Memorandum

11 November 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	**Project no.**	12591916

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.

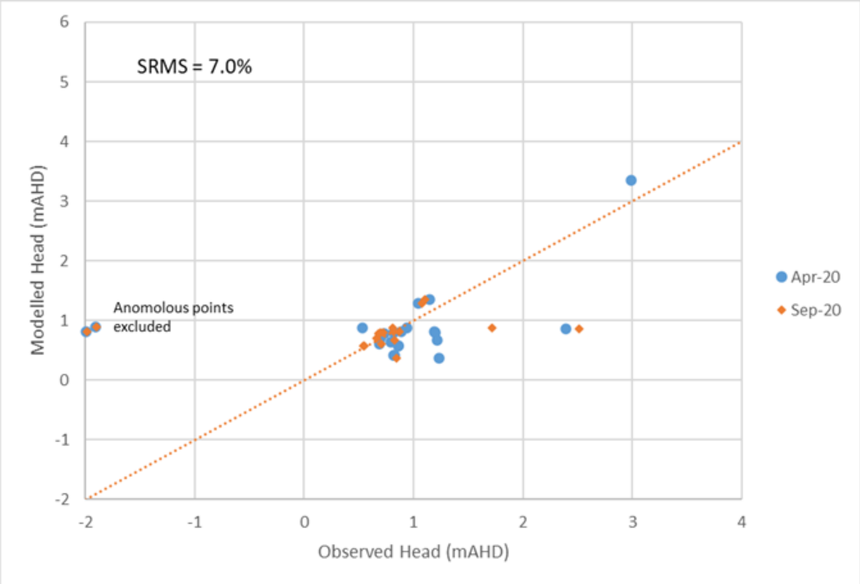


Figure 1 ***Scatterplot of Modelled vs Measured Heads***

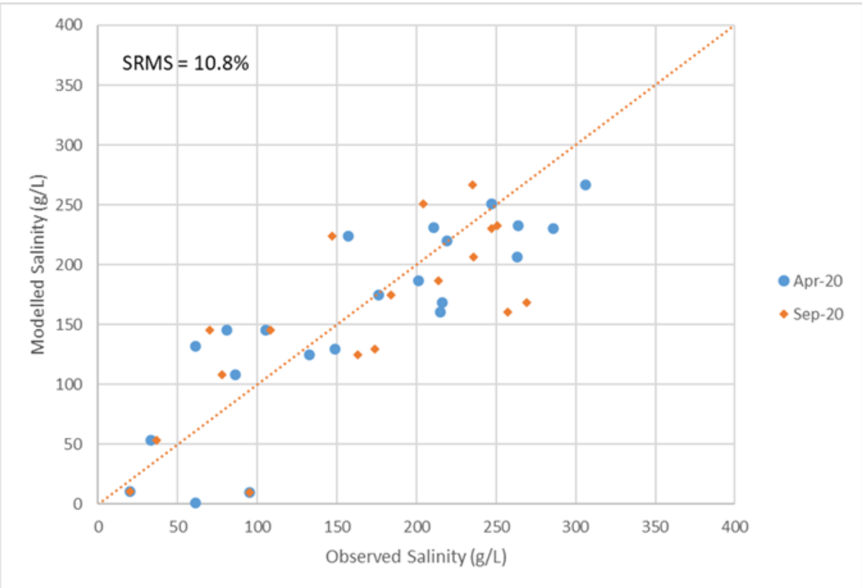
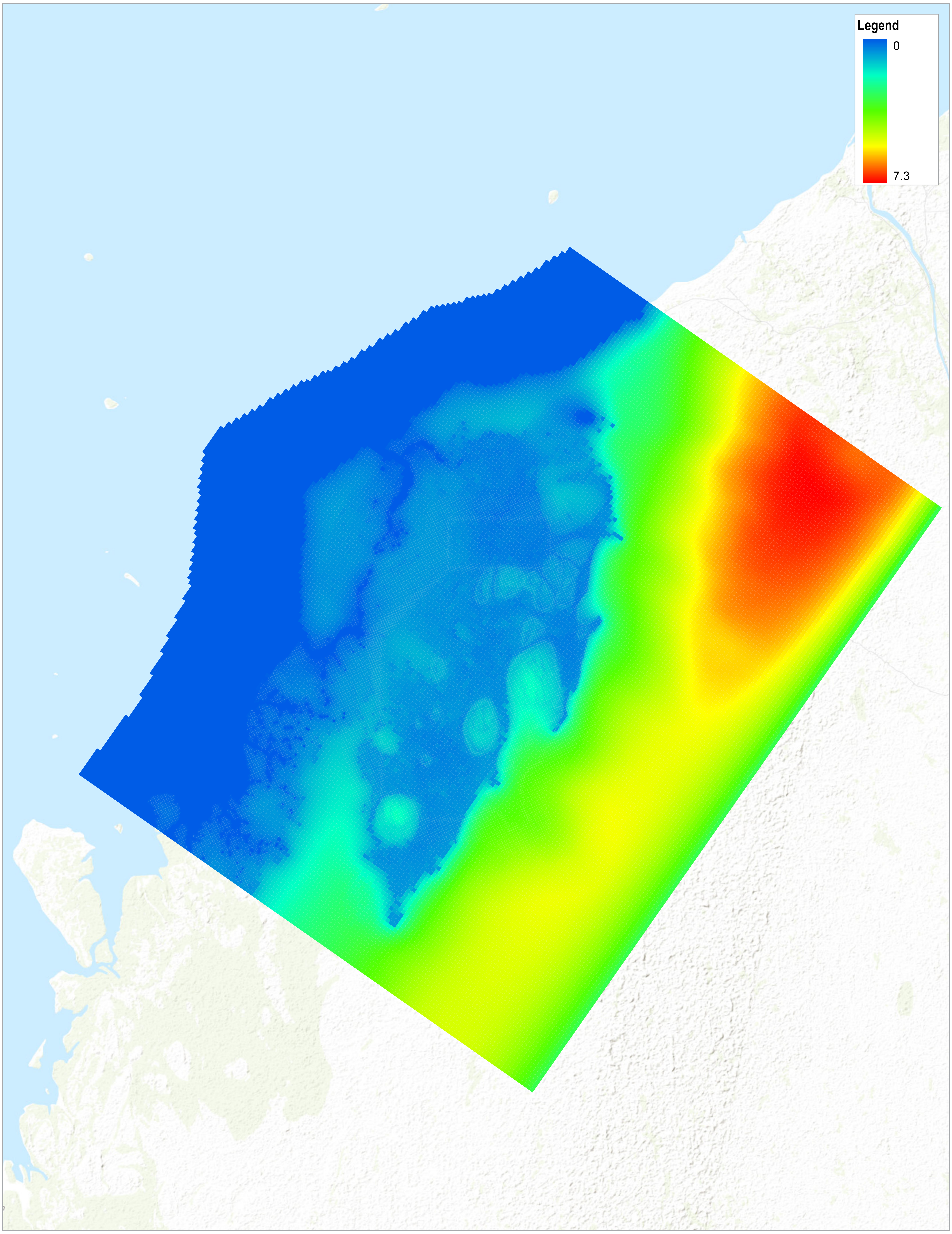


Figure 2 ***Scatterplot of Modelled vs Measured Salinity***



Paper Size ISO A3

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Kilometres

N

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

Water Table (mAHD)
End of Calibration Run

FIGURE 3

\\ghdnet.internal\ghd\AU\Perth\Projects\61\12516706\GIS\Maps\Working\A4P Groundwater Maps\Revised Model maps 18-10-22\12516706_revised_model_outputs_GIS_Team_Layouts.aprx\12516706_03_CalibrationWT_Rev0
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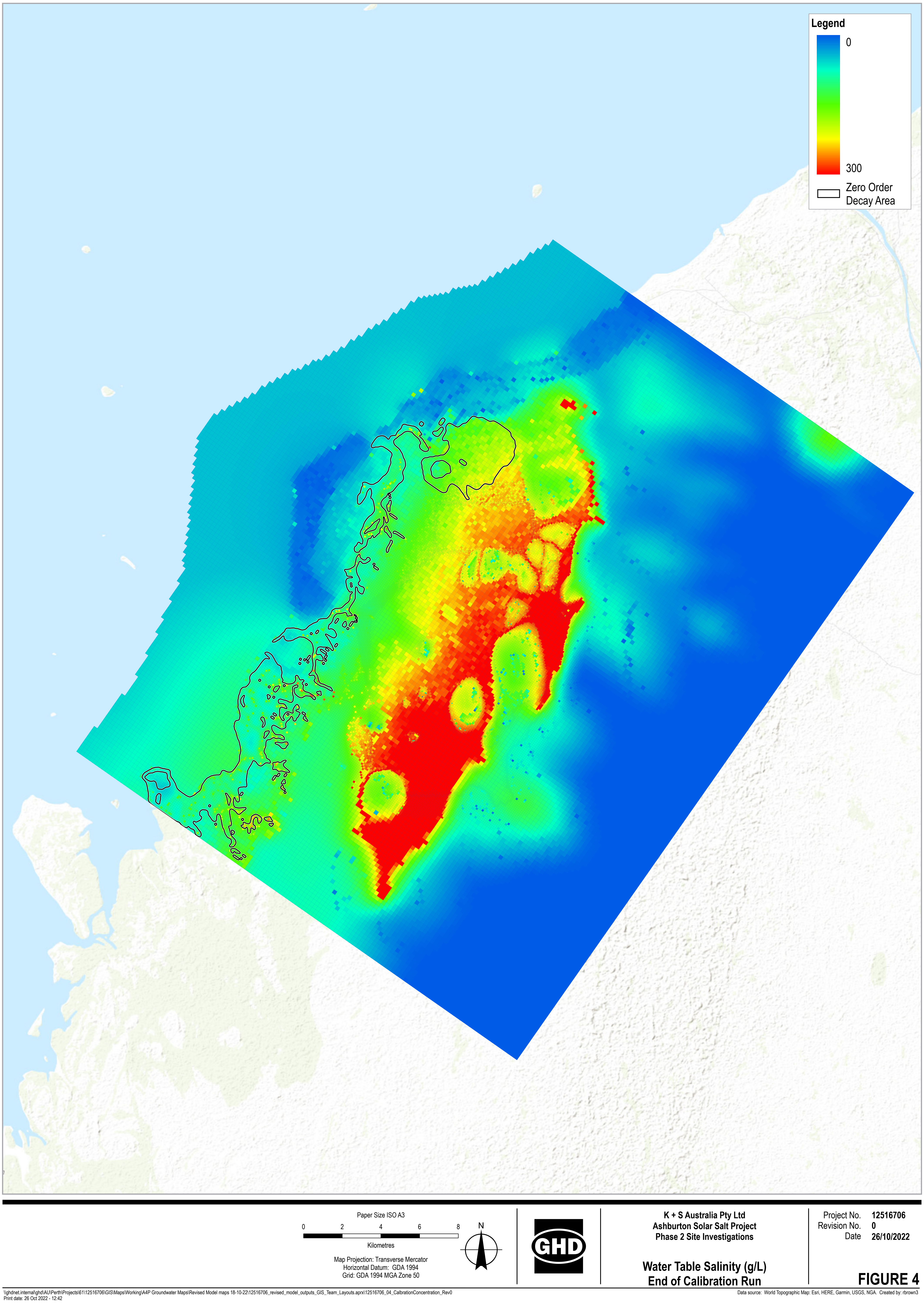

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Project No. 12516706
Revision No. 0
Date 26/10/2022

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

FIGURE 4

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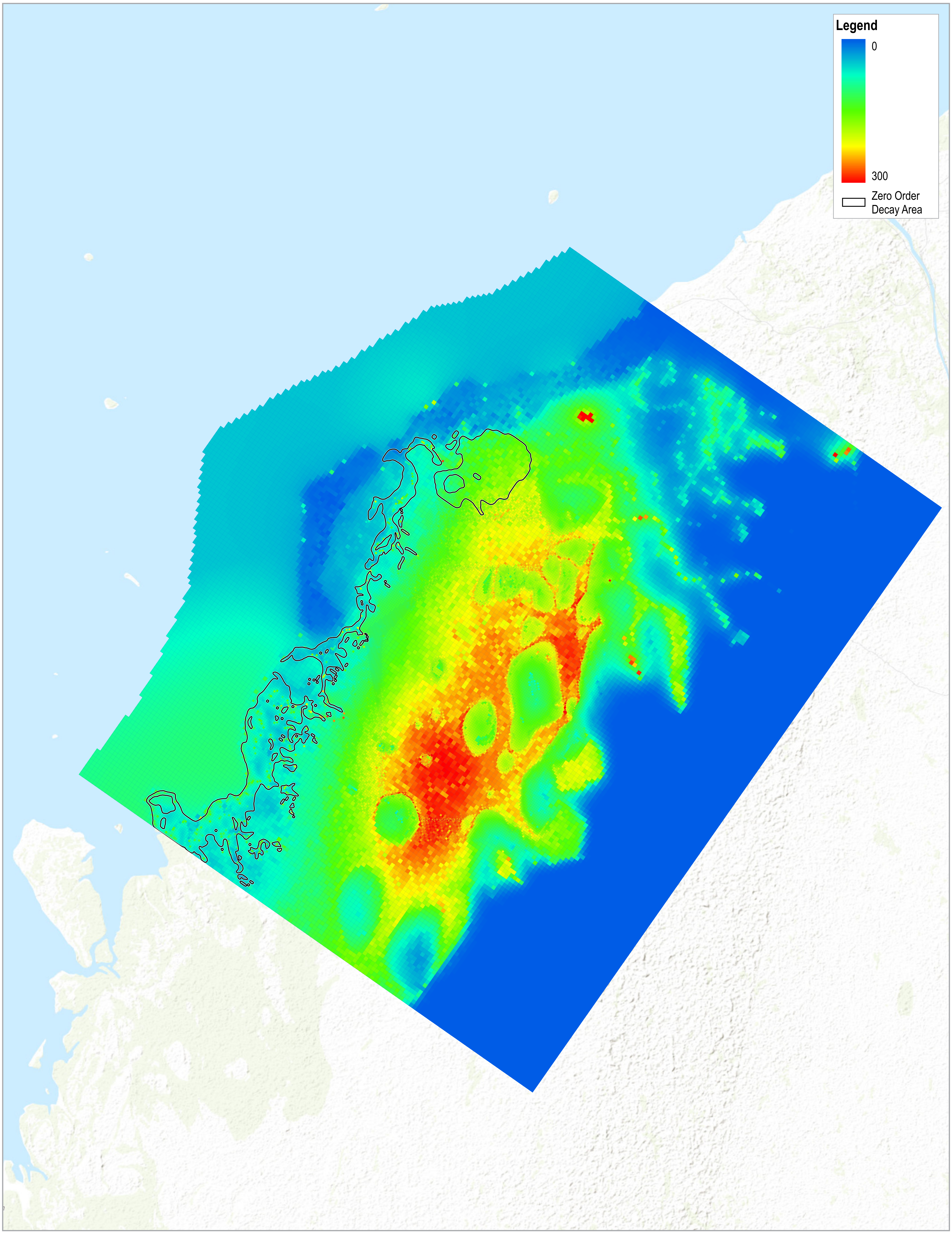

Paper Size ISO A3

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Kilometres

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

N

GHD

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Phase 2 Site Investigations

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

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

FIGURE 5

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Print date: 26 Oct 2022 - 12:41

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.

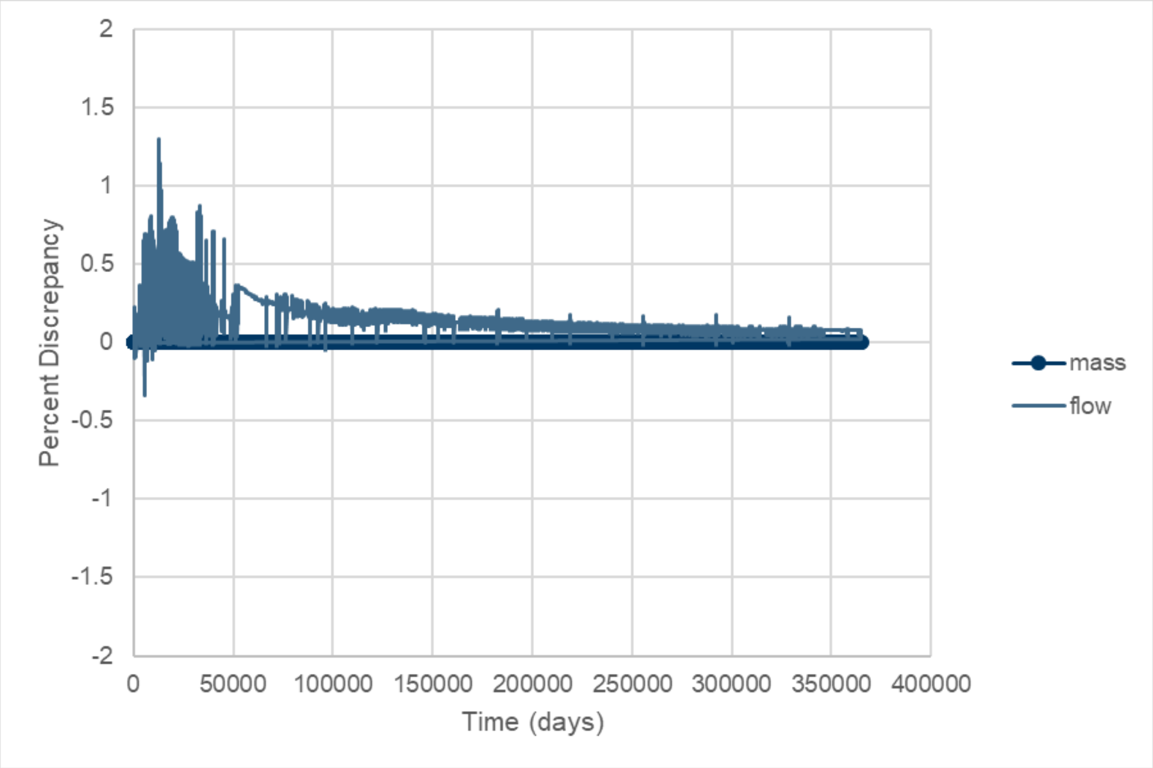


Figure 6 Calibration Global Water and Mass Balance Discrepancies

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

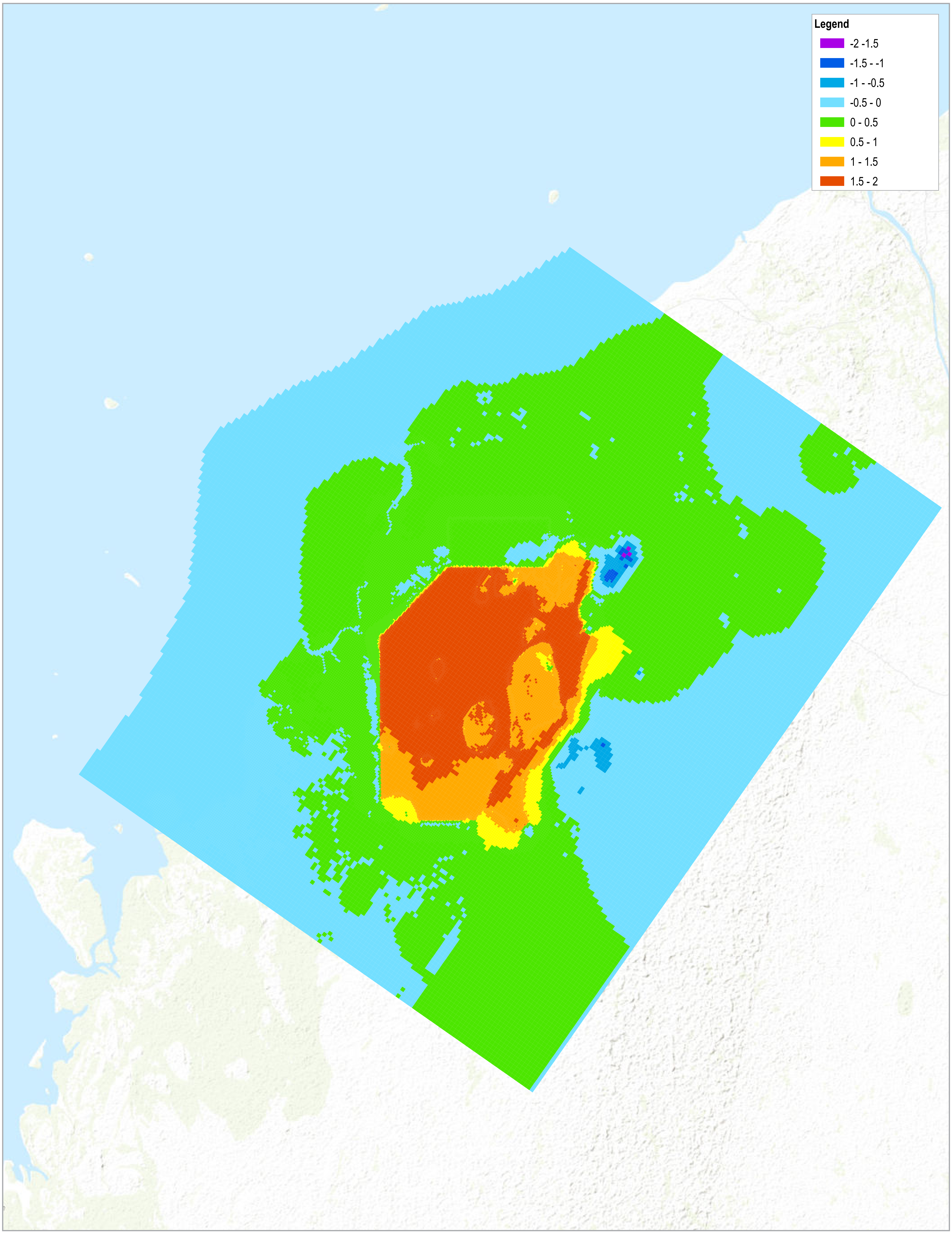
	Original	Original	Revised	Revised
Component	**In (T/d)**	**Out (T/d)**	**In (T/d)**	**Out (T/d)**
Storage	29.7	7.5	77.7	83.7
Mass Decay	0	67.9	0	1.74
Constant Head	22	43.4	15.5	55.4
River	4.53	31.9	3.10	50.0
Recharge	94.5	0	94.5	0
ET	0	0	0	0
Total	150.9	150.9	190.8	190.8

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.

A comparison between predicted water levels from the original unrevised model and the revised model is presented as Attachment A1. This figure was produced by subtracting results from the original unrevised model from the revised model.



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

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

Predicted Water Table Rise (m)
After 50 Years

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

FIGURE 7

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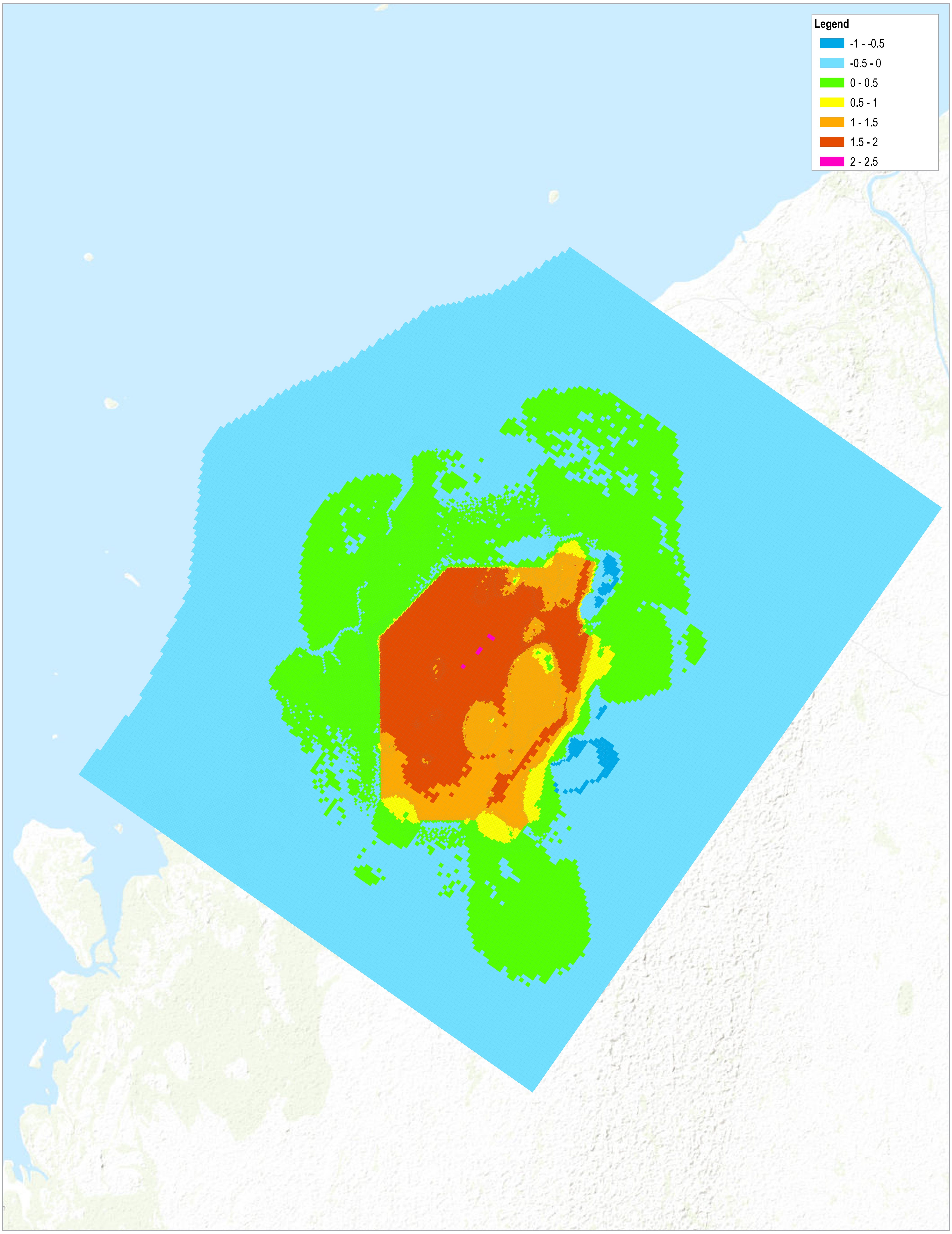

Paper Size ISO A3

0 2 4 6 8

Kilometres

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

N

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Ashburton Solar Salt Project
Phase 2 Site Investigations

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

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

FIGURE 8

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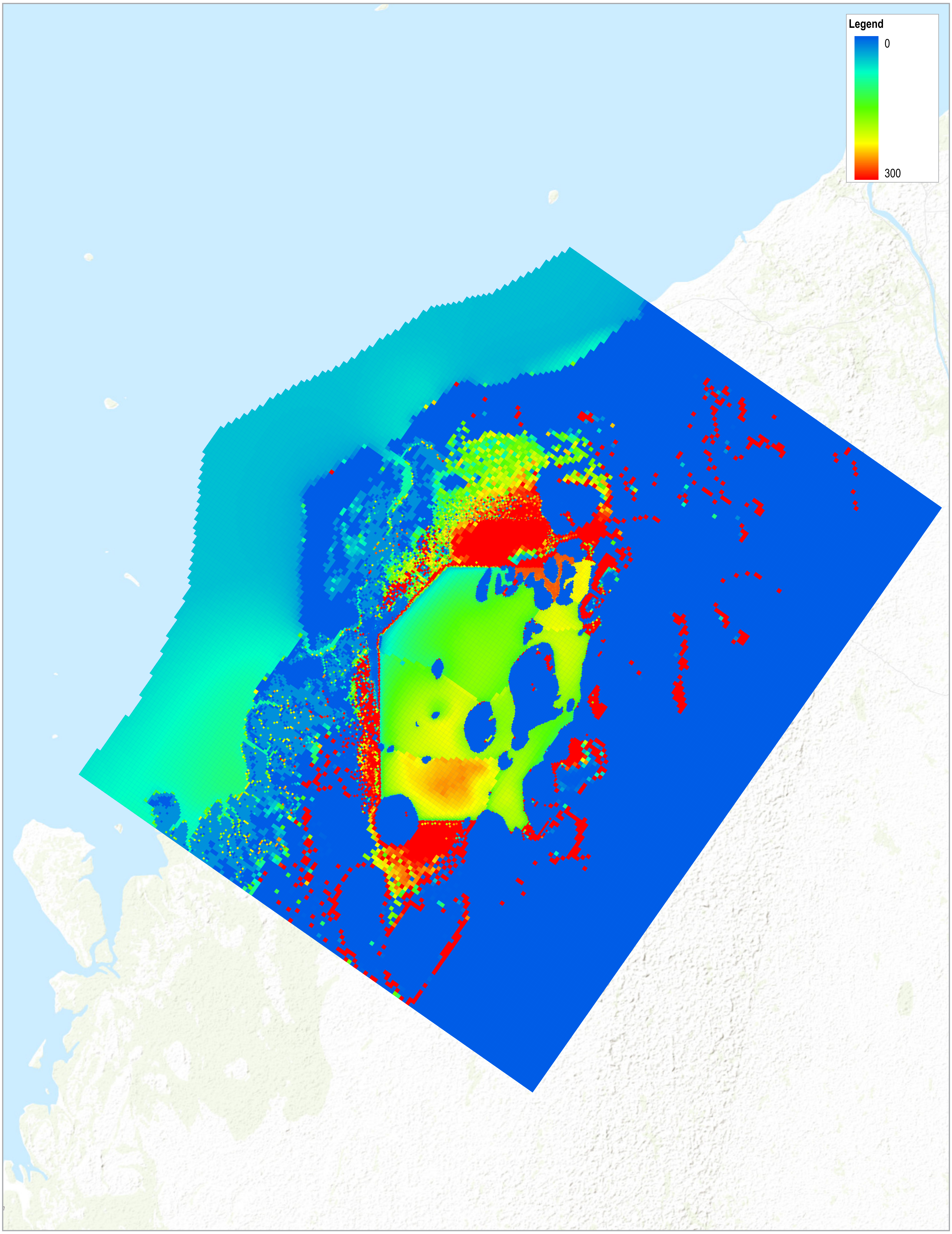
Print date: 25 Oct 2022 - 13:28

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.

A comparison between predicted salinity levels from the original unrevised model and the revised model is presented as Attachment A2. This figure was produced by subtracting results from the original unrevised model from the revised model.



Paper Size ISO A3

0 2 4 6 8 Kilometres

N

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

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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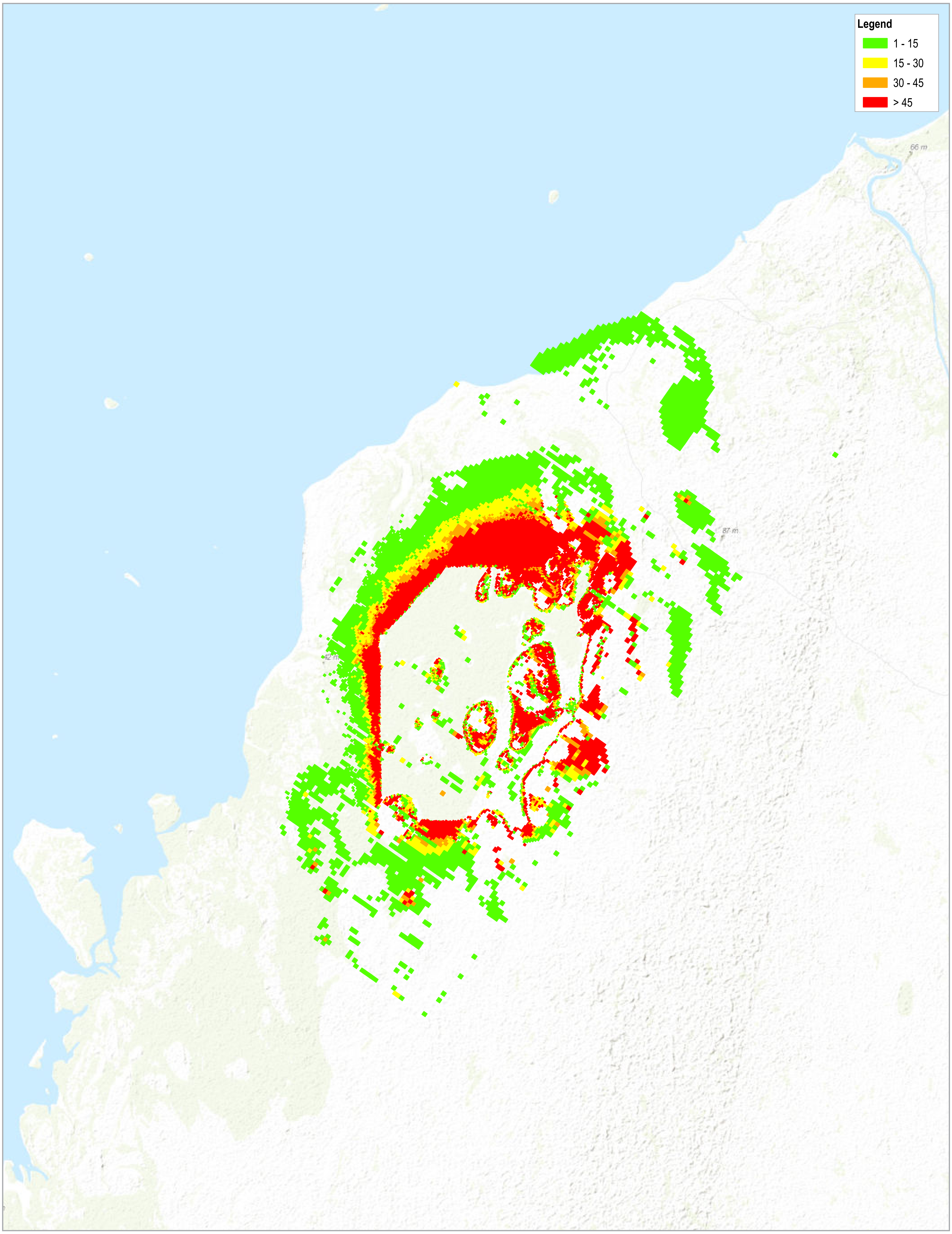

Paper Size ISO A3

0 2 4 6 8

Kilometres

N

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

GHD

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Ashburton Solar Salt Project
Phase 2 Site Investigations

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

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

FIGURE 10

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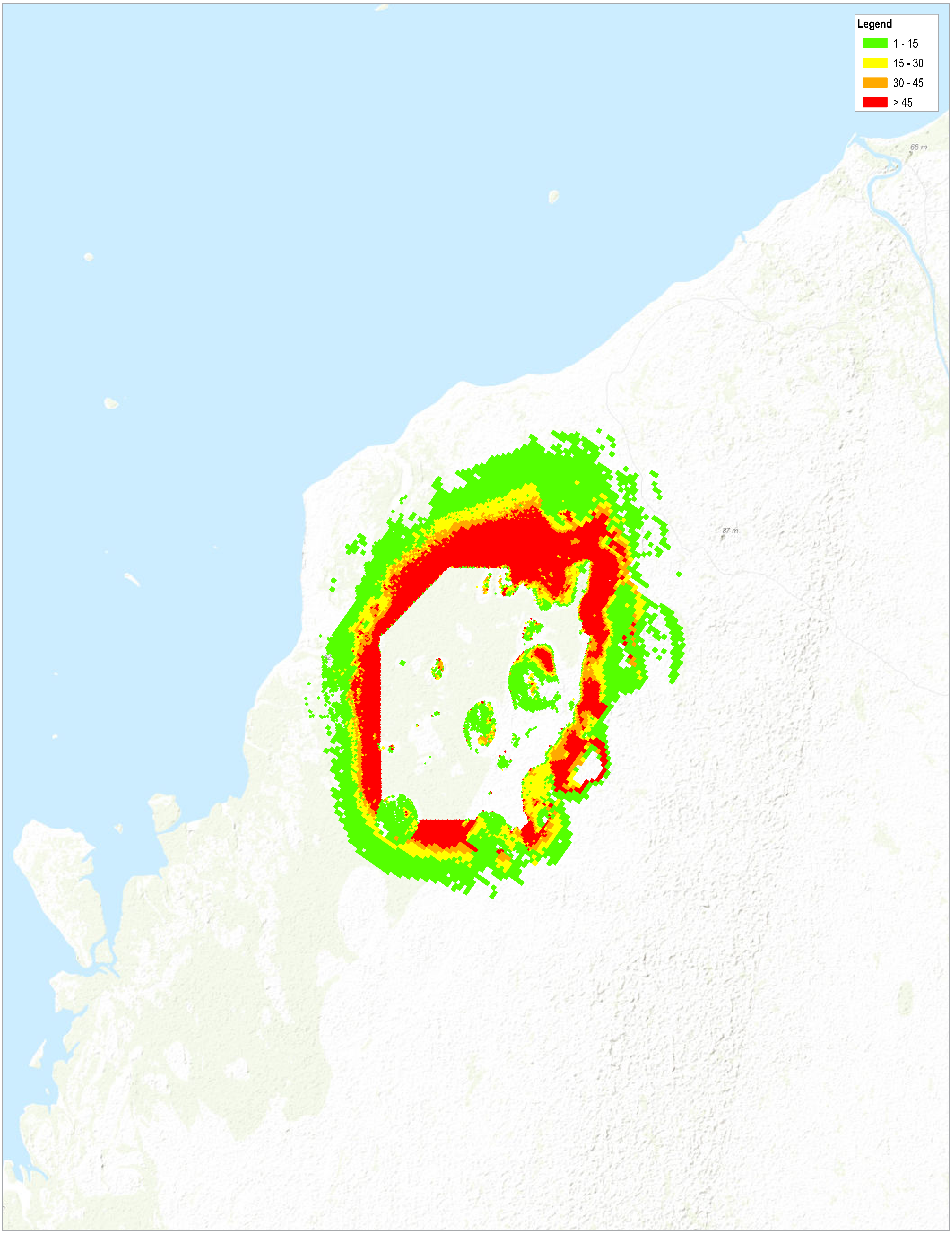

Paper Size ISO A3

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Kilometres

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

N

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Ashburton Solar Salt Project
Phase 2 Site Investigations

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

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

FIGURE 11

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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.

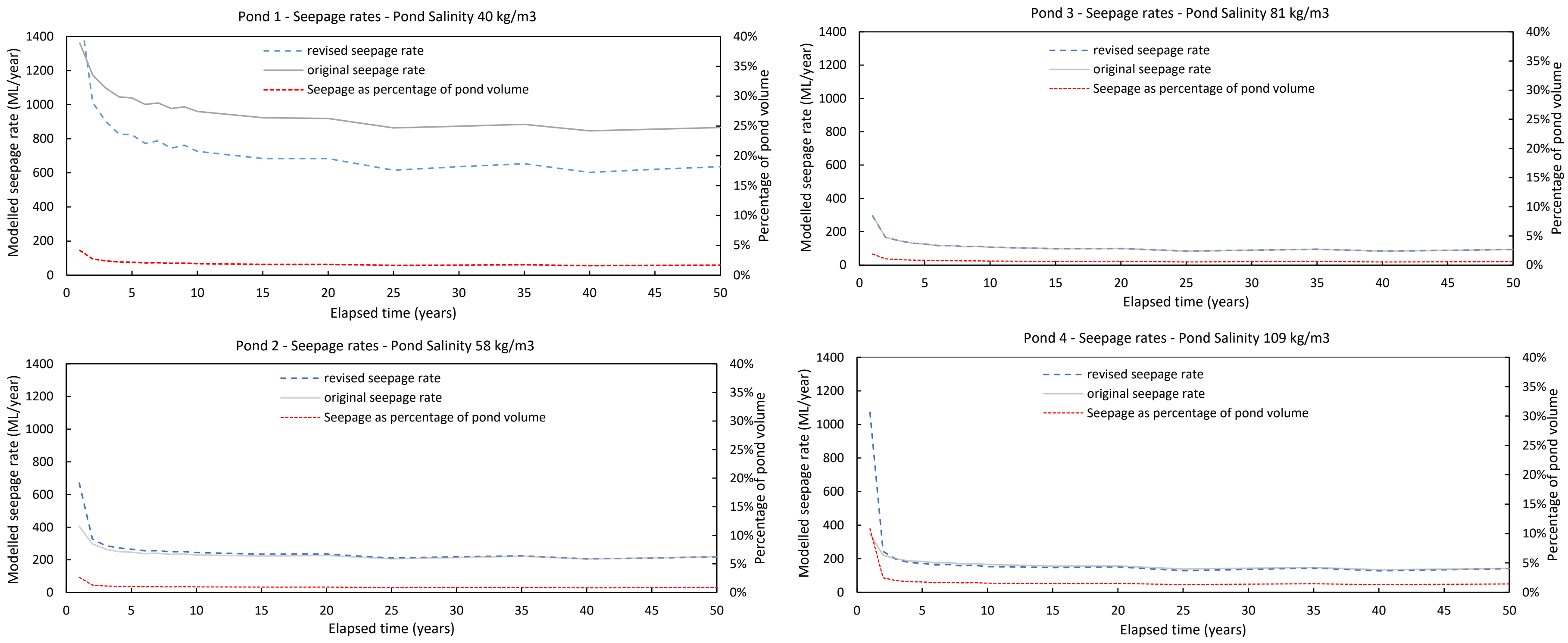


Figure 12 Pond 1 to 4 Seepage Rates

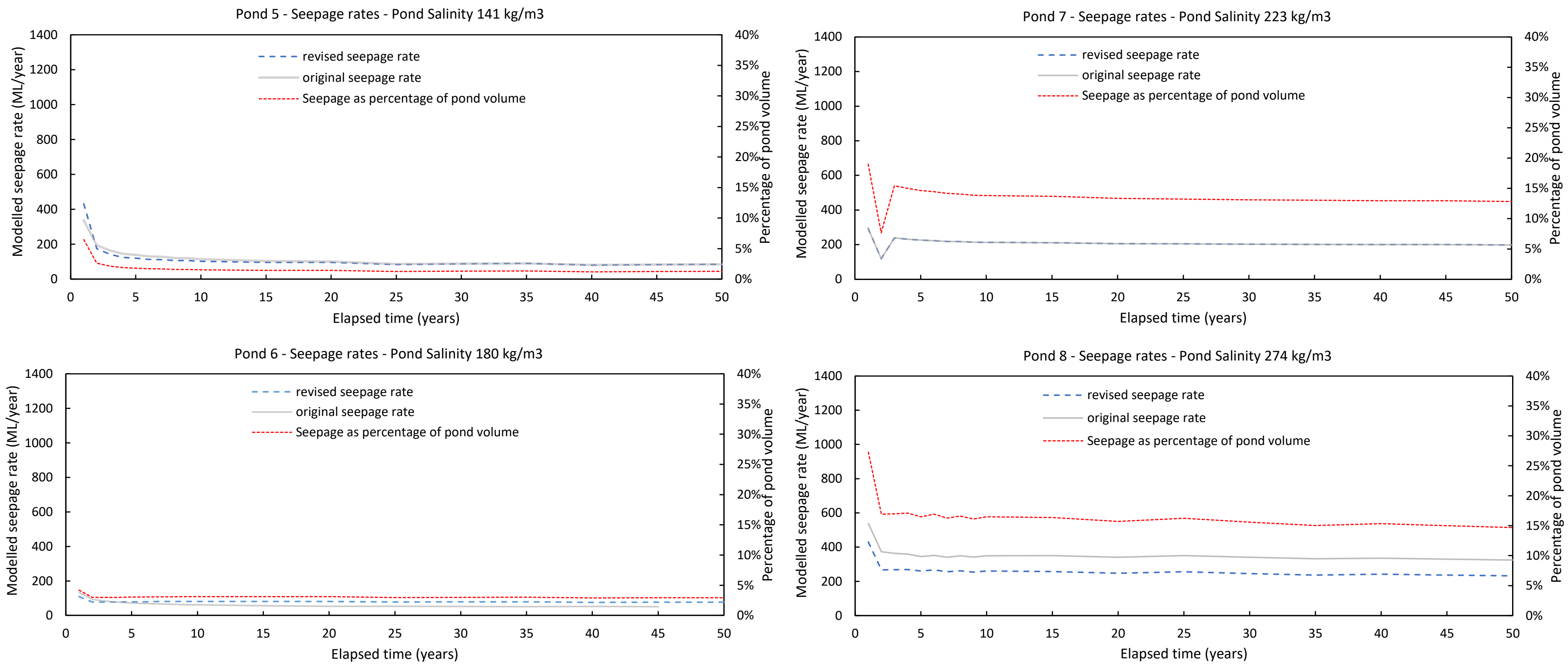


Figure 13 *Pond 5 to 8 Seepage Rates*

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.

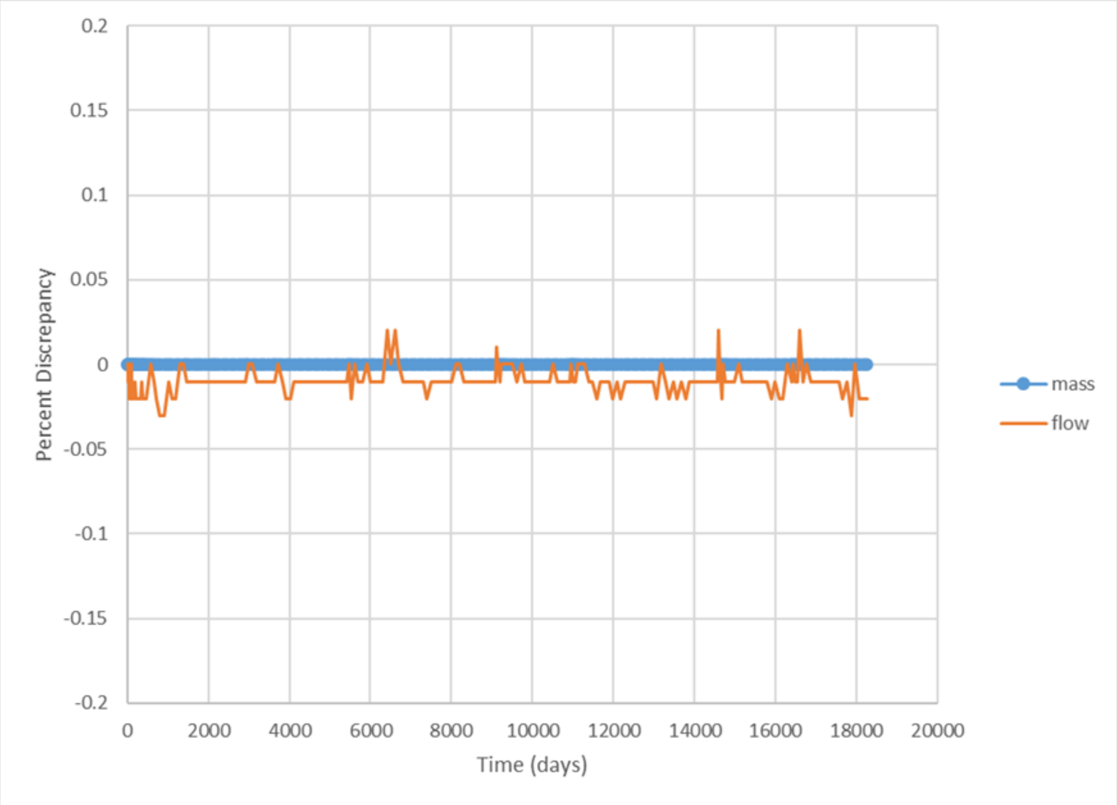


Figure 14 *Prediction Global Water and Mass Balance Discrepancies*

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

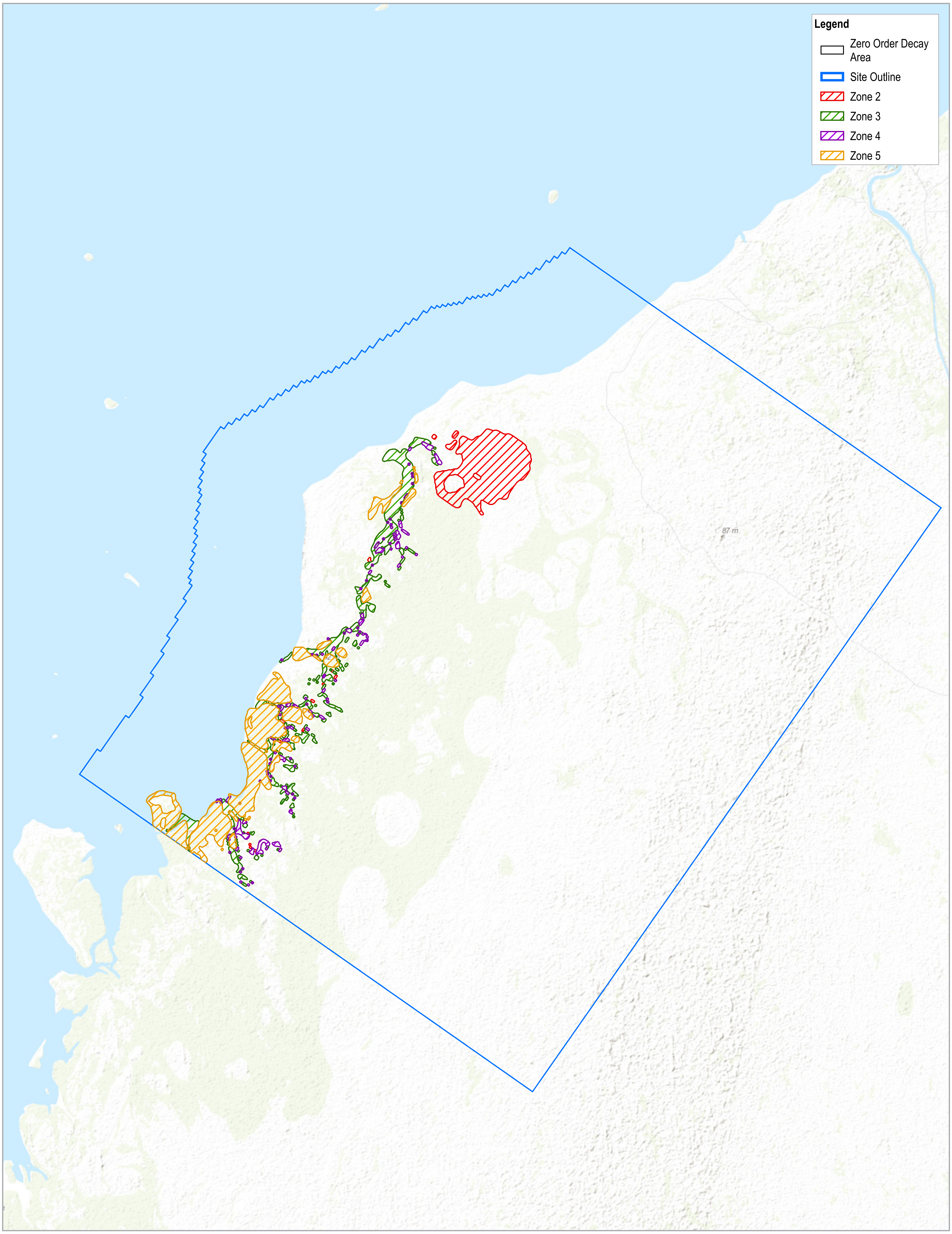
Tidal flows that would act to dilute/remove salinity in shallow horizons of the aquifer cannot be simulated within a regional model with long simulation times. To assess potential salinity levels in areas of the model where mangroves and algal mats have been mapped, the zero-order decay[1] capability 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 Figure 15.

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

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Ashburton Solar Salt Project
Phase 2 Site Investigations

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

Zero Order Decay Areas

FIGURE 15

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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,

Iain Marshall

PP

David van Brocklin
Technical Director- Hydrogeology

Marija Rosic

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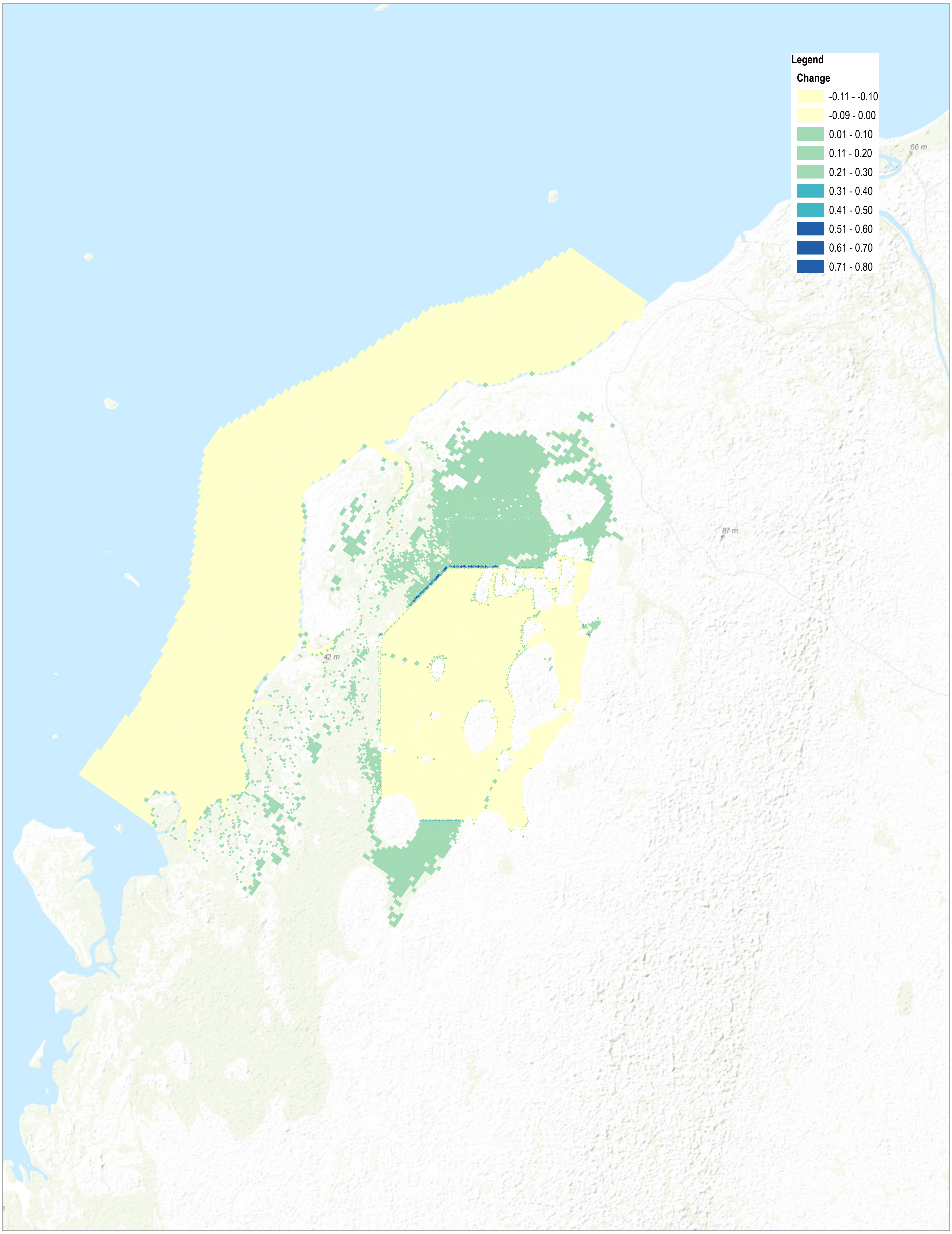
Bob Kinnell
Technical Director-Mine Water Management

Attachments



Paper Size ISO A3

0 2 4 6 8

Kilometres

Map Projection: Transverse Mercator
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 10/11/2022

FIGURE A1

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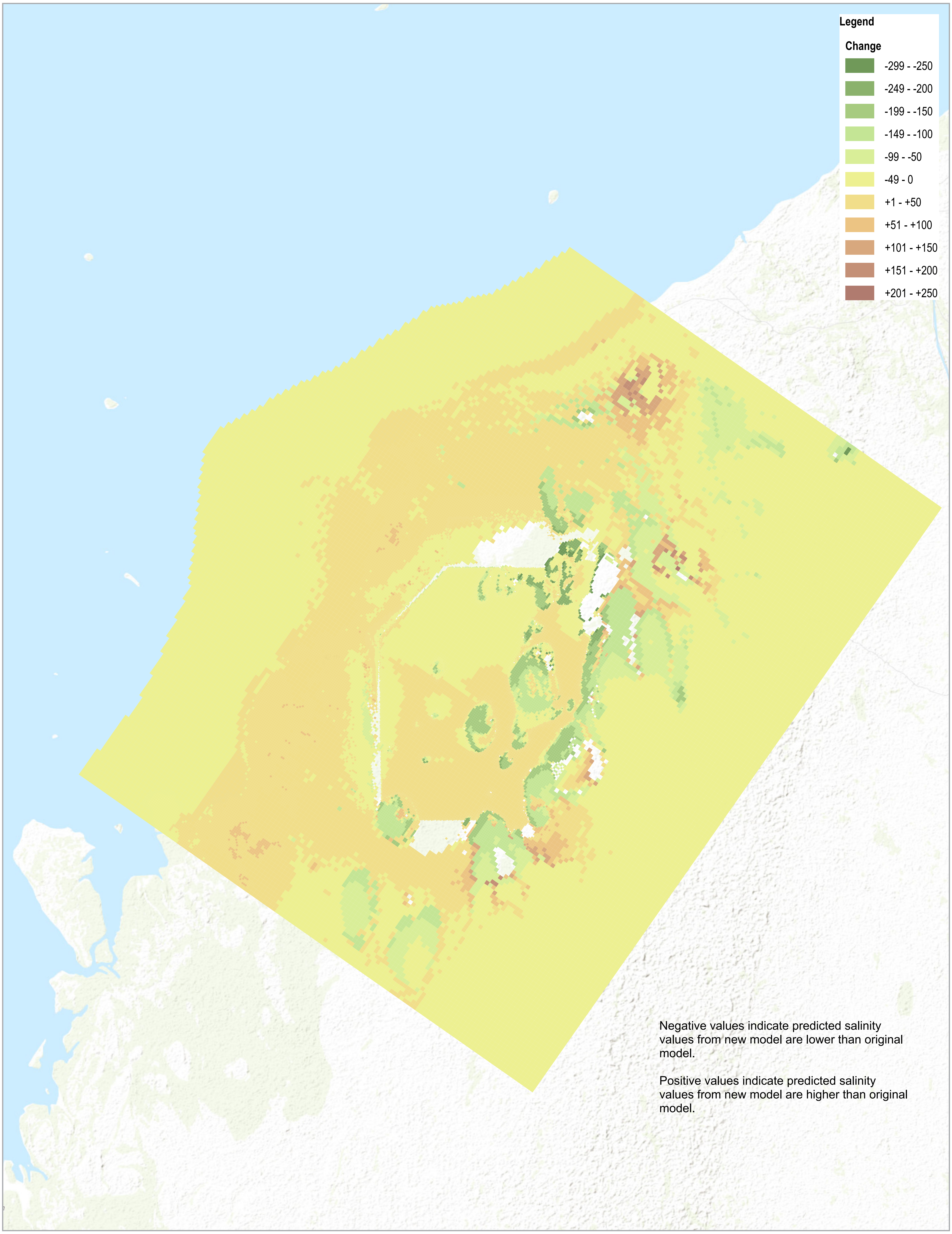

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0 2 4 6 8

Kilometres

Map Projection: Transverse Mercator
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 Salinity Between Version 1 and Version 2 Models (50 Years)

Project No. 12516706
Revision No. 0
Date 10/11/2022

FIGURE A2

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Print date: 10 Nov 2022 - 12:46

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

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