Knowledge Needs to Minimise Adverse Water Quality Events in the Edward-Wakool River System.

Darren S. Baldwin

The Murray-Darling Freshwater Research Centre
P.O. Box 991,
Wodonga, VIC 3698

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For further information contact:

Dr Darren Baldwin
Murray-Darling Freshwater Research Centre
PO Box 991, Wodonga, VIC, 3689
Ph (02) 60582300

E-mail: darren.baldwin@csiro.au

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Table of Contents

Introduction:

The Edward-Wakool River System is a complex network of inter-connecting rivers, creeks, flood-runners and artificial channels located north of the Murray River between Tocumwal and downstream of Swan Hill (Figure 1). The flow in the system is highly regulated by a series of control structures located throughout the area.

Flows:

The flows in the system have been changed since European arrival (Green 2001). Naturally, flows in the river system would have been high in spring and very low in summer and autumn (Flow modelling, using the (then) MDBC Monthly Simulation Model for stations on the Edward River at Deniliquin and the Wakool River at Kyalite both show that the flow pattern in the Edward Wakool system has undergone substantial change in both the timing and volume of flows. Under 'natural conditions' the median monthly flows at both sites would have been lower (by up to 70%) during the period January to May, and up to 3-5 times higher in the period June to December, compared to modelled 'current conditions' (Green, 2001; see also Figure 2; reproduced from Green 2001.)

The pattern of river regulation in the system has been altered since the onset of the on-going drought conditions in south-eastern Australia and this has had a marked effect on flows in the Edward-Wakool River System. Figure 3 shows the river height and calculated river flow at Stoney Crossing (towards the lower end of the Wakool River) for the last 30 years. Prior to 1996 a significant (regulated) flow event occurred in the river system on a roughly annual basis. Since 1996, there has only been one significant flow event on the lower Wakool River, in December 2000 - nearly 8 and a half years ago. Previously these large flow events helped to mitigate poor water quality in the lower Wakool River; as well as elsewhere in the system - Green 2001).

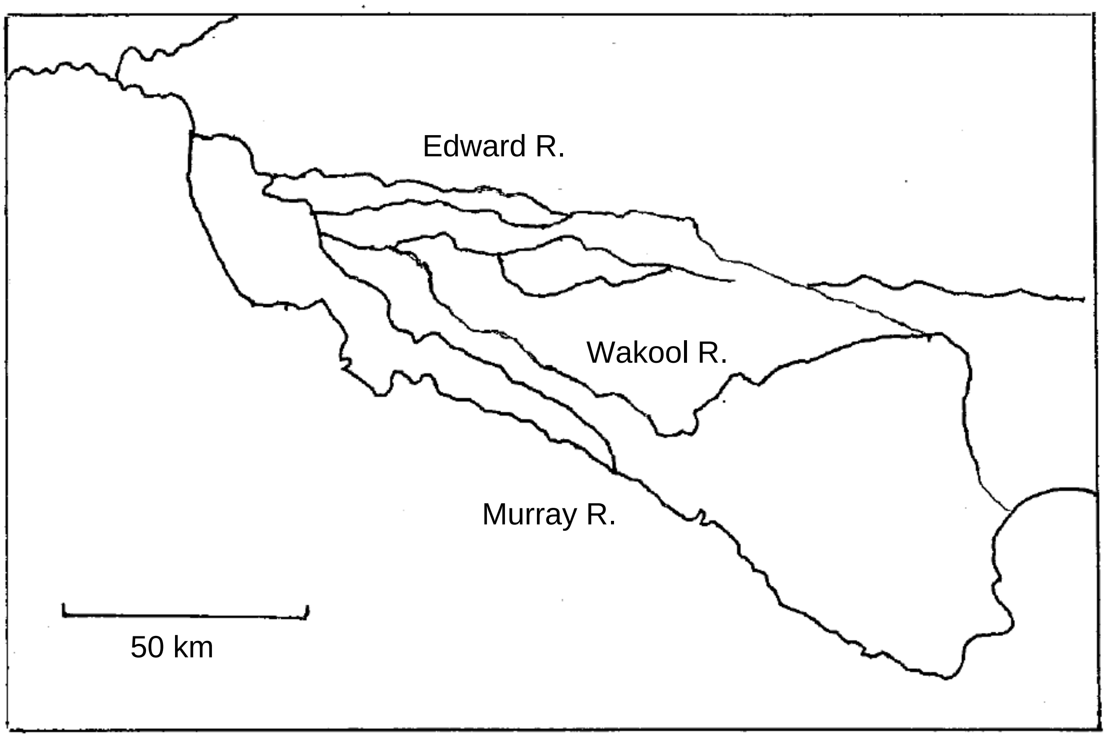

Figure 1. Schematic of the Edward Wakool River System

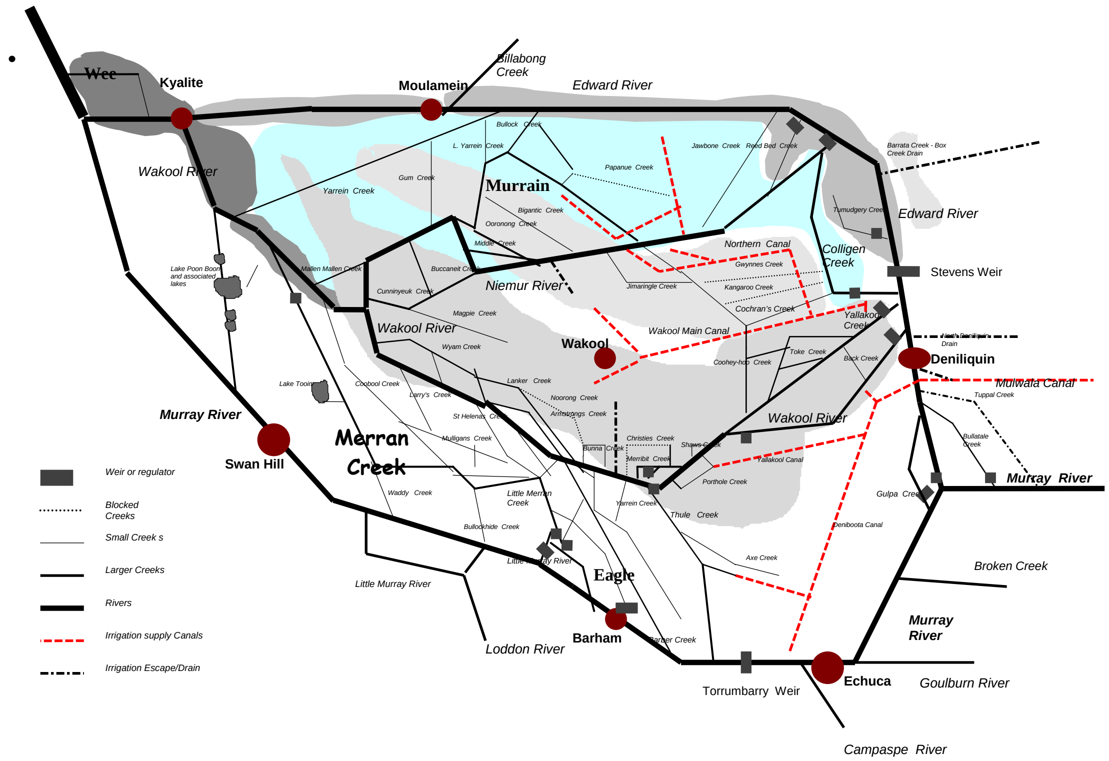

Figure 2 - Schematic of Channel system in the Edward-Wakool River System (from Green 2001Reproduced with permission).

Water Quality:

Traditionally, the Edward-Wakool River System has been thought to have periodic issues with water quality (Green 2001). Salinity in particular has been an issue - especially for channels in the western part of the system. For most of its length the Wakool River is actually the ancestral channel of the Murray River. It is deeply incised, in fact in places it is approximately 9.6 metres deeper than the current Murray River Channel at Swan Hill (Pels, 1968, quoted in Green 2001). This has meant that the river channel intercepts saline groundwater. While this may have happened prior to European settlement, land use change has resulted in groundwater level in the area rising substantially (GHD, 1070, reported in Green 2001). Increasing levels in the water table has resulted in larger areas of the region being affected by salt. A clear example of this increase in salt accumulation is the region is the incidence of dead riparian trees in some parts of the region (Figure 4). Clearly the conditions in the immediate past were conducive for the growth of both red gum and black box in areas adjacent to the watercourses. However, changing conditions, most likely rising saline groundwater, has resulted in the death of trees (Figure 4).

Salinisation has a number of important impacts on aquatic ecology (Nielsen *et al*, 2003). Salt in itself can be toxic to many aquatic organisms; in particular early life stages (see Nielsen *et al*. 2003 and references therein). For example, while the endangered Macquarie perch can withstand salinities of up to about 45,000 EC, there is 100% mortality if eggs are exposed to salt levels of about 6000 EC (O'Brien & Ryan 1997).

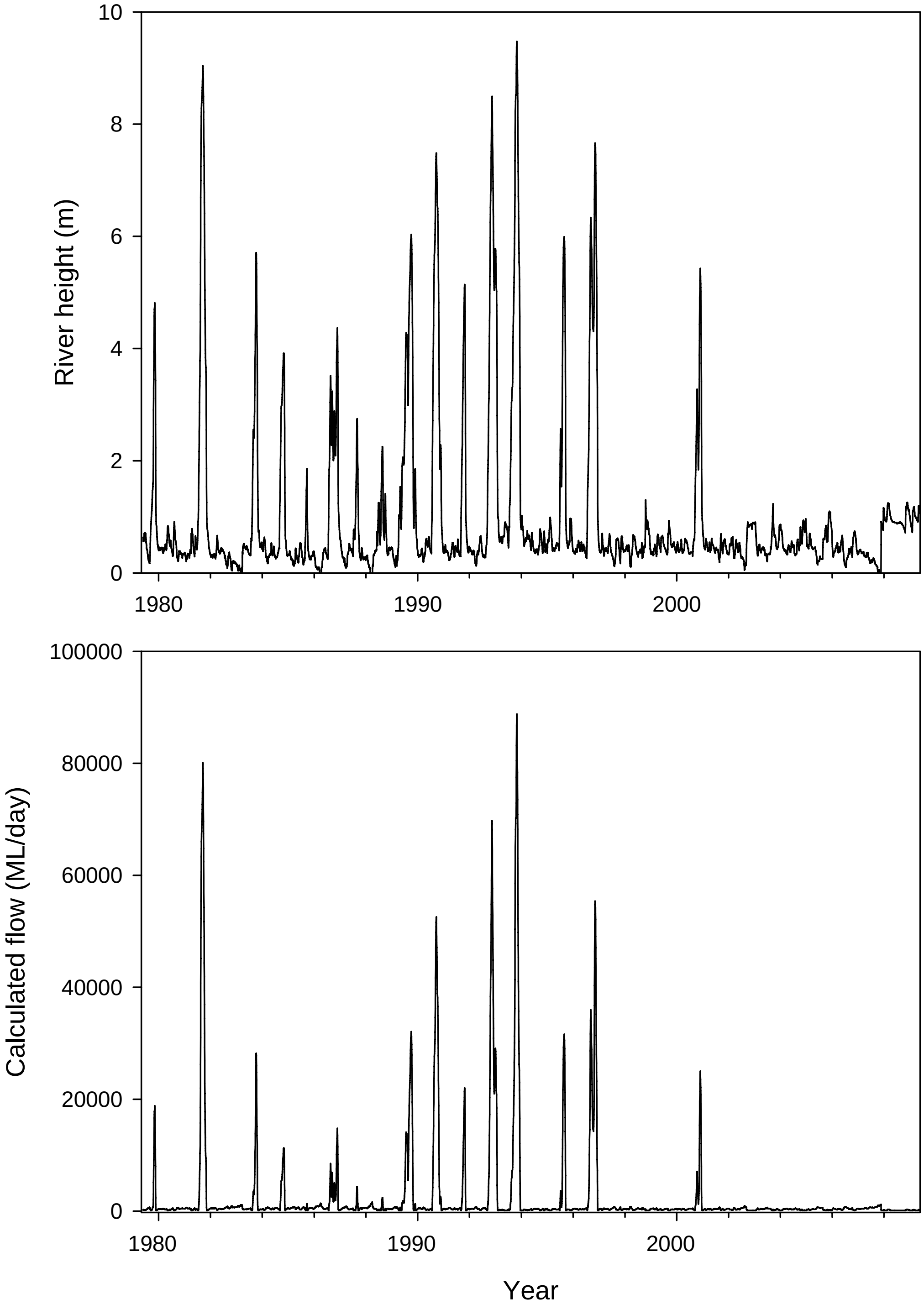

Figure 3 River flows on the Wakool River at Stoney Crossing (1979 - 2009); adapted from NSW water information Site (http://waterinfo.nsw.gov.au/)

Figure 4 - Dead riparian vegetation on the banks of Wyam Creek - August, 2008.

However direct toxicity is only one of a number of impacts of salt. Salt-dependent stratification can occur in freshwater systems following groundwater incursions. Establishment of a salt gradient can reduce mixing and solute transport within aquatic ecosystems. The halocline is a barrier for transport of materials between the surface and bottom strata and has important implications for nutrient and carbon cycling (see later). In particular, it may become a barrier for the movement of oxygen from the surface water to the bottom, causing the rate of oxygen consumption in the bottom waters to exceed the rate of replenishment from the surface, which ultimately leads to anoxia and the death of benthic organisms (Legovic *et al.* 1991). Motile aquatic organisms can't access the anoxic hypolimnion, reducing habitat availability. Furthermore, there can be a build-up of chemical compounds in the bottom water, especially ammonia and sulfides, which are known to be toxic to aquatic organisms (see for example Rees *et al*, 2004). If the halocline breaks down, these chemical can be released to the overlying water - resulting in the deaths of aquatic organisms. The fish kills in the Darling River in 2004 were attributed to a small flow event mixing toxic bottom water with surface water in remanent holes being used as refugia by fish (Ellis and Meredith, 2004). A survey by Vey (Vey, 1980 quoted in Green, 2001) showed that there were 45 holes on the Wakool River between Gee Gee Bridge and Kyalite that had saline bottom water with the majority of the water having salinities greater than 20,000 EC.

An emerging threat caused by increased salt in aquatic ecosystems is the role that salt plays in shifting the balance in the biogeochemical processes that underpin life in these systems. For example, salinisation has been shown to increase the likelihood of nuisance blue-green algal blooms forming by simultaneously increasing water clarity and nutrient release from sediments (see Nielsen *et al* 2003) and references therein. More importantly recent studies have shown that salinisation promotes the formation of sulfidic sediments in inland waterways. The build up of reduced sulfur in the sediments of inland wetlands and creeks (commonly referred to as acid sulfate soils) is an emerging risk for the management of inland waterways (Lamars *et al*., 2001). Traditionally it has been assumed that these materials are confined to the coastal regions, however over the last decade there is increasing evidence that these materials can occur in inland catchments and waterways (Lamars *et al*., 2001; Holmer and Storkholm, 2001; Hall *et al*., 2006). Sulfidic sediments have been observed across the Edward-Wakool River System including in Tuppal Creek (Richardson *et al*, 2005), Jimaringle and Cochran Creeks (Ewington and Mathers 2008), Wyam, Mallan Mallan and Merran Creeks and the Wakool River (Baldwin and Ralph, 2008) Yarrien Lagoon (Emma Wilson, pers. comm)

Sulfidic sediments pose a number of significant risks to the environment. Probably the most dramatic is the risk of acidification. When a sulfidic sediment is exposed to oxygen (oxidised) it undergoes a complex series of reactions that ultimately produces acid; the potential for oxidation is greatest in moist sediments, or sediments in very shallow water. (Lottermoser, 2007) If the amount of acid produced by the oxidation of the reduced sulfur minerals is greater than the system's ability to absorb that acid (the acid neutralising capacity - see later), then the pH of the system falls. Acidic waterholes associated with the oxidation of reduced sulfur species were observed in the Wakool River Channel prior to a stock and domestic flow in January 2008 (Gilligan *et al*, unreleased). One pool immediately upstream of Gee Gee Bridge had a pH of 2.9 before the flow. Fish deaths in the pool were attributed in part to the extreme acidity.

Acidification is not the only environmental risk associated with disturbing sulfidic sediments. Oxidation of sulfidic sediments can also lead to the build up of heavy metals (like cadmium and lead) and metalloids (like arsenic) in the environment (e.g. Burton *et al*., 2008). Furthermore, the oxidation of sulfidic sediments consumes oxygen. In extreme cases this can remove all of the oxygen from the water column, resulting in the death of aquatic organisms. This is most likely to occur when highly reactive forms of reduced sulfur, known as monosulfidic black oozes (MBO's), are physically disturbed and distributed throughout a water column (e.g. Sullivan *et al*., 2002) e.g. as a result of increased flow.

Without careful chemical analysis it is hard to differentiate between deoxygenation events caused by disturbance of sulfidic sediments and those caused by 'blackwater'. Blackwater events occur when flood waters leach carbon compounds from leaf litter laying on the floodplain or dry flood runners/creek channels in much the same way that tea is leached from tea leaves. Microbes can immediately use about one-third of the carbon leached from the leaf litter (Baldwin 1999). As the microorganisms consume the dissolved carbon they use up oxygen in the water - often at a rate faster than the oxygen can be replenished. Therefore, blackwater plumes often have very low levels of dissolved oxygen. The lack of dissolved oxygen can cause the death of fish and other aquatic animals in the plume. There were at least two fish kills in the Edward-Wakool River System in the summer of 2009. Both were attributed to deoxygenation events (Baldwin and Whitworth 2009). Both fish kills occurred following 'Stock and Domestic' flows down the respective creek systems. The fish deaths on the Colligen Creek were most probably due solely to blackwater. At the flow front, the water quality was very poor. The water temperature was approximately 30 ^{0}C, the dissolved oxygen level was less than about 0.5 mg/L and the water was dark in colour. Filtration of the water showed that all the colour was dissolved rather than particulate. Conversely while there is no doubt that 'blackwater' contributed to the fish death on the Merrin Creek, an earlier report (Baldwin and Ralph, 2008) suggested that high levels of reduced sulfur in the sediments of the Merrin creek (sulfidic sediments - caused by secondary salinisation of the creek) could lead to deoxygenation if the material was disturbed.

Workshop:

A series of fish deaths in the Edward-Wakool River System during the summer and autumn of 2009 has highlighted the need to understand the linkages between hydrology, hydrogeology and water quality to minimise adverse water quality events into the future. This is especially important as flows into the system are likely to be changed into the future as a direct result of both climate change and the subsequent competing requirements for the reduced water resource.

In order to begin to asses the knowledge needed to underpin ecologically defensible flows in the Edward-Wakool system in the future, the first of a series of workshops was convened by the Murray-Darling Freshwater

Research Centre on 20th May 2009. The first workshop was directed specifically towards Agencies with a direct interest in the delivery of either water and/or ecological outcomes in the region. A second workshop is planned to specifically target landholders and other community groups with an interest in the system. Participants in the first workshop were from the following Agencies:

- NSW Department of Water and Energy
- NSW Department of Environment and Climate Change
- NSW Department of Primary Industries (Fisheries Branch)
- Murray Catchment Management Authority
- State Water
- NSW Murray-Wetlands Working Group
- Murray-Darling Basin Authority
- Murray Irrigation Limited.

In addition there were representatives from:

- Murray-Darling Freshwater Research Centre
- Southern Cross University and,
- An independent river expert.

The outcomes from the workshop outlined in the following report do not necessarily reflect the views of individuals or organisations who participated in the workshop.

Workshop Outputs

Context

It is not possible to define the knowledge needs necessary for determining ecologically sensible flow rules in the Edward-Wakool system without placing such decisions within the following context:

1. *The system is highly modified*. Both the hydrology and hydrogeology of the system has been highly altered through river regulation and changes in land use. Communities have developed in and around these modified conditions. It is not feasible to suggest that the system be returned to a condition approaching pre European conditions.
2. *Conditions are not uniform across the whole syste*m. The ecological condition varies across the Edward Wakool system. There are different stressors in different parts of the system. Therefore, it is not possible to generalise overall condition from a select few sites. This also requires a whole of system approach.
3. *Historical legacy*. The current condition of the Edward-Wakool River System is in part a legacy of policy decisions (both State and Federal) made at least 60 years ago.
4. *Previous condition*. Although there have been water quality issues in the past, mostly associated with salinisation, historically the Edward-Wakool System has been considered to be in good ecological condition, especially in terms of its native fish community.
5. *Water quality issues are not caused at a local scale*. The poor water quality observed in the Edward-Wakool System has not been caused by the actions of individual landholders - even if examples of poor water quality (e.g. sulfidic sediments in wetlands) are observed on individual properties. Rather the current problems are a result of changes in land use and hydrologic regime at the regional and catchment scale.
6. *Drought*. The current water quality issues observed in the Edward-Wakool River System are a manifestation of the current drought

conditions. In particular, the loss of periodic flushes, either natural, or as a result of large regulated flows, has allowed the build up of material in the system, which when disturbed, can result in environmental harm.

7. *Connectivity*. The Edward-Wakool System can not be considered in isolation. Water flows and incoming water quality reflects conditions in the greater Murray River Catchment upstream (including the Billabong Creek Catchment to the north east and the Kiewa, Ovens, Goulburn and Campaspe River Catchments to the south east). Similarly, contaminants mobilised from within the Edward-Wakool System have the potential to impact on the Murray River downstream of the Murray-Wakool Junction.
8. *Legislative and policy complexit*y. Flow decisions in the Edward Wakool system exist in a complex, and potentially contradictory, legislative and policy framework; both at the state and federal level.
9. *Community engagement*. Landholders and other interested members of the community were seen as integral part of any long-term solution to water-quality issues in the system. Individually and collectively they have a knowledge of the system, that while it may differ from a reductionist scientific ways of knowing, is equally valid in addressing complex problems using 'post-normal scientific enquiry' (Funtowicz and Ravetz, 1991).

Identified Knowledge Needs:

1. Immediate Requirements:

Given current rainfall predictions and upstream storage levels, it is highly probable that water managers will be faced with the same issues in the coming summer as in the summer of 2008/09 - i.e. a need to deliver water for critical human needs without causing adverse effects to the aquatic environment; without the luxury of large volumes of water to dilute any adverse water quality effects.

In the absence of the knowledge necessary to develop robust, environmentally sensible flow rules, in the short-term, the most cost- and time-effective approach would be to convene an expert panel to review the available data and make recommendations on how best to deliver flows. It is recognised that this is only a short-term solution and in no way should it detract from a more detailed assessment of the issues facing the region. It would be anticipated that the panel consists of one or more people with the following expertise:

- Drivers of water quality in riverine systems
- Water flow and management in the Edward-Wakool system
- State and Federal Water Policy
- Impacts of poor water quality on aquatic ecology
- Fish biology

2. Condition Assessment

2.1 Review and synthesis of current knowledge:

The workshop clearly identified the need to collate and synthesise any available information that is currently available on water quality, hydrology and hydrogeology in the Edward Wakool System as a whole, including the minor creeks and irrigation channels[1]. This initial synthesis would include (but not be limited to):

- Summarising previous review articles. Green (2001) has produced an excellent synthesis of past and current hydrology and its role in

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[1] An additional review or collation of current knowledge on the physiological thresholds of fish (e.g. dissolved oxygen, temperature, tannins, pH, salinity) and the factors contributing to fish deaths was also flagged as an important knowledge need.

mobilising salt. Bogoda *et al* (1995) have summarised the hydrogeology of the system. However, neither article includes the impact of the on-going drought conditions in the region.

- Reviewing and documenting any relevant literature not covered in previous reviews.
- Accessing and interpreting unpublished data sets and research studies that can shed light on the past and current condition of the river system.
- Accessing any historical (e.g. newspaper articles) or anecdotal information on previous incidents of poor water quality resulting in adverse environmental outcomes. This could include surveying local community members on their understanding of the past and current condition of the system.
- Documenting agreed water quality parameters which, if exceeded, would result in environmental harm - especially fish kills.

This review and synthesis would serve as an objective benchmark on which to base any future management decisions. Ideally this task would be completed before the formation of the expert panel (discussed above). However, given the tight timelines associated with determining flow regimes for the 2009/10, this may not be possible.

2.2 Assessment of current ecological condition.

Prior studies (e.g. the Sustainable Rivers Audit) and anecdotal information would suggest that the Edward Wakool System was in generally good condition notwithstanding periods of poor water. However more recent studies would indicate a worsening of the ecological condition (e.g. MDFRC presentation to the workshop, unpublished). Therefore it is important to determine the current ecological condition of the system. This would serve as a reference point to gauge the effectiveness or otherwise of interventions in an adaptive management framework. Three indicators of ecological condition are proposed - riparian vegetation, fish communities and macro-invertebrate community structure.

Riparian Vegetation:

Anecdotal evidence suggests that riparian vegetation condition (particularly red gum and black box) is in decline (Figure 4). This is more noticeable in the western zone of the system. There is a need to quantify the riparian vegetation condition throughout the system in order to establish a quantative baseline to assess future changes. While there are a number of well documented protocols for assessing riparian vegetation condition (e.g. Baldwin *et al*.), emerging techniques, like assessing genetic variability of communities) should also be considered.

Fish Community:

The fish/aquatic invertebrate community in the Wakool system is recognised to be part of the Endangered Ecological Community listed under the provisions of the *Fisheries Management Act (NSW).* Several fish species within the system are also listed as threatened under the *Fisheries Management Act* including silver perch. Murray cod and silver perch are also listed as threatened under the provisions of the *Environment Protection and Biodiversity Conservation Act (Cwth)*. Sampling has indicated that the fish community in the Wakool system is generally in better condition than elsewhere within the Murray catchment.

NSW DPI the Sustainable Rivers Audit and MDFRC (in conjunction with MIL) have, or are currently undertaking, fish surveys in the region. There is an immediate need to collate this information to identify current fish community structure and identify those parts of the system that currently aren't being investigated. Ideally, a uniform assessment protocol should be developed and sites across the system be identified to undertake a full assessment of the fish community structure.

However, fish community structure was not the only knowledge need identified. The importance of the resident community to the rest of the Murray-Darling Basin was identified as important. Particularly the question of whether or not fish are currently recruiting in the system, or does the system rely on immigrants to sustain the fish population. There are also questions on the genetic diversity of fish populations in the Edward-Wakool system, and whether they are unique populations, or reflect the diversity across the basin. In particular is the question of whether or not fish populations have adapted to poor water quality that has historically occurred in the region.

Identification of the factors that contribute to effective refuges in remnant pools (e.g. complex habitat structure, aquatic vegetation, water quality) was also identified as an important knowledge gap, which if filled, could help guide future watering regimes for the river system.

Macroinvertebrates:

Macroinvertebrates have been used as indicators of ecological condition in Australian waterways for a long time. Although there are a number of questions over their appropriateness as indicators in all situations, nevertheless, their ubiquity in most assessments of aquatic ecological condition, means that they be used in any current assessment of the Edward-Wakool system.

2.3. Assessment of current hazards:

The workshop identified a number of factors that could contribute to poor water quality and lead to fish deaths, these include:

- Increased carbon loading in channels; leading to blackwater events when these channels receive water.
- Zones of poor water quality (high salinity, low dissolved oxygen and potentially high levels of dissolved toxicants like sulfide, ammonia and metals and metalloids) at the bottom of deep pools. If disturbed by flows, this water can mix with surface waters and potentially lead to fish deaths.
- Sulfidic sediments (including monosulfidic black oozes- MBO's) which if mismanaged (either through desiccation or remobilisation) can lead to acidification, deoxygenation and mobilisation of metals and metalloids.
- Rising ground water of indeterminate water quality intercepting with surface water and plant root zones
- Increased risk of eutrophication[2], from a variety of sources including the release of nutrients from dry channels on rewetting (the Birch effect - e.g. Wilson and Baldwin 2008 and references therein), anoxic release of phosphorus and ammonia from sediments in deep residual pools (e.g.) or nutrient releases from disturbing MBO's.

In the first instance it is critical that each of these hazards is mapped across the whole of the Edward Wakool system. Critical knowledge needs include quantifying:

- The standing stock of carbon (including invading riparian vegetation biomass) in dry river channels and its ability to be mobilised during flow events
- The standing stock of sulfidic and sulphuric sediments, MBO's and ancillary sediment properties in river and creek channels and floodplain wetlands in the system.

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[2] Although the blue-green algal bloom that occurred in the Edwards River in autumn 2009 was probably washed into the system from upstream.

- The distribution and quality of hypolimnetic water in the deep holes in the main river channels.
- The distribution and ionic composition[3] of groundwater.
- Sources of nutrients to the system.

Some of these issues are currently being explored, at least in part, through a variety of projects (e.g. MDBA 2009). However a whole of system approach using agreed methods needs to be undertaken.

3. Developing Predictive Capacity.

3.1 Knowledge needs to create predictive models

The quantification of hazards is an important step in the effective management of flows in the Edward-Wakool System as it underpins the development of a capacity to predict future water quality outcomes based on flow events. However in order to develop robust predictive capacity linking hydrology and water quality, there are another set of knowledge needs that needs to be addressed.

Blackwater:

A process based model already exists which predicts water quality (dissolved oxygen and dissolved organic carbon) in the Edward River based on flood characteristics in the Barmah and Milawa Forests (Howitt *et al* 2007). Because it is a process based model, it could be adapted to predict blackwater events in river channels in the Edward Wakool System. However, before it could be adapted it would necessary to determine:

- The rate of leaf litter accumulation in various areas of the Edward-Wakool system. This includes both the rate of litter input as well as the rate of litter breakdown.

[3] Composition of groundwater can be used to predict, amongst other things, the risk of acidification if sulfidic sediments are formed (Whitworth *et al*., unpublished). Composition also plays an important role in determining the toxicity of salt solutions.

- Rate of vegetation growth in exposed channels.
- Leaching and bioavailability of carbon from sources other than river red gums.
- Channel characteristics throughout the system.

Sulfidic sediments:

Probably the two most important issues arising from the mismanagement of sulfidic sediments in the Edward-Wakool System are acidification and deoxygenation.

Acidification occurs when sulfidic sediments are exposed to air and, the amount of acid that subsequently is produced, is greater than the buffering capacity of the sediments and overlying water. Many of the parameters necessary to predict the rate of acidification should have already been determined in the condition assessment project. However, to link acidification potential with hydrology it would also be necessary to know:

- The rate of oxidation of reduced sediment and,
- The rate of accumulation of reduced sulfur in the system.

This later data is particularly important to predict the amount of accumulation of sulfidic sediments between major flow events.

Deoxygenation occurs when sulfidic sediments (especially MBO's) are mobilised into the water column. Therefore, in addition to the knowledge needs necessary to predict acidification, it is also necessary to know the relationship between sediment scouring (mobilisation) and flow in different parts of the river.

Disturbance of hypolimetic water in deep holes:

In the deeper holes along the Wakool , at very low flows low EC surface water moves across the more dense saline hypolimnion, with little entrainment of bottom water (Sharp and Herat, 1989).   Intermediate flow events can break down stratification in deep holes releasing water of poor quality into surface water (Green, 2001). Because there isn't sufficient dilution, the surface water can become unsuitable for aquatic organisms resulting in deaths. At very high flows, dilution would mitigate any adverse effects of mixing surface and bottom waters. Based on empirical observation Green (2001) suggests that flows greater than about 400 ML/day are necessary to break down the halocline in the smaller holes on the Wakool, while flows of up to 1600 ML/day are required to completely breakdown stratification in the deeper hole.   It would be valuable to couple these observations with hydrodynamic mixing models (e.g. Sharp and Heart, 1989) in order to better define the flow thresholds that minimise the impact of disturbance of hypolimetic water.

3.2 Testing the models

The overall management objective is the need to link flows with water quality outcomes. This can be achieved through a variety of approaches which each, in the broadest sense, based on models:

- The expert panel approach is a best-guess based on previous experience but is underpinned by a conceptual model of how the system works
- The condition assessment approach formalises the conceptual model and allows semi-quantative (back-of the envelope) predictions based on observed loads.
- The predictive modelling approach creates a formal mathematical relationship between flow and water quality.

Each approach will produce outcomes of varying accuracy. However, notwithstanding, the model used, each should be tested within an adaptive management framework (see for example Baldwin *et al*, 2005). To do so would require the implementation of a monitoring strategy for each managed flow event.

As a suggestion, a suite of water quality parameters should be measured at a number of sites throughout the system. The number of sites will depend in part on available resources, but should reflect the variability inherent across the system[4]. At a minimum there should be continuous measurements of flow, EC, pH temperature and dissolved oxygen at the surface and bottom at, at least two sites on the Wakool, Edward, and Neimur Rivers and any other channel where flows are managed. If possible, these data would be complemented by the collection of routine flow weighted water samples (using autosamplers) for analysis for dissolved carbon, nutrients and sulfur species.

The data collected could be used to refine each of the models to better advise on appropriate flow strategies.

Resources and Co-ordination

This report has identified a number of important knowledge needs necessary for the management of water-quality in the Edward-Wakool System. The costs of achieving the desired outcomes are not trivial, and probably would reach several million dollars, if the work is to be done properly. It is improbable that this would be funded by a single organisation at one point in time; nor the work done by a single organisation. Rather, it is more likely that the work would be funded and carried out as discrete blocks, by different research providers. To be useful, this second approach requires a single entity, or agreed consortia, to oversee the work. This is to ensure that there is

[4] Noting that there are already a number of sites already monitored for some parameters on the Edwards and Wakool Rivers..

no replication of effort and, that any data collected can be applied to the overall objective of the study.

To this end it is recommended that a working group of relevant stakeholders is formed to oversee the accumulation of knowledge needs for the development of sustainable flows in the Edward-Wakool System. The group would act as an advocate for research needs in the area and identify suitable opportunities for the generation of critical knowledge needs.

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