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Executive Summary

CyMod Systems was appointed to undertake an independent review of the numerical groundwater models, which were constructed and calibrated to assess the potential impacts of the proposed K+S Ashburton Salt Project on environmental receptors.

The review found a significant amount of site-specific data has been collected by GHD and the report provides a summary of the field and laboratory analysis undertaken. As a general comment, the field data could have been collected over a larger area, and for longer periods of time, however ongoing monitoring prior to construction should address this issue. The conceptual model of the area is consistent with field investigations and includes all important processes relevant to the development area.

Based on the review of the original numerical model (V1) presented in the June 2021 report it was considered that the model is fit for purpose. However, there were two important limitations in the model that may result in model predictions having significant uncertainty: the lack of vertical resolution of the grid in the 1A/B geological unit, and an overly simplified estimate of evapotranspiration (EVT) on the supratidal area, where salt crusts are formed. In both cases the uncertainty may result in the overestimate of salinity changes in the upper layer of the model.

Subsequently, the original model was modified by dividing layer 1 into 3 additional layers. The resulting model, designated V2, is used to assess the changes in water levels and salinity in the project area, for model scenarios. Results from the V2 model are consistent with the above conceptual model, with salinity lower and water levels higher after 50 years, than in the original model. Based on the review of the updated numerical model (V2) the model is fit for purpose and should be used in preference to V1.

Given that the models are characterized as Level 1, additional transient data should be collected in the following areas:

- Intertidal area of mangroves, with water level, and water quality measured at a sub-daily interval, to better characterize tidal influences.
- The installation of additional piezometers immediately downstream of proposed ponds, to provide baseline data prior to pond construction and filling.
- After pond filling, monitoring of water levels and water quality at various distances from filled ponds should be taken at sub monthly intervals.

The above data should then be used to improve the conceptual hydrogeological model by better quantifying the relevant processes in the project area.

Baseline groundwater monitoring, in consultation with the regulator should also commence as soon as possible, to ensure an adequate time period of data acquisition, to enable required modelling revisions.

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1. Introduction

K+S appointed CyMod Systems to undertake an independent review of the numerical groundwater model of the area proposed for the Ashburton Solar Salt Operations. The model was constructed and calibrated to assess the potential impacts of the proposed Ashburton Salt Operations on environmental receptors in the vicinity of the development, due to seepage of high salinity water from solar salt ponds.

This review includes the assessment of an updated model, V2, that is a modified version of the V1 model that incorporates the changes recommended in the V1 model review undertaken in June 2021 (i.e., grid refinement and modified evaporation).

GHD Pty Ltd (GHD) undertook the numerical groundwater modelling on behalf of K+S, utilising the MODFLOW-USG-T software. Please note that CyMod Systems did not audit input and output model files and has only conducted a review of the report, and a memorandum provided in Appendix A. The review is based on the document *GHD, 2021. K+S Salt Australia Ltd Ashburton Solar Salt Project Hydrogeological Investigation, Report 12516706*, and the GHD Memorandum *Ashburton groundwater modelling - updated results.* Consequently, CyMod Systems cannot make any comment on the veracity of information presented in the GHD report.

The objectives of the review are:

1. to meet the requirements of the WA Environmental Protection Authority (EPA), who require a peer review of a groundwater model submitted in support of a regulatory approval process; and
2. provide feedback in the form of recommendations to K+S to ensure the model is fit for purpose.

The scope of work for the review consisted of:

1. Reviewing the modelling report, as submitted by GHD, against the Australian Groundwater Modelling Guidelines (National Water Commission 2012).
2. Review the supporting documents and reports; and
3. Provide recommendations that may improve the results of the model in terms of level of confidence and reduced uncertainty.

CyMod Systems conducted an independent model review based on the Australian Groundwater Modelling Guidelines (NWC, 2012). These guidelines are generic, in the sense they are applicable to any specific modelling application and represent a reasonable standard framework in which to assess groundwater modelling. The guidelines provide a series of modelling components to be considered, which includes:

- Planning;
- Conceptualization;
- Design;
- Construction;
- Calibration;
- Predictions;
- Uncertainty; and
- Solute Transport.

Each of these components was assessed by completing the relevant sections in Table 9.2 of the Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

2. Compliance Review

Table 2-1 summarizes the compliance review as set out in the Australian Groundwater Modelling Guidelines Table 9.1. The use of the term “maybe” implies that the project complies with the majority of the requirements, as set out in the question, but the lack of documentation or missing information prevents assigning a yes. Outstanding issues and deficiencies are discussed in more detail below, using Table 9.2 of the Australian Groundwater Modelling Guidelines.

Table 2-1: Compliance Review

Question	Yes/No	Comments
1. Are the model objectives and model confidence level classification clearly stated?	Yes	Model objectives are clearly stated Model is assessed as Level 1, which is correct for this model.
2. Are the objectives satisfied?	Maybe	Refer to Table 3-1
3. Is the conceptual model consistent with objectives and confidence level classification?	Yes	
4. Is the conceptual model based on all available data, presented clearly, and reviewed by an appropriate reviewer?	Yes	
5. Does the model design conform to best practice?	Yes	
6. Is the model calibration satisfactory?	Maybe	Calibration error is similar in magnitude to changes in salinity that may be important to ecological receptors. However, comparing models or the change in state of the model over time should be more accurate.
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes	
8. Do the model predictions conform to best practice?	Maybe	Model needs to better account for the export of salt and nutrients from the intertidal and supratidal areas.
9. Is the uncertainty associated with the predictions reported?	Yes	
10. Is the model fit for purpose?	Yes	Model may be conservative in that it could over predict the change in groundwater quality in environmental sensitive areas.

3. Model Planning

Table 3-1: Model Guidelines - Planning

Question	Yes Maybe No	Comments
1.1 Are the project objectives stated?	Yes	
1.2 Are the model objectives stated?	Yes	Model objectives are clearly stated
1.3 Is it clear how the model will contribute to meeting the project objectives?	Yes	
1.4 Is a groundwater model the best option to address the project and model objectives?	Yes	Provides quantitative estimates of impacts of ponds on water quality around mangroves and algal matts in the short and medium term
1.5 Is the target model confidence-level classification stated and justified?	Yes	A classification 1 is appropriate for this model, as limited time series data are available, and the model uses time invariant average values for most processes.
1.6 Are the planned limitations and exclusions of the model stated?	Yes	Model limitations are discussed in section 9.7. However, the discussion is generic and does not address the specific limitations of this model.

4. Conceptualisation

Table 4-1: Model Guidelines - Conceptual Model

Question	Yes Maybe No	Comments
2.1 Has a literature review been completed, including examination of prior investigations?	Yes	Literature review is incomplete with respect to flushing and the estimate of EVT
2.2 Is the aquifer system adequately described?	Yes	
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Yes	
2.2.2 lateral extent, boundaries, and significant internal features such as faults and regional folds	Yes	
2.2.3 aquifer geometry including layer elevations and thicknesses	Yes	Aquifer geometry has been generalized
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	Yes	Limited analysis of time varying flows
2.3 Have data on groundwater stresses been collected and analysed?	Yes	Stresses defined as long term averages – hence quasi steady state
2.3.1 recharge from rainfall, irrigation, floods, lakes	Yes	Stresses defined as long term averages – hence quasi steady state
2.3.2 river or lake stage heights	Yes	The effects of supratidal inundation at spring tides have been addressed with respect to the export of mass, while avoiding the complexity of simulating surface flow.

2.3.3 groundwater usage (pumping, returns etc.)	NA	There is no abstraction from the model area, other than what was undertaken as part of the field investigations.
2.3.4 evapotranspiration	Yes	Conceptualization may be too simple, as work done on salt crusts show they reduce evaporation significantly. Consequently, the assumption of high evaporation may only apply when the areal extensive salt crust is absent, such as after inundation or rainfall, and then only for a few days until it is re-established by evaporation of brine.
2.3.5 other?		
2.4 Have groundwater level observations been collected and analysed?	Yes	
2.4.1 selection of representative bore hydrographs	No	Only successfully measured two bores, both of which are away from the supratidal flats in the pond areas. Limited time series data restricts the model classification to Level 1.
2.4.2 comparison of hydrographs	Yes	
2.4.3 effect of stresses on hydrographs	Yes	Effect of rainfall on water levels on the tidal and supratidal flats has been established. Pumping test
2.4.4 water table maps/piezometric surfaces?	No	A constrained, density-corrected water level elevation map needs to be provided.
2.4.5 If relevant, are density and barometric effects been considered in the interpretation of groundwater head and flow data?	Yes	Density effects have been accounted for, as shown in Table 7.2. The equivalent freshwater heads are significantly higher than measured levels, suggesting hydraulic gradients are steeper and that dense groundwater under the supratidal flats may be acting as a groundwater mound
2.5 Have flow observations been collected and analysed?	Yes	Reported by Water Technology (2021)
2.5.1 baseflow in rivers	Yes	Reported by Water Technology (2021)
2.5.2 discharge in springs	NA	
2.5.3 location of diffuse discharge areas?	Yes	
2.6 Is the measurement error or data uncertainty reported?	No	
2.6.1 measurement error for directly measured quantities (e.g., piezometric level, concentration, flows)	No	
2.6.2 spatial variability/heterogeneity of parameters	Yes	
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	No	Conceptual geological model constructed in Leapfrog
2.7 Have consistent data units and geometric datum been used?	Yes	
2.8 Is there a clear description of the conceptual model?	Yes	The conceptual hydrogeological model is well described, with complete water and mass balances provided for the model area.

2.8.1 Is there a graphical representation of the conceptual model?	Yes	
2.8.2 Is the conceptual model based on all available, relevant data?	Yes	
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Yes	The model is consistent with model classification The model adequately accounts for processes in supratidal and algal mats areas.
2.9.1 Are the relevant processes identified?	Yes	
2.9.2 Is justification provided for omission or simplification of processes?	Yes	
2.10 Have alternative conceptual models been investigated?	No	

4.1 Conceptual Model Uncertainties

The conceptual model as described in the report is similar to that proposed by Blandford and Associates (2005) but includes additional mechanisms that account for the export of salt from the supratidal zone and flushing in the intertidal zone. The modified conceptual model tends to have greater fidelity to actual process occurring in the project area. The review of the conceptual model suggests that specific yield may not be adequately characterized, as indicated below.

4.2 Specific Yield

A brief review of estimates of specific yield from particle size distribution of field samples is shown in Table 4-2. Estimates of specific yield have been taken from Figure 4-1 based on silt/clay content measured in soil samples. The data suggests that a specific yield of 0.05 and an effective porosity of 0.10 as suggested in the conceptual model for the 1A/B formation are reasonable but conservative. The limited data for the 2A and 2B formations suggests a low specific yield may also be conservative.

The effective porosity of 0.10 as used in the 1A/B unit is consistent with conservative estimates of these properties, as indicated in the report. The low effective porosity will increase the impact of seepage and EVT, in terms of rate of change in salinity and groundwater level changes.

It is also noted that test pumping of BH7 TB, BH10 TB measured responses primarily in the 2A/B formation and indicated a specific yield of 0.05. It is likely the 1A/B formation will have higher specific yield, given higher sand content.

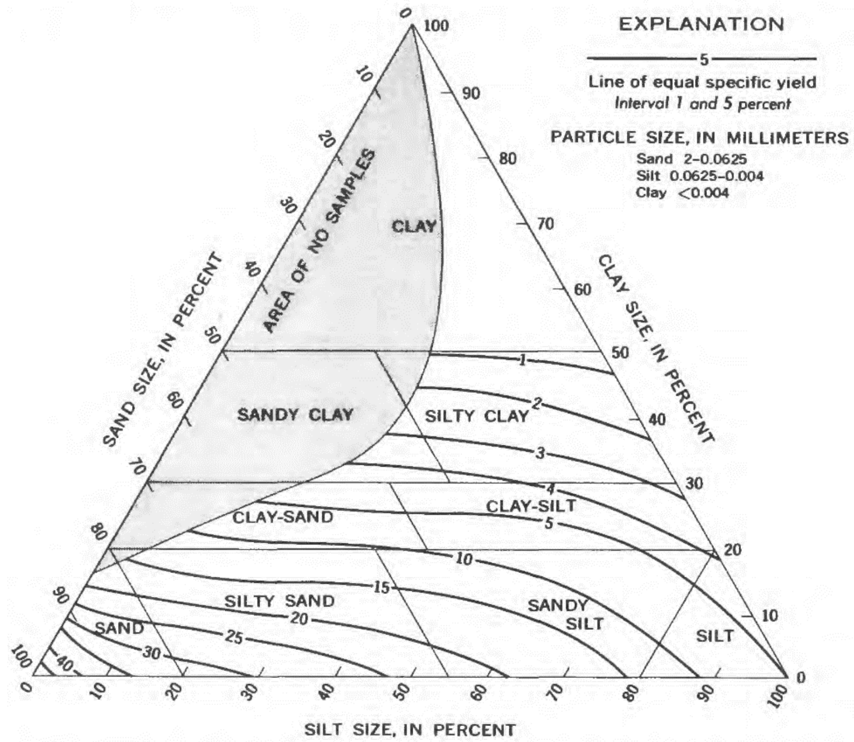

Figure 4-1: Soil Classification showing Relationship between Particle Size and Specific Yield (Johnson, 1968)

Table 4-2: Review of Specific Yield Estimates from Particle Size Distribution of Field Samples

Sample	Depth	<0.075 mm	%Clay	%Silt	Sy
BH1	4	20	10	10	0.2
BH7	2	20	10	10	0.2
BH7	7	20	10	10	0.2
BH9	1	30	10	20	0.22
BH9	5	30	10	20	0.22
BH9	13	30	10	20	0.22
BH10	2	40	20	20	0.10
BH10	7	90	50	50	0.01
BH10	11	20	10	10	0.25
AU-1	2	0	0	0	0.40
AU-2	2	25	10	15	0.15
AU-2	0.5	25	20	10	0.12
AU-2	3	30	20	10	0.12
AU-3	1	42	20	20	0.10
AU-22	1	60	30	30	0.04
AU30	2	28	15	13	0.15
AU-60	2	40	20	20	0.10
AU-101	1	50	30	20	0.04
AU-101	3	30	20	10	0.12
AU-102	1	35	20	15	0.10
BH-1	2	26	18	8	0.12
BH-07	1	34	20	14	0.10
BH-10	2	47	27	20	0.05
BH-11	1	41	30	11	0.05
BH-14	3	33	27	4	0.07
AU-74	1	58	35	24	0.04
AU-75	2	72	22	50	<0.01
AU-102	2	36	24	12	0.07
HA-10	1	40	32	8	0.04
HA-11	0.5	73	60	13	<0.01
DCP-05	0.5	51	30	20	0.045
IT-05	0.5	50	6	45	0.20

5. Model Design and Construction

Table 5-1: Model Guidelines - Design and Construct

Question	Yes Maybe No	Comments
3.1 Is the design consistent with the conceptual model?	Yes	
3.2 Is the choice of numerical method and software appropriate?	Yes	
3.2.1 Are the numerical and discretisation methods appropriate?	Yes	
3.2.2 Is the software reputable?	Yes	MODFLOW USG-T
3.2.3 Is the software included in the archive or is references to the software provided?	Yes	Panday, S., 2022: USG-Transport version 1.9.0: The Block-Centred Transport process for MODFLOW-USG. GSI Environmental.
3.3 Are the spatial domain and discretisation appropriate?	No	Non-uniform grid accounts for both calibration and forward prediction models. Vertical discretisation is coarse given the near surface processes that dominate in the model.
3.3.1 1D/2D/3D	3D	
3.3.2 lateral extent	Yes	Model covers an extensive area beyond the bounds of the development area.
3.3.3 layer geometry?	Yes	Layering is consistent with the simple geological model proposed for the area in the conceptualization. Model V2 has a refined top layer, with the addition of 3 layers in the 1A/B formation (layers 1 and 2).
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model, and target confidence level classification?	Yes	Discretisation meets solute transport criteria. Minimum grid resolution is consistent with model classification and the characteristic length of hydrogeological features. Resolution is consistent with expected hydraulic and solute gradients
3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Yes	V2 of the model has 3 additional layers in the 1A/B formation which is sufficient to model shallow aquifer processes.
3.4 Are the temporal domain and discretisation appropriate?	Maybe	Long stress periods and timesteps may not account for tidal and seasonal inundation of salt flats
3.4.1 steady state or transient	Transient	Calibration is quasi steady state – in that no time varying stresses are used. Consists of two epochs, a 2500 year and 1000 year, based on whether the area is intertidal (regular flushing) or supratidal (intermittent flushing)
3.4.2 stress periods	Yes	Calibration is based on 10 stress periods or 250 years, which is viable for simulating the present hydrogeological conditions of the salt flats.
3.4.3 time steps?	Yes	Model generated based on stability criteria.

3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	Yes	
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	No	• Inland boundary is unlikely to be a constant head, more likely to be due to variable long term recharge.
3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	Yes	Sensitivity analysis
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Maybe	Recharge has been estimated and then calibrated.
3.5.4 Are lateral boundaries time-invariant?	Yes	
3.6 Are the initial conditions appropriate?	Yes	Dynamic calibration for 2500 years while area is intertidal, and 1000 years after area becomes supratidal
3.6.1 Are the initial heads based on interpolation or on groundwater modelling?	Modelling	Dynamic calibration of quasi-steady model
3.6.2 Is the effect of initial conditions on key model outcomes assessed?	Yes	Sensitivity analysis
3.6.3 How is the initial concentration of solutes obtained (when relevant)?	Suitable	Dynamic calibration to field measurements in 2020
3.7 Is the numerical solution of the model adequate?	Yes	cumulative mass balance error for V1 is 0.03% and 0.05% for the flow and transport simulations, respectively. V2 has 0.01% and 0.07% for flow and solute transport, respectively.
3.7.1 Solution method/solver	Yes	SSM solver
3.7.2 Convergence criteria	Unknown	Not described
3.7.3 Numerical precision	Unknown	Not described

Table 5-2: Characteristics of a Class 1 Model

Data	*Calibration*	*Prediction*	*Key indicator*	*Examples of specific uses*
• Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information. • Observations and measurements unavailable or sparsely distributed in areas of greatest interest. • No available records of metered groundwater extraction or injection. • Climate data only available from relatively remote locations.	• No calibration is possible. • Calibration illustrates unacceptable levels of error especially in key areas. • Calibration is based on an inadequate distribution of data. • Calibration only to datasets other than that required for prediction.	• Predictive model time frame far exceeds that of calibration. • Temporal discretisation is different to that of calibration. • Transient predictions are made when calibration is in steady state only. • Model validation* suggests unacceptabl e errors when calibration dataset is extended in time and/or space.	• Model is uncalibrated or key calibration statistics do not meet agreed targets. • Model predictive time frame is more than 10 times longer than transient calibration period. • Stresses in predictions are more than 5 times higher than those in calibration. • Stress period or calculation interval is different from that used in calibration. • Transient predictions made but calibration in steady state only. • Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time. • Model parameters outside the range expected by the conceptualisation.	• Design observation bore array for pumping tests. • Predicting long-term impacts of proposed developments in low-value aquifers. • Estimating impacts of low-risk developments. • Understanding groundwater flow processes under various hypothetical conditions. • Provide first-pass estimates of extraction volumes and rates required for mine dewatering. • Developing coarse relationships between groundwater extraction locations and rates and associated impacts. • As a starting point on which to develop higher class models as more data is collected and used.

5.1 Surface Groundwater Interaction

The evaluation of surface groundwater has been placed in this section, as it is primarily concerned with how the conceptual model addresses processes associated with surface/groundwater interaction.

Table 5-3: Surface Groundwater Interaction

8. Surface water–groundwater interaction		
8.1 Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	Yes	Model objective is to estimate solute mobility due to surface water flows, and hence modelling of accrual surface flows in not required.
8.2 Is the implementation of surface water–groundwater interaction appropriate?	Maybe	Irregular inundation and subsequent flushing of solutes from the supratidal and tidal zone has not been account for with respect to flow. Solute interaction is accounted for by using zero order decay
8.3 Is the groundwater model coupled with a surface water model?	No	
8.3.1 Is the adopted approach appropriate?	NA	
8.3.2 Have appropriate time steps and stress periods been adopted?	NA	
8.3.3 Are the interface fluxes consistent between the groundwater and surface water models?	NA	

6. Calibration and Sensitivity

The calibration and sensitivity analysis shown in Figure 9.9 of the GHD report highlights the sensitivity of the model to horizontal and vertical hydraulic conductivity (k), recharge and storage terms. This further supports the need to model recharge processes with greater fidelity, and to expand the bounds on estimates of parameters. The sensitivity to hydraulic conductivity in layer 2A/B reflects the inclusion of the pumping test in the calibration.

Table 6-1: Model Guidelines - Calibration

Questions	Yes Maybe No	Comments
4.1 Are all available types of observations used for calibration?	Yes	Static and pumping test water levels are used for calibration of regional model Pumping test data at BH07 and BH10 are used to confirm kh, kv and infiltration
4.1.1 Groundwater head data	Yes	
4.1.2 Flux observations	No	
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations etc.	Yes	Concentrations
4.2 Does the calibration methodology conform to best practice?	Yes	
4.2.1 Parameterisation	Yes	The range of model parameter scaling factors, as used in PEST, may be too small to allow flexibility in the calibration process.
4.2.2 Objective function	Yes	
4.2.3 Identifiability of parameters	Yes	
4.2.4 Which methodology is used for model calibration?	Automated	Pest with Pilot Points
4.3 Is a sensitivity of key model outcomes assessed against?	Yes	Range of parameters may too be small to allow an effective sensitivity analysis
4.3.1 parameters	Yes	
4.3.2 boundary conditions	Yes	
4.3.3 initial conditions	Yes	
4.3.4 stresses	Yes	
4.4 Have the calibration results been adequately reported?	Yes	
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Yes	Pumping analysis
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	No	
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Yes	V1 Head error 15.2% Salinity error 13.5% V2 Head error 7.0% Salinity error 10.8%
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	No	
4.5.1 spatially	No	
4.5.2 temporally	Yes	Pumping Test
4.6 Are the calibrated parameters plausible?	Yes	Based on pilot point interpolation, resulting “bull-eyes” which may or may not be an accurate representation of parameter distributions
4.7 Are the water volumes and fluxes in the water balance realistic?	Yes	
4.8 has the model been verified?	No	Assessed against Sept 2020 measurements, but not against transient data.

7. Predictions

Table 7-1: Model Guidelines - Predictions

Questions	Yes Maybe No	Comments
5.1 Are the model predictions designed in a manner that meets the model objectives?	Maybe	Intertidal and supratidal inundation may be oversimplified as a steady state process
5.2 Is predictive uncertainty acknowledged and addressed?	Yes	
5.3 Are the assumed climatic stresses appropriate?	Maybe	Climate stresses have been averaged and input as time invariant daily averages based on historical data for the area.
5.4 Is a null scenario defined?	Yes	
5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?	Yes	
5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	NA	No pumping occurs in model area
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	NA	
5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	The Calibrated model was run for 1000 years, predictions are run for 50 years No time varying inputs specific to the site are used in the predictions. Class 1 models are limited in the confidence over the 50 year timeframe, due to a lack of time varying data
5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?	Yes	EVT may be overestimated in V1 as areas that may have salt crusts. EVT has been reduced and better reflects likely EVT in V2
5.6 Do the prediction results meet the stated objectives?	Maybe	Model predicts water level and salinity changes with model outputs provided to AECOM to assess impacts to mangroves and algal mats
5.7 Are the components of the predicted mass balance realistic?	Maybe	None presented for the prediction model.
5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?	NA	
5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?	NA	
5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks	No	
5.7.4 Is diffuse recharge from rainfall smaller than rainfall?	Yes	
5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	No	
5.8 Has particle tracking been considered as an alternative to solute transport modelling?	No	Changes in concentration are the primary criteria for determining impacts

Version 1 model results for the predictive scenarios show that leakage from the salt ponds causes increased groundwater salinity in the vicinity of the ponds, even those that are filled with much fresher seawater. These results reflect that the uncalibrated EVT is relatively large, and that pond seepage salinity is averaged in layer 1 with existing groundwater salinity. The application of a large EVT effectively removes seepage water from layer 1, resulting in increasing solute concentration in areas immediately outside of the pond embankment, relative to the initial conditions.

Monitoring undertaken at existing seawater filled ponds (*Gordon,1988),* show that seepage from seawater filled ponds acts to freshen shallow groundwater immediately outside of the embankment, and cause water levels to rise, resulting in a salt crust. The movement of lower salinity pond water is facilitated by the low EVT that occurs due to the formation of the salt crusts. These salt crusts are common on salt lakes and supratidal flats. As summarized in the abstracts by Chen and Hollins, salt crusts can reduce EVT by 98% in the absence of rainfall and inundation, compared to freshwater evaporation rates. Rainfall and inundation cause a short term increase in evaporation, until a new salt crust is established. Based on this analysis it is likely that the naturally salt encrusted supratidal flats evaporation is less than 300 mm/year in most areas, compared to the calibrated model EVT over most of the model area of 1100 mm/year. This suggests that EVT will not act to trap high salinity pond leakage as concluded in the report, but instead, in the absence of significant EVT, pond seepage water will move laterally (as groundwater) away from the pond, resulting in increasing water levels and freshening of shallow groundwater in the vicinity of ponds.

It is also noted that the 0.3m extinction depth for evapotranspiration is not a physical constraint but based on measured depth to water and is being used as an upper boundary condition of the aquifer. The use of a high EVT rate and shallow extinction depth in the model, causes EVT to effectively control the water table. Small changes in the model of depth to water (for example due to seepage from a pond) results in a large increase in EVT, and subsequent large increase in predicted salinity.

A more physical based model, accounting for the salt crusting, would have a small EVT rate constrained by the crust as dry litter, with the extinction depth defined by the thermal and hydrogeological properties of the formation and prevailing climate conditions such as temperature. The water table then becomes defined by the balance between water inflow and the energy required to remove this water as vapour under increasing salinity, as simulated by the EVT rate as a function of depth. This conceptualization does not require EVT to be zero at the existing water table and is specified to a depth that may occur given the prevailing aquifer and climatic conditions.

Version 2 of the model was run with a reduced EVT of 300 mm/year, on the supratidal flats. Results of simulations are consistent with the above conceptualization of pond leakage, and with excerpts of the papers below. The V2 model run is essentially a test of an alternative conceptualization.

Evaporation from a salt encrusted sediment surface - Field and laboratory studies
XY Chen

Australian Journal of Soil Research 30(4) 429 - 442
Published: 1992

Abstract
Estimates of hydrologic budgets from arid zones are constrained by difficulties in evaluating evaporation loss from groundwater discharge areas, especially playa surfaces. Evaporation from a salt-encrusted playa surface (Lake Amadeus, central Australia) is estimated by field measurement of moisture loss from sediment blocks in plastic receptacles set into the playa. The evaporation process consists of two distinctively different evaporative patterns. E1 is a very low rate (70 mm/year, 2.4% of pan evaporation) from the salt-encrusted surface. E2 is a much higher rate which occurs after rain dissolves the surface salt crust. The total E2 evaporation is lower than the rainfall, indicating that a portion of rainfall recharges the playa brine. Therefore, the total E1(70 mm/year) can only be used as an upper limit of the net evaporation and the actual value may be significantly lower. In a laboratory analogue experiment, a very thin (2 mm) salt crust diminishes the evaporation to about 2% of that from a freshwater surface, even though the sediments underlying the crust remain saturated. When distilled water was added to the salt crust, the evaporation rate increased by nearly 20 times for a short period, then returned to the previous low rate. However, a portion of the distilled water infiltrated to the water table and became part of the brine supply to the sediments. Both the salt crusts of Lake Amadeus and those formed in the laboratory experiment are porous and buckled, and significantly drier than the underlying sediments. The significant reduction of evaporation from salt-encrusted sediment surface seems to be mainly due to the porous, buckled, and dry nature of the crust which inhibits the removal of the vapour from the underlying sediments. The vapour pressure decrease of the brine has relatively less effects.

Similar results were also found in work done by Suzanne Hollins and Peter V. Ridd for salt flats, as shown below.

Evaporation over a tropical tidal salt flat

Mangroves and Salt Marshes ***volume 1****, pages 95–102(1997)*

Abstract

Measurements of temperature, wind speed and humidity within 6 m of the surface of a mangrove-fringed tidal tropical salt flat were performed. Using the aerodynamic method, this data was used to infer evaporation rates from the salt flat. For a few days after tidal inundation or rain, the salt flats were wet and evaporation rates of about 5×10^{-3} m day^{-1} prevailed. By 8 days after tidal inundation and with no rain, evaporation rates had dropped to less than 2×10^{-3} m day^{-1}. The monthly evaporation rate was about 7×10^{-2} m. This generates high salinity which, together with surface temperatures exceeding 50°C, prevents colonisation of these areas by mangroves.

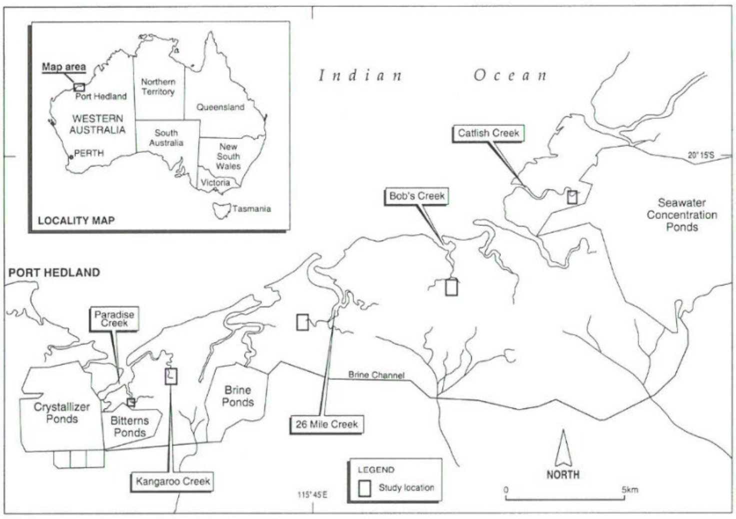

Figure 1: Mangrove Monitoring - Pilbara, 1990

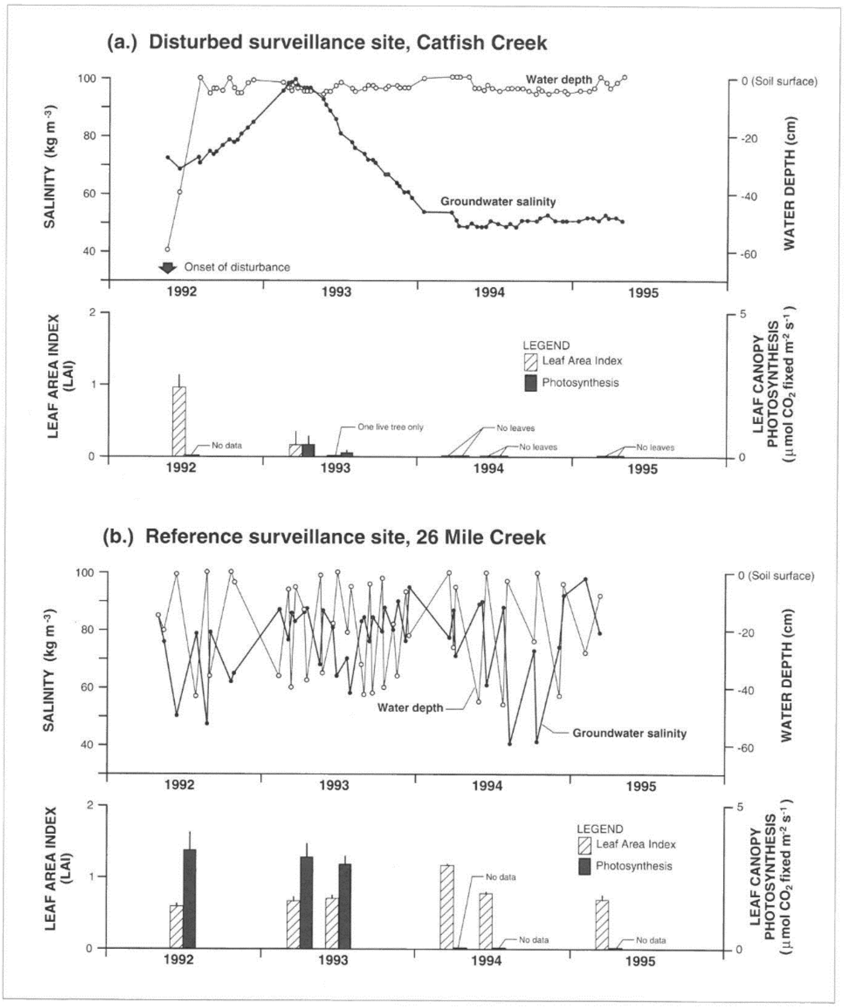

Figure 2: Impact on Water Levels and Water Quality on Mangrove Mortality, Catfish Creek

The effects of density are better modelled in V2 due to the increase layers in 1A/B formation. A comparison of the water level and solute concentration between the V1 and V2 models is given in Appendix A. Figure A1 shows that the difference in water levels in the vicinity of and to the west of the ponds is generally higher in V2 than in V1, consistent with the effect of reduced EVT and additional shallow layers in the V2 model. Similarly, Figure A2 shows the difference in solute concentration in the vicinity of, and to the west of the ponds is generally lower in V2 than in V1, consistent with lower EVT. There are some areas that have higher solute concentrations in V2 compared to V1 in the pond area and to the west that are likely due to the increased vertical resolution of layer 1. Solute concentration in V1 is averaged over a greater depth compared to V2, and hence not show as much spatial variation as in V2.

8. Uncertainty Analysis

Table 8-1: Model Guidelines – Uncertainty Analysis

Question	Yes Maybe No	Comments
6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	Yes	Linear Uncertainty Analysis
6.2 Is the model with minimum prediction-error variance chosen for each prediction?	NA	
6.3 Are the sources of uncertainty discussed?	Yes	
6.3.1 measurement of uncertainty of observations and parameters	Yes	
6.3.2 structural or model uncertainty	Yes	
6.4 Is the approach to estimation of uncertainty described and appropriate?	Yes	
6.5 Are there useful depictions of uncertainty?	Yes	

9. Solute Transport

Table 9-1: Model Guidelines – Solute Transport

Question	Yes Maybe No	Comments
7.1 Has all available data on the solute distributions, sources and transport processes been collected and analysed?	Yes	
7.2 Has the appropriate extent of the model domain been delineated and are the adopted solute concentration boundaries defensible?	Yes	
7.3 Is the choice of numerical method and software appropriate?	Yes	
7.4 Is the grid design and resolution adequate, and has the effect of the discretisation on the model outcomes been systematically evaluated?	Yes	
7.5 Is there sufficient basis for the description and parameterisation of the solute transport processes?	Yes	
7.6 Are the solver and its parameters appropriate for the problem under consideration?	Yes	
7.7 Has the relative importance of advection, dispersion and diffusion been assessed?	Yes	Implicitly done as part of the uncertainty analysis
7.8 Has an assessment been made of the need to consider variable density conditions?	Yes	Density driven flow is an important process for simulating salinity distributions and is included in the model.
7.9 Is the initial solute concentration distribution sufficiently well-known for transient problems and consistent with the initial conditions for head/pressure?	Yes	Initial condition of model is uniform salinity based on seawater submergence 2500 year ago. Modern conditions are established based on a dynamic calibration over 1000 years.
7.10 Is the initial solute concentration distribution stable and in equilibrium with the solute boundary conditions and stresses?	Maybe	Initial concentration as generated by a total of 1000 years of simulation.
7.11 Is the calibration based on meaningful metrics?	Yes	Measured salinity at monitor bores Model could also be calibrated against measured vertical conductivity as measured in monitor bores.
7.12 Has the effect of spatial and temporal discretisation and solution method considered in the sensitivity analysis?	No	
7.13 Has the effect of flow parameters on solute concentration predictions been evaluated, or have solute concentrations been used to constrain flow parameters?	No	Relevant to the analysis of vertical flow due to EVT, and salt crusting
7.14 Does the uncertainty analysis consider the effect of solute transport parameter uncertainty, grid design and solver selection/settings?	Yes	Accounts for uncertainty in solute parameters Uncertainty analysis does not account for grid and solver selection settings.
7.15 Does the report address the role of geologic heterogeneity on solute concentration distributions?	No	

10. Conclusion and Recommendations

Based on the review of the numerical models presented in the report and addendum it is considered that the models are fit for purpose and provide similar results with respect to project impacts. In particular the V2 version of the model better accounts for the conceptual hydrogeology of area, due to the refinement of 1A/B formation with three additional layers and the reduction in EVT on the salt flats. Consequently, it is recommended that the V2 version of the model be used for any new modelling of the project area.

Given that the models are characterized as Level 1, additional transient data should be collected in the following areas:

- Intertidal zone area of mangroves, with water level, and water quality measured at a sub-daily interval, to better characterize tidal influences.

- The installation of additional piezometers immediately downstream of proposed ponds, to provide baseline data prior to pond construction and filling.

- After pond filling, monitoring of water levels and water quality at various distances from the ponds should be measured at monthly intervals.

The above data should then be used to improve the conceptual hydrogeological model by better quantifying the relevant processes in the project area.

Baseline groundwater monitoring, in consultation with the regulator should also commence as soon as possible, to ensure an adequate time period of data acquisition, to support modelling revisions.

11. References

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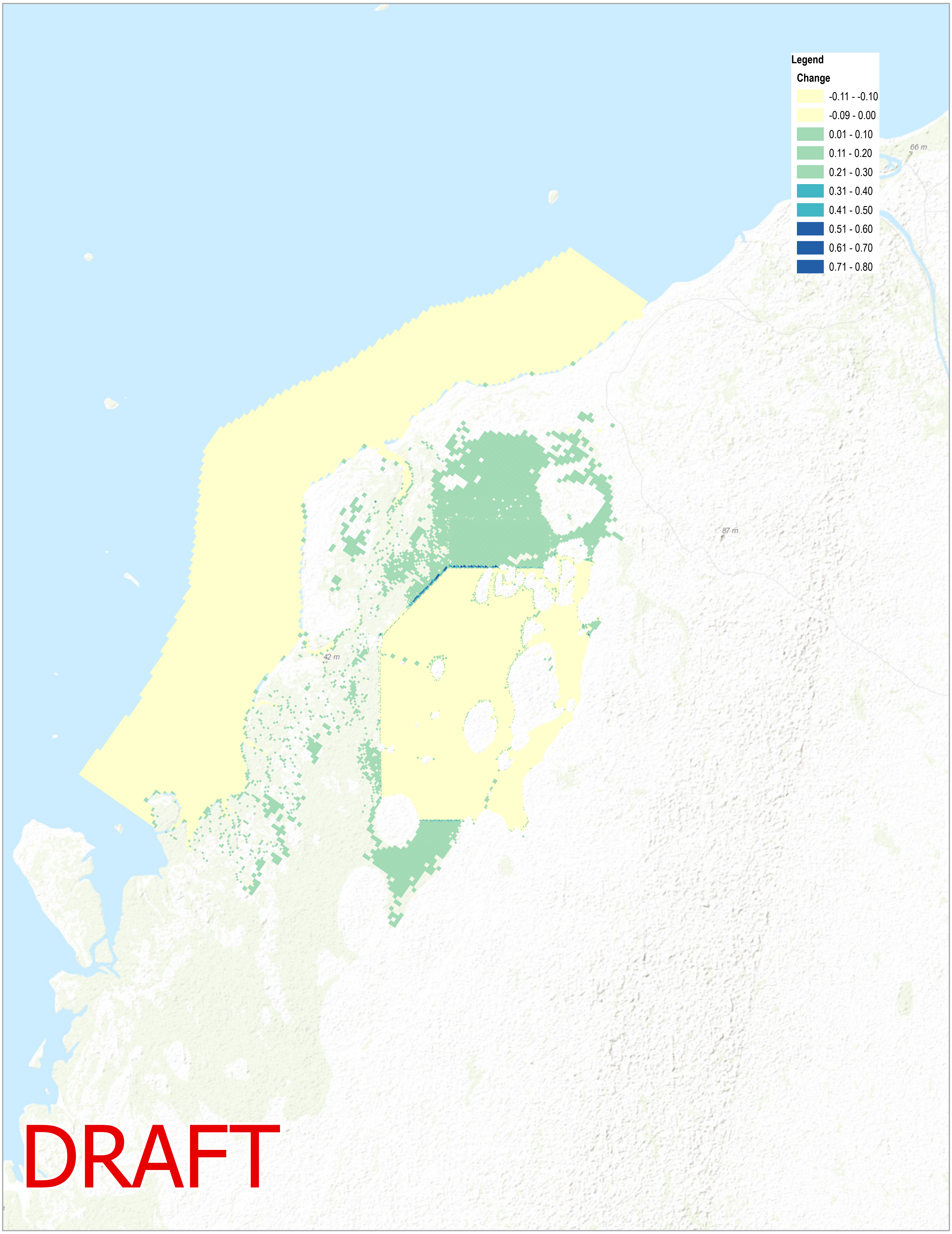
Water Technology 2021. Suite of Reports Prepared for the Ashburton Salt Project. Reports prepared for K+S:

- *Marine, Coastal and Surface Water Data Collection*
- *Marine, Coastal and Surface Water Existing Environment*
- *Surface Water Assessment and Modelling*
- *Nutrient Pathways Assessment and Modelling*
- *Marine and Coastal Assessment and Modelling.*

Appendix A: Comparison of Scenario Results from Model V1 versus Model V2



Paper Size ISO A3

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Kilometres

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Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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Ashburton Solar Salt Project
Phase 2 Site Investigations

Difference in Predicted Water Table Elevation Between Version 1 and Version 2 Models (50 years)

Project No. 12516706
Revision No. 0
Date 4/11/2022

FIGURE A1

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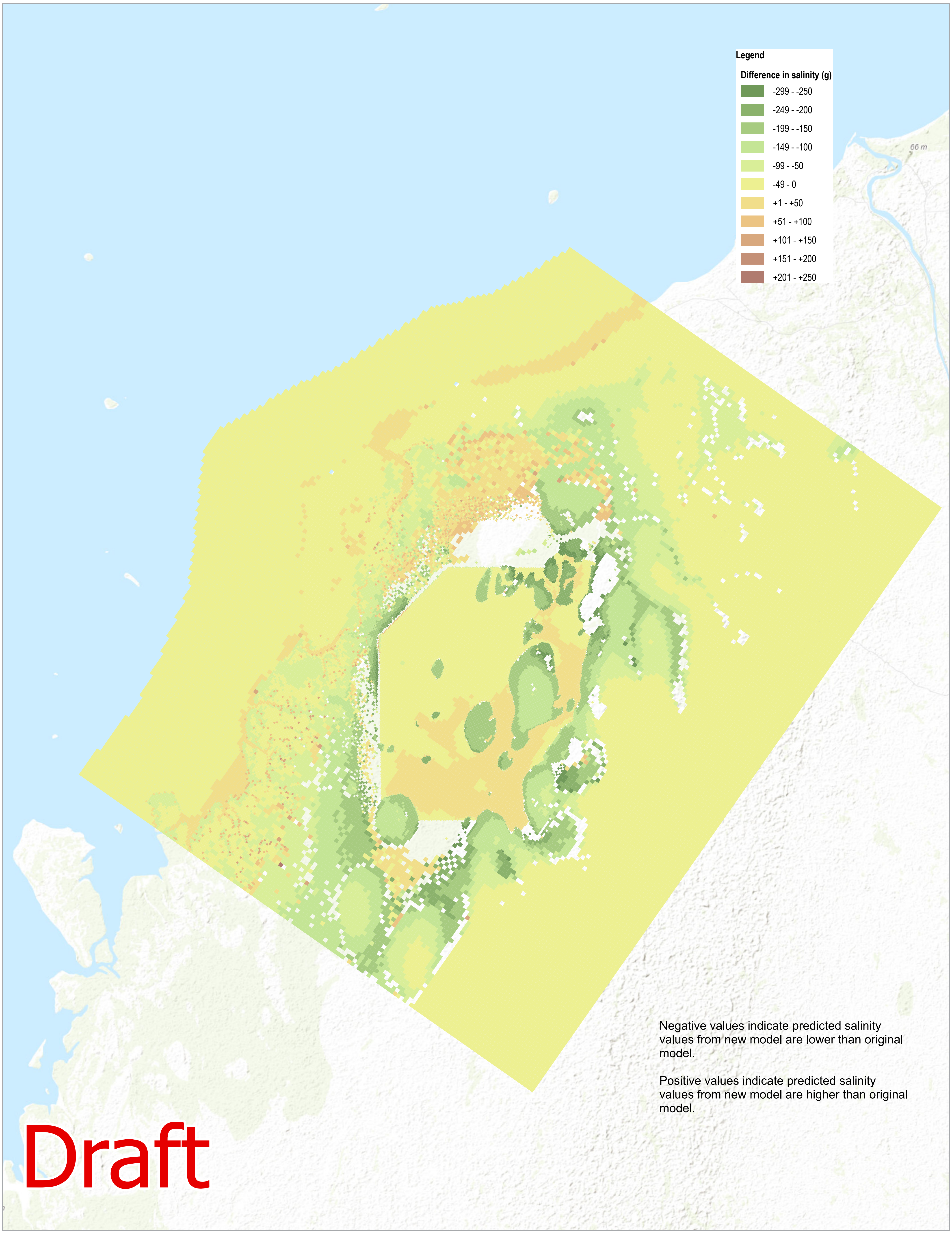

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Kilometres

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Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

GHD

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Phase 2 Site Investigations

Difference in Predicted Salinity Between Version 1 and Version 2 Models (50 Years)

Project No. **12516706**
Revision No. **0**
Date **4/11/2022**

FIGURE A2

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Appendix B: GHD Memorandum Describing the V2 (Revised) Model

Memorandum

26 October 2022

To	Tobias Thönelt and Gerrit Gödecke K + S		
Copy to			
From	Bob Kinnell and David van Brocklin	**Tel**	08 6222 8222
Subject	Ashburton groundwater modelling- updated results	**Project no.**	12516706

1. Project Overview and Summary

GHD previously completed a hydrogeological conceptualisation and numerical groundwater flow and salinity modelling (GHD, 2021) to inform the environmental impact assessment for the proposed Ashburton Solar Salt project. This project is situated within the coastal region approximately 40 km southwest of the town of Onslow, Western Australia.

The purpose of the additional work reported below was to test the sensitivity of the model predictions to two factors not considered during the previous groundwater modelling effort:

1. The presence of a salt crust in some areas. This crust is expected to significantly lower the maximum evapotranspiration rate; and
2. The spatial scale of the flow and transport processes close to the ground surface is likely smaller than the vertical discretization of the model grid.

Essentially the purpose of the modelling work described below was to test key conceptual aspects of the hydrogeological system that were not assessed during the initial modelling exercise.

This document describes modifications that were made to the existing groundwater model to test the two factors listed above and presents the calibration and prediction results of the modified model.

In summary the results of the 50-year simulations presented suggest the following:

– The predicted watertable level and groundwater salinity changes for the revised model are similar to the results of the original model. However, it is noted that the simulated area affected by the lower end range of groundwater level increases (0 to 0.5m) for the revised model is slightly larger than the corresponding results for the original model

– The simulated average concentration in the zero order zones was approximately 109g/L for the revised model. This compares to 79.8g/L for the previous model

2. Model Setup

2.1 Modelling Software and User Interface

The numerical groundwater modelling code MODFLOW-USG Transport (Panday, 2022) using the Upstream Weighting Package (UPW) was used to develop the groundwater flow model. Revisions to model input files and extraction of model results was done using a variety of utilities including: the GMS

Groundwater Modelling System) and Groundwater Vistas (Version 8 Professional) graphical user interfaces, text editors, PEST utilities, Microsoft excel, and USGS Groundwater Chart.

2.2 Original Model

The original model was developed in USG Transport version 1.5.0. The model was discretized using a quadtree grid with 8-layers and 374,104 nodes.

The model consists of four separate models run in serial with the first three runs providing initial heads for the next model. The model four models are:

1. Model run co4SS05a: Steady state flow model used to provide initial heads to co4TR05c.
2. Model run co4TR05c: Transient flow and density-coupled transport model used for an initial 2,500-year quasi-steady state conditioning run, to derive sensible distribution of salinity and density. Used to provide initial heads to co4TR13.
3. Model run co4TR13: Transient flow and density-coupled transport model used for the 1000-year quasi-steady state run with local zero order decay and higher porosity, to simulate the approximately steady state current condition. Outputs from this model run were used to assess the calibration.
4. Model prediction run co4TR15 and null scenario co4TR14a: Transient flow and density-coupled transport model used for the project case predictive model, with the salt ponds. This model uses outputs from the final time step of co4TR13 as initial conditions.

These four models were modified to obtain the revised model calibration and prediction.

2.3 Modifications to the Original Model

The following modifications were made to the original model:

1. The revised model was developed in USG Transport version 1.9.0. (The original model used 1.6.1).
2. Layer 1 of the original model was split into three layers using GMS to provide a new discretization file. Flow and transport properties for the additional layers were added to the corresponding .lpf and .bct input files using a text editor.
3. The ET in zone 1 (sea inundation area) was reduced to 300mm/day from 1200mm/d. In addition, the ET package was set to extract water from the highest active layer rather than from a specified layer.
4. Zero order decay occurs only in layer 1 of the new model, resulting in the zero-order decay being applied to a smaller aquifer volume.
5. Solver settings changed to converge the model and obtain an acceptable mass balance.

In addition to the above, Layer 1 was split according to the following scheme:

- If the original layer 1 thickness >1m, then the top 2 layers were set to 0.3m thick and layer 3 accounts for the remaining thickness
- Else, if the original layer 1 < 1m, then the layer thickness is split proportionally by the factors 0.3, 0.3, 0.4 from top to bottom.

The solver changes included turning off the use of flux mass balance errors in the mass transport solution (IFMBC flag). This change allowed the model to converge. Lower solute mass balance discrepancies were achieved than in the original model.

3. Calibration of Revised Model

3.1 Modelled vs Measured Head and Salinity

The predicted heads and salinities from the revised calibration model run (co4TR13) were compared to those of the original model calibration. No modifications were made to any parameters from the original model except for the changes outlined in the model modifications section above.

Scatterplots of modelled vs measured heads and salinities for two datasets (April and September 2020) are presented on Figure 1 and Figure 2. These figures correspond to Figure 9-3 of the original report. The SRMS of the combined head datasets for the revised model calibration was 7.0%; this is lower than 15.2% for the original calibration. The SRMS of the combined salinity datasets for the combined salinity datasets for the revised model calibration was 10.8%; this is lower than the 13.2% for the original calibration.

Predicted heads and concentrations for the revised calibration are presented on Figure 3 and Figure 4.

Thinly saturated cells (sat thickness ~0.001m) gave rise to anomalously low and high concentrations in some areas of layer 1. These occurred where extinction depth equals the layer thickness. Therefore, the concentrations presented on Figure 4 are from layer 3 if layer 3 is saturated, or from the cell containing water table if it was below layer 3. The predicted salinity from the original model are presented in Figure 5 for comparison.

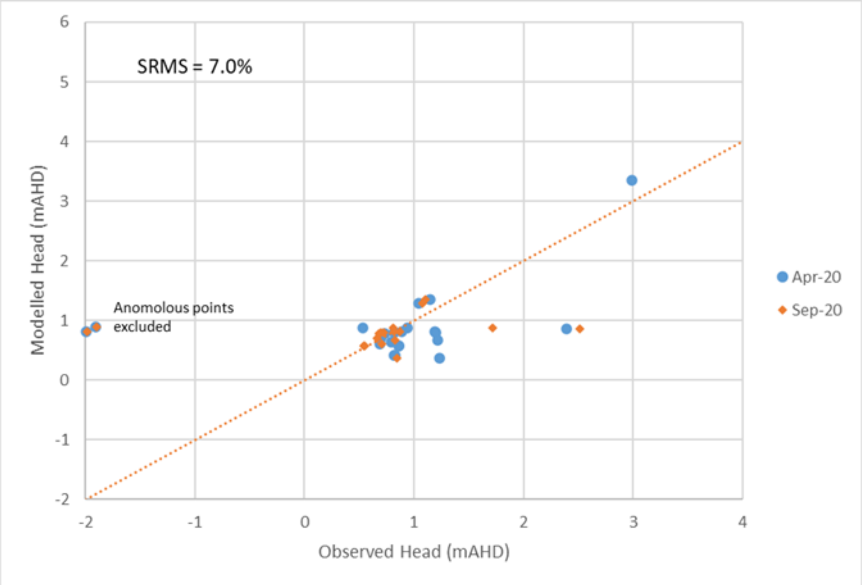


Figure 1 ***Scatterplot of Modelled vs Measured Heads***

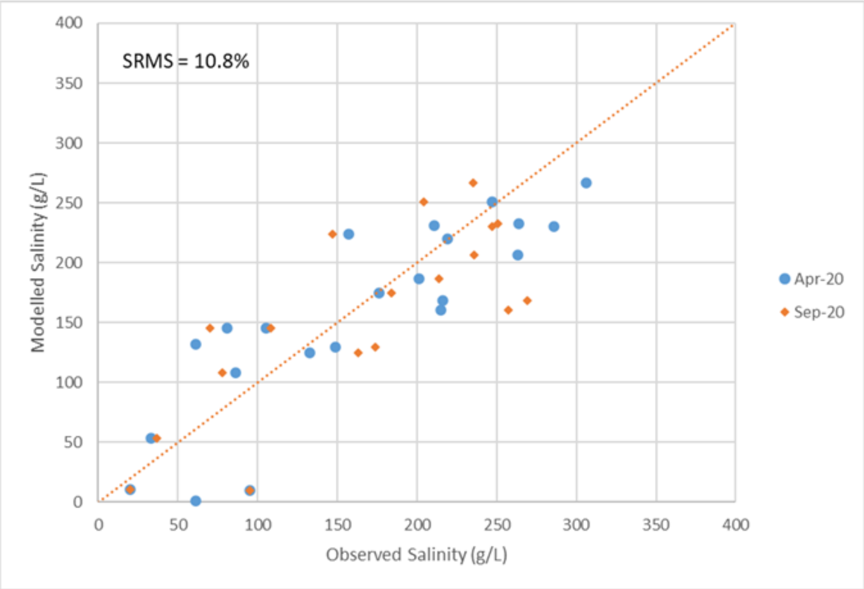
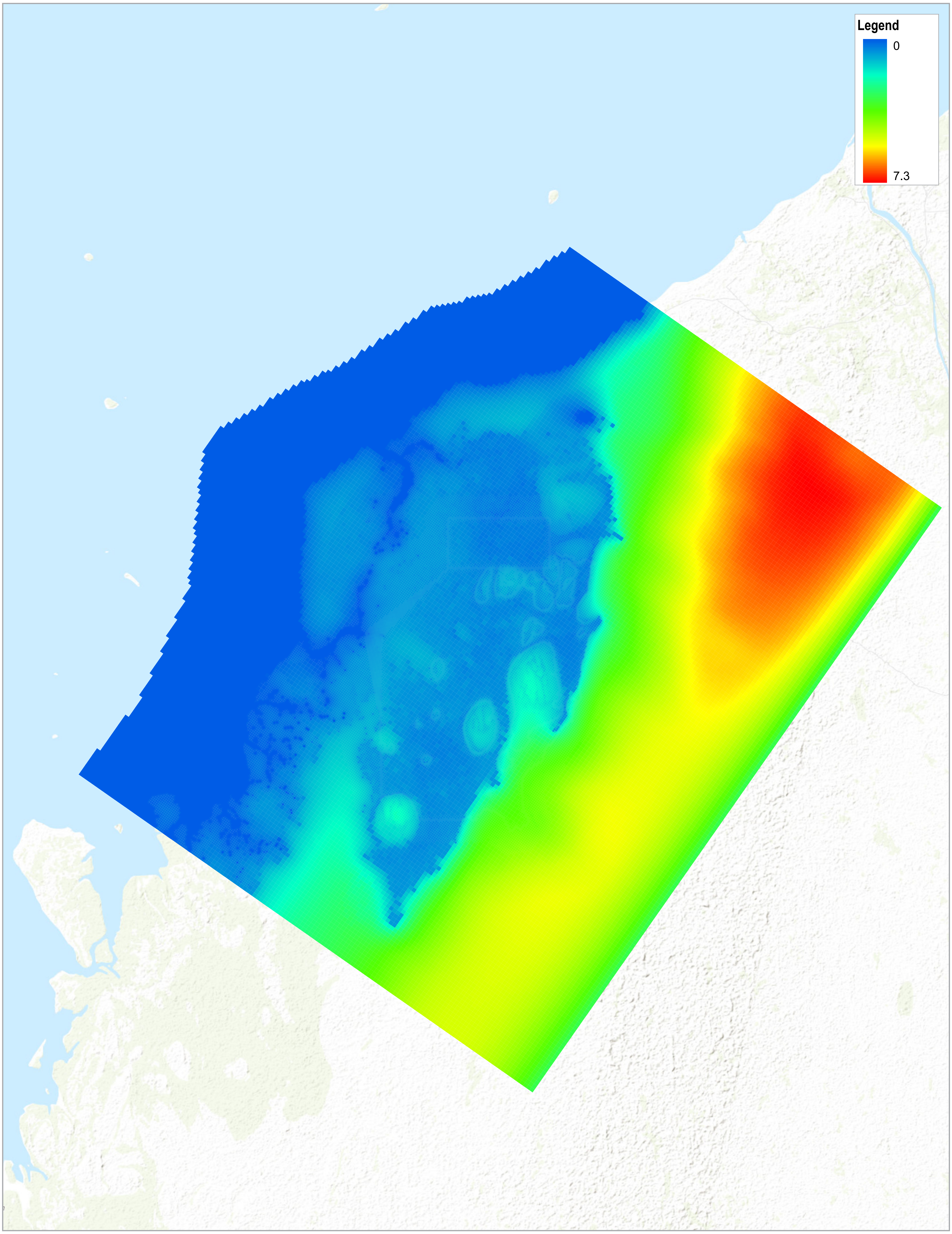
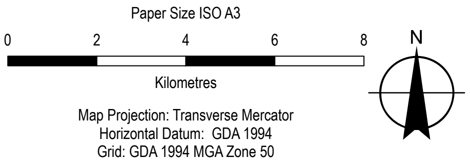


Figure 2 ***Scatterplot of Modelled vs Measured Salinity***





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Date **25/10/2022**

Water Table (mAHD)
End of Calibration Run

FIGURE 3

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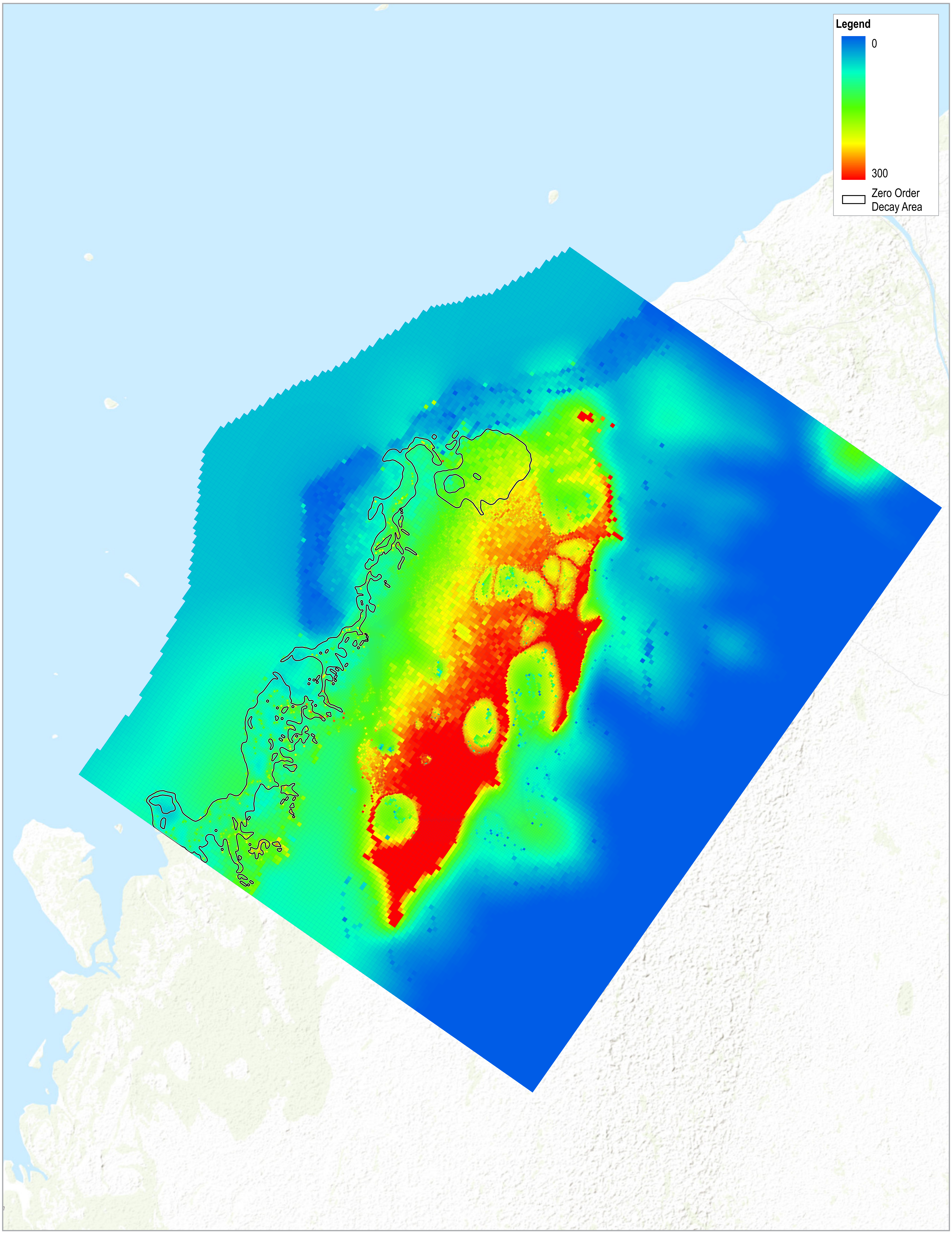

Paper Size ISO A3

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Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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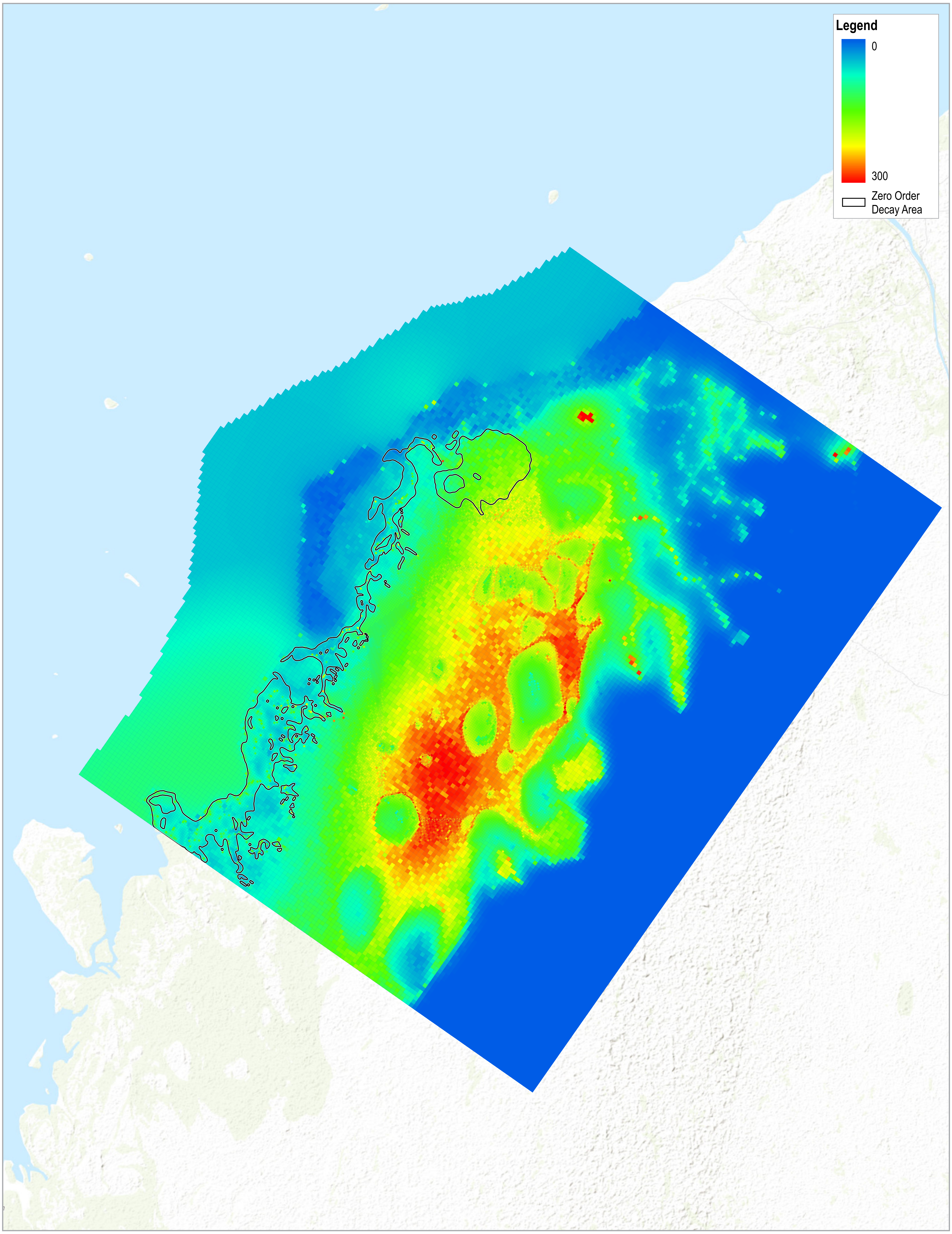
Water Table Salinity (g/L)
End of Calibration Run

Project No. **12516706**
Revision No. **0**
Date **26/10/2022**

FIGURE 4



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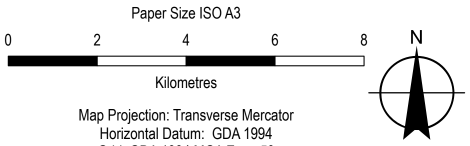

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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Water Table Salinity (g/L)
End of Calibration Run - Previous Model

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Date	**26/10/2022**

FIGURE 5

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Data source: World Topographic Map: Esri, HERE, Garmin, USGS, NGA. Created by: rbrown3

3.2 Global Flow and Mass Balance Discrepancy

The global flow and mass balance discrepancies (by time step) for the revised calibration run are presented in Figure 6. The cumulative mass balance errors were 0.07% and 0.01% for the flow and transport simulations, respectively.

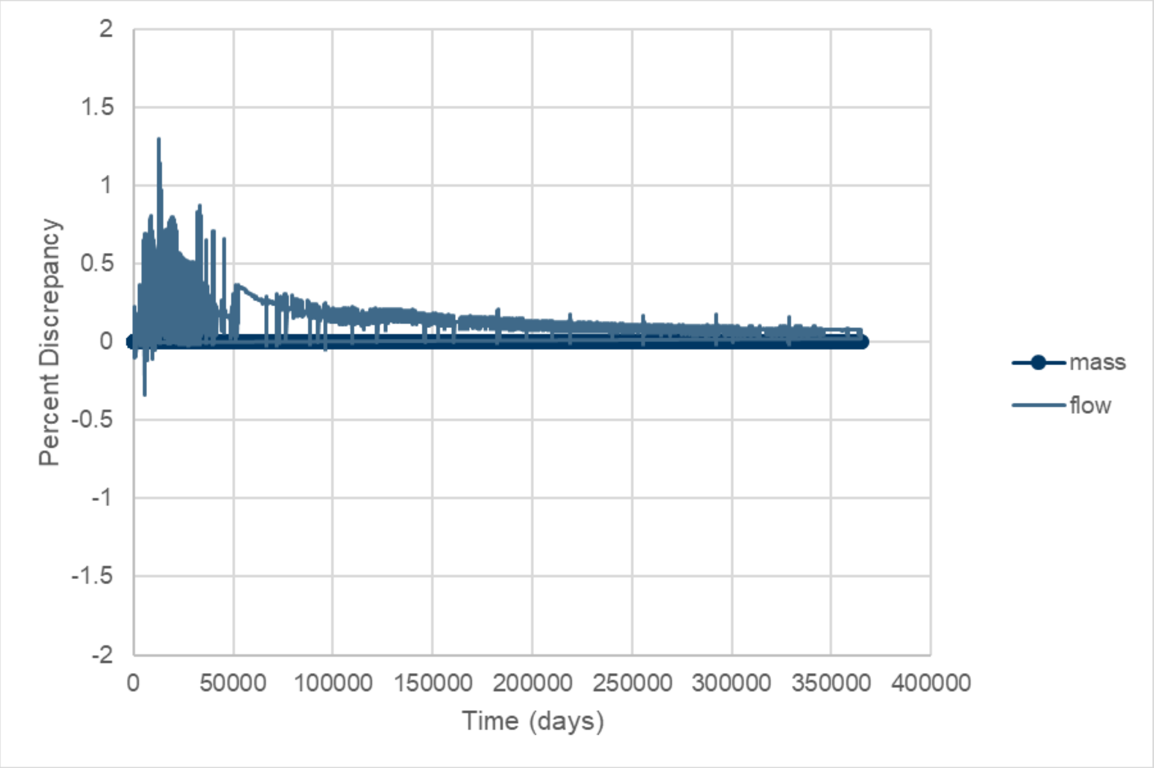


Figure 6 Calibration Global Water and Mass Balance Discrepancies

3.3 Global Water and Mass Budgets

The global water and mass budgets for the last time step of the calibration run are presented on Table 1 and Table 2.

The water budget shows that the ET out decreased in the revised model as expected due to the lowered ET rate in zone 1. Constant head in decreased in response to the decreased ET out. Similarly, constant head out increased in response to the lower ET.

The mass budget shows changes complementary to the water budget with constant head mass in decreased and mass out increased. The mass decay out component is dramatically lower because the zero order decay terms only occur in layer 1 of the revised model which has a much smaller saturated volume to apply the decay to.

Table 1 Calibration Water Budgets

	Original	Original	Revised	Revised
Component	**In (m^3/d)**	**Out (m^3/d)**	**In (m^3/d)**	**Out (m^3/d)**
Storage	0.41	1.57	4.2	8.2
Density Storage	27.64	6.57	63.6	60.5
Constant Head	785.41	1785.57	443.3	2189.6
River	129.3	531.8	88.7	525.2
Recharge	6683.7	0	6683.7	0
ET	0	5299.2	0	4497.6
Total	7626.5	7625.6	7283.7	7281.1

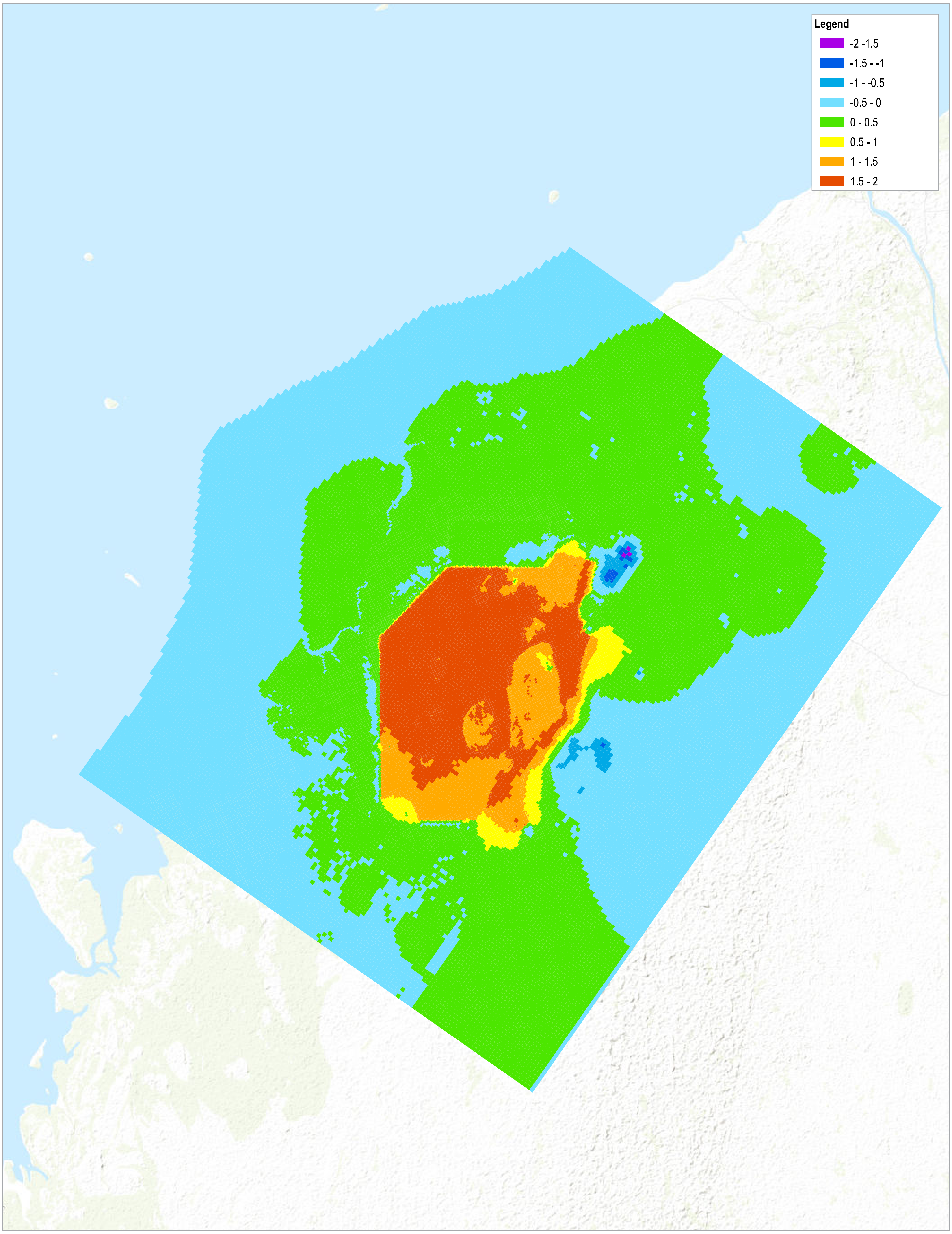
Table 2 Calibration Mass Budgets

	Original	Original	Revised	Revised
Component	**In (T/d)**	**Out (T/d)**	**In (T/d)**	**Out (T/d)**
Storage	29.7	7.5	77.7	83.7
Mass Decay	0	67.9	0	1.74
Constant Head	22	43.4	15.5	55.4
River	4.53	31.9	3.10	50.0
Recharge	94.5	0	94.5	0
ET	0	0	0	0
Total	150.9	150.9	190.8	190.8

4. Prediction Results- Revised Model

4.1 Water Levels

The predicted rise in water level due to project after 50 years from the revised model is presented in Figure 7. For comparison, the predicted rise after 50 years from the original unrevised model is presented in Figure 8.



Paper Size ISO A3

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Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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GHD

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Predicted Water Table Rise (m)
After 50 Years

Project No. **12516706**
Revision No. **0**
Date **24/10/2022**

FIGURE 7

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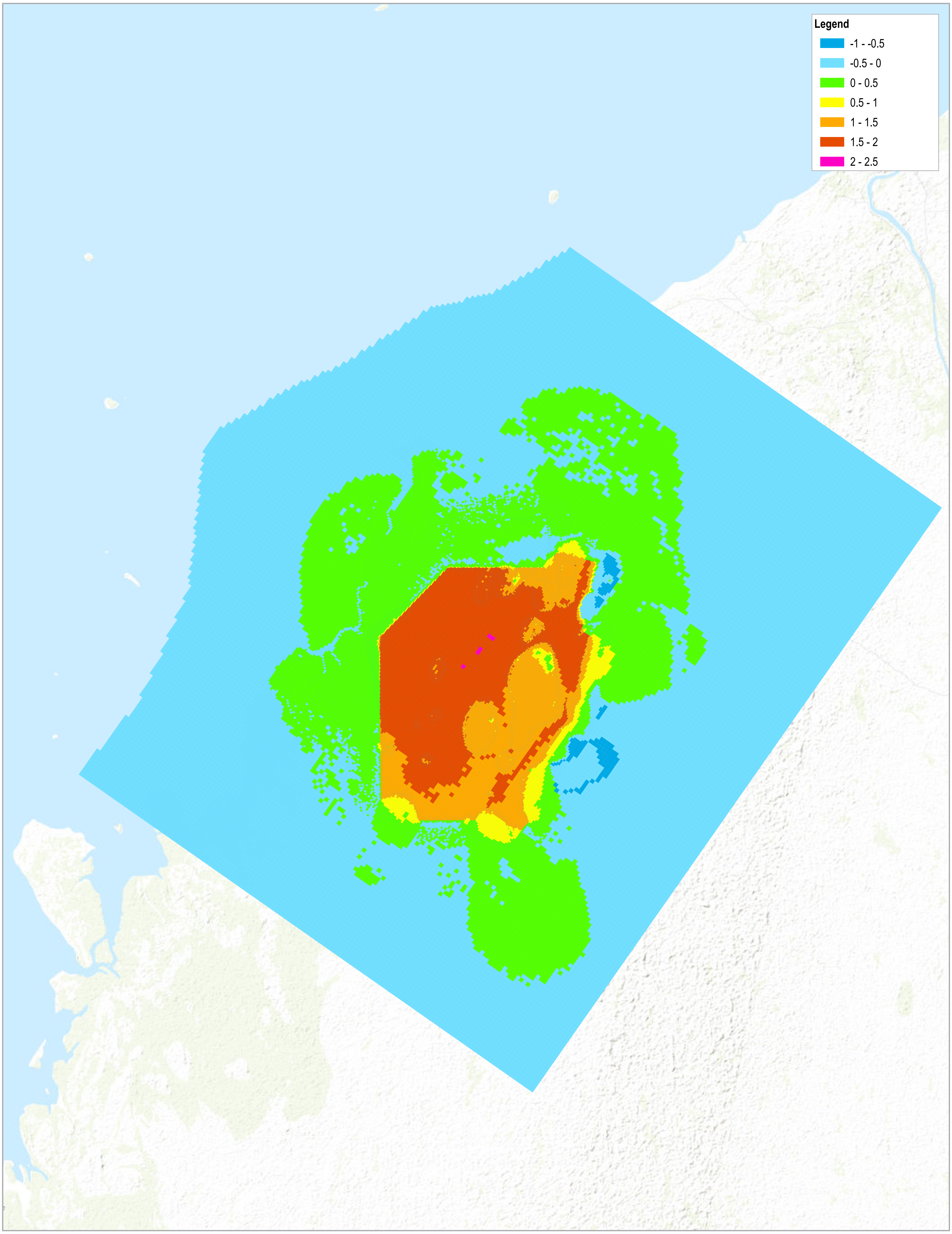

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Kilometres

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Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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Date **24/10/2022**

Predicted Water Table Rise (m)
After 50 Years, Previous Model

FIGURE 8

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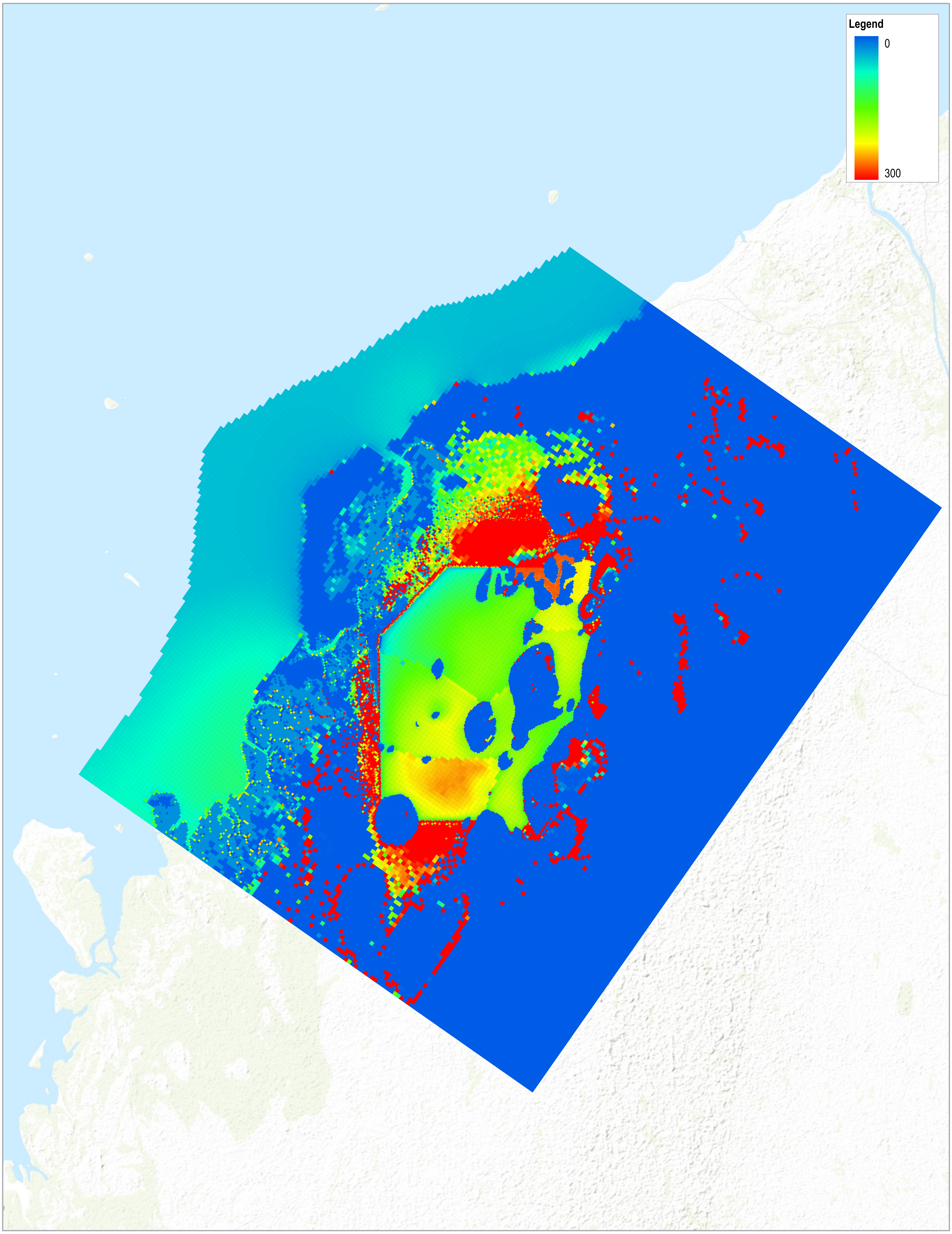
Data source: World Topographic Map: Esri, HERE, Garmin, USGS, NGA. Created by: rbrown3

4.2 Salinity

Predicted salinity and salinity changes after 50 years for the revised prediction are presented in Figure 9 and Figure 10. Due to thinly saturated cells creating anomalously low and high concentrations in some areas of layer 1, the concentrations presented on Figure 9 and Figure 10 are from layer 3 if layer 3 was saturated. or from the cell containing water table if is below layer 3. Predicted salinity differences between layer 2 and layer 3 were considered negligible. For comparison, the predicted salinity change after 50 years for the original (unrevised model) prediction is presented on Figure 11.



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Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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Predicted Concentration (g/L) at Water Table After 50 Years

Project No. **12516706**
Revision No. **0**
Date **25/10/2022**

FIGURE 9

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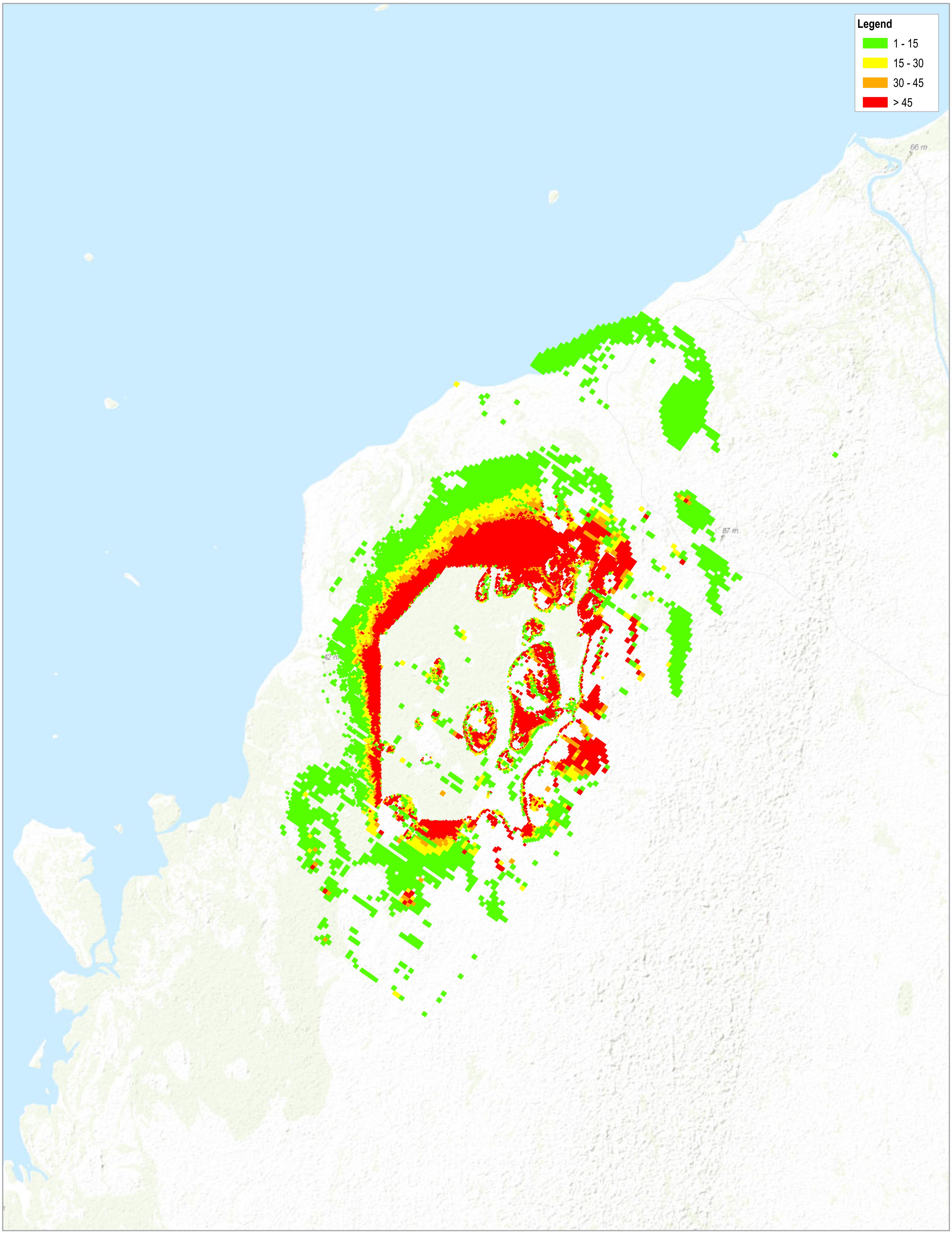

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Grid: GDA 1994 MGA Zone 50

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Revision No. **0**
Date **25/10/2022**

Predicted Concentration Change (g/L) at Water Table After 50 Years

FIGURE 10

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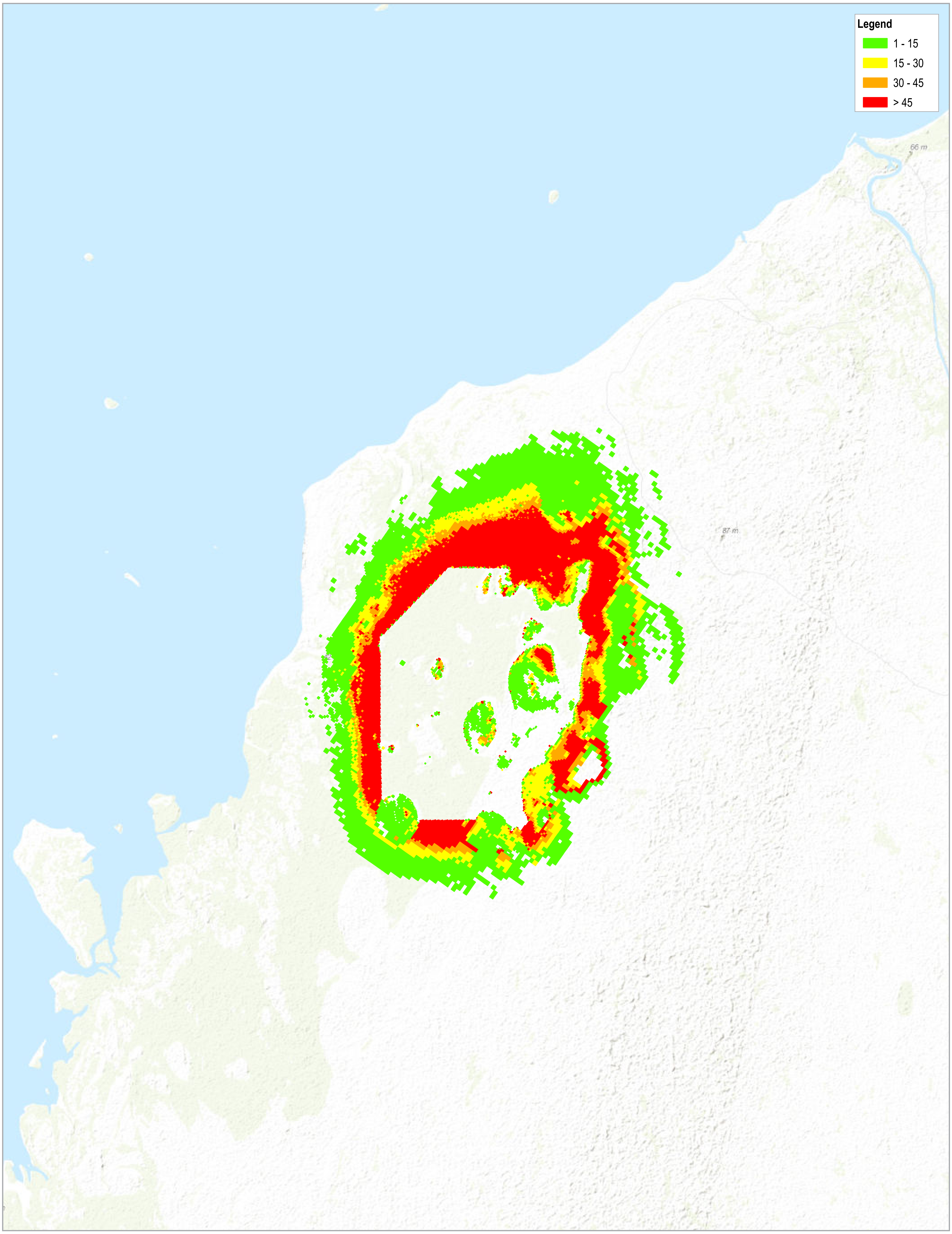

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Kilometres

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K + S Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigations

Project No. **12516706**
Revision No. **0**
Date **25/10/2022**

Predicted Concentration (g/L) at Water Table After 50 Years

FIGURE 11

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Print date: 25 Oct 2022 - 13:32

Data source: World Topographic Map: Esri, HERE, Garmin, USGS, NGA. Created by: rbrown3

4.3 Pond Seepage

Predicted seepage rates for ponds 1 through 9 for both the original and the revised model prediction are presented on Figure 12 and Figure 13 . The curves for the revised seepage rates for ponds 2 through 7 nearly overlie each other. The seepage rates at ponds 1 and 8 are decreased compared to the original model. This may be due to the proximity of these ponds to areas of lowered ET.

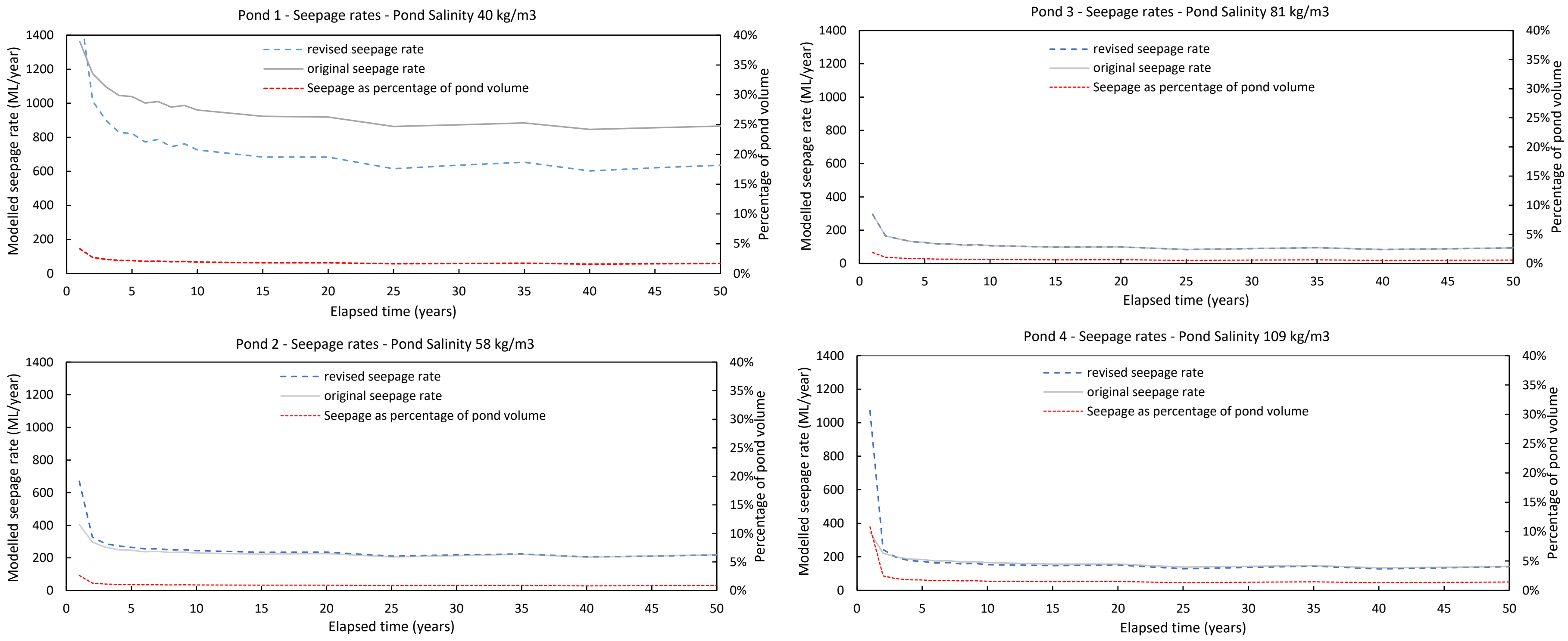


Figure 12 *Pond 1 to 4 Seepage Rates*

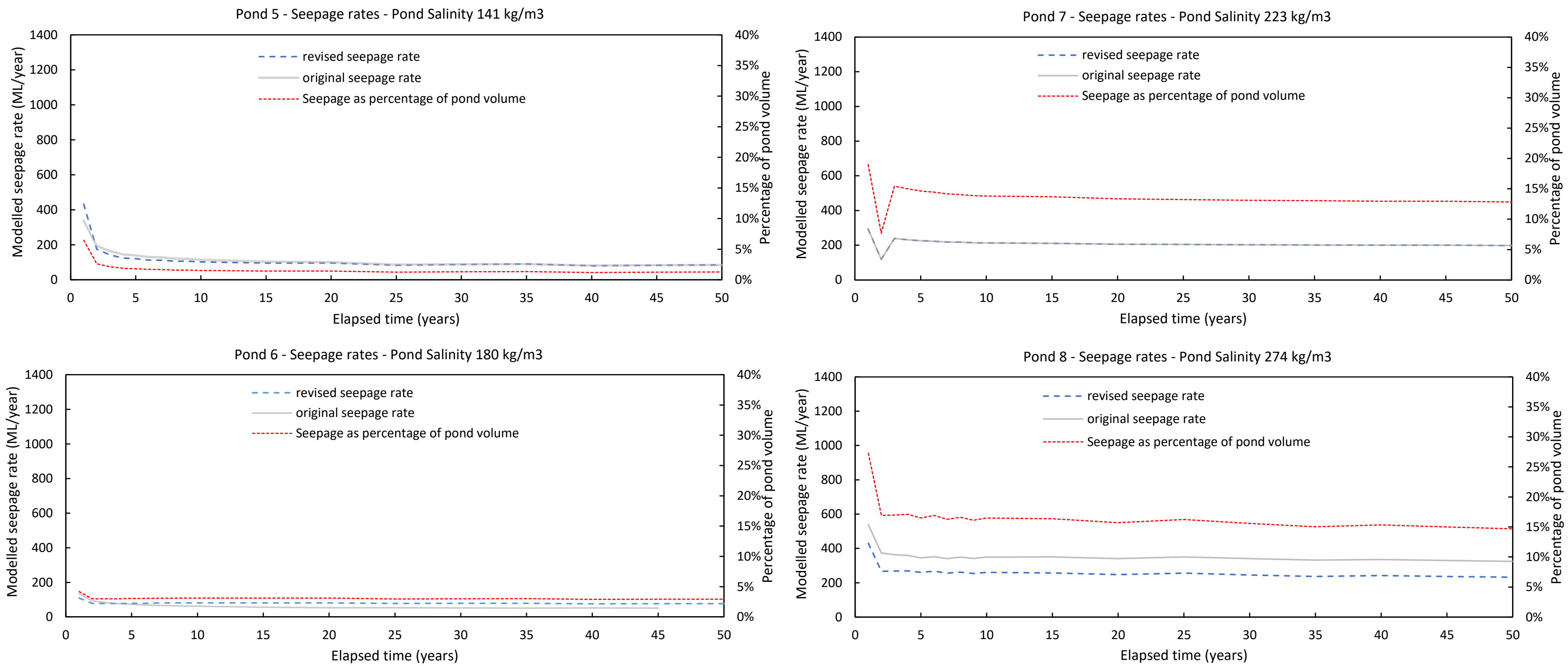


Figure 13 ***Pond 5 to 8 Seepage Rates***

4.4 Global Flow and Mass Balance Discrepancy

The global and flow and mass balance discrepancies for every time step of the revised calibration run are presented on Figure 14-. The cumulative mass balance error is 0.01% and less than 0.01% for the flow and transport simulations, respectively.

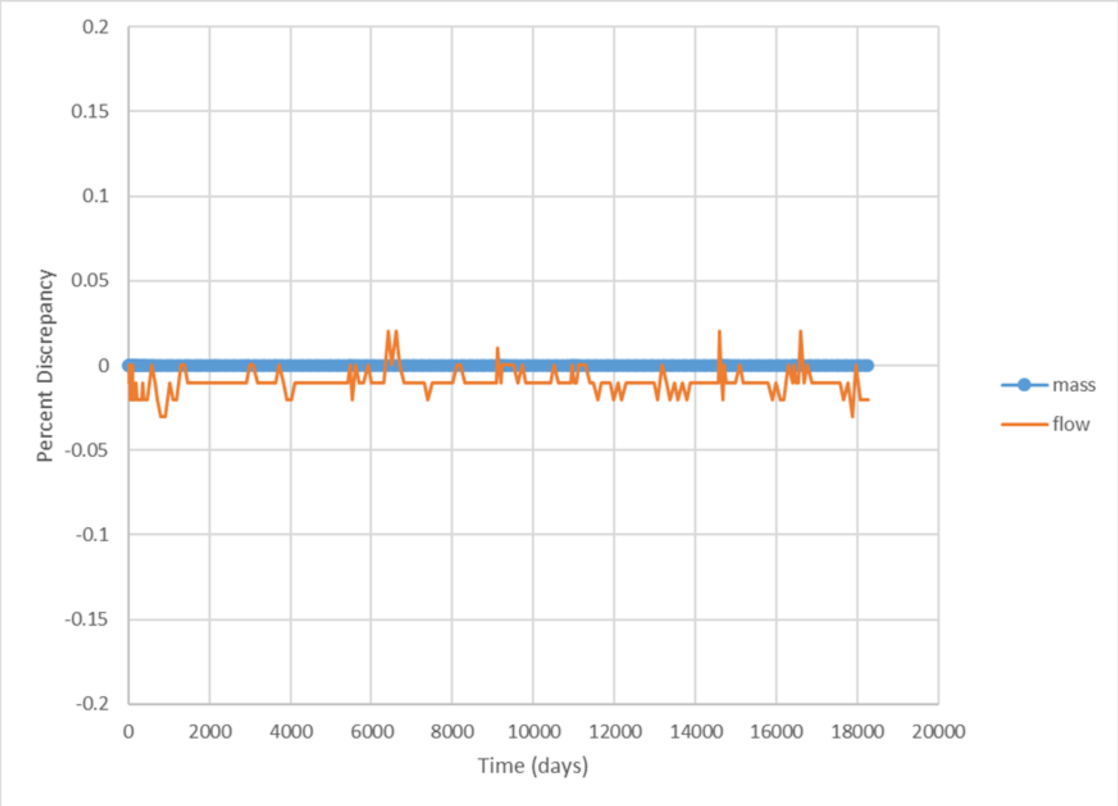


Figure 14- ***Prediction Global Water and Mass Balance Discrepancies***

4.5 Prediction Water Budget

4.6 Calibration Global Water and Mass Budgets

The global water and mass budgets for the last time step of the prediction run are presented in Table 3 and Table 4.

The two largest differences between the original and revised model water budgets are ET out and river in. The water budget shows that the ET out has decreased in the revised model as expected due to the lowered ET rate in zone 1. Since pond seepage from river cells is nearly the same in both the original and revised predictions the decrease in inflow occurs at river cells along the channels on the coast.

The largest net mass budget differences occur in the river and decay components. By far the largest difference is the decreased net mass inflow from the river package. This decreased inflow occurs in the river cells along the coastal channels. The mass decay out is dramatically lower because the zero order decay terms only occur in layer 1 of the revised model.

Table 3 *Prediction Water Budget*

	Original	Original	Revised	Revised
Component	**In (m3/d)**	**Out (m3/d)**	**In (m3/d)**	**Out (m3/d)**
Storage	22.0	21.0	39.9	31.7
Density Storage	129.1	385.9	238.6	402.9
Constant Head	786.2	1784.0	401.5	1666
River	6562.2	1711.0	5640	1614
Recharge	5254.2	0	5254.2	0
ET	0	8850.5	0	7860
Total	12753	12752	11573	11576

Table 4 *Prediction Mass Budget*

	Original	Original	Revised	Revised
Component	**In (T/d)**	**Out (T/d)**	**In (T/d)**	**Out (T/d)**
Storage	162.0	622.3	701.6	1135.0
Mass Decay	0	68.1	0	2.0
Constant Head	22.1	43.1	14.0	52.5
River	757.8	43.1	655.4	242.5
Recharge	61.1	0	61.1	0
ET	0	0	0	0
Total	1004	1004	1432	1432

5. Zero Order Decay Zones

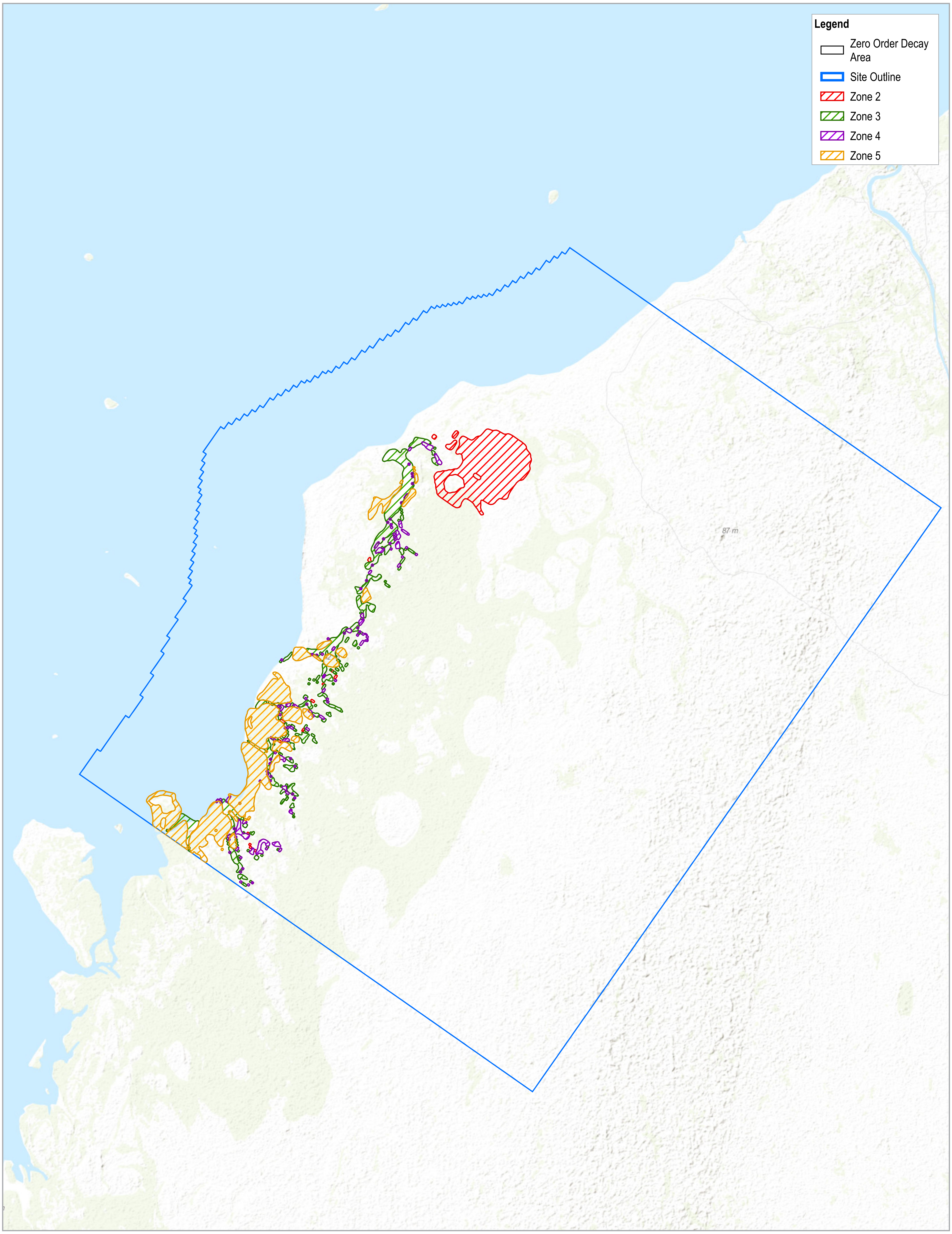
Tidal flows that would act to dilute/remove salinity in shallow horizons of the aquifer cannot be simulated within a regional model with long simulation times. To assess potential salinity levels in areas of the model where mangroves and algal mats have been mapped, the zero-order decay[1] capability of Modflow USG was activated. This code allows for the simulated removal of salt from the upper parts of the aquifer due to tidal flushing. Areas (or zones) of the model where Zero-order decay was activated are presented in

The average simulated concentration for the zero order zones were estimated for the revised model, with a result of 109.1 mg/L being obtained. The corresponding result for the original model was 79.8g/L. Detailed results for the two models are presented in Table 5 .

Table 5 *Predicted Average Salinity Values by Zone (g/L)*

Zone	Original Model Average	Revised Model Average	Area (h)
Zone 2	142.4	177.6	1219.319
Zone 3	59.8	104.1	1141.258
Zone 4	104.1	185.7	283.0647
Zone 5	73.4	92.2	1840.721
Zones 2 to 5	79.8	109.1	

[1] For a zero-order reaction, increasing the concentration of the reacting species will not speed up the rate of the reaction.



Paper Size ISO A3

0 2 4 6 8
Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

K + S Australia Pty Ltd
Ashburton Solar Salt Project
Phase 2 Site Investigations

Project No. **12516706**
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Date **26/10/2022**

Zero Order Decay Areas

FIGURE 15

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Print date: 26 Oct 2022 - 15:00

Data source: World Topographic Map: Esri, HERE, Garmin, USGS, NGA. Created by: rbrown3

6. Conclusions

The work reported above summarises the outcomes of additional modelling work to assist K+S understand potential effects of their proposed project. The additional modelling examined the simulated effects of two changes to the conceptualisation:

– Increased vertical discretisation at or just below the simulated water table.
– Lowering of recharge rates to account for the formation of a salt crust

The results of the 50 year simulations presented include the following:

– The predicted watertable level and groundwater salinity changes for the revised model are similar to the results of the original model. However, it is noted that the simulated area affected by the lower end range of groundwater level increases (0 to 0.5m) for the revised model is slightly larger than the corresponding results for the original model
– The simulated average concentration in the zero order zones was approximately 109g/L for the revised model. This compares to 79.8g/L for the previous model.

7. References

GHD, 2021: Ashburton Solar Salt Project Hydrogeological Investigation. Prepared for K+S Salt Australia Ltd. June 2021.

Panday, S., 2022: USG-Transport Version 1.9.0: The Block-Centered Transport Process for MODFLOW-USG. GSI Environmental.

Regards,

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