure 159 Water Quality Results: Submitted Option Base Case, Pit E – Salinity

Figure 148 to Figure 150 show simulated concentrations of solutes in Pit A reach an equilibrium due to the simulated outflow from Pit A to Pit B. Figure 151 to Figure 156 show that simulated concentrations of solutes in Pit B, Pit CD and Pit E are all predicted to trend upward during the simulation due to the only simulated outflow comprising evaporation via which no solutes can flow out of the voids.

5.12 ANALYSIS OF KEY MODEL RESULTS

5.12.1 Salinity: Initial Filling and Drawdown

To illustrate the effects of initial filling and drawdown, a comparison of simulated TDS in Pit CD for both Model Runs 4 and 5 is provided in Figure 160.

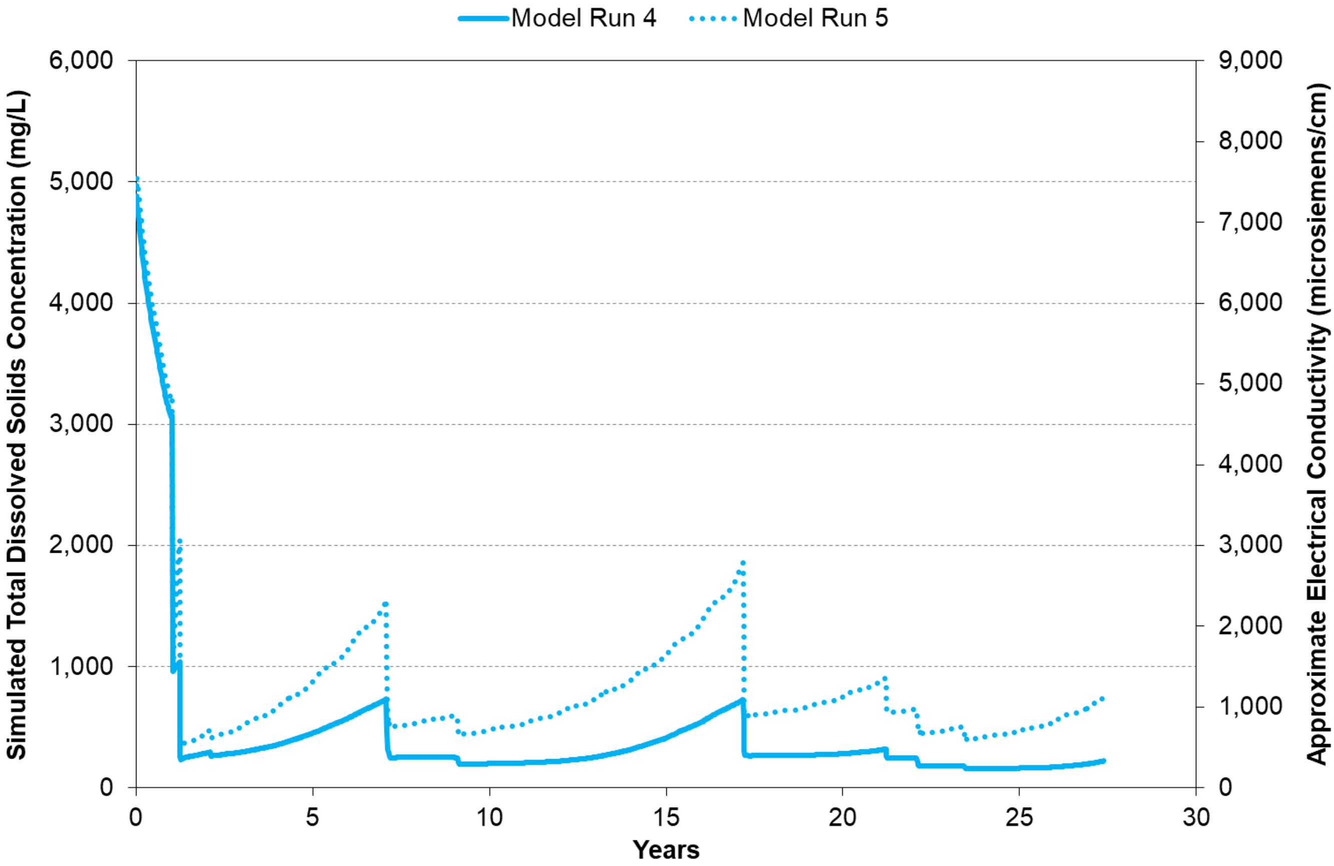

Figure 160 Salinity Comparison: Model Runs 4 and 5, Pit CD

Figure 160 shows that simulated TDS for Model Run 5 (potential elevated salinity during initial filling) is higher than simulated for Model Run 4. This is attributable to the additional salt load released from the in-pit spoil and the wall rock to the pit during the initial filling and drawdown processes. However, it is important to note that simulated TDS in Model Run 5 does not exceed the 2,000 mg/L irrigation limit after the initial inflow from the Nogoa River.

5.12.2 Supply to Irrigation Demand

Model Run 3 simulates irrigation demand from Pit B only supplying the average required water volume of 7.9 GL/year. Model Run 4 simulates irrigation demand from both Pit B and Pit CD, with an average supplied water volume of 7.9 GL/year from Pit B and 11.9 GL/year from Pit CD. Shortfalls were simulated in Model Runs 3, 4 and 4a but the salinity limit of 2,000 mg/L did not impede the ability of the voids to supply water to the irrigation demand. The impact of salt flushing assumptions on the salinity of water in Pit B and Pit CD as simulated in Model Run 5 showed that the salinity limit was reached and this decreased supply from Pit B to an average of 4.5 GL/year and from Pit CD to an average of 11.5 GL/year. However, following the initial few fill cycles, due to the dilution effects of the Nogoa River inflows (refer Section 5.5) this impact is expected to be negligible to the long term viability of water supply from Pit B and Pit CD to meet the irrigation demand. Figure 161 and Figure 162 provide plots of simulated stored water volume and salinity for Model Run 3 and Model Run 4 respectively.

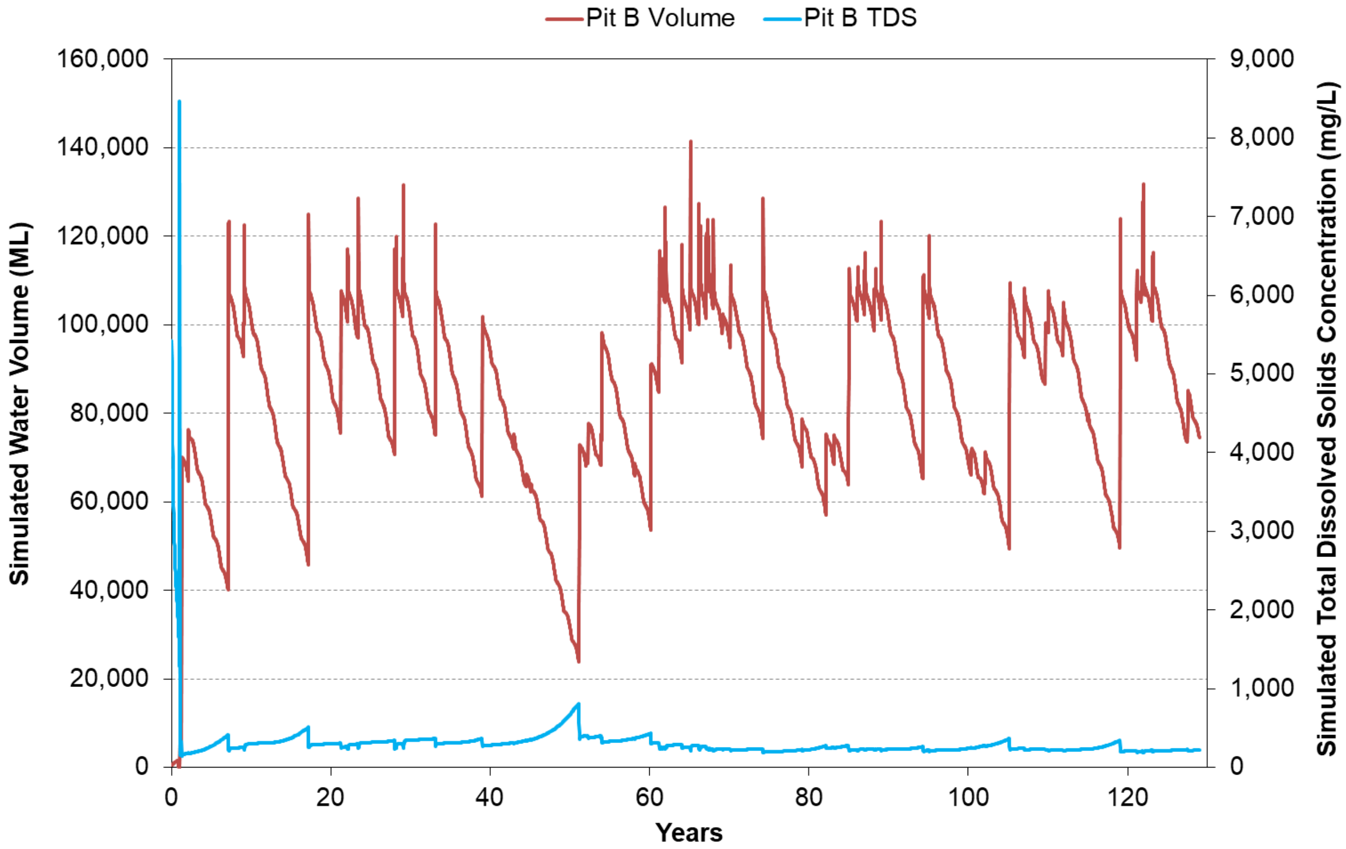

Figure 161 Irrigation Constraints: Run 3 Pit B Volume and Salinity

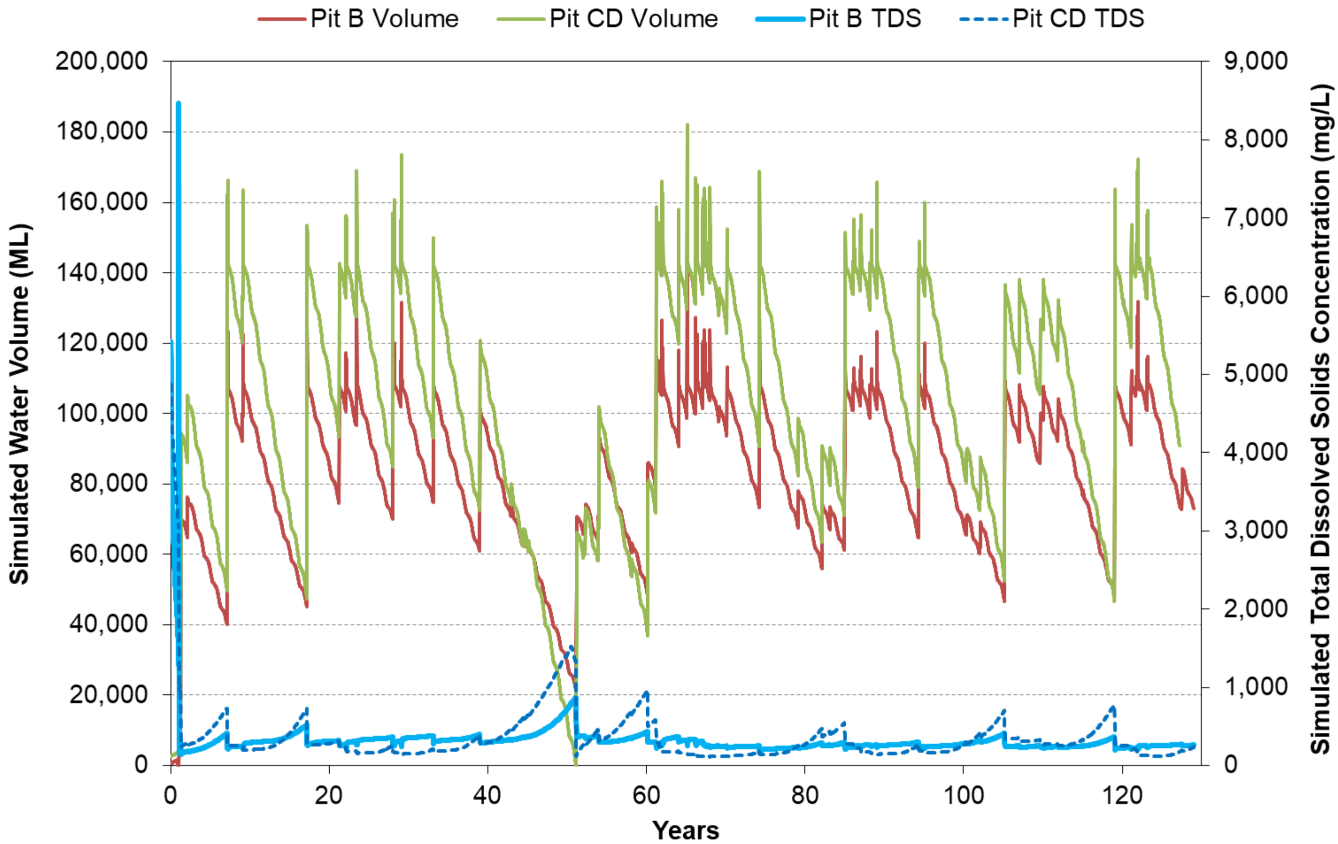

Figure 162 Irrigation Constraints: Run 4 Pit B and Pit CD Volume and Salinity

5.12.3 Nogoa River Flow Comparison

Model Runs 3, 4, 4a and 6 simulate interaction with the Nogoa River hence it was considered important to understand the impact this interaction may have on net flow in the Nogoa River downstream of the voids. Model Run 3 resulted in an average decrease in the river flow volume of 1.8%, Model Run 4 an average decrease of 3.3%, Model Run 4a an average decrease of 2.2% and Model Run 6 an average decrease of 0.9%.

5.12.4 Nogoa River Downstream TDS Comparison

Model Runs 3, 4, 4a and 6 simulate interaction with the Nogoa River hence it was considered important to understand the impact this interaction may have on TDS of flow in the Nogoa River downstream of the voids. Dilution calculations showed that the estimated Nogoa River TDS downstream of the voids would be equal to the assumed background TDS (115 mg/L) for the following percentages of time for each model run:

- Model Run 3: equal to 115 mg/L 97% of the time that outflow from the Ensham pits is occurring; and
- Model Run 4: equal to 115 mg/L 95% of the time that outflow from the Ensham pits is occurring.

5.13 SUBMITTED OPTION SENSITIVITY RUNS

5.13.1 Water Levels

Figure 163 to Figure 166 shows a comparison of the forecast equilibrium water levels for all Submitted Option sensitivity runs (refer Section 4.2) for each of the voids as box plots. Note that the value within the coloured box is the median, the value at the bottom of the box is the minimum and the value at the top of the box is the maximum.

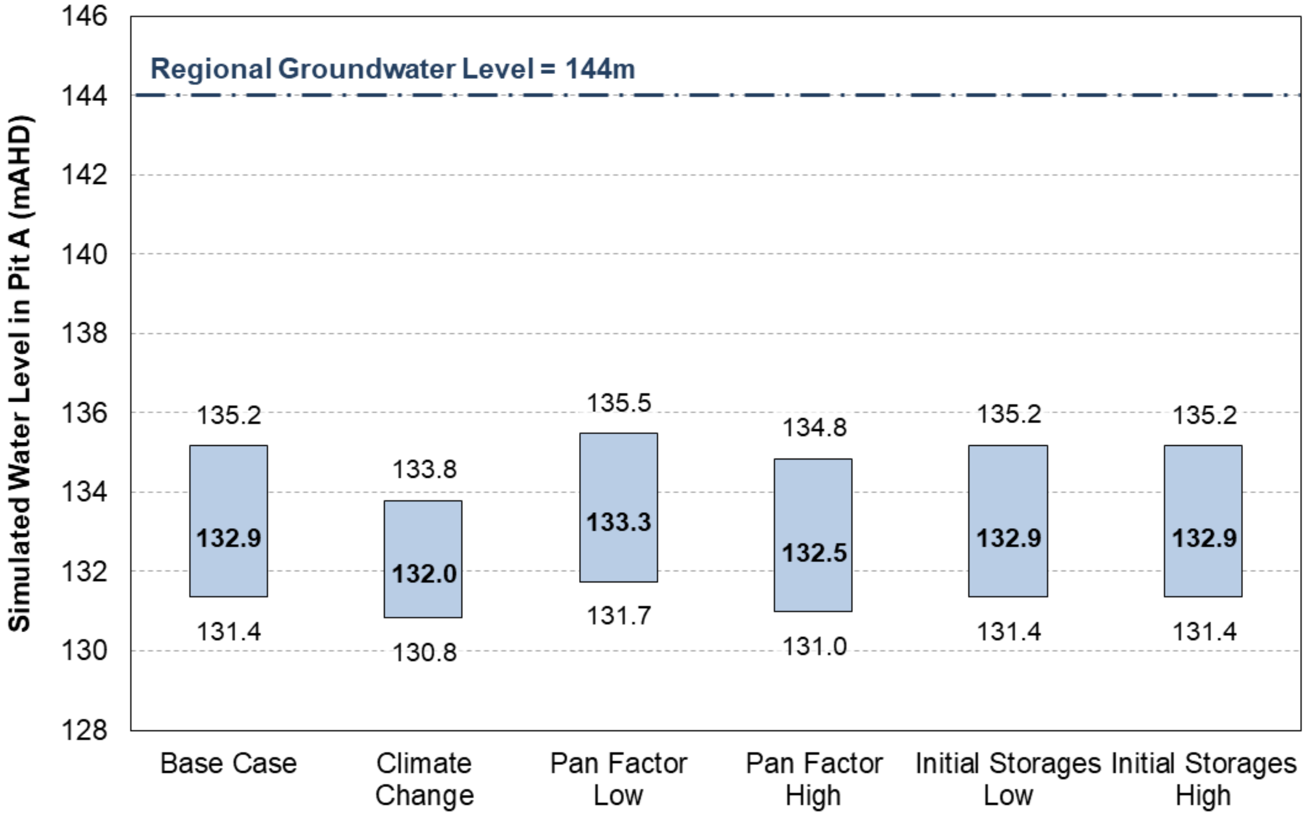

Figure 163 Water Level Results: Submitted Option Sensitivity Runs, Pit A

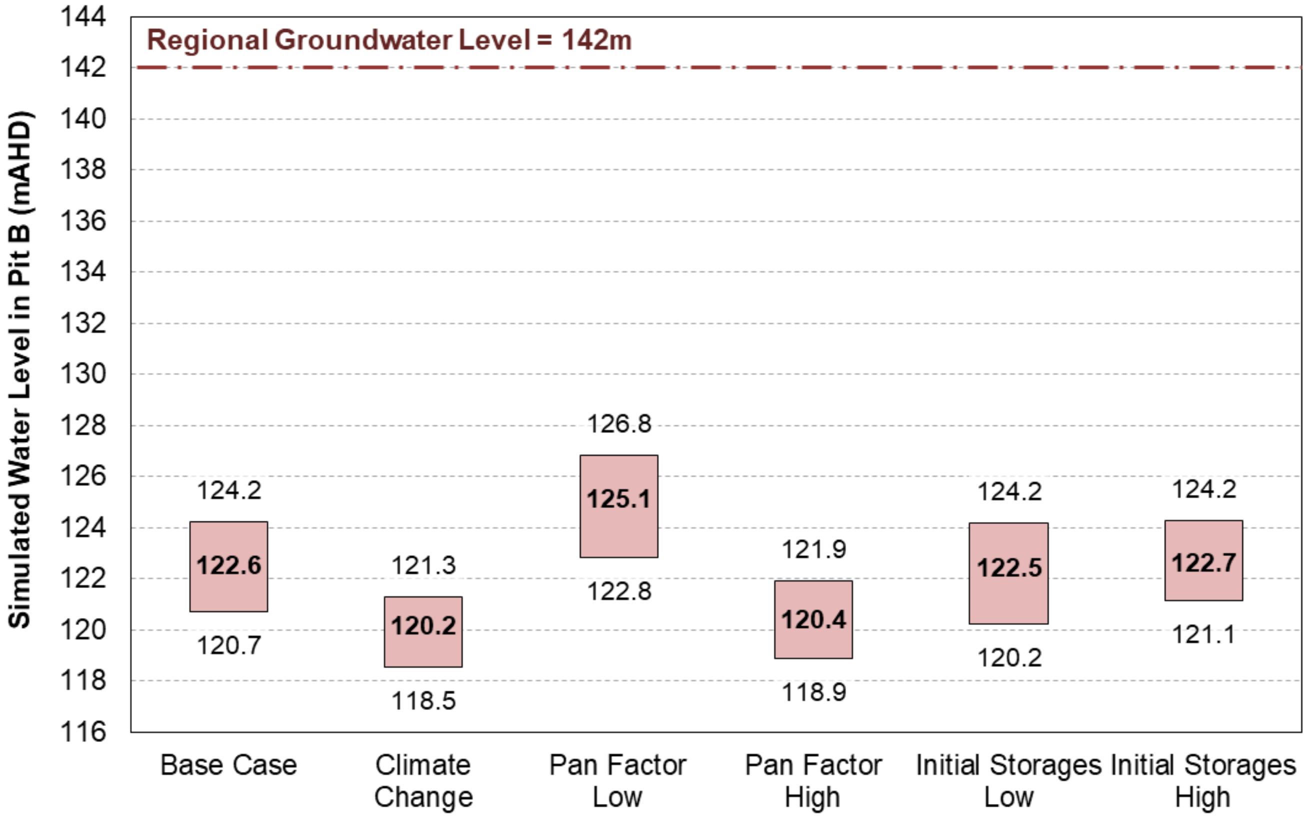

Figure 164 Water Level Results: Submitted Option Sensitivity Runs, Pit B

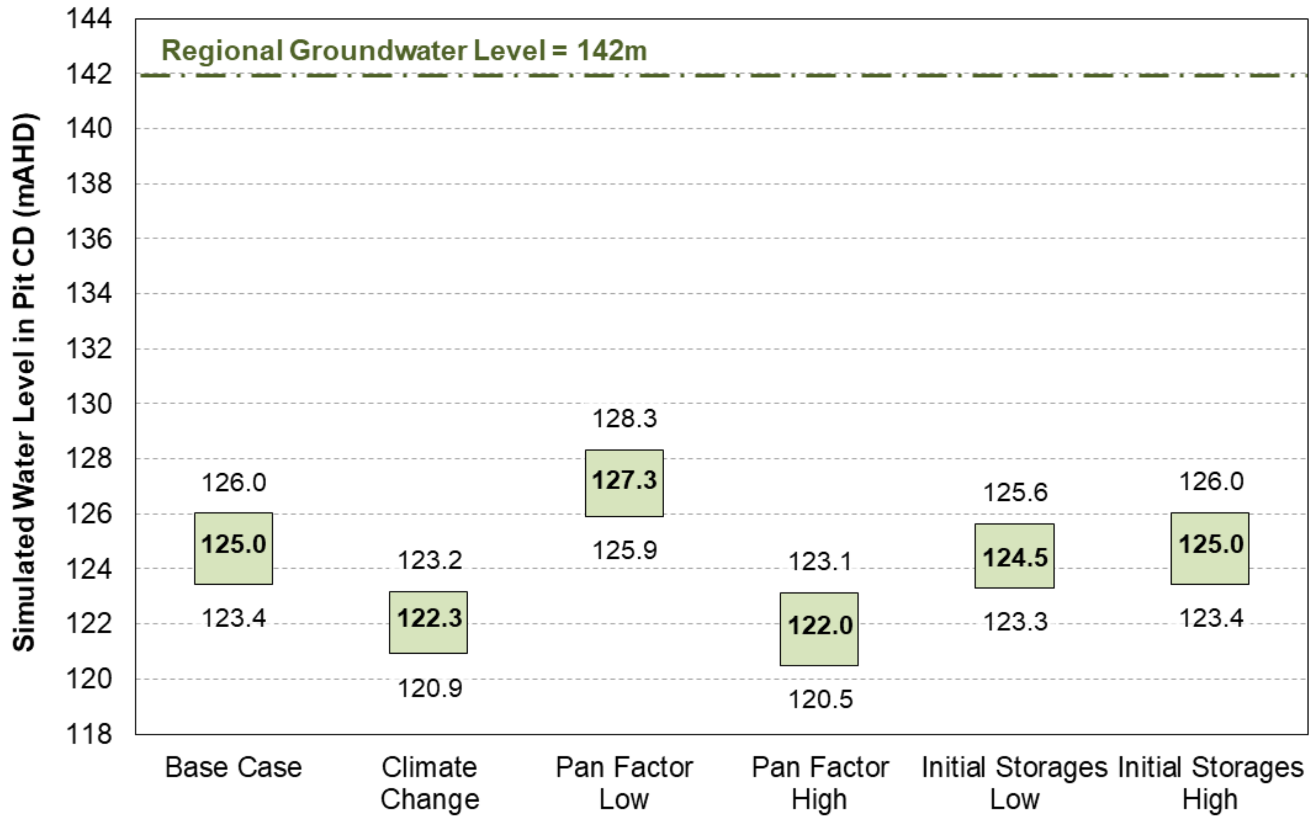

Figure 165 Water Level Results: Submitted Option Sensitivity Runs, Pit CD

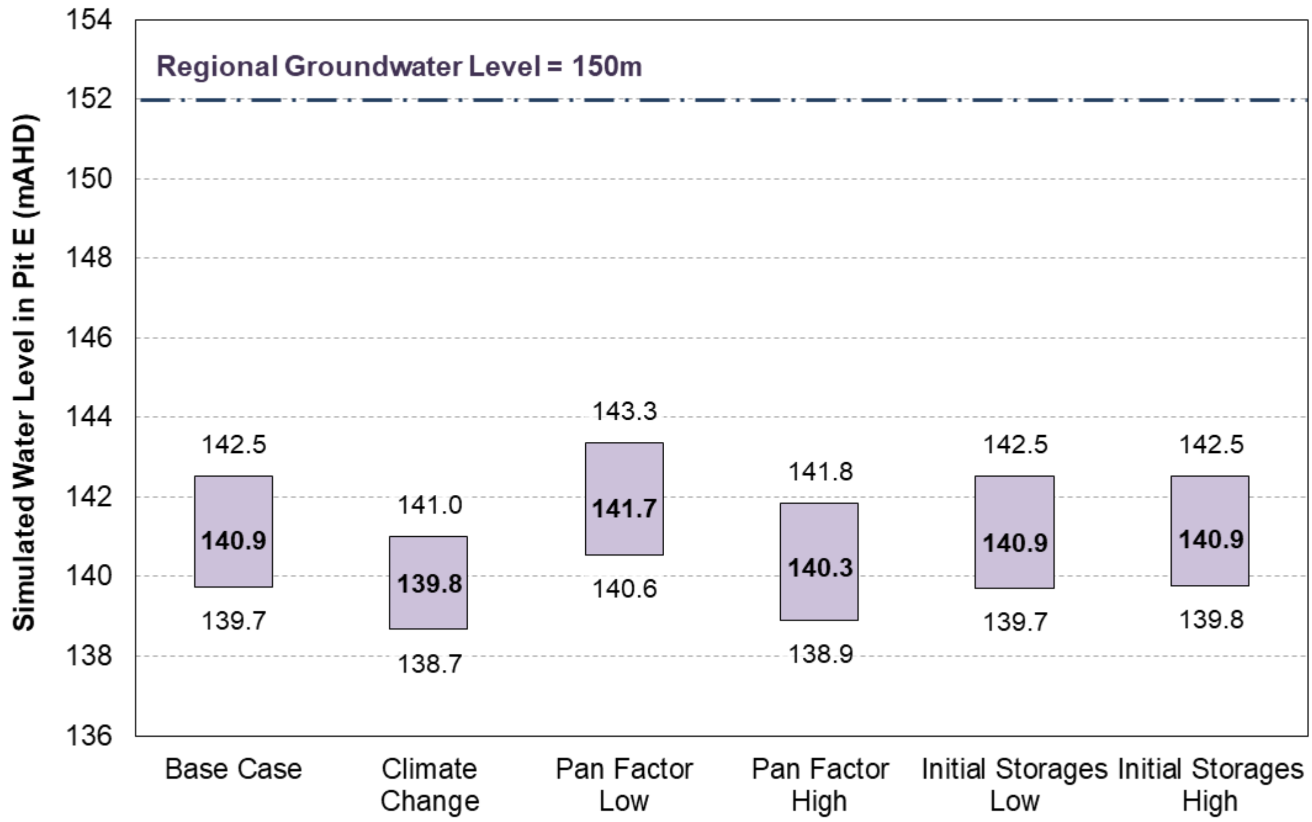

Figure 166 Water Level Results: Submitted Option Sensitivity Runs, Pit E

Figure 163, Figure 164, Figure 165 and Figure 166 show that regardless of the sensitivity run, simulated water levels in each of the voids are comparable to the Submitted Option base case levels at equilibrium. Simulated levels for the climate change run are slightly lower than the base case due to increased evaporation rates (refer Section 4.16.1). Similarly, simulated levels for the pan factor high run are slightly lower than the base case due to increased evaporation rates while the simulated levels for the pan factor low run are slightly higher than the base case due to decreased evaporation rates. While a difference in initial storages is evident in the early years of the simulation, both the initial storages low and initial storages high runs reach a similar equilibrium level to the base case.

The simulated water level results for all Submitted Option sensitivity runs show all four pits will be sinks with no external outflows and solutes within the voids will be contained.

5.13.2 Water Volumes

Figure 167 through to Figure 170 shows the simulated water volume results over the 258 year simulation period for all Submitted Option sensitivity runs for each of the voids.

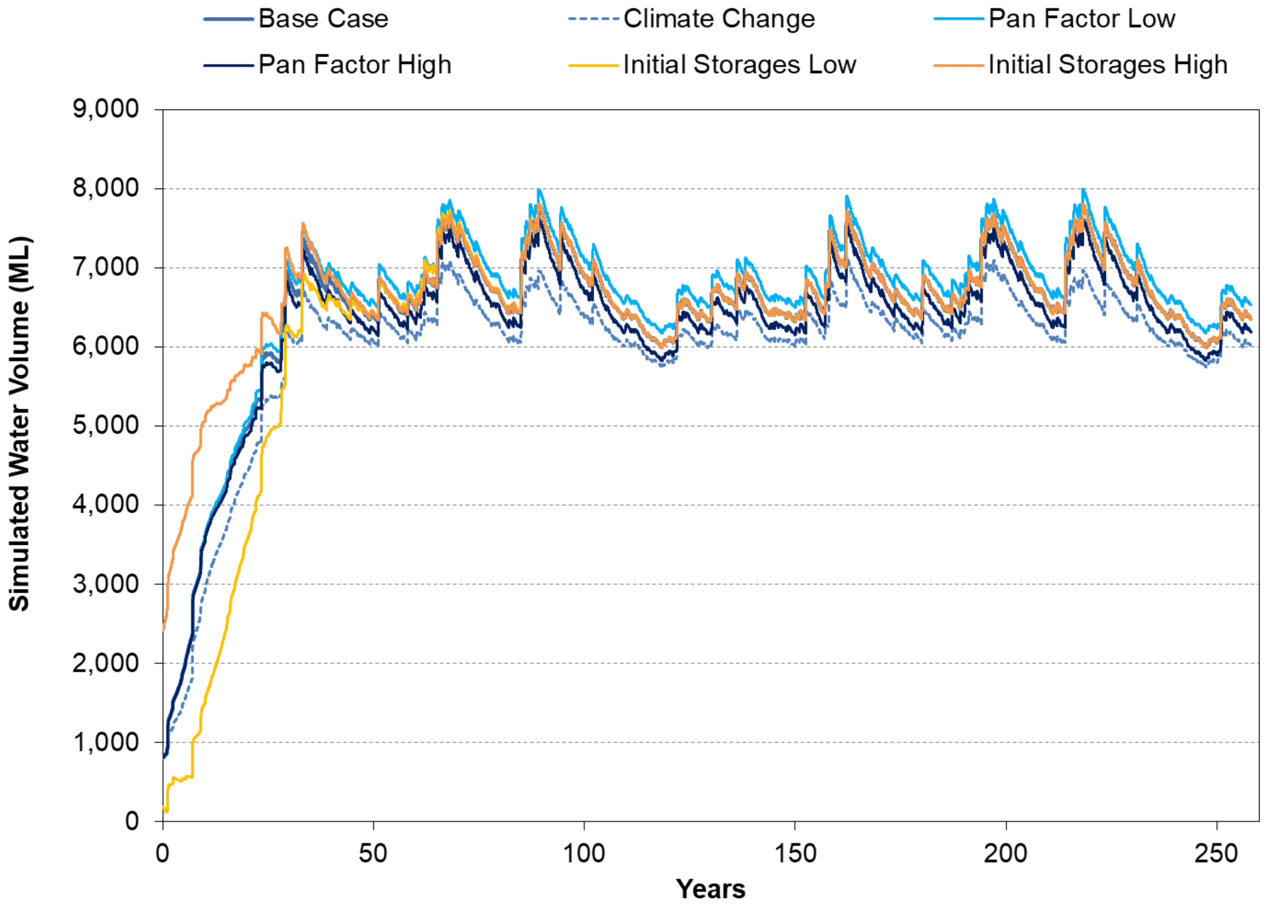

Figure 167 Water Volume Results: Submitted Option Sensitivity Runs, Pit A

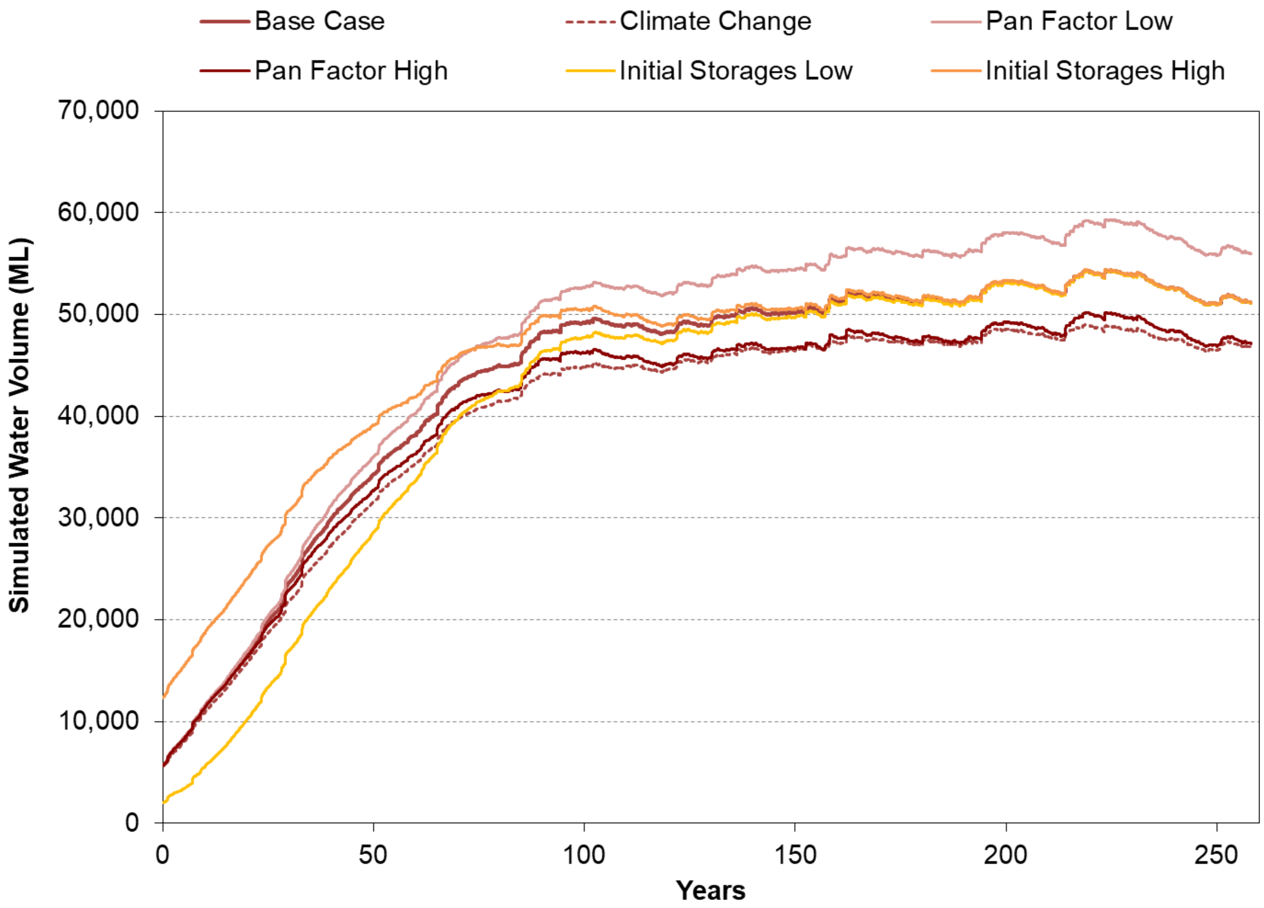

Figure 168 Water Volume Results: Submitted Option Sensitivity Runs, Pit B

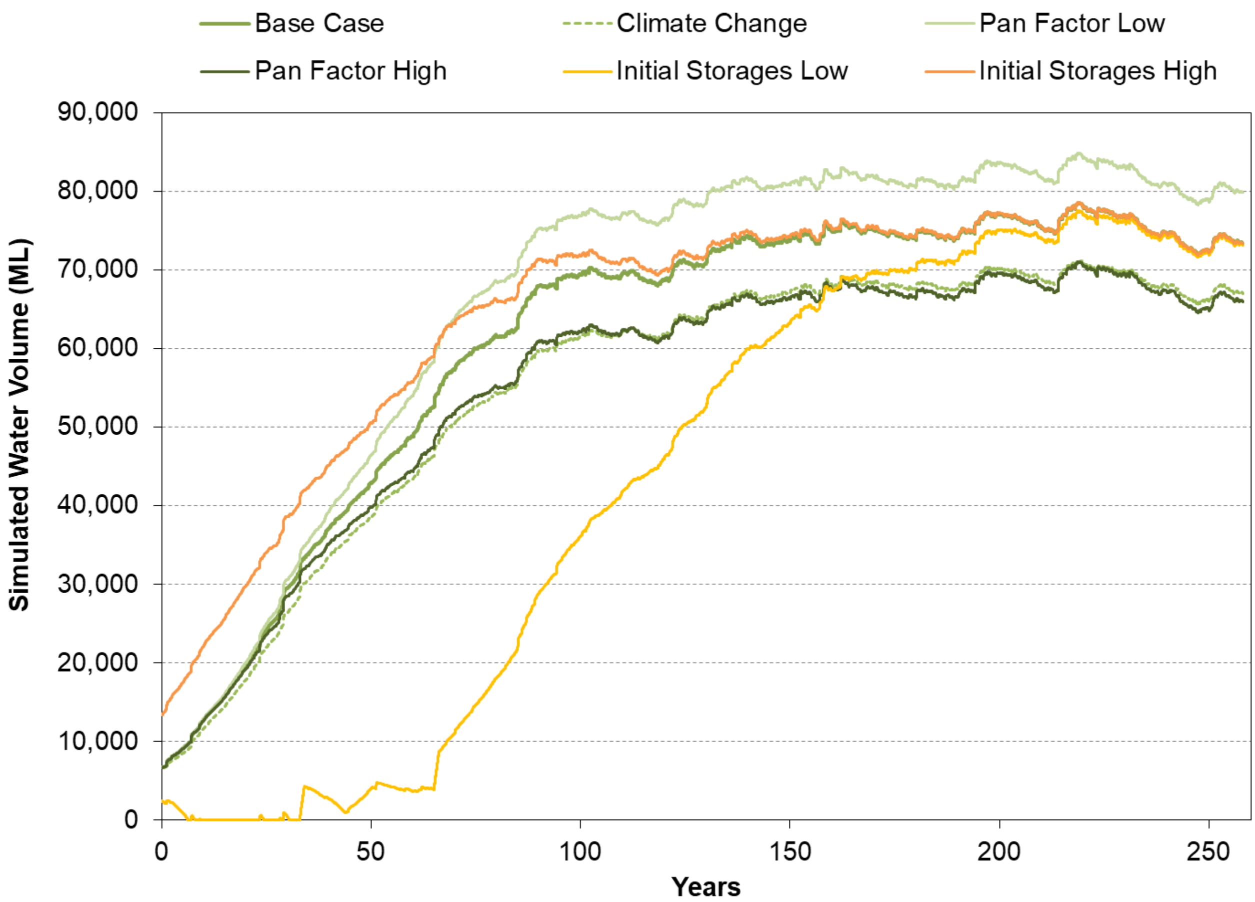

Figure 169 Water Volume Results: Submitted Option Sensitivity Runs, Pit CD

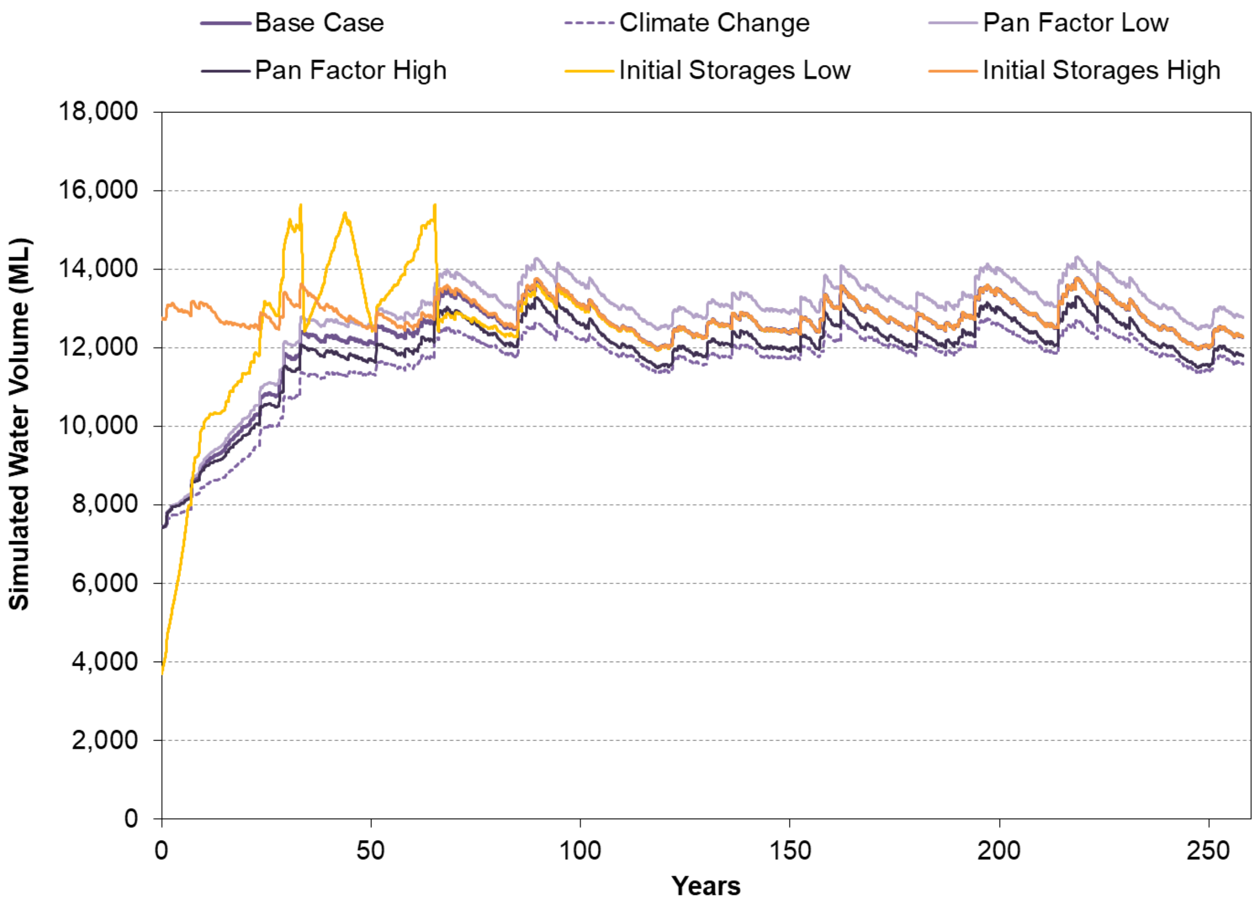

Figure 170 Water Volume Results: Submitted Option Sensitivity Runs, Pit E

Analysing the simulated water volumes provides similar conclusions to those reached when analysing the water levels: the simulated water volume results for all Submitted Option sensitivity runs show each of the four pits will be sinks with no external outflows and solutes within the voids will be contained.

5.13.3 Water Quality: Total Dissolved Solids

Figure 171 to Figure 174 show salinity results over the 258 year simulation period for all Submitted Option sensitivity runs for each of the voids.

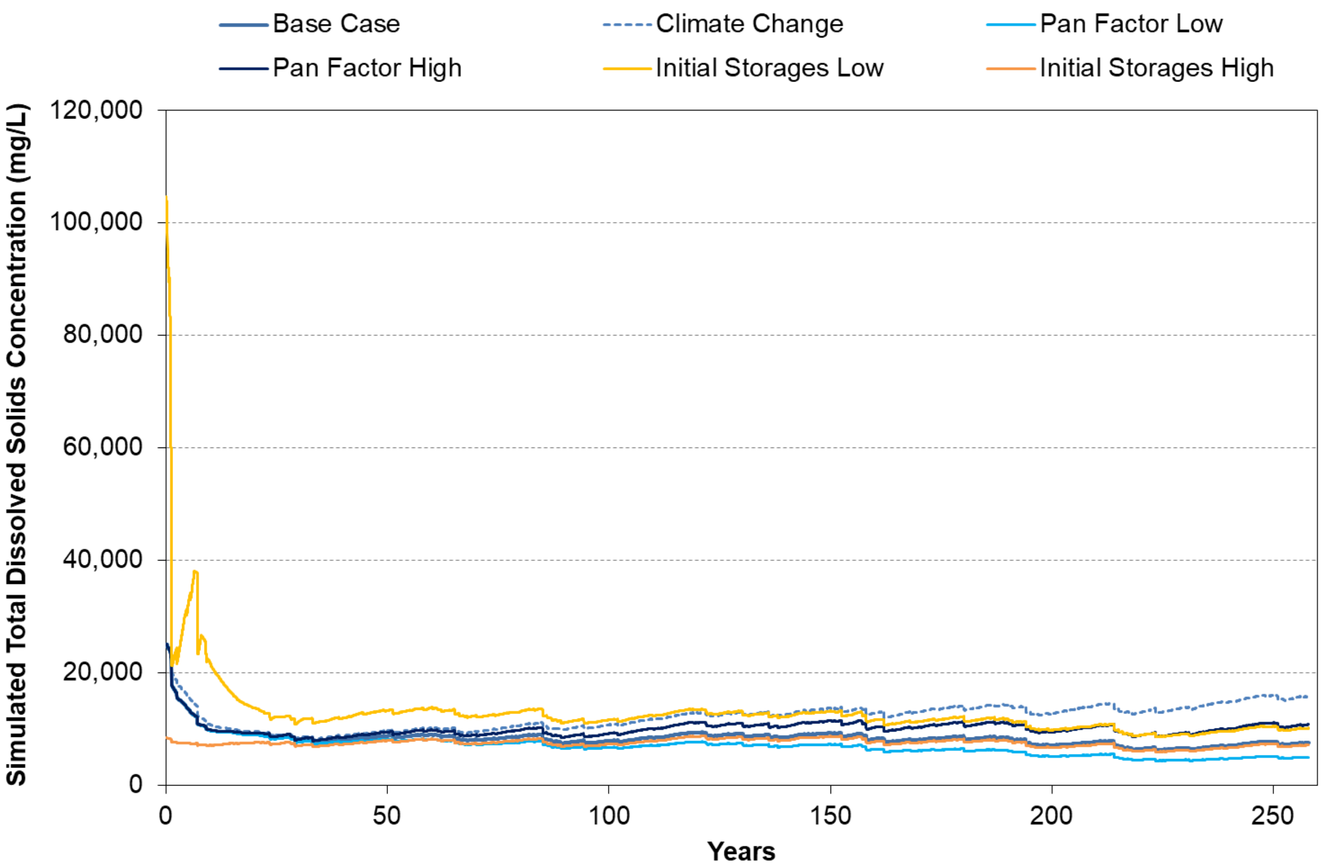

Figure 171 Total Dissolved Solids Results: Submitted Option Sensitivity Runs, Pit A

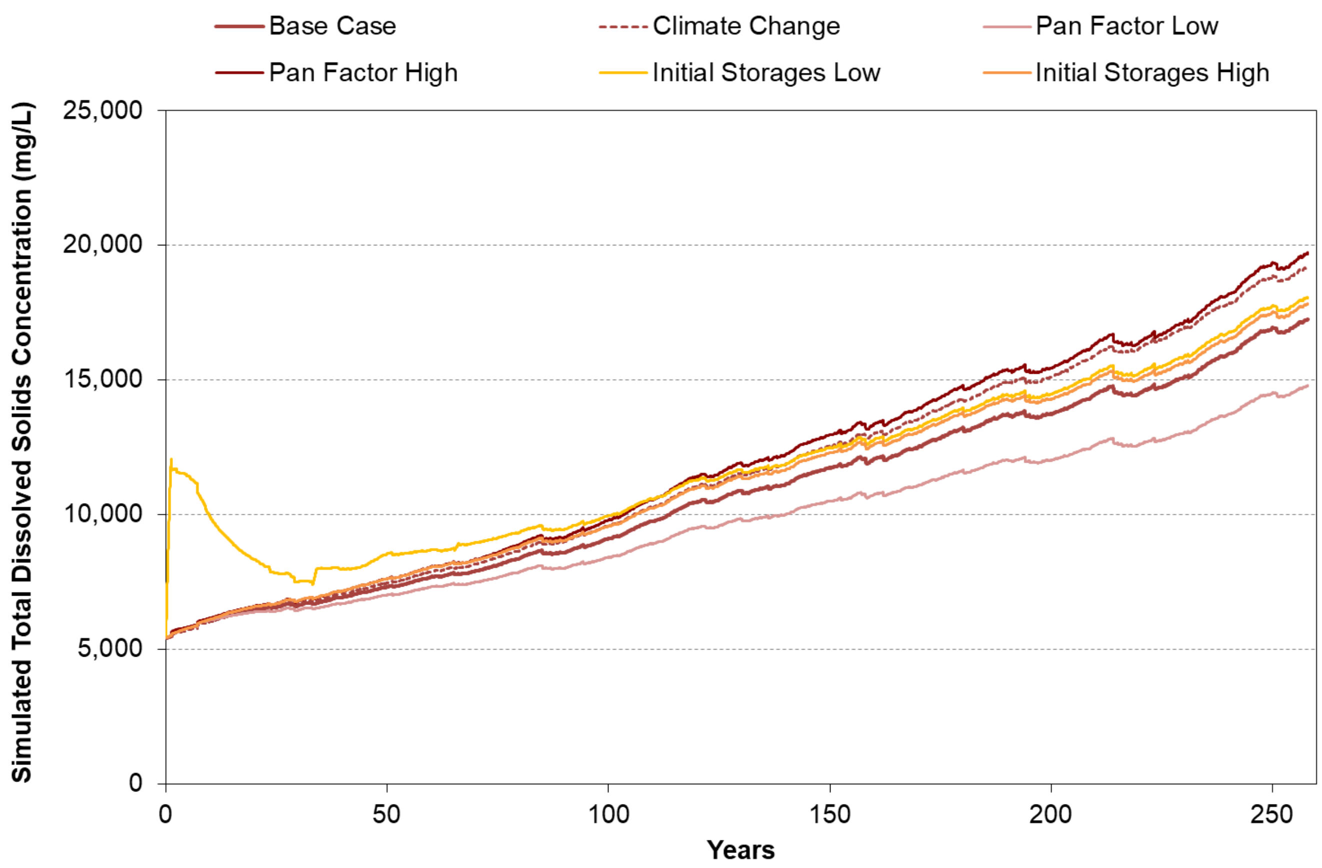

Figure 172 Total Dissolved Solids Results: Submitted Option Sensitivity Runs, Pit B

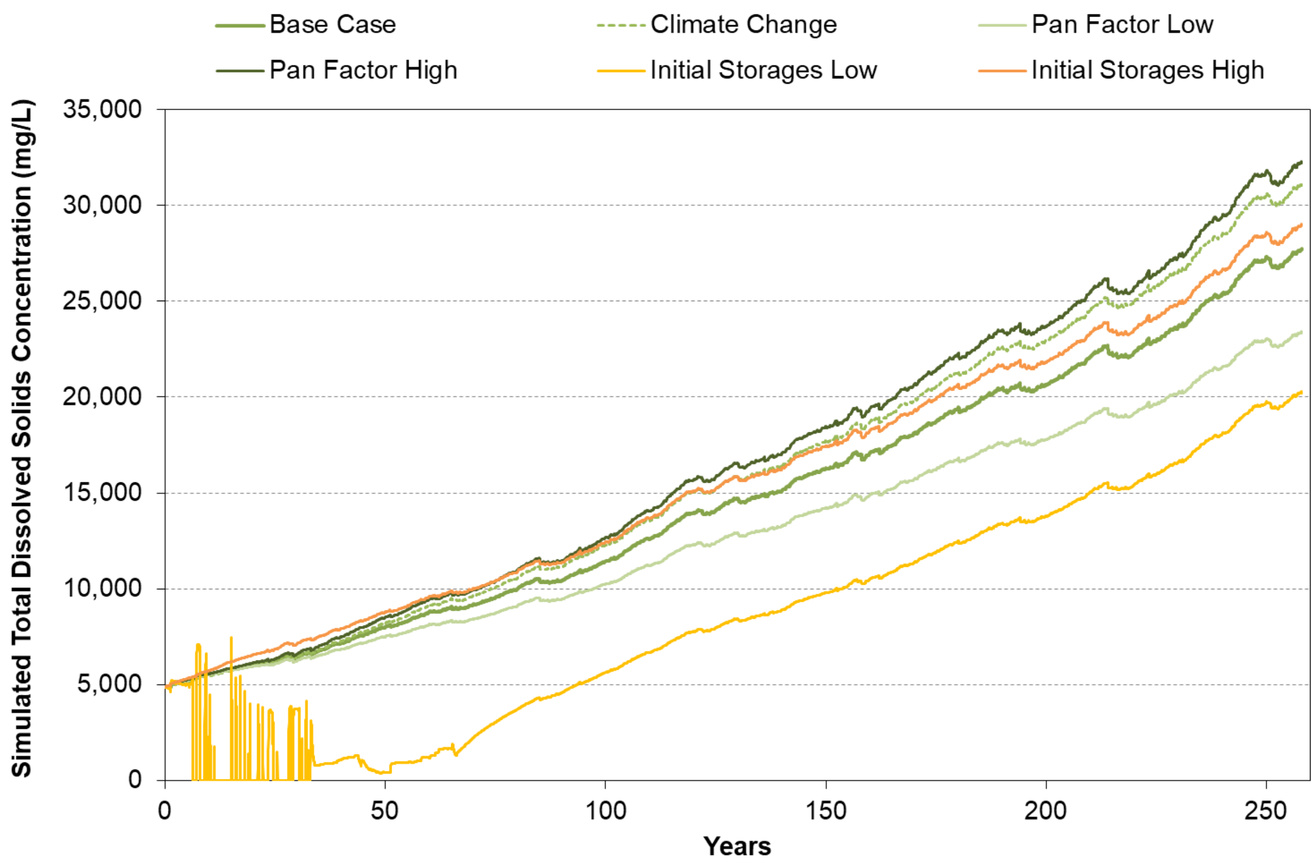

Figure 173 Total Dissolved Solids Results: Submitted Option Sensitivity Runs, Pit CD

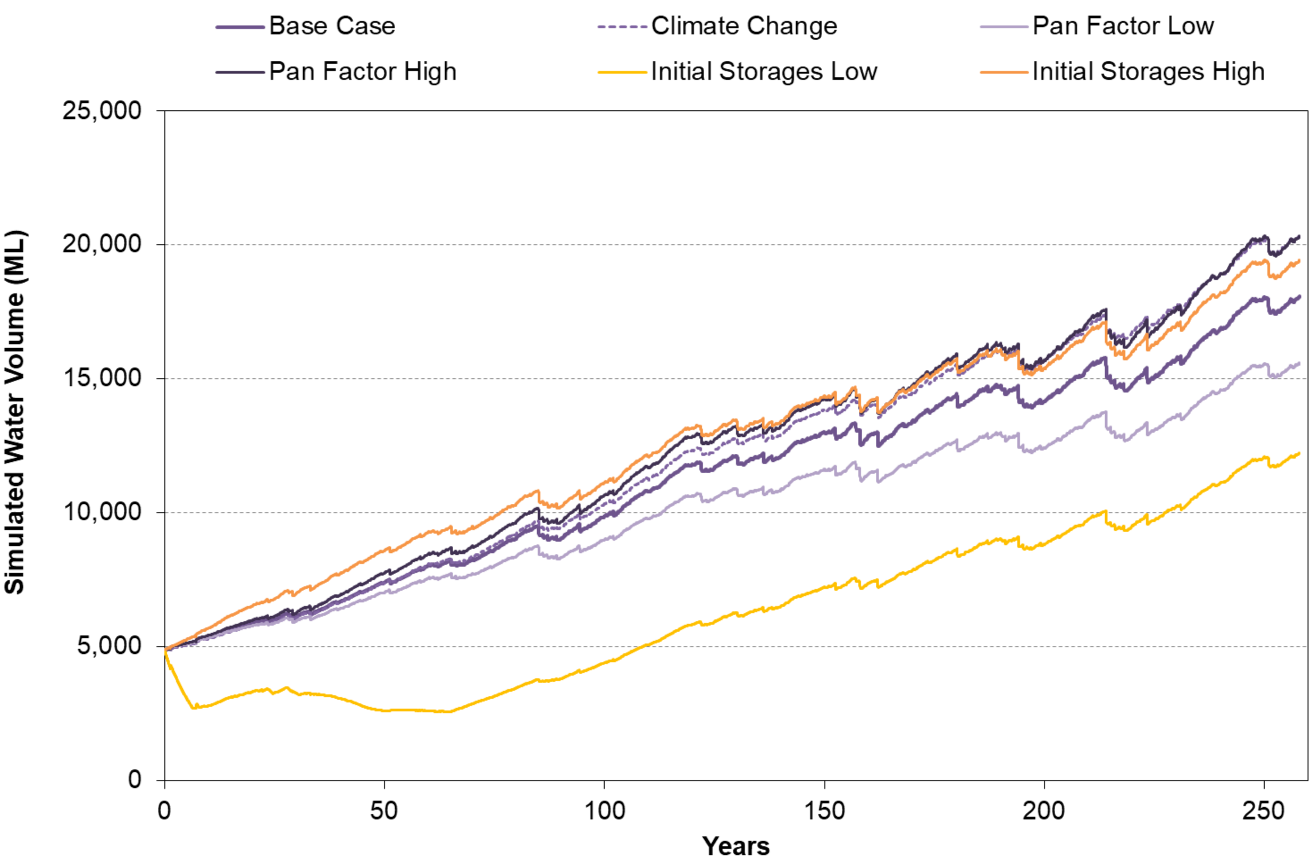

Figure 174 Total Dissolved Solids Results: Submitted Option Sensitivity Runs, Pit E

Figure 171, Figure 172, Figure 173 and Figure 174 show that regardless of the sensitivity run, simulated salinity in each of the voids are comparable to or somewhat less than the Submitted Option base case concentrations at equilibrium. Simulated concentrations for the climate change run are slightly higher than the base case due to increased evaporation rates. Similarly, simulated concentrations for the pan factor high run are slightly higher than the base case due to increased evaporation rates while the simulated concentrations for the pan factor low run are slightly lower than the base case due to decreased evaporation rates. The most notable difference in simulated concentrations from the base case is for the initial storages low run and the initial storages high run however these concentrations either return to approximate base case concentrations after initial changes or are lower than the concentrations for the base case.

Simulated water level results (refer Section 5.13.1) for all Submitted Option sensitivity runs show that each of the four pits will be sinks with no external outflows and solutes within the voids will be contained.

6.0 MODEL LIMITATIONS

The following provides a list of assumptions and model limitations:

- Climate – future climate will be similar to the past climate – over the 129 year period to 2017.
- Evaporation from void surfaces will be equivalent to pan evaporation multiplied by a depth-varying pan factor.
- Solute fluxes to and from the void would occur at the adopted solute concentrations as outlined in Section 4.10 and 4.11 and that future reductions in concentrations from baseflow would be similar to the adopted declining rate.
- Solute concentrations are calculated assuming the void waters (i.e. combined water stored in the spoils and free water in the lake) are completely mixed.
- The modelled water level in the void was assumed to be the same in the “free water” area as in the spoil emplacement (i.e. a level phreatic surface was assumed).
- The flow regime of the Nogoa River and the operating procedures of the Fairbairn Dam would not change in the future.
- Modelled historical and recorded flow rate in the Nogoa River is representative of future flow rate.
- There would be no significant additional flow regulating storages constructed in the Nogoa catchment upstream of the mine.
- The current predicted regional groundwater levels and net groundwater flux curves are reliable estimates and they would be invariant over time.
- Groundwater flux curves provide net flows rather than absolute inflows and outflows which will not impact the water balance but has implications for the solute balance.
- There would be no significant catchment land use changes into the future (that could affect rainfall runoff).
- Climate and river flow data sets were repeated to simulate 258 years.
- Comprehensive model calibration is not possible due to lack of site monitoring data.
- The actual time it would take to fill the voids will depend on climate and flow conditions experienced during the void filling period.

7.0 ASSESSMENT OF POTENTIAL IMPACTS ON ENVIRONMENTAL VALUES

An assessment of the potential impacts of each of the three preferred options and the Submitted Option on relevant environmental values (EVs) has been undertaken based on the outcomes of this study. The EVs are described in Ensham Resources (2018) and the EVs relevant to each of the Stage 3 studies have been determined by Ensham.

The assessment of impacts on EVs has been undertaken by assigning a ranking for each of the preferred options to each EV. The adopted scoring criteria, definitions of impacts and summary of the EV assessment relevant to flood-related impacts are given in Table 21, Table 22 and Table 23.

Table 21 Environmental Values Ranking - Definitions

Impact/Benefit	Definition*
Significant	Results in a change which is important, notable or of consequence to the EV having regard to its intensity/frequency. For an impact the change will result in not being able to meet published standards (if there are any). For a benefit the change should meet best practice standards (if there are any published)
Medium	Results in a change which is potentially important, notable or of consequence to the EV having regard to its intensity/frequency. For an impact, the change will result in occasions where the criterion will not meet published standards (if there are any). For a benefit the change should meet good practice standards (if there are any published).
Minor	Results in a change which is identifiable but is not important, notable or of consequence to the EV having regard to its intensity.

* The definition of significant impact has been based on the Commonwealth Government's definition of significant impact contained within Australian Government Department of the Environment (2013).

Table 22 Environmental Values Ranking – Scoring Criteria

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

The EVs related to the water aspect are irrigation use, farm supply, stock use, aquaculture, human consumption, primary recreation, secondary recreation and industrial use. Potential impacts on these EVs were assessed by selecting three criteria: downstream river quality, water availability and void water quality. A qualitative approach has been undertaken for this assessment. Preferred Options 1 and 3 result in no impact for any of the criteria nominated while Preferred Option 2 resulted in either no impact, minor impact or medium benefit. The Submitted Option results in no impact for any of the criteria nominated with the exception of the evaporative concentration of salinity within the voids. This is deemed to be a minor negative impact as while the increasing trend in salinity is expected in most voids, water would be contained within each of the voids and is not proposed for use.

Table 23 Environmental Values Ranking – Assessment Summary

Aspect	Value	Criterion	Notes	Option 1		Option 2		Option 3		Submitted Option	
				Rank	Rationale	Rank	Rationale	Rank	Rationale	Rank	Rationale
Land	Agricultural potential	Downstream river quality	Impacts to agricultural water quality objectives for life of option	0	Voids are contained (no spill)	-1	Additional load added but only during high flow events so likely minor impacts	0	Voids are contained (no spill)	0	Voids are contained (no spill)
		Water availability	Quantity of water available to downstream users compared to current	0	Voids are contained (no spill)	-1	Harvested Nogoa River flows will no longer report downstream but only during high flow events so likely minor impacts	0	Voids are contained (no spill)	0	Voids are contained (no spill)
Water	Irrigation use	Void water quality	Water quality modelling indicates suitability for irrigation within the region	0	Irrigation not proposed	2	Supply to irrigation would be limited if TDS exceeded 2,000 mg/L	0	Irrigation not proposed	0	Irrigation not proposed
		Downstream river quality	Impact on irrigation water quality objectives for life of option	0	Voids are contained (no spill)	-1	Additional load added but only during high flow events so likely minor impacts	0	Voids are contained (no spill)	0	Voids are contained (no spill)
	Farm supply	Void water quality	Water quality modelling indicates suitability for farm supply within the region	0	Farm supply not proposed	2	Farm supply would be similar to irrigation use.	0	Farm supply not proposed	0	Farm supply not proposed
		Downstream river quality	Impact on farm supply water quality objectives for life of option	0	Voids are contained (no spill)	-1	Additional load added but only during high flow events so likely minor impacts	0	Voids are contained (no spill)	0	Voids are contained (no spill)

Aspect	Value	Criterion	Notes	Option 1		Option 2		Option 3		Submitted Option	
				Rank	Rationale	Rank	Rationale	Rank	Rationale	Rank	Rationale
	Stock use	Void water quality	Water quality modelling indicates suitability for stock use within the region	0	Stock use not proposed	2	Stock use would be similar to irrigation use.	0	Stock use not proposed	0	Stock use not proposed
		Downstream river quality	Impact on stock use water quality objectives for life of option	0	Voids are contained (no spill)	-1	Additional load added but only during high flow events so likely minor impacts	0	Voids are contained (no spill)	0	Voids are contained (no spill)
	Aquaculture	Downstream river quality	Impact on aquaculture water quality objectives prior to supply	0	Voids are contained (no spill)	-1	Additional load added but only during high flow events so likely minor impacts	0	Voids are contained (no spill)	0	Voids are contained (no spill)
		Void water quality	Water quality modelling indicates suitability for aquaculture within the region	0	Aquacultur e not proposed	0	Aquaculture not proposed	0	Aquacultur e not proposed	0	Aquaculture not proposed
	Human consumption	Downstream river quality	Impact on human consumption water quality objectives (pre treatment) for life of option	0	Voids are contained (no spill)	-1	Additional load added but only during high flow events so likely minor impacts	0	Voids are contained (no spill)	0	Voids are contained (no spill)
	Primary recreation	Void water quality	Water quality suitability for primary recreation use within the voids	0	Primary recreation not proposed	0	Primary recreation not proposed	0	Primary recreation not proposed	0	Primary recreation not proposed

Aspect	Value	Criterion	Notes	Option 1		Option 2		Option 3		Submitted Option	
				Rank	Rationale	Rank	Rationale	Rank	Rationale	Rank	Rationale
	Secondary recreation	Void water quality	Water quality suitability for secondary recreation use within the voids	0	Secondary recreation not proposed	0	Secondary recreation not proposed	0	Secondary recreation not proposed	0	Secondary recreation not proposed
	Industrial use	Void water quality	Water quality suitability for industrial uses within the region	0	Industrial use not proposed	0	Industrial use not proposed	0	Industrial use not proposed	0	Industrial use not proposed
Flooding	Changes in flooding and runoff characteristics	Impact on local runoff volumes to river	Compared to current mine footprint	0	Relatively small changes to catchment area reporting to Nogoa River compared to catchment upstream	0	Relatively small changes to catchment area reporting to Nogoa River compared to catchment upstream	0	Relatively small changes to catchment area reporting to Nogoa River compared to catchment upstream	0	Relatively small changes to catchment area reporting to Nogoa River compared to catchment upstream
Waste	Waste generation and environmental dispersal	Evaporative concentration on salinity with the voids	Salinity issues in the void over the life of the option	-1	Increasing trend in salinity is expected in some voids however use of that water is not proposed	-1	Increasing trend in salinity is expected in some voids however use of that water is not proposed	-1	Increasing trend in salinity is expected in some voids however use of that water is not proposed	-1	Increasing trend in salinity is expected in most voids however use of that water is not proposed

8.0 CONCLUSIONS AND RECOMMENDATIONS

The following summary conclusions are made regarding the void water quantity and quality balance modelling of the three preferred options and the Submitted Option based on the outcomes from the ten model runs:

1. Model Run 1 – Preferred Option 1 base case:
    a. Simulated water levels in all voids are below the external spill level.
    b. Simulated outflows from voids comprise evaporation only hence solute concentrations trend upwards over the simulation period.
2. Model Run 2 – Preferred Option 1 with climate change:
    a. Simulated water levels are lower in all voids than for Model Run 1.
    b. As for Model Run 1, simulated outflows from voids comprise evaporation only hence solute concentrations trend upwards over the simulation period.
    c. Reducing rainfall and increasing evaporation reduces inflows (volume and solutes) to the voids but increases outflows (volume only) via evaporation. Hence major ions and salinity concentrations are simulated to be higher in Model Run 2 compared to Model Run 1.
3. Model Run 3 – First stage of Preferred Option 2 development using only southern voids:
    a. Simulated water levels in Pit A and Pit B rise mainly due to inflows from the Nogoa River. Water levels in Pit A are drawn down in line with Pit B due to the hydraulic connection between the pits.
    b. Simulated outflow from Pit B is dominated by irrigation and post-flood return flow to the Nogoa River which includes volume and solutes outflows. This differs to Model Runs 1 and 2 where evaporation was the sole outflow and thus, there is no outflow of solute.
    c. Simulated water quality in Pit B is improved by the regular inflows from the Nogoa River which has the dual effects of:
        i. topping up the void such that there is sufficient water available to pump to irrigation; and
        ii. diluting solute concentrations, particularly salinity such that the salinity in the void remains below the salinity threshold for suitability for irrigation and therefore the water from the void remains suitable to supply the irrigation demand.

       Simulated solute concentrations in Pit A are higher than Pit B but, due to the hydraulic connection modelled, are also improved by the interaction with the Nogoa River.
    d. On average, Pit B can supply 7.9 GL/year to the irrigation demand of 8 GL/year.
    e. A comparison of cumulative flow in the Nogoa River downstream of the voids shows an average decrease in the river flow volume of 1.8% with the development of the first stage of Preferred Option 2.
    f. Dilution calculations for backflow from the voids to the river immediately after the peak of a flood event show that for 97% of the time backflow is occurring, the estimated Nogoa River TDS downstream of the voids would be equal to the adopted background TDS of 115 mg/L.
4. Model Run 4 – Full development of Preferred Option 2 using all floodplain voids:
    a. Simulated water levels in all voids rise mainly due to inflows from the Nogoa River to Pit B and Pit CD. Water levels in Pit E are drawn down in line with Pit CD due to the hydraulic connection between the pits.

b. Simulated outflow from Pit B and Pit CD is dominated by irrigation and post-flood return flow to the Nogoa River which includes both volume and solute outflows. This is similar to Model Run 3.

c. Simulated water quality in Pit B and Pit CD is improved by the regular inflows from the Nogoa River which has the dual effects of:

   i. topping up the voids such that there is sufficient water available to pump to irrigation; and

   ii. diluting solute concentrations, particularly salinity such that the salinity in the voids remains below the salinity threshold for suitability for irrigation, therefore the water from the voids remains suitable to supply the irrigation demand.

   Simulated solute concentrations are higher in Pit A than Pit B however the modelled hydraulic connection between the voids is such that the Pit A solute concentrations are diluted by interaction with Pit B. Similarly, simulated solute concentrations are higher in Pit E than Pit CD however the modelled hydraulic connection between the voids is such that the Pit E solute concentrations are diluted by interaction with Pit CD.

d. On average, Pit B can supply 7.9 GL/year to the irrigation demand of 8 GL/year while Pit CD can supply 11.9 GL/year to the irrigation demand of 12 GL/year.

e. A comparison of cumulative flow in the Nogoa River downstream of the voids shows an average decrease in the river flow volume of 3.3% with the full development of Preferred Option 2.

f. Dilution calculations for backflow from the voids to the river immediately after the peak of a flood event show that for 95% of the time, the estimated Nogoa River TDS downstream of the voids would be equal to the adopted background TDS of 115 mg/L.

5. Model Run 4a – Full development of Preferred Option 2 using all floodplain voids with climate change:

   a. Simulated water levels are generally higher in all voids in Model Run 4a when compared to Model Run 4 due to the decreased total irrigation demand of 10 GL/year compared to the total demand in Model Run 4 of 20 GL/year.

   b. Simulated solute concentrations are comparable to those in Model Run 4 mainly due to the dominant interaction with the Nogoa River but also due to the balancing effect of:

      i. inflow solutes decreasing due to decreased rainfall;

      ii. outflow solutes decreasing due to less pumping to irrigation;

      iii. outflow volume increasing due to increased evaporation; and

      iv. more water stored to dilute the solutes.

   c. A comparison of cumulative flow in the Nogoa River downstream of the voids shows an average decrease in the river flow volume of 2.2% with the full development of Preferred Option 2 with climate change.

6. Model Run 5 – Preferred Option 2 assessment of potential elevated salinity during initial filling and drawdown:

   a. Simulated solute concentrations in Pit B and Pit CD are higher than simulated in Model Run 4. Following the initial fill with water from the Nogoa River, salinity in Pit B does exceed the irrigation salinity upper limit of 2,000 mg/L while salinity in Pit CD remains below the trigger. However, following the initial few fill cycles, due to the dilution effects of the Nogoa River inflows this impact is expected to be negligible to the long term viability of water supply from Pit B and Pit CD to meet the irrigation demand.

7. Model Run 6 – Preferred Option 2 rehabilitated mining area after cessation of beneficial use:
    a. All voids are filled by inflows from the Nogoa River.
    b. Simulated water quality in Pit B and Pit CD is improved by the regular inflows from the Nogoa River.
    c. A comparison of cumulative flow in the Nogoa River downstream of the voids shows an average decrease in the river flow volume of 0.9% with Preferred Option 2 after cessation of beneficial use.
8. Model Run 7 – Preferred Option 3 base case:
    a. Simulated water levels in Pit A and Pit E are well below the external spill level
    b. Simulated outflows from Pit A and Pit E comprise evaporation only hence solute concentrations trend upwards over the simulation period.
9. Model Run 7a – Preferred Option 3 base case with climate change:
    a. Simulated water levels are lower in Pit A and Pit E than for Model Run 7.
    b. As for Model Run 7, simulated outflows from Pit A and Pit E comprise evaporation only hence solute concentrations trend upwards over the simulation period.
    c. Reducing rainfall and increasing evaporation reduces inflows (volume and solutes) to the voids but increases outflows (volume only) for those pits dominated by evaporation hence solute concentrations are simulated to be higher in Model Run 7a compared to Model Run 7.
10. Model Run 8 (Submitted Option) – Preferred Option 2 design criteria but does not include the installation of intake structures, thereby removing the ability to harvest water from or release water to the river. It is also proposed to incorporate the existing levees into the landform design, with overburden emplacement areas behind the levee being reshaped in a manner that achieves a stable landform:
    a. Simulated water levels in all voids for all model runs undertaken are below the external spill level and the regional groundwater level.
    b. Simulated outflows voids comprise evaporation or transfer to adjacent voids hence, solute concentrations trend upwards over the simulation period. However, as there is no outflow from the voids to the receiving environment, solutes are contained and the voids are non-polluting.

The following recommendations are made for future studies:

- Site monitoring data (i.e. water levels, water quality and pumped volumes) should continue to be collected and used to update the site water balance model ultimately allowing for comprehensive calibration of the model.
- Refine the water quality predictions by obtaining long-term leaching data.

9.0 REFERENCES

Australasian Groundwater and Environmental Consultants (2015), Groundwater flux spreadsheet titled "G1787 Ensham _Final_ Void_Recovery_WL&Fluxes_3_12_2015.xls", prepared for Idemitsu Australia Resources.

Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand (2000), *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, October.

Australian Government Department of the Environment (2013). "Matters of National Environmental Significance Significant Impact Guidelines 1.1 Environment Protection and Biodiversity Conservation Act 1999", © Commonwealth of Australia.

Boughton, W.C. (2004), "The Australian Water Balance Model". *Environmental Modelling & Software*, Vol. 19, pp 943-956.

CSIRO and BoM (2015). "Climate Change in Australia", accessed 16th August 2018, http://www.climatechangeinaustralia.gov.au/en/. Commonwealth Scientific and Industrial Research Organisation and the Australian Bureau of Meteorology, Australia.

Ensham Resources Pty Limited (2017). "Residual Void Project Ensham Coal Mine Terms of Reference". May.

Ensham Resources Pty Limited (2018). "Ensham Residual Void Project Stage 2 Environmental Values Workshop Report". March.

Gilbert & Associates Pty Ltd (2012), Final Void Hydrology and Water Quality Assessment – Ensham Coal Mine", December 2012.

Hydro Engineering & Consulting Pty Ltd (2016), *Updated Final Void Hydrology and Water Quality Assessment – Ensham Coal Mine*, prepared for Ensham Resources Pty Limited, January.

Hydro Engineering & Consulting Pty Ltd (2018a), *Ensham Coal Mine Residual Void Project Stage 2 Void Water and Salt Balance Modelling*, prepared for Ensham Resources Pty Limited, January.

Hydro Engineering & Consulting Pty Ltd (2018b), *Ensham Coal Mine Residual Void Project Stage 2 Catchment Hydrology and Flood Study*, prepared for Ensham Resources Pty Limited, April.

Hydro Engineering & Consulting Pty Ltd (2018c), *Ensham Coal Mine Residual Void Project Stage 3 Catchment Hydrology and Flood Study*, prepared for Ensham Resources Pty Limited, September.

HydroSimulations (2018a), *Residual Void Project – Groundwater Assessment Stage 2*, Report: HS2018/08, prepared for Idemitsu Australia Resources Pty Ltd, April.

HydroSimulations (2018b), *Residual Void Project – Groundwater Assessment Stage 3*, Report: HS2018/33, prepared for Idemitsu Australia Resources Pty Ltd, November.

Kellogg, Brown & Root Pty Ltd (2012), *Ensham Flood Levees Preferential Overtopping Assessment*, Report: BEW801-W-REP-014 Rev. B, prepared for Idemitsu Australia Resources, August.

Kellogg, Brown & Root Pty Ltd (2013), *Ensham Flood Levees Model Upgrade*, Report: BEW801-W-REP-015 Rev. 0, prepared for Idemitsu Australia Resources, September.

MEC Mining (2018), Spoil volume spreadsheets titled “081106 Void and Spoil Reserving All Options MEC Surfaces V3.xlsx”, prepared for Idemitsu Australia Resources.

OD Hydrology (2018), *Ensham Resources Residual Void Project (FINAL DRAFT): Modelling assessment of Preferred Option 2 – Flood mitigation and Beneficial Use*, prepared for Ensham Resources Pty Ltd, Report: 88001-rpt01g.docx, November.

RGS (2018), *Technical Report: Material Characterisation and source term development for the Ensham Coal Mine Final Void Plan*, prepared for Ensham Resources Pty Ltd and Idemitsu Australia Resources Group, August.

SLR (2020), *Clarification of Groundwater Inflow/Outflow to/from Pits A-E*, Memorandum, File: ENSHAM RVP Sw_Gw Levels, prepared for Ensham Resources Pty Ltd, February.

SRK (2018), *Project Memo: Correction factors – Geochemical Source Terms for the Ensham Backfill and Pit Walls*, File: ERP002_MEMO_Ensham - Source Term Corrections_Rev0, prepared for Ensham Resources Pty Ltd, November.

SRK (2020), *Project Memorandum: Sulphide and Metal/Metalloid Source Depletion Estimates*, File: ERP002_MEM_SourceDepletions_Rev0, prepared for Ensham Resources Pty Ltd, February.

URS Australia Pty Ltd (2006), *Geochemical Characterisation and Assessment of Overburden and Potential Coal Reject Material at the Ensham Central Project*, Report: 42625576 / R001-FINAL, prepared for Hansen Consulting on behalf of Ensham Resources Pt Ltd, January.

WSP (2018), *Stage 3 Technical Report: Civil Design*, prepared for Ensham Resources Pty Ltd, September.