Eastern Pilbara Hub Water Balance

OB32 Surplus Water GoldSim Modelling - Stochastic and Sensitivity Assessments

Prepared for BHP
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1 Introduction

1.1 Project background

EMM Consulting Pty Limited (EMM) was commissioned by BHP to undertake a review and update of the East Pilbara Hub water balance model developed to support and inform the Eastern Pilbara Surplus Water Strategy. The review and water balance modelling was primarily focused on supporting the identification phase study (IPS) assessment of potential impacts of the discharge of surplus water from OB32 surplus water (OB32SW) to Ophthalmia Dam.

The key outcomes of the work provided an estimation of the potential sustainable capacity of Ophthalmia Dam under different operating scenarios (surplus discharge, climate, dam release), specifically:

- the capacity of the Dam to accept proposed volumes of surplus water without overtopping the spillway; and
- whether hydrological parameters in the Dam and Ethel Gorge aquifer system remain within the criteria set out in the *Eastern Pilbara Water Resource Management Plan* (EPWRMP) (BHP 2018).

Feedback provided in the OB32SW IPS independent peer review (IPR) Functional report concluded that the level of uncertainty inherent in predictions of water balance salinity, more specifically in the Ethel Gorge aquifer system, represents the most significant risk to the effective estimation of the Ophthalmia Dam surplus water management capacity.

The extent of the upstream catchments discharging to Ophthalmia Dam are presented in Figure 1.1.

1.2 Objectives

To further investigate the level of uncertainty in the model predictions, BHP requested further water balance modelling assessments to be explored. The key objectives of the assessment are:

- to review the potential sensitivity of groundwater balance and total dissolved solids (TDS) predictions to alternative water balance model parameterisations
- to identifying and test a set of (feasible) water balance parameters, and operational conditions that could potentially result in simulated dam and groundwater salinity to exceed the criteria set out in the EPWRMP (BHP 2018).

1.3 Assessment scope

EMM have undertaken a review and assessment of Eastern Pilbara Hub water balance model sensitivity and variability with respect to predicted dam and groundwater salinity. This process was undertaken through two phases of work that focused on the following:

- Phase 1 – Sensitivity analysis to explore the potential influence of alternative model parameterisations
- Phase 2 – Stochastic modelling of key (predefined) model variables and parameters, incorporating findings and outcomes from the (Phase 1) sensitivity analysis.

For the Phase 1 sensitivity analysis a performance assessment was undertaken to test whether alternative (feasible) model parameterisations may be equally valid in terms of their ability to produce acceptable simulations and predictions of the available data. This process will focus primarily on exploring the sensitivity of hydraulic conductivity (K) of the groundwater system of the water balance on predictions of groundwater salinity.

For the Phase 2 component of work the extensive modelling was undertaken by applying stochastic modelling approaches. The stochastic modelling approach enables the representation of potential estimation uncertainty inherent in key model variables, parameters and/or input data to be defined by probability distribution. Or a feasible range of values with assumed equal probability. Therefore, the potential influence of parameter uncertainty (either singularly or collectively) on water balance salinity predictions can be explicitly assessed and presented.

Based on an initial review by BHP the following modelling elements are proposed to be incorporated in the stochastic modelling assessment:

- **Surplus Water Volume:** varied within the range of plausible annual discharges, based on forecast discharge from all of BHP eastern mines, up to the maximum predicted Dam capacity of 140 megalitres per day (ML/d).

- **Surplus Water TDS:** varied within the maximum natural range of groundwater TDS found in the EPH orebodies that require dewatering, noting that the actual average surplus water TDS from BHP's existing hubs range between 550 and 950 mg/L (EMM 2020).

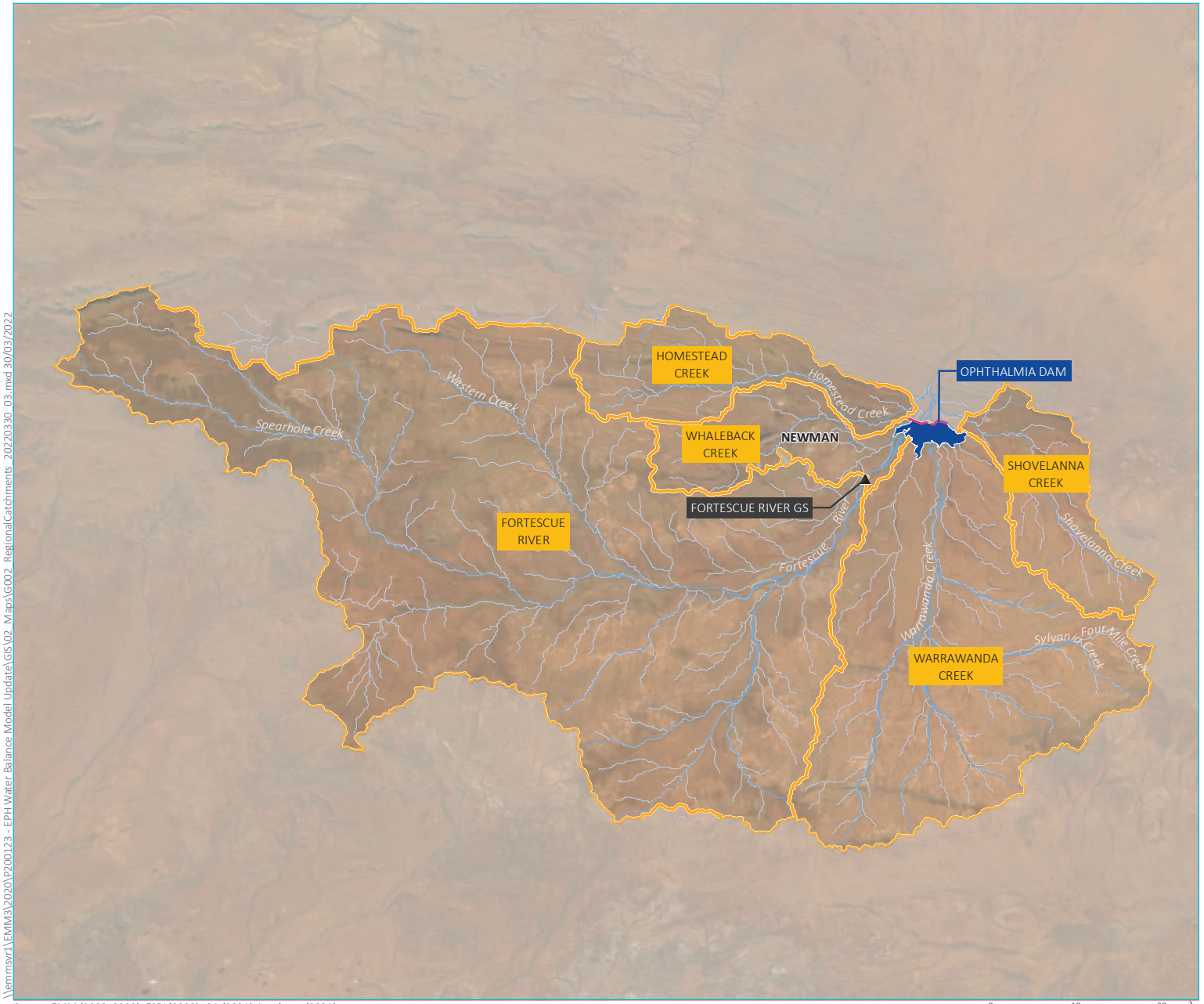
- **Dam Wall Valve Operation:** varied from zero annual discharge to the plausible range of discharge rates/durations that could be achieved within current operational practices and regulatory approvals.

- **Alternative Model Parameterisation:** assessment of the influence and sensitivity of alternative hydraulic conductivity (K) parametrisations, which provide satisfactory performance when compared with historic groundwater monitoring data and groundwater salinity predictions.

The inherent uncertainty and influence in the climatic and catchment hydrology influences on the Ophthalmia Dam and groundwater system water balance are assumed to be effectively captured in the 40-year historic record adopted for the model runs.

Water balance model results and predictions are presented against the following dam water quality, groundwater quality and groundwater level criteria set out in the EPWRMP (BHP 2018):

- Ophthalmia Dam water quality criteria:
    - Early Response Indicator: dam water TDS exceeds 4,000 milligrams per litre (mg/L)
    - Trigger: dam water TDS exceeds 5,000 mg/L.
- Ethel Gorge aquifer water quality criteria:
    - Early Response Indicator: groundwater TDS exceeds 2,500 mg/L
    - Trigger: groundwater TDS exceeds 3,000 mg/L
    - Threshold: groundwater TDS exceeds 4,000 mg/L.
- Ethel Gorge aquifer groundwater level criteria:
    - Early Response Indicator: aquifer groundwater level changes more than 5 m or at a rate higher than 4 m/year
    - Trigger: aquifer groundwater level changes more than 6 m or at a rate higher than 4 m/year
    - Threshold: aquifer groundwater level changes more than 12 m or at a rate higher than 8 m/year.





KEY

- Ophthalmia Dam
- Ophthalmia Dam and Ethel Gorge Sub-Catchments
- Fortescue River gauging station
- Ophthalmia Dam embankment
- Rivers / creeks (delineated)
- Rivers (DWER)

INSET KEY

- National Park
- Reserve
- Other conservation/management area

Source: EMM (2020, 2022); ESRI (2022); GA (2021); Landgate (2021)

0 10 20 km

GDA 1994 MGA Zone 50

N

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Regional catchments

Eastern Pilbara Hub Water Balance - OB32 Surplus Water GoldSim Modelling

Figure 1.1

EMM creating opportunities

2 Phase 1 – Sensitivity analysis

2.1 Background

The integrated GoldSim water balance model for the Ophthalmia Dam and Ethel Gorge aquifer system was developed for BHP by Golder Associates (2016, 2019) based on earlier assessments and conceptual model developments undertaken by RPS (2014a, 2014b). RPS (2015) presents a conceptual model of the Ethel Gorge groundwater dependent ecosystem (refer to Appendix A), summarising key fluxes and processes represented in the groundwater system component of the water balance model. The spatial extent of the water balance model domain is presented in Figure 2.1, including monitoring and production bores and water inflows and infrastructure controls.

A recent model update and performance review was undertaken by EMM (2020) to incorporate model data for the period up to early 2020. The performance review used the labelled monitoring bores presented in Figure 2.1. Through the review process the dam seepage estimation method was refined to improve estimation of predicted seepage losses and low dam storage conditions. Other model parameters and inputs were reviewed, but there were no changes made to the modelling approach and structure applied to the groundwater response component.

The sensitivity analysis phase of the water balance modelling assessment presents the following:

- A review of the conceptual model and description of proposed modifications and parameterisation scenarios are provided in Section 2.3.
- Results of the sensitivity analysis based on model performance, a summary of the annual water and mass balance and review of the influence on zonal groundwater TDS predictions are detailed in Section 2.4

2.2 Water balance model limitations and assumption

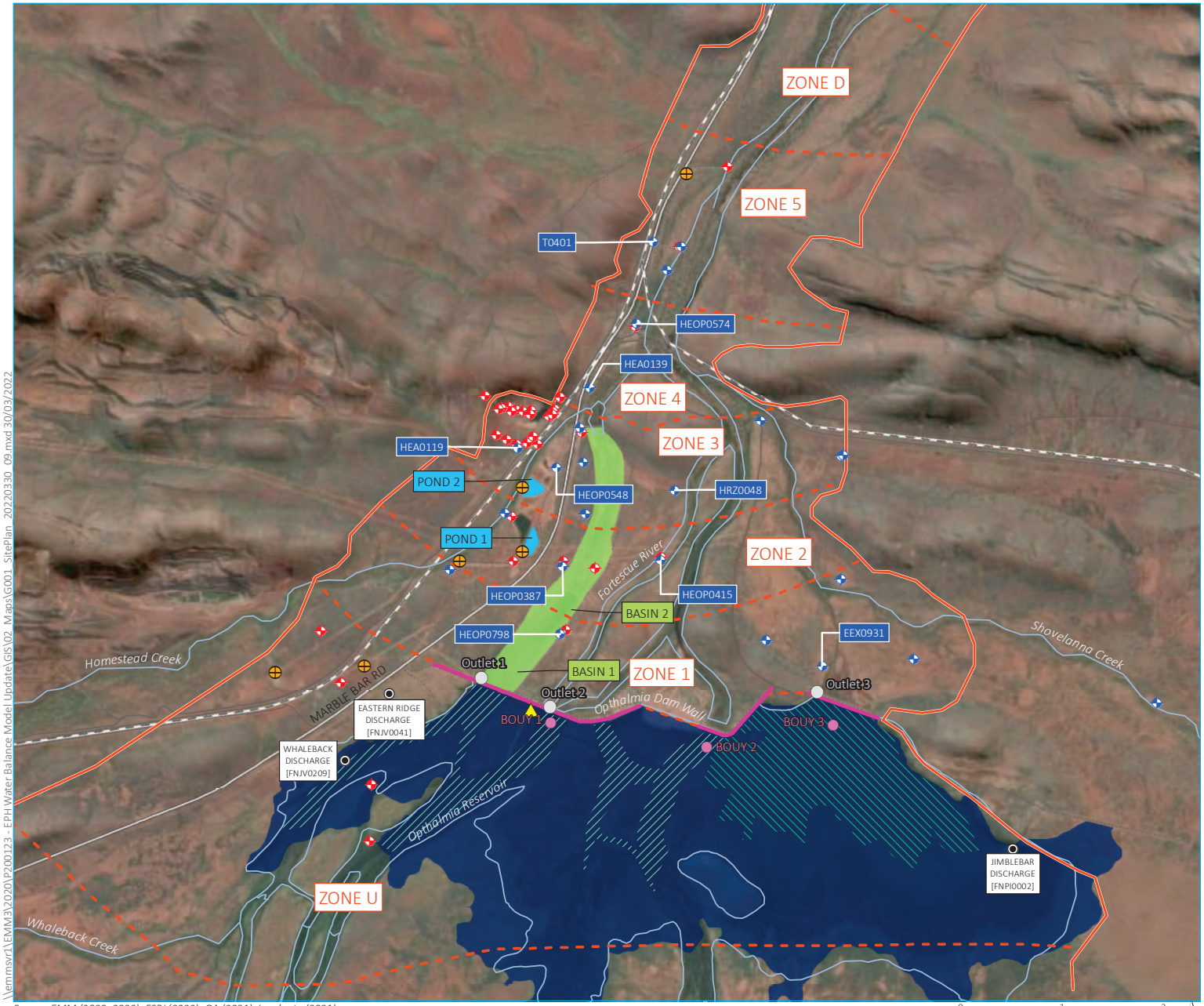
As defined in the recent model update and performance report (EMM 2020), there are a range of limitations and assumptions associated with the water balance model, particularly pertinent to the representation of the groundwater system, which should be acknowledged when interpreting the model results and outputs. The water balance modelling approach has largely been developed to:

- provide an efficient and integrated approach to simulate the 'linked' surface and groundwater systems
- understand the potential influence of changes to the dam water balance and therefore groundwater seepage from the dam, on the downstream groundwater system.

The modelling approach is not explicitly designed equivalent to a numerical groundwater model and is a simplified representation of a complex system.

The model simulations and outputs relating to the groundwater system are best used to identify potential 'response predictions' to changes in operation or under alternative catchment responses, as opposed to a model that can be 'accurately' history matched to groundwater levels or TDS concentrations. As such, the modelling approach was to identify trends and/or the potential magnitude of change in key parameters of water level and TDS concentrations, particularly for comparing relative changes between operational scenarios, rather than to be interpreted as accurate (absolute) predictions of future groundwater levels and TDS concentrations.

The water balance for Ophthalmia Dam has been shown, through the model performance review process (EMM 2020), to provide a good level of agreement between observed and simulated water volumes and TDS concentrations. The key uncertainties for the dam balance largely relate to the unmeasured components of inflow contributions from the ungauged portion of the dam catchment and seepage losses.



KEY

- BHP abstraction bore
- BHP groundwater monitoring bore
- Dam outlet
- DWER monitoring station
- BHP monitoring buoy
- Surplus discharge point
- Flow meter
- Rail line
- Major road
- Minor road
- Track
- Model boundary
- Zone boundary
- Recharge basin
- Ophthalmia Dam embankment
- Recharge pond
- Ophthalmia Dam
- Watercourse

Low dam storage area

- Fortescue pool (alluvial area)
- Warrawanda pool

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Source: EMM (2020, 2022); ESRI (2022); GA (2021); Landgate (2021)

Water balance model domain and performance review monitoring bores

Eastern Pilbara Hub Water Balance - OB32 Surplus Water GoldSim Modelling
Figure 2.1

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2.3 Conceptual model review

The conceptual approach and parameterisation applied to the Ethel Gorge aquifer system component of the water balance was developed to provide consistency with the RPS (2015) conceptual model of the Ethel Gorge groundwater dependent ecosystem (refer to Appendix A). A key observation of this conceptual model is the relatively low groundwater throughflow (groundwater outflow), in the range of 2.0 to 3.0 ML/d, relative to other major recharge and discharge fluxes.

The RPS (2015) study provides steady-state condition estimates of groundwater recharge of approximately 75 ML/d occurring in the Fortescue River catchment, with seepage from Ophthalmia Dam representing the major contributor to groundwater recharge. With respect to major discharge fluxes from groundwater, it was estimated that evapotranspiration losses of approximately 60 ML/d occurs on the Fortescue River floodplain in the area around Ethel Gorge and water supply abstraction (historically) accounts for approximately 10 to 12 ML/d.

A key observation of the estimated groundwater fluxes from RPS (2015) is the dominance of evapotranspiration as the major groundwater loss flux. This has potential to result in increasing concentration of TDS through the groundwater system due to limited opportunity to lose (or flush) TDS mass from the groundwater system through groundwater throughflow or water abstraction. The groundwater balance (and mass balance) may also be highly sensitive to localised (discrete), intensive fluxes such as water supply abstraction which may be of a greater magnitude than local groundwater throughflow.

The model representation and parameterisation of groundwater flow defines a lumped hydraulic conductivity (K) parameter influencing groundwater flow through the model domain. The Existing K parameterisation (7 m/d) was defined to provide a good verification with historic groundwater level records (refer to Section 2.4.1 and results presented in Section B.3 (Appendix B)). It is noted also that for the water balance scenario presented in Table 2.2, showing K of 7 m/d and surplus mine water discharge of 100 ML/d, the groundwater throughflow estimate of 2.4 ML/d, based on downstream groundwater outflow, is comparable to the RPS (2015) groundwater outflow estimates.

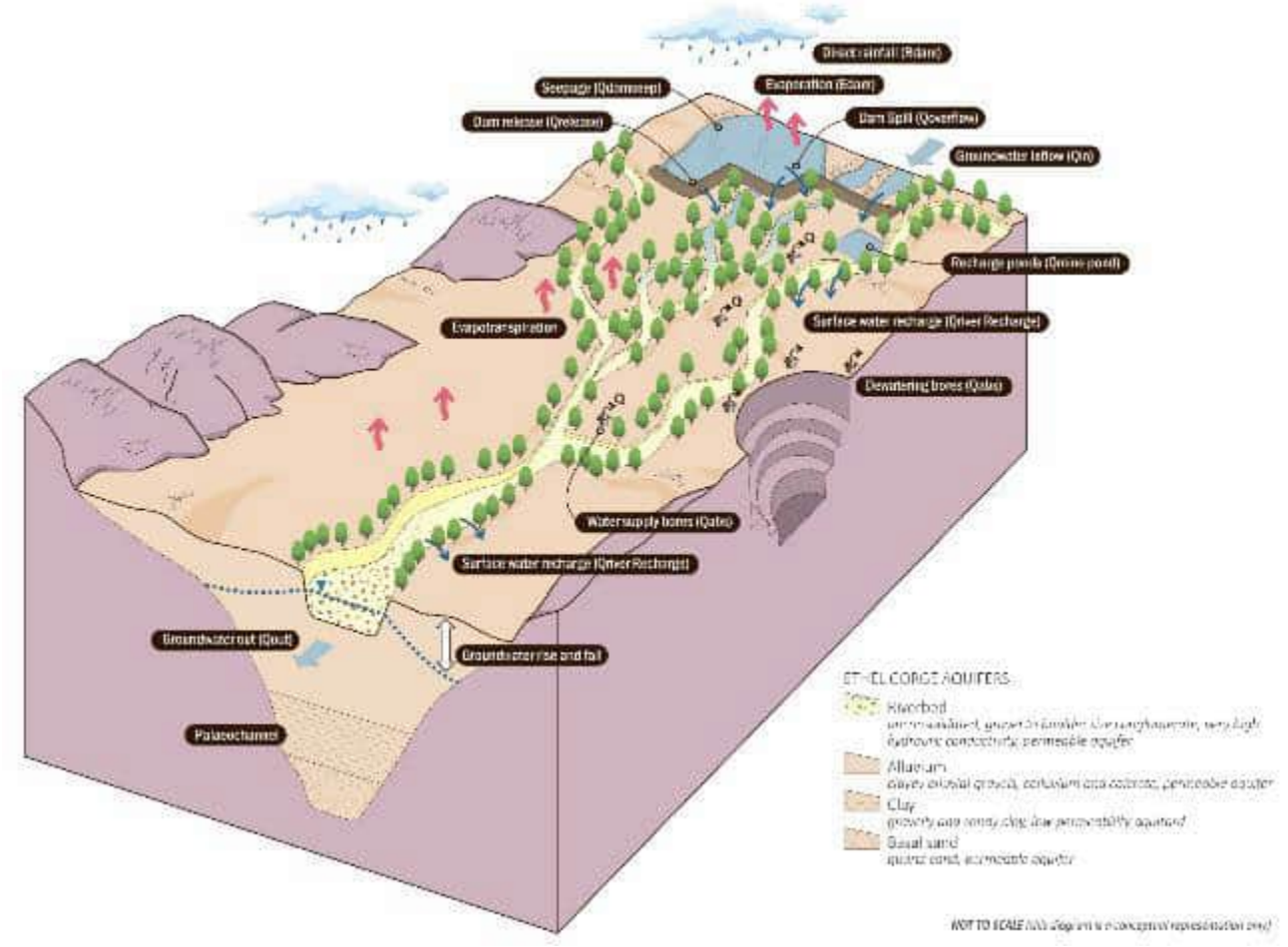


Figure 2.2 Groundwater conceptual model indicating high K aquifer units

2.3.1 Initial sensitivity review

A preliminary review of model sensitivity and predictions of groundwater TDS concentration, based on detailed examination of the groundwater TDS predictions at a zonal level, identified the following:

- Simulated evapo-concentration effects and increasing groundwater TDS concentrations are significantly enhanced in the upstream groundwater zones associated with Ophthalmia Dam seepage and directly downstream (i.e. Zones U and 1).

- Increasing the assumed storage capacity of the conceptual groundwater store in Zone U (i.e. below and upstream of Ophthalmia Dam) provides some mitigation of the evapo-concentrating effect on groundwater salinity on these zones and the propagation of its effects to downstream model zones.

- The identified sensitivity to storage parameters may explain the upward trend in Zones 1 identified in previous modelling scenarios and water balance validation period (historic) model runs.

It is noted that there is an absence of reliable, representative, and consistent groundwater TDS concentration monitoring to verify the model against.

The revised parameterisation (increased storage capacity) of the upstream conceptual groundwater store was viewed, in consultation with BHP, to provide a more realistic representation of expected groundwater balance and TDS concentration relationship. The water balance model revisions are potentially more aligned with observations, from limited available data, that historic monitoring does not indicate any clear upward trend in groundwater salinity.

The changes to groundwater parameters were not found to reduce the model performance with regards to verification of predicted and observed groundwater levels over the historic period.

A summary of water balance performance is presented in Appendix B with the following graphical summaries provided for the July 1980 to February 2020 historic period:

- Ophthalmia Dam – simulated and observed water storage (Section B.1)
- Ophthalmia Dam – simulated and measured TDS concentration (Section B.2)
- groundwater system simulated and measured groundwater elevation for available monitoring bores (Section B.3).

The updated model, incorporating the increased storage capacity parameters for the upstream conceptual groundwater store, was adopted and carried through to the sensitivity assessment and stochastic model runs presented in the following sections of this report.

2.3.2 Review of groundwater throughflow assumptions

A limitation of the groundwater system representation in the water balance model is the assumption of a lumped hydraulic conductivity (K) parameter influencing groundwater flow through the model domain. It is also highlighted that the simulated mass balance of TDS, within and between the modelled zonal groundwater balances, is also significantly influenced by groundwater throughflow and the parameterisation of the lumped K parameter.

The analysis presented in the following sections presents a comparison of sensitivity of groundwater TDS predictions to the lumped K parameter by comparing the 'Existing K' parameterisation (K = 7 m/d), defined and assessed through previous model calibration and performance reviews (Golder Associates 2016, Eastern Pilbara Hub Integrated Water Balance Model Development and Updates 2019, EMM 2020), with an alternative 'High K' condition (K = 49 m/d). The investigation of a higher (increased) K parametrisation is supported by the groundwater conceptual model presented in Figure 2.2, highlighting the alluvial aquifer units, consisting of unconsolidated boulder and gravel conglomerates within incised riverbeds, that provide direct connection to Ophthalmia Dam seepage.

A range of (increasing) K values were reviewed in steps between 7 m/d up to 49 m/d, which highlighted potential model instabilities occurring for K values above 49 m/d. The adopted K values (7 m/d and 49 m/d) therefore represents the plausible range of K values (Existing and High values) for the assessment of potential influence and sensitivity of the water and TDS balance of the Ethel Gorge aquifer system. Note that the groundwater conceptual model presented in Figure 2.2 supports the assessment of the potential influence of increased groundwater through flow, therefore K values below the 'Existing K' parameterisation (K = 7 m/d) were not considered.

Underlying the incised riverbed is Quaternary age alluvium, colluvium and calcrete up to 90m thick (Tahal Consulting Engineers Ltd 1980) in (Parsons Brinkerhoff 2015). The Quaternary sediments overlie a gravel and sandy clay of Neogene (Late Tertiary) age up to 30 m thick overlying a Palaeogene to Neogene age fluvial quartz sand and basal conglomerate approximately 20 m thick. The Quaternary sediments and lower quartz sand represent aquifers with assumed high hydraulic conductivity, whilst the Neogene age clays are of low hydraulic conductivity (Figure 2.1).

As such the Ethel gorge "aquifer" comprises of a multilayered aquifer system. The average horizontal conductivity, of laterally continuous sedimentary beds in parallel is given by an arithmetic mean hydraulic conductivity based on

the relative thickness and conductivity of each hydrogeological unit. Given the relatively thin sedimentary sequence (~140 m) the average hydraulic conductivity is greatly influenced by the higher conductivity units in the sequence. For example, given the range in hydraulic conductivity and the estimated aquifer thickness provided in Table 2.1 the range in the average hydraulic conductivity is between ~17 and 31 m/d. The lumped hydraulic conductivity of the model is representative of the average hydraulic conductivity.

Table 2.1 Aquifer hydraulic conductivity estimates for Ethel Gorge (from RPS 2015) and thickness (after Tahal 1980)

Unit	Thickness (m)	Hydraulic Conductivity K (m/d)		Comments
		Min	Max	
Alluvium	50	3.0	30.0	10 to 30 m/d predominant range around Ethel Gorge
TD3 Calcrete	<40	40.0	40.0	
TD2 (Clay)	30	0.1	0.1	Formations not differentiated in regional hydrogeology; 30 m/d predominant range; higher values in Ethel Gorge
TD1 Alluvium (deep aquifer)	20	30.0	60.0	

2.3.3 Proposed sensitivity analysis scenarios

Based on the conceptual model review and identification of the potential limitations of the lumped K parameter to effectively represent the groundwater conceptual model (presented in Table 2.2) and the potential influence on the groundwater and TDS balance of alluvial aquifer units providing direct connection to Ophthalmia Dam seepage, the range of hydraulic conductivity (K) model scenarios were simulated. The adopted groundwater balance sensitivity scenarios applying low and high K parameterisation (based on the feasible range of model parameters) were defined as follows:

- existing calibration (Low K) scenario: K = 7.0 m/d
- high groundwater throughflow (High K) scenario: K = 49.0 m/d.

Water balance modelling sensitivity runs have been completed to review and present the influence of varying the lumped groundwater K parameter against:

- historic groundwater level observations for the 1980 to 2020 period
- predictions of zonal groundwater TDS for potential future surplus water discharge rates (applied as 50 ML/d, 100 ML/d to 140 ML/d) and for varying surplus water discharge TDS concentrations.

The performance review and prediction scenarios have been run using the historic (40 year) climate and hydrology records which includes both wet and dry periods.

2.4 Sensitivity analysis results

The results of the sensitivity assessment for the existing and high K scenarios are presented in the following sections with reference to:

- model performance against historic groundwater level observations (Section 2.4.1)
- a water and TDS (mass) balance comparison for the surface and groundwater system (Section 2.4.2)
- future predictions of groundwater TDS concentrations for the two scenarios (Section 2.4.3).

2.4.1 Model performance review

Model performance review results for Existing and High K scenarios are presented in Section B.3 (Appendix B) for the labelled monitoring bores across model zones 1 to 5 shown in Figure 2.1. Selected plots of monitoring bores in Zones 1, 2 and 5 are presented in Figure 2.3 below.

The comparison of model performance runs compared to historic groundwater monitoring shows the following:

- Existing K scenario results provide a more effective simulation of groundwater response to anthropogenic influences (groundwater abstraction), particularly to groundwater drawdown in the early-1990s and more significant groundwater drawdown from 2007 to 2017 associated with dewatering of nearby ore bodies (i.e. OB23).
- Review of alternative K scenarios results (between 7.0 m/d and 49 m/d) highlighted the general influence of a general flattening of predicted groundwater levels and a dampening of groundwater responses to natural and anthropogenic influences, i.e. reducing seasonal variability and magnitude of drawdown.
- High K scenario results show reduced model performance for simulating significant groundwater drawdown and a reduced influence of local groundwater abstraction and/or dewatering.
- Over the intervening periods, such as through the 1980s, early 2000s, and from 2017 onwards, there is no clear difference in model performance between the two K parametrisation scenarios.
- For selected monitoring bores, such as T0401M located in Zone 5 (refer to Figure 2.3), the High K scenario appears to provide an improved model performance relative to historic groundwater monitoring compared to the Existing K (K = 7.0 m/d) parametrisation.

It is noted that the variability in model performance may be significantly influenced by the aquifer unit being targeted by the monitoring bores with some located in aquifers representative of lower K lithologies and others (such as TM0401M) potentially more closely associated with the higher K alluvial aquifers.

As described above, the modelling approach assumes a ‘lumped’ groundwater system and therefore assumes the same predictions of groundwater level laterally across the model zone. Model results may therefore reflect an average groundwater response rather than an accurate simulation of groundwater levels at a particular point or location. Additionally, as shown in Figure 2.1, the available long-term groundwater monitoring bores across Zones 1 to 4 are likely to be affected by potable groundwater abstraction and/or mine dewatering.

Therefore, it should be acknowledged that although the Existing K (K = 7.0 m/d) model scenario appear to perform better with regards to simulating historic, measured groundwater levels, this doesn't necessarily mean this parameterisation provides a better simulation performance, or provides better predictions, for groundwater levels and responses across the wider aquifer or selected aquifer units.

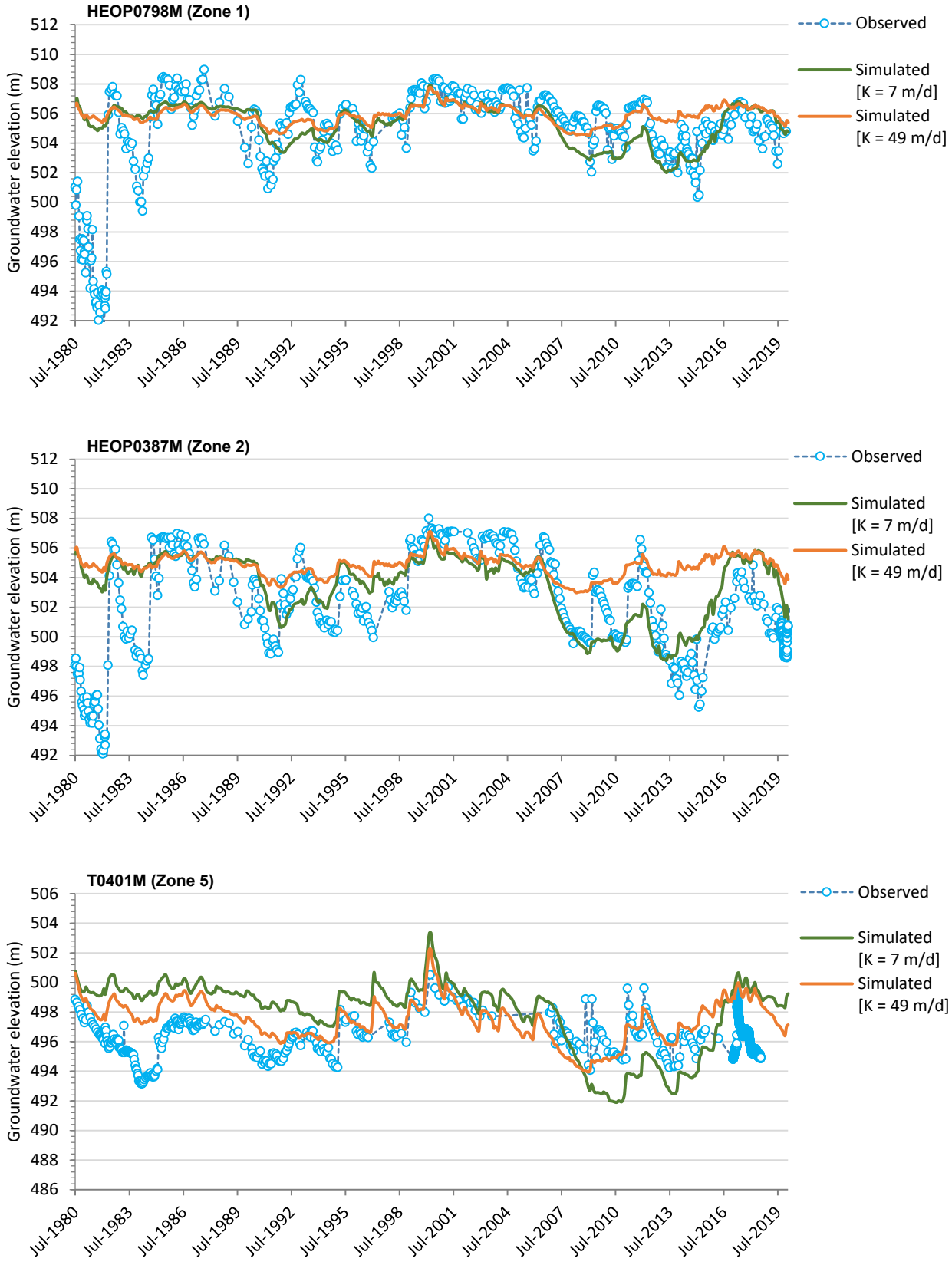


Figure 2.3 **Comparison of observed and simulated groundwater elevations for selected monitoring bores**

2.4.2 Annual water and mass (TDS) balance summary

A schematic representation of the water and mass (TDS) balance for Ophthalmia Dam and the Ethel Gorge shallow aquifer system downstream of the dam is presented in Table 2.2 and Table 2.3. The data presents an annual summary of modelled fluxes, inflows and outflows, and net changes in storage, for both the surface water and groundwater within the model domain. The annual periods are defined for the July to June water year period. The annual balance summary aims to provide a simple 'snapshot' of the water and TDS balance for the defined annual period and a visual presentation of the key simulated fluxes, based on the current water balance model structure and process representations.

Annual water and mass (TDS) balance summaries for the Existing K (K = 7 m/d) and High K (K = 49 m/d) scenarios are presented in Table 2.2 and Table 2.3 respectively. Fluxes are presented as daily averages (ML/d or t/d) and changes in storage (i.e. ΔVG, ΔMG, etc) are shown as the difference in volume or mass between the start and end of the year.

Due to the dynamic nature of the water and TDS balance over time, annual water and mass balance terms are presented for two years of the 40-year (2020-2060) prediction period:

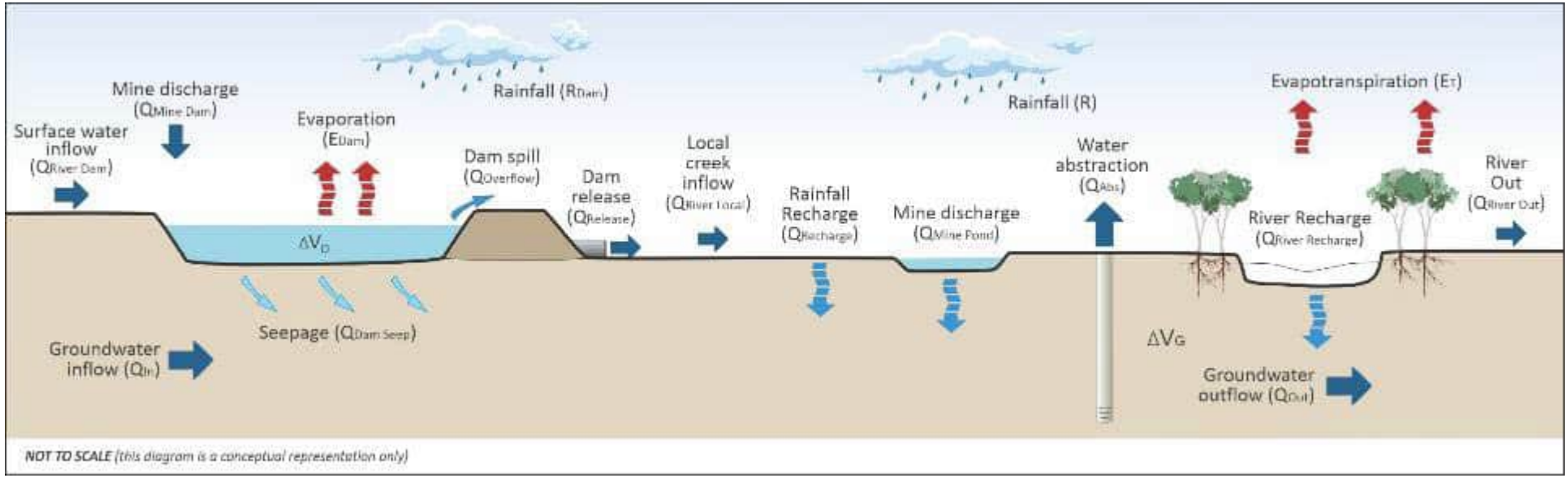
- 2024-25 – early phase with increasing salt mass.
- 2059-60 – late phase where the salt balance is potentially approaching equilibrium (i.e. mass of salt in the groundwater system is not increasing; or is increasing less rapidly).

Key observations from the comparison of annual water and TDS balance for the Existing K and High K model scenarios include the following:

- Increasing K results in a transition of water losses from the groundwater store from evaporation (E_T) and an almost commensurate increase in downstream groundwater outflow (Q_{Out}).
- Increasing Q_{Out} provides an increase in loss of mass (TDS) (M_{Out}) from the groundwater store (TDS mass is not removed from the system through E_T).
- The only other loss of mass from the groundwater store (under the existing water balance structure) is through groundwater abstraction (Q_{Abs} and M_{Abs}), that occurs dominantly in Zones 1, 2 and 4.
- Evaporative loss from the groundwater store (ET) does not result in the removal of mass (TDS) and acts to increase TDS concentration of the groundwater system.
- The change in mass of the groundwater store (ΔMG) is lower for the high K scenario and reduces more over the simulation period.
- Increasing TDS mass loss from the groundwater store, through increase groundwater throughflow, indicates that a lower equilibrium of TDS mass (and lower groundwater salinity concentration) will be reached under a High K model parametrisation scenario.
- The Existing K scenario appears to limit the degree to which increasing TDS mass (from surplus water discharge) can leave the groundwater store as the water balance preferentially increases evaporative loss.
- Increasing the effective hydraulic conductivity (K) of the groundwater system results in an increased loss (flushing) of TDS mass and reduces the evapo-concentrating influence on the groundwater mass balance.

The annual water and TDS mass balance summaries highlight that for the Existing K scenario (presented in Table 2.2), low groundwater flow rates, between groundwater zones and out of the model at the downstream boundary, potentially results in vertical fluxes (i.e. river recharge, abstraction and evaporative loss) becoming the dominant components of the zonal water and mass balances. This can potentially lead to variation and inconsistency in water balance responses between groundwater zones, depending upon the distribution and magnitude of the vertical fluxes. The High K scenario (presented in Table 2.3) significantly increases lateral fluxes through the groundwater system and provides a pathway to reduce TDS mass accumulation and increases the consistency in water and mass balances between zones.

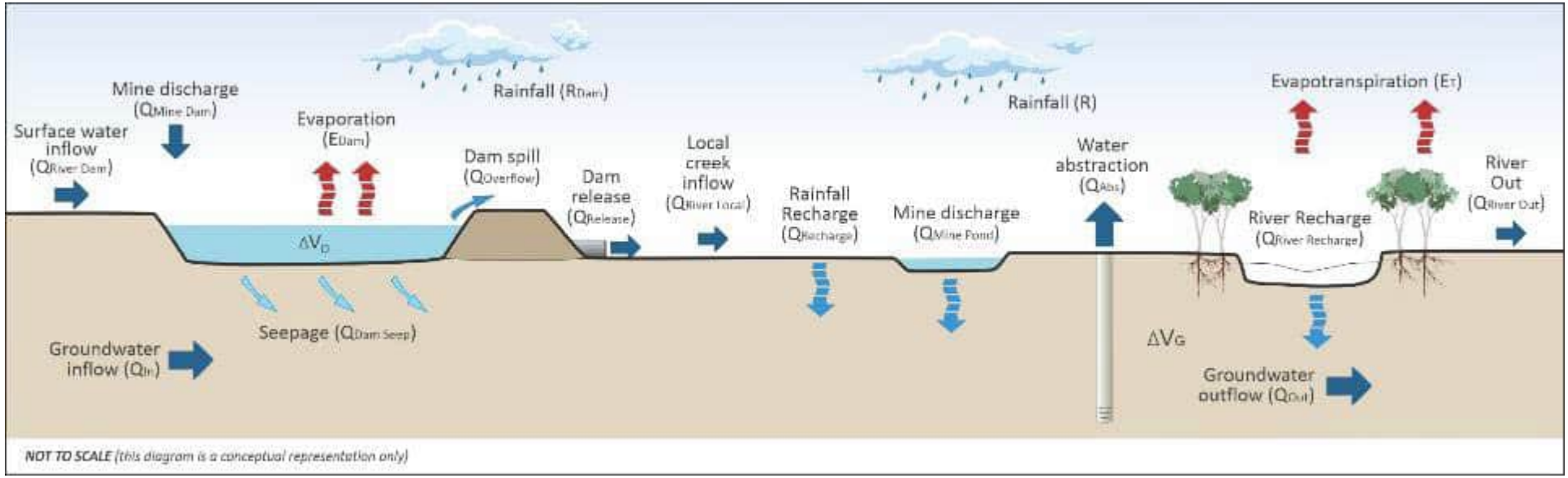
Table 2.2 Annual water balance summary for Scenario K = 7 m/d, 100 ML/d surplus mine water discharge, 1,000 mg/L (2024-25 and 2059-60)



	Dam Inflows				Dam Outflows			Change in Storage	Local Creek Inflow	Groundwater Inflows					Groundwater Outflows			Change in storage	River Outflow
Water (ML/d)	$Q_{River\ Dam}$	R_{Dam}	$Q_{Mine\ Dam}$	E_{Dam}	$Q_{Dam\ Seep}$	$Q_{Release}$	$Q_{Overflow}$	ΔV_D (ML)	$Q_{River\ Local}$	Q_{In}	$Q_{Recharge}$	$Q_{Dam\ Seep}$	$Q_{River\ Recharge}$	$Q_{Mine\ Pond}$	Q_{Abs}	E_T	Q_{Out}	ΔV_G (ML)	$Q_{River\ Out}$
2024-25	85.6	11.7	100.0	67.3	36.3	42.0	32.1	7,223	9.3	1.5	2.5	36.3	12.5	11.9	13.0	42.3	2.4	2,586	70.9
2059-60	98.3	11.6	100.0	59.1	35.3	61.1	29.0	9,388	10.7	1.5	3.7	35.3	11.3	12.0	13.0	40.8	2.4	2,843	86.5
Mass (t/d)	$M_{River\ Dam}$	M_{RDam}	$M_{Mine\ Dam}$	E_{Dam}	$M_{Dam\ Seep}$	$M_{Release}$	$M_{Overflow}$	ΔM_D (t)	$M_{River\ Local}$	M_{In}	$M_{Recharge}$	$M_{Dam\ Seep}$	$M_{River\ Recharge}$	$M_{Mine\ Pond}$	M_{Abs}	E_T	M_{Out}	ΔM_G (t)	$M_{River\ Out}$
2024-25	3.4	0.03	100.0	-	43.2	41.8	29.7	-4,041	0.4	1.5	0.1	43.2	11.0	11.3	14.5	-	2.5	18,231	60.9
2059-60	3.9	0.03	100.0	-	42.6	52.0	30.3	-7,476	0.4	1.5	0.1	42.6	13.3	11.4	17.4	-	5.3	14,720	69.4

Notes:
1. Inflow and outflows (simulated water and mass balance fluxes) presented as daily averages for the year.
2. Change in water storage (Ophthalmia Dam (ΔV_D) and groundwater (ΔV_G) system) presented as total volumetric change over the year.
3. Change in mass storage (Ophthalmia Dam (ΔM_D) and groundwater (ΔM_G) system) presented as total mass change over the year.
4. Mine discharge inflow to Ophthalmia Dam ($Q_{Mine\ Dam}$) represented as an assumed constant rate discharge to Ophthalmia Dam the Surplus Scenario (increasing) input to the water balance.
5. Mine discharge inflow to the groundwater system ($Q_{Mine\ Pond}$) represents the assumed constant rate recharge from surplus water discharge to the Recharge Ponds (same rate applied to all scenarios).

Table 2.3 Annual water balance summary for Scenario K = 49 m/d, 100 ML/d surplus mine water discharge, 1,000 mg/L (2024-25 and 2059-60)



	Dam Inflows				Dam Outflows			Change in Storage	Local Creek Inflow	Groundwater Inflows					Groundwater Outflows			Change in storage	River Outflow
Water (ML/d)	$Q_{River\ Dam}$	R_{Dam}	$Q_{Mine\ Dam}$	E_{Dam}	$Q_{Dam\ Seep}$	$Q_{Release}$	$Q_{Overflow}$	ΔV_D (ML)	$Q_{River\ Local}$	Q_{In}	$Q_{Recharge}$	$Q_{Dam\ Seep}$	$Q_{River\ Recharge}$	$Q_{Mine\ Pond}$	Q_{Abs}	E_T	Q_{Out}	ΔV_G (ML)	$Q_{River\ Out}$
2024-25	85.6	11.7	100.0	67.3	36.3	42.0	32.1	7,223	9.3	1.5	2.3	36.3	12.5	11.9	13.0	29.7	15.9	2,192	70.9
2059-60	98.3	11.6	100.0	59.1	35.3	61.1	29.0	9,388	10.7	1.5	3.4	35.3	11.3	12.0	13.0	27.9	15.9	2,554	89.5
Mass (t/d)	$M_{River\ Dam}$	M_{RDam}	$M_{Mine\ Dam}$	E_{Dam}	$M_{Dam\ Seep}$	$M_{Release}$	$M_{Overflow}$	ΔM_D (t)	$M_{River\ Local}$	M_{In}	$M_{Recharge}$	$M_{Dam\ Seep}$	$M_{River\ Recharge}$	$M_{Mine\ Pond}$	M_{Abs}	E_T	M_{Out}	ΔM_G (t)	$M_{River\ Out}$
2024-25	3.4	0.03	100.0	-	43.2	41.8	29.7	-4,041	0.4	1.5	0.1	43.2	11.0	11.3	15.0	-	16.5	12,949	60.9
2059-60	3.9	0.03	100.0	-	42.3	52.0	30.3	-7,476	0.4	1.5	0.1	42.6	13.3	11.4	23.4	-	28.9	6,028	69.4

Notes:
1. Inflow and outflows (simulated water and mass balance fluxes) presented as daily averages for the year.
2. Change in water storage (Ophthalmia Dam (ΔV_D) and groundwater (ΔV_G) system) presented as total volumetric change over the year.
3. Change in mass storage (Ophthalmia Dam (ΔM_D) and groundwater (ΔM_G) system) presented as total mass change over the year.
4. Mine discharge inflow to Ophthalmia Dam ($Q_{Mine\ Dam}$) represented as an assumed constant rate discharge to Ophthalmia Dam the Surplus Scenario (increasing) input to the water balance.
5. Mine discharge inflow to the groundwater system ($Q_{Mine\ Pond}$) represents the assumed constant rate recharge from surplus water discharge to the Recharge Ponds (same rate applied to all scenarios).

2.4.3 Zonal groundwater salinity predictions

Results of the sensitivity analysis are presented graphically comparing predicted zonal groundwater TDS concentrations and the influence of alternative surplus water discharge rates (50 ML/d, 100 ML/d and 140 ML/d) and dam operation (i.e. no controlled release and 3-month controlled release from Outlet 3).

The following K value scenarios are presented:

- Existing K scenario (K = 7 m/d):
  - 50 ML/d surplus discharge in Figure 2.4;
  - 100 ML/d surplus discharge in Figure 2.6
  - 140 ML/d suplus discharge in Figure 2.8.
- High K scenario (K = 49 m/d):
  - 50 ML/d surplus discharge in Figure 2.5
  - 100 ML/d surplus discharge in Figure 2.7
  - 140 ML/d surplus discharge in Figure 2.9.

The comparison of zonal groundwater TDS predictions for Existing K and High K scenarios highlights the following:

- Increasing the global K parameter from 7 m/d (Existing) up to 49 m/d (High Scenario), and thereby increasing the system throughflow rate, results in flattening of predicted increases in groundwater TDS and predicts a more consistent (normalised) TDS concentration across the groundwater zones.
- The reduction in TDS predictions for the High K scenario is likely a function of increased flushing of water through the system and reduction of the evapo-concentration potential in the upper zones of the model where groundwater inflows (i.e. dam seepage) are significant.
- The Existing K scenario TDS predictions indicate the groundwater system is more sensitive to the Ophthalmia Dam operational scenarios, with controlled releases leading to increases in TDS predictions in some groundwater zones (i.e. Zone 4) and reductions in TDS predictions in other zones (i.e. Zone 1).
- Sensitivity to controlled dam releases is likely a reflection of the influence of increased zonal river recharge. River recharge may exceed the rate of groundwater outflow, under the Existing K scenario, and in the absence of other TDS (mass) flux losses (i.e. groundwater abstraction), results in increased evaporative losses.
- Increasing K results in a consistent reduction in predicted increases in groundwater salinity over the 40-year forecast period. For the high (140 ML/d) surplus discharge scenarios, maximum predicted groundwater TDS concentration for the K of 7 m/d scenario are in the range of 2,500-4,200 mg/L (exceeding the TDS trigger and threshold levels in Zone 4 and 5). For the K of 49 m/d scenario the maximum predicted TDS is reduced to within the 2,000-2,500 mg/L range.

- The High K scenario supports existing (largely anecdotal) observations and limited groundwater TDS monitoring that the groundwater system can accept significant surplus inflows (i.e. surplus discharge to Ophthalmia Dam and the Recharge Ponds) and groundwater TDS concentration does not show a strongly historically increasing trend.

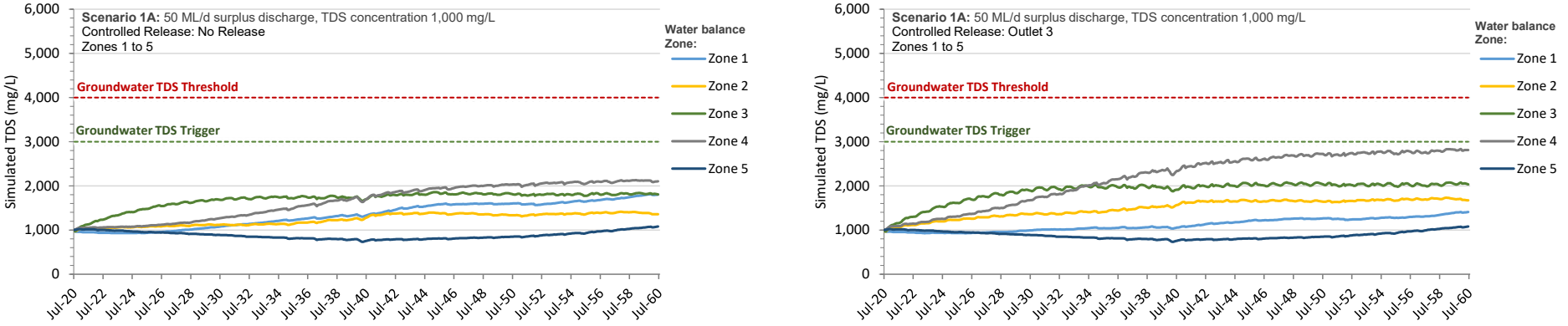


Figure 2.4 Zonal groundwater salinity predictions for Scenario K = 7 m/d, 50 ML/d surplus mine water discharge, TDS concentration 1,000 mg/L

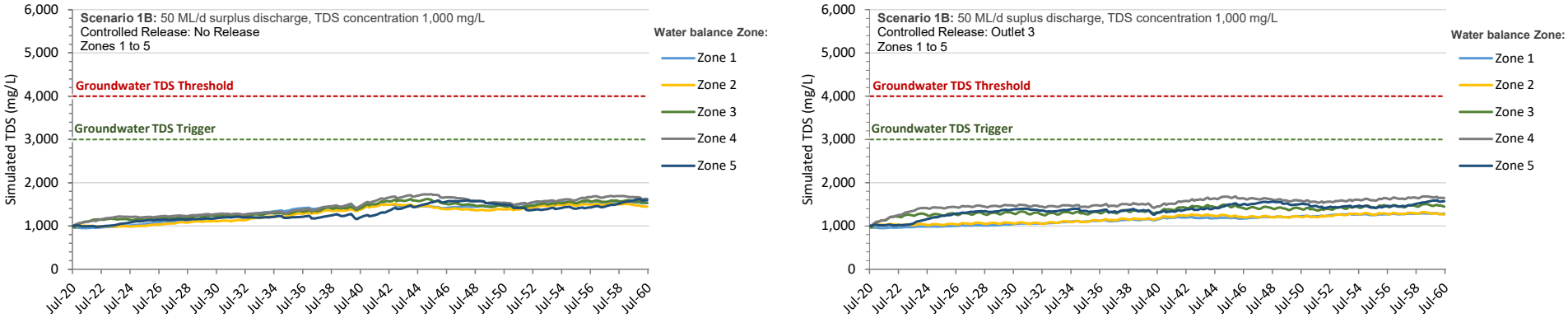


Figure 2.5 Zonal groundwater salinity predictions for Scenario K = 49 m/d, 50 ML/d surplus mine water discharge, TDS concentration 1,000 mg/L

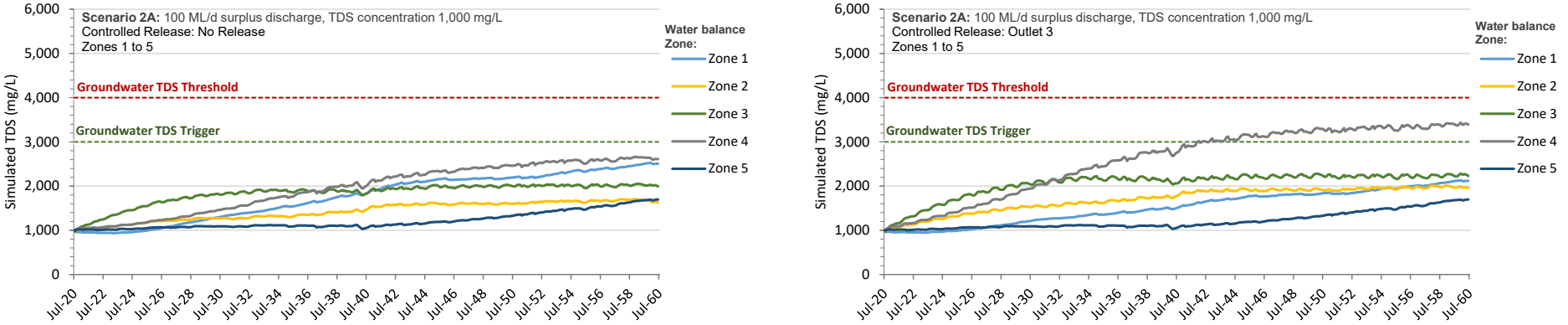


Figure 2.6 Zonal groundwater salinity predictions for Scenario K = 7 m/d, 100 ML/d surplus mine water discharge, TDS concentration 1,000 mg/L

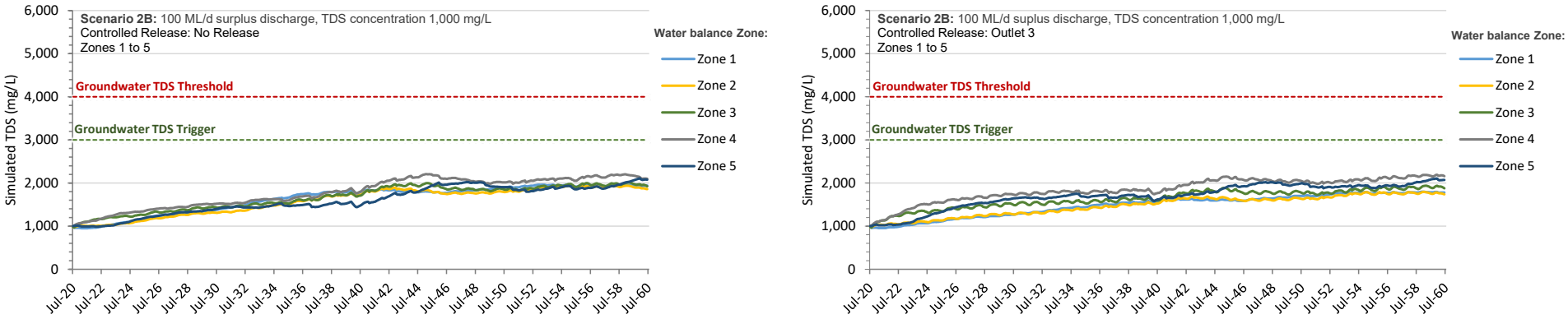


Figure 2.7 Zonal groundwater salinity predictions for Scenario K = 49 m/d, 100 ML/d surplus mine water discharge, TDS concentration 1,000 mg/L

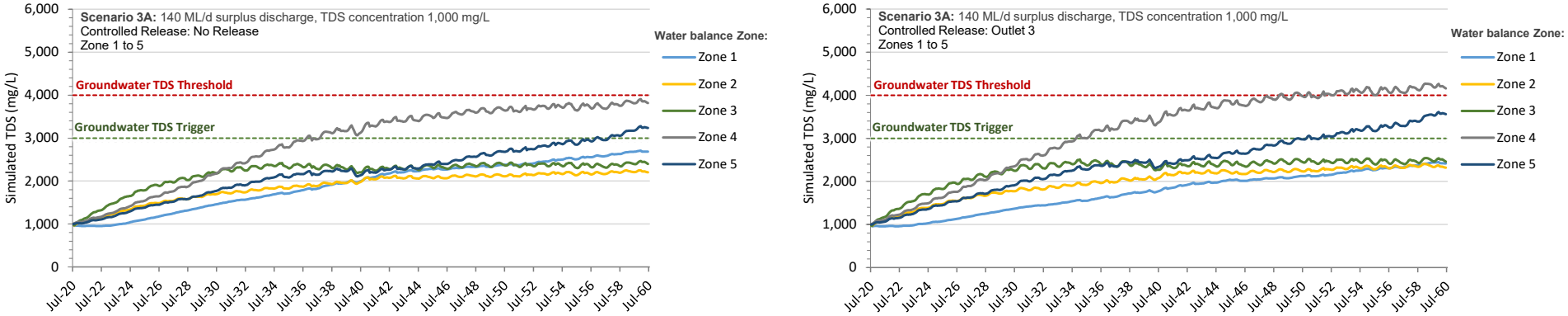


Figure 2.8 Zonal groundwater salinity predictions for Scenario K = 7 m/d, 140 ML/d surplus mine water discharge, TDS concentration 1,000 mg/L

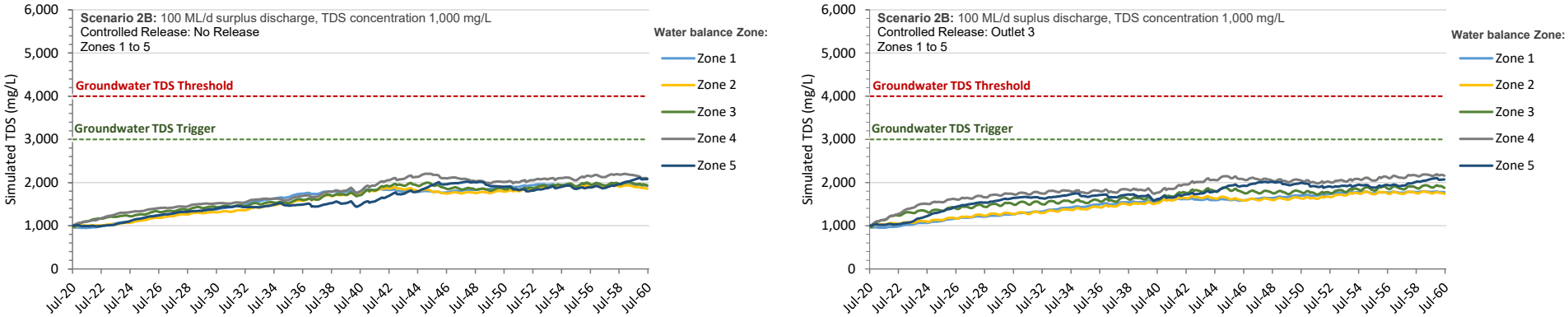


Figure 2.9 Zonal groundwater salinity predictions for Scenario K = 49 m/d, 140 ML/d surplus mine water discharge, TDS concentration 1,000 mg/L

3 Phase 2 Stochastic modelling

3.1 Background

The Phase 2 stochastic modelling assessment was undertaken with the objective to explore the potential influence of varying key model variables, parameters, and alternative Ophthalmia Dam operational approaches on predicted dam and groundwater TDS concentrations. In particular, the model scenarios (detailed in the following sections) aim to identifying and test a range of 'feasible' water balance parameters, and operational conditions that could potentially result in simulated dam and groundwater salinity to exceed the criteria set out in the EPWRMP (BHP 2018). Dam water quality, groundwater quality and groundwater level criteria are listed in Section 1.3.

The stochastic assessment has also been applied to both groundwater system K scenarios (i.e. Existing K and High K) described in the sensitivity analysis (refer to Section 2). Both K scenarios were applied in the water balance model structure incorporating the increased storage capacity parameters for the upstream conceptual groundwater store (as detailed in Section 2.3.1).

3.2 Modelled scenarios

The water balance parameters and operational scenarios identified for the stochastic modelling scenarios are:

- surplus water discharge rates – applying three levels of discharge of 50 ML/d, 100 ML/d and 140 ML/d, ranging between recent actual discharge, forecast discharge and the estimated dam capacity
- surplus water TDS concentration – applying a TDS concentration range of 500 to 3,000 mg/L (applied as an incremental TDS concentration increase of 250 mg/L), noting that the actual average surplus water TDS from BHP's existing hubs range between 550 and 950 mg/L (EMM 2020)
- Ophthalmia Dam controlled release valve operation – assessing the influence of alternate controlled releases scenarios on the stochastic elements listed above, namely:
    - no controlled release
    - Outlet 3 controlled release – 3-month controlled release from C wall outlet (starting in August each year)
    - Outlet 1 controlled release – 3-month controlled release from A wall outlet, approx. 2 x capacity of C wall outlet (starting in August each year - noting that the A Wall valve is out of service and there is currently no intention of changing from using the C wall valve for releases.

All of the above model scenarios have been run using the historic (40 year) climate and hydrology which includes both wet and dry periods.

An additional set of 'dry climate' scenarios were run to investigate the potential impact of consecutive extreme dry years (i.e. zero catchment or rainfall flux to the dam) on predicted TDS concentration in Ophthalmia Dam. These scenarios were investigated to potentially understand the maximum potential dam TDS concentration range for alternate surplus discharge rates and TDS concentrations.

3.3 Summary of results

3.3.1 Stochastic model results

A summary of stochastic modelling results are presented graphically in the following appendices:

- Predicted Ophthalmia Dam storage and TDS concentration in Appendix C.
- Predicted Groundwater elevation (level) and TDS concentration (Existing K = 7 m/d scenario) in Appendix D.
- Predicted Groundwater elevation (level) and TDS concentration (High K = 49 m/d scenario) in Appendix E.
- Dry climate scenarios predicted Ophthalmia Dam storage and TDS concentration in Appendix A.

The model outputs present simulated dam volume, simulated dam TDS concentration and simulated groundwater TDS concentration (Zone 1 to Zone 5) applying a surplus discharge TDS concentration range of 500 mg/L to 3,000 mg/L for each of the three dam release scenarios (No release, Outlet 3 (C wall valve) and Outlet 1 (A wall valve)).

The following three surplus water discharge rate cases were adopted to represent the range of potential surplus water discharge rates:

- 50 ML/d surplus water discharge
- 100 ML/d surplus water discharge
- 140 ML/d surplus water discharge.

Water balance modelling results are presented relative to the Ophthalmia Dam water quality, Ethel Gorge groundwater quality and groundwater level criteria set out in the EPWRMP (BHP 2018). Simulated groundwater level results are presented graphically with a y-axis range of groundwater elevation (level) limited to 6.0 m (Appendix D.1). This corresponds with the EPWRMP Ethel Gorge Trigger that relates to aquifer groundwater level changing more than 6.0 m.

Key observations from the stochastic model runs for the Ophthalmia Dam water and TDS balance include the following:

- Increasing surplus water TDS concentration has a significant influence on predicted dam salinity.
- Variations in dam TDS concentration are highly seasonal with peak concentrations occurring during and towards the end of the dry season (i.e. up to November/December) with rapid reductions in TDS concentration from ‘fresh’ catchment inflows during the wet season period.
- Peaks in TDS concentration occur during dry periods, particularly extended dry periods (i.e. 2028-29 and 2058-59) where the dam receives low natural inflows over consecutive wet seasons and where natural ‘flushing flows’ into the dam are minimal / absent.
- Increasing controlled release rates (and annual volume) from the dam reduces predicted dam TDS concentration (particularly peaks) by releasing TDS loads from the dam, allowing it to move down the system, and increasing dam capacity to accept catchment inflows.
- Increasing surplus volume does not appear to correlate strongly with increasing TDS concentration.

- Surplus discharge TDS concentration appears to be the key factor and increasing surplus discharge rate can potentially act to dilute salinity in the dam when the dam salinity approaches a salinity threshold or equilibrium.

- For all surplus discharge rate scenarios (50 ML/d, 100 ML/d and 140 ML/d) the Ophthalmia Dam TDS Trigger concentration (5,000 mg/L) is predicted to be exceeded only under the high surplus water discharge TDS conditions (i.e. when discharge TDS concentrations are in excess of 2,000 mg/L).

- The frequency and duration of trigger level exceedances, under high surplus TDS concentrations, are notably reduced by the operation of controlled dam releases, with larger releases (i.e. Outlet 1) providing marginally greater benefit.

- The Ophthalmia Dam water balance indicates that if surplus discharge TDS concentrations are below 1,500 mg/L the Ophthalmia Dam TDS Early Warning Indicator concentration (4,000 mg/L) is unlikely to be exceeded, even under the 'worst case' no controlled release scenario.

The graphical results of groundwater TDS concentrations for the various water balance scenarios present predicted TDS concentrations for ranges of surplus discharge TDS concentrations (i.e. in 500 mg/L ranges up to a maximum of 3,000 mg/L). This provides an opportunity to follow a predicted trajectory of groundwater TDS concentration, for each of the modelled groundwater zones, under alternative surplus discharge rates and concentrations.

The following sections provide a summary of the key observations from the stochastic groundwater system water balance scenario results. It is noted that there are a large number of results and graphical outputs presented in Appendix D and Appendix E, reflecting the complexity of the model and number of scenarios included.

Therefore, the summary is structured to present the results of the Existing K (K = 7 m/d) scenarios first and then the results of the High K (K= 49 m/d) scenarios.

Key observations for the Existing K scenario results presented in Appendix D include the following:

- For the 50 ML/d discharge rates scenarios, predicted groundwater TDS concentration in Zone 1 appear to be most sensitive to surplus discharge concentration. Higher groundwater TDS concentrations are predicted with no controlled releases from the dam (which increases dam seepage rates) and controlled release from the dam appears to reduce predicted groundwater TDS concentrations in Zone 1.

- Increases in groundwater TDS concentrations are predicted to be relatively slow and cumulative, with concentrations trending upwards over a number of years or decades. This contrasts with the rapid responses and variations of TDS concentrations in Ophthalmia Dam (refer to Appendix C), and the original predictions of groundwater salinity for OB32 (EMM 2020) due to the theoretical constant discharge volumes used in the sensitivity analysis (compared to the variable discharge forecast used for the 2020 modelling).

- Zones 2 to 5 show much lower sensitivity to surplus water discharge under the 50 ML/d surplus discharge scenario with no controlled release from the dam, however, groundwater TDS predictions in these zones show a much greater increase under controlled release scenarios, particularly in Zones 4 and 5 where Ethel Gorge groundwater quality criteria are predicted to be exceeded.

- The sensitivity of zonal groundwater TDS concentrations potentially reflects the influence of river recharge as a dominant groundwater flux and highlights limited inter-zonal groundwater (and mass) flows.

- For the high surplus discharge rate scenarios, 100 and 140 ML/d, EPWRMP groundwater quality criteria (Trigger and Threshold) are predicted to be exceeded in Zones 1, 4 and 5, even for low surplus discharge TDS concentrations.

- The increasing occurrence and rate of dam overflow (spill) predicted for high surplus discharge rate scenarios appears to be acting to increase the rate of rising groundwater TDS concentrations through enhanced river recharge fluxes to the zonal groundwater balances.

- Even under the high surplus discharge scenario (140 ML/d), Zones 1 and 2 reflect different TDS concentration responses compared to the upstream and downstream zones. This may support the earlier observation (refer to Section 2.4.2) that under the Existing (low) K scenario vertical fluxes are dominant controls on Zonal water and mass balances.

- It is possible that Zone 2 (and Zone 3 downstream) may be losing significant TDS mass through groundwater abstractions and these abstractions can act to limit evaporative losses through drawdown of groundwater levels.

Key observations for the High K scenario results presented in Appendix E include the following:

- For the High K scenarios there is clearly a more consistent response to groundwater TDS concentrations across the zones. This potentially reflects a clearer and more active link between increasing surplus discharge (and TDS load) to Ophthalmia Dam and TDS concentration responses throughout the groundwater system.

- Predicted groundwater TDS concentrations across all zones can be more directly related to increase in the rate and TDS concentration of surplus discharge to Ophthalmia Dam.

- Operation of controlled releases from Ophthalmia Dam appear to have a freshening effect on groundwater TDS concentrations and acts to mitigate (reduce) the increasing groundwater TDS concentration trends.

- At low surplus discharge TDS concentrations (500–1,500 mg/L) EPWRMP groundwater quality (TDS) criteria are not predicted to be exceeded, apart from a possible minor exceedance of the Early Warning Indicator (3,000 mg/L) in Zones 4 and 5 under the 140 ML/d discharge scenarios. These potential exceedances occur in the second half of the 40-year forecast period.

- For the 50 ML/d surplus discharge scenario, the groundwater quality TDS Early Warning Indicator (3,000 mg/L) is potentially only exceeded for the high discharge TDS concentration (2,000–3,000 mg/L) scenarios in Zone 1 and 2 for the no dam discharge scenario.

- For the 140 ML/d surplus discharge scenario, the groundwater quality TDS Early Warning Indicator (3,000 mg/L) is predicted to be exceeded in all zones for surplus discharge conditions with TDS concentrations greater than 1,500 mg/L. The groundwater quality TDS trigger (4,000 mg/L) is predicted to be exceeded only if surplus discharge TDS concentrations are higher than, 2,000 mg/L over a long period (i.e. consistently high TDS concentration discharge at a high rate (140 ML/d) for 20 years or more).

3.3.2 Dry climate scenario model results

A summary of 'dry climate' scenario modelling results are presented graphically in Appendix F.

Each scenario presents predicted dam salinity under a theoretical extreme dry scenario (i.e. no natural inflow) for three surplus water salinity cases (500 mg/L, 1,500 mg/l, 3,000 mg/L) for each of the three dam release scenarios (no release, C wall outlet and A wall outlet).

Results are presented for the following three surplus water discharge rate cases:

- 50 ML/d surplus water discharge rates - Section C.1 (Appendix C)
- 100 ML/d surplus water discharge rates - Section C.2 (Appendix C)
- 140 ML/d surplus water discharge rates - Section C.3 (Appendix C).

Key observations from the dry climate model runs indicate the following:

- For all scenarios the Ophthalmia Dam TDS concentration is predicted to progressively increase over a number of years and stabilises at a new 'balanced' TDS concentration. The period until the balanced equilibrium is longer for the no release scenarios compared to the controlled release scenarios.
- Operating a controlled release from the dam is predicted to reduce the dam TDS concentration equilibrium with the larger release rate (and volume) from the Wall A valve (Outlet 1) providing a marginal benefit compared to the operation of the Wall C valve (Outlet 3).
- For the highest surplus discharge TDS concentration scenario (3,000 mg/L) the maximum predicted equilibrium TDS concentrations for Ophthalmia Dam are estimated as follows:
    - approximately 8,000 mg/l for the 50 ML/d discharge rate
    - approximately 10,000 mg/L for the 100 ML/d discharge rate
    - approximately 9,000 mg/l for the 140 ML/d discharge rate.
- Under higher surplus discharge rate scenarios, the dam is predicted to reach a slightly lower balanced (equilibrium) salinity level than for the low surplus discharge scenarios. This is due to the dilution influence of the surplus discharge as inflows increase in influence relative to evaporative loss rates, combined with marginally increasing salt load loss through increased dam spill and seepage to groundwater.

4 Conclusions

This report details the outcomes and results of the review and assessment of the Eastern Pilbara Hub water balance model sensitivity and variability with respect to predicted dam and groundwater salinity.

The sensitivity analysis provides a relatively comprehensive summary of the potential sensitivity of the groundwater system representation in the water balance model to the assumption of a lumped hydraulic conductivity (K) parameter. This K parameter was, by definition, shown to influence the magnitude of simulated groundwater throughflow, particularly relative to other key groundwater balance (inflow and outflow) fluxes, as well having a commensurate effect on the simulated mass balance of TDS both within and between the modelled zonal groundwater balances.

The stochastic modelling assessment provides a comprehensive summary of the potential influence of varying key model variables, parameters, and alternative Ophthalmia Dam operational approaches on predicted dam and groundwater TDS concentrations. Based on the outcomes of the sensitivity analysis, the influence of alternative assumptions relating to the lumped K parameter on stochastic predictions of groundwater TDS concentration, i.e. showing the potential influence of a plausible range of K values (K = 7.0 m/d and K = 49 m/d), was also presented for completeness.

The following points provide a summary of the key outcomes and conclusions from the assessment of updated surplus water management scenarios:

- Ophthalmia Dam seepage, in conjunction with open water evaporative losses, represent the major source and control of groundwater recharge upstream of Ethel Gorge.
- Controlled releases and dam spill (overflow) potentially lead to significant, but ephemeral, river recharge responses.
- Increasing surplus water discharge to Ophthalmia Dam is predicted to result in increases in dam seepage rates, increased requirement for controlled releases to manage water levels and mitigate dam TDS concentration and increase frequency and duration of seasonal dam spill (overflow) events.
- Elevated TDS concentrations in Ophthalmia Dam are highly seasonal with peak concentrations occurring during and towards the end of the dry season (i.e. up to November/December) with rapid reductions in TDS concentration from ‘freshening’ catchment inflows during the wet season period.
- Peaks in dam TDS concentration occur during dry periods, particularly extended dry periods where the dam receives low natural inflows over consecutive wet seasons and where natural ‘flushing flows’ into the dam are minimal/absent.
- The frequency and duration of criteria exceedances are notably reduced by the operation of controlled dam releases, with larger volumetric releases (i.e. Outlet 1) providing marginally greater benefit.
- The water balance modelling indicates that if surplus discharge TDS concentrations are below 1,500 mg/L the Ophthalmia Dam TDS Early Response Indicator concentration (4,000 mg/L) is unlikely to be exceeded, even under the ‘worst case’ extended dry period and no controlled release scenario. Note that data for historic surplus water TDS concentrations for Whaleback, Eastern Ridge and Jimblebar hub range between 550 mg/L and 950 mg/L.

- Modelled groundwater balance (levels) and TDS concentration responses are shown to be sensitive to hydraulic conductivity parameter (K) assumptions which provide a key control on estimated groundwater throughflow.

- The use of a lumped groundwater system conceptualisation and adoption of a single K parameter for the simulation of groundwater throughflow is limited in its ability to effectively represent the complex geology and aquifer properties through the Ethel Gorge system.

- The calibrated (Low) K value of 7.0 m/d used during all previous model runs results in variable responses through and between groundwater zones, particularly where vertical loss fluxes (groundwater abstraction) are locally dominant and act to supress evapotranspiration losses.

- A Low K parameterisation results in zonal groundwater balances being dominated by vertical fluxes, including river recharge, groundwater abstraction (local) and evapotranspiration losses, relative to groundwater flow (zonal inflow and outflow).

- The alternative High K parametrisation acts to increase groundwater throughflow and reduce evapotranspiration losses from the groundwater system.

- Increasing groundwater throughflow results in a more direct connection between groundwater zones and results in more consistent responses in terms of predicted groundwater TDS concentrations, which aligns more consistently with historical observations.

- High groundwater throughflow reduces the potential for increasing groundwater TDS concentration by increasing the rate of flushing (removal) of TDS mass from the groundwater system, as well as reducing the evapo-concentration influence of evaporative losses.

- Review of model performance and history matching indicate that a plausible range for the lumped K parameter could be lie within the 7–49 m/d range.

- The stochastic modelling results show that the adoption of a higher K value for the groundwater system result in lower predicted TDS estimates, as well as reduced spatial and temporal variability, therefore supporting the view that the original predictions from the K = 7m/d model scenarios are likely to represent the worst case scenario in terms of potential TDS responses to increased surplus water discharge.

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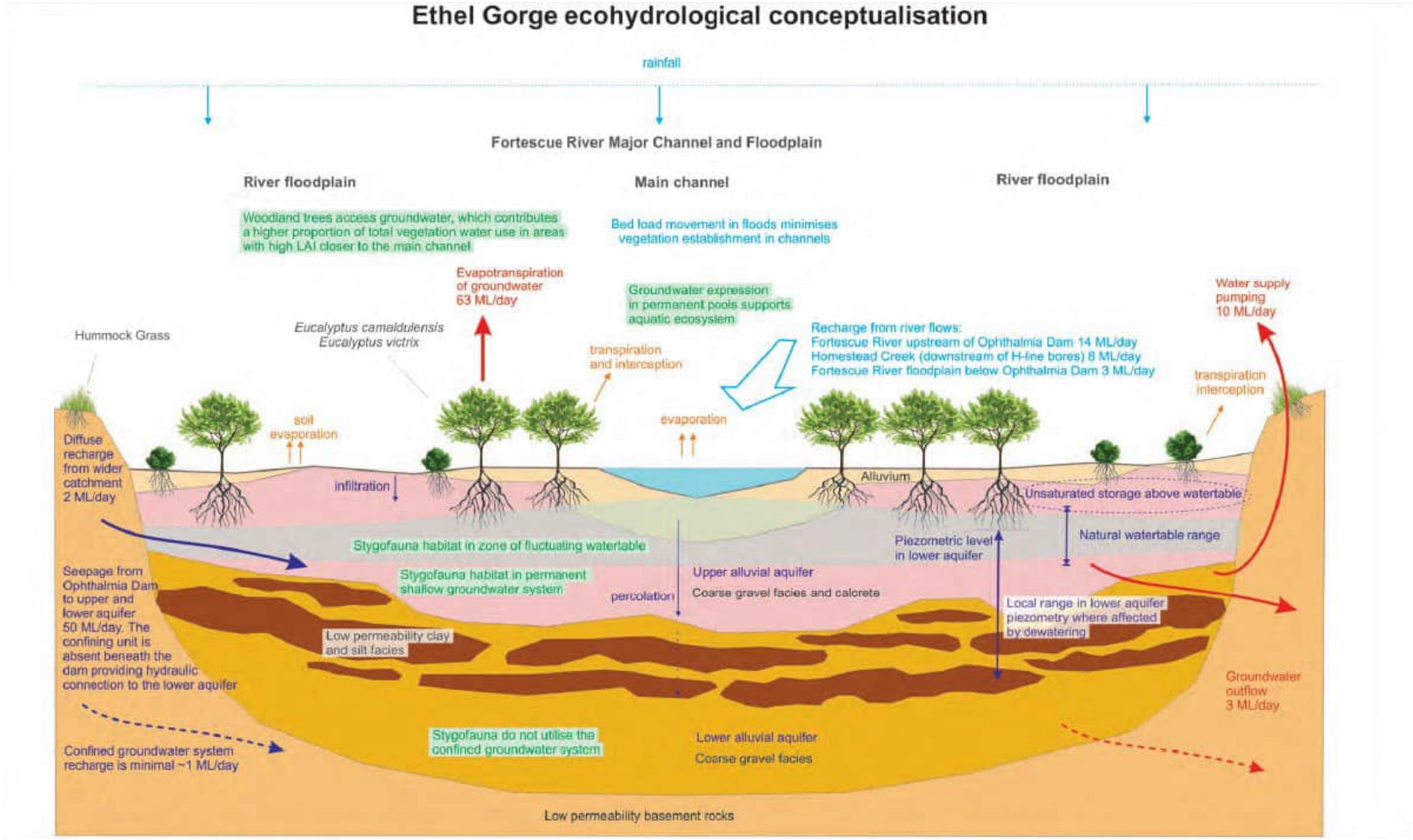
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Tahal Consulting Engineers Ltd. 1980. *Newman water resources development project stage 1.* Tahal Consulting Engineers Ltd.

Appendix A

Ethel Gorge conceptual ecohydrological model (RPS 2015)

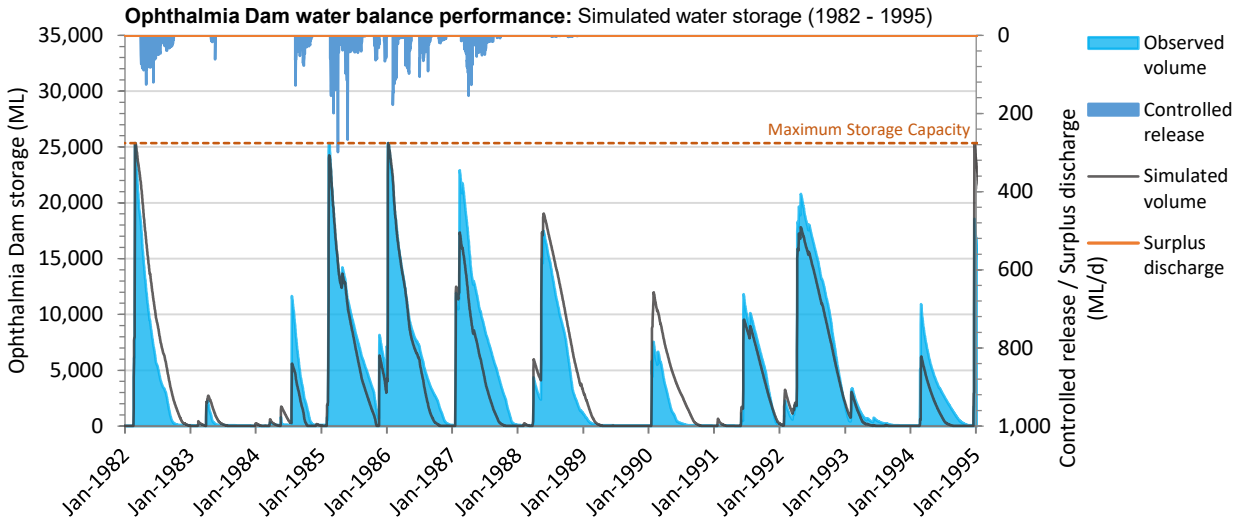
A.1 Ethel Gorge ecohydrological conceptualisation (RPS 2015)

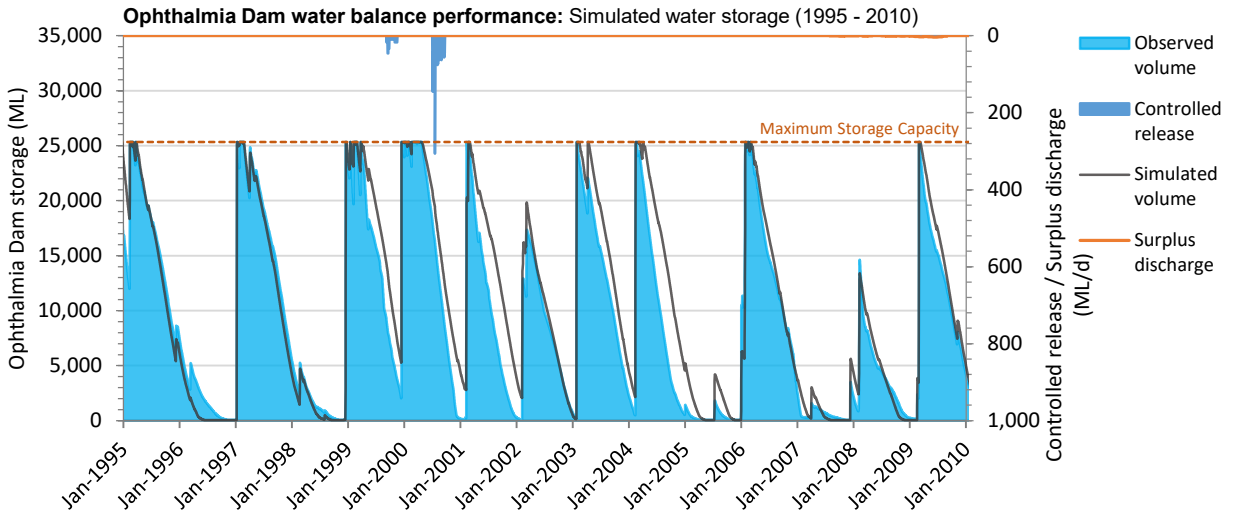


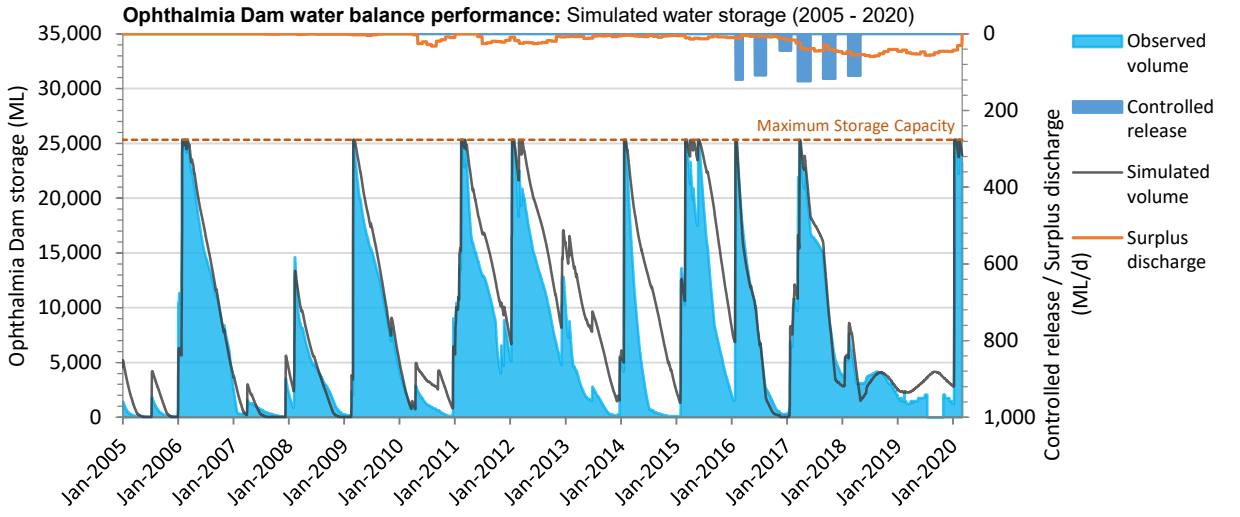
Appendix B

Water balance performance summary

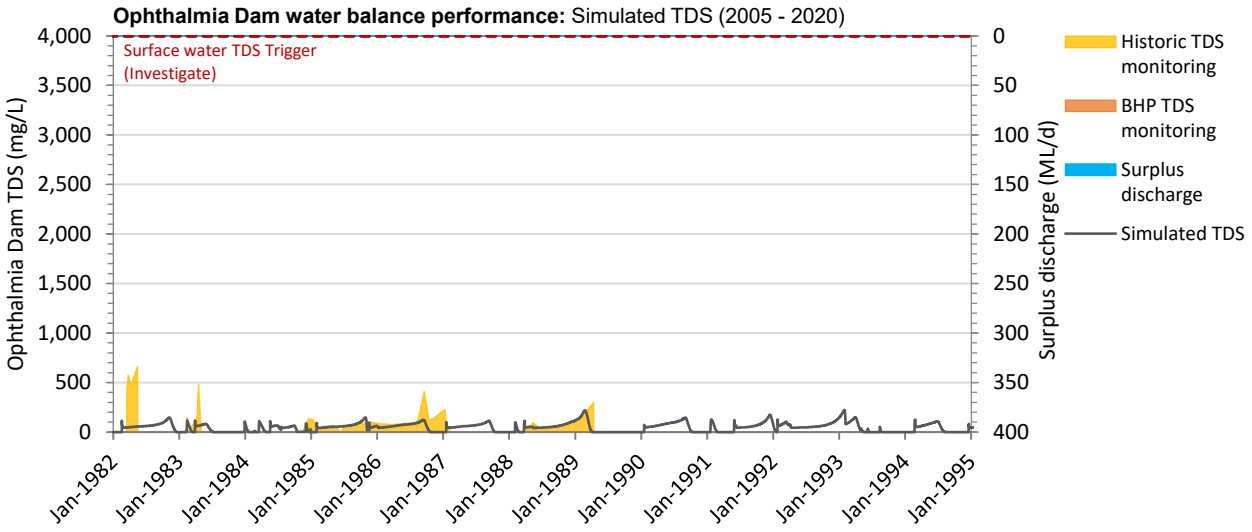
B.1 Ophthalmia Dam- historic simulation vs observed storage volume

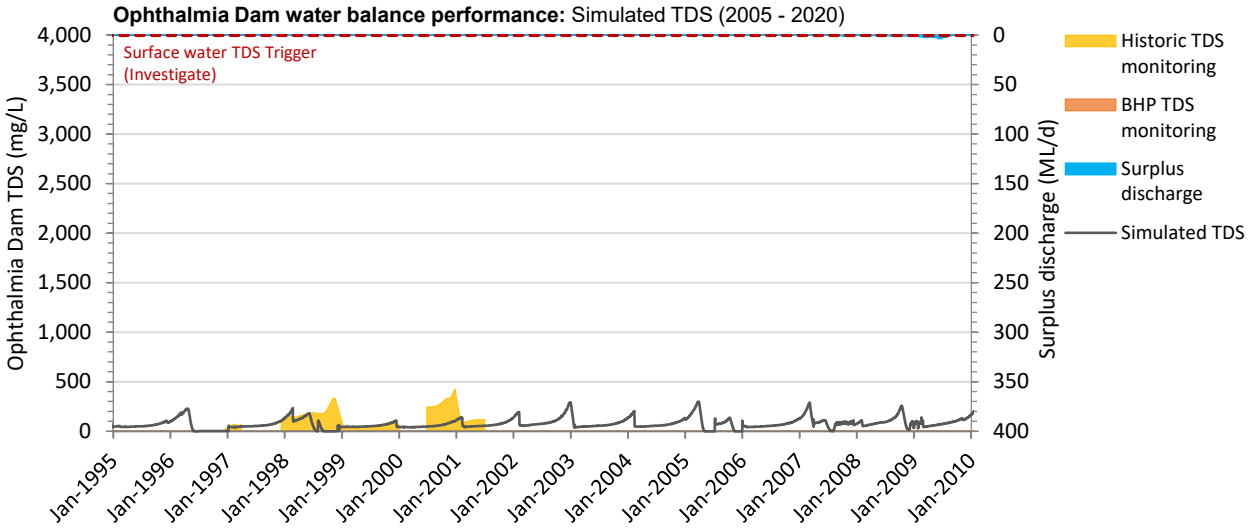


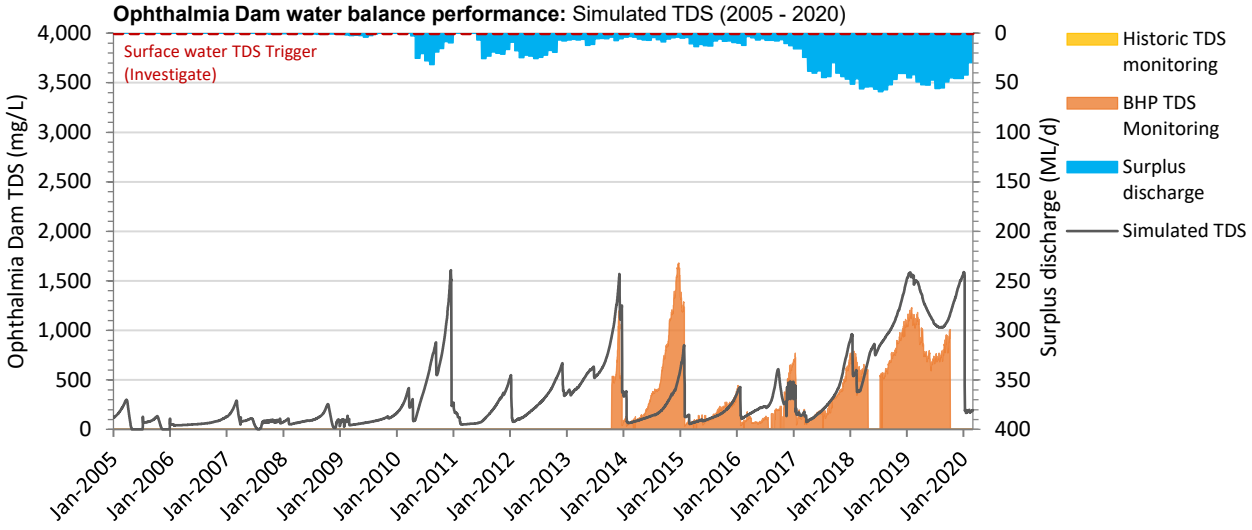




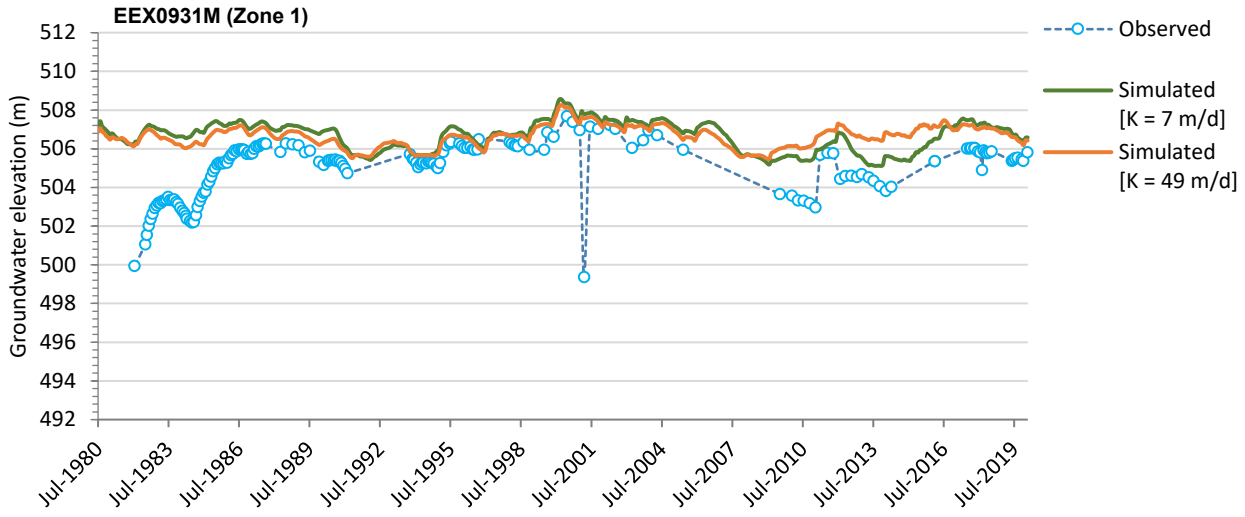
B.2 Ophthalmia Dam- historic simulation vs observed TDS

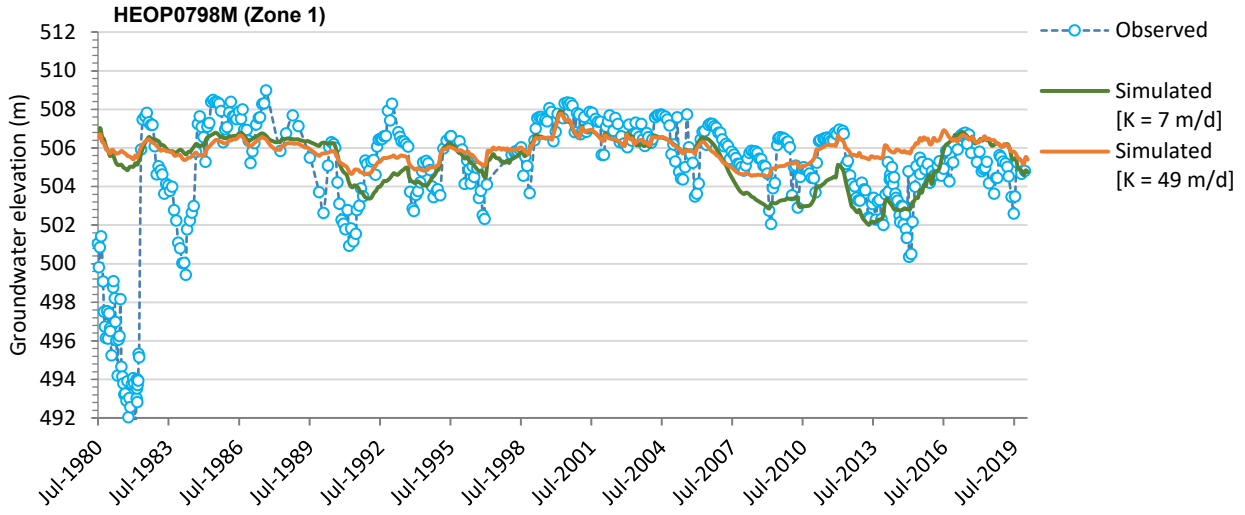


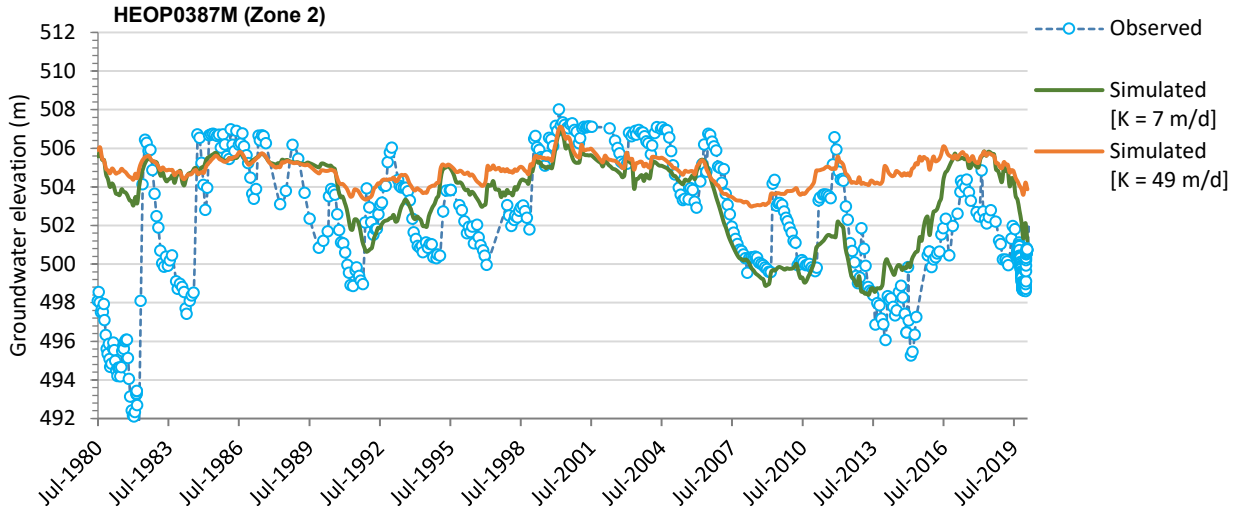


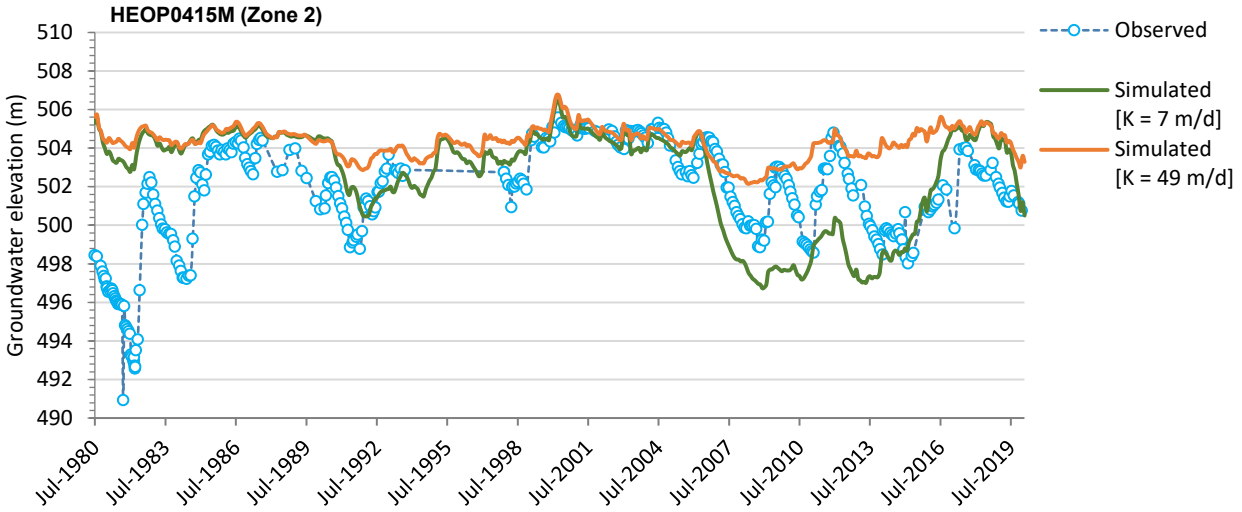


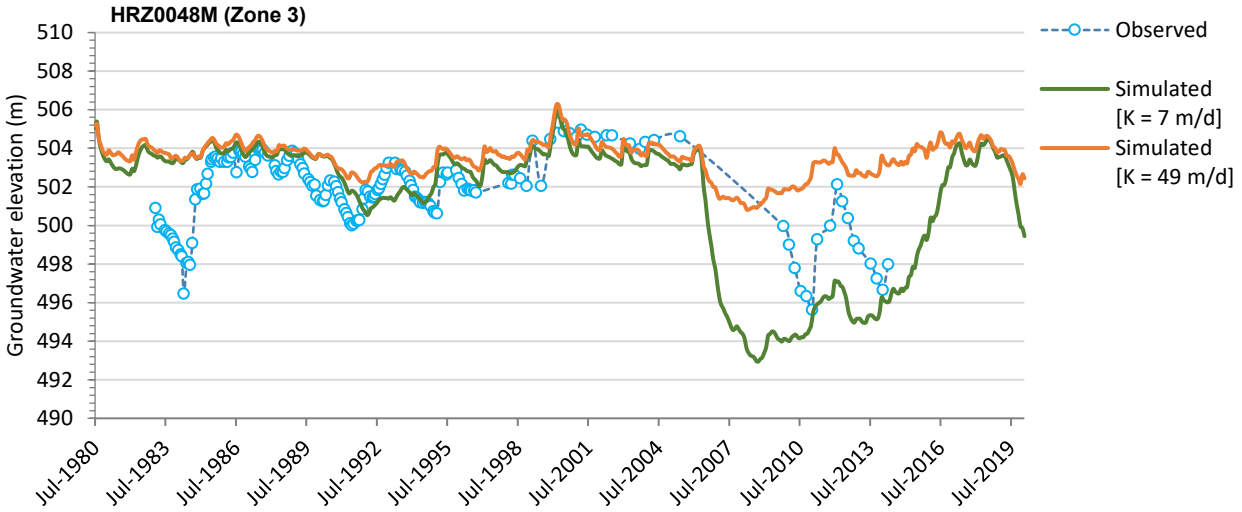
B.3 Groundwater system- historic simulation vs observed water elevations

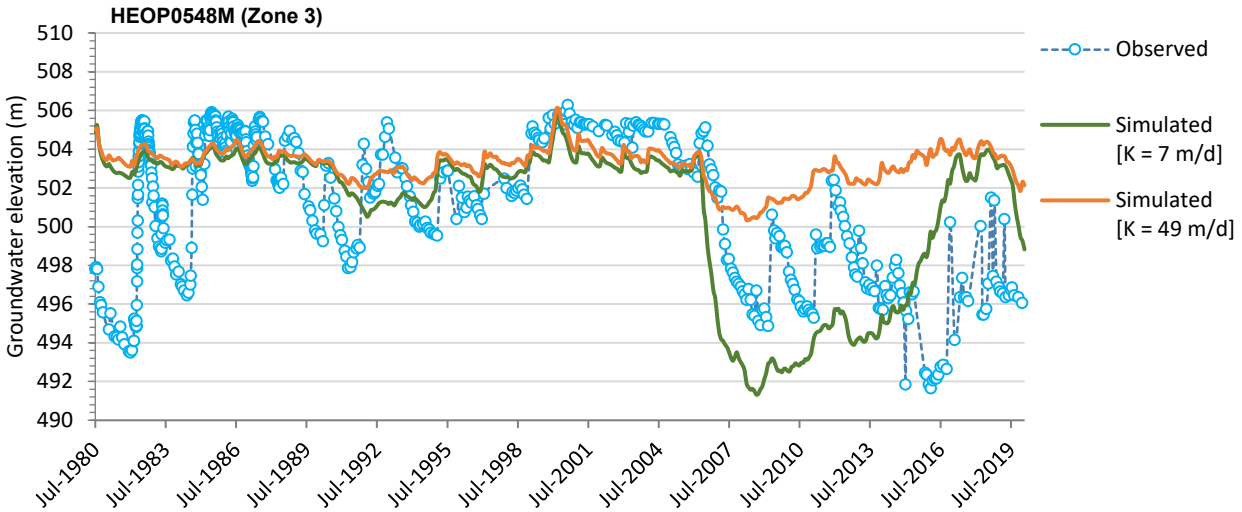


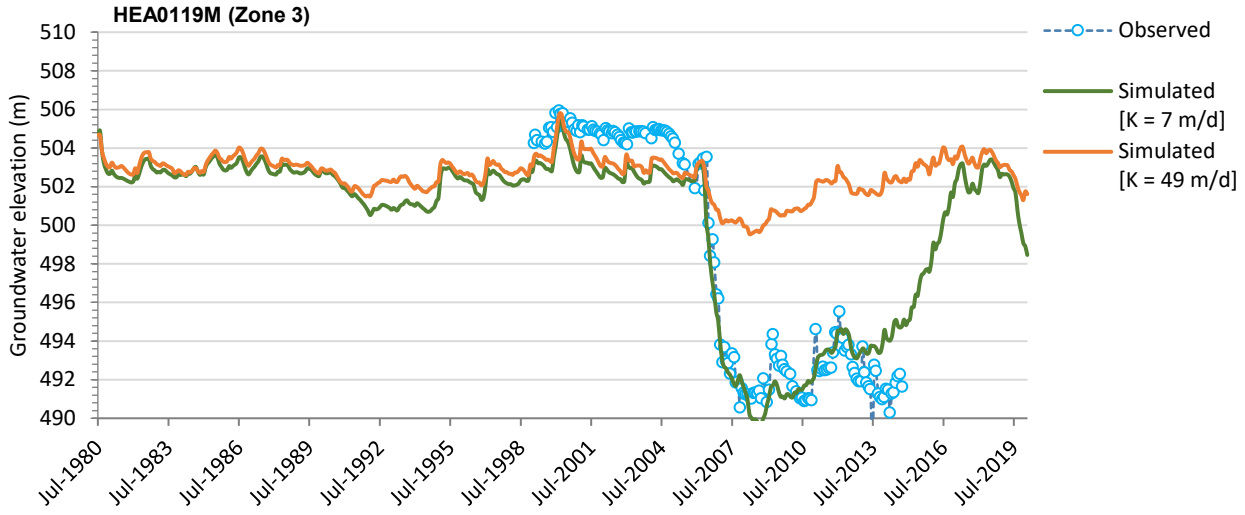


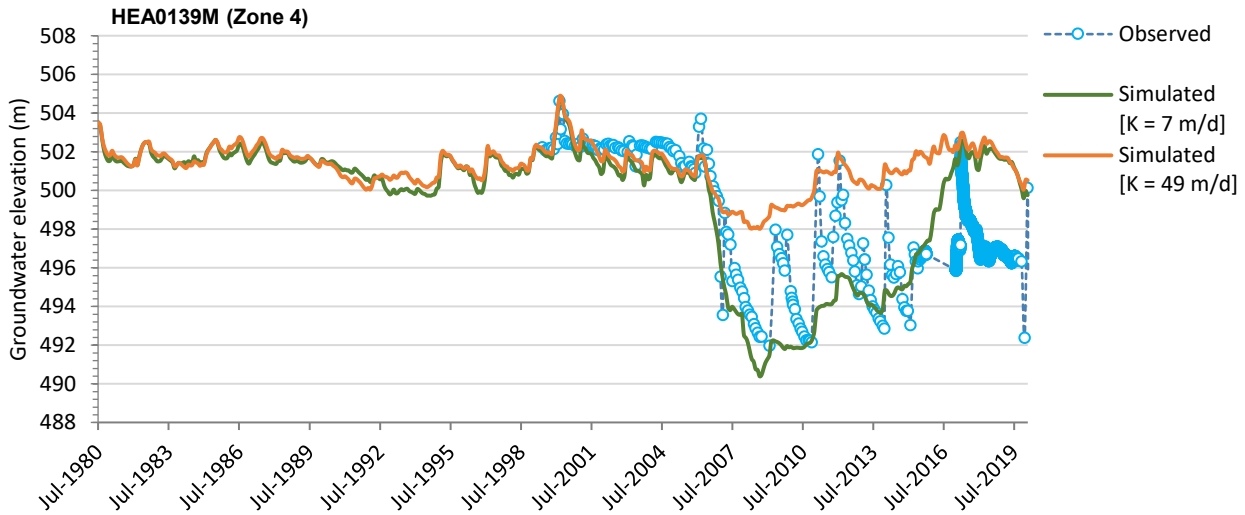


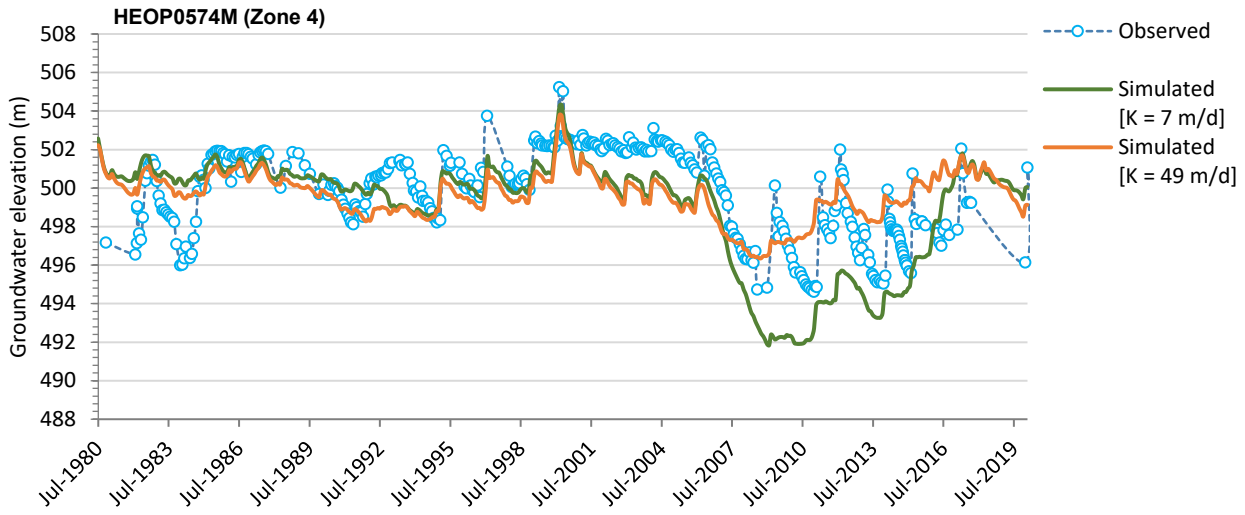

HEOP0415M (Zone 2)
Groundwater elevation (m)
510
508
506
504
502
500
498
496
494
492
490
Jul-1980
Jul-1983
Jul-1986
Jul-1989
Jul-1992
Jul-1995
Jul-1998
Jul-2001
Jul-2004
Jul-2007
Jul-2010
Jul-2013
Jul-2016
Jul-2019
Observed
Simulated [K = 7 m/d]
Simulated [K = 49 m/d]

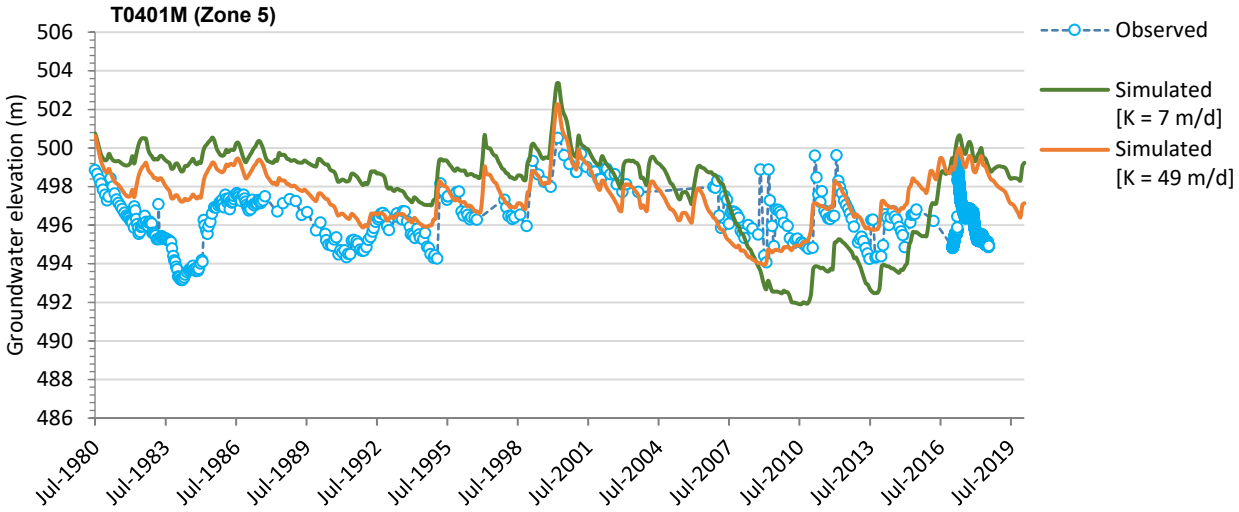

HRZ0048M (Zone 3)
Groundwater elevation (m)
510
508
506
504
502
500
498
496
494
492
490
Jul-1980
Jul-1983
Jul-1986
Jul-1989
Jul-1992
Jul-1995
Jul-1998
Jul-2001
Jul-2004
Jul-2007
Jul-2010
Jul-2013
Jul-2016
Jul-2019
Observed
Simulated [K = 7 m/d]
Simulated [K = 49 m/d]


HEOP0548M (Zone 3)
Groundwater elevation (m)
510
508
506
504
502
500
498
496
494
492
490
Jul-1980
Jul-1983
Jul-1986
Jul-1989
Jul-1992
Jul-1995
Jul-1998
Jul-2001
Jul-2004
Jul-2007
Jul-2010
Jul-2013
Jul-2016
Jul-2019
Observed
Simulated [K = 7 m/d]
Simulated [K = 49 m/d]


HEA0119M (Zone 3)
Groundwater elevation (m)
510
508
506
504
502
500
498
496
494
492
490
Jul-1980
Jul-1983
Jul-1986
Jul-1989
Jul-1992
Jul-1995
Jul-1998
Jul-2001
Jul-2004
Jul-2007
Jul-2010
Jul-2013
Jul-2016
Jul-2019
Observed
Simulated [K = 7 m/d]
Simulated [K = 49 m/d]


HEA0139M (Zone 4)
Groundwater elevation (m)
508
506
504
502
500
498
496
494
492
490
488
Jul-1980
Jul-1983
Jul-1986
Jul-1989
Jul-1992
Jul-1995
Jul-1998
Jul-2001
Jul-2004
Jul-2007
Jul-2010
Jul-2013
Jul-2016
Jul-2019
Observed
Simulated [K = 7 m/d]
Simulated [K = 49 m/d]


HEOP0574M (Zone 4)
Groundwater elevation (m)
508
506
504
502
500
498
496
494
492
490
488
Jul-1980
Jul-1983
Jul-1986
Jul-1989
Jul-1992
Jul-1995
Jul-1998
Jul-2001
Jul-2004
Jul-2007
Jul-2010
Jul-2013
Jul-2016
Jul-2019
Observed
Simulated [K = 7 m/d]
Simulated [K = 49 m/d]

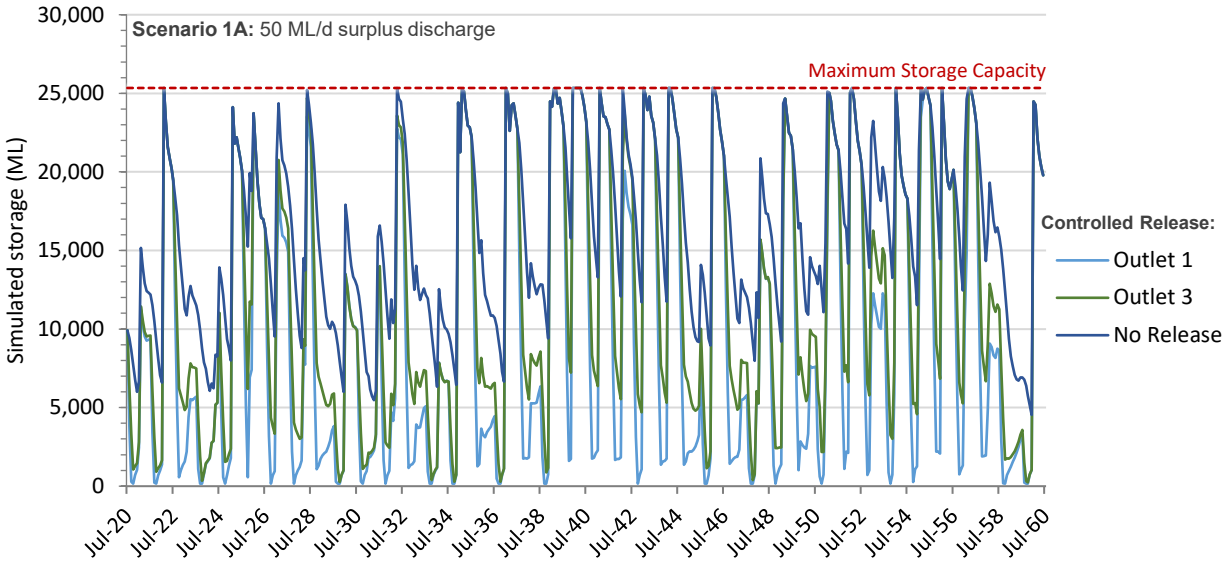

T0401M (Zone 5)
Groundwater elevation (m)
506
504
502
500
498
496
494
492
490
488
486
Jul-1980
Jul-1983
Jul-1986
Jul-1989
Jul-1992
Jul-1995
Jul-1998
Jul-2001
Jul-2004
Jul-2007
Jul-2010
Jul-2013
Jul-2016
Jul-2019
Observed
Simulated [K = 7 m/d]
Simulated [K = 49 m/d]

Appendix C

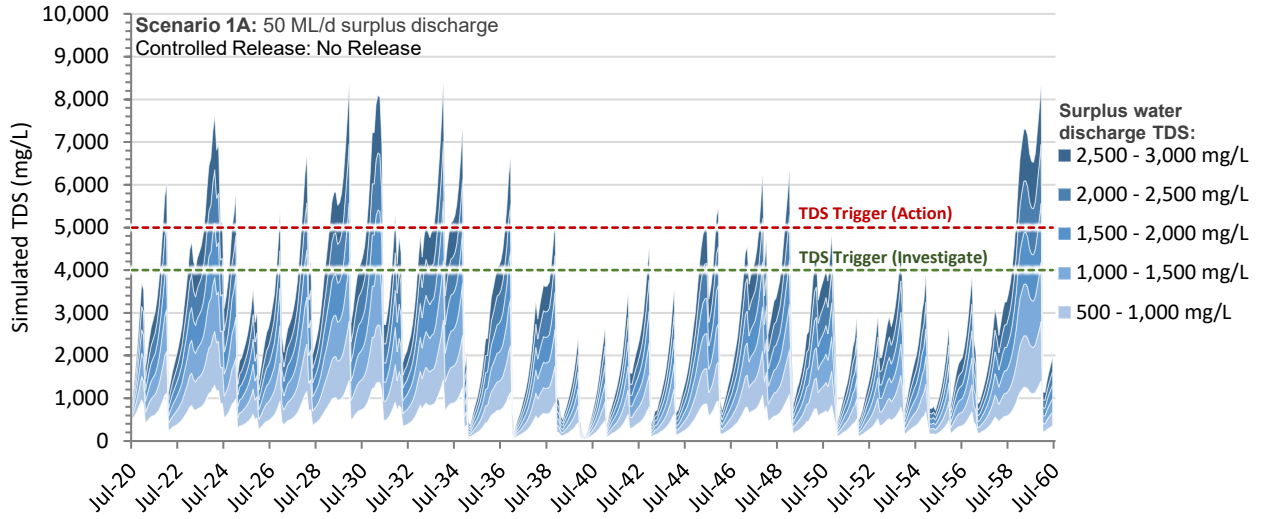
Water balance scenarios – Ophthalmia Dam

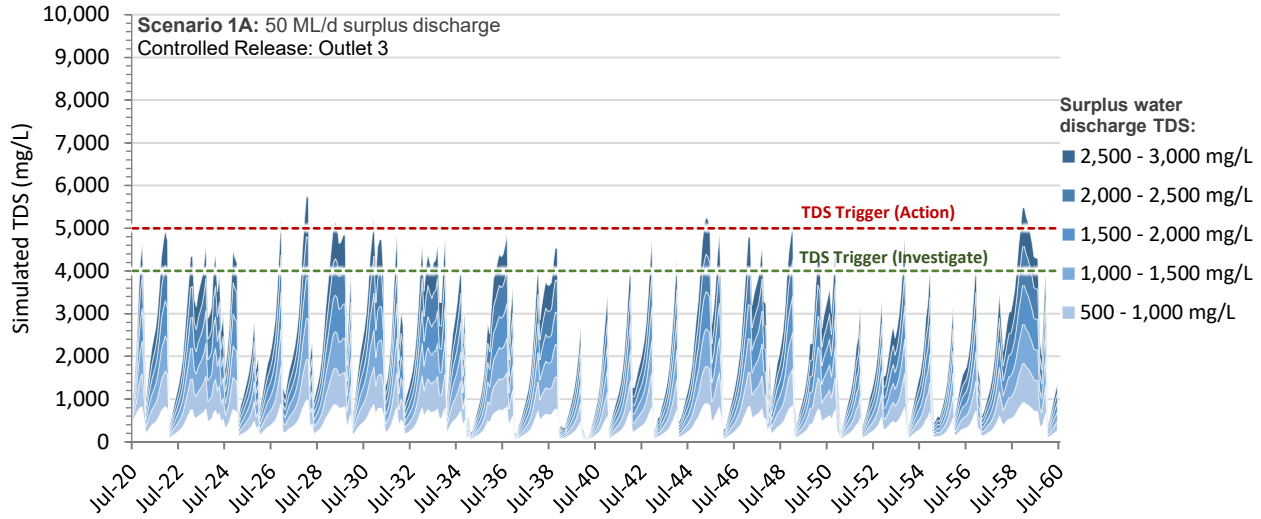
C.1 50 ML/d Surplus discharge, TDS concentration 500 mg/L to 3000 mg/L, 3 discharge scenarios

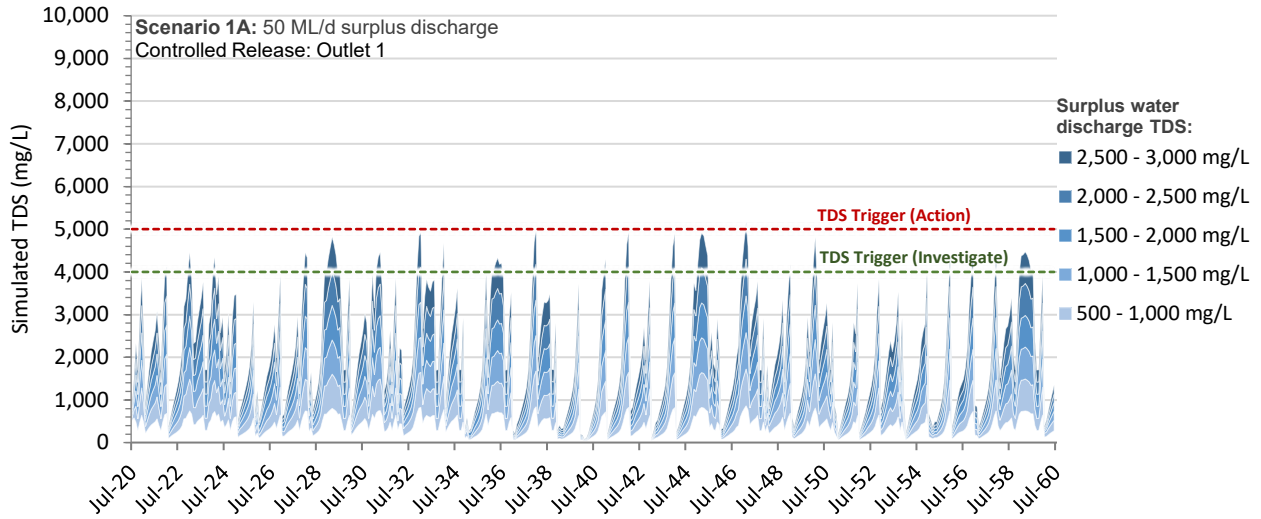
C.1.1 Predicted dam volume



C.1.2 Predicted dam TDS

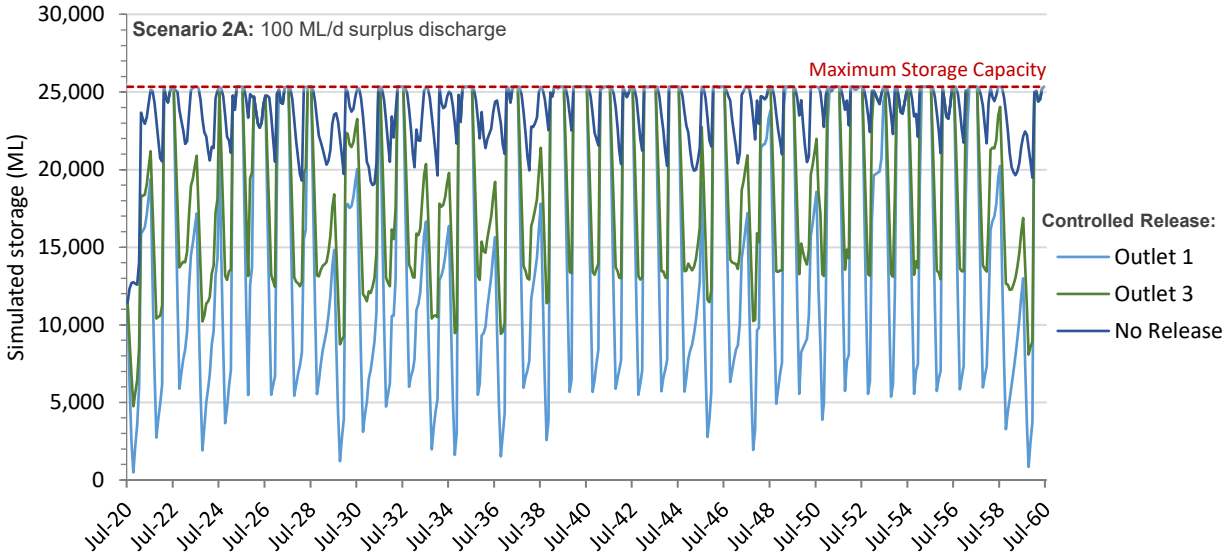




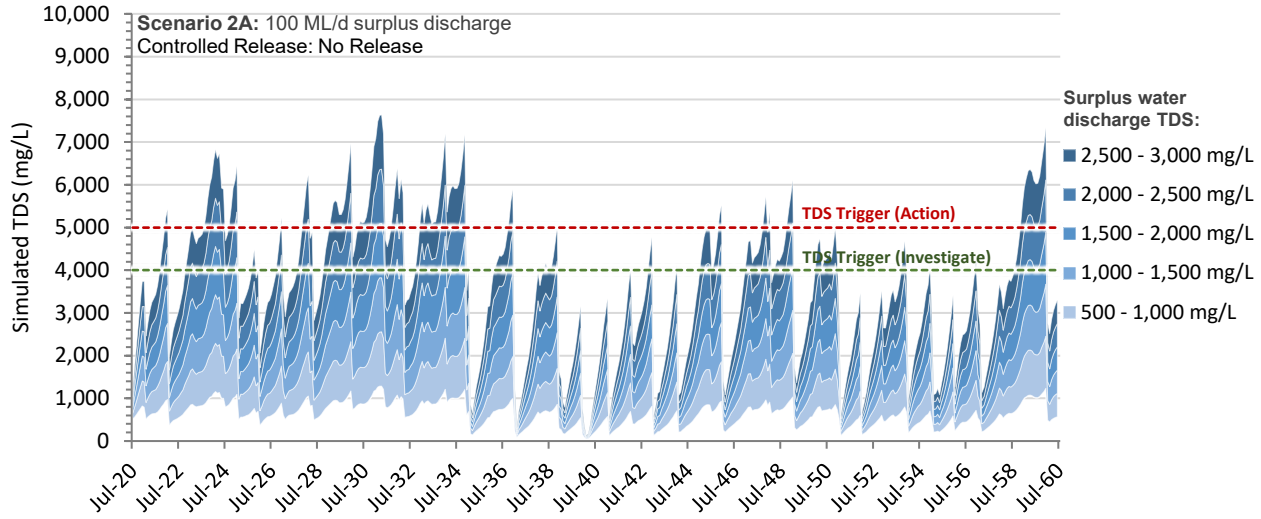


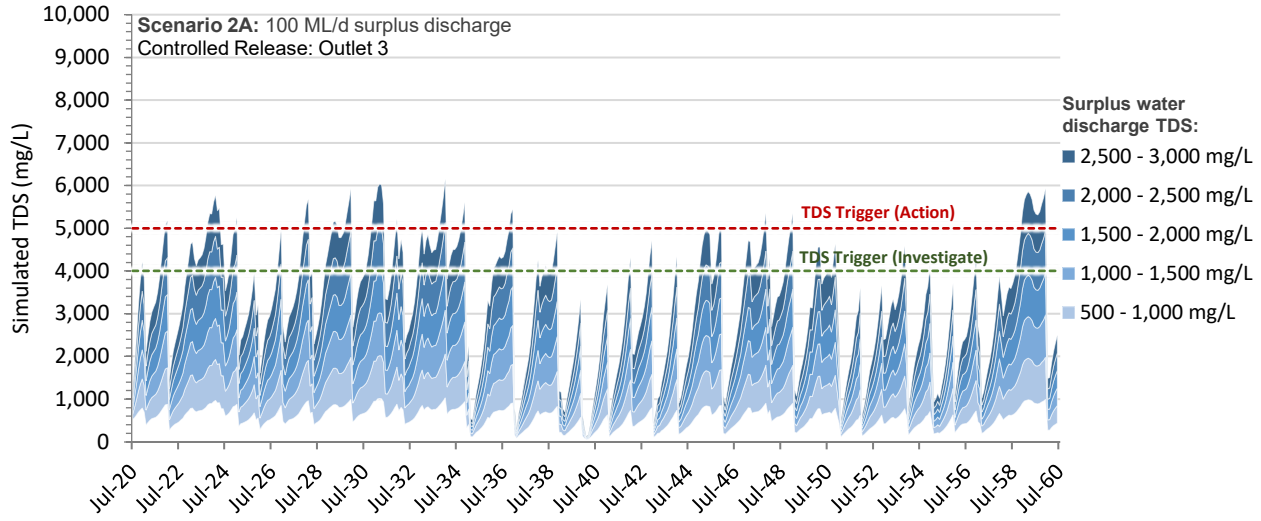
C.2 100 ML/d Surplus discharge, TDS concentration 500 mg/L to 3000 mg/L, 3 discharge scenarios

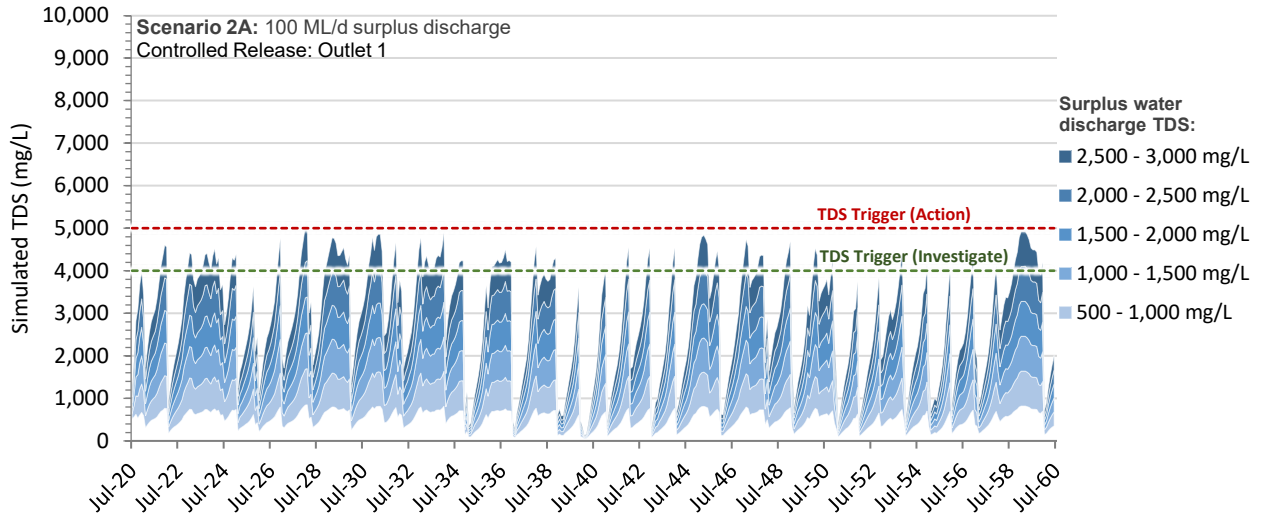
C.2.1 Predicted dam volume



C.2.2 Predicted dam TDS

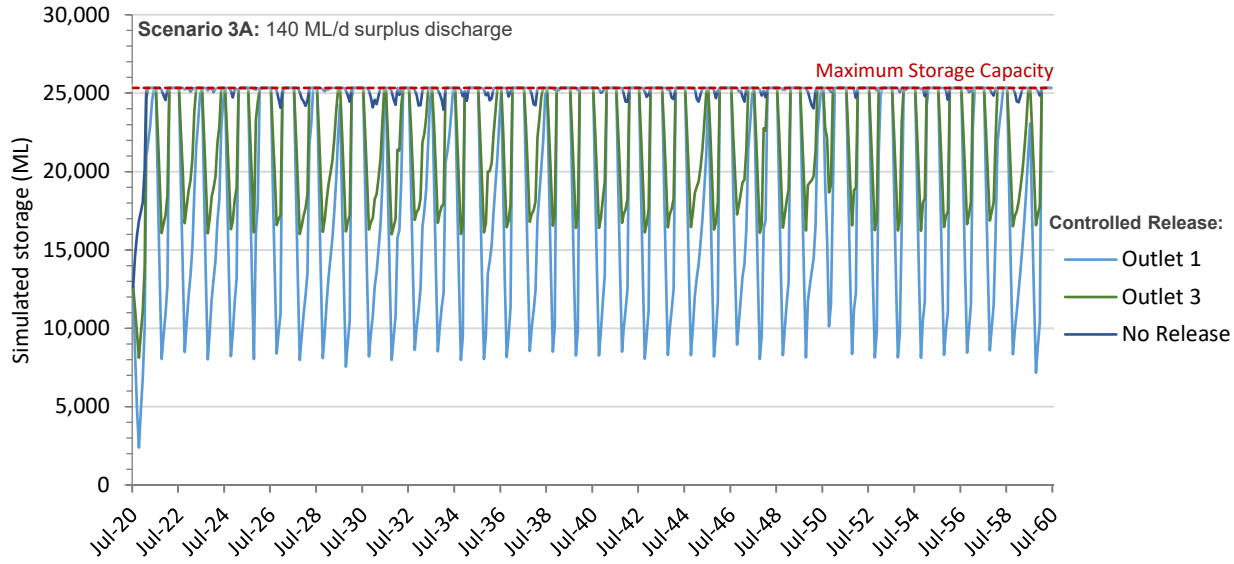




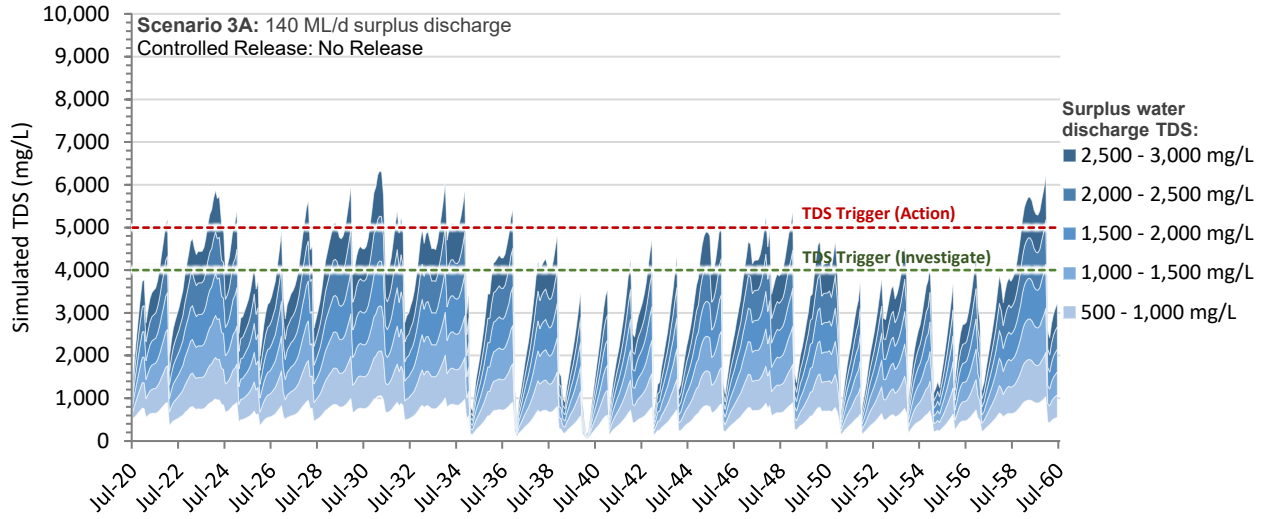


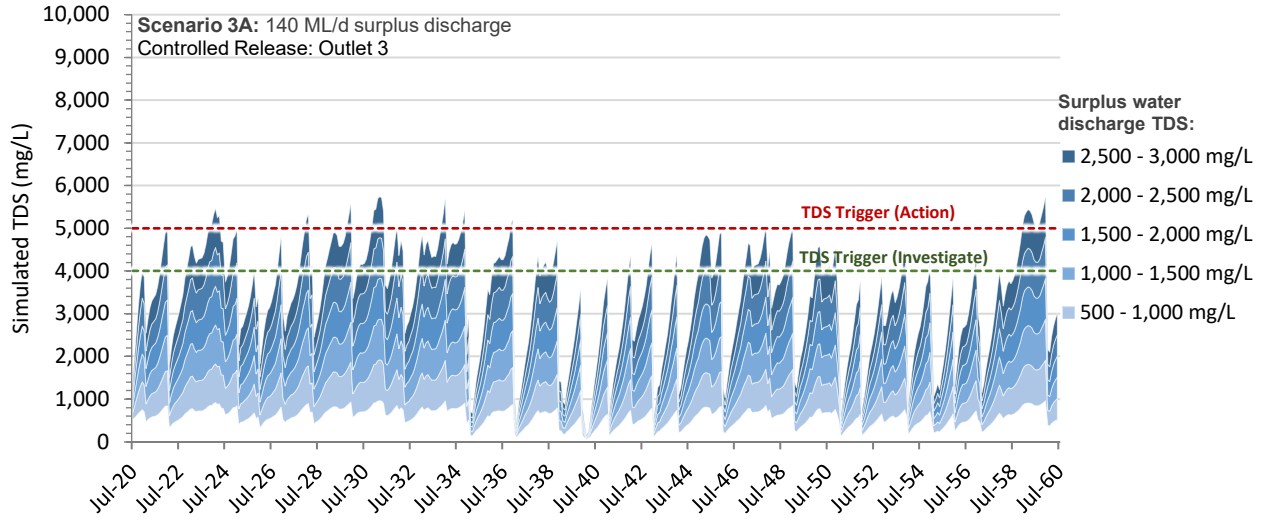
C.3 140 ML/d Surplus discharge, TDS concentration 500 mg/L to 3000 mg/L, 3 discharge scenarios

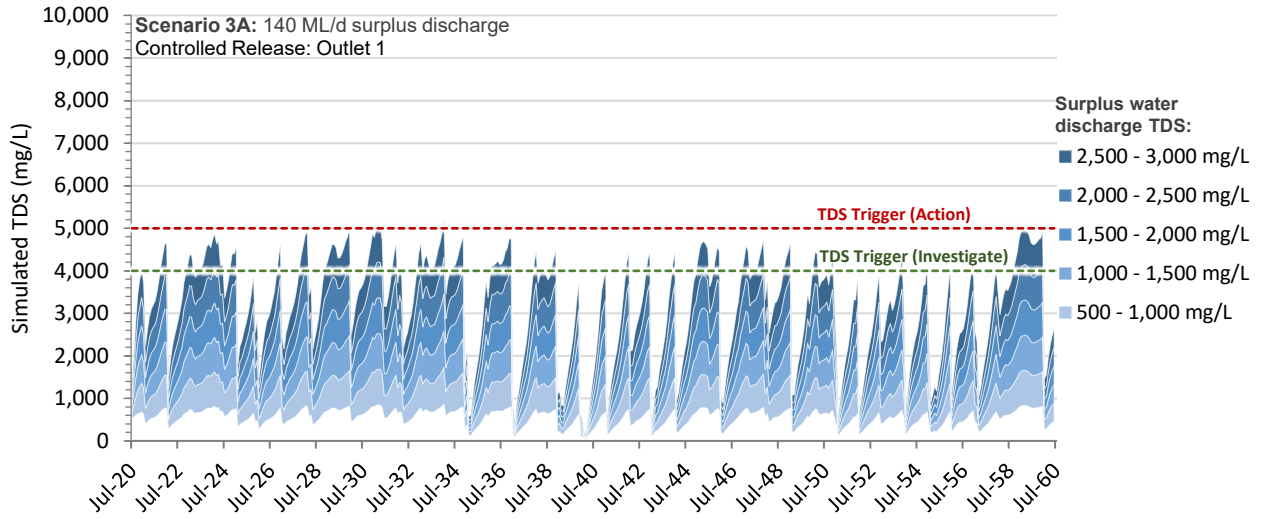
C.3.1 Predicted dam volume



C.3.2 Predicted dam TDS





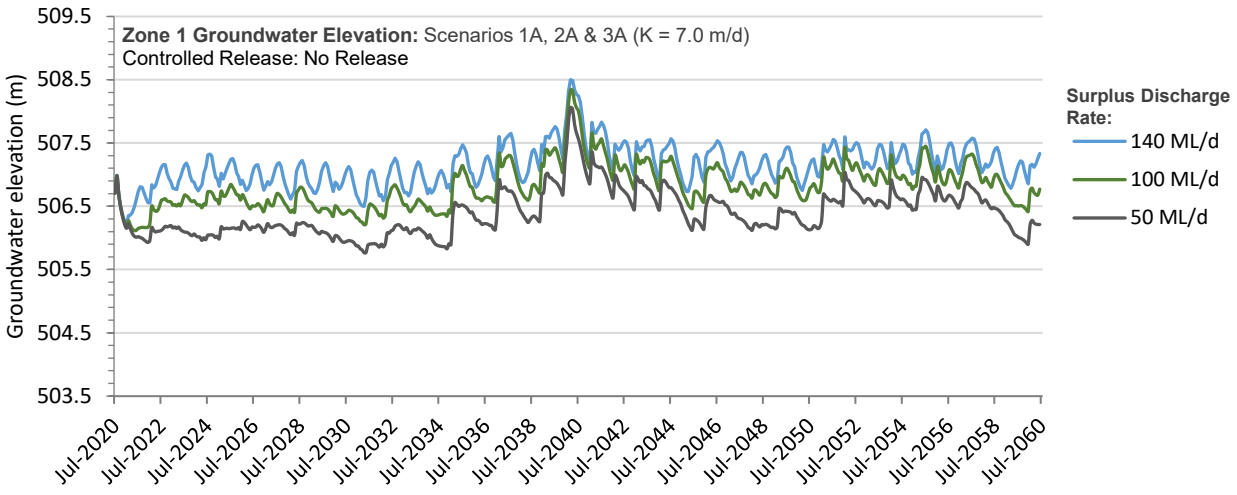


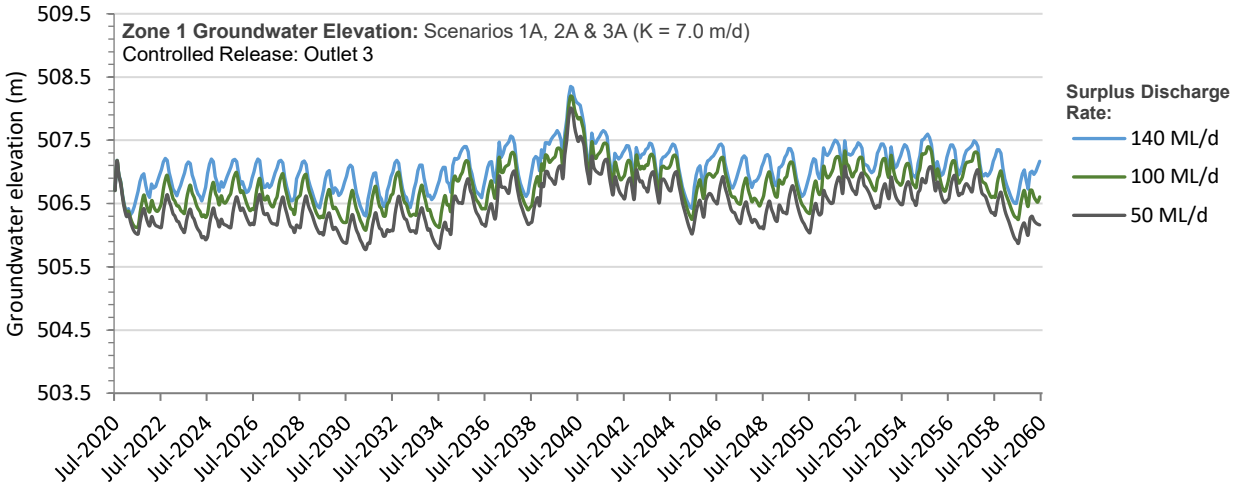
Appendix D

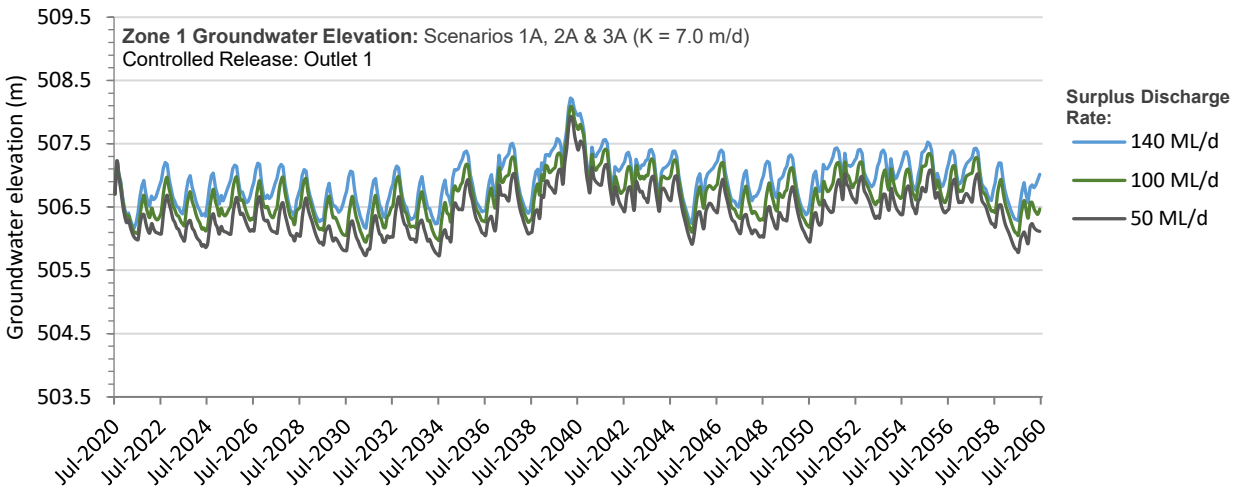
Water balance scenarios – Groundwater system (K = 7.0 m/d)

D.1 Simulated groundwater elevation: Scenarios 1A, 2A, 3A

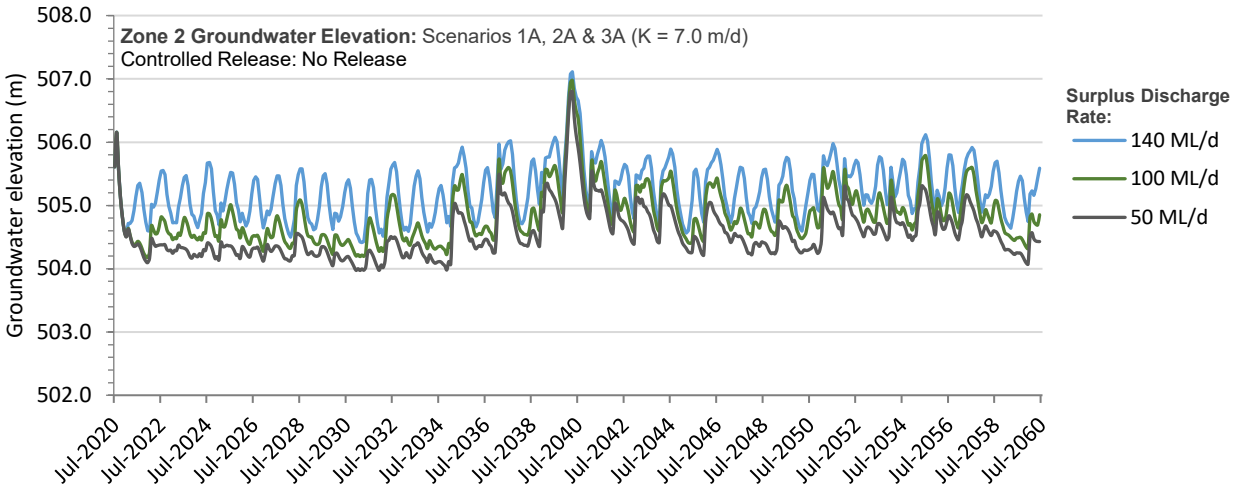
D.1.1 Predicted groundwater elevation (Zone 1)

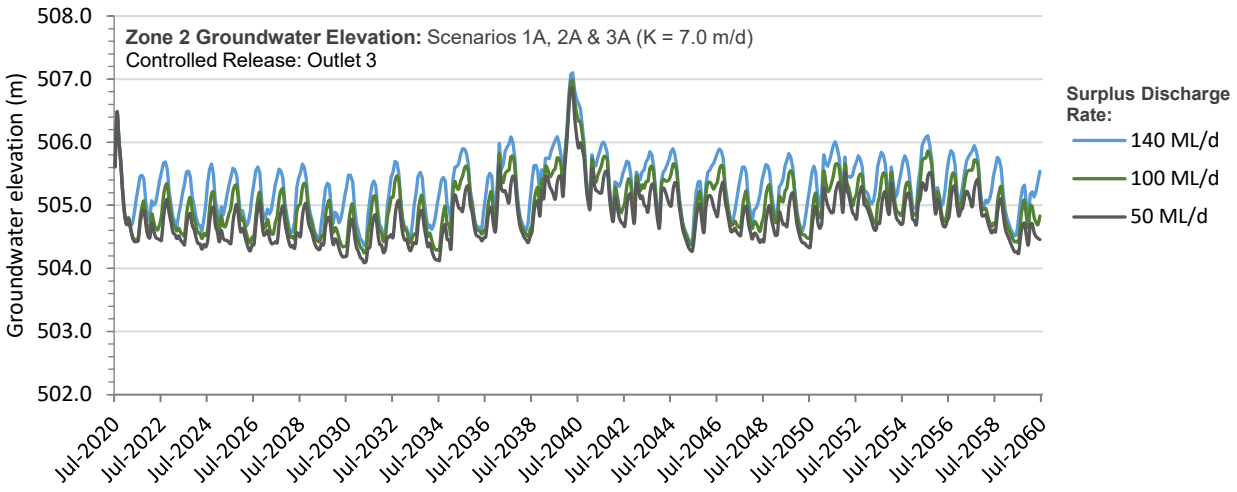


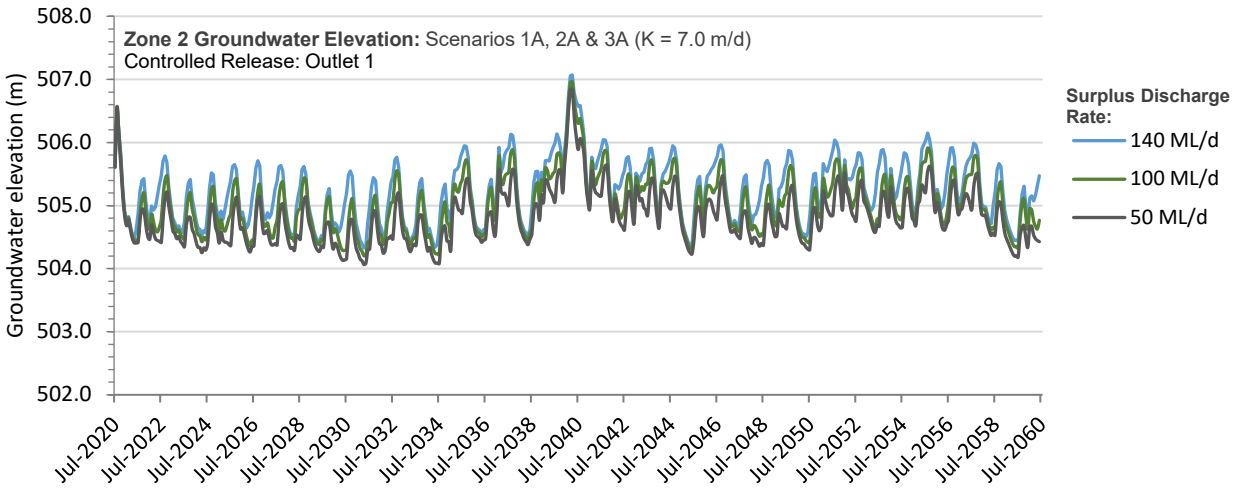




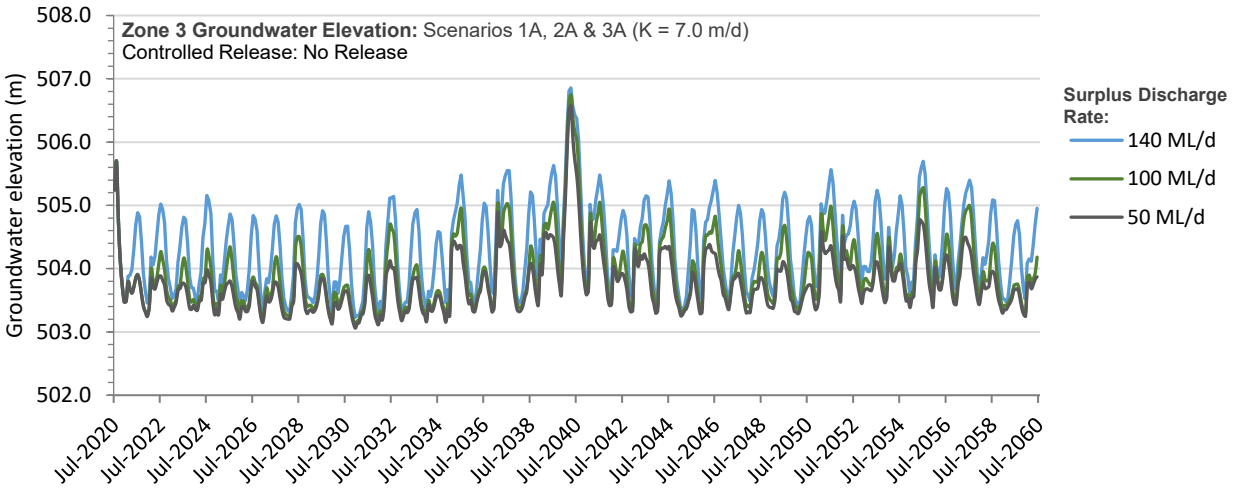
D.1.2 Predicted groundwater elevation (Zone 2)

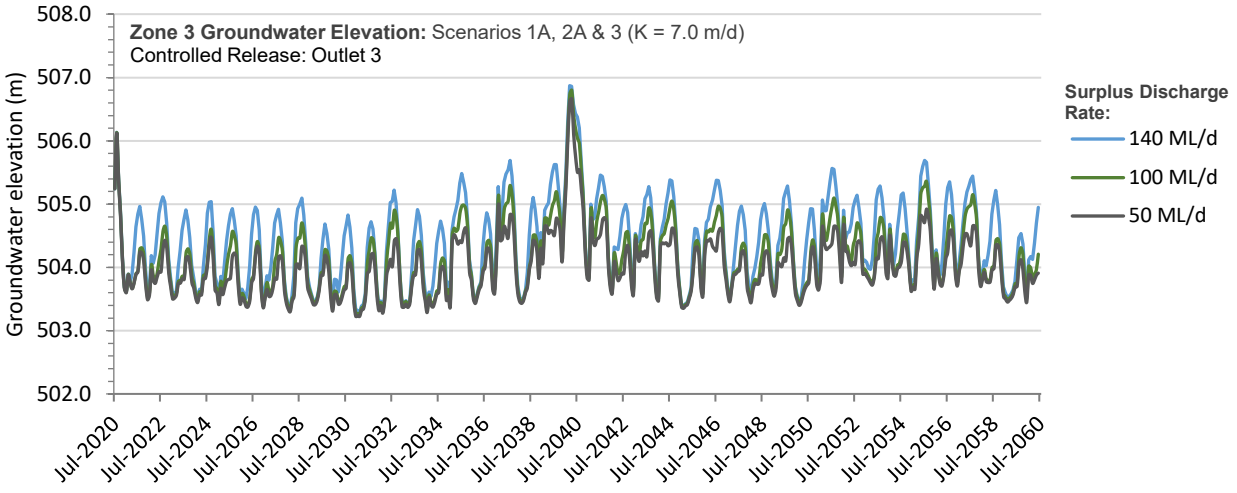


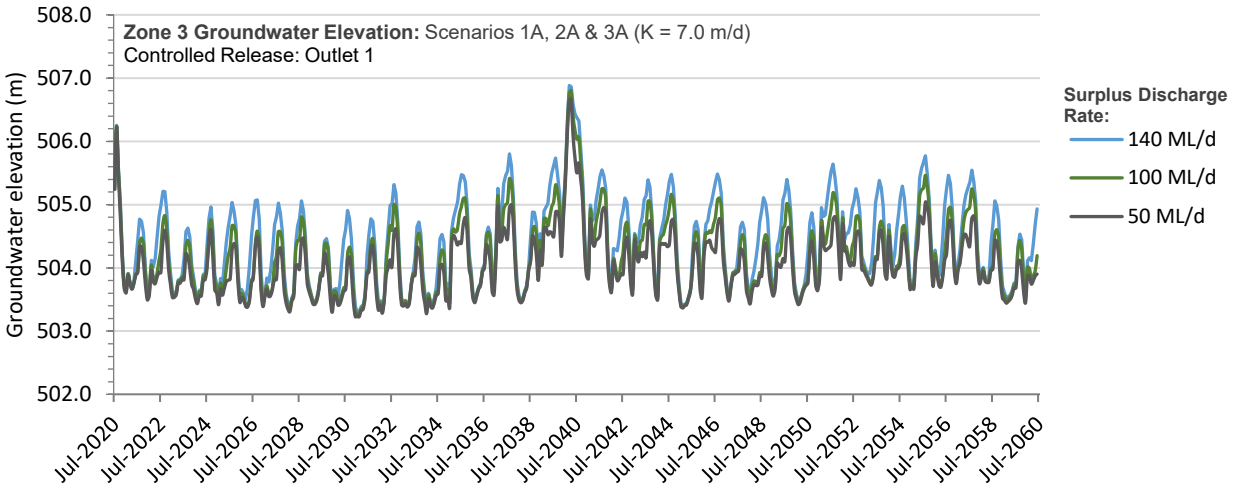




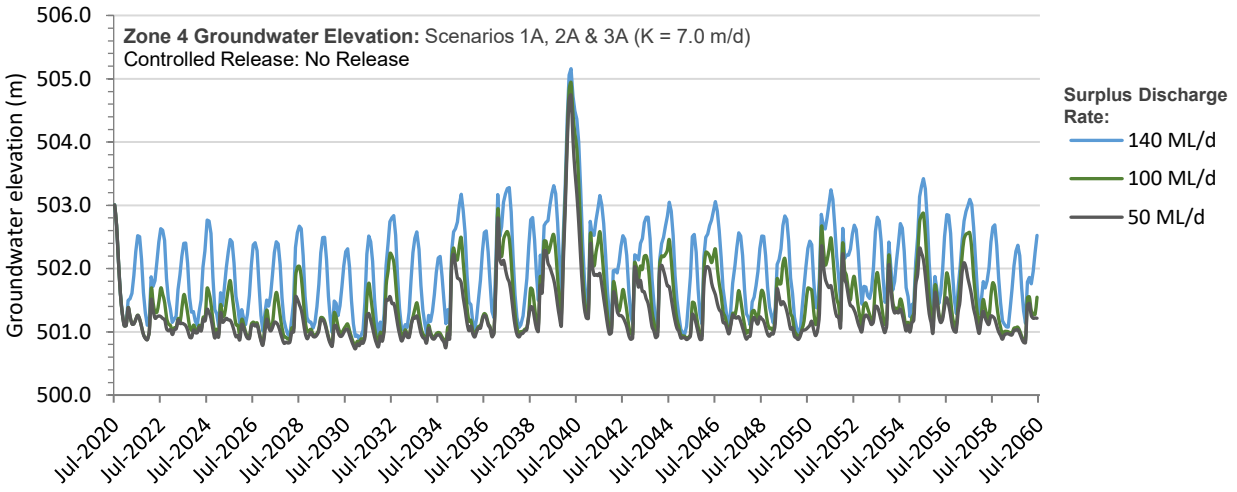
D.1.3 Predicted groundwater elevation (Zone 3)

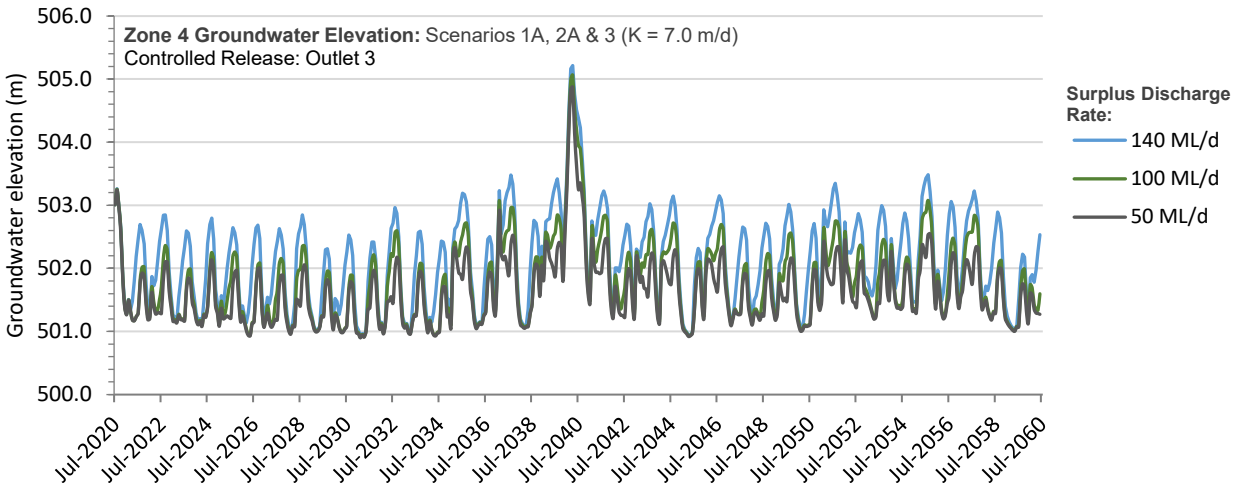


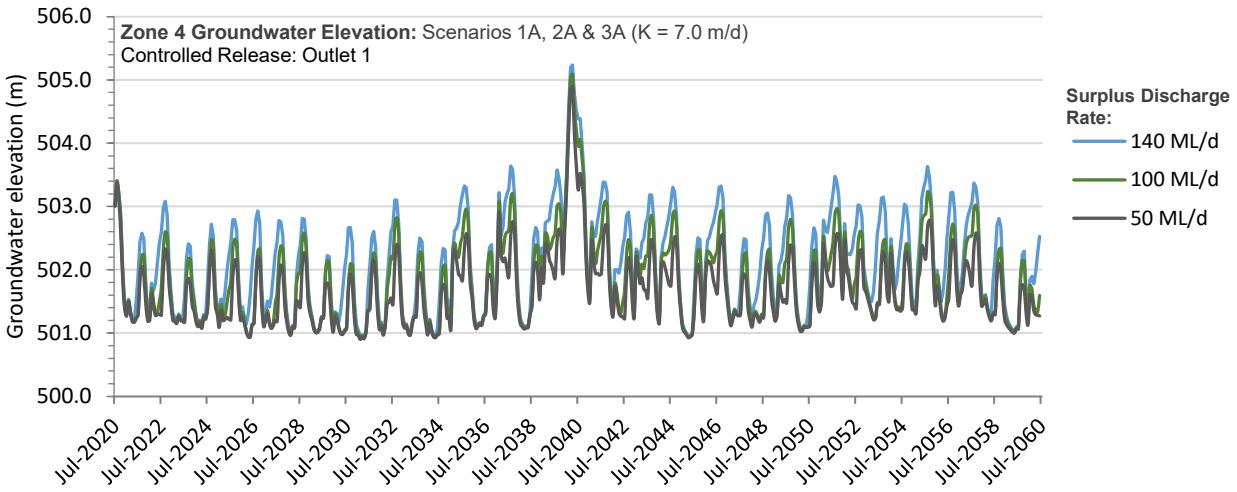




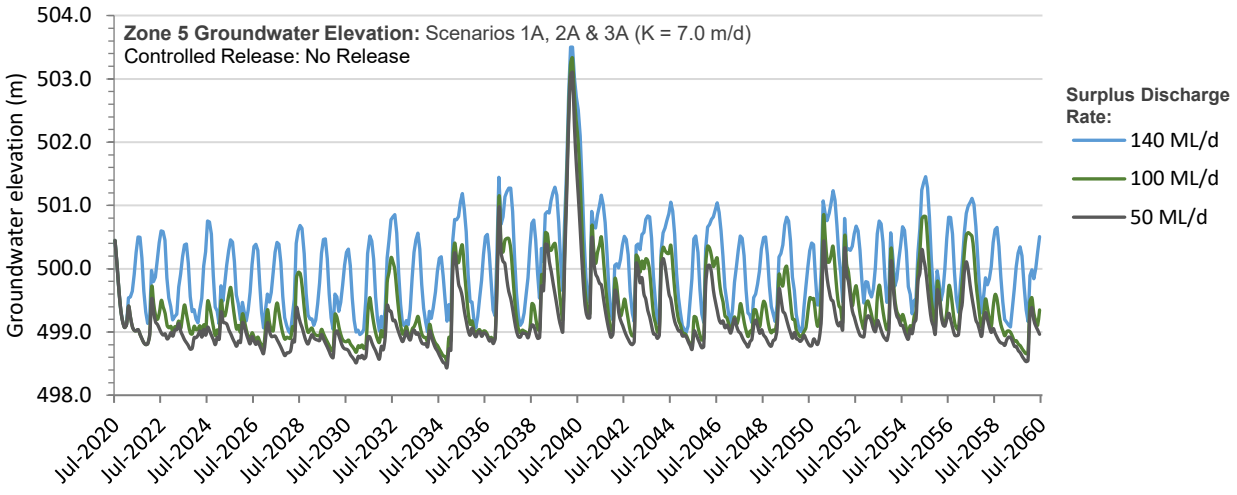
D.1.4 Predicted groundwater elevation (Zone 4)

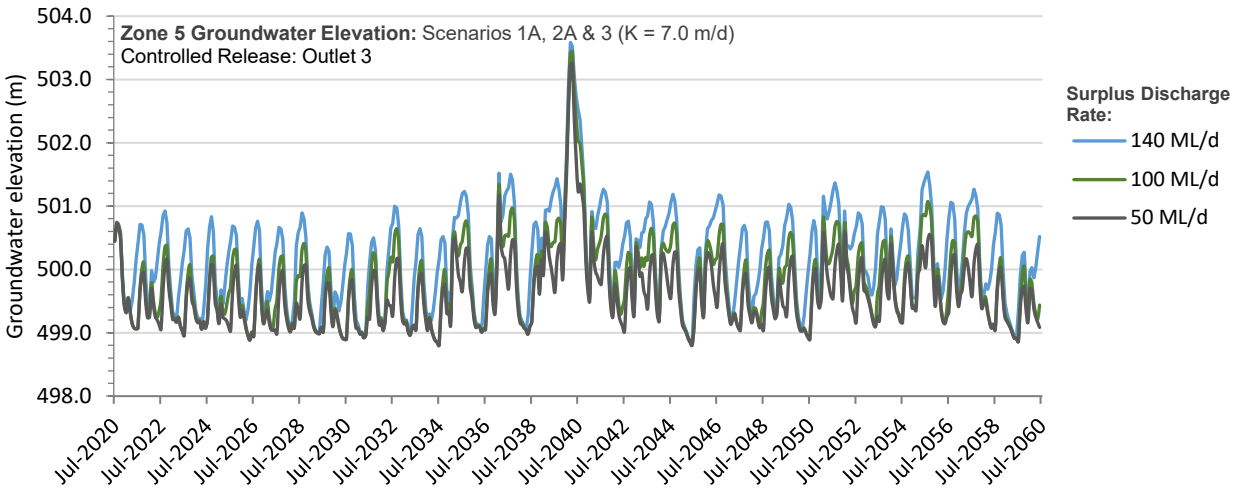


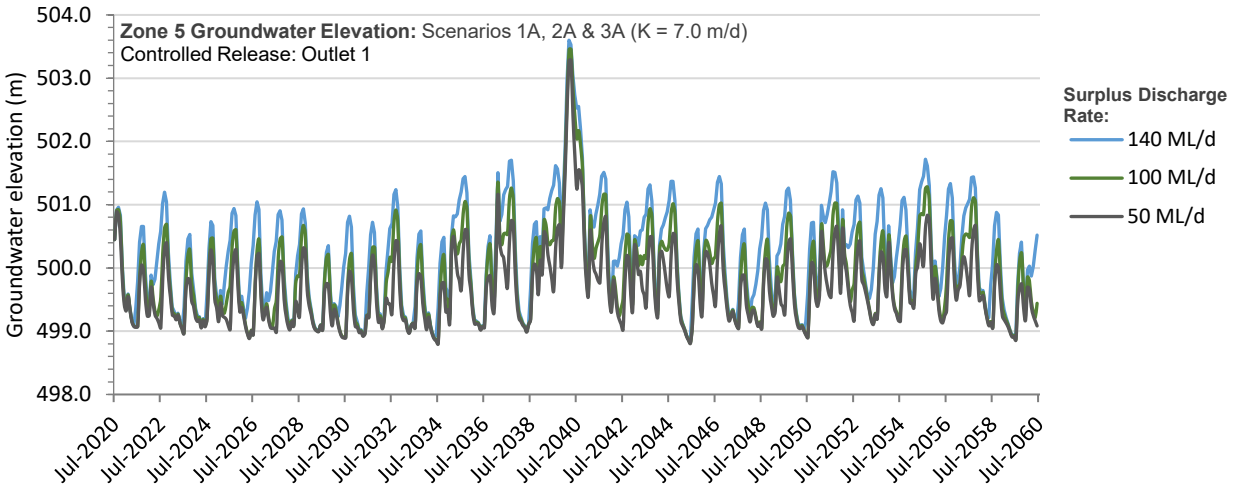




D.1.5 Predicted groundwater elevation (Zone 5)

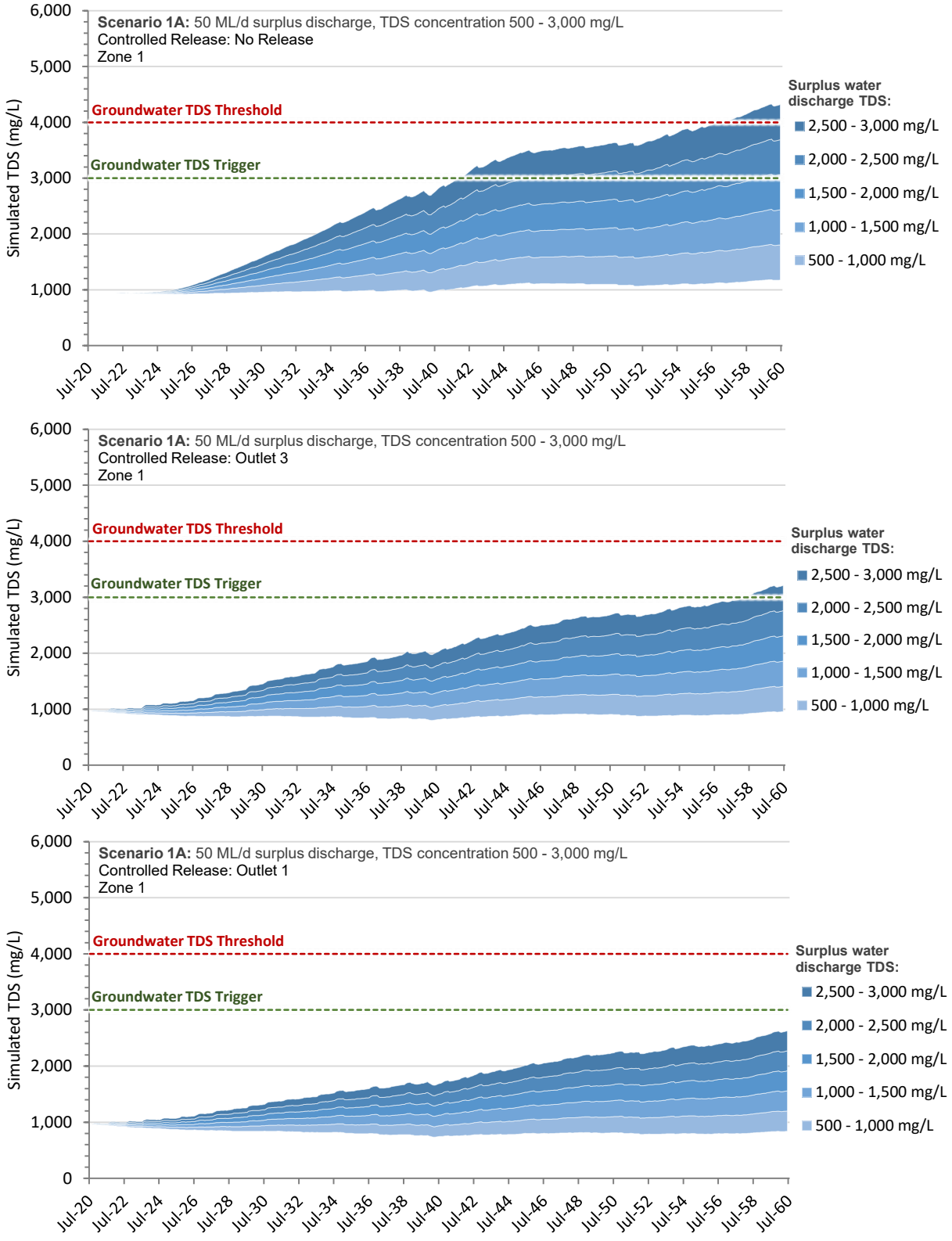




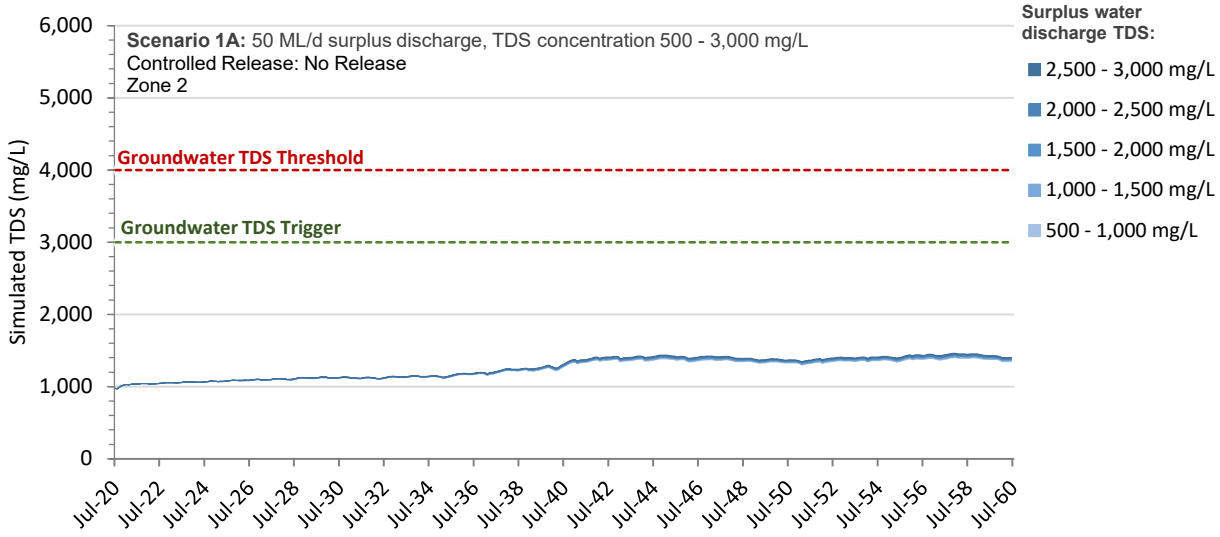


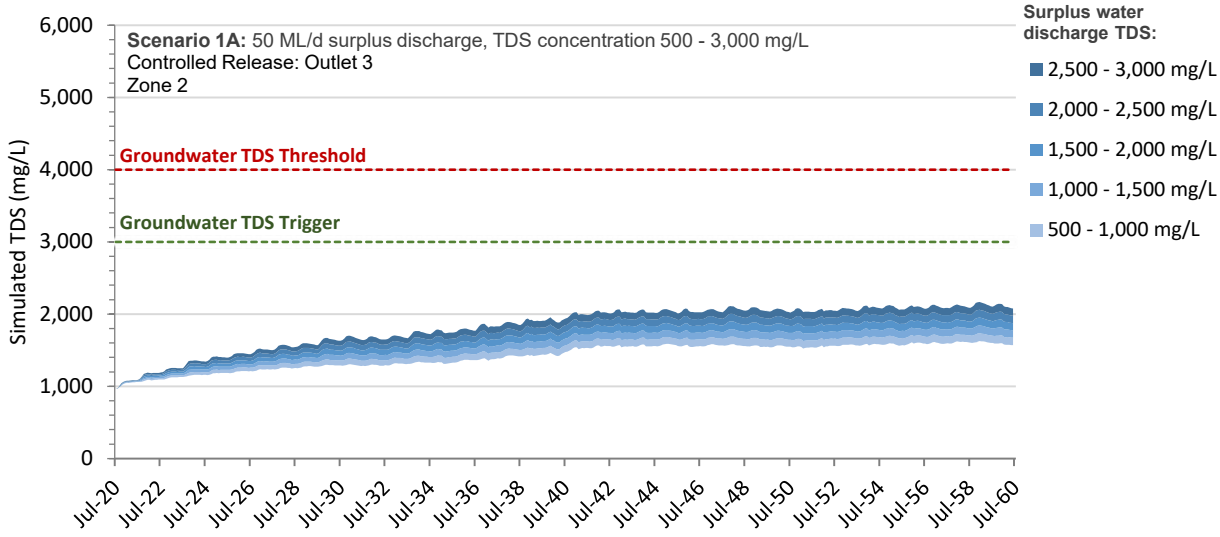
D.2 Groundwater TDS predictions: Scenario 1A: Surplus discharge 50 ML/d

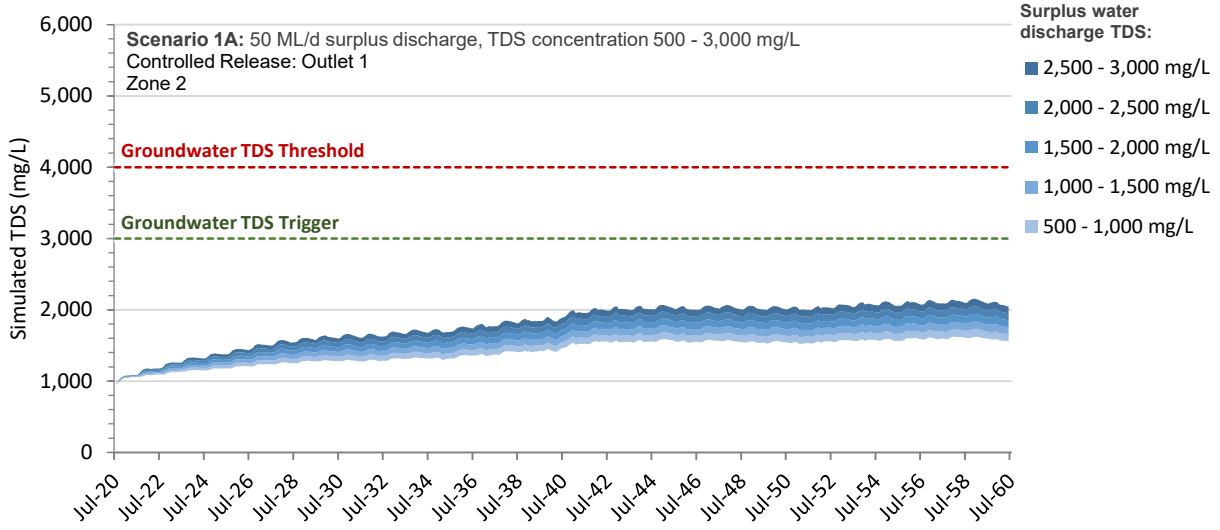
D.2.1 Predicted groundwater TDS (Zone 1)



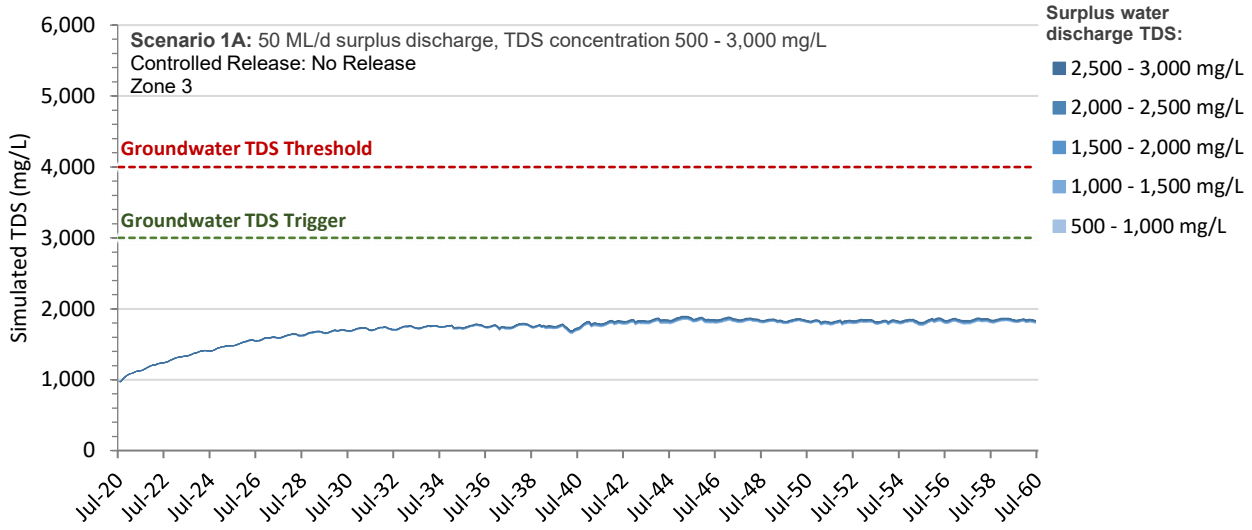
D.2.2 Predicted groundwater TDS (Zone 2)

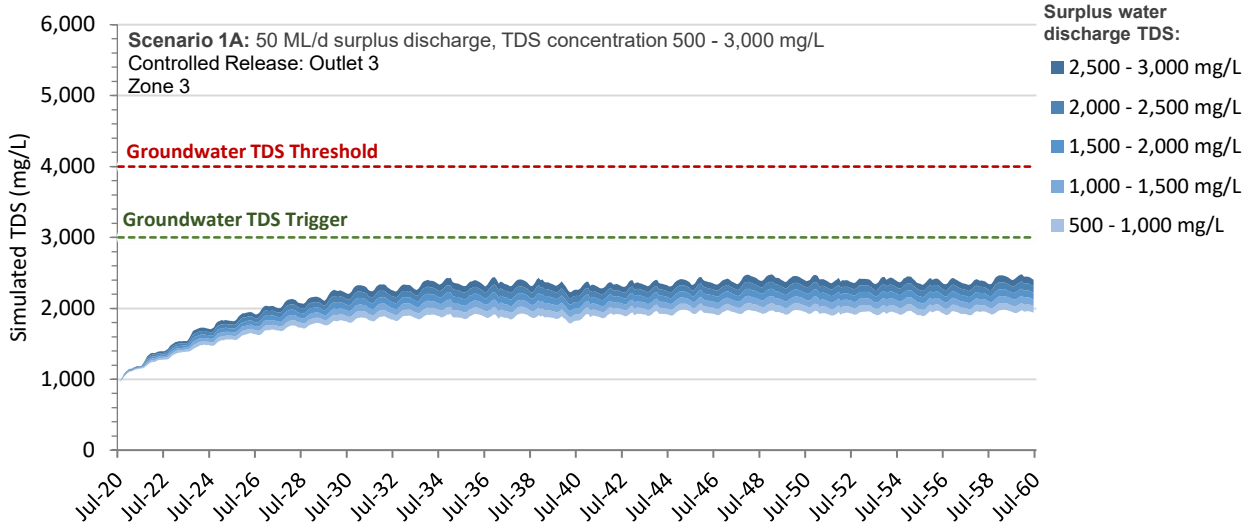


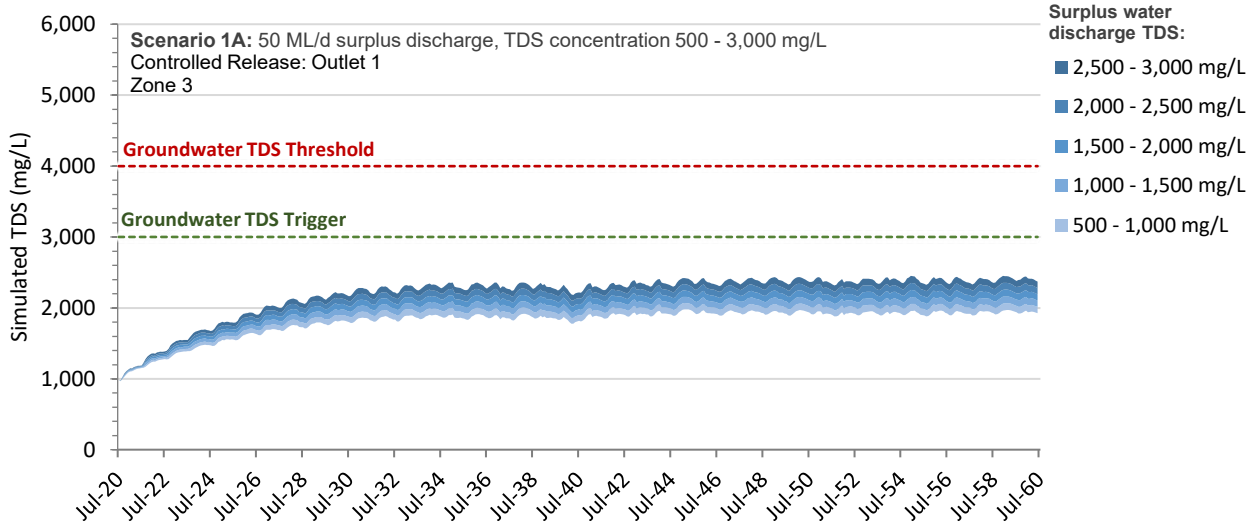




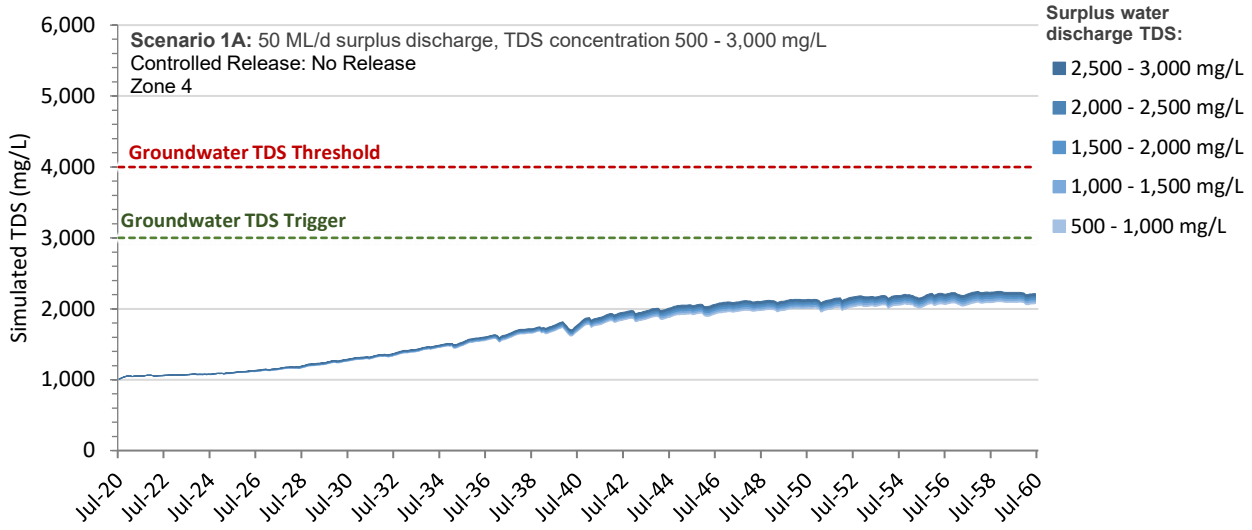
D.2.3 Predicted groundwater TDS (Zone 3)

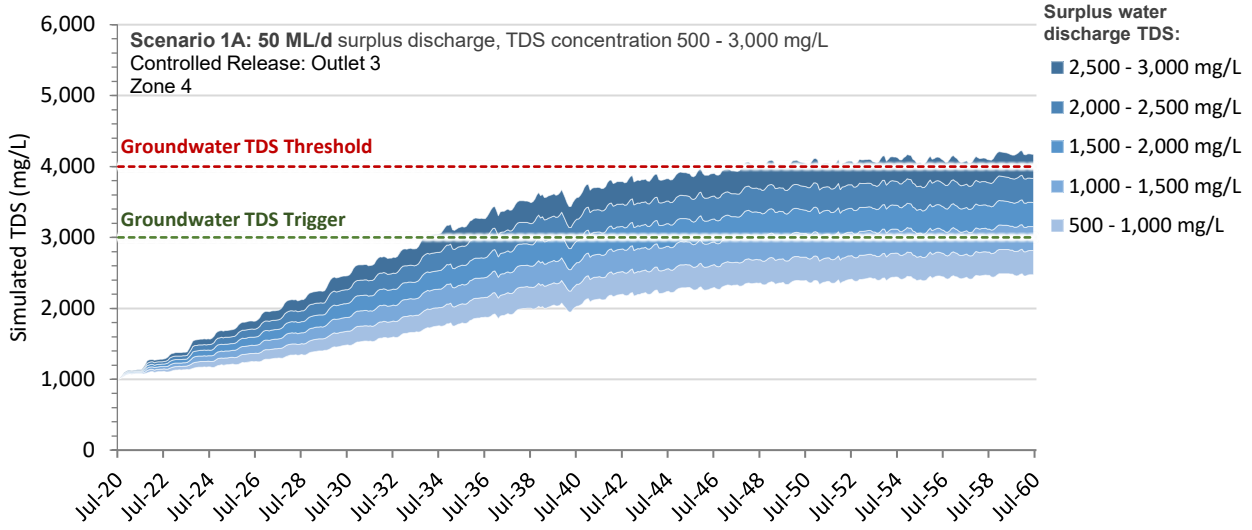


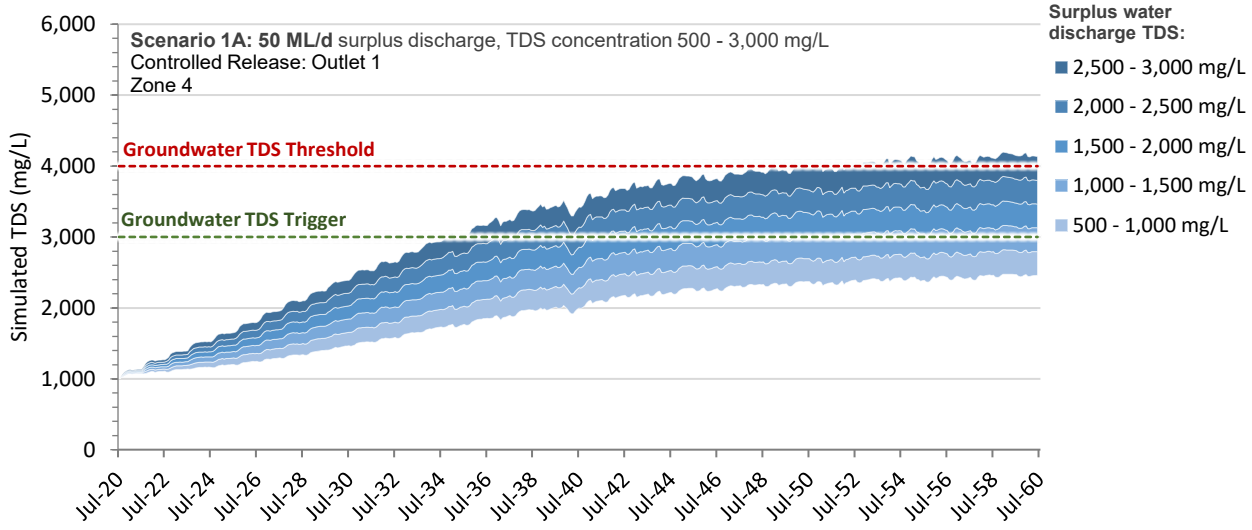




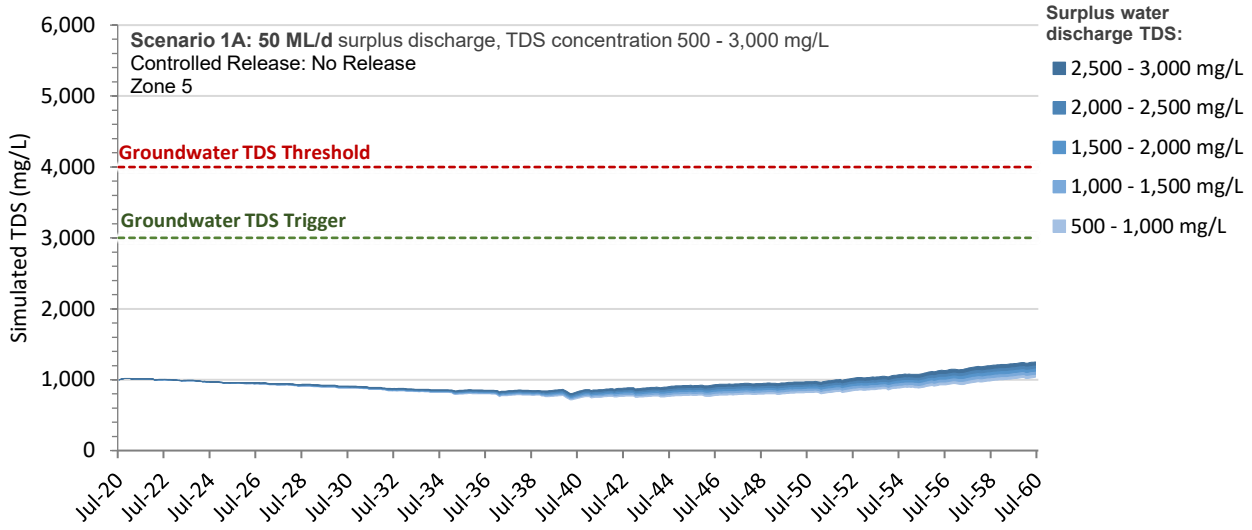
D.2.4 Predicted groundwater TDS (Zone 4)

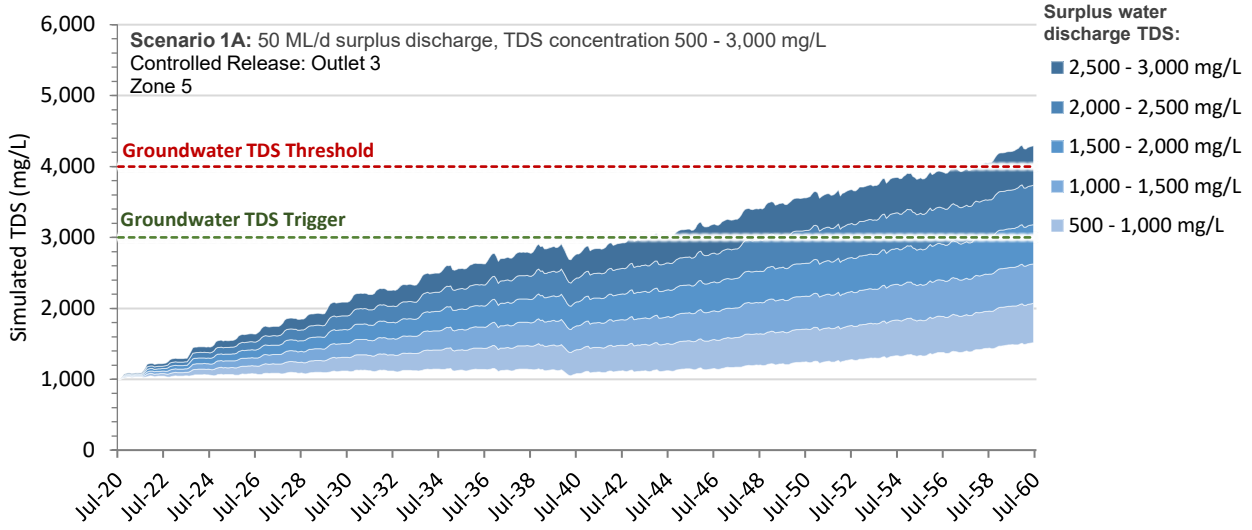


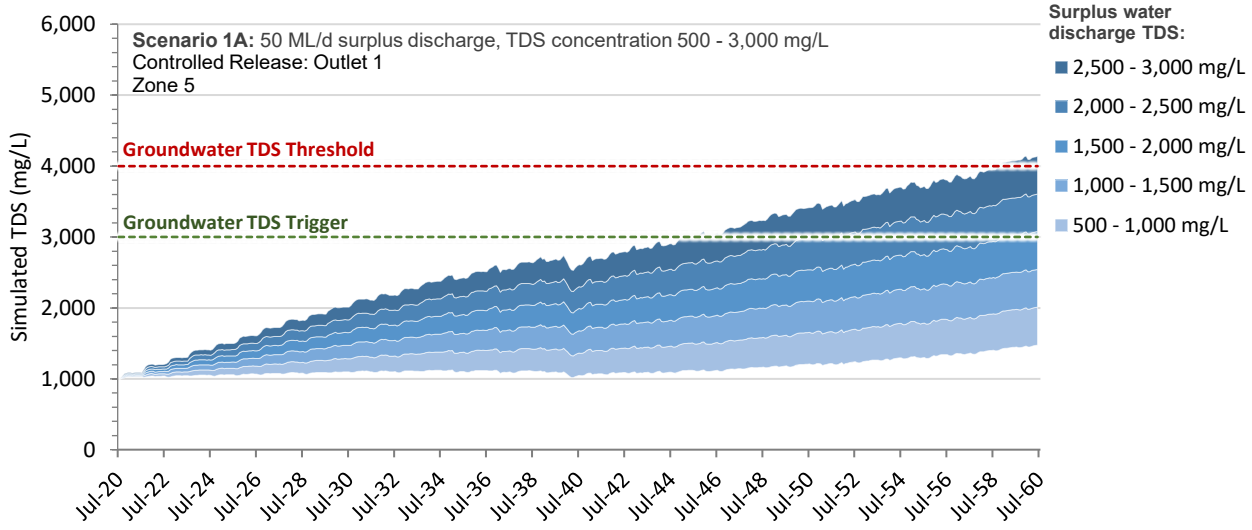




D.2.5 Predicted groundwater TDS (Zone 5)

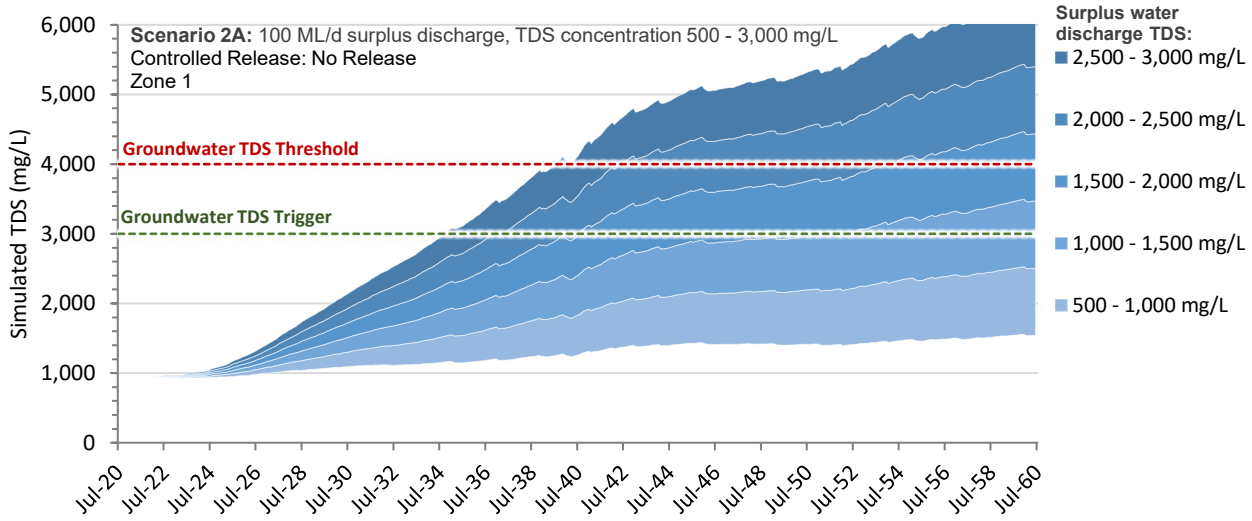


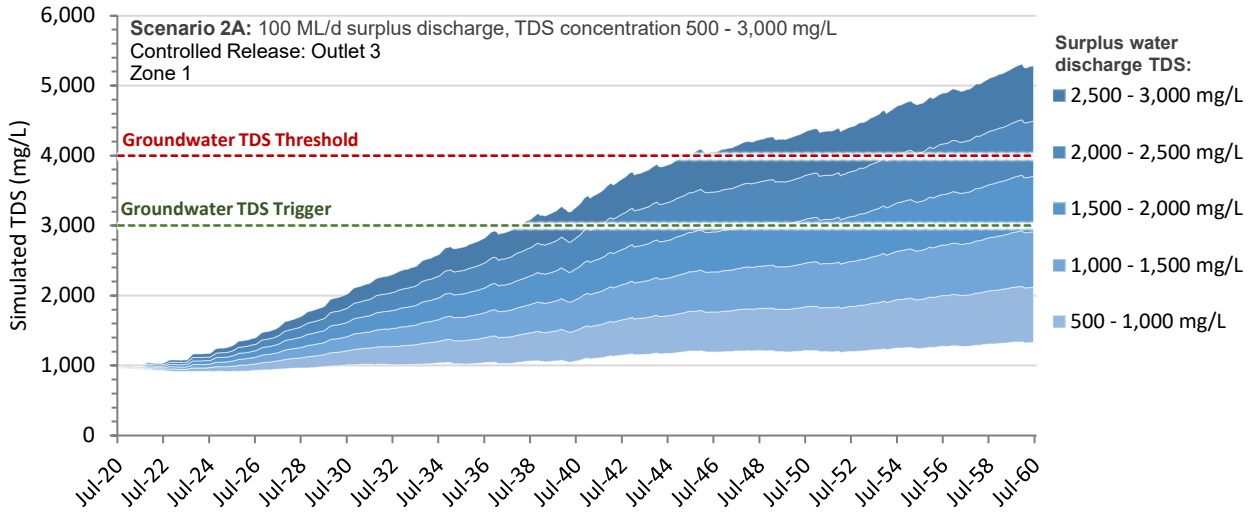


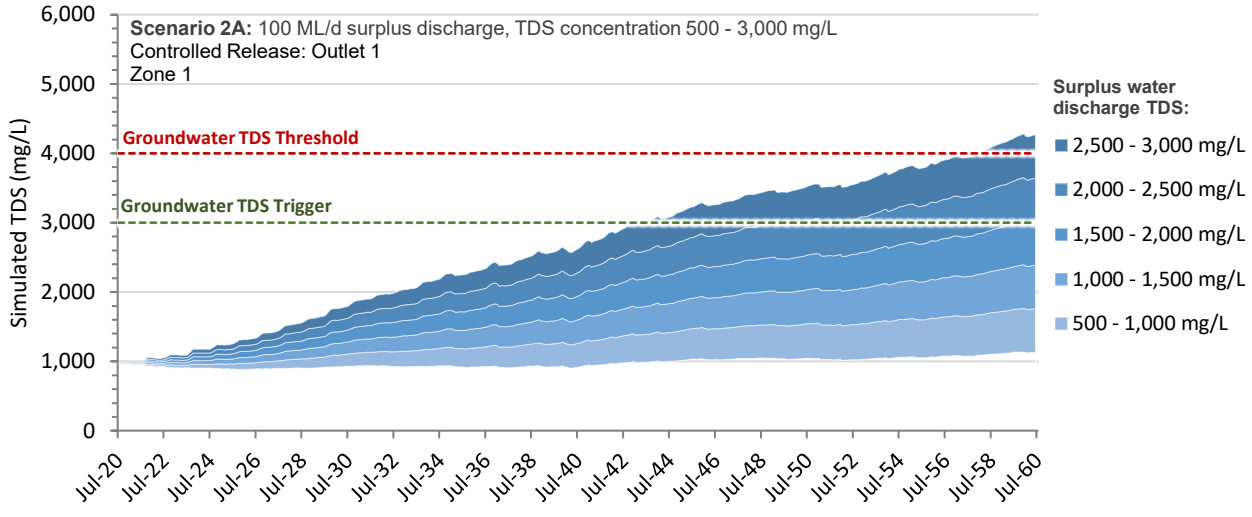


D.3 Groundwater TDS predictions: Scenario 2A: Surplus discharge 100 ML/d

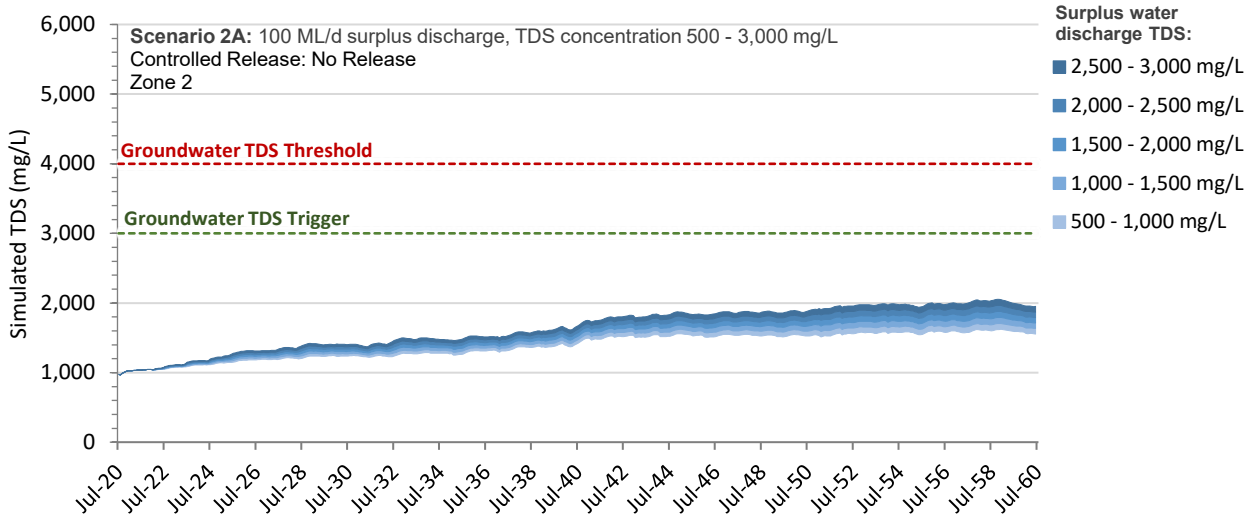
D.3.1 Predicted groundwater TDS (Zone 1)

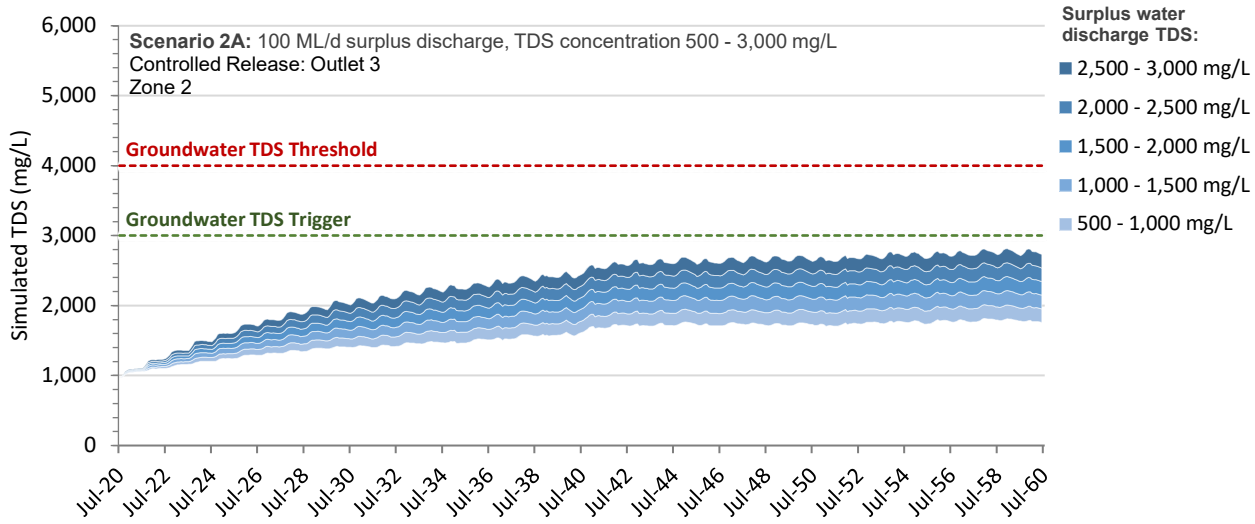


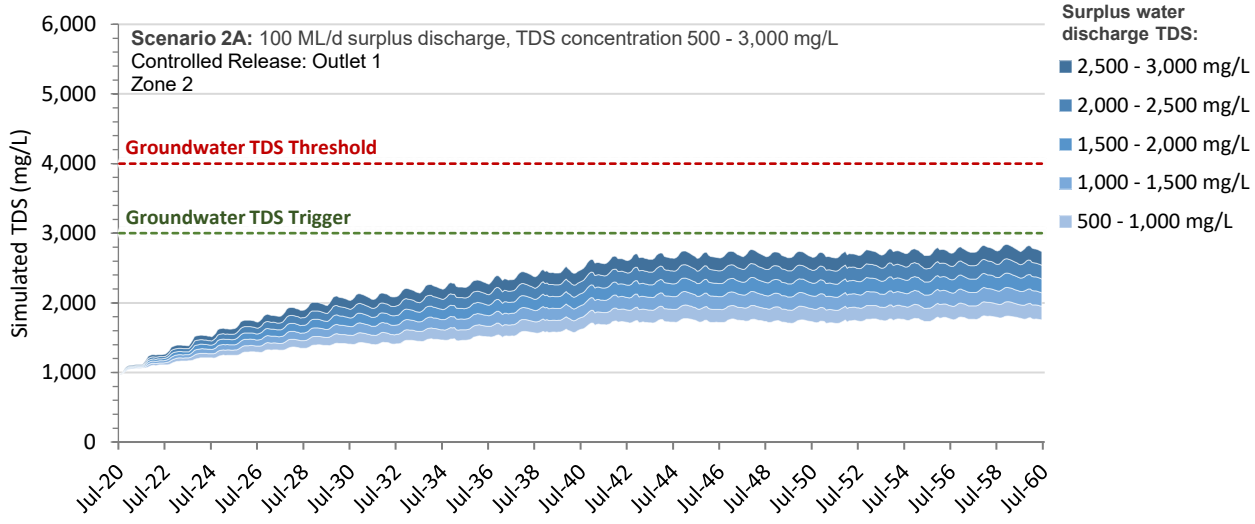




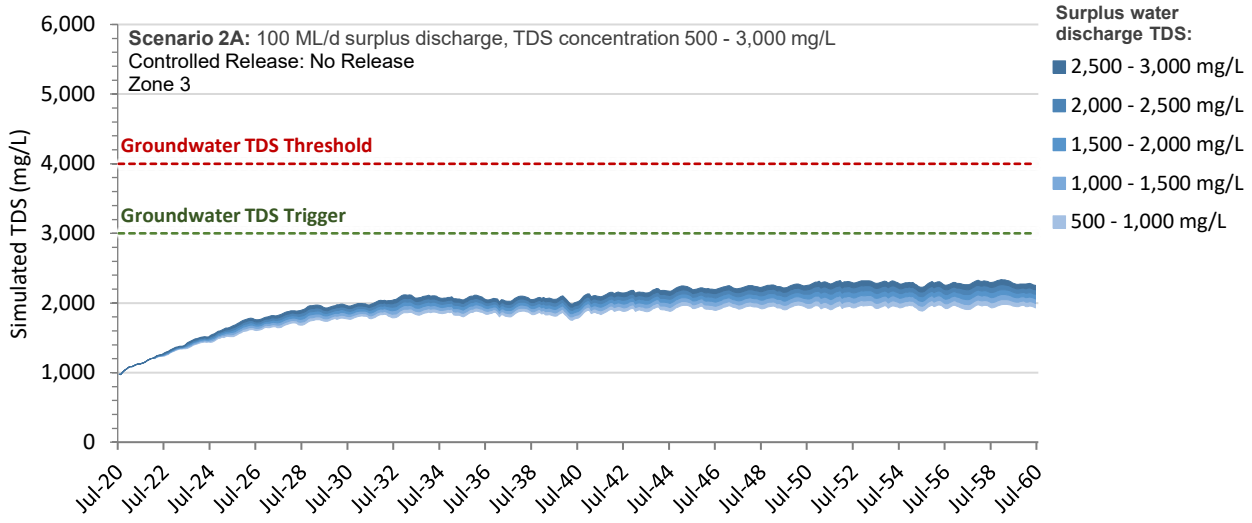
D.3.2 Predicted groundwater TDS (Zone 2)

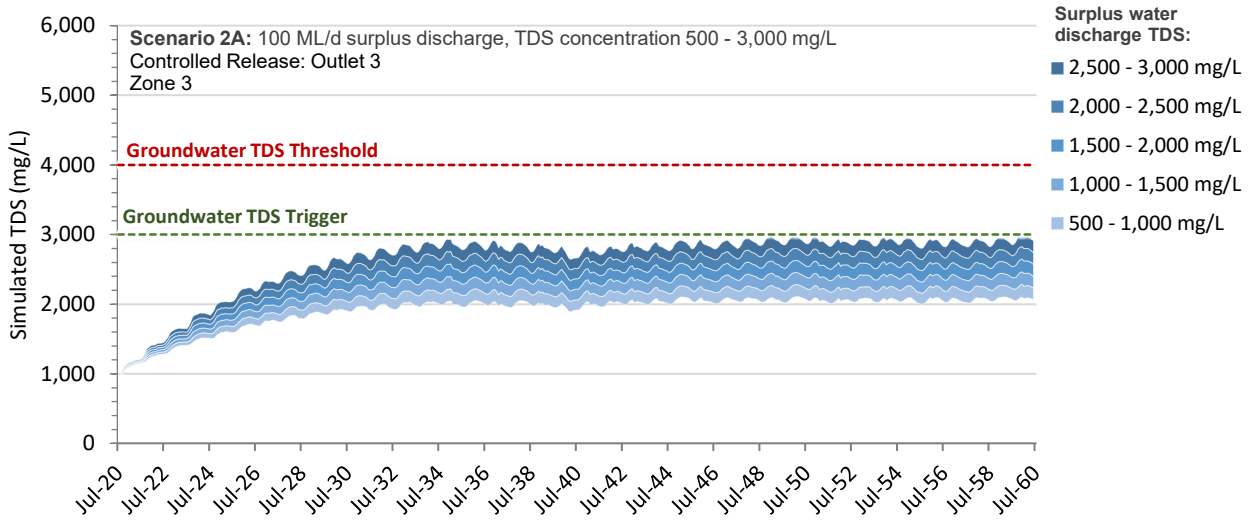


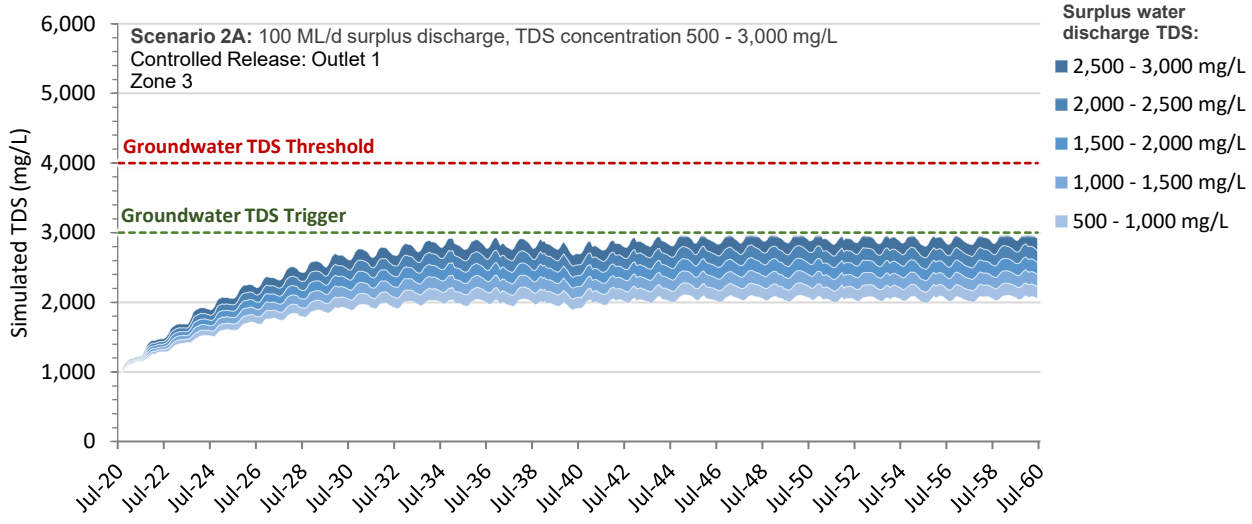




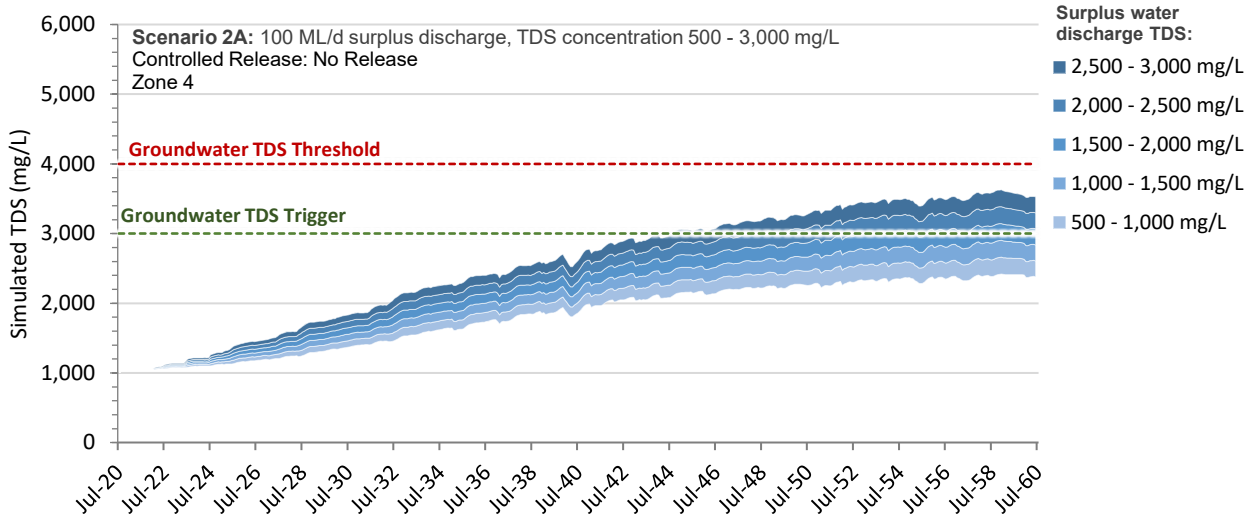
D.3.3 Predicted groundwater TDS (Zone 3)

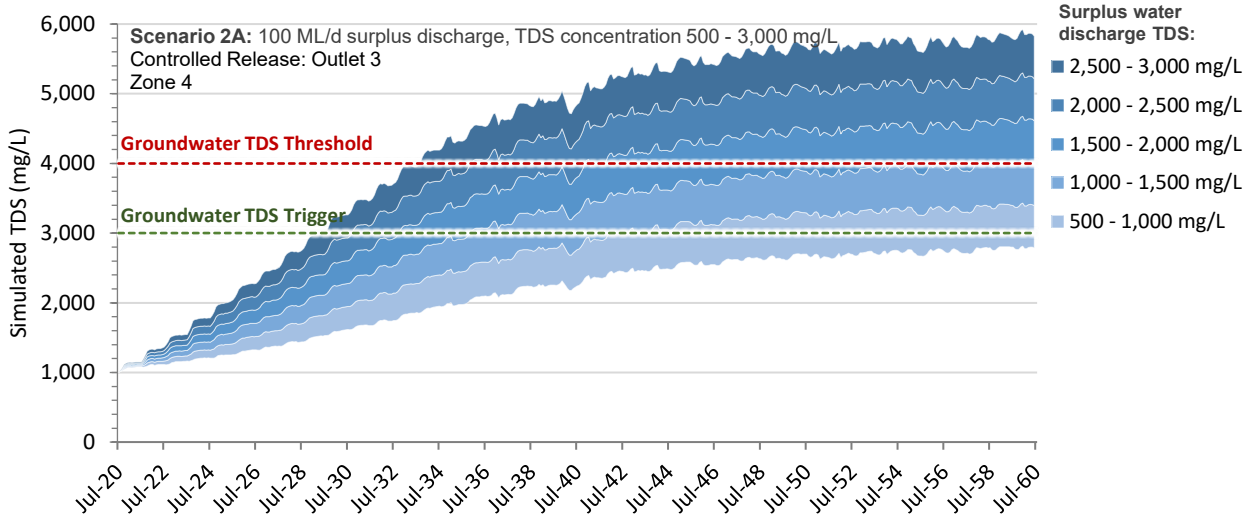


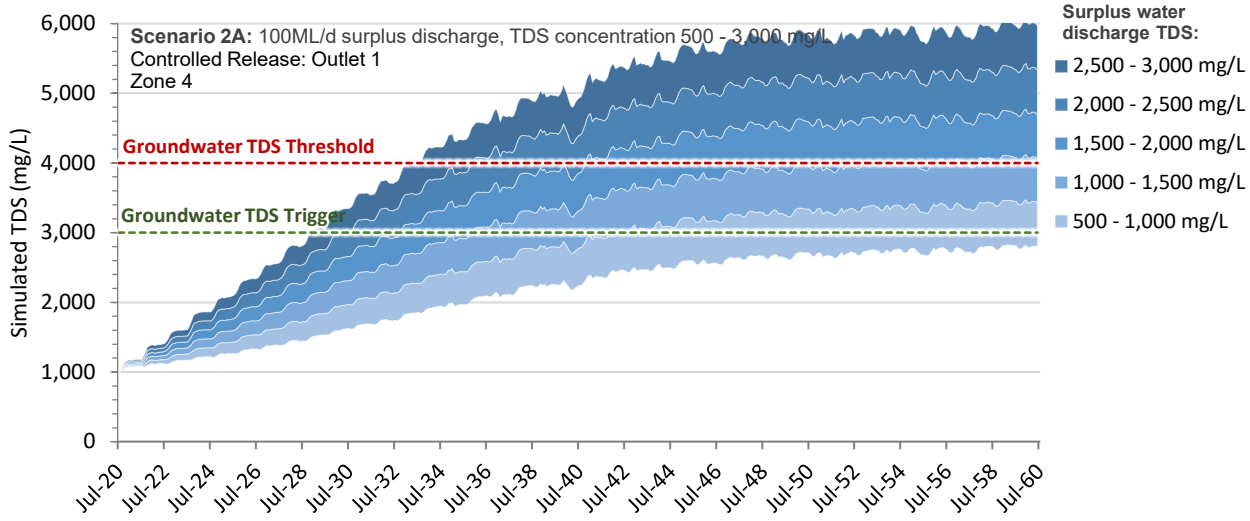




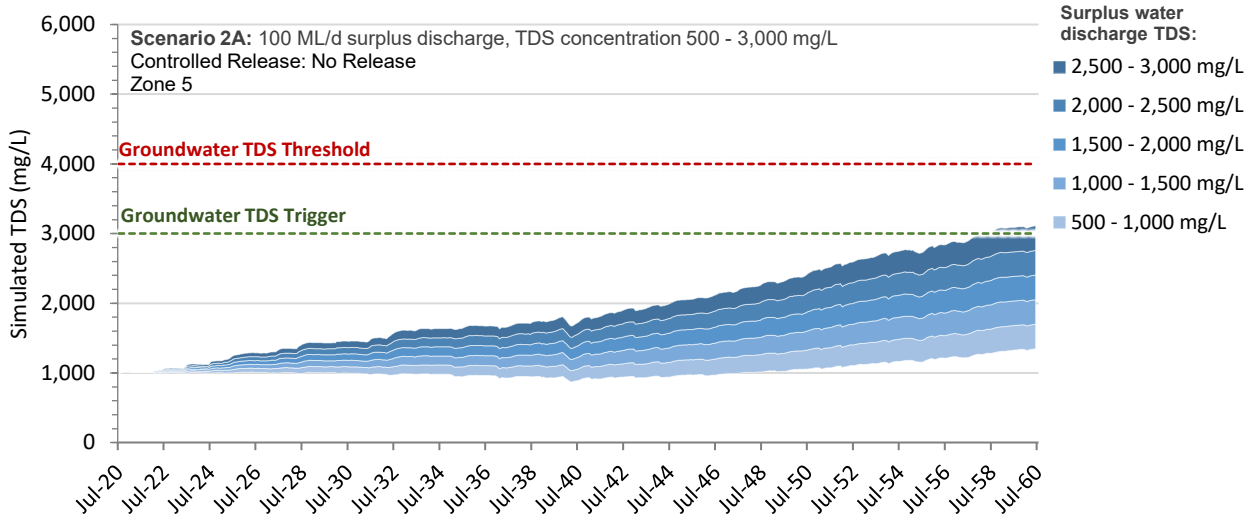
D.3.4 Predicted groundwater TDS (Zone 4)

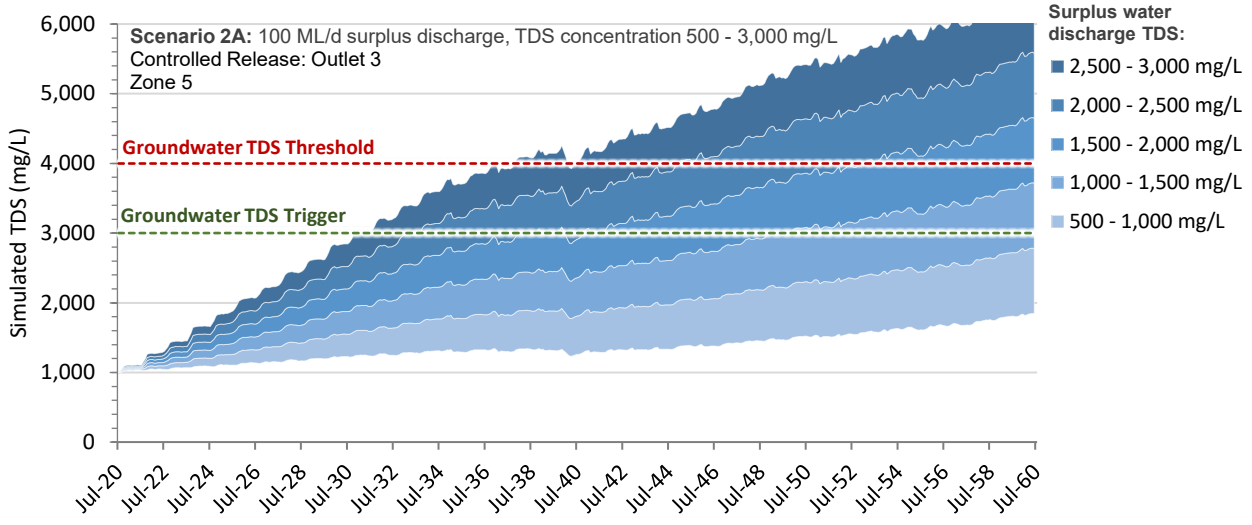


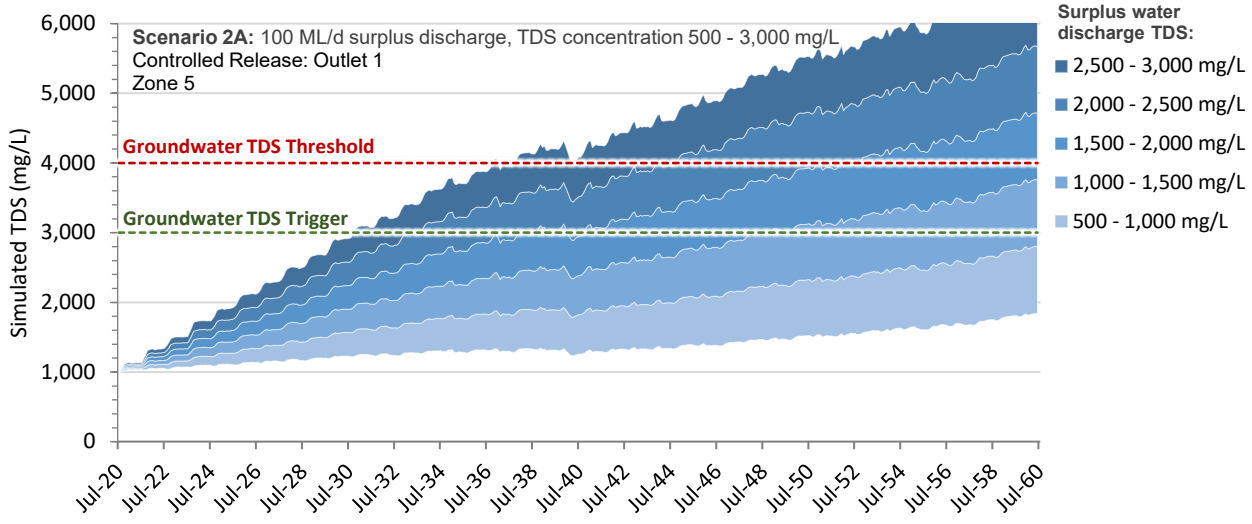




D.3.5 Predicted groundwater TDS (Zone 5)

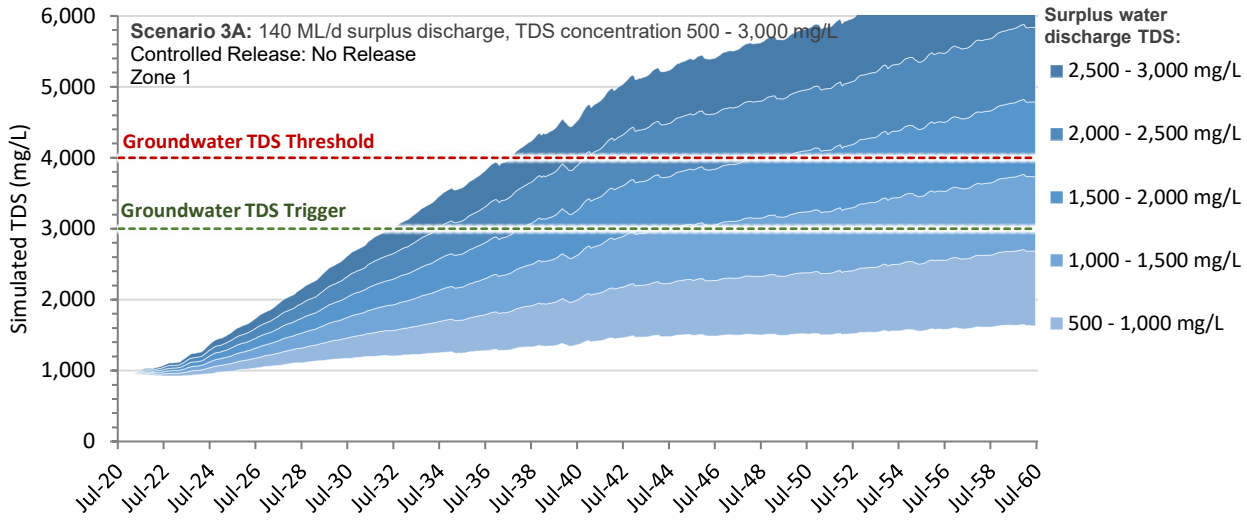


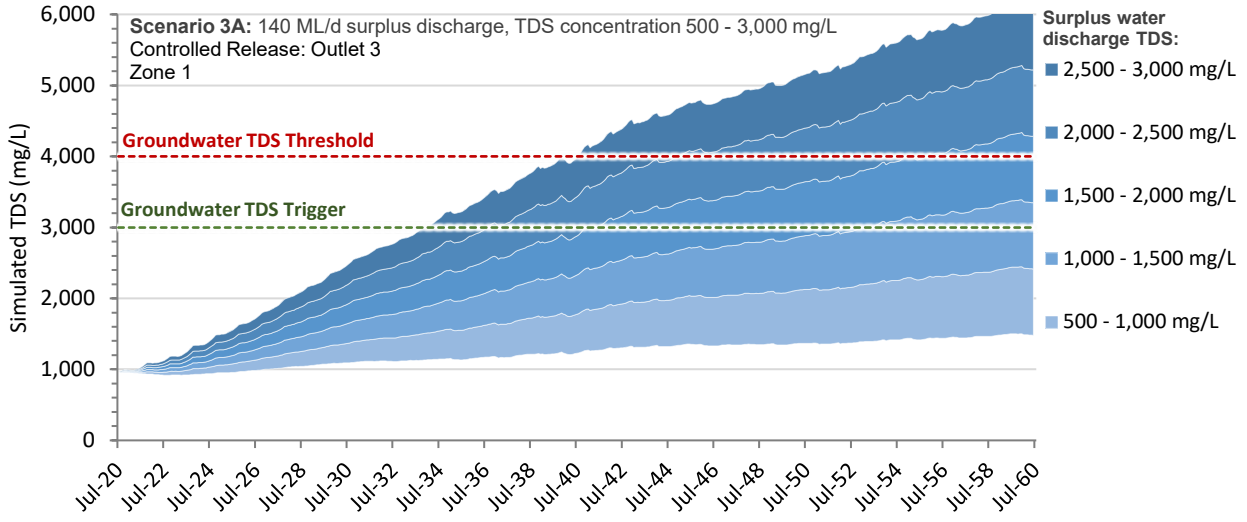


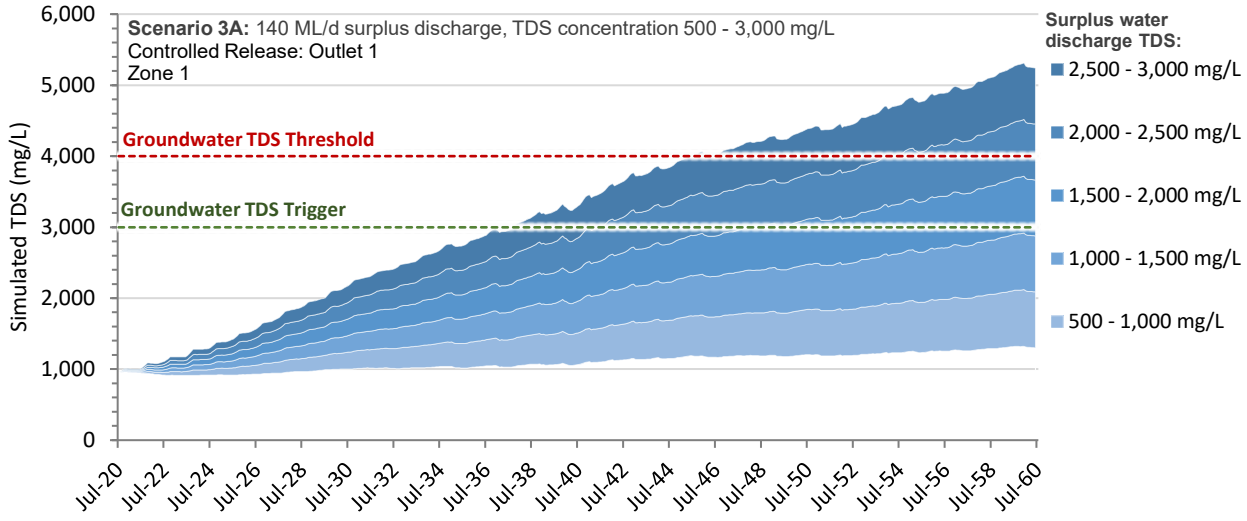


D.4 Groundwater TDS predictions: Scenario 3A: Surplus discharge 140 ML/d

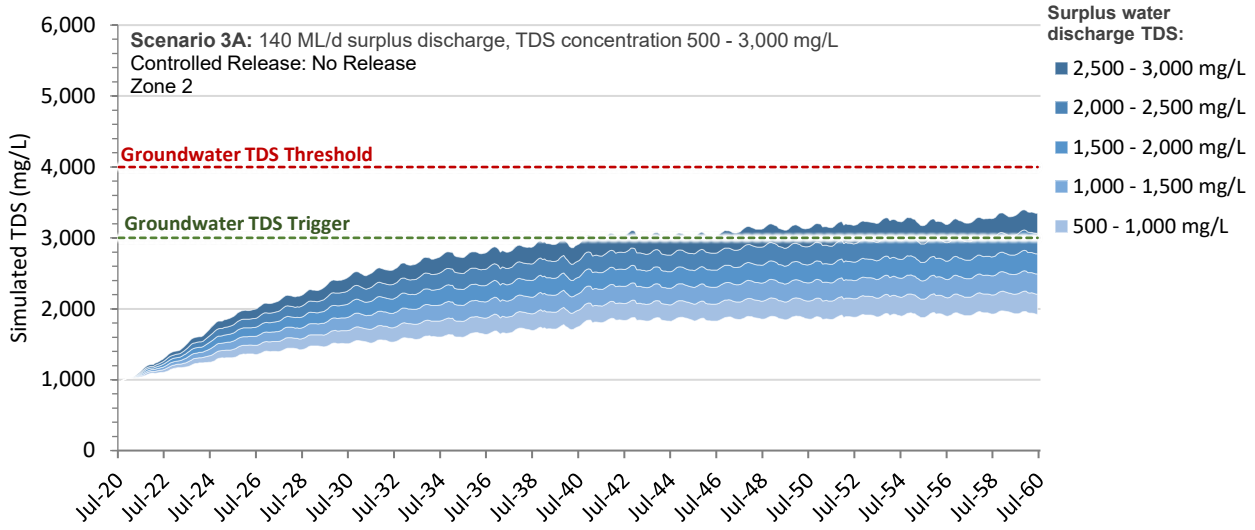
D.4.1 Predicted groundwater TDS (Zone 1)

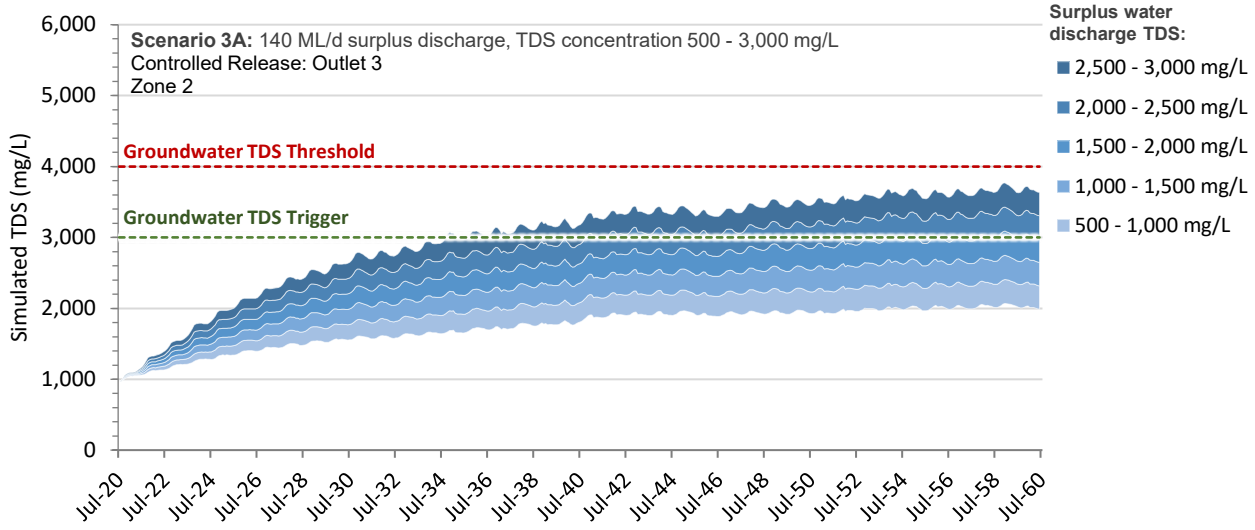


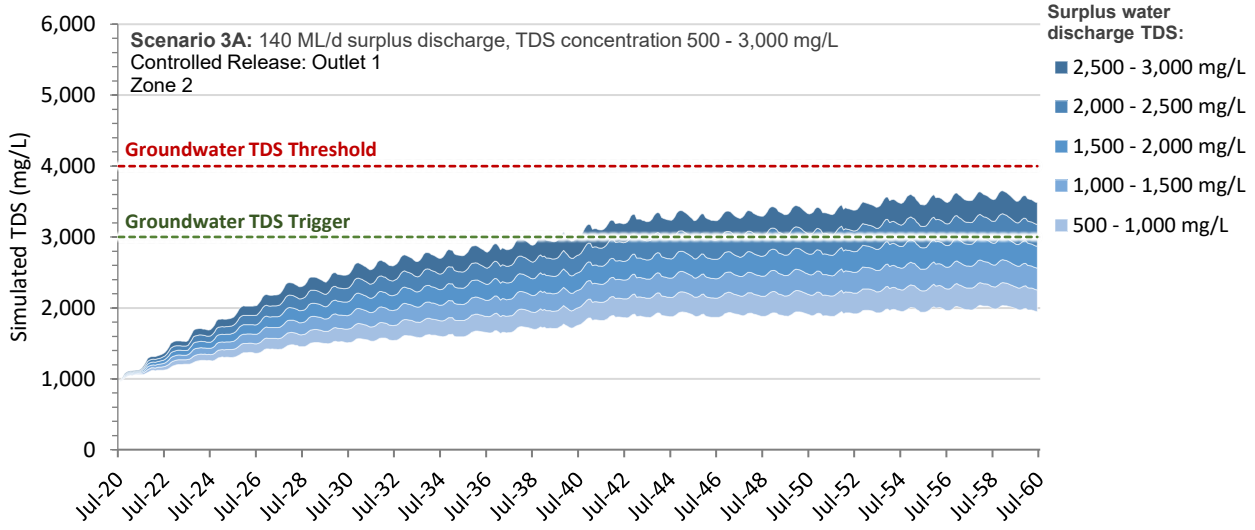




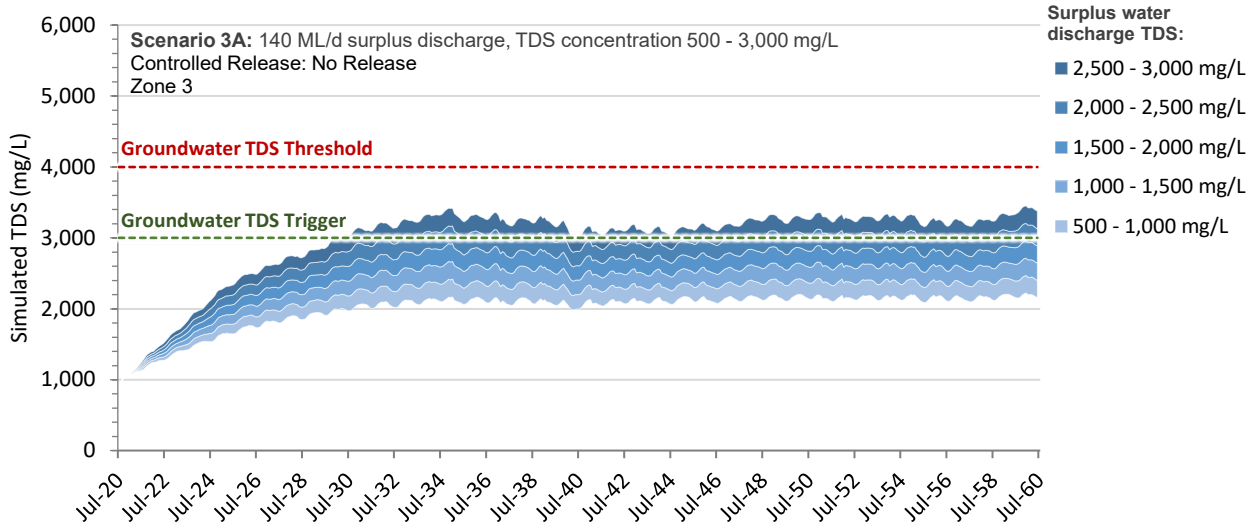
D.4.2 Predicted groundwater TDS (Zone 2)

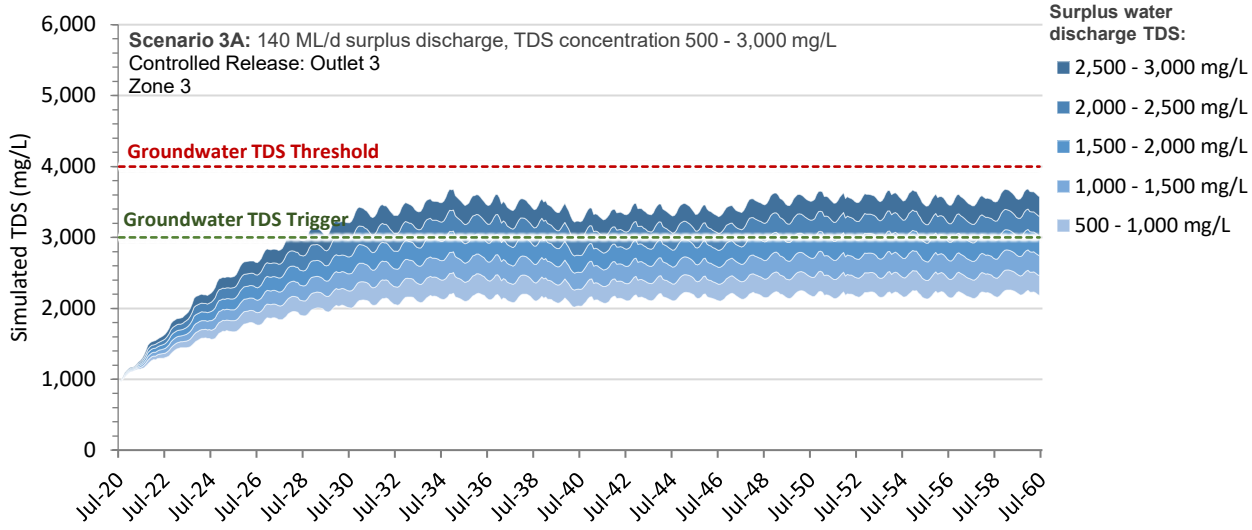


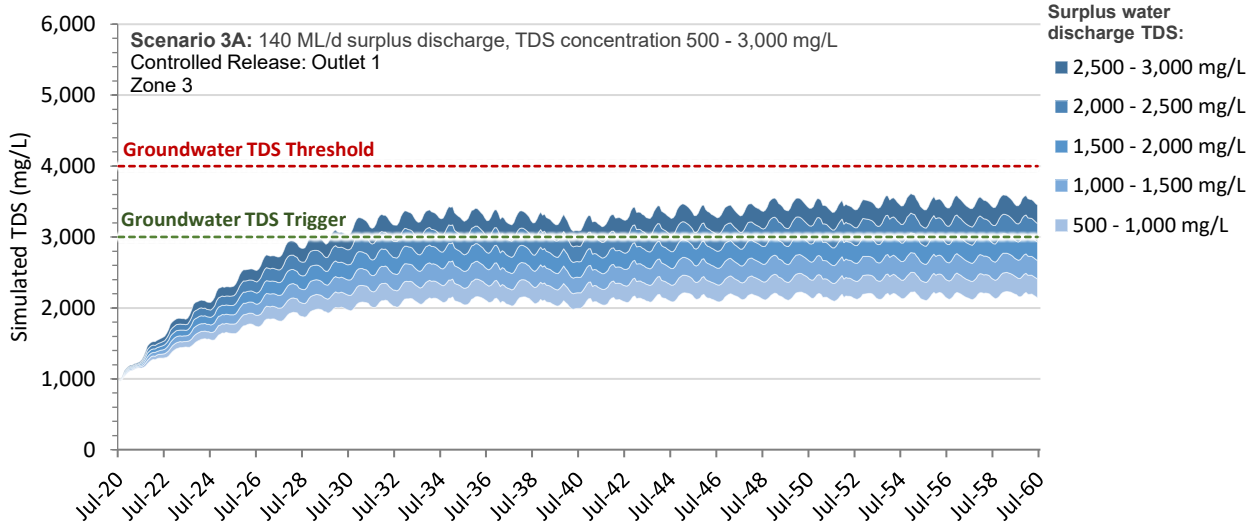




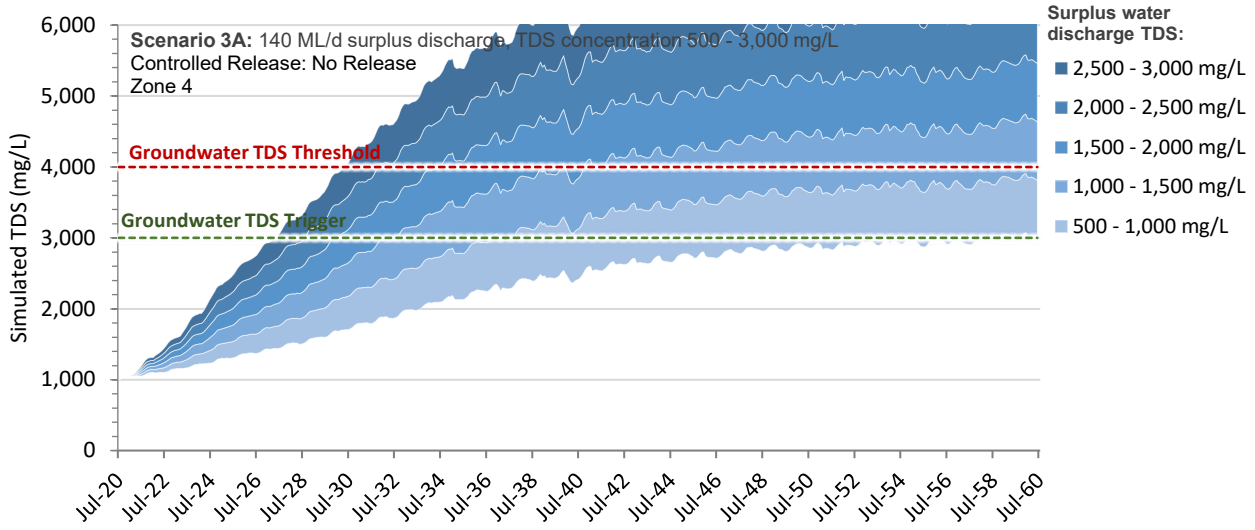
D.4.3 Predicted groundwater TDS (Zone 3)

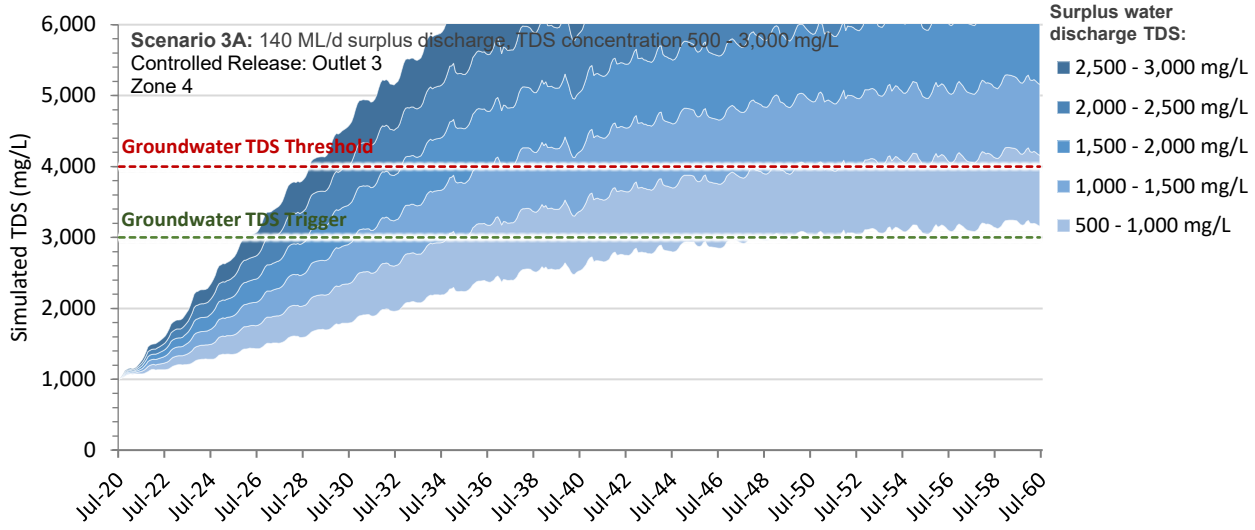


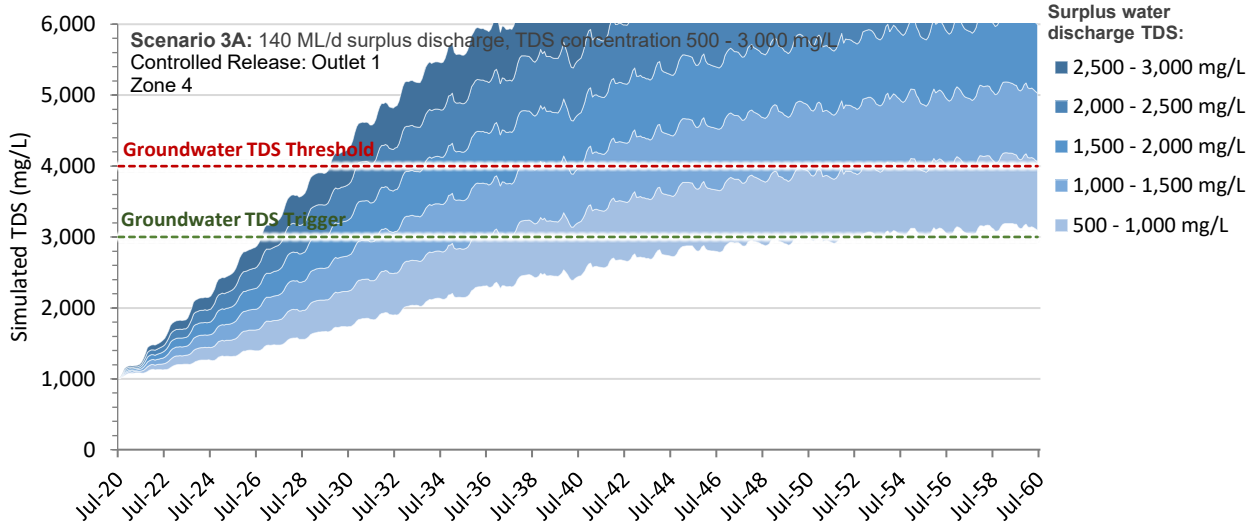




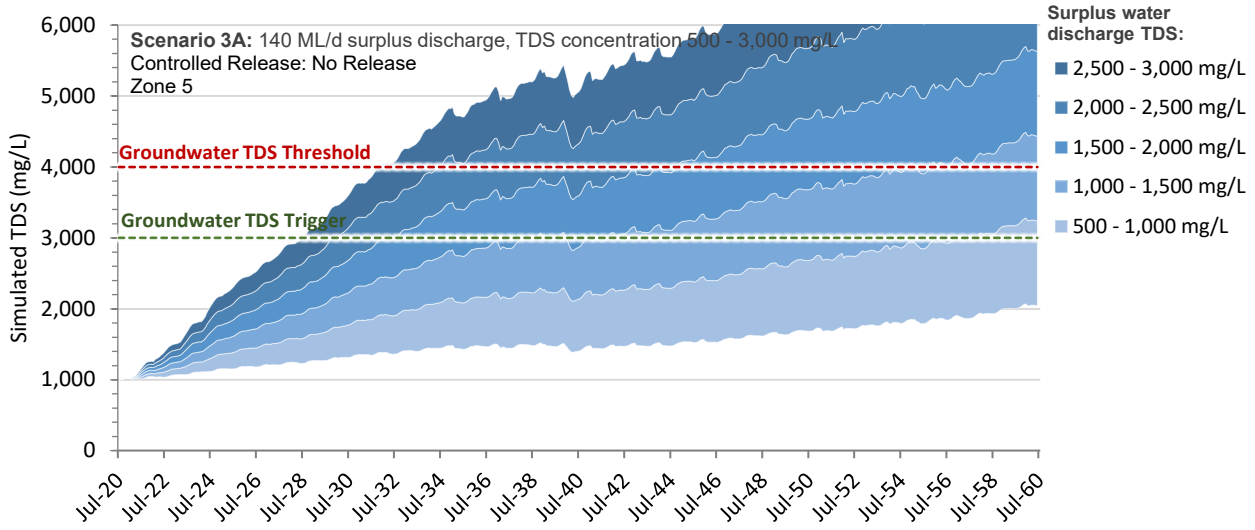
D.4.4 Predicted groundwater TDS (Zone 4)

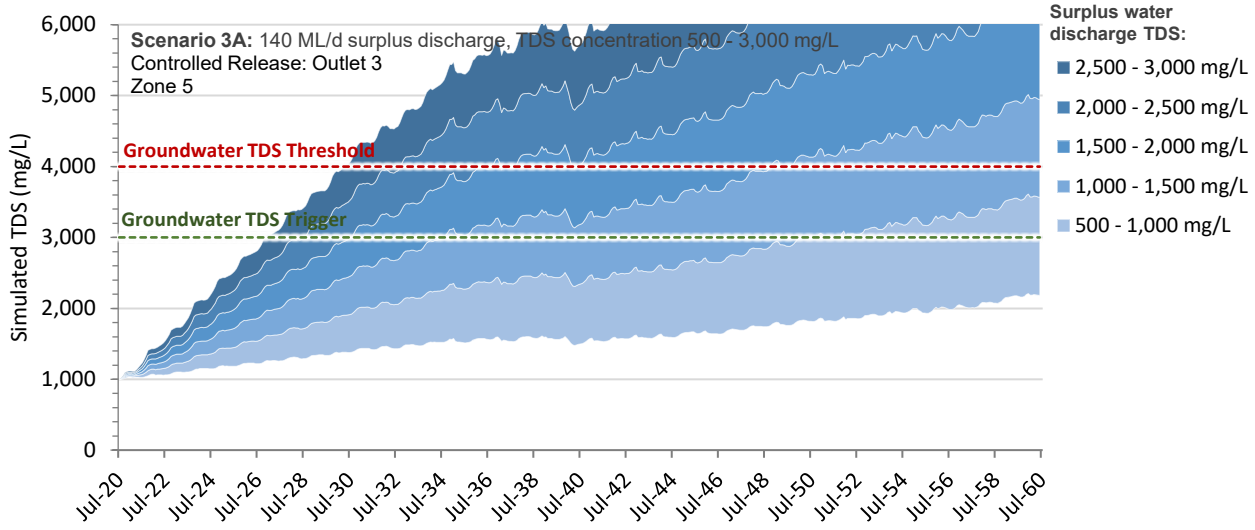


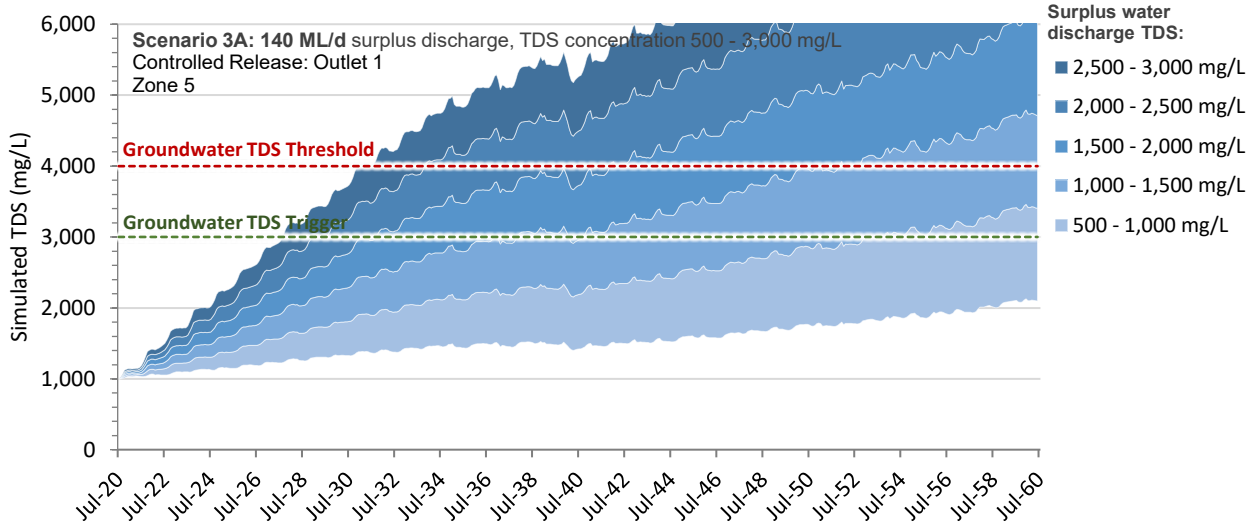




D.4.5 Predicted groundwater TDS (Zone 5)





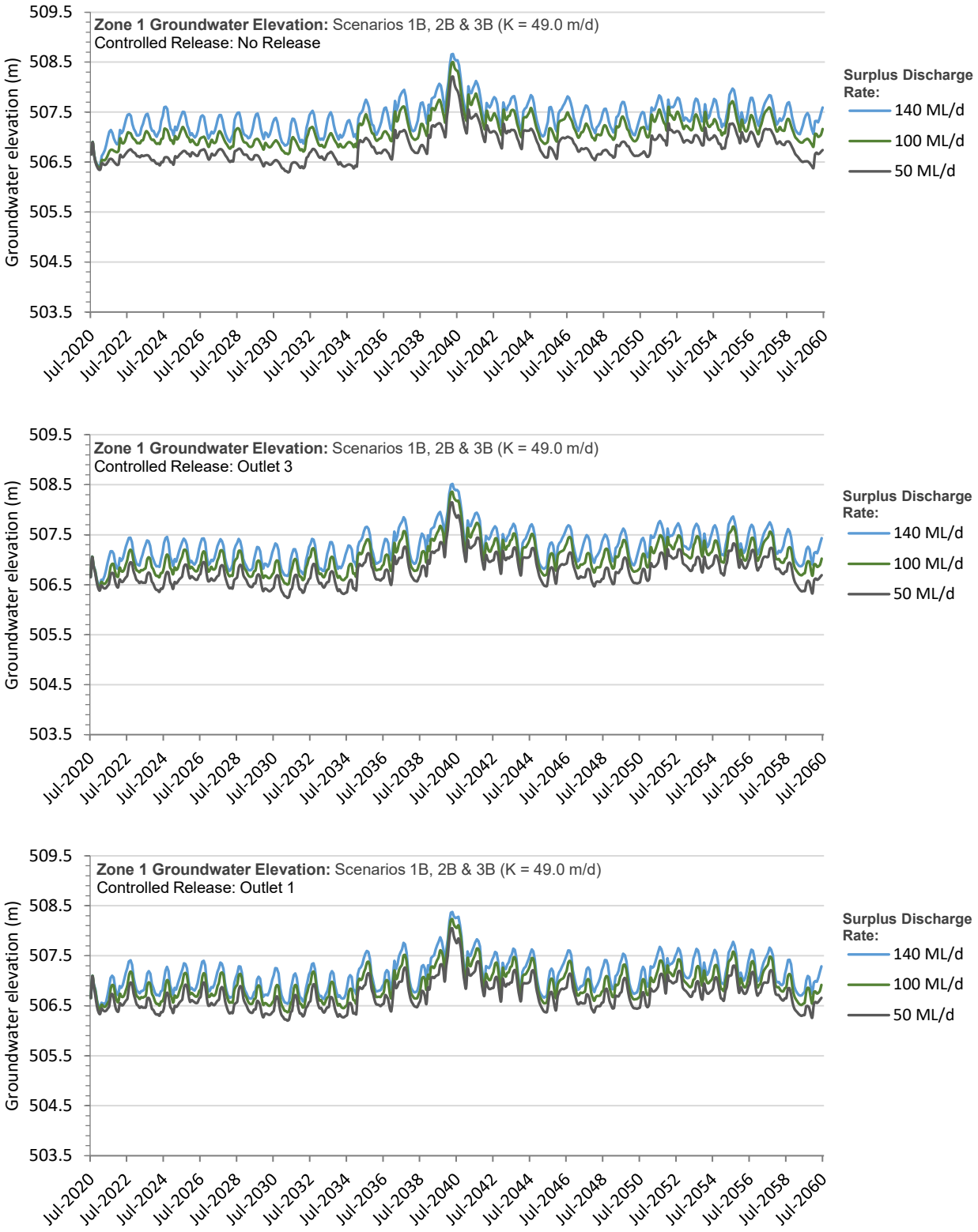


Appendix E

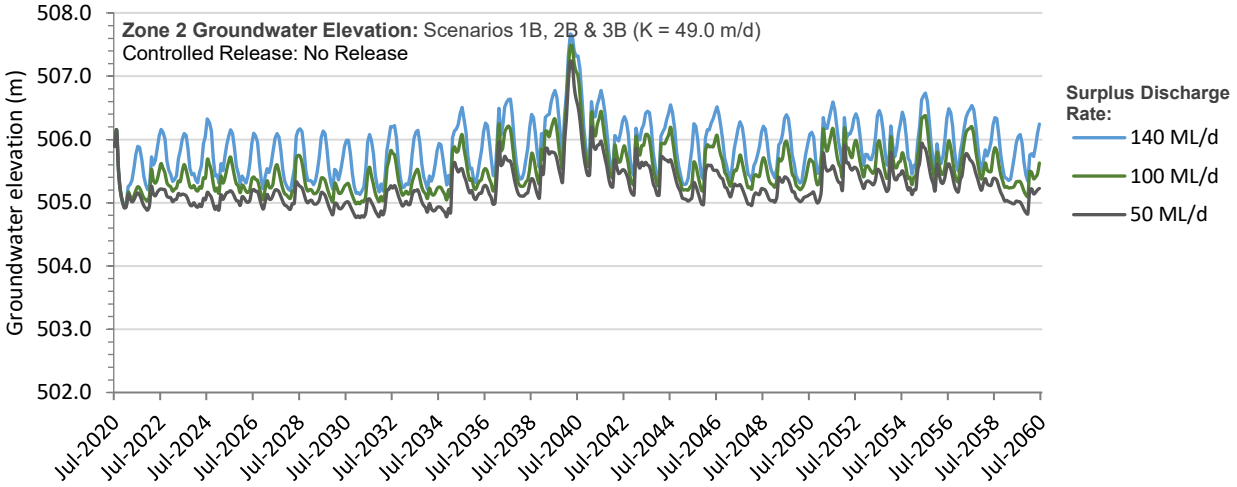
Water balance scenarios – Groundwater system (K = 49.0 m/d)

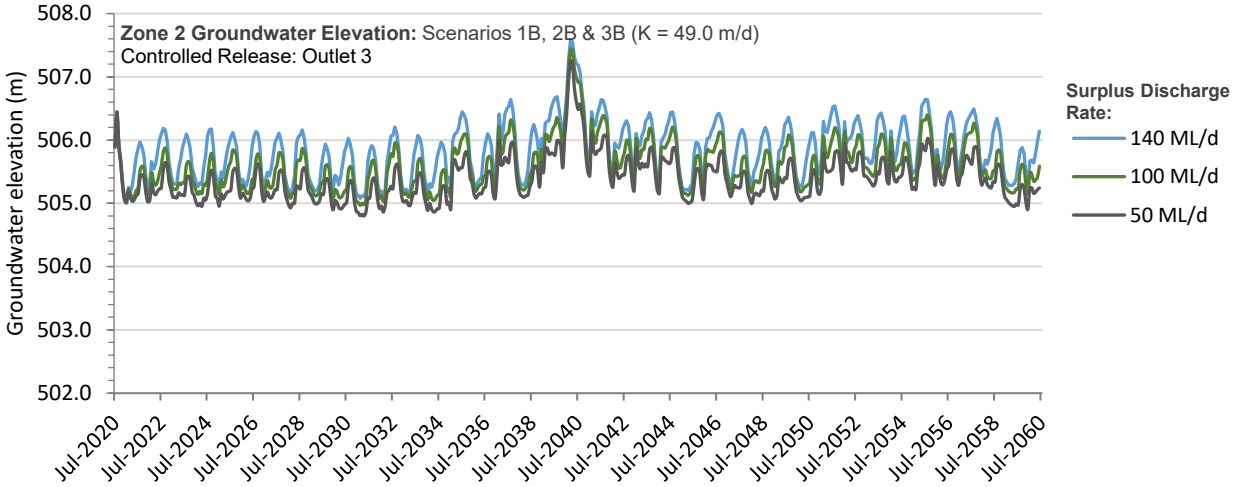
E.1 Simulated groundwater elevation: Scenarios 1B, 2B, 3B

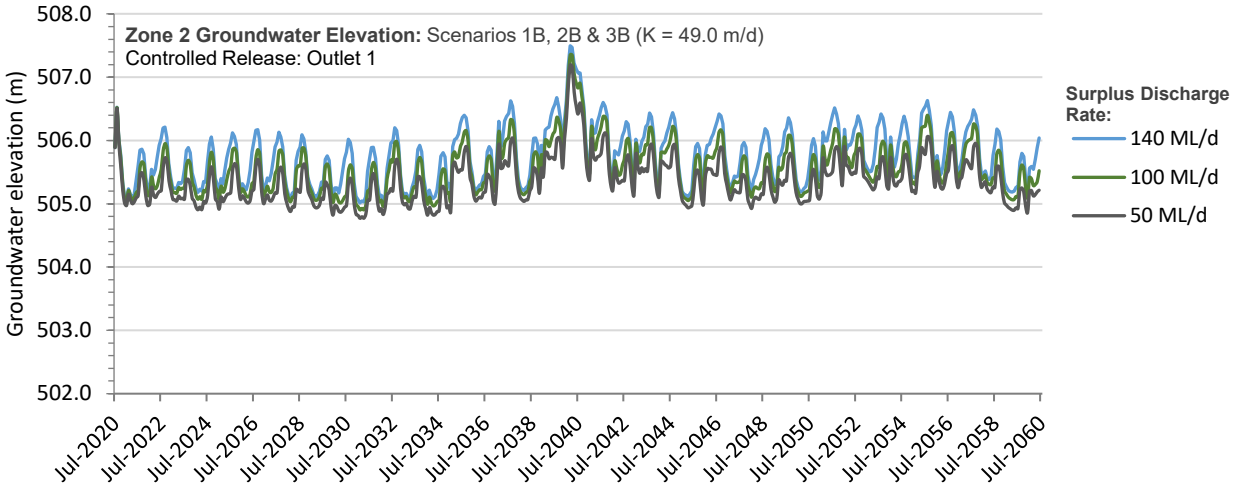
E.1.1 Predicted groundwater elevation (Zone 1)



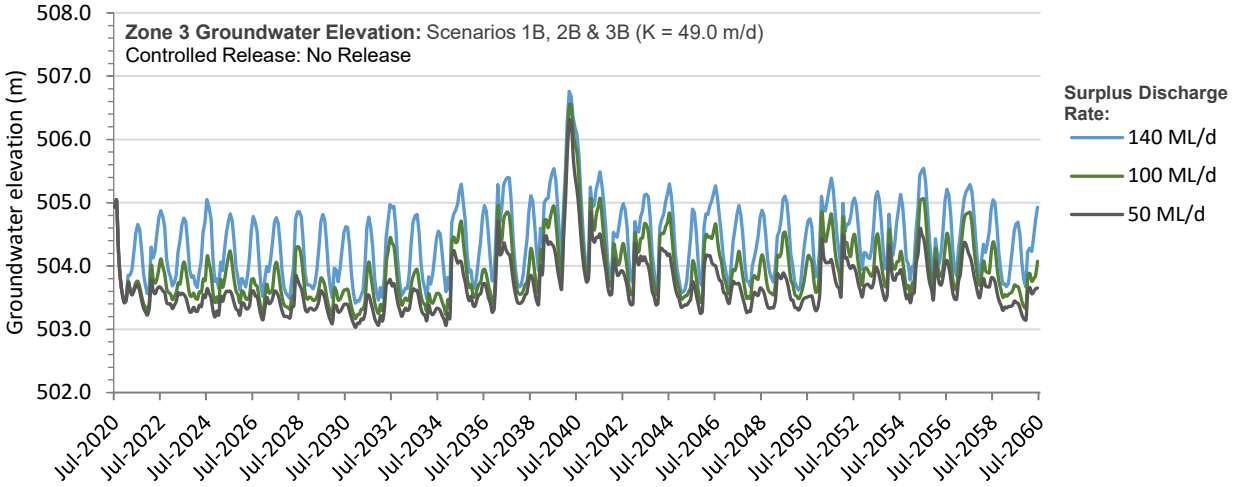
E.1.2 Predicted groundwater elevation (Zone 2)

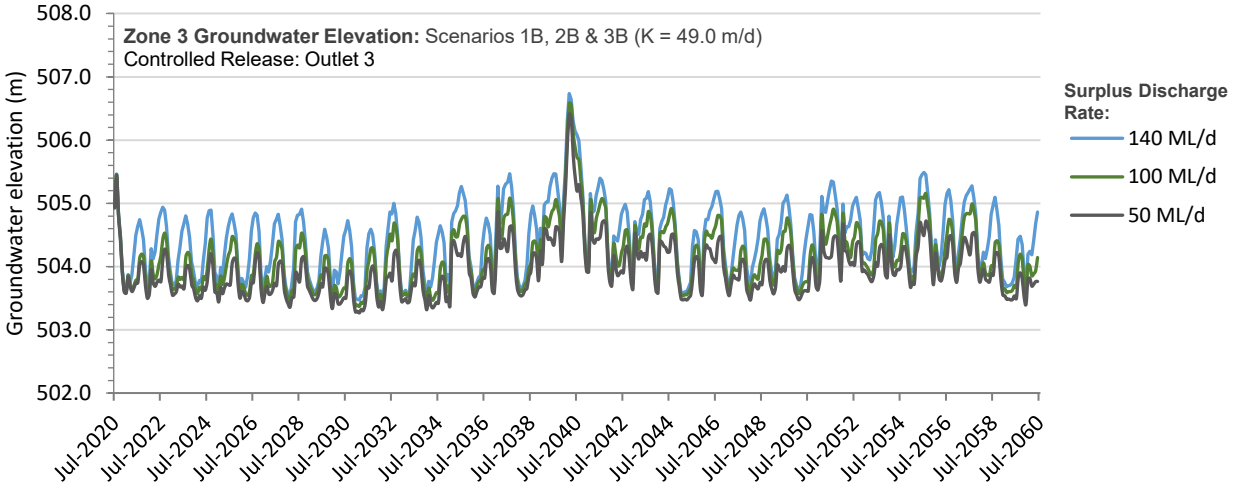


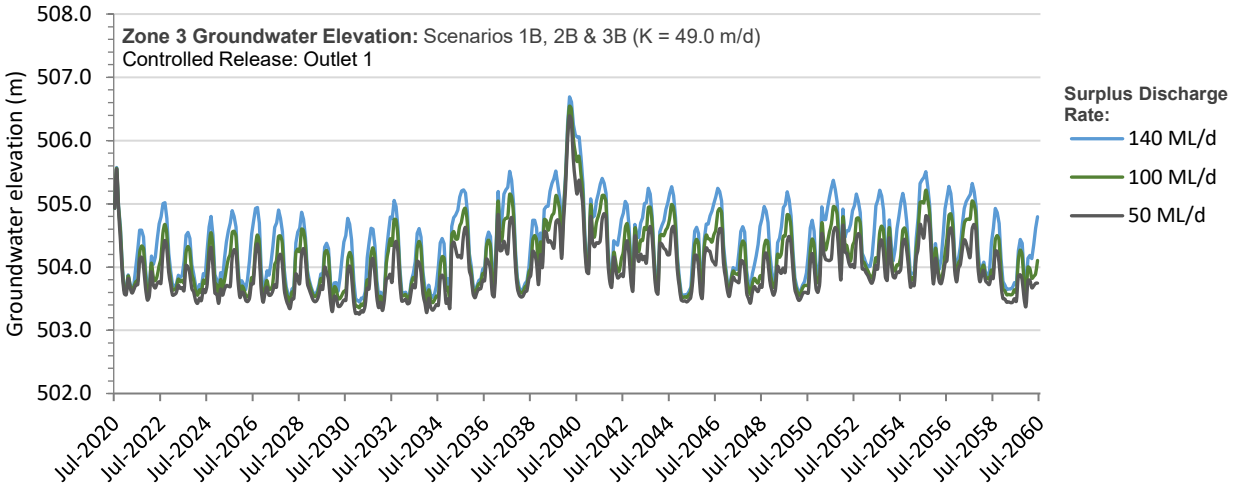




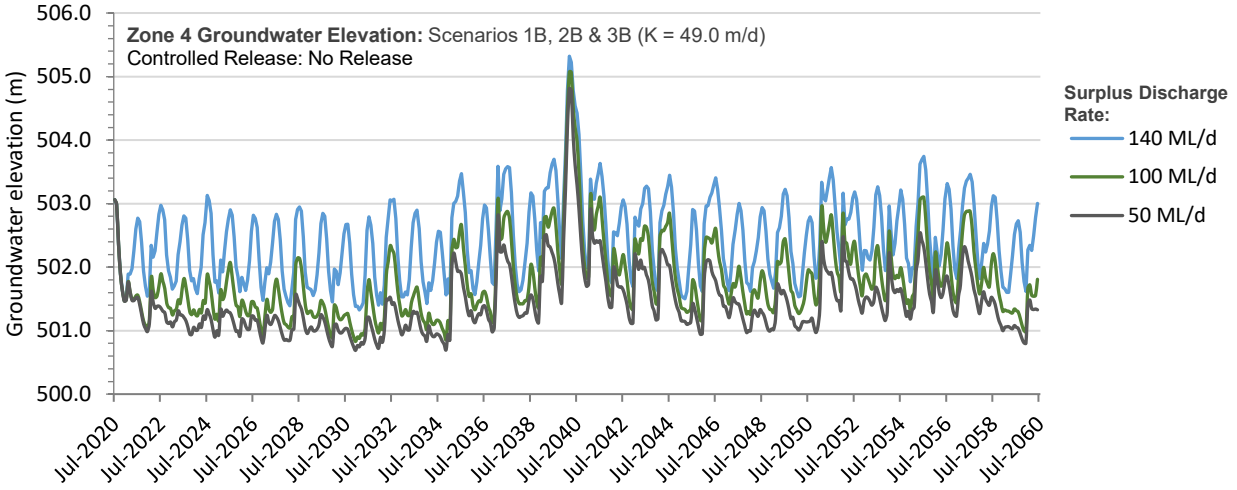
E.1.3 Predicted groundwater elevation (Zone 3)

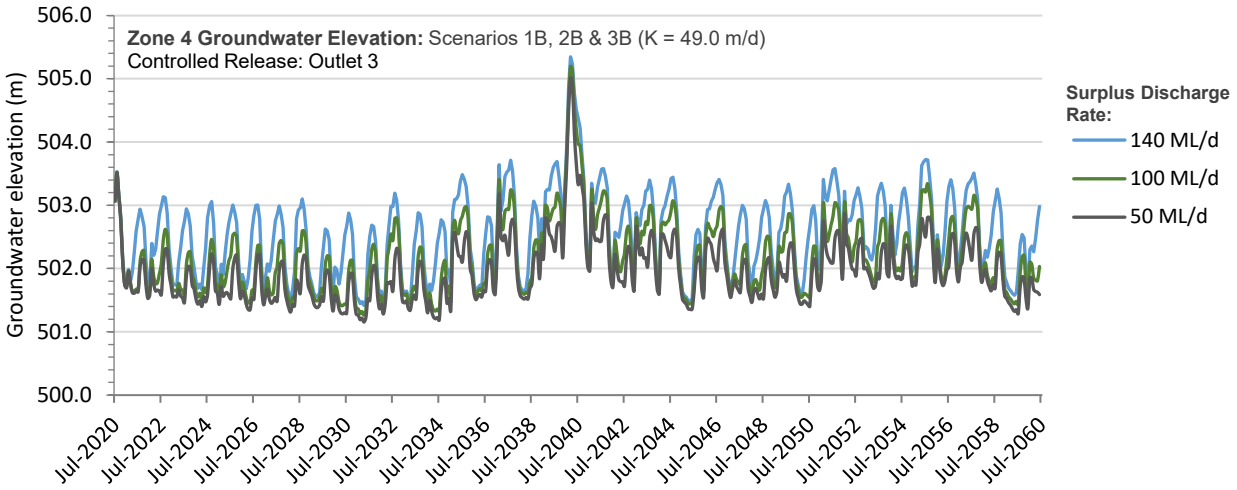


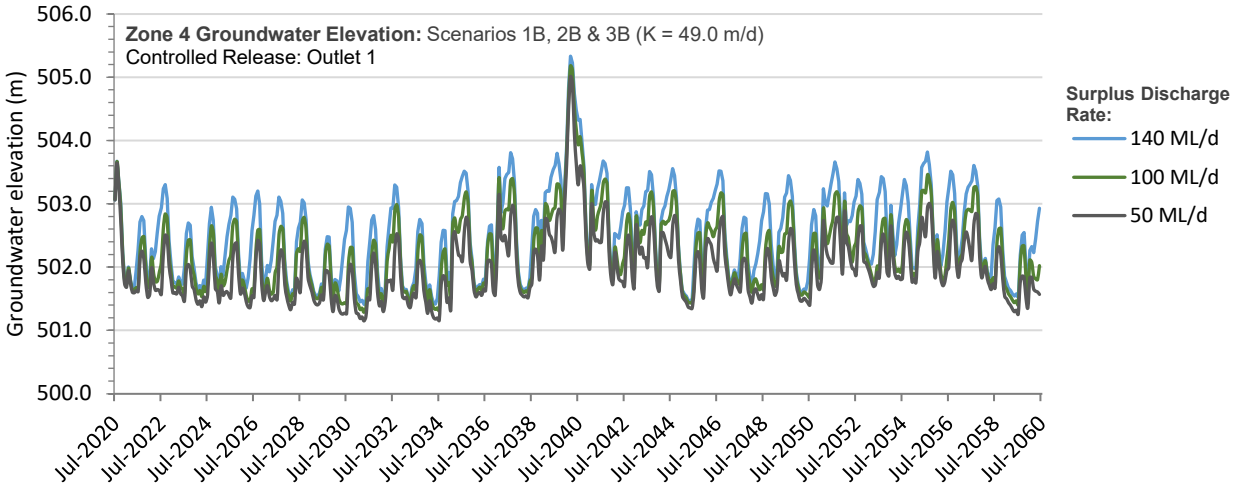




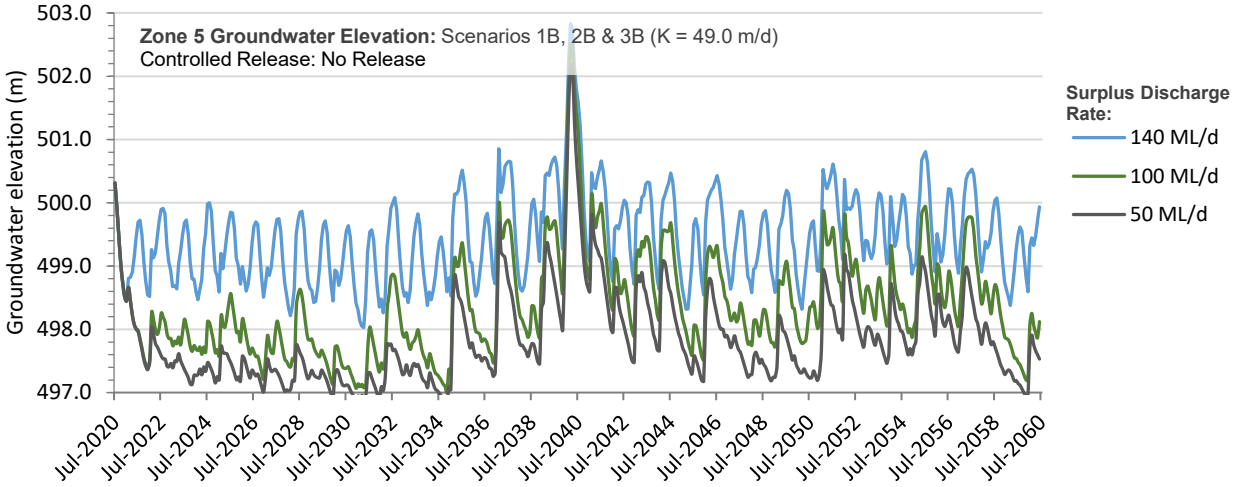
E.1.4 Predicted groundwater elevation (Zone 4)

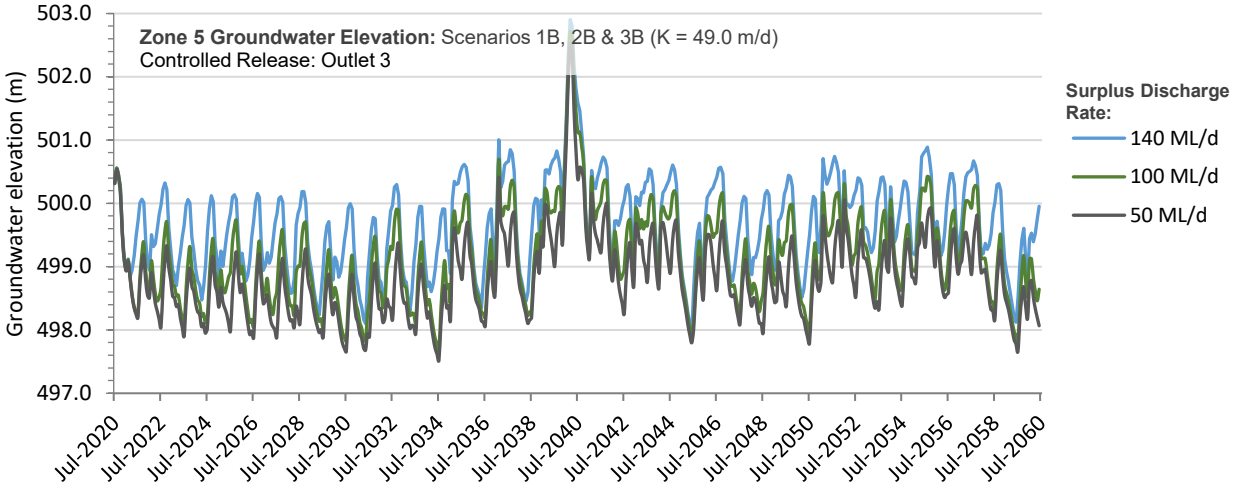


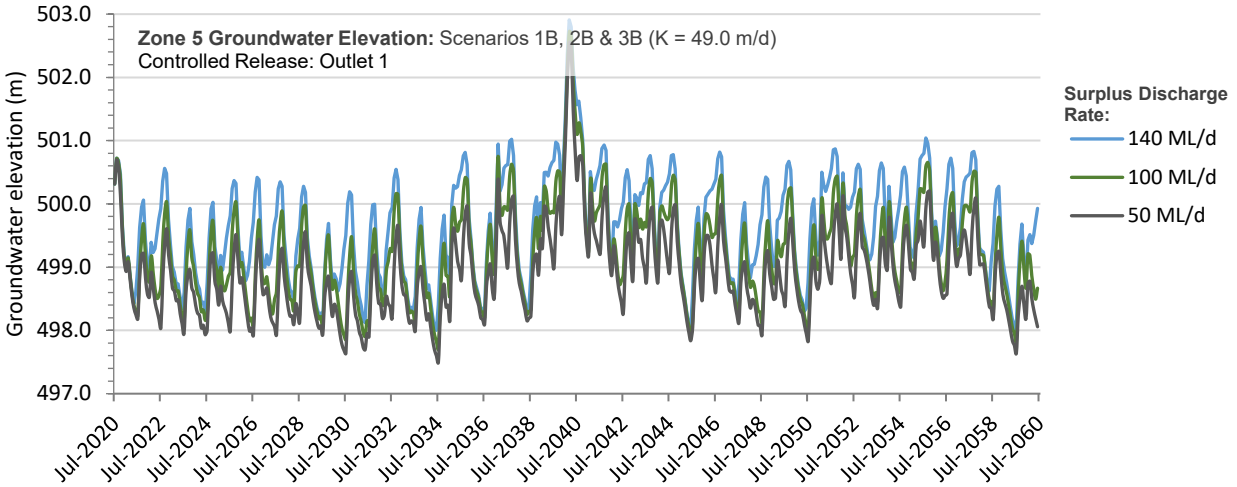


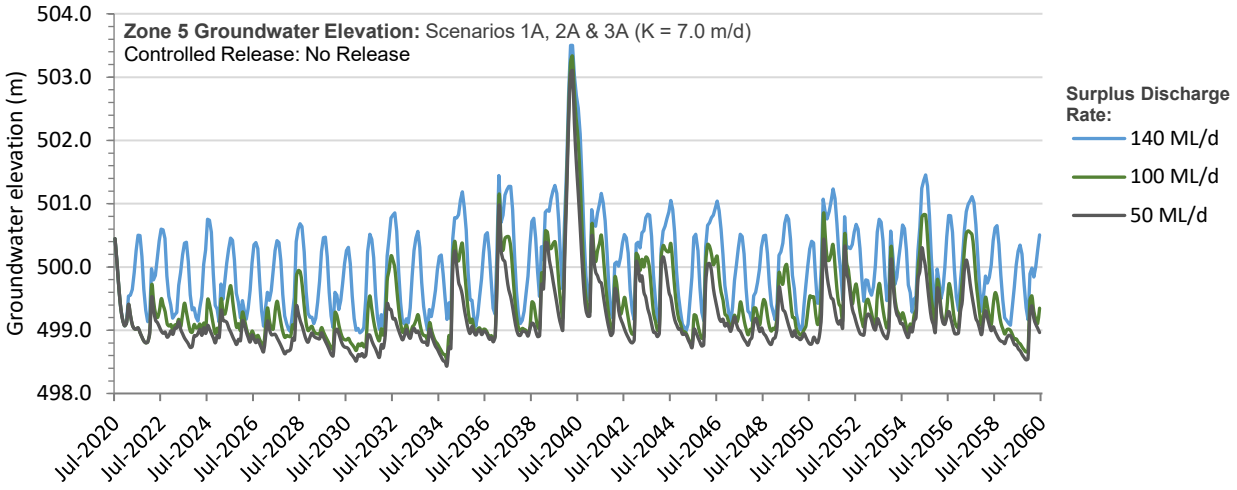


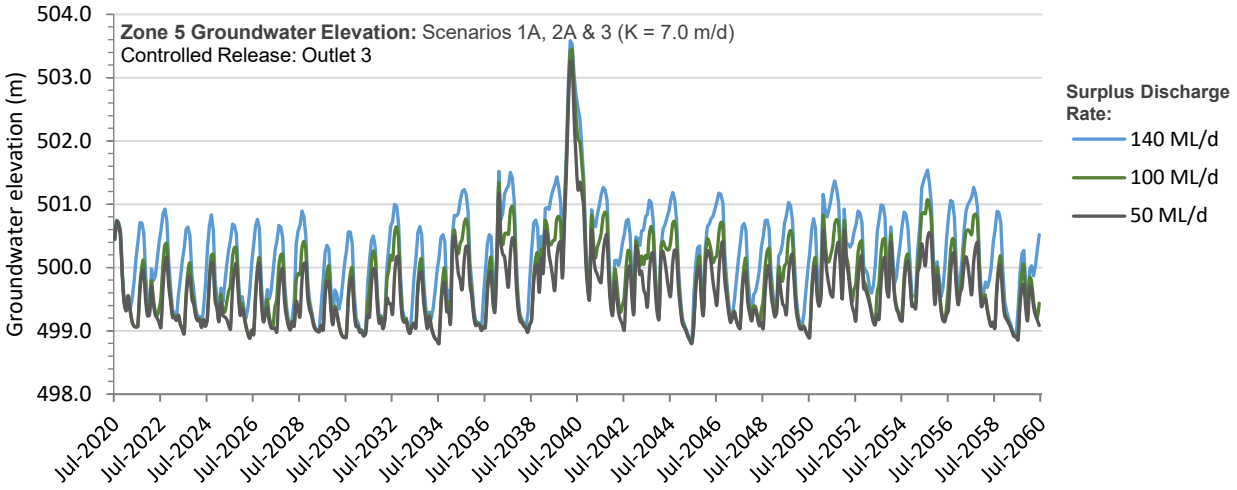
E.1.5 Predicted groundwater elevation (Zone 5)

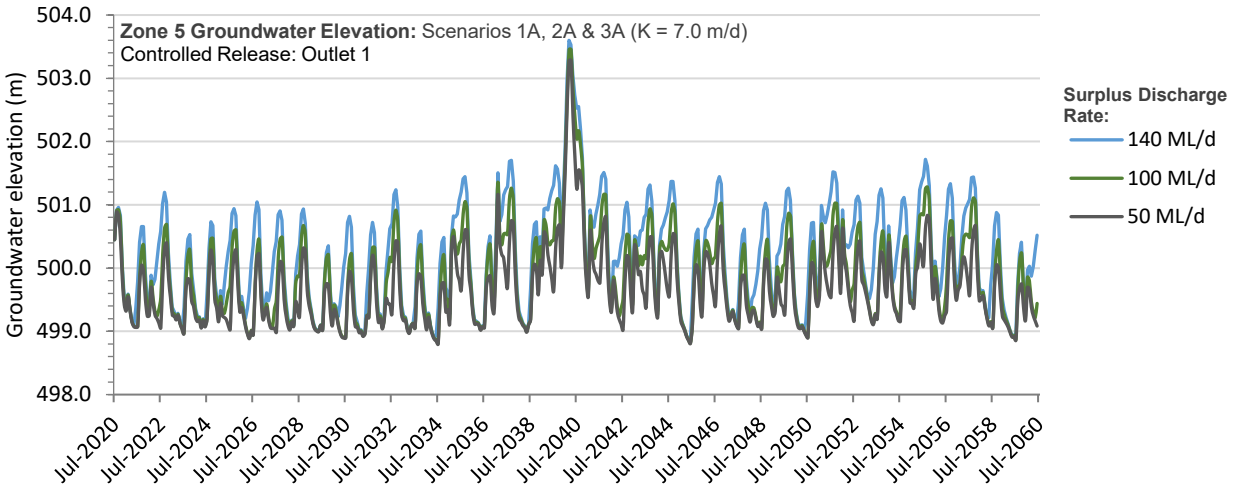






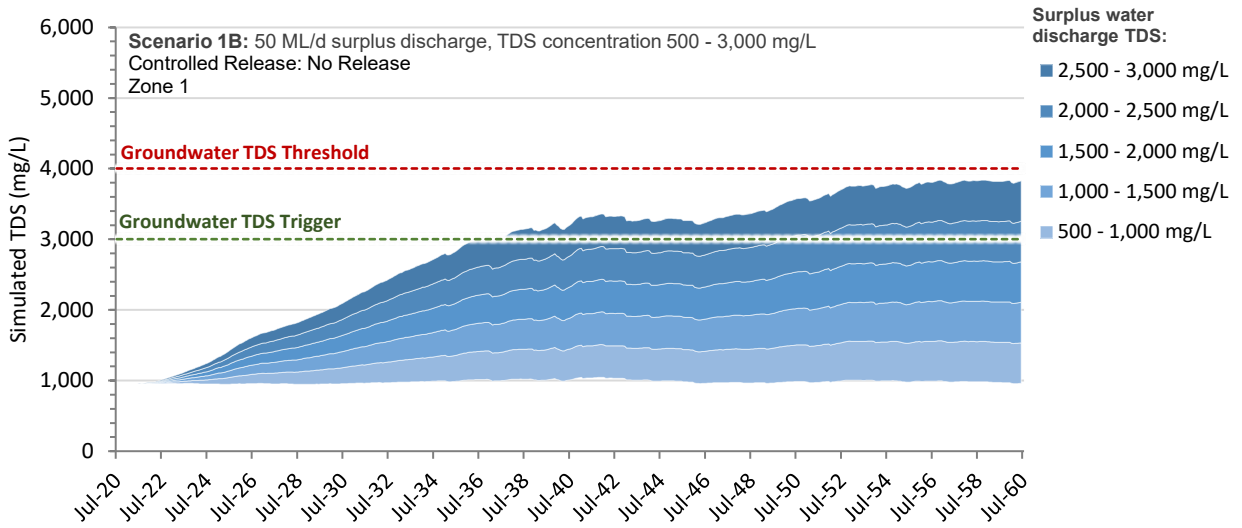

Zone 5 Groundwater Elevation: Scenarios 1A, 2A & 3A (K = 7.0 m/d)
Controlled Release: No Release
Groundwater elevation (m)
504.0
503.0
502.0
501.0
500.0
499.0
498.0
Jul-2020
Jul-2022
Jul-2024
Jul-2026
Jul-2028
Jul-2030
Jul-2032
Jul-2034
Jul-2036
Jul-2038
Jul-2040
Jul-2042
Jul-2044
Jul-2046
Jul-2048
Jul-2050
Jul-2052
Jul-2054
Jul-2056
Jul-2058
Jul-2060
Surplus Discharge Rate:
140 ML/d
100 ML/d
50 ML/d

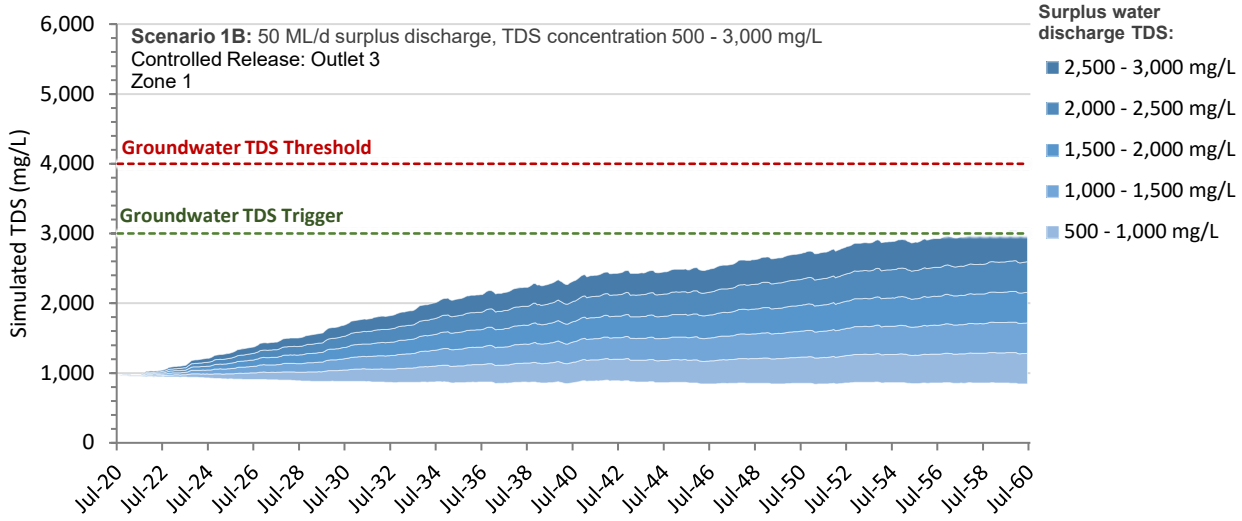

Zone 5 Groundwater Elevation: Scenarios 1A, 2A & 3 (K = 7.0 m/d)
Controlled Release: Outlet 3
Groundwater elevation (m)
504.0
503.0
502.0
501.0
500.0
499.0
498.0
Jul-2020
Jul-2022
Jul-2024
Jul-2026
Jul-2028
Jul-2030
Jul-2032
Jul-2034
Jul-2036
Jul-2038
Jul-2040
Jul-2042
Jul-2044
Jul-2046
Jul-2048
Jul-2050
Jul-2052
Jul-2054
Jul-2056
Jul-2058
Jul-2060
Surplus Discharge Rate:
140 ML/d
100 ML/d
50 ML/d

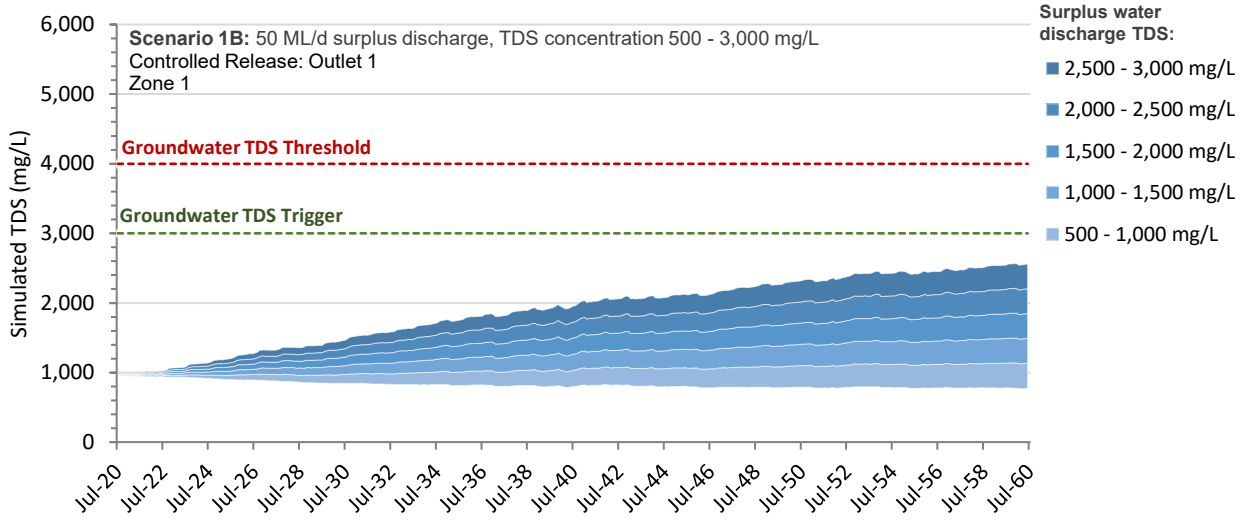

Zone 5 Groundwater Elevation: Scenarios 1A, 2A & 3A (K = 7.0 m/d)
Controlled Release: Outlet 1
Groundwater elevation (m)
504.0
503.0
502.0
501.0
500.0
499.0
498.0
Jul-2020
Jul-2022
Jul-2024
Jul-2026
Jul-2028
Jul-2030
Jul-2032
Jul-2034
Jul-2036
Jul-2038
Jul-2040
Jul-2042
Jul-2044
Jul-2046
Jul-2048
Jul-2050
Jul-2052
Jul-2054
Jul-2056
Jul-2058
Jul-2060
Surplus Discharge Rate:
140 ML/d
100 ML/d
50 ML/d

E.2 Groundwater TDS predictions: Scenario 1B: Surplus discharge 50 ML/d

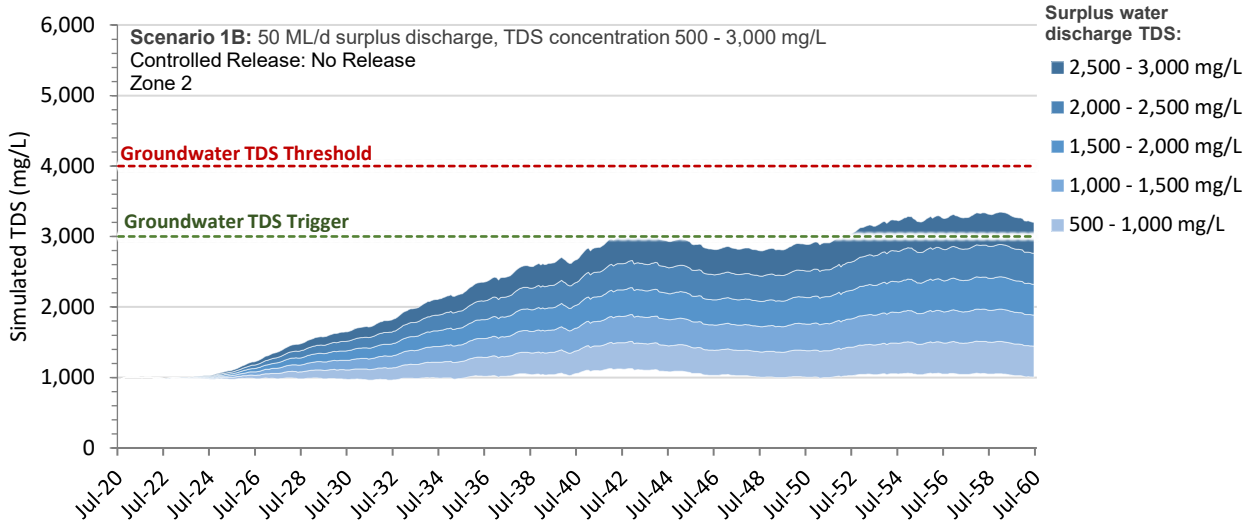
E.2.1 Predicted groundwater TDS (Zone 1)

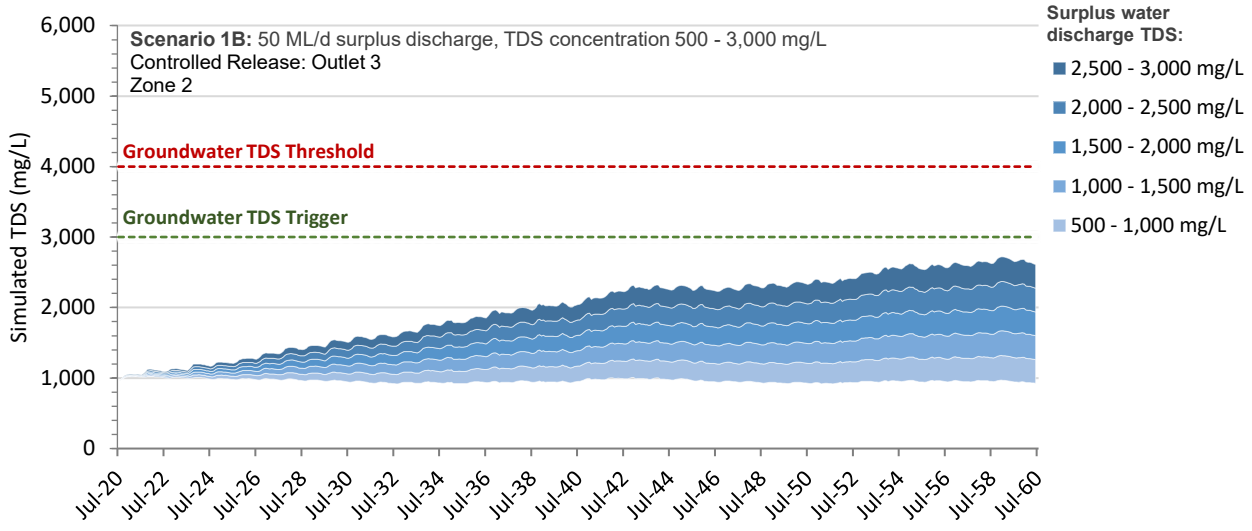


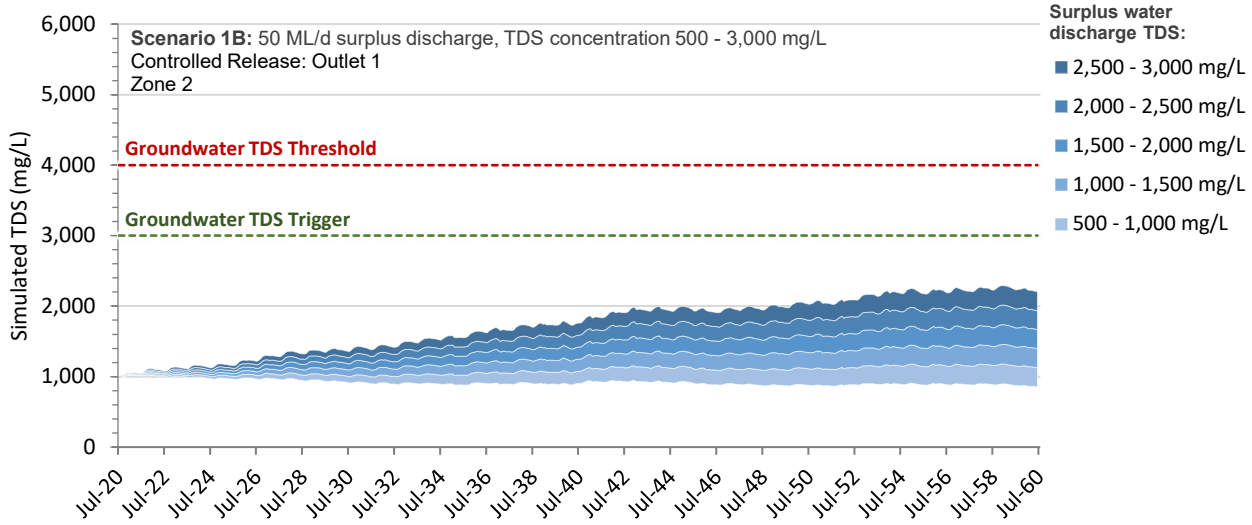




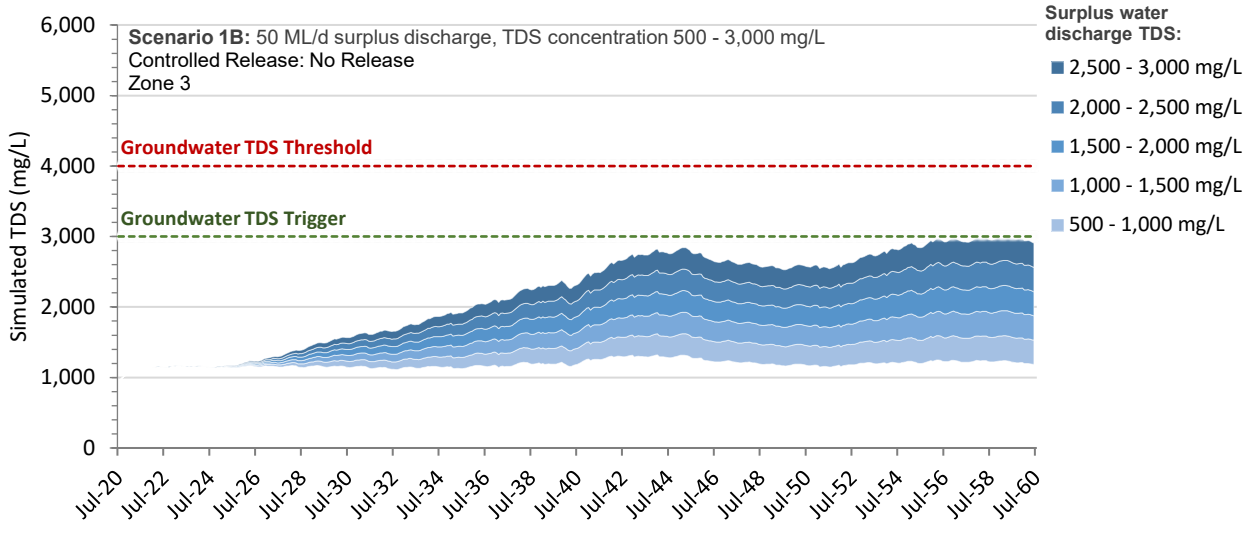
E.2.2 Predicted groundwater TDS (Zone 2)

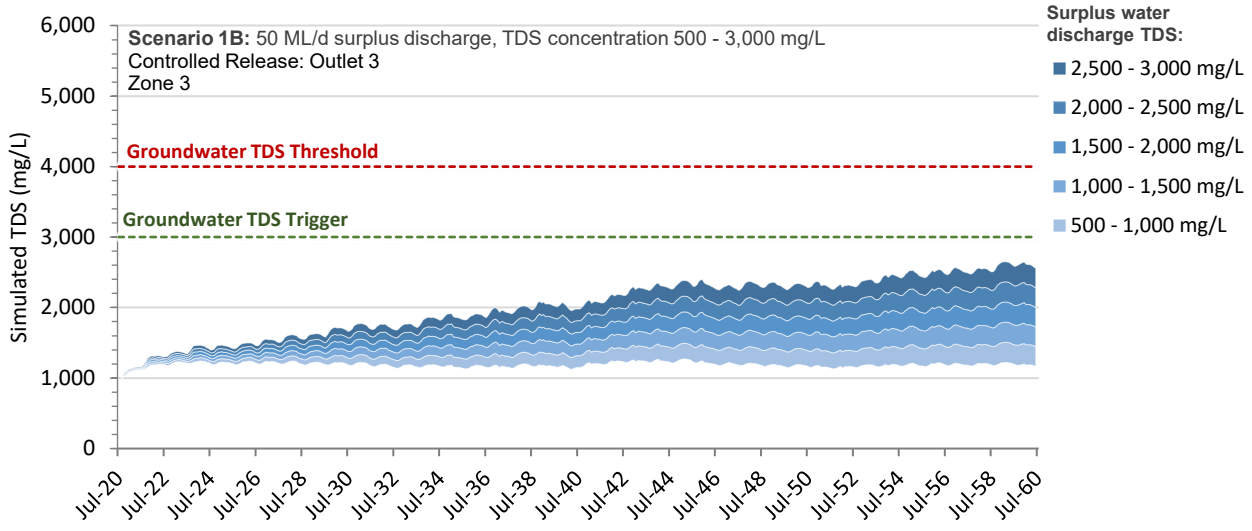


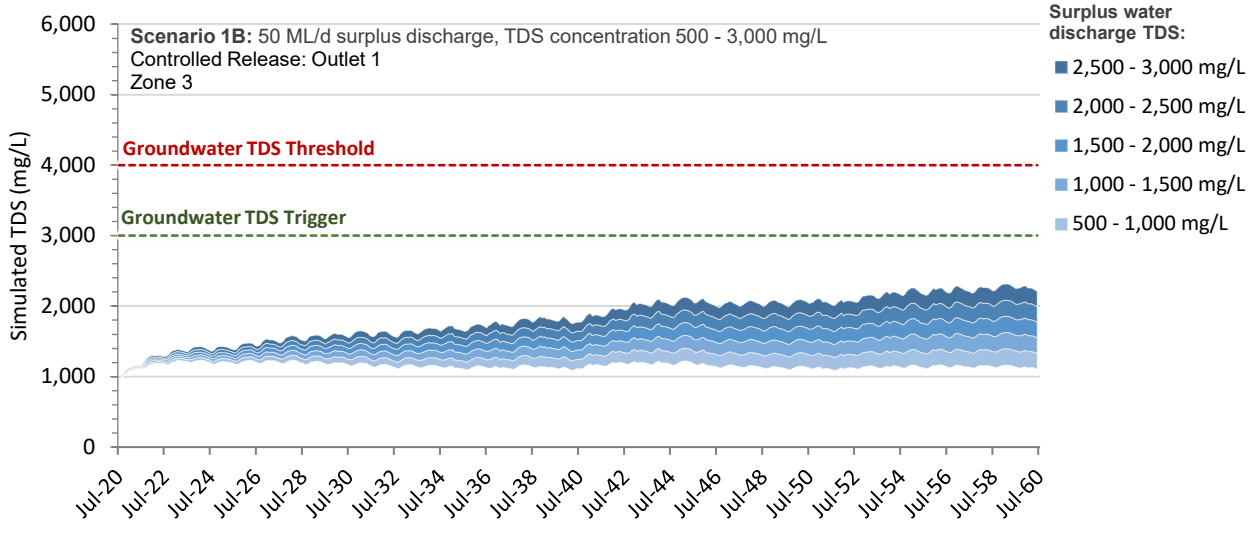




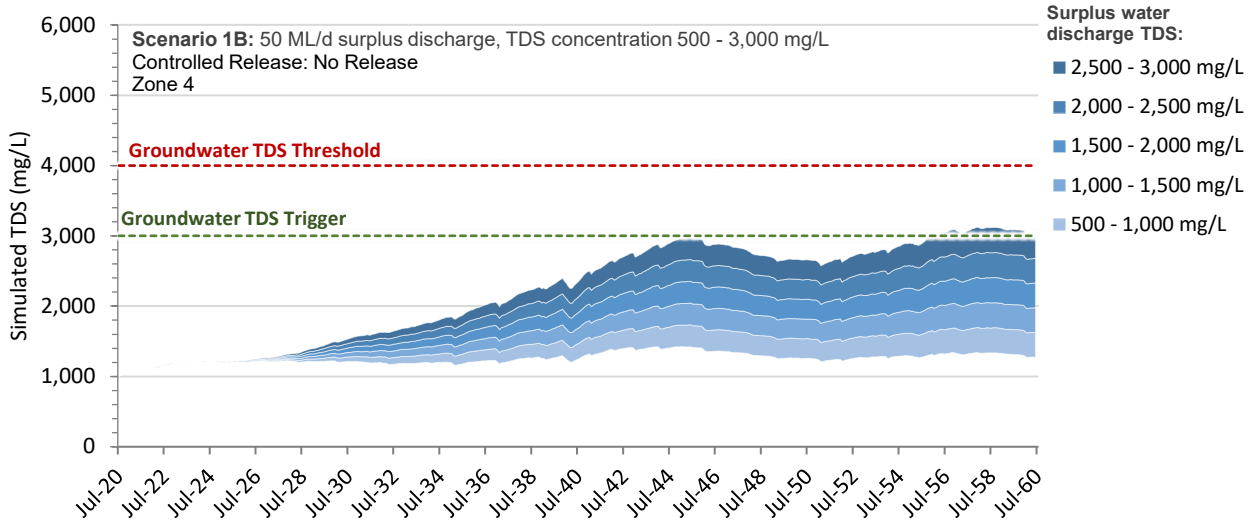
E.2.3 Predicted groundwater TDS (Zone 3)

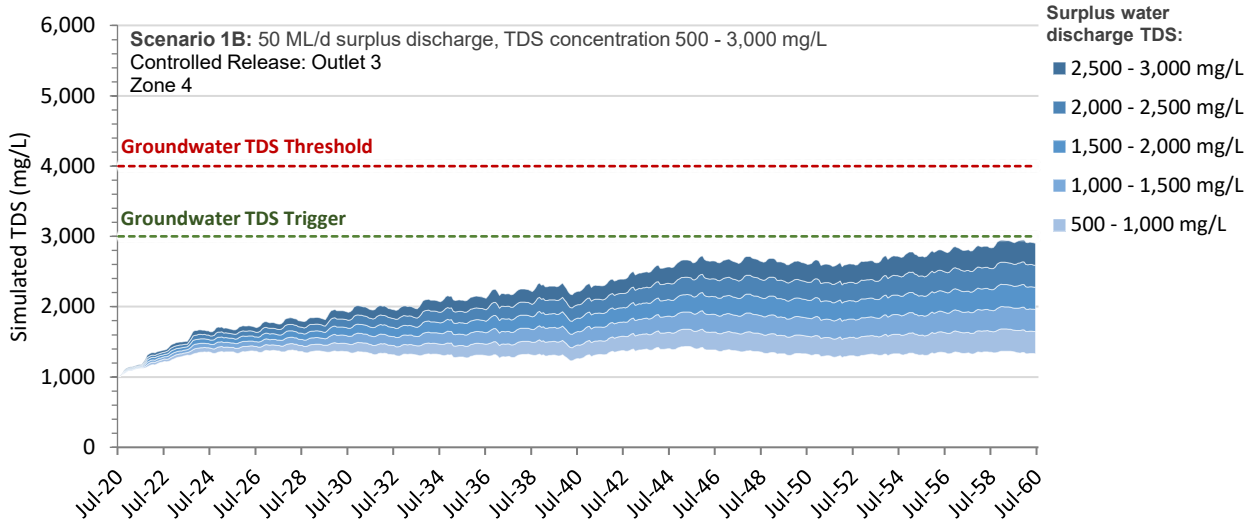


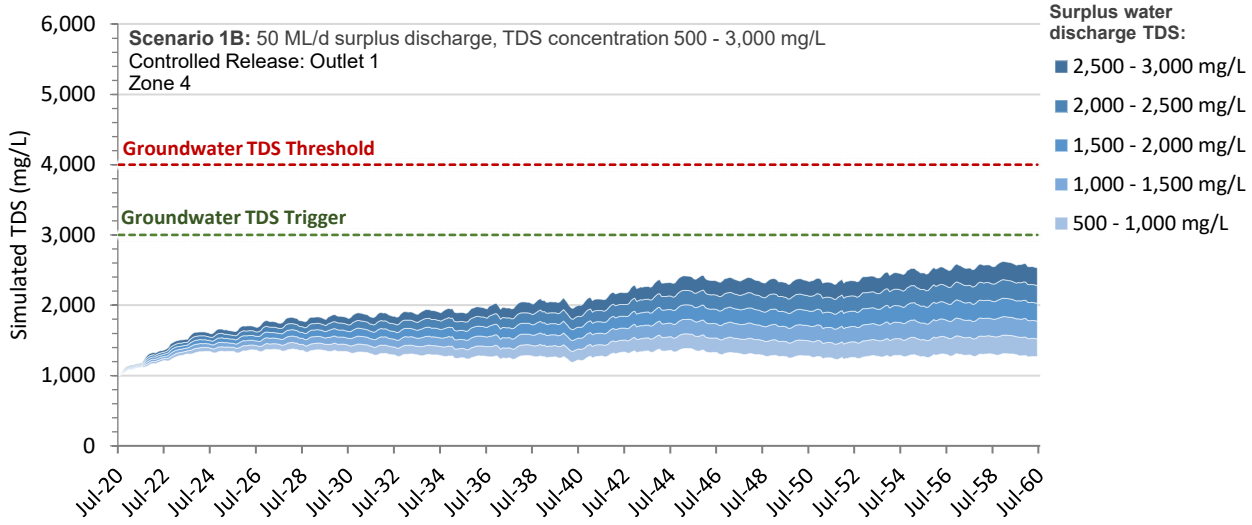




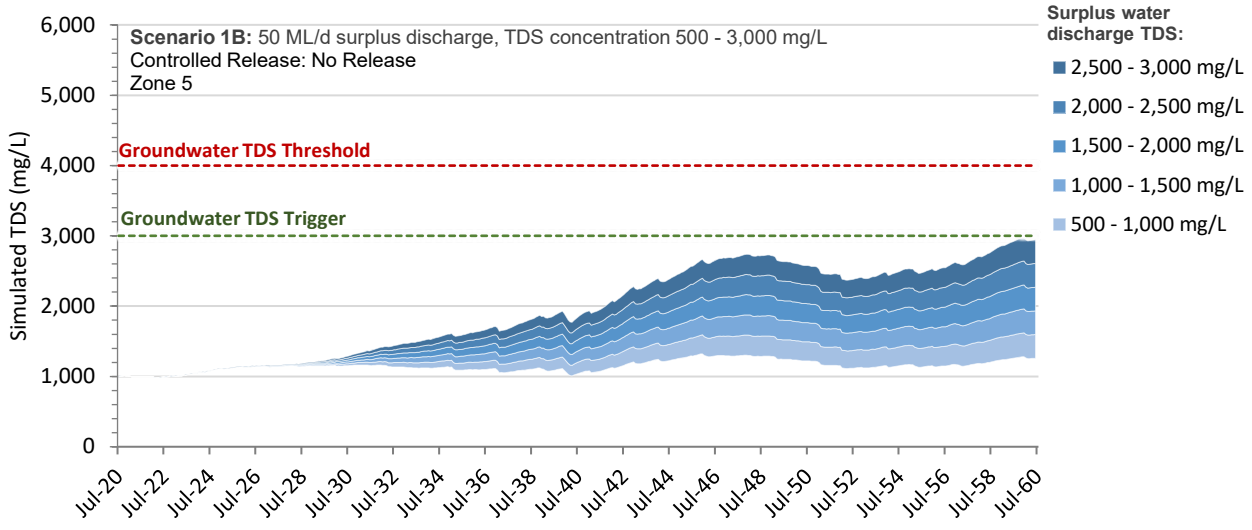
E.2.4 Predicted groundwater TDS (Zone 4)

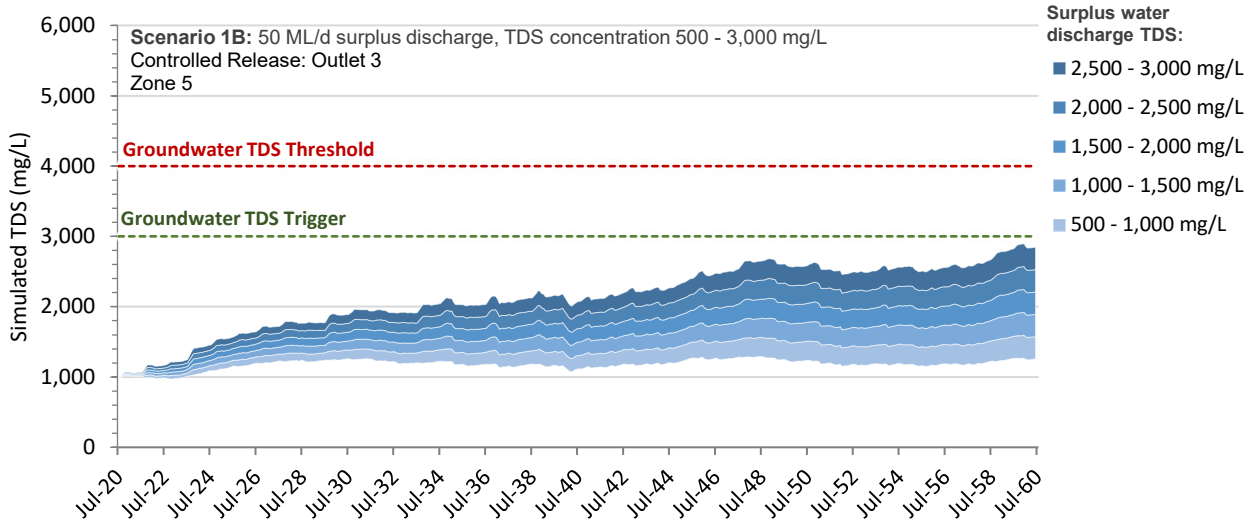


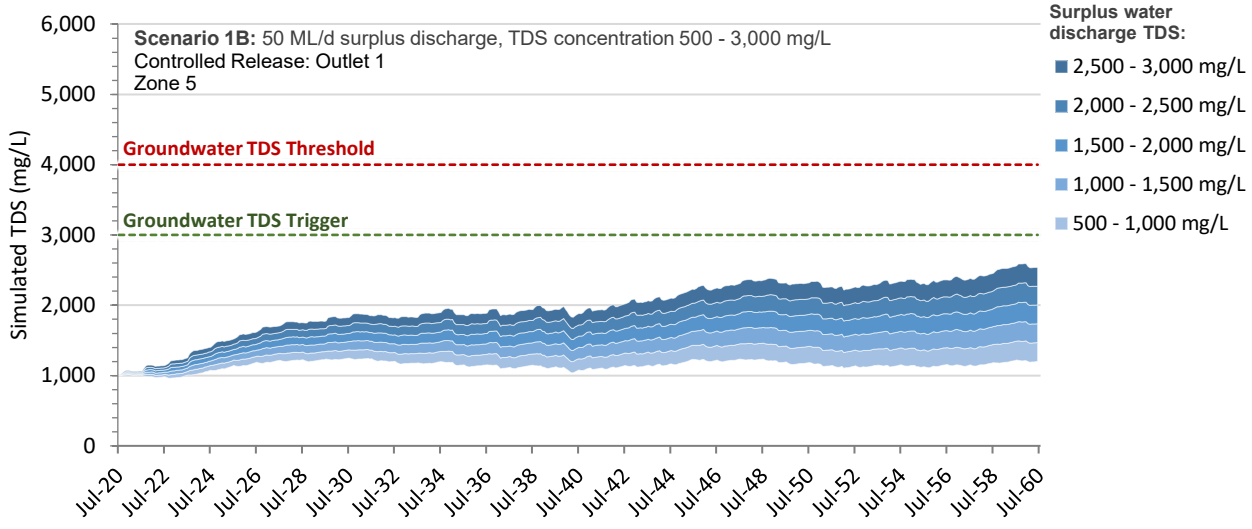




E.2.5 Predicted groundwater TDS (Zone 5)

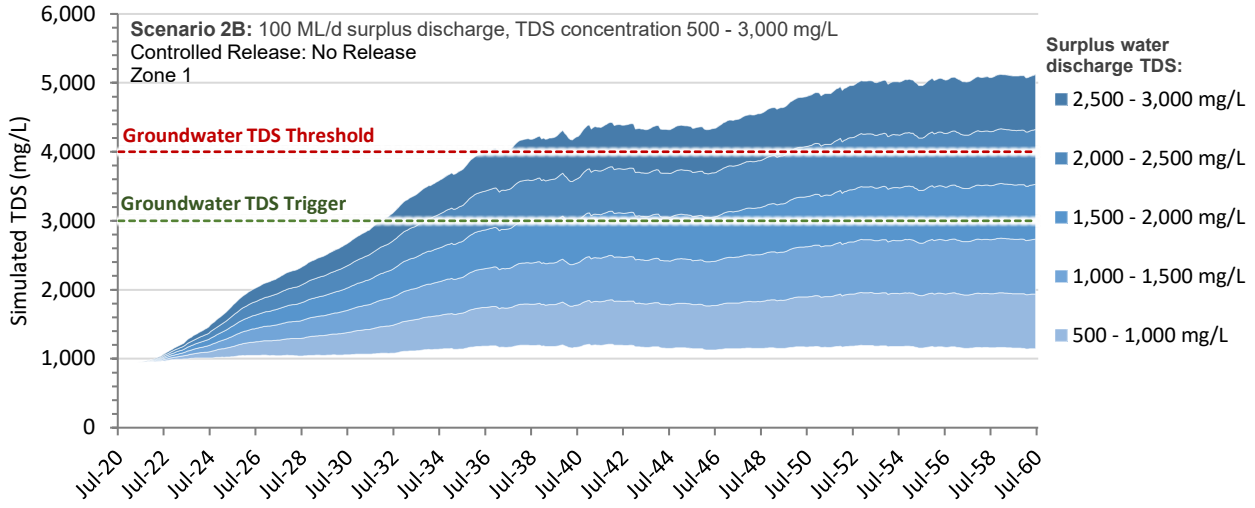


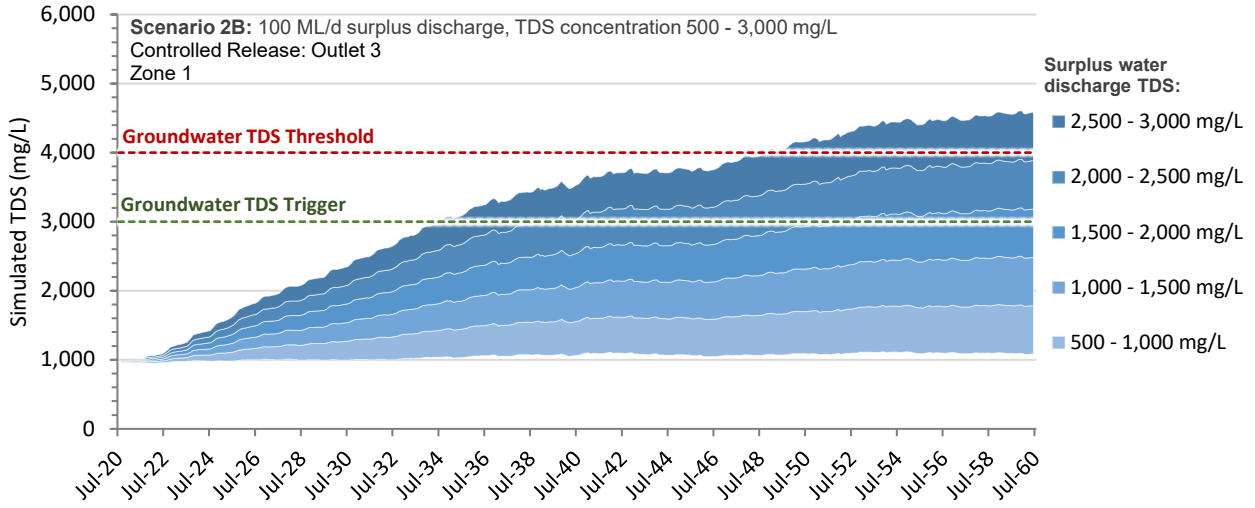


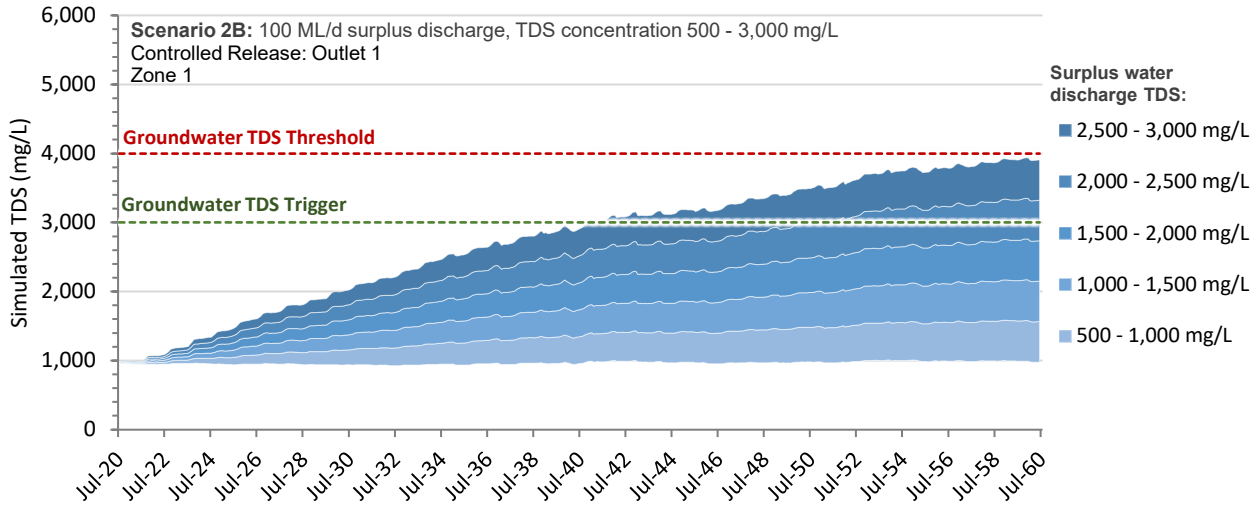


E.3 Groundwater TDS predictions: Scenario 2B: Surplus discharge 100 ML/d

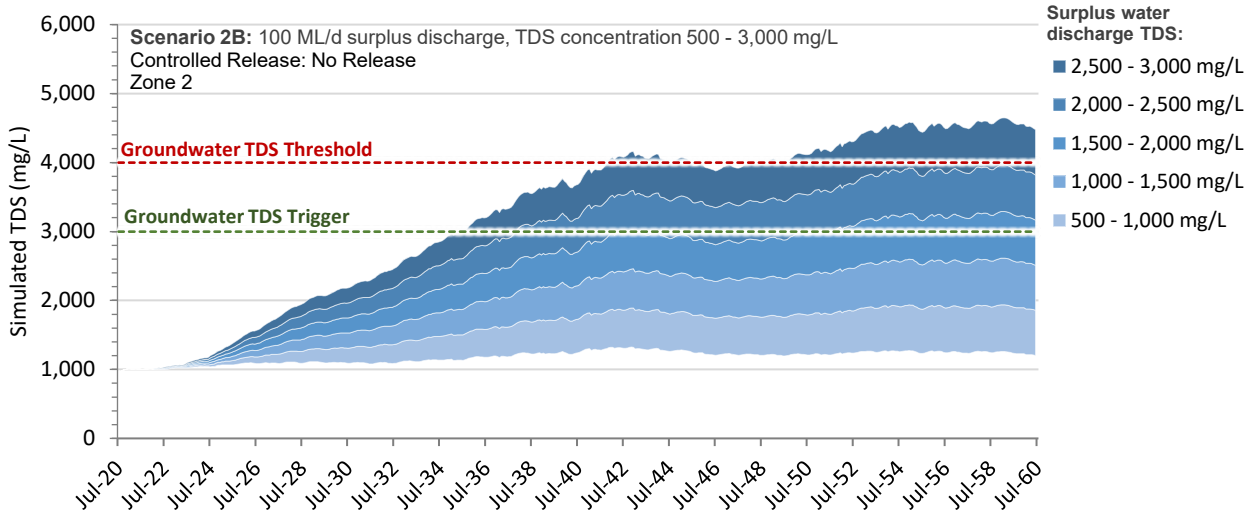
E.3.1 Predicted groundwater TDS (Zone 1)

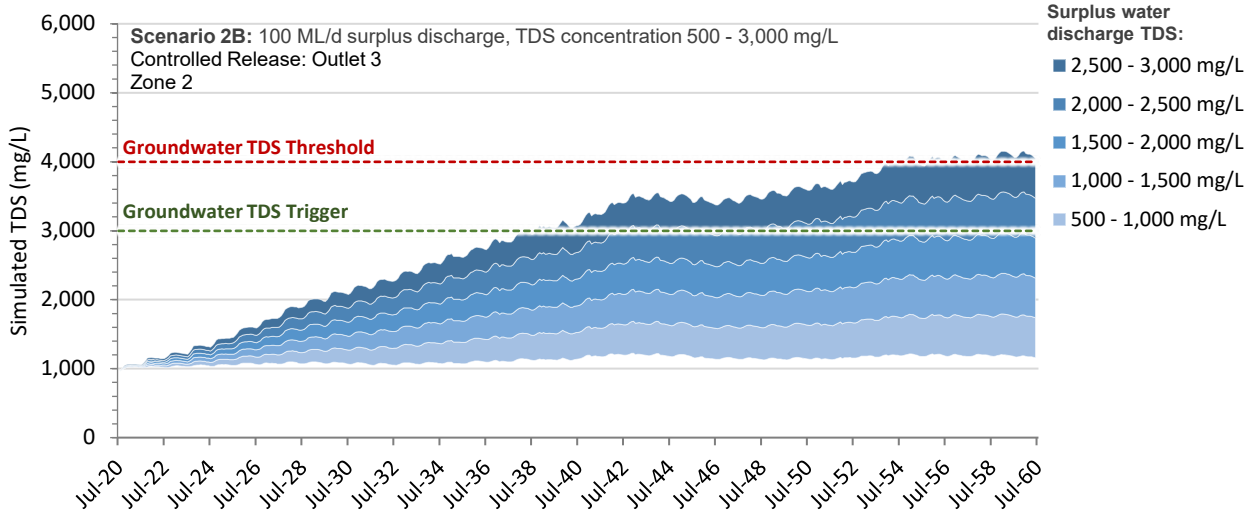


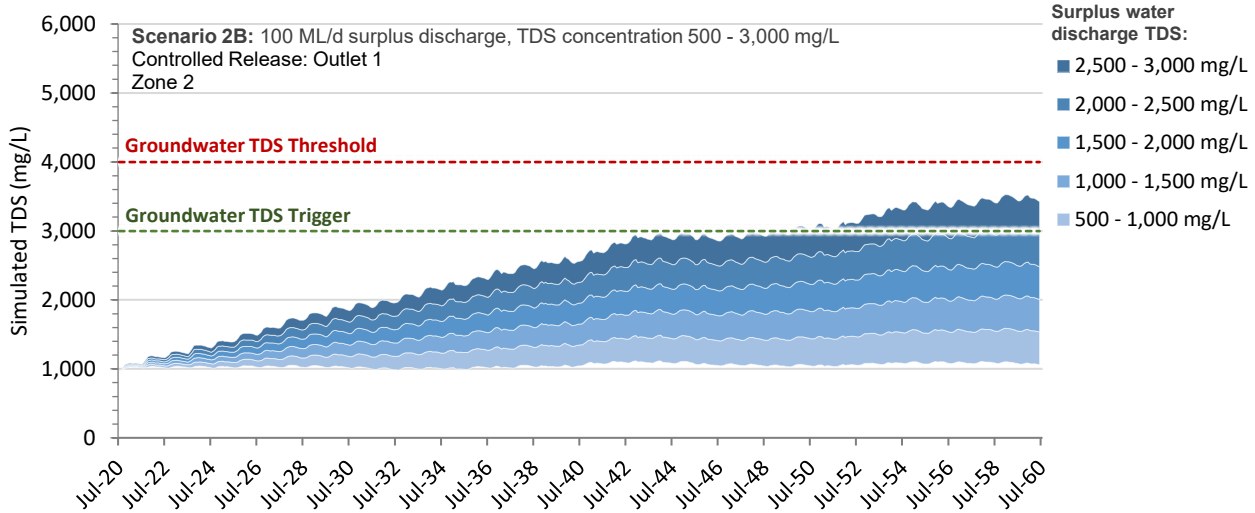




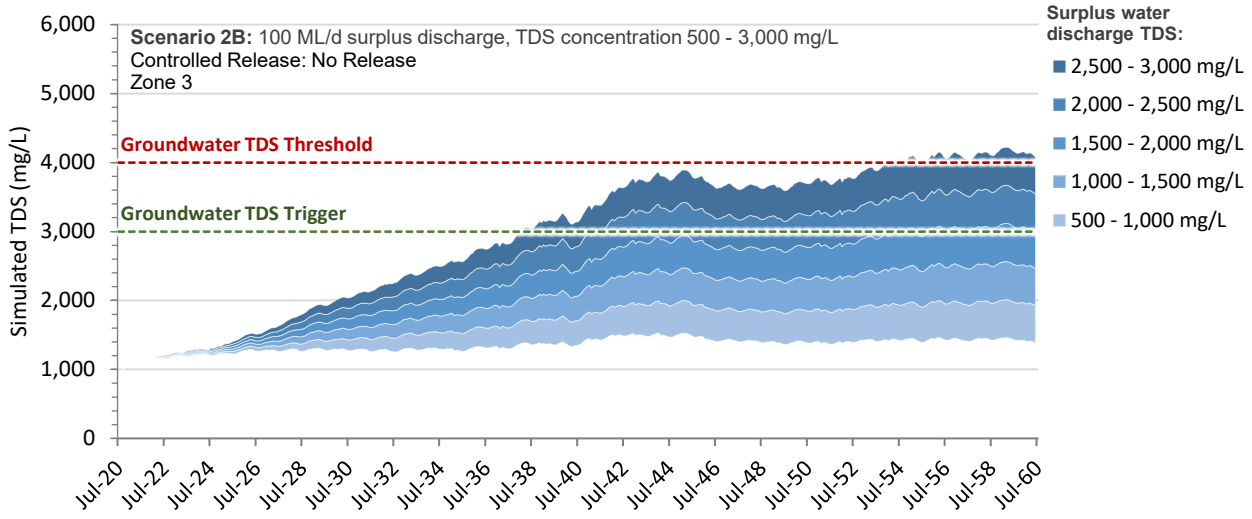
E.3.2 Predicted groundwater TDS (Zone 2)

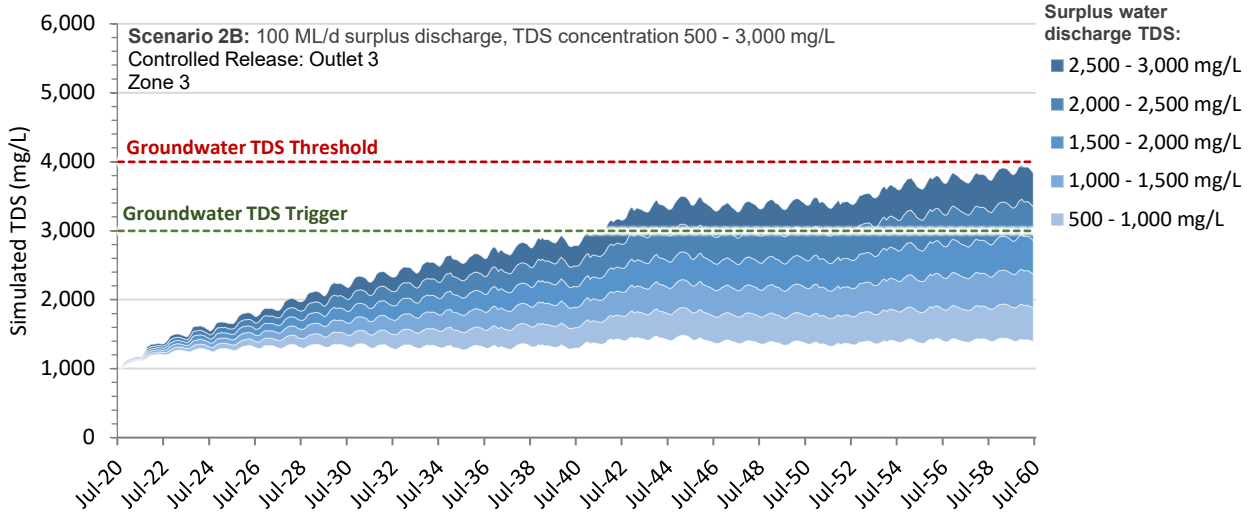


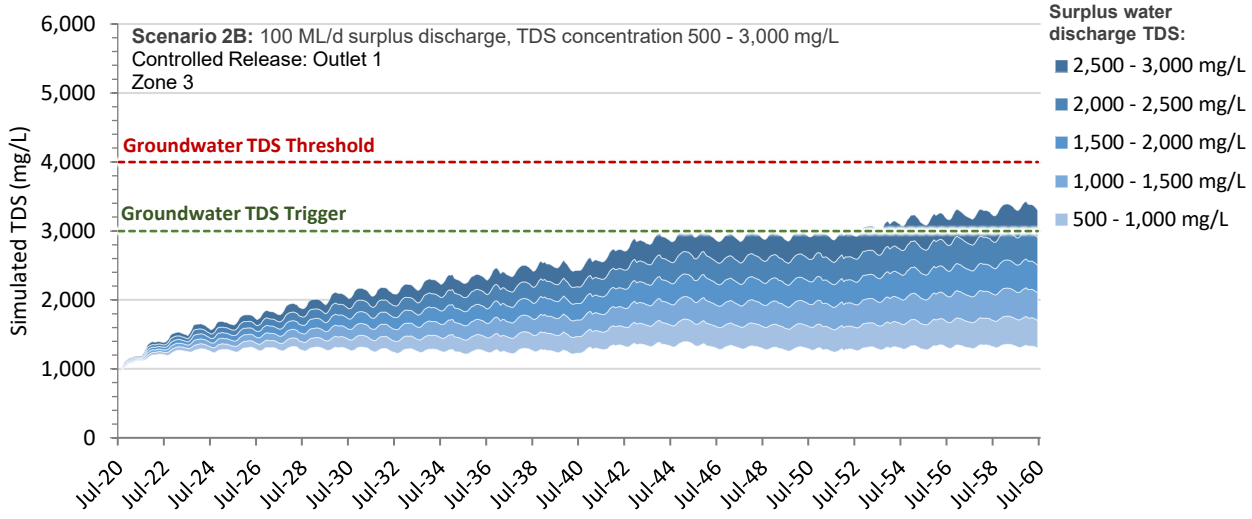




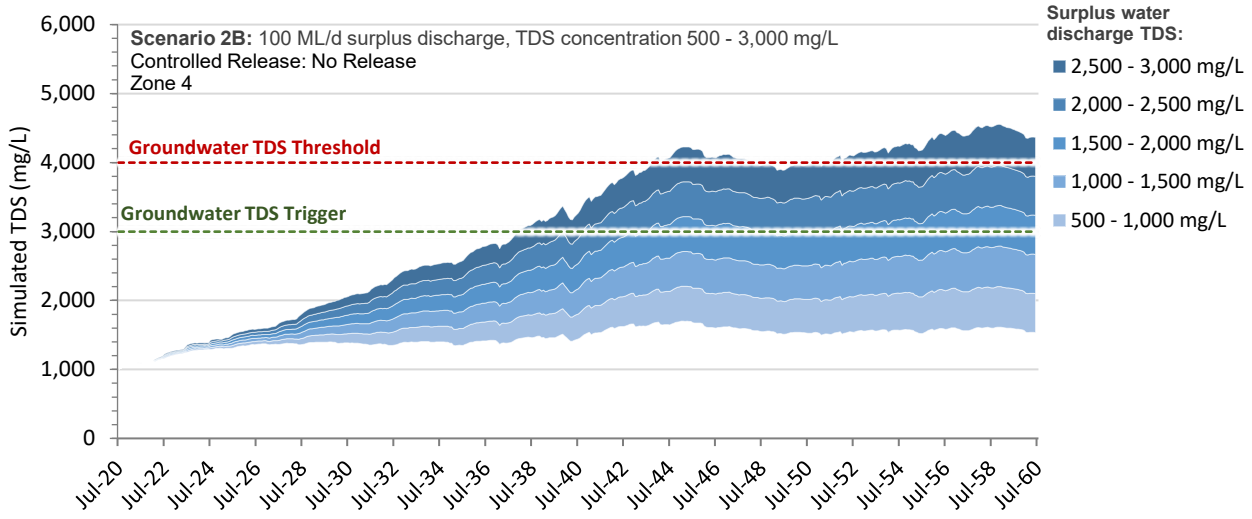
E.3.3 Predicted groundwater TDS (Zone 3)

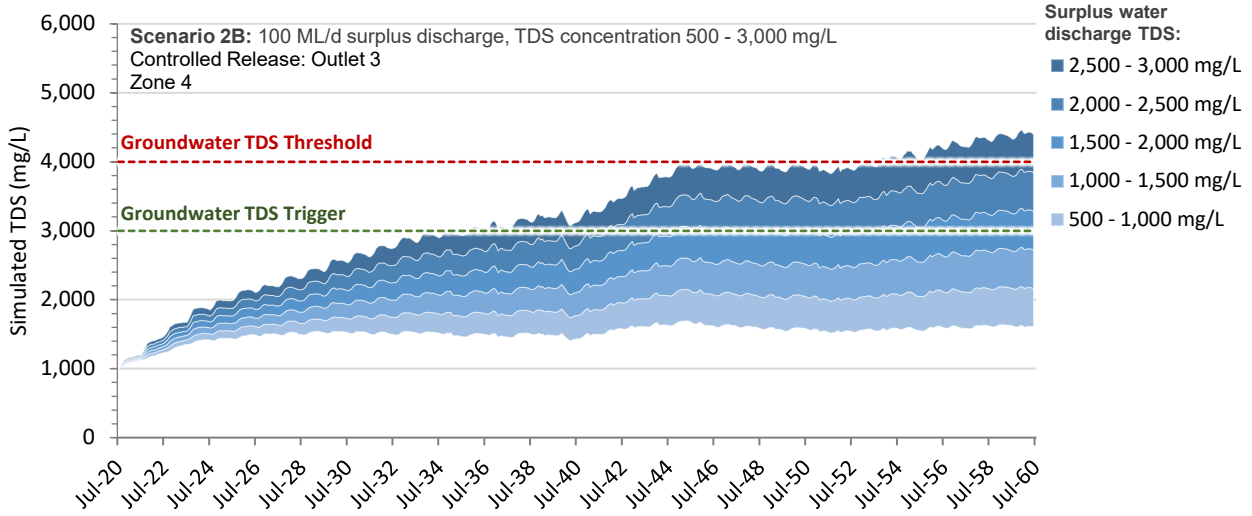


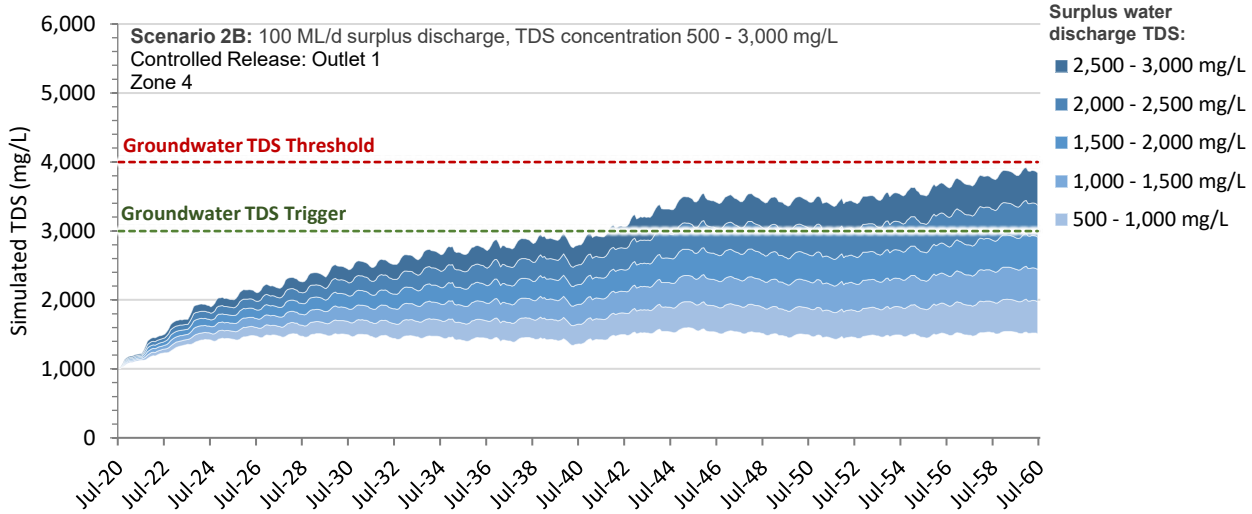




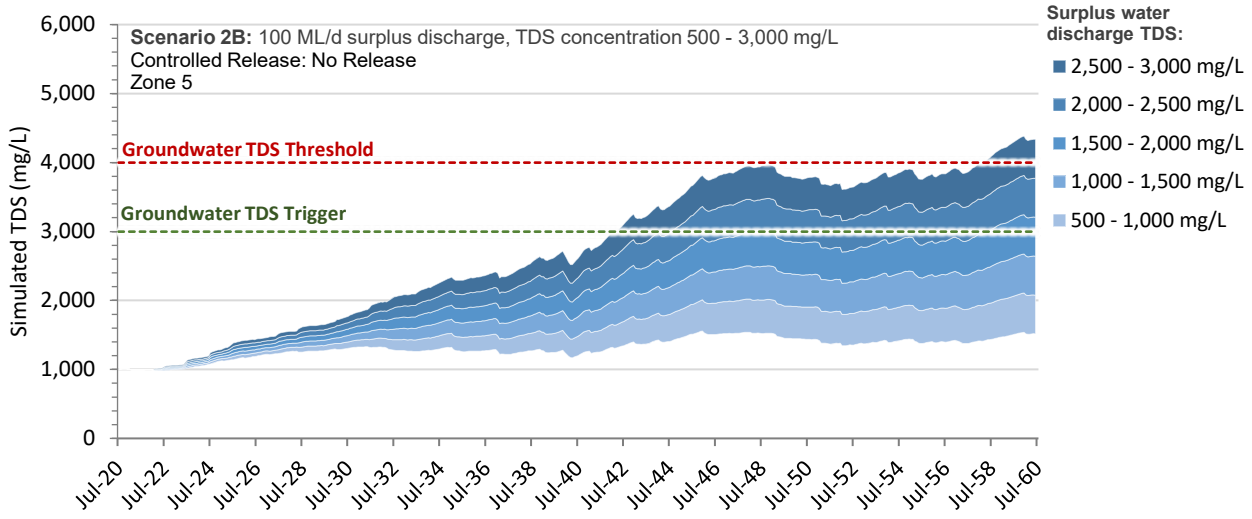
E.3.4 Predicted groundwater TDS (Zone 4)

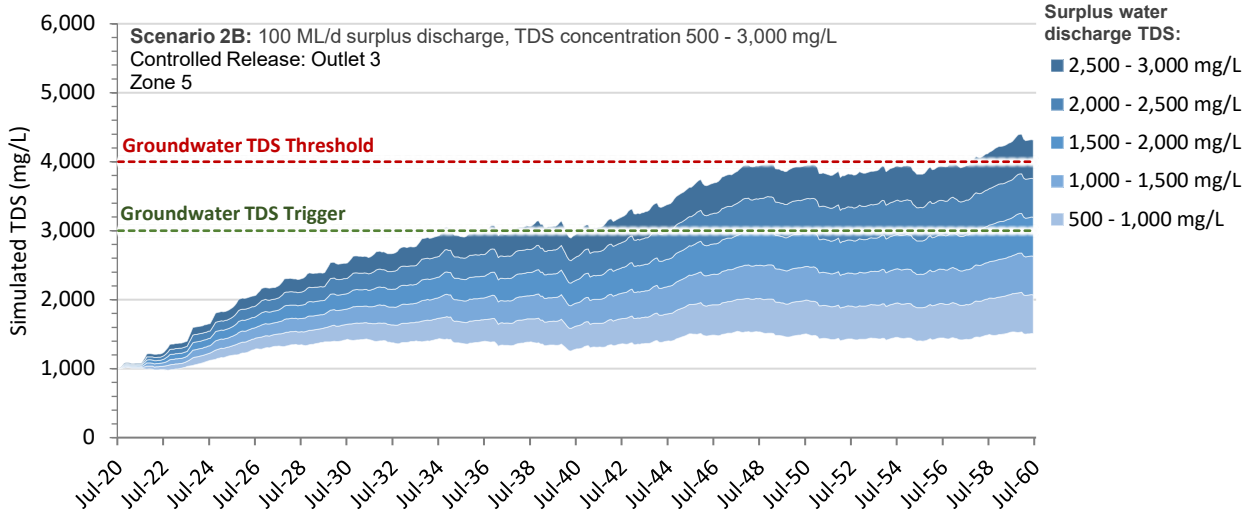


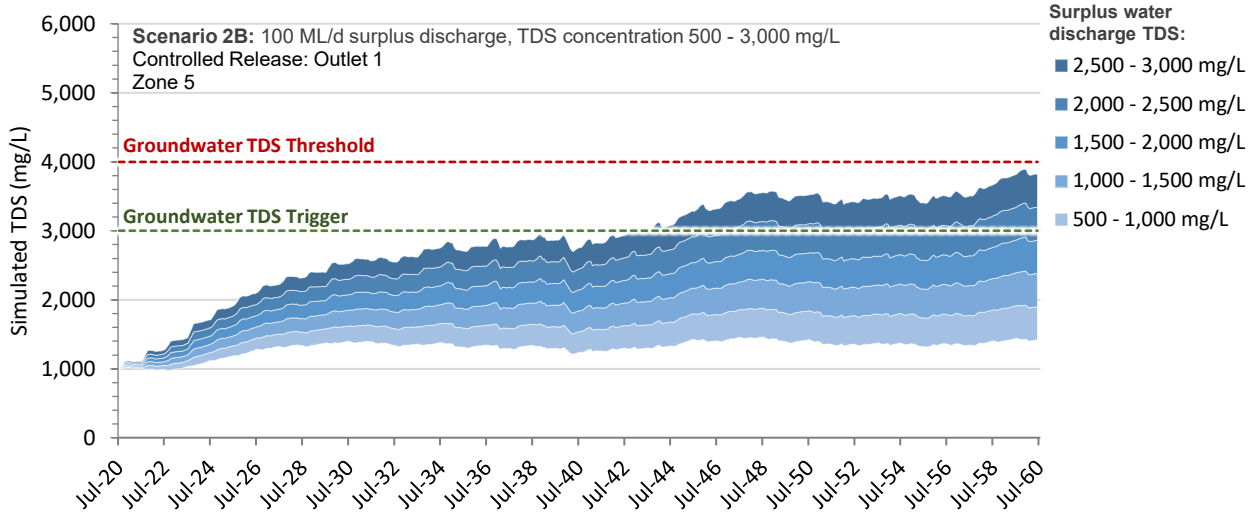




E.3.5 Predicted groundwater TDS (Zone 5)

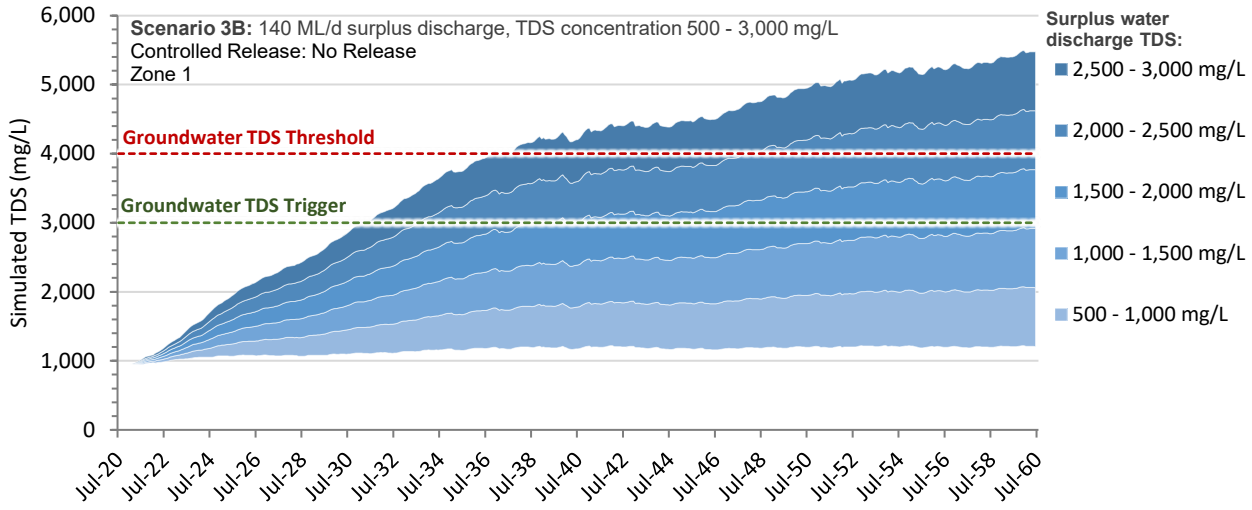


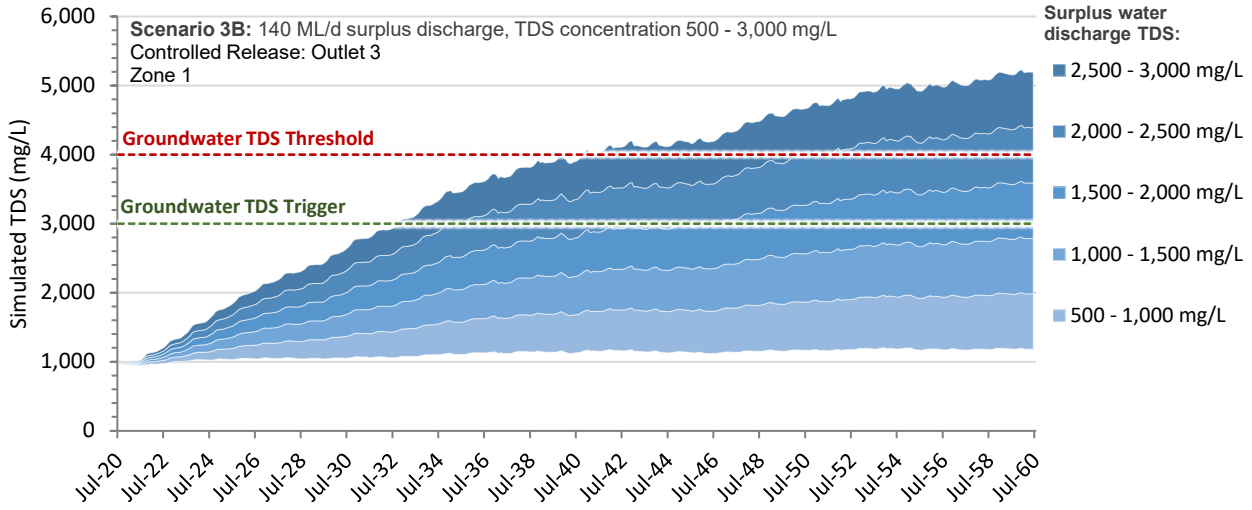


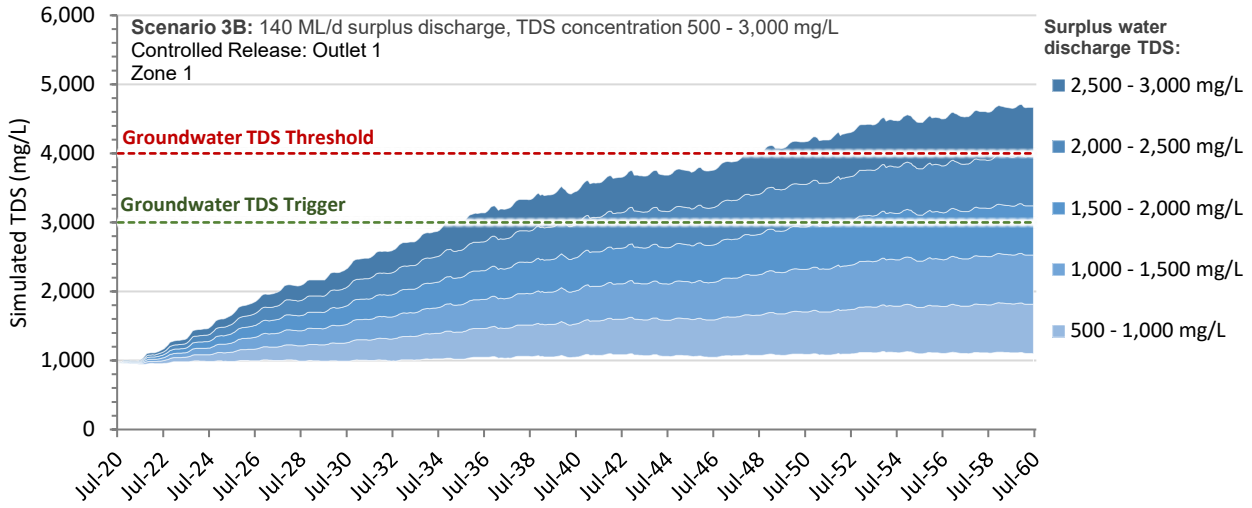


E.4 Groundwater TDS predictions: Scenario 3B: Surplus discharge 140 ML/d

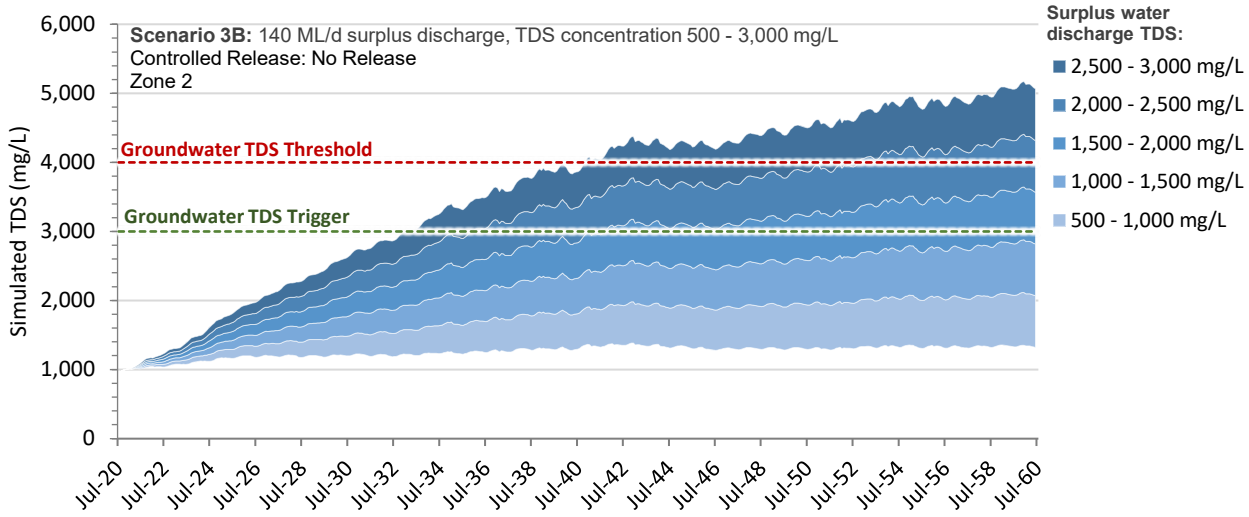
E.4.1 Predicted groundwater TDS (Zone 1)

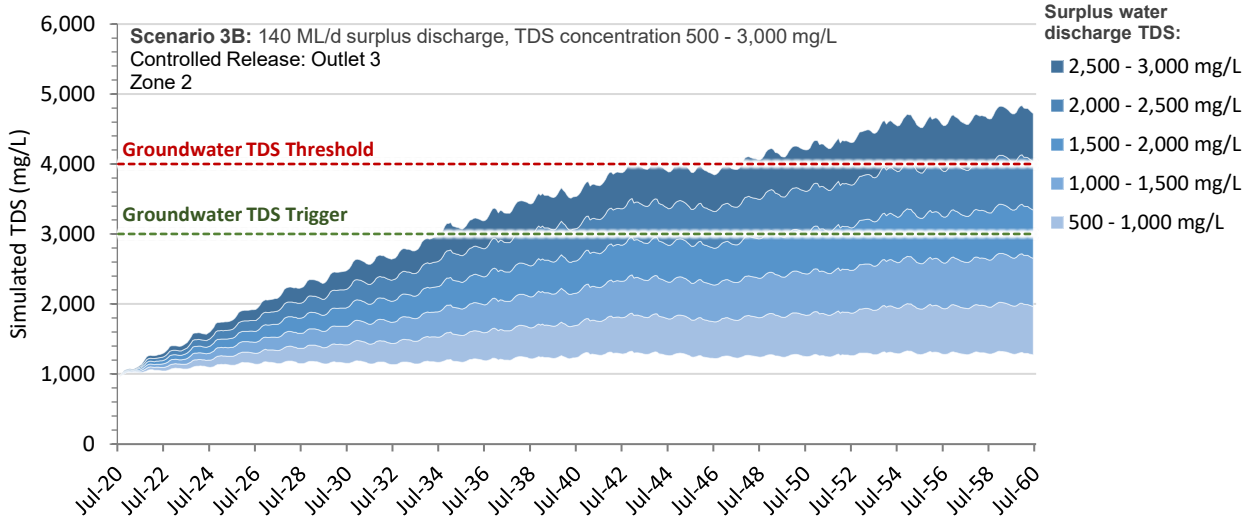


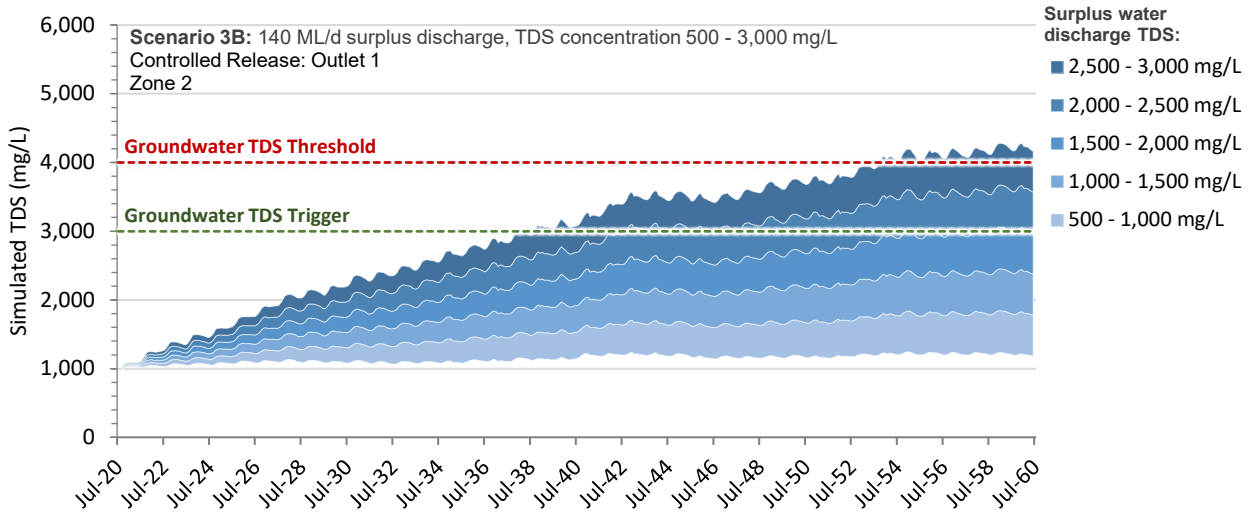




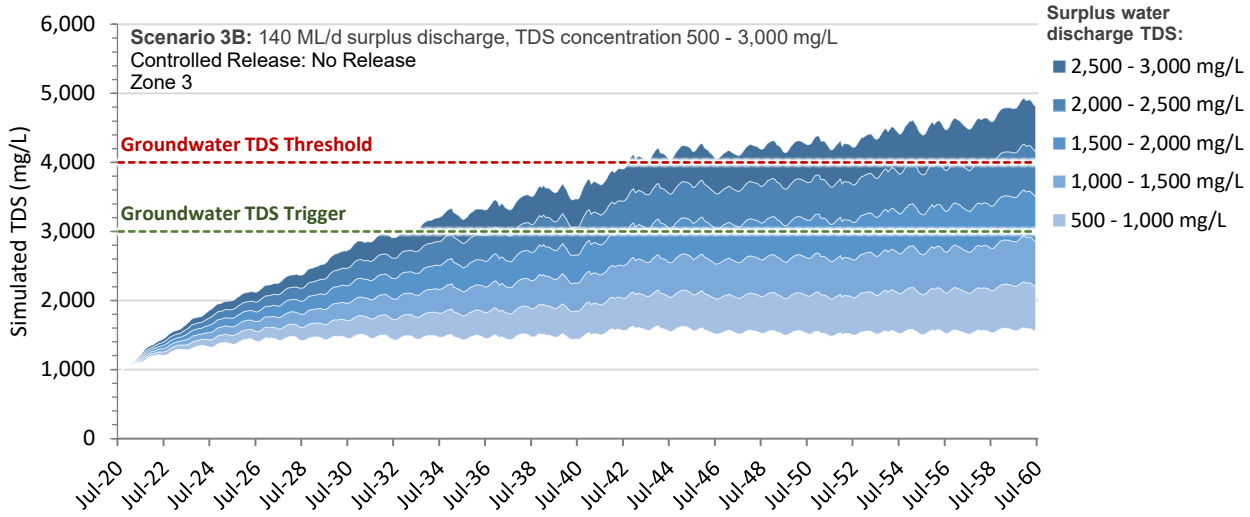
E.4.2 Predicted groundwater TDS (Zone 2)

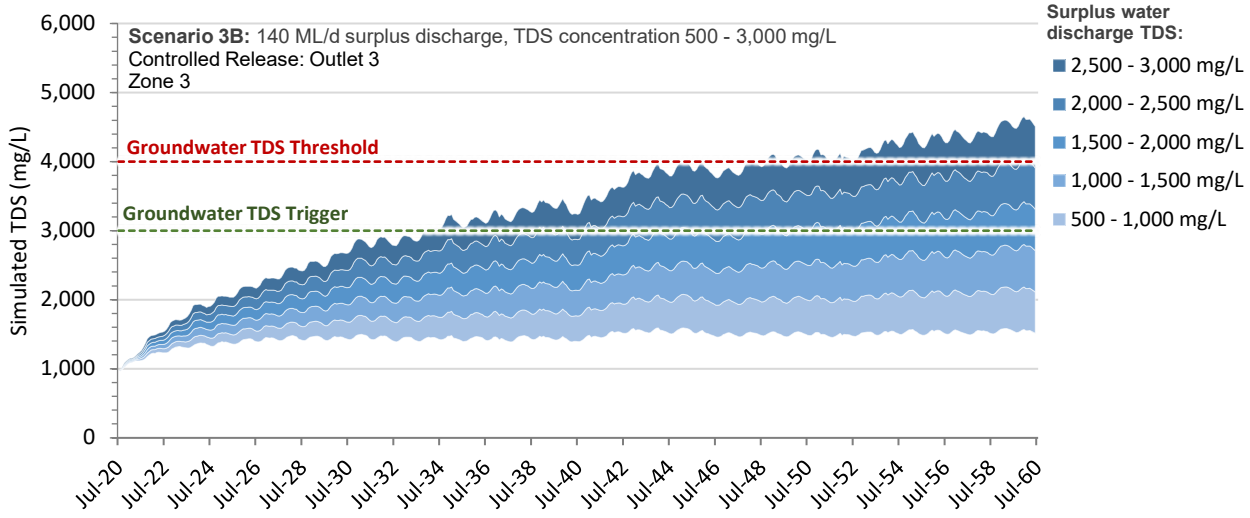


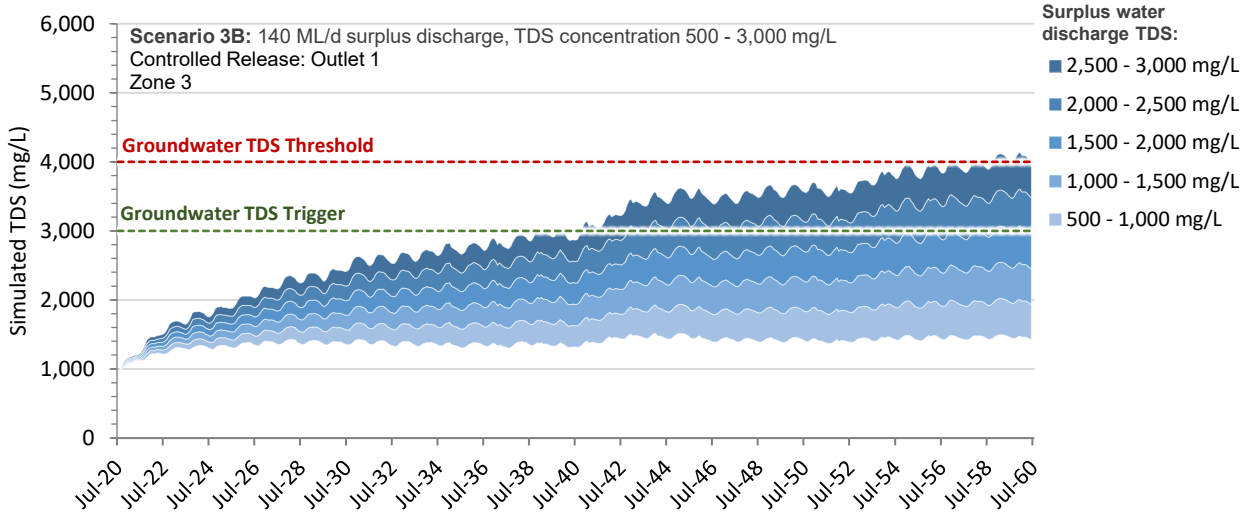




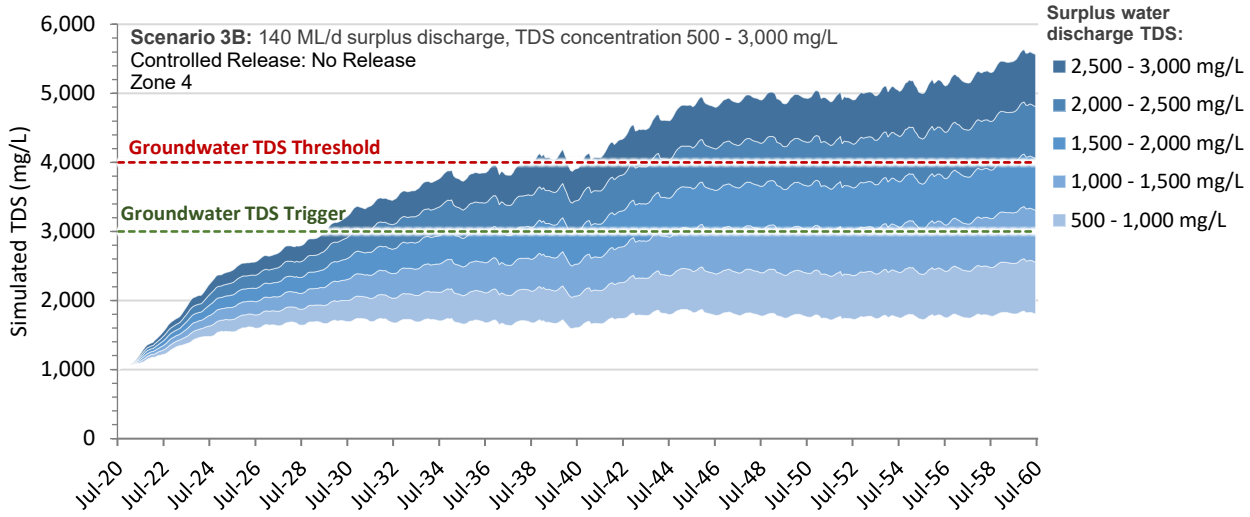
E.4.3 Predicted groundwater TDS (Zone 3)

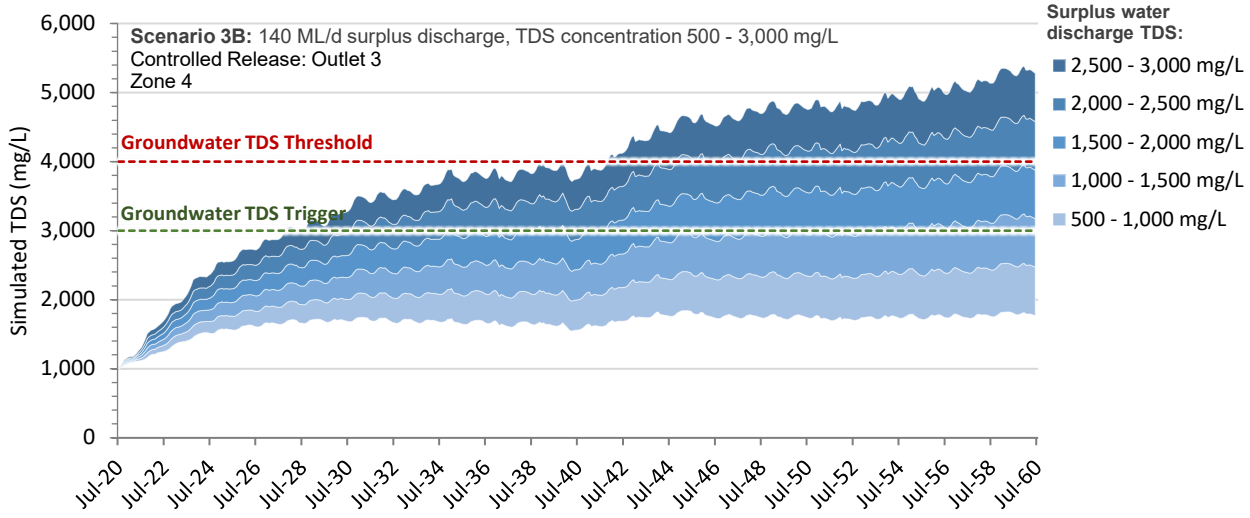


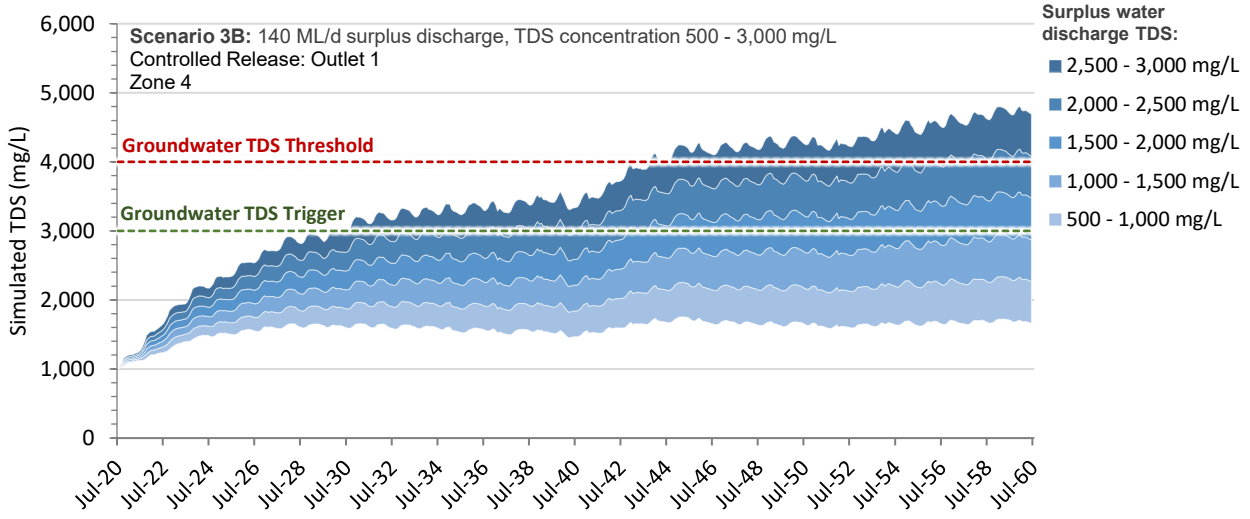




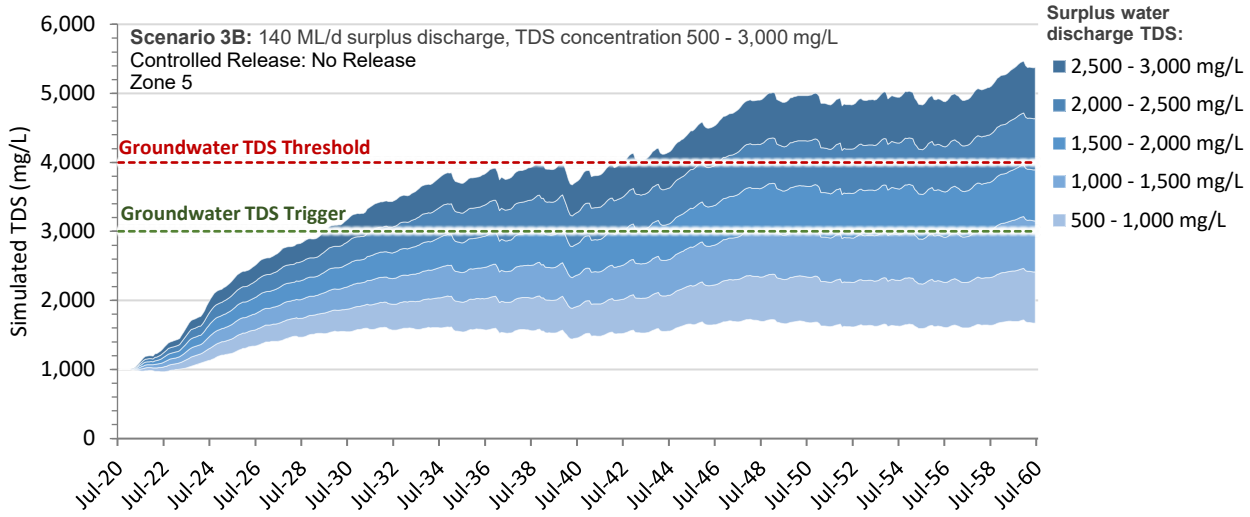
E.4.4 Predicted groundwater TDS (Zone 4)

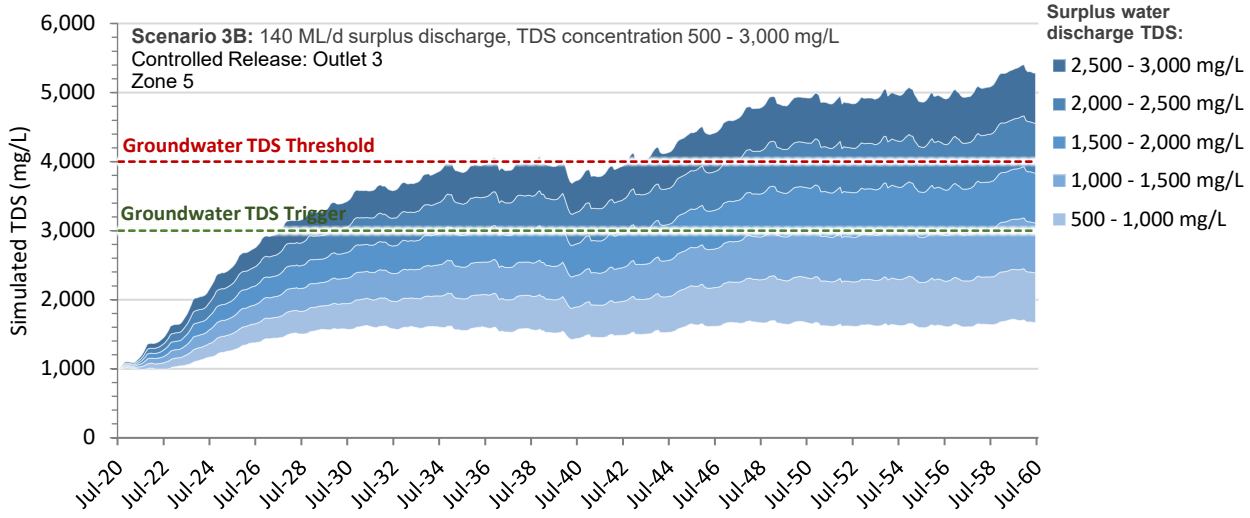


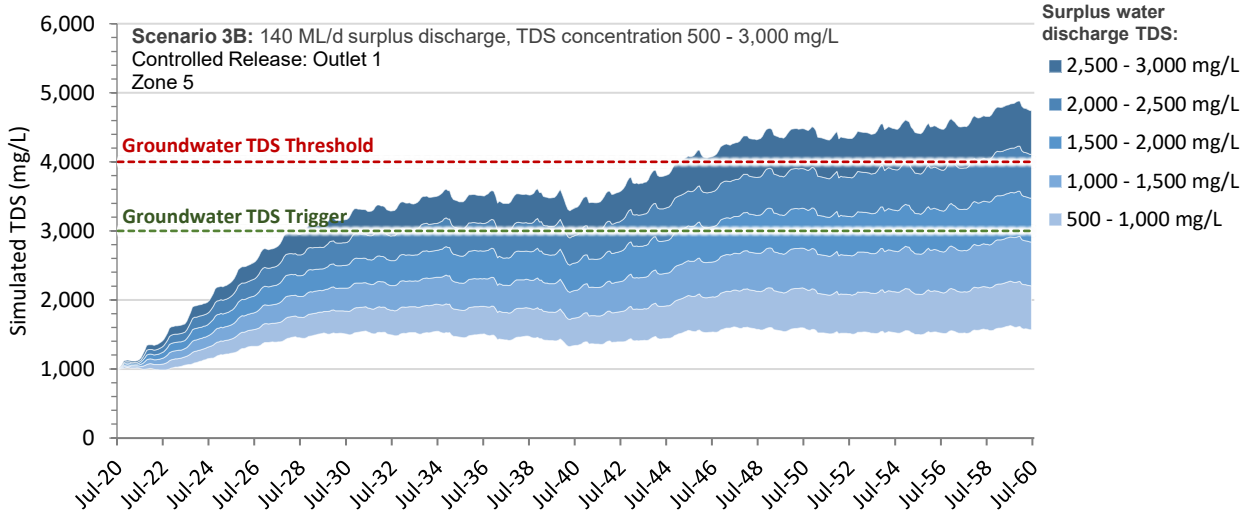




E.4.5 Predicted groundwater TDS (Zone 5)



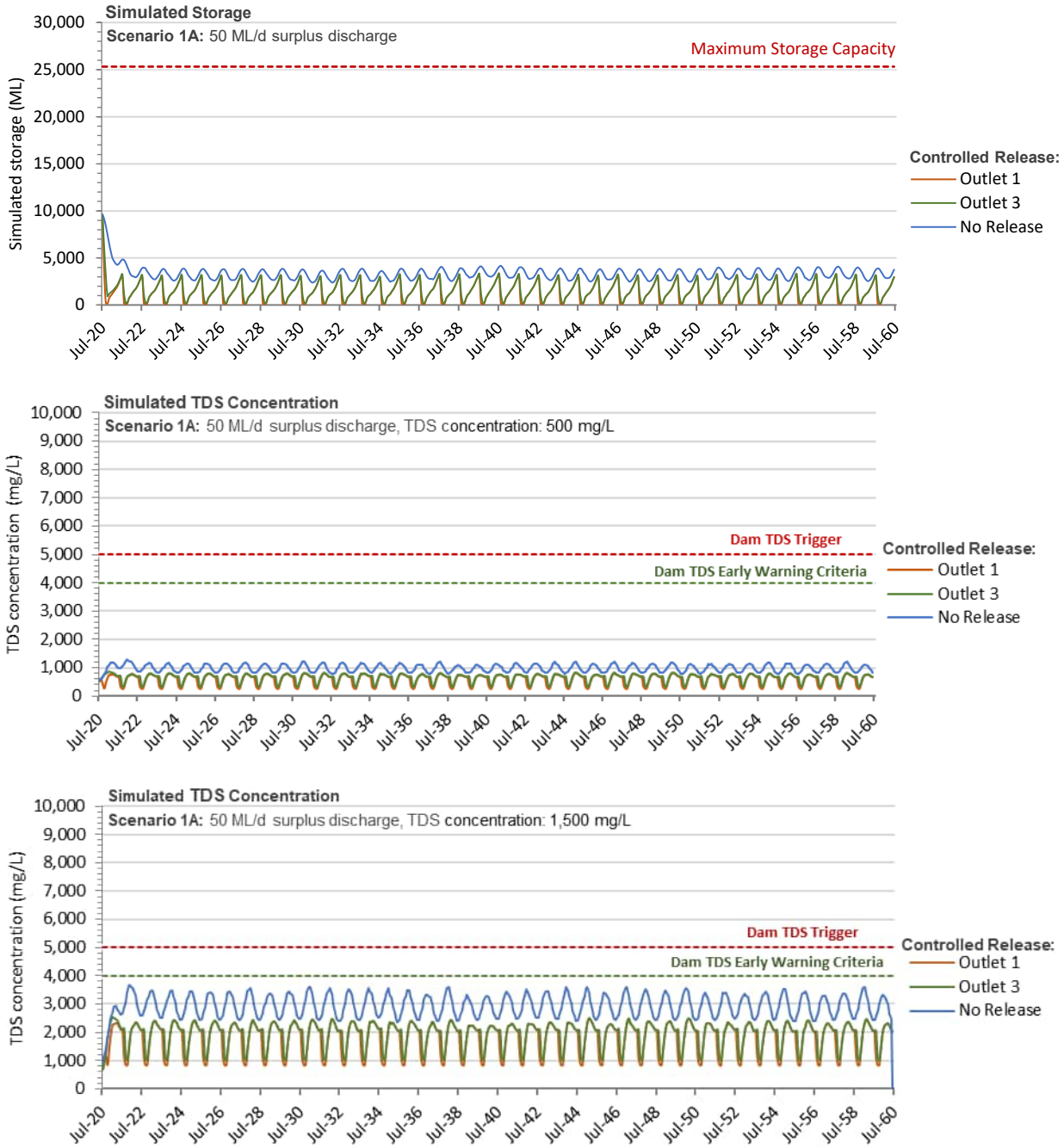


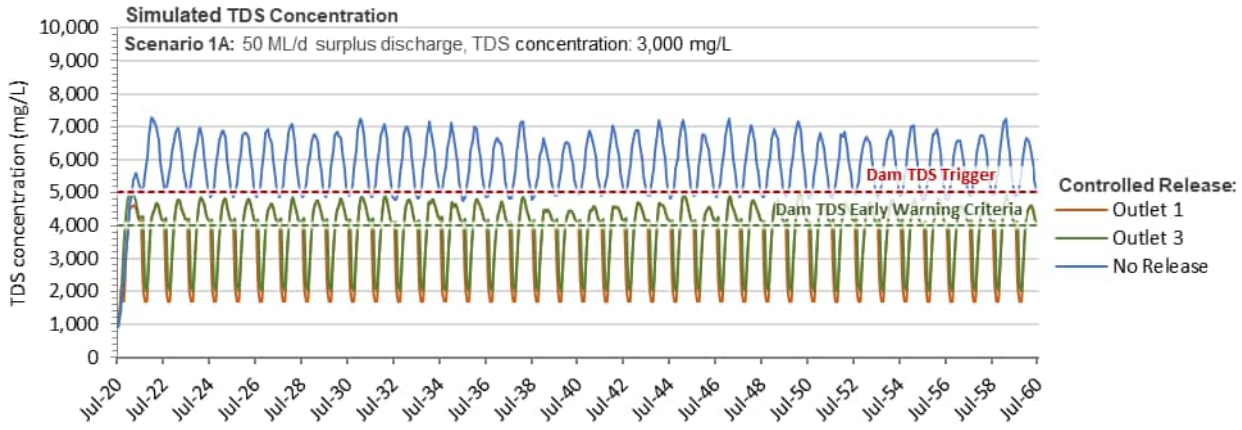


Appendix F

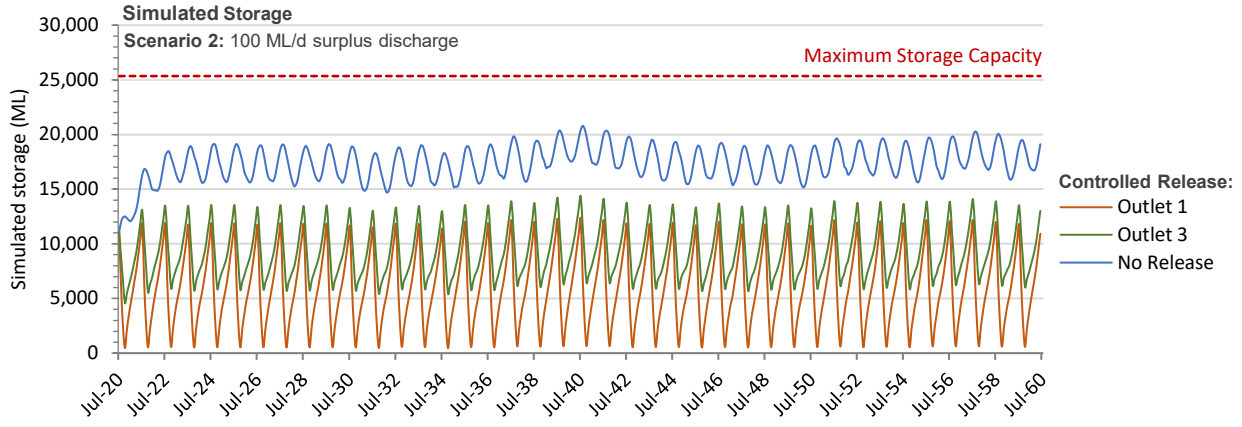
Dry climate scenarios

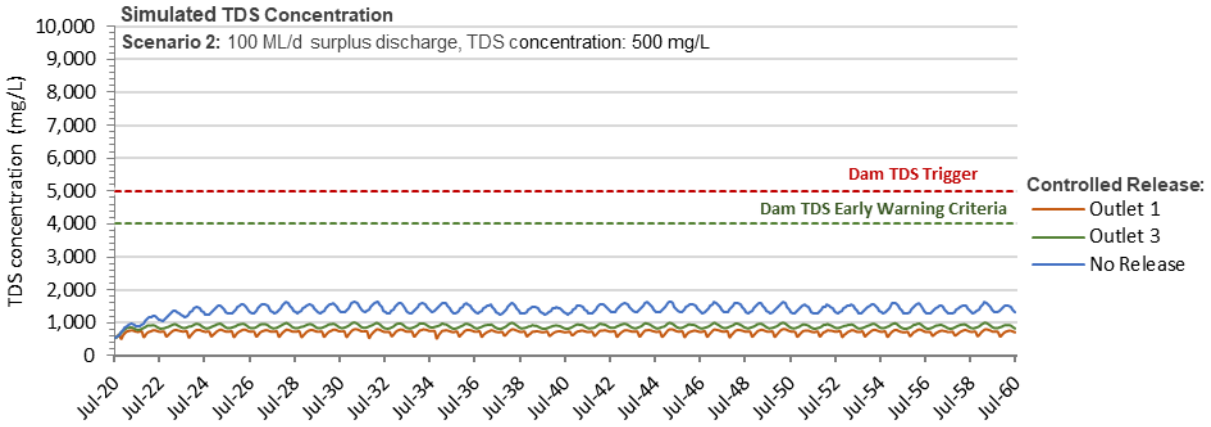
F.1 Ophthalmia Dam TDS predictions: Scenario 1: Surplus discharge 50 ML/d

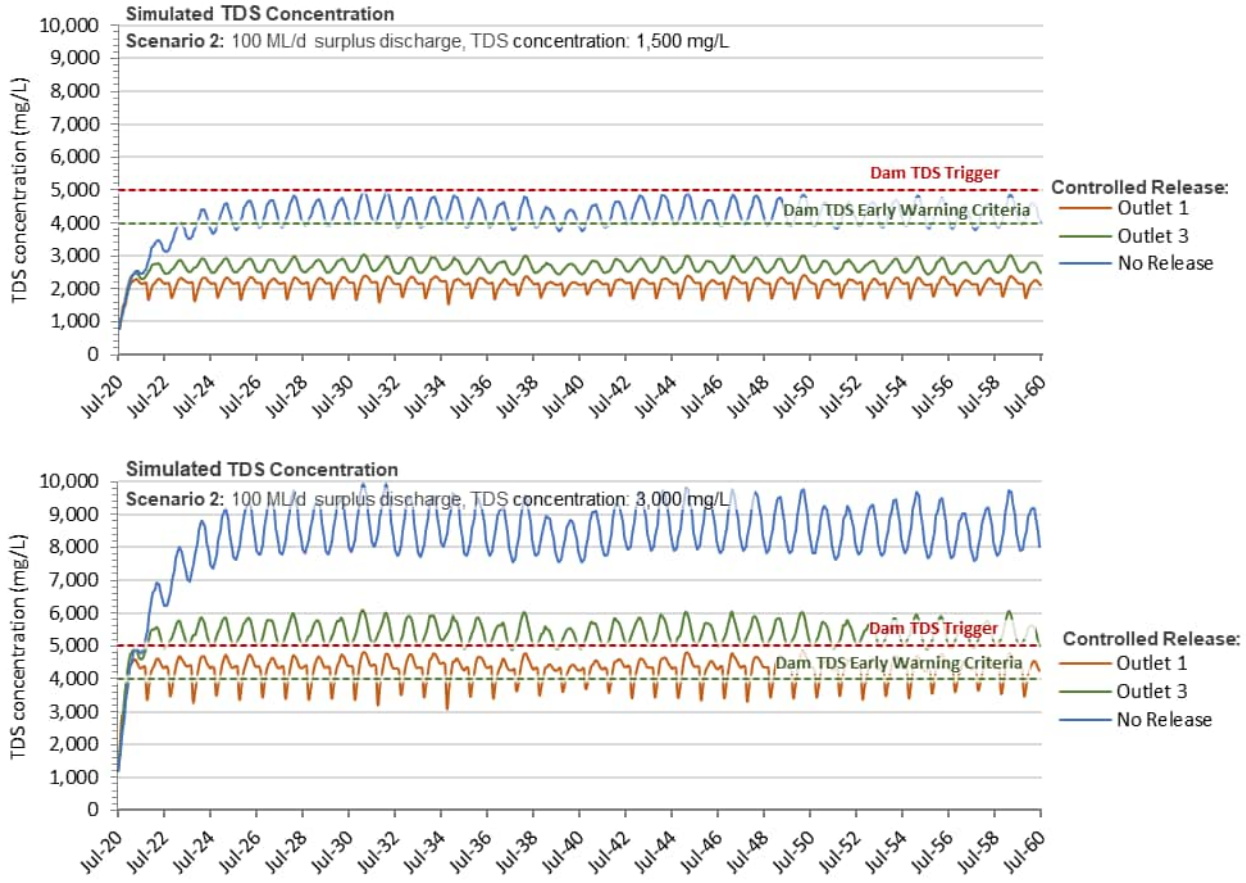




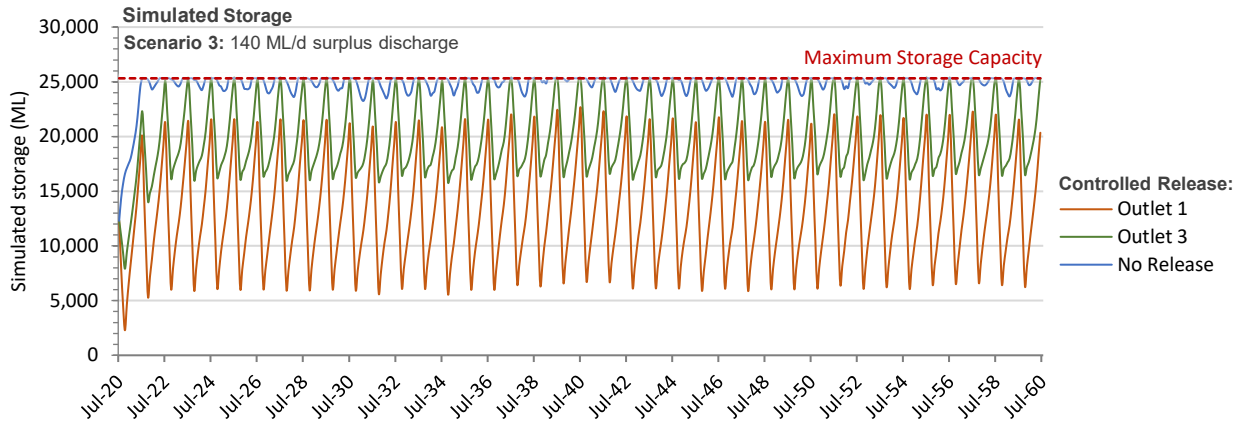
F.2 Ophthalmia Dam TDS predictions: Scenario 2: Surplus discharge 100 ML/d

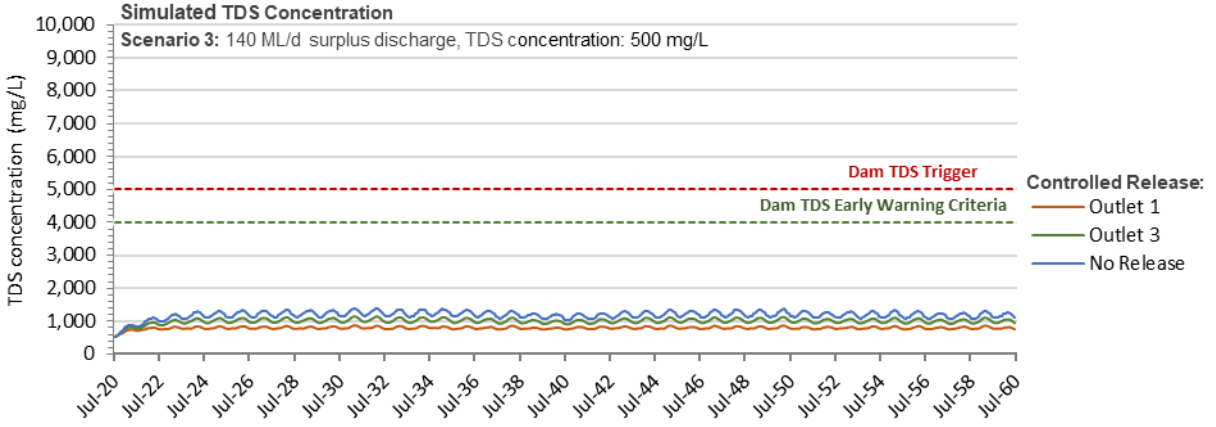


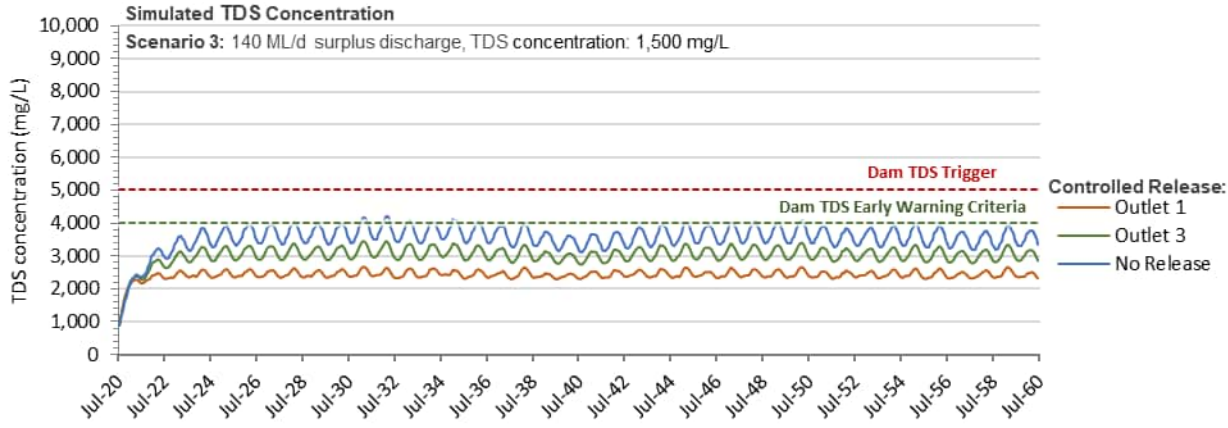


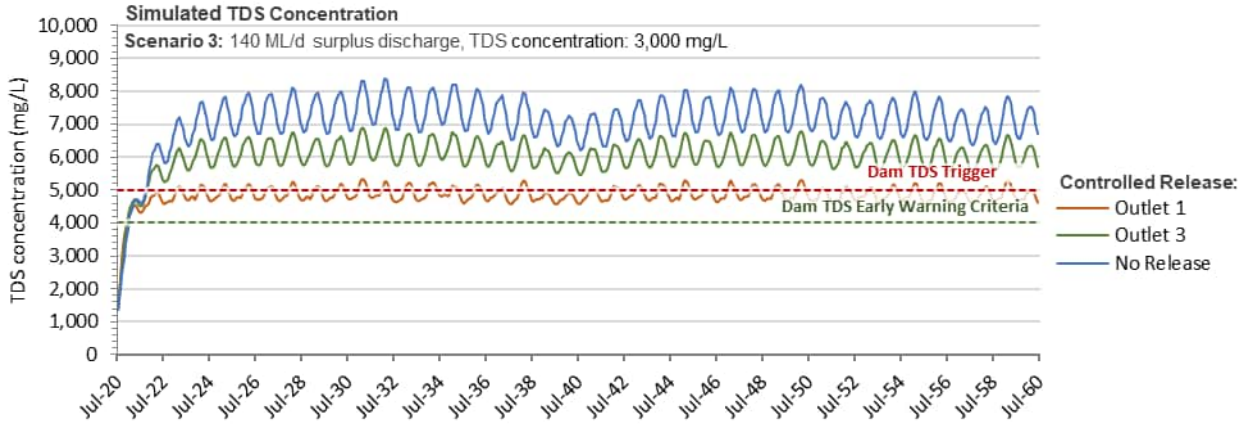


F.3 Ophthalmia Dam TDS predictions: Scenario 2: Surplus discharge 140 ML/d




Simulated TDS Concentration
Scenario 3: 140 ML/d surplus discharge, TDS concentration: 500 mg/L
TDS concentration (mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Dam TDS Trigger
Dam TDS Early Warning Criteria
Controlled Release:
Outlet 1
Outlet 3
No Release
Jul-20
Jul-22
Jul-24
Jul-26
Jul-28
Jul-30
Jul-32
Jul-34
Jul-36
Jul-38
Jul-40
Jul-42
Jul-44
Jul-46
Jul-48
Jul-50
Jul-52
Jul-54
Jul-56
Jul-58
Jul-60


Simulated TDS Concentration
Scenario 3: 140 ML/d surplus discharge, TDS concentration: 1,500 mg/L
TDS concentration (mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Dam TDS Trigger
Dam TDS Early Warning Criteria
Controlled Release:
Outlet 1
Outlet 3
No Release
Jul-20
Jul-22
Jul-24
Jul-26
Jul-28
Jul-30
Jul-32
Jul-34
Jul-36
Jul-38
Jul-40
Jul-42
Jul-44
Jul-46
Jul-48
Jul-50
Jul-52
Jul-54
Jul-56
Jul-58
Jul-60


Simulated TDS Concentration
Scenario 3: 140 ML/d surplus discharge, TDS concentration: 3,000 mg/L
TDS concentration (mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Dam TDS Trigger
Dam TDS Early Warning Criteria
Controlled Release:
Outlet 1
Outlet 3
No Release
Jul-20
Jul-22
Jul-24
Jul-26
Jul-28
Jul-30
Jul-32
Jul-34
Jul-36
Jul-38
Jul-40
Jul-42
Jul-44
Jul-46
Jul-48
Jul-50
Jul-52
Jul-54
Jul-56
Jul-58
Jul-60