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Lower Lakes Water Quality Recovery Dynamics

Final Report

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Executive Summary

Widespread decreases in rainfall throughout the Murray-Darling Basin from 2004-2009 resulted in an order of magnitude reduction in flow through the system relative to the long-term average. In particular, this resulted in a dramatic shift in flow regimes and biogeochemical cycling of the Lower River Murray, including an unprecedented rate of water level decline in the Lower Lakes during 2008-2010. Of particular concern was the exposure of pyrite-bearing lake sediments and the increased risk from acid sulfate soil impacts and it is now well documented that several areas around the perimeter of the lake experienced acidification in 2009 and 2010. In the winter of 2010 increased regional rainfall and flow rapidly raised the lake levels, which led to a significant recovery in most lake water quality properties. While the 2010 flows have had a positive outcome for the system, the recovery process is ongoing and there is a need to further understand the complex response pathways of the lake ecosystem to change in order to support improved management into the future.

Analysis of acid sulfate soil dynamics and a detailed modelling assessment of various management scenarios was recently conducted by developing a multi-dimensional hydrodynamic-biogeochemical model. This model was able to link lake hydrodynamics and biogeochemistry with the hydrology and biogeochemistry of the surrounding (riparian) acid sulfate soil material. The model was used to explore the relationship between water level decline and acidification risk in both Lake Alexandrina and Lake Albert. However, at the time of development of this model, limited water quality data was available for validation and numerous uncertainties were identified.

In this report we outline the further development and validation of this spatially resolved hydro-geochemical model of the system to improve the predictive ability and robustness of this tool to support improved decision-making and management outcomes. This includes application across the full lake system, in addition to a specific focus on the validation of the “Currency-Creek region”, from Goolwa Barrage to Clayton in the south-west of Lake Alexandrina, with the aim to identify the dominant controls on the acidification process and water quality response. This region was of particular interest due to acidification of large expanses during 2009 that led to a large-scale management response. Further, since the original analysis, acidification events and subsequent recovery have occurred in the areas of Loveday Bay and Boggy Lake, and provide further opportunity to assess the model performance and gain insights into the driving processes that control acidification.

In addition to the acid sulfate soil model, the hydro-geochemical model presented here allows for the simulation of a wide range of lake water quality parameters, that were not the focus of the earlier study. In this report simulation domains previously developed have been updated, and also a new high resolution full lakes domain has been created able to simulate the dynamics of the system following removal of the Clayton and Narrung regulators. Software infrastructure has been developed to allow for the combining of the discrete domains for the purposes of running a continuous simulations over the period from 2008, and testing against the full spectrum of water quality data.

The validation presented here is based on all water quality data for the region from 2008 to April 2011 which was compiled from various agencies and used to comprehensively test the model simulations at a wide range of locations. Overall, greater than 42 main validation sites within the domain were adopted and data for PO_4, NO_3, NH_4, TN, TP, Chl-a, TSS, pH, alkalinity, Ca, Na, SO_4, Mg, Cl, Al, and Fe were tested against model equivalents for the entire period. Specifically, the model was also tested against acidification events that occurred in Currency Creek, Loveday Bay and Boggy Lake, in addition to simulating the recovery dynamics during the period of flooding that occurred in 2010-2011.

The model accurately predicted:

- The autumn/winter 2009 acidification event in the disconnected pools of the Currency Creek tributary region, and the subsequent water quality recovery following refill.

- The acidification of Loveday Bay, preliminarily in 2009 and then during filling of the pools in 2010.
- The acidification of Boggy Lake in the north-east area of Lake Alexandrina during the autumn/winter period of 2010.
- The stability of pH in Lake Albert, and other regions of the domain

The present analysis therefore shows the model and parameters that have been adopted previously and used for guiding management decisions, is able to successfully capture the spatial extent and timing of acidification events, and provides support as to the robustness of predictions made previously for a range of flow and management scenarios.

The outputs and analysis of the main acid flux pathways has identified that management actions performed in the high impact areas, such as isolation of flows in the Currency Creek tributary, limestone doing of surface waters, and pumping to maintain the level in Lake Albert, were appropriate and prevented development of further degraded areas.

This analysis also further assessed the level of risk of acid sulfate soils to the lake ecosystem should the system enter a new cycle of water level drawdown. The results of this analysis suggest that a renewed phase of water level decline below -1.0m AHD would lead to acidification risks, despite potential depletion of sulfidic material over the past two years. The scenarios highlighted that the predicted hotspots for acidification were similar to those that have been a major concern historically, and that the extent and timing of these events was similar whether the model was run with sediment depleted in sulfides, or if they were assumed to have been regenerated during prior inundation. Other water quality parameters in the scenarios indicated steep increases in salinity and increased nutrient levels and turbidity, highlighting that multiple stressors during prolonged low water levels provide increased pressure on the lake ecosystem. Therefore, allocation of water to the lakes to maintain above them above the critically low levels seen in 2009-2010 is recommended to prevent further degradation of the lake ecosystem and to protect the lakes natural diversity.

The model and field data validation process has also been semi-automated and setup for transfer to relevant stakeholders for further application for assessing water quality and risks from acid sulfate soils.

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Introduction & Objectives

Background

Widespread decreases in rainfall throughout the Murray-Darling Basin from 2004-2009 resulted in an order of magnitude reduction in flow through the system relative to the long-term average (Mosley et al., submitted). In particular, this has resulted in a dramatic shift in flow regimes and biogeochemical cycling of the Lower River Murray, including significant changes to water quality properties such as salinity, nutrients, algae and turbidity (Hipsey et al., 2010). Below Wellington, the river enters Lake Alexandrina, which in turn is connected to Lake Albert, collectively referred to as the Lower Lakes. The lakes have been separated from the Coorong, an estuarine-hypersaline lagoon, by barrages since the 1930s, and are listed under the Ramsar Wetland Convention owing to their high natural diversity.

The unprecedented rate of water level decline in the lakes during 2008-2009 generated several water quality related management concerns. Of particular concern was the exposure of pyrite-bearing lake sediments and the increased risk from acid sulfate soil impacts. Acidification of water courses can occur when reduced sulfides are exposed to oxygen (Ward et al., 2004). While high concentrations of sulfides have been reported to occur in inland water systems (Baldwin et al., 2007), they are typically associated with coastal areas, since high sulfate concentrations in seawater fuel sulfate reduction in anoxic sediments and promote the subsequent formation of sulfidic materials such as pyrite. Surface waters become at risk of acidification when pyritic material is disturbed and oxidised, for example, as a result of altered drainage or dredging/reclamation activities, and the resulting acidity is transported into the surface waterbody. While the Lower Lakes are mainly fresh (Muller et al., submitted) and no drainage actions have occurred to trigger the oxidation process, they have however been exposed to high sulfate concentrations that has led to a build up of pyrite over geological time (Fitzpatrick et al., 2009). In this case the oxidation process has occurred due to the relatively rapid (and unprecedented) rate of water level decline exposing perimeter regions of the lake sediment to the atmosphere (Fitzpatrick et al., 2009).

This led to several management options being implemented, including disconnection of Lake Alexandrina, Lake Albert and the Finniss/Currency region (from west of Clayton to Goolwa); large-scale limestone additions to acidified areas; and reintroduction of organic matter to exposed sediments to enhance alkalinity generation. Other options considered also included the potential for seawater introduction to stabilise water levels (BMTWBM, 2010). However, in the winter of 2010 increased regional rainfall and flow rapidly raised the lake levels, which led to a significant recovery in most lake water quality properties. A considerable drop in alkalinity has been observed and it is not certain what role dilution vs. acidity transport from the acid sulfate soils has played. The recovery has also led to flows reaching the Coorong for the first time in several years, and has had associated ecological benefits. While the 2010 flows have had a positive outcome for the system, the recovery process is ongoing and there is a need to further understand the complex response pathways of the lake ecosystem to change in order to support improved management outcomes into the future.

The long-term sustainable management of wetland and river systems such as the Lower Lakes, and preservation of their ecological value, requires a quantitative understanding of ecosystem processes and services to guide management activities. Analysis of acid sulfate soil dynamics (Hipsey et al., 2011) and modelling assessment of various management scenarios (BMTWBM, 2010) associated with the above conditions was recently conducted using multi-dimensional hydrodynamic-biogeochemical models. This model was unique in that for the first time was able to integrate lake hydrodynamics and biogeochemistry with the hydrology and biogeochemistry of the surrounding (riparian) acid sulfate soil material. In summary, the model includes:

- 3D hydrodynamics, including prediction of circulation patterns, inflows (including pumping and seawater entrance), wetting and drying, temperature, salinity, surface thermodynamics and evaporation;

- 2D spatially variable specification of soil texture and geochemistry, which allows for heterogeneity in soil hydraulic properties, pyrite content, and acid neutralising capacity at high-resolution;
- Vertically resolved pyrite oxidation reaction kinetics in exposed cells based on dynamically predicted moisture content profiles, and subsequent neutralisation kinetics;
- Estimation of acidity flux to the surface water following re-wetting of exposed cells during flooding, and also from overland flow and lateral seepage processes;
- Buffering of water pH by lake and river alkalinity and internal lake biogeochemical dynamics, including approximation of alkalinity generation by organic matter decomposition in submerged sediments.

For a detailed description of the model components and mathematical basis the reader is referred to Hipsey et al. (2011). The model is parameterised based on available data and other strategic experimental work (eg. Fitzpatrick et al., 2009; Earth Systems, 2010). In this report we outline the further development and validation of the spatially resolved hydro-geochemical model of the system to provide an improved quantitative understanding of ecosystem processes and services during this period of rapid environmental change. By further understanding the complex response pathways of the lake ecosystem to change, our aim has been to improve the predictive ability and robustness of this tool to support improved decision-making and management outcomes. This includes application across the full lake system, in addition to a specific focus on the validation of the "Currency-Creek region", from Goolwa Barrage to Clayton in the south-west of Lake Alexandrina, to identify the dominant controls on the acidification process and water quality response. This region was of particular interest due to acidification of large expanses during 2009 (Fitzpatrick et al., 2009) that led to a large-scale management response. Further, since the original analysis, acidification events and subsequent recovery have occurred in the areas of Loveday Bay and Boggy Lake, and provide further opportunity to assess the model performance and gain insights into the driving processes that are control acidification.

Aims and objectives

It is the overarching aim of the work to date to continue development of the Lower Lakes hydro-geochemical model to improve its accuracy and prediction ability for lake management purposes. This involves the development of ability to simulate the system since reconnection in Sept 2010, and further and much more detailed validation of the hydrodynamic, biogeochemical and acid sulfate soil components of the model against the substantial data collected over the past 24 months by the DFW real-time sensors (e.g. data.rivermurray.sa.gov), and monitoring data from the EPA, SA Water, and DENR.

Specifically, the aims of the work presented in this report were to:

1. Compile and review data from the lake system from the period from Jan 2008 to April 2011 from the various agencies responsible for data collection and monitoring;

2. Revise and improve the quality and rigour of the model validation through increased testing against this compiled dataset;

3. Add value to the observed water quality data that has been collected through application for the model for synthesis activities, identifying hot-spots and guiding monitoring;

4. Understand the mechanisms in the observed drop in alkalinity during refill of winter 2010 and the potential significance of the acid flux from inundated soil;

5. Explore the implications of rapid refilling and the higher stability level over the foreseeable future on water quality properties;

6. Explore the potential for acidification risks should the lakes be subject to a second cycle of water level drawdown and sediment exposure.

7. Development of a long term modelling and model-validation infrastructure with potential for subsequent real-time data integration and associated technology transfer and support;

Relevant previous work

Field and laboratory analyses of the Lower Lakes and Lower Murray River:

- *ASS soil classification and spatial analysis* (Fitzpatrick et al., 2009; Fitzpatrick et al., 2010): Detailed measurement of surficial sediment properties across the lake system and geo-statistical analysis. This data is used as the basis to drive the sediment model predictions reported in this report.
- *Monitoring and assessment of ASS in Currency Creek / Finniss River* (Fitzpatrick et al., 2011): updated analysis of soil geochemical properties in the Currency Creek and Finniss River region after a period of acidification and subsequent re-inundation.
- *Hydro-geochemical assessment and acidty flux estimation* (Earth Systems, 2010): Range of field and laboratory determinations exploring controls on pyrite oxidation and characterisation of soil hydrological properties at sites in Lake Alexandrina and Lake Albert.
- *Contaminant mobilisation field study* (Hicks et al., 2009): Plot-scale assessment of acidity and contaminant fluxes following re-inundation with fresh and saline water
- *Acidity and contaminant flux laboratory assessments* (Simpson et al., 2009; Sullivan et al., 2010): Detailed laboratory experimentation measuring flux rates from a range of soils taken from Lake Alexandrina and Lake Albert.

Previous relevant modelling studies of the Lower Lakes, Lower Murray River and Coorong:

- *Hydrodynamic model of the Coorong* (Webster, 2007): describes the development and application of a one-dimensional hydrodynamic model that will be used both to better understand and to quantify the relationship between system drivers and water levels, salinity, and mixing conditions in the North and South Lagoons of the Coorong.
- *Numerical investigation of ASS risk on lower lakes* (Hipsey and Salmon, 2009): This study conducted initial assessment of the potential loads of acidity on lake alkalinity.
- *Ecosystem response model of the Coorong* (Lester and Fairweather, 2009): provides detail into the the construction of a response model for organisms within the Coorong, including a description of the model itself and the simulated ecosystem states, and a range of model evaluation and sensitivity analyses.
- *Coorong biogeochemical model* (Grigg et al., 2009): considers the biogeochemistry of the Coorong and develops budgets for the major nutrients and chlorophyll a. The budgets include quantifying riverine inputs and marine exchanges of nutrients as well as describing internal exchanges of nutrients between different sections of the system and identifying their internal sources and sinks.
- *Lower Murray HydroModel* (Hipsey et al., 2010): Model focused on the river water quality properties.
- *Lower Lakes hydrogeochemical model and assessement of acidification risks* (Hipsey et al., 2011): the initial development and validation of the model presented here.
- *Model studies associated with the Barrage EIS* (BMTWBM, 2010): Application of the model presented here to explore the effectiveness of seawater flooding on the potential for lake acidification.
- *Barrage hydraulics study* (BMTWBM, 2011): assessment of flow through barrages following the 2010-2011 flooding cycle.

Data Collation & Processing

Our previous analysis (Hipsey et al. 2011) tested the Lake Alexandrina, Lake Albert and Currency domains against available water quality data from the main EPA water quality monitoring stations to September 2009. A substantial quantity of data has been collected since then, both over a longer period, and also at numerous ‘event-based’ monitoring locations in high priority management areas displaying signs of acidification. Additionally the DFW sensor data network has advanced and ongoing data collection of the Coorong by DENR has been conducted, all of which provides an opportunity to more rigorously test the performance of the model, and guide adjustments to the model parameter sets.

We have therefore sought to compile all possible data relevant to water quality in the lakes and Coorong region from Jan 2008 to April 2011, and develop a flexible analysis framework so that data spreadsheets from different organisations can be easily updated to facilitate rapid updates to the data plots and model validation plots.

The range of data sources and summary of the data monitoring stations is summarized in Appendicies A and B. Overall the analysis now includes 34 DFW real-time monitoring sites (data at high frequency), and 340 EPA WQ unique monitoring locations (varying in frequency from once off to weekly/monthly). To condense the number of sites to report on, and to focus the analysis, we have defined 77 key reporting stations, and allocated all data sites to one of these, though individual station reporting is possible.

Some discrepancies between versions of EPA data sheets we have available have required that we plot both sets (EPA Jan 2011, and EPA Apr 2011). This has meant some data points are duplicated on plots, but means we have a complete data set with which to compare to the model.

Model Description & Approach

General framework

During the previous EIS modeling work (Hipsey et al. 2011), the model was configured to run as three domains only connected through pumping transfers at Clayton and Narrung; these were Lake Alexandrina, Lake Albert and a high-resolution “Currency” region (covering Goolwa -> Clayton East). These simulations were configured using actual hydrological and meteorological forcing data to September 2009, and predictions beyond this time were based on agreed forecast assumptions for both flow and meteorology.

In this study the simulations were extended to use updated data for flow and meteorology from the previous September 2009 period to April 2011. This including using updated information for flow from Wellington, updated flow estimates from the Eastern Mt Lofty Ranges (EMLR) tributaries (based on the catchment model outputs supplied by EPA from the eWater E2 platform), and updated meteorological data from Currency and Narrung stations.

In addition, due to the removal of barriers at Narrung and Clayton during September 2010, the lakes domain became fully reconnected, and eventually overflowed into the mouth area and Coorong. This therefore necessitated a combined model domain rather than the individual disconnected domains that were run previously. A high-resolution “full-domain” model grid was therefore developed that covers the area from Wellington to the mouth, and the North Coorong as far as Parnka Point. Due to the complex interactions between the lakes and Coorong during the filling and subsequent overflow phase, estimated exchange between the systems was input directly into the model based on TUFLOW-FV model outputs conducted by BMTWBM Pty Ltd.

The combination of model configurations therefore simulates the lakes domain from 2008 until April 2011 for validation and beyond for assessment of future conditions (Figure 1). The hydrodynamic and biogeochemical configuration of each model is identical, and is as described in earlier reports (Hipsey et al., 2011) with numerous minor changes as described below. The following sub-sections describe work conducted on the setup and application of the combined model system.

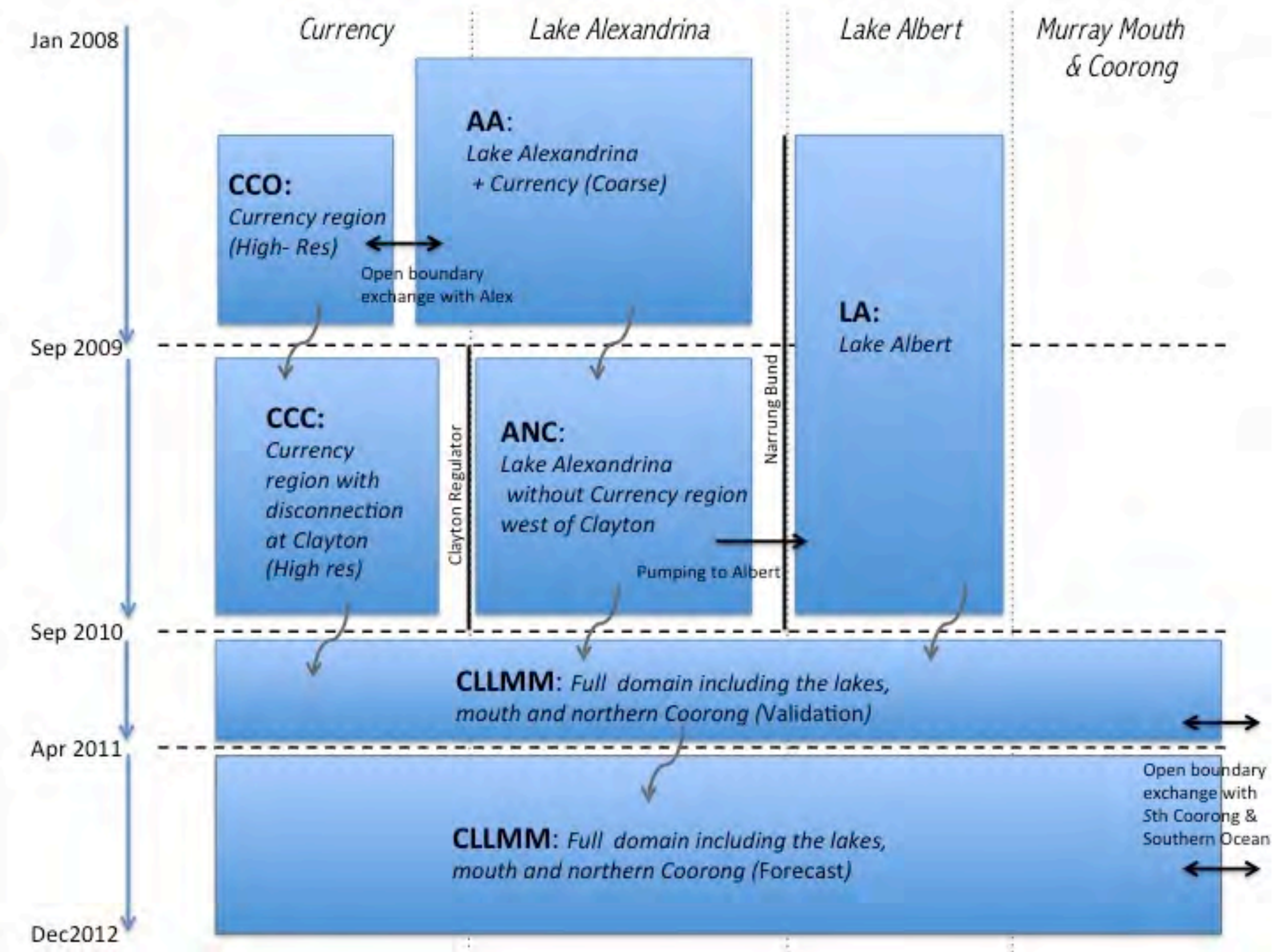


Figure 1: Schematic of model system outlining how the different simulations are configured to cover the spatial and temporal range of the study.

Water quality and Acid Sulfate Soil model updates

The present study offered an opportunity to improve configuration and specification of various model components, based on review and relevant discussions over the past modelling initiatives. These can be broadly categorised into two main areas: water quality model biogeochemical configuration, and acid sulfate soil module developments.

Water quality configuration updates:

The configuration of CAEDYM variables is similar to the HydroModel and Seawater EIS simulations with an updated variable table provided in Appendix C. The main changes relate to:

- Sedimentation of particulate mineral phases – All simulations include $Fe(OH)3_{(s)}$, $MnO_{2(s)}$, $Al(OH)_{3(s)}$, and $CaCO_{3(s)}$ as particulate minerals, and the sedimentation dynamics of each are now included in all simulations in this report.
- Inclusion of suspended sediment (turbidity), and the associated effect on light attenuation, is now included and two suspended solids groups are configured (fine and coarse). It is known that resuspension in the lake is important, however due to the large computational overhead that the

resuspension module in CAEDYM requires, we chose to leave resuspension disabled and therefore reduced the settling rate of the particles groups to keep them in suspension longer.

- Adsorption/desorption of PO_4 – the PIP (Particulate Inorganic Phosphorus) sub-module was also enabled to account for changes in the adsorption of PO_4 to particles, particularly the iron (oxy)hydroxides.
- Adjustments to organic matter cycling rate parameters to prevent unrealistic seasonal concentration of dissolved organic matter (DOM), including both N and P fractions (DON and DOP; as reflected in the over-prediction of TN and TP in summer that was previously reported). Readers are referred to Table C1 in Appendix C for a list and description of simulated N and P variables.
- Adjustments to the sediment release of N to improve water column N predictions.

Acid Sulfate Soil (ASS) Module developments:
The previously reported ASS model was updated under the present study to include:

- Fe and SO_4 included in ASS acid leachate – this is based on stoichiometric release of FeII and SO_4 according to the pyrite oxidation equation.
- Inclusion of a ASS leachate tracer (denoted "COL" in below plots) – to follow the fate of material that enters the lake system from the ASS soil material. This is intended as a conservative tracer to give a qualitative indication of potential heavy metal risk hot-spots.

Updated Clayton-Goolwa model domain

The previously reported high-resolution Currency domain (from Goolwa->Clayton East) in Hipsey et al. (2011) was run over the period during acidification of Currency Creek pools and finished pre-installation of the Clayton regulator. Subsequent processes occurring within this region following re-inundation after the installation of both the Clayton and Currency regulator's were therefore not previously simulated. However this period was necessary to be simulated in order for development of the conditions for the starting of the full domain from September 2010.

We therefore configured a new high-resolution Currency domain, identical to the original reported in Hipsey et al. (2011), but with barriers configured to prevent flow exchange at the Clayton Regulator and at the Currency Regulator; the domain is denoted "CCC" in Figure 1. Flows for Currency Creek and Finniss River and meteorology data from the Currency Creek station were updated to run this domain, as outlined in the following sections.

Full CLLMM model domain

In September 2010 the increased flows led to the removal of the Narrung and Clayton regulators and these effectively reconnected the entire domain. A new grid was therefore necessary to extend the earlier simulations. This was developed to include the full domain at 200x200m, and included the mouth area and estuary, and the northern Coorong (Figure 2). The domain includes inflows from the River Murray and the four EMLR tributaries (Angas, Bremer, Finniss & Currency). Barrages were also configured to restrict flow, representing the Goolwa, Mundoo, Ewe Island and Tauwitchere barrages.

Numerous simulations were conducted to get the overflow of water over the barrages, however, this led to poor predictions of water level (eg. Figure 3). The frequent manipulation of the barrage gates (dashed vertical lines in Figure 3) meant that the simple facilities for dealing with barrage hydraulics in ELCOM were not sufficient. Therefore the four barrage sites were not configured to allow overflow, were to have pseudo-pumping boundary conditions and the exchange was set based on the detailed flow analysis conducted by BMTWBM Pty Ltd. and provided in May 2011 (see Figure 9b-e).

The Coorong and mouth region was configured at identical resolution to the other reaches (200x200m), and forcing at the mouth was set based on height and other available data from Barker's Knoll (Figure 3). At the eastern tip of the Northern Coorong, the connection with the Southern Coorong was accounted for by creating an open boundary at Parnka Point, and prescribing the measured height and salinity values.

Initial conditions and soil maps for the CLLMM domain were calculated through analysis of relevant simulations including the ANC, CCC and LA simulations (see Figure 1). Key relevant inputs for this domain are shown in Figures 4-8. These include variable starting water level at the time immediately prior to removal of the flow regulation structures, sediment type (clay, fine sand or coarse sand), soil potential acidity and acid neutralising capacity, and including the relevant available soil acidity (UZAASS). The soil PASS, UZAASS, ANC, and also water table height (where not inundated) were all interpolated onto this 200x200m grid using data from output predicted by the Lake Alexandrina and Lake Albert domain simulations for the equivalent period.

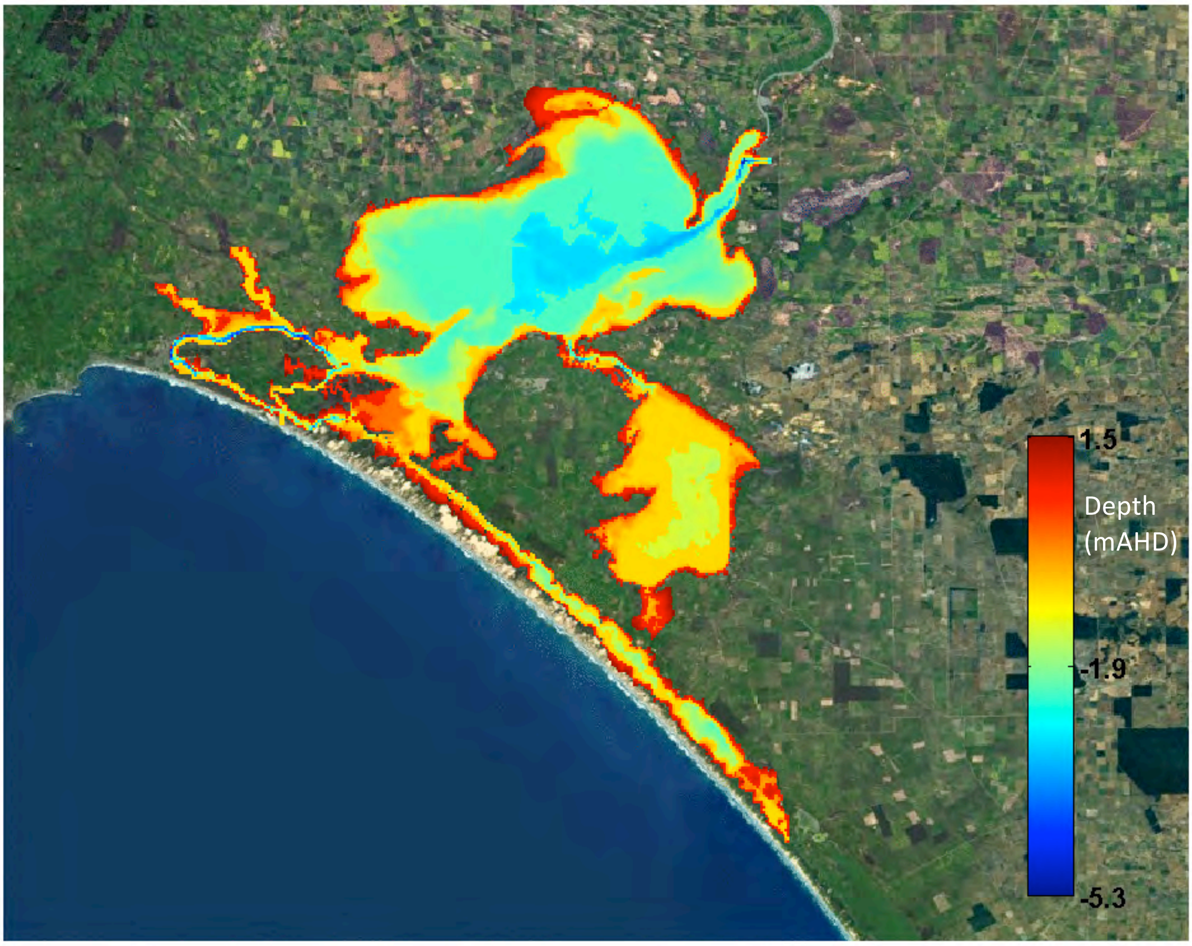


Figure 2: Full domain (CLLMM) model bathymetry (depth in mAHD) developed for the study (200x200m).

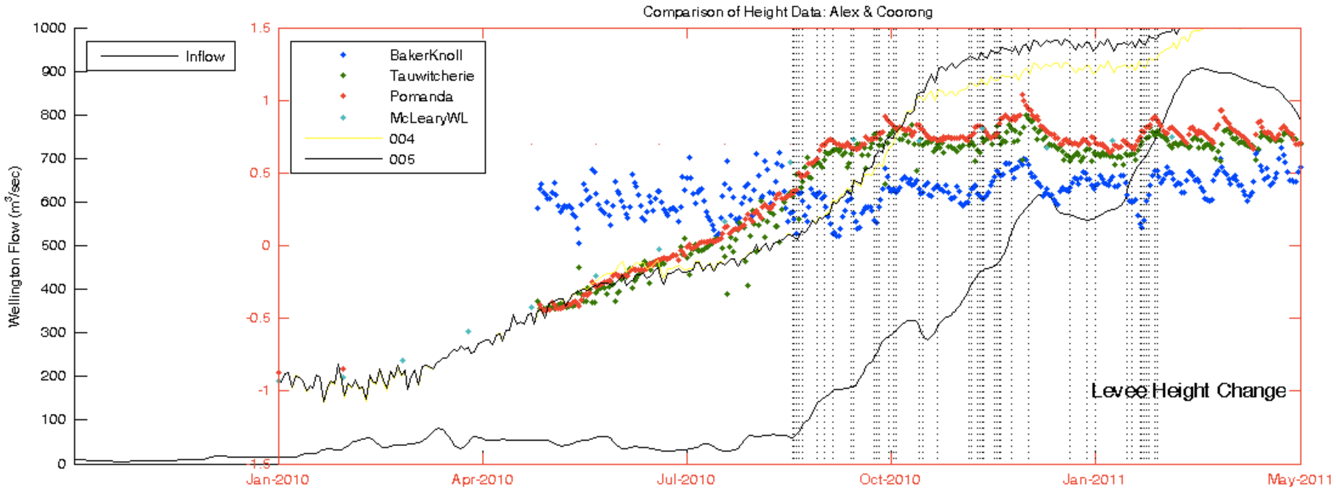


Figure 3: Initial water level validation for simulations 004 and 005 using a fixed 0.7m levee. Dashed vertical lines indicate SA Water operational changes to gates.

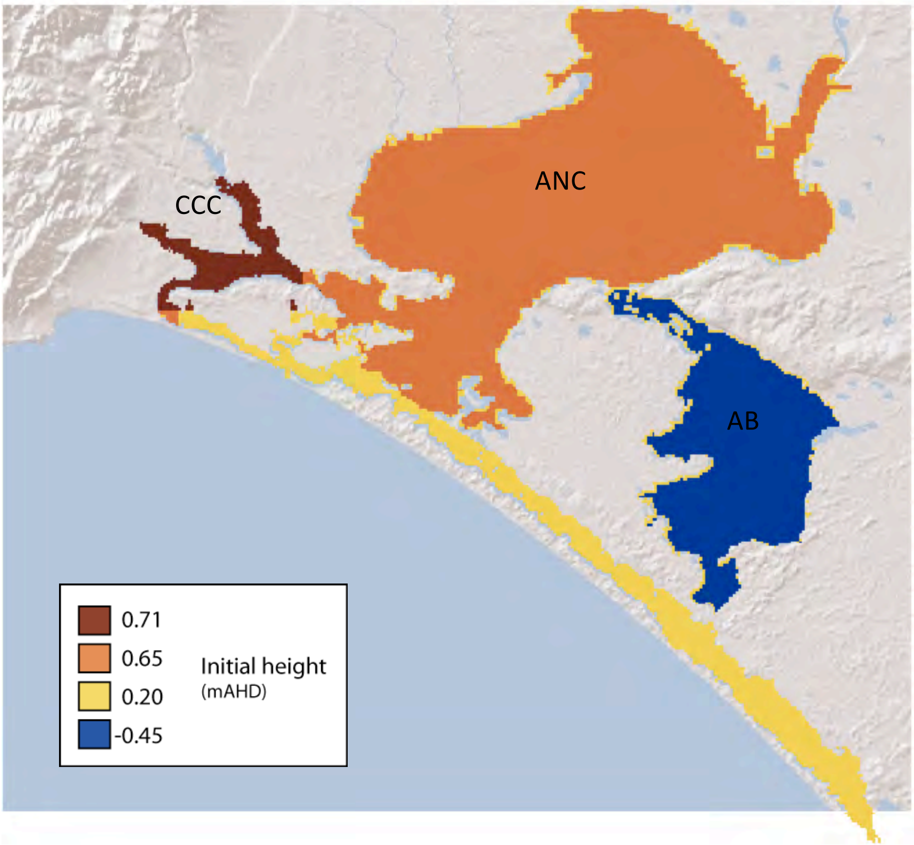


Figure 4: Full domain (CLLMM) model initial water heights used to start the model in September 2010. Data is from the AB, ANC and CCC simulations for the equivalent period.

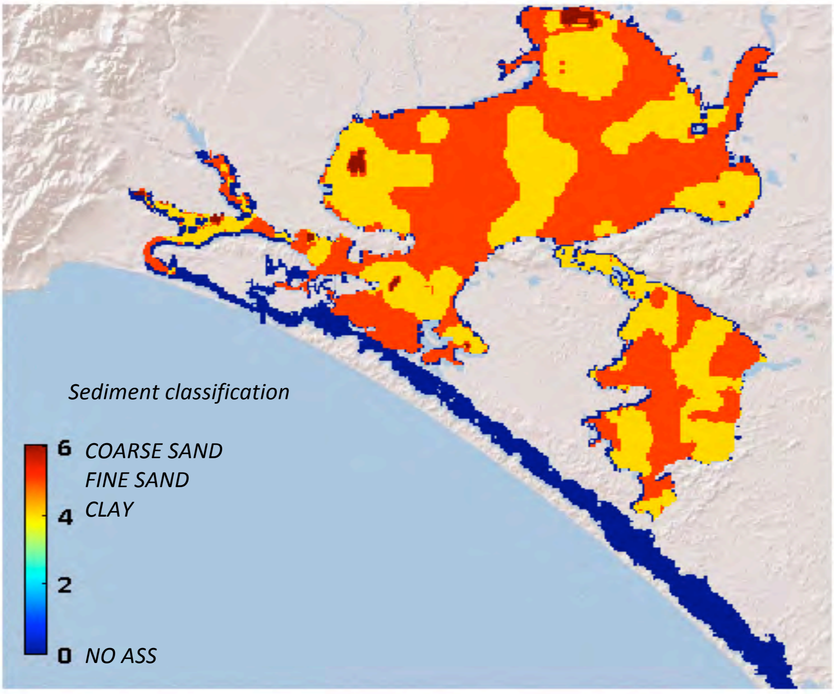


Figure 5: Full domain (CLLMM) model soil classification defining different ASS classes. [blue = no ASS potential; orange: clay sediment; yellow: fine sand sediment; brown: coarse sand sediment]. Data is from the ANC, AB and CCO domains re-interpolated onto the CLLMM grid.

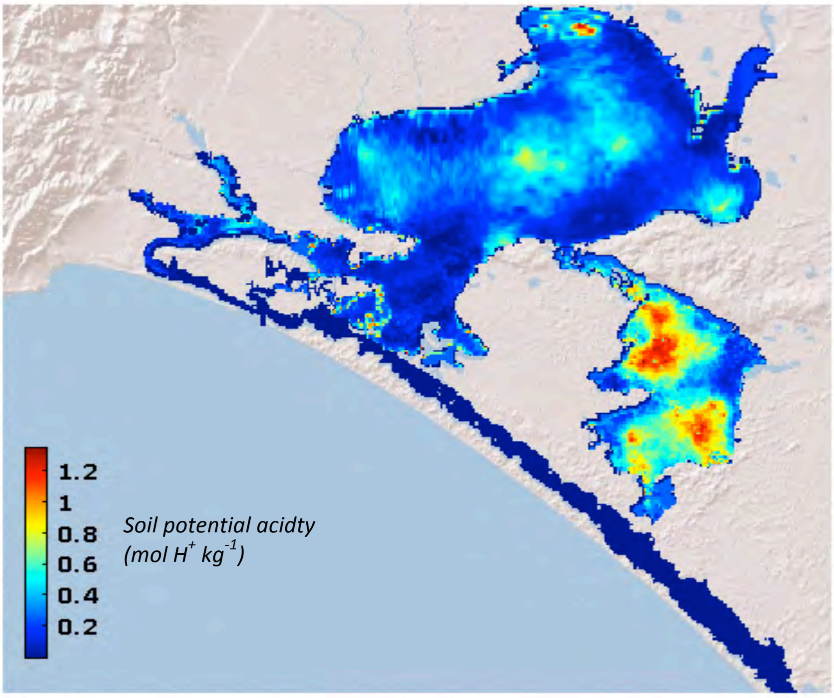


Figure 6: Full domain (CLLMM) initial PASS map. Data is from the ANC, AB and CCO domains taken in September 2010 and re-interpolated onto the CLLMM grid.

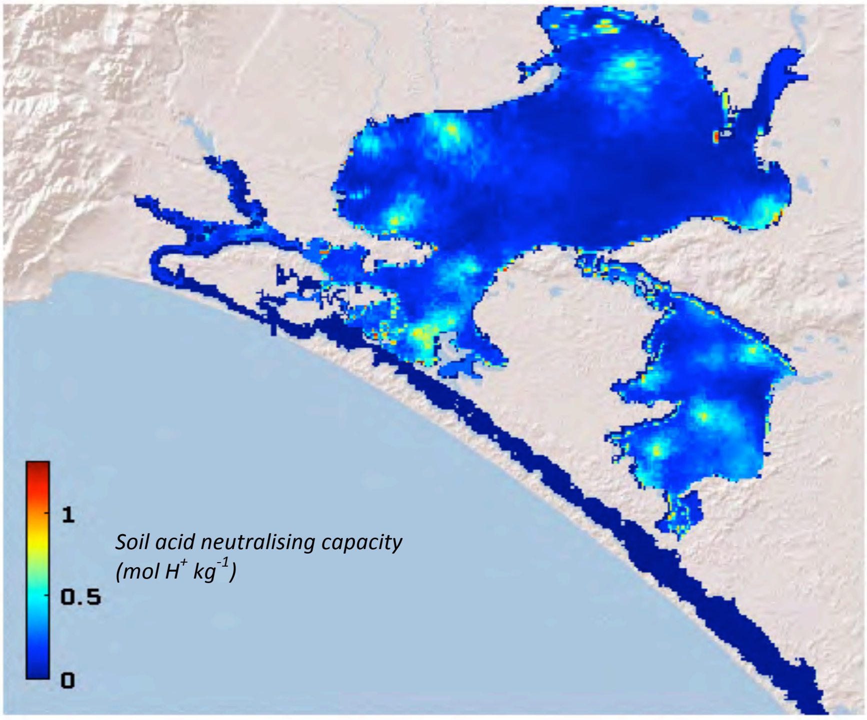


Figure 7: Full domain (CLLMM) initial Acid Neutralising Capacity (ANC, mol H^+ kg^{-1}) map. Data is from the ANC, AB and CCO domains taken in September 2010 and re-interpolated onto the CLLMM grid.

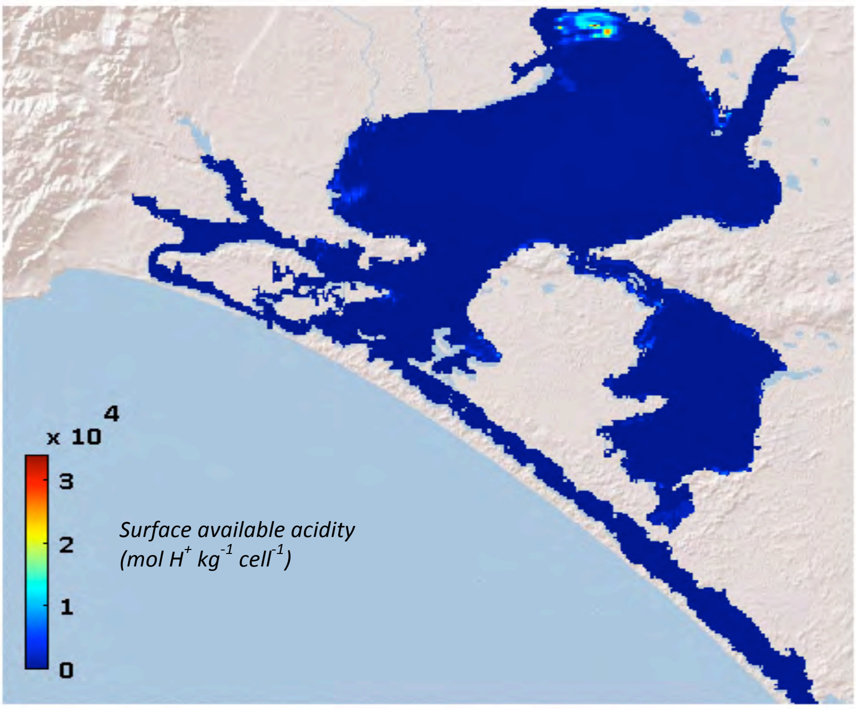


Figure 8: Distribution of initial soil available acidity (unsaturated zone sulfuric material; UZAASS, mol H^+ kg^{-1} per cell, each cell is 40000m^2) into the CLLMM domain, derived from predictions of the ANC, AB, and CCC domains output at September 2010.

Updated river, outflow and meteorological forcing data

Updates to flow values from the River Murray and EMLR tributaries have been provided, in addition to flow estimates over the barrages during the flood period (discussed below), and these are outlined together in Figure 9.

Based on data provided by Department for Water (DFW), the Murray River flow was shown to rise rapidly throughout 2010/2011 to over 900 m^3s^{-1} (78 GL day^{-1}). Flows from the EMLR tributaries peaked at values greater than 200 m^3s^{-1} (17 GL day^{-1}), however these flow rates were only reached for short events during winter, and not a sustained increase as was the case for the Murray River flow. The barrage overflows indicated large variability in the flow rate due to tidal sloshing, however combined overflows of >1000 m^3s^{-1} (86 GL day^{-1}) were observed for periods in the tidal cycle. Some negative flows occurred and demonstrated the potential for reintroduction of (diluted) estuary / ocean water back into this region.

There was some discrepancy in flows provided at different times, and here we have plotted these to clarify the differences. For the Wellington inflow, the flows used by BMTWBM to calculate the barrage flow were different to those provided directly (Figure 10), however the former were adopted in order that they match the barrage outflow volume estimates, also provided by BMTWBM. The Currency Creek and Finniss River tributary flows also varied for the period from 2008-2009 than what was used previously in Hipsey et al (2011), and so only post September 2009 flows from the new records were used (Figure 11) to maintain consistency with the earlier Currency Creek domain validation simulation.

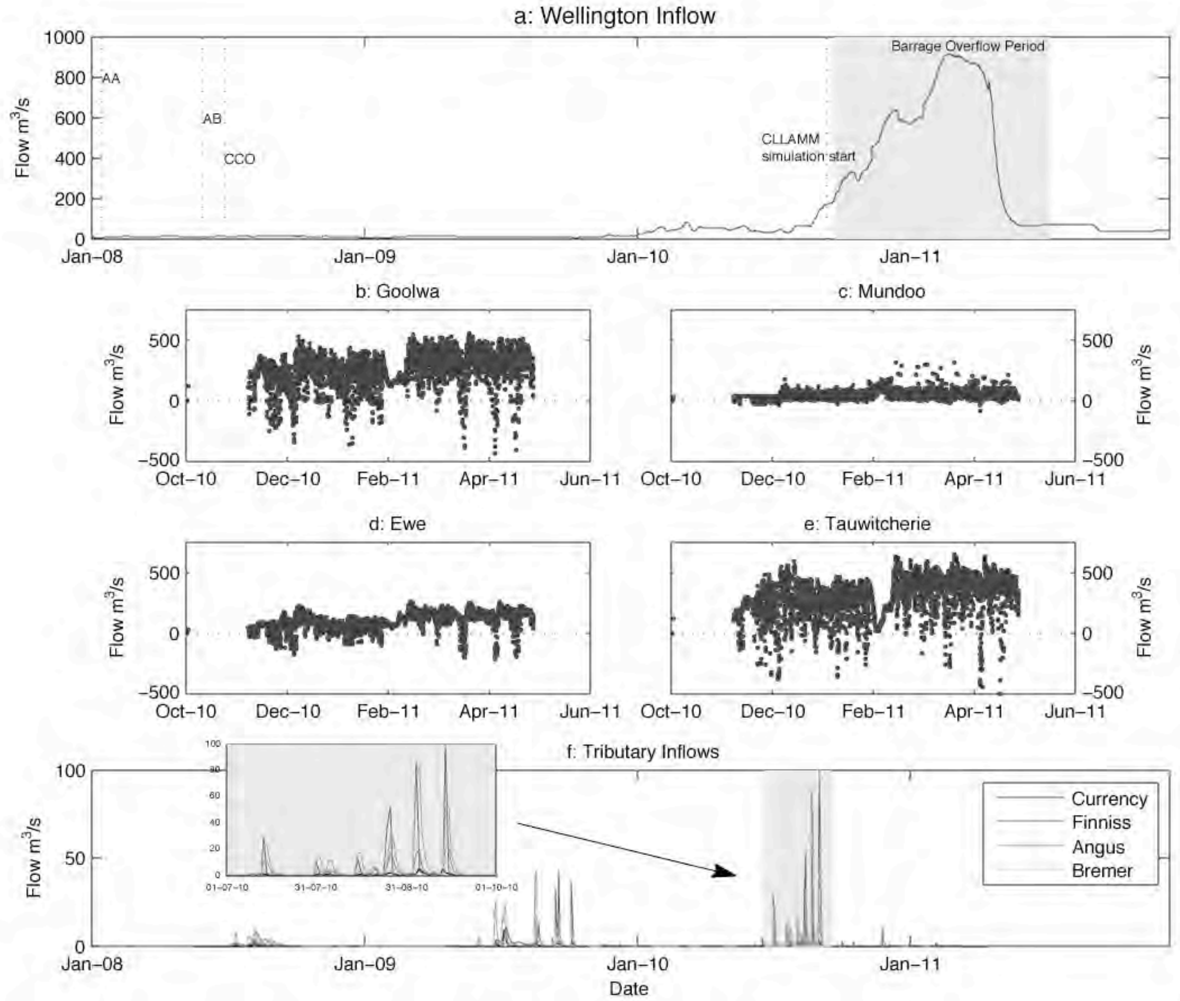


Figure 9: Compiled flow data used within the updated model simulations for (a) the Murray River inflows, (b-e) the barrage flows, and (f) the EMLR tributary flows.

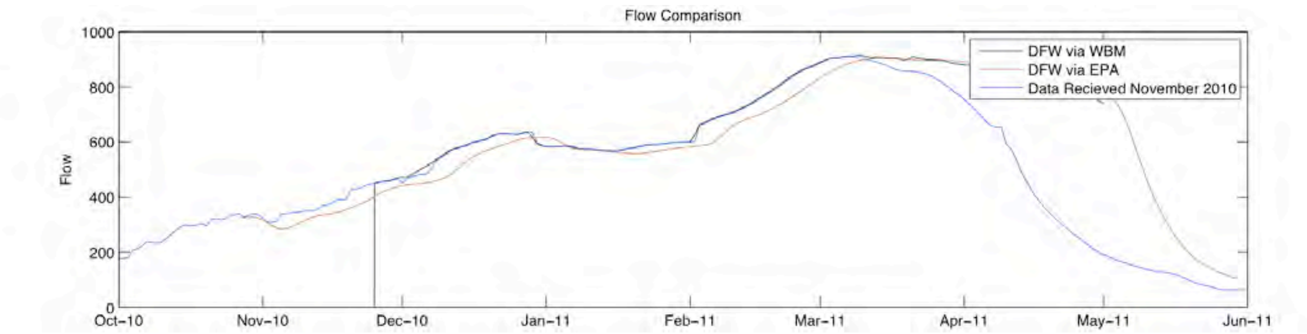


Figure 10: Zoomed plot of Murray River flow data for post October 2010 flows, highlighting different flow assumptions – the DFW flow data received from BMTWBM was used for these simulations to match the barrage flows also provided by them.

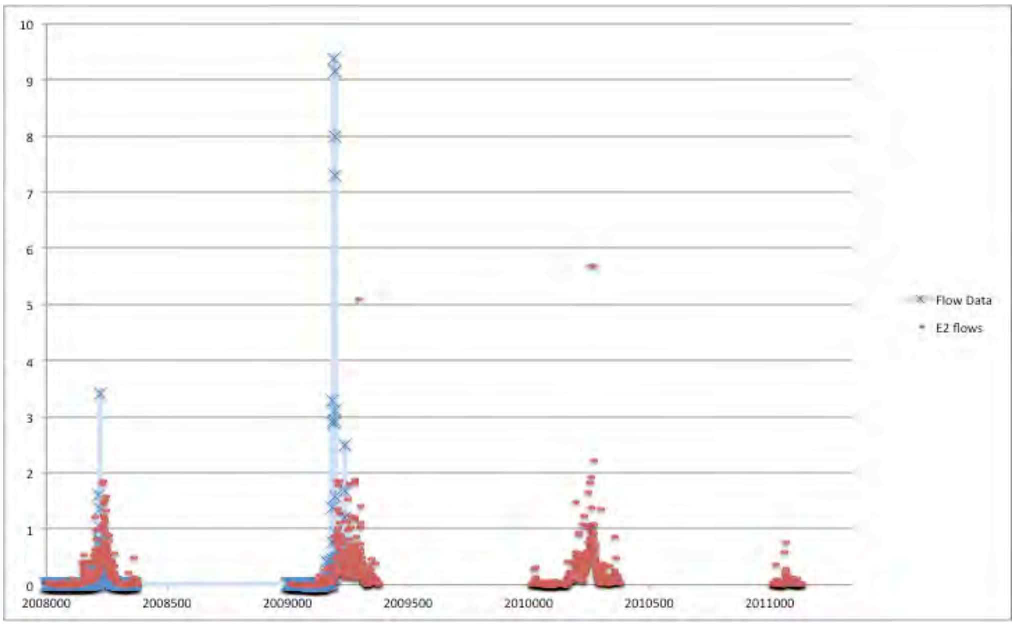


Figure 11: Available Currency Creek flow data showing the previously provided flow data (blue) based on observed flows, and the recently provided flow data from the EPA E2 catchment model. To preserve the existing calibration, a combined time-series was used in this study, adopting the observed data to September 2009 and the E2 catchment model data beyond this time.

Table 1: Summary of meteorological data sources for different simulation domains and time periods.

Simulation domain:	Air temperature	Relative humidity	Wind speed and direction	Shortwave and longwave radiation	Rainfall
AA	Narrung MS	Narrung MS	Narrung MS	Hindmarsh Valley	Narrung MS
ANC	Narrung MS	Narrung MS	Narrung MS	Hindmarsh Valley	Narrung MS
AB	Narrung MS	Narrung MS	North domain: Pelican Point South domain: Narrung MS	Hindmarsh Valley and Tailem Bend (SA Water)	Narrung MS
CCO	Currency MS	Currency MS	Currency MS	Hindmarsh Valley	Currency MS
CCC	Currency MS	Currency MS	Currency MS	Tailem Bend (SA Water)	Currency MS
CLLMM	Narrung MS	Narrung MS	Narrung MS	Tailem Bend (SA Water)	Narrung MS

Model Validation & Analysis

Lake water quality

The model system has been extensively tested against data collected within the region from 2008 to April 2011. In total, more than 1200 validation plots have been prepared comparing all simulated variables against field equivalents for all the major reporting stations. All plots are available for download at the following link:

http://aed.see.uwa.edu.au/downloads/LowerLakesModelValidation.zip

In this report, plots from the main stations across the lake system are presented for the range of simulated physical, geochemical and water quality variables to highlight the main features of the lake water quality evolution and performance of the model. Discussion of acid sulfate soil parameters are discussed separately in a section below.

Hydrodynamics

The general predictions of water level, salinity and temperature demonstrate that overall the model performs well in capturing the temporal and spatial trends in the water balance and patterns of mixing. There is a tendency for the model to over-predict the decline in the water level during the drawdown by up to 25cm, particularly in the summer of 2009/10, prior to arrival of the flood-waters (Figure 12). Conversely there is some over-prediction in the water level during the flood in 2010 and period where the barrages were overflowing. The initial low water level in Lake Albert rapidly increased at the time of opening the Narrung bund in September 2010, and this rapid flooding is well captured by the full-grid (connected) CLLMM domain model. The water level recovery behind the Clayton regulator is also well captured, however the subsequent decline during the summer of 2009-2010 is not as marked in the model predictions as is observed. This suggests either the evaporative losses during this period are insufficient or alternatively that there is a significant loss of water to seepage into the groundwater system.

The exchange dynamics within the Narrows are also well predicted as the EC at the “Albert Entrance” site and other Lake Albert sites, including “AlbertSW”, are very accurately predicted and show the spatial gradient along Lake Albert and the sharp seasonal increases. There is some over-concentration of salinity in the model predictions in Lake Alexandrina during the drawdown phase (Figure 13), and this is related to the over-prediction in water level decline, suggesting that the amount of evaporation (and subsequent evapo-concentration) is causing the errors in the water balance. The predicted EC in the main body of Lake Albert peaked at over 20,000 $uScm^{-1}$ in the summer of 2010 and this rapidly reduced due to winter rainfall, and then even further following opening of the Narrung narrows. Since opening of the bund the salinity in Lake Albert has remained above 5,000 $uScm^{-1}$, despite Lake Alexandrina falling to below 1,000 $uScm^{-1}$, based on the EPA and DFW data. This suggests the exchange processes between the lakes are slow, and it is estimated that recovery of pre-drought salinity levels in Lake Albert will take several years.

Within the Goolwa/Finniss/Currency region, the patterns of change in EC are more complex and related to the installation and (partial) removal of the Clayton and Currency regulators. Patterns of change in the model are well captured, particularly in the Finniss River tributary and the main Goolwa Channel, except for a notable over-prediction in the Summer of 2008-2009. The Currency Creek tributary generally showed an under-prediction in EC, and this is thought to be due to the drying out of the Currency ‘pools’ – in ELCOM, once a pool dries out the accumulated salt in the pool is lost upon subsequent re-inundation, and therefore not conserved. Since these pools did not form in Finniss River tributary or in the main Goolwa Channel, this under-prediction was not observed. As a result the under-prediction of salinity behind the Clayton regulator is of the order of 50% of the observed value.

Temperature predictions are accurate in the main body of Lake Alexandrina throughout the seasonal cycle, but tend to be slightly lower than observations by a small amount during most periods in the shallow reaches of Lake Albert and the Currency and Finniss tributaries (Figure 14). Therefore either the extinction coefficients are potentially too low, or wind speed values from the Pelican Point wind station maybe too high for this domain. Since the error is more noticeable in 2009/2010 when the water is shallower it suggests there is an under-prediction of light attenuation and sediment heating. Error could also be introduced in the longwave radiation estimates since these were calculated from the Tailem Bend station maintained by SA Water and this is potentially overestimating the longwave radiation loss from Lake Albert due to different water conditions.

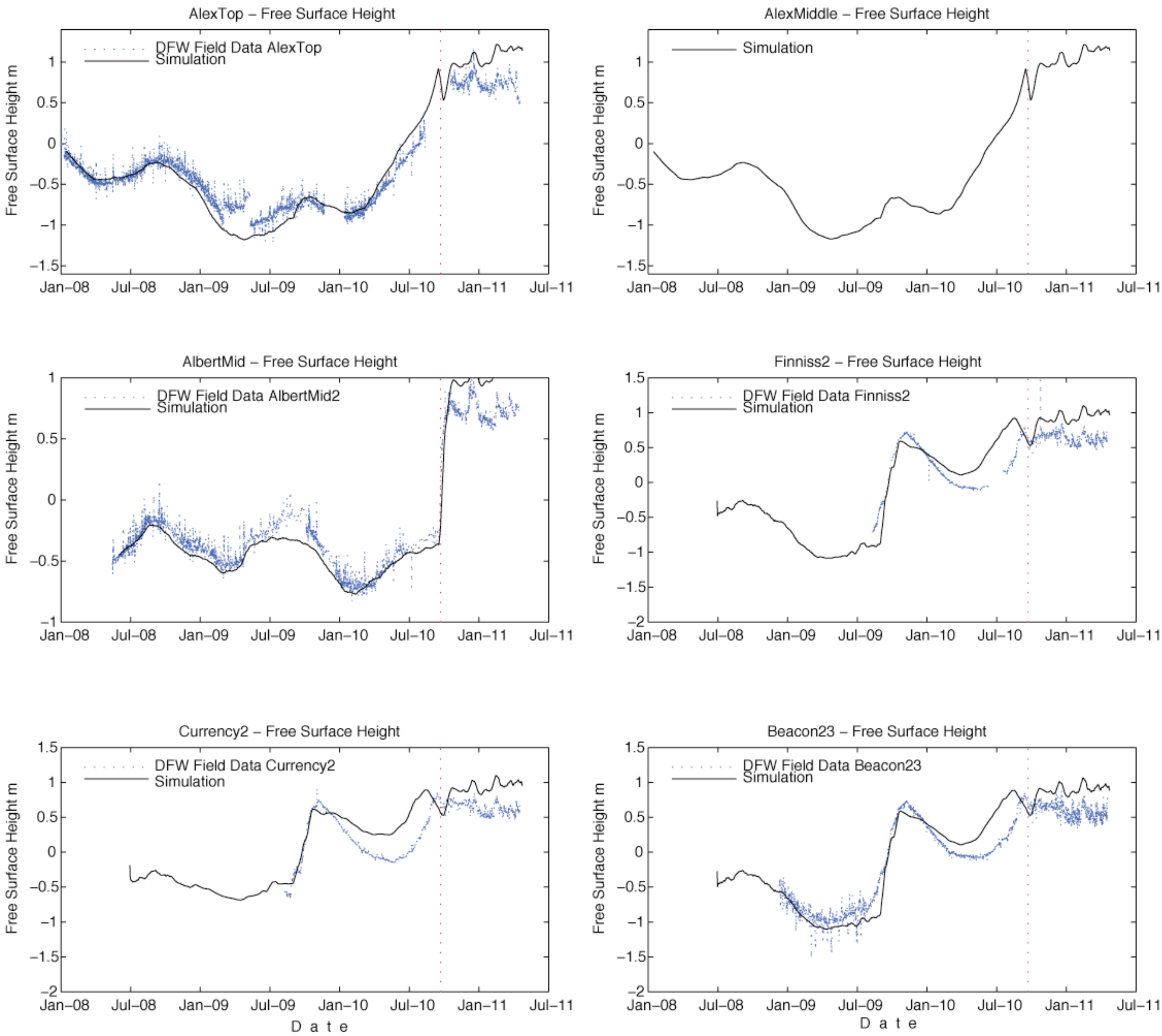


Figure 12: Evolution of modelled water level (m AHD) from selected locations and comparison with observed data.

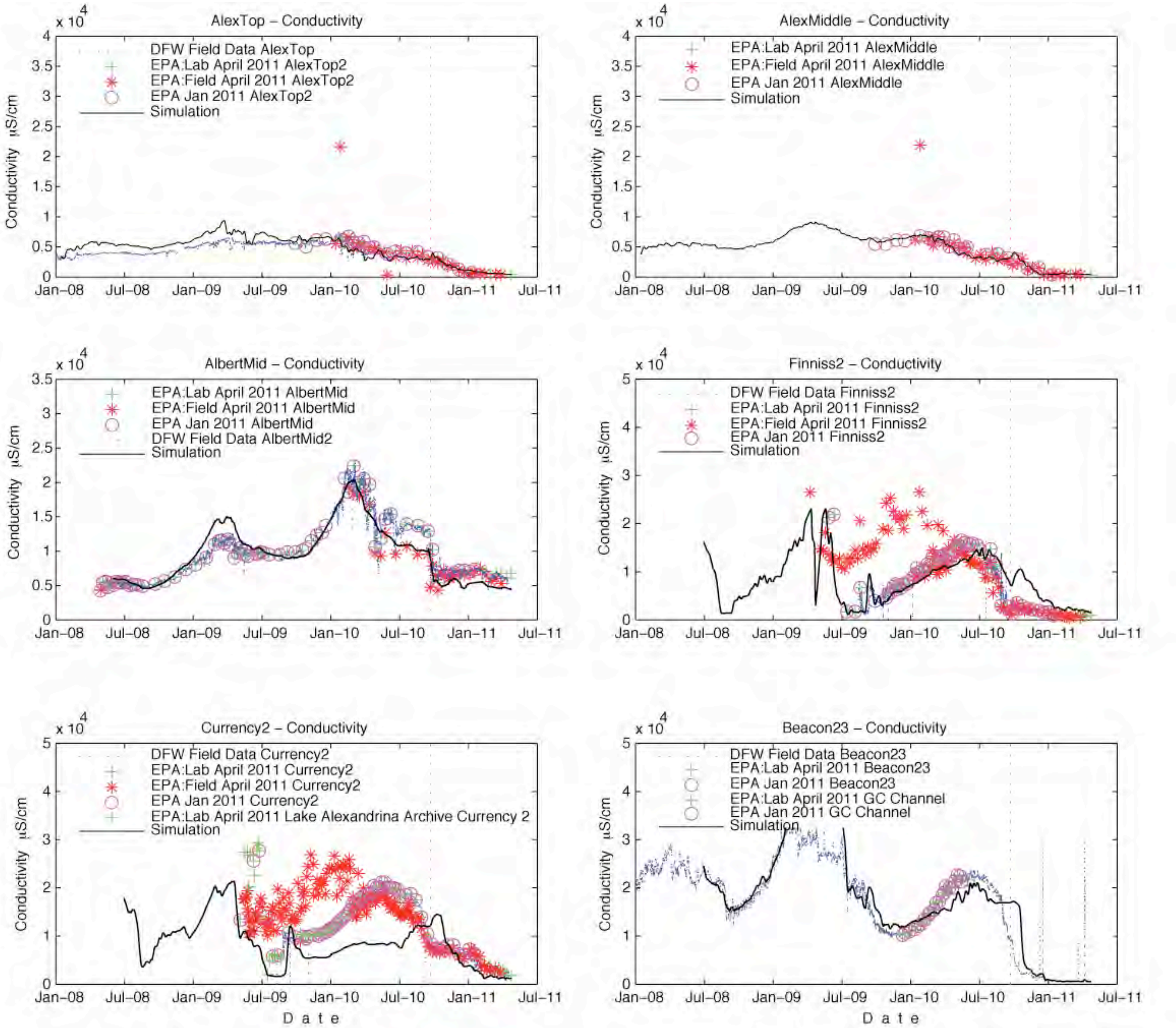


Figure 13: Evolution of modelled EC (µS/cm) from selected locations and comparison with observed data.

All major ions and metals including Fe and Al have also been simulated and validated against the monitoring data. Conservative ions such as Cl are very well predicted at most sites, except in the areas such as Loveday Bay and Currency Creek pools where the pools completely dried out, as per the above description (Figure 15). The predictions of SO_4 are reasonably well-captured, however it is noted that in Lake Albert, for example, the model under-predicts the SO_4 concentrations (by around 30%) in contrast to other ions (Na, Cl etc.), which are more accurately predicted (Figure 16); this suggests the SO_4:Cl ratio is increasing due to delivery of SO_4 from leaching from acid sulfate soils. This flux term is included in the model in the present validation runs, however it has made limited impact on the SO_4 predictions suggesting this is either under-predicted or there is an alternative source impacting the SO_4 budget.

There is also an over-concentration of dissolved Ca predicted by the model following January 2010 (Figure 17), and this is being further investigated since it could be the result of an incorrect boundary condition value for the pumping water from Lake Alexandrina, however it is likely that this in fact related to calcite precipitation and subsequent sedimentation of calcite particles to the sediment, which would lead to a reduction in alkalinity and Ca in the water column.

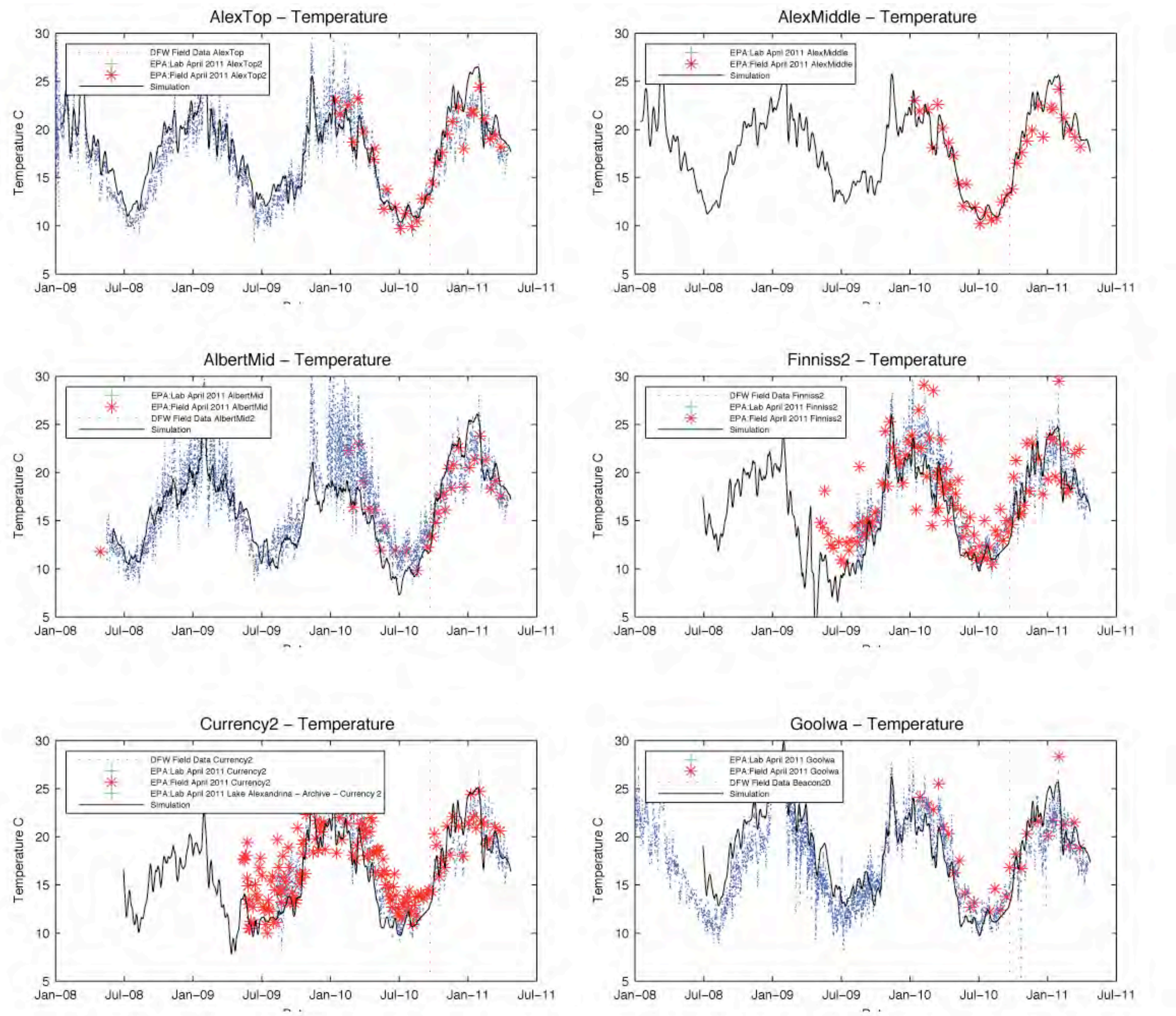


Figure 14: Evolution of modelled temperature (^oC) from selected locations and comparison with observed data.

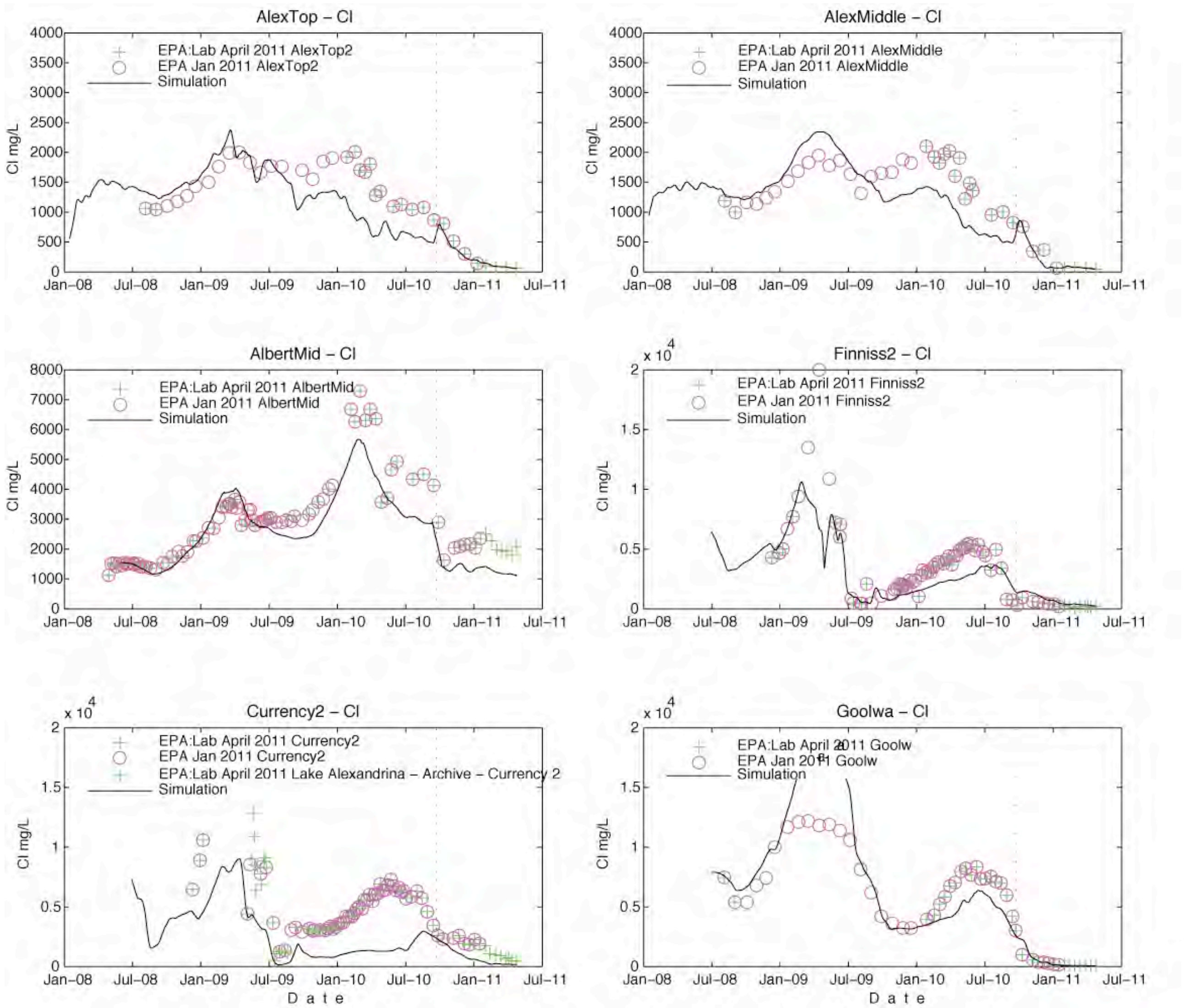


Figure 15: Evolution of modelled Cl (mg/L) from selected locations and comparison with observed data.

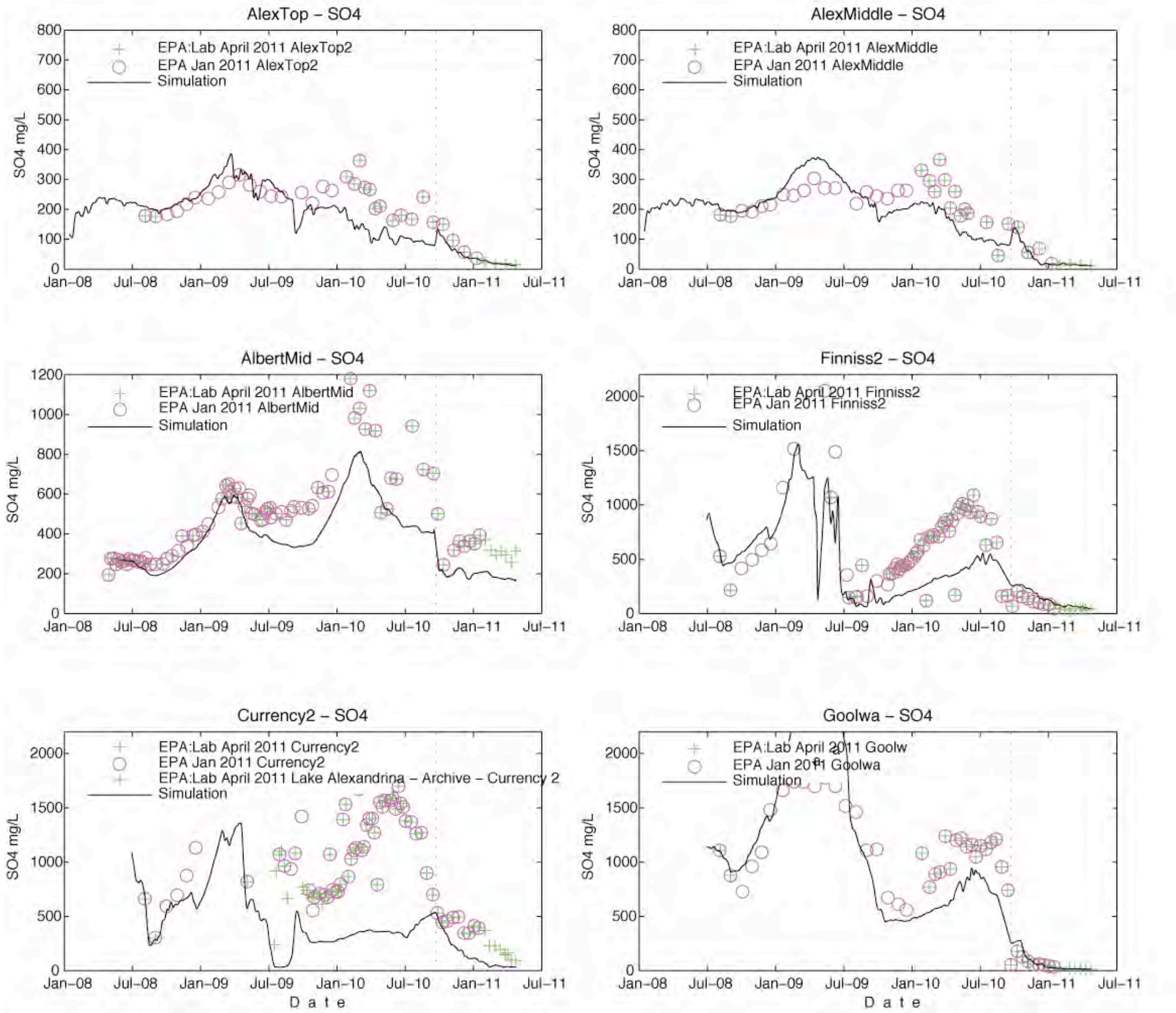


Figure 16: Evolution of modelled SO_4 (mg/L) from selected locations and comparison with observed data.

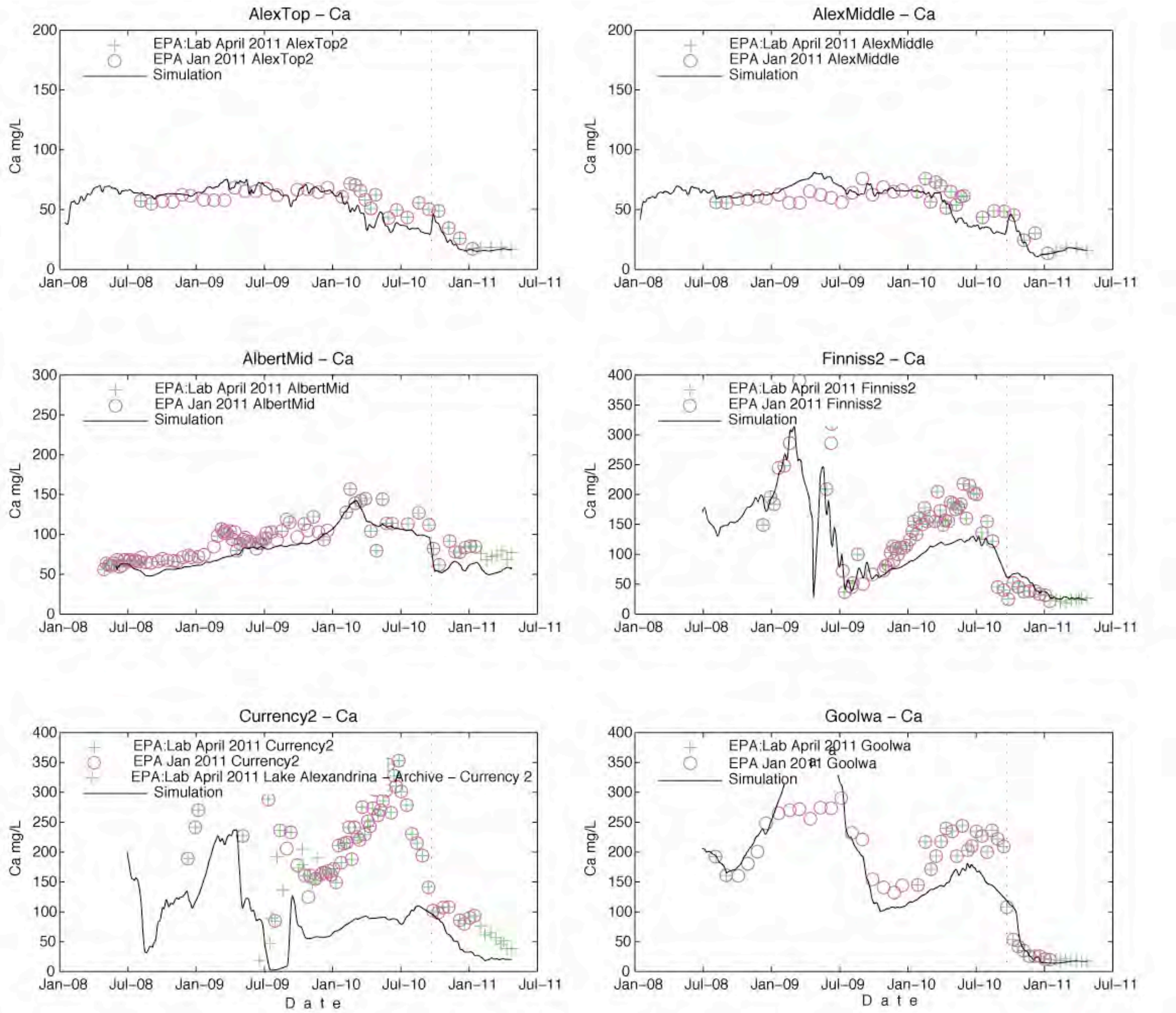


Figure 17: Evolution of modelled Ca (mg/L) from selected locations and comparison with observed data.

The metals Al and Fe are simulated as dissolved and particulate species, and given much of the data for dissolved species is at detection level, and there is high variability in particulate concentrations, it is difficult to validate the model. The high variability in particulate concentrations is similar to that seen in the turbidity data, suggesting that resuspension is a key driver shaping there concentrations and the observed variability. Where high dissolved values do occur they are also characterized by high variability in space and time, and large values are predicted in areas of acidification .

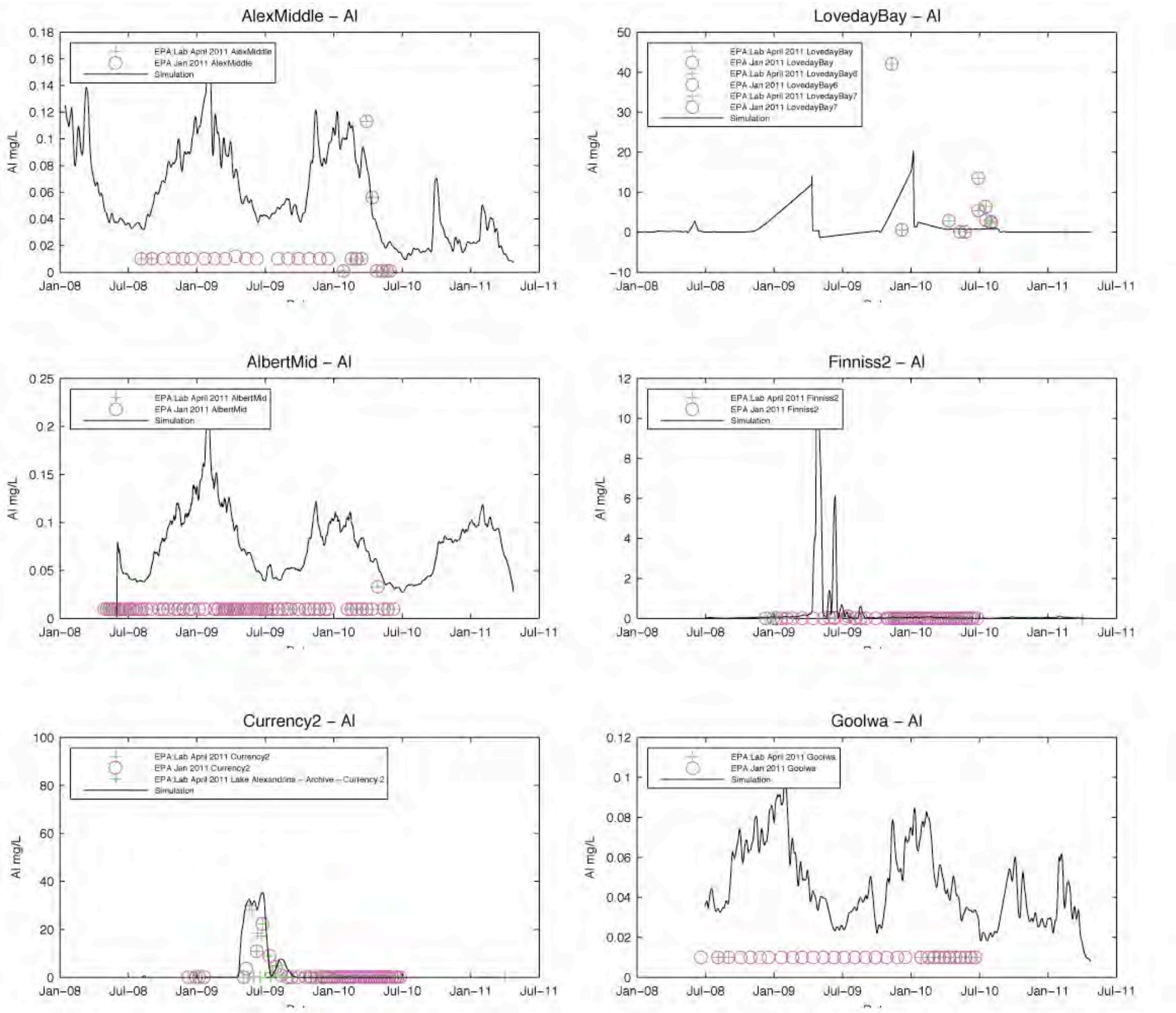


*Figure 18: Evolution of modelled dissolved Al (mg/L) from selected locations and comparison with observed data. **Note**: scale difference between sub-plots.*

Oxygen, nutrients, Chl-a and turbidity

Oxygen concentrations (Figure 19) are observed to be quite variable in the data, however the simulations generally capture the main trends. The main point of interest in relation to oxygen predictions is the large pulse of relatively hypoxic water entering from the River Murray during the flood, as seen in the Alex Opening figure, and the subsequent re-oxygenation of this water as it moves through the lakes.

Nutrients are generally well-captured, and in particular the dissolved nutrients are low over the drought period, and begin to increase during lake flooding. The total nutrients (both TN and TP) demonstrate a pattern of concentration over the summer that is similar to the major ions (Figure 20). Total chlorophyll-a is generally well-predicted by the model in terms of magnitude and spatial variability (Figure 20). The general concentration of turbidity is well-captured, including the increased pulse associated with the flood event in late 2010 (Figure 21). There is some under-prediction, most likely due to a lack of resuspension, which is not presently simulated in our model due to the high computational constraints of this module. The turbidity introduced during the floodwaters in 2010/11 is captured, and given turbidity is somewhat peripheral to the main focus of the study, the performance of the module with regards to particulate sedimentation and resuspension is left to a subsequent study.

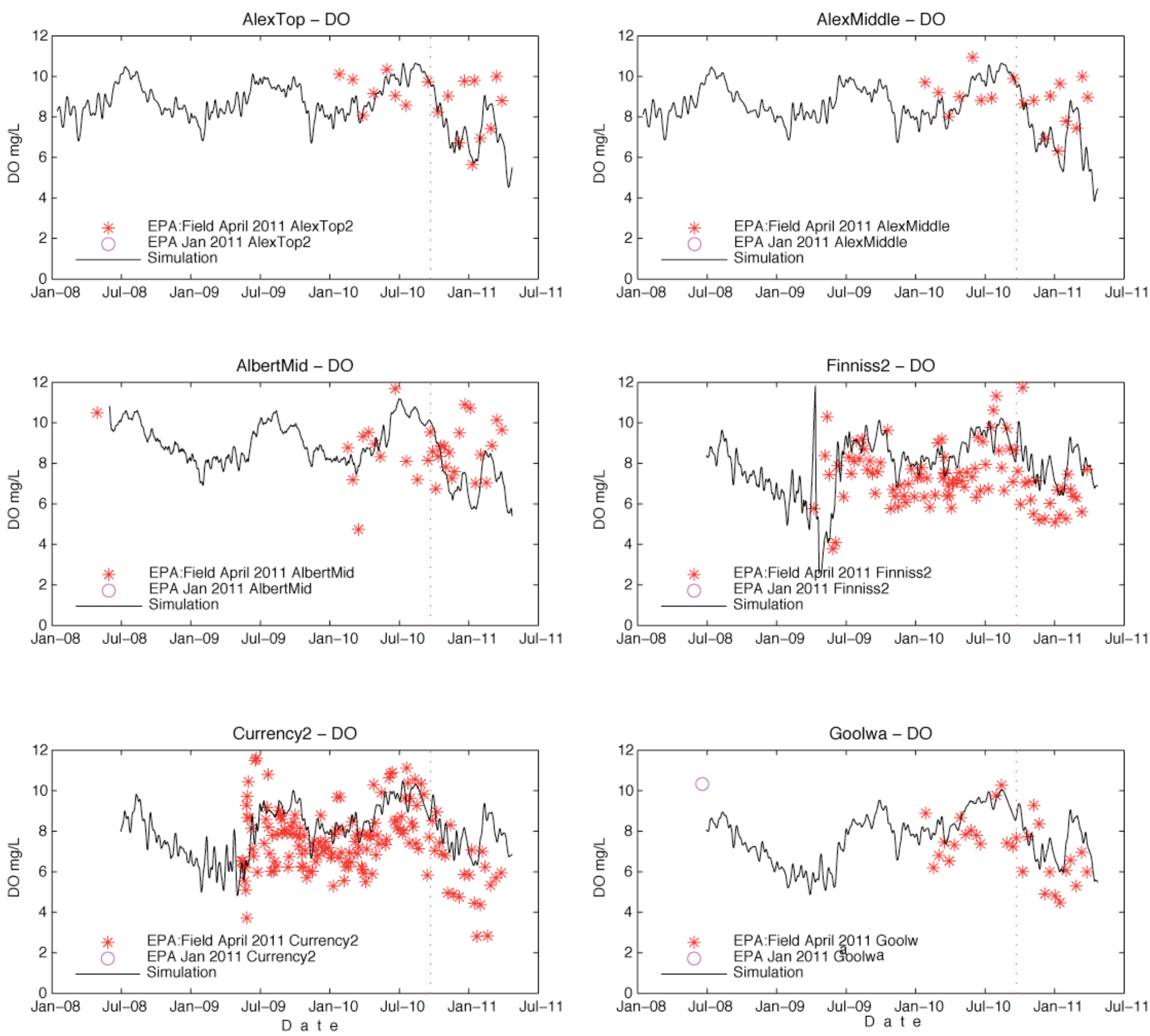


Figure 19: Evolution of modelled DO (mg/L) from selected locations and comparison with observed data.

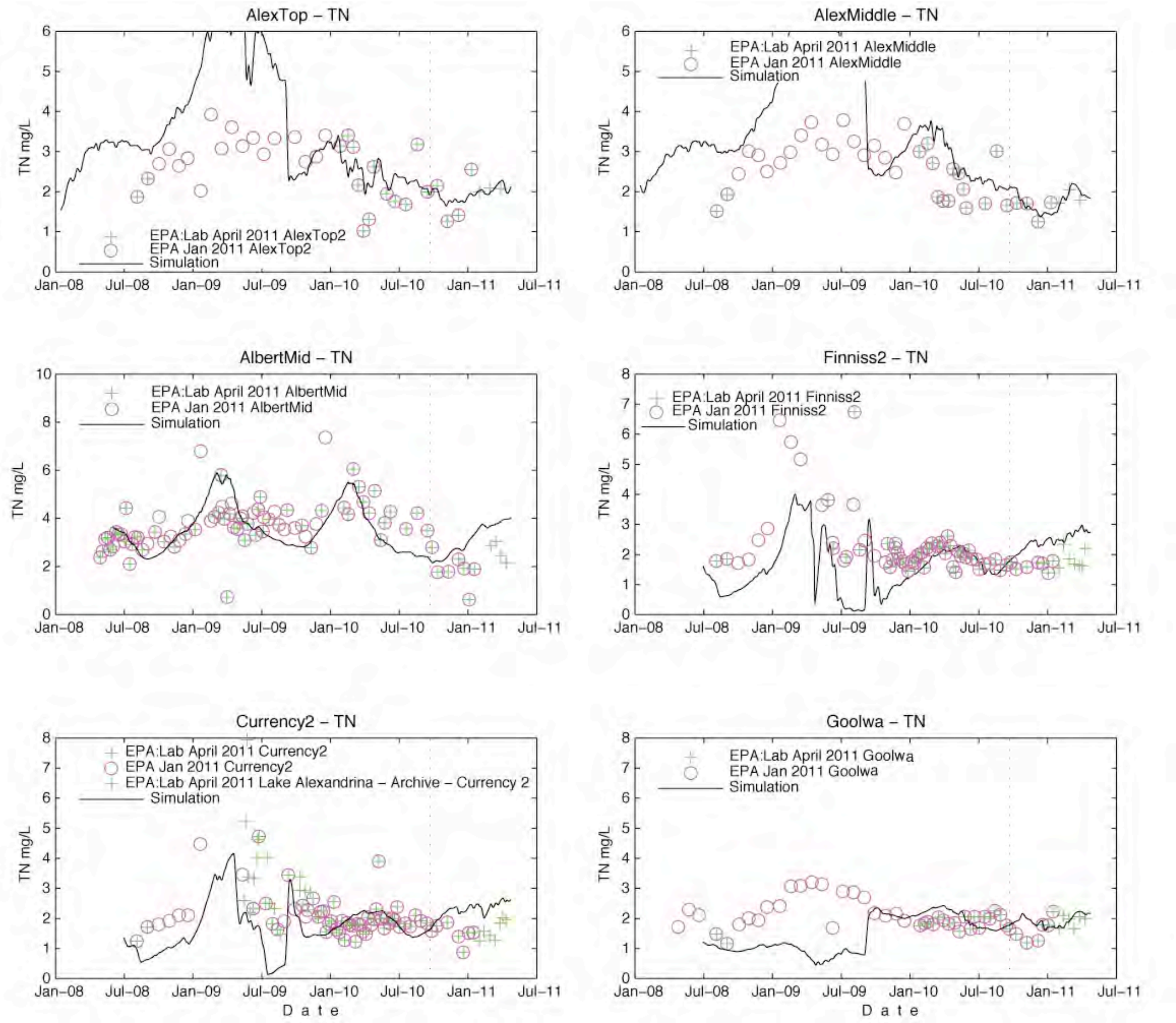


Figure 20: Evolution of modelled TN (mg N/L) from selected locations and comparison with observed data.

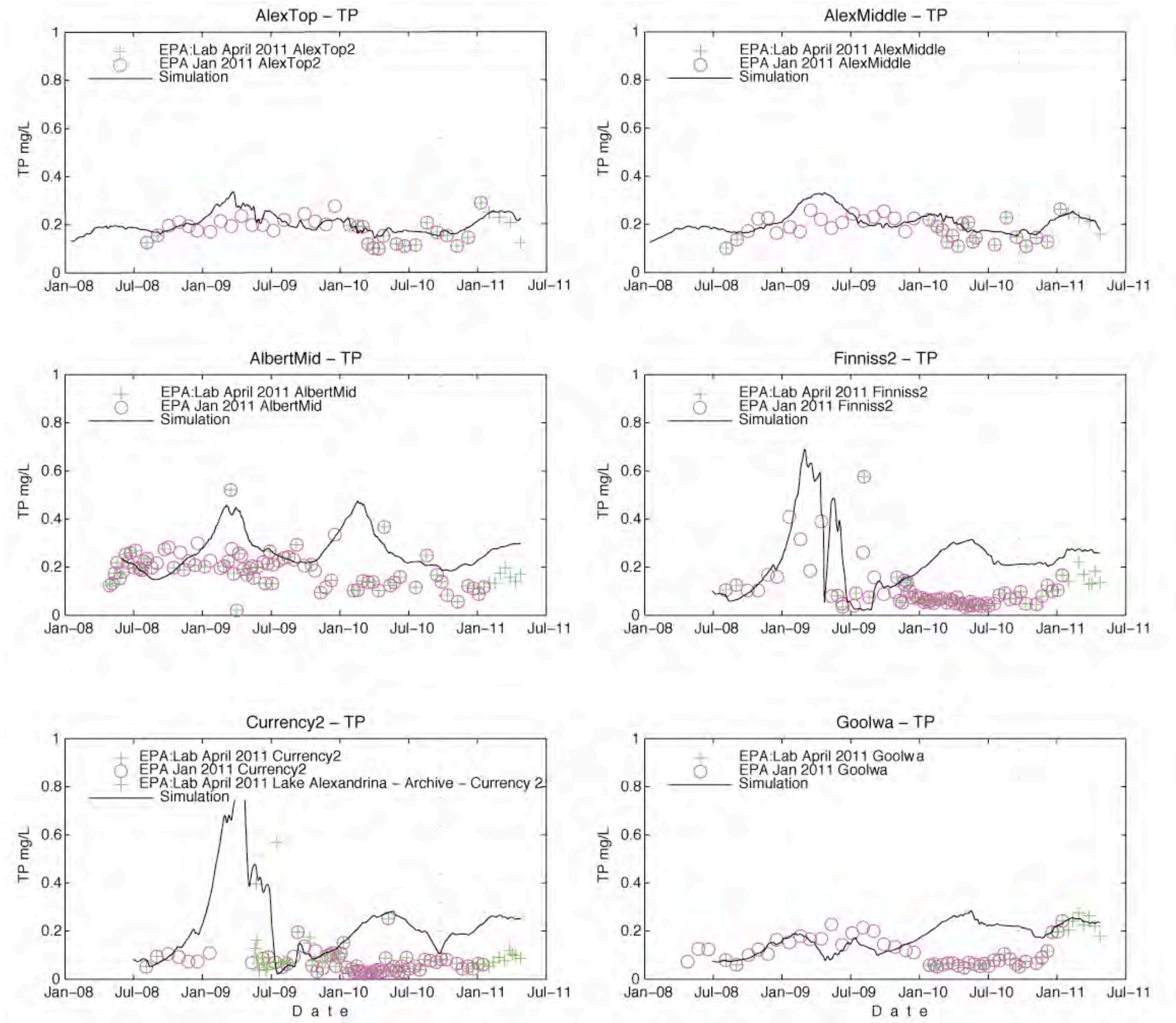


Figure 21: Evolution of modelled TP (mg P/L) from selected locations and comparison with observed data.

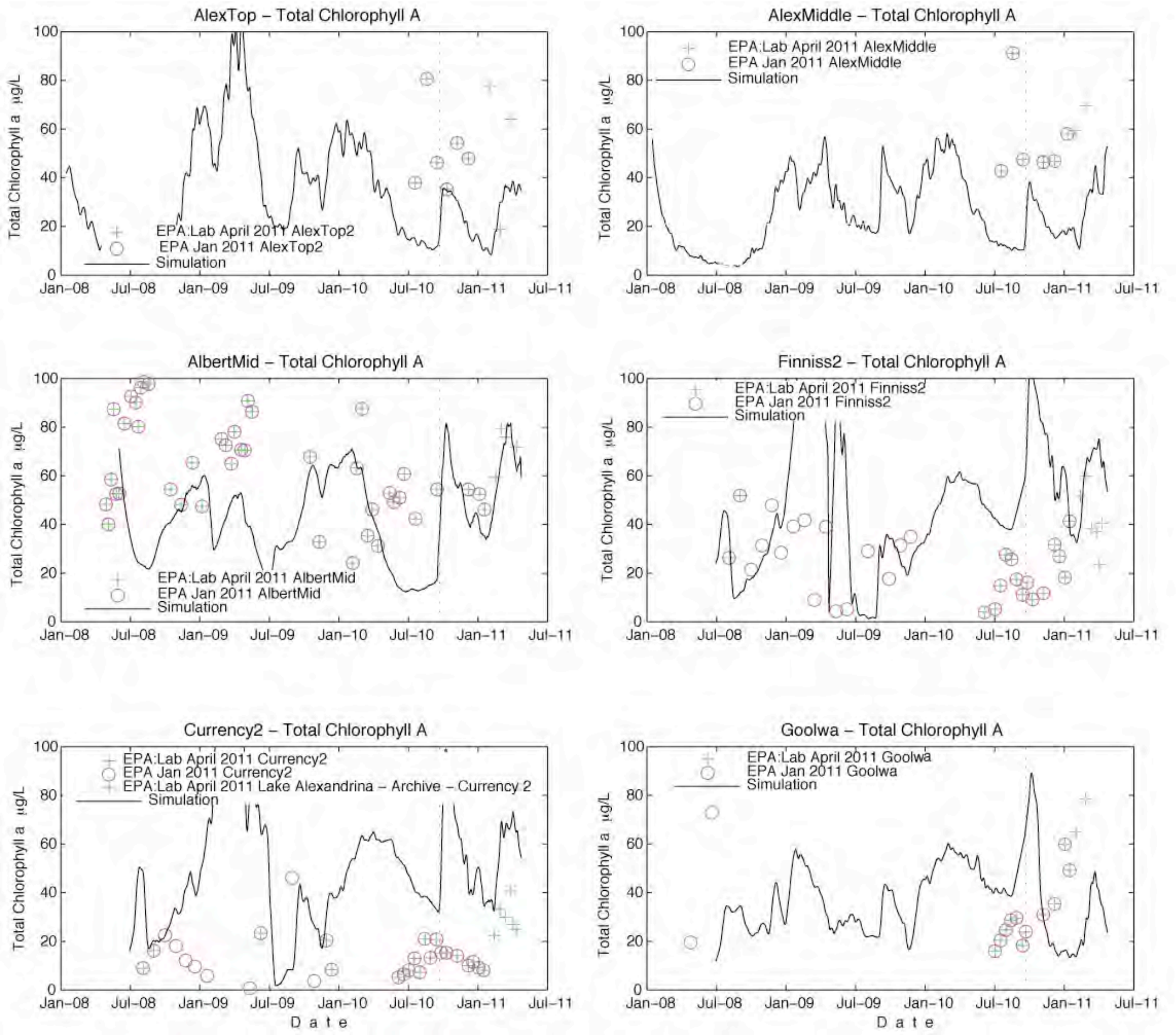


Figure 22: Evolution of modelled Chl-a (ug Chl-a/L) from selected locations and comparison with observed data from Lake Alexandrina and Lake Albert.

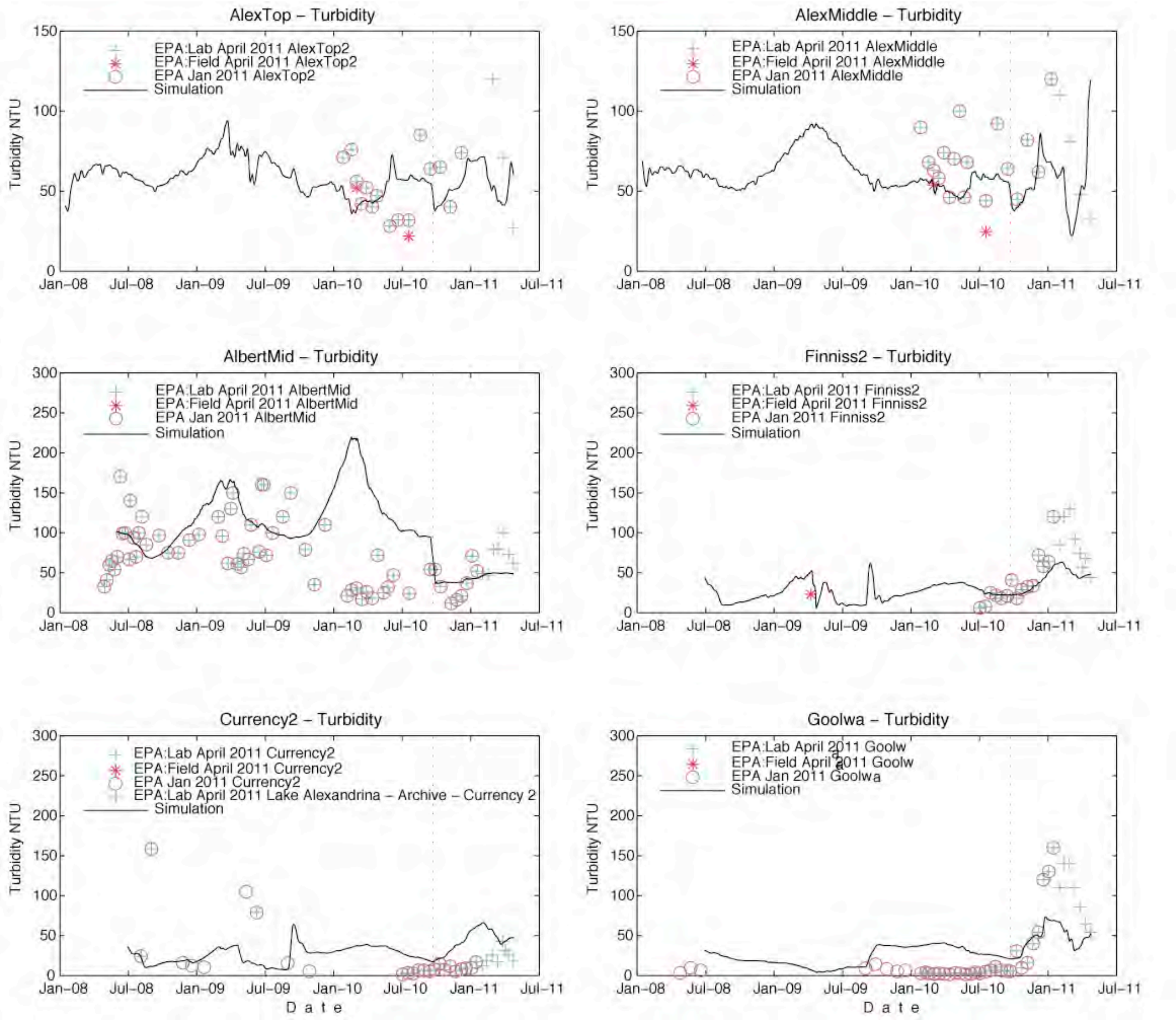


Figure 23: Evolution of modelled Turbidity (NTU) from selected locations and comparison with observed data.

Acidification and recovery analysis

The validation of the acid sulfate soil module has been updated through testing of the model against all available water column data, much of which was not considered in the earlier ASS model analysis. Since this time the Currency acidification area was inundated behind the Currency regulator, and acidification in areas of Loveday Bay, Boggy Lake and other areas has been observed. The model predictions of these events are summarized here with plots of pH and alkalinity for key sites of interest as summarized in Figure 24-25, but note that pH and alkalinity plots for all sites are available from the above web data link. The model validation to date has demonstrated the performance of the model in capturing acidification in high-risk areas, and there has generally been good agreement in the locations and time-periods of acidification.

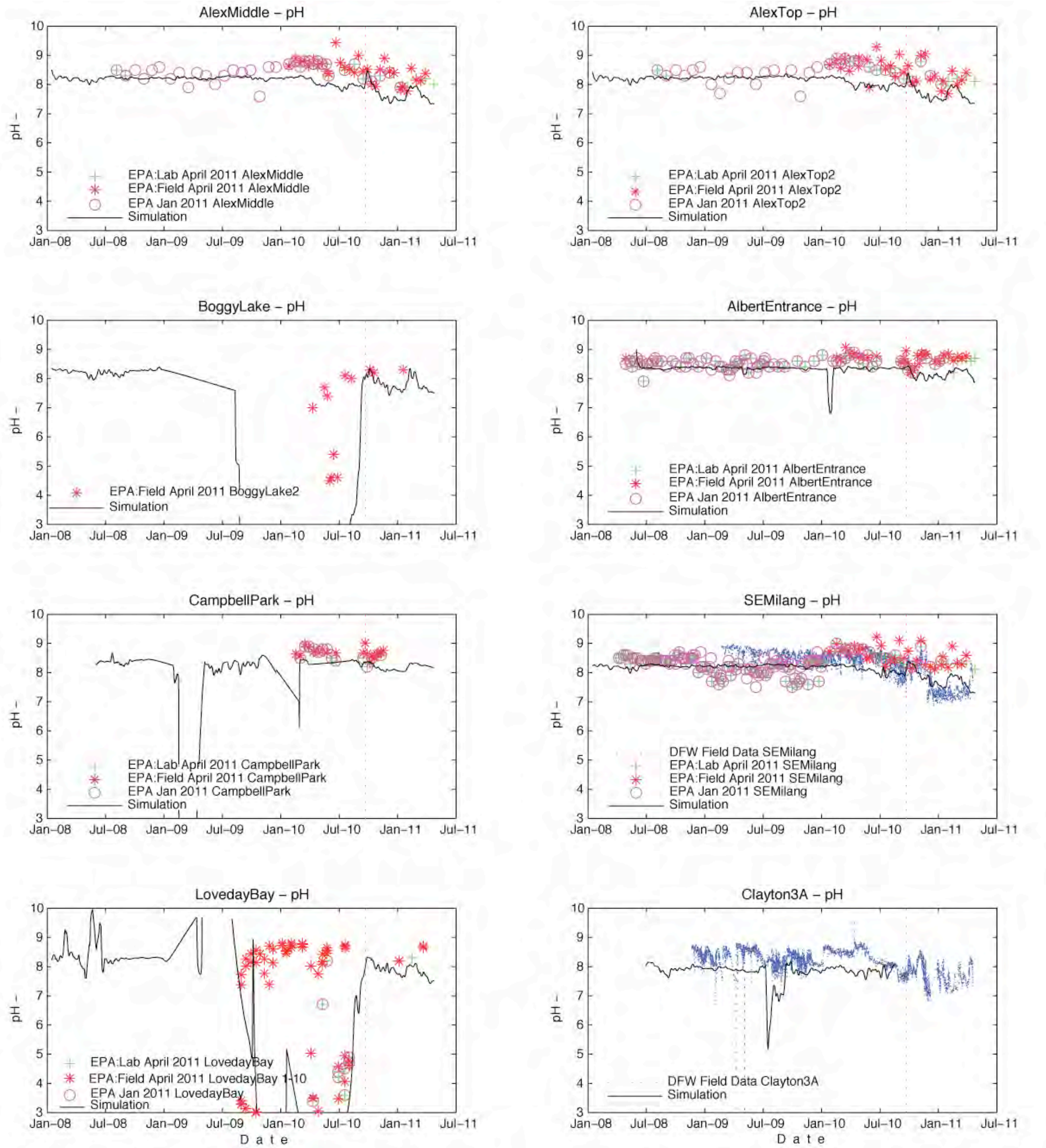


Figure 24a: Evolution of modelled pH (-) from selected locations and comparison with observed data.

These highlight the spatial and temporal variability in the manifestation of geochemical processes, and in particular the acid sulfate soil drivers. Generally, the model predicts accurately the pH measured by the point data, and slightly under-predicts that measured by the real-time sensor data. The general stability of the pH in the main water bodies is reproduced well, and the slight reduction in pH following the increased flows in winter 2010 is also detected, although not as marked as that observed at Beacon 90. The stations of more interest are those susceptible to acidification risks discussed separately next.

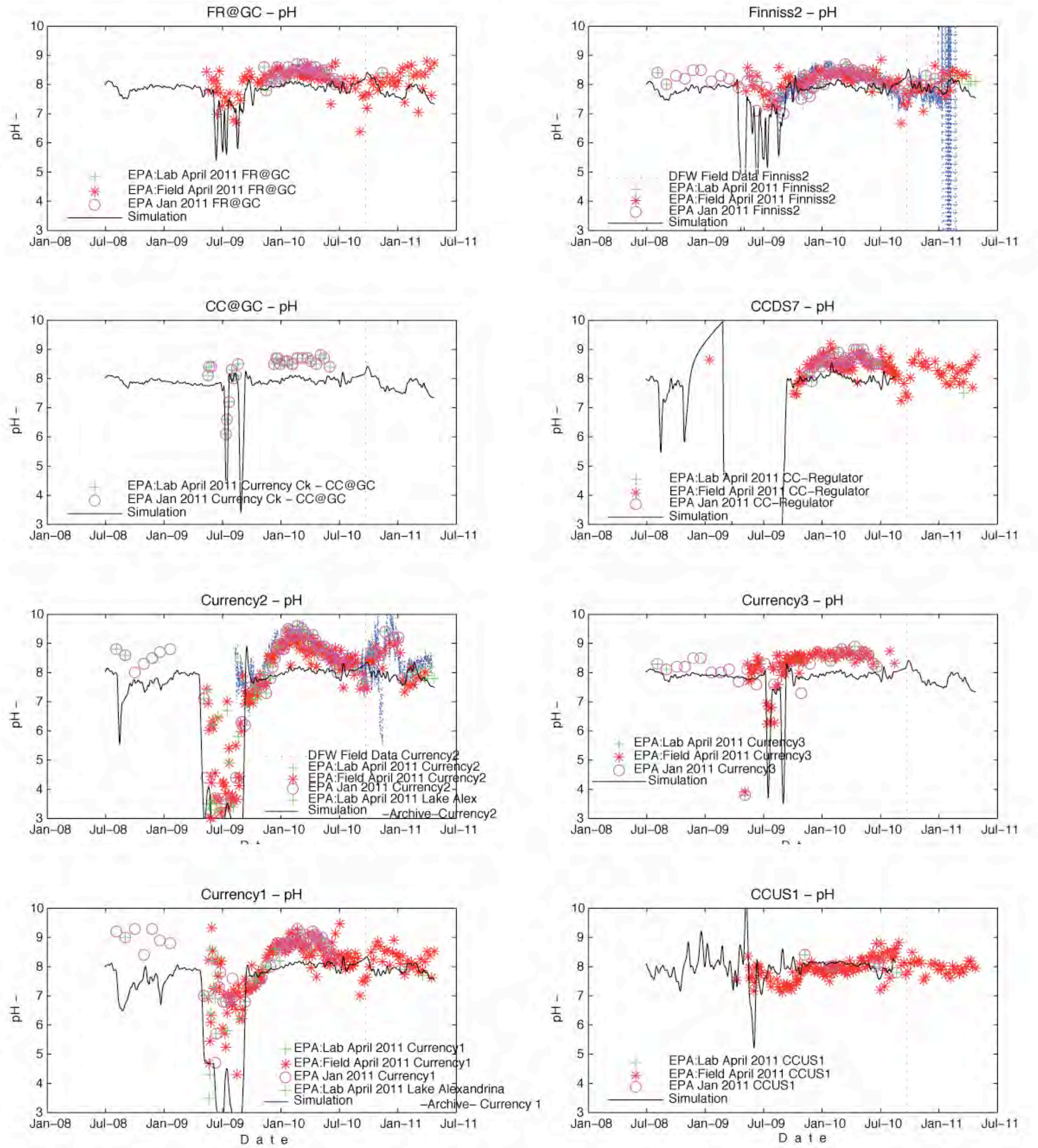


Figure 24b: Evolution of modelled pH (-) from selected locations and comparison with observed data.

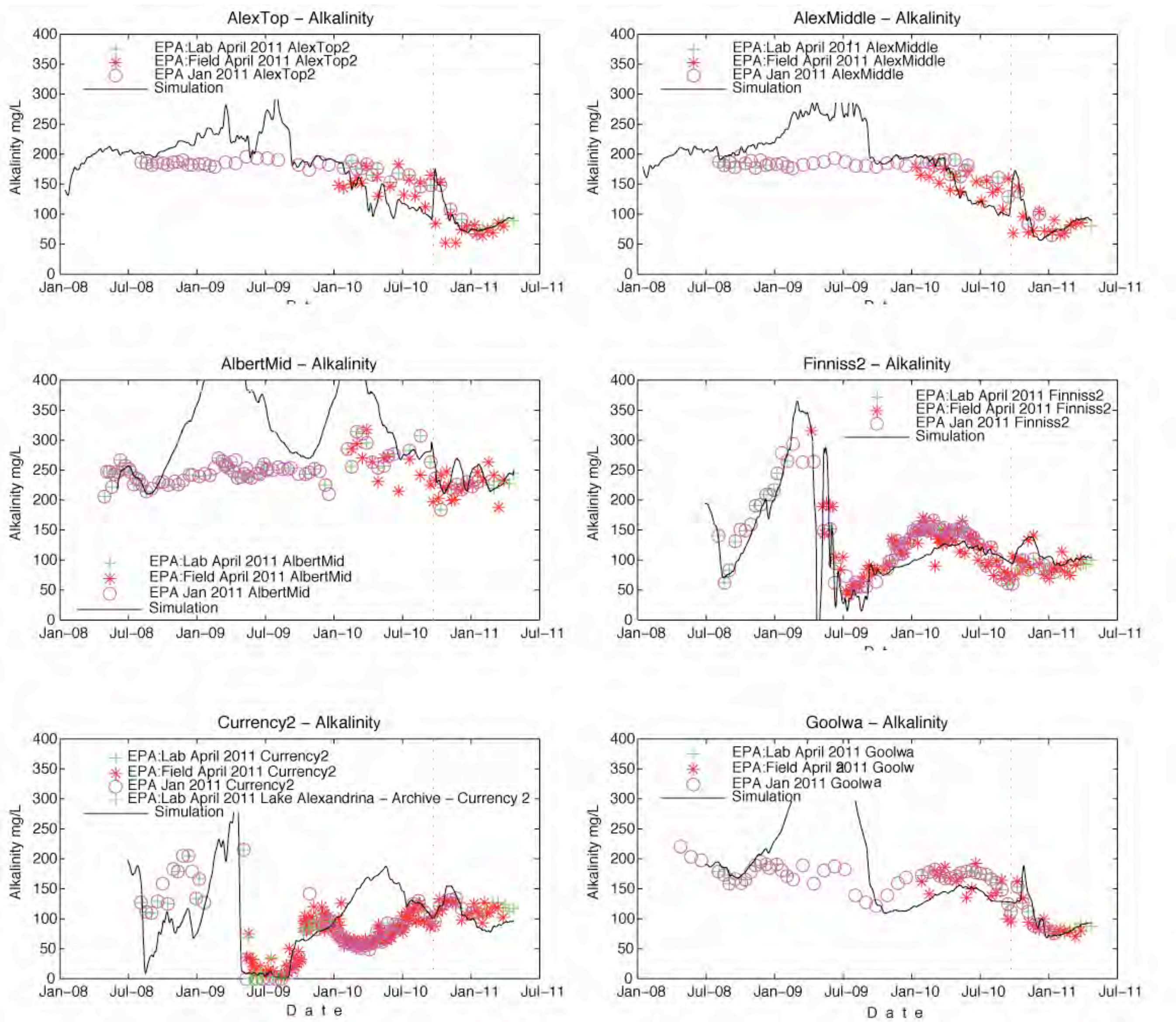


Figure 25: Evolution of modelled alkalinity (mg $CaCO_3$/L) from Lake Alexandrina and Lake Albert comparison with observed data.

Currency Creek acidification and recovery

Due to the history of this region in having major acidification incidents, numerous plots from around this region are shown (Figure 24b). They demonstrate in general accurate timing and distribution of the acidification occurrences, mainly in the pools of the Currency Creek tributary, including from the western regions (CCUS1), the main Currency basin (e.g. Currency1-3) and even including the brief pulse of low pH water recorded at the main Goolwa Channel (CC@GC). The acidity flux from the model is small until the first rains of 2009, at which point both the Currency Creek tributary pools go acidic, in May 2009 (Figure 24b). The model predicts the timing and recovery of acidic conditions well.

There was a prediction for a smaller reduction in pH in Finniss River that was not observed so significantly in the data, however, minor declines in pH were seen that dropped to ~ pH 7 suggesting some acidification pressure may have been occurring, and potentially this was just over-predicted by the acid sulfate soil module, either do to insufficient consumption of acid neutralising capacity, or due to uncertainties in specification of soil properties.

A closer inspection of the patterns of soil potential and available acidity within the Currency region show that these pools were not only disconnected but also had a high portion of acidified perimeter relative to pool area (Figure 26). Whilst the sulfide concentrations in the region was not the highest, the available acidity in this area was much higher than elsewhere, due to the prevalence of more sandy material allowing for more rapid draining and oxidation of the reduced sulfides. The model also predicted a large area of potential and available acidity in the confluence region between the Currency Creek tributary and the main Goolwa Channel, however since the area receiving this leachate experienced exchange with the main water body this region did not manifest in a low pH, though plumes of slightly lower pH water are visible in the simulation output.

The simulated EC and alkalinity in the region (Figure 26) shows very good performance against the observed data. The alkalinity in Currency2 during the recovery period is however over-predicted and does not capture the observed reduction in the summer period of 2009-2010. This is most likely associated with inaccuracies in specification of the boundary conditions for the Currency Creek inflow and potentially due to an under-prediction of the continued acidity leaching that occurs into the domain following reflooding.

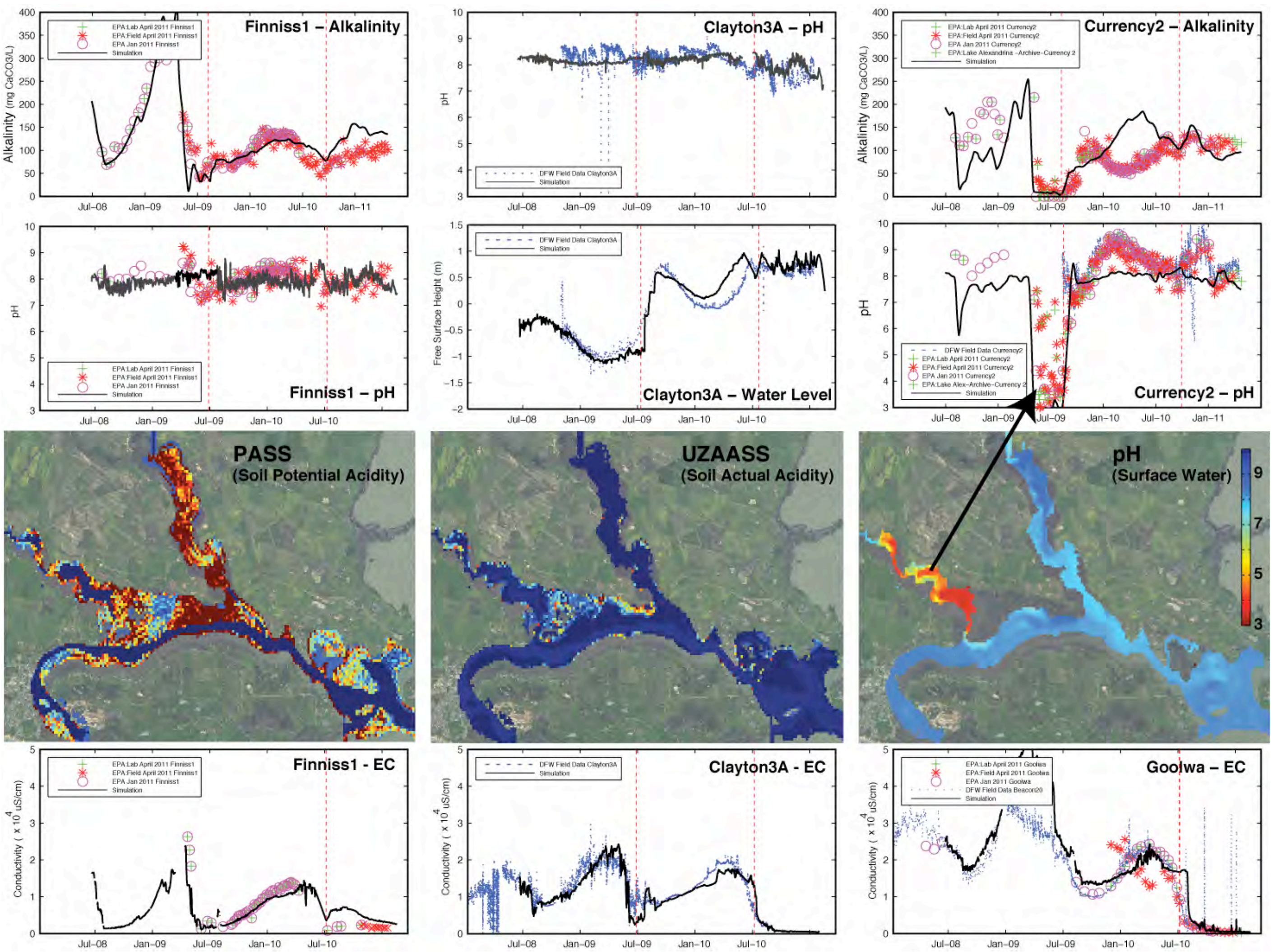


Figure 26: Spatial distribution of soil PASS and AASS and water pH in July 2009 with associated time-series plots comparing model water level, conductivity, alkalinity and pH at key points.

The model analysis also included simulation of the conservative acid sulfate soil leachate tracer ("COL"), which indicates the surface water areas with a higher concentration of acid leachate loading. This is also an indicator of metal contaminant loading associated with leachate material, though assumes conservative behaviour and no reactions or transformations. For the Currency Creek and Finniss River tributary (Figure 27), the outputs highlight the build-up in the Currency Creek pools relative to the high level of dilution in Finniss River and the main Goolwa-Clayton channel during the main acidification period in May 2009. After it had refilled the loading of acid leachate to the water column was still apparent 12 months later, however, at a level not able to induce a drop in pH. It is apparent from the simulations that it is contained upstream of the Clayton regulator (note that sharp boundary in concentration in the middle plot), until later in the winter of 2010 when the regulator was partially removed, and the signal can be seen moving downstream to the Goolwa Channel. This output indicates the level of risk from potentially contaminated leachate, but it is important to consider that many metal contaminants wont behave conservatively once in the water column – for example Al^{3+} will precipitate as gibbsite and be returned to the sediment, as seen in the rapid decline in dissolved Al in this region following water level recovery despite the persistence of the ASS tracer plotted here. Nonetheless, the analysis highlights the effectiveness of the Clayton regulator containing the poor quality water until water levels recovered in that latter half of 2010.

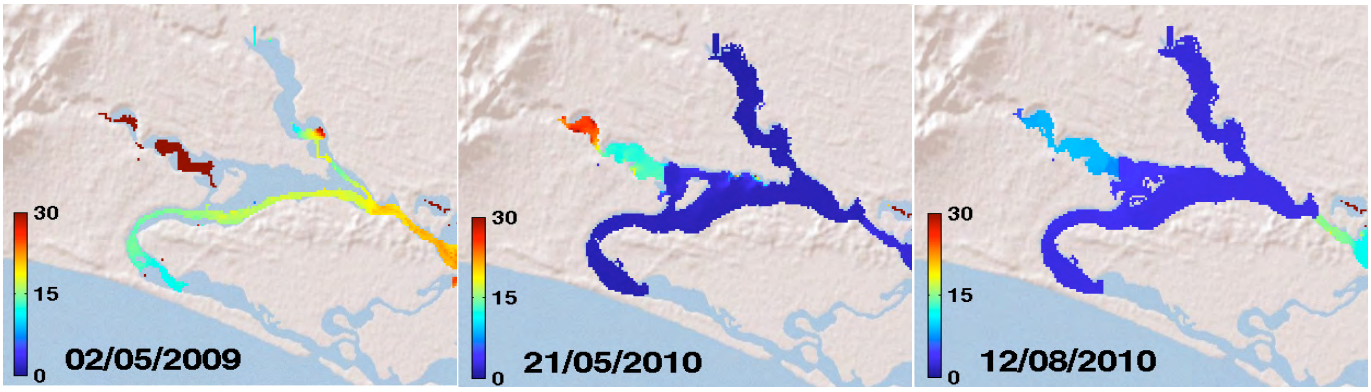
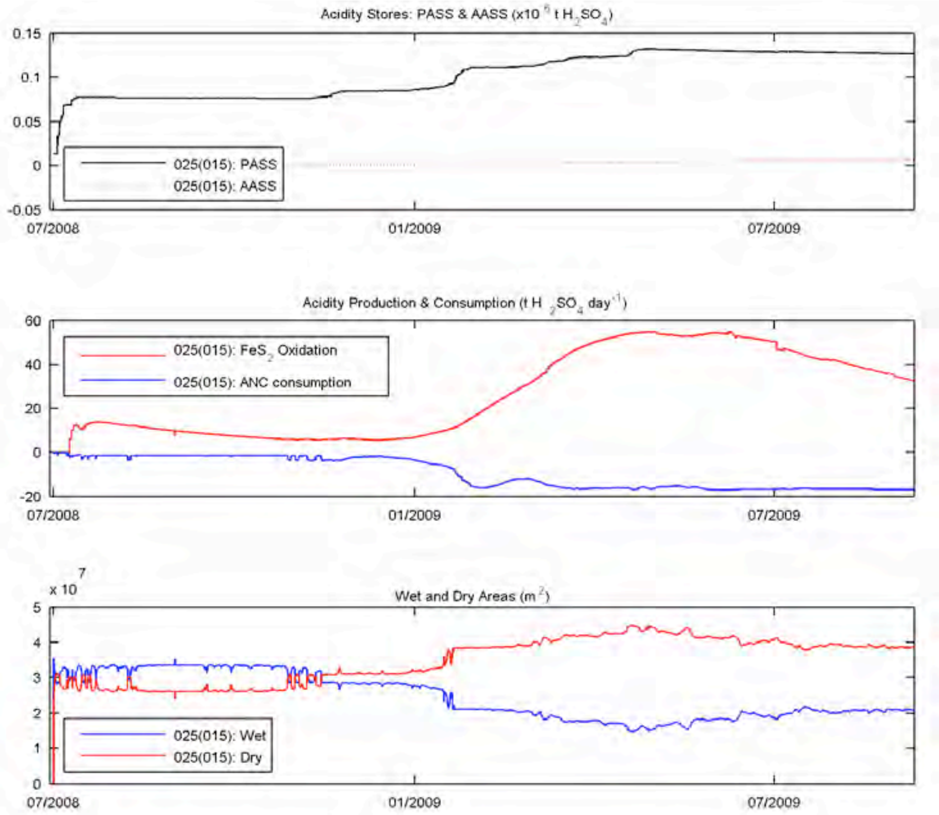


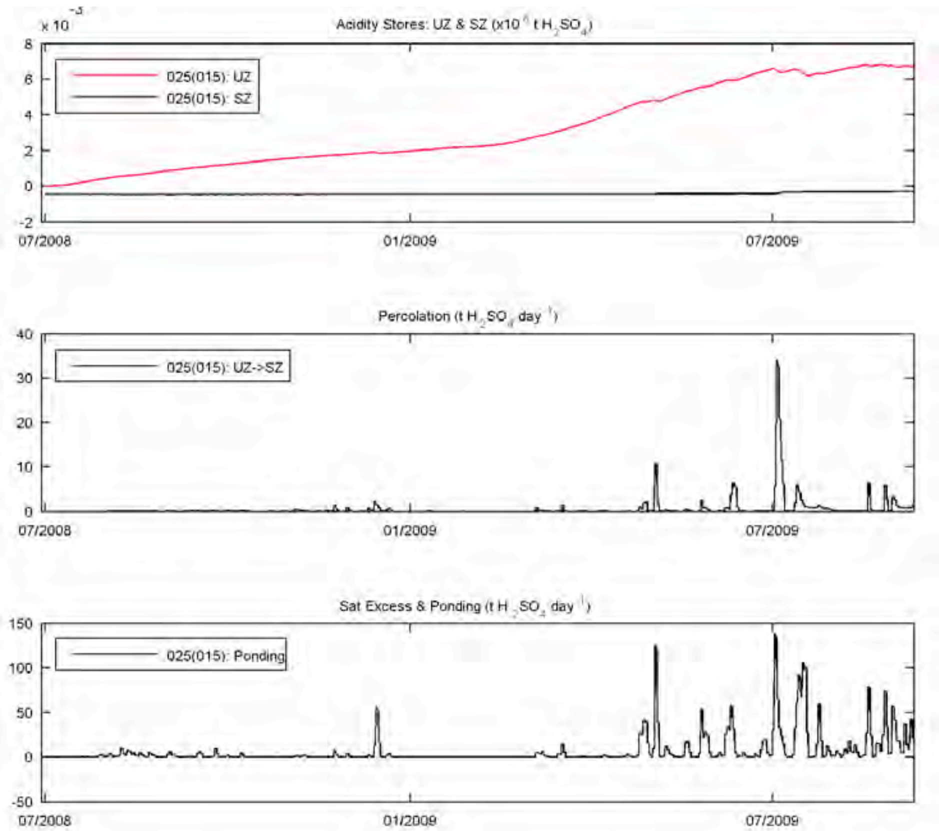
Figure 27: Distribution in acid sulfate soil leachate concentration (arbitrary units) in the water column, for the period during Currency Creek acidification (left), and the period following re-inundation prior to winter inflows (middle) and the period following re-inundation during the winter flows (right), highlighting the areas of accumulation and the transport and dilution of potential contaminants. Note the presence of the temporary Currency Creek regulator in the middle and right plots that is acting to restrict downstream flow of Currency Creek water.

Whilst Figure 27 show the spatial variability, the model provides spatial integrations of key acidity pools and fluxes that demonstrate the system-scale production, neutralisation and transport pathways. An annual average budget of these key acidity fluxes and stores of acidity was compiled for the Sep 2008 – Sep 2009 period to gain insights into the dominant drivers of the acidification dynamics during the 2009 acidification event (Figure 28). The results demonstrate the build up of sulfidic material exposed above the water table (PASS) that is only partially converted to sulfuric material (AASS), at least at this integrated spatial scale. The budget shows it is mobilised to the water mainly via surface processes. These annual sums indicate that the amount of available acidity in the unsaturated zone of the Currency Creek region was around 60,000 tonnes of H_2SO_4, of which approximately 12 tonnes per day (averaged over the year) was transported to the lake. Note that this was significantly higher during the period of higher rainfall. The key flux process appeared to be via overland flow and shallow transient flow through the unsaturated zone (interflow) following intense rainfall events, with only minor fluxes arising from the lateral movement of water from within the saturated zone (-0.01 tonnes per day). The mobilised amount was approximately 22% of the acidity that was oxidised during the period, and a further 30% of the oxidised material was neutralised by the acid neutralising capacity or balanced by alkalinity produced via SO_4 reduction. Diffusive fluxes from rewetting of acid soil were also relatively small (0.003 tonnes per day).



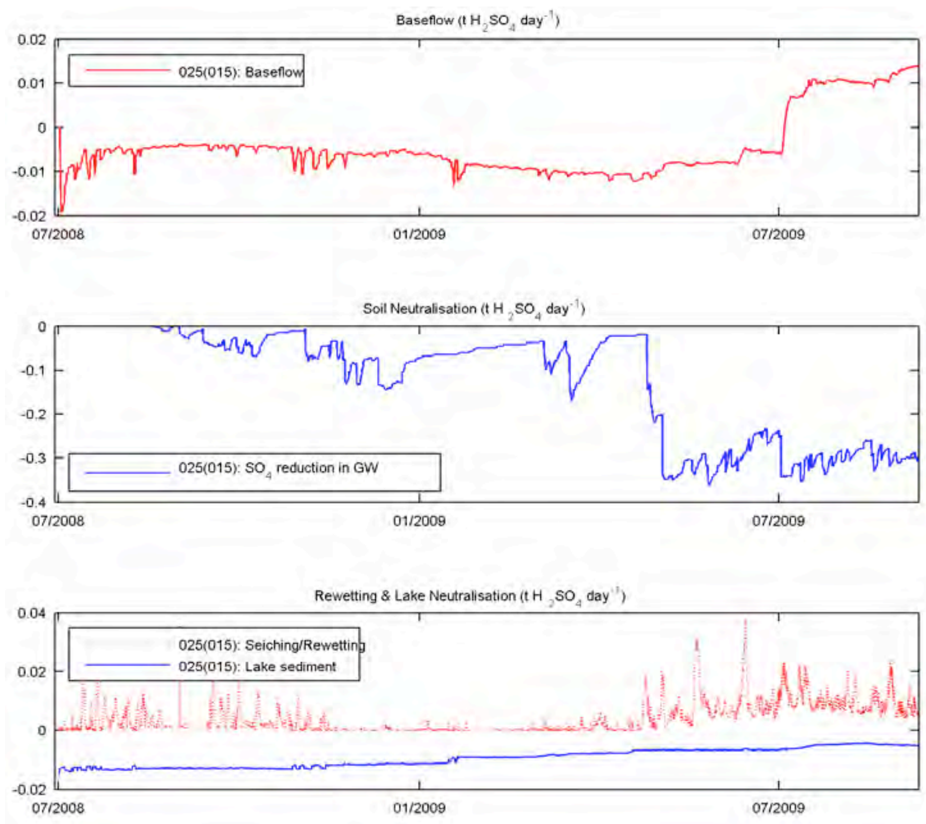
Currency Creek Domain
(area west of Clayton regulator location)

Figure 28a: Spatially integrated output from the Currency Creek (CCO) validation simulation showing accumulation of exposed sulfidic material (PASS) and subsequent production and consumption of sulfuric material (AASS).



Currency Creek Domain
(area west of Clayton regulator location)

Figure 28b: Spatially integrated output from the Currency Creek (CCO) validation simulation showing the accumulation of acidity in the unsaturated and saturated zone, and process controlling mobilisation including percolation, and from saturation excess runoff and surface ponding.



Currency Creek Domain

(area west of Clayton regulator location)

Figure 28c: Spatially integrated output from the Currency Creek (CCO) validation simulation showing the baseflow acidity flux rate, the in-soil neutralisation of acidity by sulfate reduction in the groundwater, and the rewetting acidity flux and in-lake alkalinity flux from the deeper sub-aqueous sediment.

Whilst we cannot quantify the precise role of management actions aimed at directing surface flow through mounded limestone in order to raise alkalinity, it is logical from this analysis that it was an effective approach since it was targeting alkalinity addition to the surface flow pathways most likely to be impacted by acidity. Facilitating the re-formation of the pool behind the Currency Regulator has also contributed to isolating the acidified material and potential downstream delivery of poor quality water to the main reach of Goolwa Channel, as evidenced by the model prediction of the ASS tracer in Figure 27.

The spatial extent of low pH for this period in the context of the wider lake basin is shown in Figure 29, and highlights this area of acidification as the hot-spot location at this time and water level condition. It highlights the significance of the lake morphometry in isolating these pools from the main tributary and allowing the accumulation of acidity without any dilution or flushing from the main body of the lake. There are some parts of the larger domain at this time that were also predicted to experience short-lived acid pulses that are not observed such as in the Narrung Narrows. These are most likely due to erroneous specification of soil textural properties near the domain perimeter. The alkalinity (Figure 25) shows a build up over the summer of 08/09, and a sharp drop during refilling in mid-2009, followed by a quick recovery and stabilisation upon refilling.

Sensitivity of key model parameters was conducted (not shown here) to understand the key processes that shape the degree and extent of lake water acidification. This analysis suggested that the soil hydrological processes were very important and in particular the rate of soil drying and the height of the capillary fringe, and also the vertical percolation rate of acidity in pore-water leachate following rainfall. Further field research is recommended to characterise the dominant controls on hydrological pathways in the exposed sediment since many of the hydrological module parameters are assumed and could be further refined.

Lake Alexandrina (main body including Loveday Bay and Boggy Lake)

Stability of the pH in the main lake water body is well captured, at stations including “Alex Top”, “Pomanda” and “Poltalloch”. The gradual decline in 2010 is also reflected. Predictions of low pH at key peripheral locations during times of rising water level in winter-autumn 2010 are captured (Figure 30), however the model is delayed in the time period in which it refills, and therefore the time of onset of acidification is not exact (Figure 24). In particular the acidification of Boggy Lake is predicted, and the subsequent recovery of pH following continued water level increases.

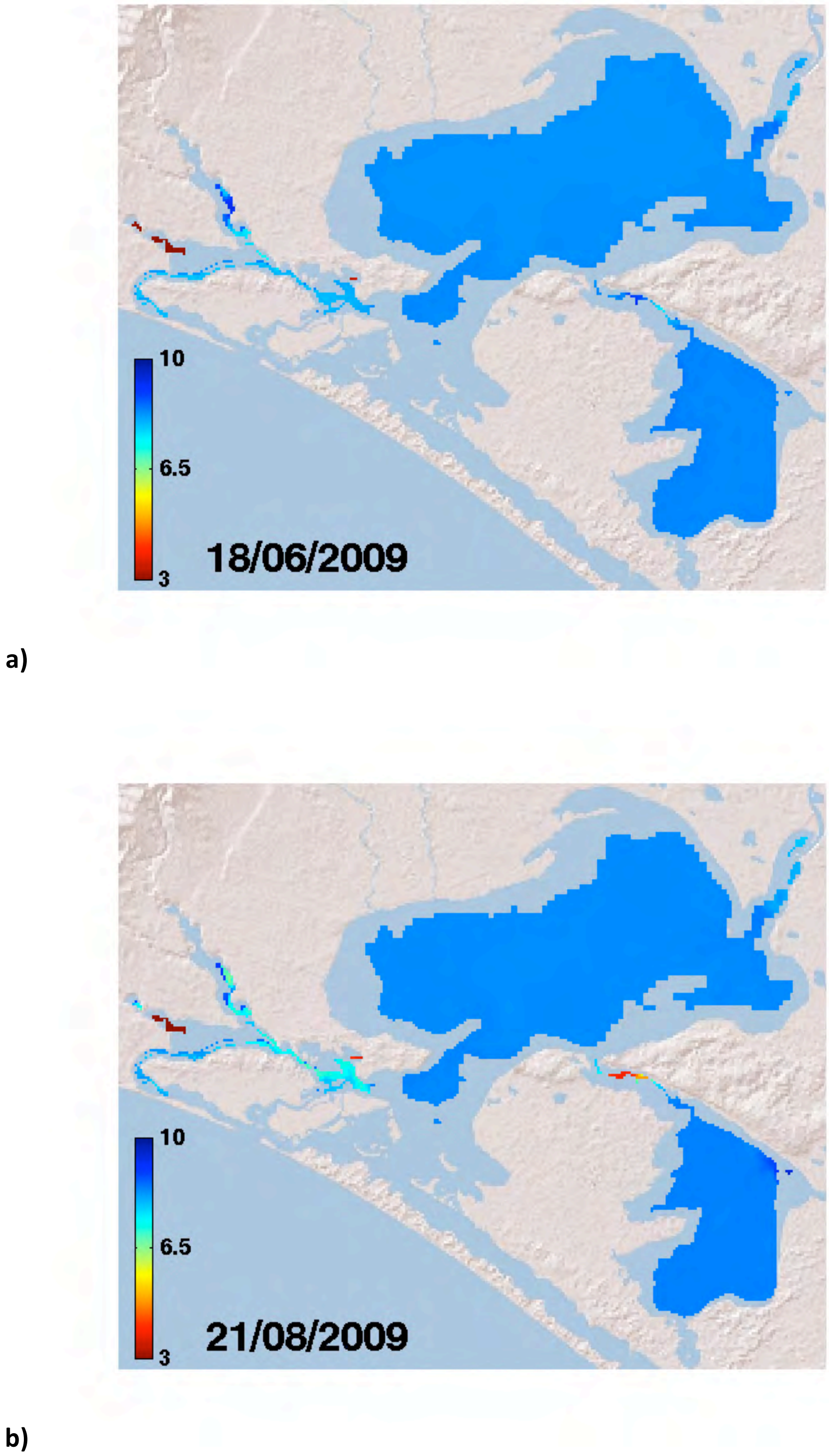
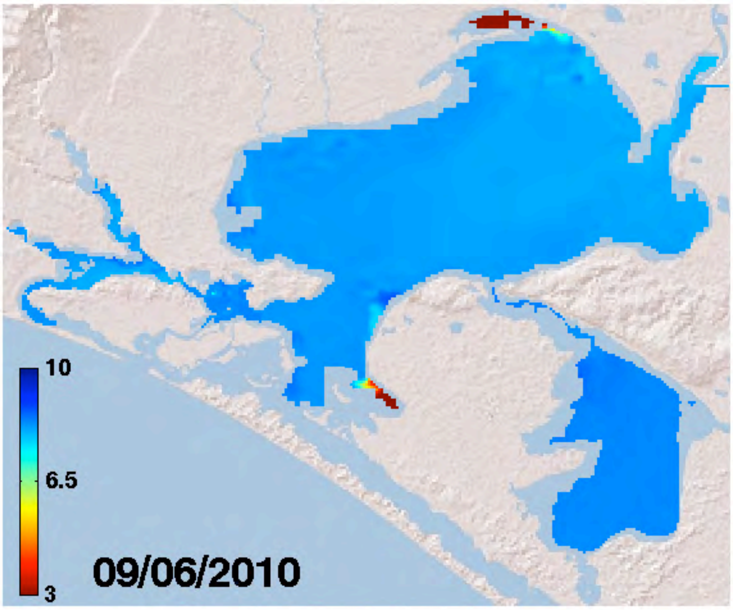
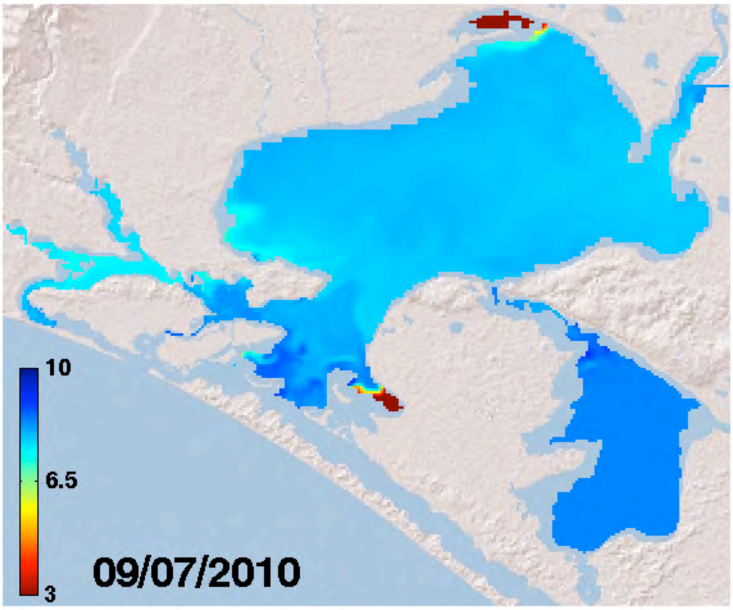


Figure 29: Spatial variability in pH identifying areas of predicted acidification in a) Jun and b) Aug 2009.



a)



b)

Figure 30: Spatial variability in pH identifying areas of predicted acidification in a) Jun and b) Jul 2010.

Model predictions of pH at "Pt McLeay" are fairly stable, however, in the field data there is a decline in pH during winter 2009. This is only seen in the real-time pH sensor data and not in the EPA pH grab data, and therefore this decline could be related to sensor drift, and not a true reduction in pH. In the areas north of the Tauwitchere Barrage, the model successfully predicted the lack of acidification following the drying and subsequent inundation. In Loveday Bay, the model simulates acidification during refill in winter 2009 and 2010. At this station there is large variation in both the observed and simulated pH, with the former due to grouping of several nearby stations in the Loveday Bay area responding differently to rainfall events. The model resolution predictions here are also less accurate than in Currency Creek due to a coarser resolution in the "ANC" model domain during drawdown. As with Boggy Lake, the delay in the predicted recovery in winter 2010 of approximately one month is due to a under-estimation of the rate of refill and rise in water level. Therefore, improvements in specification of the hydrology of the lake basin will lead to improved biogeochemical predictions.

Examination of the model surficial porewater acidity (Figure 31) highlights the spatial distribution during these events, and clearly identifies that the north-west area as a major acidity hot-spot with available acidity in the surface sediment greater than two times other areas by winter 2010. These other hotspot areas are present at several sites around the lake, most notably including Loveday Bay and the western most reach of the main basin, but these are subject to more dynamic flushing regimes in response to the dominant circulation patterns, whereas the Boggy Lake and Loveday Bay regions had a high proportion of acidity in areas with relatively low exchange rates with the main lake body.

The Lake Alexandrina (not including area west of Clayton or east of Narrung regulators) lake-wide acid sulfate soil dynamics (Figure 32) show a rapid expansion of the exposed sulfidic (PASS) material in the summer of 2009/2010, however the overall oxidation rate quickly drops as the water level starts increasing. Large amounts of acidity (pulses of with a magnitude of approximately 200-5000 t H_2SO_4 /day) were mobilised to the water in 2010 in the late autumn / early spring via surface processes as was observed in the Currency Creek domain. The baseflow was less sporadic and more constant, but overall, was relatively low (approximately 0.2 t H_2SO_4 /day), and the rate of lateral movement quickly reduced as the water level began to increase prior to Sept 2010. The water level increases were accompanied by three large spikes of acidity mobilised through upward diffusion from inundated sediment, but this flux was relatively small compared to that moving by surface processes to the lake perimeter following intense rainfall events.

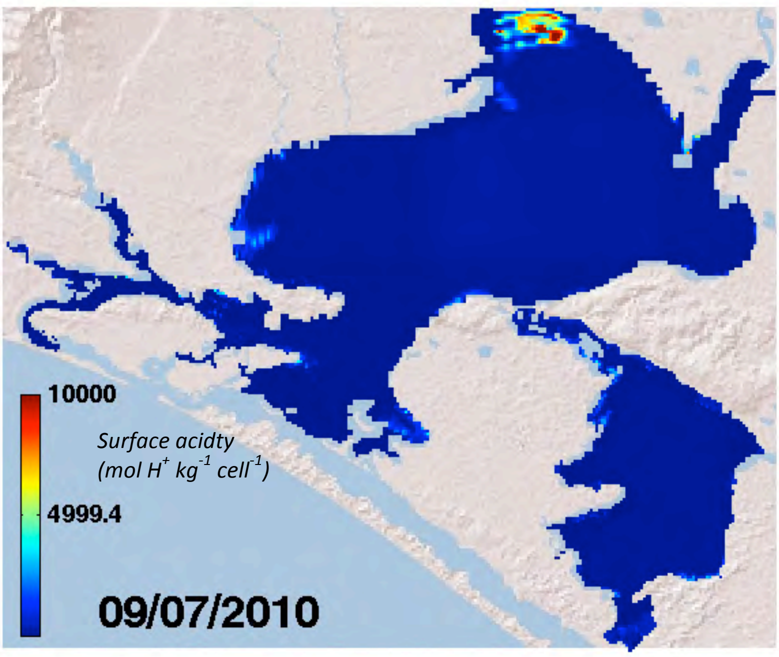
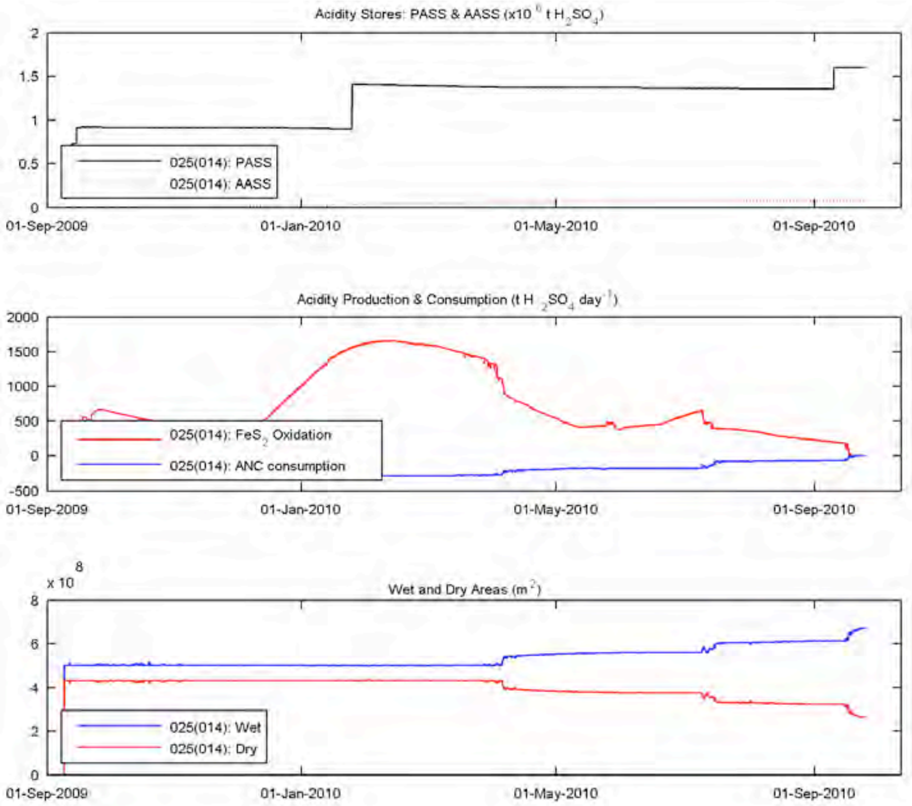
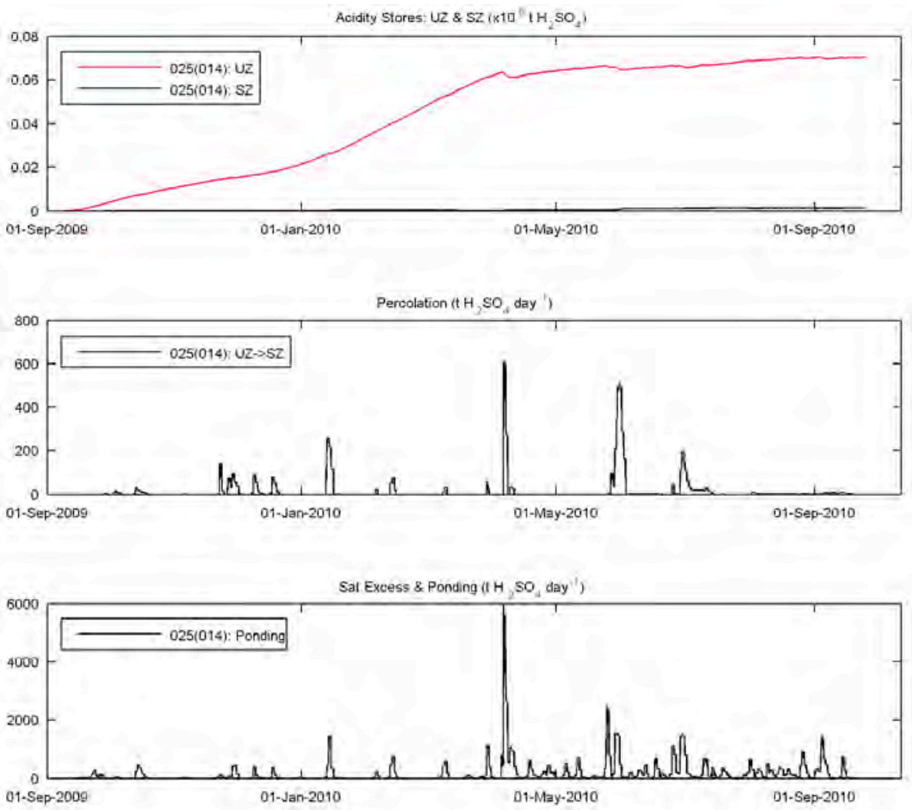


Figure 31: Spatial variability in surficial soil acidity (mol H^+ kg^{-1} per cell; each cell is 40000m^2) in Jul 2010, highlighting the large accumulation in the soils of the Boggy Lake area.



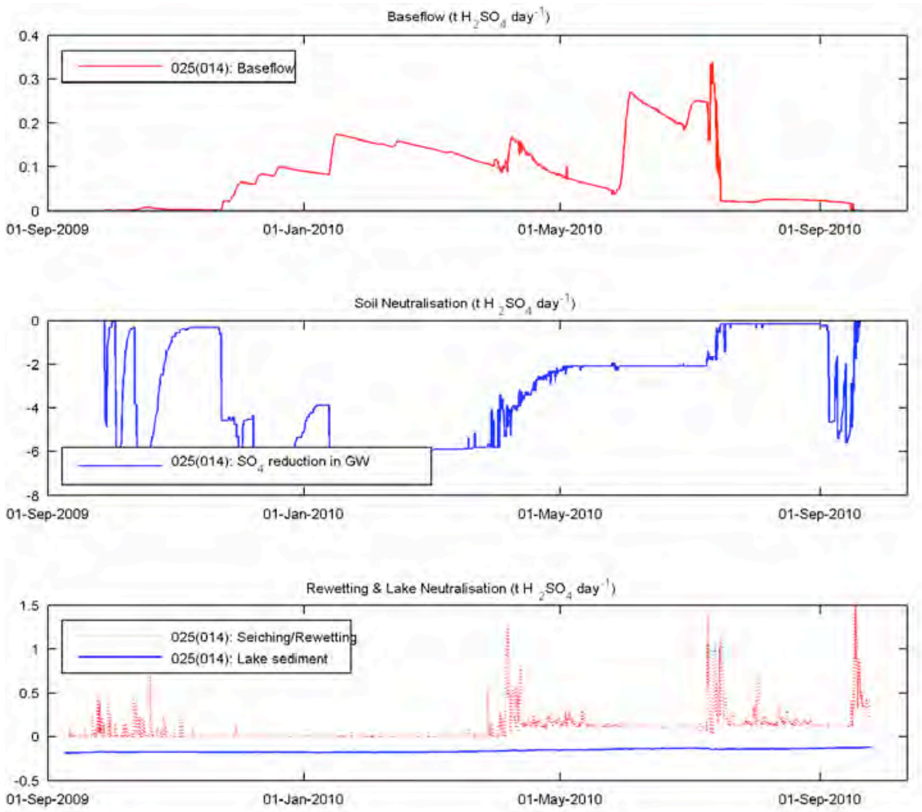
Lake Alexandrina Domain
(not including area west of Clayton or east of Narrung regulators)

Figure 32a: Spatially integrated output from Lake Alexandrina (ANC) validation simulation showing accumulation of exposed sulfidic material (PASS) and subsequent production and consumption of sulfuric material (AASS).



Lake Alexandrina Domain
(not including area west of Clayton or east of Narrung regulators)

Figure 32b: Spatially integrated output from the Lake Alexandrina (ANC) validation simulation showing the accumulation of acidity in the unsaturated and saturated zone, and process controlling mobilisation.



Lake Alexandrina Domain
(not including area west of Clayton or east of Narrung regulators)

Figure 32c: Spatially integrated output from the Lake Alexandrina (ANC domain) validation simulation showing the baseflow acidity flux rate, the in-soil neutralisation of acidity by sulfate reduction in the groundwater, and the rewetting flux and in-lake alkalinity flux

<u>Lake Albert</u>

Stability of the pH in the main lake body is captured, and the model simulates a brief acidification at "Campbell Park" in winter 2009 and January of 2010 (Figure 33). This is in response to the wetting/drying cycles, and in particular was most notable to seasonal re-wetting in winter 2009. This prediction is consistent with highly acid soils measured by Earth Systems (2010) and Fitzpatrick et al. (2010) in this region, though surface water shoreline monitoring data was not available for the relevant time periods. Some tendency for moderate acidification is revealed in the Narrung Narrows region (Figure 33) which also influences the "Albert Entrance" station, however this appears to be an over-prediction by the model and is not seen in the data for this region. Alkalinity in Lake Albert is over-predicted during the summer periods when evapo-concentration is high (Figure 25). Since this includes both dissolved alkalinity and that stored in particulate $CaCO_3$ (simulated here as calcite/aragonite), there appears to be a an unaccounted for alkalinity loss term. Since Ca is predicted very well, the concentration and sedimentation rate of particulate $CaCO_3$ is accurate (more $CaCO_3$ sedimentation would lead to more precipitation and loss of Ca from the system). A similar error is seen in the main body of Lake Alexandrina during the drawdown phase, suggesting this is most likely not due to unaccounted for acid leachate, but rather a inaccuracy in the model alkalinity budget.

The integrated process trends (Figure 34) summarise the dynamics as the lake draws down. In particular the rewetting flux in Lake Albert is considerable compared to the other domains simulated. This is because it is a large flat lake and also since the clays are not as conducive to lateral transport and have a higher rewetting acidity flux. Nonetheless the baseflow/seepage component following winter rainfall is substantial, and increases further as the water level declines. In conjunction with the predicted perimeter acidification near "Albert Entrance", the trend of accumulation of acidity over the simulated period highlight that the lake was relatively close to experiencing large-scale acidification of the surface water.

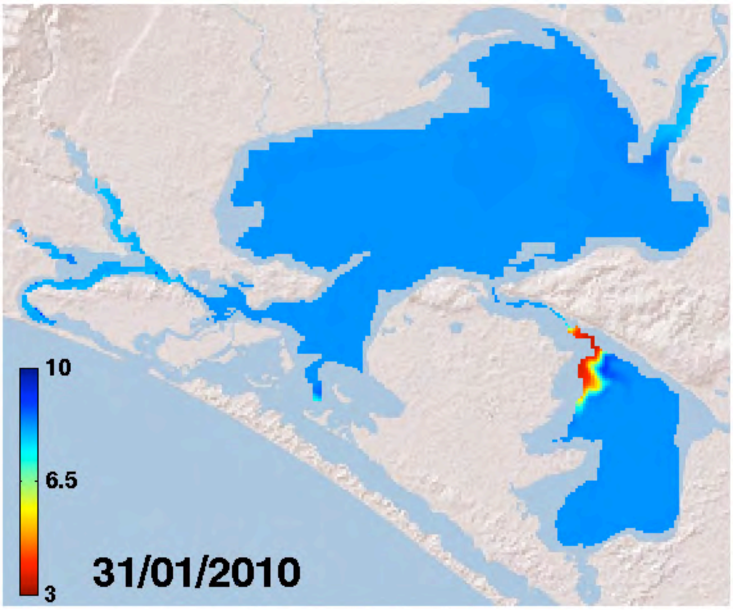
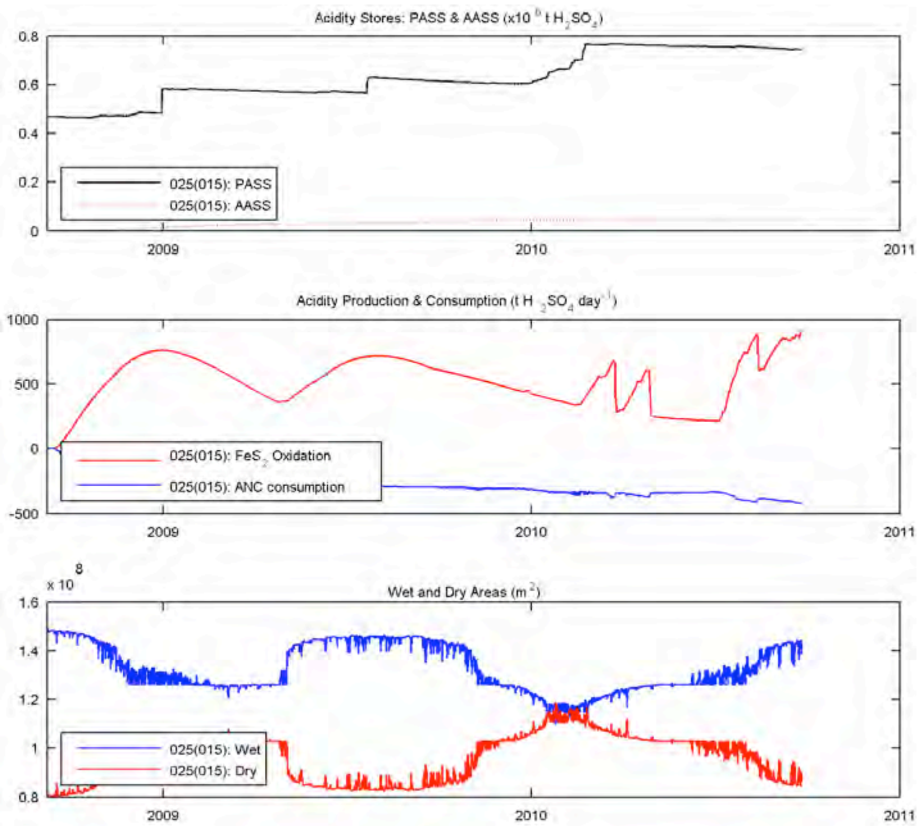
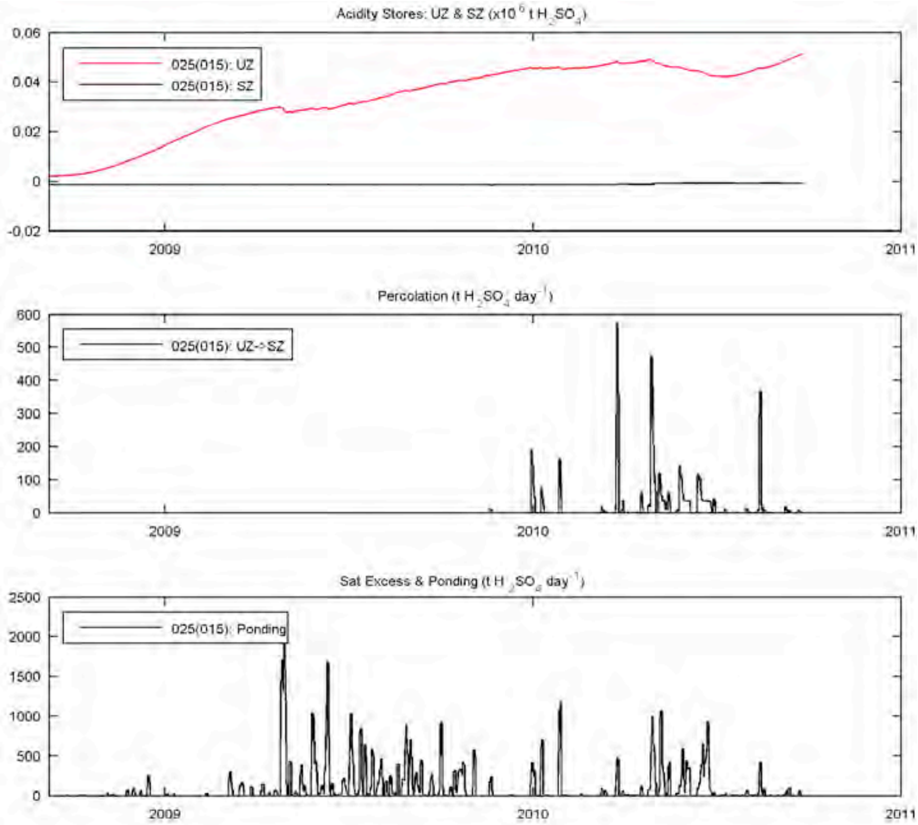


Figure 33: Spatial variability in pH identifying areas of predicted acidification in Lake Albert during Jan 2010.



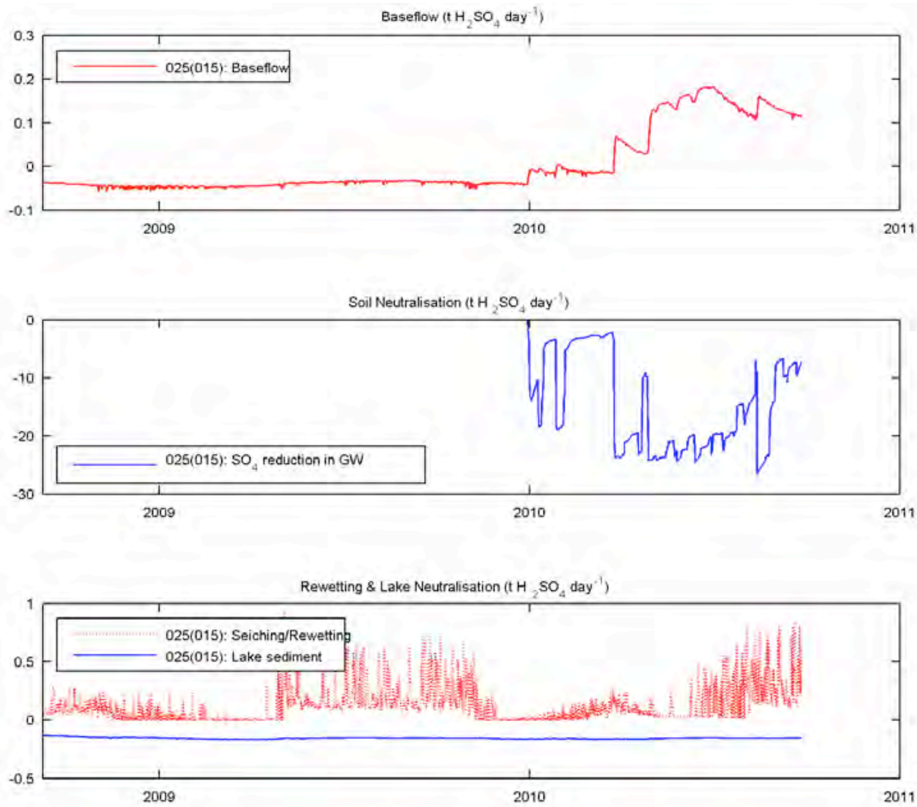
Lake Albert Domain

Figure 34a: Spatially integrated output from the Lake Albert (AB) validation simulation showing accumulation of exposed sulfidic material (PASS) and subsequent production and consumption of sulfuric material (AASS).



Lake Albert Domain

Figure 32b: Spatially integrated output from the Lake Albert (AB) validation simulation showing the accumulation of acidity in the unsaturated and saturated zone, and process controlling mobilisation.



Lake Albert Domain

Figure 34c: Spatially integrated output from the Lake Albert (AB) validation simulation showing the baseflow acidity flux rate, the in-soil neutralisation of acidity by sulfate reduction in the groundwater, and the rewetting flux and in-lake alkalinity flux

Management actions which were implemented to stabilise water level, involving the Narrung Bund and pumping from Lake Alexandrina, were therefore beneficial in slowing this accumulation and greatly reducing this risk; since the main ASS module parameters have not been adjusted from the earlier assessment (Hipsey et al., 2011), the different drawdown and water level stabilisation scenarios contained therein remain relevant.

Effect of reflooding

A significant question motivating this analysis was the observed decline in alkalinity following arrival of the 2010 floodwaters, and to determine the extent to which this is related to inundation of sulfuric ASS material and subsequent flux of acidity from upper soil horizons. No areas of low pH were identified from October 2010 in response to the rapid refilling (e.g., Figure 35), however the acidity flux from re-inundated sediment was predicted to occur and this led to a reasonably rapid depletion of the available acidity in the surface soil horizon, for example as noted in the Boggy Lake area (Figure 36). Figure 37 indicates the spatial pattern of H^+ flux to the water column and how it varied over the inundation period from October 2010 to March 2011. While there were predicted areas of high acidity flux, overall the rapid rate of refilling prevented local manifestations of the acidity loading occurring due to the replenishment of inflow alkalinity and the high amount of exchange and mixing with the main basin. The movement of acidity from the affected regions is seen in Figure 38, which shows dispersion of the acid sulfate soil leachate tracer within the main basin.

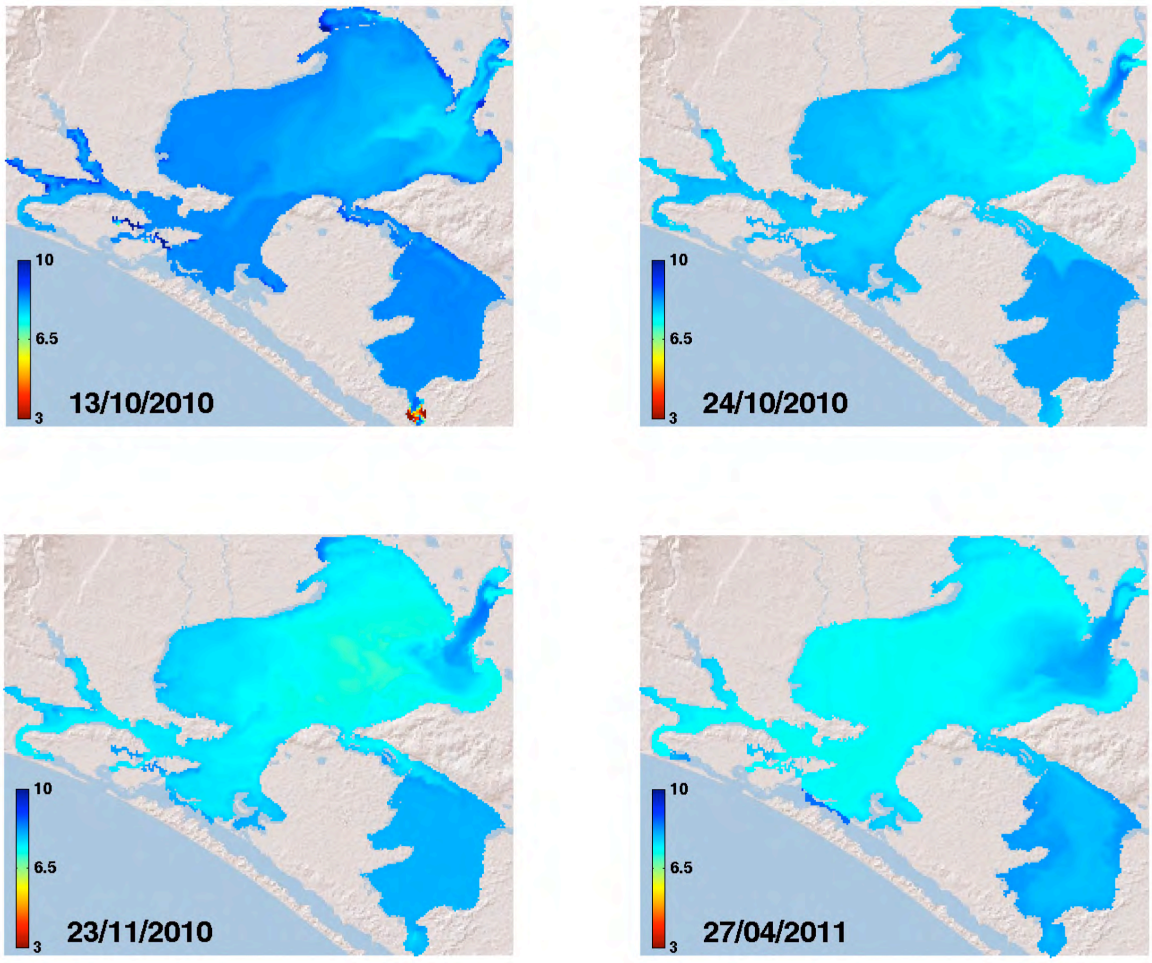


Figure 35: Spatial variability in pH over the flooding period from Oct 2010 to Apr 2010.

The alkalinity decline in the lakes is consistent with the alkalinity decline observed in the floodwaters, and this is evident in the Tailem Bend data indicating alkalinity values falling from 100 mg $CaCO_3$/L down to low of 30 mg $CaCO_3$/L during Oct 2010. The spatial pattern of alkalinity (Figure 39) were quite varied over the simulation period from the first acidification event in 2009 to the eventual recovery.

The spatially integrated acid sulfate soil processes for the fully reconnected domain from September 2010 (Figure 40) shows the stabilisation of growth in the area of exposed PASS, an almost immediate reduction in acidity production, an initial spike in the rewetting flux and a sharp decrease in the baseflow contribution in October. Despite the increase in inundated sediment, the overall SO_4 reduction rate was predicted to decline to the rapid freshening of the water and decline in water column SO_4 concentration.

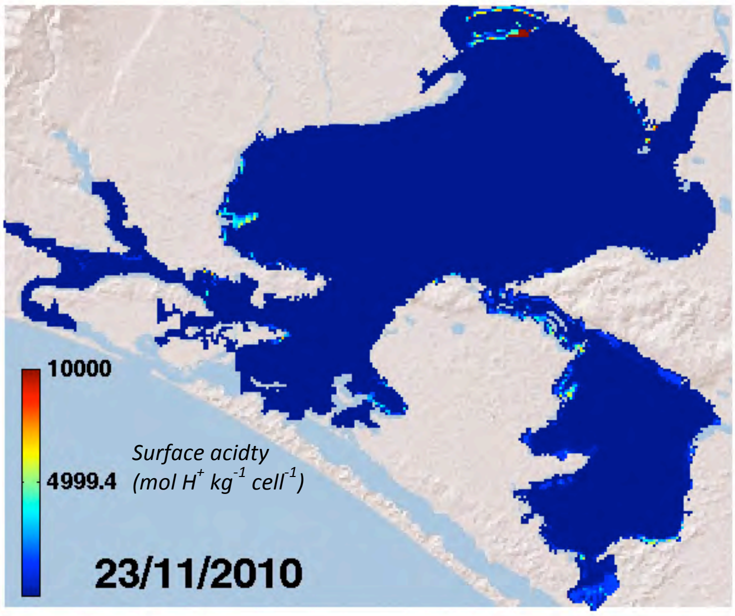


*Figure 36: Spatial variability in surface soil acidity (mol H^+ kg^{-1} per cell) for **23th Nov 2010**. Note difference between this and Figure 31, highlighting the pre- and post-flooding conditions, respectively.*

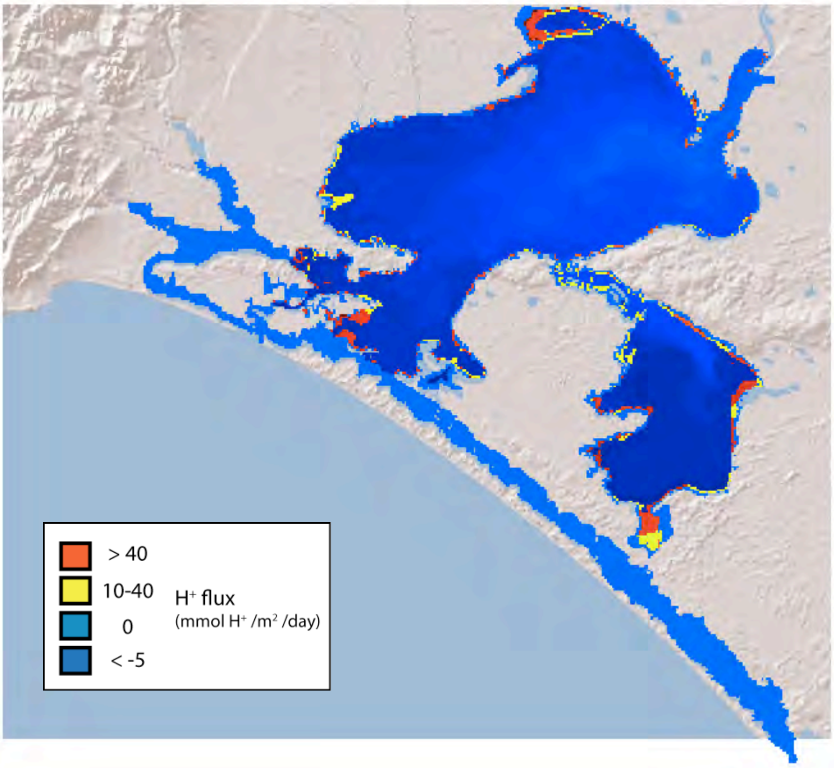


*Figure 37a: Spatial variability in H^+ flux (mmol H^+/m^2/day) from the sediment to the water column as predicted for **30th Oct 2010**. Orange/red colour indicates a high +ve flux to the water from acidified sediment, yellow indicates low-medium flux to the water, light blue ndicates no net flux to the water, and dark blue indicates a –ve acidity flux created by SO_4 reduction inducing alkalinity generation within the sediment.*

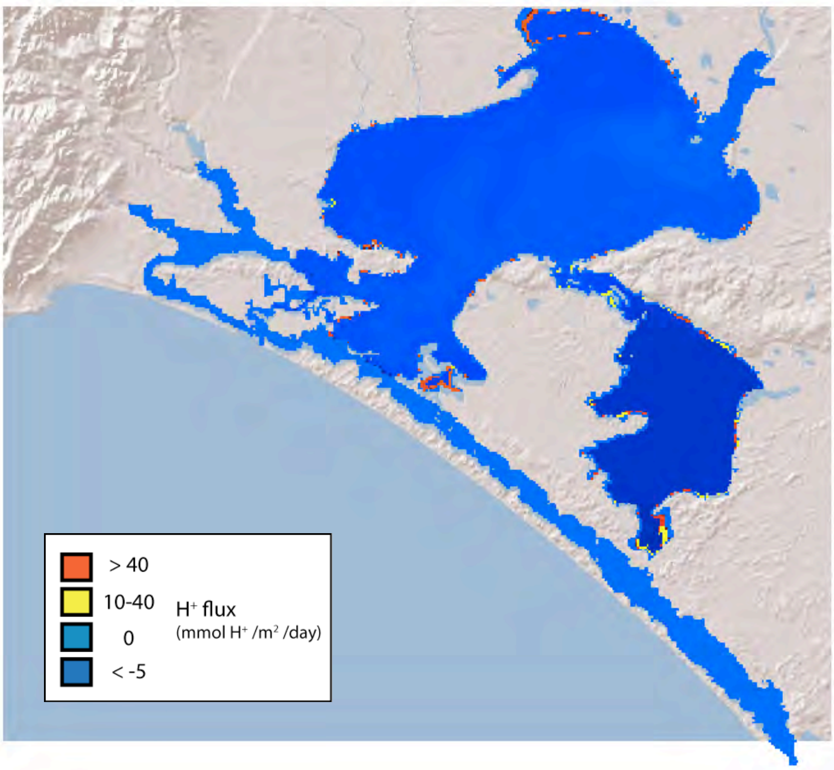


*Figure 37b: Spatial variability in H+ flux (mmol H^+/m^2/day) from the sediment to the water column as predicted for **30th Jan 2011**.*

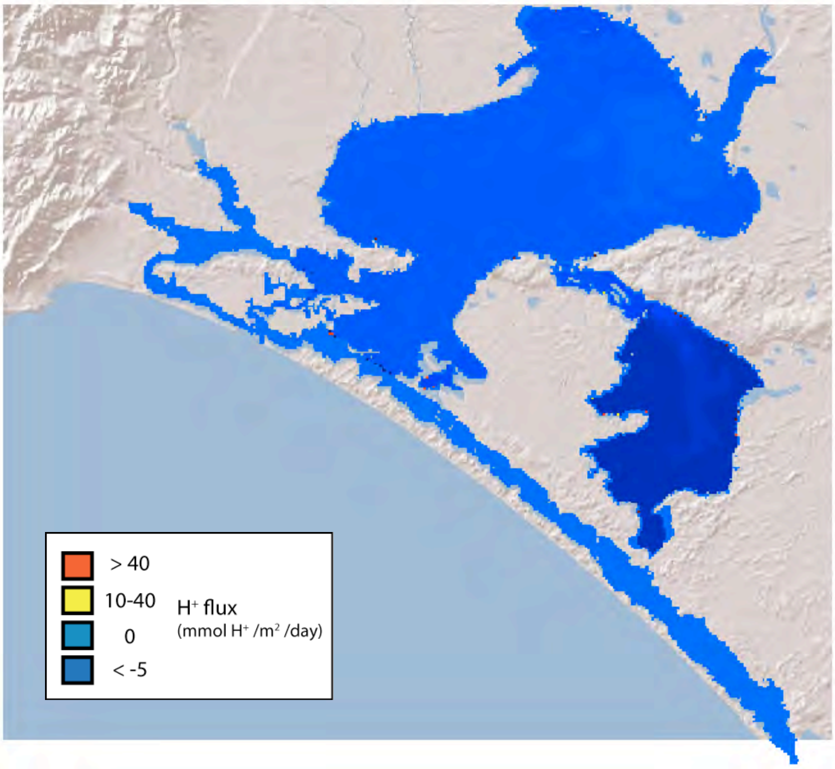


*Figure 37c: Spatial variability in H+ flux (mmol H^+/m^2/day) from the sediment to the water column as predicted for **30th Mar 2011**.*

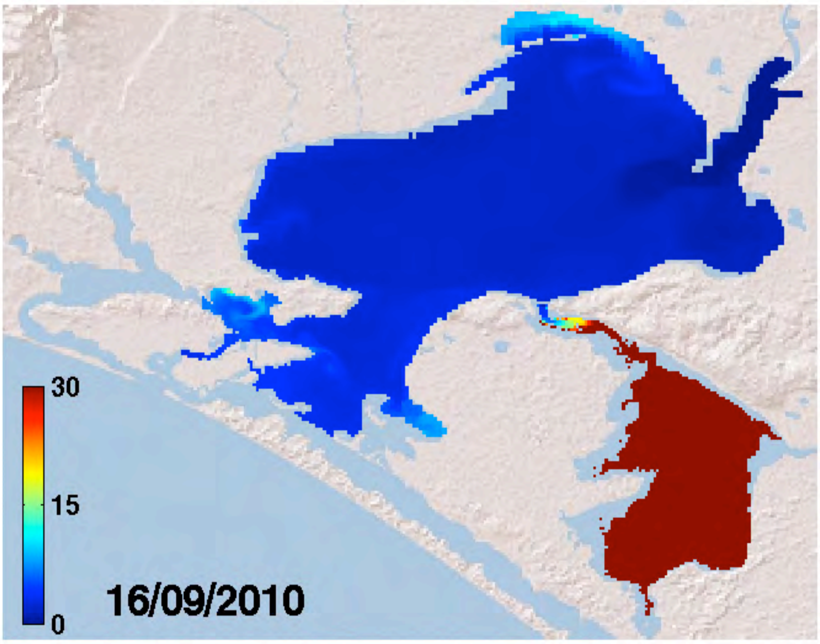


Figure 38: Distribution in acid sulfate soil leachate (arbitrary units) in the water column, for the period pre-breaching of the Narrung bund, highlighting the areas of accumulation and the transport and dilution of material drained into the lake from surrounding sediment and indicating the pathways of dilution of potential contaminants.

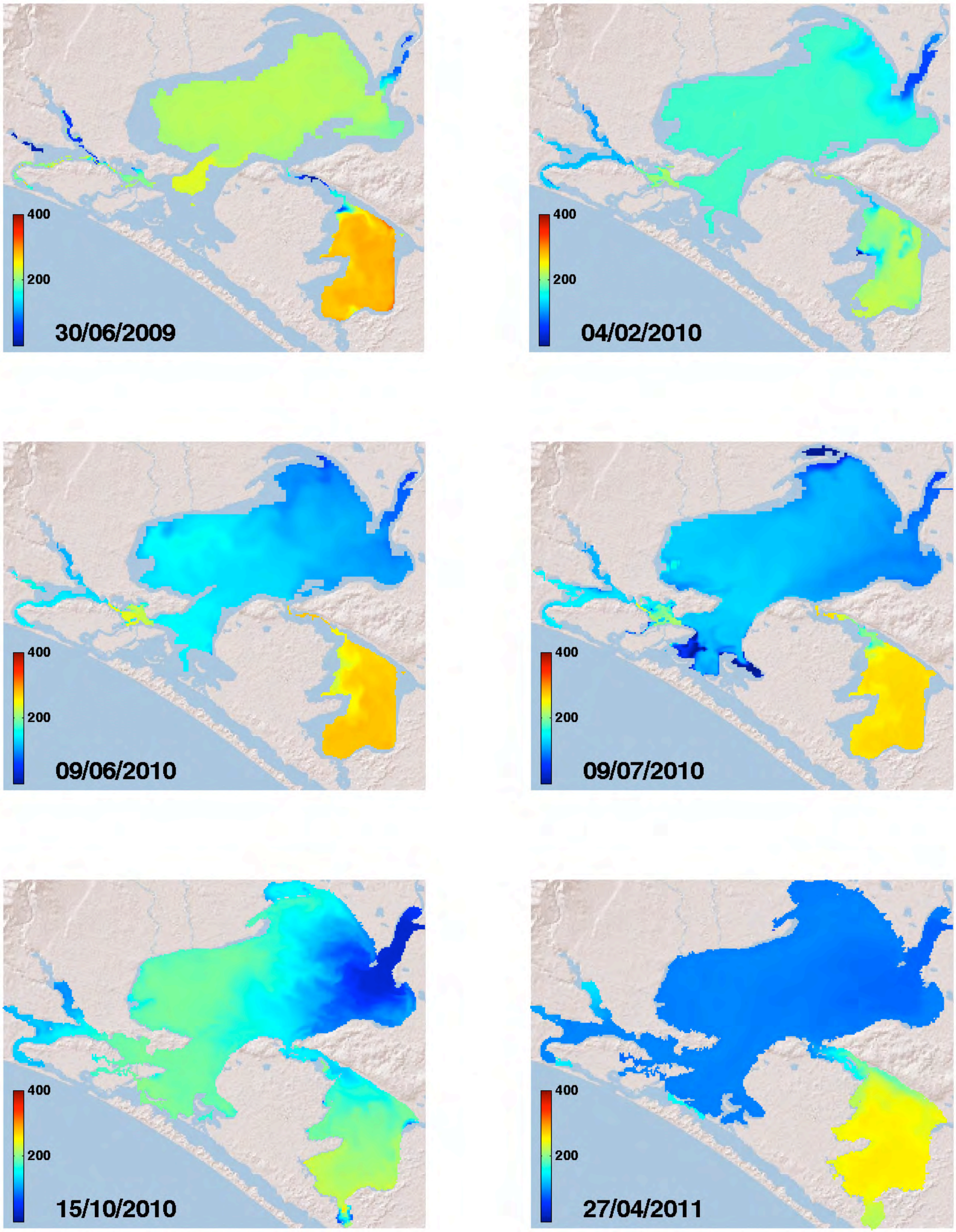
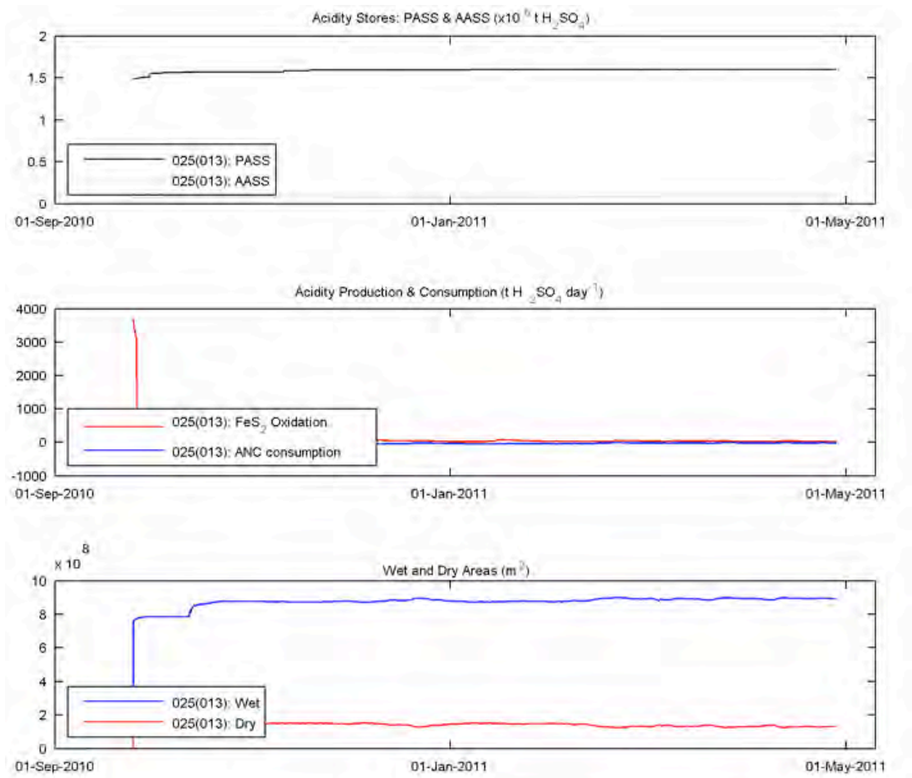
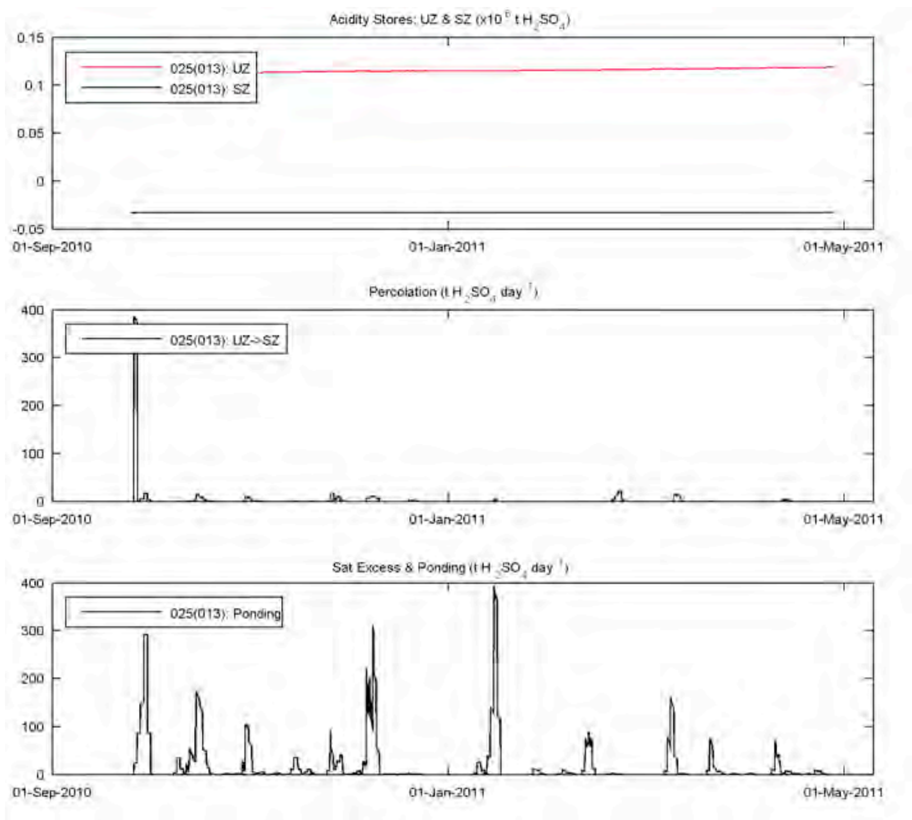


Figure 39: Spatial variability in alkalinity (mg $CaCO_3$/L), for the periods experiencing acidification (top four panels; three individual domains simulated) and the period of recovery (bottom two panels; single lake domain).



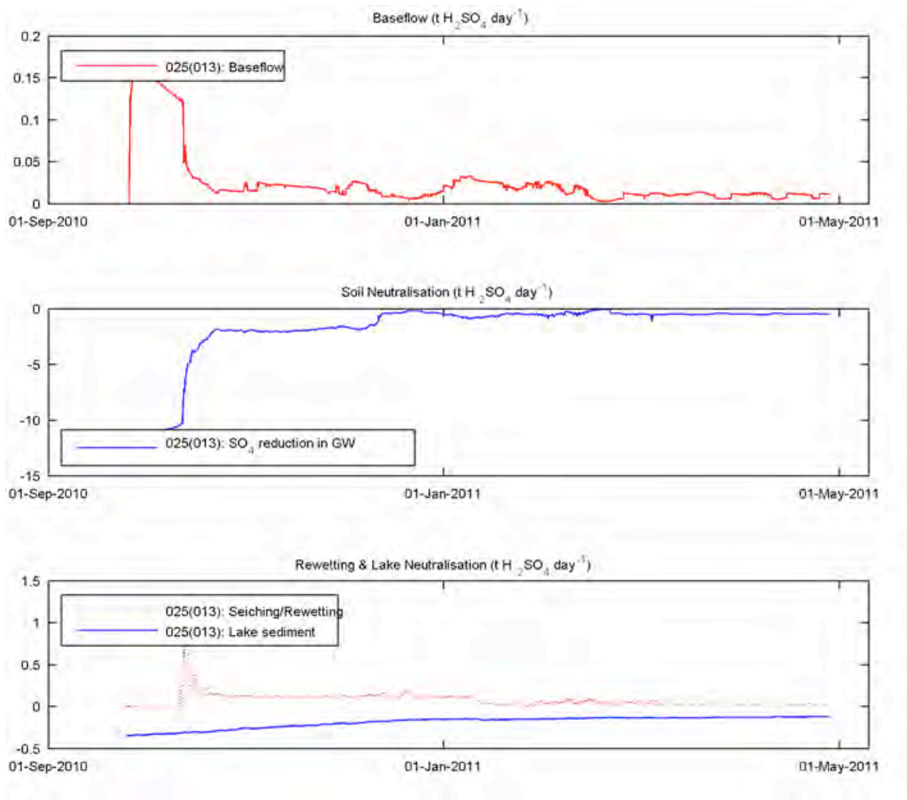
CLLMM Full Lakes Domain

Figure 40a: Spatially integrated output from the full lake system domain (CLLMM) following system reconnection and flooding, showing stabilisation of exposed sulfidic material (PASS) and drop in the production of sulfuric material (AASS).



CLLMM Full Lakes Domain

Figure 40b: Spatially integrated output from the full lake system domain (CLLMM) following system reconnection and flooding, showing the acidity stores in the unsaturated and saturated zone, and process controlling mobilisation.



CLLMM Full Lakes Domain

Figure 40: Spatially integrated output from the full lake system domain (CLLMM) following system reconnection and flooding, showing the baseflow acidity flux rate, the in-soil neutralisation of acidity by sulfate reduction in the groundwater, and the rewetting flux and in-lake alkalinity flux.

Future Scenario Risk Assessment

Scenario definition

The major scenarios being considered were prepared in order to attempt to answer the following questions:

- If further water level drawdown occurred during 2009-2010, would the risks and area of acidification have been worse?
- Over what time-scales does the 'biogeochemical recovery' occur in the lakes? That is, under continued high flow scenarios, do the acid impacts previously experienced remediate? And if so, over what time-scale?
- Should a further cycle of rapid drawdown continue, will we observe a repeat of the acidification occurrences, or are the sulfides potentially depleted following the previous cycle to limit future acid potential in the exposed sediment?

To answer these questions fully is difficult given that we only have a single 'snapshot' of soil sulfidic material (as conducted by Fitzpatrick et al., 2010 and used as the model initial condition) in high resolution across the lakes, and it is unclear how this has evolved since then. New monitoring by CSIRO has updated measurements of soil geochemistry parameters for 57 sites and CSIRO has conducted analysis of how these have changed, however further analysis and more detailed interpretation of this data is necessary for comparison of the acid sulfate soil module.

Here three main scenario simulations have been run:

1. Long-term average flow conditions (i.e. maintained water level), equivalent to an ongoing commitment of ~900GL/yr flow past Wellington.
2. A new 3yr drawdown cycle with reduced sediment sulfides (PASS) based on the assumption of removal of sulfide material previously oxidized by the end of the CLLMM run that completed in May 2011. The flow was set at 696GL @ SA border (~300GL at Wellington) and an assumed water level starting condition of 0.5m AHD was used. This simulation was termed "Depleted".
3. As above, but with the original Fitzpatrick et al. (2010) PASS and ANC concentration maps, assuming that any acidity lost from the profile during the previous 2 years has re-accumulated by processes such as sulfate reduction following inundation in 2010-2011. This simulation was termed "Regenerated".

Comparison of the latter two is expected to explore the range of uncertainty in soil sulfide and acidity profiles, with the latter regenerated simulation serving as the most conservative estimate of potential acidity since it is unlikely sulfides would build up quick enough to exceed those originally measured by Fitzpatrick et al. (2010).

These scenarios are not based on actual forecast estimates of flow and climatic conditions for the region and are purely hypothetical for the purposes of understanding how the system would respond under potential future drought conditions. Meteorological data used for these scenarios was 2009 data repeated year-on-year for the 3 year simulation period.

Water quality under continued allocation flow conditions

Water quality conditions under average flow conditions were conducted and show continuation of conditions that are currently observed during 2011. The high flows dominate the lake water quality properties and they become similar to those observed in the main river channel which were prescribed in the inflow. Therefore, no further plots or discussion are included here, however, of interest to the recovery of the lakes is the flushing of salts from Lake Albert through the Narrung Narrows. This was relatively low despite higher water levels, and model predictions run for two years only showed a 60% dilution of salinity over this time.

Risk of Acid Sulfate Soil impacts during renewed drawdown cycle

Scenarios were run with low flow inputs to the lakes for both the “depleted” and “regenerated” sulfide concentrations in the surface sediment. These scenarios began from Aug 2011 conditions forward for 3 years and were characterised by a general decline in water level from 0.5m up to -1.0m AHD (Figure 41). Over this period Lake Alexandrina dropped to a minimum of around -1.0mAHD which is higher than the threshold level of acidification of ~ -1.5mAHD previously reported, and this scenario therefore doesn't have such a rapid rate of decline as in earlier analyses. Nonetheless, within 1 year Boggy Lake and Loveday Bay and Currency Creek were predicted to be dry, and within 2 years, Lake Albert had dried out. Since this is a hypothetical scenario, these are indicative drawdown rates for the purposes of assessing potential risk, and also it is important to note that a single water level may not accurately portray risk due to the link between dynamic patterns of rainfall and antecedent conditions that may influence the acidity generation and delivery.

The pH for the main locations are shown in Figure 42, and highlight the predicted acidification of areas in

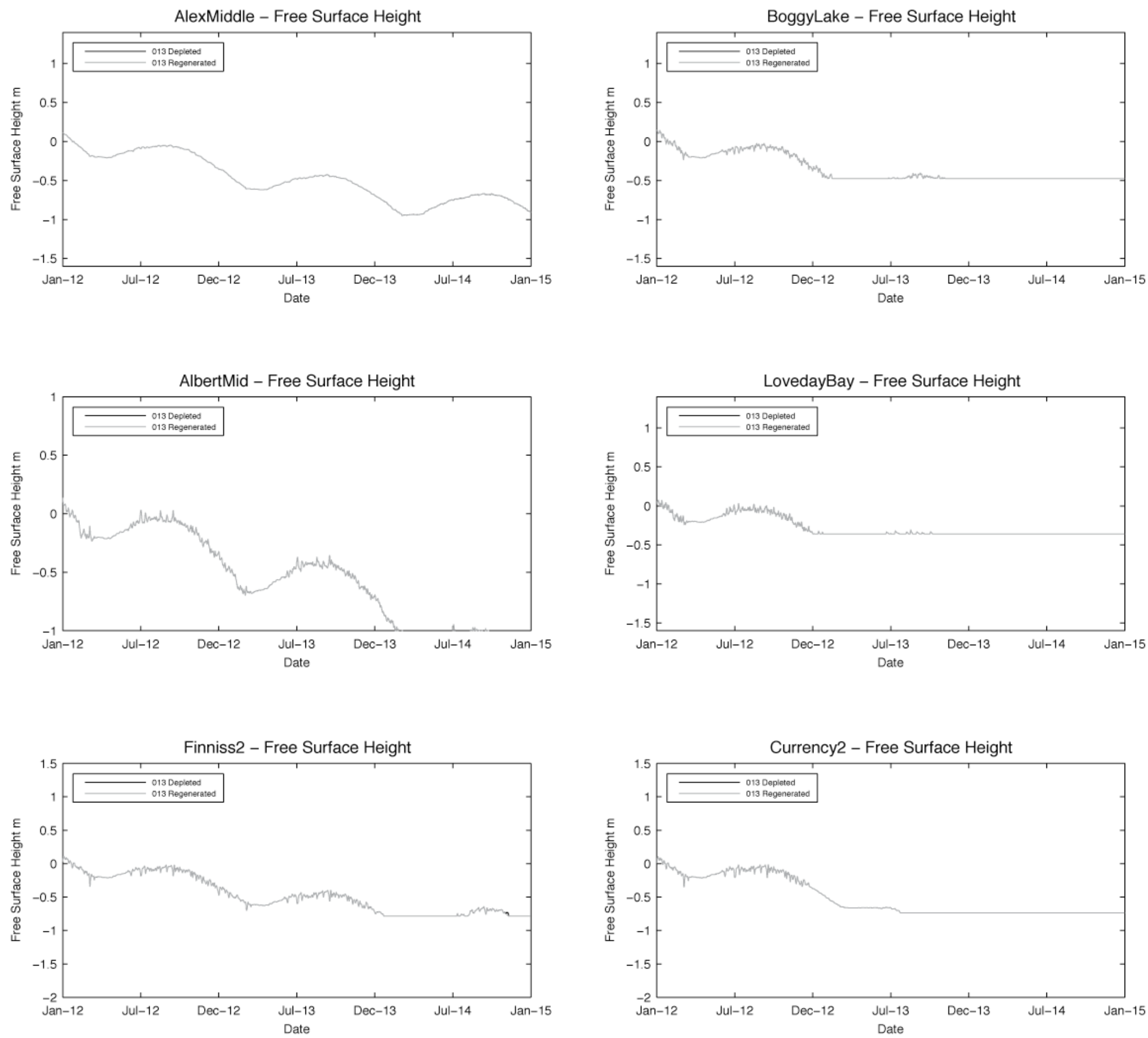


Figure 41: Predictions of water level from selected locations for the main areas of interest for the forward forecast period.

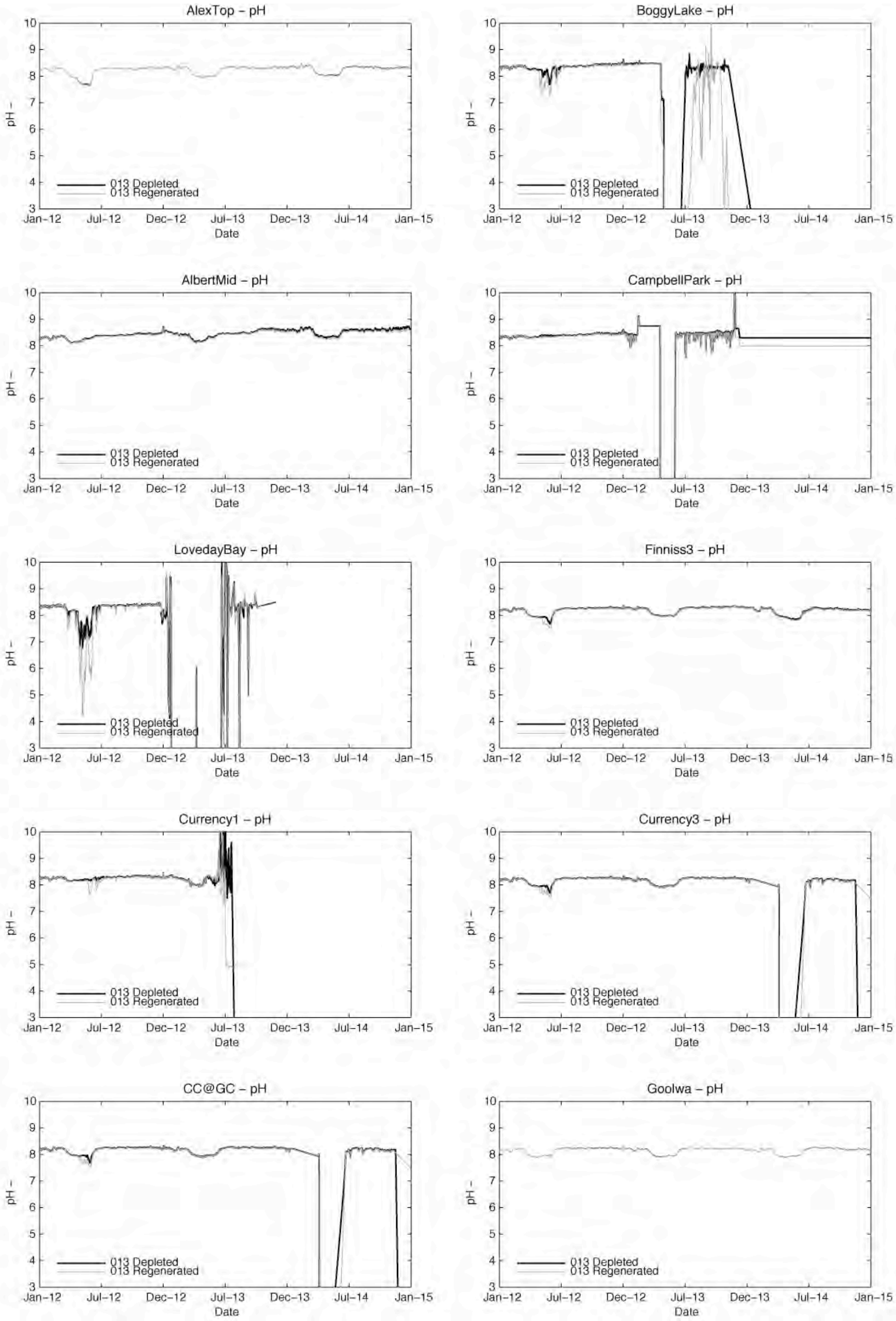


Figure 42: Predictions of pH from selected locations for the main areas of interest for the 3-yr forward forecast period.

the main body and periphery of the lakes. The spatial pattern of areas subject to acidification is similar to that observed historically, with areas of Boggy Lake, Currency Creek and Loveday Bay experiencing acidification, mainly occurring during the wetter months. Areas in the main body of Lake Alexandrina and around Goolwa maintain a stable pH, except for a pulse of acidification in the 3rd year when the acidified Currency Creek tributary pool is flushed into the upstream Goolwa channel region. Somewhat unexpectedly, the model predicts the reduced pool in Lake Albert to maintain a neutral pH, despite peripheral areas such as Campbell Park becoming acidic during the first large rains of the 2nd year, and a large build up of the ASS leachate tracer in the remaining water (not shown). This is in contrast to the earlier analysis where acidification in Lake Albert was particularly severe in the Lake Albert pool once it dropped below -1.0m.

There is a mostly similar response in the surface water pH between the sulfide content scenarios, though there is a notable delay in the timing of periods when the acidification occurs under the "depleted" scenario compared to the "regenerated" scenario. However, overall there is only one area (Loveday Bay) of the sites shown here that shows an acidification event below pH 6.5 in the "regenerated" scenario that was not seen in the "depleted" simulation.

The similarity between the simulations therefore indicates that the water level targets and drawdown scenario analysis conducted previously (Hipsey et al. 2011; BMTWBM 2010) remains valid for most of the selected locations. In those reports more detailed drawdown scenarios identified that water levels below -0.5mAHD could lead to acidification of perimeter areas, water levels below -1.0mAHD would lead to potential acidification of Lake Albert and water levels below -1.5m would potentially lead to large scale acidification, potentially even including large sections of Lake Alexandrina. Whilst numerous updates to the model simulation have been implemented in this report, the main spatial distribution of soil hydrological and geochemical properties remain unchanged, and the acid sulfate soil model parameters have also been unchanged from the earlier analysis (see parameter summary in Appendix C). Since the manifestation of acidification impacts is relatively insensitive to differences between the "depleted" and "regenerated" soil sulfide concentrations, and that the model configuration and parameters are unchanged, it therefore

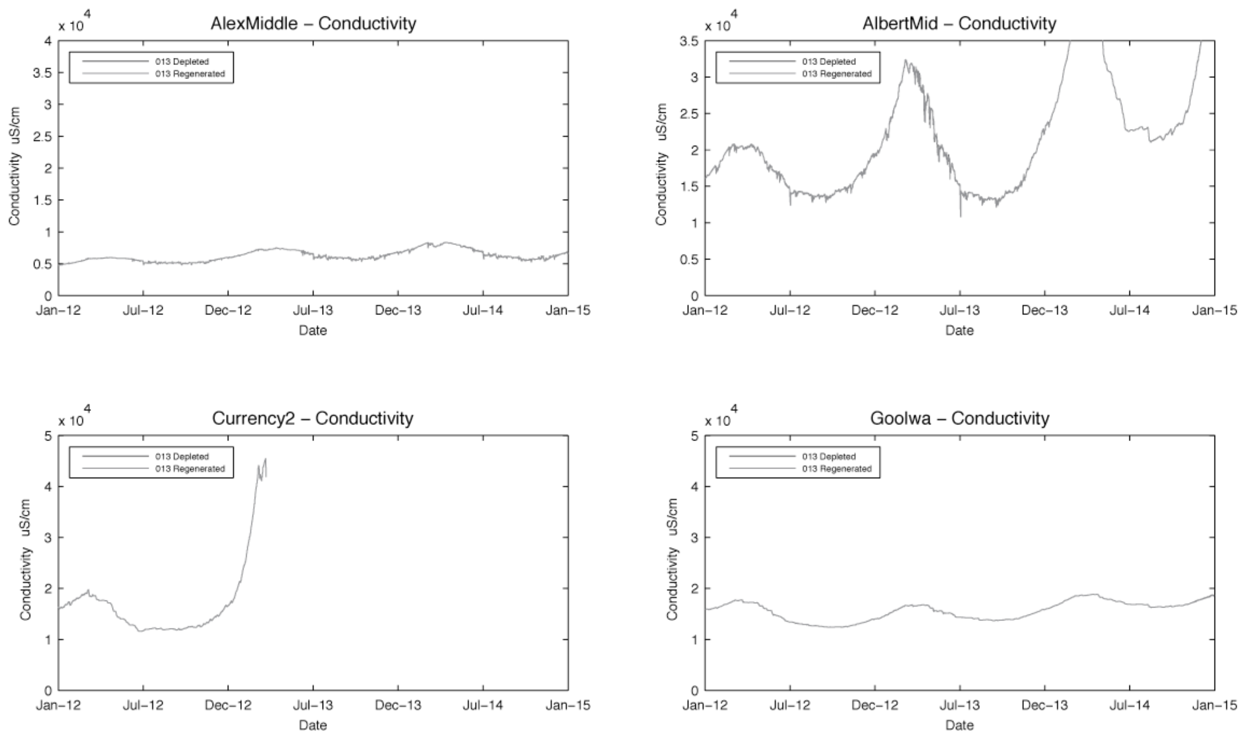


Figure 43: Predictions of EC from selected locations for the main areas of interest for the 3-yr forward forecast period.

follows that management policies related to water level maintenance and provision of environmental flows implemented in light of the earlier predictions remains relevant under future prolonged low flow periods.

The importance of maintaining lake level conditions is not solely to reduce acidification impacts on the ecosystem, but also due to large increases in salinity, nutrients and turbidity, as a response to the lakes having a reduced volume. In these scenarios, the salinity over this period increased displaying a seasonal pattern of concentration and dilution (Figure 43). For most parameters an increase in concentration commensurate with the reduced water level occurred (refer to the complete set of water quality plots on the provided web link to view other attributes). In Lake Albert and Currency Creek, rapid rises in salinity, similar to that observed throughout 2009-2010, are also likely to have a significant impact on water quality and ecosystem health.

Conclusions & Recommendations

The Lower Lakes hydro-geochemical model presented here allows for the simulation of a wide range of lake water quality parameters as impacted by a spatially resolved acid sulfate soil model, which is active in the dry cells of the numerical domain. The report has updated the simulation domains and compiled all water quality data for the region from 2008 to April 2011 for detailed testing against the model simulations. This has included testing the model against acidification events that occurred in Currency Creek, Loveday Bay and Boggy Lake, in addition to simulating the recovery dynamics during the period of flooding that occurred in 2010-2011. The model was then used to understand the level of risk of acid sulfate soils to the lake ecosystem should the system enter a new cycle of water level drawdown. The model and field data validation process has also been semi-automated and setup for transfer to relevant stakeholders.

Validation summary

- Data was collated from DFW, EPA and other sources for >300 sites to provide a comprehensive synthesis of observed water quality behaviour for the purposes of model validation.
- Various model grids were applied to Lake Alexandrina and Lake Albert and validated against a large range of water quality variables for the period for 2008-2011, including:
    - PO_4, NO_3, NH_4, TN, TP, Chl-a, TSS, pH, alkalinity, Ca, Na, SO_4, Mg, Cl, Al, Fe
- In particular, the model was assessed and it accurately predicted:
    - The autumn/winter 2009 acidification event in the disconnected pools of the Currency Creek tributary region, and the subsequent water quality recovery following refill.
    - The acidification of Loveday Bay, preliminarily in 2009 and then during filling of the pools in 2010.
    - The acidification of Boggy Lake in the north-east area of Lake Alexandrina during the autumn/winter period of 2010.
    - The stability of pH in Lake Albert and other areas in Lake Alexandrina.
- The alkalinity is much better predicted than in previous reports and it generally performs well, except during periods of high evapo-concentration in both Lake Albert and Alexandrina. The model predictions of alkalinity evolution in the Currency Creek tributary following installation of the regulator are also over-predicted, suggesting continued acid loading over and above that predicted by the model.
- In general the model over-predicts the degree and severity of acidification, however the timing and spatial extent of the predictions reflect the patterns seen in the data.
- The model captures the large increase in Al that occurs following acidification
- The analysis has been developed using parameters almost identical to those reported earlier (Hipsey et al., 2011) – therefore the present report supports the earlier predictions for threshold trigger levels reported therein, bearing in mind the abovementioned points.
- Other water quality variables including dissolved oxygen, nutrients, total chlorophyll-a and turbidity are all also simulated well, however both turbidity and Chl-a are highly variable and reflect the importance of resuspension on the particulate variables.
- Validation of the Coorong was started however due to the focus on the lake response to drying and recovery, detailed reporting of the model performance in the Coorong is left to a future study.

Management implications

- The model is used to demonstrate the large spatial variability in the manifestations of acid sulfate soils, and the potential for 'hotspot' locations that require priority management.
- Key dynamics show that the dominant flux of the acidity occurs following pulses of rain that collect acidity from surficial regions of the exposed sediment and drive lateral flow to the lake edge.

Acidification of groundwater and subsequent baseflow to the lake was a much less significant delivery mechanism, and in this case the diffusive flux of acidity following re-flooding was also low on average.

- The model simulations highlight the importance of flushing and dilution in preventing lessening the impacts of acid sulfate soils around the perimeter of the lake. Boggy Lake was however connected to the main lake and still experienced acidification, but the very large expanse of predicted sediments that were able to quickly convert potential acidity to actual acidity in this region highlighted this as a particularly problematic region.
- Continued pumping to maintain Lake Albert water levels during the drought served to prevent potentially large areas of acidification, however it did place increasing pressure on Lake Alexandrina perimeter areas.
- The predictions suggest that a substantial portion of stored acidity was released from sediments of the Currency Creek tributary and Boggy Lake region during the recent drought cycle, however, forecast simulations run with both 'depleted' and 'regenerated' sediment potential acidity demonstrated that a renewed cycle of water level decline would still lead to a notable acidification risk.
- In particular, re-acidification of areas like Boggy Lake and Loveday Bay was likely to occur again in the future as water levels decline to below -0.75m AHD, and the risk of other areas being affected exists as water levels approached or exceed -1.0mAHD. Although new 'trigger-level' scenario simulations were not conducted here, the fact that parameters used in this analysis remain mostly unchanged from the previous assessment suggests that the reported risks of large-scale acidification are still valid. Therefore, it is highly recommended that water levels below -1.5m and -1.0mAHD in Alex and Albert respectively should be avoided and that prolonged periods below -1.0mAHD would still constitute a ecological risk and would lead to perimeter acidification events as seen in 2009 and 2010.
- Whilst we were not able to quantify the precise effect of limestone addition in Currency Creek for the purposes of raising alkalinity, it is logical from this analysis that it was an effective approach since it was targeting alkalinity addition into the surface flow pathways that were driving acidity loading to the lake. Further, the re-formation of the pool behind the Currency Regulator contributed to isolating the acidified material and potential downstream delivery of poor quality water to the main reach of Goolwa Channel, as evidenced by the model predictions of the ASS contaminant build up.
- The validated model has also been used to estimate the range of time-frames for large-scale lake acidification through forecast scenarios, in order to allow for planning mitigation strategies and to highlight targeted areas for further field and laboratory research to help reduce model uncertainty.
- Future drawdown of the lake with historical or "depleted" concentrations of sediment sulfides both indicated a continued risk of lake acidification and the potential for contaminant release. The predictions in terms of the timing and location were identical in the simulations suggesting that the large reservoir of acidity that is not mobilised is able to be drive acidification under future drought conditions.
- Therefore, it is recommended that low lake levels should be avoided to prevent degradation of the exposed soil, water quality, and the associated habitat, and that environmental flow allocation must consider the potential for acidification during drought conditions, and not simply treat acid sulfate soils as a "once-off" risk. In addition to acidity and associated contaminants, the rising salinity levels at low lake levels are also evident and above levels that can cause significant mortality to benthic communities as has been documented in other studies. Therefore, allocation of water to the lakes to maintain above the critically low levels seen in 2009-2010 is recommended to prevent further degradation of the lake ecosystem.

Further work

The following items of work relate to further understanding the process of acidification and the associated risks and/or relate to improving the model capacity for simulating acid sulfate soils:

- Analysis of change in soil chemical parameters (in particular PASS, TAA and ANC) from the original survey with more recent analyses and associated comparison with predicted acidity declines / changes. This in particular should be used to understand the level of depletion of sulfides following oxidation in key sites, and the potential for (relatively) rapid reformation of new sulfides following recovery and re-inundation. This information will allow:
    i. Validation of the predicted level of depletion of sulfides and thus the oxidation efficiency – to date the validation has been on the manifestation of acid sulfate soils and this step would allow more rigorous assessment of the soil module.
    ii. Improved confidence in specifying the starting condition for a renewed drawdown cycle, and therefore less uncertainty in predictions used to set future minimum water level targets.

- The predictions of lateral water level flow across a range of soil types should be further investigated to:
    i. Better understand soil textural and hydraulic parameters for key hot-spot areas including Currency Creek, Finniss River, Boggy Lake, Dog Lake, Narrung Narrow and Loveday Bay, plus others deemed to be of substantial risk of acidification.
    ii. Further understand the threshold rainfall values that lead to significant interflow, surface ponding and overland flow processes, and how they differ between sites

- Develop and incorporate an improved conceptual model for SO_4 reduction and alkalinity generation processes, and assess the role of heterogeneous organic matter content on the potential for acidity neutralisation.
- Understanding the geochemical controls on alkalinity to unravel the reasons for the over-prediction in alkalinity in the lakes when solubility control with calcite is configured.

The following items of work relate to further understanding the more general biogeochemical and water quality processes, including:

- The dynamics of resuspension in shaping particulate nutrient and metal concentrations. It is clear from the turbidity, Chlorophyll-a and particulate Al and Fe that wind-induced resuspension shapes the variability in these species.
- PO_4 adsorption – this was included here using assumed partitioning coefficients for the adsorption process, however further laboratory or field work to allow the characterisation of the partitioning dynamics under different water conditions would enable better understanding on the availability of phosphorus.
- Determination of phytoplankton functional groups through more detailed analysis of the observed species across the lake system, as important drivers of sedimented organic matter.
- Improved spatial heterogeneity in the inundated sediment biogeochemical reactions to account for variability in organic matter content and oxygen, nutrient and metal flux rates.

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Appendix A: Monitoring Stations Summary

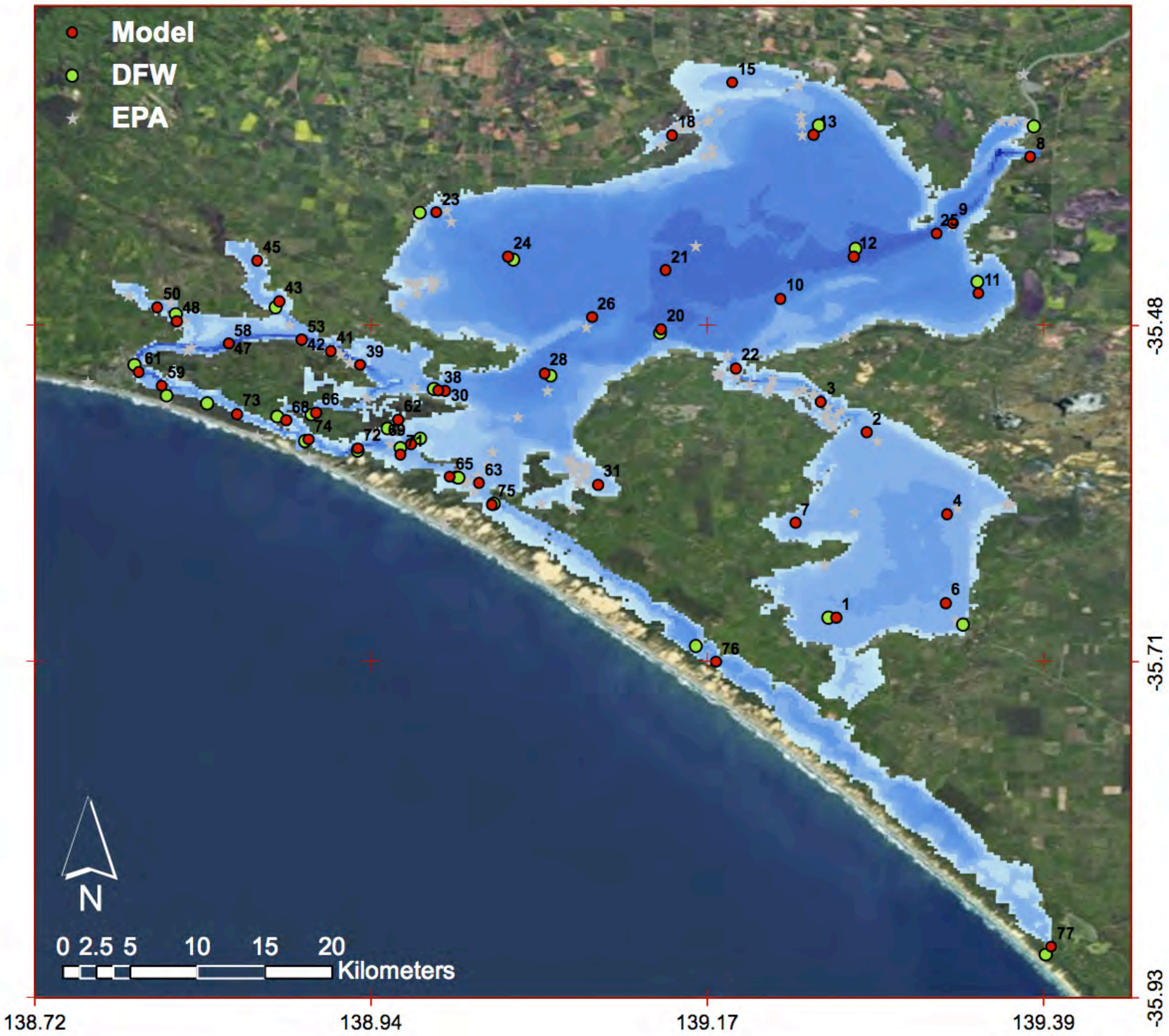

Figure A1: Major output analysis stations outlining where reporting and analysis are presented (needs updating)

Table A1: Major output analysis stations outlining the station name and ID, the relevant DFW monitoring site, and relevant EPA data station names. Stations with a common PlottingID are combined for the purposes of plotting and validation, and also supplemented where relevant with data from Table A2 (below) that have an identical PlottingID.

Name	Station ID	Plotting ID	Region	*DFW Site ID*	*DFW Station Name*	*EPA WQ Title*
AlbertSW	1	1	Albert	A4261155	2km N Warringee Point	*Lake Albert - South West*
AlbertEntrance	2	2	Albert	*None*	*None*	Lake Albert - Opening
AlbertNarrung	3	3	Albert	*None*	*None*	Lake Albert - Narrung
AlbertMid	4	4	Albert	*None*	near Waltowa Swamp	Lake Albert - Water Level Recorder
AlbertMid	5	4	Albert	A4261153	*None*	Lake Albert - Waltowa WT2 - pore

Meningie	6	6	Albert	A4260630	Meningie Sailing Club Jetty	Lake Albert - Meningie
CampbellPark	7	7	Albert	None	*None*	Lake Albert - Campbell Park
Wellington	8	8	Alex	A4261159	2km DS Wellington Ferry	Lake Alexandrina: Wellington
AlexOpening	9	9	Alex	*None*	*None*	Lake Alexandrina: Opening
Poltalloch	10	10	Alex	*None*	None	Lake Alexandrina: Poltalloch
PoltallochPlains	11	11	Alex	A4260575	Poltalloch Plains	None
Pomanda	12	12	Alex	A4261158	4km W Pomanda Point	*None*
AlexTop	13	13	Alex	A4260574	near Mulgundawa	Lake Alexandrina @ Mulgundawa Recorder
AlexTop	14	13	Alex	None	None	Lake Alexandrina: Top
McHughes	15	15	Alex	None	*None*	Lake Alexandrina - McHughes Bay 1
BoggyLake	16	16	Alex	None	None	Lake Alexandrina - Boggy Lake 6
BoggyLake	17	16	Alex	None	None	Lake Alexandrina - Boggy Lake 7
DogLake	18	18	Alex	None	*None*	Lake Alexandrina - Dog Lake 7
EckartsRd	19	19	Alex	None	*None*	Lake Alexandrina - Eckerts Road
Beacon90	20	20	Alex	A4261133	Beacon 90 - offshore Raukkan	*None*
AlexMiddle	21	21	Alex	*None*	*None*	Lake Alexandrina: Middle
AlexNarrung	22	22	Alex	*None*	*None*	Lake Alexandrina: Narrung
MilangJetty	23	23	Alex	A4260524	Milang Jetty	None
SEMilang	24	24	Alex	A4261157	7km SE Milang	Lake Alexandrina: Milang
Beacon94	25	25	Alex	*None*	*None*	*None*
Sturt	26	26	Alex	*None*	*None*	Lake Alexandrina: off Point Sturt
Point-S	27	27	Alex	*None*	*None*	*None*
PointMcLeay	28	28	Alex	A4261156	3km W Point McLeay	Lake Alexandrina: Off Point McLeay
ReedyPoint	29	29	Albert	*None*	*None*	Lake Albert - Reedy Point 5
RatIsland	30	30	Alex	*None*	*None*	Lake Alexandrina: off Rat Island
LovedayBay	31	31	Alex	*None*	*None*	Loveday Bay - LB1
LovedayBay	32	31	Alex	*None*	*None*	Loveday Bay - LB12
LovedayBay	33	31	Alex	*None*	*None*	Loveday Bay - LB5
LovedayBay	34	31	Alex	*None*	*None*	Loveday Bay - LB5
LovedayBay	35	31	Alex	*None*	*None*	Loveday Bay - LB6
LovedayBay	36	31	Alex	*None*	*None*	Loveday Bay - Salt Lagoon - SL4
LovedayBay	37	31	Alex	*None*	*None*	Loveday Bay - Salt Lagoon - SL5
Beacon75	38	38	Alex	A4261129	Beacon 75 - 500m South Stony Point	Lake Alexandrina: Islands
ClaytonEast	39	39	Currency	*None*	*None*	Lake Alexandrina: Clayton (east of regulator)
ClaytonEast	40	39	Currency	*None*	*None*	*Clayton2*
Clayton	41	41	Currency	A4261124	West Clayton - Beacon 65	Clayton 1
Finniss3	42	42	Currency	*None*	*None*	Lake Alexandrina: Finniss 3
Finniss2	43	43	Currency	A4261202	Lower Finniss River	Lake Alexandrina: Finniss 2
Finniss2	44	43	Currency	*None*	*None*	FR-DS3
Finniss1	45	45	Currency	*None*	*None*	Lake Alexandrina: Finniss 1
Finniss1	46	45	Currency	*None*	*None*	FR-DS2
Currency3	47	47	Currency	*None*	*None*	Lake Alexandrina: Currency 3
Currency2	48	48	Currency	A4261203	Lower Currency Ck	Lake Alexandrina: Currency 2
Currency2	49	48	Currency	*None*	*None*	DS4
Currency1	50	50	Currency	*None*	*None*	Lake Alexandrina: Currency 1
Currency1	51	50	Currency	*None*	*None*	DS3
Clayton3A	52	52	Currency	*None*	*None*	Clayton3A
FR@GC	53	53	Currency	*None*	*None*	FR@GC
FRWL2	54	54	Currency	*None*	*None*	FR-WL2
CCUS1	55	55	Currency	*None*	*None*	CC-US1
CC291	56	56	Currency	*None*	*None*	CC-291
CCDS7	57	57	Currency	*None*	*None*	CC-DS7
CC@GC	58	58	Currency	*None*	*None*	CC@GC
Goolwa	59	59	Currency	A4261034	Goolwa Barrage US	Lake Alexandrina: Goolwa Barrage (Upstream)
Beacon20	60	59	Currency	A4261122	Goolwa Barrage - Beacon 20	None
Beacon23	61	61	Currency	A4261123	DS Hindmarsh Bridge - Beacon 23	Goolwa Bridge
USBoundaryCreek	62	62	Alex	A4261205	US Boundary Ck EC	Tauwitchere - Boundary Creek North

Tauwitchere	63	63	Alex	A4260527	Tauwitchere Barrage US	Tauwitchere - Barrage (Upstream)
Tauwitchere	64	63	Alex	A4261207	US Tauwitchere Bg EC	None
TauwitcherieBarrageDS	65	65	Mouth	A4261048	Tauwitchere Barrage DS	None
MundooBarrageUS	66	66	Alex	A4261042	Mundoo Barrage US	Tauwitchere - Mundoo Channel North
USMundooBgEC	67	67	Alex	A4261204	Us Mundoo Bg EC	None
MundooBoatRamp	68	68	Mouth	A4261128	Mundoo Boat Ramp	None
USEweIslandEC	69	69	Alex	A4261206	US Ewe Isl Bg EC	None
EweIslandBarrageUS	70	69	Alex	A4261047	US Ewe Isl Bg EC	None
EweIslandBarrageDS	71	71	Mouth	A4261046	Ewe Island Barrage DS	None
Beacon1	72	72	Mouth	A4261043	Beacon 1 - near Ewe Island	None
Beacon17	73	73	Mouth	A4261036	Beacon 17 - adjacent Reedy Island	None
BarkerKnoll	74	74	Mouth	A4261039	Adjacent Barker Knoll	None
Beacon19	75	75	Coorong	A4261134	Beacon 19 - Pelican Point	None
LongPoint	76	76	Coorong	A4261135	Long Point	None
ParnkaPoint	77	77	Coorong	A4260633	Parnka Point	None

Table A2: Supplementary output stations in EPA data, outlining linking to major stations in Table A1 for plotting and validation purposes.

Station ID	**Main Station to Link to for Plotting**	**Region**	**EPA Station Name**
78	58	Currency	CC-Opening
79	57	Currency	CC-Regulator
80	56	Currency	CC-US of Narrows
81	55	Currency	CCUS1
82	41	Currency	Clayton 1
83	41	Currency	Clayton 3A
84	41	Currency	Clayton 3B
85	41	Currency	Clayton 3C
86	86	Mouth	Coorong - Boundary Creek 1
87	87	Mouth	Coorong - Boundary Creek 2
88	88	Mouth	Coorong - Boundary Creek 3
89	89	Mouth	Coorong - Coorong Channel 1
90	90	Mouth	Coorong - Coorong Channel 2
91	91	Mouth	Coorong - Ewe Island 1
92	71	Mouth	Coorong - Ewe Island barrage
93	65	Coorong	Coorong - Tauwitchere 1
94	65	Coorong	Coorong - Tauwitchere 2
95	95	Currency	Currency Ck CC-292
96	96	Currency	Currency Ck CC-DS5
97	97	Currency	Currency Ck CC-DS6
98	98	Currency	Currency Ck DS1
99	99	Currency	Currency Ck DS2
100	48	Currency	Currency Ck DS4@TP surface water.
101	58	Currency	Currency Ck - CC@GC
102	102	Currency	Dunns Lagoon - DL Jetty
103	103	Currency	Dunns Lagoon - DL1 Kayak
104	104	Currency	Dunns Lagoon - DL10 Kayak
105	105	Currency	Dunns Lagoon - DL2 Kayak
106	106	Currency	Dunns Lagoon - DL3 Kayak
107	107	Currency	Dunns Lagoon - DL4 Kayak
108	108	Currency	Dunns Lagoon - DL6 Kayak
109	109	Currency	Dunns Lagoon - DL7 Kayak
110	110	Currency	Dunns Lagoon - DL8 Kayak
111	111	Currency	Dunns Lagoon - DL9 Kayak

112	112	Currency	Dunns Lagoon - DLT10
113	113	Currency	Dunns Lagoon - DLT3
114	114	Currency	Dunns Lagoon - DLT7
115	115	Currency	EPA - ad hoc sampling
116	54	Currency	FR-DS of WL
117	117	Currency	FRUS1
118	118	Currency	Finniss River FR-DS1
119	119	Currency	Finniss River: Wallys Landing (FR-WL)
120	61	Currency	GC Channel
121	41	Currency	GC@CB
122	122	Alex	Hindmarsh Island - Boggy Creek 1
123	123	Alex	Hindmarsh Island - Boggy Creek 2
124	124	Alex	Hindmarsh Island - Boggy Creek 3
125	125	Alex	Hindmarsh Island - Boggy Creek 4
126	126	Alex	Hindmarsh Island - Boggy Creek 5
127	127	Alex	Hindmarsh Island - Boggy Creek 6
128	128	Alex	Hindmarsh Island - Boggy Creek 7
129	129	Alex	Hindmarsh Island - Estick Creek 1
130	130	Alex	Hindmarsh Island - Estick Creek 2
131	131	Alex	Hindmarsh Island - Estick Creek 3
132	132	Alex	Hindmarsh Island - Estick Creek 4
133	133	Alex	Hindmarsh Island - Estick Creek 5
134	134	Alex	Hindmarsh Island - Hunters Creek 1
135	135	Alex	Hindmarsh Island - Hunters Creek 2
136	136	Alex	Hindmarsh Island - Hunters Creek 3
137	137	Alex	Hindmarsh Island - Hunters Creek 4
138	138	Alex	Hindmarsh Island - Hunters Creek 5
139	139	Alex	Hindmarsh Island - Hunters Creek 6
140	140	Alex	Hindmarsh Island - Mundoo Channel 1
141	141	Alex	Hindmarsh Island - Mundoo Channel 2
142	142	Albert	Lake Albert - Bascombe Bay 1
143	143	Albert	Lake Albert - Bascombe Bay 2
144	144	Albert	Lake Albert - Bascombe Bay 3
145	145	Albert	Lake Albert - Bascombe Bay 4
146	146	Albert	Lake Albert - Bascombe Bay 5
147	147	Albert	Lake Albert - Bascombe Bay 6
148	148	Albert	Lake Albert - Bascombe Bay 7
149	149	Albert	Lake Albert - Bascombe Bay 8
150	7	Albert	Lake Albert - Campbell park (site 2)
151	151	Albert	Lake Albert - Granite 2
152	152	Albert	Lake Albert - Juron Swamp 1
153	153	Albert	Lake Albert - Juron Swamp 2
154	154	Albert	Lake Albert - Juron Swamp 3
155	155	Albert	Lake Albert - Juron Swamp 4
156	3	Albert	Lake Albert - Narrows 1
157	3	Albert	Lake Albert - Narrows 10
158	3	Albert	Lake Albert - Narrows 11
159	3	Albert	Lake Albert - Narrows 12
160	3	Albert	Lake Albert - Narrows 13
161	3	Albert	Lake Albert - Narrows 14
162	3	Albert	Lake Albert - Narrows 15
163	3	Albert	Lake Albert - Narrows 16
164	3	Albert	Lake Albert - Narrows 17
165	3	Albert	Lake Albert - Narrows 18
166	3	Albert	Lake Albert - Narrows 19
167	3	Albert	Lake Albert - Narrows 2
168	3	Albert	Lake Albert - Narrows 3
169	3	Albert	Lake Albert - Narrows 4
170	3	Albert	Lake Albert - Narrows 5
171	3	Albert	Lake Albert - Narrows 6
172	3	Albert	Lake Albert - Narrows 7
173	3	Albert	Lake Albert - Narrows 8
174	3	Albert	Lake Albert - Narrows 9

175	3	Albert	Lake Albert - Narrung Narrows Swamp 1
176	3	Albert	Lake Albert - Narrung Narrows Swamp 2
177	3	Albert	Lake Albert - Narrung Narrows Swamp 3
178	3	Albert	Lake Albert - Narrung Swamp 1
179	29	Albert	Lake Albert - Reedy Point 1
180	29	Albert	Lake Albert - Reedy Point 2
181	29	Albert	Lake Albert - Reedy Point 3
182	29	Albert	Lake Albert - Reedy Point 4
183	29	Albert	Lake Albert - Reedy Point 6
184	29	Albert	Lake Albert - Reedy Point 7
185	29	Albert	Lake Albert - Reedy Point A
186	29	Albert	Lake Albert - Reedy Point B
187	29	Albert	Lake Albert - Reedy Point C
188	29	Albert	Lake Albert - Reedy Point D
189	29	Albert	Lake Albert - Reedy Point E
190	29	Albert	Lake Albert - Reedy Point F
191	29	Albert	Lake Albert - Reedy Point G
192	29	Albert	Lake Albert - Reedy Point H
193	29	Albert	Lake Albert - Reedy Point I
194	29	Albert	Lake Albert - Reedy Point Pool
195	29	Albert	Lake Albert - Reedy Point South 1
196	29	Albert	Lake Albert - Reedy Point South 2
197	29	Albert	Lake Albert - Reedy Point South 3
198	29	Albert	Lake Albert - Reedy Point South 4
199	29	Albert	Lake Albert - Reedy Point South Scum
200	200	Albert	Lake Albert - Rumply Point
201	201	Albert	Lake Albert - Rumply Point North 1
202	202	Albert	Lake Albert - Rumply Point North 2
203	203	Albert	Lake Albert - Rumply Point North 3
204	204	Albert	Lake Albert - Rumply Point North A
205	205	Albert	Lake Albert - Rumply Point Pool
206	206	Albert	Lake Albert - Rumply Point Pool 1
207	207	Albert	Lake Albert - Rumply Point Pool 2
208	208	Albert	Lake Albert - Rumply Point South 1
209	209	Albert	Lake Albert - Rumply Point South 2
210	210	Albert	Lake Albert - Rumply Point South 3
211	211	Albert	Lake Albert - Rumply Point South West Pool 1
212	212	Albert	Lake Albert - Rumply Point South West Pool 2
213	213	Albert	Lake Albert - Rumply Point South West Pool 2 (A)
214	214	Albert	Lake Albert - Rumply Point South West Pool 2 (B)
215	215	Albert	Lake Albert - Rumply Point South West Pool 2 (C)
216	216	Albert	Lake Albert - Rumply Point South West Pool 2 (D)
217	217	Albert	Lake Albert - Teringie Swamp 1
218	4	Albert	Lake Albert - Waltowa
219	4	Albert	Lake Albert - Waltowa WT2 - pore
220	4	Albert	Lake Albert - Waltowa WT3 - pore
221	4	Albert	Lake Albert - Waltowa WT6 - pore
222	4	Albert	Lake Albert - Waltowa 2
223	223	Albert	Lake Albert - Waringie Point
224	224	Albert	Lake Albert: golf course irrigation pipe tap.
225	50	Currency	Lake Alexandrina - Archive - Currency 1
226	48	Currency	Lake Alexandrina - Archive - Currency 2
227	227	Alex	Lake Alexandrina - Boggy Lake 1
228	228	Alex	Lake Alexandrina - Boggy Lake 10
229	229	Alex	Lake Alexandrina - Boggy Lake 11
230	230	Alex	Lake Alexandrina - Boggy Lake 12
231	231	Alex	Lake Alexandrina - Boggy Lake 13
232	232	Alex	Lake Alexandrina - Boggy Lake 14
233	233	Alex	Lake Alexandrina - Boggy Lake 15
234	234	Alex	Lake Alexandrina - Boggy Lake 16
235	235	Alex	Lake Alexandrina - Boggy Lake 17
236	236	Alex	Lake Alexandrina - Boggy Lake 18
237	237	Alex	Lake Alexandrina - Boggy Lake 19

238	238	Alex	Lake Alexandrina - Boggy Lake 2
239	239	Alex	Lake Alexandrina - Boggy Lake 20
240	240	Alex	Lake Alexandrina - Boggy Lake 21
241	241	Alex	Lake Alexandrina - Boggy Lake 22
242	242	Alex	Lake Alexandrina - Boggy Lake 23
243	243	Alex	Lake Alexandrina - Boggy Lake 24
244	244	Alex	Lake Alexandrina - Boggy Lake 25
245	245	Alex	Lake Alexandrina - Boggy Lake 26
246	246	Alex	Lake Alexandrina - Boggy Lake 27
247	247	Alex	Lake Alexandrina - Boggy Lake 28
248	248	Alex	Lake Alexandrina - Boggy Lake 29
249	249	Alex	Lake Alexandrina - Boggy Lake 3
250	250	Alex	Lake Alexandrina - Boggy Lake 30
251	251	Alex	Lake Alexandrina - Boggy Lake 31
252	252	Alex	Lake Alexandrina - Boggy Lake 32
253	253	Alex	Lake Alexandrina - Boggy Lake 33
254	254	Alex	Lake Alexandrina - Boggy Lake 34
255	255	Alex	Lake Alexandrina - Boggy Lake 35
256	256	Alex	Lake Alexandrina - Boggy Lake 36
257	257	Alex	Lake Alexandrina - Boggy Lake 37
258	258	Alex	Lake Alexandrina - Boggy Lake 38
259	259	Alex	Lake Alexandrina - Boggy Lake 39
260	260	Alex	Lake Alexandrina - Boggy Lake 4
261	261	Alex	Lake Alexandrina - Boggy Lake 40
262	262	Alex	Lake Alexandrina - Boggy Lake 41
263	263	Alex	Lake Alexandrina - Boggy Lake 42
264	264	Alex	Lake Alexandrina - Boggy Lake 43
265	265	Alex	Lake Alexandrina - Boggy Lake 44
266	266	Alex	Lake Alexandrina - Boggy Lake 45
267	267	Alex	Lake Alexandrina - Boggy Lake 46
268	268	Alex	Lake Alexandrina - Boggy Lake 5
269	269	Alex	Lake Alexandrina - Boggy Lake 6
270	270	Alex	Lake Alexandrina - Boggy Lake 7
271	271	Alex	Lake Alexandrina - Boggy Lake 8
272	272	Alex	Lake Alexandrina - Boggy Lake 9
273	18	Alex	Lake Alexandrina - Dog Lake 1
274	18	Alex	Lake Alexandrina - Dog Lake 10
275	18	Alex	Lake Alexandrina - Dog Lake 11
276	18	Alex	Lake Alexandrina - Dog Lake 1b
277	18	Alex	Lake Alexandrina - Dog Lake 2
278	18	Alex	Lake Alexandrina - Dog Lake 3
279	18	Alex	Lake Alexandrina - Dog Lake 4
280	18	Alex	Lake Alexandrina - Dog Lake 5
281	18	Alex	Lake Alexandrina - Dog Lake 6
282	18	Alex	Lake Alexandrina - Dog Lake 8
283	18	Alex	Lake Alexandrina - Dog Lake 9
284	15	Alex	Lake Alexandrina - McHughes Bay 2
285	15	Alex	Lake Alexandrina - McHughes Bay 3
286	15	Alex	Lake Alexandrina - McHughes Bay 4
287	287	Alex	Lake Alexandrina - Wellington Upstream
288	288	Alex	Lake Alexandrina: Beacon 19
289	289	Alex	Lake Alexandrina: Beacon 97
290	41	Alex	Lake Alexandrina: Clayton (west of regulator)
291	291	Alex	Lake Alexandrina: Ewe Island Barrage site 1
292	292	Alex	Lake Alexandrina: Ewe Island Barrage site 2
293	293	Alex	Lake Alexandrina: Ewe Island Barrage site 3
294	294	Mouth	Lake Alexandrina: Goolwa Barrage (Downstream)
295	295	Alex	Lake Alexandrina: Goolwa Barrage (Upstream)
296	24	Alex	Lake Alexandrina: Milang B
297	24	Alex	Lake Alexandrina: Milang D
298	26	Alex	Lake Alexandrina: Point Sturt 1
299	26	Alex	Lake Alexandrina: Point Sturt 2
300	26	Alex	Lake Alexandrina: Point Sturt 3

301	26	Alex	Lake Alexandrina: Point Sturt 4
302	26	Alex	Lake Alexandrina: Point Sturt 5
303	26	Alex	Lake Alexandrina: Point Sturt 6
304	26	Alex	Lake Alexandrina: Point Sturt 7
305	26	Alex	Lake Alexandrina: Point Sturt 8
306	10	Alex	Lake Alexandrina: Poltalloch 1A
307	10	Alex	Lake Alexandrina: Poltalloch 1C
308	10	Alex	Lake Alexandrina: Poltalloch 1E
309	63	Alex	Lake Alexandrina: Tauwitcherie Barrage site 1
310	63	Alex	Lake Alexandrina: Tauwitcherie Barrage site 2
311	63	Alex	Lake Alexandrina: Tauwitcherie Barrage site 3
312	63	Alex	Lake Alexandrina: Tauwitcherie Barrage site 4
313	13	Alex	Lake Alexandrina: Top A
314	13	Alex	Lake Alexandrina: Top E
315	13	Alex	Lake Alexandrina: Top G
316	56	Currency	Lake Alexandrina: Upper Currency
317	54	Currency	Lake Alexandrina: Upper Finniss
318	31	Alex	Loveday Bay - LA Nth
319	31	Alex	Loveday Bay - LA Sth
320	31	Alex	Loveday Bay - LB10
321	31	Alex	Loveday Bay - LB11
322	31	Alex	Loveday Bay - LB2
323	31	Alex	Loveday Bay - LB3
324	31	Alex	Loveday Bay - LB4
325	31	Alex	Loveday Bay - LB7
326	31	Alex	Loveday Bay - LB8
327	31	Alex	Loveday Bay - LB9
328	328	Alex	Loveday Bay - Salt Lagoon - SL1
329	329	Alex	Loveday Bay - Salt Lagoon - SL10
330	330	Alex	Loveday Bay - Salt Lagoon - SL11
331	331	Alex	Loveday Bay - Salt Lagoon - SL12
332	332	Alex	Loveday Bay - Salt Lagoon - SL13
333	333	Alex	Loveday Bay - Salt Lagoon - SL14
334	334	Alex	Loveday Bay - Salt Lagoon - SL15
335	335	Alex	Loveday Bay - Salt Lagoon - SL16
336	336	Alex	Loveday Bay - Salt Lagoon - SL17
337	337	Alex	Loveday Bay - Salt Lagoon - SL2
338	338	Alex	Loveday Bay - Salt Lagoon - SL3
339	339	Alex	Loveday Bay - Salt Lagoon - SL6
340	340	Alex	Loveday Bay - Salt Lagoon - SL7
341	341	Alex	Loveday Bay - Salt Lagoon - SL8
342	342	Alex	Loveday Bay - Salt Lagoon - SL9
343	74	Mouth	Murray Mouth
344	73	Mouth	Murray Mouth - Goolwa Beach 1
345	73	Mouth	Murray Mouth - Goolwa Beach 2
346	73	Mouth	Murray Mouth - Goolwa Beach 3
347	74	Mouth	Murray Mouth - S Ocean 1
348	74	Mouth	Murray Mouth - S Ocean 2
349	74	Mouth	Murray Mouth - S Ocean 3
350	72	Mouth	Murray Mouth - Young Husband 1
351	72	Mouth	Murray Mouth - Young Husband 2
352	72	Mouth	Murray Mouth - Young Husband 3
353	353	Albert	Rainwater - Yule Street, Meningie
354	62	Alex	Tauwitchere - Boundary Creek (upstream of barrage)
355	355	Alex	Tauwitchere - Barrage (East)
356	356	Alex	Tauwitchere - Bogon Island East
357	357	Alex	Tauwitchere - Long Island North
358	358	Alex	Tauwitchere - Mud Island 1
359	359	Alex	Tauwitchere - Mud Island 2

Appendix B: Monitoring Variables

Table B1: Available data from agencies for model specification and validation.

DFW	***EPA***					***SA Water***	
data.river murray	**Currency & Finniss**	**EPA Database (Summary)**		**EPA Database (Full)**		**WaterScope.mat**	
Variables	**Variables**	**Variables**	**Short Names**	**Variables**	**Short Names**	**Variables**	**Short Names**
Water level	Temp	Hydroxide		colour		x2methylisoborneolSPME	
EC	EC	TKN (as N)	TKN	conductivity (25C)	Conduct-ivity	AlgaeComment	
pH	ORP	alkalinity (as CaCO3)	Alkalinity	copper (soluble)		AlgaeTotal	
	DO	aluminium (soluble)	Al	copper (total)		AlkalinityasCalciumCarbonate	DIC
	Turb	aluminium (total)	TAl	dissolved oxygen	DO	AluminiumAcidSoluble	Al
	TDS	ammonia (as N)	NH4	dissolved solids		AluminiumTotal	Gibbsite
	Alkalinity	bicarbonate	HCO3	enterococci		AmoebaeTotal	
	Acidity	calcium (soluble)	Ca	enterococci presumptive		AntimonyTotal	
		carbonate	CO3	fluoride		ArsenicTotal	
		chloride	Cl	hardness (total as CaCO3)	CaCO3	BariumTotal	
		iron (soluble)	Fe	hydroxide		BerylliumTotal	
		iron (total)	TFe	ion balance		Bicarbonate	
		magnesium (soluble)	Mg	iron (soluble)	Fe	BlueGreenAlgaeComment	
		manganese (soluble)	Mn	iron (total)	TFe	BlueGreenAlgaeTotal	
		manganese (total)	TMn	lead (soluble)		BoronSoluble	
		nitrogen (total as N)	TN	lead (total)		Bromide	
		organic carbon (dissolved)	DOC	magnesium (soluble)		CadmiumTotal	
		organic carbon (total)	TOC	magnesium (total)	TMg	Calcium	Ca
		oxidised N (as N)	NO	magnesium hardness (as CaCO3)		CalciumHardnessasCaCO3	
		pH	pH	manganese (soluble)	Mn	CarbonDioxideFree	
		phosphorus (sol as P)	P	manganese (total)	TMn	Carbonate	
		phosphorus (total as P)	TP	nickel (soluble)		CarbonatehardnessasCaCO3	
		potassium (soluble)	K	nickel (total)		Cells_L	
		sodium (soluble)	Na	nitrate (as N)	N	Cells_ml	
		strontium (soluble)		nitrate (as NO3)	NO3	Chloride	Cl
		sulphate	SO4	nitrogen (total as N)	TN	ChloridesTotalasNaCl	
		sulphur - (total as S)		noncarbonate hardness (as CaCO3)		Chlorophylla	TCHLA
				organic carbon (dissolved)	DOC	Chlorophyllb	
				organic carbon (total)	TOC	Chlorophyllcomment	
				oxidised N (as N)	NO	ChromiumTotal	
				oxidised N (as NO3)	NO3	CobaltTotal	
				pH	pH	Coliforms	PATH1_V1
				phosphorus (sol as P)	P	ColiformsPresumptive	
				phosphorus (total as P)	TP	ColourTrue_456nm	
				potassium (soluble)		Conductivity	Conductivit y
				potassium (total)	TK	CopperSoluble	
				selenium (soluble)		CopperTotal	
				selenium (total)		CryptosporidiumConfirmed	PATH3_V1
				silica (reactive)	Si		

						CryptosporidiumPresumptive	
				silver (sol)		CryptosporidiumSpeciation	
				silver (total)		CryptosporidiumPositiveControl	
				sodium (soluble)		CyanideasCNTotal	
				sodium (total)	TNa	DissolvedOrganicCarbon	DOCL
				sodium adsorption ratio		DissolvedOxygen	DO
				sodium to total cations ratio		Dissolvedsolidsbycalculation	
				strontium (soluble)		E0x2Ecoli	
				sulphate	SO4	E0x2EcoliPresumptive	
				sulphur - (total as S)		EntericProtozoaSampleVolume	
				temperature		Fluoride	
				total dissolved solids (by EC)		GeosminSPME	
				turbidity	Turbidity	GiardiaConfirmed	
				vanadium (soluble)		GiardiaPresumptive	
				vanadium (total)		GiardiaPositiveControl	
				zinc (soluble)		Hydroxide	
				zinc (total)		Iodide	
				sulf-chlo-ratio		Ionbalance	FeII
				ALK:CL Ratio		IronSoluble	FeOH3A
						IronTotal	
						LangelierIndex	
						LeadTotal	
						Magnesium	Mg
						MagnesiumHardnessasCaCO3	
						ManganeseSoluble	MnII
						ManganeseTotal	Bernessite
						MercuryTotal	
						MolybdenumTotal	
						NaegleriaTotal	
						NickelTotal	
						NitrateNitriteasN	NO3
						NitrateNitriteasNO3	NO3_1
						NoncarbonatehardnessasCaCO3	
						PercentSampleProcessed	
						PhosphorusFilterableReactiveasP	PO4
						PhosphorusTotal	TP
						Potassium	K
						SeleniumTotal	
						SilicaReactive	SiO2
						SilverTotal	
						Sodium	Na
						SodiumAdsorptionRatioCalculation	
						Sodium_Totalcationsratio	
						Sulphate	SO4
						TKNasNitrogen	TKN
						Temperature	Temperature
						TextResult	

						TinTotal	
						TotalDissolvedSolids_byEC	
						TotalHardnessasCaCO3	
						Turbidity	Turbidity
						UraniumTotal	
						VanadiumTotal	
						ZincTotal	Zn
						pH	pH
						AlgaeComment	
						AlgaeTotal	
						AmmoniaasN	NH4
						BlueGreenAlgaeTotal	
						Cells_ml	
						Chlorophylla	TCHLA
						Chlorophyllb	
						Chlorophyllcomment	
						DissolvedOrganicCarbon	DOCL
						NitrateNitriteasN	NO3
						NitrateNitriteasNO3	NO3_1
						NitrateasNitrogen	
						NitriteasNitrogen	
						PhosphorusFilterableReactiveasP	FRP
						PhosphorusTotal	TP
						SilicaReactive	SiO2
						TKNasNitrogen	TKN

Appendix C: Model Configuration

Simulated variables

Table C1: Simulated variable list and descriptions.

Variable	Units	Common Name	Process Description
Physico-Chemical Variables			
T	°C	Temperature	Temperature supplied by hydrodynamic driver.
S	psu	Salinity	
EC	uS cm^{-1}	Electrical conductivity	
I	mE m^{-2} s^{-1}	Shortwave light intensity	Incident light, I_0, is attenuated as a function of depth
η_{PAR}	m^{-1}	PAR extinction coefficient	
SS_1	g m^{-3}	Inorganic suspended solids - small	Settling, resuspension
SS_2	g m^{-3}	Inorganic suspended solids – large	Settling, resuspension
CT	NTU	Turbidity	Derived from SS1+SS2 using empirical eq:
DO	g DO m^{-3}	Dissolved oxygen	Algal production/respiration, organic decomposition, nitrification, surface exchange, sediment oxygen demand
DOC	g C m^{-3}	Dissolved organic carbon	Mineralization, settling, algal mortality/excretion
POC	g C m^{-3}	Particulate organic carbon	Mineralization, settling, algal mortality/excretion
FRP	g P m^{-3}	Filterable reactive phosphorus	Algal uptake, organic mineralization, sediment flux
DOP	g P m^{-3}	Dissolved organic phosphorus	Mineralization, settling, algal mortality/excretion
POP	g P m^{-3}	Particulate organic phosphorus	Mineralization, settling, algal mortality/excretion
PIP	g P m^{-3}	Particulate inorganic phosphorus	Adsoprtion/desorption
TP	g P m^{-3}	Total Phosphorus	Sum of all P state variables
NH_4^+	g N m^{-3}	Ammonium	Algal uptake, nitrification, organic mineralization, sediment flux
NO_3^-	g N m^{-3}	Nitrate	Algal uptake, nitrification, denitrification, sediment flux
DON	g N m^{-3}	Dissolved organic nitrogen	Mineralization, settling, algal mortality/excretion
PON	g N m^{-3}	Particulate organic nitrogen	Mineralization, settling, algal mortality/excretion
TN	g N m^{-3}	Total Nitrogen	Sum of all N state variables
RSi	g Si m^{-3}	Reactive Silica	Algal uptake, sediment flux
Biological Variables			
a		Phytoplankton group index, a={D,G,B}	
N_A		Number of simulated phytoplankton	
A_D	g chla m^{-3}	Diatoms	Growth, respiration, mortality, excretion, settling, resuspension
A_G	g chla m^{-3}	Greens	Growth, respiration, mortality, excretion, settling, resuspension
A_B	g chla m^{-3}	Blue-Greens	Growth, respiration, mortality, excretion, settling, resuspension
IP_D	g P m^{-3}	Diatom Internal Phosphorus store	Growth, mortality, excretion, settling, resuspension
IP_G	g P m^{-3}	Greens Internal Phosphorus store	Growth, mortality, excretion, settling, resuspension
IP_B	g P m^{-3}	Blue-Greens Internal Phosphorus store	Growth, mortality, excretion, settling, resuspension
IN_D	g N m^{-3}	Diatoms Internal Nitrogen store	Growth, mortality, excretion, settling, resuspension
IN_G	g N m^{-3}	Greens Internal Nitrogen store	Growth, mortality, excretion, settling, resuspension
IN_B	g N m^{-3}	Blue-Greens Internal Nitrogen store	Growth, mortality, excretion, settling, resuspension
ISi_D	g Si m^{-3}	Diatoms Internal Silica store	Growth, mortality, excretion, settling, resuspension

Table C1 (continued)

Variable	Units	Common Name	Process Description
Lake Geochemical Variables			
DIC	g C m^{-3}	Dissolved inorganic carbon	Algal uptake, organic mineralization, sediment flux
pCO_2	atm	Partial pressure of CO_2	Calculated as a function of DIC from Henry's Law
SO_4	g SO_4 m^{-3}	Dissolved Sulfate	
FeII	g Fe m^{-3}	Dissolved Ferrous Iron	
FeIII	g Fe m^{-3}	Dissolved Ferric Iron	
$Fe(OH)_{3(s)}$	mol L^{-1}	Iron Hydroxide	
Na	g Na m^{-3}	Dissolved Sodium	
Cl	g Cl m^{-3}	Dissolved Chloride	
Ca	g Ca m^{-3}	Dissolved Calcium	
Calcite	mol L^{-1}	Calcite	
K	g K m^{-3}	Dissolved Potassium	
Mg	g Mg m^{-3}	Dissolved Magnesium	
MnII	g Mn m^{-3}	Dissolved Manganese (II)	
$MnO_{2(s)}$	mol L^{-1}		
Al	g Al m^{-3}		
$Al(OH)_{3(s)}$	mol L^{-1}		
pH	-	pH	
CHGBAL	meq	Charge Imbalance	Assumes electroneutrality
Soil Hydro-geochemical Model			
SUBSTRATE	-	Soil type: Clay/Sand etc	
SOILST	m	S_t: Soil water storage	Rainfall, evaporation, runoff, baseflow
PHREATIC	m	h_{sat}: Depth of Phreatic Surface	Evaporation, infiltration and percolation
UZMOIST	%w	ψ: Unsaturated Zone Moisture	Evaporation, infiltration and percolation
PASS	mol	χ : Potential Acid Sulfate Soil Material	Exposure and subsequent oxidation
ANC	mol	Acid Neutralising Capacity	Acidity consumption
UZAASS	mol	φ_{UZ} : Unsaturated Zone Available Acidity	Oxidation, percolation and consumption losses
SZAASS	mol	φ_{SZ} : Saturated Zone Available Acidity	Percolation, baseflow and consumption losses

Parameter justification

Table C2: Overview of acid sulfate soil model parameters and justifications

Parameter	Units	lower	mean	upper	Comments/References
REWETTING PARAMETERS					
Freshwater acidity flux 1st day following soil inundation – *SAND*, F_{1st}	mol H^+ m^{-2} day^{-1}	0.050	0.138	0.150	Hicks et al. (2009): 0.138 mol H^+ m^{-2} day^{-1} acidity flux during first ¼ of a day following inundation of mesocosm at Pt Sturt (min 0.129; max 0.147). EC =1.48 dS/m. Sullivan et al. (2010): Study of the 15 sites (including the Point Sturt South site) over the first 4 days of inundation with freshwater the first pulse mean acidity was 0.016 mol H^+ m^{-2} $day^{-,}$ (min -0.015 ; max 0.044 mol H^+ m^{-2} day). For this period the acidity flux was 0.027 mol H^+ m^{-2} day for the Pt Sturt site also examined by Hicks et al. (2009) and is comparable given that our 4 days inundation period is 16 times longer than their ¼ of a day measurement period.
Freshwater acidity flux 1st day following soil inundation – *CLAY*, F_{1st}	mol H^+ m^{-2} day^{-1}	0.159	0.161	0.163	Hicks et al. (2009): 0.161mol H^+ m^{-2} day^{-1} acidity flux during first ¼ of a day following inundation of mesocosm at Boggy Crk (min 0.159; max 0.163). EC =2.18 dS/m.
Acidity Flux after prolonged soil inundation (day 2-90) – *SAND*, F_{dif}	mol H^+ m^{-2} day^{-1}	0.002	0.007	0.010	Sullivan et al. (2010): -ve fluxes measured in lab for 13 sandy cores from Lower Lakes, implies 0.0 acidity flux (it was a positive alkalinity flux if we take into account sulfate reduction) Hicks et al. (2009): ~0.010 mol H^+ m^{-2} day^{-1} acidity flux during first ¼ of a day following inundation of mesocosm at Pt Sturt, corrected for evaporation and seepage. EC=0.81 dS/m day 5 to 2.2 dS/m day 85. 5–12 days: 0.011 (min 0.010; max 0.012) 5–85 days: 0.007 (min 0.006; max 0.008)
Acidity Flux after prolonged soil inundation (day 2-90) – *CLAY*, F_{dif}	mol H^+ m^{-2} day^{-1}	0.006	0.010	0.012	Hicks et al. (2009): ~ 0.010 mol H^+ m^{-2} day^{-1} acidity flux following initial inundation of mesocosm at Boggy Crk, corrected for evaporation and seepage. EC= 1.2 dS/m day 7 to 4.0 dS/m day 87. 7–14 days: 0.006 (min 0.006; max 0.006) 7–87 days: 0.010 (min 0.010; max 0.010)
RW dependence on salinity – *SAND*, k_{dif}	(mol H^+ m^{-2} day^{-1}) $35psu^{-1}$	0.001	0.006	0.011	Sullivan et al. (2010): 0.011 mol H^+ m^{-2} day^{-1} increase in acidity flux per unit psu increase in salinity averaged from 13 sediment columns from the Lower Lakes Hicks et al. (2009): 0.0011 mol H^+ m^{-2} day^{-1} increase in acidity flux per unit psu increase in salinity from mesocosms at Pt Sturt, based on comparison of fresh water flux rates (above) and seawater inundated experiments (EC=56.1 dS/m day 5 to 59.7 day 85): 5–12 days: 0.012 (min 0.009; max 0.015) 5–85 days: 0.007 (min 0.007; max 0.007)
RW dependence on Salinity	(mol H^+ m^{-2}	0.026	0.033	0.040	Hicks et al. (2009): 0.033 mol H^+ m^{-2} day^{-1}

– *CLAY*, k_{dif}	day^{-1}) 35psu^{-1}				increase in acidity flux with increase in salinity from mesocosms at Pt Sturt, based on comparison of fresh water flux rates (above) and seawater inundated experiments (day 7 EC=53.8 dS/m to 56.8 day 63): 7–14 days: 0.034 (min 0.027; max 0.041) 7–63 days: 0.014 (min 0.013; max 0.014)
PYRITE OXIDATION PARAMETERS					
Max Oxidation Rate – *SAND*, $R_{Ox}(\theta)$	day^{-1}	0.008	0.018	0.08	Ward et al. (2004a): 0.0086 day^{-1} ASS. Not fully oxic, (gauze bag). Fully oxic examples were also provided in these papers. Borma et al. (2003): 0.0001 – 0.0024 day^{-1}, sediments, "crumbled" samples, layer <1cm. Di Nanno et al. (2007): 0.086 day^{-1}, sediments, with nutrients and microbial inoculation. Oxygen concentrations not measured, and samples high in organic matter. Morse (1991): 0.086 & 0.0017 day^{-1}, marine sediments, initial (<10d) & later rate , oxic (but no details), oxidation in seawater. Initial rate due to v. fine particles (<0.3 um). Hollings et al. (2001): Laboratory measurement of oxidation rate via data-logged O_2 sensor fitted inside test chamber (O_2 consumption assumed to be entirely attributable to sulfide oxidation). Earth Systems (2010): 1.8 wt% FeS_2 day^{-1}, estimated by oxygen consumption rate in soil with varying moisture.
Max Oxidation Rate – *CLAY*, $R_{Ox}(\theta)$	day^{-1}		0.006		Ward et al. (2004b): 0.0017 day^{-1} ASS. Not fully oxygenated, light clay, 40 um thick plastic bag Fully oxic examples were also provided in these papers. Rigby et al. (2006): 0.017 day^{-1}, Oxygen limitation in at least one of the experiments Earth Systems (2010): 0.6 wt% FeS_2 day^{-1}, estimated by oxygen consumption rate in soil with varying moisture.
Ox dependence on Moisture – *SAND*, $R_{Ox}(\theta)$	-		*poly-nomial*		Earth Systems (2010): change in oxygen consumption rate in sand per fractional decrease in % moisture generated the following relationship: y = -9.7011x^3 + 2.1949x^2 + 0.0025x + 0.0006 (R^2 = 0.8409, n=8), where y = wt% FeS_2 day^{-1} and x = gravimetric moisture content (wt%). Above x=23% y=0. Hollings et al. (2001): similar relationship between moisture and oxidation rate as Taylor for waste rock piles
Ox dependence on Moisture – *CLAY*, $R_{Ox}(\theta)$	-		*poly-nomial*		Earth Systems (2010): change in oxygen consumption rate in sand per fractional decrease in % moisture generated the following relationship: y = -0.0142x + 0.0068 (R^2 = 0.4022, n=5) where y = wt% FeS_2 day^{-1} and x = gravimetric moisture content (wt%). Above x=48% y=0.

					Below 23% y = 0.0142x is assumed.
$FeS_2:H^+$ stoichiometry	-	3	4	4	Related to completeness of pyrite oxidation reaction (4 implies complete oxidation; less implies acidity storage in intermediate minerals such as jarosite, etc,). Almost complete oxidation is modelled as phases such as schwertmmanite indicate 7/8 of the acidity has already been generated and released from this secondary assemblage, and jarosite only permits temporary storage and cannot buffer acidity. Also, montmorillonite can buffer acidity, but rates will be very slow.
SOIL ACIDITY NEUTRALISATION & ALKALINITY PRODUCTION					
Acid Neutralising Capacity (ANC) rate coefficient, $R_{neut}(ANC)$	day^{-1}	0	2.74 $x10^{-4}$	5.48 $x10^{-4}$	Assumes ANC is not immediately available and follows a first order kinetic consumption rate. Mean number provided is equivalent to 10 wt% of available ANC consumed per year. The upper limit is based on experience from Currency Creek – i.e. no more than 20 wt % per year could have been used during this event based on mass balance calculations.
Saturated Zone soil acidity consumption rate, R_{SO4}	day^{-1}	0	0.005	0.02	Sullivan et al. (2010)
Mobilisable acid fraction, f_{mob}	-	0.4	0.5	0.75	Estimated based on indicative porewater solution analysis using PHREEQC
LAKE SEDIMENT ALKALINITY PRODUCTION					
Max alkalinity production (eg. SO_4 reduction) @ 20C of inundated sediment, F_{SO4}	mol H^+ m^{-2} day^{-1}	0.002	0.005	0.008	Koschorreck & Tittel (2007): Eutrophic lake ~6.85 mmol H^+ m^{-2} day^{-1}; oligotrophic lake ~1.06 mmol H^+ m^{-2} day^{-1} Sullivan et al. (2010): ~ -5.0 mmol H^+ m^{-2} day^{-1} noted in sand cores inundated for 35 days with fresh water implying net alkalinity generation due to process such as SO_4 reduction.
Half-saturation constant for effect of SO_4 limitation on sediment alkalinity production, K_{SO4}	mM		1.60		Boudreau & Westrich (1984): Marine sediments reported to have K_{SO4} of ~ 1.6mM
SOIL HYDROLOGICAL PARAMETERS					
SAND average depth to clay layer, $Z_{c,s}$	m		1.50		Earth Systems (2010): Albert = 1.1m max and Alexandrina = ~ 2.0m max. Also data in Hicks et al. (2009) Also data in Fitzpatrick et al. (2009)
CLAY nominal depth, Z_f	m		1.50		Assumed
Porosity – *SAND*, ϕ_s	-		0.42		Earth Systems (2010): 0.40 - 0.48 Hicks et al. (2009): 0.422 – surficial sediment (0-20cm) at Pt Sturt (medium sand)
Porosity – *CLAY*, ϕ_f	-		0.60		Hicks et al. (2009): 0.49-0.67 – surficial sediment (0-20cm) at Boggy Creek (sandy clay)
Evaporation extinction depth	m	0.30	0.40	0.55	Cook and Rassam (2002): Numerical estimate of depth where evaporation is uninhibited

– *SAND*, h_{ep}					from the free value (H_a) as 0.3-0.55m for sandy loam dependent on evaporation intensity. Here a slightly higher value is assumed since evaporation continues below H_a, just at a reduced rate.
Evaporation extinction depth – *CLAY*, h_{ep}	m	0.15	0.2	0.3	Cook and Rassam (2002): Numerical estimate of depth where evaporation is uninhibited from the free value (H_a) as 0.1-0.35m for clay dependent on evaporation intensity. Here a slightly higher value is assumed since evaporation continues below H_a, just at a reduced rate.
Field capacity – *SAND*, θ_{fc}	v%		0.15		15% volumetric water content typical field capacity for sands after 1 day free drainage
Field capacity – *CLAY*, θ_{fc}	v%		0.40		40% volumetric water content typical field capacity for clays after 1 day free drainage
Baseflow a coefficient – *SAND*, α_{ss}	day^{-1}		0.005		0.5% of full soil storage above lake level discharged per day (reduced as a function of S_b/S_{max} using B parameter) Farmer et al (2003): Used values of 0.03 – 0.003 for similar capacitance model approach Section 4.3: 0.003 day^{-1} based on HYDRUS-2D cross-sectional numerical model output analysis
Baseflow a coefficient – *CLAY*, α_{ss}	day^{-1}		5.00×10^{-4}		Assumed to be very low for poorly conductive clays
Baseflow B coefficient – *SAND*, β_{ss}	-	1.0	2.0	3.0	Farmer et al (2003): Recession curve analysis of ~30 catchments reported to give typical value of 2.0. Section 4.3: ~1.0 based on HYDRUS-2D cross-sectional numerical model output analysis (Figure 4.8)
Baseflow B coefficient – *CLAY*, β_{ss}	-		3.0		Assumed, as above.
Head threshold, ε	m		0.1		Head difference between soil groundwater and lake level that must be exceeded before flow occurs ~0.1 based on HYDRUS-2D cross-sectional numerical model output analysis (Figure 4.8)
Bulk density – *SAND*, ρ_s	kg m^{-3}		1530	1750	Hicks et al. (2009): 1.53 t m^{-3} – surficial sediment (0-20cm) at Pt Sturt (medium sand)
Bulk density – *SAND*, ρ_s	kg m^{-3}		1230	1600	Hicks et al. (2009): 0.88-1.35 t m^{-3} – surficial sediment (0-20cm) at Boggy Creek (sandy clay)

Appendix D: Model Operation

Connections between model domains

The current analysis has required the connection of numerous model domains, and comparison of each with a large quantity of data collected by numerous agencies. New data processing scripts and model input and output processing scripts have been developed to facilitate the coupling of models and comparison of model outputs against field data.

Model connections include:

- AA domain -> ANC initial conditions
- AA domain -> CCO Clayton (East) open boundary condition
- CCO -> CCC initial condition
- CCC / ANC / LA -> CLLMM initial condition

Data processing & validation plotting scripts

The Lower Lakes MATLAB plotting routine is designed to provide the user with a simplified method to validate multiple modal domains against temporal and spatially variable validation data. This is accomplished through a series of pre-processing functions designed to integrate data collected by external agencies with a standard AED data model.

The final routine allows the user to plot numerous model NETCDF output across a preset range of domains, matching the model output locations to any available field data. In conjunction to a simple matching algorithm, the set-up of the routine allows for the specification of "groups" of spatially similar field sites.

Figure D1: Spatial grouping of EPA data sites with a single model output point

Below is a simplified flowchart of the MATLAB routine, highlighting the basic design and construction. Each user specified NETCDF model output is imported and geo-referenced, as is any external validation data. Data is then standardized into a common structure, as well as any unit conversions that may be required.

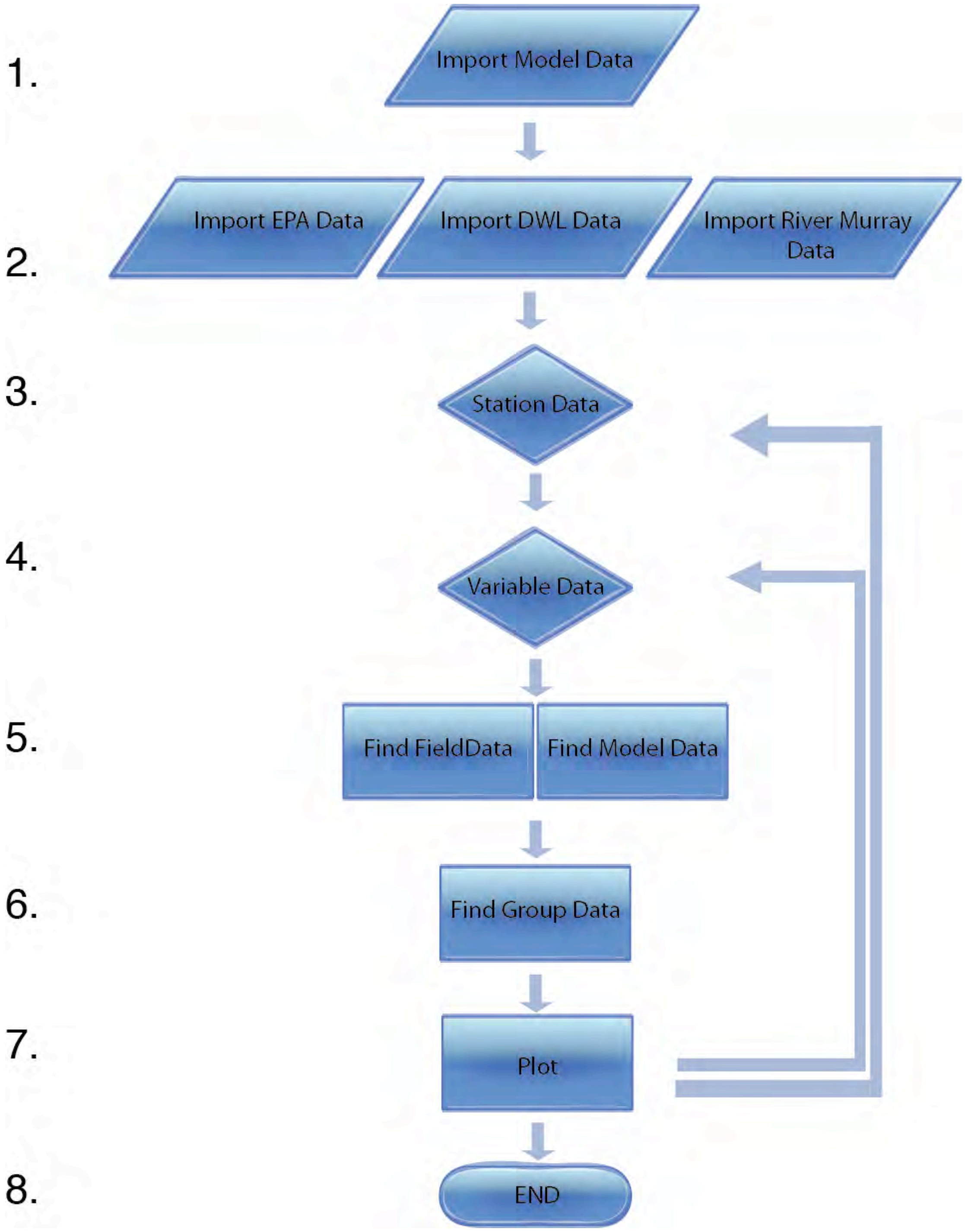

Figure D2: Simplified flowchart of the Lower Lakes MATLAB routine.

Initial Configuration

Initial configuration of the system is carried out using a combination of .xls, .csv and MATLAB .m files. This design was chosen to allow users with little to no programming experience to utilize the data visualization tools MATLAB provides, whilst not sacrificing the simplicity of data manipulation within modern office suites (Microsoft Office, Open Office etc.).

The configuration will be described within the context of the following categories:

- **Location**
- **Variables**
- **Models**
- **Visualisation**

The directory structure has been created to segregate the configuration of the system from the MATLAB function. With the exception of the main runtime .xls sheet, all of the configuration files can be found within the "configuration" directory.

Location

The set-up of the spatial data required is conducted though the following files:

- */gis/reference.xls*
- */plot/sitelist.xls*
- */site/"project"/site.xls*

The most complex of these is the site.xls file. This file contains configuration details for each site data site, as well as matching information to both geographically similar locations. For each site that is to be plotted, the following information must be configured:

- **ID** – Unique identifier for each site
- **Group ID** – Matches to ID to allow for multiple sites plotted on the one graph.
- **Short Name** – A generic name for each site.
- **Agency Names**: To allow for as little pre-processing of validation data, each site is given an identifier, which matches the name used by the agency responsible for the data collection.
- **Datablock** – Each Grid is given a unique name (cllamm, aa, cc etc.) that is used to throughout the configuration. This section matches the order of the ELCD curtain output with its corresponding location information.

The */plot/sitelist.xls* file is simply a list of ID numbers which will be plotted. The user can choose how many sites will be plotted in a single run.

The */gis/reference.xls* file contains the geo-spatial information for each ELCD model domain. The plotting routine uses UTM as it's projection system, and the reference file contains this information. Configuration of this file requires the X, Y and UTM Zone of the top left cell of each ELCD bathymetry.

Variables

The variable information is configured via:

- */variable/variablenames.xls*
- */variable/variablelist.xls*

Like the *site.xls* configuration file, the *variablenames.xls* contains all of the information required to match variables across different model platforms and sampling programs.

- **Variable** – This column contains the standard variable name used through out the model code.
- **Title** – Descriptive string used to create a more readable plot title. This can potentially be any string or phrase the user desires.
- **Model Specific Name** – The specific string used to identify the data from various models. This field case specific and must match exactly the models naming convention.
- **Dependent** – ELCD specific name of a variable required for data conversion. For example, Conductivity is plotted, not Salinity, so Temperature is required for the conversion. "None" is used if no other data is required.
- **Units** – Units for each variable, which is used in the yLabel property of the Line plot. Some LaTeX symbols can be used (e.g. \muS/cm).

- **Legend** – The MATLAB abbreviation for where on the Line plot the legend will appear (e.g. NW refers to the North West corner of the figure).

The other variable configuration file is the companion to the sitelist file, called *variablelist.xls*. This file contains a list of variable names (matching the Variable column in the *variablenames.xls* file) that the user wishes to be plotted. There is also a field that contains the exact name of any alternative colormap that should be used instead of the MATLAB default "Jet". This functionality is very limited at the moment; however, it is possible to integrate many of the third party produced colormaps, with only a small amount of code changes.

Models

Model configuration is very minimal, with only the server information and bathymetry rotation information required by the user. Server configuration is finalized through two files, the */project/paths.xls* and */server/server.xls* sheets. As the routine is constructed to be exist on multiple platforms, it is required to specify the location of the model data using different file path conventions. Each file path is configured in three parts, the **"Initial Path" / "Project Directory / Final Folder".** The */server/server.xls* file contains the Initial Path for each operating system that will be used. The headers is broken up into *Windows, Apple and Linux* , However, it is not necessary to configure all three if one will not be using that platform. The script itself determines which platform the routine is running one, so this information only has to be configured once.

The routine is designed to work for multiple projects, so the folder structure of each project needs to be specified. The Project ID is a case specific name given to each project and is used throughout the plotting code. The path column is simply the root project directory, which will be joined to the server path (e.g. "*Z://*" from the server file is joined to "*RiverMurray/LowDO/*" from the paths file to give the exact location of the model directory.

Visualisation

The final configuration is conducted through the */plot/default.xls* file and the */runtime/RUNTIME.xls* file. MATLAB is extremely powerful in regards to the amount of control it gives the user to customize their visualizations. However, this leads to a degree of complexity that can be difficult for most users. As such, many of these properties have been extracted and placed in the defaults.xls file for ease of use. From this file, the following plot properties can be configured:

Table D1: Plotting options

Area	Name	Default
title	fontname	helvetica
title	fontsize	10
title	fontweight	bold
title	location	center
title	show	off
colorbar	fontname	helvetica
colorbar	fontsize	10
colorbar	fontweight	bold
colorbar	location	[0.12 0.12 0.02 0.3]
colorbar	fontside	right
xaxis	fontname	helvetica
xaxis	fontsize	6
xaxis	fontweight	bold
xaxis	alignment	bottom

xaxis	**colour**	**k**
yaxis	**fontname**	**helvetica**
yaxis	**fontsize**	**6**
yaxis	**fontweight**	**bold**
yaxis	**alignment**	**bottom**
yaxis	**colour**	**k**
datetick	**format**	**dd/mm/yyyy**
datestamp	**format**	**dd/mm/yyyy**
datestamp	**location**	**[0.2 0.15 0.2 0.2]**
lineplot	**height**	**8**
lineplot	**width**	**20**
sheet	**height**	**10**
sheet	**width**	**10**
lineplot	**smoothJoined**	**13**
lineplot	**smoothdefault**	**3**

The final configuration file is the */runtime/RUNTIME.xls* file. This provides the final model information, and is the file that, once the routine has been configured, will provide the engine that will tailor each plotting routine. The following properties need to be specified:

Generic Information

- **StartDate**: Start of the plotting loop for Sheets, and the XMIN value for line plots
- **EndDate**: End of sheet plotting, and XMAX value for the line plots
- **Plot Type**: Sheet or Line
- **Model Type**: Which model type is being run (ELCD, GETM)
- **Output Directory**: Main directory output will be saved to. It is referenced from the */Output* directory.
- **Process Validation**: As some external data processing can take time, this on/off flag allows the user to skip this set if it's unnecessary.

Sheet Information

- **NETCDF info**: 2D ELCD output, "surf "or "base". Used to create the filename when importing model data.
- **Plot Focus**: Grid ID of which grid the surface X and Y limits plot will be clipped to. This ID is also used to load the background image.
- **Background Type**: 'relief" or "sat". Relief or satellite image to be used as a background image. These files are PNG world files generated by ARCmap and located in */image/grid/*.
- **Show Plot**: 'on/off' flag on whether to display plot to screen during the routine.
- **Caxis Region**: As multiple grids can be plotted on the one surface plot, the user can specify which caxis info will be used (MATLAB only allows one colormap per plot). The caxis information is specified in the */variable/caxis.xls* file, which simply specifies the variable name, and each regions colour limits.
- **Plot Interval**: Integer value that specifies data points to skip during the plotting routine.

Line Information

- **Line Type**: "Joined" or "NotJoined". Given several grids were used during the Lower Lakes Project, the ability to have plots that were joined to create a seamless visual proved incredibly valuable. As such, this functionality has been included. If 'Joined" is selected, all of the models specified are interpolated, plotted, and given a single legend entry.
- **Validation**: Whether to plot any validation data that may correspond.
- **Site File**: Currently unused, however functionality to be added.
- **Show Plot**: 'on/off' flag on whether to display plot to screen during the routine.

Model Information

- **Project**: Name corresponds to the path.xls configuration
- **Server**: Server ID that matches the server.xls configuration.
- **Folder**: Top folder for the specific simulation.
- **Grid**: Matches the *reference.xls* / image files / *model.xls* / *site.xls* configurations
- **Colour**: RGB colour information for the line colour for each model.
- **Legend**: Legend string to use for each model.

Running the MATLAB Routine

The routine is started inside MATLAB by the command ***plotaed('RUNTIME.xls'),*** from within the */runtime/* directory. It is not necessary for the user to add any of the folders to the MATLAB path, as the function handle this automatically. However, there are some MATLAB pre-requisites required. These are:

- MATLAB 2010a or above: There are several features used within the routine that did not exist in prior versions. In addition, MATLAB changed their NETCDF functionality after 2009b, which allows for a simplified import routine.
- NETCDF installed: Although the routine contains all of the import functions required for MATLAB to access the NETCDF files created by the models, the initial installation of NETCDF functionality is not. Post version 2009b, the installation is simple, requiring the downloading of several free files and running a single script. For more information, please contact Brendan Busch at brendan.busch@uwa.edu.au.
- Office Software: Careful consideration has been taken to allow for full cross platform functionality, so Microsoft Office is not required to be installed, however an office suite is needed to open the .xls files. Both OpenOffice and LibreOffice can be used as an open source alternative of Microsoft Office.

Given that each office suite and platform have their own slight eccentricities that can affect the import routines, it is advisable to maintain the current .xls version each file is saved as. If there is any doubt, save files in Microsoft excel as '95 compatible. These files have the least amount of program specific data that may interfere with MATLAB.

Validation Data

Although data from external agencies can be imported and plotted against the model data, the configuration in not included in the standard .xls format, but require tailored MATLAB code. This is due to the variability of not only the file formats data is exchanged in, but also particular Units and Naming Conventions.

As such, the import and unit conversion is carried out by the main function, "*loadvalidationdata.m*", as well as the highly customised "*importEPA.m*" and "*importDWL.m*". The raw data itself is contained within the */data/* directory, and the processing functions in the */function/data/conversion/* and */function/data/import/* directories.

Finally, although the current policy is of having the external data being stored in sheets on the local machine, the routine has been implemented with database integration in mind. MATLAB has ODBC drivers natively installed, allowing for the import and conversion functions to be replaced by database queries. This will allow for a much simpler upgrade methodology for new laboratory and real-time data sources.

MATLAB Functions

Table D2: Summary of MATLAB data and model processing functions

Function Name	Description
createvariablelist.m	*Process All netcdf file to match variables*
importEPA.m	*Import EPA data from spreadsheet*
importdwl.m	*Import DWL data from spreadsheet*
loadvalidationdata.m	*Loads process validation data*
readconfvariablelist.m	*Import User List of Variables*
processDWL.m	*Part of DWL import routine*
processEPA.m	*Part of EPA import routine*
readconfgis.m	*Read Reference Information*
referencencfile.m	*Geo-reference NetCDF files*
convertNCdata.m	*Formats NetCDF data*
unitELCDConversion.m	*Converts ELCD units to standard*
buildfilepath.m	*Build path to file NetCDF file*
loadncfiles.m	*Load NetCDF file*
readconfmodel.m	*Read User Run Time file*
plotLineData.m	*Plots final Line Data*
plotimage1surf.m	*Used to add Background to sheet image*
readconfcaxis.m	*Read user specified Caxis Information*
readconfdefaults.m	*Read User specified plot defaults*
getmultiplesites.m	*Checks if other validation sites to be plotted*
plotsheetdata.m	*Plots final Sheet Data*
plotvalidationdata.m	*Plots external Validation data on line plot*
readconfpath.m	*Read paths information*
readconfserver.m	*Reads server information*
addpath_recurse.m	*Add path to MATLAB*
getpath.m	*Finds users computer paths*
readconfruntime.m	*Reads main runtime file*
readconfsite.m	*Reads Site information file*
readconfvariable.m	*Reads Variable Information File*