Koondrook-Perricoota Forest
Flood Enhancement Works

Appendix E
Water quality Assessment

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NSW Office of Water and Forests NSW

Report for Koondrook-Perricoota Flood Enhancement Project

Water Quality Assessment

December 2009

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

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1. Introduction

1.1 Purpose of this report

The NSW Office of Water and NSW Industry and Investment propose to undertake the Koondrook-Perricoota Forest Flood Enhancement Works Project (referred to in this report as 'the project'). This report has been prepared to provide an assessment of the potential water quality impacts of the project as an input to the environmental impact assessment. The environmental impact assessment is being prepared in accordance with the requirements of Part 3A of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act).

The report addresses the requirements of the Director-General of the NSW Department of Planning (the Director-General's Requirements) dated 22 May 2009 relating to assessment of potential impacts on water quality.

1.2 Project overview

1.2.1 Location

The Gunbower-Koondrook-Perricoota Forest covers an area of around 50,000 hectares and is located downstream of Torrumbarry Weir on the Murray River, between Echuca and Koondrook-Barham. The project is to be located within the Koondrook-Perricoota Forest which forms the component of the forest which is located on the northern or NSW side of the Murray River. The Koondrook-Perricoota component of the forest covers an area of approximately 32,000 hectares.

The project location is shown in Figure 1.

1.2.2 Key features of the project

The proposed Koondrook-Perricoota Forest Flood Enhancement Works have been designed to reinstate a more natural flood regime to Koondrook-Perricoota Forest as this is critical to improving forest health.

The project involves the construction of a diversion channel and engineering structures to divert environmental flows from the Murray River to the Koondrook-Perricoota Forest. The scheme would be operated so as to mimic a natural flood regime and as such has been designed to allow regular flooding of the forest. One of possibly many delivered events would be to divert water every three to four years for a period of up to 100 days, however, diversion of smaller flows events will occur more frequently.

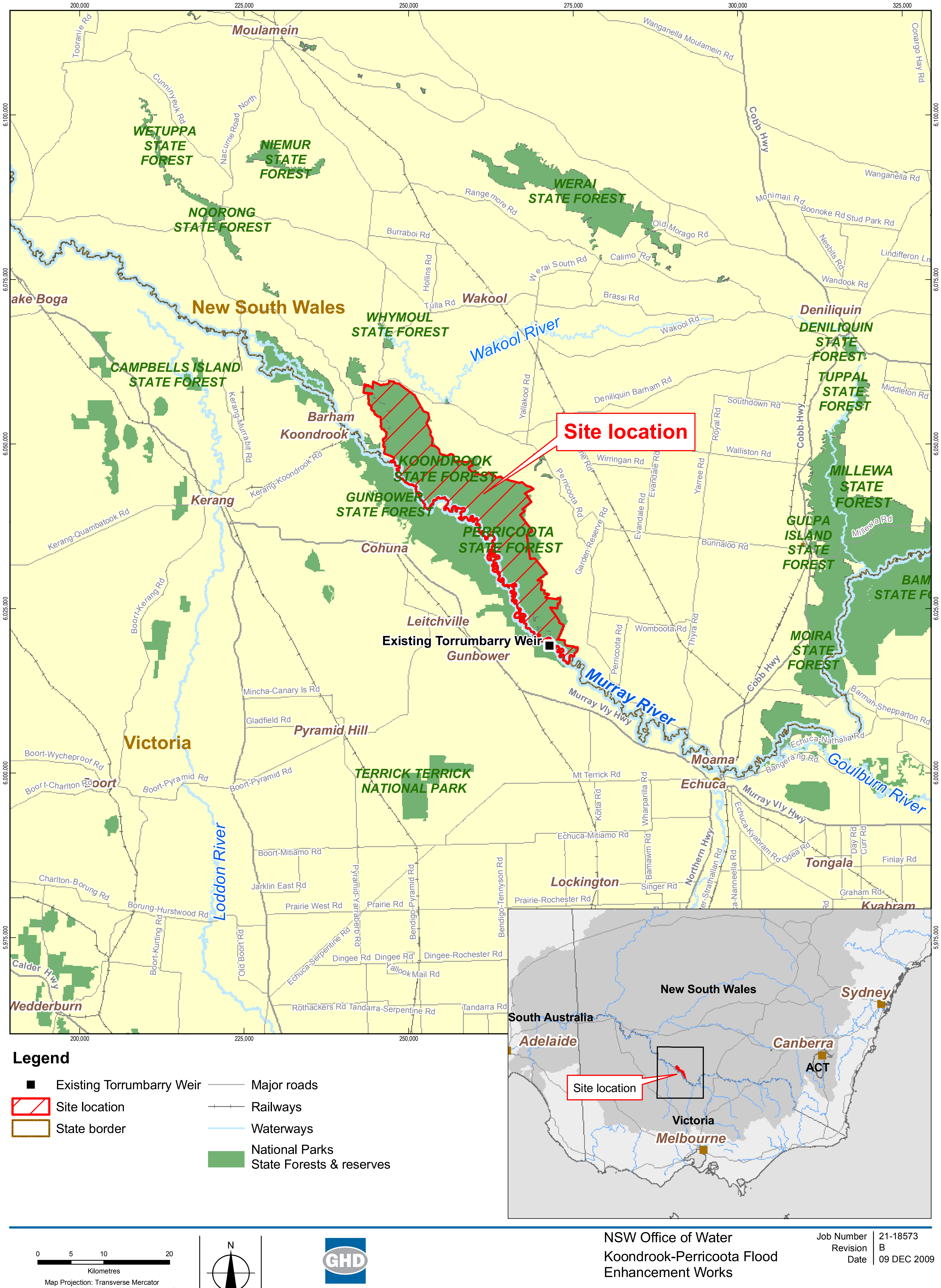
The works can be summarised as:

- Upstream structures to allow diversion of water into the forest from the Torrumbarry Weir pool, and regulators at Swan Lagoon to control flows re-entering the Murray River; and
- Downstream structures to control water leaving the forest and to maximise return flows back to the Murray River. These structures include a return channel to

discharge flow back to the Murray River and a floodway to increase water returns to the Murray River. Regulators would be required to control the flow of the water from the downstream end of the forest to existing waterways. A levee generally located around the downstream perimeter of the forest would connect the regulators and is required to retain water within the forest and protect adjoining land from flooding.

A summary of the engineering works for the project is provided below and locations shown in Figure 2.

- Construction of a 3.8 km long earth-lined inlet channel extending north from the Torrumbarry Weir pool on the Murray River to Bullock Head Creek;
- Construction of a gated regulator structure within the inlet channel approximately 200 m from the Murray River;
- Construction of an access bridge across the inlet channel at River Road;
- Erosion protection works at the point the inlet channel discharges to Bullock Head Creek;
- Two regulators and associated works at Swan Lagoon;
- Downstream stop log regulators at Runner A, Barbers, Cow, Calf and Thule Creeks. Provision would be made for a fishway to be retrofitted at the regulator on Barbers Creek;
- Construction of a return channel from Crooked Creek to allow return flow back to the Murray River;
- A gated regulator structure within the return channel from Crooked Creek to the Murray River;
- Floodway to enhance return flows to the Murray River;
- Provision of a levee generally around the downstream perimeter of the forest and connecting four of the above regulators (Barbers Creek, Runner A, Cow Creek, Calf Creek, and Thule Creek); and
- A drop down structure at the entry of the return channel to the Murray River.



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Koondrook-Perricoota Flood Enhancement Works

Job Number 21-18573
Revision B
Date 09 DEC 2009

Figure 1. Location of the project

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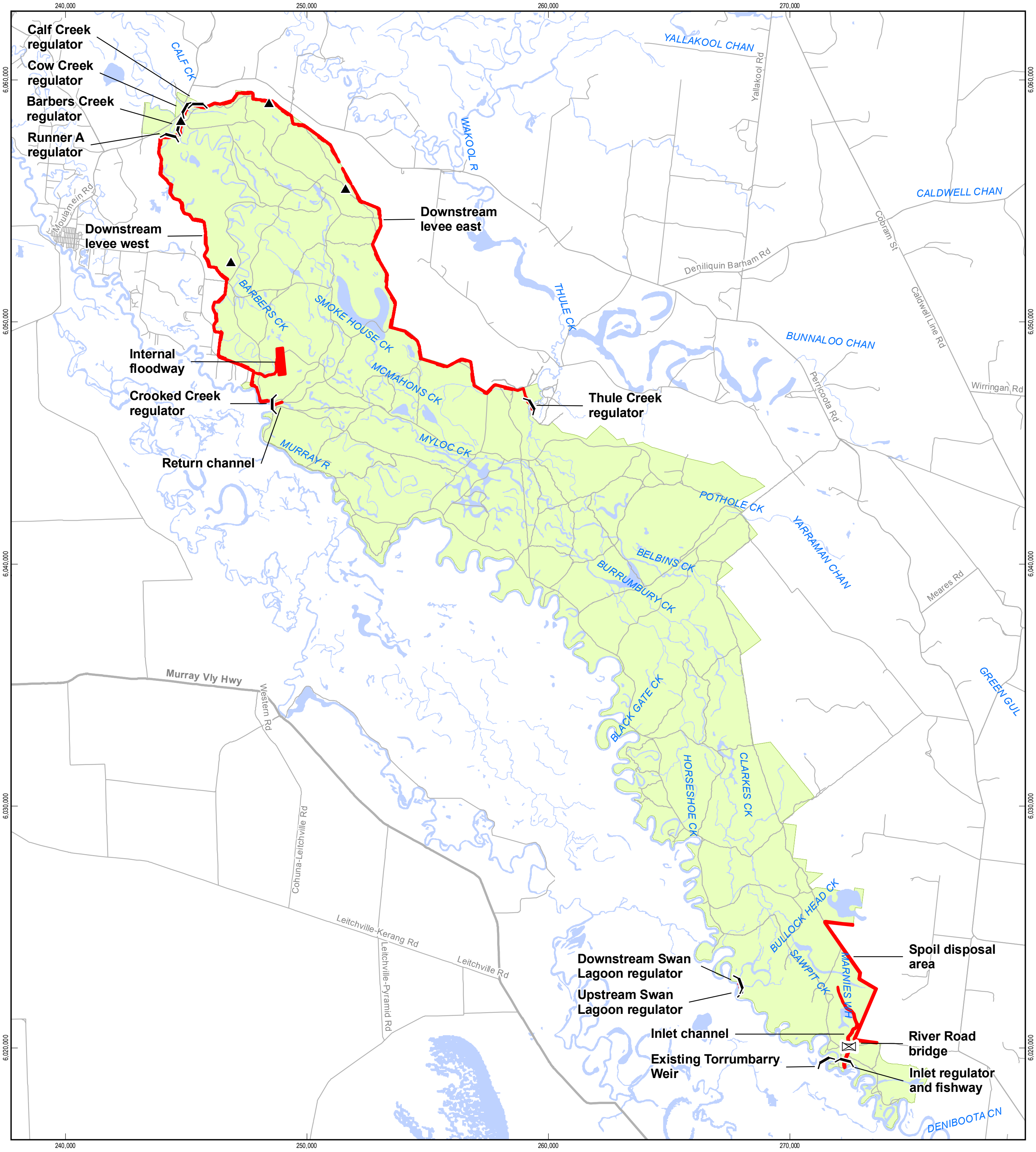
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: StreetMap - Navegate, Drawn: Cwilson



Legend

- ▲ Turkey's nest dam
- ⊠ River Road bridge
- Regulator
- Construction features
- Roads
- Waterway
- Koondrook Perricoota Forest Site

0 1 2 4
Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia (GDA)
Grid: Map Grid of Australia 1994, Zone 55

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Koondrook-Perricoota Flood Enhancement Works

Job Number	21-18573
Revision	C
Date	01 FEB 2010

Figure 2. Location of the main structures

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Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: Dept of Commerce, Street Map- Navtec, Drawn: Cwilson, cwilson

1.2.3 Operation of the project

The Living Murray Environmental Works and Measures Program is developing and implementing projects that will construct and utilise engineering structures to direct water to the wetland and forest ecosystems without the dependency on natural high flows or floods. This will enable watering of the ecosystems at the scale, frequency, timing and duration required to achieve the environmental objectives.

Implementing this type of intervention in a regulated river system that is operated for multiple outcomes brings with it some risks and trade-offs that will need to be managed. Early awareness of this issue has led to the projects being designed to enable highly varied and flexible operations. This flexibility enables adaptive management in response to:

- Differing water availability and river conditions;
- Risk management requirements; and
- The targeting of specific environment outcomes (eg vegetation response, bird breeding events) that may be required from time-to-time to achieve long term objectives.

The overarching objective for the Gunbower-Koondrook-Perricoota Forest is to maintain and restore a mosaic of healthy floodplain communities.

The project will be operated in accordance with an Operating Plan developed specifically for the project. The purpose of the Operating Plan will be to provide a framework for the operation of the structures to meet key ecological objectives within the broader context of The Living Murray Program and Scheme's governance.

The Operating Plan will not prescribe particular watering events, however it will provide an effective platform for operational decision making based on knowledge development and strong understanding of what the project should aim to achieve.

With reference to hydrologic conditions in the River Murray downstream of Torrumbarry Weir, the operation of the project will occur in one of three general ways:

- For flow events <18000 ML/d, water can be delivered to the forest through the inlet channel;
- For flow events >18000 ML/d, water can enter the forest through natural watercourses/effluents, potentially supplemented with water delivered through the inlet channel; and
- There will also be larger flood events within the forest when the flood enhancement project is not operated.

The natural flow regime at the site provides a guide to the water requirements of the ecological processes and communities that exist there. This regime is highly variable, and comprises floods of various magnitudes and durations, occurring at a range of frequencies. In general, small floods occur more frequently, and larger floods less frequently. It is highly desirable that the project provide a very flexible delivery mechanism that is capable of delivering a range of flood events, able to sustain a range of ecological processes and elements, for example:

- Frequent, low flows (but exceeding the commence to flow levels) to maintain the wetland habitats occurring in lagoons, depressions and flood runners;
- Less frequent floods of medium magnitude to maintain the extent of the Red Gum communities, with larger floods maintaining the extremities, and smaller floods supporting the core areas with flood dependent understorey communities;
- Flood events of long duration to cue and facilitate bird breeding; and
- Very large, infrequent flood events to provide an occasional boost to the fringing Black Box communities.

Water efficiencies would be maximised by returning water directly to the Murray River via the return channel.

While predictive models provide some guidance, the exact ecological outcomes arising from operation of the project will be unknown until they have been operated in real time, under a range of antecedent conditions. In line with adaptive management principles, it will be important to be able to alter the operation of the structures, both during operations and from one operation to the next, in order to react to the ecological response observed. Furthermore, the exact nature of both unregulated and regulated river flows, and the quantum of environmental water available, is unknown. Flexible operation and the ability to capitalise on a variety of flow events, is therefore an important element of structure design.

Reference should be made to the Environmental Assessment for a description of the operation of the project, including aspects such as:

- The planning and institutional framework;
- Water availability, including regulated water, unregulated flows, Commonwealth water, NSW environmental water, and The Living Murray water;
- Operational constraints; and
- Water operations, including governance, watering principles, decision making, and predicted operations.

1.3 Report structure

The report structure is set out as follows:

- Section 1 – Introduction;
- Section 2 – Existing water quality in waterways in the vicinity of the site;
- Section 3 – Assesses potential impacts of turbidity on water quality;
- Section 4 – Discusses potential impacts on salinity;
- Section 5 – Discusses potential impacts associated with
- Section 5 – Recommended mitigation measures;

- Section 6 – Conclusion; and
- Section 7 - References.

2. Existing water quality

2.1 Overview

Four issues of concern have been identified in relation to water quality when the flood enhancement project commences in the Koondrook – Perricoota Living Murray Icon site. These are turbidity issues arising from construction sediment or erosion within the forest, possible salinity issues arising from saline groundwater or soils, blooms of potentially toxic blue-green algae (Cyanobacteria) and blackwater events triggered by leaching of organic material from plant litter accumulated on the forest floor.

If the water quality within the flooded Forest is poor, this may have consequences both within the Forest, particularly for the aquatic biota, and for the waters receiving the outflow from the Forest – the Murray River and Barbers Creek, and the streams into which it flows, primarily the Wakool River.

The water quality in the forest will depend on processes which may occur within the Forest, but also on the quality of the water entering the Forest. So the water quality of the Murray River at Torrumbarry is important.

This report is part of a desk-top study, and is thus based only on existing and available data. No data were available for Barbers Creek, or for any water body within the proposed inundation area.

2.1.1 Water quality in the River Murray

Limited water quality information is available for streams in the area (Table 1). Data on key water quality parameters has been summarized for three sites on the River Murray, the Wakool River (but at a site well downstream of the project area, and from Gunbower Creek which is located on the Victorian side of the river but flows through a River Red Gum forest similar to that at Koondrook Perricoota.

The Murray River sites show a general trend of decreasing water quality downstream with nutrient levels, turbidity and salinity all increasing from Torrumbarry Weir (Table 1). Oxygen levels are variable, presumably reflecting the impact of primary production in the channel, since algae produce oxygen during the day as a by-product of photosynthesis.

The Wakool River and Gunbower Creek results are not substantially different from the Murray River, although turbidity levels are higher in the Wakool River. Dissolved Organic Carbon (DOC) levels are also slightly higher in these two tributary streams, and nutrient levels are also relatively high.

Table 1 summarises water quality data from three sites on the Murray River close to the Koondrook Perricoota forest and from two tributary streams in the vicinity. Data are presented as the median values together with the 25th and 75th percentile values to give an indication of the range. N.A. indicates data not available.

Table 1 Water quality data

Parameter	Murray River (Torrumbarry)	Murray River (Barham)	Murray River (Wakool Jn)	Wakool River (Kyalie)	Gunbower Creek (Koondrook)
Chlorophyll *a* (µg/L)	14	24	N.A.	22	N.A.
25%	9.1	17	N.A.	15	N.A.
75%	19	39	N.A.	53	
Dissolved O_2 (mg/L)	9.4	8.3	9.1	N.A.	9.0
25%	8.2	8.1	8.1	N.A.	8.2
75%	10.5	9.4	10.4	N.A.	10.5
DOC (mg/L)	4	4	N.A.	5	5
25%	3	3	N.A.	4	4
75%	5	7	N.A.	7	7
Conductivity ms/cm	110	110	250	220	120
25%	86	86	190	150	97
75%	130	130	300	290	170
Total Kjeldahl N (mg/L)	0.45	0.49	0.58	0.53	0.61
25%	0.35	0.39	0.48	0.43	0.5
75%	0.60	0.60	0.73	0.70	0.76
Total P (mg/L)	0.061	0.065	0.075	0.068	0.077
25%	0.043	0.048	0.064	0.052	0.059
75%	0.082	0.086	0.088	0.092	0.099
Turbidity (ntu)	18	21	32	40	28
25%	13	16	24	30	22
75%	27	28	33	58	38

3. Turbidity impacts

3.1 Overview of the potential issue

There is an extensive published literature available on the effects of suspended particulate material on running waters (Campbell and Doeg 1989, ANZECC 1992, ANZECC 2000). The usual impacts include a reduction in light penetration reducing primary production, interference with feeding by visual predators and filter feeders, and smothering and modification of habitat for bottom dwelling organisms. Essentially the extent of the impact depends on the amount of sediment generated and the length of time over which it is generated.

The presence and strength of currents to disperse the sediment is also a factor. Strong currents will widen the area of impact when large sediment loads are delivered, or sediment is delivered over a long time period, and scour away deposited sediment once sediment delivery has ceased (Campbell and Doeg, 1989).

Within floodplain river systems water movement over the floodplain is often slow, and sediment tends to be deposited rather than eroded.

3.2 Existing environment

Turbidity in the River Murray increases downstream from Torrumbarry Weir to downstream of the Wakool Junction, but none of the values are considered to be high (Table 1). Nutrient levels also increase, and it is likely that the increase in turbidity reflects, at least in part, an increase in suspended algae. The river will also be accumulating suspended particulate organic material from terrestrial sources.

3.3 Impact assessment

There is potential for sediment to be generated in the creek channels, through bank erosion, from construction sites if bare soil is left exposed, and from other areas where bare soil is exposed, especially if fine sediment has accumulated through the activities of humans or stock. Implementation of appropriate construction site environmental management plans will ensure that sediment delivery to the system from erosion at construction sites is limited and short term. Erosion along creek channels can be minimised by adaptively managing the flow regime to maintain low water velocities, and erosion from elsewhere in the forest can also be controlled by managing stock and areas intensively used by people.

In general, risks to water quality from sediment are considered of low consequence, since much of the transported sediment will be deposited within the forest during the period while the water is retained and thus will have little impact on the river downstream. The forest will be a net sediment trap rather than a sediment source. If any erosion from construction sites does occur it will be short term, and only contribute to downstream turbidity where the source is near the discharge point.

3.4 Mitigation measures

Mitigation measures to manage potential impacts on water quality relating to turbidity are detailed in the soil, landform stability and erosion hazard assessment.

4. Salinity

4.1 Overview of the potential issue

The risk of the flooding process causing substantial increases in river salinity is considered to be low. Previous assessments of risk of salinization from groundwater have concluded that, while knowledge of the hydrogeology of the forest area is limited, it appears to be primarily a groundwater recharge area rather than a discharge area (Evans and Barnett 2007, Salient Solutions 2008). Consequently there is little risk of the seepage of saline groundwater from the area entering either the Murray River or other streams in the area. Salt wash off is likely to be responsible for the highest salt loads returning to the surface water as a result of forest flooding (Salient Solutions 2008). In order to raise the conductivity of the pooled floodwater by 1 µS cm-1 the inundated soils would need to contribute about 0.75 gm m^{-2} of salt, a relatively high level that would be expected only where there was evidence of dryland salinity issues within the forest. An increase on 1 µS cm-1 in the pooled water would result in a far lower concentration change in the Murray and Wakool Rivers downstream because of dilution processes.

A detailed discussion of potential impacts of the project on groundwater salinity and the associated surface water interactions is provided in the groundwater assessment.

5. Cyanobacterial (blue-green algal) blooms

5.1 Overview of the issue

Nutrient enrichment of lakes and rivers which may trigger toxic algal blooms has been the subject of scientific study for over 50 years (e.g. National Academy of Sciences 1970). Within Australia investigations have been conducted for almost as long (Wood 1975), and led to the development of nutrient criteria for inland waters (Bowles 1982) and later the identification of trigger levels for major nutrients (ANZECC 1992, 2000).

In inland waters blooms of cyanobacteria, or blue-green algae have been of greatest concern. Blooms of any algae can cause kills or aquatic organisms through depletion of dissolved oxygen in the water either through respiration processes which predominate at night, or through decomposition processes as dead cells decompose. However, a number cyanobacterial species also produce toxins which can kill both aquatic organisms and, potentially, terrestrial animals, including humans, that drink the water. Phosphorus and nitrogen are the two major nutrients required by algae and other plants. A number of cyanobacteria have the ability to fix nitrogen gas, rather than depending on other forms of soluble nitrogen such as the oxides of nitrogen. As a consequence cyanobacteria tend to be favoured when phosphorus is abundant in aquatic systems, but when nitrogen is in shorter supply.

Within the Murray-Darling an intense toxic cyanobacterial bloom stretching over 1,000 km of the Darling River in the summer of 1991-2 (GHD 1992) triggered a state of emergency in NSW and focussed public attention on nutrient enrichment of Australian inland waters. The Murray Darling Basin Commission (MDBC) had already commissioned a consultants report on nutrient sources in the basin (GHD 1992) and subsequently developed an algal management strategy (MDBC 1992).

The MDBC algal management strategy identified high nutrient levels, calm water conditions and degraded aquatic ecosystems as the three most important conditions contributing to algal blooms in the Murray-Darling (MDBC 1994). Consequently their management strategy focussed on nutrient reduction and provision of environmental flows as the physical objectives to reduce bloom incidence.

ANZECC (2000) identified trigger values for nutrients in slightly disturbed westward flowing lowland rivers in southeastern Australia as outlined in Table 2 :

Table 2 **ANZECC (2000) identified trigger values for nutrients in slightly disturbed westward flowing lowland rivers in southeastern Australia**

Parameter	**Chl *a***	**TP**	**FRP**	**TN**	**NO_x**	**NH_4^+**
Unit	µg L^{-1}	µg P L^{-1}	µg P L^{-1}	µg N L^{-1}	µg N L^{-1}	µg N L^{-1}
Trigger Value	5	50	20	500	40	20

These values are the values below which algal blooms would not generally be expected. The report commissioned by MDBC (GHD 1992) identified point sources such as sewage treatment plant discharges, as the major nutrient sources to the Murray-Darling in dry years, but non-point sources, such as runoff from agricultural areas, as the major nutrient sources during wet years.

Since the development of the MDBC strategy a number of researchers have investigated algal blooms within the rivers of the Murray-Darling basin attempting to understand the factors responsible and to quantify or model the factors that can lead to algal blooms. A reliable predictive model would be an invaluable management tool.

Grace *et al.* (1997) concluded that phosphorus was probably not the critical factor in triggering the algal bloom in the Darling River, and other researchers have concluded that physical factors play a key role (e.g. Mitrovic *et al*. 2003, Westwood and Ganf 2004). Davis and Koop (2005) identify stratification and light penetration, rather than nutrient availability, as the triggers for bloom formation in the impounded rivers of southeastern Australia, although nutrient exhaustion limits the biomass of blooms. They consider that nitrogen plays as important a role as phosphorus does in controlling the biomass of these freshwater blooms.

Davis and Koop (2005) believed that the biophysical processes involved in eutrophication have now been quantified sufficiently for models to be developed of such processes as sediment-nutrient release, stratification, turbidity and algal growth in freshwater systems. However all of the modelling attempts for algal blooms in the Murray-Darling of which GHD is aware, such as those of Maier and co-workers (e.g. Maier and Dandy 1997, Maier *et al*. 2001, Kingston et al. 2006) have been described by their developers as being of more value in identifying research questions than as management tools at present. The models developed by Maier *et al.* (2001) identified some contributing factors to *Anabaena* blooms, such as the passing of a flood hydrograph, which differ from those suggested by Davis and Koop (2005).

Whether cyanobacterial blooms occur in the Koondrook-Perricoota forest during watering events will depend on a number of critical variables including the timing of the flood, the retention period and water quality. The time of year of the flood is important because warmer temperatures will favour stratification, and light availability is greater in summer. The retention period is important because longer retention periods favour algal growth as stratification develops in the pool. Stratification, with deoxygenation of the deeper water, will lead to increased nutrient release from the sediments, which would tend to promote algal growth. Stratification develops in summer when water temperatures are high, and at times when water turbulence is low. So it is more likely to occur when water is pooled rather than flowing through the forest, and in areas sheltered from the wind or on calm days. It is also more likely to develop and persist in deeper rather than in shallow water

Water quality parameters which will be important in influencing algal growth include nutrient concentrations, which will influence the size of the algal standing crop, and the ratio of phosphorus to nitrogen, with higher relative phosphorus levels tending to favour cyanobacteria many of which can fix atmospheric nitrogen. Light penetration into the water which will be influenced by the colour of the water and levels of turbidity is also important. Shading by the forest will also tend to reduce the potential for blooms by reducing light availability.

5.2 Existing water quality parameters relevant to cyanobacteria

Data on water quality are available for Torrumbarry Weir which is close to the inflow point for the Koondrook-Perricoota Forest Flood Enhancement Project, and so is representative of the water which will be used to flood the forest. Both nitrogen and phosphorus are sampled weekly, and data since January of 2004 have been analysed. The time period was selected because it was sufficiently long (5.5 years) to give a meaningful data set that is representative of current conditions at the site. Median total Phosphorus (P) concentration was 36µg L^{-1} while the 75th percentile level was 47 µg L^{-1}. These values are below the ANZECC and NSW trigger values, but exceed the Victorian trigger value which is 32 µg L^{-1}.

Median total nitrogen was 370 µg L^{-1} with a 75th percentile value of 460 µg L^{-1}. The median value is below the ANZECC, NSW and Victoria trigger values, but the 75th percentile value exceeds the Victoria trigger which is set at 422 µg L^{-1}.

5.3 Impact assessment

Based on the nutrient values outlined in Section 5.2, it would not be expected that cyanobacterial blooms would occur in the forest as a result of the quality of the inflowing water. However, the nutrient levels are elevated, so management activities such as intensive grazing resulting in accumulations of animal manure could be sufficient to raise nutrient concentration above trigger levels, increasing the risk.

Estimating the light availability is more difficult because it is influenced by shading, for which not data is available, and by colour of the water. Water colour, as discussed in Section 6, will be influenced by leaching of materials from the inundated forest plant litter. The greater the colouration of the water the more likely there will be blackwater events and the less likely there will be algal blooms. For the initial floods, the levels of colour are likely to be high and thus the risk of algal blooms will be low. If subsequent floods occur only every three years there is likely to be sufficient accumulation of plant litter to ensure that DOC levels, and thus water colour, is also high for future flood events, and the risk of algal blooms within the inundation area will not increase.

5.4 Recommended mitigation measures

The risk of cyanobacterial blooms is greater in summer than at other times of the year because of the higher water temperature levels and greater light availability. Thus the most effective mitigation measure would be to avoid holding pooled water within the Forest during the warm months.

Secondly any management activities which can reduce the potential for nutrient accumulation and release from the flooded area would help to reduce the risk of algal blooms. Maintaining the condition of the forest understory, and restricting stock access would be advantageous.

6. Blackwater events

6.1 Overview of the issue

6.1.1 Introduction

Blackwater events have been defined as flood events which have elevated levels of dissolved organic carbon (DOC) in the water sufficient to give the water a dark colour, which is associated with levels of dissolved oxygen in the water column sufficiently reduced to cause fish kills. The oxygen levels are lowered when oxygen is used by microbes in suspension as they metabolize the organic carbon.

There have been a number of blackwater events in the Murray-Darling basin, of which the most serious, and relevant to the project, was the event following the artificial flooding of the Barmah-Millewa Forest in 2000. This resulted in blackwater returning to the Murray River mainstream causing fish and crustacean kills downstream (Baldwin et al. 2001). A subsequent artificial flooding at the same location in 2005/6 appears not to have resulted in a fish kill (O'Connor et al. 2007) although it did cause changes in river water colour (DIPNR 2005).

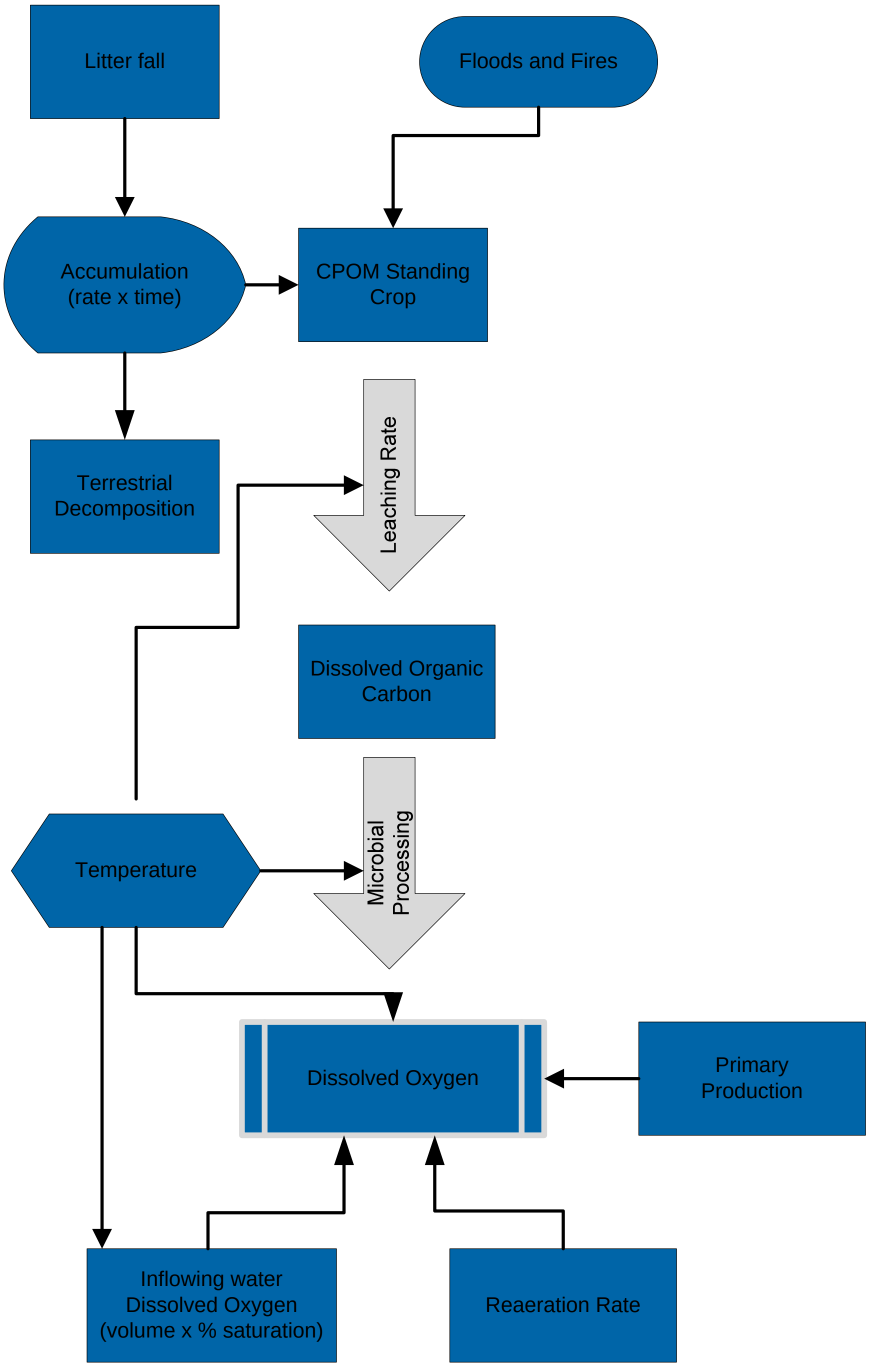
The main source of dissolved organic carbon appears to be River Red Gum leaves, rather than wood or bark (Francis and Sheldon 2002). The decomposition of River Red Gum leaves in streams and wetlands has been investigated a number of times (e.g. Briggs and Maher 1983, Campbell and Fuchshuber 1995, Janssen and Walker 1999, Glazebrook and Robertson 1999, Francis and Sheldon 2002). The process is similar to that for most other leaves (Petersen and Cummins1974, Webster and Benfield 1986) with a rapid leaching of soluble components, generally comprising 10-20% of the leaf dry weight, within the first 24 hr of leaf submergence, and a slower breakdown of the less soluble leaf components subsequently, generally following some form of negative exponential decline in leaf weight remaining.

The key issue of concern arising from blackwater events is the low concentration of dissolved oxygen which occurs on the floodplain, but can also occur in channels downstream. In this case that could mean the Murray, Barber Creek or the Wakool River. There are a range of processes potentially influencing the DO concentration of water on the floodplain, and these are illustrated in the conceptual model in Figure 1.

6.1.2 Standing Crop of Plant Litter

The main source of DOC is River Red Gum (*Eucalyptus camaldulensis*) leaf material, so a key variable influencing the concentration of DOC is the standing crop or amount of River Red Gum leaf material present on the floodplain This is highly variable both spatially and temporally. Glazebrook and Robertson (1999) cite dry mass levels in prior to autumn and winter floods at two sites in the Barmah-Millewa forest, which

Figure 3 Flow chart of issues related to blackwater events



is also a River Red Gum forest and only about 50km from Koondrook-Perricoota, ranging from 53 to 228 g m^{-2}, and total plant litter ranging from 495 to 2350 g m^{-2} – in each case a four fold difference. The spatial variation will occur because the trees shedding the litter are not evenly distributed, and because the material dropped will be redistributed by wind and water, accumulating more in depressions such as flood runners, and against obstructions such as branches. At a larger scale the presence of other vegetation types and areas which have been cleared or partly cleared by logging or fire will have differing rates of litter accumulation and thus different standing crops.

The standing crop of plant litter will also vary temporally. Glazebrook and Robertson (1999) found higher standing crops in autumn than in winter, presumably because the peak litterfall occurs in summer in temperate eucalypt forests (e.g. Campbell *et al.* 1992), and shed material decomposes on the ground with standing crop decreasing from the end of the summer peak once the rate of litterfall falls below the decomposition rate. Over longer time periods the standing crop will tend to increase year by year unless it is reduced by a fire or flood. Eventually the standing crop will reach a level where the annual rate of decomposition is equal to the rate of litterfall, although that is probably rare in these relatively dry forests.

Glazebrook and Robertson (1999) estimated nett litter accretion rates of leaf litter as 16 kg ha^{-1} day^{-1} in autumn and 6.5 kg ha^{-1} day^{-1} in winter in Barmah-Millewa. However Howitt *et al*. (2007) used a summer value for leaf accession of 9 kg ha^{-1} day^{-1} and an annual mean of 3.9 kg ha^{-1} day^{-1} in their Barmah Blackwater model. We retained that figure when the model was adapted for Koondrook Perricoota, although it is likely that, at least initially, the litter fall in Koondrook will be lower because the forest is drier, and wetter forest generally has higher rates of litter fall (Bray and Gorham 1964).

Floods influence litter standing crop in two ways: wash out and decomposition. Where the flood results in substantial water movement, plant litter loose on the ground may be transported and redistributed by the water. In addition, leaf decomposition is more rapid in the water than terrestrial decomposition and Glazebrook and Robertson (1999) estimated that during flood periods there would be a nett loss of leaf litter standing crop of about 14 kg ha^{-1} day^{-1} in autumn and about 10 kg ha^{-1} day^{-1} in winter due to decomposition processes exceeding litter-fall rates.

Decomposition rates of plant litter obviously influence the standing crop that is present when a forest floods. The factors influencing the decomposition process include temperature, water chemistry and the size of the litter accumulations. At higher temperatures the decomposition is faster, partly because the speed of solution of DOC is more rapid, and partly because the other breakdown processes, which are microbially mediated, speed up. Higher nutrient levels, and especially nitrogen concentrations, in the water speed up processing rates, presumably through their influence on microbial growth rates (Webster and Benfield 1986). The size of the litter accumulation also influences decomposition rate presumably because as the leaves form large packs, the relative surface area exposed to the water is reduced (Campbell *et al.* 1994).

6.1.3 Concentrations of dissolved organic carbon and dissolved oxygen

The concentration of dissolved organic carbon (DOC) in the flood water will depend on the standing crop of leaf and other plant litter material, and on the leaching of organic compounds from the plant litter. The leaching process generally follows a negative exponential pattern, with a rapid rate of initial leaching which slows over time as the most water soluble materials are most rapidly leached leaving less soluble material.

The rapid initial leaching of DOC usually results in leaves losing 10-20% of their biomass within the first 24-48 hours of immersion in water. The speed of leaching is important because it means that even if the first flood in the forest is “flushed through” it will still have the potential to accumulate a substantial concentration of DOC. O’Connell *et al.* (2000) estimated that River Red Gum leaves released 45-80 mg DOC g^{-1} over a 29 day period of which about half was released in the first two days. Bark and twigs released 5-20 mg DOC g^{-1} over 29 days, and a much smaller proportion over the first two days. They estimated the first order rate constants for both DOC release from leaves, and for release from twigs and bark. There was an eightfold difference between the smallest and largest rate constants for the leaf leaching process.

The concentration of dissolved oxygen (DO) in the floodplain waters at any given time will depend on a number of factors. The first is temperature. The solubility of oxygen is inversely related to temperature, so the concentration of oxygen in the water will be less in summer than winter, and oxygen related fish kills will be more likely to occur in summer, and particularly on hot days.

The final concentration of oxygen in water on the flood plain will be influenced by the oxygen concentration in the incoming water, which, in the absence of an algal bloom which will reduce the night time concentrations and elevate the day time concentrations, will probably be close to saturated. On the floodplain the temperatures may rise in summer as the water inflowing water flows over warm soils, resulting in a lowering of DO.

As bacteria in the water begin to utilize the DOC which has leached from the leaves they will utilize DO and reduce it. The rate at which DOC is metabolised is temperature dependant, and about 40% of the DOC released from leaf litter is utilised with a lesser proportion (25-30%) of the DOC from twigs and bark being utilised O’Connell *et al.* 2000). Howitt *et al.* (2007) suggest that about 1% of the total DOC present is metabolised each day on the Barmah forest model, a number that they attribute to O’Connell *et al.* (2000), but the value must have been derived from unpublished data.

While bacterial metabolism will utilize dissolved oxygen in floodplain waters, algal photosynthesis will increase it, at least during the day. The levels of oxygen producing primary production will depend on a range of factors including water temperature and light availability. Thus they will be higher in summer than winter, and will be lower in flooded areas where forest canopy is denser and the water is shaded. DOC released from the plant litter which colours the water will also reduce primary production by reducing light penetration.

Finally, if the oxygen concentration in the floodplain water drops below the100% saturation concentration for the particular temperature, physical reaeration processes will commence to replenish the DO. The rate at which reaeration occurs will depend on physical factors such as wind speed, with reaeration rates increasing on windy days, and also on whether the water stratifies – forming layers with little mixing between them. Under those conditions the upper water layers may have high oxygen concentrations while the lower strata remain deoxygenated.

6.2 Impact assessment

6.2.1 Potential issues in the Koondrook-Perricoota Forest and downstream waterways due to operation of the project

Blackwater issues may arise both on the inundated floodplain and in downstream channels. The extent to which they occur in downstream channels will depend on the dilution of the released blackwater in the receiving channel, and the concentration of dissolved oxygen in the receiving water, which will depend on the water temperature.

When the first enhanced flood is conducted at Koondrook-Perricoota Forest, high concentrations of DOC will accumulate in the water, as suggested by DWE (2008), because, in the absence of floods for some years, there will be a substantial accumulation of plant litter on the floodplain. The extent to which this creates a blackwater event will depend mainly on the temperature. If the flooding occurs in cold weather, sufficient concentrations of oxygen are likely to remain in the floodplain water to avoid fish kills.

Whether the return of water to the Murray River, the Wakool and other channels causes an environmental issue is also likely to depend on the season and river conditions at the time of release. For the Murray, the release is least likely to create an issue if it occurs when river water levels are high – since this will maximise the dilution potential and also river turbulence which enhances reaeration. Returning the floodwater when water temperatures are cold will also lessen the risk of fish kills, because DO concentrations in both the released water and the river will be maximised. However, if the floodplain water is released when water temperatures are high and river flows are low, fish kills are far more likely.

In Barbers Creek and the Wakool and other river channels, the impact of releases is likely to be more complicated. In some cases these channels have not received flows for some years, and so contain large standing crops of plant litter which will add to the DOC levels already present in the released water. In the case of the Wakool, a number of the pools downstream also contain water of very poor quality as a result of litter leachates, salinity and acid sulphate soils. The lack of flows in recent years has meant that this poor quality water has concentrated rather than being flushed out. Consequently, the first flush of material down these systems will almost certainly be very poor quality water, likely to trigger fish kills in any pools which still support fish and also in the main river channel. Again the risk will be far greater if the release occurs at a time when water temperatures are high.

6.2.2 Impact on Town Drinking Water

Concern has been expressed about the consequences of blackwater releases for drinking water supplies for townships downstream. Blackwater colour is caused by tannins and other chemicals leached from leaves, in the same process used for making tea. The material is not considered dangerous to the health of humans or other animals if it is consumed. It is not a material of concern in the Australian Drinking Water Guidelines. Similarly the reduction in dissolved oxygen which could occur as a result of a blackwater event is not a health hazard from humans or terrestrial animals, so it does not pose a risk to drinking water supplies. If the colour is too intense it may cause concern amongst consumers used to colourless water supplies, but this can be managed by ensuring adequate dilution by passing flows from Torrumbarry.

As far as can be determined all the towns downstream which would be potentially exposed to blackwater have activated carbon water treatment which will remove the coloured DOC from water (along with other organic contaminants). Towns definitely known to have activated carbon water treatment include Barham, Koondrook, Swan Hill, Cohuna, Wakool, and Moulamein.

6.2.3 Blackwater modelling

Howitt et al. (2007) developed a model to predict the occurrence of blackwater events at Barmah-Millewa, and this has been adapted to apply to the Koondrook-Perricoota Forest, primarily by adjusting the hydrological inputs to fit the Koondrook Perricoota situation. For this project, GHD has assumed that ecological parameters such as leaf litter accumulation rates do not differ between Barmah and Koondrook-Perricoota.

The model has been developed partly as a management tool, and partly as a research exercise. It can be considerably simplified to make it more management focussed, and there a number of weaknesses of which model users should be aware.

One of the key inputs to the model is the standing crop of leaf and other plant litter on the forest floor as this is the ultimate source of the dissolved carbon that causes the blackwater. The model derives an estimate of the litter standing crop from estimates of the seasonally adjusted rates of litter fall and litter decomposition in Millewa Forest as measured by Glazebrook and Robertson (1999) and the time since the previous flood. For simplicity it is assumed that each flood removes all previous accumulated litter. The advantage of this method of determining litter standing crop is that the only data inputs required are the dates of the previous flood, and the date of the next flood. This allows predictions to be made well in advance.

The reason for using litter fall rates rather than direct measures of litter standing crop as the input that model uses to estimate standing crop is to allow the model to be easily operated to compare the effects of differing interflood periods. However once consequence is that it restricts the ability of users to adjust the model by taking a single pre-flood measure of standing crop of litter. However, for reasons previously enunciated, it would be unwise to rely on a single measure, or even a small number of measures at a single time, of litter standing crop as an estimate of forest-wide standing crop.

It has been suggested that the litter standing crop in Barmah is likely to be considerably higher than that in Koondrook because of the forest watering in Barmah. That may be true, however the measurements from Barmah were taken in 1997, when Barmah was drier than now, and in the absence of flooding Koondrook has had about 12 years to accumulate litter load. The model has been run for several time intervals since the previous flood, which has the effect of testing the sensitivity to pre-existing litter load. The longest period to the previous flood was set at 30 months, because of concerns that Koondrook has a lower litter accretion rate.

The model as it is presently constituted does not allow for a flushing effect for DOC as water is released during a managed flood. That would result in higher DOC levels in the model than would occur in an actual event. Whether this creates a significant error, given the other model uncertainties will become evident during calibration.

The model has been run with scenarios including the managed flood commencing on the first of each month from August through to November, and assuming the previous flood ended at the end of January in the same year as the flood, the year prior to the flood and two years prior to the flood (Appendix A).

The key output parameter is the dissolved oxygen concentration (DO), which can trigger fish kills if it drops below about 2 mg/L. For most of the scenarios, DO dropped below this level either in January or February as water temperatures rose, or where there had been no prior flood for 2 years, so there were higher amounts of accumulated organic material on the floodplain to leach dissolved organic carbon.

GHD did not attempt to develop the parts of the original model which predicted downstream consequences for either the Murray from releases via the return channel or Barber Creek/Wakool system. In the case of the return channel, a simple mixing model would suffice to get a first order estimate of the dilution and thus the consequences. For the Barber Creek system there was insufficient data, and developing a model for that system would be a substantial exercise.

When the return channel is operating at maximum flow rates of 1,850ML/day, flows in the Murray River downstream of the Torrumbarry Weir are likely to be at least 5,000 - 6,000 ML/day. As a result, blackwater would be diluted by flows in the Murray River.

If blackwater is released down Barbers Creek at the maximum rate of 250ML/day, it would flow approximately 58km downstream before being diluted by the Wakool River which is likely to have flows in the order of 500 – 600ML/day at this time. If flows from the Merran Creek system are entering Barbers Creek upstream of the confluence with the Wakool River, this would assist in diluting blackwater.

Recommended mitigation measures

6.2.4 Potential Amelioration of Blackwater Risks

The key amelioration strategy to reduce potential blackwater impacts will be to time the release of the blackwater to periods when water temperatures are low, and if possible, when river flows are high.

Other operational measures may be to increase the frequency of flooding so that there is less litter accumulation on the floodplain between floods, although that option will obviously be constrained by water availability.

It may also be possible to ameliorate the blackwater impact on the main river by aerating the ponded water before release. Aeration systems are widely used in reservoirs and aquaculture systems (e.g. Schladow 1993, Stephens and Imberger 1993) and may be applicable in the Koondrook. In particular it may be possible to aerate the area of the flooded forest immediately upstream of the release point thus reducing the impact. The great difficulty is that the water depths will generally be small, and aeration is most effective in deeper waters, such as reservoirs. However the installation and operation of a bubbler curtain across the outlet may be feasible for short periods if blackwater becomes critical. Alternatively the discharge points could be engineered to aerate the water as it is released. This could be done through some sort of drop structure, although attention would need to be paid to allow for fish passage.

For managed floods, mitigation of effects caused by water discharged via the Murray return channel will be relatively straightforward. The water release can be controlled by controlling either the release structure or the volume of water flowing into the forest, or both. In addition the amount of dilution can be controlled by controlling the volume of water passed through Torrumbarry weir.

6.2.5 Refining the blackwater model

The blackwater model developed for the Barmah-MIllewa Forest would be able to be customised to provide a more accurate representation of blackwater events and enable it to be used as an effective management tool during planning for watering events. Firstly, the Barmah-MIllewa model it is based on very little data, a single year of litter fall data at only two sites, and not in the Koondrook-Perricoota Forest. However, litter fall is difficult to quantify over large areas such as the Koondrook-Perricoota Forest for the reasons previously discussed. It would be useful to collect Koondrook-Perricoota specific litter standing crop data, and it would be simpler and more useful to simply measure standing crop over a time series after a flood than to try to assess litter fall rate and decomposition rate. That would produce a simple site specific equation for litter standing crop over time, simplifying the model and also reducing some potential errors.

The Howitt *et al.* (1999) model also includes subroutines to assess DOC leaching from soil and from live and dead grass. However O'Connell *et al.* (2000) had concluded that there was relatively little release of DOC from soil, and the contribution from living and dead grass was primarily included because they are one of the factors in forests amenable to management – stock grazing can be used to reduce grass cover, and may in itself be a controversial management issue. These components would seem to be a relatively unnecessary complication unless grazing is an important management issue.

The rate of primary production used in the Howitt *et al.* (1999) model was based on measurements taken in the Murray River, and then adjusted to allow for the inhibitory effect of colour from DOC on light penetration. If the model is to be used over the long term it would be advisable to collect primary production data from the Koondrook-Perricoota Forest and adjust the model accordingly.

The revised model has not been adjusted to allow for the release of the Koondrook-Perricoota inundation water into the Murray River and the Barber Creek and Wakool systems. This will have consequences both for assessments of the concentrations of DOC pooled in the forest, because there is no flushing effect, as well as limiting conlusions that can be drawn about the effects in the rivers. Substantial additional modelling work will be required to refine the consequences of releases into the Wakool in particular. Baldwin and Whitworth (2009) identified a high risk of fish kills caused by blackwater and deoxygenation from rapid oxidation of sulphidic sediments in the Wakool River system if “stock and domestic” flows were passed down the the Yallakool Creek and into the Wakool during periods when ambient temperatures are high.

The model should be calibrated against controlled flood events to ensure it accurately predicts blackwater events prior to the results being used for routine management purposes.

7. Conclusion

The generation of blackwater, highly coloured water caused by the leaching of organic compounds from leaf litter, is the greatest water quality risk arising from the inundation of the Koondrook Perricoota Forest. Blackwater does not pose a toxic hazard to either aquatic life or to animals (including humans) drinking it, but the microbial decomposition of the organic material may lead to deoxygenation of the water, especially in warm weather. The deoxygenated water can cause fish kills and stress or death to other aquatic animals such as crayfish. The risk can be reduced by avoiding retention of floodwater in the forest over the summer months, especially from January to March. The floodwater will need to be monitored for both dissolved organic carbon and dissolved oxygen, and the releases to the Murray managed by manipulating the Torrumbarry passing flows and the rate of release, to ensure adequate dilution within the river channel.

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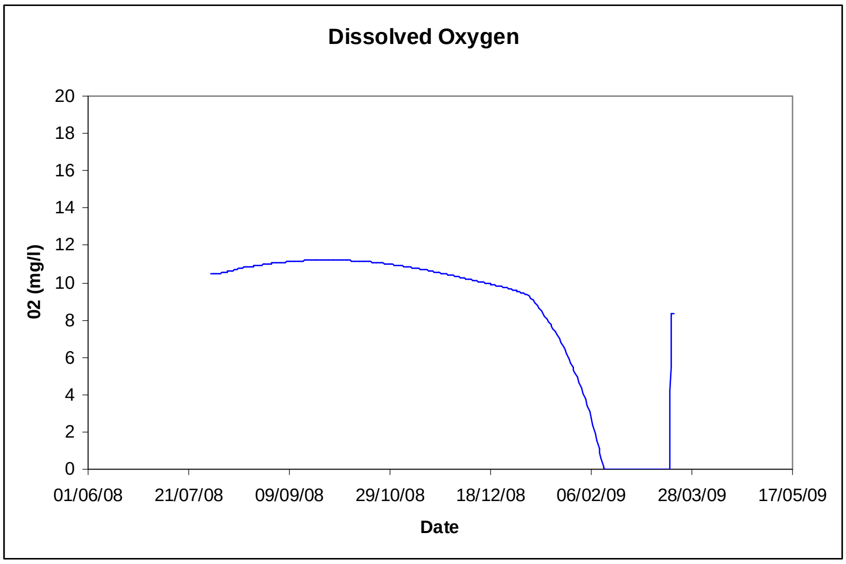
Appendix A

Blackwater model outputs



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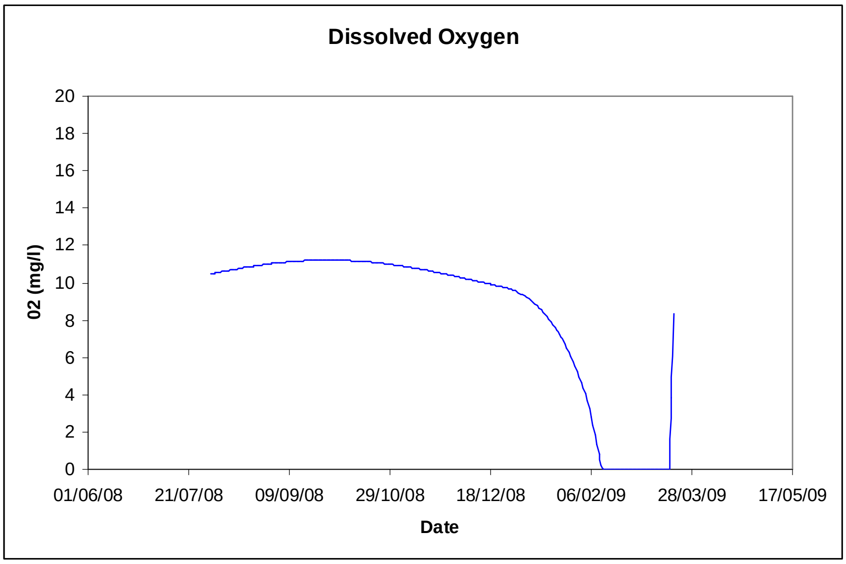

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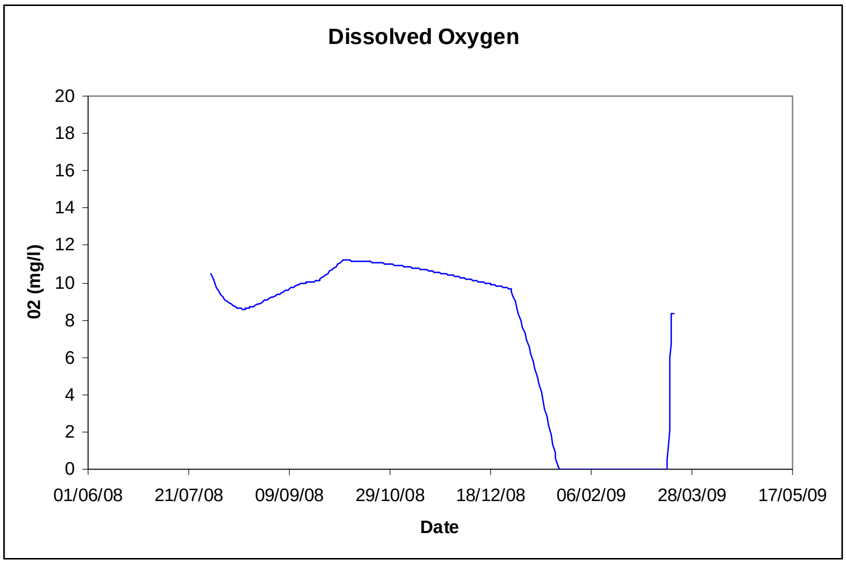

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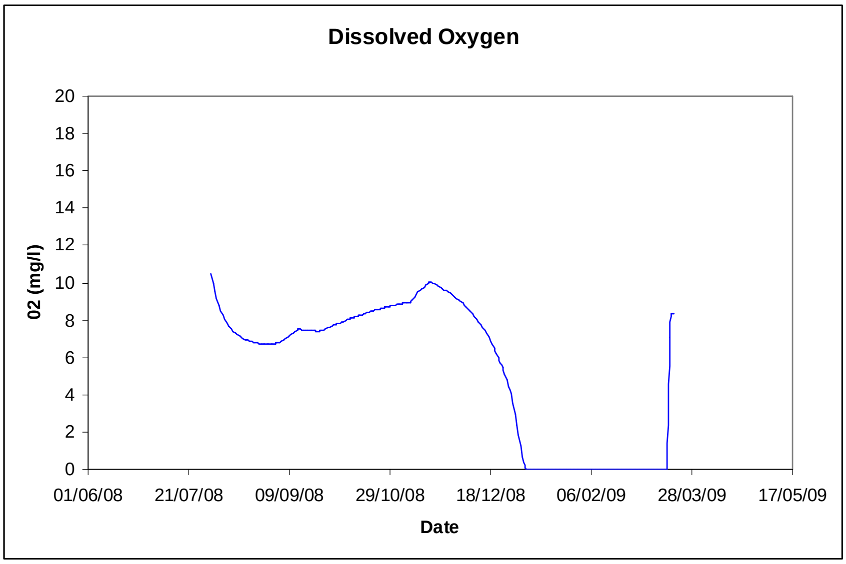

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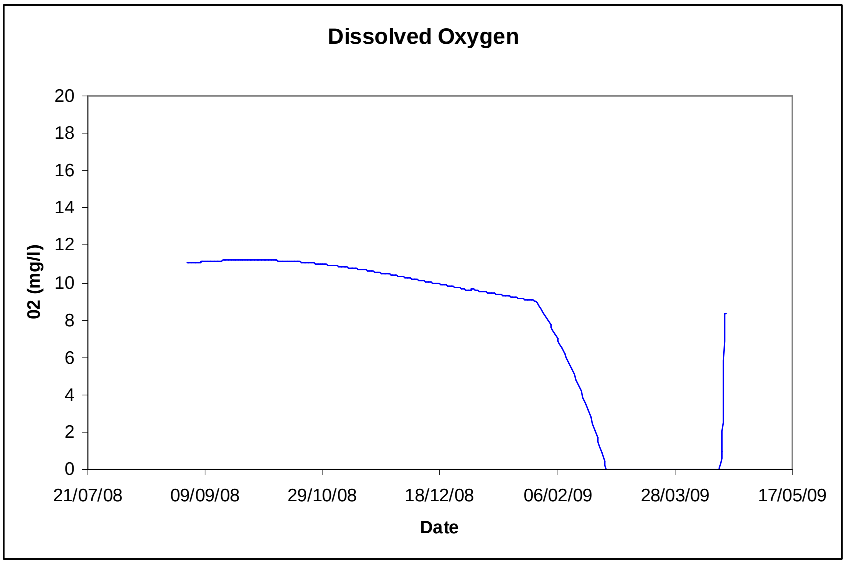

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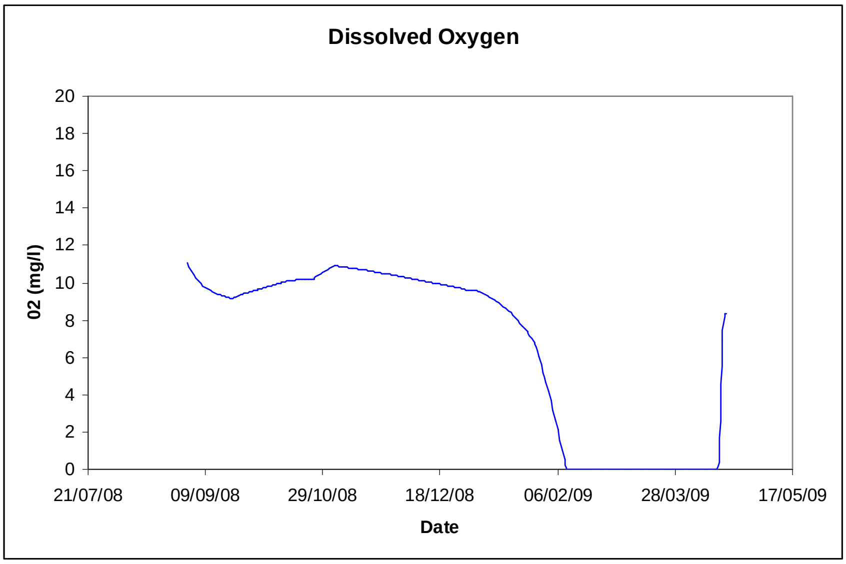

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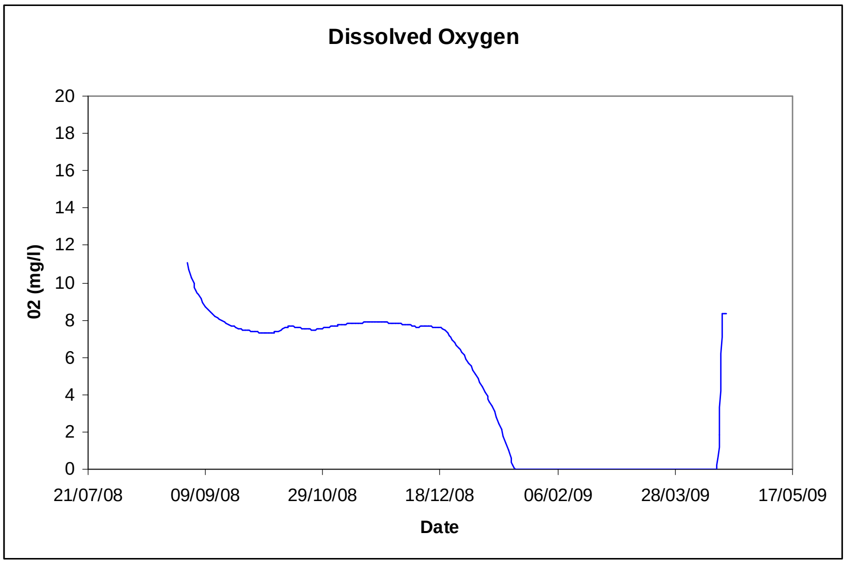
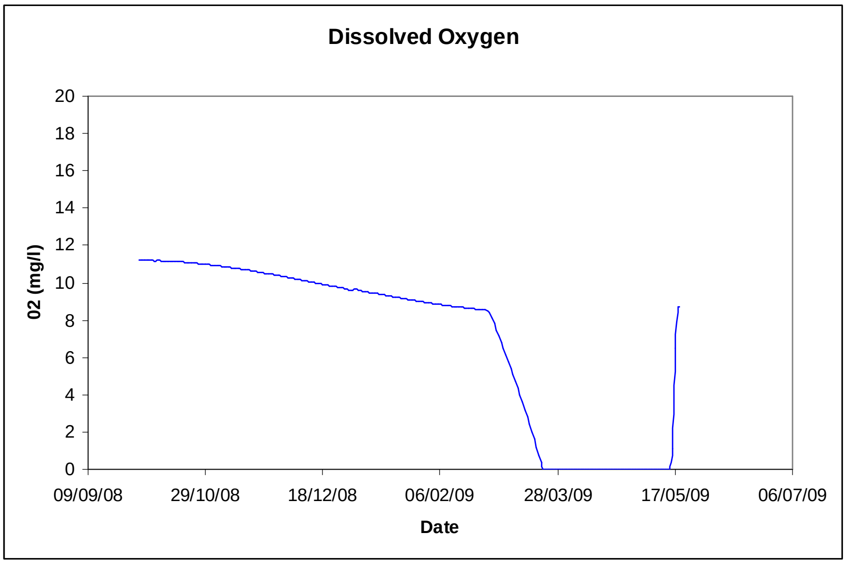
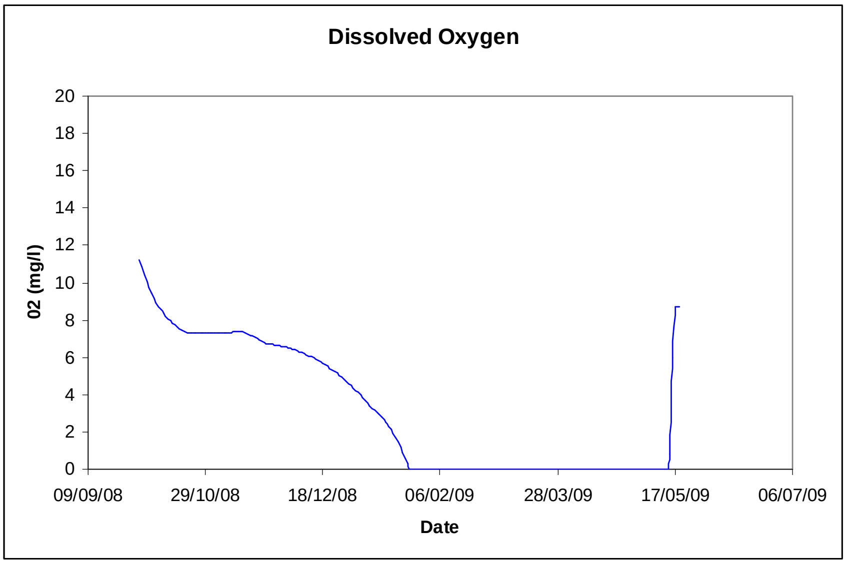


September Flooding, 30 months since previous flood finished



October Flooding, 6 months since previous flood finished



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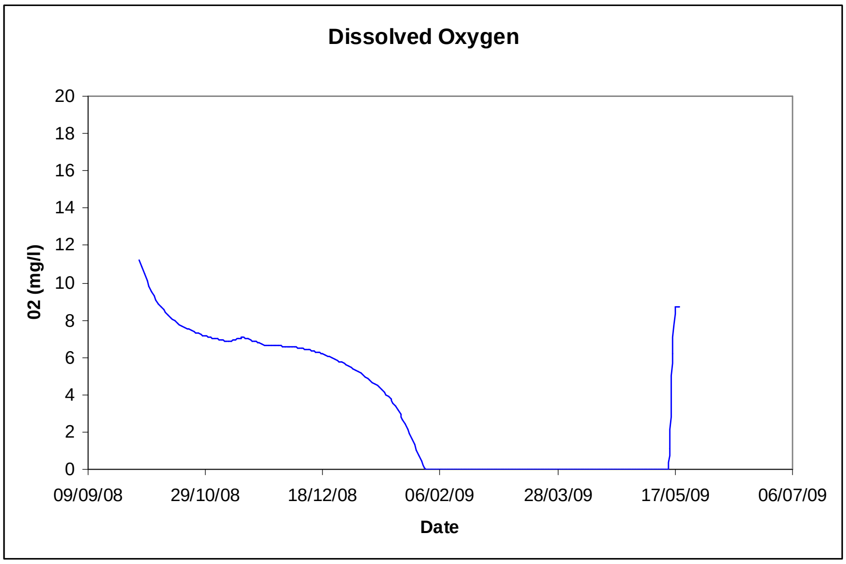

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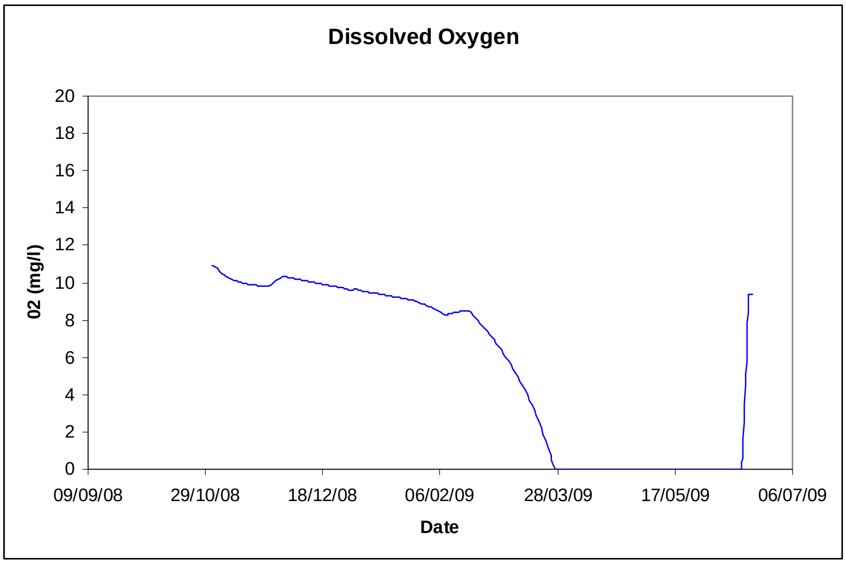

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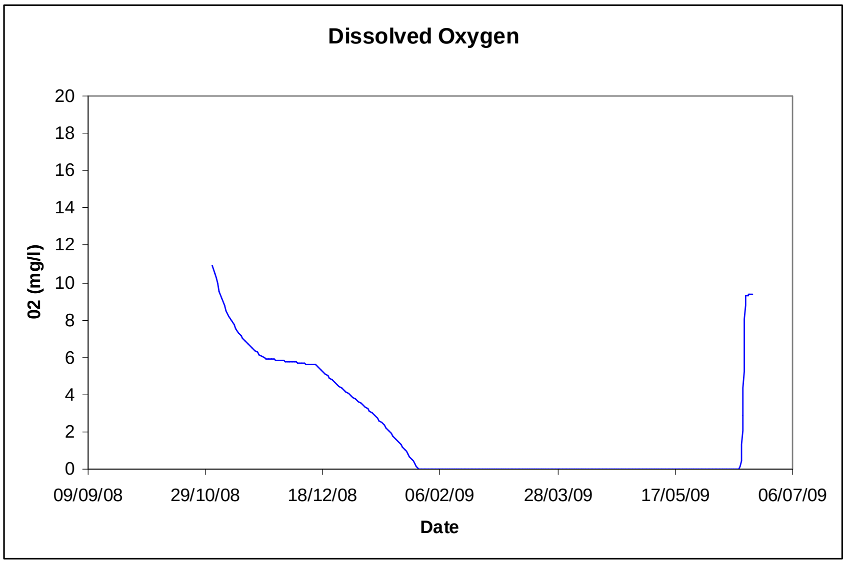

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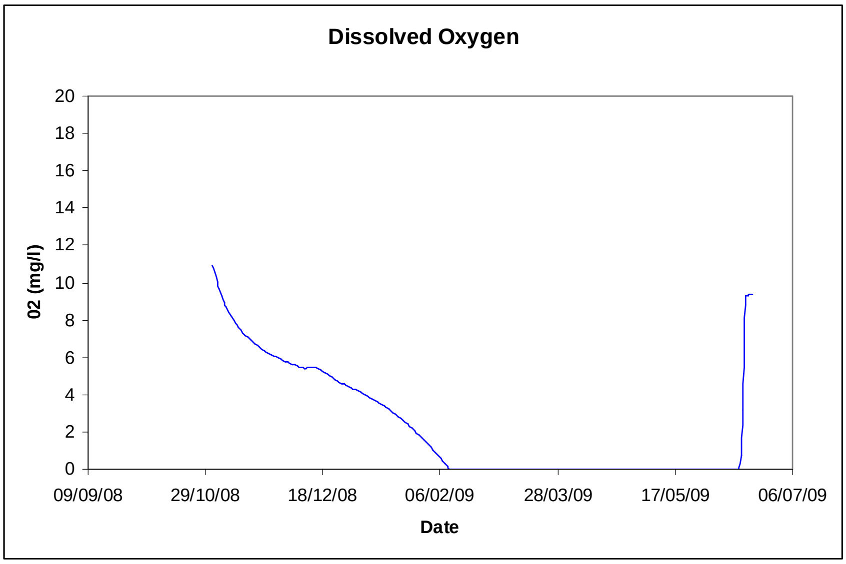

November Flooding, 30 months since previous flood finished

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Document Status

Rev No.	Author	Reviewer		Approved for Issue		
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