Warramboo TSF Seepage Study For Environmental Approvals

Final report

Rio Tinto Technical Services

Report

November 2018

The expert in **WATER ENVIRONMENTS**

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Warramboo TSF Seepage Study For Environmental Approvals

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Aerial view of the Warramboo site (Google Earth)

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CONTENTS

FIGURES

TABLES

Executive Summary

Rio Tinto Iron Ore (RTIO) is proposing to abstract additional groundwater from the Warramboo area to supply water to a new wet processing plant at Mesa A. Water quality sampling indicates that groundwater quality varies across the Warramboo area. Modelling was undertaken to assess the potential for changes to water quality in and near the mining area as a result of groundwater drawdown extending towards naturally occurring higher salinity areas.

Waste fines will be generated by the wet processing plant and will be disposed of to an in-pit tailings storage facility (TSF) in mined-out pits at Warramboo along with effluent from a reverse osmosis plant. Modelling was undertaken to assess the potential for changes to water quality as a result of seepage from the tailings storage facility.

A detailed water and chloride balance model was created in Goldsim to determine the chloride levels in the future TSF. These concentrations were then used as another boundary condition for groundwater modelling, which was carried out to assess an overall chloride migration across the site and to determine if seepage from the TSF would impact groundwater quality in the Warramboo area. Chloride was chosen as a suitable analyte for the modelling of groundwater quality for several reasons, namely that the groundwater at Warramboo is of the Na-Mg-Cl type and generally of good quality with metals and trace element concentrations usually at or below limits of detection (RTIO 2015), Total Dissolved Solids (TDS) was found to be dominated by chloride concentrations and to follow similar distribution patterns to chloride across the site (RTIO 2015), and chloride is generally a conservative solute.

The Goldsim model incorporates either the case of no return of effluent from the reverse osmosis plant (No RO) to the Warramboo pit, or a maximum return of effluent from the reverse osmosis plant (Maximum RO) to describe additional chloride supply to the TSF as well as all relevant meteorological and hydraulic boundary conditions. Two potential ponded water scenarios were considered (either ponded water volume limited to 1 Mm^3, or no ponded water volume limit). The first scenario is based on a safety limit imposed during prior water balance calculations (GHD 2018), whereas the second scenario removes this constraint to determine whether chloride levels are sensitive to this condition.

Results from the Goldsim modelling show the scenario with no ponded water volume limit results in lower chloride concentrations, with chloride concentrations up to 950 mg/L expected to be experienced under no ponded water limitations, as opposed to 1400 mg/L where a ponded water volume limit is imposed.

Results from the groundwater modelling show that

- Naturally occurring areas of higher chloride concentration located towards the coast to the west of the Warramboo pits will likely result in some increase in chloride concentrations in some of the water supply bores over the life of the mine (LOM). This is due to dewatering of Warramboo pits and water abstraction, which creates a drawdown that extends towards higher chloride areas towards the coast.
- Naturally occurring areas of higher chloride concentration located east of the Warramboo pit will have limited impact on water supply bores during LOM. This is due to no flow boundary conditions imposed to the north-east of the pits. This limits the transport to dispersive processes, with advection playing a minor role
- The presence of the TSF will increase the groundwater chloride concentration by up to 470 mg/l in 2036
- The modelling indicates that the increase in chloride concentration due to the TSF will not extend beyond the cone of depression resulting from water supply to the wet plant and that the majority of the increase in chloride concentration will remain within the pit area and is not expected to reach water supply bores or

- The effects of areas of higher chloride concentration to the west of Warramboo make chloride concentrations in the study area likely to be relatively insensitive to the TSF chloride concentrations.

1 Introduction

Rio Tinto Iron Ore (RTIO) is proposing to abstract additional groundwater from the Warramboo area to supply water to a new wet processing plant at Mesa A. Groundwater water quality sampling indicates that the water quality varies across the Warramboo area with a naturally occurring higher salinity area present to the west of the mining area. There is potential for higher salinity water to be entrained into the cone of depression, potentially changing the water quality beneath the Warramboo mine pits and/or at the water supply bores. Waste fines will be generated by the proposed wet processing plant at Mesa A and will be disposed of to an in-pit tailings storage facility (TSF) in mined-out pits at Warramboo. The proposed waste fines stream is considered to be chemically benign with its geochemistry similar to the original ore excavated from Warramboo with slight enrichment in some minerals (such as Al_2O_3 and SiO_2). RTIO also proposes to dispose of effluent from a reverse osmosis plant to the in-pit TSF at Warramboo. Elevated salinity is expected in the effluent from the reverse osmosis plant. There is potential for seepage from the TSF to change the quality of groundwater beneath the proposed TSF.

As part of environmental impact assessment and to inform metallurgical and process design, modelling is required to assess:

- the potential for changes to water quality in and near the mining area as a result of groundwater drawdown extending towards naturally occurring higher salinity areas.
- the potential changes to water quality as a result of seepage from the TSF.

Chloride was chosen as a suitable analyte for the modelling of groundwater quality for several reasons, namely that the groundwater at Warramboo is of the Na-Mg-Cl type and generally of good quality with metals and trace element concentrations usually at or below limits of detection (RTIO 2015), total dissolved solids (TDS) was found to be dominated by chloride concentrations and was found to follow similar distribution patterns to chloride across the site (RTIO 2015), and chloride is a conservative solute, meaning that chloride does not undergo degradation reactions; and as such, it represents the worst case scenario for solute transport modelling.

Key dates used herein are as follows:

- 2021 – Beginning of additional water supply requirements and transfer of tailings to Pit 1 & 2
- 2036 – Predicted end of water supply requirements from the Warramboo borefield, and thus end of groundwater model simulation Scenario 1 and 2
- 2086 – End of groundwater model simulation Scenario 3

2 Scope and objectives

The scope of this work is as follows:

- Develop a water and chloride balance for the Warramboo TSF based on existing Goldsim models for similar TSF's.
- Simulate the flow and transport of chloride emanating from the Warramboo TSF in the groundwater and determine the extent of chloride plume formation, if any.

3 Methodology

3.1 Goldsim model

The base model for this work is a Goldsim model built for water balance calculations for the Tom Price South East Prongs Pit (GHD 2016). A chloride balance was added to the model, with the Goldsim model to be transferred back to RTIO as part of the project deliverables. The model basis and key assumptions are described in Section 3.3.

3.2 Groundwater model

The groundwater model to be used for this project is the RTIO Warramboo Numerical Model (RTIO 2017), a one layer 2D model.

3.3 Goldsim model basis

The following assumptions were made in the model development regarding waste fines:

- Tailings discharge was assumed to commence to Pit 1 / 2 in 2021, with transfer to Pit 3 once Pit 1 / 2 reaches full capacity, based on GHD (2018).
- A void ratio (voids volume / solids volume) of 1.5 in the final pits was assumed, based on a final stored density of 1.5 t/m^3 (GHD 2018) This differs to the Tom Price model which includes a variable void ratio based on the level of consolidation ranging between 1.1 and 1.7, however sensitivity tests demonstrate this difference to not be material to the results.
- Pit volumes are as provided by GHD (provided via email, 20/12/2017) and outlined in Table 3-1 and Table 3-2. Note the incremental volumes decrease above 60m RL for Pit 1&2 and 40m RL for Pit 3, indicative of the sloping final landform surface to be developed to maximise solids storage.
- The dry tonnage production follows the medium case scenario of 853 tph based on 6000 hours operation per annum. This gives a total of 41 Mt of waste fines for an 8 year production period (GHD 2018).

Key definitions are as follows:

- Ponded water refers to the total water in the pit minus the pore water in the pit. It thus represents only the water that is visible above the level of the solids.
- Pore water is the volume of water contained within the deposited solids matrix.

Assumption related to water and chloride balance are as follows:

- Water production considers two cases, either the “no RO” case of 1117 tph water, or the “max RO” case of 1549 tonnes per hour water production (Calibre, provided via email). Chloride in the waste fines is as provided by Calibre (Table 3-3).
- Two cases for decant are considered. The first case presented (“Ponded water limit”) limits the ponded water volume in the pit to 1 Mm3 (GHD 2018). The second case presented (“No ponded water limit”) removes this constraint to determine whether the prediction of chloride levels are sensitive to any limits imposed.
- Seepage rates to the groundwater were set to 20% of the water fraction of the tailings discharge rate when tailings were being discharged, based on information provided by RTIO from measurements and modelling at Mesa J. This value was decreased linearly to zero based on the difference between the water table elevation and the base of the pit.
- Groundwater inflow to pits, including seepage between pits, was not considered as dewatering will be ongoing.

- Rainfall was generated using the Markov Rainfall Generator module in Goldsim. Rainfall data was derived from the Patched Point data set for station 5032 Yarraloola Homestead (provided by RTIO), with parameters calculated by DHI based on these data defined in Table 3-4. Cumulative distribution functions are shown in Figure 3-1 and Figure 3-2 comparing data with Markov Rainfall Generator results.
- Evaporation data were derived from BOM monthly pan evaporation data for the Warramboo site (Table 3-4). Pan factors were applied as in the Tom Price model, varying monthly and ranging between 0.564 – 0.654.
- Evaporation rates were applied to the planar surface area of the pit, with ponded water assumed to cover the full surface area in order to be conservative with respect to chloride concentrations
- Ponded water and pore water are considered fully mixed for the purposes of chloride concentrations.
- Simulations were only run until the ponded water level (total water minus pore water) reached the minimum crest elevation (60m RL for Pit 1&2, 45m RL for Pit 3). Simulation beyond this point required consideration of beach formation beyond the scope of this study.
- Chloride concentrations in the rainfall were provided by RTIO as 1 mg/L (median of 8 samples collected at Mesa J), and in the runoff from the pit wall 90 mg/L (median of all lithologies for Warramboo rock).
- Chloride concentrations in ponded and pore water were considered as uniform.

Table 3-1. Warramboo Pit 1&2 Storage Data (from GHD, provided via email).

Top RL (m)	Volume (base at RL) (m^3)	Cumulative volume (m3)
70	605,481	12,979,868
65	2,893,256	12,374,387
60	4,190,584	9,481,131
55	3,689,784	5,290,547
50	1,407,709	1,600,763
45	193,054	193,054
40	-	0

Table 3-2. Warramboo Pit 3 Storage Data (from GHD, provided via email)

Top RL (m)	Volume (base at RL) (m^3)	Cumulative volume (m3)
55	230,166	10,536,677
50	2,965,252	10,306,511
45	4,780,212	7,341,259
40	1,789,538	2,561,047
35	503,033	771,509
30	205,866	268,476
25	52,268	62,610
20	10342	10342

Table 3-3. Chloride concentrations for waste fines under "no RO" and "max RO" cases (from Calibre, provided via email)

Year	Chloride for no RO case	Chloride for max RO case
2021	658	711
2022	739	784
2023	656	738
2024	759	826
2025	665	773
2026	758	863
2027	790	910
2028	843	977
2029	956	1094
2030	1070	1220
2031	1214	1379
2032	1343	1542
2033	1537	1771
2034	1810	2084
2035	2097	2444

Table 3-4. Climate data inputs, with inputs to Markov rainfall generator and evaporation data generated by DHI based on Patched Point data set for station 5032 Yarraloola Homestead provided by RTIO.

Month	Mean length of rainy periods (days)	Mean monthly rainfall (mm)	Mean probability of a rainy period	Monthly evaporation rate (mm)
Jan	1.69	46.9	12.4	369.62
Feb	1.87	67.9	18.1	306.32
Mar	1.82	58.2	11.9	322.64
Apr	1.38	19.4	4.6	272.25
May	1.59	34.0	6.6	209.94
Jun	1.56	34.3	8.5	165.31
Jul	1.52	14.0	5.0	177.83
Aug	1.49	7.0	3.0	213.99
Sep	1.58	1.5	0.9	266.23
Oct	1.19	1.2	0.5	336.98
Nov	1.19	2.9	0.9	362.3
Dec	1.49	14.0	3.8	384.84

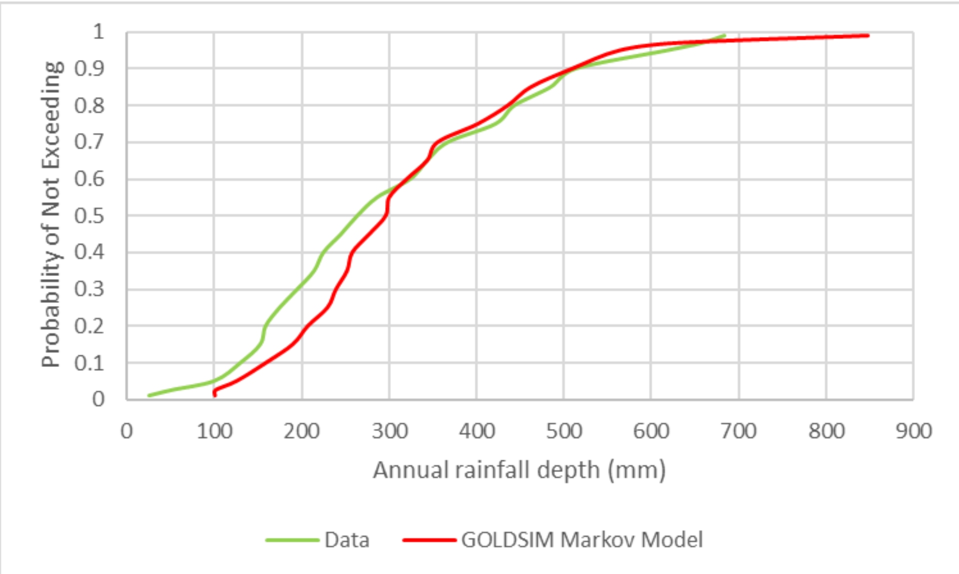


Figure 3-1. Annual rainfall (mm) comparison between data and results from a 100 year simulation in Goldsim using the Markov rainfall model parameters from Table 3-4.

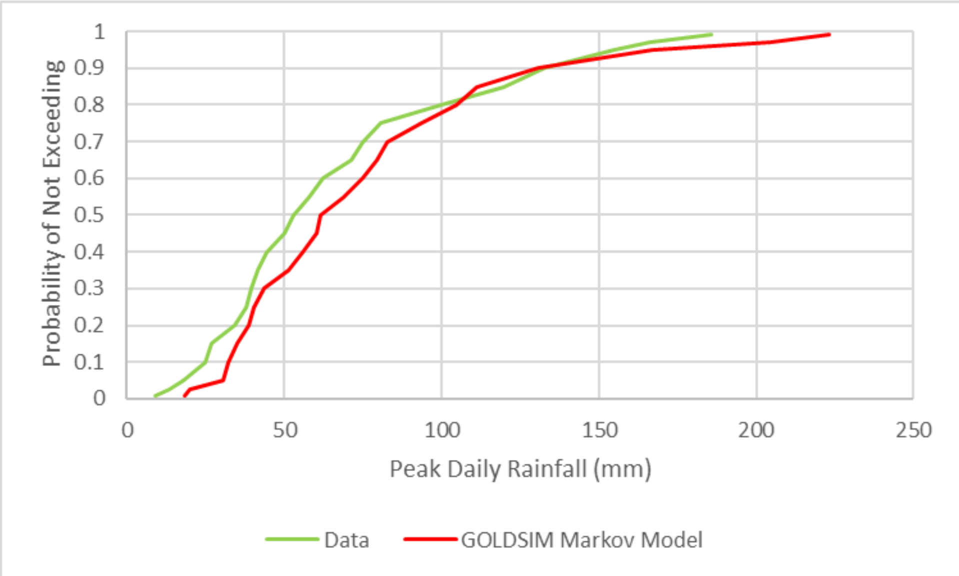


Figure 3-2. Peak daily rainfall (mm) comparison between data and results from a 100 year simulation in Goldsim using the Markov rainfall model parameters from Table 3 4

4 Results

4.1 Water and chloride balance

4.1.1 Water balance

A simplified water balance is provided in Table 4-1 to give an overview of the key processes. The following assumptions were made in preparation of the water balance:

- An average annual rainfall of 301 mm was applied
- The pit wall runoff coefficient was 1.0.
- Local catchment inflow is assumed negligible.
- Evaporation proceeds using the maximum pit surface area and a pan factor of 0.61.
- The water in tails is defined by the “no RO” case.
- Waste fines operations run for 6000 hours per annum.
- No decant pumping is assumed.
- Seepage loss is 20% of water in tails.

The results demonstrate that the water balance is always positive under these assumptions. For the month with minimum net evaporation (June), this positive water balance exceeds 10,000 m^3/day.

Table 4-1. Daily water balance (m^3/day) for combined storage Warramboo pits, based on average, minimum net evaporation and maximum net evaporation.

Component	Mean monthly	Minimum net evaporation (June)	Maximum net evaporation (November)
Rainfall / pit wall runoff	1481	2051	173
Water in tails	18349	18349	18349
Evaporation	-10301	-6019	-13206
Seepage loss	-3670	-3670	-3670
Net water balance	**5860**	**10711**	**1646**

4.1.2 Water levels and chloride concentration (ponded water limit)

Results are presented for two cases: no RO or max RO, for transfer firstly to Pit 1&2 followed by discharge to Pit 3. The evolution of each pit is demonstrated individually. A total of 100 realisations were run for each case, with a randomly chosen realisation selected for illustration purposes.

Items shown in the water balance figures are defined as follows:

- Direct rainfall – rainfall onto the ponded water surface or solids surface (source)
- Pit Wall Runoff – runoff from rainfall directly falling onto pit walls (source)
- Tailings water – water contained in the tailings delivered to the pit (source)
- Decant – water removed via decant (sink)
- Evaporation – evaporation of ponded water (sink)

- Groundwater seepage – water lost to seepage (sink)

Items shown in the levels figures are defined as follows:

- Max Pit Level – crest level at which water will spill to surrounds
- Pit Level (Solids) – level of the top of the solids matrix
- Total Water Volume – pore water plus ponded water volume
- Water Table – water level once ponded water is absent
- Ponded Water Volume – volume of free water on the solids surface (total water minus pore water)
- Pit Level (Solids + Water) – visible level of (solids + water) in the pit
- Pore Water Volume – water volume contained in the pore space of the deposited solids

The Pit 1&2 case of no RO flow demonstrates significant decant water requirements (Figure 4-1) in order to maintain a maximum ponded water volume of 1 Mm3 (Figure 4-2). Chloride concentrations reach approximately 1450 mg/L before declining to approximately 1200 mg/L after the cessation of tailings water input and the addition of rainfall.

The Pit 1&2 case of maximum RO shows greater decant requirements (Figure 4-4) of 10,000 – 15,000 m3/day before rainfall events are taken into account. Chloride concentrations reach a peak of approximately 1900 mg/L before declining to approximately 1500 mg/L with rainfall input after tailings discharge ceases.

Decant requirements for pit 3 are similar for the Pit 1&2 case for both no RO (Figure 4-7) and max RO (Figure 4-11). Chloride concentrations also show a similar trend, with the no RO case reaching a peak of 1500 mg/L before reducing to 1300 mg/L (Figure 4-9), with the max RO case reaching a peak 1900 mg/L before reducing to 1400 mg/L (Figure 4-12).

Note the filling times indicated (~900 days for Pit 1&2, ~700 days for Pit 3) are only to the minimum crest level (60m RL for Pit 1&2, 40m RL for Pit 3), and do not take into account tailings deposition up to maximum storage capacity due to model limitations with handling ponded water under complex beach profiles.

No RO case, Pit 1&2

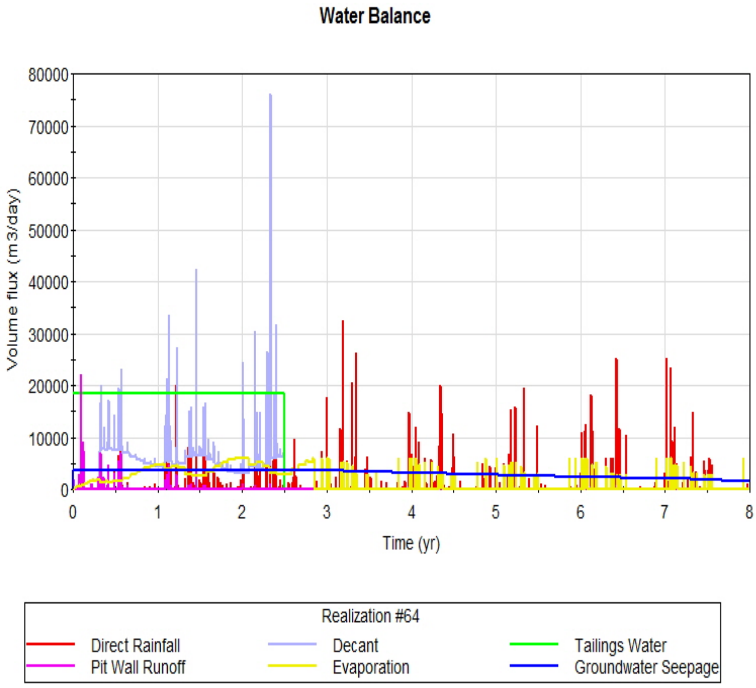


Figure 4-1. Water balance for no RO case for Pit 1&2.

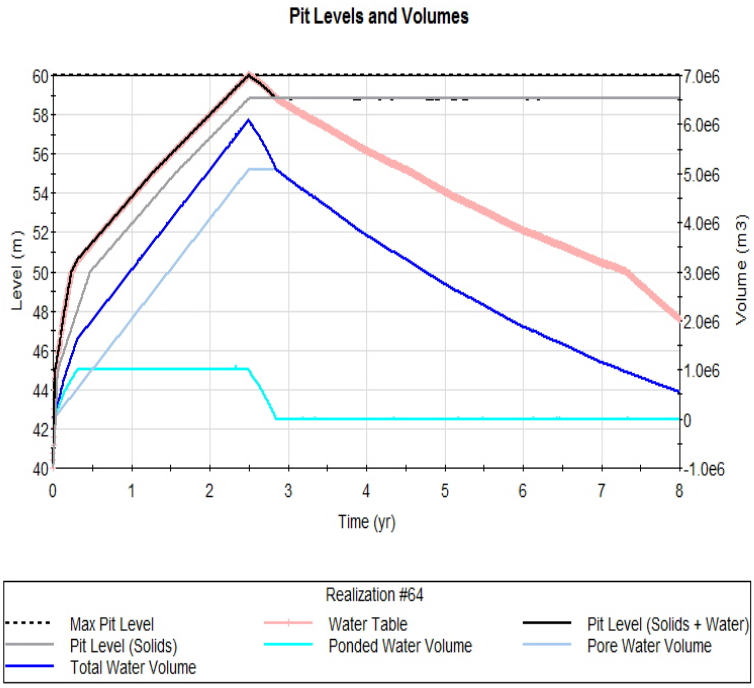


Figure 4-2. Pit levels and water volumes for no RO Pit 1&2.

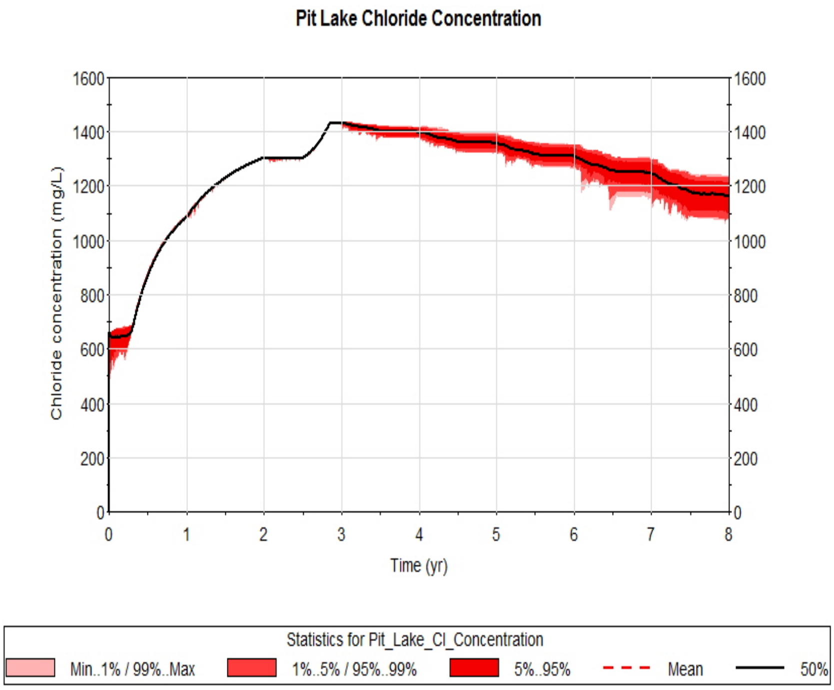


Figure 4-3. Range of pit lake chloride concentrations for no RO case, Pit 1&2.

Max RO case, Pit 1&2

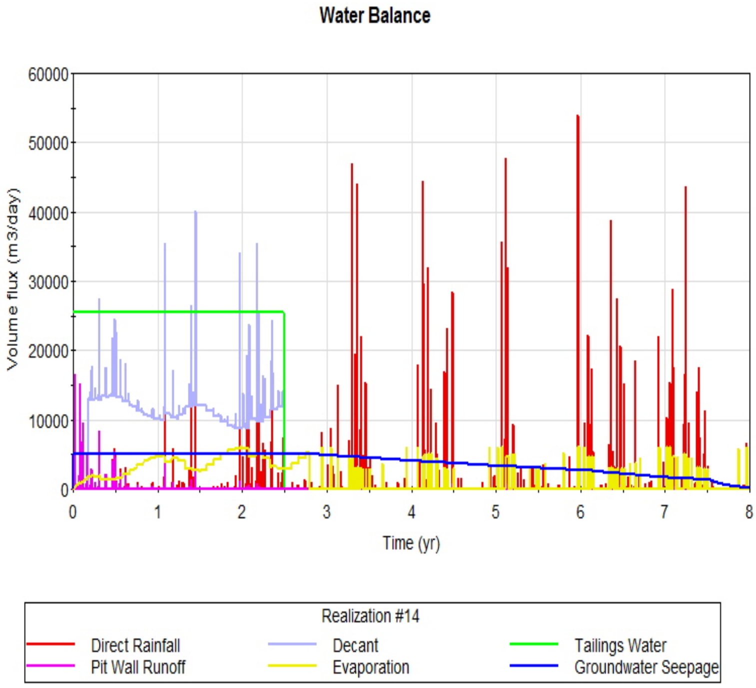


Figure 4-4. Water balance for max RO case for Pit 1&2.

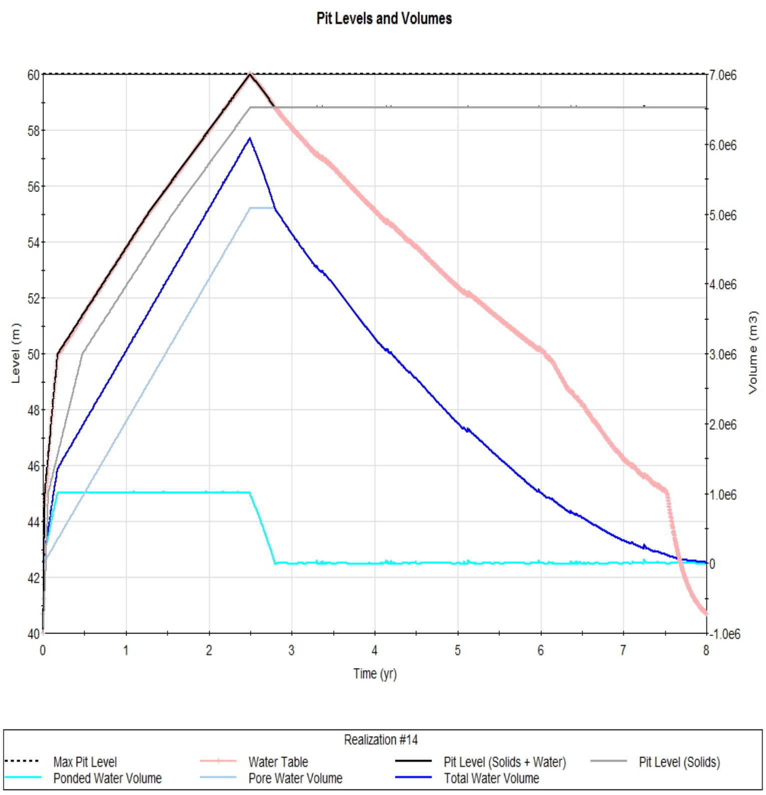


Figure 4-5. Pit levels and water volumes for max RO Pit 1&2.

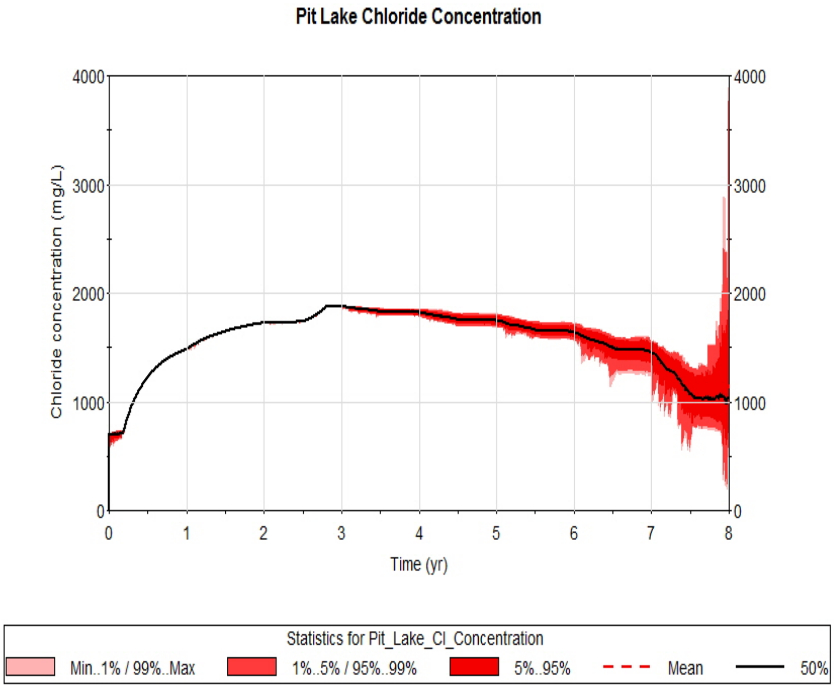


Figure 4-6. Range of pit lake chloride concentrations for max RO case, Pit 1&2.

No RO case, Pit 3

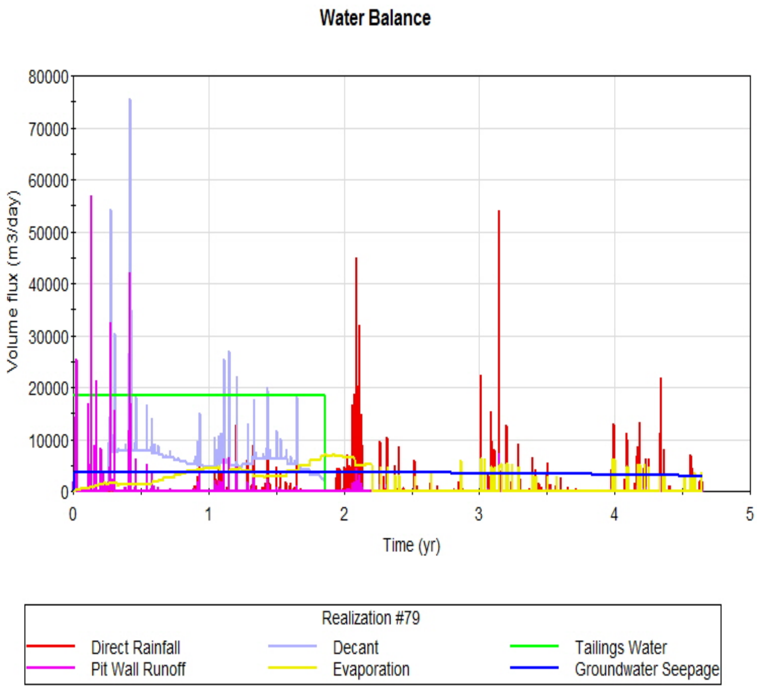


Figure 4-7. Water balance for no RO case for Pit 3.

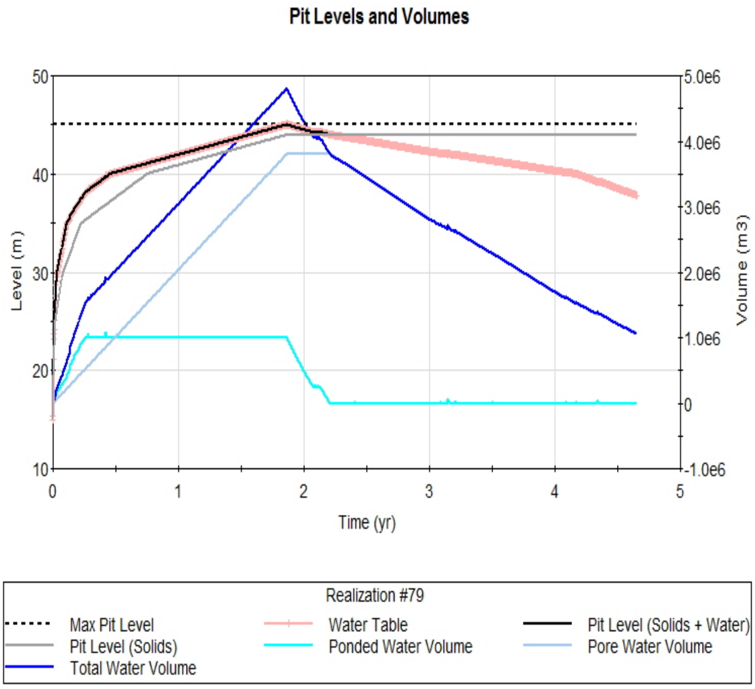


Figure 4-8. Pit levels and water volumes for no RO Pit 3.

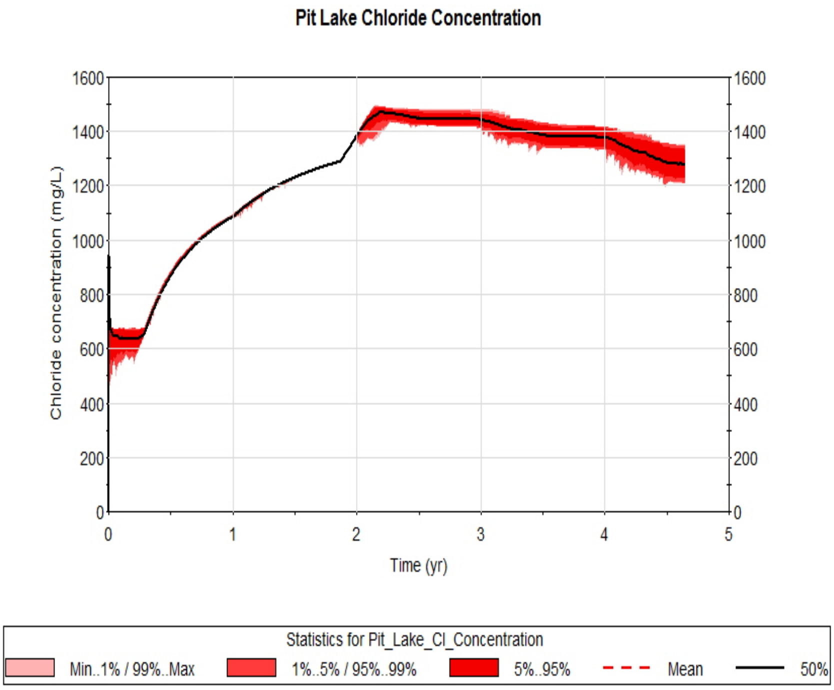


Figure 4-9. Range of pit lake chloride concentrations for no RO case, Pit 3.

Max RO case, Pit 3

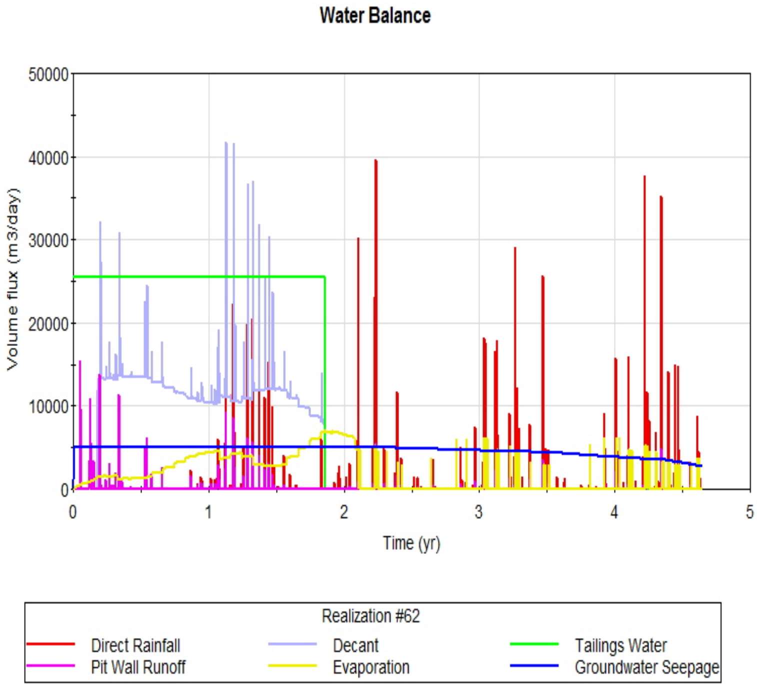


Figure 4-10. Water balance for max RO case for Pit 3.

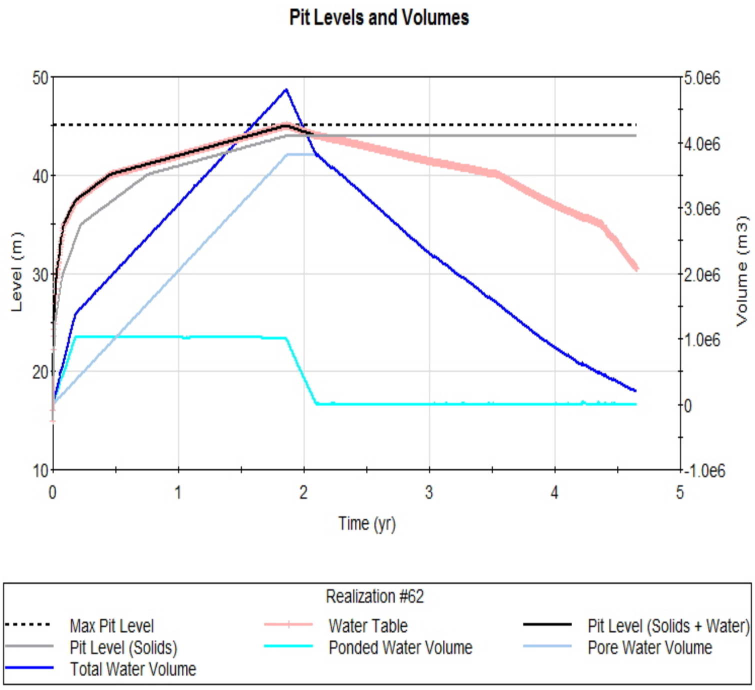


Figure 4-11. Pit levels and water volumes for max RO Pit 3.

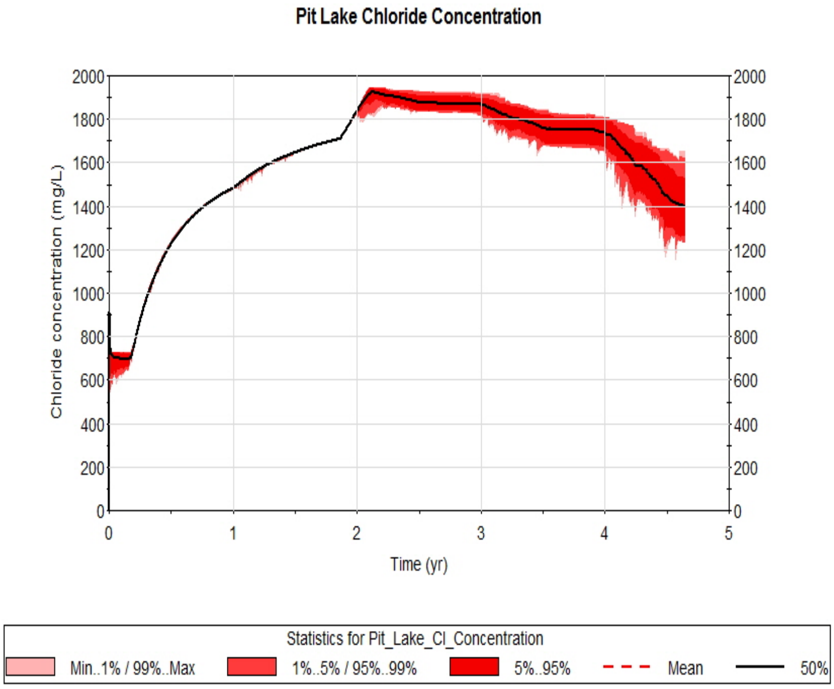


Figure 4-12. Range of pit lake chloride concentrations for max RO case, Pit 3.

4.1.3 Water levels and chloride concentration (no ponded water limit)

The previous case applies a limit of 1 Mm^3 of ponded water before decant pumping is applied, based on a safety limit imposed in previous water balance calculations (GHD 2018). In this scenario, a different operating logic is applied whereby ponded water is allowed to accumulate until the pit volume (tails + pore water + ponded water) equals 90% of the total available volume, at which point decant pumping is allowed. This allows for a greater accumulation of ponded water in the pit, and a later implementation of decant pumping infrastructure. It also allows for an assessment as to whether chloride concentrations are sensitive to the ponded water management approach.

Water balance, pit levels and chloride concentrations for the No RO case for Pit 1 and 2 are shown in Figure 4-13 - Figure 4-15. Decant pumping be seen to switch off and on from approximately 1.5 years onwards until the pit fills with solids just prior to the start of year 3. Lower chloride levels are reached compared to the case where ponded water volume is limited, as evapo-concentration during the ponded water stage is less effective in building up chloride concentrations due to the increased ponded water volume. Results for the Max RO case show slightly higher chloride concentrations, but otherwise similar outcomes are predicted (Figure 4-16 - Figure 4-18). Cases for Pit 3 show similar trend (Figure 4-19 - Figure 4-24), and are not overall particularly different for the case with the ponded water limit.

No RO case, Pit 1&2

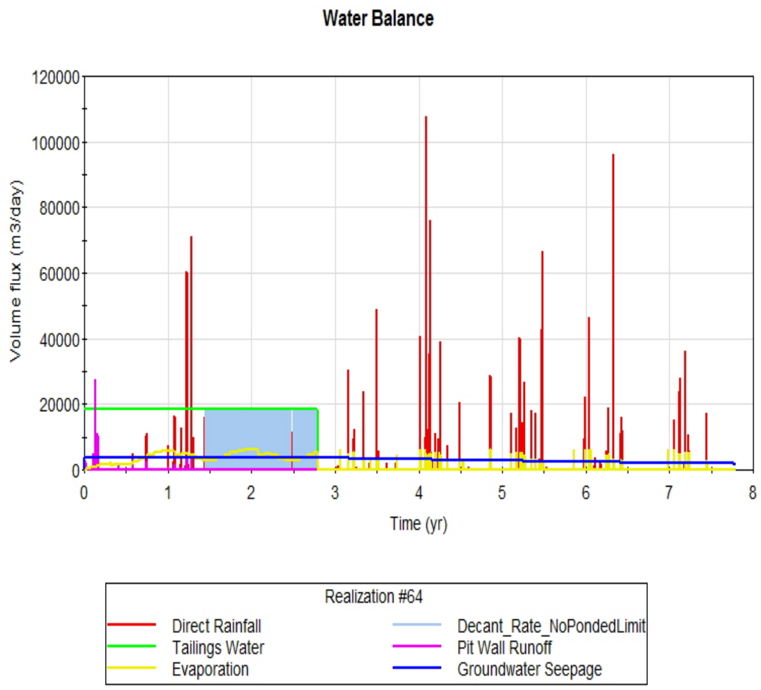


Figure 4-13. Water balance for no RO case for Pit 1&2, with no ponded water limit.

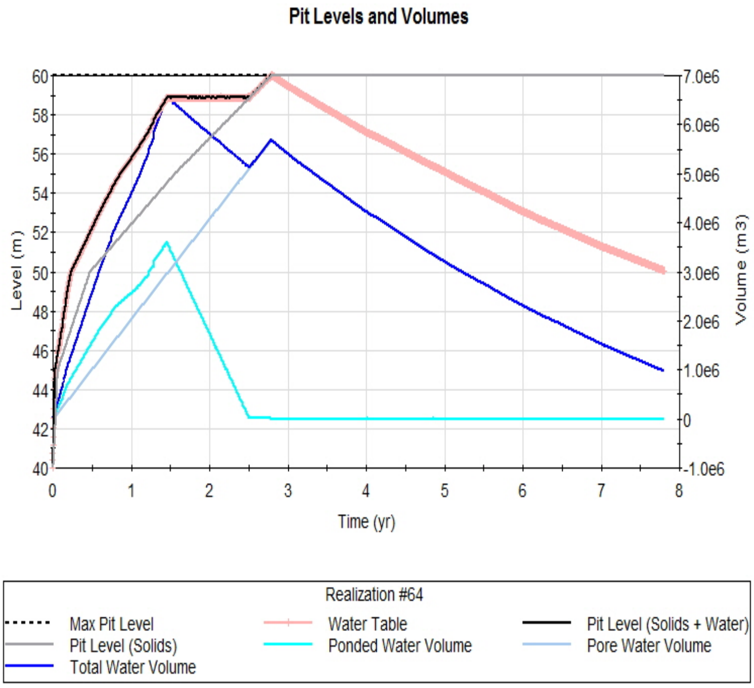


Figure 4-14. Pit levels and water volumes for no RO case for Pit 1&2, with no ponded water limit.

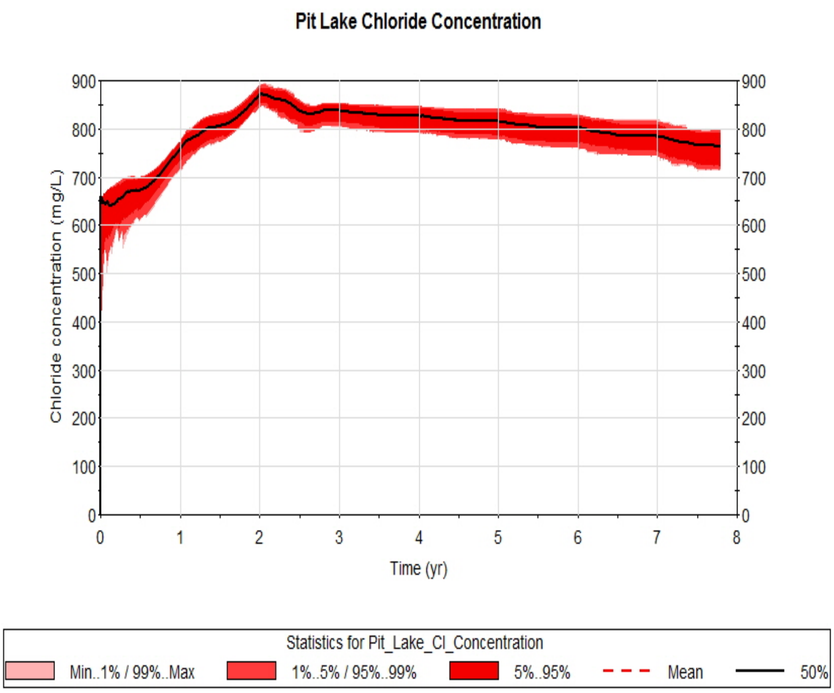


Figure 4-15. Range of pit lake chloride concentrations for no RO case for Pit 1&2, with no ponded water limit.

Max RO case, Pit 1&2

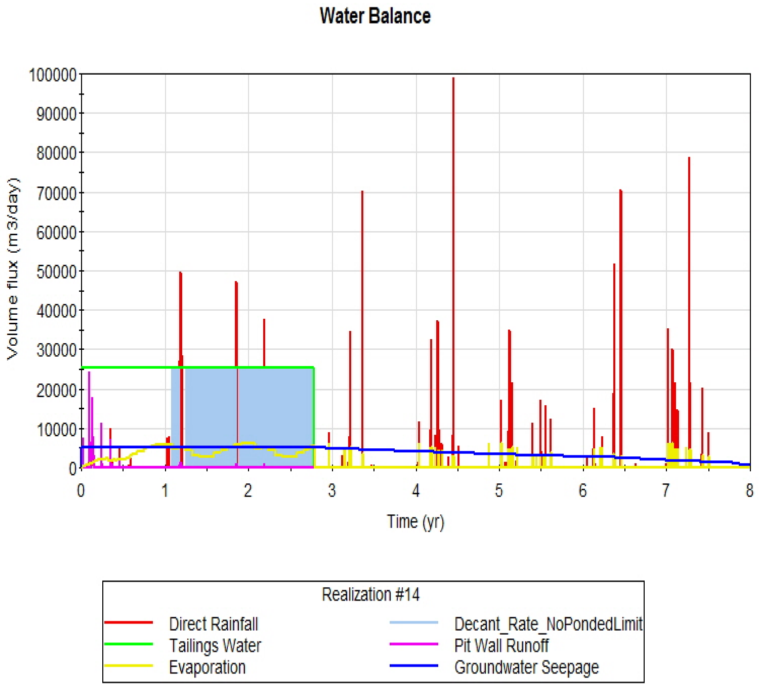


Figure 4-16. Water balance for max RO case for Pit 1&2, with no ponded water limit

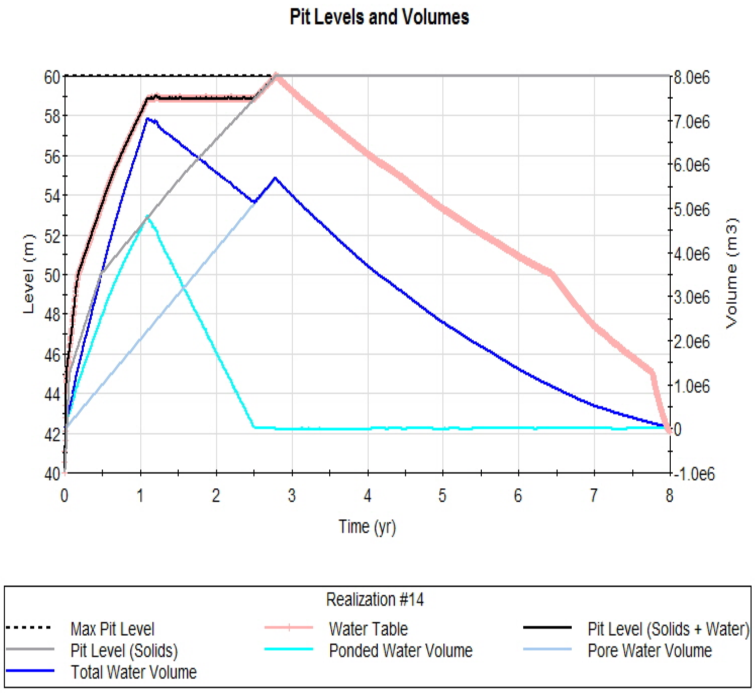


Figure 4-17. Pit levels and water volumes for max RO case for Pit 1&2, with no ponded water limit.

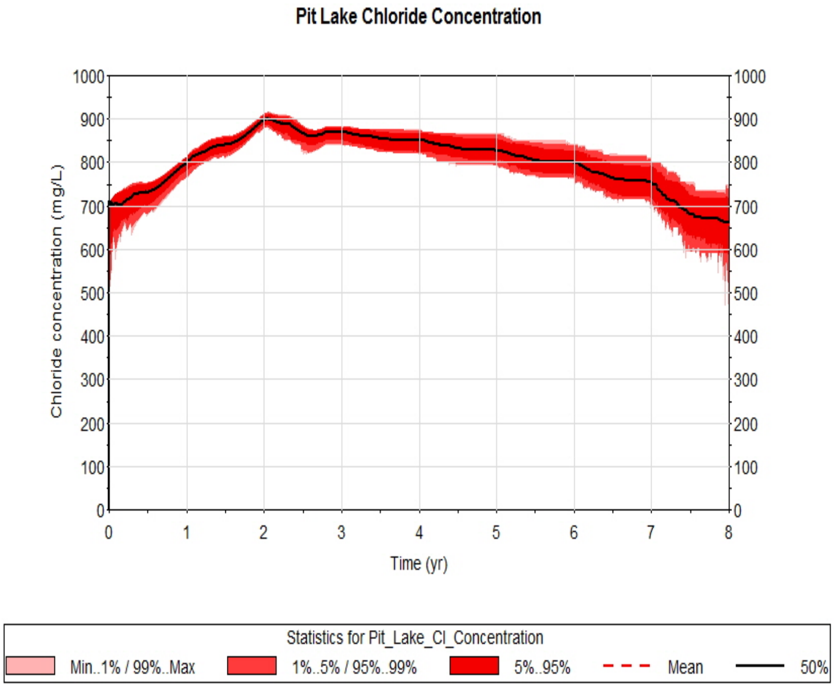


Figure 4-18. Range of pit lake chloride concentrations for max RO case for Pit 1&2, with no ponded water limit

No RO case, Pit 3

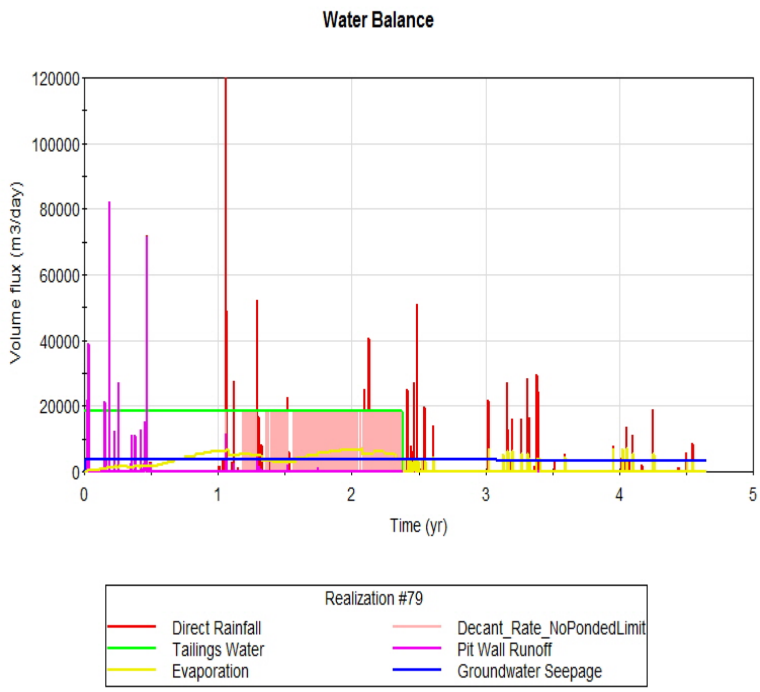


Figure 4-19. Water balance for no RO case for Pit 3, with no ponded water limit

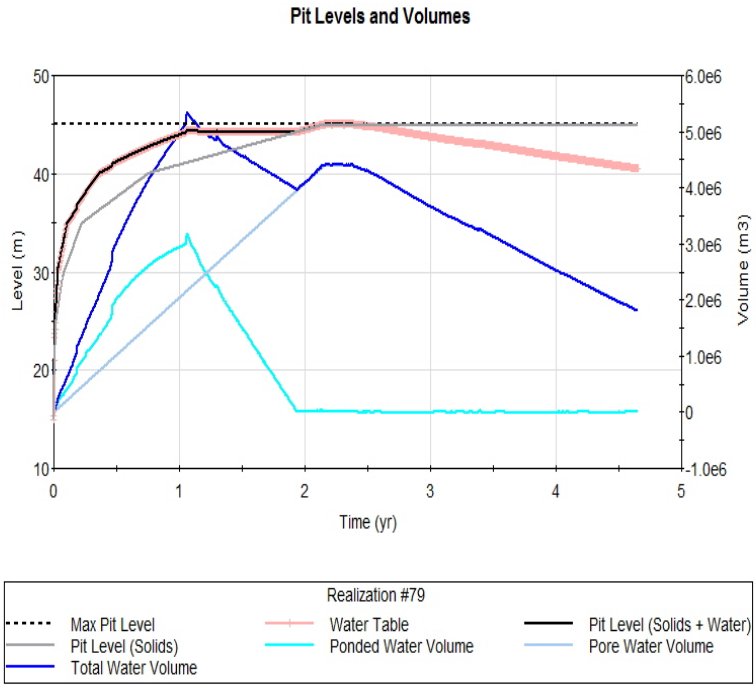


Figure 4-20. Pit levels and water volumes for no RO case for Pit 3, with no ponded water limit

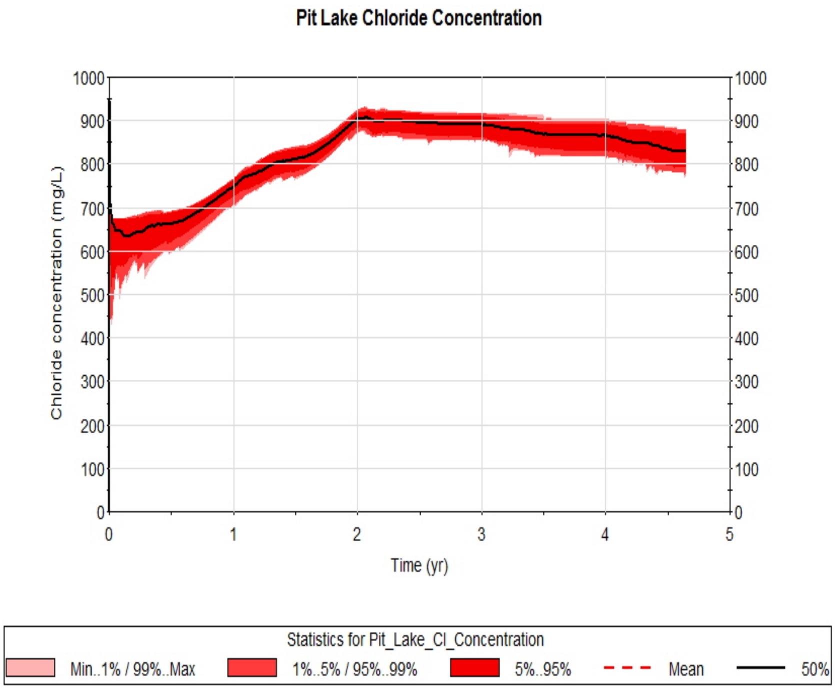


Figure 4-21. Range of pit lake chloride concentrations for no RO case for Pit 3, with no ponded water limit

Max RO case, Pit 3

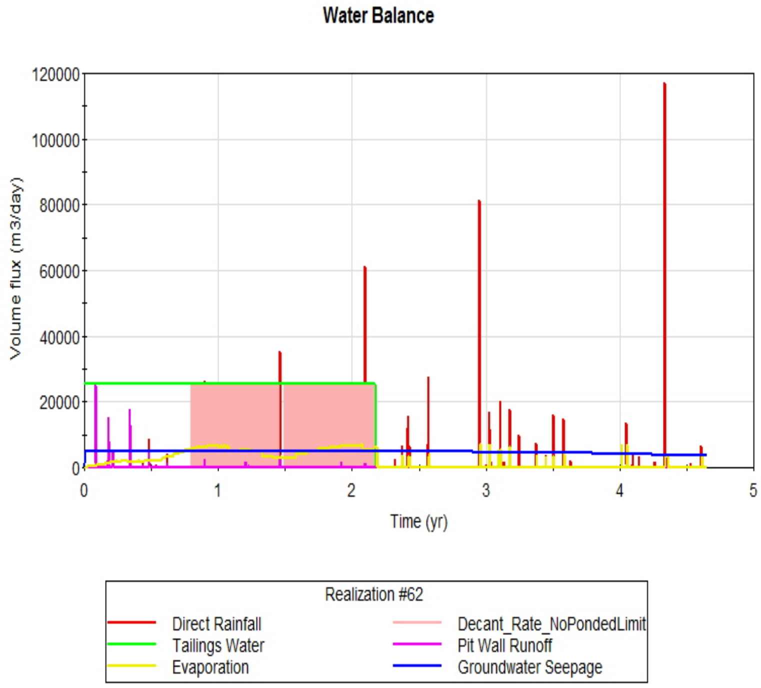


Figure 4-22. Water balance for max RO case for Pit 3, with no ponded water limit

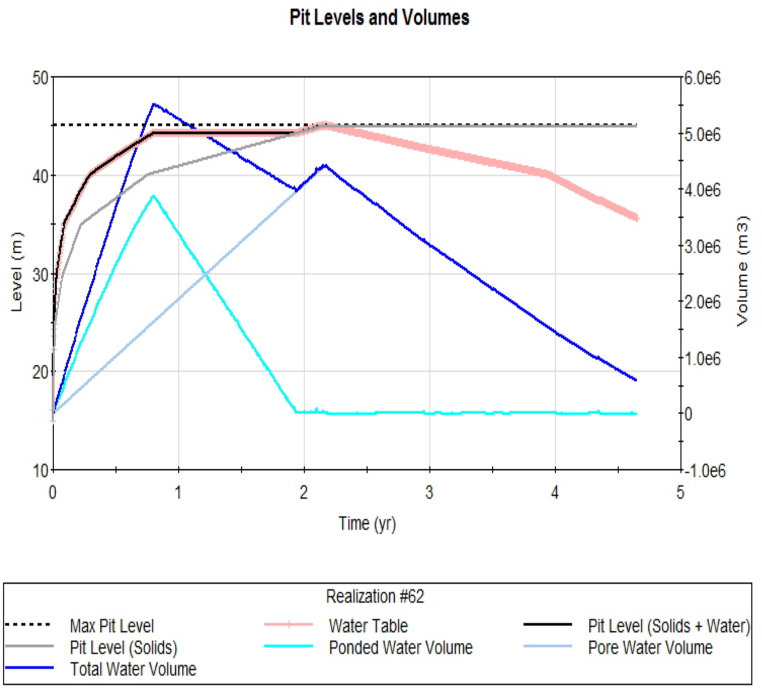


Figure 4-23. Pit levels and water volumes for max RO case for Pit 3, with no ponded water limit

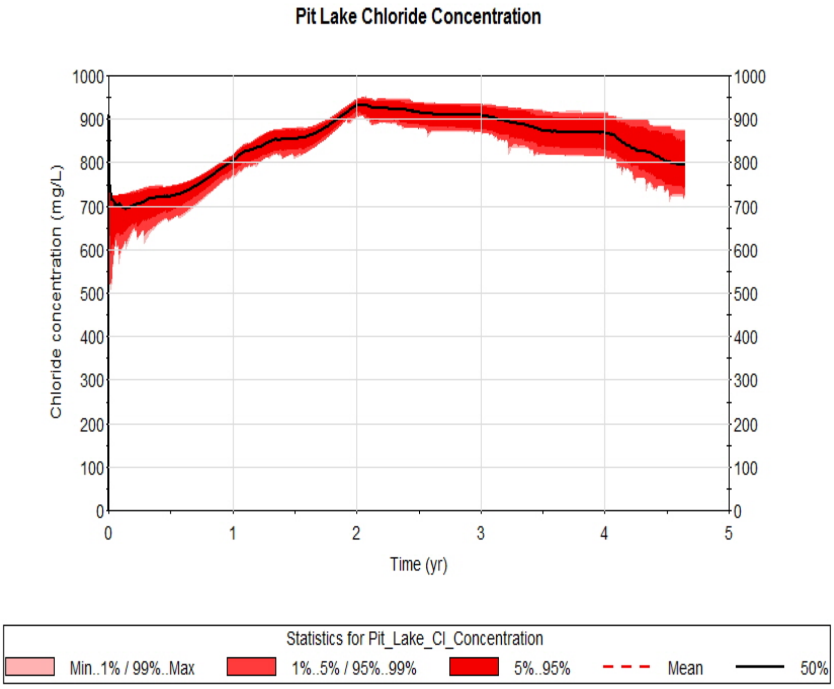


Figure 4-24. Range of pit lake chloride concentrations for max RO case for Pit 3, with no ponded water limit

4.2 Groundwater model

The primary consideration of this study is the potential impact of chloride on groundwater downgradient of the Warramboo pits. The above analysis indicates a range of chloride concentrations are possible in the pits depending on the operational conditions. However, on the basis of the discussions held with the Rio Tinto representative it was decided to adopt the Pit 1&2 tailing storage facility option for the groundwater modelling exercise.

An existing model developed in March 2018 by Rio Tinto (2018) to assess the dewatering and water supply requirements was adapted for the transport simulation of chloride. The model was built with only one layer (two - dimensional modelling) with Groundwater Vistas version 7 and run with Modflow Surfact version 4.

During the course of this assessment, it is important to note prior findings on the groundwater behaviour in this area, primarily for the purposes of this study that the groundwater flow direction matches current surface topography flowing from southeast to northwest in the catchment (RTIO 2017).

4.2.1 Groundwater Model set up

The flow component of the groundwater model developed by Rio Tinto was not modified. Instead a transport component was enabled to simulate the fate and transport of chloride.

The model was used for predictive simulations and no calibration of the transport parameters was performed due to the absence of sufficient observation data (time series of concentrations). To simplify the analysis it was agreed with RTIO to use a snapshot in time of the field concentrations sampled in October 2016. Results were not found to be sensitive to this simplification.

The abovementioned data were used to assign the baseline concentration of chloride into the model. A preliminary screening of these concentration data was required to avoid model instabilities and inconsistencies. In particular, amongst all the measurements collected within a radius of 50 m only the sample with the highest concentration was selected. The final list of concentration data used for the interpolation of the initial model concentrations is shown in Figure 4-25.

The model domain, however, covers an area bigger than the extent of the concentration measurement field. This required an extrapolation of a preliminary interpolation of the data. The extrapolation was performed by assuming the following:

1. In the northern side of the model for an area parallel to the coastline it was assumed an initial concentration of 1700 mg/l. This concentration is consistent with the monitoring location MB08MEA004.
2. The measurements in the mining area were interpolated. Subsequently some contour lines have been subjectively extrapolated in other areas of the model domain where observations were not available. As a guiding principle the gradient of contour lines produced by the mathematical interpolation was preserved as much as possible.

The result of this extrapolation exercise is shown in Figure 4-25 and Figure 4-26. Besides the high chloride concentrations observed to the northwest, these figures highlight an area of high concentration of chloride (in the order of 3000 mg/l) at the bore MB16WARR0029 to the north east of Warramboo pits. This area is located outside the active groundwater model domain, i.e. in a geological zone identified as an aquiclude (Ashburton unit).

Three other bores (MB13WARR005, MB13WARR014 and MB13WARR006) located in the active area of the model show a high chloride concentration (ranging between 1200 and 2000 mg/l) in the vicinity of MB16WARR0029. A verification of the bore stratigraphy demonstrated that these bores are screened both in aquifer units (CID and Yarraloola Conglomerate) and the basement (Ashburton unit). Therefore, it is most likely that the high concentration measurements sampled in this area are a direct measurement of the chloride concentration of the Ashburton unit. Indeed, the bore MB16WARR0029 placed at a similar distance from the high concentration zone, but screened in the aquifer units only, shows a very low concentration (304 mg/l).

The very low hydraulic conductivity nature of the Ashburton unit suggests that the movement of the chloride plume from the high concentration zone would be very slow and mainly due to dispersion only rather than advection. To simulate this phenomenon a constant concentration boundary condition with a concentration of 2000 mg/l was placed at the border of the no flow zone of the model in the vicinity of MB16WARR0029 (Figure 4-27).

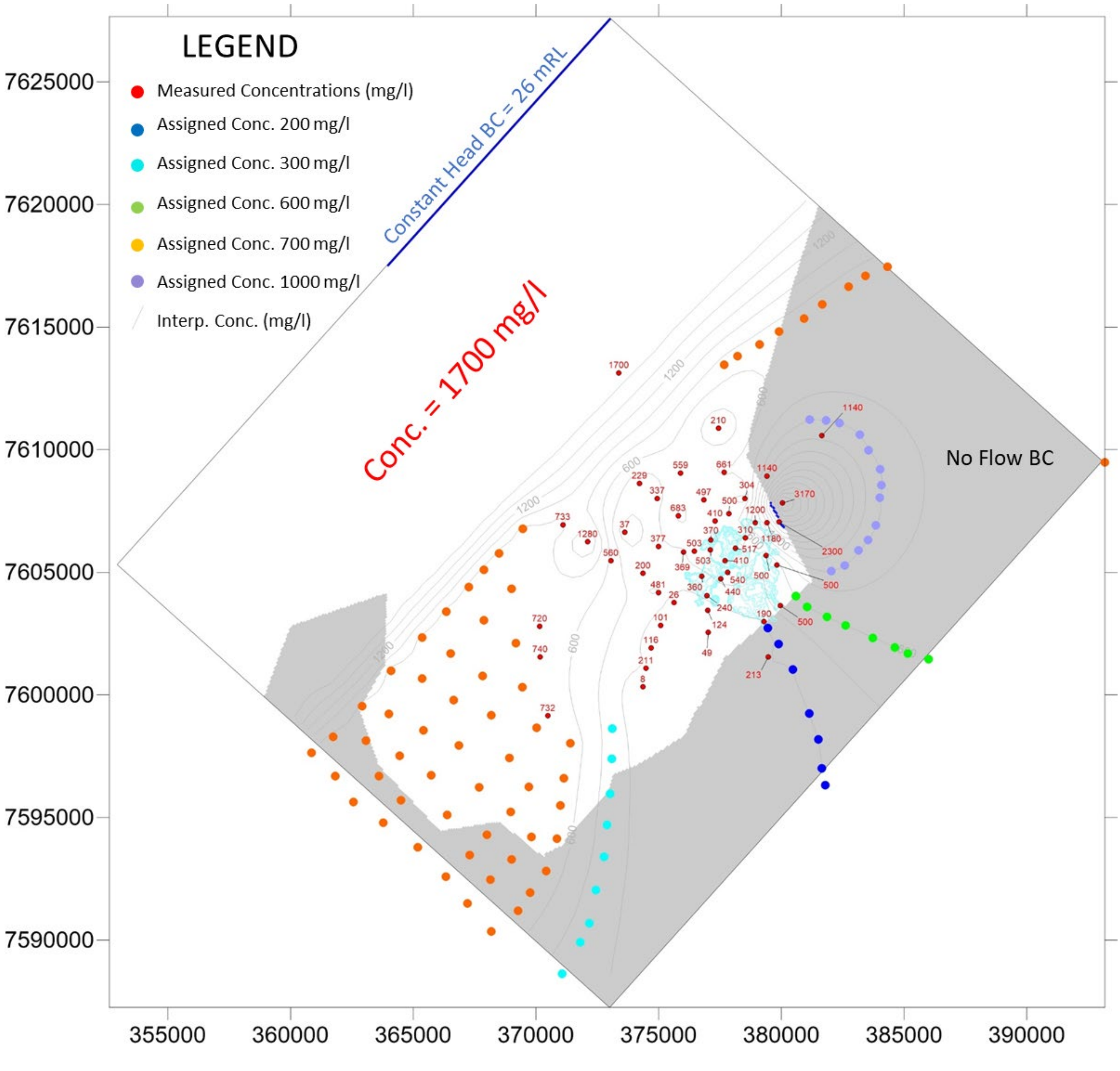


Figure 4-25: Initial chloride concentration and source data.

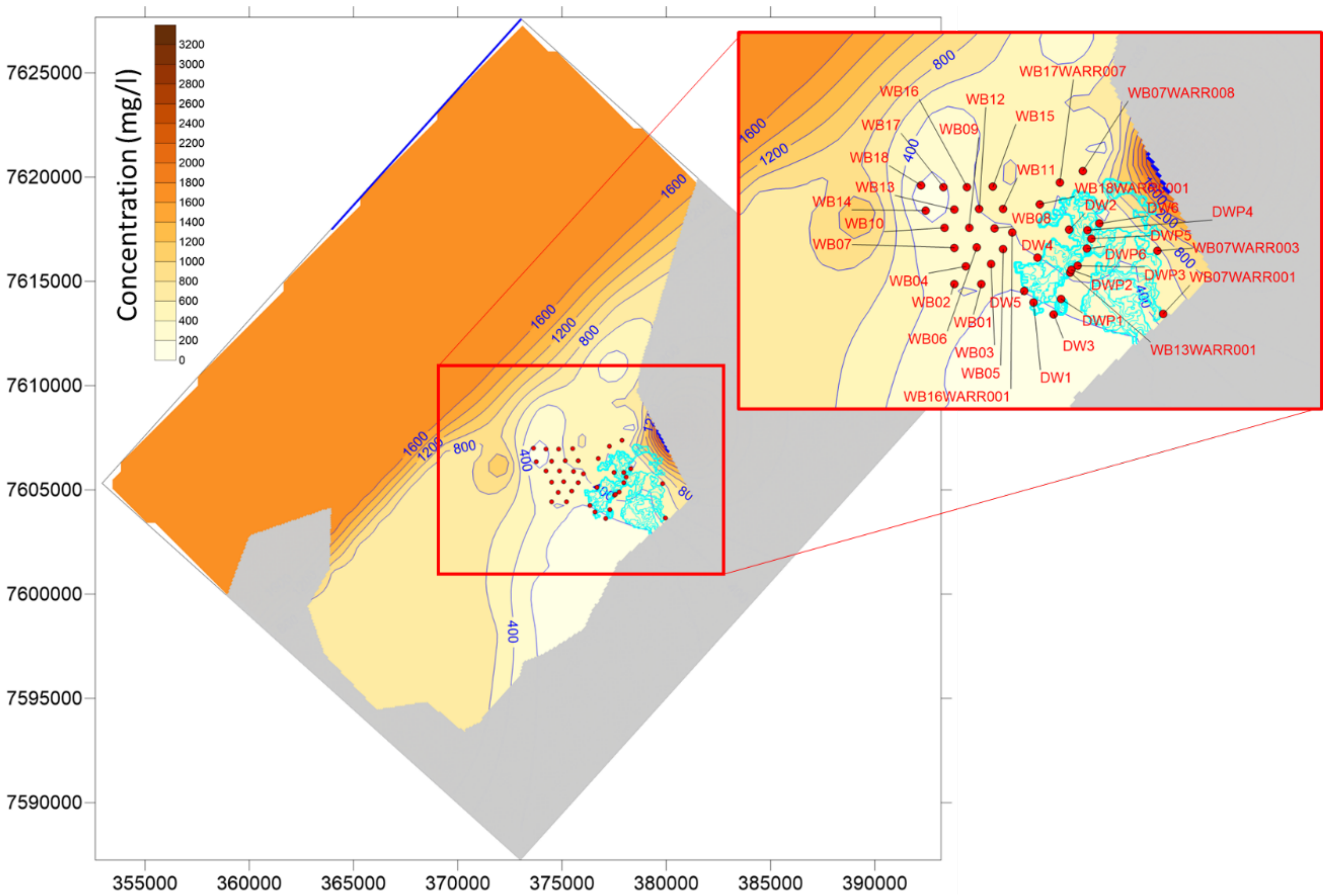


Figure 4-26: Interpreted initial concentration and abstraction bore locations.

The TSF was simulated with an additional recharge and concentration load applied to the Pit 1&2 outline area as indicated in Figure 4-27. Actual time series of the recharge rates and concentrations were obtained from the GoldSim simulation as shown in Table A-2.

The model simulated both advection and dispersion for which the following homogeneous parameters have been assigned:

- Total Porosity: 15%
- Longitudinal dispersivity: 100 m
- Transverse dispersivity: 10 m

The dispersity parameters satisfy the condition that the Peclet number (approximately the ratio between the cell size and the longitudinal dispersivity) should be lower than 4 (Barnett et al, 2012).

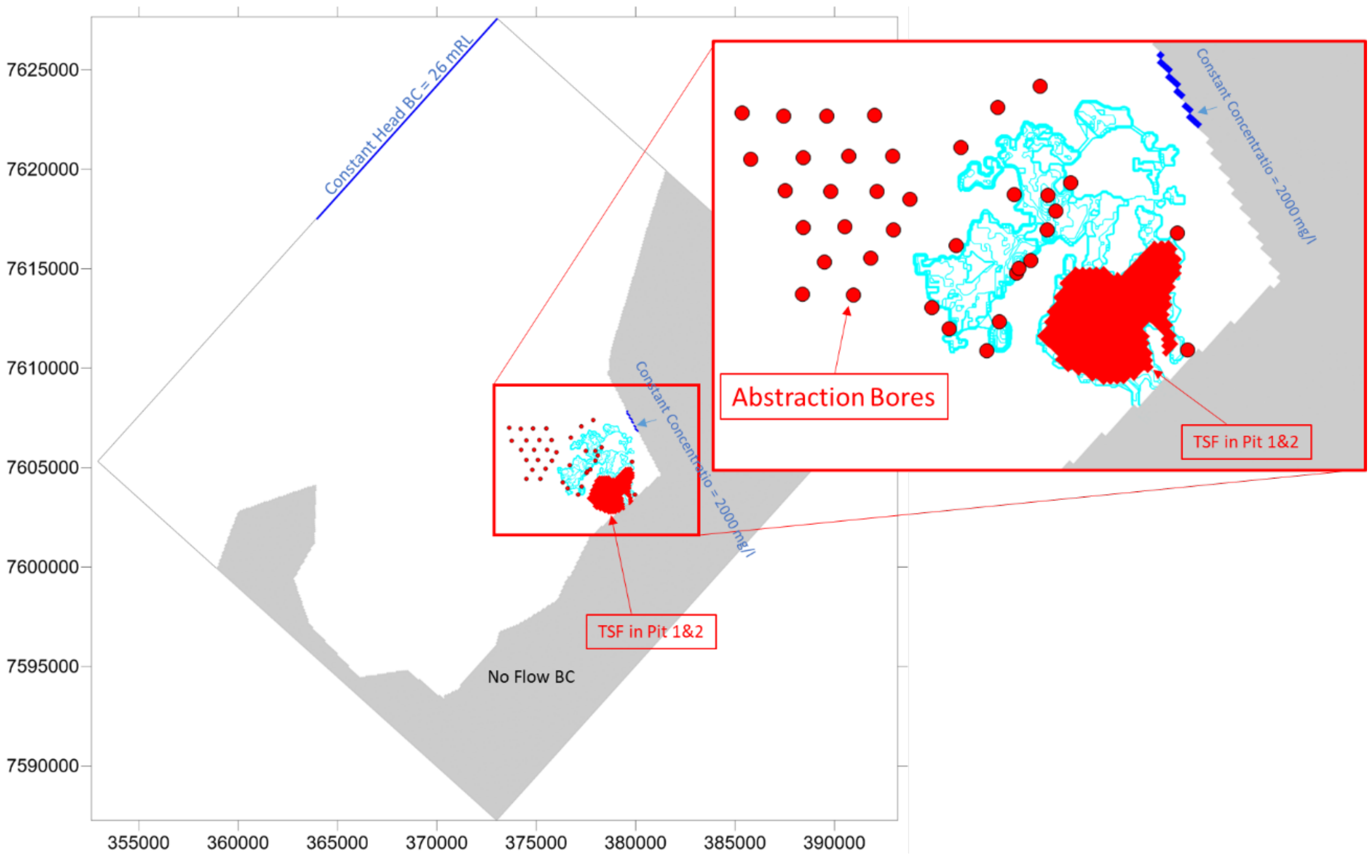


Figure 4-27: Model boundary conditions.

4.2.2 Scenario predictions

The objective of the predictive runs was to evaluate:

a) The effect of chloride migration from the higher chloride zone to the north east of Warramboo on the water quality of the abstraction bores used for water supply. Higher chloride zones to the north and north-west are significantly further away from the pit, generally downgradient, and fall outside the cone of depression (RTIO 2017) and so have much less potential to alter groundwater quality than the areas to the north east. They; are, however, included in the model for completeness.

b) The effect of the installation of a TSF in Pit 1&2 on the water quality (i.e chloride concentrations) at the water supply bores.

In order to answer the first question, two simulations were tested:

1) A first simulation was run with a constant concentration of 2000 mg/l applied as a boundary condition shown in Figure 4-27, consistent with the observed data in the area (Scenario 1).

2) A sensitivity simulation was assessed with a higher concentration at the same boundary condition. For this simulation a concentration of 3000 mg/l was used instead (Scenario 2).

The above scenarios were simulated until the end of 2036, i.e. at the end of the predicted water supply requirements and waste fines placement (Rio Tinto, 2018)

The results of the breakthrough curves at the simulated abstraction bores are presented in Appendix B, whilst a final distribution of the chloride concentration is shown in Figure 4-28.

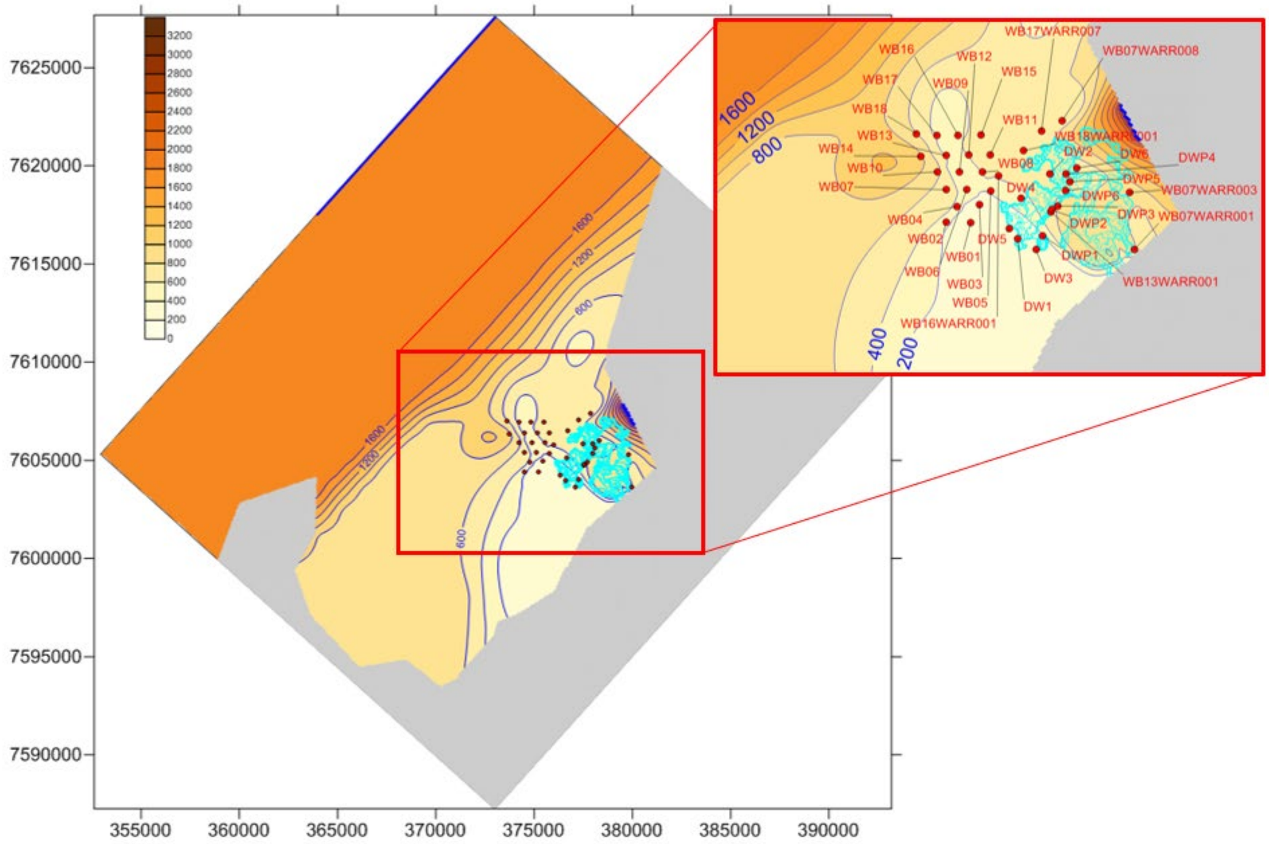


Figure 4-28: Scenario 1 final chloride distribution (end of 2036).

The breakthrough curves show that:

- The model is effectively insensitive to the constant concentration applied to the high concentration zone (ie Scenario 1 and 2 curves are almost identical). This can be explained by the fact that the mobilisation of chloride in the higher chloride zone to the north-east can happen only via dispersion.
- The concentration of chloride decreases with time for the bores located in the southern area, whereas for the bores located north of the mine (WBx bores) the modelling shows an increase in concentration over time.. The latter is due to the vicinity of the high concentration zone of 1700 mg/l located to the north of Warramboo.

Figure 4-28 shows that the final concentration of chloride in the mining area can range between 200 and 600 mg/l. In particular in the area of Pit 1&2 the concentration of chloride is in the order of 300 mg/l.

A further simulation (Scenario 3) was run to assess the effect of a TSF in Pit 1&2. This scenario examines the potential change in chloride concentration due to the TSF firstly while groundwater abstraction and placement of waste fines are taking place and secondly following cessation of groundwater abstraction and placement of waste fines during recovery of the groundwater level. This simulation was run for 50 additional years until the end of 2086. The constant boundary condition in the southern portion of the model was kept at 3000 mg/l to allow additional conservativism.

The results of the breakthrough curves are represented in Appendix B, whilst Figure 4-29 and Figure 4-31 show the chloride concentration distribution in the end on 2036 and 2086 respectively. In Figure 4-30 we also present the difference between the Scenario 3 and Scenario 1 chloride distribution in the end of 2036.

Major conclusions for Scenario 3 are:

- The breakthrough curves demonstrate the only bores affected by an increment of chloride concentration caused by the presence of the TSF will be the ones located in the vicinity of Pit 1&2 (DPW1, DPW2, DPW3, DPW5, DPW6, WB07WARR001, WB07WARR003, WB07WARR008 and WB13WARR001). The other bores do not appear to be affected by the presence of the TSF.
- The maximum concentration reached around the TSF is 716 mg/l at the end of 2025 for WB07WARR001.
- The concentration of chloride for Pit 1&2 area ranges between 600 and 750 mg/l at the end of 2036 (Figure 4-29) and between 300 and 730 mg/l at the end of 2086 (Figure 4-31) and is contained well-within the cone of depression resulting from groundwater abstraction.
- A comparison between Scenario 1 and Scenario 3 demonstrates that in the end of 2036 the additional increment in chloride concentration in the Pit 1&2 area due to the presence of the TSF reaches a maximum of approximately 470 mg/l (Figure 4-30).

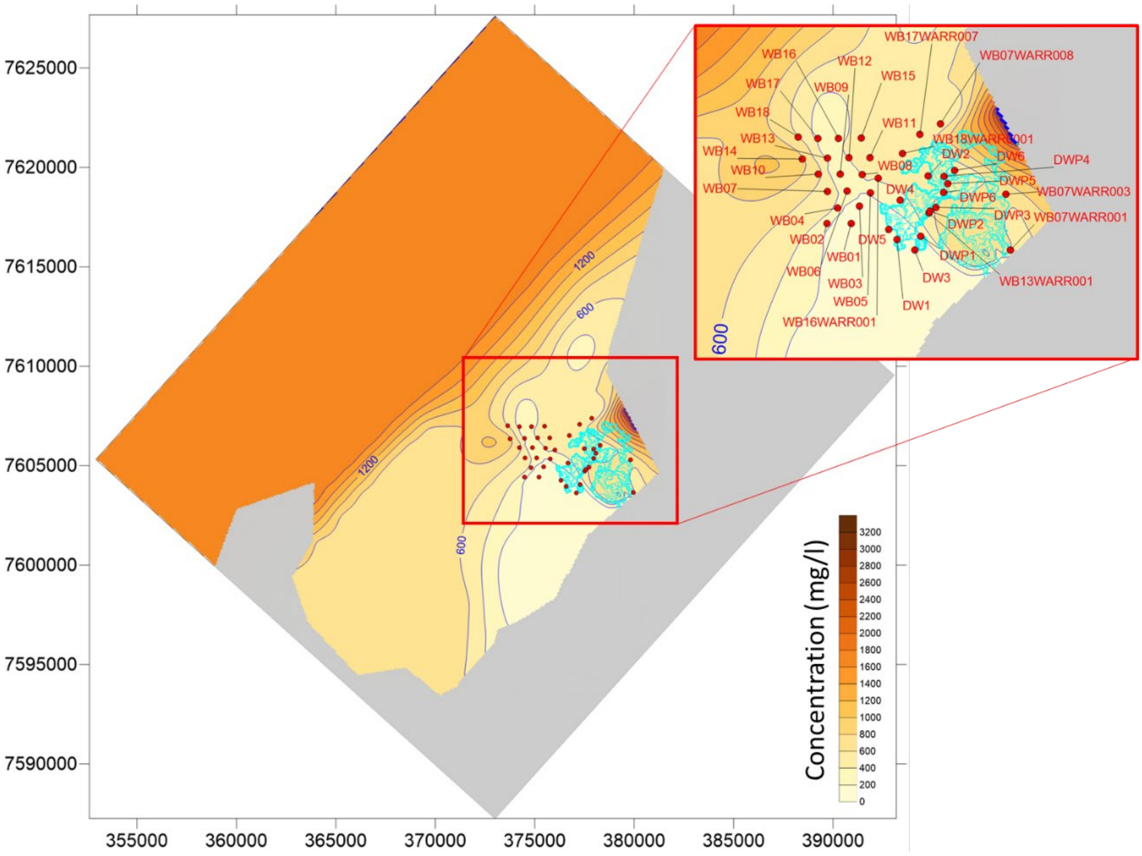


Figure 4-29: Scenario 3 chloride distribution in end of 2036.

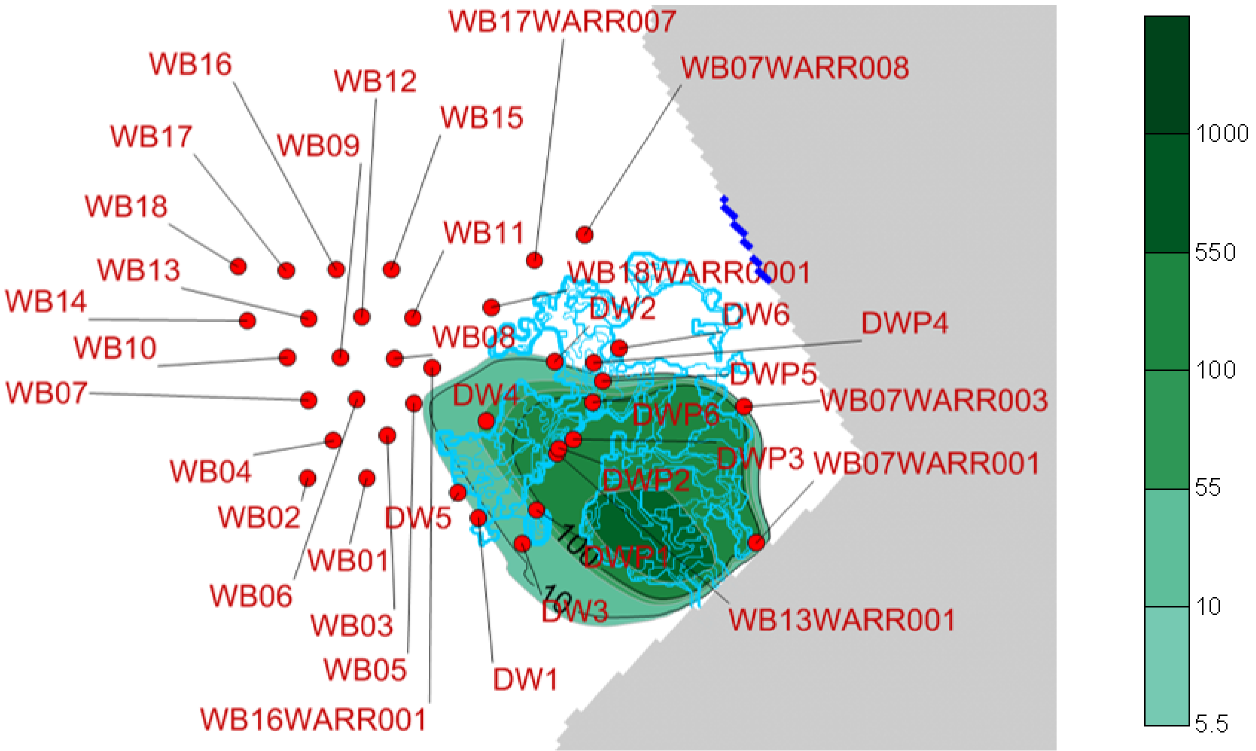


Figure 4-30: Difference between the Scenario 3 and Scenario 1 chloride concentration in the end of 2036. Positive values indicate an increase in chloride relative to the case with no TSF present.

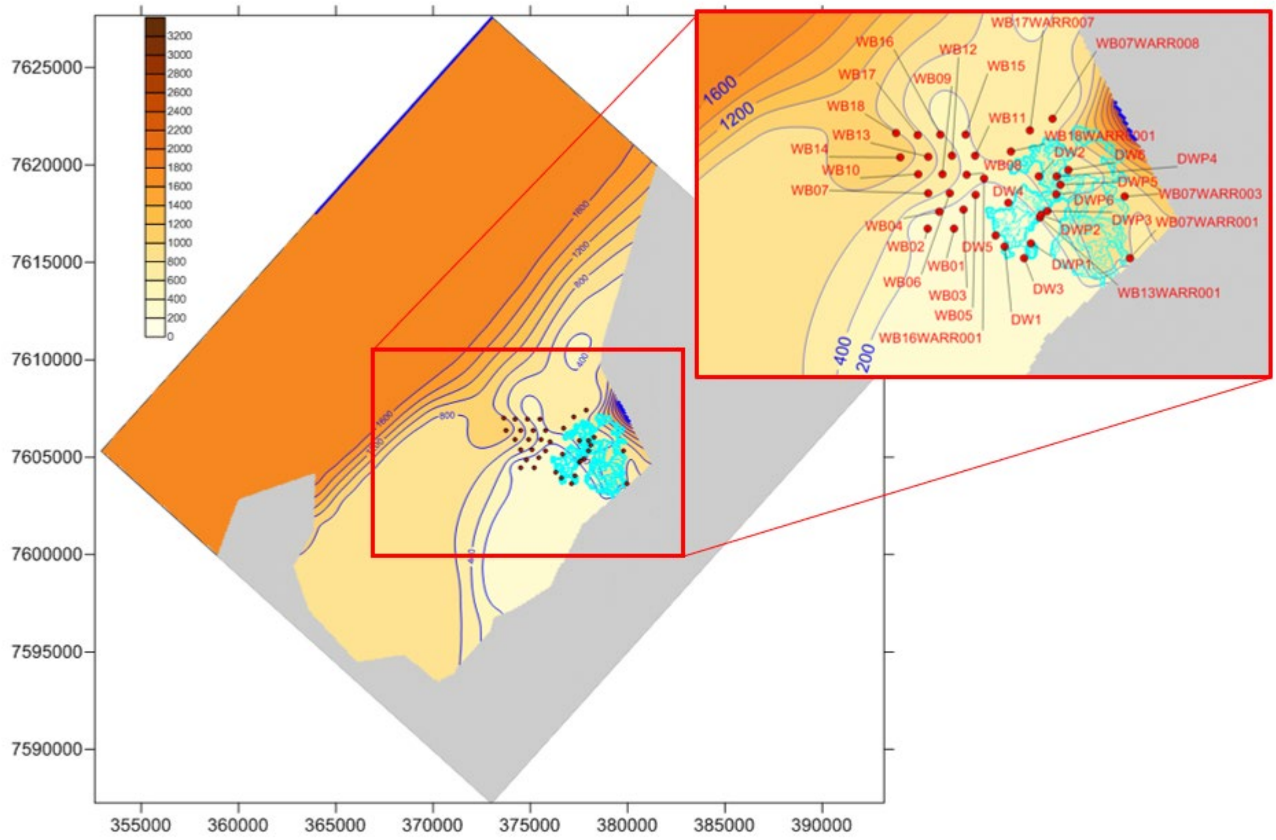


Figure 4-31: Scenario 3 final chloride distribution (end of 2086).

5 Conclusions

The following conclusions can be drawn from the combined modelling of the TSF and potential impacts on chloride downstream of the Warramboo pits:

- Peak chloride concentrations in the pit reach approximately 1100 – 1400 mg/l
- Naturally occurring areas of higher chloride concentration located towards the coast to the west of the Warramboo pits will likely increase the chloride concentrations in some water supply bores over the life of mine. This is due to dewatering of Warramboo pits and water abstraction for water supply, which creates a drawdown that extends towards the higher chloride areas to the west.
- Naturally occurring higher chloride areas located east of the Warramboo pit will have limited impact on water supply bores during the Life of plant. This is due to the low rate of regional groundwater flow through the pits caused by the presence of no flow boundary conditions to the south-east and north-east of the pits. This limits the transport to dispersive processes, with advection playing a minor role
- The presence of the TSF will increase the groundwater chloride concentration by up to 470 mg/l in 2036 in the Warramboo pit area.
- The modelling indicates changes to groundwater chloride concentrations due to seepage from the TSF will be contained within the cone of depression resulting from groundwater abstraction and that the majority of the increase in chloride concentration due to the presence of the TSF will remain within the pit area and is not expected to reach water supply bores located approximately 400 m from the pit boundary.
- The effects of areas of higher chloride concentrations to the west of Warramboo make chloride concentrations in the study area likely to be relatively insensitive to the TSF chloride concentrations.

6 References

/1/ RTIO 2015. 2014 Review of Existing Water Quality Data Warramboo / Mesa A Mine. RTIO-PDE-0130272.

/2/ RTIO. 2017. Warramboo Numerical Model. Water Resource Evaluation and Services. RTIO-PDE-0149328.

/3/ GHD 2016. Tom Price SEP Goldsim Model, Letter to Cecilia Lazo-Skold, GHD ref# 61 32479. 8 April 2016, 20pp.

/4/ GHD. 2018. Mesa A Warramboo WFSF Design, Water Balance and Chloride Balance (Rev B). RVSG4100/R01/0003.

/5/ SKM and NCGRT. 2012. Australian Groundwater Modelling Guidelines. Waterlines Report Series n. 82, June 2012.

/6/ RTIO. 2018. Warramboo Numerical Groundwater Model. 16/04/2018. RTIO-PDE-0159785

APPENDICES

APPENDIX A – Groundwater data

A Groundwater data

Table A-1. Chloride concentration measurements (October 2016).

Sample Point	Easting	Northing	Chloride concentration (mg/L)
MB16WARR0037	370169.211	7601547.122	740
MB16WARR0043	370150.71	7602797.52	720
MB16WARR0025	370480.528	7599144.58	732
MB16WARR0038	371091.946	7606942.102	733
MB16WARR0020	372099.659	7606240.763	1280
MB16WARR0016	373051.497	7605468.798	560
MB08MEA004	373375.069	7613133.309	1700
MB16WARR0026	373617.678	7606628.95	37
MB16WARR0009	374358.074	7600324.081	8
MB16WARR0033	374362.527	7604956.115	200
MB16WARR0012	374217.193	7608620.787	229
MB16WARR0040	374485.752	7601084.104	211
MB16WARR0007	374685.741	7601917.54	116
MB16WARR0006	375081.677	7602834.88	101
MB16WARR0003	374985.107	7604171.073	481
MB16WARR0011	374985.08	7606053.196	377
MB16WARR0028	374942.998	7608015.032	337
MB16WARR0005	375624.085	7603757.536	26
MB16WARR0018	375797.541	7607302.452	683
WB16WARR0005	375893.214	7609050.599	559
MB13WARR011	376004.268	7605829.163	369
WB08WARR003	376759.706	7604843.773	360
MB13WARR012	376452.562	7605860.856	503
MB13WARR007	377024.22	7602548.061	49
MB13WARR013	376992.408	7603454.469	124

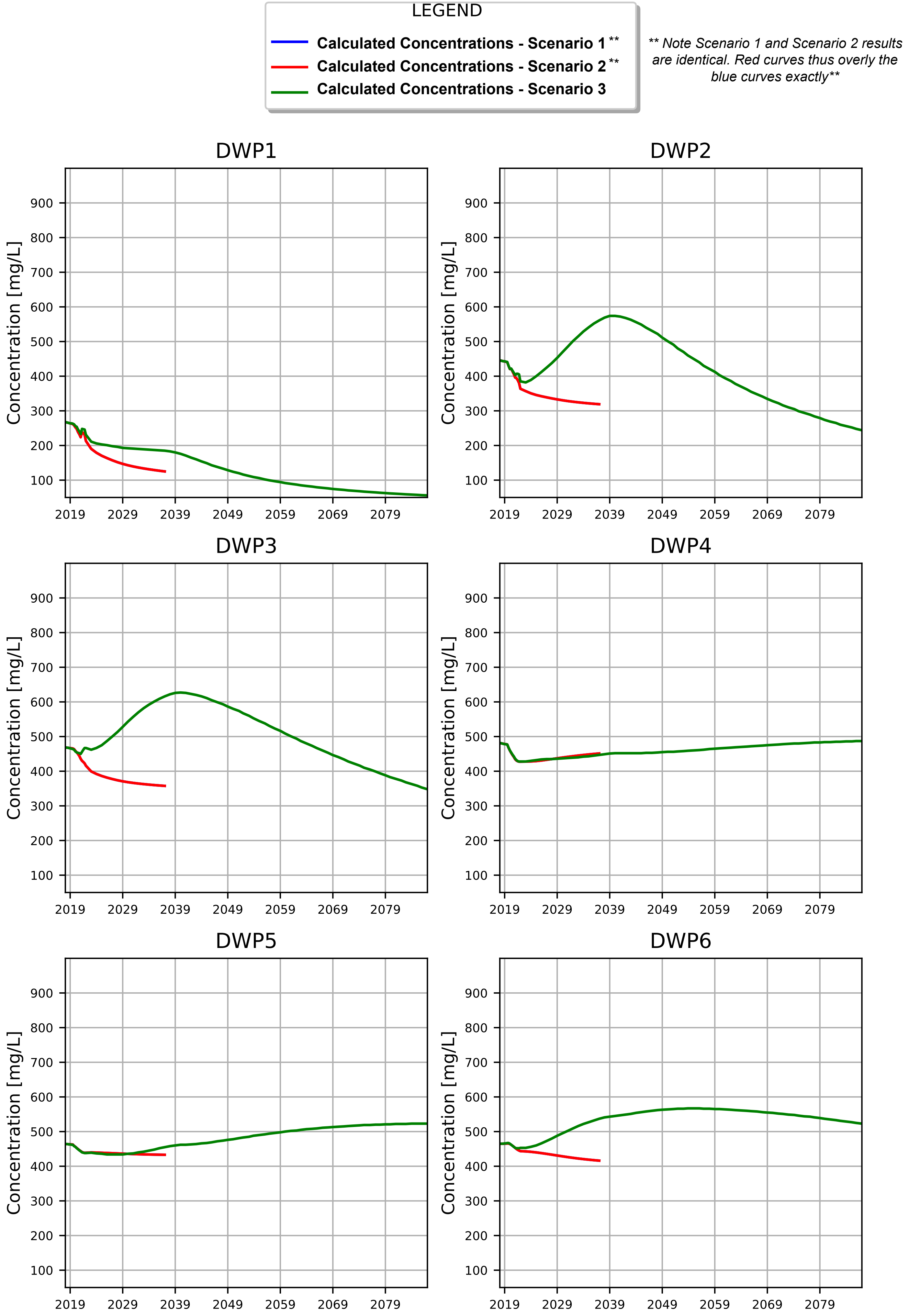
MB13WARR009	376966.784	7604042.825	240
MB13WARR010	377108.999	7605908.859	503
WB08WARR002	377129	7606309	370
MB16WARR0023	376837.913	7607950.572	497
WB13WARR001	377525.329	7604736.527	440
WB08WARR001	377295.52	7607086.953	410
MB08MEA005	377436.294	7610876.161	210
MB13WARR002	377805.72	7605001.299	540
WB13WARR003	377707.315	7605478.424	410
WB07WARR008	377861.182	7607389.767	500
MB16WARR0036	377668.781	7609075.938	661
MB13WARR004	378126.206	7605975.973	517
WB07WARR005	378530.953	7606408.913	310
MB16WARR0001	378519.217	7608014.768	304
MB13WARR005	378942.217	7607018.354	1200
MB13WARR015	379467.244	7601546.04	213
WB05WARR001	379287	7602983	190
WB07WARR006	379376.015	7605682.76	500
MB13WARR014	379418.685	7607022.876	1180
MB16WARR0031	379413.476	7608927.8	1140
WB07WARR001	379955.766	7603643.231	500
WB07WARR003	379811.67	7605300.095	500
MB13WARR006	379901.971	7607052.336	2300
MB16WARR0029	380045.369	7607824.375	3170
MB16WARR0002	381652.285	7610570.93	1140

Table A-2: Recharge rates and concentrations applied in Pit 1&2.

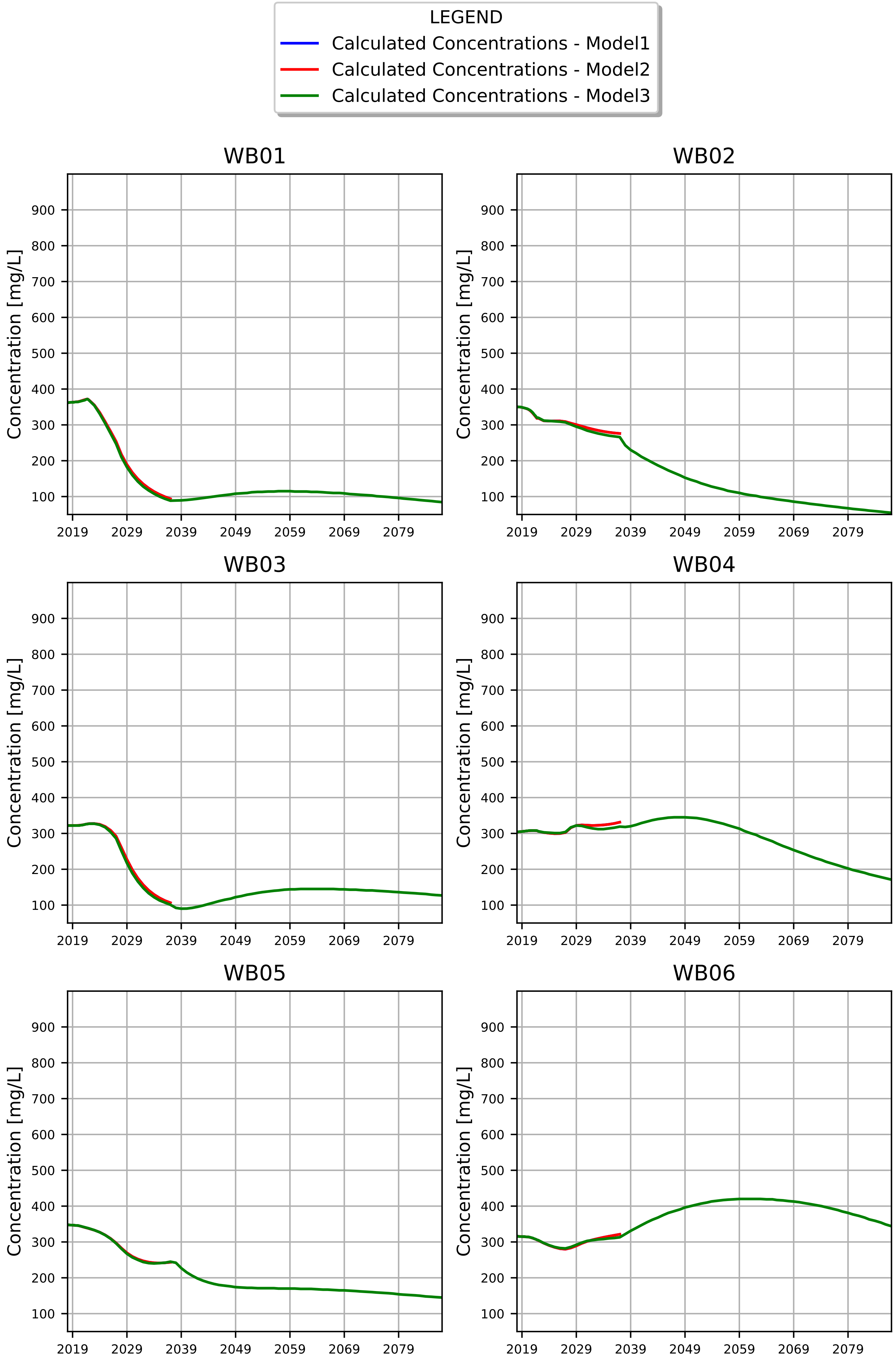
Date	Stress Period	Time Step	Time	Recharge (kL/d)	Concentration (mg/l)
31/03/2018	1	13	90	3670	649.7
30/06/2018	2	14	181	3670	758.35
30/09/2018	3	14	273	3670	936.5
31/12/2018	4	14	365	3670	1046
31/03/2019	5	13	455	3670	1128.5
30/06/2019	6	14	546	3670	1200
30/09/2019	7	14	638	3670	1250.5
31/12/2019	8	14	730	3670	1288
31/03/2020	9	14	821	3670	1303.5
30/06/2020	10	14	912	3670	1303
30/09/2020	11	14	1004	3670	1341.5
31/12/2020	12	14	1096	3632	1405.5
31/03/2021	13	13	1186	3539	1423
30/06/2021	14	14	1277	3430.5	1409.5
30/09/2021	15	14	1369	3319	1402.5
31/12/2021	16	14	1461	3205.5	1400
31/12/2022	17	41	1826	2945.5	1378.5
31/12/2023	18	41	2191	2548	1334
31/12/2024	19	41	2557	2195	1277.5
31/12/2025	20	41	2922	1755.5	1203.5
31/12/2026	21	41	3287	0	0
31/12/2027	22	41	3652	0	0
31/12/2028	23	41	4018	0	0
31/12/2029	24	41	4383	0	0
31/12/2030	25	41	4748	0	0
31/12/2031	26	41	5113	0	0
31/12/2032	27	41	5479	0	0
31/12/2033	28	41	5844	0	0

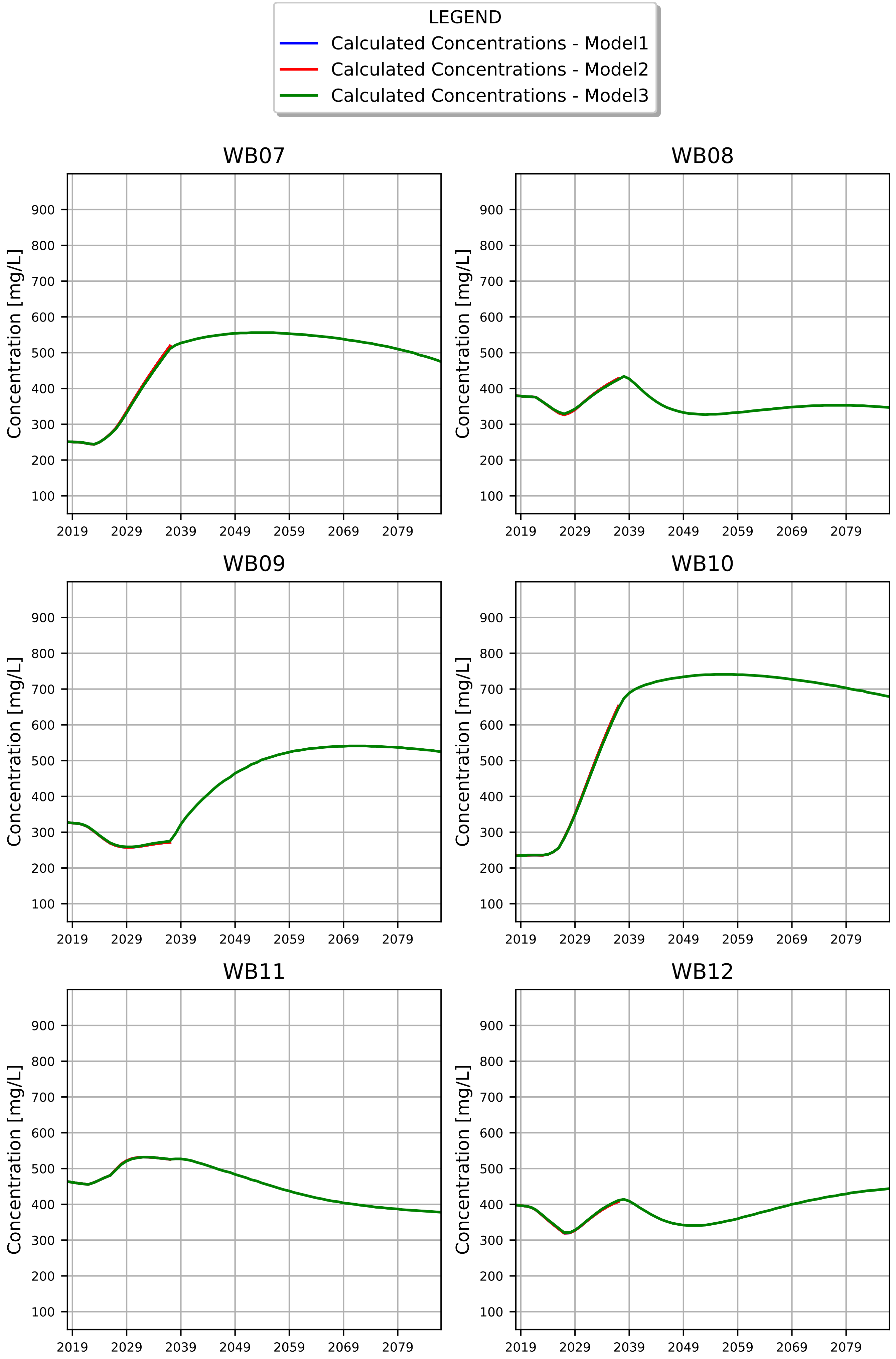
31/12/2034	29	41	6209	0	0
31/12/2035	30	41	6574	0	0
31/12/2036	31	41	6940	0	0

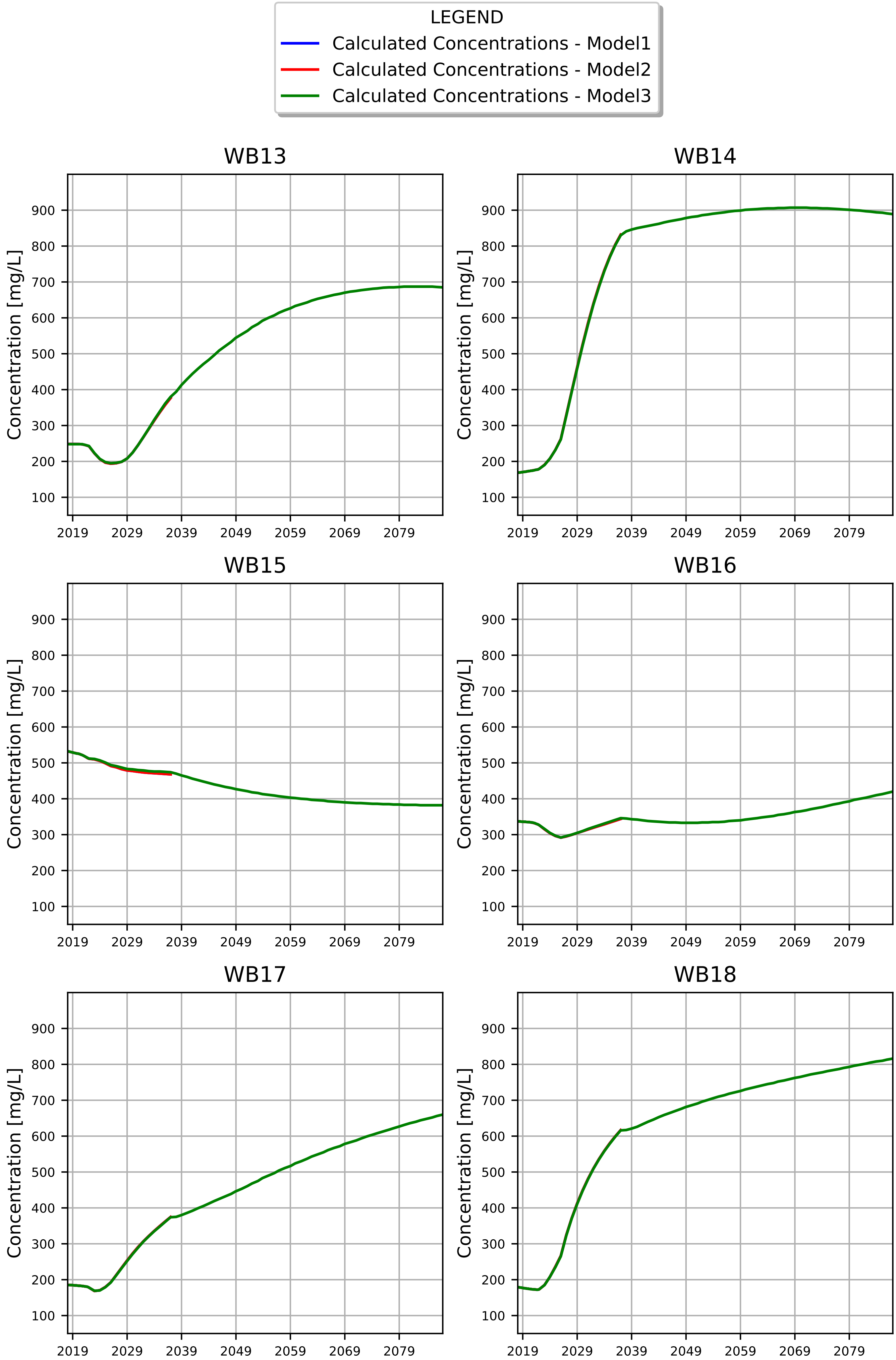
APPENDIX B–Breakthrough curves

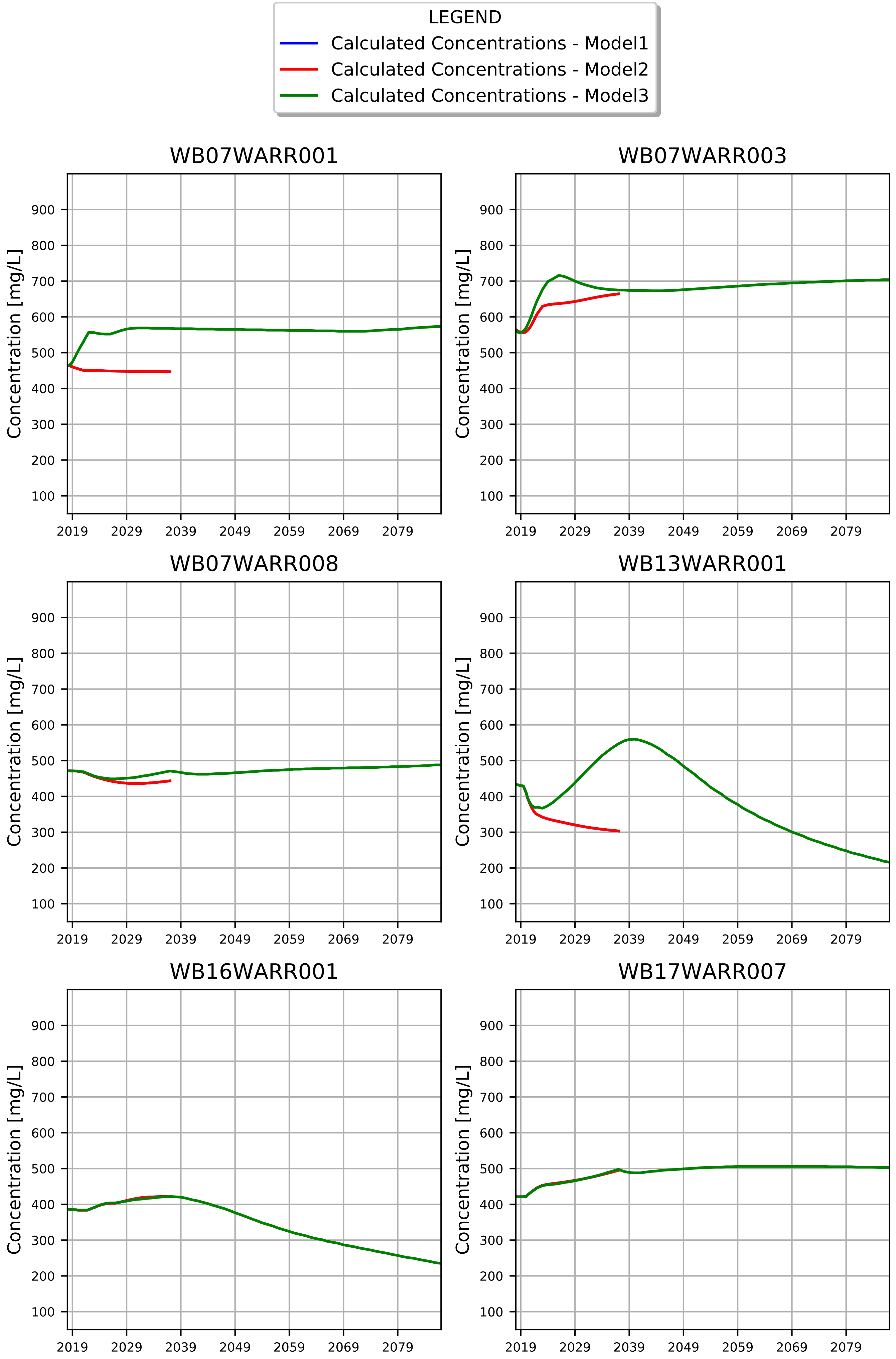


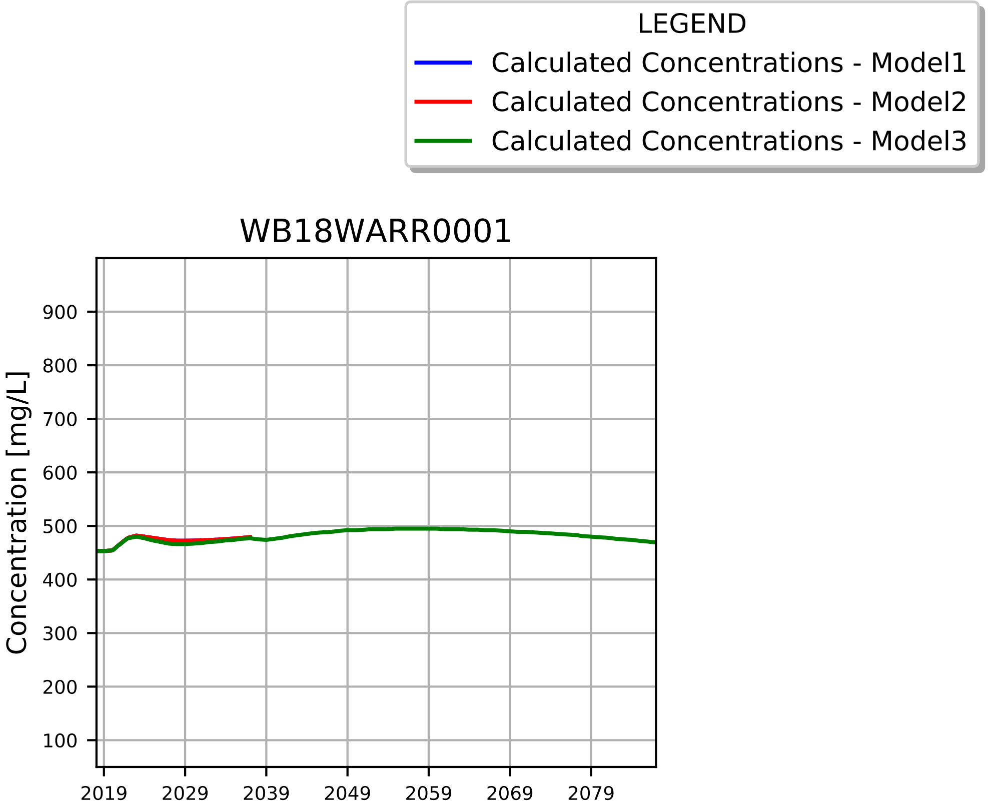
LEGEND
Calculated Concentrations - Scenario 1 **
Calculated Concentrations - Scenario 2 **
Calculated Concentrations - Scenario 3
** Note Scenario 1 and Scenario 2 results are identical. Red curves thus overly the blue curves exactly**
DWP1
DWP2
DWP3
DWP4
DWP5
DWP6
Concentration [mg/L]
100
200
300
400
500
600
700
800
900
2019
2029
2039
2049
2059
2069
2079


LEGEND
Calculated Concentrations - Model1
Calculated Concentrations - Model2
Calculated Concentrations - Model3
WB01
WB02
WB03
WB04
WB05
WB06
Concentration [mg/L]
100
200
300
400
500
600
700
800
900
2019
2029
2039
2049
2059
2069
2079


LEGEND
Calculated Concentrations - Model1
Calculated Concentrations - Model2
Calculated Concentrations - Model3
WB07
WB08
WB09
WB10
WB11
WB12
Concentration [mg/L]
100
200
300
400
500
600
700
800
900
2019
2029
2039
2049
2059
2069
2079


LEGEND
Calculated Concentrations - Model1
Calculated Concentrations - Model2
Calculated Concentrations - Model3
WB13
WB14
WB15
WB16
WB17
WB18
Concentration [mg/L]
100
200
300
400
500
600
700
800
900
2019
2029
2039
2049
2059
2069
2079


LEGEND
Calculated Concentrations - Model1
Calculated Concentrations - Model2
Calculated Concentrations - Model3
WB07WARR001
WB07WARR003
WB07WARR008
WB13WARR001
WB16WARR001
WB17WARR007
Concentration [mg/L]
100
200
300
400
500
600
700
800
900
2019
2029
2039
2049
2059
2069
2079



LEGEND
Calculated Concentrations - Model1
Calculated Concentrations - Model2
Calculated Concentrations - Model3
WB18WARR0001
Concentration [mg/L]
900
800
700
600
500
400
300
200
100
2019
2029
2039
2049
2059
2069
2079