Understanding the relationship between stream flows, dissolved oxygen and native fish in the lower Yarra River

Yarra River Focus Catchment Summary Report

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Contents

1 Introduction .................................................................................................................1
  1.1 The Yarra River catchment .........................................................................................1
  1.2 Recent catchment pressure .........................................................................................1
  1.3 Focus catchment project .........................................................................................3

2 Approach ..................................................................................................................4
  2.1 Modelling of hydrology and dissolved oxygen .........................................................4
  2.2 Long-term water quality at Chandler Highway ........................................................5
  2.3 Stratification and dissolved oxygen .........................................................................5
  2.4 Native fish movement ............................................................................................7

3 Key findings .............................................................................................................9
  3.1 Modelling of hydrology and dissolved oxygen .........................................................9
  3.2 Long-term water quality at Chandler Highway ........................................................14
  3.3 Stratification and dissolved oxygen .......................................................................18
  3.4 Native fish movement ...........................................................................................21

4 Conclusion .............................................................................................................26

5 Full technical reports ............................................................................................28
1 Introduction

1.1 The Yarra River catchment

The Yarra River catchment covers an area of approximately 4,000 km² and extends north and east of Melbourne on the southern slopes of the Great Diving Range (Figure 1). The upper reaches of the Yarra River flow through forested, mountainous areas, while the middle and lower reaches, from Yering Gorge (near Yarra Glen) to Dights Falls (Kew), flow through the Yarra Valley district and Melbourne’s eastern suburbs until the river finally discharges into Port Phillip near Melbourne’s CBD.

Today around 20% of the Yarra catchment is forested, 60% is rural and 20% is urban. Home to nearly 2 million people (around 1/3 of Victoria’s population), the Yarra catchment also incorporates extensive reaches of parklands that are popular for a range of recreation activities, including boating and fishing. A large variety of aquatic life inhabits the river, including several native fish species, frogs, water birds and platypus.

Total annual stream flow volumes can vary greatly in the Yarra River, from over 1000 GL in a wet year to less than 200 GL in a dry year. Flows in the Yarra River (and many of its tributaries) are highly regulated, with numerous farm dams and several major water storages to meet urban and agricultural water demands. Water is extracted via weirs as well as a 1000 ML/d pumping station in the mid Yarra (Yering Gorge Pumping Station).

1.2 Recent catchment pressure

As has occurred in many parts of Australia, the state of Victoria has recently experienced a severe drought for over 10 years. The drought has led to an increase in competing water use to meet the demands of urban and agricultural activities as well as the need to protect the environmental health of the Yarra River.

As a consequence of persisting drought conditions, long-term stream flow and water quality monitoring in the lower Yarra River indicates a steady decline in both stream flows and dissolved oxygen. For example, there have been several instances of very low dissolved oxygen (DO) concentrations (i.e. <4 mg/L) in the middle and lower reaches of the river (Figure 2). There also appears to be a significant increase in the variability of DO concentrations in later years (see Figure 10).

The downward trend in DO, especially the formation of anoxic conditions in deep pools during summer, was considered a major risk to the ecological health of the Yarra River. There was particular concern for the impact on nationally threatened species such as the Macquarie perch (*Macquaria australasica*), Murray cod (*Maccullochella peelii peelii*) and Australian grayling (*Prototroctes maraena*).

In October 2006, the Victorian Government declared the Yarra Environmental Entitlement that included a 17 GL share of reservoir inflows and storage space and minimum passing flows at various points e.g. 200 ML/d below the Yering pumping station in summer and 350ML/day in winter. This was to reflect the Yarra River environmental flow...
recommendations in comparison to the historical all year requirement of 245ML/day at Yering pumping station. However, in response to rapidly deteriorating storage levels during the drought, the Minister for Water declared a water shortage in April 2007 and deferred the Environmental Entitlement. In October 2007, a further ‘qualification of rights’ by the Minister reduced the minimum passing flows at Yering from the historical requirement of 245 ML/day to 200 ML/day ‘cease to pump level’ all year. In this qualification releases were made to maintain 150 ML/day if inflows to storages were sufficient in comparison to 245ML/day that was maintained at Yering historically. Provision of minimum passing flows at Yering were re-instated to 200 ML/day in July 2010 and in October of the same year, the qualification of rights were removed and minimum passing flows at Yering were re-instated to 200 ML/day in summer and 350ML/day in winter (for both ‘cease to pump level’ as well as releases to maintain passing flow requirements).

Figure 1: Yarra River Catchment indicating monitoring sites, reservoirs, streams and broad land use classes.
1.3 Focus catchment project

eWater CRC and partner organisations with an interest in the health of the Yarra River commenced the Yarra Application Project in 2008. The purpose of the project was to investigate the relationships between stream flows, dissolved oxygen (DO), water temperature and the behavioral responses of native fish.

An understanding of the circumstances in which low DO events can develop will assist decisions about water extraction and environmental flow regimes to protect the environmental health of the river.

Specifically, the objectives of the project were to:

- Generate a hydrological time series for DO modeling in the Yarra River using eWater’s Source modeling software.
- From field measurements determine correlations between flow, DO and temperature and how native fish (Macquarie perch and short finned eels) respond to changing DO conditions and other environmental factors.
- Use water quality-stream flow relationships to establish trigger levels that could guide stream flow management in the Yarra River.

Modelling using Source was undertaken to predict the hydrological behavior of the Yarra catchment and help derive flow-water quality relationships. The Source model of the Yarra also enabled scenario testing to explore implications of various management interventions and future threats e.g. water extraction regimes, urban expansion, and climate change.

The Yarra River project is one of a number of projects across south eastern Australia that tested the applicability of new eWater software to ‘real world’ situations. A mixture of researchers, consultants, natural resource managers all had active involvement in setting the project direction and undertaking research.

Figure 2: Decreasing trend in minimum daily dissolved oxygen concentration plotted against monthly flow in the Yarra River at Chandler Highway (1998-2008).
2 Approach

Relationships between stream flows, water quality and native fish behavior were determined by analyses of historical hydrologic and water quality data, as well as analyses of contemporary data collected for this project.

There is a lack of information on the prevalence and effects of low DO conditions on fish and other biota in the Yarra River. Rather than rely solely on the occurrence of concentrations known to be lethal to fish, the aim of the study was to monitor fish behavior and habitat use to detect potential sub-lethal responses to changing conditions that might act as an early warning indicator for management.

New data collected during this project included the measurement of water quality at various depths at key locations and continuous tracking of native fish movements and behaviours over extended periods. Further details on methods and results from various components of this project can be found in the technical reports listed in the references section of this summary report.

2.1 Modelling of hydrology and dissolved oxygen

Source is a water quality and quantity modeling framework that supports decision-making on a whole-of-catchment scale. The model structure operates as a node-link network and gives access to a collection of models, data and knowledge that simulate the effects of climatic characteristics (e.g. rainfall and evaporation) and catchment characteristics (e.g. land use or vegetation cover) on runoff and contaminant loads from unregulated catchments. Source can operate at a daily time step and can be used to predict the flow and load of constituents at any location in the catchment over time.

The most recent available data was used to construct the Source model, and a modeling period of 32 years was chosen (June 1978-2009) to represent both wet and dry periods.

QUASAR (QUAlity Simulation Along River systems) is a non-commercial product (available from www.ceh.ac.uk) that models transport and transformation of solutes, including dissolved oxygen, along rivers. Using simple flow and load addition equations at the start of a reach, QUASAR is capable of modelling DO on large branched river systems with multiple influences such as effluent discharges, abstractions and weirs. At the end of a reach the results are stored and then used as the upstream influence on the next reach. QUASAR has a temporal constraint where the maximum duration of a single run is one year.

The QUASAR software was applied to model Dissolved Oxygen (DO) within two reaches of the Yarra River: 1) Chandler Reach (from Chandler Highway, Kew to Dights Falls, Abbotsford) and 2) Banksia Reach (from Fitzsimons Lane, Templestowe to Banksia Street, Heidelberg.

Using the Source hydrologic time series and QUASAR DO modeling, various scenarios were run to assess their impact on DO in the lower Yarra River. Hydrological time series scenarios for input into the DO model were:
### Scenario Description

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base Case (current flow conditions) Calibrated Model</td>
</tr>
<tr>
<td>2a</td>
<td>No Diversions No Yering Pumping, No diversions</td>
</tr>
<tr>
<td>2b</td>
<td>No Yering Pumping No Yering Pumping, but with full diversions</td>
</tr>
<tr>
<td>2c</td>
<td>Increased Environmental Flow Minimum flow upstream of Yering before pumping starts set to 500 ML/d</td>
</tr>
<tr>
<td>3a</td>
<td>Climate Change 2030 Rainfall and PET from CSIRO GCM model</td>
</tr>
<tr>
<td>3b</td>
<td>Climate Change 2060 Rainfall and PET from CSIRO GCM model</td>
</tr>
</tbody>
</table>

#### 2.2 Long-term water quality at Chandler Highway

Continuous (6-minute intervals) surface water measurements of DO and temperature, as well as stream flow data, collected by Melbourne Water in the Yarra River at Chandler Highway (229143A) were analysed for:

- Historical DO trends
- The relationship between stream flow and DO
- The relationship between water temperature and DO
- The possibility of forecasting low DO events 10 days in advance

After a thorough data quality check, the period from May 1998 to November 2008 was chosen for these analyses. Continuous stream flow and water quality data were aggregated from 6-minute to daily. For stream flows and temperature, the average value for each day was used, however given the interest in low DO concentrations, minimum daily DO values were used.

#### 2.3 Stratification and dissolved oxygen

The development of stratification and subsequently low DO (hypoxia <40% saturation) in the lower Yarra River, was investigated through the use of in-situ water quality loggers and spot measurements at different depths (depth profiles) at key locations.

Specific questions being asked by this component of the project were:

- What reaches of the Yarra are affected by stratification and low DO?
- At what time of year does stratification and low DO develop?
- What are the main drivers of stratification and low DO?
- How quickly do these conditions develop?
- What flow is required to de-stratify the water column?
- What minimum base flow is likely to provide protection from stratification?

Initially, a longitudinal survey of water quality in the lower Yarra River was conducted in November 2008 at 27 sites between Yering Gorge and Dights Falls. At these sites, DO and
water temperature were measured at depth intervals of 0.5 metres or near the bottom, middle and top of the water column. An additional 99 spot depth measurements were also recorded. Based on habitat characteristics and water quality, the longitudinal survey identified four reaches to be the focus of further investigations:

- Downstream of Henley Golf Course to Lower Homestead Road
- Downstream of Fitzsimmons Lane to Porter Street
- Ivanhoe Public Golf Course to Chandler Highway
- Chandler Highway to Dights Falls
During 2009 and summer 2010, a total of 61 water quality depth profiles were measured at 20 sites, including when data loggers were deployed or retrieved. Variables recorded by the data loggers using a multi parameter probe were water depth, temperature, DO (both % saturation, mg/L), electrical conductivity (EC) at 25°C, pH and turbidity. The depth interval of measurements was 0.5 metres (shallow sites <=3m) or 1 metre (deep sites > 3 metres). Water quality data loggers were usually deployed at the surface (about 20 – 30 cm depth) and at the bottom (about 20 cm above the bottom) of the water column. The main site for logger deployment was Yarra Bend Park (Site 1) in the Chandler Highway to Dights Falls reach. This site is approximately 500 metres upstream of Dights Falls and has a maximum water depth of 6-7 metres under low flow conditions. Loggers were deployed at this site on seven occasions from February 2009 to February 2010. Deployment periods at this site varied from 48 hours to three weeks. Because of its depth and most downstream location, this site was considered the ‘worst case’ location in terms of stratification and low dissolved oxygen.

The next site upstream used for logger deployment was upstream of Kew Main Drain (Site 5). This site is about 6-7 km upstream of the Yarra Bend Park site and about 2 km upstream of Chandler Highway. It also represents the upstream extent of the weir pool behind Dights Falls. Maximum water depth is around five metres under low flow conditions. A total of three logger deployments were made at this site in February 2009 and February 2010.

Further upstream in the reach through Heidelberg, data loggers were set at three sites (Sites 16, 17 and 19) on five occasions. These three sites were within the reach used for the fish tracking component of this study. This reach is shallow with a maximum depth of 1.5 to 2 metres.

The most upstream location where data loggers were set was at Lower Homestead Road (Site 8) within the Henley Golf Course to Lower Homestead Road reach. This site was upstream of Warrandyte and downstream of Yering Gorge, and had the greatest variation in depth with several deep pools (up to 7 metres deep) and riffles. At this location there was one logger deployment of 48 hours in March 2009.

2.4 Native fish movement

This project focused on two native fish species, namely Macquarie perch (*Macquaria australasica*) and short finned eel (*Anguilla australis*) – see Appendix A. Along a 3 km reach of the Yarra River at Heidelberg, fish movements were tracked using a high-density array of acoustic telemetry stations.

The key variables monitored during the study were:

- Use of the water column (depth relative to patterns of DO stratification)
- Macro-habitat use (riffles, runs and pools in response to DO and flow)
- Longitudinal movement (larger-scale movement responses to flow)

A total of 25 Macquarie perch and 17 short-finned eels were collected in August-September 2009 and tagged with depth and activity sensing acoustic transmitters. Twenty-four acoustic logging stations were installed at 100-200 m intervals within the study reach. As the logging stations can detect and record information from transmitters at a range of 200 m or more, the
array of listening stations provided almost full coverage of the study reach. Additional logging stations were positioned 0.5 and 2 km upstream and approximately 10 km downstream of the study reach.
3 Key findings

3.1 Modelling of hydrology and dissolved oxygen

Total predicted stream flow volumes by the Source model of the Yarra River were within 10% of observed flow volumes for 5 of the 9 calibration gauges (e.g. Figure 3). Two of the other calibration gauges were within 20% and two were within 40% of observed flow volumes. Weaker calibrations at these four gauges related mostly to data quality and gauge resolution during low flows, therefore calibration of these sites focused on improving medium event flow predictions. Coefficient of efficiency values (E), which are a measure of the correlation between measured and modeled data, ranged from 0.40 – 0.69 for daily (E_{daily}) predicted and observed values. The monthly correlation (E_{monthly}) was generally higher than the daily data (e.g. Table 1).

A recurring problem during the calibration of tributary gauges (as well as some of the main stream gauges) was the availability of reliable low flow data. Most Melbourne Water flow gauging stations were installed for flood warning systems and therefore, do not require high resolution at low flows. However, given that the focus of this project was on the main stem of the Yarra River, maximising the E value in the tributaries was not considered critical.

An initial comparison of daily predicted and observed flows in the model highlighted that there was a flow lag in the runoff routing through the main stretch of the river. A lag of one day applied upstream of the Yering Gorge pumping station significantly improved the daily predicted and observed flow comparisons.

![Figure 3: Typical cross verification daily hydrograph on the Yarra River](image-url)
Table 1: Summary calibration results for stream flow gauges used as inputs for the ‘Base Scenario’ in the QUASAR DO model.

<table>
<thead>
<tr>
<th>Gauge</th>
<th>Location</th>
<th>Nash Sutcliffe Criteria (E_{daily})</th>
<th>Nash Sutcliffe Criteria (E_{monthly})</th>
<th>Predicted/Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>229142</td>
<td>Yarra River at Fitzsimons Lane</td>
<td>0.54</td>
<td>0.87</td>
<td>0.95</td>
</tr>
<tr>
<td>229143</td>
<td>Yarra River at Chandler Highway</td>
<td>0.69</td>
<td>0.89</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Scenarios run in Source to produce a flow time-series for input into the QUASAR DO model are summarized below and Figure 4:

- **Scenario 2a – No diversions and No Yering Pumping**
  Compared to the base scenario the total average annual runoff increased by 33% for the dry (2006) year and 34% for the average (2004) year.

- **Scenario 2b – No Yering Pumping**
  Total average annual runoff is only marginally less than that of Scenario 2a, with an increase of 29% for the dry year and 25% greater for the average year compared to the base case. This suggests that diversions in the Yarra system have less of an impact on flows in the lower reaches of the Yarra River than pumping at Yering.

- **Scenario 2c – Increased Environmental Flow**
  Increasing the minimum environmental flow is notably greater in dry years with an increase in total average annual runoff of 17% compared to a 4% increase for the average year.

- **Scenario 3a,b– Climate Change 2030 & 2060**
  Total average annual runoff was reduced significantly for the two climate change scenarios due to decreased rainfall. The dry year yielded a decrease of 25% and 35% compared to the base scenario for the 2030 and 2060 climate change, while the average year showed a decrease of 35% and 46%, respectively.
Figure 4: Modelled total annual stream flow in the Yarra River at Chandler Highway during a dry (2006) and average year (2004) for base conditions and scenarios 2a-No diversions and no Yering pumping, 2b-No Yering pumping, 2c-Increased environmental flow ,3a-Climate change 2030 ,3b-Climate change 2060.
DO modelling results for Chandler and Banksia reaches are presented as time series, exceedance plots and spells plots during a typical wet year, dry year, average rainfall year and current year (e.g. Figures 5-7 show time series, exceedance and spells plots for an average rainfall year, and Figure 8 a spells plot for a dry year, in the Chandler reach).

All years modelled indicate that DO is lower during the warmer months and higher during the cooler months. Seasonal variation is lowest in the wet year (1996). The dry year (2006) and ‘current’ year (2008), have the longest durations of low DO. This suggests that stream flow has a strong influence on DO as well as seasonal influences. There was little variation between the altered flow scenarios (particularly at the Banksia site) although, the base case had lower DO and more frequent low DO periods.

Results of the DO modeling under climate change scenarios typically show lower DO than the base case (Scenario 1) and altered flow regime scenarios (Scenarios 2a-c). Hence, climate (dry versus average or wet conditions) and climate change are predicted to have the greatest impact on DO via reductions in flow that translate to longer periods and increased frequency of low DO (Figures 5-8).
Figure 6: Chandler DO exceedance plot for an average flow year, 2004

Figure 7: Chandler DO spell durations of less than 6mg/L for an average flow year, 2004

Figure 8: Chandler DO spell durations of less than 6mg/L for a dry year, 2006
3.2 Long-term water quality at Chandler Highway

Extremely dry conditions that resulted in very low flows in the Yarra River are apparent in 1997, 2002, 2006, 2007 and 2008 (Figure 9). As well as seasonal changes in DO and general downward trend in concentrations, an increase in the variance of DO concentrations over time was also evident (Figure 10). In addition, there were distinct declines in DO in the summer of 2004/05 and 2007/08.

During the 10-year data period (1998-2008), there was a total of 104 days where the minimum daily DO at Chandler Highway was equal to or below 4 mg/L, 271 days when it was below 5 mg/L and 542 days when it dropped below 6 mg/L. Most low DO events occurred from 2004 onwards and the variability in minimum daily DO increased by 75% in a step change that occurred around July 2004.

There is a trend of decreasing daily minimum DO of 0.24 mg/L per year. This trend has resulted in the average daily minimum DO decreasing from about 9 mg/L to about 6 mg/L between 1998 and 2008. During this time, low DO events rarely occurred when the average daily water temperature was less than 16°C i.e. about 47% of days (Figure 11). Above 16°C the relationship between average minimum DO and temperature is less evident.

Grouping flows from low to high shows that low DO is more likely when flow is less than 300 ML/d (Figure 12), and when a Generalized Additive Model (GAM) is used to smooth the data (Figure 13), 300 ML/d is a break point. For flows less than 300 ML/d a relationship between flow and DO is apparent, while for larger flows, DO and flow seem to be independent.

These results suggest that increasing the minimum flow at Chandler Highway to 300 ML/d, is likely to increase DO (i.e. about 2 mg/L increase for every 100 ML/d increase in flow below 300 ML/d). There is no evidence that increasing flow beyond 300 ML/d will further increase DO at Chandler Highway (although a higher base flow may improve water quality further downstream in the Dights Falls Weir pool – see ‘Stratification and Dissolved Oxygen’ section). Given variability in the flow-DO relationship, the response to increased flow on any particular occasion is uncertain. Instead, it can be said that increasing the average daily minimum flow at Chandler Highway to 300 ML/d when the water temperature is greater than 16°C will decrease the risk of low DO events.

Extremely low DO events (DO < 2 mg/L) are of concern because they pose a heightened threat to ecological assets within this reach of the Yarra River. The majority of events where DO is less than 2 mg/L have all occurred when the water temperature is greater than 20°C and the flow is less than 300 ML/d. Under these conditions, increasing the flow to 300 ML/d is likely to result in improved DO. Some DO events less than 2 mg/L have occurred when the flow is higher, although not many in comparison to when flow is < 300 ML/d.
Figure 9: Average daily stream flows in the Yarra River at Chandler Highway (1975-2010)

Figure 10: Minimum daily DO in the Yarra River at Chandler Highway (1998-2008)
Figure 11: Average daily temperature for the Yarra River at Chandler Highway. Periods of DO less than 6 mg/L are highlighted in red.

Figure 12: Relationship between average daily flow by flow groups and minimum daily DO in the Yarra River at Chandler Highway (1998-2008).
There was a period in the summer of 2004-2005 where high flows appear to be associated with low DO (Figure 14). In November 2004, high flows occurred across much of Victoria – recording the highest November rainfalls since 1992. There were also record high rainfalls in February 2005, including the highest flood levels in the Yarra River since 1934. It is possible that high levels of organic matter in runoff (especially urban stormwater, given much of the heavy rain fell in urban parts of the catchment) may have increased Biological Oxygen Demand, leading to low DO in the Yarra River at Chandler Highway a few days after the high flows. This is another possible mechanism that could cause low DO events, but the available data suggests this is a rare occurrence, with only two examples in the 10-year record assessed by this project.
Analyses undertaken during this project suggest that most low DO events are related to low flow and high water temperature. Using either a logistic regression or tree-based prediction approach, it is possible to forecast 10 days in advance the probability of a low DO event occurring e.g. probability that it will be below 5 mg/L (Figure 15). Determination of an appropriate threshold probability to trigger action will depend on the cost of action and the losses incurred if action is not undertaken and an event occurs.

If the 10-day forecast of a low DO event is a high probability, one possible mitigation action could be to increase flows in the lower Yarra River. Even though all analyses suggest that as flows increase, the probability of a low DO event decreases, the effect of a feasible intervention is small. If we assume it is feasible to temporarily increase flows by about 100 ML/d from about 250 ML/d to about 350 ML/d, it is likely to decrease the probability of a low DO event by only 2% to 3%.

Temperature has a much greater effect on the likelihood of a low DO event in 10 days time. A two degree decrease in temperature can decrease the probability of a low DO event by 10% or more, depending on the other variables. It seems likely that a deliberate increase in flow could also decrease temperature if water was released from an upstream dam or aquifer with a lower water temperature. For example, releasing water into the Yarra River from the aqueduct at Yering may result in a greater change in water temperature than the same releases from Maroondah, but further work is required given data variability for flow and temperature at Chandler Highway.

![Figure 15: Contour plot showing the probability of a low DO event (<5mg/L) in the Yarra River in ten days time given flow and water temperature and a starting DO concentration of 5 mg/L](image)

3.3 Stratification and dissolved oxygen

Stratification and low DO (<40% saturation) were observed during the months of November to March 2009, and mainly in the reach downstream of the Chandler Highway to Dights Falls where the river is deeper (up to 7 metres at low flows) and flows are slower – encompassing
the weir pool behind Dights Falls. At the Chandler Highway, stratification was never observed to occur. About 2 kilometres upstream of Chandler Highway near the Kew Main Drain (Site 5), the river deepens to a maximum depth of 5 metres. This area is close to the upstream extent of the Dights Falls weir pool. Weak stratification and mild hypoxia in the bottom levels was observed at this site on only two occasions (January and February 2009). The lowest DO concentration measured in this reach was 40% saturation at 5 metres on 28th January 2009.

Stratification or hypoxia was never observed in the reach above Heidelberg to Fitzsimmons Lane (Templestowe). This reach is generally shallow, particularly around Heidelberg (usually less than 2 metres) where fish tracking was undertaken. Further upstream near Lower Homestead Road upstream of Warrandyte, there are many deep pools and shallow runs and riffles. Site 8 in this reach had a maximum depth of 7 metres and stratification was observed there on two occasions (January and March 2009). On January 2009, hypoxia was observed with DO dropping to 10% saturation within 1 metre of the bottom, although generally the water column was well oxygenated. The greater extent of riffles and rapids may be increasing aeration of surface water in this reach.

Across all study reaches, temperature differences between the top and bottom waters appear to be the primary driver of stratification. Large differences between top and bottom water temperature (generally 5-7°C) were observed during stratified conditions. A distinct decline in DO levels at the depth at which electrical conductivity was observed to increase may be indicating the depth of downward mixing of the water column at night.

DO levels in the bottom of stratified waters were measured as low as 0.4% saturation. After the onset of stratification, bottom DO levels were observed to decline rapidly in a linear fashion over several days. Deoxygenated water was often observed to extend upwards to quite close to the surface during hot periods with extended low flows. For example, profile measurements for January 2009 for sites 1, 2 and 3 indicate that near zero DO occurs within 2.5 to 3 metres of the surface and at site 1 the DO at 1 metre was only 40% saturated and at the same time DO was 70% saturation at the surface. Again in February 2009 the DO at 1 metre at site 1 was only 39% saturated and 70% at the surface, and in February 2010 the DO at site 1 at one metre was only 30% saturated, 120% at the surface, and near zero at 3 metres. It is clear that during stratified conditions a considerable proportion of the water column can experience very low DO.

There were a few instances where a linear decline in bottom DO was observed after the onset of stratified conditions. For the Yarra River at Yarra Bend Park, the average rate of decline of the bottom DO (measured over six discrete declines on two separate logging runs) was -12%/day with a range of -7% to -18%/day. Such estimates enable a prediction of the amount of time it would take for bottom waters to reach critical DO thresholds – depending upon the initial bottom DO concentration at the onset of stratification. At the other sites (Sites 5 and 8) there was one occasion for each when a similar DO depletion rate could be estimated and for both sites this was about -20%/day.

As well as concern for low DO when the river stratifies, there is also concern when the river subsequently de-stratifies. On occasions when the river de-stratified and mixed, very low DO levels (<30% saturation) occurred throughout the entire water column. This mixing was observed after flow events or when the surface waters cooled at night to the temperature of the bottom waters (e.g. February 2010 at site 1 has examples of both types of mixing events causing low DO levels – see Figure 16). DO levels of <30% saturation throughout the water column would be likely to stress a number of organisms requiring oxygen for respiration, and
would also be expected to distribute sulphides and other toxicants throughout the water column.

In addition, during stratified conditions when the bottom waters may have very low DO or near zero, the surface waters can experience very high oxygen levels during the daytime (up to 180% saturation). Elevated DO such as this, indicate high rates of primary productivity in the surface layer.

Figure 16: Continuous water quality data logger measurements in the Yarra River at Yarra Bend Park, 3-24 February 2010.

Figure 17: Continuous water quality data logger measurements in the Yarra River at Yarra Bend Park, 13-23 November 2009.

The onset of stratification (indicated by a divergence in DO concentrations between the surface and bottom waters) following higher flows was observed on three occasions at the Yarra Bend Park site. The flows that were followed by the onset of stratification at the Yarra Bend Park site were 450 ML/d (14th February 2010), 476 ML/d (20th September 2009) and 550 ML/d (1th November 2009). The onset of stratification during these flows also coincided
with times when there was only a small difference in water temperature between the surface and bottom (<1°C). In all three instances surface water temperatures were rising rapidly and flows were decreasing steadily.

An example of flow conditions where persistent stratification was observed is the logging run from the 13th to 23rd Nov 2009 at Yarra Bend (Figure 17). There was an eight day period of very stable stratification when flow was around 300 to 310 ML/day. The temperature difference between the top and bottom was large with the minimum surface temperatures, at night, getting no closer than about 5-6 degrees of the bottom temperature which is quite cool at 18°C. A small flow pulse of about 425 ML/day had no discernible effect upon the state of mixing of the water column, although the large event around the 22nd November 2009 clearly resulted in greater mixing of surface and bottom waters. Another period when persistent stratification occurred at this site was from 23-25 February 2009 when flows were 160 to 180 ML/day.

It is difficult to be confident about identifying the minimum flow increase that ensures de-stratification of the water column – given the limited number of events recorded during the study. On 30/10/2009 at Yarra Bend Park, flows increased rapidly from about 200 ML/day to a brief peak of 1150 ML/day. This sudden change in flow resulted in a rapid and complete mixing of a strongly stratified water column and was the smallest flow pulse observed to do so during this project. Flow pulses that peaked briefly at 426 and 630 ML/day at Yarra Bend Park did not de-stratify a strongly stratified water column. However in the instance of the 630 ML/day event, it would appear that some upward mixing of anoxic water occurred as the DO at the surface plunged briefly to 23% saturation suggesting that the water body did at least partially de-stratify (i.e. but not down to the depth of the bottom logging probe).

It is possible that if the flow peak was broader or if there had been a smaller temperature difference between top and bottom instead of a large temperature difference that the water body may have de-stratified during a smaller flow peak than 1150 ML/d. At this stage it can only be said that the minimum size flow pulse that would de-stratify the Yarra River at Yarra Bend Park would be somewhere between 630 and 1150 ML/day (but probably closer to 630 ML/d). Importantly, although large flows around 1150 ML/d were able to de-stratify the water column, these flows provided only a very temporary change with stratification rapidly reforming in the following days.

3.4 Native fish movement

The period when native fish movements in the Yarra River at Heidelberg were tracked (2009/10) coincided with a much wetter summer than previous years. During that period, base flows rarely reached the minimum threshold below Yering of 150 ML/day. Nevertheless, there were several short periods during which low DO concentrations occurred with temperatures sufficiently high to act as a potential stress to fish (Figure 18).

In total, over 2.7 million fish ‘detections’ were recorded during the study. This led to a relatively complex process of data summary and analysis. Preliminary data analysis shows that individuals of each species exhibited distinct diel patterns in their activity (Figure 19, Figure 20) and use of depth (Figure 21, Figure 22).

Periods of high flow appear to be associated with the use of deeper habitats, but further work is required to differentiate the effects of increased water depth associated with higher flows from potential behavioural responses e.g. seeking shelter behind submerged structures.
Both fish species tended to have restricted home ranges that were usually less than 600 metres (Figure 23, Figure 24). Larger-scale movements occurred more frequently during periods of high flow (mostly 1-2 km but a small number greater than 5 km). Large movements by eels and Macquarie perch occurred during periods of peak migration and spawning, respectively. Further analysis is required to reveal whether periods of heightened movement were also associated with aggregation of individual fish in particular spawning areas.

In regards to the aims of the study, initial examination of the data suggests that an increased proportion of fish congregated below oxygenated riffle habitats during periods of relatively low DO (3-4 mg L\(^{-1}\)). This suggests a macro-habitat shift by some fish in response to DO depletion, although further analyses are required to test this preliminary observation.

Figure 18: Flow, DO and temperature time series from the Yarra River at Chandler Highway for the period over which fish were monitored
Figure 19: Diel activity patterns for Short-finned eels during the study period (commencing August 13th).

Figure 20: Diel activity patterns for Macquarie Perch during the study period (commencing August 13th).
Figure 21: Diel depths for Short-finned eels during the study period (commencing August 13th). Note the overlay of hydrology (green line inverted) to indicate the influence of flow and increased stage on depths that may possibly explain the apparent use of deeper water rather than a shift in habitat use.

Figure 22: Diel depths for Macquarie perch during the study period (commencing August 13th). Note the overlay of hydrology (green line inverted) to indicate the influence of flow and increased stage on depths that may possibly explain the apparent use of deeper water rather than a shift in habitat use.
Figure 23: Average home range distance (m) of Short-finned eels during the study period. Peak migration period is highlighted.

Figure 24: Average home range distance (m) of Macquarie perch during the study period. Peak spawning period is highlighted.
Conclusion

A primary objective of this project was to build a whole-of-catchment Source model for the Yarra River. The model will be used to help inform the revision of environmental flow thresholds, as well as determining when and how to augment flow in the river to reduce the likelihood of low dissolved oxygen events and associated ecological impacts. As part of this assessment process, hydrological time series from various scenarios using the Source model were input into a QASAR DO model for the river.

The Yarra River Source model produced good calibrations for the main stem of the river, with predicted runoff volumes in the focus area of the lower Yarra River within 5% of the observed flow. Improvements in gauged data from many of the tributaries are needed to improve calibrations at low flows. Refined modeling of the Yering Gorge pumping station operations is also expected to improve model performance.

DO modelling using the hydrologic time series generated by Source, has shown that climate (i.e. dry versus average and wet years) has more influence on DO concentrations in the lower Yarra River rather than the specific demand scenarios applied in this project. Climate change was predicted to have an impact on flow which in turn, is expected to lead to more frequent and longer periods of low DO. These predictions should be interpreted in the context of the limitations of the hydrologic and water quality models developed e.g. parameter values used, calibration during low flows.

Stratification in the lower Yarra River is largely a summer, low flow phenomenon – with flow, temperature and water depth being the main factors influencing the likelihood of stratification. It is clear that maintaining the lower reaches of the Yarra River in a mixed condition would maintain elevated DO levels, but would also require higher flows to achieve mixed conditions (see below).

Analyses of long-term data from Chandler Highway suggests that the risk of low DO events occurring in the lower Yarra River could be reduced by increasing the minimum average daily flow at Chandler Highway to 300 ML/d when the average daily water temperature is greater than 16°C. It has also been demonstrated that it is possible to forecast the probability of a low DO event occurring 10 days in advance. Once suitable thresholds for action are determined, the proposed forecasting methods could provide a useful stream flow management tool.

Further downstream in the Dights Falls weir pool, data from the lower Yarra River adjacent to Yarra Bend Park indicates that stratification can develop at flows in the range of 450 to 550 ML/day and that flow events greater than 630 ML/day are needed to reverse stratification. Similar to Chandler Highway, thresholds for Yarra Bend Park are probably lower under cooler weather conditions e.g. de-stratification was apparent at 220 ML/day when night time cooling was sufficient to mix surface and bottom waters. Further investigations may be able refine these thresholds.
Based on this study, a flow of 550 ML/day at Yarra Bend Park is likely to maintain the lower reaches of the river in a well mixed condition. It is recommended the minimum base flows for the lower reaches are reviewed considering this information. Differences in thresholds for Chandler Highway and Yarra Bend Park may relate to differences in reach characteristics, especially water depths and velocities as a result of the ponding of water at the Yarra Bend site behind the Dights Falls weir.

Periods of very low DO events did not occur during the native fish tracking period, limiting the strength of conclusions regarding the influence of hypoxia upon fish behaviour. Nonetheless, preliminary findings, together with other findings from the project, provide an insight into the potential threats posed by low DO in the Yarra River and its relation to flow and other water quality indicators, as well as providing valuable information on life history and behavioral responses to flow and other environmental factors.
5 Full technical reports

This report summarises the follow technical reports developed for the eWater Yarra River Application project:


Appendix A

MACQUARIE PERCH

Translocated self-supporting populations of Macquarie perch (*Macquaria australasica*) occur within the Yarra River, typically having a home range of approximately 1km. Abundance and distribution of the species has decreased with the construction of dams and changes to the flow regimes, leading to listing as endangered under the federal EPBC Act 1999 and Victorian Flora and Fauna Guarantee Act 1988.

Macquarie perch typically spawn between October and November amongst stones and gravel in riffle areas with females producing up to 32,000 eggs per kg of fish. Hatching of eggs takes between 13-18 days when water is between 11-18 degrees Celsius. Males typically reach maturation at 2yrs, whilst females attain maturation at approximately 3yrs. The species feeds predominantly on insects, as well as crustaceans and molluscs.

The largest threats facing the Macquarie perch include interactions with introduced fish species, habitat degradation and alterations to natural flow regimes.

SHORT FINNED EEL

The short finned eel (*Anguilla australis*) is found across eastern Australia, in still waters such as lakes and dams, as well as low flowing streams and rivers. Mature eels are known to travel thousands of kilometres from fresh waters to the salt waters of the Coral Sea off the Nth Coast of Queensland to spawn. Mature females can reach a length of 1m, and can hold more than 3 million eggs. Once spawning is complete it is believed that the eels die. The eel larvae are then carried south by the East Australian Current to the continental shelf where they migrate to estuaries and then upstream into freshwater. Eels are known to live for more than 35yrs, although migration typically occurs at 6-15 years of age.

Eels are opportunistic carnivores and are tolerant of a wide range of water temperatures, salinities and oxygen levels.