Science to inform operational decisions of major environmental infrastructure on the Chowilla Floodplain and other regulated floodplains in the SA River Murray:

Wallace, T.A., Furst, D., Upadhyay, S and Daly, R.

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Enquires should be addressed to: Goyder Institute for Water Research
Level 1, Torrens Building
220 Victoria Square, Adelaide, SA, 5000
tel: 08-8303 8952
e-mail: enquiries@goyderinstitute.org

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EXECUTIVE SUMMARY

GENERAL BACKGROUND

There is growing interest in the construction and operation of new, large infrastructure specifically designed, constructed and operated for environmental outcomes as a management tool (Windsor Report, 2011). However, there is considerable uncertainty in the ability of environmental water allocations to achieve balanced ecological outcomes when delivered to specific sites *via* constructed infrastructure rather than being delivered to interconnected ecosystems *via* landscape (river reach) scale releases. Potential challenges to achieving ecologically equivalent outcomes include, but are not limited to, (i) provision of cues to trigger biotic responses, (ii) facilitating lateral and longitudinal connectivity, (iii) provision of diverse hydraulic conditions, and (iv) maintenance of appropriate water quality.

Within South Australia, large infrastructure to deliver environmental water to floodplain assets has been constructed at Chowilla Floodplain *via* the Murray Darling Basin Authority's The Living Murray (TLM) program. Planning is proceeding for similar infrastructure to be constructed and operated on the Pike Floodplain and the Eckerts-Katarapko Floodplain *via* the South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP). The Chowilla floodplain is one of the MDBA Living Murray nominated Icon Sites in the Murray-Darling Basin Authority's *The Living Murray Program* (http://www.mdba.gov.au/what-we-do/working-with-others/ten-years-of-tlm-program). The Chowilla Environmental regulator and ancillary structures represent an investment of approximately $68 million in restoring the condition and ecological function of the Chowilla Floodplain. Over the last decade, the Department of Environment Water, and Natural Resources (DEWNR) has facilitated significant investment in assessment of risks and benefits associated with the operation of the Chowilla regulator and associated infrastructure and in the development of risk mitigation strategies. This work has been undertaken by multi-disciplinary teams of technical experts and the accumulated knowledge underpins the Chowilla Operations Plan (Wallace & Whittle, 2014c).

Initial testing operations of the Chowilla Environmental Regulator and ancillary structures will be heavily reliant on computer models and accumulated conceptual understanding of the impact the infrastructure will have on hydraulic conditions and water quality within the floodplain-anabranch complex. The consequences of these models providing incorrect information include potential exceedance of guideline values, (ANZECC, 2000), South Australian statutory limits (Government, 2003) and limits for water quality specified in the Basin Plan (Commonwealth of Australia, 2012) and create challenges at SA Water's water treatment plants located further downstream. More importantly, failing to manage the system in a manner that maintains appropriate water quality and habitat could be catastrophic for the organisms that the infrastructure aims to protect, and for community acceptance of large engineering solutions in the floodplain environments along the River Murray.

PROJECT PURPOSE

There is existing data on release of dissolved organic carbon (DOC) and changes in dissolved oxygen (DO) associated with ponded flooding (managed watering) of individual wetlands at Chowilla (Wallace, 2008; Wallace & Lenon, 2010), and data on hypoxic blackwater processes at upstream locations (e.g. Barmah Forest) where hypoxic blackwater events have occurred (Howitt *et al.*, 2007; Whitworth *et al.*, 2013). However, there is not adequate data relating changes in dissolved oxygen to changes in concentration and bioavailability of nutrients resulting from managed floodplain inundations under low flow conditions in the lower River Murray. Given the potential risk associated with hypoxic blackwater events, this is a critical knowledge gap for the delivery of environmental water via constructed infrastructure.

This project enabled use of the first testing event of the Chowilla Regulator and the associated ancillary structures in 2014 to (i) collect the field data required to validate the hydraulic model used in the development of the operations regimes; and (ii) assess some of key water quality hazards that had been identified in the Chowilla Operations Plan (Wallace & Whittle, 2014c). The knowledge gained in this project has application to directly influence operational rules and procedures used in decision making for delivery of environmental water to large floodplain assets *via* constructed infrastructure.

It is reasonable to anticipate a large degree of transferability of knowledge generated from studies at Chowilla to other sites that are planning the construction and use of similar infrastructure. It will be important to take advantage of the opportunity to transfer learning between sites for a range of scientific, ecological and economic reasons. Examples of benefits include (i) accelerated learning, (ii) improved predictions of outcomes under different conditions, (iii) enhanced capacity to test the ability of planned mitigation techniques to actually manage risks, (iv) avoid repeating negative outcomes, (v) being aware of and hence able to respond to previously unconsidered issues; and (vi) the inherent economic value in coordinated monitoring.

PROJECT SCOPE

The project is split into three primary tasks:

1. Assess changes in water quality associated with the operation of the Chowilla Regulator

2. Modify the existing Blackwater Risk Assessment Tool

3. Validate and recalibrate the 1D-2D Mike FLOOD hydrodynamic models that are used to predict water exchange and changes to hydraulic habitats on the floodplain.

Task 1 represents the majority of the workload undertaken directly by the project team, and represents the main body of this report. Task 2 involved (i) modification of the existing Blackwater Risk Assessment Tool (Whitworth *et al.*, 2013) to be appropriate for use at sites in South Australia, and (ii) assessing the utility of the modified model for predicting changes in water quality. Task 3 was funded and managed by DEWNR through the TLM program and represents a major in-kind contribution to the project.

The combined outcomes of the project contribute to identifying knowledge gaps in existing risk assessments, mitigation capability and refining the cumulative risk profiles for e-water delivery using floodplain infrastructure. In addition to the synthesis of the findings of the monitoring (the main report presented here) the lead author has participated in two reviews of the outcomes of the testing event that have been facilitated by DEWNR. Three presentations of the findings of the project have been made to date: (i) the Goyder Institute Annual Conference 2015 – Water Research Showcase (ii) the Chowilla Community Reference Committee; and (iii) the SARFIIP working group including representatives from DEWNR and MDBA.

RESULTS:

ORGANIC LOADING

Floodplain eucalypts, particularly river red gum and to a lesser extent black box generate a large standing biomass of leaf litter (Wallace, 2009) and represent a large source of allochthonous organic matter to floodplains and wetlands (Glazebrook & Robertson, 1999; Francis & Sheldon, 2002). Measurement of organic loading enables (i) generation of an estimate of the potential load of carbon and nutrients that could be released into the water column; and (ii) the potential impact on dissolved oxygen both in the impounded area and in the receiving waters. Natural Organic Matter (NOM) loading at the riparian tree line of permanent and temporary creeks, within temporary wetlands and on open (non-wooded) floodplain sites was highest and most variable (average = 2,087 ± 3,718 gm^{-2}) along the permanent creek lines.

In an estimate of the relative importance of flooding as a source of carbon to aquatic foodwebs, Robertson *et al*., (1999) calculated that with daily phytoplankton productivity of 0.6 $gCm^{-2}day^{-1}$, annual net production by riverine phytoplankton in a river reach 100 km long by 100 m wide, would be 2,190 tonnes of carbon. Gawne et al., (2007) used a lower estimate of phytoplankton productivity (0.28 $gCm^{-2}d^{-1}$) and estimated that the annual productivity within such a reach would be 1,022 tonnes of carbon. Robertson *et al*., (1999) calculated that a flood that inundated ca 44 km^2 would deliver as much DOC to the river as the net annual in-stream phytoplankton production in the 10 km^2 reach. Gawne *et al*., (2007) estimated that only 34 km^2 would need to be inundated. The area inundated during the 2014 testing event was estimated to be 23.02 km^2 (MDBA, 2015). Using data on NOM loading collected in this study and the data on nutrient release from floodplain plant material published by Brookes *et al*., (2007), we estimate that 603 tonnes of DOC would have been mobilised into the water column from the inundation of the floodplain. Based on this, 3901.6 ha would need to be inundated to produce the 1,022 tonnes of net annual in-stream phytoplankton production in the 10 km^2 reach estimated by Gawne et al., (2007). This area is well within the capacity of the maximum inundation extent achievable with the Chowilla Environmental Regulator; at QSA = 40,000 $MLday^{-1}$, the estimated inundation area is 7,060 ha. An estimate of the potential increase in biomass of higher order consumers resulting from the 2014 testing event indicates that approximately 600 kg of DOC may have been assimilated into higher trophic levels (e.g. fish).

Salinity impacts

Discharge of saline groundwater into the anabranch creek and the river following floods and high flows is a natural occurrence, but represents a hazard to surface water salinity that must be managed. However, during the 2014 test event, there were no exceedances of the Ecological Target for in-stream salinity; the daily data for salinity (measured as EC) recorded at the water quality station in the river downstream of Chowilla (Station A4260704) indicates that during the period 25th September 2014– 30th January 2015, peak EC was 276 μScm^{-1}, well below the EC target of 580 μScm^{-1}. The magnitude of increase above ambient EC (recorded upstream of Lock 6 at station A4261022) was small, peaking at 59 μScm^{-1} on the 2nd November 2014.

Turbidity and pH

The water quality parameters; pH, turbidity and chlorophyll *a* were measured *in-situ via* vertical profiles conducted at each sampling site at the time of collecting the water samples. There is some temporal variability in pH evident in the data. However, the values recorded remained within the range (6.5 – 9.0) specified in Schedule 2 of the Environment Protection (Water Quality) Policy (2003). The median value for turbidity recorded across the sampling period remained below the 50 NTU threshold specified in schedule 11 of the Basin Plan (Commonwealth of Australia, 2012) for the reference site upstream of Lock 6 (A4261022), all sites in the Lock 5 weir pool (A4260705, A4260704, A1, A4260703) and the anabranch (A4261107, A4261224).

Algal community

Chlorophyll *a* was typically higher in the anabranch (A4261224) compared to the upstream reference site (A4261022), particularly during the recession phase when concentrations were 2-3 μgL^{-1} higher in the anabranch. This indicates that conditions within the anabranch were amenable to supporting faster growth rates within the anabranch. The data for the receiving waters of the Lock 5 weir pool indicate that chlorophyll *a* was elevated in the river downstream of Chowilla. It is possible that the increased values observed are a result of phytoplankton growth resulting in an accumulation of biomass within the relatively slow flowing tail water section of the Lock 5 weir pool.

The data for chlorophyll *a* in Coppermine wetland and Werta Wert wetland demonstrate that there was an algal bloom in both of these wetlands. Key differences between the two wetlands include the species present, and that in Werta Wert wetland the high algal biomass appeared to "crash" in late November-early December, possibly as a result of exhaustion of the available pool of available phosphorus in this wetland. In contrast, in Coppermine wetland the bloom was sustained throughout the sampling period, and the pool of available phosphorus did not appear to be limiting. Coppermine wetland also sustained a large biomass of the emergent macrophyte Moira grass (also known as spiny mud grass) (*Pseudoraphis spinescens*) during the 2014 testing event. Wallace and Lenon (2010) also recorded high algal biomass in this wetland during a pumped and ponded managed inundation during late spring-summer (November 2009-February 2010). These observations demonstrate (i) that Coppermine wetland has a very high capacity to sustain plant productivity; and (ii) that the phytoplankton community in each of the large wetlands is likely to respond differently during managed inundations.

In the anabranch and receiving waters of the Lock 5 weir pool, the combined total concentration of geosmin+MIB were less than the SA Water River Murray Water Quality target (<10 ngL^{-1}) throughout the testing event. In addition, the concentration of iron (Fe) and manganese (Mn) was below the threshold limits specified in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) at all times.

Carbon and nutrients

The time series data for the concentration of total nitrogen (TN), total phosphorus (TP), oxidised nitrogen (NOx), ammonia (NH_3), filterable reactive phosphorus (FRP), dissolved organic carbon (DOC) and 5-day biochemical oxygen demand (BOD_5) demonstrate that the concentrations of these resources remained below the respective limits stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003).

A comparison of the results from the two reference sites; (i) upstream of Lock 6 (A4261022) and (ii) the Lock 5 weir pool upstream of Chowilla Creek (A4260705) reveals that there are significant differences in the concentration of resources between the two reference sites at varying times. This result is considered to be a result of a large proportion of flow to SA (QSA) being diverted through the anabranch, such that the reach between Lock 6 and the junction of Chowilla Creek experienced very low flows during the rising limb and peak of the hydrograph. Consequently, it is considered that A4261022 is considered to be a more reliable indicator of ambient water quality.

There were significant differences in the concentration of resources at the upstream reference site (A4261022) and the receiving waters in the Lock 5 weir pool (A4260704) at various dates during the testing event. Of the 28 significant differences in water quality detected over the 20 sampling periods, 18 of the significant differences occurred during the 5 sampling periods conducted between the 8th of October and the 4th November 2014, indicating that the largest influence of return flows from the anabranch to the river occurred during the rising limb and peak of the hydrograph. It is considered that the paucity of differences between A4261022 and A4260704 during the recession phase reflects the dilution being provided by an increasing proportion of QSA being delivered down the main channel during the recession and the progressive lowering of Lock 6 from the peak height required to achieve the inundation back to routine operation level (19.25 mAHD).

A comparison between the sites within the anabranch reveals that there was a higher frequency of significant differences between the most upstream site (A4260580) and the sites further downstream in the anabranch. This trend is potentially due to dilution of resources as a result of the substantial inflow into the anabranch *via* Pipeclay Creek, Slaney Creek (upstream of A4261107) and Boat Creek (upstream of A4261224) respectively. There are significant differences in the concentration of resources at various dates during the testing period between the reference site upstream of Lock 6 (A4261022) and the sites in the Lock 5 weir pool downstream of Chowilla including the site immediately downstream of the junction of Chowilla Creek (A4260704), the site in the mid-reach of the Lock 5 weir pool (A426A1) and the site in the lower-reach of the Lock 5 weir pool (A4260703). This indicates that return flows from the Chowilla Anabranch are influencing the abundance of resources to fuel primary productivity for at least 40 km downstream of the return flows.

DISSOLVED OXYGEN

The data demonstrate that ambient DO in the receiving water in the river channel downstream of the junction of Chowilla Creek and the river (station A4260704) was always above 8 mgO_2L^{-1} during the testing event. Therefore, it is considered that the management regime utilised in the testing event was successful in maintaining appropriate conditions within the Lock 5 weir pool.

Wallace (2008) utilised observed oxygen depletion rates recorded *in-situ* during ponded floods within managed wetlands at Chowilla Floodplain to calculate that with an expected oxygen depletion rate of 0.82 $mgO_2L^{-1}day^{-1}$, a daily exchange equivalent to 20% of the stored volume (replacement with fresh, oxygenated water from the creek/river) would be sufficient to ensure a low likelihood of dissolved oxygen in the impounded area falling below 6 mgO_2L^{-1}. Data from the telemetered monitoring stations within anabranch demonstrates that dissolved oxygen was always above 6 mgO_2L^{-1} at each of the anabranch sites. The minimum daily exchange for the total impounded volume was 19.8% on the 13th October. Apart from this single day, daily exchange for the total impounded volume was always >22%. It is considered that the maintenance of normoxic conditions (DO above 6 mgO_2L^{-1}) validates the 20% daily exchange rate as an operational limit offering a low likelihood of onset of hypoxia.

Within the permanent creeks, the greatest depletion in DO occurred at the most upstream site within the anabranch (A4260580). The data shows that in the anabranch upstream of Punkah Crossing (A4260580) between the 15th and 26th October, DO declined in a linear manner from approximately 9.6 to 6.6 mgO_2L^{-1}. (rate of loss = approximately -0.2 $mgO_2L^{-1}day^{-1}$). Although dissolved oxygen did not fall below the 6 mgO_2L^{-1} threshold, it is probable that dissolved oxygen would have fallen below the threshold at this site if any additional load of NOM was added to the system; i.e. if the inundated area was increased at this time, prior to a stabilisation in conditions. During the period between the 15th and 26th October average daily dilution for the total stored volume was 26% (range = 23-27%). However, the average daily exchange for the water upstream of A4260580 was 15.8% (std dev = ±0.86). Consequently, lower rates of daily exchange may have resulted in a more substantial and potentially problematic decline in dissolved oxygen.

It is considered likely that the difference in magnitude of oxygen depletion that is observed between A4260580 and the two sites that are further downstream in the anabranch (A4261107 and A4261224) is primarily in response to dilution upstream of A4261107 from riverine inflows *via* Pipeclay and Slaney Creeks, and additional dilution upstream of A4261224 due to riverine inflows *via* Boat Creek. Whilst the inflows provide much needed dilution and maintenance of diverse hydraulic conditions, the potential for even higher inflows into the middle of the anabranch system *via* Pipeclay Creek, Slaney Creek and Boat Creek to exacerbate conditions in the upper anabranch also needs some consideration during planning of future events; visual observations during the weekly sampling included comparatively low turbulence at the water surface and large accumulations of floating plants and organic debris in Punkah Creek upstream of the junction of Slaney Creek. This indicates that during periods of high inflows, the driving head and discharge through Slaney Creek, Pipeclay Creek, and Boat Creek may create a partial "hydraulic dam" effect whereby water in Punkah Creek upstream of these major inlets has an increased retention time within the system.

ZOOPLANKTON

The abundance of zooplankton was higher in the anabranch (A4261224) than the reference site in the river upstream of Chowilla Creek (A4260705) during the peak of the hydrograph. This result demonstrates that the anabranch was a major source of resources to the river channel during the 2014 testing event. The estimated load of zooplankton was similar at all three sites on the 30th September, but was markedly higher in both the anabranch (A4261224) and the receiving waters in the Lock 5 weir pool (A4260704) than the reference site (A4260705) on the 14th and 28th of October. On the last two sampling periods, the load in the anabranch (A4261224) was similar to the upstream reference site, but was elevated in the river downstream of Chowilla (A4260704). It is considered that the relatively low abundance of zooplankton recorded in the return flows (A4261224) during the recession phase of the hydrograph is due to a combination of (i) high dilution, and (ii) the regulators on the large wetlands (Werta Wert and Lake Limbra) being closed during the recession phase. The high dilution rate is an artefact of the maintenance of high inflow through the regulated (i.e. Pipeclay and Slaney) creeks whilst stored volume within the anabranch was decreasing. The regulators at Werta Wert wetland and Lake Limbra were closed in order to achieve an extended inundation period in the wetlands. Consequently, once lateral disconnection of the creek from the shedding floodplain had occurred, there would have been a limited supply of zooplankton back to the creek, and the relatively high velocity in the creeks may not have been conducive to *in-situ* growth of the zooplankton community.

Open water productivity

It is widely recognised that return flows containing high loads of readily available DOC may be one of the most important sources of carbon in lowland rivers (Robertson *et al.*, 1999; Hadwen *et al.*, 2009; Findlay & Sinsabaugh, 1999). As already outlined, we estimate that 603 tonnes of DOC would have been mobilised into the water column from the inundation of the floodplain. Consequently, the 2014 testing event may have mobilised as much carbon as produced annually in a 5.9 km^2 reach of river. The carbon and nutrient data indicate that an increase in resources was detected 40 km downstream. These resources can be expected to stimulate open water productivity. In effect, the upstream site would be expected to be resource limited (i.e. in low flow mode) and the downstream site would be expected to have improved access to resources, and hence be substantially more productive. The preliminary results of the primary productivity modelling for the period spanning the peak of the hydrograph (17^{th} to 26^{th} October 2014) indicate an increased rate of community respiration, and consistent negative values of net ecosystem productivity (NEP) at the site in the river upstream of the regulator. Negative values of NEP indicate the system is dominated by heterotrophic process; positive values indicate the system is dominated by autotrophic processes.

Management Implications including application of observations from this project to other managed floodplains and multi-site watering

Refining the minimum monitoring required

Based on recent trends in funding to undertake assessments of ecological outcomes resulting from delivery of environmental water, it is expected that resources to fund monitoring will come under increasing pressure. The data generated from this study provides a basis for an informed assessment of the minimum parameters, number of sites and frequency of monitoring for future events at Chowilla and monitoring at other managed floodplains such as Eckerts-Katarapko and Pike Flooplain. It is beyond the scope of this project to undertake such an assessment, which will require multiple stakeholder input, but it will be imperative to determine the minimum number of monitoring sites and parameters required to provide the data to (i) support informed decision making, (ii) report on outcomes, and (iii) improve future events. It is reasonable to anticipate that there would be a minimum essential baseline, and that the range of parameters, sites and frequency of sampling would increase as the magnitude of the planned event, and the associated likelihood of poor quality outcomes increases. The minimum monitoring requirements could then become part of the annual water bid-process.

Selection of reference sites for ambient water quality

The observation that there were significant differences between the two reference sites; (i) upstream of Lock 6 (A4261022) and (ii) the Lock 5 weir pool upstream of Chowilla Creek (A4260705) has direct application to the selection of appropriate sites for ongoing monitoring programs. Developing an understanding of how water quality at locations upstream and downstream of weirs may change between routine river operations and managed inundations, when the majority of discharge in the river may be diverted around the potential sampling site, will be an important part of that decision process.

Location of monitoring stations within the managed inundation zone

A comparison between the sites within the anabranch reveals that there was a higher frequency of significant differences between the most upstream site (A4260580) and the sites further downstream in the anabranch. This trend is potentially due to dilution of resources as a result of the substantial inflow into the anabranch via Pipeclay Creek, Slaney Creek (upstream of A4261107) and Boat Creek (upstream of A4261224) respectively. This result demonstrates that in order to collect data representative of conditions throughout the impounded area, it is necessary to distribute sites relative to the dominant flow paths. For example, in complex systems with multiple flow paths, it is unlikely that establishing a single station upstream of a regulatory structure will provide data that represents the conditions occurring throughout the impounded area.

Downstream water quality

The data indicates that return flows from the Chowilla Anabranch are influencing the abundance of resources to fuel primary productivity for at least 40 km downstream of the return flows. Therefore, it is reasonable to conclude that return flows from managed inundations have the potential to stimulate productivity at the weir pool scale and possibly beyond. A challenge posed by this is the potential impact of one or more upstream sites on watering actions at downstream sites. The managed inundation of an upstream site may not increase the concentration of nutrients outside of the range that can occur over inter-annual periods. For example, variations in the primary source of water (e.g. regulated releases from upper Murray catchment storages v's unregulated flows from major tributary systems) can substantially alter nutrient concentrations. However, the bioavailability of the resources (recalcitrant v's labile compounds), ratio of resources (e.g. C:N:P ratio) and availability of trace nutrients/elements that may be limiting productivity is likely to be more important than absolute concentrations.

There are three major requirements for cyanobacterial growth; (i) inoculum (source of cyanobacteria); (ii) light, and (iii) sufficient nutrients. The data from the stations in the receiving waters of the Lock 5 weir pool indicate that chlorophyll *a* and nutrients were elevated in the river downstream of Chowilla. It is possible that the increased values of chlorophyll *a* observed are a result of phytoplankton growth resulting in an accumulation of biomass within the relatively slow flowing tail water section of the Lock 5 weir pool. Delivering water that is "pre-loaded" with labile resources (readily bioavailable nutrients and DOC), bacteria and phytoplankton into a downstream floodplain would be considered beneficial during an unmanaged flood driven by high riverine discharge. However, delivery of the "pre-loaded" water into a floodplain during a managed inundation conducted with comparatively low daily exchange and long retention times may result in a higher likelihood of exceeding the assimilation capacity of the managed area and subsequent exceedance of "safe" or "acceptable" limits of water quality to other beneficial users.

The data indicates that during the 2014 testing event, cyanobacteria abundance at the downstream sites increased after the watering event, but the levels detected were not of concern for downstream users (e.g., SA Water). However, during future watering events at different scales (e.g. extent of inundation), prevailing conditions (e.g. QSA), season and management sites (Chowilla, Pike, Eckerts-Katarapko), monitoring will be required to ensure maintenance of acceptable water quality.

An assessment of the influence of lower rates of daily exchange

As already outlined, Wallace (2008) utilised observed oxygen depletion rates recorded *in-situ* during ponded floods within managed wetlands at Chowilla Floodplain to calculate that with an expected oxygen depletion rate of 0.82 $mgO_2L^{-1}day^{-1}$, a daily exchange equivalent to 20% of the stored volume would be sufficient to ensure a low likelihood of dissolved oxygen in the impounded area falling below 6 mgO_2L^{-1}. The maintenance of normoxic conditions (DO above 6 mgO_2L^{-1}) during the 2014 testing event validates the 20% daily exchange rate as an operational limit for the Chowilla Anabranch that offers a low likelihood of onset of hypoxia during managed inundations that are undertaken within late winter-spring-early summer. However, it is recognised that at some managed floodplain sites (i.e. the Pike Floodplain) a daily dilution rate of 20% will not be achievable with the infrastructure that is being considered for construction. Consequently, an assessment of the potential outcomes of managed floods with lower dilution rates has been undertaken here. The results indicate that with a low rate of oxygen depletion (-0.4 mgO_2L^{-1}), 10% daily exchange may offer a low likelihood of dissolved oxygen falling below 6 mgO_2L^{-1}. At oxygen depletion rates ≥-0.5 mgO_2L^{-1}, there is an increased likelihood of DO falling below the 6 mgO_2L^{-1} threshold if daily exchange is 10%. The results also indicate that for a daily exchange rate of 5%, DO is likely to fall below the 6 mgO_2L^{-1} threshold for all of the oxygen depletion rates assessed, and that DO is likely to fall below the 4 mgO_2L^{-1} threshold for depletion rates ≥- 0.6 mgO_2L^{-1}. The modified BRAT model (see section 3 of this report) will provide an additional pathway to explore the potential outcomes from a range of possible management scenarios.

Value of logged data

The value of the telemetered monitoring network cannot be overstated. During the testing event, the access to data in near real-time provided a means to assess the progress of the event and the margin between prevailing conditions and the thresholds for key water quality parameters such as dissolved oxygen and salinity. The continuous dissolved oxygen data and the data from the Automated Weather Station is critical to the primary productivity calculations discussed above. The data from the EXO Sonde detected numerous peaks in chlorophyll *a*, turbidity and dissolved organic matter that were not detected in the weekly sampling. The peaks may be an anomaly (or malfunction) in the sensor. However, it is considered more likely that the episodic spikes represent return flows from areas with low dilution and/or long retention times. The spike in turbidity may also reflect episodic spikes in suspended solids associated with isolated sections of bank failure during the falling of the hydrograph. Generating an increased understanding of the likelihood of the episodic peaks being sensor malfunction v's transient variations in water quality should be a priority. Sensor technology is likely to offer a cost-effective method of monitoring key parameters in near real time, and this advantage is likely to become increasingly important as resources to fund monitoring come under increasing pressure.

Due to the dependence of water density on temperature and salinity, monitoring networks that seek to investigate stratification need to incorporate both temperature and salinity. Cross validation of sensors fitted to water quality loggers, particularly for parameters such as chlorophyll *a* where independent calibration via commercially available standards is not practicable, will be an important component of the QA/QC process of using logged data to monitor and report on outcomes.

Management of individual wetlands in association with floodplain scale managed inundations

The practice of closing wetland regulators in order to achieve extended inundation periods needs to be planned and managed in the context of the ramifications of eliminating (or delaying) lateral connectivity for large fauna such as fish and preventing the return flow of resources to fuel riverine food webs. The results presented here demonstrate the role of the wetlands as a source of resource rich water that would be delivered to the creek and subsequently the river during periods where lateral connectivity is maintained during the falling limb of the hydrograph. Conversely, under some circumstances closing wetland regulators may provide a tool to mitigate against risks of triggering negative water quality outcomes such as problematic salinity spikes and for preventing the return flow of high algal biomass to the river which could seed problematic algal blooms in the downstream weir pools.

Potential implications of weir pool raisings during periods of low QSA

Modelling of the potential impacts of weir pool raising on in-channel flow velocity in the Lock 3 weir pool undertaken by Wallace *et al*., (2014a) indicates that at 10,000 ML day^{-1}, a +50 cm weir pool raising increases the proportion of habitat with very low velocity (<0.1 ms^{-1}) from 21.1% to 28%. Low mixing energy may result in (i) the affected reach becoming a sink for propagules that cannot control their position in the water column, and (ii) deoxygenation of the water column below the mixing boundary (hypolimnion). The observation from this study that persistent stratification was observed at the station upstream of Lock 6 (A4261022) appears to support the hypotheses that weir pool manipulations at low flows may reduce water column mixing and therefore increase the likelihood of persistent thermal stratification developing. However, due to some anomalies between (i) the observed extent of stratification, (ii) the data from the automatic weather station and (iii) prevailing conceptual understanding of the drivers of formation and breakdown of thermal stratification in weir pools, it is currently unclear if the persistent stratification indicated at this site is a reliable assessment, or an artefact within the data. Developing a more comprehensive understanding of the dynamics of thermal stratification, and the depth within the water column that the boundary layer occurs at should be quantified as a priority.

SUMMARY

This project provides evidence that carefully managed delivery of environmental water using constructed infrastructure can achieve extensive inundation extents without exceeding guideline and statutory limits for water quality; i.e. without triggering key hazards to river function, ecology and social values , including drinking water supplies. Furthermore, the data indicates that return flows from the Chowilla Anabranch are influencing the abundance of resources to fuel primary productivity for at least 40 km downstream of the return flows. Therefore, it is reasonable to conclude that return flows from managed inundations have the potential to stimulate productivity at the weir pool scale and possibly beyond. However, it is important to note that data from the upper reaches of the Chowilla Anabranch (station A4260580) indicates that further increasing the inundation extent prior to allowing conditions to stabilise may have caused a problematic decline in dissolved oxygen. This reinforces the value of the data available from the telemetered monitoring network. Furthermore, it must be noted that only approximately 25% of the maximum area that can be inundated using the Chowilla Regulator and ancillary structures was inundated during the 2014 testing event. Lake Littra and Coombool Swamp were not inundated, only a small portion of Gum Flat was inundated, and other large areas of woodland were not inundated. Larger inundation extents can be expected to produce different outcomes to those observed in 2014.

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1. INTRODUCTION:

1.1. GENERAL BACKGROUND

A key challenge for managers throughout the Murray-Darling Basin is that the system is characterised by a multitude of extensive floodplain-river systems that rely on frequent (sub-decadal scale) flooding to maintain their ecological function, yet there is a limited volume of accessible environmental water that can be utilised to sustain the system. Managers therefore need to maximise the outcomes that can be achieved with the smallest practicable volume of environmental water at any given site in order to achieve management objectives at as many locations as possible. Consequently, there is growing interest in the construction and operation of new, large infrastructure specifically designed, constructed and operated for environmental outcomes as a management tool (Windsor Report, 2011). However, there is considerable uncertainty in the ability of environmental water allocations to achieve balanced ecological outcomes when delivered to specific sites *via* constructed infrastructure rather than being delivered to interconnected ecosystems *via* landscape (river reach) scale releases.

On floodplains, environmental water delivery has typically, but not exclusively, targeted keystone species such the large long lived floodplain trees, River Red Gum (*Eucalyptus camaldulensis* Dehnh.) and Black Box (*Eucalyptus largiflorens* F.Muell). Targeting these long-lived (hundreds of years) ecosystem engineers has considerable merit; as they are key component of the ecological character of floodplain rivers, a dominant provider of habitat for a wide range of biota, and a major source of carbon and nutrients for foodwebs (Colloff & Baldwin, 2010). However, by selecting constructed infrastructure as the means to deliver environmental water to specific floodplain sites, there is inevitably a trade-off between maximising the inundation of areas that support these vegetation types, and minimising the potential consequences to sub-sets of the ecosystem that may be dis-benefited by this delivery mechanism. Achieving an acceptable balance is perhaps the greatest challenge that managers will face over the coming decades as pressure to demonstrate ecological outcomes increases within the context of the impacts of climate change on reduced water availability.

Within South Australia, large infrastructure to deliver environmental water to floodplain assets has been constructed at Chowilla Floodplain *via* the Murray Darling Basin Authority's The Living Murray (TLM) program. Planning is proceeding for similar infrastructure to be constructed and operated on the Pike Floodplain and the Eckerts-Katarapko Floodplain *via* the South Australian Riverland Floodplain Integrated Infrastructure Program (SARFIIP). Despite the uncertainty associated with the use of large constructed infrastructure to deliver environmental water to floodplain assets, this approach has become a key component of the Basin Plan Sustainable Diversion Limit (SDL) adjustment project which seeks to assess the potential of large infrastructure to achieve ecologically equivalent outcomes using less water.

1.2. PROJECT PURPOSE

This project enabled use of the first testing event of the Chowilla Regulator to (i) collect the field data required to validate the hydraulic model used in the development of the operations regimes; and (ii) assess some of key water quality hazards that had been identified in the Chowilla Operations Plan (Wallace & Whittle, 2014c). The knowledge gained in this project has application to directly influence operational rules and procedures used in decision making for delivery of environmental water to large floodplain assets *via* constructed infrastructure. The Basin Plan (Commonwealth of Australia, 2012) establishes the Water Quality and Salinity Management Plan (WQSMP) for the water resources of the Murray-Darling Basin. As part of the implementation of the WQSMP all river operators and holders of environmental water are required to have regard to 'Targets for managing water flows' (section 9.14 of the Basin Plan) when making decisions relating to flow management and the use of environmental water.

It is reasonable to anticipate a large degree of transferability of knowledge generated from studies at Chowilla to other sites that are planning the construction and use of similar infrastructure. It will be important to take advantage of the opportunity to transfer learning for a range of scientific, ecological and economic reasons. Examples of benefits include (i) accelerated learning, (ii) improved predictions of outcomes under different conditions, (iii) enhanced capacity to test the ability of planned mitigation techniques to actually manage risks, (iv) avoid repeating negative outcomes, (v) being aware of and hence able to respond to previously unconsidered issues; and (vi) the inherent economic value in coordinated monitoring.

1.3. The Chowilla Floodplain

The Chowilla floodplain (see Figure 1) is one of the MDBA Living Murray nominated Icon Sites in the Murray-Darling Basin Authority's *The Living Murray Program* (http://www.mdba.gov.au/what-we-do/working-with-others/ten-years-of-tlm-program). The Chowilla Environmental regulator and ancillary structures represent an investment of approximately $68 million in restoring the condition and ecological function of the Chowilla Floodplain. Over the last decade, the Department of Environment Water, and Natural Resources (DEWNR) has facilitated significant investment in assessment of risks and benefits associated with the operation of the Chowilla regulator and associated infrastructure and in the development of risk mitigation strategies. This work has been undertaken by multi-disciplinary teams of technical experts and the accumulated knowledge underpins the Chowilla Operations Plan (Wallace & Whittle, 2014c).

Initial testing operations of the Chowilla environmental regulator and ancillary structures is heavily reliant on computer models and accumulated conceptual understanding of the impact the infrastructure will have on hydraulic conditions and water quality within the floodplain-anabranch complex. The consequences of these models providing incorrect information include potential exceedance of guideline values, (ANZECC, 2000), South Australian statutory limits (SA Government, 2003) and limits specified in the Basin Plan (Commonwealth of Australia, 2012) for water quality. More importantly, failing to manage the system in a manner that maintains appropriate water quality and habitat could be catastrophic for the organisms that the infrastructure aims to protect, and for community acceptance of large engineering solutions in the floodplain environments along the River Murray.

1.4. Project Scope

The project was developed in recognition of the high priority to be able to monitor outcomes of the early testing events of the Chowilla environmental regulator and ancillary structures. The project was co-funded by the Goyder Institute, the Murray-Darling Basin Authority (MDBA) *via* The Living Murray (TLM) Program, the South Australian Department of Environment Water, and Natural Resources (DEWNR) *via* both TLM and the South Australian Riverine Integrated Infrastructure (SARFIIP), and SA Water. Significant *in-kind* contributions to the project were made *via* The University of Adelaide, DEWNR (Resource Management Unit of SMK) and SA Water. The project is split into three key tasks:

1. Assess changes in water quality associated with the operation of the Chowilla Regulator
    - This task represents the majority of the workload undertaken directly by the project team, and represents the main body of this report. The results are presented in the context of testing hypotheses related to management of key hazards (risk mitigation)

2. Modify the existing Blackwater Risk Assessment Model (Whitworth *et al.*, 2013) and assess its utility for predicting changes in water quality at Chowilla
    - This task was undertaken by Rob Daly (SA Water) and involved modification of the existing Blackwater Risk Assessment (BRAT) model. A description of the modifications made and the performance of the modified BRAT model is presented here. A revised BETA version of the BRAT model will be presented to DEWNR for testing.

3. Validate and recalibrate the 1D-2D Mike FLOOD hydrodynamic models that are used to predict water exchange and changes to hydraulic habitats on the floodplain.
    - This task was funded and managed by DEWNR through the TLM program and represents a major in-kind contribution to the project. A brief overview of the task is provided in this document

The combined outcomes of the project contribute to identifying knowledge gaps in existing risk assessments, confirming mitigation capability and refining the cumulative risk profiles for e-water delivery using floodplain infrastructure. In addition to the synthesis of the findings of the monitoring (the main report presented here) the lead author has participated in two reviews of the outcomes of the testing event that have been facilitated by DEWNR.

- The first "Chowilla Testing Event 2014" review workshop was held in Berri on 11th March 2015 with representatives from DEWNR, SAWater, MDBA, CEWO, SARDI, and the University of Adelaide. The key objectives of this workshop were to:
    i. establish a shared understanding of what went well and should be replicated or built upon to do even better in the future; and what didn't work so well and needs to be dropped or changed for any future event
    ii. identification of any problems that need to be solved / processes that need to be improved prior to any future operation, and how, and who should make this happen
    iii. a list of any tasks that need to be completed prior to any future operation and by who
- A Monitoring review workshop held on the 21st May 2015. The key objective of this monitoring review workshop was to generate a shared understanding of outcomes; review programs and methods; identify gaps and inform future monitoring requirements.

A presentation of the preliminary findings was made at the Goyder Institute Annual Conference 2015 – Water Research Showcase held in Adelaide on 17 and 18th February 2015. That presentation was presented to the Chowilla Community Reference Committee on the 25th March 2015.

A presentation on the findings and their applicability to other floodplain sites was also made to the SARFIIP working group including representatives from DEWNR and MDBA staff involved in site management and planning of constructed infrastructure for Pike and Eckerts-Katarapko Floodplains in Berri in on the 8th April 2015.

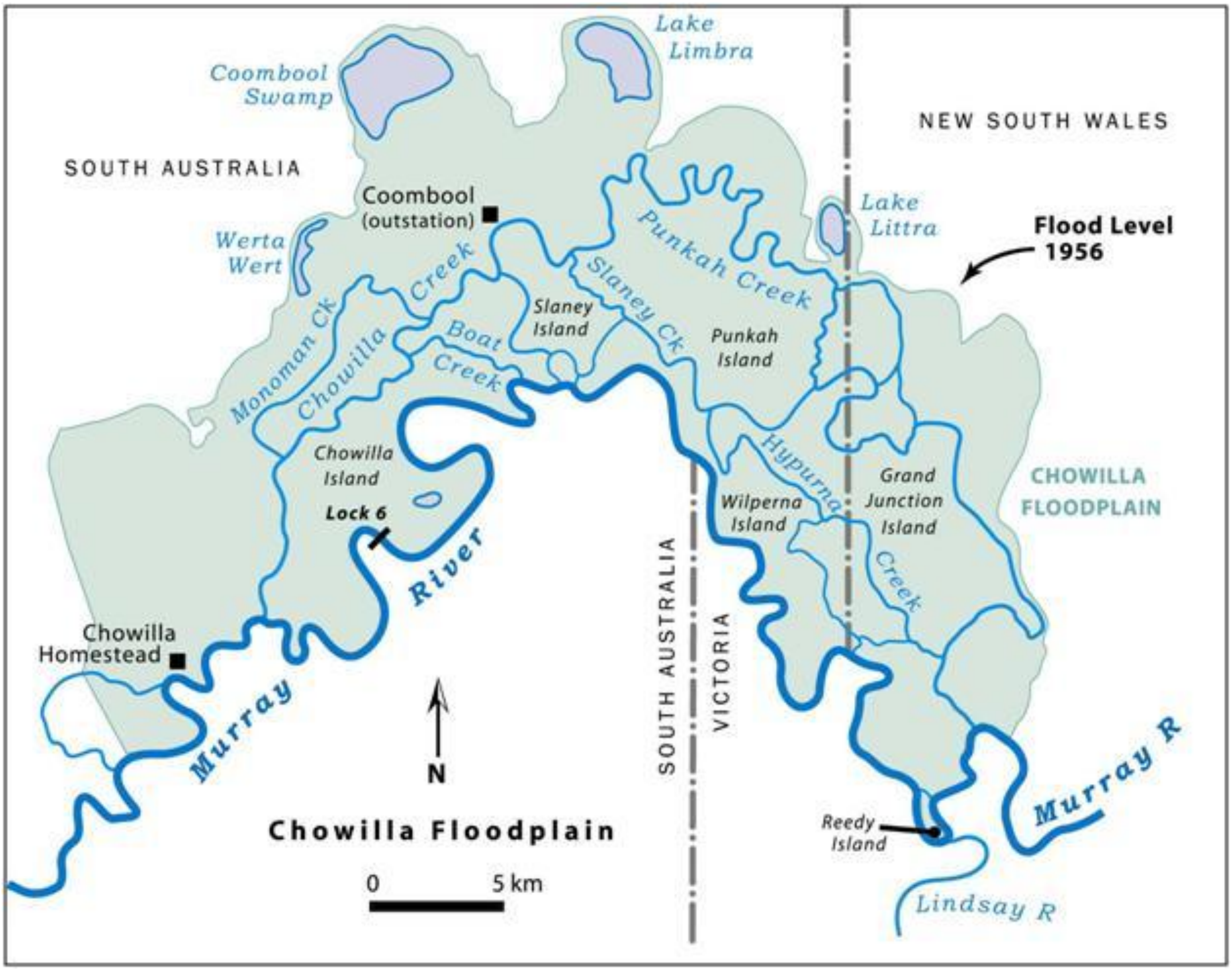


Figure 1: Map showing location of Chowilla Floodplain.

2. TASK 1: ASSESSMENT OF CHANGES IN WATER QUALITY ASSOCIATED WITH THE TESTING OPERATION OF THE CHOWILLA REGULATOR

2.1. GENERAL INTRODUCTION

2.1.1. POTENTIAL FOR DIFFERENCES BETWEEN NATURAL (UNMANAGED) FLOODING RESULTING FROM UNREGULATED FLOWS AND MANAGED FLOODING RESULTING FROM USE OF CONSTRUCTED INFRASTRUCTURE TO DELIVER ENVIRONMENTAL WATER ALLOCATIONS

A synthesis document assessing the potential outcomes of 'Natural' versus 'Artificial' watering of floodplains and wetlands produced in 2011 (Wallace *et al*., 2011) highlighted that there are a number of key differences in expected outcomes between unmanaged floods (periods of high flow (discharge) that result in out-of-channel flows that engage the floodplain) and managed floods (those that are achieved utilising constructed infrastructure to distribute water to elevated sections of the floodplain during relatively low flows when these systems would otherwise remain in a drying phase). Biogeochemical processes control the way that energy and nutrients move through ecosystems and therefore, are fundamental to the way ecosystems function (Baldwin & Wallace, 2009). Many of the biogeochemically mediated and biotic processes that drive the observed ecological outcomes occur over a period spanning hours-weeks. Differences in hydraulics (dilution, daily exchange, mixing energy, retention time within the managed area) and lateral plus longitudinal connectivity, combined with the time (lag phase) required for ecological response to manifest provides opportunities for differences in responses between natural and managed floods to cascade across multiple levels (Wallace *et al.*, 2011).

2.1.2. RELEASE OF CARBON AND NUTRIENTS DURING INUNDATION EVENTS

The inundation of a floodplain results in the wetting of soils and the vegetative material within the inundated area. This results in the rapid release (within hours) of water soluble compounds from natural organic material (e.g. leaf litter from floodplain trees - Baldwin 1999; O'Connoll *et al*. 2000) and soils (Scholz *et al.*, 2002; Kobayashi *et al.*, 2008; Wilson *et al.*, 2010; Banach *et al.*, 2009). The amount of carbon leached into the water column during any given event will depend on a number of factors including; (i) the type of leaf litter/vegetation inundated (ii) the age of the leaf litter, (iii) the amount of litter that has accumulated on the floodplain or in dry creek channels, and (iv) whether or not the litter has been flooded before (O'Connell *et al.*, 2000).

Floodplain eucalypts, particularly river red gum (*E. camaldulensis*) and to a lesser extent black box (*E. largiflorens*) generate a large standing biomass of leaf litter (approximately 2,500 gm^{-2} and 600 gm^{-2} respectively (Wallace, 2009)) and represent a large source of allochthonous organic matter to floodplains and wetlands (Glazebrook & Robertson, 1999; Francis & Sheldon, 2002). The organic loading in the centre of large wetlands may be an order of magnitude lower than that at the fringing tree line (Wallace *et al*. 2009). Consequently, the spatial extent of a given inundation may have a substantial influence on dissolved carbon and nutrient concentrations by influencing the amount and type of plant material submerged.

The carbon and nutrients released into the water column are available to be incorporated into microbial and algal biomass (Schemel *et al*. 2004); with the fate of carbon and nutrients largely dependent on the length of time water remains on the floodplain (Schramm *et al.*, 2009). Approximately one-third of the dissolved organic carbon (DOC) leached from litter can be utilised within ten days. Phosphorus and nitrogen is either taken up by microorganisms oralgae. Nitrate may be respired through denitrification (Forshay & Stanley, 2005). The assimilated carbon and nutrients are subsequently cycled though the food web to higher trophic level organisms (e.g. birds and fish) via multiple pathways, including via micro- and macro-invertebrates. This process is referred to as 'trophic upsurge' (Kern & Darwich, 1997; Furch & Junk, 1997; Geraldes & Boavida, 1999; Scharf, 2002; Lourantou, Thomé & Goffart, 2007; Talbot *et al.*, 2006). It is widely recognised that return flows containing high loads of readily available DOC may be one of the most important sources of carbon in lowland rivers (Robertson *et al.*, 1999; Hadwen *et al.*, 2009; Findlay & Sinsabaugh, 1999). However, very high loading (inundation of large amounts of organic material relative to the volume of water used) can lead to a number of problems.

2.1.3. Blackwater events

Blackwater events can be described as conditions where the concentration of dissolved organic carbon (DOC) in surface water is sufficient to discolour the water such that is resembles dark "tea". These events are often, but not always, associated with low concentrations of dissolved oxygen (DO) (Howitt *et al.*, 2007; Meyer, 1990), as the dissolved oxygen that is normally present in water is utilised during heterotrophic metabolism (microbial degradation) of the DOC. Rapid oxidation of large pools of labile DOC may deplete oxygen faster than it can be replenished through the air-water interface or *via* photosynthesis by aquatic plants (Baldwin & Wallace, 2009). Low dissolved oxygen resulting from managed flooding is considered to be a cumulative risk for a number of reasons, including:

- Hypoxia may trigger lethal or sub-lethal impacts to fish and other aquatic biota, or negatively affect other water quality parameters.
- Hypoxic water from a floodplain may lead to substantially reduced DO in receiving waters outside of the managed site.
- Hypoxic water travelling downstream from an upstream management actions or natural outcomes may restrict or entirely preclude managed flooding at a downstream site.
- High DOC presents major challenges where water is treated for potable supply.

A number of factors are critical in determining whether or not a blackwater event will result in a fish kill. The two most important factors are water temperature and carbon loading (Baldwin & Wallace, 2009). The factors influencing carbon loading are described in the preceding sub-section of this report. Season has a substantial influence on (i) water temperature, (ii) solubility of oxygen in water, and (iii) the rates at which biogeochemical processes occur. At 10 °C fresh water can contain about 11.3 mgO_2L^{-1}. At 20 and 30 °C, this decreases to 9.1 mgO_2L^{-1} and 7.6 mgO_2L^{-1} respectively. Introduction of an oxygen demand equivalent to 4 mgO_2L^{-1} when ambient temperature is 20 °C and the water is at saturation point (9.1 mgO_2L^{-1}) will draw dissolved oxygen down to 5.1 mgO_2L^{-1}. This is not likely to have any adverse effects on biota or biogeochemical processes. However, introducing the same oxygen demand into 30 °C water will depress dissolved oxygen concentrations to approximately 3.6 mgO_2L^{-1}. Concentrations of dissolved oxygen this low are considered to be capable of causing stress to fish communities. While this example is based on first principles and does not take into account re-aeration processes, it demonstrates the importance of taking season and water temperature into account when planning the delivery of environmental water allocations.

There is existing data on release of DOC and changes in DO associated with ponded flooding (managed watering) of individual wetlands at Chowilla (Wallace, 2008; Wallace & Lenon, 2010), and data on hypoxic blackwater processes at upstream locations (e.g. Barmah Forest) where hypoxic blackwater events have occurred (Howitt *et al.*, 2007; Whitworth *et al.*, 2013). However, there is not adequate data relating changes in dissolved oxygen to changes in concentration and bioavailability of nutrients resulting from managed floodplain inundations under low flow conditions in the lower River Murray. Given the potential risk associated with hypoxic blackwater events, this is a critical knowledge gap for the delivery of environmental water via constructed infrastructure, and therefore a primary driver for investment in this project.

2.1.4. Stratification

Water density is a function of water temperature and total dissolved solids (and hence salinity). A difference in density can preclude mixing of the water column if there is not sufficient kinetic energy available to overcome the density difference. Salinity driven stratification occurs where the river channel intercepts saline groundwater (Turner & Erskine, 2005). The extent of thermal stratification is primarily determined by the relative input of thermal energy (causes stratification). Turbulent kinetic energy resulting from wind driven mixing or turbulence generated by water flow over the stream bed can break down stratification (Bormans *et al.*, 1997). The low bed slope dominant throughout the lower River Murray, combined with regional discharge of saline groundwater into the river channel, makes the river susceptible to stratification during periods of low flow. Therefore, in systems such as the lower River Murray, the onset of thermal stratification is a function of flow, solar radiation, wind speed (Maier, Burch & Bormans, 2001; Bormans *et al.*, 1997) and groundwater inputs.

Due to the dependence of water density on temperature and salinity, assessments of stratification should include both temperature and salinity. However, the majority of published studies in the lower River Murray have concentrated on thermal stratification. The studies that have been published conclude that during periods of entitlement flow in the lower reaches of the South Australian River Murray when water velocity is low (0.04-0.06 ms^{-1}) and solar radiation is high (i.e. summer), wind speed is the dominant factor limiting the development and persistence of thermal stratification (Bormans *et al.*, 1997; Maier, Burch & Bormans, 2001). The depth of the mixed layer can vary from one side of the river to the other due to protection from wind-driven mixing and shading by the riverside cliffs (Bormans *et al.*, 1997).

The provision or maintenance of hydraulic conditions that provide sufficient turbulence (water column mixing) to maintain propagules (e.g. plant and invertebrate seeds, fish eggs and fish larvae) that are otherwise unable to maintain their position in the water column is an important consideration in river management. For example, downstream drift of eggs and/or larvae and juveniles is an important life stage for many riverine fish (Brown & Armstrong, 1985) including Murray cod, golden perch and silver perch (Humphries, King & Koehn, 1999). Slow flow conditions may not maintain these propagules in suspension and could result in the reach acting as a sink rather than a productive nursery environment for native fish (Wallace *et al.*, 2014b). Slow velocities also increase the likelihood of the onset of persistent stratification and associated water quality problems including algal blooms and hypoxic/anoxic conditions. During periods of persistent stratification the water column below the boundary layer can become anoxic (Wallace *et al.*, 2008).

2.1.5. Open water productivity

In surface waters, the concentration of dissolved oxygen increases as a product of photosynthesis by autotrophs (i.e. phytoplankton and macropyhtes) and is depleted (consumed) *via* respiration by heterotrophs (bacteria, fungi, and animals) during the day and night. At night, respiration demand increases due to dark respiration by autotrophs. Chemical oxygen demand may also result in the depletion of dissolved oxygen. The net change in oxygen concentration during daylight hours estimates gross productivity (GP) as both photosynthesis and respiration occur simultaneously. In the dark hours, the decline in dissolved oxygen provides an estimate of community respiration (CR). The difference between GP and CR provides an estimate of net ecosystem productivity (NEP). Increases in the amount of available energy in the source of organic carbon resulting from the inundation of floodplains can be expected to alter the balance between CR and GP and therefore dramatically alter NEP. Productivity is a signal for the flux of energy through food webs (Odum, 1956). Negative values for NEP indicate the system is dominated by heterotrophic processes. Positive values of NEP indicate the system is dominated by autotrophic processes.

Under low flow conditions, autotrophic sources of carbon are believed to dominate foodwebs (Bunn, Davies & Winning, 2003; Hadwen *et al.*, 2009). Oliver and Merrick (2006) and Oliver and Lorenz (2007) demonstrated that the River Murray is energy constrained with net production close to zero. Studies in the Logan, Gwydir and Ovens Rivers (Hadwen *et al.*, 2009) and Lachlan River (Moran, 2011) have demonstrated that respiration of the heterotrophic bacterial community and DOC consumption is limited by the quality of DOC present. This is considered to be the case for the majority of Australian rivers during low flow conditions when allochthonous DOC supply is limited (Robertson *et al.*, 1999).

2.1.6. PHYTOPLANKTON

Phytoplankton blooms are problematic when they impact users of untreated water (i.e. irrigators, graziers), recreational users and the suitability of water for potable supply (Codd *et al.*, 1994). Algal blooms have been considered problematic in the lower Murray for 135 years, with scums of algae reported as early as 1853. The hazards associated with cyanobacteria range from public-health toxicity to aesthetic taste and odour issues. The toxins produced by cyanobacteria include hepatotoxins (liver-damaging) and neurotoxins (nerve-damaging). The taste and odour compounds produced by cyanobacteria are geosmin (trans-1, 10-dimethyl-trans-9-decalol) and MIB (2-methylisoborneol). These are difficult to remove with conventional methods, and require expensive activated carbon for adequate removal. In addition to impacts to consumptive users (e.g. humans, stock), blooms of cyanobacteria may affect aquatic food webs. For example, cyanobacteria are considered to be a non-preferred food resource for invertebrate grazers (Carney & Elser, 1990; De Benardi & Giussani, 1990). Consequently, dominance of the phytoplankton community by cyanobacteria may interfere with transfer of resources into higher trophic levels.

2.2. PROJECT SCOPE AND HYPOTHESES

This task assessed the loading of Natural Organic Matter at 150 sites across four macro-habitats and tested 16 specific hypotheses (Table 1). The sites referred to in the hypotheses are described in Table 2 and depicted spatially in Figure 2: In addition, it is recognised that at some managed floodplain sites (i.e. the Pike Floodplain) a daily dilution rate of 20% will not be achievable with the infrastructure that is being planned for construction. Consequently, an assessment of the potential outcomes of managed floods with lower dilution rates and additional oxygen depletion rates has been undertaken here.

2.3. METHODOLOGY

2.3.1. MONITORING STATIONS

In order to collect data required to assess changes in water quality, a number of monitoring stations have been established. The location and description of these monitoring stations is presented in Table 2 and their respective locations are displayed graphically in Figure 2.

The five telemetered permanent stations in the anabranch creeks and the river (see Table 2) are based on existing surface water monitoring pontoons in the SA River Murray monitoring network that are maintained by DEWNR and MDBA https://www.waterconnect.sa.gov.au/Systems/SitePages/Home.aspx. At these stations, water salinity (EC; μScm^{-1}) and temperature (°C) are recorded at approximately 600 mm below the air-water interface (surface) and approximately 400 mm above the sediment-water interface (bottom). Dissolved oxygen (DO; percent saturation and mgO_2L^{-1}) is recorded using D'Opto loggers manufactured by ZebraTech. At the two telemetered permanent stations on the floodplain (A4261160 and A4261166), water temperature and DO was recorded approximately 400 mm above the sediment-water interface.

At the two permanent salinity monitoring pontoons where telemetered stations were not established (A4260705 and A4260703), water salinity (EC μScm^{-1}) and temperature (°C) are recorded at approximately 600 mm below the air-water interface (surface).

A YSI (Yellow Springs Instruments) EXO multiparameter water quality sonde was deployed at A4261224 (upstream of Chowilla Regulator) to facilitate collection of continuous data on a number of physico-chemical water quality parameters. The EXO Sonde was equipped to measure: temperature (°C), salinity (EC μScm^{-1}), pH, turbidity (NTU), chlorophyll *a* (μgL^{-1}) dissolved oxygen (% saturation and mgO_2L^{-1}) and fDOM (the fraction of dissolved organic matter (DOM) which fluoresces (f) when exposed to high-wavelength ultraviolet (UV) light (ca. 365 nm). fDOM is recorded in units of "quinine sulfate units (QSUs)" where 1 QSU = 1 ppb quinine sulfate. This EXO Sonde logged data every 15 minutes at a depth of 2m below the air-water interface. Due to delays in delivery of the equipment, the sonde was not installed for the full period of the testing event. Data collection commenced on the 23rd October 2014.

At each of the wetland sites, a temporary station was established using a standard 300 mm buoy, 4 mm chain and concrete ballast to suspend a stand-alone D'Opto logger at approximately 400 mm below the air-water interface. An automatic weather station (A4261167) was established on Chowilla Island. This station is equipped to record rainfall, barometric pressure (hPa), air temperature (°C), humidity (%), wind direction and velocity (km/h), and incident solar radiation (Wm^{-2}). Data was recorded every 10 minutes. At all telemetered water quality stations, data is recorded every five minutes and polled every hour, except for station A4261022 where data is polled every three hours as this site is serviced by a satellite modem.

The station at site A4260704 (see Table 2 and Figure 2) is approximately 2 km downstream of the junction of Chowilla Creek, but less than 800 m downstream from the outlet at Woolshed Creek South where return flows from the floodplain-anabranch complex discharge directly into the river channel. Due to concerns with the proximity of the station to the return flows and the potential for incomplete mixing of return flows and river water flow within this travel distance, a second pontoon (station A4261168) was commissioned approximately 4 km downstream of the junction of Chowilla Creek. Sampling was transferred from A4260704 to A4261168 on the 28th October 2014. The single site code A4260704 is retained in the reporting presented here in order to minimise the potential for confusion.

2.3.2. Water quality sampling

Sampling dates for each station are shown in Table 3. During the non-operational period, water samples were collected from the five telemetered permanent stations in the anabranch creeks and the river at quasi 6-weekly intervals. During the 2014 testing operation samples were collected on a weekly basis from all of the river and anabranch sites. Samples were also collected from the wetlands on a weekly basis during a truncated period around the peak of the testing hydrograph.

A boat was used to access each sampling station. At each station, three independent samples were collected from spatially separated (>10m) locations centred on the logging station. At the river and anabranch sites, samples were collected from locations spanning the width of the channel (i.e. left bank, mid-channel and right bank). Composite samples were generated by using a 4 L Haney trap and transferring a "grab" from the top, middle and bottom of the water column respectively, to a pre-rinsed 20L drum to produce a 12L composite sample. A sub-sample was subsequently collected from the composite sample into pre-washed PET (polyethylene terephthalate) bottles for subsequent processing and analysis. All collected samples were stored in the dark in an ice-filled insulated box and returned to the laboratory for processing and analysis.

2.3.3. Zooplankton community

Samples were collected for enumeration and identification of zooplankton during the 2014 testing operation from the river and anabranch sites and the wetlands on a weekly basis (see Table 3) at times coinciding with collection of the water quality samples (described above). At each station, three independent samples were collected from spatially separated (>10m) locations centred on the logging station. Composite samples were generated by using a 4 L Haney trap and transferring a "grab" from the top, middle and bottom of the water column respectively, to a pre-rinsed 20L drum to produce a 12L composite sample. The total volume was concentrated to ca 50 mL by filtering through a 35 µm net. This concentrated sample was transferred to a 200 mL PET jar and preserved with 70% ethanol. Quantitative samples were inverted three times and a 1 mL sub-sample was transferred into a pyrex gridded Sedgewick-Rafter cell. The entire sub-sample was counted and zooplankton identified using an Nikon diaphot compound microscope. This was repeated three times for each sample. The average number of zooplankton were then calculated and expressed as numbers of individuals per litre (individuals L^{-1}). An estimate of load was generated by multiplying the numbers of individuals per litre by the daily flow ($MLday^{-1}$) at the nearest relevant gauging station to the sampling site.

2.3.4. In-situ assessment of water quality

During the 2014 testing event, a vertical profile of physico-chemical water quality parameters including; pH, temperature (°C), EC (μScm^{-1}), dissolved oxygen (mgO_2L^{-1}), turbidity (NTU) and chlorophyll *a* (μgL^{-1}) were made at each of the logging station at the time of collection of the composite water samples. The vertical profile was generated by lowering a YSI 6600V2(4) multiparameter water quality Sonde attached to a YSI hand-held logger down through the water column. Data was automatically recorded at 2 s intervals. Profiles were post-processed using the logged data for depth intervals of ca 0.1 m. The water column average was utilised to provide a value for pH, turbidity, and chlorophyll *a* (μgL^{-1}) for each sampling location.

2.3.5. Water quality analysis

Collected samples (as described in 3.3.2) were analysed for dissolved organic carbon (DOC), total phosphorus (TP) total nitrogen (TN) and dissolved nutrients; filterable reactive phosphorus (FRP), nitrate, nitrite, NOx (Nitrate + Nitrite), and ammonium. For analysis of dissolved carbon and dissolved nutrients, each replicate sample was filtered through Whatman GF/C filters and then 0.45 µm pore-sized Millipore Millex-HV PVDF filters (Millipore, Cork, Ireland). All filters were pre-washed with at least 20 mL of deionised water. Samples for nutrient analysis were frozen and despatched in batches for analysis to be undertaken by the Environmental Analysis Laboratory at the Southern Cross University using APHA Standard Methods; TN (APHA 4500 N-C), TP (APHA 4500 P-H), nitrate (APHA 4500 NO_3-F), nitrite (APHA 4500 NO_2-I), ammonia (APHA 4500 NH_3-H) and FRP (APHA 4500 P-G). 5-day Biochemical Oxygen Demand (BOD_5) (APHA 5210-B) was undertaken at the Water Research Centre at The University of Adelaide on unfiltered samples without nutrient addition. DOC was measured at the Water Research Centre with an SGE ANATOC II total organic carbon analyser in non-purgeable organic carbon (NPOC) mode.

For selected sites (A4261224, A4260705, A4260704, A426A1 and A4260703), a composite sample comprising 1/3 volume from each of the independent samples was submitted to the Australian Water Quality Centre for (i) analysis of iron and manganese and (ii) cell counts for dominant algal species including toxin producing blue-green algae.

2.3.6. Calculation of stratification

The presence of persistent thermal stratification was assessed via an analysis of data collected from the water quality stations. At described in sub-section 3.3.1. the water quality stations are equipped to record temperature (°C) and salinity (EC; μScm^{-1}) at approximately 600 mm below the air-water and approximately 500 mm above the sediment-water interface (bottom). The vertical distance (depth) between the loggers varies between stations and over time as depth at the station changes. Delta EC was calculated as salinity recorded by logger at surface – salinity recorded by logger at bottom of the water column. Delta T was calculated as temperature recorded by logger at surface – temperature recorded by logger at bottom of the water column. Following Mitrovic *et al.*, (2003), persistent thermal stratification is considered to be represented by a temperature difference between the top and bottom of the water column constantly >0.5 °C (Δt = 0.5 °C) for more than 5 days.

2.3.7. Calculation of primary productivity

Open water metabolism was estimated from analyses of the daily time series of dissolved oxygen concentrations and light intensities following Oliver and Lorenz (2013). Data on dissolved oxygen and water temperature was taken from the telemetered monitoring stations described in section 3.3.1.
Data on solar radiation, wind speed and barometric pressure was taken from the Automatic Weather Station (A4261167). The rate of gas exchange and the metabolic parameters were estimated by fitting the experimental data with a numerical model (Oliver and Merrick 2006). Rates of dissolved oxygen concentration change (dO/dt) attributable to photosynthesis, respiration and exchange of oxygen at the air-water interface are calculated *via* Equation 1 (Oliver & Merrick, 2006; Young & Huryn, 1996)

$$\text{Equation 1} = dO/dt = AE_t^{\,p} + kD + CR$$

The term $AE_t^{\,p}$ describes the dependence of integral GPP on irradiance intensity (Young & Huryn, 1996; Kosinski, 1984) where:

- dO/dt = Rate of dissolved oxygen concentration change
- E_t = incident photosynthetically active solar radiation (PAR µmol photocs $m^{-2}s^{-1}$) at time *t*
- *P* = provides for the possibility that the integrated gross primary production shows a saturating response to irradiance through the day (Kosinski, 1984)
- CR = community respiration
- k = re-aeration coefficient ($time^{-1}$)
- D = oxygen deficit; the difference between the saturation oxygen concentration and the measured oxygen concentration in the water (Odum, 1956; McCutchan, Lewis & Saunders, 1998)
- kD = atmospheric gas exchange

Calculation of saturated oxygen concentrations were made from the water temperatures measured at ten minute intervals using formulae from the International Oceanographic Tables (1973) without salinity correction. D was estimated using the data from the loggers and the respective calculated saturated oxygen concentrations. E_t was obtained from A4261167. A three dimensional curve fitting routine was applied with these time series to estimate average values for *CR*, *k*, *A* and *p*. Equation 1 was then re-arranged to provide *GP* ($AE_{t\,p}$) and values calculated for 10 minute time intervals and summed over the day (per Oliver and Merrick 2006; Oliver and Lorenz 2010). All calculations were performed in the software platform *R* using coding written by Zygmunt Lorenz (version PPCalcX1.R – Last modified 26/08/2014).

2.3.8. Natural Organic Matter Loading

Natural Organic Matter (NOM) loading was assessed in September 2014 by collecting natural organic matter *via* an adaptation of the method previously utilised at Chowilla Floodplain (Brookes *et al.*, 2007; Hackbusch, 2011; Wallace & Lenon, 2010; Wallace, 2008) and Pike Floodplain (Wallace, 2009). 150 samples were collected from 38 locations incorporating the riparian tree line of permanent (n = 48) and temporary (n = 51) creeks, temporary wetlands (n = 20) and floodplain (n = 31). The location of assessment sites was chosen *a priori* to provide a representative assessment of the habitats present in locations that were readily accessible *via* the existing vehicle track network, and that were within the area expected to be inundated during the 2014 testing event.

At each location, samples were collected from pseudo-randomly selected positions on site via a "blind-throw" in which a marker was thrown backwards over the shoulder. Samples were collected from the location at which the marker landed. The position of each subsequent sample was selected in this manner from the site of the preceding sample. The position of each sampling location was recorded using a hand held GPS. At each position, a 30 L bucket was inverted over the marker, organic material outside the bucket was cleared away, and the bucket re-inverted. From within the area that had been covered by the inverted bucket, all recognisable organic material from tree's (leaf litter, twigs and bark), understory vegetation and animal scats down to the soil horizon was transferred to the buckets and weighed on-site to produce a measure of organic loading (grams per m^2). Following Wallace (2009) and Wallace and Lenon (2010), because of the high ambient air temperatures experienced during sampling and the long antecedent period since the last rain event, air drying was not considered necessary on these samples prior to weighing. Excluding this process from the assessment removed the need to transport large volumes of organic material from the floodplain.

2.3.9. Data Analysis

Data were plotted using Sigma Plot (Version 10.0, SPSS Inc). An assessment of changes in nutrient and DOC dynamics was assessed on un-transformed data using a euclidean distance resemblance matrix. Analysis of zooplankton abundance was undertaken on square root transformed data (to down-weight the influence of samples with very high or low abundances), with a Bray-Curtis distance resemblance matrix. Analysis was conducted as a PERMANOVA with the two factors "Site" and "Date" fixed and crossed. Analysis was performed using 9999 permutations under an unrestricted model. Significant effects were accepted at $\alpha < 0.05$, with *a posteriori* pair-wise comparisons run as a "Site x Date" interaction. Monte Carlo tests were used due to low numbers of unique permutations for pair-wise tests. For wetlands, an MDS ordination was produced (using a euclidean distance resemblance matrix) to provide a visual display of the change in condition at the respective sites over time. PERMANOVA, SIMPER and MDS ordinations were generated within the software package PRIMER v6 utilising the PERMANOVA+ add in (Anderson, Gorley & Clarke, 2008).

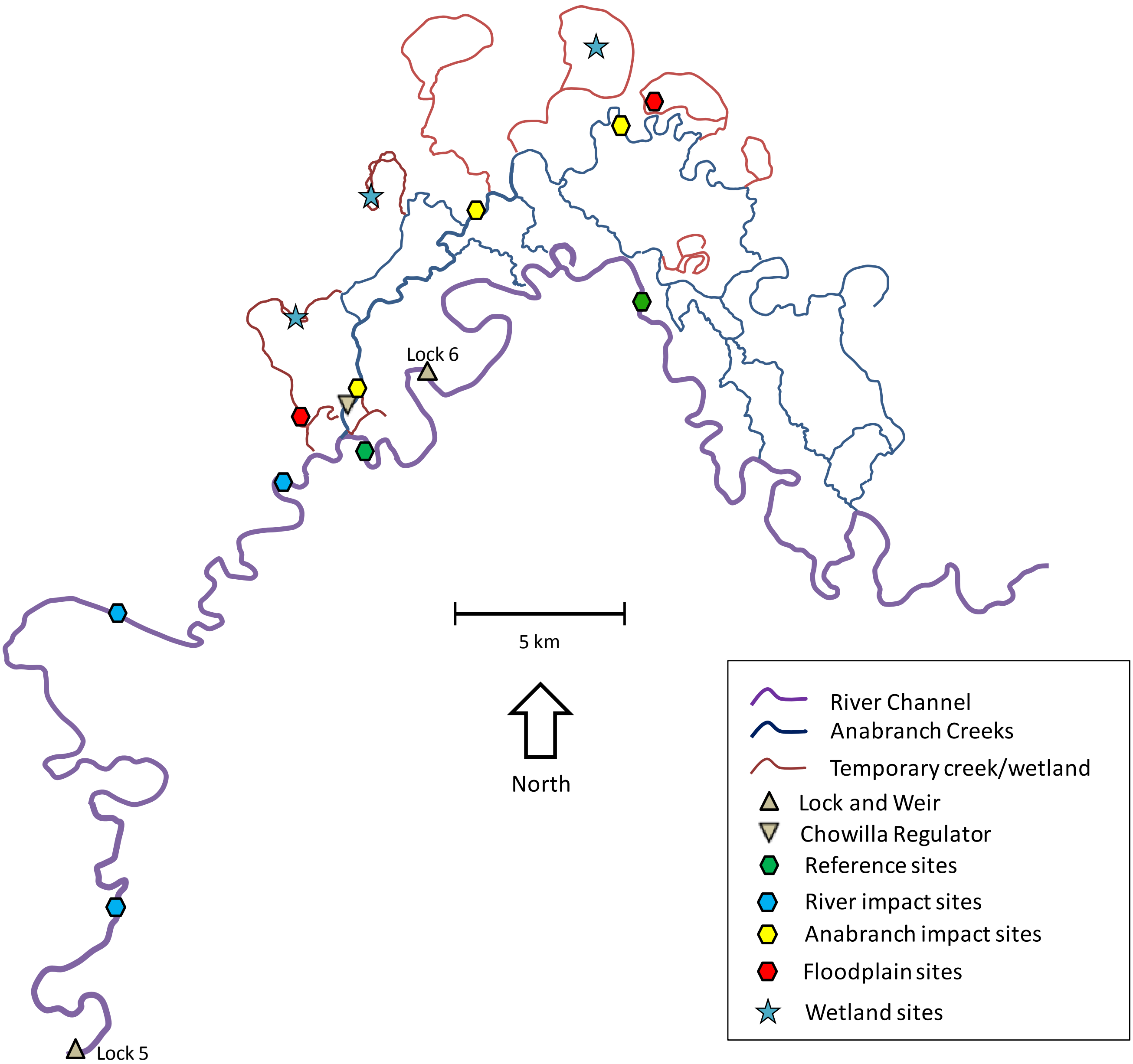


Figure 2: Site schematic. Details of locations are provided Table 2.

Table 1: Hypotheses tested in this project. Detail on sampling stations is provided in Table 2 and Figure 2.

Hypotheses #	Hypotheses tested
1	The management regime utilised during the testing event maintained the key water physico-chemical water quality parameters; salinity, pH and Turbidity within acceptable ranges
2	The management regime utilised during the testing event maintained the key water biological water quality parameters; chlorophyll *a*, cell counts of cyanobacteria, MIB, geosmin, iron and manganese within acceptable limits
3	During the managed inundation, the concentration of resources (nutrients and dissolved organic carbon) will be higher at the site immediately upstream of the Chowilla regulator (A4261224) compared to the reference sites (A4261022 and A4260705) located in the River Murray channel
4	During the managed inundation, return flows from Chowilla Anabranch will result in increased concentrations of resources (nutrients and dissolved organic carbon) in the receiving waters of the Lock 5 weir pool (A4260704) relative to the upstream reference site (A4261022)
5	During the managed inundation, return flows from Chowilla Anabranch (A4261224) will result in increased concentrations of resources (nutrients and dissolved organic carbon) in the mid- (A1) and lower- reaches (A4260703) of the Lock 5 weir pool relative to the upstream reference site (A4261022)
6	During the managed inundation, the concentration of resources (nutrients and dissolved organic carbon) will vary between sites within the anabranch
7	During the managed inundation, 5-day biochemical oxygen demand will be higher at the site immediately upstream of the Chowilla regulator (A4261224) compared to the reference site (A4261022)
8	During the managed inundation, the concentration of resources (nutrients and dissolved organic carbon) will vary between the large wetlands that were inundated (Werta Wert, Coppermine and Lake Limbra) compared to concentrations recorded in the upstream river reference site (A4261022) and in the anabranch at the Regulator (A4261224)
9	During the managed inundation, 5-day biochemical oxygen demand will be higher in the large wetlands that were inundated (Werta Wert, Coppermine and Lake Limbra) compared to the upstream river reference site (A4261022) and in the anabranch at the Regulator (A4261224)
10	The management regime of maintaining daily water exchange of the impounded volume ≥20% and ensuring dilution flows in the river above 7,000 $MLday^{-1}$ is an effective tool to maintain dissolved oxygen within the river above 6 mgO_2L^{-1}
11	The management regime provided sufficient dilution flows in the river channel such that dissolved oxygen within the anabranch was maintained above 6 mgO_2L^{-1}
12	Dissolved oxygen in the wetlands was maintained above 4 mgO_2L^{-1}
13	During managed inundations, return flows from the anabranch (A4261224) result in a significant increase in zooplankton abundance in the receiving waters of the lock 5 weir pool (A4260704) compared to the reference site in the lock 5 weir pool (A4260705)
14	The management regime of maintaining daily water exchange of the stored volume within the anabranch ≥20% is an effective tool to prevent the establishment of persistent stratification within the anabranch
15	The management regime of maintaining flow at Lock 6 > 1,000 $MLday^{-1}$ is sufficient to prevent the establishment of persistent stratification within the river channel upstream of Lock 6
16	Return flows from the managed inundations result in a significant increase in *in-situ* primary productivity in the anabranch (A4261224) and in the receiving water of the Lock 5 weir pool (A4260704) relative to the reference site upstream of Lock 6 (A4261022)

Table 2: Site List. Telemetered permanent station = DO at surface, temperature and salinity at surface and bottom. Locations are provided in UTM zone 54

Site code	Name	Type	Description	Easting	Northing
A4261022	River at Customs House	River upstream reference; Lock 6 weir pool	Telemetered permanent station	496445	6240065
A4260705	River upstream of junction of Chowilla Creek and river	River upstream reference; Lock 5 tail water	Permanent salinity pontoon	487415	6235645
A4260704	River ca. 770 m downstream of return flows from Woolshed Creek South to the river	River – impact site: Lock 5 tail water	Telemetered permanent station	485648	6235167
A4261168	River ca. 1,900 m downstream of return flows from Woolshed Creek South to the river	River – impact site: Lock 5 tail water	Telemetered permanent station	485263	6234888
A426A1	River ca. 17.5 km downstream of junction of Chowilla Creek and river	River – impact site: Lock 5 mid pool	No infrastructure	479790	6230669
A4260703	River ca. 40 km downstream of junction of Chowilla Creek and river	River – impact site: Lock 5 weir pool	Permanent salinity pontoon	479663	6220718
A4261224	Chowilla Creek ca. 80 m upstream of Environmental Regulator	Anabranch – impact site within inundated zone	Telemetered permanent station	487336	6237575
A4261107	Chowilla Creek ca. 9.5 km upstream of Environmental Regulator	Anabranch – impact site within inundated zone	Telemetered permanent station	490956	6243115
A4260580	Punkah Creek ca. 19.5 km upstream of Environmental Regulator	Anabranch – impact site within inundated zone	Telemetered permanent station	495614	6246575
A4261160	Gum Flat	Floodplain	Telemetered permanent station	496402	6246621
A4261166	Coppermine	Floodplain	Telemetered permanent station	486807	6237530
A4261167	AWS	Automatic weather station	Telemetered permanent station	489706	6238952
WWW	Werta Wert Wetland	Temporary Wetland	Temporary Station	487664	6244099
LL	Lake Limbra	Temporary Wetland	Temporary Station	494599	6249019
CMW	Coppermine Wetland	Temporary Wetland	Temporary Station	485223	6240149

Table 3. Sampling dates from each respective location. Sites/dates marked with • indicate sampling was undertaken on that day

Site / Date	A4260580	A4260703	A4260704	A4261168	A4260705	A4261022	A4261107	A4261224	A426A1	Coppermine	Lake Limbra	Werta Wert
18/03/2009	•		•			•	•	•				
7/04/2009	•		•			•	•	•				
29/04/2009	•		•			•	•	•				
19/05/2009	•		•			•	•	•				
5/06/2009	•		•			•	•	•				
1/07/2009	•		•			•	•	•				
4/02/2010	•	•	•		•	•	•	•				
18/03/2010	•	•	•		•	•	•	•				
13/05/2010	•	•	•		•	•	•	•				
17/06/2010	•	•	•		•	•	•	•				
29/07/2010	•	•	•		•	•	•	•				
9/09/2010	•	•	•		•	•	•	•				
16/09/2010	•	•	•			•	•	•	•			
22/09/2010		•	•		•	•	•	•	•			
30/09/2010	•	•	•		•	•	•	•	•			
7/10/2010	•	•	•		•	•	•	•	•			
14/10/2010	•	•	•		•	•	•	•	•			
21/10/2010	•	•	•		•	•	•	•	•	•	•	•
28/10/2010	•	•		•	•	•	•	•	•	•		
29/10/2010											•	•
3/11/2010	•	•		•	•	•	•	•	•			
4/11/2010										•	•	•
5/11/2010	•	•		•	•	•	•	•	•			
10/11/2010										•		•
11/11/2010	•	•		•	•	•	•	•	•			
17/11/2010										•		•
18/11/2010	•	•		•	•	•	•	•	•			
24/11/2010										•		•
25/11/2010	•	•		•	•	•	•	•	•			
1/12/2010										•		•
2/12/2010	•	•		•	•	•	•	•	•			
8/12/2010										•		•
9/12/2010	•	•		•	•	•	•	•	•			

2.4. FLOWS DURING THE 2014 TESTING EVENT

The operational target for the 2014 testing event was to achieve a water level at the Chowilla Regulator of 19.1 mAHD, with two additional short hold periods at intermediate points below the peak to enable engineering checks and flow gauging. These intermediate points were at 17.7 mAHD and 18.4 mAHD. The results from the modelling undertaken for the development of the Chowilla Operations Plan, showing the minimum flows required in order to maintain the Critical Operational Limits (≥20 % daily exchange, maintenance of velocity >0.18 ms^{-1} in 75% of the core habitat) for the peak target water level (19.1 mAHD) are presented in Table 4. The hydrograph that was implemented is shown in Figure 3A. The daily values for (i) percent daily exchange (percentage of total stored volume (excluding terminal wetlands) in the anabranch ÷ by daily inflow) and (ii) percentage of core habitat with velocity >0.18 ms^{-1} that was maintained is shown in Figure 3B. The total area (including permanent creeks) inundated during the testing event is shown in Figure 3[C]. These data demonstrate compliance with the management objective to ensure constant flow through the anabranch (Figure 3[A]), and the two Critical Operational Limits: (i) maintain ≥ 20% daily exchange, and (iii) maintain >75% of core habitat with velocity >0.18 ms^{-1} (Figure 3[B]). The high daily exchange rate late in the testing event is a result of maintaining relatively high inflows via Pipeclay and Slaney Weirs whilst the stored volume was being reduced by lowering the Chowilla Regulator and ancillary structures.

Table 4. Modelled conditions required to maintain the Critical Operational Limits specified in the Chowilla Operations Plan (Wallace & Whittle, 2014c); values from Table 4.1 of the Chowilla Events Plans and Risk Mitigation Strategy document (Wallace & Whittle, 2014a).

QSA	Lock 6		Chowilla Regulator			Pipeclay	Slaney	Area inundated (ha)	% of core habitat maintained	Volume impounded (ML)	% daily exchange
ML/day	mAHD	Q = ML/day	US mAHD	DS mAHD	Q = ML/day	Q = ML/day	Q = ML/day				
8,500	19.68	1,465	19.10	16.44	5,767	3,637	1,315	3,085	78	28,721	20.1

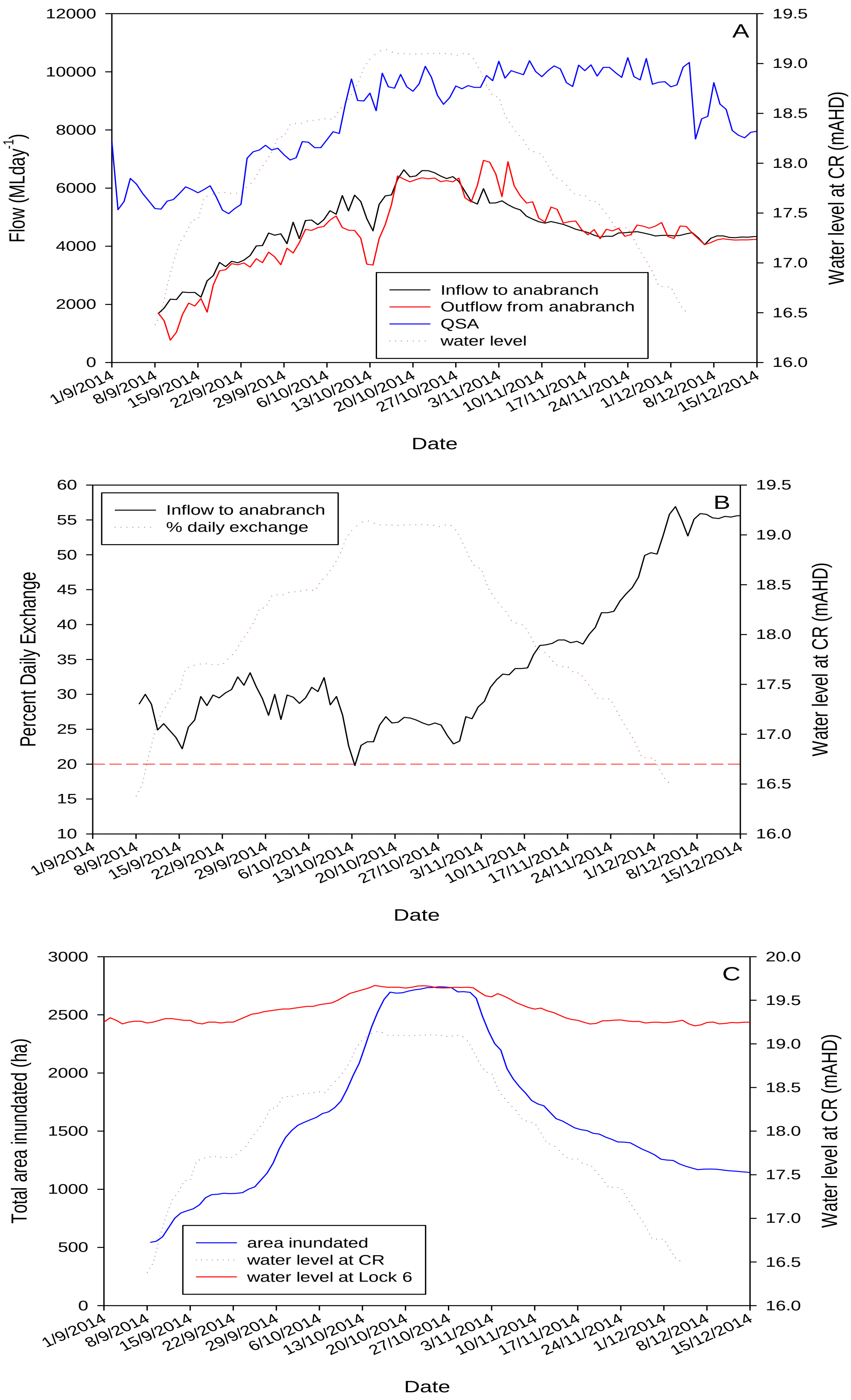


Figure 3: [A] Flows including QSA (flow to SA), combined inflow to anabranch, outflow from anabranch (MLday^{-1}) and water level at the Chowilla Regulator (mAHD); [B] percent daily exchange during the 2014 testing event; and [C] total area (including permanent creeks) inundated during the testing event is shown in Figure 3[C]. Data provided by Andrew Keogh (MDBA) as outputs from Bigmod.

2.5. NATURAL ORGANIC MATTER LOADING

Measurement of organic loading allows for (i) generating an estimate of the potential load of carbon and nutrients that could be released into the water column; and (ii) the potential impact on dissolved oxygen both in the impounded area and in the receiving waters. Calculations can be made either using simple modelling approaches based on first principles or *via* the Black Water Risk Assessment Tool (BRAT) (Whitworth *et al.*, 2013) (see section 4 of this report for information on the BRAT model).

2.5.1. RESULTS

Natural Organic Matter (NOM) loading at the riparian tree line of permanent and temporary creeks, within temporary wetlands and on the open (non-wooded) floodplain is shown in Figure 4. The data shows that the average load is highest and most variable (average = 2,087 ± 3,718 gm^{-2} [StdDev]) along the permanent creek lines where the maximum recorded value was 24,436 gm^{-2}. These results are of the same magnitude as results from a previous assessment of NOM loading at Chowilla Floodplain during which Brookes *et al.*, (2007) recorded average loading in river red gum woodlands of 2,564 ±1,130 gm^{-2}. The lowest average NOM loading in the 2014 assessment was recorded at the floodplain sites (674 ± 595 gm^{-2}). This compares to NOM loadings recorded by Brookes *et al.*, (2007) in grassland (floodplain) areas of 439 ± 90 gm^{-2} and lignum shrubland (floodplain) of 404 ±68 gm^{-2} respectively. Based on the categories presented in Table 5, the average loading at the floodplain sites during the 2014 sampling was low, at the temporary creeks and wetlands was moderate, and at the permanent creeks was high.

Table 5: Categories used for the description of NOM loads (gm^{-2})

Description	minimum	maximum
very low	0	500
low	501	1000
moderate	1001	2000
high	2001	3000
very high	>3001	

2.5.2. DISCUSSION

Robertson *et al*., (1999) could not identify any published estimates for lateral transport of carbon for Australian floodplain rivers. However, those authors estimated the spatial scale of flooding that would be required to result in a significant input to the pool of labile carbon into the river channel. For a hypothetical 10 km^2 section of the mid-Murray (a 100 km long reach with an average width of 100 m) with average daily phytoplankton productivity over the whole year of 0.6 $gCm^{-2}day^{-1}$, annual net production by riverine phytoplankton in the river reach would be 2,190 tonnes of carbon. Gawne et al., (2007) used a lower estimate of phytoplankton productivity (0.28 $gCm^{-2}d^{-1}$). This yields an estimate of 1,022 tonnes of carbon per year. Robertson *et al*., (1999) assumed a standing load of 200 gCm^{-2} and that the DOC release from inundated NOM would be 50 gCm^{-2} to calculate that one flood per year that inundated ca 44 km^2 would deliver as much DOC to the river as the net annual in-stream phytoplankton production in the 10 km^2 reach. Gawne *et al*., used DOC yield data from Baldwin (1999) and O'Connell *et al*., (2000) and estimated that a flood of approximately 34 km^2 would be sufficient.

The area inundated during the 2014 testing event was estimated to be 2,142 ha, plus an additional 160 ha on the southern side of the river (total = 2,302 ha = 23.02 km^2) (MDBA, 2015). An estimate of the load of carbon and nutrients released from inundation of this area can be made using data on NOM loading collected in this study and the data on nutrient release from floodplain plant material published by Brookes *et al*., (2007). The results of the assessment are presented in Table 6 with calculations provided for (i) wetland, (ii) river red gum woodland; and (iii) a pooled average load. The data demonstrate the relative differences in loads of different nutrients and DOC from wetland versus woodland areas. Utilising the average NOM loading for all pooled samples for data collected in 2014 (1,436 gm^{-2}), the estimated total load of NOM that was inundated during the 2014 testing event was 33,057 tonnes, and 603 tonnes of DOC (26.207 gCm^{-2}) would have been released into the water column from the inundation of the floodplain. Based on this estimate, 3901.6 ha would need to be inundated to produce the 1,022 tonnes of net annual in-stream phytoplankton production estimated by Gawne et al., (2007). This is well within the capacity of the maximum inundation extent achievable with the Chowilla environmental regulator operated to full extent; at QSA = 40,000 $MLday^{-1}$, the estimated inundation area is 7,060 ha.

The calculations provided here (Table 6) demonstrate that the allochthonous NOM mobilised during the 2014 testing event represents a very large pool of energy for organisms. However, the fate of the majority of this NOM remains largely speculative. It is generally considered that a large part of the allochthonous NOM may not be assimilated by higher trophic levels. This is because allochthonous material typically has a high carbohydrate content, resulting in high carbon to nitrogen (C:N) and carbon to phosphorus (C:P) ratios, and grazers (e.g. macroinvertebrate shredders) tend to preferentially select food with C:N ratios close to their body tissue (Deegan & Ganf, 2008). Elser *et al*. (2000) showed that median allochthonous C:N ratios were 32:1, compared to 9.6:1 for autochthonous material (median C:P ratios 799:1 and 256:1; N:P ratios 27.3:1 and 26.5:1, respectively). In comparison, median C:N ratios for aquatic invertebrate herbivores are 6.0:1 (range 4–10). Thus, autochthonous NOM sources have median C:N ratios 1.6 times higher than their potential consumers; whilst allochthonous sources have median C:N ratios that are more than fivefold that of their potential consumers. High C:N ratios are considered likely to reduce the efficiency of utilisation and the flow of allochthonous material through the food web. However, the flow-on effects are likely to depend on the pathways through which resources are assimilated (Douglas, Bunn & Davies, 2005; Brookes *et al.*, 2005). Assimilation of soluble carbon and nutrients from leaf litter (and other allochthonous sources) by planktonic heterotrophs, phytoplankton and biofilms may represent the main pathway through which allochthonous NOM enters the food web, rather than *via* shredders and other macroinvertebrates.

Sherr and Sherr (1988) proposed that the microbial food web is capable of transporting a significant proportion of carbon to zooplankton. An estimate of the potential increase in biomass of higher order consumers resulting from the inundation of a given area can be made based on the litter loading, knowledge on release rates of DOC and assumptions on the transfer efficiency of energy (carbon) between trophic levels. Using the DOC release data from Brookes *et al*., (2007) an average NOM loading of 1,436 gm^{-2} and a conservative transfer efficiency of 1% between bacteria and zooplankton, and then a 10% transfer efficiency to higher level grazers, if the estimated total pool of 603 tonnes of allochthonous DOC (Table 6) was cycled through bacteria → zooplankton → plankitvores (e.g. early life stage of large bodied fish), 603 kg of DOC may have been assimilated in higher trophic levels. The BRAT model (Whitworth *et al.*, 2013), which utilises different algorithms for DOC release, predicts that for the same loading and assuming two trophic levels between DOC and fish, 538 kg of carbon could be transferred to fish biomass.

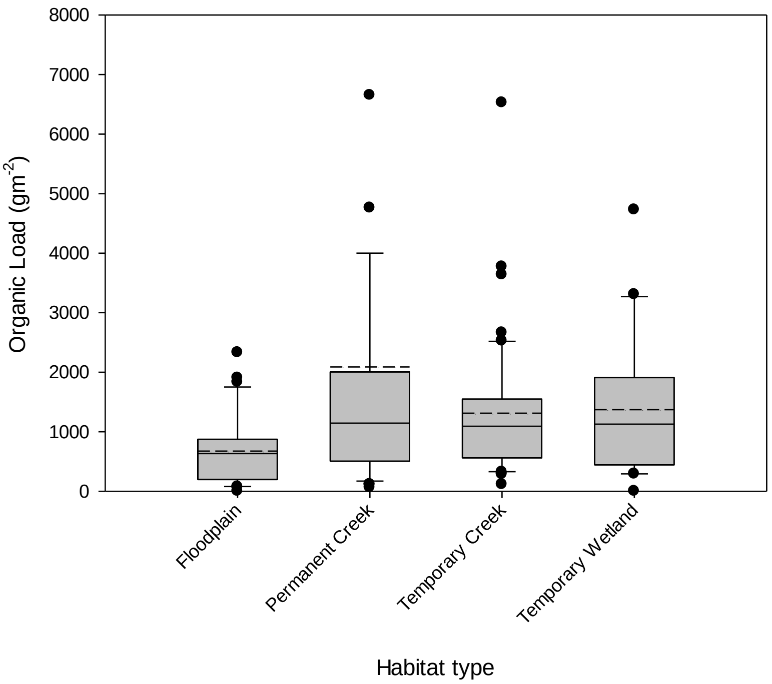


Figure 4: Natural Organic Matter Loading at the four meso-habitats assessed. 150 samples were collected from 38 locations incorporating the riparian tree line of permanent (n = 48) and temporary (n = 51) creeks, temporary wetlands (n = 20) and floodplain (n = 31). Boxes enclose the 25th to 75th percentiles, whiskers enclose the 10th to 90th percentiles, outliers are identified by closed circles; dashed line within box plots depicts mean and solid line the median. Two extreme outliers for the Permanent Creek sites with very high loading (9,012 and 24,436 gm^{-2}) are not shown in this plot but are included in the mean, median and percentiles shown.

Table 6: Estimate of release of nutrients and dissolved organic carbon resulting from the inundation of 2,302 ha of floodplain during the 2014 testing event. Organic loading for wetlands and river red gum woodlands is derived from the data presented in Figure 4. The data on nutrient release per gram of NOM is from mesocosm experiments conducted by Brookes *et al*., (2007).

Habitat	Nutrient	mg nutrient released per g NOM (from Brookes *et al*., 2007)	mg nutrient released per m^2	kg nutrient released per ha	estimated total (tonnes) released during testing event
wetland (NOM load = 674 gm^2)	FRP	0.39	262.86	2.6286	
	TP	0.59	397.66	3.9766	
	TN	1.74	1172.76	11.7276	
	NOx	0.19	128.06	1.2806	
	DOC	12.7	8559.8	85.598	
river red gum woodland (NOM load = 2,087 gm^2)	FRP	0.04	83.48	0.8348	
	TP	0.12	250.44	2.5044	
	TN	1.61	3360.07	33.6007	
	NOx	0.51	1064.37	10.6437	
	DOC	23.8	49670.6	496.706	
average of 2014 loading (NOM load = 1,436 gm^2)	FRP	0.22	308.74	3.0874	7.1
	TP	0.36	509.78	5.0978	11.7
	TN	1.68	2405.3	24.053	55.4
	NOx	0.35	502.6	5.026	11.6
	DOC	18.25	26207	262.07	603.3

2.6. Assessment of hypotheses related to water quality

The full time series data for nutrients (March 2013-December 2014) is presented in Figures A1-7 (Appendix A). The data indicates that there is a substantial degree of temporal variation across the full sampling period. This temporal variability reduces the ability to differentiate between differences in concentration due to management actions and inherent variability in ambient concentrations over multi-year temporal spans. Hence the primary focus of the assessment made here is based on the data from the period coinciding with the testing event (i.e. September-December 2014).

2.6.1. Ho#1: The management regime utilised during the testing event maintained the key water physico-chemical water quality parameters; salinity, pH and Turbidity within acceptable ranges

Salinity

Discharge of saline groundwater into the anabranch creek and the river following floods and high flows is a natural occurrence, but represents a hazard to surface water salinity that must be managed. The salinity target specified in the Basin Plan (Commonwealth of Australia, 2012) is that EC should not exceed 580 μScm^{-1} in the River Murray at Lock 6 for 95% of the time. Given that management actions will influence salinity downstream of Lock 6, this target has been modified (Wallace & Whittle, 2014b) to be applicable for the management of Chowilla yet remain consistent with Basin Plan target, i.e.

- Salinity measured at Water Quality Station A4260704 (River Murray downstream of Lock 6) will be ≤580 μScm^{-1} for 95% of the time

The time series data for salinity recorded at the upstream reference site (A4261022) and the receiving water in the Lock 5 weir pool (A4260704) is presented in Figure 5[A]. The time series data for salinity recorded at the anabranch creek sites (A4260580, A4261107 and A4261224) is presented in Figure 5[B]. The time series data (Figure 5[B]) indicates a substantial salinity spike at A4260580 in late September-early October 2014, with a muted spike at the two sites further downstream in the anabranch. The source of the large spike at A4260580 is considered to be a result of mobilisation of salt from localised sources of high salinity water within the floodplain anabranch complex upstream of the sampling station such as Anderson Creek or Tareena Bong. The magnitude of the salinity spike was substantially smaller at the downstream sites (A4261107 and A4261224), and it is considered that this is most likely due to the inflow *via* Pipeclay and Slaney Creeks diluting the salt load.

The data for the river sites (Figure 5[A]) demonstrate that there was an small increase in EC recorded in the receiving waters (A4260704) relative to ambient salinity recorded upstream of Lock 6 (A4261022). However, there were no exceedances of the Ecological Target for in-stream salinity; the daily data for salinity (measured as EC) recorded at the water quality station in the river downstream of Chowilla (A4260704) indicates that during the period 25th September 2014 to the 30th January 2015, peak EC was 276 μScm^{-1}, well below the EC target of 580 μScm^{-1}. The magnitude of increase above ambient EC (recorded upstream of Lock 6 at station A4261022) was small, peaking at 59 μScm^{-1} on the 2nd November 2014.

The data for salinity in the wetlands, measured as the water column average of the vertical profile conducted at the logger stations, is presented in Figure 8[A]. These data demonstrate that salinity in Werta Wert wetland and Coppermine wetland increased in a quasi linear fashion, and at the final sampling date was 516 μScm^{-1} and 331 μScm^{-1} respectively. These increases above ambient salinity are likely to reflect a combination of release of salt from the soil profile and evapo-concentration of salt as water levels in the respective wetlands decreased. Salinity in Lake Limbra was markedly higher, with the EC on the final sampling date recorded at 1,123 μScm^{-1}. The higher values in Lake Limbra are not unexpected, as soil salinities in this wetland have previously been shown to be (i) relatively high; and (ii) to decrease substantially following managed inundations (Wallace, 2013).

pH

pH was measured *in-situ via* the vertical profiles conducted at each sampling site at the time of collecting the water samples. The time series data for the upstream reference site (A4261022) and the site upstream of the Chowilla Regulator (A4261224) are presented in Figure 6[A]. The time series data for pH at the sites in the Lock 5 weir pool is presented in Figure 6[B]. There is some temporal variability in pH evident in the data. However, the values recorded remained within the range (6.5 – 9.0) specified in Schedule 2 of the Environment Protection (Water Quality) Policy (2003).

There is a divergence between ambient pH values recorded upstream of Lock 6 and those within the anabranch (Figure 6[A]), with pH values in the anabranch generally being lower than at the upstream reference site (A4261022). This is particularly evident after mid-November 2014, when pH values upstream of Lock 6 were higher by 0.3-0.4 pH units than those recorded in both the anabranch (Figure 6[A] and at the other monitoring sites in the Lock 5 weir pool (Figure 6[B]). It is probable that the difference observed is due to diurnal variation in pH, and that the observed trend may simply be a reflection of the sampling sequence. Throughout the sampling period, sampling commenced at A4261022, and subsequent sites were assessed in downstream order. Evidence to support the suggestion that the variation observed may be at least partially due to diurnal variation is provided from the data collected by the EXO Sonde deployed at A4261022 (Figure 6[C]), where during the 7-day period 6th-12th December 2014, diurnal variation of 0.24 (±0.037) pH units was recorded.

The data for pH in the wetlands, measured as the water column average of the vertical profile conducted at the logger stations, is presented in Figure 8[B]. These data demonstrate that pH in Werta Wert wetland (peaked at 8.4) and Lake Limbra (peaked at 7.6) remained within the range (6.5 – 9.0) specified in Schedule 2 of the Environment Protection (Water Quality) Policy (SA Government, 2003). However, pH at Coppermine Wetland peaked at 9.9. The pH values recorded at Coppermine Wetland increased markedly during the later stages of the sampling period, particularly after the 10th of November when the wetland would have started to disconnect from the creek system. It is considered that the driver for the observed increase in pH would be the assimilation of CO_2 from the water column by the increasing biomass of algae observed throughout this phase of the sampling (see sub-section 3.7.2).

Turbidity

Turbidity was measured *in-situ via* the vertical profiles conducted at each sampling site at the time of collecting the water samples. The time series data for the upstream reference site (A4261022) and the site upstream of the Chowilla Regulator (A4261224) is presented in Figure 7[A]. The time series data for pH at the sites in the Lock 5 weir pool is presented in Figure 7[B]. The value for turbidity specified in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 20 NTU. This value is considered low for the lower River Murray. For example, median turbidity in the Lock 10 weir-pool, upstream of the Murray-Darling junction is <25 NTU. Downstream of the junction, median turbidity increases to about 60 NTU (Mackay & Eastburn, 1990). The Ecological Target specified in the Chowilla Operations Plan (Wallace & Whittle, 2014c) is for turbidity to be <40 NTU during base flows, when water is being delivered from the upper Murray system, and <76 NTU when water is being delivered from the Darling River system. The annual median limit specified in schedule 11 of the Basin Plan (Commonwealth of Australia, 2012) is 50 NTU.

There was a marked increase in turbidity at A4261224 compared to the upstream reference site during the recession, and this is particularly evident on the last two sampling dates (Figure 7[B]). This is potentially due to return flows of water draining from the inundated areas of the shedding floodplain back to the anabranch creeks. The data collected by the EXO Sonde deployed at A4261022 (Figure 7[C]) demonstrates four brief spikes in turbidity. For example, between midnight on the 30th November and midday on the 1st December, median turbidity was 376 NTU but the maximum recorded turbidity was 18,170 NTU. These large spikes in turbidity may be associated with either (i) short-term sensor malfunction, or (ii) episodic bank slumping during the recession. Isolated sections of bank where slumping occurred were noted during the field sampling conducted during the recession phase. The median value for turbidity recorded across the sampling period (Figure 7) remained below the 50 NTU threshold specified in Schedule 11 of the Basin Plan (Commonwealth of Australia, 2012) for the reference site upstream of Lock 6 (A4261022) and all sites in the Lock 5 weir pool (A4260705, A4260704, A1, A4260703) and the anabranch (A4261107, A4261224).

The data for turbidity in the wetlands, measured as the water column average of the vertical profile conducted at the logger stations, is presented in Figure 8[C]. These data demonstrate that turbidity in Werta Wert wetland and Coppermine wetland remained below the 50 NTU threshold specified in schedule 11 of the Basin Plan (Commonwealth of Australia, 2012). Values in Lake Limbra peaked at 97.6 NTU. The high NTU values observed in this wetland are consistent with the morphology of the wetland; a large shallow basin with high exposure to wind and the associated water column turbulence and resuspension of sediments generated by waves during windy periods. Werta Wert wetland and Coppermine wetland are comparatively sheltered from the wind due to their morphology and the relatively dense tree line surrounding these wetlands. Differences in soil type and ground cover may also be co-factors explaining the variation in turbidity observed between wetlands.

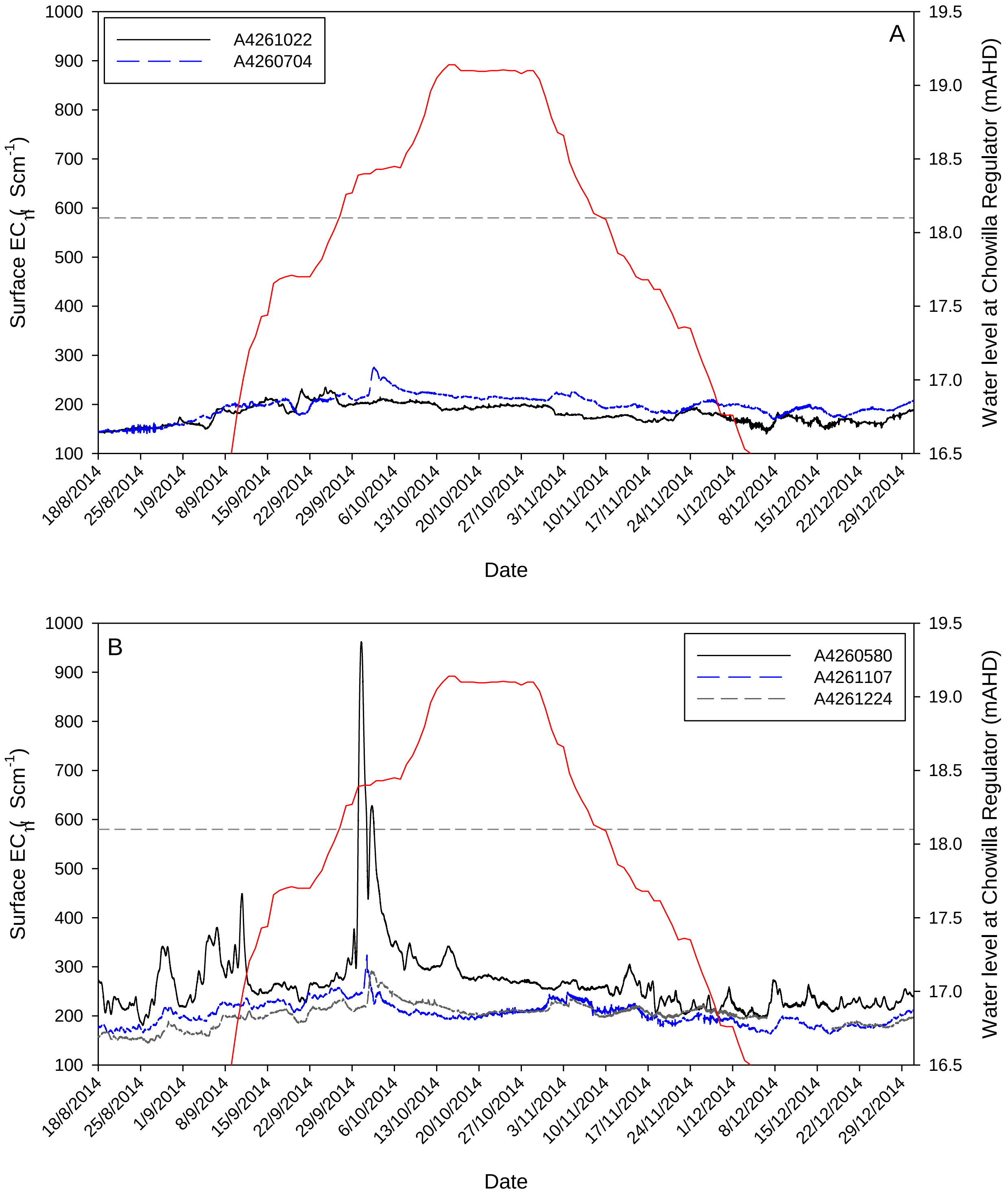


Figure 5: Surface salinity (EC; µScm^{-1}) at [A} the upstream reference site in the Lock 6 weir pool (A4261022) and in the receiving waters of the Lock 5 weir pool (A4260704); and [B] in the anabranch (A4260580, A4261107 and A4261224). The broken horizontal reference line represents the adopted threshold upper limit for EC of 580 µScm^{-1}) at A4260704 as specified in the Chowilla Operations Plan (Wallace & Whittle, 2014c). Red line represents water level at the Chowilla Environmental Regulator.

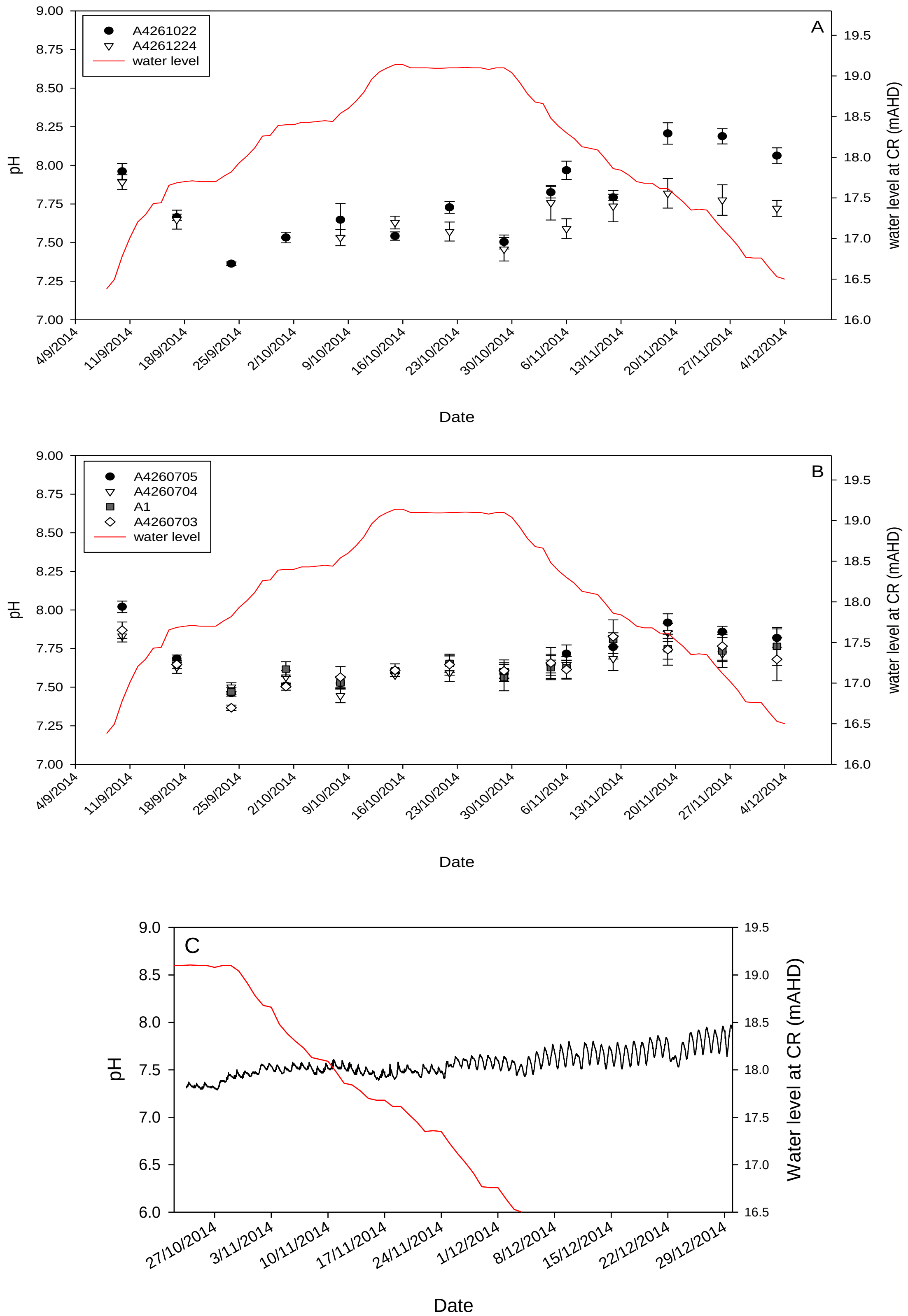


Figure 6: pH [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); [B] within the receiving waters of the Lock 5 weir pool; [C] at A4261224. Data points in plots [A] and [B] are means of water column vertical profiles. Error bars are ±1 Standard Error. Data in Plot C is from the EXO logger deployed at A4261224. The guideline limit for pH stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 6.5-9.0.

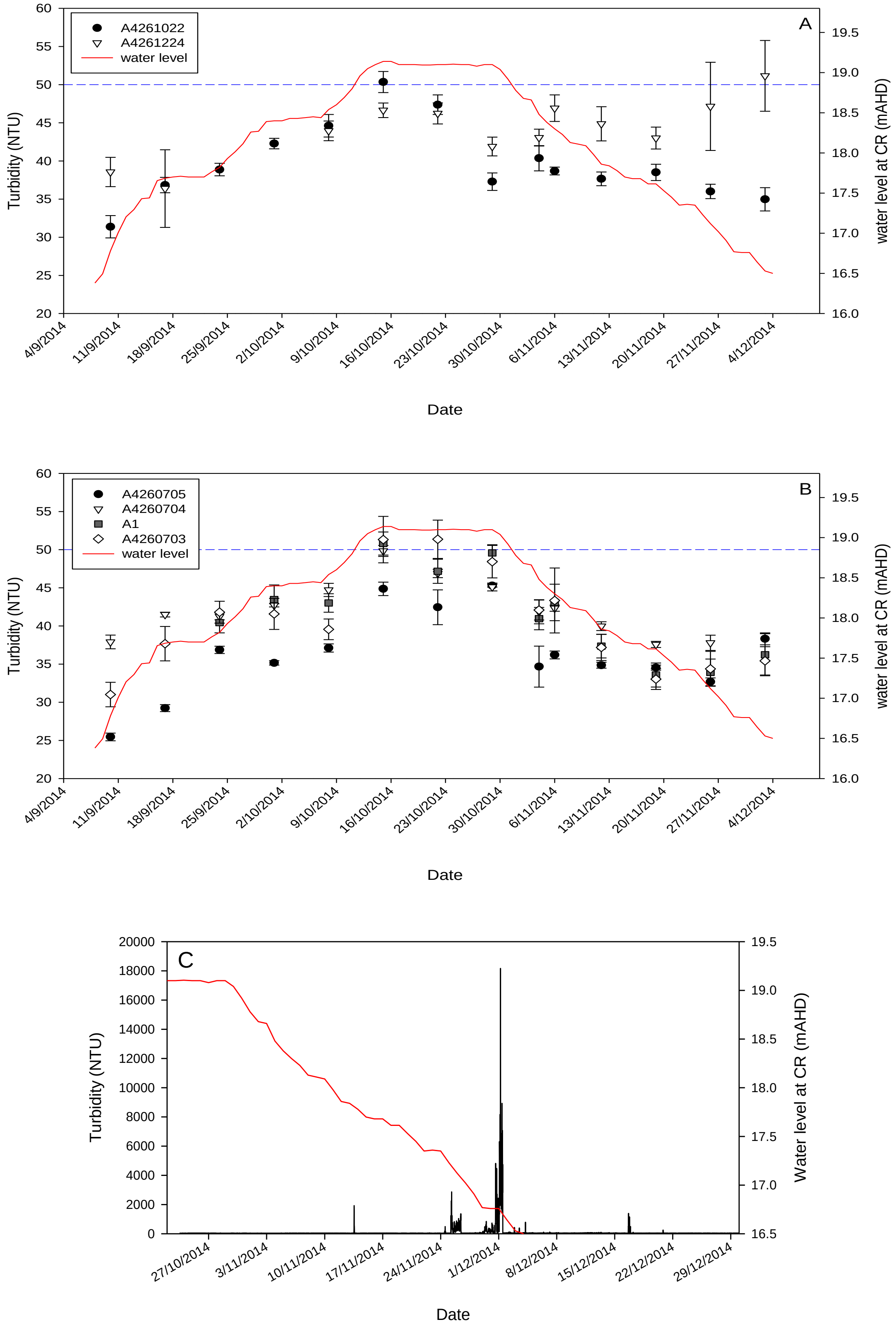


Figure 7: Turbidity (NTU) [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Data points in plots [A] and [B] are means of water column vertical profiles. Error bars are ±1 Standard Error. Data in Plot C is from the EXO logger deployed at A4261224. The blue horizontal reference line in plot A and B represents the annual median limit specified in the Basin Plan (schedule 11) for turbidity (50 NTU).

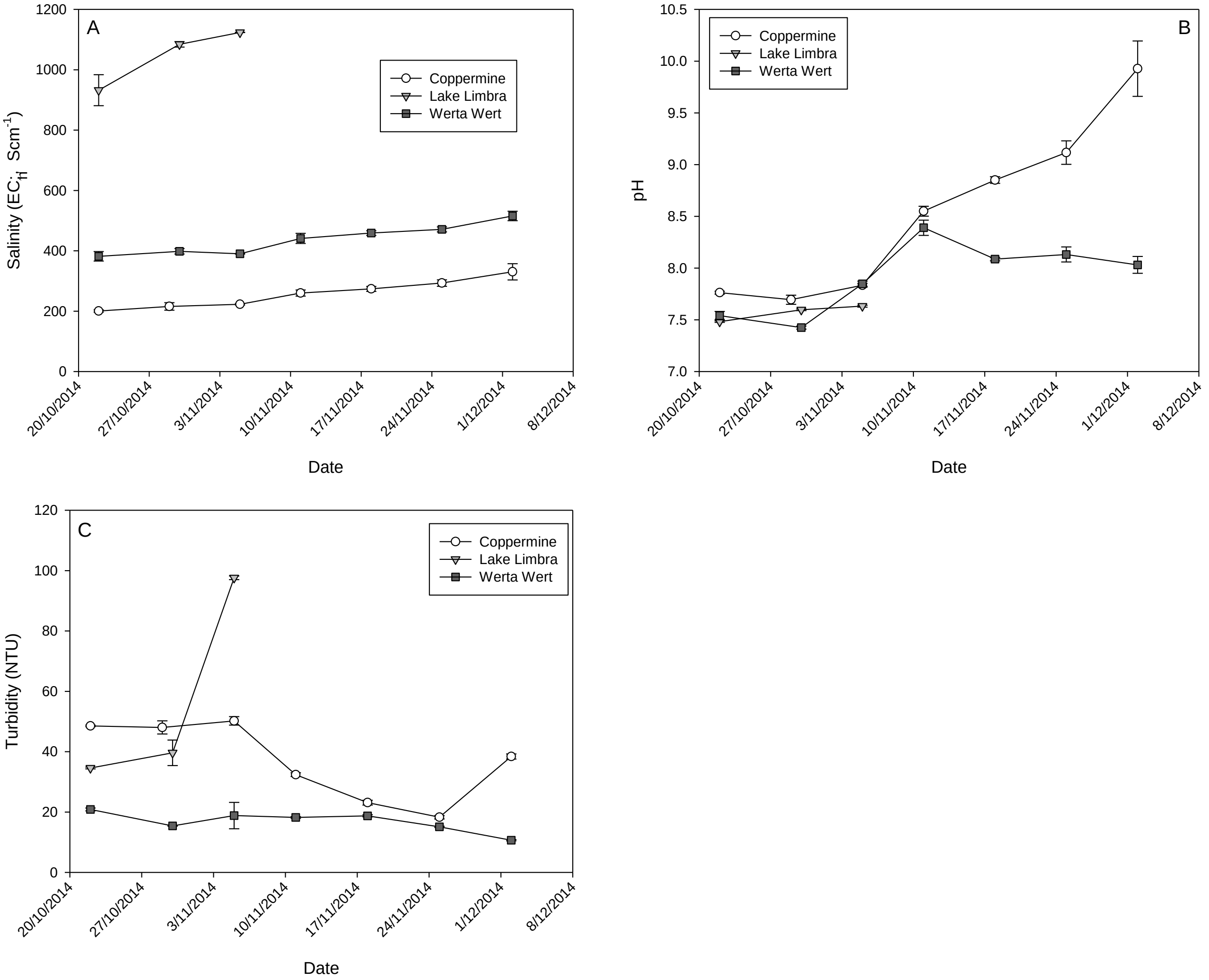


Figure 8: [A] Salinity (EC; µScm^{-1}), [B] pH and [C] Turbidity within Coppermine Wetland, Lake Limbra, and Werta Wert wetlands. The guideline limit for pH stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 6.5-9.0. The guideline limit for Turbidity stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 20 NTU. The annual median limit specified in the Basin Plan (schedule 11) is 50 NTU.

2.6.2. HO#2: THE MANAGEMENT REGIME UTILISED DURING THE TESTING EVENT MAINTAINED THE KEY WATER BIOLOGICAL WATER QUALITY PARAMETERS; CHLOROPHYLL A, CELL COUNTS OF CYANOBACTERIA, MIB, GEOSMIN, IRON AND MANGANESE WITHIN ACCEPTABLE LIMITS

CHLOROPHYLL

There is no Ecological Target for chlorophyll *a* specified in the Chowilla Operations Plan (Wallace & Whittle, 2014c). However, chlorophyll *a* provides a rapid and widely used method of assessing phytoplankton biomass. The guideline value for chlorophyll *a* presented in the ANZECC water quality guidelines (2000) is 5 μgL^{-1}. This value is considered unrealistically low for the lower River Murray; apart from occasional summer blooms, the chlorophyll concentration in the SA Murray River is typically between 10-20 ugL^{-1} (Oliver & Lorenz, 2013).

Chlorophyll *a* was measured *in-situ via* the vertical profiles conducted at each sampling site at the time of collecting the water samples. The time series data for the upstream reference site (A4261022) and the site upstream of the Chowilla Regulator (A4261224) is presented in Figure 9[A]. The time series data for sites in the Lock 5 weir pool is presented in Figure 9[B]. It is of note that the peak values for chlorophyll *a* were recorded prior to the testing event commencing. Chlorophyll *a* was typically higher in the anabranch (A4261224) compared to the upstream reference site (A4261022), particularly during the recession phase when concentrations were 2-3 μgL^{-1} higher in the anabranch (Figure 9[A]). This indicates that conditions within the anabranch were amenable to supporting faster growth rates within the anabranch. The data for chlorophyll *a* in the receiving waters of the Lock 5 weir pool (Figure 9[B] indicate that chlorophyll *a* is elevated in the sites downstream of Chowilla. Throughout the period coinciding with the peak of the inundation (mid-October-early November 2014) the highest values for chlorophyll *a* were recorded at the most downstream site assessed in the Lock 5 weir pool (A4260703). It is possible that the increased values observed at A4260703 are a result of phytoplankton growth resulting in an accumulation of biomass within the relatively slow flowing tail water section of the weir pool.

The data collected by the EXO Sonde deployed at A4261022 (Figure 9[C]) demonstrates three brief spikes in chlorophyll *a*, where values peaked above 40 μgL^{-1}. These large spikes in chlorophyll *a* may be associated with either (i) short-term sensor malfunction, or (ii) coincide with return flows of water from wetlands and/or sections of shedding floodplain that contain high phytoplankton biomass. Evidence to support the suggestion that the episodic spikes may be due to return flows from areas with low dilution and/or long retention times is provided from the data from the wetlands (Figure 10) which demonstrate very high readings of chlorophyll *a*. Peak values in Coppermine Wetland and Werta Wert Wetland where ca. 30 μgL^{-1} (Figure 10).

The data for chlorophyll *a* in the wetlands, measured as the water column average of the vertical profile conducted at the logger stations, is presented in Figure 10. These data demonstrate that by the final sampling period for Lake Limbra, chlorophyll *a* values in this wetland had peaked at 18.65 μgL^{-1}. The data suggests that there was an algal bloom in Werta Wert wetland during which chlorophyll *a* values peaked at 27.9 μgL^{-1}, but the high biomass (indicated by the chlorophyll *a*) appeared to "crash" in late November-early December. It is probable that the collapse of this "bloom" may be a result of exhaustion of the available pool of available phosphorus in this wetland. High chlorophyll *a* values were also recorded in Coppermine wetland where chlorophyll *a* values peaked at 31.4 μgL^{-1}. A key difference between Coppermine wetland and Werta Wert wetland is that the bloom in Coppermine wetland appeared to be sustained, and the pool of available phosphorus did not appear to be limiting. Total Phosphorus increased throughout the sampling period and high concentrations of FRP were recorded at Coppermine wetland on all sampling occasions. It is also of note that Coppermine wetland sustained a large biomass of the emergent macrophyte Moira grass (also known as spiny mud grass) (*Pseudoraphis spinescens*) during the 2014 testing event. High algal biomass was also recorded by Wallace and Lenon (2010) in this wetland during a pumped and ponded managed inundation during late spring-summer (November 2009-February 2010). These observations demonstrate that this wetland has a very high capacity to sustain plant productivity.

Cell counts of cyanobacteria

Blue green algae – river sites:

The sampling site used for the upstream reference was changed from upstream of Lock 6 (A4261022) to downstream of Lock 6 (A4260705) on the 29th October 2014. Peak cell counts recorded for blue-green algae (BGA) were 7,530 cells mL^{-1} at A4260704 on the 30th July 2014 (Table 5), prior to the Chowilla regulator testing event. During the period 10th September-29th October 2014, BGA cell counts at A4261022 ranged from 0 to 290 cells mL^{-1}. During the period 29th October-3rd December 2014, BGA cell counts at A4260705 ranged from 0 to 240 cells mL^{-1}, but peaked at 1,480 cells mL^{-1} on the final sampling date (10th December 2014).

At station A4260704, in the River Murray downstream of Chowilla Creek, BGA cell counts during the testing period peaked at 1,570 cells mL^{-1} on the 10th December 2014. This peak appears to be attributable to high ambient BGA cell counts rather than high cell counts in return flows from the anabranch. High BGA cells counts (840 cells mL^{-1}) were also recorded at A4260704 on the 29th October. However, the relatively high cell counts recorded at this time may be attributable to return flows, as BGA cell counts on this sampling date were higher in the sample from A4261224 (222 cells mL^{-1}) than that at the upstream reference site. During the 2014 testing event, cell counts for blue-green algae at the site in the mid-reach of the Lock 5 weir pool (A426A1) (Table 7) peaked at 478 cells mL^{-1} on the 12th November. At the most downstream site (A4260703), a small peak was observed on the 19th November (136 cells mL^{-1}) and another peak on the 10th December (316 cells mL^{-1}).

The temporal sampling (weekly) used in this study is not fine enough to align specific peaks between sites. However, it is possible that the large peak observed at A4260705 and at A4260704 on the 10th December 2014 was not observed at A426A1 and A4260703 due to travel times between the top and bottom of the weir pool. Similarly, the peak at A426A1 recorded on the 12th November, and the peak recorded at A4260703 recorded on the 19th November, may be associated with the high cell counts recorded at A4260704 on the 29th November.

At the wetlands no BGA were recorded in the samples collected from Lake Limbra. At Werta Wert wetland, BGA cell counts peaked at 334 cells mL^{-1} following an earlier peak (and subsequent crash) in cell counts on the 11th November 2014. The highest BGA cell counts were consistently recorded in Coppermine Wetland where BGA counts peaked at 1,650,000 cells mL^{-1} on the 25th November. This reflects the large peaks in chlorophyll *a* recorded in this wetland (Figure 10). High BGA cell counts were also recorded by Wallace and Lenon (2010) in this wetland during a pumped and ponded managed inundation during late spring-summer (November 2009-February 2010).

Geosmin producing blue green algae:

For the period of the testing operation (September – December 2014), the highest values for cell counts of geosmin producing blue-green algae (gBGA) for all river sites were recorded at the reference site (Table 8). gBGA counts peaked at 316 cells mL^{-1} on the 10th December, and were also relatively high on the 8th October and 26th November (290 and 240 cells mL^{-1}). The highest cell counts for samples from the anabranch (A4261224) were recorded on the 15th October (140 cells mL^{-1}) and 10th December (102 cells mL^{-1}). At the downstream sites in the Lock 5 weir pool, cell counts for gBGA were typically <100 cells mL^{-1}, with the highest cell counts recorded on the 10th December.

No gBGA were recorded in the samples collected from Lake Limbra or Werta Wert wetland. However, at Coppermine Wetland where very high cell counts for BGA were recorded, high cell counts for gBGA were observed, peak gBGA cell counts of 19,000 cells mL^{-1} were recorded on the 25th November 2014.

MIB and Geosmin

MIB concentrations were <4 ngL^{-1} in the samples that were submitted to SA Water for analysis. At the upstream reference site in the Lock 6 weir pool (A4261022) the geosmin concentration was 8 ngL^{-1} on the 22nd October 2014. For the subsequent samples collected from the upstream control in the Lock 5 tail water (A4260705) geosmin concentrations peaked at 3 ngL^{-1} on the 29th October 2014, and were subsequently <2 ngL^{-1} for all remaining sampling dates. At the Chowilla Regulator (A4261224) geosmin concentrations peaked at 5 ngL^{-1} on the 22nd October 2014, and were subsequently <2 ngL^{-1} for all remaining sampling dates. Concentrations of geosmin were <2 ngL^{-1} for those sampling dates (6th, 12th, 19th November) when concentrations were assessed at the receiving water (A4260704) site in the Lock 5 weir pool. The combined total concentration of geosmin+MIB at each of the respective sites in the anabranch and receiving waters of the Lock 5 weir pool, were less than the SAWater River Murray water quality target (<10 ngL^{-1}) throughout the testing event.

Iron and Manganese

Hypoxic conditions can lead to an increase in solubilised metals, ammonia and sulphide. Some of these are toxic to fish and other aquatic biota. Metals such as iron and manganese which can be released from the sediments under anoxic conditions (Davison, 1993) degrade the quality of water for potable use (NRMMC, 2011). The data for soluble and total iron (Fe) and manganese (Mn) is presented in Figures 11 and 12. There is a substantial spike in soluble Mn (0.0296 mgL^{-1}) at A4261224 on the 6th November 2014 (Figure 12[A]). No spike was observed at the receiving water (A4260704) downstream of the confluence of Chowilla Creek and the river. Consequently it is unclear if this spike is a real observation or an anomaly generated via either sampling error or analysis (e.g. sample contamination). Irrespective of this, the concentration of iron (Fe) and manganese (Mn) was below the threshold limits specified in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) at all times.

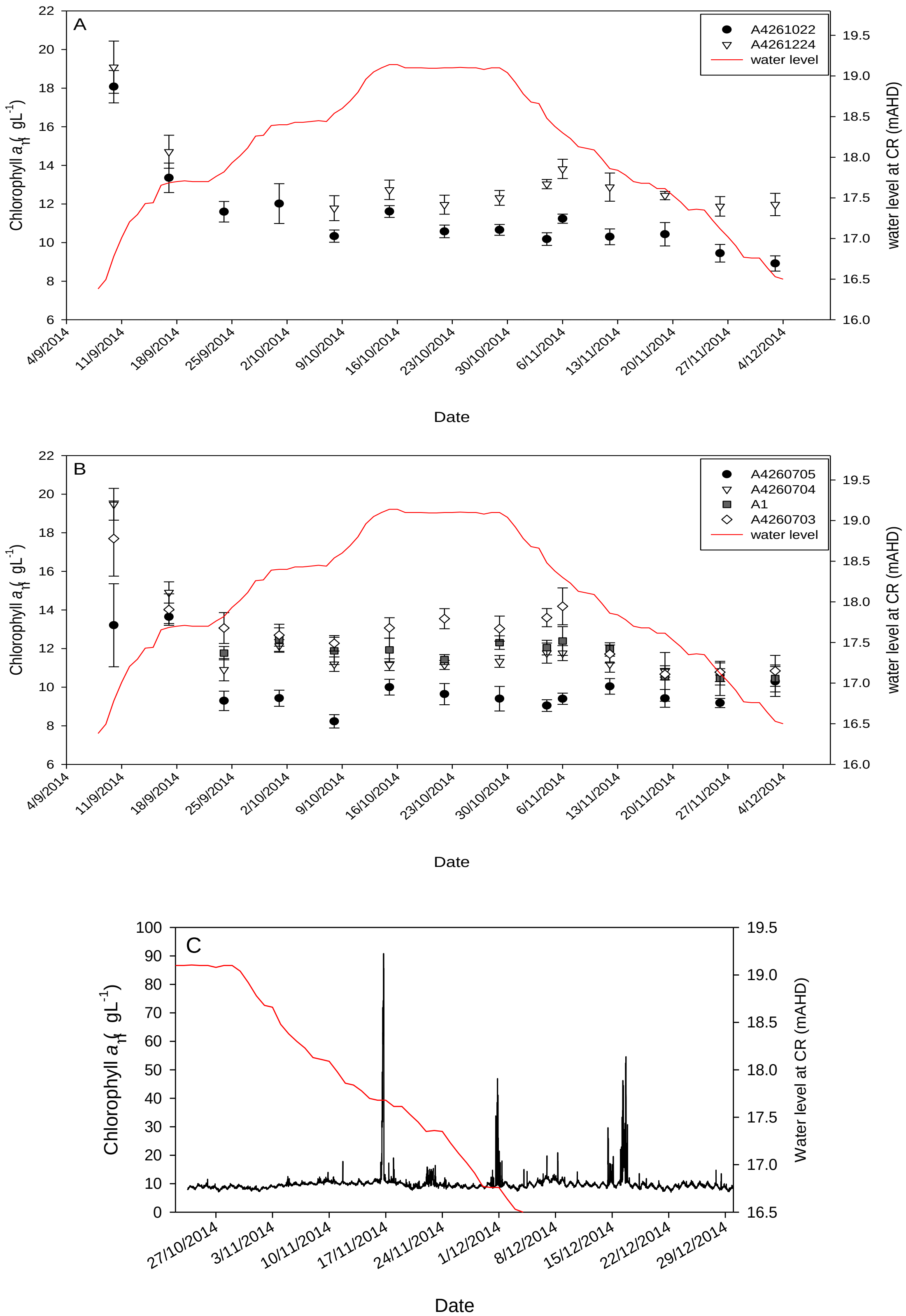


Figure 9: Chlorophyll *a* (µgL^{-1}) at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Data points in plots [A] and [B] are means of water column vertical profiles. Error bars are ±1 Standard Error. Data in Plot C is from the EXO logger deployed at A4261224.

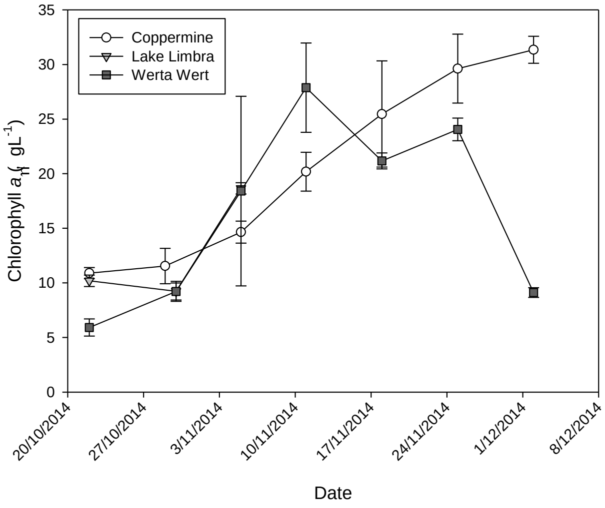


Figure 10: Chlorophyll *a* in the wetlands. Lines between data points do not imply values between sampling periods but are presented for visual clarity.

Table 7: Cell counts for blue-green algae for samples collected from key sites (samples were not processed for all sites to manage costs associated with algal identification).

Row Labels	A4260703	A4260704	A4260705	A4261224	A426A1	Coppermine	Lake Limbra	Werta Wert
19/03/2014		854	23					
14/05/2014		1,400	992	1270				
18/06/2014								
30/07/2014		7,530	258	206				
10/09/2014		0	0	0				
17/09/2014	0	0	0	0	0			
23/09/2014		29	42	47				
1/10/2014		18	0	14				
8/10/2014		18	290	90				
15/10/2014		58	0	140				
22/10/2014	0	30	82	50	32	0	0	0
29/10/2014	0	840	0	222	0	0		
30/10/2014							0	0
4/11/2014		0	45	74				
5/11/2014						2,270	0	0
6/11/2014	28	50	14	160	0			
11/11/2014						5,440		126
12/11/2014	60	0	0	0	478			
18/11/2014						23,900		0
19/11/2014	136	0	0	0	0			
25/11/2014						1,650,000		0
26/11/2014	0	92	240	46	144			
2/12/2014						138,000		334
3/12/2014	50	0	0	114	122			
9/12/2014						452,000		0
10/12/2014	316	1,570	1,480	582	170			

Table 8: Cell counts for geosmin producing blue-green algae for samples collected from key sites (samples were not processed for all sites to manage costs associated with algal identification).

Date	A4260703	A4260704	A4260705	A4261224	A426A1	Coppermine	Lake Limbra	Werta Wert
19/03/2014		14	23					
14/05/2014		825	308	560				
18/06/2014								
30/07/2014		450	88	102				
10/09/2014		0	0	0				
17/09/2014	0	0	0	0	0			
23/09/2014		26	42	47				
1/10/2014		18	0	14				
8/10/2014		18	290	90				
15/10/2014		58	0	140				
22/10/2014	0	30	38	26	32	0	0	0
29/10/2014	0	0	0	0	0	0		
30/10/2014							0	0
4/11/2014		0	6	74				
5/11/2014						468	0	0
6/11/2014	16	0	14	0	0			
11/11/2014						3,120		0
12/11/2014	60	0	0	0	38			
18/11/2014						180		0
19/11/2014	0	0	0	0	0			
25/11/2014						19,000		0
26/11/2014	0	0	240	46	92			
2/12/2014						12,600		0
3/12/2014	50	0	0	94	24			
9/12/2014						1,420		0
10/12/2014	92	230	316	102	156			

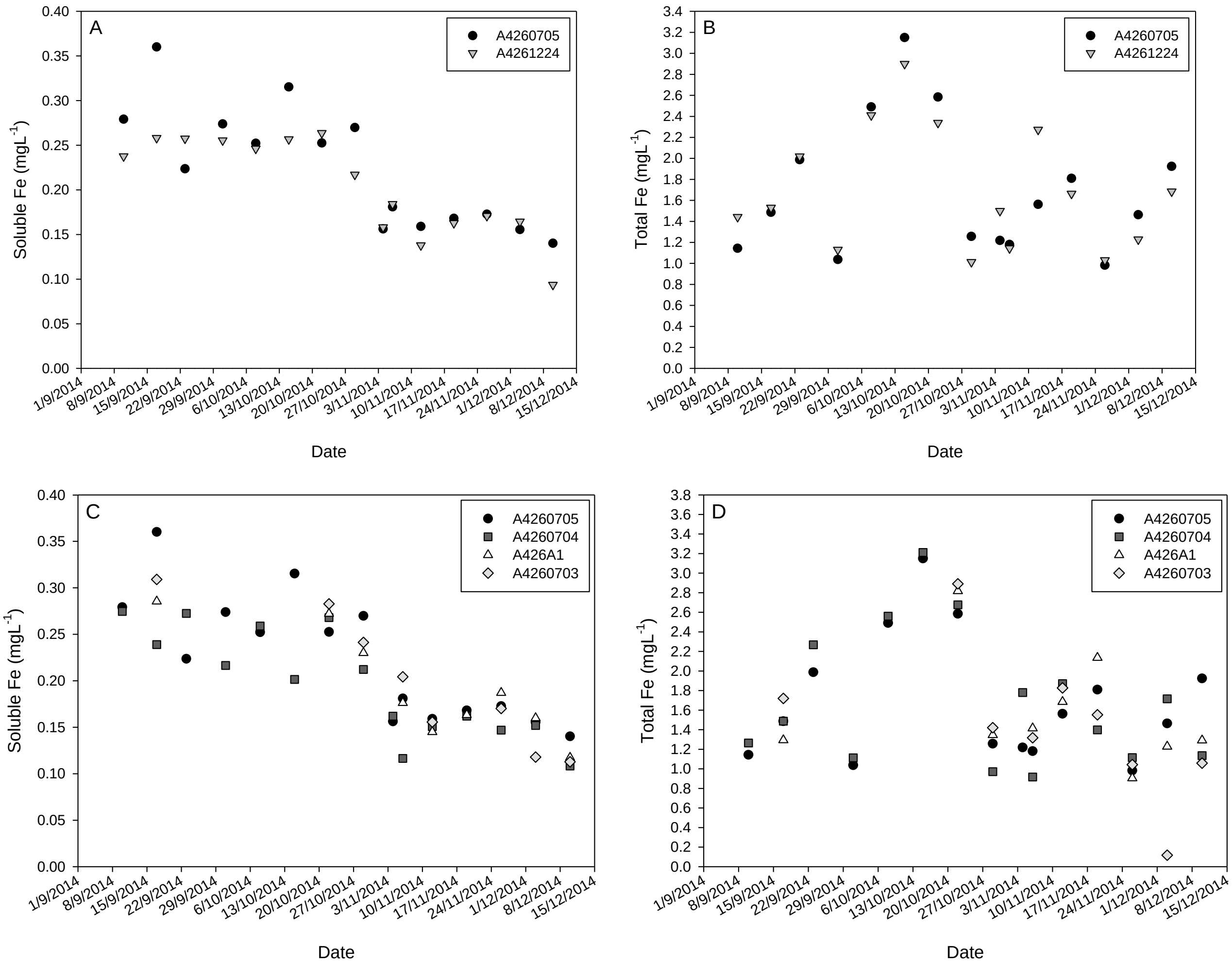


Figure 11: Concentration of soluble and total iron (Fe; mgL^{-1}) at [A] and [B] the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [C] and [D]) within the receiving waters of the Lock 5 weir pool. The guideline limit for soluble and total iron (Fe) state in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 1 mgL^{-1}.

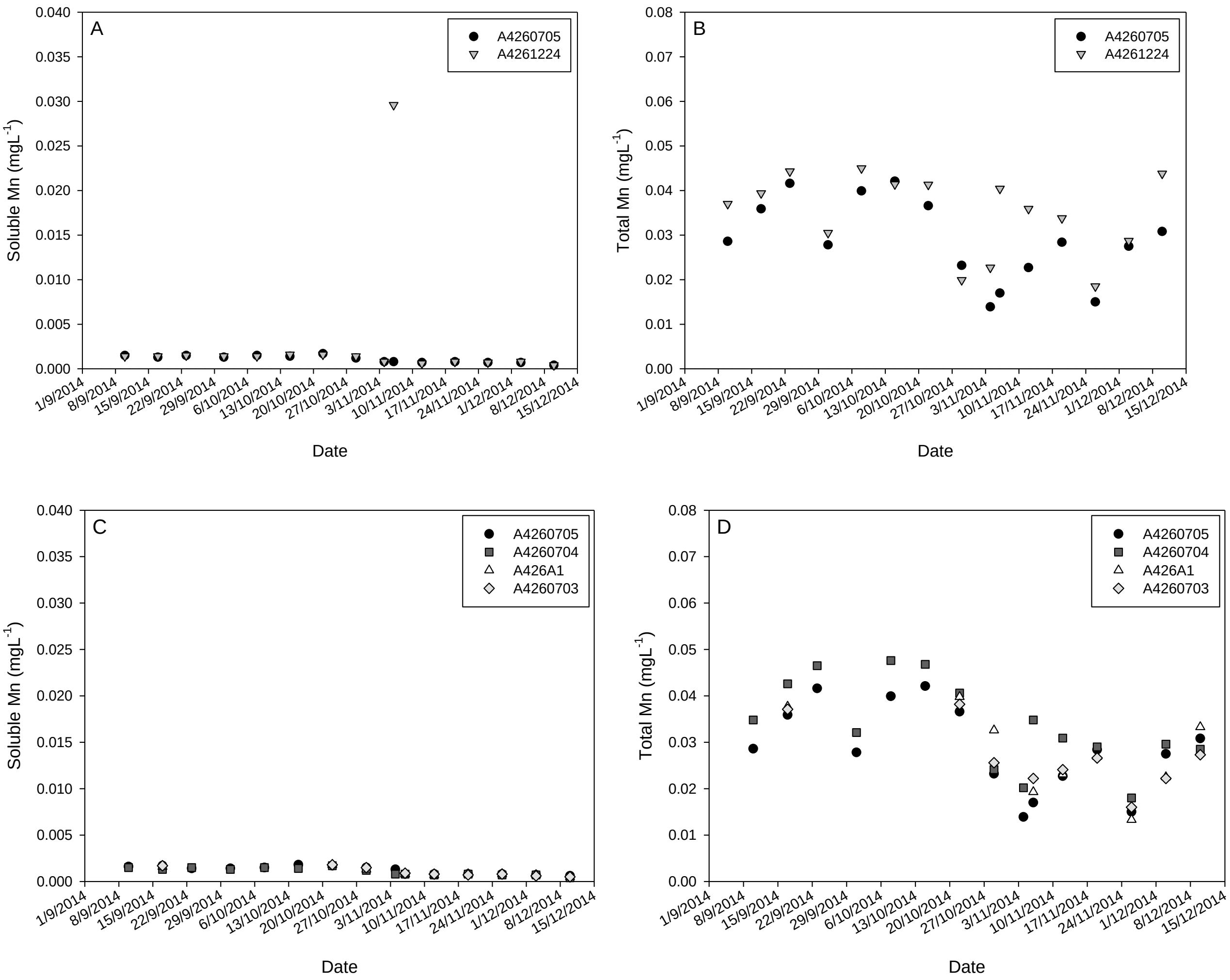


Figure 12: Concentration of Manganese (Mn; mgL^{-1}) at [A] and [B] the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [C] and [D]) within the receiving waters of the Lock 5 weir pool. The guideline limit for soluble and total Manganese (Mn) state in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 0.5 mgL^{-1}. The Australian Drinking Water guidelines (ADWG) identify an aesthetic limit is 0.1 mgL^{-1} (ADWG health limit is <0.5 mgL^{-1})

2.6.3. HO#3: DURING THE MANAGED INUNDATION, THE CONCENTRATION OF RESOURCES (NUTRIENTS AND DISSOLVED ORGANIC CARBON) WILL BE HIGHER AT THE SITE IMMEDIATELY UPSTREAM OF THE CHOWILLA REGULATOR (A4261224) COMPARED TO THE REFERENCE SITES (A4261022 AND A4260705) LOCATED IN THE RIVER MURRAY CHANNEL

The time series for concentration of total nitrogen (TN), total phosphorus (TP), oxidised nitrogen (NOx), ammonia (NH_3), filterable reactive phosphorus (FRP) and dissolved organic carbon (DOC) are presented in Figures 13-18. The plots demonstrate that the concentrations of these resources were all below the respective limits stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003).

A comparison of the results from the two reference sites; (i) upstream of Lock 6 (A4261022) and (ii) the Lock 5 weir pool upstream of Chowilla Creek (A4260705) reveals that there are a significant differences in the concentration of resources between the two reference sites at varying times (see Table 9 for PERMANOVA results). This result is considered to be a result of a large proportion of flow to SA (QSA) being diverted through the anabranch, particularly during the testing event, such that the reach between Lock 6 and the junction of Chowilla Creek experienced very low flows. Consequently, it is considered that A4261022 is a more reliable indicator of ambient water quality.

A comparison between the reference site (A4261022) and the site immediately upstream of the Chowilla Regulator (A4261224) reveals that there are significant differences in the concentration of all resources at various dates during the sampling period (see Table 10 for PERMANOVA results). The majority of the differences occur during the period after the 15th October 2014; i.e. during the peak of the testing hydrograph and during the recession. It is of note that despite the DOC values being markedly higher upstream of the regulator (A4261224) on the 6th of November than at the reference site (A4261022) (see Figure 18), the PERMANOVA analysis did not reveal a statistically significant difference. It is considered that this finding is a result of the wide variation in the results at A4261124 on this day. A cross-check of the results of the PERMANOVA analysis utilising a one-way ANOVA revealed that the differences in the mean values are not great enough to exclude the possibility that the difference is due to random sampling variability. However, the power of the test with alpha at 0.050 was 0.424, well below the desired power of 0.800. This indicates that the analysis is less likely to detect a difference when one actually exists, and the negative result (no significant difference) should be interpreted cautiously. A one-tailed t-test for the DOC data reveals a significant difference ($P = 0.0323$). Therefore, it is considered that the difference in DOC values recorded on the 6th of November is likely to be meaningful from a water quality perspective, despite not being statistically significant.

The data from the EXO Sonde deployed at A4261224 indicates that fDOM (fluorescing dissolved organic matter) was elevated during the peak of the hydrograph and declined throughout the recession (Figure 19[A]). There are a number of distinct peaks in fDOM late in the hydrograph period (early-mid December). An overlay of the data on chlorophyll a, turbidity and fDOM is presented in Figure 19[B]. There is some alignment between the peaks suggesting that these peaks may be associated with return flows of water from the inundated areas that contain high concentrations of suspended sediments and natural organic matter.

2.6.4. HO#4: DURING THE MANAGED INUNDATION, RETURN FLOWS FROM CHOWILLA ANABRANCH WILL RESULT IN INCREASED CONCENTRATIONS OF RESOURCES (NUTRIENTS AND DISSOLVED ORGANIC CARBON) IN THE RECEIVING WATERS OF THE LOCK 5 WEIR POOL (A4260704) RELATIVE TO THE UPSTREAM REFERENCE SITE (A4261022).

A comparison between the upstream reference site (A4261022) and the receiving water (A4260704) reveals significant differences in the concentration of resources at various dates during the testing period (see Table 11 for PEMANOVA results). Of the 28 significant differences in water quality detected over the 20 sampling periods, 18 of the significant differences occurred during the 5 sampling periods conducted between the 8th of October and the 4th November 2014, indicating that the largest influence of return flows from the anabranch to the river occurred during the rising limb and peak of the hydrograph. It is considered that the paucity of differences between A4261022 and A4260704 during the recession phase reflects the dilution being provided by an increasing proportion of QSA being delivered down the main channel during the recession as a result of (i) the comparatively high flows during the recession (see Figure 3[A]) and the progressive lowering of Lock 6 (see Figure 3[C]).

2.6.5. HO#5: DURING THE MANAGED INUNDATION, RETURN FLOWS FROM CHOWILLA ANABRANCH (A4261224) WILL RESULT IN INCREASED CONCENTRATIONS OF RESOURCES (NUTRIENTS AND DISSOLVED ORGANIC CARBON) IN THE MID- (A426A1) AND LOWER- REACHES (A4260703) OF THE LOCK 5 WEIR POOL RELATIVE TO THE UPSTREAM REFERENCE SITE (A4261022).

A comparison between the reference site (A4261022) and the site in the mid-reach of the Lock 5 weir pool (A426A1) reveals significant differences in the concentration of resources at various dates during the testing period (see Table 12[A] for PERMANOVA results). Resources to support sampling during the baseline period were not available. Therefore it is not possible to ascertain if the differences could be attributed to the return flows, or from diffuse inputs of resources between the two sampling locations. A comparison between the reference site (A4261022) and the site in the lower-reach of the Lock 5 weir pool (A4260703) reveals significant differences in the concentration of resources at various dates during the testing period (see Table 12[B] for PEMANOVA results). There are a high proportion of significant differences during the testing period relative to the baseline period. It is considered that the increased concentrations of resources at A4260703 are a result of the return flows from the Chowilla Anabranch. This indicates that return flows from the Chowilla Anabranch are influencing the abundance of resources to fuel primary productivity for at least 40 km downstream of the return flows.

2.6.6. HO#6: DURING THE MANAGED INUNDATION, THE CONCENTRATION OF RESOURCES (NUTRIENTS AND DISSOLVED ORGANIC CARBON) WILL VARY BETWEEN SITES WITHIN THE ANABRANCH

A comparison between the sites within the anabranch reveals that there are significant differences in the concentration of resources at various dates throughout the sampling period (see Tables 13 A-C for PERMANOVA results). During the period of the testing event (10th September-10th December), there were substantially more occurrences of significant differences between A4260580 and A4261107 (n = 37, see Table 13[A]) than between A4260580 and A4261224 (n = 27, see Table 12 [B]), and between A4261107 and A4261224 (n = 16, see Table 13[C]). The higher frequency of differences between the most upstream site (A4260580) and the sites further downstream is potentially due to dilution of resources as a result of the substantial inflow into the anabranch via Pipeclay Creek, Slaney Creek (upstream of A4261107) and Boat Creek (upstream of A4261224) respectively.

Table 9: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of concentration of nutrients and dissolved organic carbon at the two reference sites (i) upstream of Lock 6 (A4261022) and (ii) Lock 5 weir pool upstream of Chowilla Creek Cell (A4260705). Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

A4261022 compared to A4260705	5/02/2014	19/03/2014	15/05/2014	18/06/2014	30/07/2014	10/09/2014	17/09/2014	23/09/2014	1/10/2014	8/10/2014	15/10/2014	22/10/2014	29/10/2014	4/11/2014	6/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
TN	0.6993	0.6033	**0.0474**	0.5345	0.8807	0.1370	**0.0010**	0.2780	0.7330	**0.0080**	0.5220	0.3720	0.3930	0.0800	0.6240	0.7410	0.2090	0.7250	0.2880	1.0000
TP	0.9500	**0.0080**	**0.0015**	0.3771		0.7937	**0.0146**	**0.0054**	0.5428	0.0574	0.1566	0.4859	0.4268	0.8905	0.4227	0.5012	0.1435	0.0768	**0.0364**	0.3093
NOx	0.2556	0.5141	0.5696	**0.0136**	0.8164	0.5916	0.4989	0.6711	0.2593	0.7640	0.4088	0.5042	**0.0006**	0.1298	0.4025	0.6438	0.1602	0.4878	0.7172	
FRP	0.3618	0.0929	**0.0083**	0.2252	0.2602	0.5605	**0.0018**	1.0000	**0.0492**	**0.0334**	0.7591	0.2882	0.4670	**0.0244**	0.6469	0.7318	0.8267	0.0989		**0.0262**
NH_3	0.4051	0.0987	1.0000	0.2925	0.2886	0.5347	0.3971	0.2838	0.0702	0.1037	**0.0241**	0.1758	0.1515	0.6439	0.4665	0.2056	0.4900	0.7116	0.5104	**0.0255**
DOC			0.8076	0.7914	0.6867	0.4498	0.3705	0.1257	1.0000	**0.0190**	0.2052	0.5170	**0.0041**	**0.0203**	0.1090	0.2063	0.2487		0.3139	0.1213

Table 10: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of concentration of nutrients and dissolved organic carbon between the reference site upstream of Lock 6 (A4261022) and the site immediately upstream of the Chowilla Regulator (A4261224). Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

A4261022 compared to A4261224	5/02/2014	19/03/2014	15/05/2014	18/06/2014	30/07/2014	10/09/2014	17/09/2014	23/09/2014	1/10/2014	8/10/2014	15/10/2014	22/10/2014	29/10/2014	4/11/2014	6/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
TN	0.5286	0.4522	0.2286	0.2896	0.6518	0.7416	0.7427	0.3650	0.0931	**0.0075**	0.4732	**0.0333**	0.1563	0.1479	0.0712	0.6126	0.1622	0.0990	0.1530	**0.0251**
TP	0.5992	0.5268	**0.0187**	0.9326	0.3654	0.5167	**0.0460**	0.6832	0.1786	0.0811	0.1542	**0.0068**	**0.0109**	0.1440	0.0622	0.7444	0.0553	**0.0014**	**0.0438**	0.1062
NOx	**0.0003**	**0.0190**	0.6880	0.1638		0.9264	0.3918	0.6240	0.3188	0.4933	0.1923	0.3304	**0.0400**	**0.0294**	**0.0118**	**0.0038**	**0.0076**	0.3292	**0.0133**	**0.0283**
FRP	0.0777	0.1668	0.4146	0.4291	0.1088	0.8280	0.1810	0.6397		0.4406	0.4710	0.7719	0.4323	**0.0209**	0.6819	**0.0114**	**0.0209**	0.3747	0.1159	**0.0018**
NH_3	0.0886	0.9122	0.8595	0.5312	0.3471	0.4599	0.4207	0.3235	0.3789	0.0662	**0.0201**	**0.0413**	**0.0018**	**0.0226**	0.4694	0.0597	0.6419	0.6859	0.8007	**0.0245**
DOC			0.4870	0.8400	0.3247	0.6348	0.1598	0.3748	0.5283	0.3842	0.7851	**0.0145**	**0.0058**	**0.0005**	0.0662	**0.0327**	0.2101	0.0937	**0.0017**	0.1842
Pooled			0.5880	0.3231	0.2874	0.7276	0.3738	0.5350	0.3637	0.1979	0.2637	**0.0292**	**0.0139**	**0.0099**	**0.0442**	**0.0123**	**0.0207**	**0.0155**	**0.0306**	**0.0114**

Table 11: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of concentration of nutrients and dissolved organic carbon between the upstream reference sites (A4261022) and the site in the river immediately downstream of the junction of Chowilla Creek with the River (A4260704). Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

A4261022 compared to A4260704	5/02/2014	19/03/2014	15/05/2014	18/06/2014	30/07/2014	10/09/2014	17/09/2014	23/09/2014	1/10/2014	8/10/2014	15/10/2014	22/10/2014	29/10/2014	4/11/2014	6/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
TN	0.2623	0.9858	**0.0138**	0.1217	0.3948	0.7960	1.0000	0.5940	0.4970	**0.0040**	0.7920	0.0930	**0.0260**	**0.0380**	0.6710	0.1200	0.1450	0.5880	0.2250	0.0550
TP	0.2950	0.4139	**0.0015**			0.5112	0.1179	0.0708	0.8914	**0.0260**	**0.0031**	**0.0008**	**0.0067**	**0.0101**	0.6932	0.7114	0.3479	**0.0075**	0.3071	0.4048
NOx	0.1894	0.3829	0.5032	0.1027	1.0000	0.4709	0.7258	0.3372	0.1447	0.2138	0.0785	**0.0175**	0.1782	0.1911	0.3387	0.5648	0.7953	0.6497	0.1081	0.3698
FRP	0.5036	0.2601	**0.0107**	0.1454	0.5411	0.0670	0.8335	0.3834	0.4354	0.8324	0.2515	0.3636	0.3358	0.2288		0.6378	0.2958	**0.0149**	0.4878	**0.0025**
NH_3	0.1509	0.5517	0.7122	0.4123	0.8145	0.1776	0.4755	0.3734	**0.0325**	0.7707	**0.0071**	**0.0052**	**0.0163**	0.1507	1.0000	**0.0107**		0.2936	0.7623	0.7570
DOC			0.9521	0.4534	0.1367	**0.0104**	**0.0018**	0.1204	0.4473	0.5280	0.9023	**0.0017**	**0.0004**	0.2986	0.0823	0.3276		0.1160	0.5553	
Pooled			0.0541	0.1739	0.6040	0.5031	0.4684	0.3796	0.2978	**0.0181**	**0.0399**	**0.0039**	**0.0026**	0.0538	0.7330	0.1064	0.4112	0.0639	0.2930	0.4819

Table 12[A]: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of concentration of nutrients and dissolved organic carbon between the upstream reference site (A4261022) and the site within the mid-reach of the Lock 5 weir pool (A1). Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites. There was no sampling conducted at A1 during the baseline sampling period.

A426A1 compared to A4261022	5/02/2014	19/03/2014	15/05/2014	18/06/2014	30/07/2014	10/09/2014	17/09/2014	23/09/2014	1/10/2014	8/10/2014	15/10/2014	22/10/2014	29/10/2014	4/11/2014	6/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
TN						**0.0028**	0.6225	0.5686	**0.0387**	**0.0305**	0.0517	**0.0402**	**0.0138**	0.1200	**0.0424**	0.5950	**0.0173**	0.5859	0.2029	0.8555
TP						**0.0335**	0.5203	0.4170	0.0636	0.0504	**0.0159**	**0.0234**	**0.0144**	**0.0316**	0.2289	0.8515	0.1160	0.2563	**0.0275**	0.3797
NOx						0.0659	0.8822	0.1830	0.4667	0.7185	0.1704	0.2860	0.0660	0.5943	0.0693	**0.0024**	0.2770	0.3925	0.8407	0.2377
FRP						**0.0001**	0.1896	0.2073	0.1008	0.3806	0.6854	0.7937	0.4607	0.0754	0.0921	0.1744	**0.0104**	0.3727	**0.0199**	**0.0443**
NH_3						0.2390	0.9084	0.6270	**0.0140**	0.5634	0.3701	0.5644	0.1779	0.2294	0.1143	0.5863	0.4860	0.4156	0.6697	0.0881
DOC						**0.0028**	0.7206	**0.0322**	0.2359	0.2009	0.3979	0.1200	**0.0088**	0.2969	0.7690	0.0505	**0.0025**	0.6084	0.2318	0.6738
Pooled						**0.0027**	0.9707	0.0809	**0.0229**	0.3658	0.055	**0.0439**	**0.0127**	0.2146	**0.0408**	**0.0107**	**0.0167**	0.4414	0.1151	0.1513

Table 12[B]: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of concentration of nutrients and dissolved organic carbon between the upstream reference site (A4261022) and the site within the lower-reach of the Lock 5 weir pool (A4260703). Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

A42610703 compared to A4261022	5/02/2014	19/03/2014	15/05/2014	18/06/2014	30/07/2014	10/09/2014	17/09/2014	23/09/2014	1/10/2014	8/10/2014	15/10/2014	22/10/2014	29/10/2014	4/11/2014	6/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
TN	0.0910	0.4506	0.1506	0.4781	0.8875	0.4455	0.8747	0.8893	0.1011	0.2416	**0.0153**	**0.0174**	**0.0102**	**0.0236**	0.1392	0.3736	0.1913	0.7244	0.2023	0.4096
TP	0.3387	0.7709	**0.0171**		0.1000	0.3742	0.6425	0.4126	0.2690	**0.0449**	**0.0178**	**0.0141**	**0.0041**	**0.0161**	0.3233	1.0000	0.9084	0.1049	0.0601	0.6546
NOx	**0.0053**	0.2265	0.2261	**0.0125**	0.4758	0.1420	0.6557	0.9222	0.6825	0.3146	0.0500	0.3023	0.2260	0.1854	**0.0007**	**0.0071**	0.8436	**0.0478**	1.0000	0.4919
FRP	0.7022	0.7965	**0.0443**	0.1940	0.3703	0.3754	0.3794	0.3581	0.8003	0.1087	0.6437	0.7971	0.0975	**0.0243**	0.6670	0.3515	**0.0011**	0.6445	0.1569	**0.0011**
NH_3	0.3707	0.4648	0.5070	0.7609	0.7152	0.6890	0.4813	0.4735	0.1125	0.2860	**0.0075**	0.2019		0.4623	0.5444	0.0985	0.4884	0.3745	1.0000	0.1722
DOC			0.5056	0.1439	0.1185	**0.0093**	**0.0148**	0.0833	0.7501	**0.0064**	0.5636	0.1552	**0.0092**	**0.0442**	**0.0128**	0.0891	**0.0274**	0.2769	0.2338	0.1855
Pooled			0.1984	0.3804	0.5664	0.1901	0.5021	0.6854	0.1070	**0.0130**	**0.0199**	0.0811	**0.0203**	**0.0160**	**0.0018**	**0.0204**	**0.0089**	0.0500	0.1793	0.1928

Table 13[A]: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of concentration of nutrients and dissolved organic carbon between sites within the anabranch. Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

A4260580, A4261107	5/02/2014	19/03/2014	15/05/2014	18/06/2014	30/07/2014	10/09/2014	17/09/2014	23/09/2014	1/10/2014	8/10/2014	15/10/2014	22/10/2014	29/10/2014	4/11/2014	6/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
TN	0.1218	0.2740	0.1846	0.5747	0.0670	**0.0090**	**0.0150**	0.5830	**0.0050**	**0.0000**	**0.0360**	**0.0450**	**0.0100**	0.0560	0.8550	0.1850	**0.0190**	**0.0320**	0.1250	**0.0010**
TP	0.2158	0.3494	0.7235	0.5283	0.1175	**0.0017**	0.0561	**0.0181**	0.4957	**0.0016**	0.3503	**0.0010**	0.0696	0.7791	0.1399	0.6789	0.1246	**0.0004**	**0.0066**	**0.0316**
NOx	0.2847	0.3868	0.7891	0.3708	0.2933	0.0683	0.3656	**0.0134**	0.7278	0.1164	0.1455		0.7457	**0.0483**	0.6561	0.1557	**0.0142**	**0.0033**	**0.0425**	0.0823
FRP	0.1328	0.2839	0.3706	0.0942	0.2281	0.3276	0.2611	**0.0001**	0.1507	0.7755	0.2827	0.3329	0.6539	0.8133	0.3855	0.2283	**0.0103**		0.2244	**0.0250**
NH_3	0.6640	0.7697	0.6752	0.7671	0.1168	0.4971	0.4714	**0.0280**	0.8892	**0.0291**	0.3845	**0.0416**	0.4486	0.3777		0.5537	0.7217	0.1170	**0.0172**	0.2098
DOC			**0.0250**	0.7677	**0.0004**	0.8766	0.5634	**0.0005**	0.3812	0.6070	**0.0028**	0.8474	0.9220	0.3993	0.6439	0.1648	**0.0303**	0.0659	0.3508	0.9182
Pooled			0.5262	0.8015	0.0979	0.0596	0.3302	**0.0005**	0.3221	**0.0020**	0.1617	0.1340	0.0697	0.2697	0.5131	0.3339	**0.0136**	**0.0007**	**0.0031**	0.0757

Table 13[B]: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of concentration of nutrients and dissolved organic carbon between sites within the anabranch. Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

A4260580, A4261224	5/02/2014	19/03/2014	15/05/2014	18/06/2014	30/07/2014	10/09/2014	17/09/2014	23/09/2014	1/10/2014	8/10/2014	15/10/2014	22/10/2014	29/10/2014	4/11/2014	6/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
TN	**0.0003**	**0.0277**	0.4265	0.6249	0.2545	**0.0070**	**0.0420**	0.0600	**0.0380**	**0.0010**	0.1040	0.0810	0.1430	0.0560	0.4620	0.1110	0.0580	0.0690	0.6310	**0.0000**
TP	**0.0005**	0.1059	0.0649	0.6489	0.1134	**0.0233**	0.0557	0.1197	0.2624	**0.0014**	0.4264	**0.0126**	0.0724	0.1732	0.1788	0.2205	0.2039	**0.0008**	0.3572	**0.0421**
NOx	**0.0336**	**0.0010**	0.8678	0.1671	0.7106	0.3871	0.3624	0.3733	0.5366	0.5135	0.1640	0.5811	0.6937	0.0776	**0.0341**	**0.0021**	0.0898	0.1462	**0.0258**	
FRP	**0.0169**	0.0864	0.8591	0.8946	0.4982	0.3941	0.0636	**0.0001**	0.3922	0.6464	0.7041	0.8347	0.1655	**0.0132**	0.3707	0.7965	0.1924		0.1027	
NH_3	0.7108	0.3325		0.5783	0.1473	0.5516	0.7546	**0.0397**	0.4830	**0.0480**	0.1832	0.4111	0.1392	0.1236	0.3946	0.4335	0.3382	0.1018		0.6205
DOC			0.2377	0.4840	**0.0021**	0.5927	**0.0413**	**0.0021**	0.2471	0.5732	0.4312	0.3398	0.0760	0.3362	0.1169	0.9176	**0.0001**	**0.0025**	**0.0025**	0.5314
Pooled			0.7174	0.2368	0.2492	0.1289	0.3189	**0.0031**	0.4638	**0.0037**	0.3281	0.3104	**0.0445**	**0.0353**	0.0908	0.0993	0.0571	**0.0030**	0.0880	0.1236

Table 13[C]: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of concentration of nutrients and dissolved organic carbon between sites within the anabranch. Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

A4261107, A4261224	5/02/2014	19/03/2014	15/05/2014	18/06/2014	30/07/2014	10/09/2014	17/09/2014	23/09/2014	1/10/2014	8/10/2014	15/10/2014	22/10/2014	29/10/2014	4/11/2014	6/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
TN	0.4863	0.5278	0.2699	0.6349	0.4495	0.5890	0.6380	0.2250	0.4100	**0.0030**	0.7680	0.1020	0.2000	0.2610	0.5010	0.7610	0.5670	0.5830	0.9240	0.3660
TP	0.3605	0.6299	**0.0397**	0.8507		0.5164		0.5960	0.1973	0.5719	0.8091	0.3009	0.1622	0.2183	0.5410	0.1558	0.5105	0.0554	0.3150	0.6602
NOx	0.4295	**0.0023**	0.8345	0.3333	0.1953	0.4959	0.3689	0.2466	0.6398	0.3414	0.3395	0.7216	0.9224	0.6002	**0.0230**	**0.0004**	**0.0046**	0.0956	0.4107	0.0831
FRP	0.7669	0.2140	0.6149	0.4965	**0.0447**	0.8138	0.2799	**0.0212**	0.3201	0.7774	0.9372	0.6681	0.4599	**0.0065**	0.5648	0.1005	**0.0123**		0.7383	
NH_3	0.7967	0.3788	0.6524	0.7324	0.3757	0.5555	0.1545	0.7780	0.4641	0.3702	0.6413	0.3901	**0.0024**	**0.0399**	0.3508	0.6457	0.6271	0.6516	0.1748	0.2424
DOC			0.2793	0.5922	0.0982	0.5654	**0.0145**	0.8721	0.6123		0.8739	0.3279	**0.0097**	0.8266	0.1534	0.1253	**0.0495**	0.8220	**0.0010**	0.0558
Pooled			0.7022	0.7023	0.2317	0.6209	0.1325	0.3912	0.4637	0.4505	0.8944	0.6813	0.1166	**0.0230**	0.1016	**0.0225**	**0.0423**	0.0884	0.0852	0.1161

Table 14: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of results for 5-day Biochemical Oxygen Demand between the upstream reference site (A4261022) and sites within the anabranch and the river. Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

A4261022 v's	5/02/2014	19/03/2014	15/05/2014	18/06/2014	30/07/2014	10/09/2014	17/09/2014	23/09/2014	1/10/2014	8/10/2014	15/10/2014	22/10/2014	29/10/2014	4/11/2014	6/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
A4261224	0.3242	**0.0011**	0.1425	0.5914	0.7631	0.8705	**0.0003**	**0.0187**	**0.0770**	0.0596	**0.0326**	**0.0154**	0.0628	0.9923	0.103	0.3303	0.3715	**0.0002**	0.9566	0.2747
A4260704	0.7467	**0.0095**	**0.0005**	**0.0233**	0.4461	0.9363	0.1470	0.3104	0.2552	**0.0080**	0.1607	0.2988	**0.0419**	0.3296	0.9099	0.7965	0.5170	0.1133	0.7565	**0.0076**
A426A1							**0.0034**	0.7448	**0.0902**	**0.0027**	0.5281	0.1157	0.1007	0.4588	0.7422	0.2103	0.2067	**0.0287**	0.1782	0.6438
A4260703	0.6098	**0.0117**	**0.0006**	0.5719	0.5729	**0.0411**	**0.0105**	0.0598	0.4664	**0.0001**	0.8291	0.3256	0.0957	0.2294	0.5249	0.4161	**0.0024**	**0.0005**	0.3118	0.6010

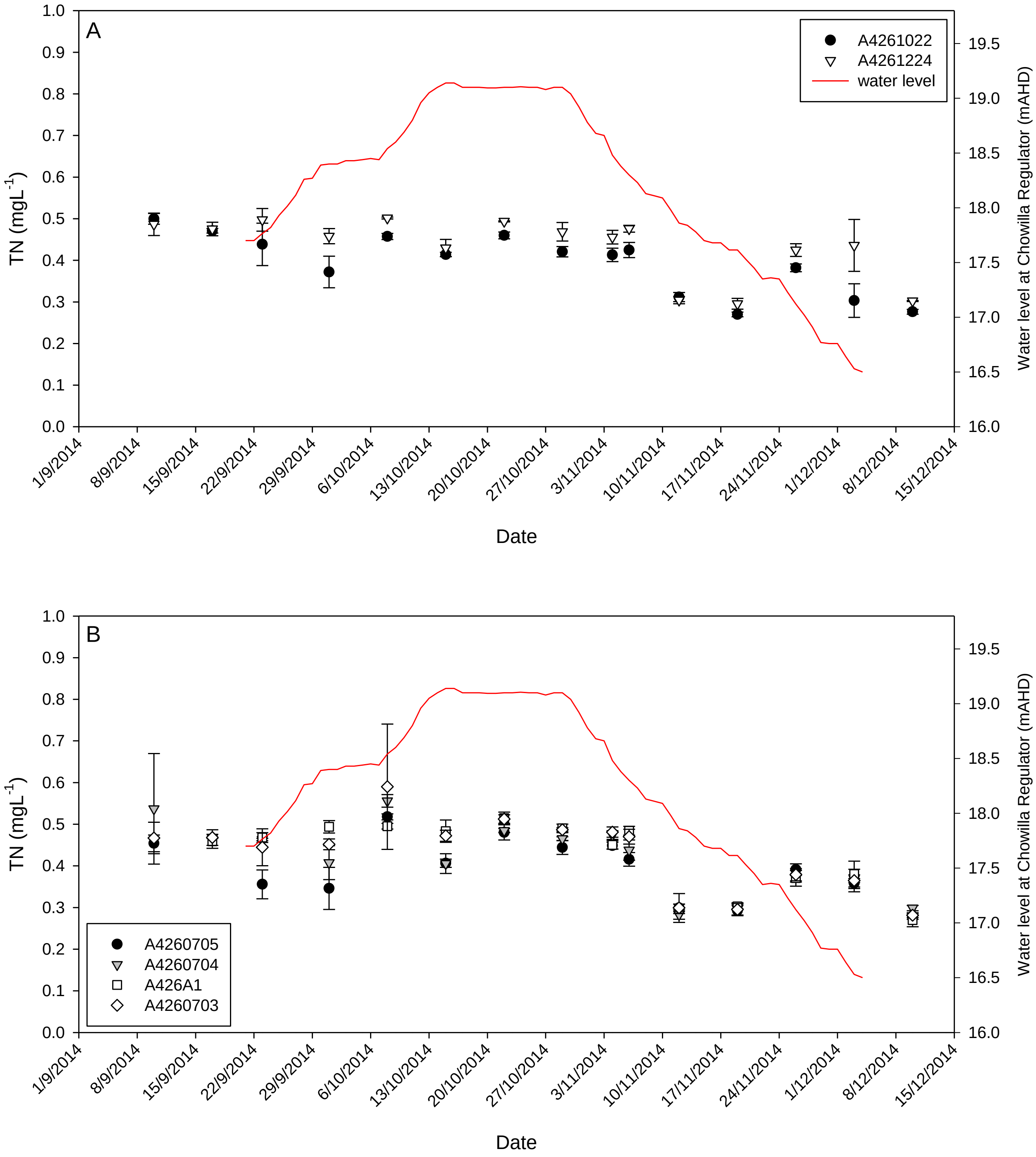


Figure 13: Total Nitrogen (TN) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for TN stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 5 mgL^{-1}.

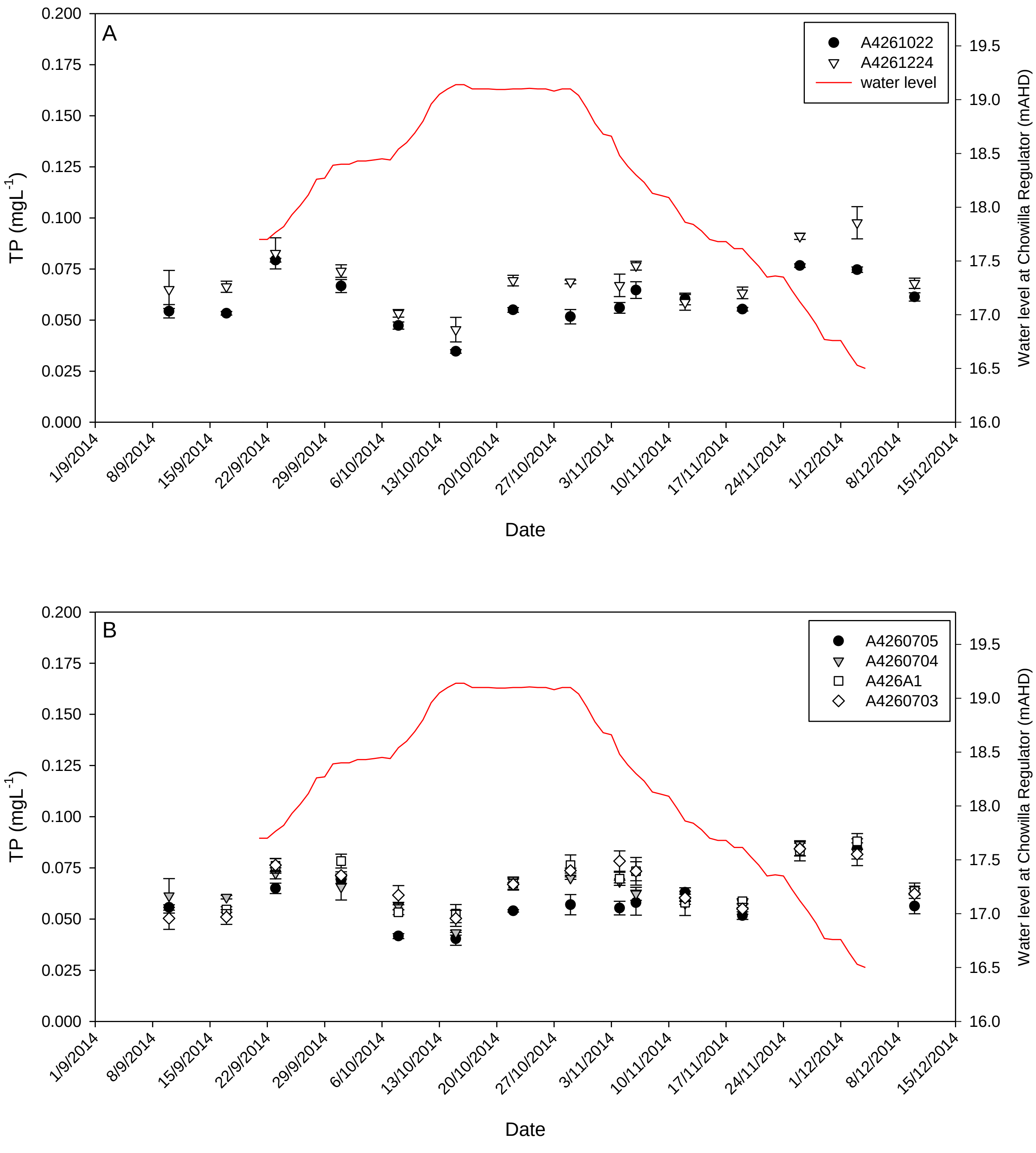
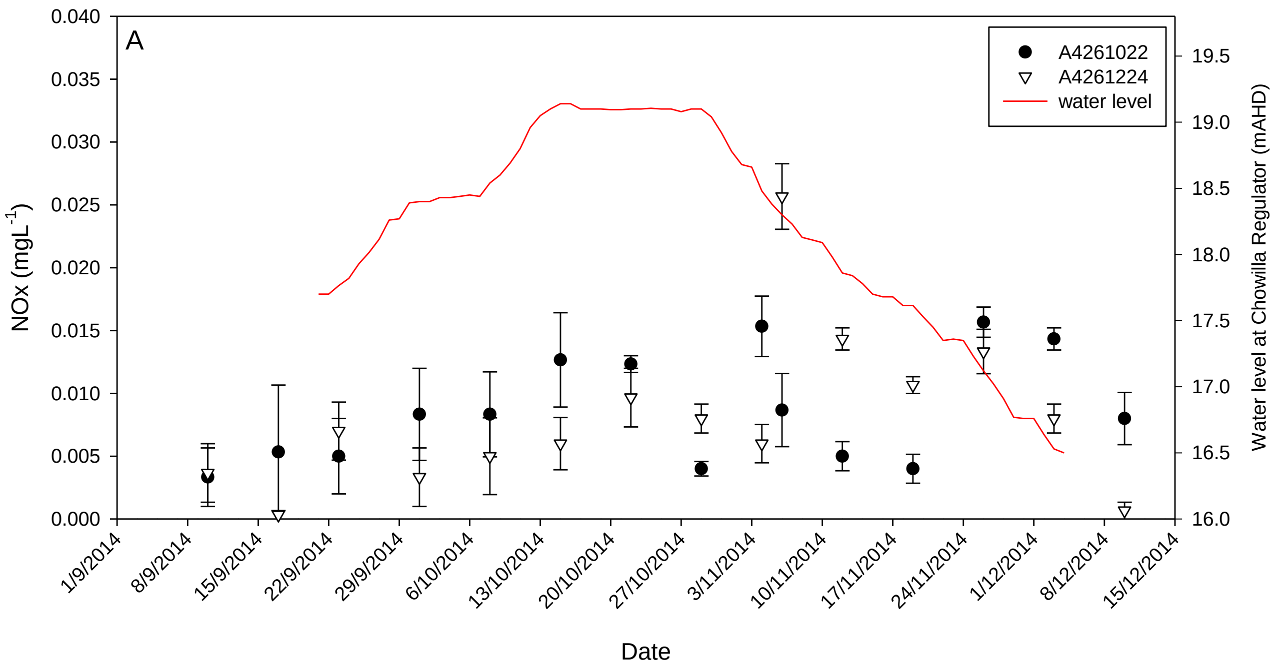


Figure 14: Total Phosphorus (TP) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for TP stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 0.5 mgL^{-1}.



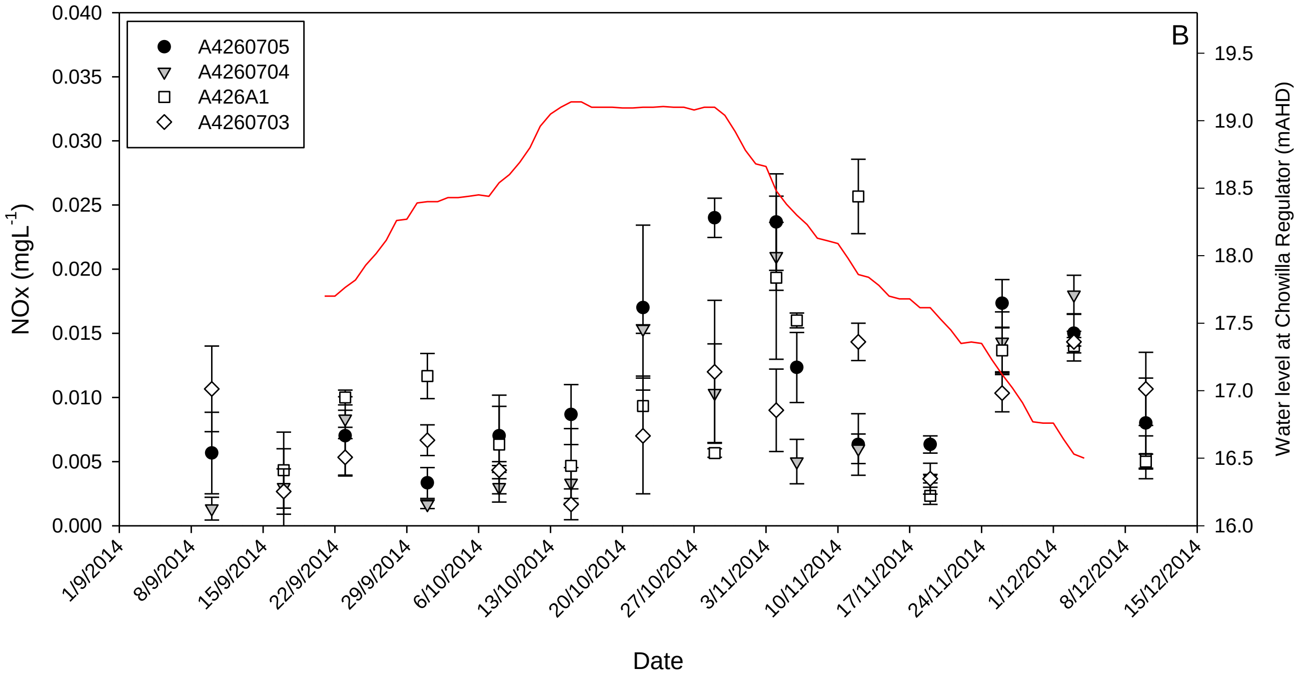
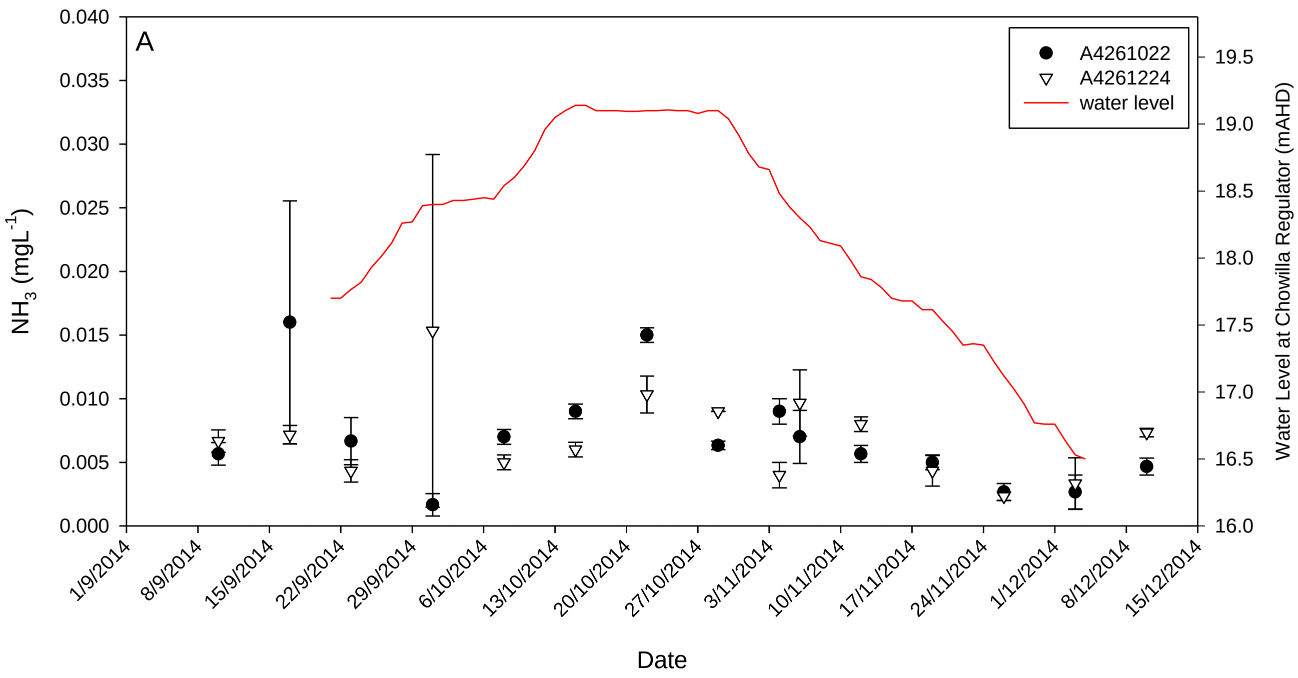


Figure 15: Oxidised Nitrogen (NOx = nitrate+nitrite) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for NOx stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 0.5 mgL^{-1}. Results for samples collected on 20th May 2013 and 6th June 2013 were in the range 0.21-0.36 mgL^{-1} and hence because they are atypical, are not here shown in order to maintain visual clarity in the plots, but are included in statistical analysis.



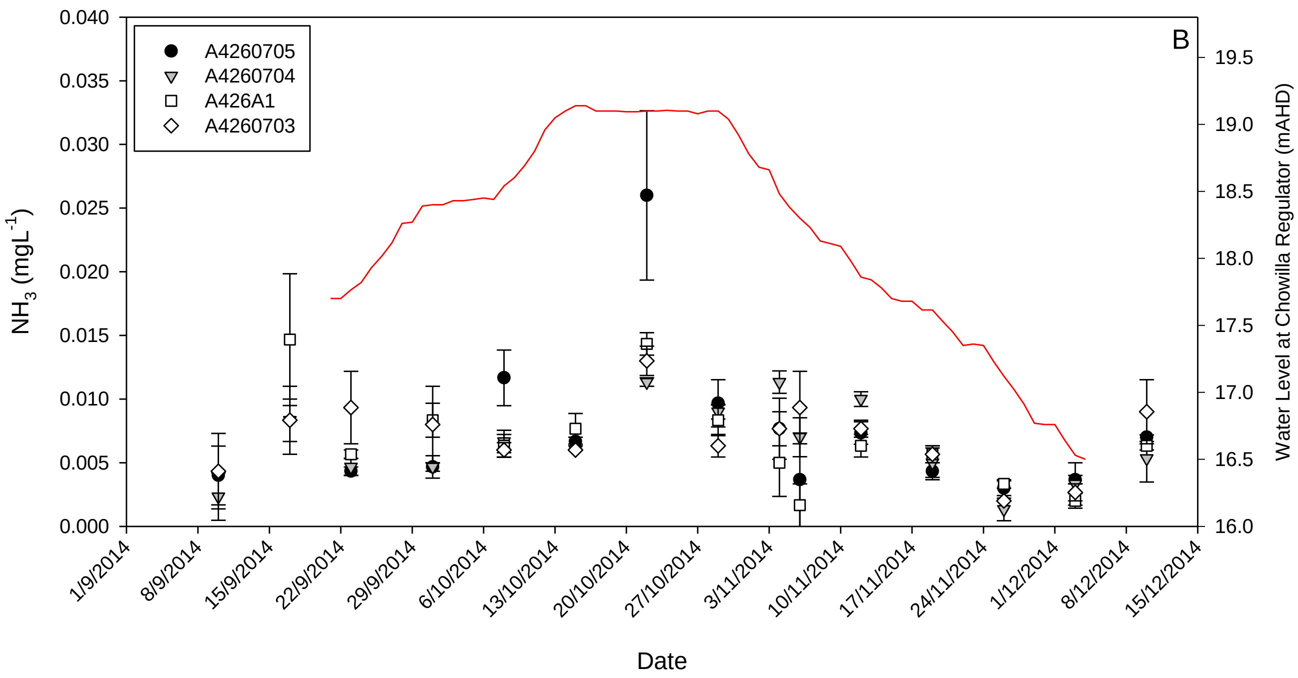


Figure 16: Ammonia (NH_3 as N) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for NH_3 stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 0.5 mgL^{-1}.

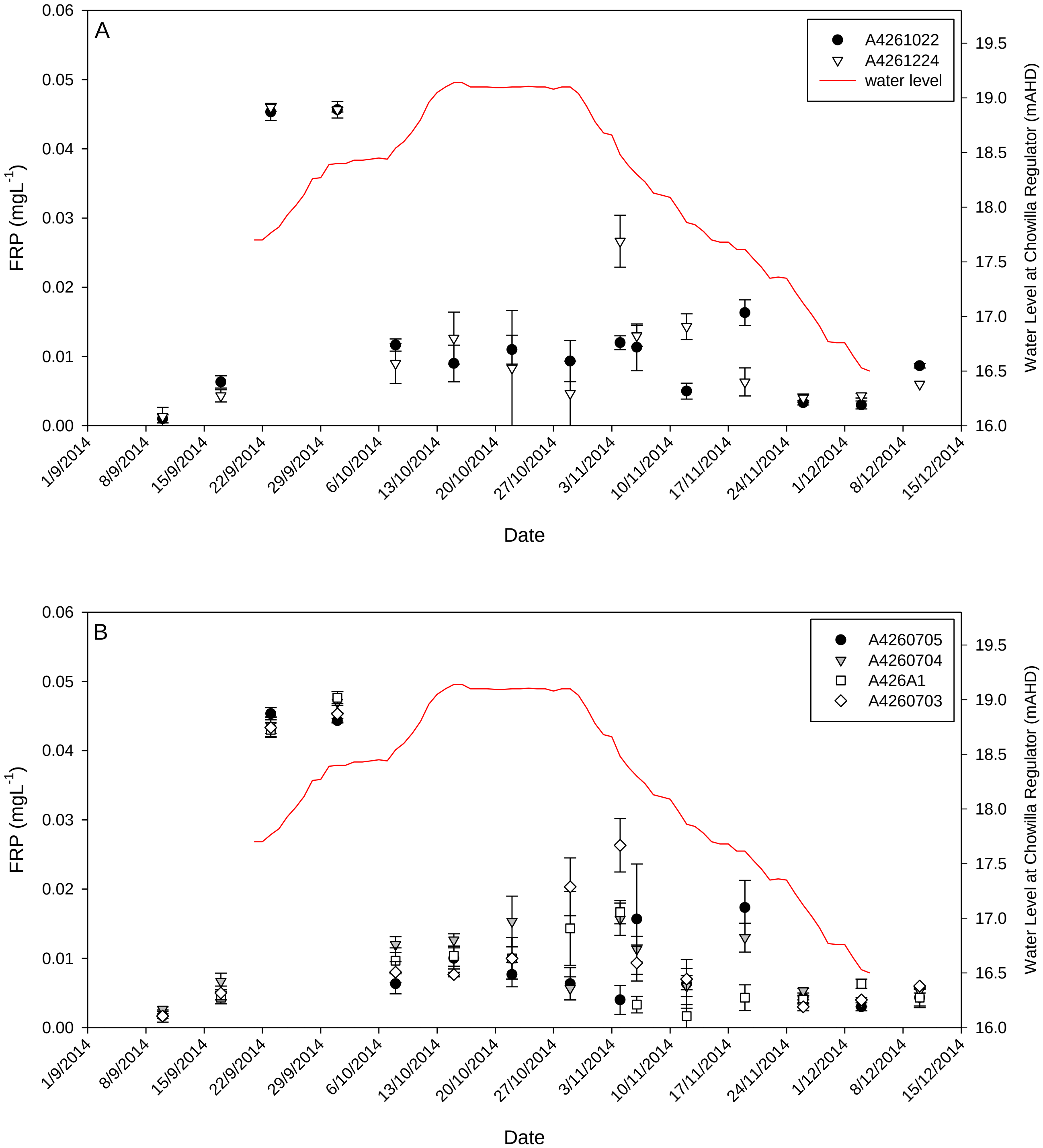
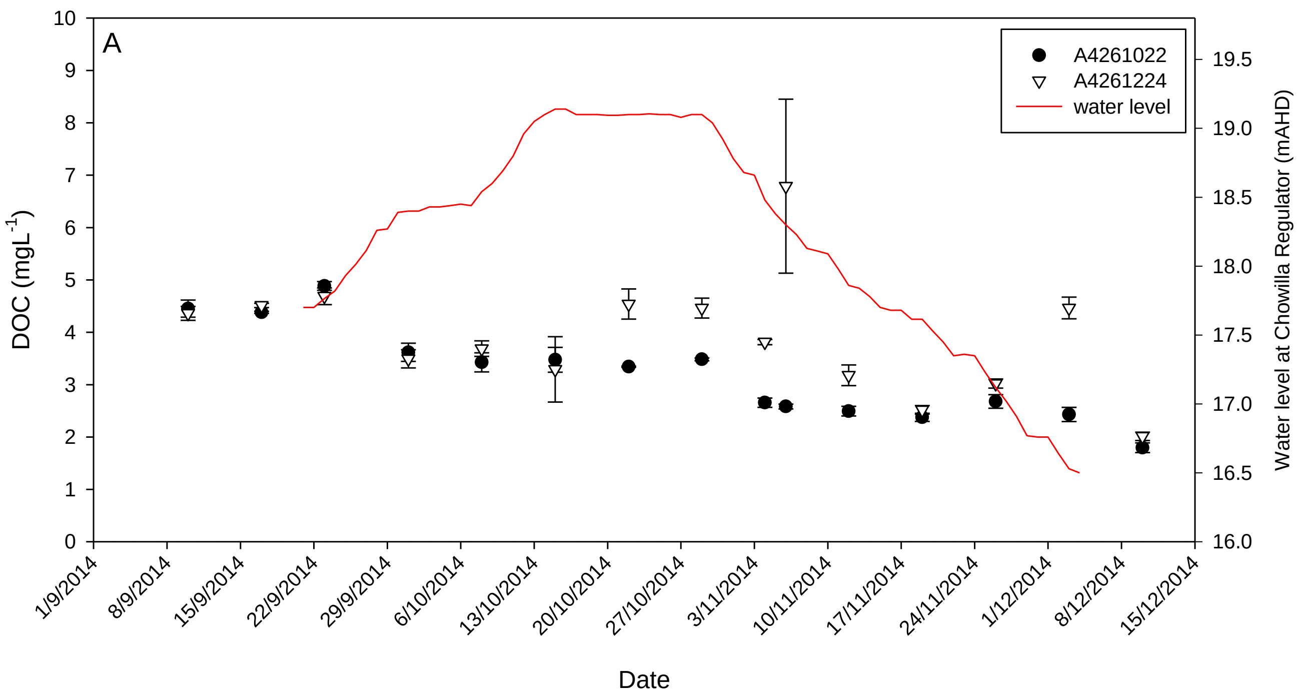


Figure 17: Filterable reactive Phosphorus (FRP) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for FRP stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 0.1 mgL^{-1}.



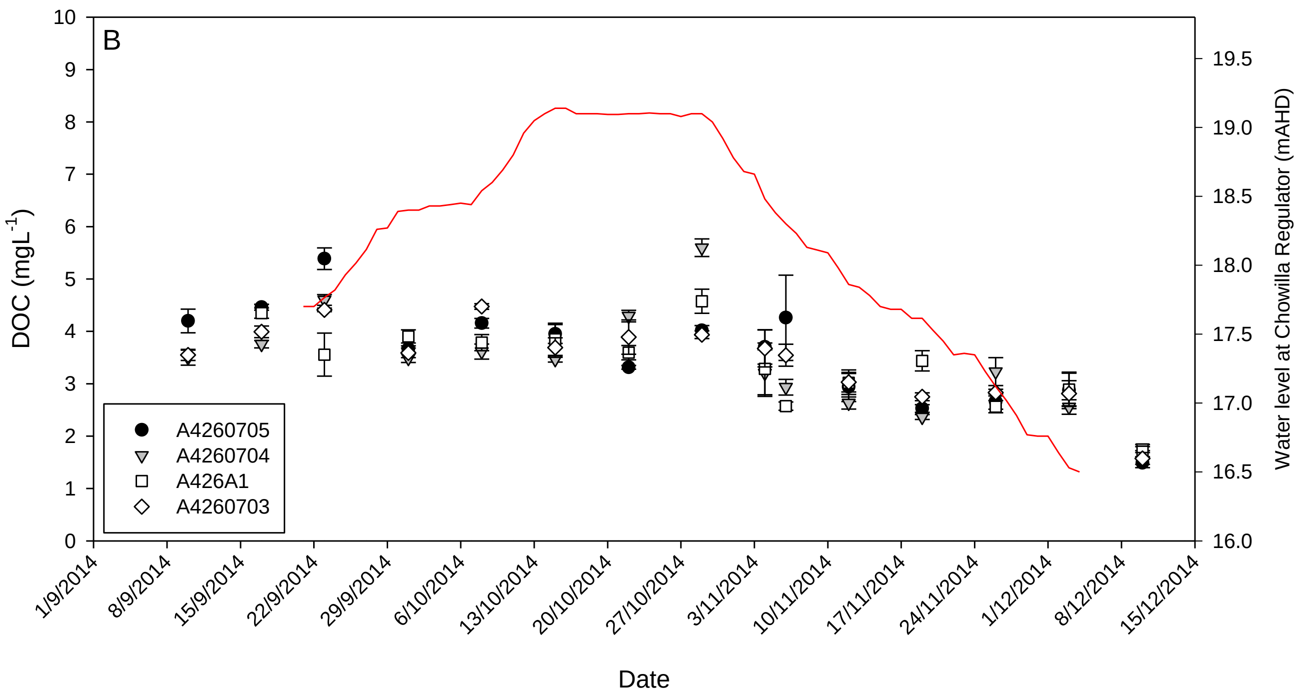
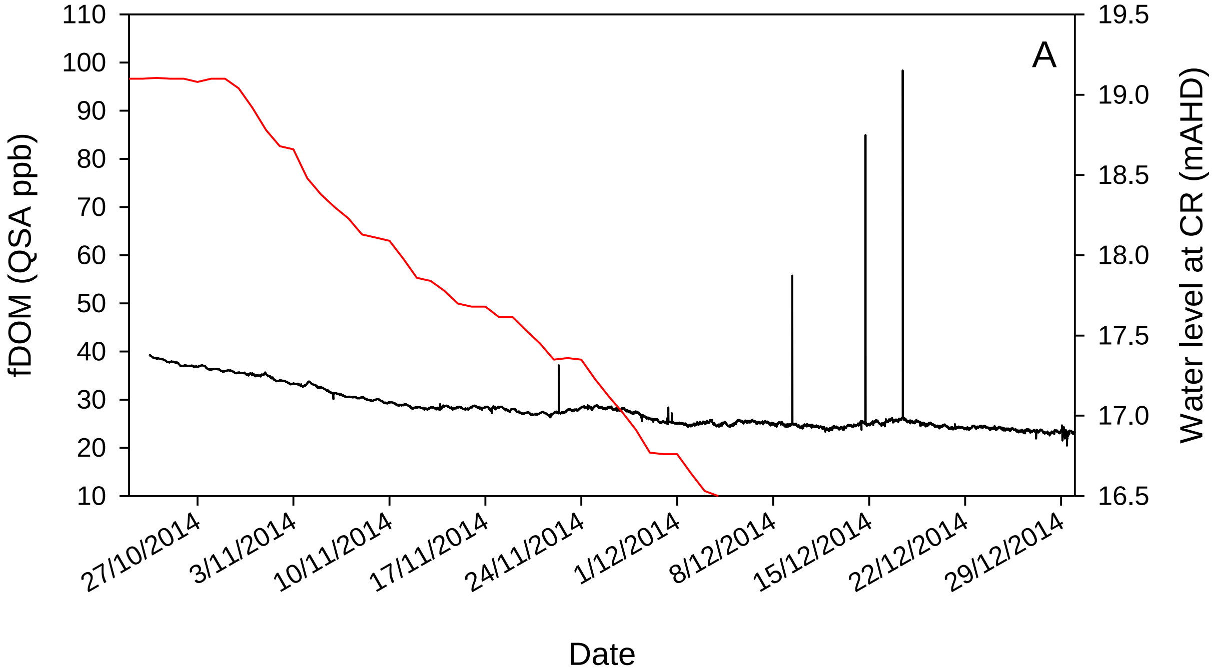


Figure 18: Dissolved Organic Carbon (DOC) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for Total Organic Carbon (TOC) stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 15 mgL^{-1}.



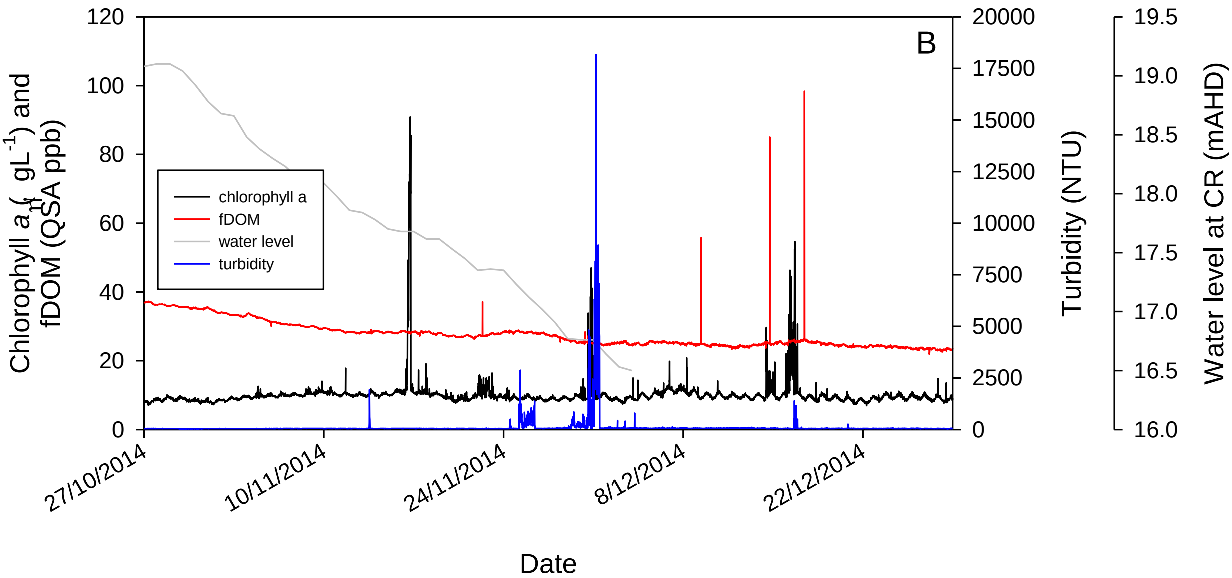


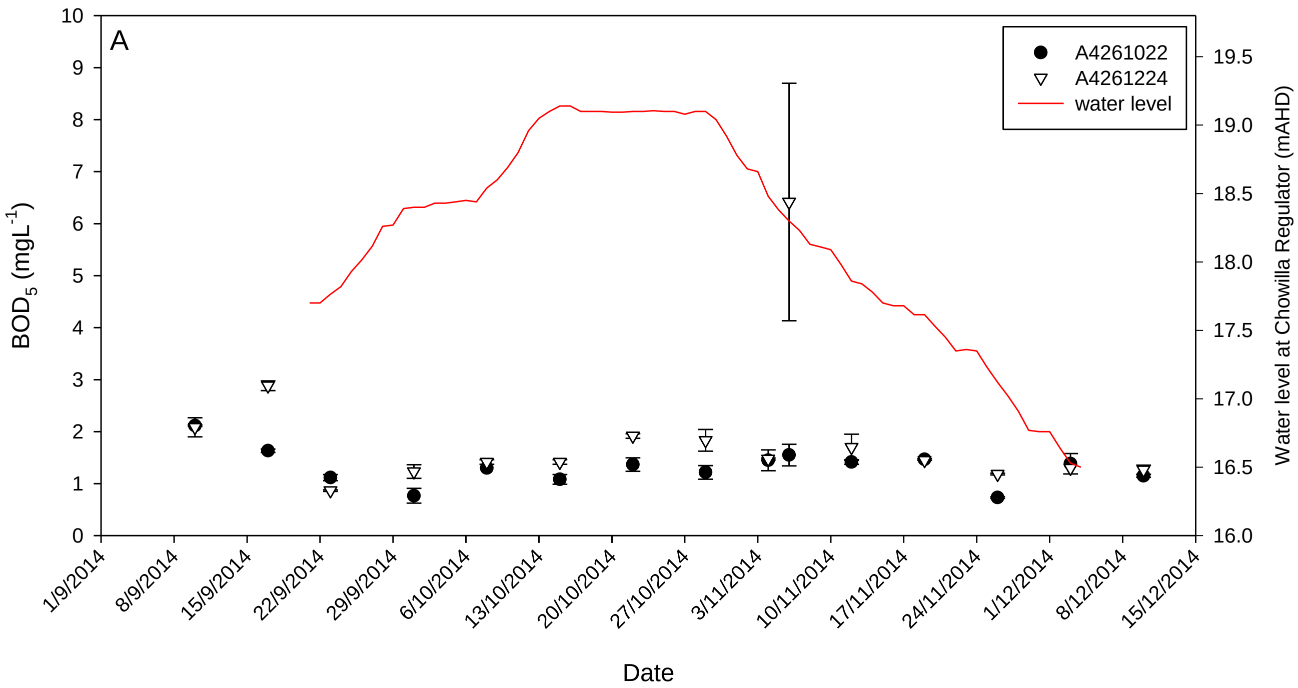
Figure 19: [A] fDOM (fluorescing dissolved organic matter (QSA ppb) measured using the EXO Sonde deployed at A4261224 [B] overlay of fDOM, chlorophyll a, turbidity and water level at the Chowilla Environmental Regulator demonstrating alignment of episodic peaks in values that may indicate wither sensor malfunction, (ii) return flows of discrete parcels of water from shedding sections of the floodplain or (iii) bank collapse (failure)

2.6.7. HO#7: DURING THE MANAGED INUNDATION, 5-DAY BIOCHEMICAL OXYGEN DEMAND WILL BE HIGHER AT THE SITE IMMEDIATELY UPSTREAM OF THE CHOWILLA REGULATOR (A4261224) COMPARED TO THE REFERENCE SITE (A4261022)

The time series for 5-day biochemical oxygen demand (BOD_5) is presented in Figure 20. The plots demonstrate that BOD_5 remained below the 10 mgO_2L^{-1} stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003). The BOD_5 limit of 10 mgO_2L^{-1} may be excessively high to be relevant; Connell (1981) states that under most circumstances, clean river should have a BOD_5 of approximately 1 mgO_2L^{-1}, and that a BOD_5 greater than 10 mgO_2L^{-1} indicates that the water is seriously polluted.

A comparison between the reference site (A4261022) and the site immediately upstream of the Chowilla Regulator (A4261224) (Figure 20[A]) reveals that there are small but significant differences in the results for BOD_5 during the sampling period (see Table 14 for PERMANOVA results). It is of note that despite the BOD_5 values being markedly higher upstream of the regulator (A4261224) on the 6th of November (6.42 mgO_2L^{-1}, std dev = ±3.95) than at the reference site (A4261022; BOD5 = 1.55 mgO_2L^{-1}, std dev = ±0.36), the PERMANOVA analysis did not reveal a statistically significant difference. It is considered that this anomaly despite a large difference in the mean BOD_5 values is a result of the wide variation in the results at A4261124 on this day. A cross-check of the results of the PERMANOVA analysis utilising a one-way ANOVA revealed that the differences in the means are not great enough to exclude the possibility that the difference is due to random sampling variability. However, the power of the test with alpha at 0.050 was 0.298, well below the desired power of 0.800. This indicates that the analysis is less likely to detect a difference when one actually exists, and the negative result (no significant difference) should be interpreted cautiously. Therefore, it is considered that the difference in BOD_5 values recorded on the 6th of November is likely to be meaningful from a water quality perspective, despite not being statistically significant.

A comparison of BOD_5 values between the reference site (A4261022) and the sites in the Lock 5 weir pool downstream of the junction of Chowilla Creek and the river (A4260704, A426A1, A4260703) (see Figure 20) reveal a number of significant differences during the sampling period (see Table 14 for PERMANOVA results). However, there is not a clear pattern that indicates that the differences are due to downstream dispersion of water that is enriched in oxygen demanding material. It is probable that the differences are attributable to differences in phytoplankton biomass between samples and the concomitant respiration demand of phytoplankton in the dark (no-light) conditions of the BOD_5 bioassay.



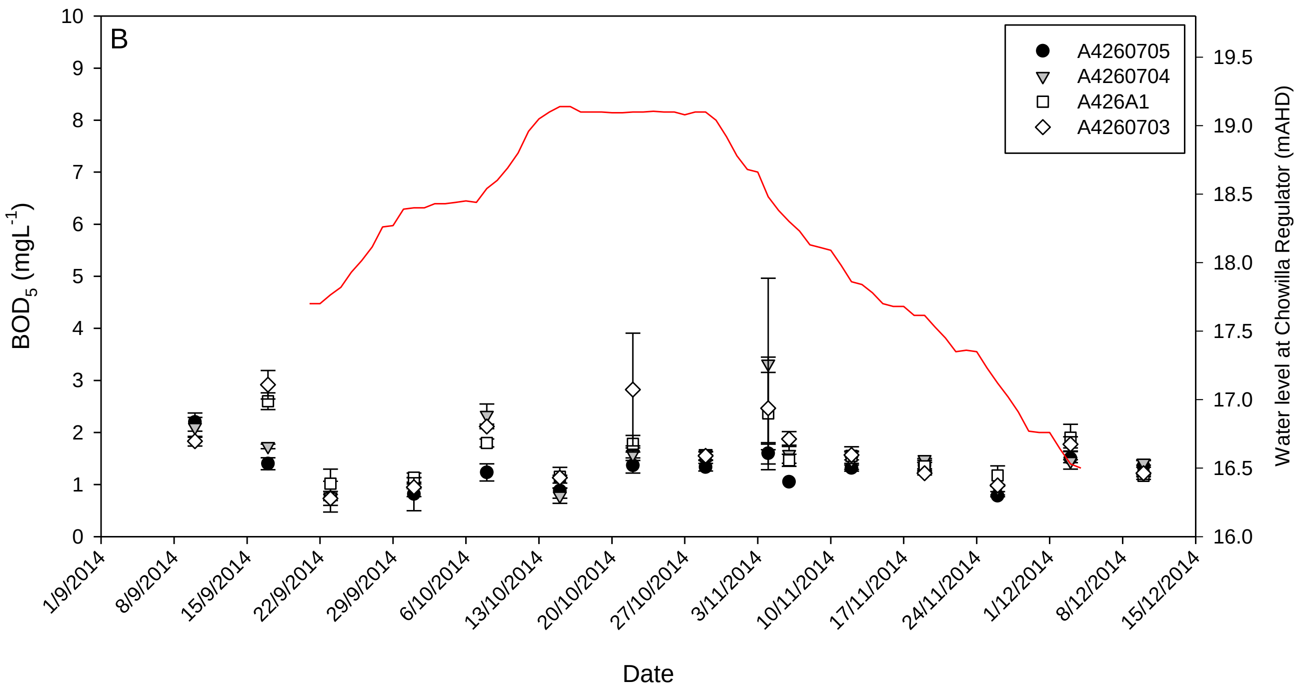


Figure 20: 5-day Biochemical Oxygen Demand (BOD_5) at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for BOD_5 stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 10 mgL^{-1}.

2.6.8. Ho#8: During the managed inundation, the concentration of resources (nutrients and dissolved organic carbon) will vary between the large wetlands that were inundated (Werta Wert, Coppermine and Lake Limbra) compared to concentrations recorded in the upstream river reference site (A4261022) and in the anabranch at the Regulator (A4261224)

The time series for concentration of total nitrogen (TN), total phosphorus (TP), oxidised nitrogen (NOx), ammonia (NH_3), filterable reactive phosphorus (FRP) and dissolved organic carbon (DOC) in the three large wetlands (Werta Wert, Lake Limbra, and Coppermine) relative to the reference site upstream of Lock 6 (A4261022) are presented in Figure 21. A comparison of the pooled data (all six resources pooled) demonstrates that the quality of the water varied significantly between sites (see Table 15 for PERMANOVA results). Each wetland was significantly different to the upstream reference site (A4261022) on all sampling occasions. Coppermine Wetland was not significantly different to the site immediately upstream of the regulator (A4261224) in the sampling that occurred in the week of the 22nd and the 29th of October 2014. During this period, the wetland would have been functioning as a flow through system. On the subsequent sampling dates (week of 4th November to 10th December 2014), water quality was significantly different between Coppermine Wetland and A4261224. This period coincides with the falling limb of the hydrograph, and at this time the wetland would have disconnected from inflows *via* Monomon Creek and outflows *via* Woolshed Creek. Werta Wert wetland and Lake Limbra are effectively terminal at the inundation height achieved during the testing event, and water quality was significantly different from the reference site on all sampling occasions.

The differences between the creek/river and the wetlands are displayed graphically in the MDS ordination (Figure 22), in which the tight clustering of A4261022 and A4261224, relative to the spatial and temporal scatter throughout the ordination space for the wetlands is evident. ANOSIM reveals that the difference between A4261022 and Lake Limbra is primarily due to TP (41.85%), DOC (24.9%) and FRP (21.38%). The differences between A4261022 and Werta Wert are due to NH3 (29.82%), DOC (28.34%) and NOx (26.24%). The differences between A4261022 and Coppermine are due to TP (27.23%), FRP (27.22%) TN (25.72%) and DOC (17.73%). The differences between Werta Wert and Coppermine are due to NOx (21.4 %), NH3, (21.32%) FRP (20.91%) and TP (16.91%). The differences in concentration of resources between the wetlands and the anabranch (A4261224) demonstrates the importance of lateral connectivity and return flows from the wetlands to the river in ensuring that the floodplain derived resources are available to fuel the riverine foodweb.

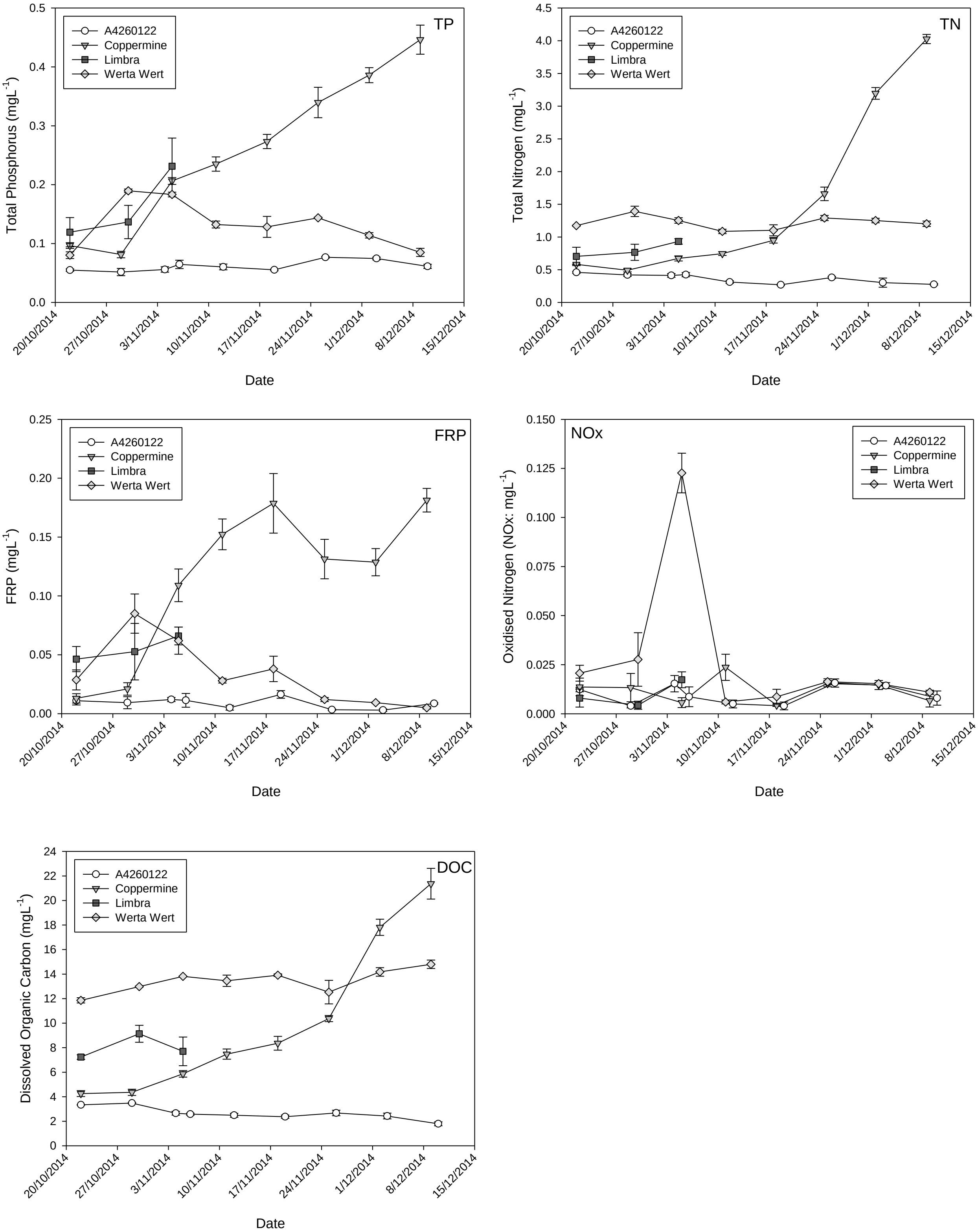


Figure 21: Time series of nutrients and DOC in wetlands (Coppermine wetland, Lake Limbra and Werta Wert Wetland, compared to the upstream reference site (source water) in the Lock 6 weir pool (A4261022). Lake Limbra was sampled for a short period relative to the other wetlands due to the shallow nature of the wetland and associated difficulties with access associated with low water levels once the drawdown commenced.

Table 15: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of concentration of pooled resources (nutrients and DOC) in the three large wetlands; Werta Wert, Lake Limbra and Coppermine relative to the reference site in the River upstream of Lock 6 (A4261022) and in Chowilla Creek immediately upstream of the Environmental Regulator (A4261224). Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

comparison	22/10/2014	29/10/2014	4/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
A4261022, A4261224	0.1704	**0.0259**	**0.0089**	**0.0033**	**0.007**	0.1070	**0.0096**	**0.0213**
A4261022, Lake Limbra	**0.0029**	**0.0078**	**0.0020**					
A4261022, Werta Wert	**0.0001**	**0.0002**	**0.0001**	**0.0013**	**0.0003**	**0.0001**	**0.0001**	**0.0001**
A4261022, Coppermine	**0.0087**	**0.0248**	**0.0004**	**0.0001**	**0.0002**	**0.0002**	**0.0001**	**0.0003**
A4261224, Lake Limbra	**0.0102**	**0.0139**	**0.0007**					
A4261224, Werta Wert	**0.0001**	**0.0001**	**0.0001**	**0.0022**	**0.0005**	**0.0002**	**0.0001**	**0.0001**
A4261224, Coppermine	0.1479	0.1204	**0.0003**	**0.0001**	**0.0001**	**0.0004**	**0.0001**	**0.0002**
Lake Limbra, Werta Wert	**0.0006**	**0.0003**	**0.0002**					
Lake Limbra, Coppermine	**0.0101**	**0.0234**	**0.0128**					
Werta Wert, Coppermine	**0.0002**	**0.0002**	**0.0001**	**0.0005**	**0.0005**	**0.0006**	**0.0001**	**0.0005**

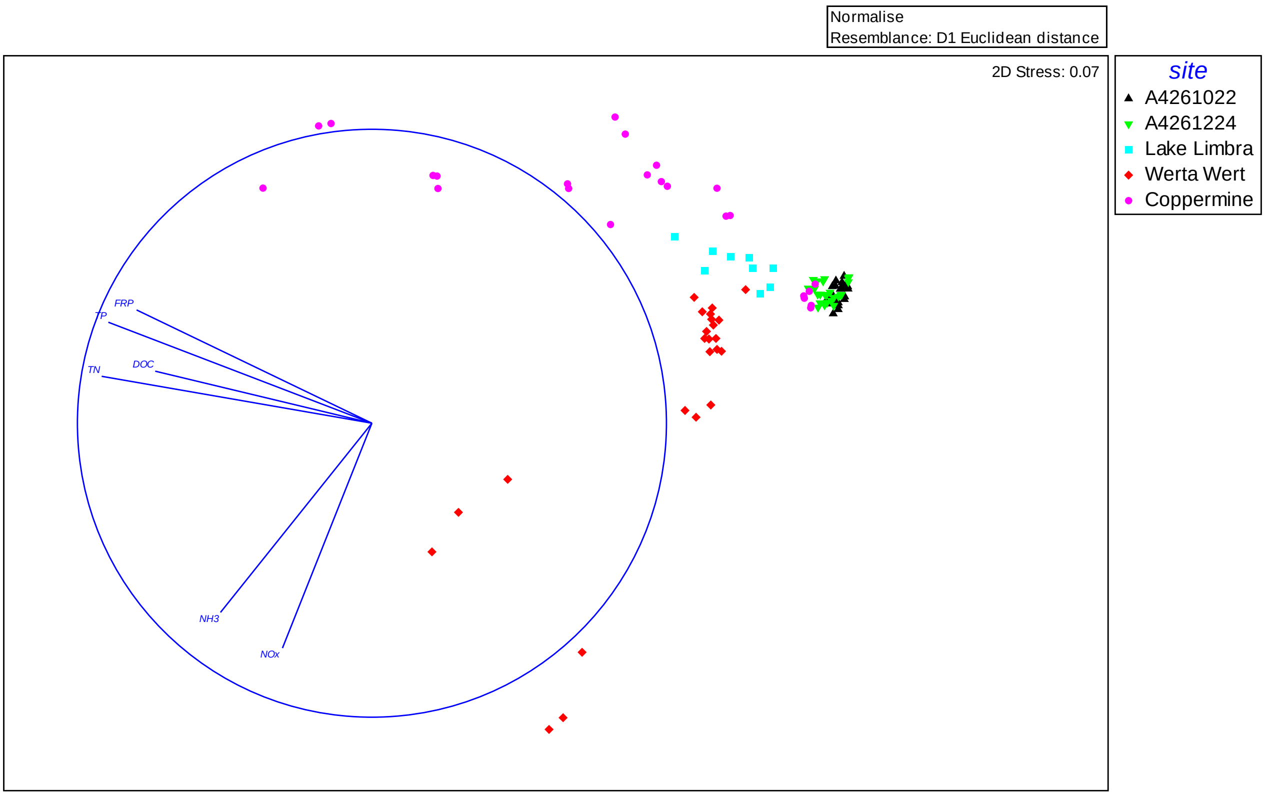


Figure 22: MDS ordination of pooled data for resources (nutrients and DOC) in the three large wetlands; Werta Wert, Lake Limbra and Coppermine relative to the reference site in the River upstream of Lock 6 (A4261022) and in Chowilla Creek immediately upstream of the Environmental Regulator (A4261224).

2.6.9. HO#9: DURING THE MANAGED INUNDATION, 5-DAY BIOCHEMICAL OXYGEN DEMAND WILL BE HIGHER IN THE LARGE WETLANDS THAT WERE INUNDATED (WERTA WERT, COPPERMINE AND LAKE LIMBRA) COMPARED TO THE UPSTREAM RIVER REFERENCE SITE (A4261022) AND IN THE ANABRANCH AT THE REGULATOR (A4261224)

The time series for 5-day Biochemical Oxygen Demand (BOD_5) in the three large wetlands (Werta Wert, Lake Limbra, and Coppermine) relative to the reference site upstream of Lock 6 (A4261022) are presented in Figure 23. It is evident that the BOD_5 values in the wetlands are consistently higher than at the upstream reference site (A426102) and are typically higher than in the anabranch site upstream of the regulator (A4261224). This is supported by the results of the PERMANOVA analysis (Table 16).

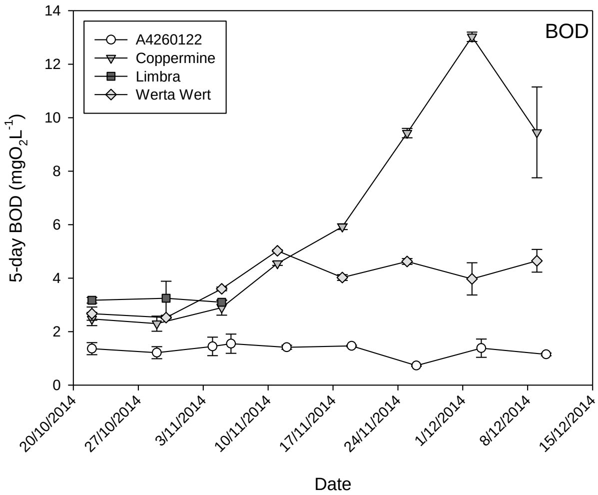


Figure 23: Time series of 5-day Biochemical Oxygen Demand (BOD_5) in wetlands (Coppermine wetland, Lake Limbra and Werta Wert Wetland, compared to the upstream reference site (source water) in the Lock 6 weir pool (A4261022). Lake Limbra was sampled for a short period relative to the other wetlands due to the shallow nature of the wetland and associated difficulties with access associated with low water levels once the drawdown commenced.

Table 16: Results of PERMANOVA analysis (P values are Monte Carlo analysis); comparison of 5-day Biochemical Oxygen Demand (BOD_5) in the three large wetlands; Werta Wert, Lake Limbra and Coppermine relative to the reference site in the River upstream of Lock 6 (A4261022) and in Chowilla Creek immediately upstream of the Environmental Regulator (A4261224). Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites.

comparison	22/10/2014	29/10/2014	4/11/2014	12/11/2014	19/11/2014	26/11/2014	3/12/2014	10/12/2014
A4261022, A4261224	**0.0151**	0.0648	0.3814	0.3315	0.3778	**0.0001**	0.1533	0.2770
A4261022, Lake Limbra	**0.0021**	**0.0126**	**0.0080**					
A4261022, Werta Wert	**0.0092**	**0.0037**	**0.0033**	**0.0001**	**0.0001**	**0.0001**	**0.0071**	**0.0012**
A4261022, Coppermine	**0.0142**	**0.0161**	**0.0169**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0029**
A4261224, Lake Limbra	**0.0002**	**0.0470**	0.1669					
A4261224, Werta Wert	**0.0135**	0.0853	0.0815	**0.0023**	**0.0001**	**0.0002**	0.1323	**0.0010**
A4261224, Coppermine	**0.0316**	0.2292	0.2522	**0.0028**	**0.0001**	**0.0001**	**0.0008**	**0.0027**
Lake Limbra, Werta Wert	0.1233	0.2438	**0.0212**					
Lake Limbra, Coppermine	0.0669	0.1908	0.4290					
Werta Wert, Coppermine	0.5101	0.3804	0.0796	**0.0145**	**0.0032**	**0.0015**	**0.0022**	0.0552

2.6.10. HO#10: THE MANAGEMENT REGIME OF MAINTAINING DAILY WATER EXCHANGE OF THE IMPOUNDED VOLUME ≥20% AND ENSURING DILUTION FLOWS IN THE RIVER ABOVE 7,000 MLDAY^{-1} IS AN EFFECTIVE TOOL TO MAINTAIN DISSOLVED OXYGEN WITHIN THE RIVER ABOVE 6 MGO_2L^{-1}

The requirement for dissolved oxygen to be ≥6 mgO_2L^{-1} is derived from Schedule 2 of the Environment Protection (Water Quality) Policy (2003) and was adopted as the Ecological Target and Critical Limit in the receiving waters of the Lock 5 weir pool. The dissolved oxygen data from the upstream reference station in the Lock 6 weir pool (A4261022) and the site below the confluence of the Chowilla Creek (A4260704) is presented in Figure 24. These data demonstrate that ambient DO in the receiving water in the river channel downstream of the junction of Chowilla Creek and the river, was always above 8 mgO_2L^{-1} during the testing event. Therefore, it is considered that the management regime utilised in the testing event was successful in maintaining appropriate conditions within the Lock 5 weir pool.

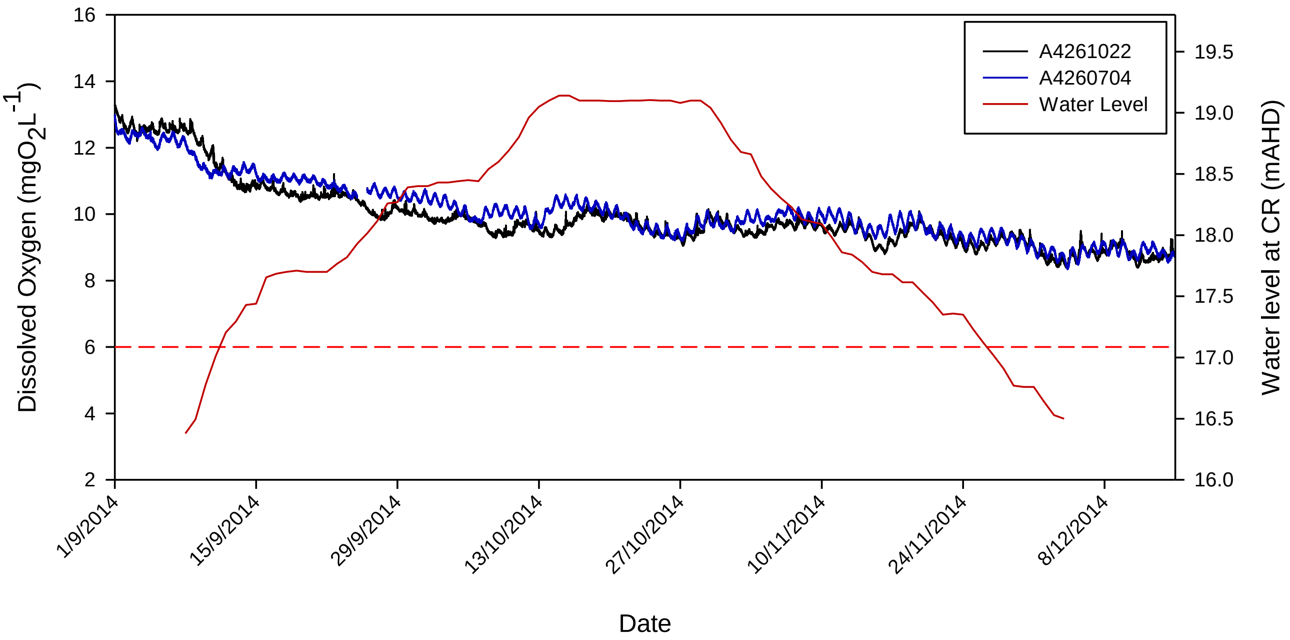


Figure 24: Dissolved Oxygen (mgLO_2L^{-1}) at the upstream reference sites in the Lock 6 weir pool (A4261022), and in the Lock 5 weir pool below the confluence of the Chowilla Creek and the River Murray. The guideline limit for dissolved oxygen stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 6 mgO_2L^{-1} (shown here as broken red horizontal reference line).

2.6.11. HO#11: THE MANAGEMENT REGIME PROVIDED SUFFICIENT DILUTION FLOWS IN THE RIVER CHANNEL SUCH THAT DISSOLVED OXYGEN WITHIN THE ANABRANCH WAS MAINTAINED ABOVE 6 MGO_2L^{-1}

Wallace (2008) utilised observed oxygen depletion rates recorded *in-situ* during ponded floods in managed wetlands at Chowilla to calculate that with an expected oxygen depletion rate of -0.82 mgO_2L^{-1}day^{-1}, a daily exchange equivalent to 20% of the stored volume (replacement with fresh, oxygenated water from the creek/river) would be sufficient to ensure a low likelihood of dissolved oxygen in the impounded area falling below 6 mgO_2L^{-1}. 20% daily exchange was subsequently used as a Critical Operational Limit in the Chowilla Operations Plan (Wallace & Whittle, 2014c).

The data for dissolved oxygen from the three telemetered monitoring sites in the anabranch (A42605080, A4261107, A4261224) is presented in Figure 25, with the modelled data for daily exchange for the total impounded volume (outputs from BigMod, data provided by Andrew Keough, MDBA) overlayed. Dissolved oxygen was always above 6 mgO_2L^{-1} at each of the anabranch sites, and the daily exchange for the total impounded volume was 19.8% on the 13th October. Apart from this single day, daily exchange for the total impounded volume was always >22%.

The data presented in Figure 25 shows that at A4260580, between the 15th and 26th October, DO declined in a linear manner from approximately 9.6 to 6.6 mgO_2L^{-1}. Although dissolved oxygen did not fall below the 6 mgO_2L^{-1} threshold, the threshold was approached, and it is considered that it is probable that dissolved oxygen would have fallen below the threshold at this site if any additional load of NOM was added to the system; i.e. if the inundated area was increased at this time, prior to a stabilisation in conditions. An extrapolation of the linear decline observed indicates that at the prevailing rate of oxygen depletion, the 6 mgO_2L^{-1} threshold could have been triggered on the 1st of November. During the period between the 15th and 26th October average daily dilution for the total stored volume was 26% (range = 23-27%). This bulk rate does not take into account spatial variation in dilution caused by large inflow from the regulated creeks (i.e. Pipeclay and Slaney Creek) in the mid-reaches of Chowilla Anabranch. An assessment of the modelled data for daily exchange of the stored volume upstream of A4260580 is presented in Figure 26. These data indicate that the minimum daily exchange of the stored volume upstream of A4260580 was 10.4% on the 12th October 2014. During the period between the 15th and 26th October, when DO was declining in a linear manner at this site, the average daily exchange for the water upstream of A4260580 was 15.8% (std dev = ±0.86). Consequently, lower rates of daily exchange may have resulted in a more substantial and potentially problematic decline in dissolved oxygen.

It is considered likely that the difference in magnitude of oxygen depletion that is observed between A4260580 and the two sites that are further downstream in the anabranch (A4261170 and A4261224) is primarily in response to dilution upstream of A4261107 from riverine inflows *via* Pipeclay and Slaney Creeks, and additional dilution upstream of A4261224 due to riverine inflows *via* Boat Creek. Whilst the inflows provide much needed dilution and maintenance of diverse hydraulic conditions, the potential for even higher inflows into the middle of the anabranch system *via* Pipeclay Creek, Slaney Creek and Boat Creek to exacerbate conditions in the upper anabranch also needs some consideration; visual observations during the weekly sampling included comparatively low turbulence at the water surface and large accumulations of floating plants and organic debris in Punkah Creek upstream of the junction of Slaney Creek. This indicates that during periods of high inflows, the driving head and discharge through Slaney Creek, Pipeclay Creek, and Boat Creek may create a partial “hydraulic dam” effect whereby water in Punkah Creek upstream of these major inlets has an increased retention time within the system.

The maximum *in-situ* depletion rate in the logger data for the telemetered monitoring stations was recorded at A4260580 between the 15th and 26th October 2014 ($y=8222-0.1959\,x$, $r^2 = 0.88$, $P = <0.0001$, Figure 26[A], regression not shown in figure). This depletion rate (0.2 $mgO_2L^{-1}day^{-1}$) is substantially slower than the 0.82 $mgO_2L^{-1}day^{-1}$ rate recorded in ponded floods and subsequently utilised by Wallace (2008) to establish the 20% daily exchange threshold, However, unlike the ponded floods in managed wetlands, the *in-situ* depletion rate observed during the 2014 testing event incorporated daily exchange dilution with “fresh” river water. Insight into the oxygen demand that may have been observed without ongoing daily dilution can be obtained *via* the BOD_5 values recorded in the samples collected from A4260580. On the 15th, 22nd and 29th October and 4th November 2014, BOD_5 was 1.7, 2.1 and 2.3 and 3.2 mgO_2L^{-1} respectively. Assuming the rate of decline in DO is quasi-linear over the 5-day bioassay period (sensu Wallace, Ganf & Brookes, 2008), these values equate to 0.34, 0.42, 0.46 and 0.64 $mgO_2L^{-1}day^{-1}$.

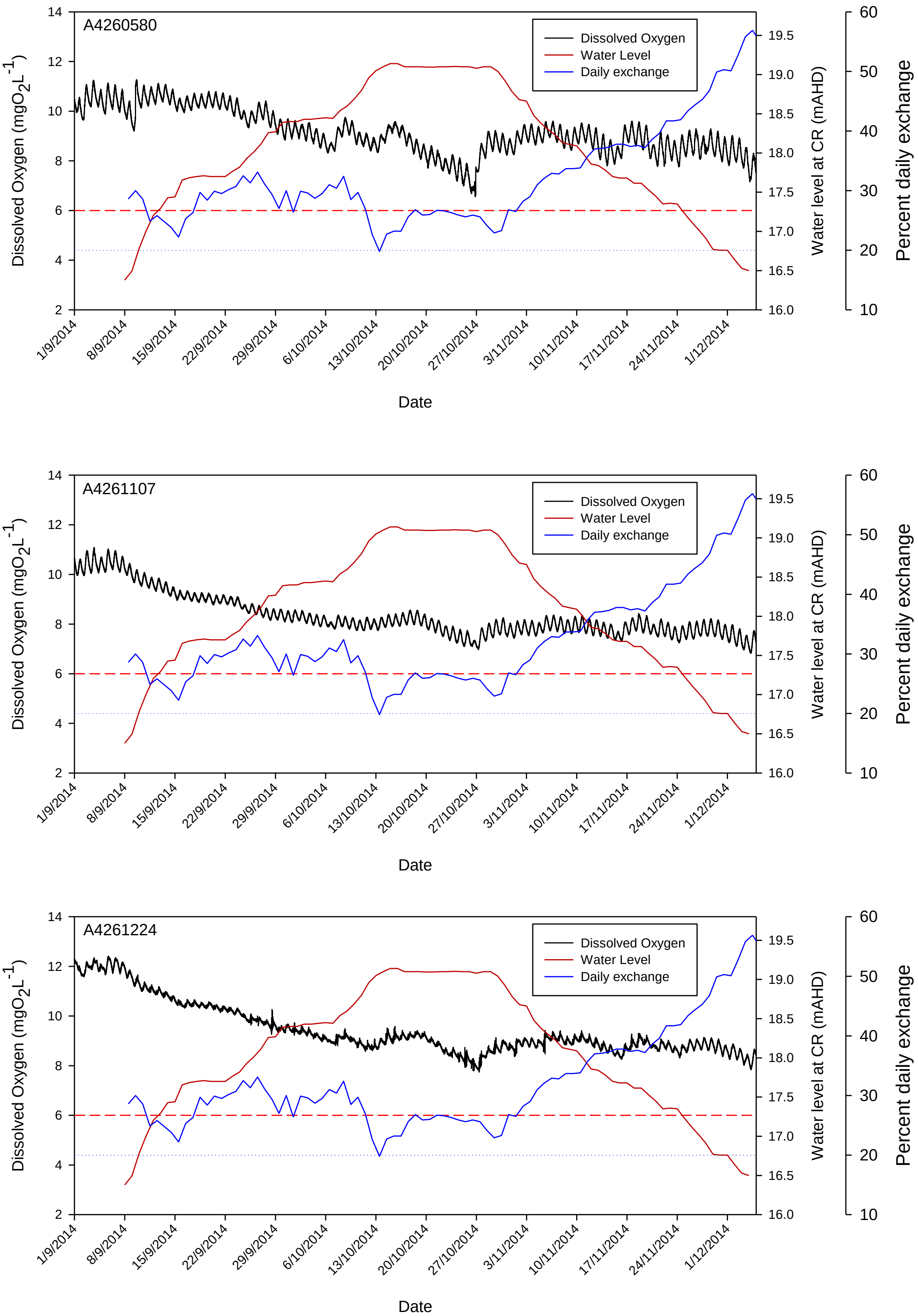


Figure 25: Dissolved Oxygen (mgO_2L^{-1}) at the anabranch creek sites [A] upstream of Punkah Creek Crossing (A4260580); and [B] upstream of Monomon Creek (A4261107); and [C] upstream of the regulator (A4261224) The guideline limit for dissolved oxygen stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 6 mgO_2L^{-1} (shown here as broken red horizontal reference line).

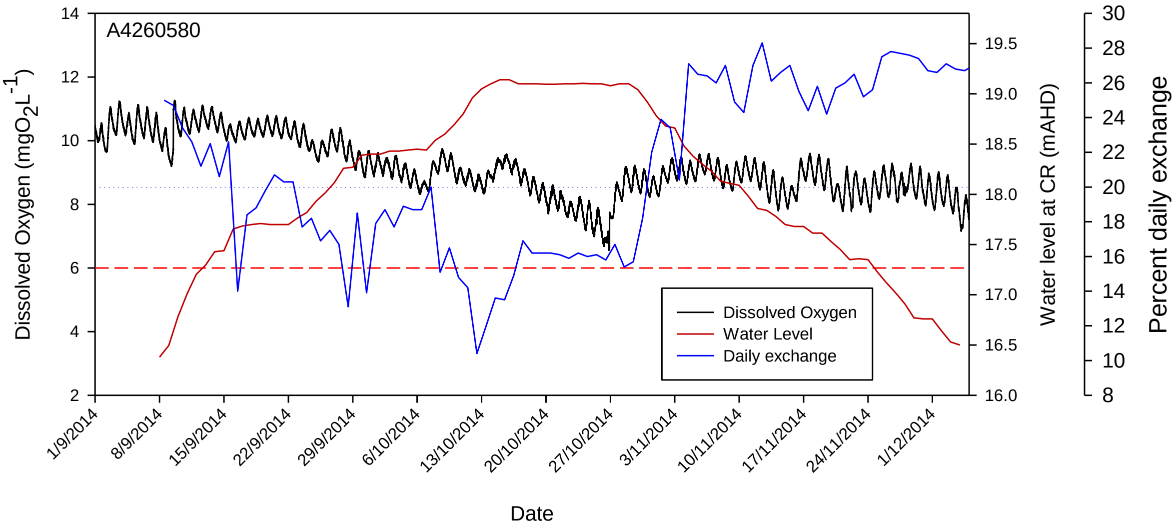


Figure 26: Dissolved Oxygen (mgO_2L^{-1}) at the anabranch creek sites upstream of Punkah Creek Crossing (A4260580). The guideline limit for dissolved oxygen stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 6 mgO_2L^{-1} (shown here as broken red horizontal reference line). The daily exchange rate shown here has been calculated to be specific to this site.

2.6.12. Ho#12: Dissolved oxygen in the wetlands was maintained above 4 mgO_2L^{-1}

The requirement for dissolved oxygen to be >6 mgO_2L^{-1} is derived from Schedule 2 of the Environment Protection (Water Quality) Policy (2003), and was adopted as the Ecological Target in both the anabranch creeks and within the receiving waters of the Lock 5 weir pool. However, this value is considered unrealistically high in recently flooded lowland wetlands where enhanced primary productivity resulting from the inundation of organic material should be anticipated as a normal, and desirable biogeochemical process. Based on data collected from wetlands at Chowilla during delivery of environmental water via ponded floods (water pumped from nearest creek and retained within the wetland via earthen banks), it is recognised that wetlands that are effectively terminal have a high likelihood of becoming hypoxic or anoxic as natural organic material within the managed area becomes inundated (Wallace, 2008; Wallace & Lenon, 2010). A benchmark of 4 mgO_2L^{-1} was selected as an indicator of oxygen conditions within the managed wetlands. Wetlands that have large surface area relative to the perimeter (i.e. relative low loading of NOM from riparian trees) such as Lake Limbra and Lake Littra are considered to have a lower likelihood of onset of hypoxia compared to wetlands that have little exposure to wind driven mixing or have comparatively low surface area relative to the perimeter (i.e. relative high loading of NOM from riparian trees) such as Werta Wert Wetland and Coppermine Wetland.

Werta Wert wetland (Figure 27[A]) was already partially full prior to the 2014 testing event due to retaining water from a previous delivery of environmental water to the wetland. The logger at this site experienced heavy biofouling from periphyton and a large mass of insect eggs deposited on the optical sensor. Consequently, data for the period 9th to 16th October is unreliable and not presented. The remaining data demonstrates that dissolved oxygen was frequently below the 4 mgO_2L^{-1} benchmark in this wetland. Lake Limbra (Figure 27[B]) was in a dry phase at the commencement of the 2014 testing event, and was filling through a narrow flowpath at the time of logger deployment. The data indicates that DO was above the 4 mgO_2L^{-1} benchmark for the majority of the period for which data was collected.
Coppermine wetland was in a dry phase at the commencement of the 2014 testing event. The data from the sensor deployed in the wetland (Figure 28[A]) indicates that there was a rapid onset of anoxic conditions upon filling, followed by an improvement and subsequent stabilisation of dissolved oxygen on the 8th of

October 2014. It is likely that the initial depletion of dissolved oxygen corresponds to the inundation of NOM within the wetland with low effective dilution in the first few days whilst the wetland was functioning as a terminal wetland prior to water levels increasing sufficiently (on or around the 8th of October) to exceed the natural sill at the back edge of the wetland which subsequently allowed the wetland to function as a flow through system.

The data from the monitoring station (A4261166) on the lignum shrubland on the flow path through which water that had passed through the wetland must travel prior to discharging in to Woolshed Creek and subsequently to the River is shown in Figure 28[B]. The data demonstrate a rapid depletion of dissolved oxygen on the 21st October 2014 which coincides with the rapid increase in impounded volume in the Coppermine Complex-Woolshed Creek area during this period (see Figure 29). A review of the daily operational data from the ancillary regulators at Woolshed Creek East and South (Figure 30) indicates that the period of hypoxia recorded at A4261166 coincided with a period of acute hypoxia (0.5 mgO_2L^{-1}) at Woolshed Creek East. It is considered that the driver for this brief period of acute hypoxia was the installation of extra boards in the ancillary regulator structures to achieve the targeted inundation level and allow flows to leave the impounded area via the regulator structure at Woolshed Creek South. Removal of one row of boards by SA Water staff following identification of the problem allowed a reinstatement of exchange through the area and water quality subsequently improved. This observation reinforces our understanding of the need to manage (i) the rate of daily increase in inundated area; and (ii) the daily exchange rate in order to maintain acceptable water quality conditions within inundated areas.

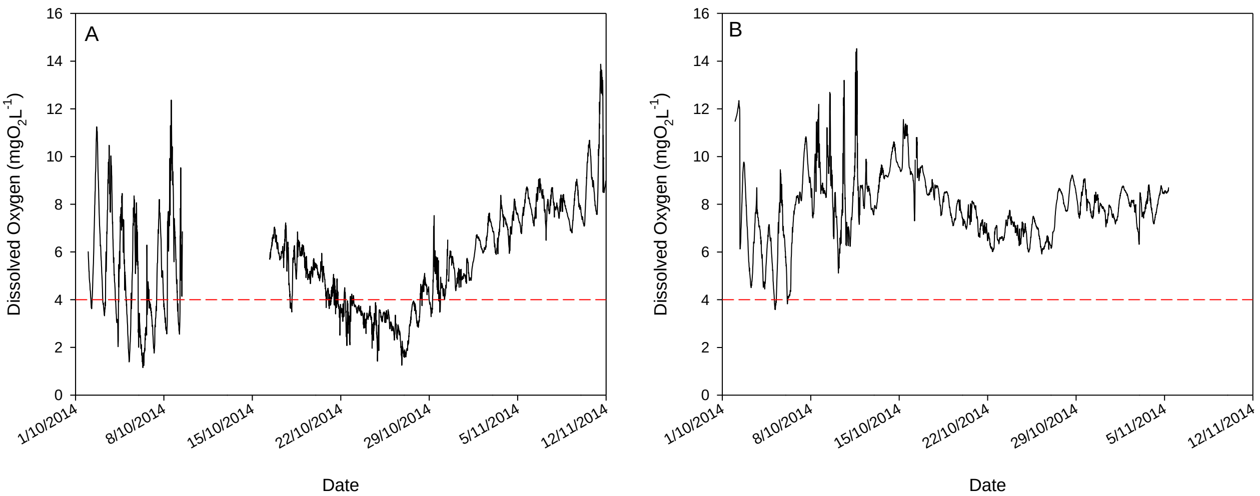


Figure 27: Dissolved Oxygen (mgO_2L^{-1}) in [A] Werta Wert wetland and [B] Lake Limbra. The benchmark selected for assessing oxygen conditions (shown here as broken red horizontal reference line) is 4 mgO_2L^{-1}

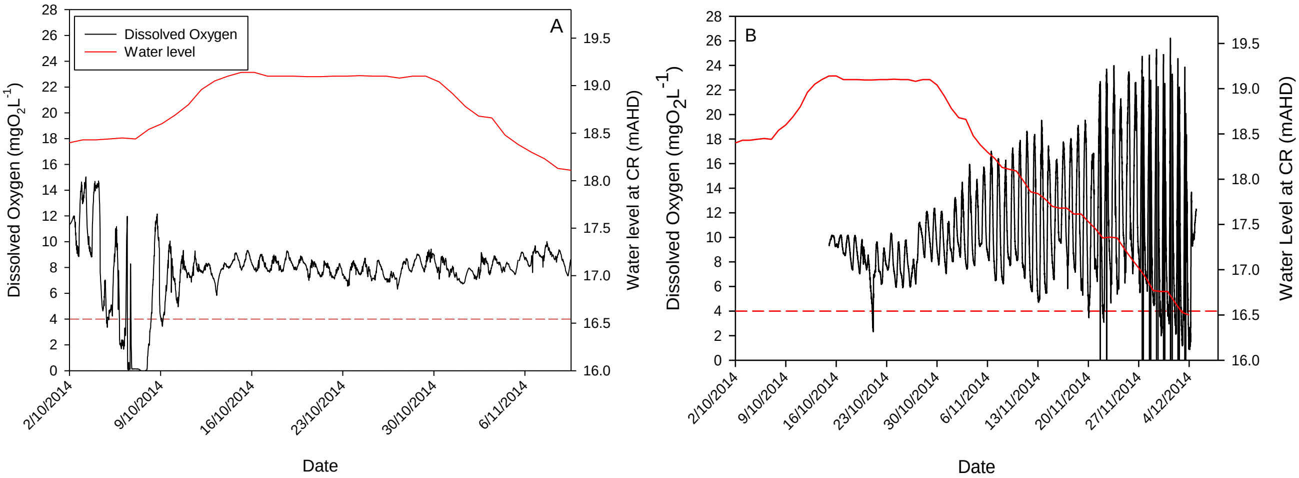


Figure 28: Dissolved Oxygen (mgO_2L^{-1}) in [A] Coppermine wetland; and [B] at station A4261166 on the Coppermine complex (lignum shrubland/floodplain). The benchmark selected for assessing oxygen conditions is 4 mgO_2L^{-1} (shown here as broken red horizontal reference line).

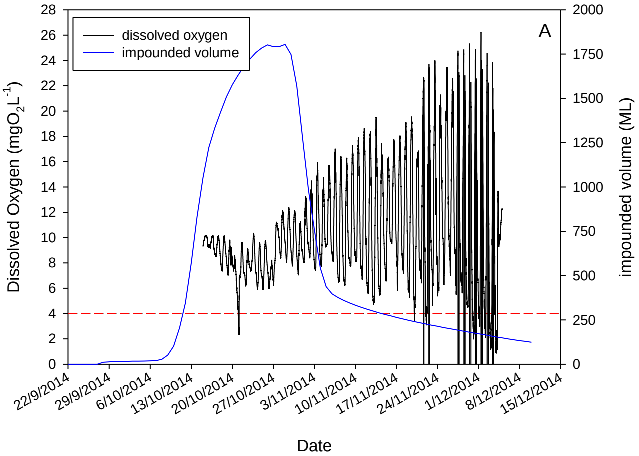


Figure 29: Dissolved oxygen at station A4261166 on the Coppermine complex (lignum shrubland/floodplain) relative to the stored volume in the area incorporating Coppermine Complex and Woolshed Creek. The low dissolved oxygen recorded on the 21st October 2014 (2.3 mgO_2L^{-1}) coincides with the rapid increase in water level. The benchmark selected for assessing oxygen conditions (shown here as broken red horizontal reference line) is 4 mgO_2L^{-1}

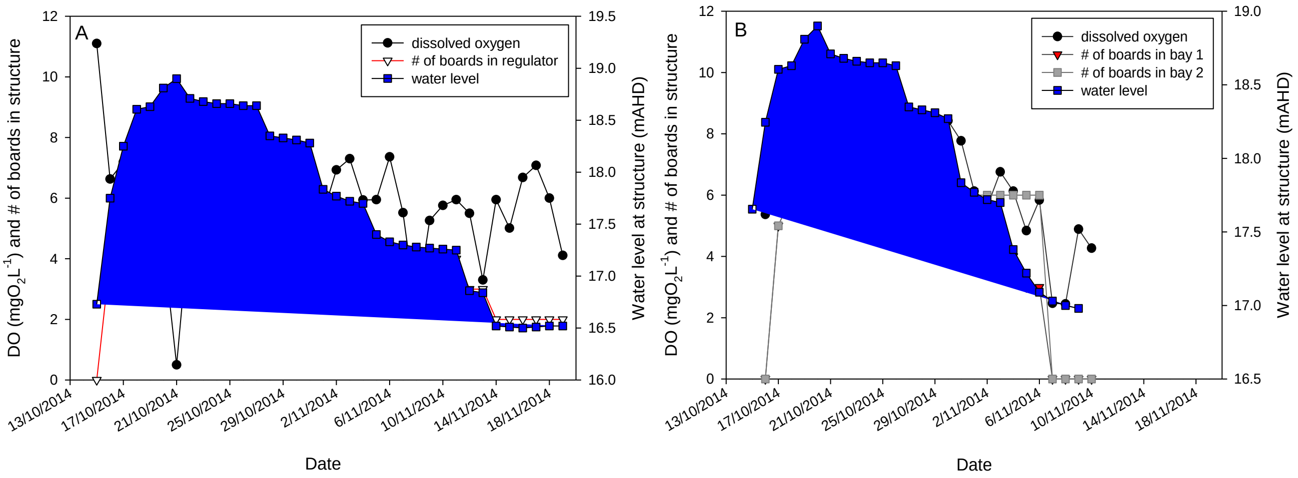


Figure 30: Dissolved oxygen, water level and number of stop boards in the regulator structure at [A] Woolshed Creek East, and [B] Woolshed Creek South. The low dissolved oxygen recorded on the 21st October 2014 at Woolshed Creek East (0.5 mgO_2L^{-1}) coincides with the installation of extra boards in the regulator structure

2.6.13. HO#13: During managed inundations, return flows from the anabranch (A4261224) result in a significant increase in zooplankton abundance in the receiving waters of the Lock 5 weir pool (A4260704) compared to the reference site in the Lock 5 weir pool (A4260705)

Only a preliminary assessment of the results has been provided here as this component is being delivered as a value-adding component and sample processing is not yet complete. The full data set which includes samples from the wetlands Lake Limbra, Coppermine wetland and Werta Wert wetland will be published in the peer review literature.

The data for the abundance of zooplankton (individuals L^{-1}) and estimated load of zooplankton for the reference site in the river upstream of the junction of Chowilla Creek and the river (A4260705), in the anabranch upstream of the Chowilla Regulator (A4261224), and in the receiving water of the Lock 5 weir pool downstream of Chowilla Creek (A4260704), is presented in Figure 31[A] and [B] respectively. The data demonstrate that the abundance of zooplankton (see Table 17 for PERMANOVA results) at the downstream site (A4260704) was significantly higher than at the upstream reference site (A4260705) during the peak (15th and 29th October) and the middle of the recession phase of the hydrograph (12th November). The abundance of zooplankton was higher in the anabranch (A4261224) than the upstream reference site (A4260705) during the peak of the hydrograph demonstrating that the anabranch was a major source of resources to the river channel during this period. The estimated load (Figure 31[B]) of zooplankton was similar at all three sites on the 30th September, but was markedly higher in both the anabranch (A4261224) and the receiving waters in the Lock 5 weir pool (A4260704) than the reference site (A4260705) on the 14th and 28th of October. On the last two sampling periods, the load in the anabranch (A4261224) was similar to the upstream reference site, but elevated in the river downstream of Chowilla (A4260704).

It is considered that the relatively low abundance and load of zooplankton recorded in the return flows (A4261224) during the recession phase of the hydrograph is due to a combination of (i) high dilution, and (ii) the regulators on the large wetlands (Werta Wert and Lake Limbra) being closed during the recession phase. The high dilution rate is an artefact of the maintenance of high inflow through the regulated (i.e. Pipeclay and Slaney) creeks whilst stored volume within the anabranch was decreasing. The regulators at Werta Wert wetland and Lake Limbra were closed in order to achieve an extended inundation period in the wetlands. Consequently, once lateral disconnection of the creek from the shedding floodplain had occurred, there would have been a limited supply of zooplankton back to the creek. Furthermore, the relatively high velocity in the creeks may not have been conducive to *in-situ* growth of the zooplankton community.

Table 17: Results of PERMANOVA analysis; comparison of abundance (individuals L^{-1}) in samples collected from the reference site in the river upstream of the junction of Chowilla Creek and the river (A4260705), in the anabranch upstream of the Chowilla Regulator (A4261224), and in the receiving water of the Lock 5 weir pool downstream of Chowilla Creek (A4260704), Shaded cells denote that there is a statistically significant difference in the concentration of the respective parameter between the two sites. P values are Monte Carlo analysis.

Groups	1/10/2014	15/10/2014	29/10/2014	12/11/2014	26/11/2014
A4260704, A4261224	0.6061	0.3803	0.1423	**0.0257**	0.6643
A4260704, A4260705	**0.0118**	**0.0115**	**0.0215**	**0.0143**	0.6384
A4261224, A4260705	0.3283	**0.0275**	**0.0132**	0.5409	0.8720

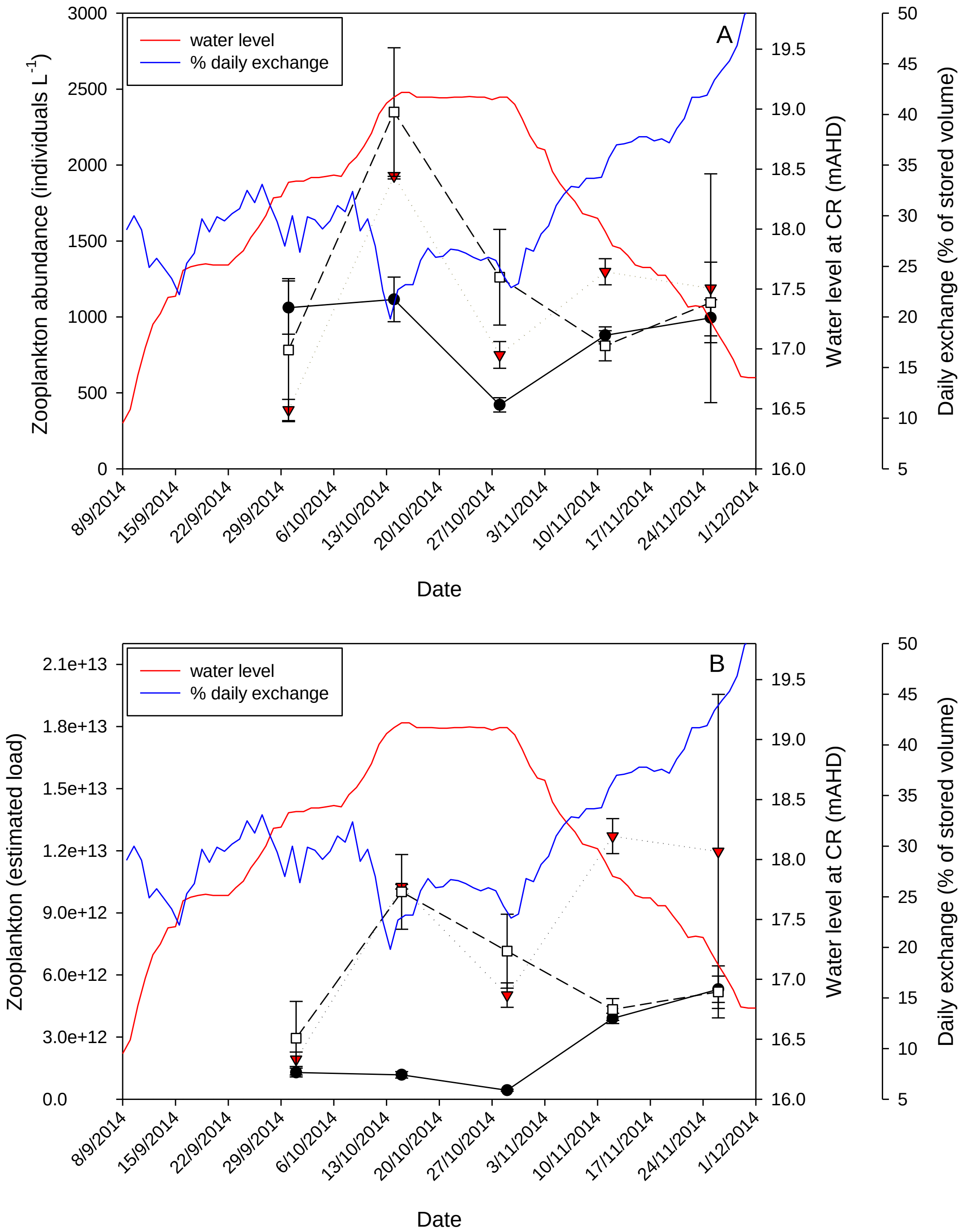


Figure 31: [A] Abundance of zooplankton (individuals L^{-1}), and [B] estimated load (individuals L^{-1} x daily flow at nearest gauging point to sampling station) in surface water samples collected from the reference site in the river upstream of the junction of Chowilla Creek and the river (A4260705; black solid circles), in the anabranch upstream of the Chowilla Regulator (A4261224, open squares), and in the receiving water of the Lock 5 weir pool downstream of Chowilla Creek (A4260704, red inverted triangles). Error bars are ± 1 Standard Error

2.6.14. HO#14: THE MANAGEMENT REGIME OF MAINTAINING DAILY WATER EXCHANGE OF THE STORED VOLUME WITHIN THE ANABRANCH ≥20% IS AN EFFECTIVE TOOL TO PREVENT THE ESTABLISHMENT OF PERSISTENT STRATIFICATION WITHIN THE ANABRANCH

The data for salinity and thermal stratification from the site immediately upstream of the Chowilla Regulator (A4261224) is presented in Figure 32. The data indicates that there is a salinity gradient between the top and the bottom of the water column. The spike in salinity in late September-early October is also observed at the upstream sites within the anabranch (discussed in section 3.6.1. of this report). The temperature data indicates that there are periods of strong diurnal stratification where the temperature gradient between the top and the bottom of the water column is >1.5 °C, but there is no evidence that persistent thermal stratification (Delta T ≥ 0.5 C for more than 5 days) occurs at this site. However, the data for water density (kgm^{-3}) calculated from temperature and salinity (Figure 33) suggests that there are periods where the difference in density between the top and the bottom of the water column may have limited or prevented complete mixing of the water column.

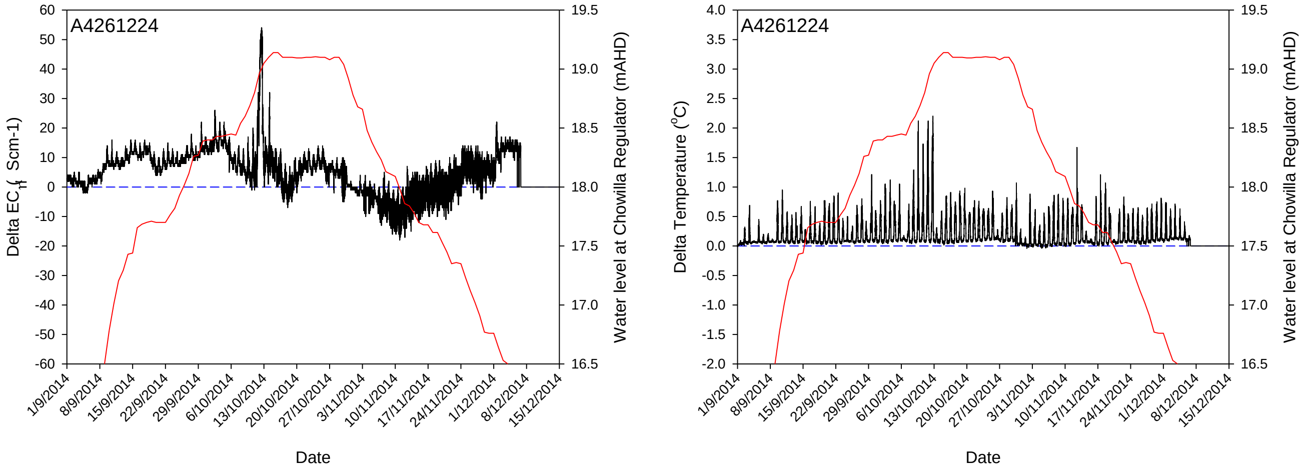


Figure 32: Salinity and temperature stratification measured as the difference in salinity (EC; µScm^{-1}) and temperature (°C) between the surface and bottom loggers at A4261224. The blue horizontal reference line denotes no difference between the top and bottom of the water column. The red line is water level at Chowilla Regulator

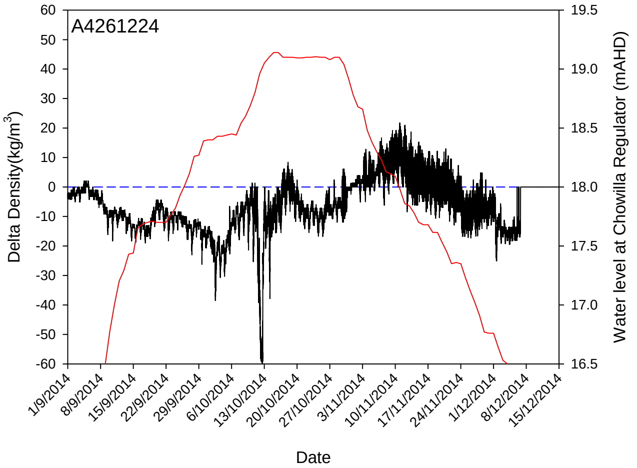


Figure 33: Density stratification measured as the difference in water density (kg/m^3) between the surface and bottom loggers at A4261224. The blue horizontal reference line denotes no difference in density between the top and bottom of the water column. The red line is water level at Chowilla Regulator

2.6.15. HO#15: THE MANAGEMENT REGIME OF MAINTAINING FLOW AT LOCK 6 > 1,000 MLDAY^{-1} IS SUFFICIENT TO PREVENT THE ESTABLISHMENT OF PERSISTENT STRATIFICATION WITHIN THE RIVER CHANNEL UPSTREAM OF LOCK 6

The data from the reference site upstream of Lock 6 (A4261022) indicates that there was a salinity gradient between the top and the bottom of the water column (Delta EC) for extensive periods of the study (see Figure 34). Furthermore, the temperature data indicates that there was a period of near continuous thermal stratification throughout the testing event. The data for water density (kgm^{-3}) suggests that there are periods where the difference in density between the top and the bottom of the water column may have limited or prevented complete mixing of the water column (Figure 35). However, this result needs to be interpreted with caution; data for temperature and salinity from the quasi-weekly vertical profiles conducted at this site (the vertical profiles were undertaken primarily to attain data on chlorophyll *a*, pH and turbidity, not stratification), do not indicate the presence of thermal or salinity stratification (data not shown here). Consequently, it is unclear if the persistent stratification indicated at this site is a reliable assessment, or an artefact within the data. An exploration of the lines of evidence for the observation of persistent thermal stratification is provided below.

A conceptual model for the development of thermal stratification developed by Baker *et al*. (2000) proposed that:

- At 10,000 ML day^{-1}, diurnal stratification may occur if wind speed is <1.2 m s^{-1},
- At 4000 ML day^{-1}, persistent stratification may develop if wind speed is <1.2 m s^{-1},
- Diurnal stratification may occur at wind speeds of 1.3–3.0 m s^{-1},
- Wind speeds >3 m s^{-1} disrupt stratification, irrespective of flow

An assessment of persistent thermal stratification at Nildottie was undertaken by Burch *et al*., (2004). This compared low-flow conditions from 16 November 2003 to 8 January 2004 (mean flow downstream of Lock 3 = 4,911 ML day^{-1}. A similar assessment was undertaken during very-low flow conditions from 16 November to 18 December 2007 (mean flow = 1,622 ML day^{-1}) (unpublished data courtesy of SA Water). Under very-low flow conditions, stratification was more persistent than under low-flow conditions. Under low-flow conditions, the river exhibited diurnal stratification that did not persist for longer than 3 days. In contrast, under very-low flow conditions, stratification was more frequent, with seven occurrences lasting from 2–7 days.

The flow at Lock 6 was very low (average = 1,146 MLday^{-1}) between the 9th September and the 30th October 2014 when the majority of flow into SA was being directed into the Chowilla Anabranch in order to achieve the target inundation extent. Flows subsequently increased to in excess of 4,000 MLday^{-1} by the 7th November 2014 during the falling limb of the testing hydrograph. Based on the observations of Burch *et al*., (2004) and the conceptual model of Baker *et al*. (2000), it is possible that persistent stratification may have established upstream of Lock 6 during the period between the 9th September and the 30th October 2014. However, the increased flow observed after the 7th November 2014 (Figure 36[A]) combined with the lowering of the Lock 6 weir pool should have been sufficient to break-down the thermal stratification. In addition, several periods of wind speed greater than 3 ms^{-1}, which should have been sufficient to break down stratification, were recorded during the period of persistent stratification (Figure 36[B]). Further assessment of the data for October 2014 (Figure 37) indicates that the stratification was substantially reduced in association with periods with wind speeds >3 ms^{-1}. However, complete mixing of the water column was not observed. Hence it is considered that either (i) the loggers drifted out of calibration, (ii) the loggers may not be sufficiently sensitive to reliably discriminate the small changes in temperature that are relevant to studies of thermal stratification, or (iii) that the EC and temperature loggers deployed at the bottom of the water column became fouled and grounded on (or near to) the sediment water interface and consequently were not suspended in the water column at the intended depth. Developing a more comprehensive understanding of the dynamics of thermal stratification, and the depth within the water column that the boundary layer occurs at should be quantified as a priority. Very low mixing energy may result in (i) the affected reach becoming a sink for propagules that cannot control their position in the water column, and (ii) deoxygenation of the water column below the mixing boundary (hypolimnion).

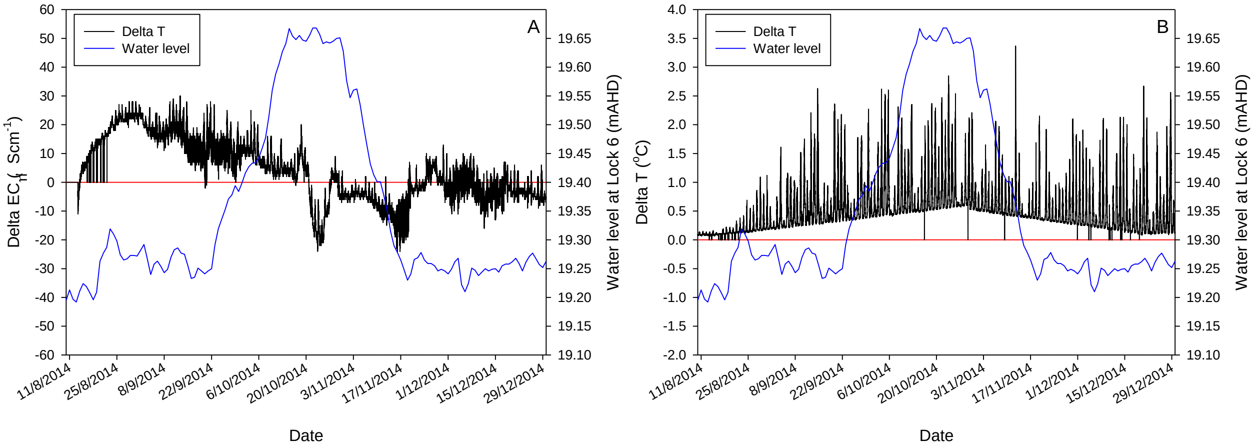


Figure 34: [A] salinity and [B] temperature stratification measured as the difference in salinity (EC; µScm^{-1}) and temperature (°C) respectively between the surface and bottom loggers at A4261022. The red horizontal reference line denotes no difference between the top and bottom of the water column. The blue line is water level at Lock 6.

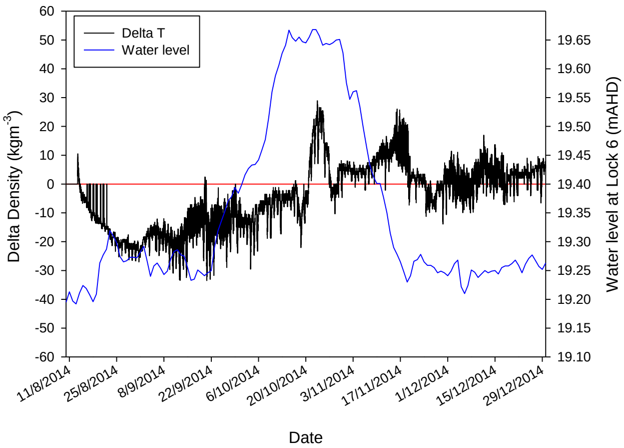


Figure 35: Density stratification measured as the difference in water density (kg/m^3) between the surface and bottom loggers at A4261022. The red horizontal reference line denotes no difference between the top and bottom of the water column.

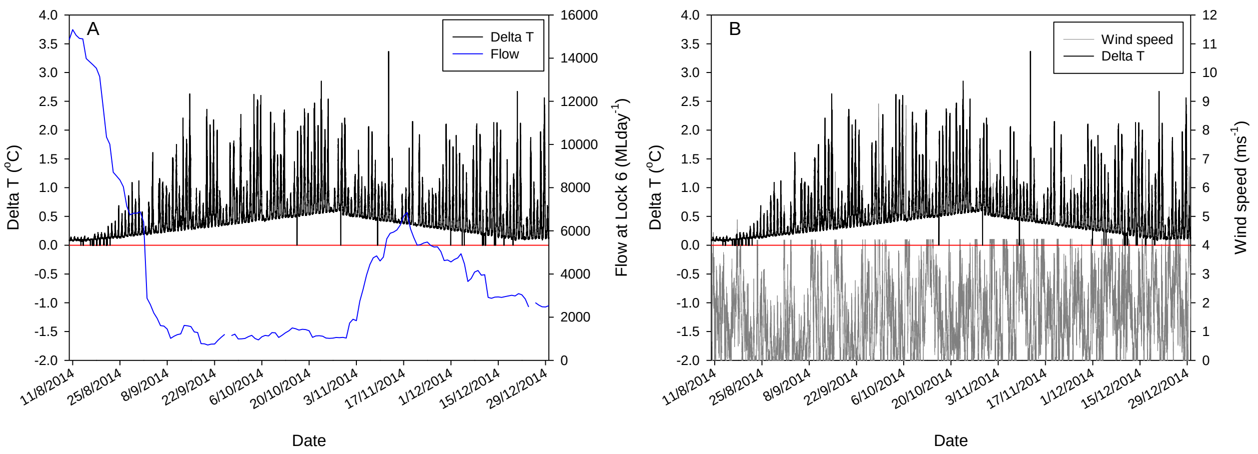


Figure 36: Thermal stratification (delta T °C) at A4261022 relative to [A] flow at Lock 6 and [B] wind speed (recorded at the Automated Weather Station A4261167). The red horizontal reference line denotes no difference in temperature between the top and bottom of the water column.

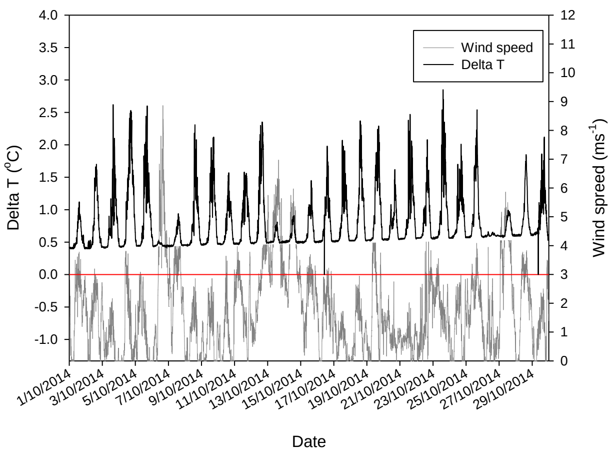


Figure 37: Thermal stratification (delta T °C) at A4261022 relative to [A] flow at Lock 6 and [B] wind speed (recorded at the Automated Weather Station A4261167). The red horizontal reference line denotes no difference in temperature between the top and bottom of the water column.

2.6.16. HO#16: RETURN FLOWS FROM THE MANAGED INUNDATIONS RESULT IN A SIGNIFICANT INCREASE IN *IN-SITU* PRIMARY PRODUCTIVITY IN THE ANABRANCH (A4261224) AND IN THE RECEIVING WATER OF THE LOCK 5 WEIR POOL (A4260704) RELATIVE TO THE TWO REFERENCE SITE UPSTREAM OF LOCK 6 (A4261022)

A brief overview of the results is presented here. Detailed reporting on this component will be published in the peer review literature. It is anticipated that a manuscript will be submitted to the Journal Marine and Freshwater Research for a special issue has been allocated to studies on allochthonous DOC.

It was expected that the resources in the return flows from the anabranch would stimulate primary open water productivity. In effect, the upstream site would be expected to be resource limited (i.e. in low flow mode) and the downstream site would be expected to have improved access to resources, and hence be in a high flow or flood mode. The data presented in Figure 38 demonstrates that there is a marked difference in the magnitude of the diurnal variation in dissolved oxygen in the downstream receiving waters of the Lock 5 weir pool (A4260704) compared to the reference site upstream of Lock 6 (A4261022). This is interpreted as evidence of (i) an increase in CR and NP in the water within the impounded area; and (ii) that the return flows stimulate primary productivity in the Lock 5 weir pool.

The preliminary results of the primary productivity modelling for the period spanning the peak of the hydrograph (17th to 26th October 2014) indicate that there are some differences in gross productivity (Figure 39 [A]), community respiration (Figure 39 [B]), and net ecosystem productivity (Figure 39[C]) between the upstream reference site (A4261022) and the site within the anabranch (A4261224). The data indicates a (i) a higher rate of community respiration, and consistent negative values of net ecosystem productivity (NEP) at the site upstream of the regulator. Negative values of NEP indicate the system is dominated by heterotrophic process; positive values indicate the system is dominated by autotrophic processes. Although dissolved oxygen did not fall below the 6 mgO_2L^{-1} threshold, the data demonstrates that heterotrophic metabolism was stimulated during the 2014 testing event.

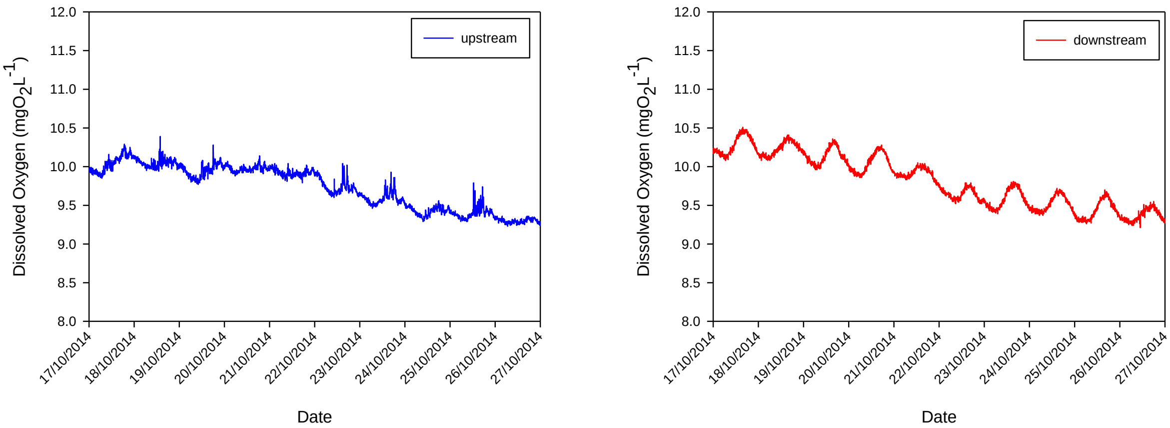


Figure 38: Time series of dissolved oxygen at the reference site upstream of Lock 6 (A4261022), the receiving site in the river downstream of the junction of Chowilla Creek (A4260704).

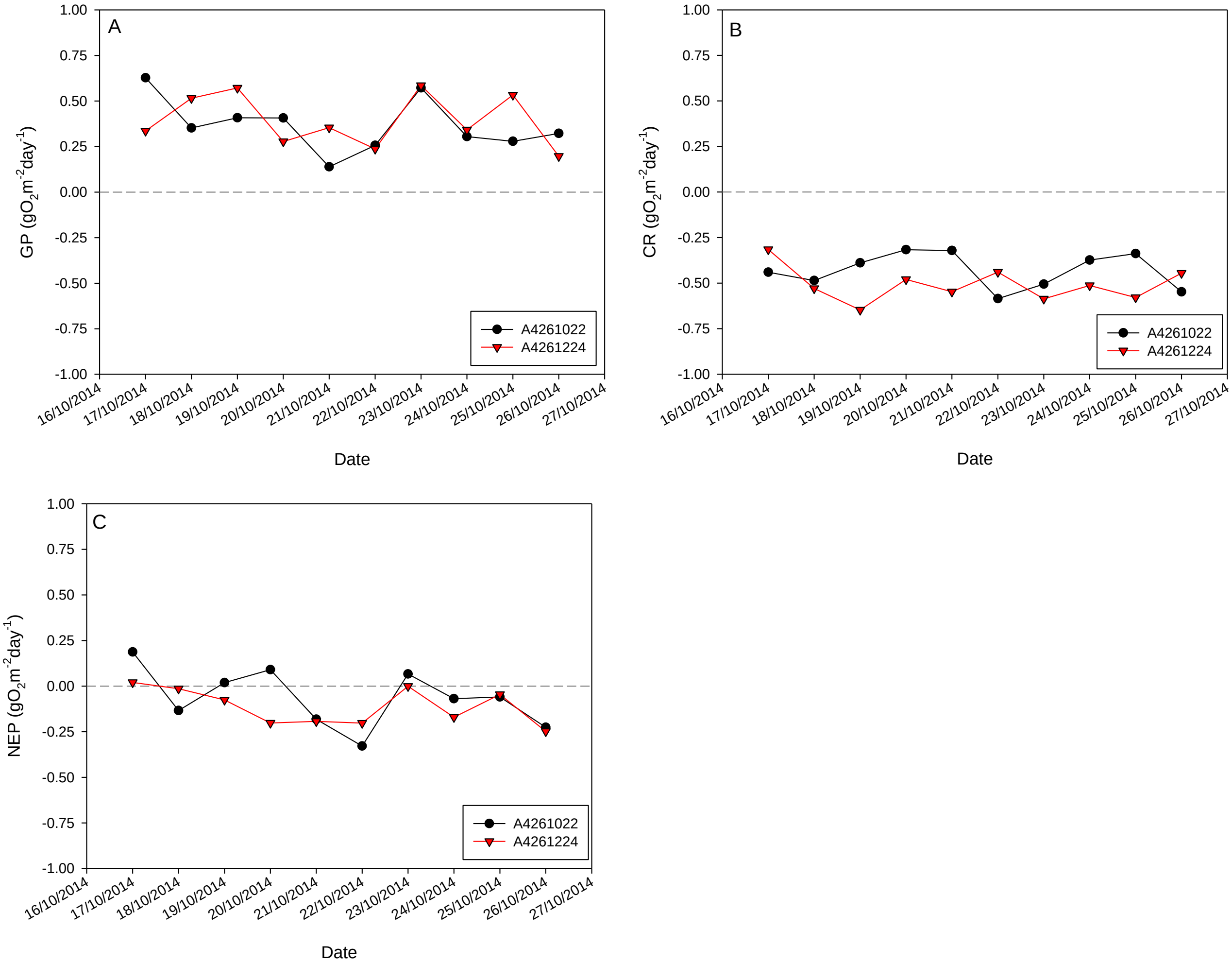


Figure 39: Time series of [A] gross production (GP), [B] community respiration (CR); and [C] net ecosystem productivity (NEP) for the reference site upstream of Lock 6 (A4261022) and the site immediately upstream of the regulator (A4261224).

2.7. In-situ oxygen depletion and first principles modelling of dilution required to maintain minimum water quality standards

Wallace (2008) utilised observed oxygen depletion rates recorded *in-situ* during ponded floods within managed wetlands at Chowilla Floodplain to calculate that with an expected oxygen depletion rate of 0.82 $mgO_2L^{-1}day^{-1}$, a daily exchange equivalent to 20% of the stored volume would be sufficient to ensure a low likelihood of dissolved oxygen in the impounded area falling below 6 mgO_2L^{-1}. Data from the telemetered monitoring stations within anabranch demonstrates that during the 2014 testing of the Chowilla Environmental Regulator, dissolved oxygen was always above 6 mgO_2L^{-1} at each of the anabranch sites (Figure 23). It is considered that the maintenance of normoxic conditions (DO above 6 mgO_2L^{-1}) validates the 20% daily exchange rate as an operational limit for the Chowilla Anabranch that offers a low likelihood of onset of hypoxia during managed inundations that are undertaken within the normal seasonal period (i.e. avoiding summer flooding when water temperatures are elevated).

It is recognised that at some managed floodplain sites (i.e. the Pike Floodplain), a daily dilution rate of 20% will not be achievable with the infrastructure that is being planned for construction. Consequently, an assessment of the potential outcomes of managed floods with lower dilution rates and additional oxygen depletion rates has been undertaken here. The modelling approach taken in this current project follows that used by Wallace (2008) and is a simple model constructed on first principles. The influence of 0, 5, 10 and 20% daily exchange was undertaken for oxygen depletion rates ranging from -0.4 to -0.9 $mgO_2L^{-1}day^{-1}$. In this approach, daily exchange is considered to be replacement of the specified percentage of water from within the impounded area (that can be expected to have high concentrations of DOC and low concentrations of dissolved oxygen), with water from the river (which can be expected to have low concentrations of DOC and high concentrations of dissolved oxygen). The oxygen calculations take into account the proportion of water replaced each day, the residence time of water (estimated as the time until all water within the impounded area would be replaced based on the % daily exchange rate) and the oxygen drawdown rate. The model assumes total mixing of residual and new water to equilibrate dissolved oxygen concentration across the water column.

Although the simple model used here does not take into account reaeration, primary productivity or the influence of temperature, it is considered that the approach is fit for purpose as the modelled oxygen drawdown rates are based on *in-situ* values that include a reaeration and primary productivity component. The influence of temperature on biogeochemical rates (achieved by delivery of water during different seasons) could be accounted for by utilising relatively low oxygen depletion rates for a winter inundations versus relatively high oxygen depletion rates for a summer inundations.

For the purpose of this assessment it was assumed that the initial concentration of dissolved oxygen in incoming river water is 8.00 mgO_2L^{-1}. This default value was selected on the basis of the saturation constant for freshwater at 25°C being 8.26 mgO_2L^{-1} (Eaton, Clesceri & Greenberg, 1995) and being consistent with values previously recorded in the creeks of the Chowilla Anabranch complex under regulated flow conditions (Wallace, unpublished data). Minimum thresholds for water quality standards can be set at different levels dependent on the ecological system under consideration, and the Ecological Objectives for the site. A dissolved oxygen target of ≥6 mgO_2L^{-1} is derived from Schedule 2 of the Environment Protection (Water Quality) Policy (2003) and was adopted in the Chowilla Operations Plan as the Critical Limit in the receiving waters of the Lock 5 weir pool. The target specified in (section 9.14(5a) the Basin Plan (Commonwealth of Australia, 2012) is “Maintain dissolved oxygen at a target value of at least 50% saturation”. This equates to ca 4 mgO_2L^{-1} at 20 °C. Both thresholds (6 and 4 mgO_2L^{-1}) are utilised in this assessment. The justification for not utilising the Basin Plan target as an Ecological Target is that if managed inundations are conducted with DO at 50% saturation, there is very little margin for unexpected changes in flow, weather, or biogeochemical processes that could result in a rapid decrease in dissolved and subsequently long-term or irreversible damage.

The results of this modelling approach (Figure 40) indicate that with a low rate of oxygen depletion (-0.4 mgO_2L^{-1}), 10% daily exchange would offer a low likelihood of dissolved oxygen falling below 6 mgO_2L^{-1}. At depletion rates ≥-0.5 mgO_2L^{-1}, there is an increased likelihood of DO falling below the 6 mgO_2L^{-1} threshold if daily exchange is 10%. The results also indicate that for a daily exchange rate of 5%, DO is likely to fall below the 6 mgO_2L^{-1} threshold for all of the oxygen depletion rates assessed, and that DO may fall below the 4 mgO_2L^{-1} threshold for depletion rates ≥- 0.6 mgO_2L^{-1}.

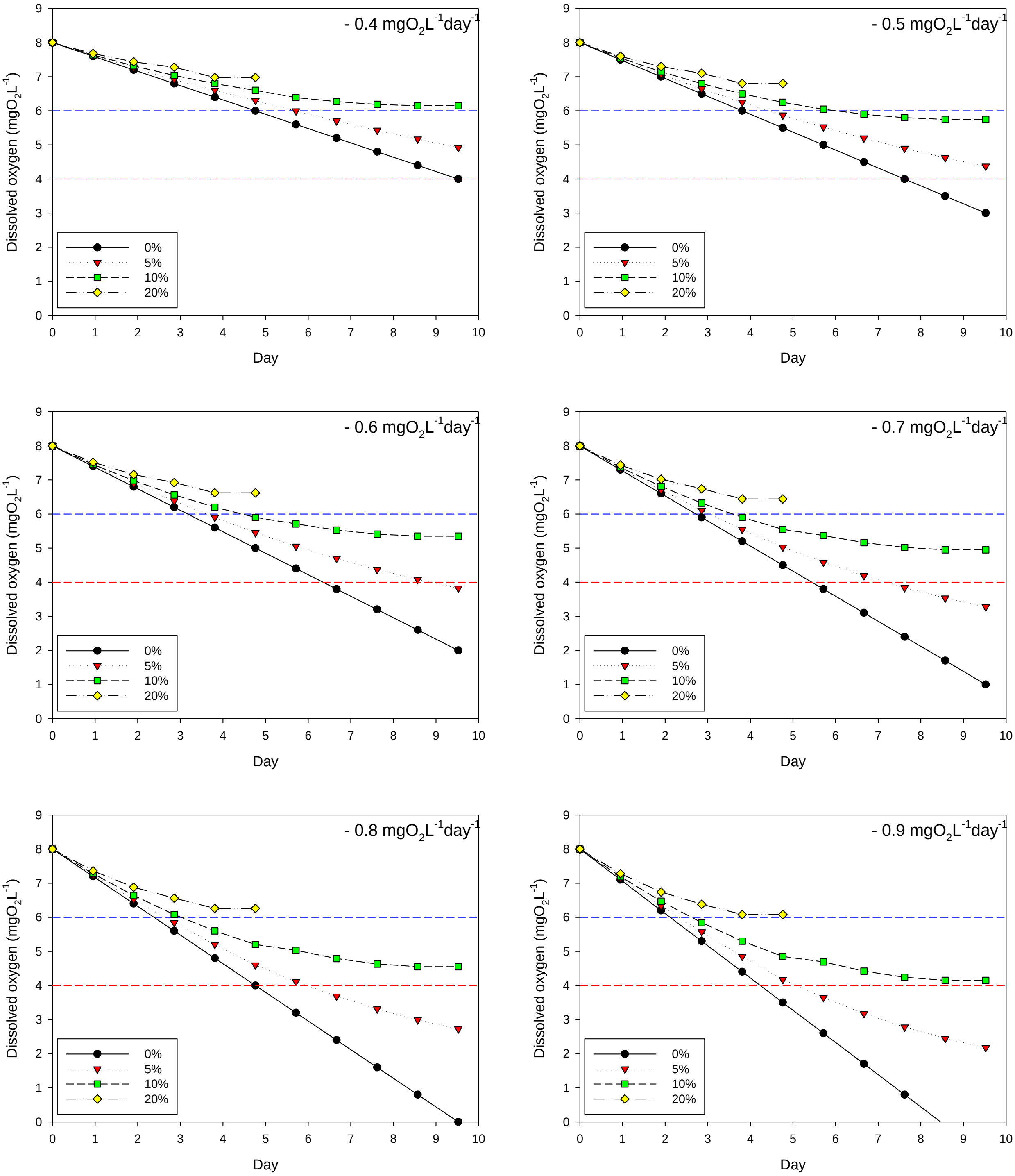


Figure 40. Modelled dissolved oxygen concentrations that could occur during the primary oxygen draw down phase following filling (inundation) utilising observed and hypothetical drawdown rates ranging from 0.4 to 0.9 $mgO_2L^{-1}day^{-1}$ and rates of exchange (floodwater turnover) of 0, 5, 10 and 20 % per day. The horizontal references line depicts the thresholds of 6 and 4 mgO_2L^{-1} respectively.

3. TASK 2: MODIFY THE EXISTING BLACKWATER RISK ASSESSMENT MODEL (BRAT) AND ASSESS ITS UTILITY FOR PREDICTING CHANGES IN WATER QUALITY AT CHOWILLA

3.1. BACKGROUND

The Murray-Darling Freshwater Research Centre (MDFRC) was commissioned by the MDBA to develop a desktop model for predicting the occurrence of blackwater events, and the efficacy of management approaches to reduce the severity of events that occur. The Blackwater Risk Assessment Tool (BRAT) that was developed is a MS Excel spreadsheet that functions as a process-based model for assessment of the risk of hypoxic blackwater generation based on variable flooding scenarios for a generic floodplain. A BETA version of the BRAT model is available as supplementary material to the published journal article produced as an output of that work (Whitworth *et al.*, 2013). In the model, water is routed onto a floodplain with a defined maximum input volume, inflow duration and inundation area. Carbon leached from inundated organic material on the floodplain, and carbon and oxygen consumption from the water column, are calculated on daily time steps. Water exits the floodplain after a defined transit time, with a defined maximum outflow rate. Dissolved oxygen and carbon in the outflow water, and in receiving waters immediately after dilution, are calculated on a daily time step. The model utilises a number of simplifications and assumptions including:

- normal distribution of inflow and outflow
- constant inundation depth
- complete mixing of influent water with that already on the floodplain
- fixed re-aeration rate constant

This method provided a simple user-friendly way of creating the required time- series of flows the model needs to simulate the processes occurring and assess the risk of management activities resulting in a blackwater event.

3.2. SCOPE

3.2.1. LIMITATIONS OF EXISTING BRAT MODEL FOR APPLICATION AT CHOWILLA AND OTHER SA SITES

The managed inundation of floodplain assets such as Chowilla, Katarapko and Pike utilising constructed infrastructure will operate differently to the scenario modelled by the BRAT model produced by Whitworth *et al*., (2013). The primary differences are: (i) with the existing BRAT water flows into the floodplain on a rising hydrograph and drains on recession as opposed to flowing through the wetland; (ii) water is delivered and drained via an anabranch of the river, and (iii) the anabranch can be used to deliver dilution flows to help manage the DO and DOC in the water returning to the main river channel. Consequently, the parameters of the model that describe the hydraulic characteristics of the managed inundation needed to be modified to be representative of those that will occur at managed floodplains in the SA section of the lower River Murray. The key objective of this task was to modify the existing BRAT model to be fit for purpose for trial as a generic predictive tool to assist with planning of delivery of environmental water *via* managed inundations at SA floodplain sites.

3.2.2. AVAILABLE INPUTS TO BRAT MODEL

As part of the process for planning managed inundations, modelling using both the 1D MIKE11 model and the 1D-2D MIKE FLOOD model is used to calculate the conditions required to achieve a targeted inundation height and remain within the Critical Operational Limits stipulated in the Operations Plans and the Event Plans for the Operation of the Chowilla Regulator (Wallace & Whittle, 2014a): The Critical Operational Limits are:

1. Maintain flows >0.18 ms^{-1} in 75% of core fish habitat at all times
2. Maintain minimum daily water exchange ≥20%
3. Limit the maximum rate of rise (averaged over 3 consecutive days) to 0.1 $mday^{-1}$
4. Limit the maximum rate of drawdown (averaged over 3 consecutive days) to ≤0.1 $mday^{-1}$ whilst surface water levels are out of channel and to ≤0.05 $mday^{-1}$ when surface water levels are within channel
5. Maintain minimum flow of 1,000 $MLday^{-1}$ over Lock 6

The outputs from the 1D MIKE11 model and the 1D-2D MIKE FLOOD model include:

- Required flow to South Australia (QSA; $MLday^{-1}$)
- Inflow to the anabranch ($MLday^{-1}$) via regulated creeks (i.e. Pipeclay and Slaney Weir)
- The operational height of Lock 6 and the Chowilla Environmental Regulator (mAHD)
- Outflow from the anabranch ($MLday^{-1}$)
- Area inundated (ha)
- Velocity (ms^{-1}) in the impounded area
- Daily exchange (% stored volume)

Information on the required configuration for a range of potential operational scenarios is provided in Section 4 the Chowilla Operations Plan (Wallace and Whittle, 2014). The output from this modelling is also available as a daily time-series and can serve as input to the BRAT model.

3.3. MODIFICATIONS MADE TO THE BRAT MODEL

The BRAT model was modified to accept a time-series of modelled data instead of using the original parametrised equation to generate flows. In order to facilitate this, additional columns in the BRAT spreadsheet were configured to be able to accept the modelling outputs for QSA, inflow to the anabranch, outflow from the anabranch and the area inundated for any given inundation event. Parameters that were no longer required were removed from the model's user interface. Modifications were made to account for the dilution that occurs within the anabranch as the result of additional flow through the system (daily exchange). The system was represented in three sections as illustrated in Figure 41.

1. The floodplain is considered as single body of water and the flow into or out of it determined as the difference between the daily inflow/outflow to the anabranch i.e. $Q_{fp} = Q_{in} - Q_{out}$
   All of the DOC and DO dynamics is assumed to occur in the floodplain.

2. Anabranch dilution flow is calculated by subtracting any floodplain flows from the anabranch inflow i.e.
   $Q_{ana} = Q_{in} - |Q_{fp}|$
   DO concentration is assumed to be saturated or a value provided by the user. DOC is assumed to be a constant value provided by the user.

3. River dilution flow is calculated by subtracting the anabranch inflow from the required river flow i.e.
   $Q_{dil} = Q_{riv} - Q_{in}$
   As above, DO concentration is assumed to be saturated or a value provided by the user. DOC is assumed to be a constant value provided by the user.

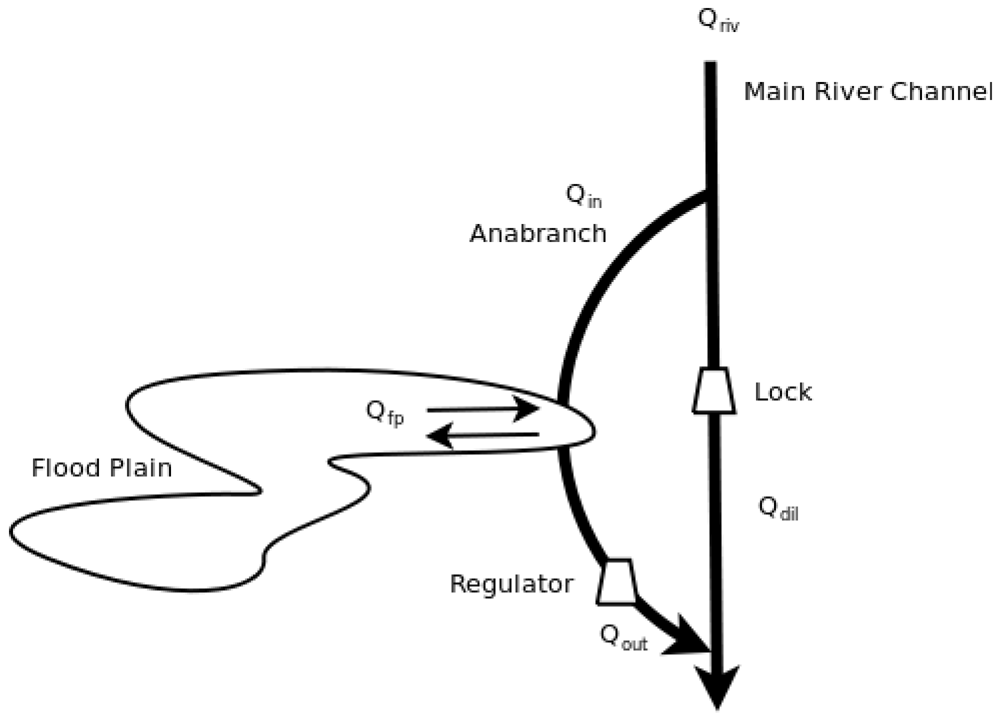


Figure 41. Schematic of modified BRAT model.

The additional anabranch dilution component uses an identical algorithm to the existing river dilution i.e.

$$WQ_{dil} = \frac{(WQ_{fp}.Q_{fp}) + (WQ_{ana}.Q_{ana})}{Q_{fp} + Q_{ana}}$$

The algorithms that predict water quality (DOC and dissolved oxygen) have not been altered from the original version. The model has a number of internal parameters for DOC and DO dynamics such as relative composition of litter (leaves, bark, twigs & grass) with corresponding leaching rates and yields; these were also unchanged.

3.4. Comparison of the modified BRAT model with data from the 2014 testing event

The modified version of the BRAT model was trialled using actual data on DOC and DO recorded at the upstream reference site (A4261022), upstream of the Chowilla Environmental Regulator (A4261224) and the receiving waters of the Lock 5 weir pool (A4260704) from the 2014 testing event (see section 3 of this report for details of the monitoring undertaken), against the outputs from the modified BRAT model for DOC and DO. Input data for QSA (MLday^{-1}), inflow and outflow (QSA) and area inundated (ha) for daily time steps during the 2014 testing event was sourced from the MDBA (data used was achieved values, not minimum planned values). User defined inputs are shown in Table 18.

Predictions for peak DOC concentrations at both the regulator and main river channel match closely with those that were observed (Figure 42). The timing of the peak is not consistent between that observed at the regulator (day 54) and the river (day 46), with the model prediction falling in-between these two values (day 49). Minimum DO at the regulator is slightly over predicted by the model and occurs after what was observed. In the main river channel recorded data showed only a slight decrease in DO while the model predicted a 1.1 mgO_2L^{-1} drop.

At both the regulator and river sites there was a significant increase in DOC in advance of when the model predicted. The time span this occurs over corresponds with the two week period when the regulator was held at the maximum height (19.1 mAHD) for this event. During this time there is still a net inflow to the floodplain due to losses (i.e. evaporation and seepage) and for this reason the model does not predict any return of carbon to the anabranch. However, under conditions of low inflow it is likely that wind would still cause some exchange between the floodplain and the anabranch (Webster *et al.*, 1997).

The rate of floodplain-anabranch exchange is dependent on a number of factors such as wind and the size of connections and so would be different for each site and would be difficult to estimate without significant effort. It is possible that the MIKE model could be used to also estimate the exchange rate. Alternatively values could be determined from observations during an inundation event using a number of methods. For example:

- A simple dilution model (CSTR) for the wetland can be fitted to the salt load in the floodplain.

$$c_t = c_i + (c_0 - c_i)e^{-\rho t}$$

  where c_t is the mean concentration in the floodplain at time t, c_0 is the initial concentration in the floodplain (at maximum height), c_i is the concentration in the anabranch and ρ is the flushing rate of the wetland.

- The concentration of water quality parameters in the floodplain and the anabranch inflow can be compared to what is measured at the regulator. This method was used to estimate the floodplain/anabranch exchange rate for 21/10/2014 (day 39). The modelled DOC concentration in the floodplain was used together with the observed upstream and regulator DOC concentrations as well as the anabranch dilution flow. i.e.

$$Q_{exchange} = \frac{(DOC_{reg} - DOC_{ana})Q_{ana}}{DOC_{fp} - DOC_{reg}}$$

  The result was 353 $MLday^{-1}$.

An additional column was added to the model time-series inputs so that a value for the floodplain/anabranch exchange can be entered for each time step of the model (optional). This flow is added to both the floodplain inflow and outflow within the model. This operation does not change the net inflow/outflow but allows water quality in the floodplain to influence the anabranch and river. An example using 353 $MLday^{-1}$ exchange rate for the two week period when water levels were constant is shown in Figure 43.

Including the exchange increased the modelled DOC concentration during the peak inundation to give values closer to those that were observed in both the anabranch and the river. Since carbon was leaving the floodplain earlier than in the previous simulation, the peak DOC values have been lowered by the exchange but are still a reasonable estimate for what was observed. The peak dissolved oxygen levels did not change due to adding the exchange but the DO during the period before recession were lowered.

Table 18: Model inputs utilised in the test runs for the modified BRAT model

Model Input	**Value**
Litter load	$674 g/m^2$
Maximum inundation area	2741 ha
DO inflow mode	Saturated
Inflow DOC	Interpolated daily values from A4261022 (further modification to spreadsheet)
Anabranch inflow & outflow	As recorded. Smoothed using 3 day moving average
DO dilution mode	Saturated
Dilution DOC	Interpolated daily values from A4261022 (further modification to spreadsheet)
River dilution flow	Lock 6 recorded values

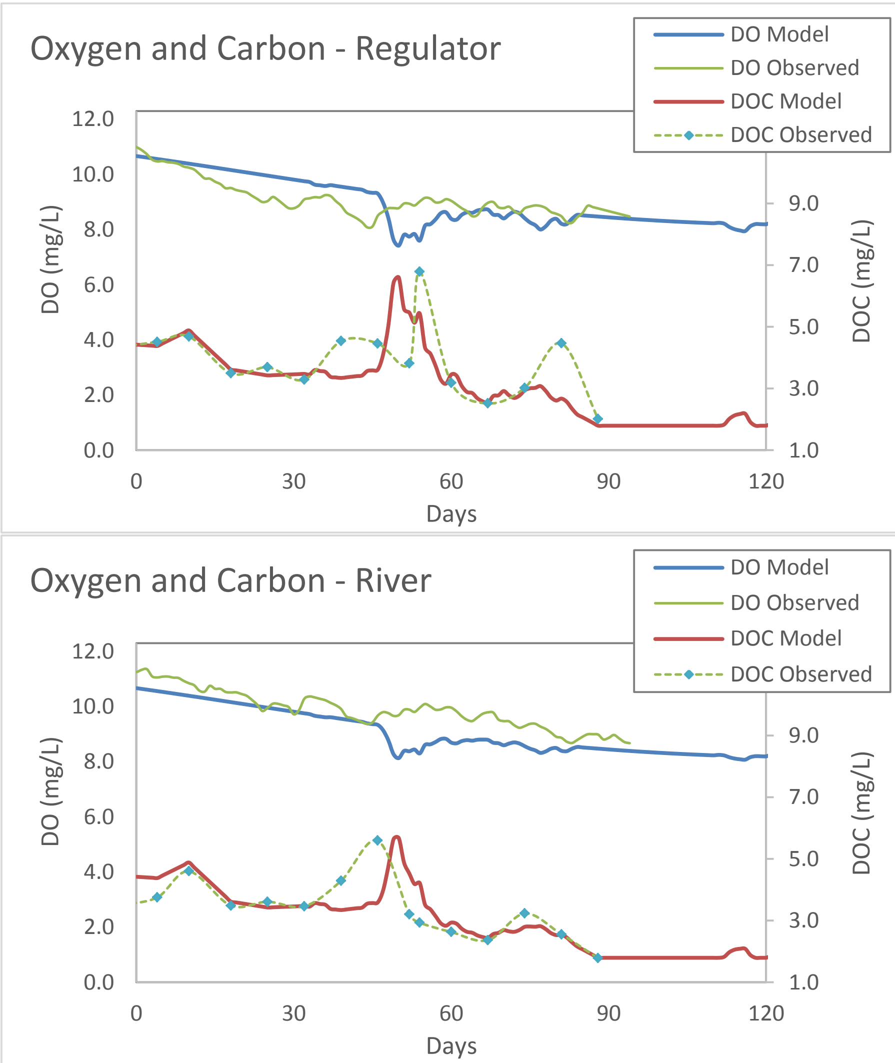


Figure 42. Model output from modified BRAT model.

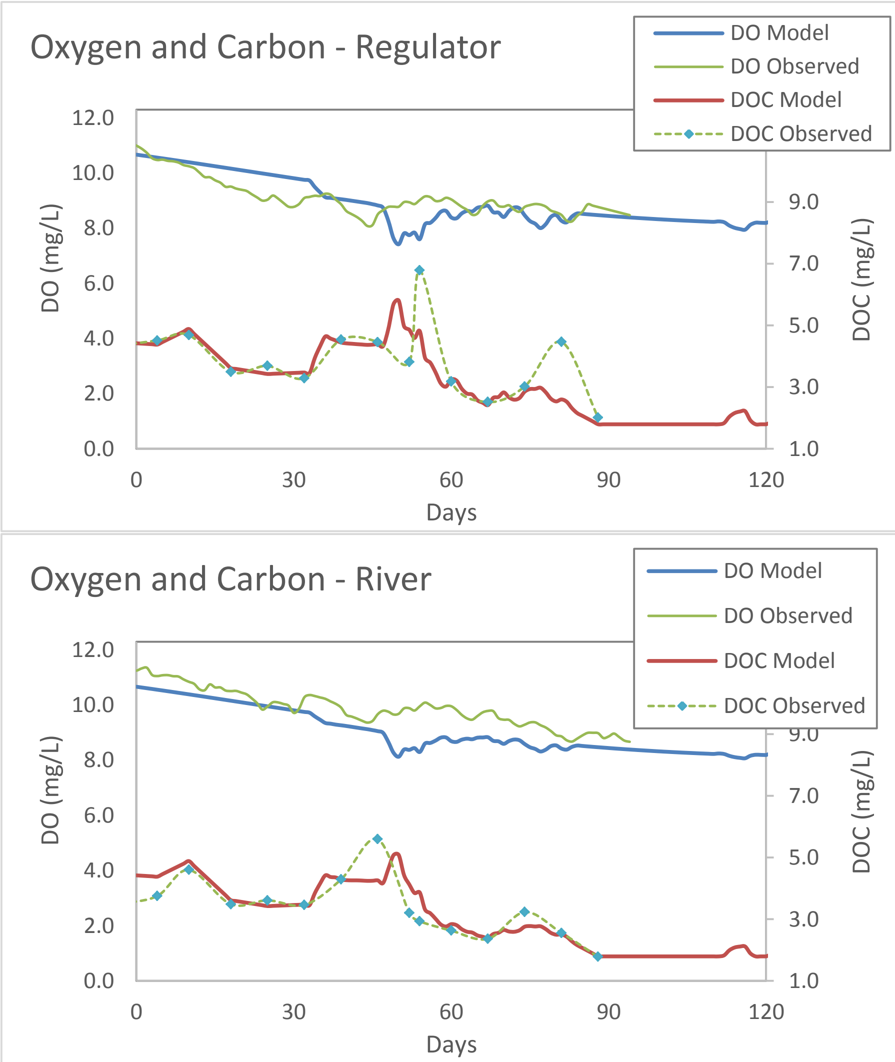


Figure 43. Model output from modified BRAT model including floodplain/anabranch exchange

3.5. Test of modified BRAT model using planning inputs

The test runs of the modified BRAT model presented above utilise actual data on DOC and DO recorded at the upstream reference site (A4261022), upstream of the Chowilla Environmental Regulator (A4261224) and the receiving waters of the Lock 5 weir pool (A4260704) and QSA (MLday^{-1}), and daily values for inflow and outflow (QSA) and area inundated (ha) derived from the 1D MIKE11 model and the 1D-2D MIKE FLOOD model and validated against the gauged data for discharge and velocity and satellite imagery of inundation extent. During the planning phase of managed inundations, this data would not be available. However, outputs from the 1D MIKE11 model and the 1D-2D MIKE FLOOD model for potential scenarios that could be implemented can be made available. In order to assess the performance of the model as a predictive tool, the daily values for minimum required QSA (MLday^{-1}), inflow to the anabranch (MLday^{-1}), outflow from the anabranch (MLday^{-1}) and area inundated (ha) for the "planned hydrograph" for the 2014 testing event were sourced from modelling undertaken by the MDBA. The user selected parameters were set as follows:

- Date of commencement = 1/9/2014
- Total volume of water delivered = 55 GL
- Temperature mode = seasonal
- Inflow dissolved oxygen (DO) = "saturation"

- Inflow concentration of dissolved organic carbon (DOC) = 4.0 mgL^{-1}
- area inundated = 3,061 ha
- dominant litter type = litter
- Litter load = 1,436 gm^{-2}

The leaf litter load 1,436 gm^{-2} was chosen as it is the average for all pooled samples (n=150) of the measured load recorded at Chowilla Floodplain in the weeks prior to the commencement of the 2014 testing event (see section 2.5 of this report for detail). The results (Figure 44) indicate that the modified BRAT model predicts DO concentrations that are similar to the values recorded by the monitoring network (see section 2 of this report for detail on the monitoring network and the sampling program). The modified BRAT model provides a reasonable indication of the magnitude in concentration of DOC, but the model predicts the peak of DOC occurring earlier than it is recorded in the samples collected. The difference in timing is potentially attributable to a mis-match between actual and model floodplain/anabranch exchange and transit time. The discrepancy in the concentration of DOC is potentially attributable to the fixed DOC concentration in the model compared to the recorded variation in ambient DOC.

3.6. USE OF THE MODIFIED BRAT MODEL TO UNDERPIN PLANNING DECISIONS

The modified BRAT model offers an additional pathway to assess the potential outcomes for DO and DOC using outputs from the 1D MIKE11 model and the 1D-2D MIKE FLOOD model for potential scenarios that could be implemented. It is imperative that it is understood that the modified BRAT model remains a development version, and that whilst the predictions generated by the model may provide insight into the likely outcomes of a given management scenario, the performance and reliability across different sites and different scenarios remains untested, and consequently the model cannot be relied upon as a stand-alone decision tool. As highlighted by the authors of the original BRAT model (Whitworth *et al.*, 2013) the model is for illustrative purposes only, with the outputs considered to represent an indication of the potential concentrations of DOC and DO rather than as absolute values. Before taking any action or decision based on the outputs of either the original or the modified version of the BRAT model, readers should seek expert professional, scientific and technical advice and form their own view of the applicability and correctness of the outputs of this model.

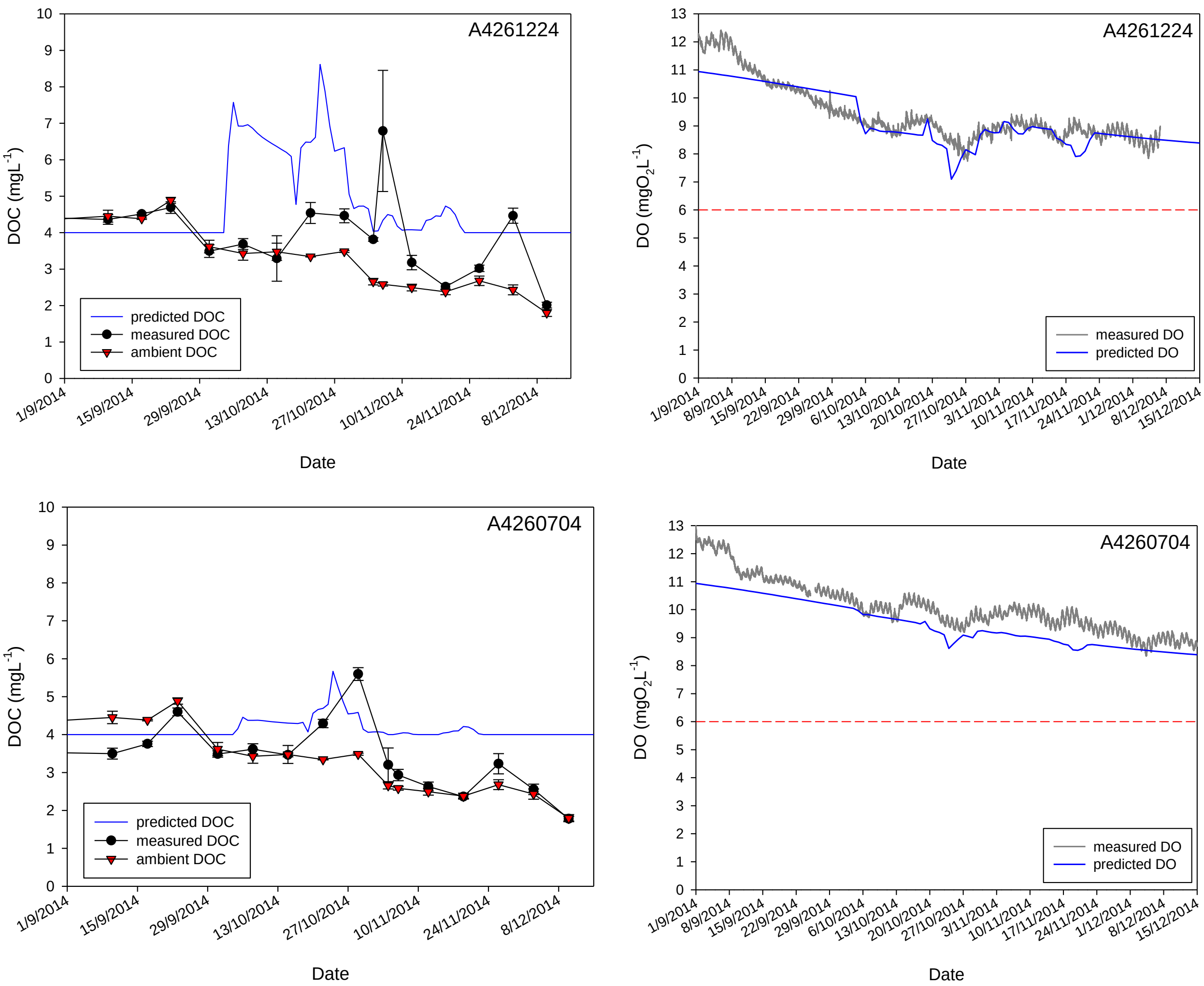


Figure 44: Comparison of predicted concentration of dissolved organic carbon (DOC) and dissolved oxygen (DO) from the modified BRAT model using “planned” hydrograph data with concentrations of DOC recorded in the sampling program and DO recorded at the monitoring stations. Station A4261224 = immediately upstream of the Chowilla Environmental Regulator; A4260704 = River channel; Lock 5 weir pool downstream of the junction of Chowilla Creek. Ambient DOC = reference site upstream of Lock 6 (A426102). Details of the monitoring network and sampling program are provided in section 2 of this report.

4. TASK 3: VALIDATING THE 1D-2D MIKE FLOOD HYDRODYNAMIC MODEL

This component was funded and managed by DEWNR through the TLM program and represents a major in-kind contribution to the project. A brief overview of this task is provided here.

4.1. BACKGROUND

A set of Critical Operational Limits were established during the development of the Event Plans for the Operation of the Chowilla Regulator (Wallace & Whittle, 2014a): These Critical Operational Limits are:

1. Maintain flows >0.18 ms^{-1} in 75% of core fish habitat at all times
2. Maintain minimum daily water exchange ≥20%
3. Limit the maximum rate of rise (averaged over 3 consecutive days) to 0.1 $mday^{-1}$
4. Limit the maximum rate of drawdown (averaged over 3 consecutive days) to ≤0.1 $mday^{-1}$ whilst surface water levels are out of channel and to ≤0.05 $mday^{-1}$ when surface water levels are within channel
5. Maintain minimum flow of 1,000 $MLday^{-1}$ over Lock 6

Prior to the 2014 testing event for the Chowilla Regulator, extensive pre-event modelling of the ability to meet the Critical Operating Limits over a range of potential operating configurations was undertaken using the existing 1D-2D MIKE FLOOD hydrodynamic model (Water Technology 2010 and 2012). The model had been iteratively refined, and calibrated based on existing hydrometric gauging data and inundation extent data. The parameters available from the modelling include; (i) the inundation extent (including area (ha) and geographic location of the inundated zone), (ii) the discharge required to achieve and maintain inundation (including QSA, inflow and outflow from the anabranch), and (iii) required structure configurations (i.e. relative height of Lock 6 and the Chowilla environmental regulator). The outputs of those assessments are provided in the Events Plans (Wallace & Whittle, 2014a). Validating, calibrating and adapting the model during testing operations are key steps in the risk management process. This requires monitoring of velocities at key locations across a range of different structure height-inflow-outflow configurations to validate modelled velocities over a variety of operational conditions. If there are discrepancies between observed and model predicted conditions, the model can be recalibrated, and what have previously been defined as low risk operational boundaries in the Operations and Event Plans can then be adjusted if necessary.

In addition to understanding the spatial influence of any potential discharge-structure configuration, it is important to understanding the potential impact on water exchange to manage water quality and hydraulic habitat. The importance of water exchange in managing water quality is described elsewhere in this report. Hydraulic habitat represents the 'dynamic' components of the water column including depth, velocity and turbulence. Temporal variability is driven by changes in discharge and depth (Bice *et al.*, 2013). Spatial hydraulic diversity in any reach is driven by local structure/channel features. The mosaic of hydraulic habitats that is present in the creeks that comprise the Chowilla Anabranch is considered to be one of the key reasons why the Chowilla floodplain maintains a high diversity of species. Of particular importance are the streams which have both high water velocity and complex snag structures, known to be important habitat for Murray Cod. Without careful analysis and management, these hydraulic features could be significantly disrupted, with the potential to lead to a significant decline in the species that utilise them, and the other ecological processes that these macrohabitats support. In order to maintain the mosaic of hydraulic habitats and protect water quality,

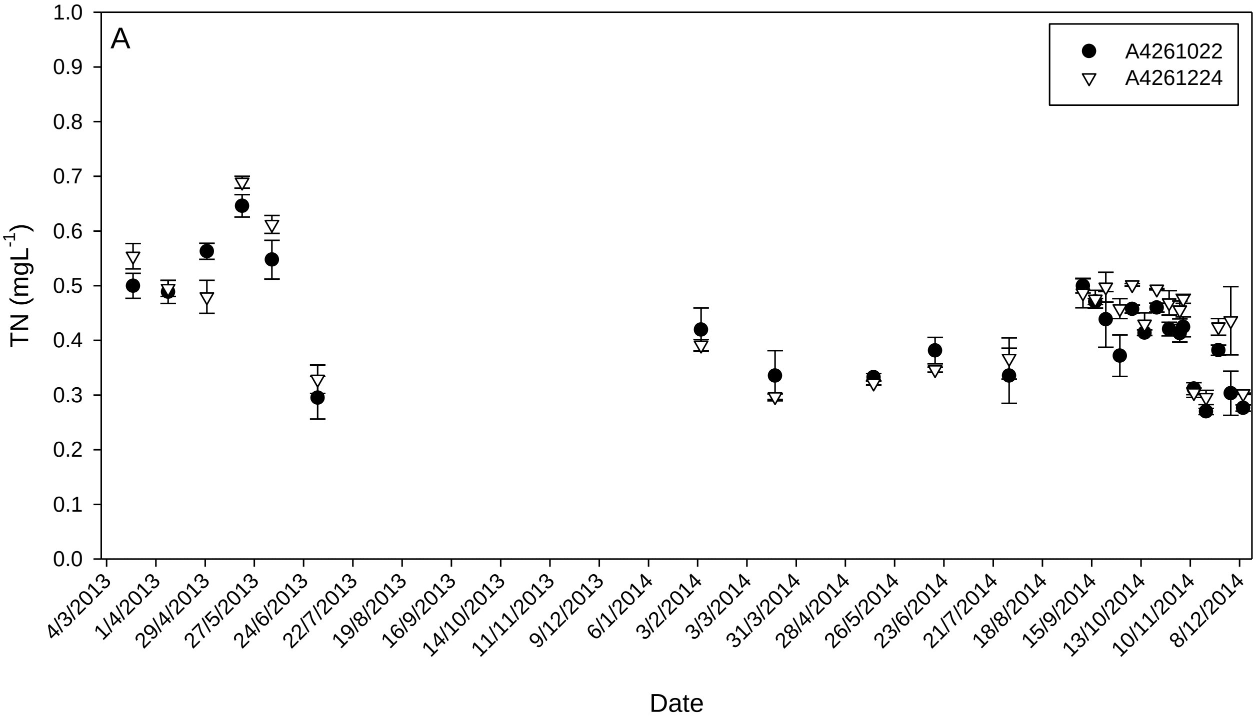
4.2. DELIVERABLES

The testing hydrograph that was developed and implemented (see section 2.4 of this report for detail) included three "hold-points" that were included in the hydrograph to allow engineers to assess specific criteria relevant to the defects liability period of the infrastructure. These three “hold-points” were also utilised to collect data on in-stream velocity. Staff from Science, Monitoring and Knowledge (SMK), DEWNR utilised an Acoustic Doppler Current Profiler (ADCP) to measure in-stream velocity and discharge at 14 locations (see Table 19). Gauging was undertaken on 17-18 September 2014, (hold point 1; 17.7 mAHD), 1-3 October (hold point 2; 18.4 mAHD) and 21-22 October (hold point 3; 19.1 mAHD). Each of the locations are part of an existing gauging network, such that the data builds upon existing knowledge and is collected within an existing QA/QC framework. The data collected by DEWNR staff was provided to a hydraulic modeller within the MDBA who subsequently validated and recalibrated the velocity component of the 1D model. Satellite imagery of the inundation extent at 2-day intervals was collected and used to validate and recalibrate the inundation component of the 2D model.

Table 19. Locations of gauging undertaken by staff from SMK where an Acoustic Doppler Current Profiler (ADCP) was used to measure in-stream velocity and discharge.

Site No	Site name	Easting	Northing
A4261090	Salt Creek Flow Site	503497	6238106
A4260580	Punkah Ck/Sheep Brdg	495614	6246575
A4260600	I Bank Ck us Hyperna	496962	6240828
A4261091	Site 40	487239	6239358
A4261092	Acoustic Flow site result	487239	6239358
-	Down Stream of Regulator	486817	6236927
A4260579	Slaneys/Chowilla	493832	6244258
A4261064	Slaneys Creek	495713	6242571
A4260578	Pipeclay Ck/Chowilla	492472	6244008
A4260511	R Murray ds Lock 6	489539	6238282
A4261027	SA/NSW Border	500261	6241936
A4261092	Boat Creek	490459	6242389
-	Slayneys; Southern Anabranch	493616	6243972
A4260599	Hyperna Creek, spot check gauging	497014	6240448

APPENDIX A1



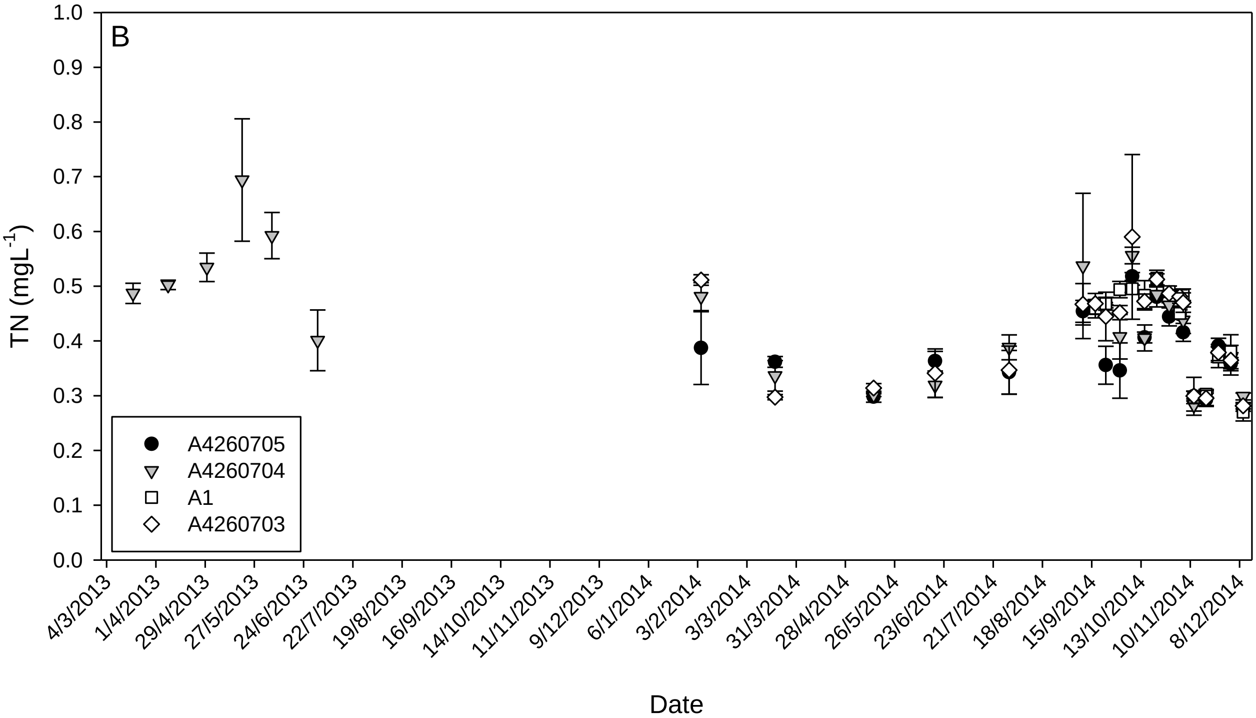


Figure A1: Total Nitrogen (TN) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for TN stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 5 mgL^{-1}.

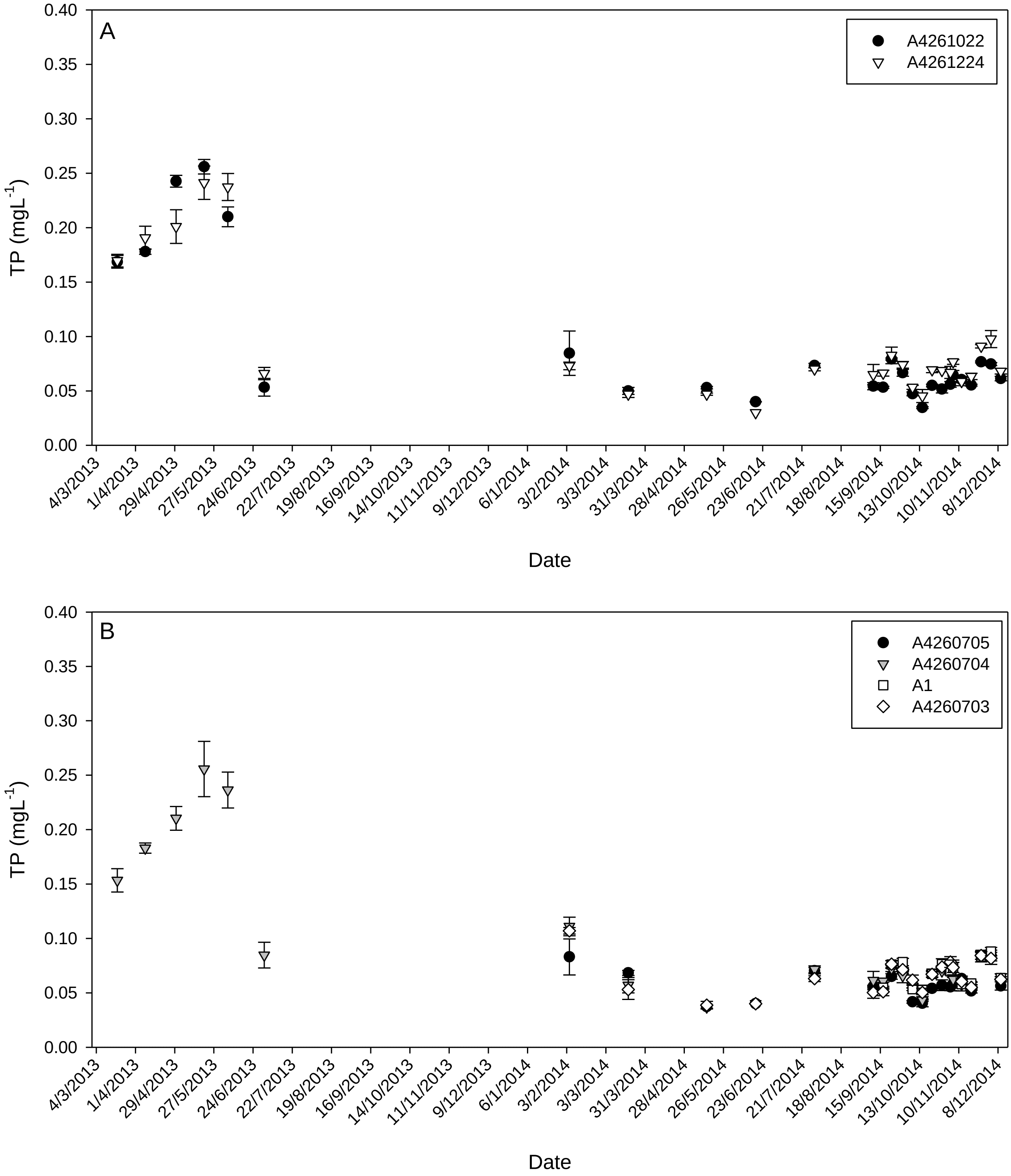
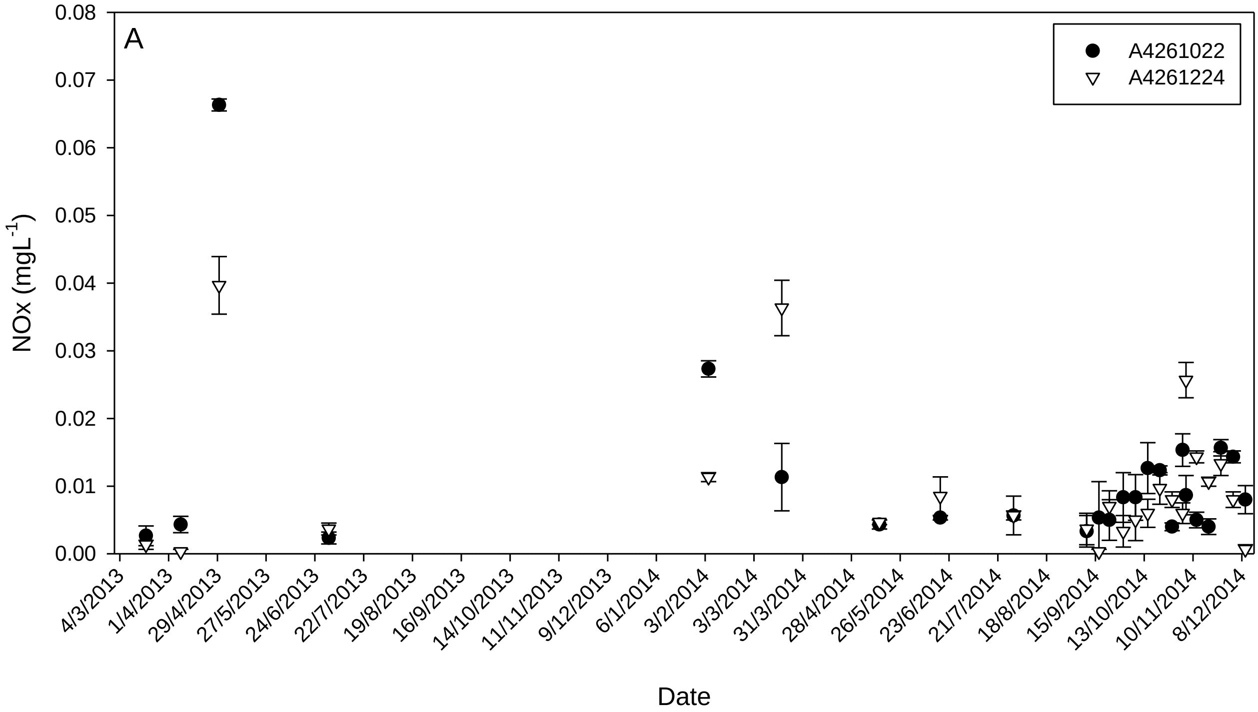


Figure A2: Total Phosphorus (TP) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for TP stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 0.5 mgL^{-1}.



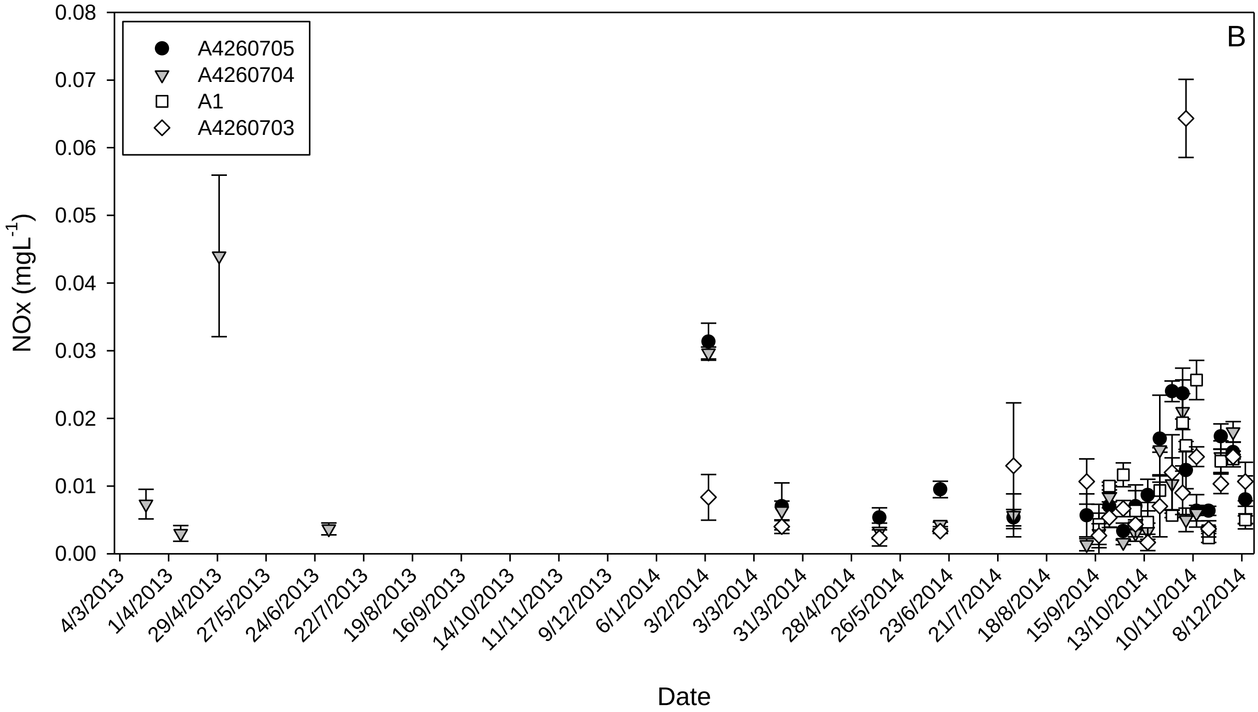


Figure A3: Oxidised Nitrogen (NOx = nitrate+nitrite) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for NOx stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 0.5 mgL^{-1}. Results for samples collected on 20th May 2013 and 6th June 2013 were in the range 0.21-0.36 mgL^{-1} and hence because they are atypical, are not here shown in order to maintain visual clarity in the plots, but are included in statistical analysis.

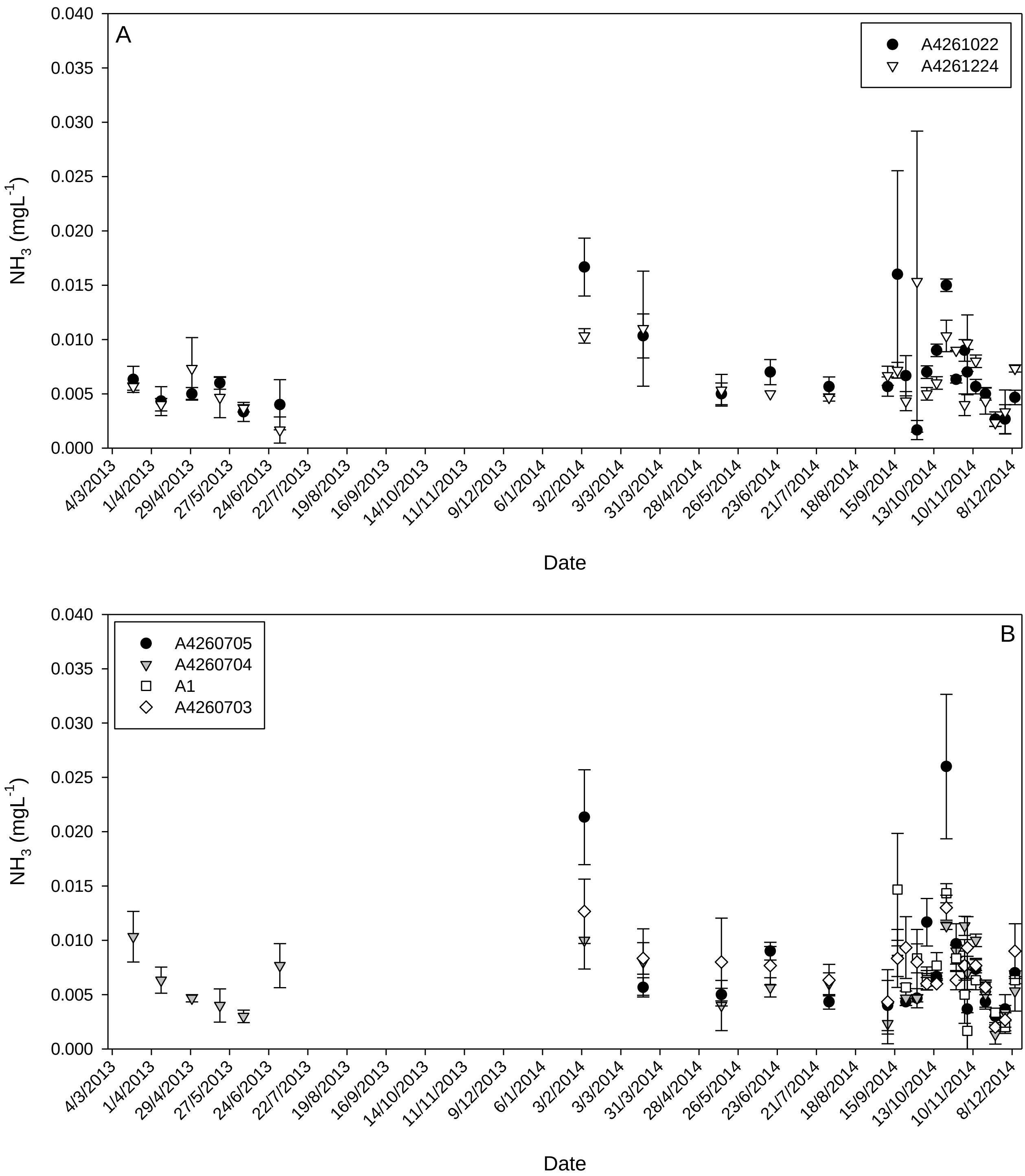


Figure A4: Ammonia (NH_3 as N) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for NH_3 stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 0.5 mgL^{-1}.

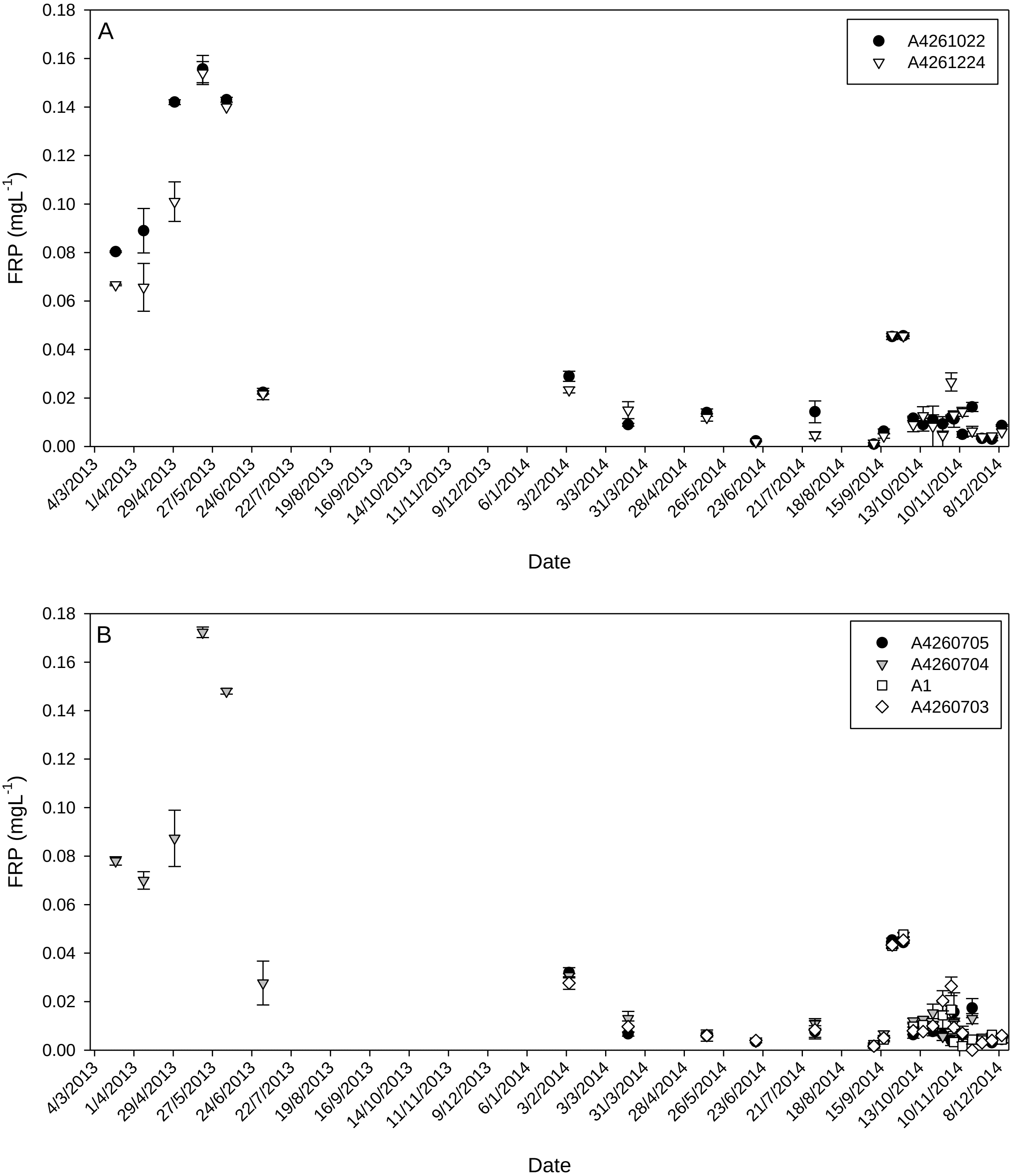
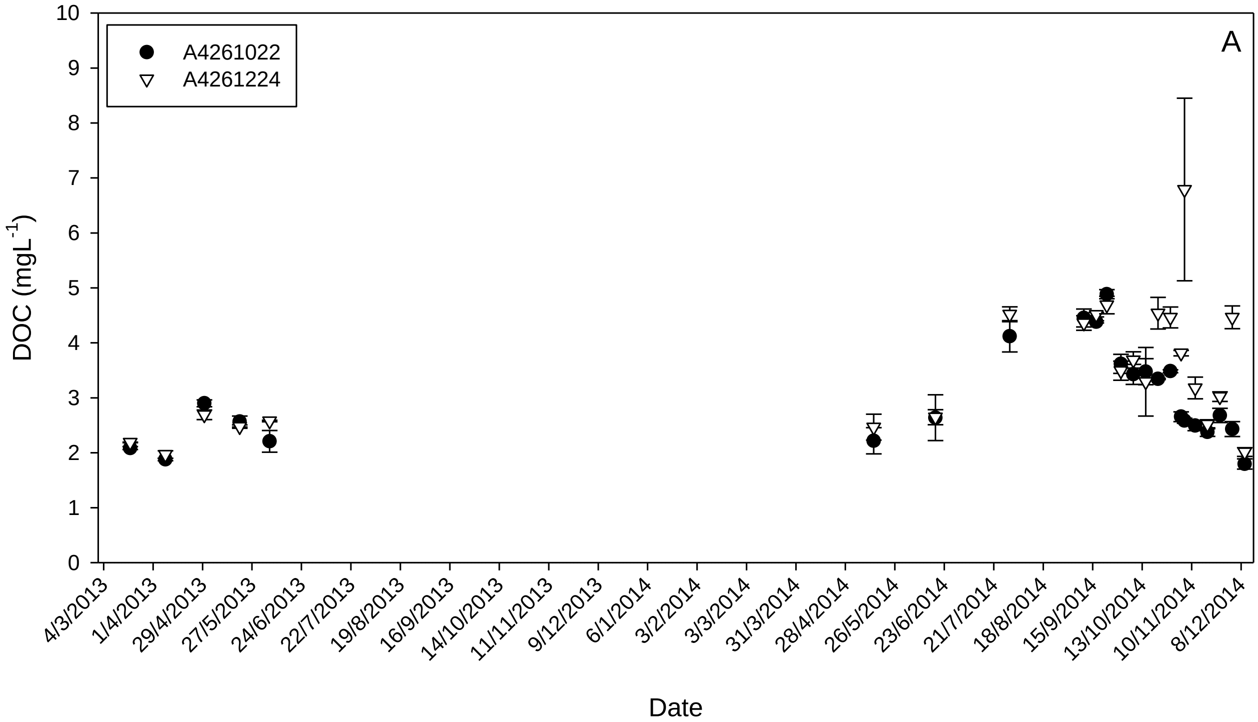


Figure A5: Filterable reactive Phosphorus (FRP) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for FRP stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 0.1 mgL^{-1}.



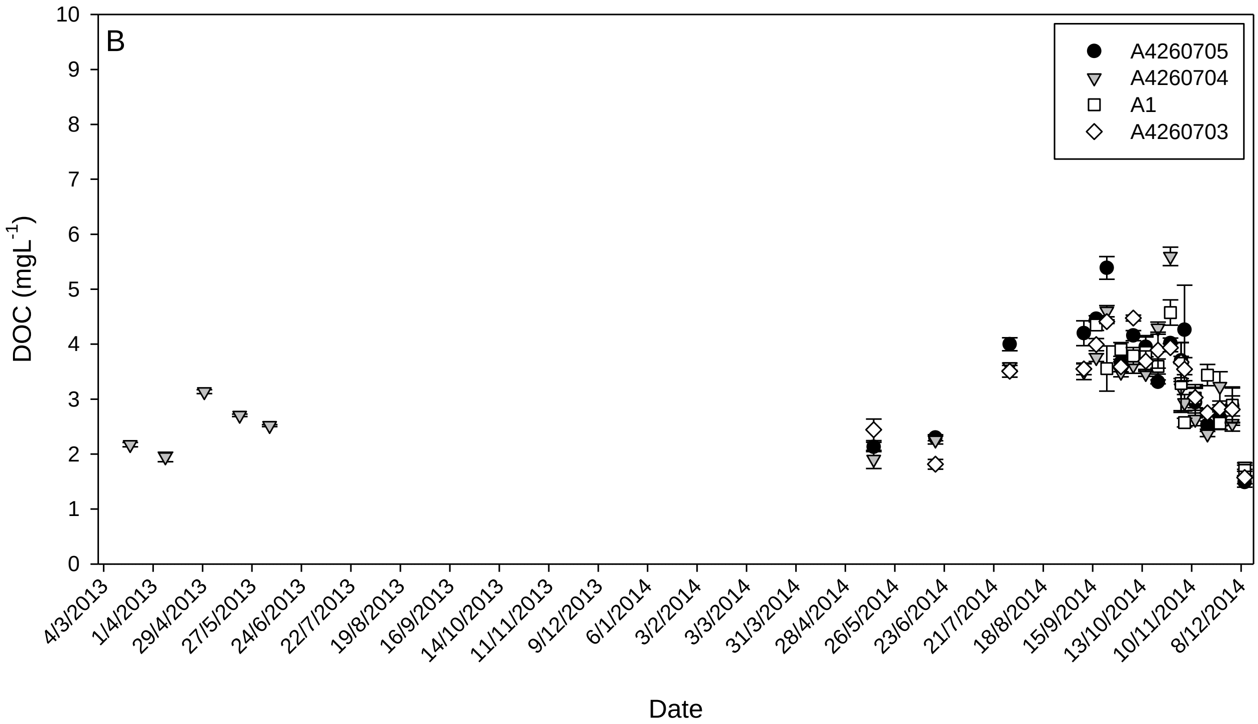
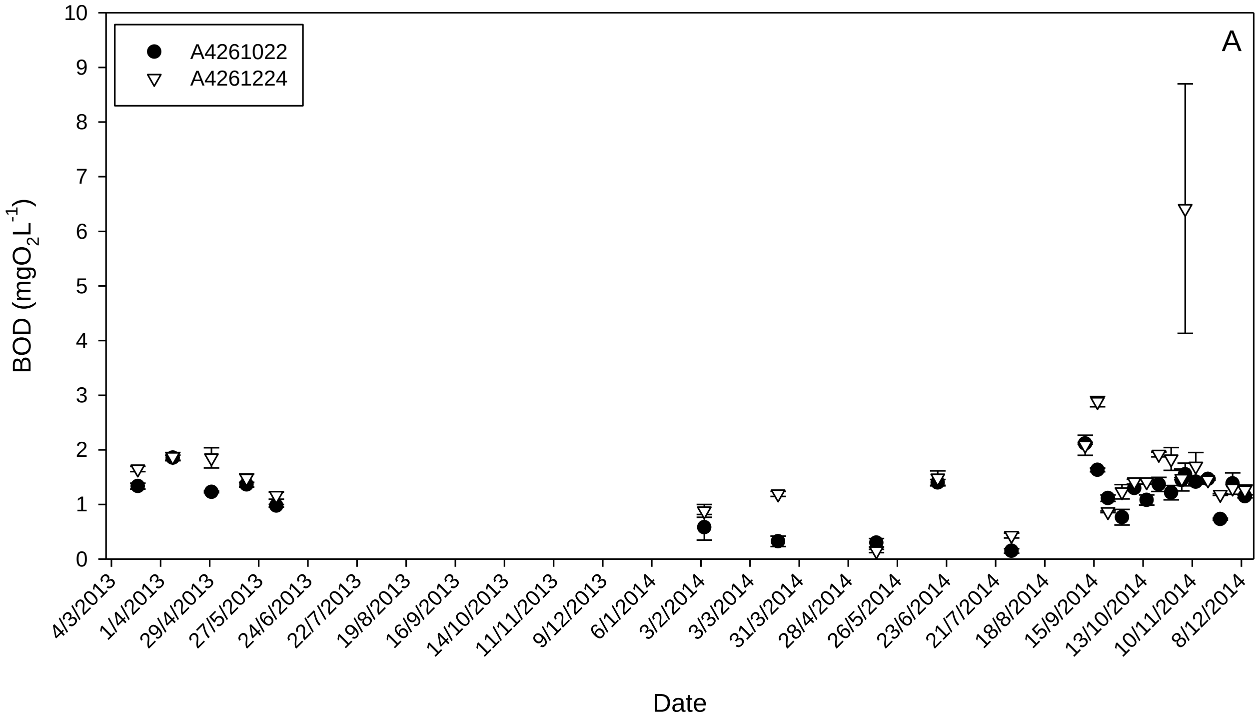


Figure A6: Dissolved Organic Carbon (DOC) concentration at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for Total Organic Carbon (TOC) stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 15 mgL^{-1}.



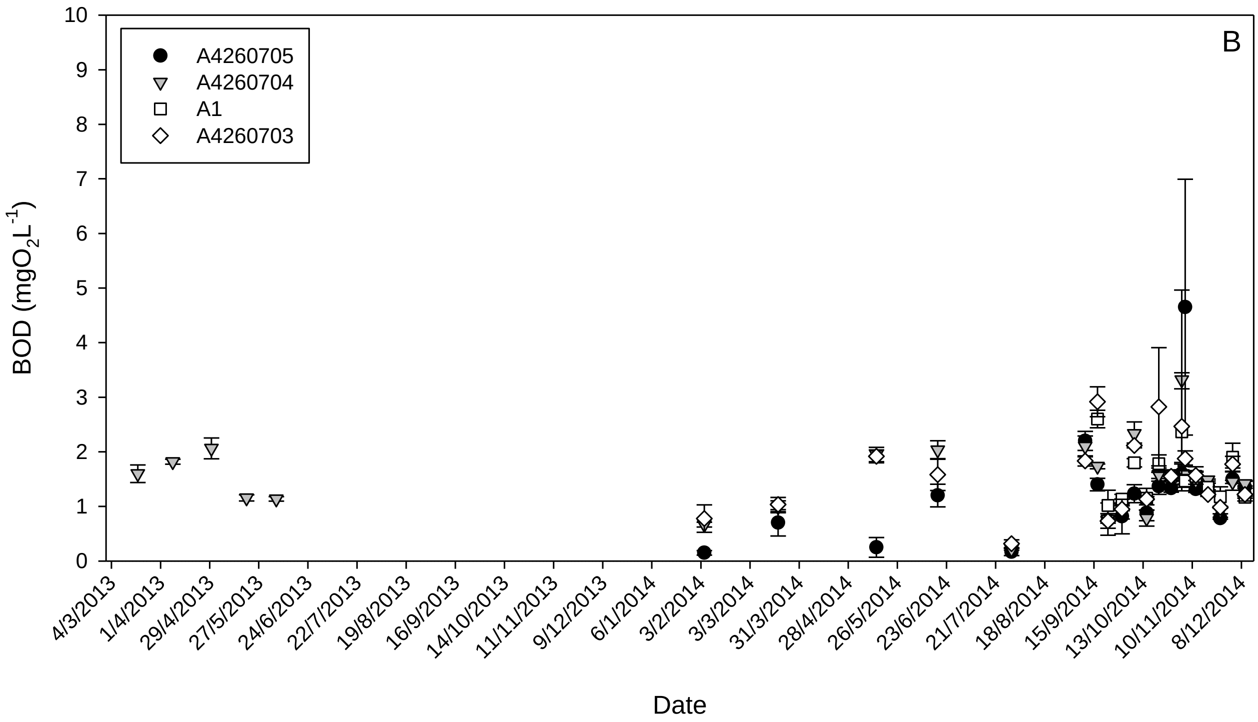


Figure A7: 5-day Biochemical Oxygen Demand (BOD_5) at the sampling sites; [A] = within the anabranch creek system at the regulator (A4261224) relative to the upstream control in the Lock 6 weir pool (A4261022); and [B] within the receiving waters of the Lock 5 weir pool. Error bars are ±1 Standard Error. The guideline limit for BOD_5 stated in Schedule 2 of the Environment Protection (Water Quality) Policy (2003) is 10 mgL^{-1}.

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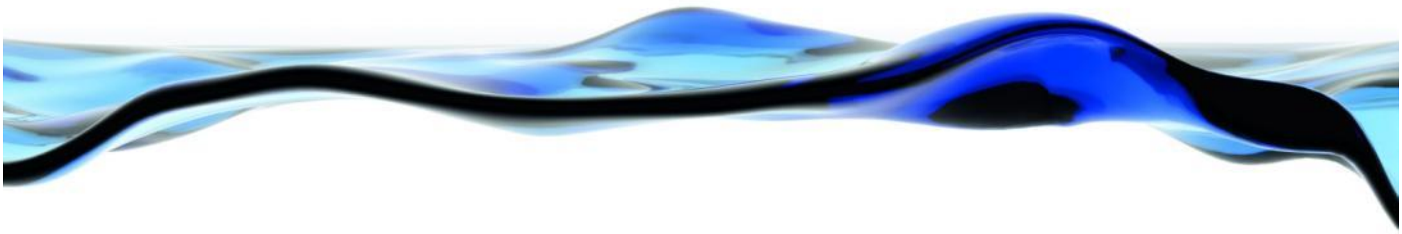

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