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# Commonwealth Environmental Water Office Long Term Intervention Monitoring Project Goulburn River Selected Area evaluation report 2014-15

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**Final Report** 

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## Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project – Goulburn River Selected Area evaluation report 2014-15

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## **Table of Contents**

| Execu | utive Summary   | 1  |
|-------|---|----|
| 1.    | Introduction  | 2  |
| 1.1   | Lower Goulburn River selected area                                      | 2  |
| 1.2   | Environmental values and flow regulation of the lower Goulburn River    | 5  |
| 1.3   | Overview of Commonwealth environmental watering                         | 5  |
| 1.3.1 | What type of watering is proposed?                                      | 6  |
| 1.3.2 | What are the expected watering outcomes?                                | 6  |
| 1.3.3 | Practicalities of watering  | 6  |
| 1.4   | Environmental water delivered in 2014-15 and context                    | 7  |
| 2.    | Overview of monitoring undertaken in 2014-15                            | 9  |
| 3.    | Physical habitat and bank erosion                                       | 10 |
| 3.1   | Evaluation  | 10 |
| 3.1.1 | Area specific evaluation questions                                      | 10 |
| 3.2   | Main findings from physical habitat and bank erosion monitoring program | 11 |
| 4.    | Stream metabolism   | 14 |
| 4.1   | Evaluation  | 14 |
| 4.1.1 | Basin-scale evaluation questions  | 14 |
| 4.1.2 | Area specific evaluation questions                                      | 15 |
| 4.2   | Main findings from stream metabolism monitoring program                 | 15 |
| 5.    | Macroinvertebrates  | 16 |
| 5.1   | Evaluation  | 16 |
| 5.1.1 | Area specific evaluation questions                                      | 16 |
| 5.2   | Main findings from macroinvertebrate monitoring program                 | 17 |
| 6.    | Vegetation diversity  | 20 |
| 6.1   | Evaluation  | 20 |
| 6.1.1 | Basin-scale evaluation questions  | 20 |
| 6.1.2 | Area specific evaluation questions                                      | 20 |
| 6.2   | Main findings from vegetation monitoring program                        | 21 |
| 7.    | Fish  | 22 |
| 7.1   | Evaluation  | 22 |
| 7.1.1 | Basin-scale evaluation questions  | 22 |
| 7.1.2 | Area specific evaluation questions                                      | 22 |
| 7.2   | Main findings from fish monitoring program                              | 24 |
| 8.    | Adaptive management   | 26 |
| 9.    | Stakeholder communications  | 27 |
| 9.1   | Media Releases and Articles   | 27 |
| 9.2   | Social Media  | 27 |
| 9.3   | Fact sheets   | 27 |
| 9.4   | Videos  | 27 |
| 9.5   | Radio   | 27 |

| 9.6     | Presentations   | 27 |
|---------|---|----|
| 10.     | References cited  | 29 |
|         |   |    |
| Apper   | ndix A. Hydrology and Hydraulics methods  | 32 |
| A.1     | Introduction  | 32 |
| A.2     | What hydrological data have been used for the analysis?   | 32 |
| Apper   | ndix B. Detailed results for Physical habitat and Bank erosion  | 34 |
| B.1     | Introduction  | 34 |
| B.2     | How are environmental flows expected to affect physical habitat and bank erosion in the lower Goulburn River and specific evaluation questions? | 34 |
| B.2.1   | Basin-scale evaluation questions  | 34 |
| B.2.2   | Area-specific evaluation questions  | 35 |
| B.3     | Monitoring methods  | 37 |
| B.3.1   | Hydraulic habitat   | 37 |
| B.3.2   | Bank condition  |    |
| B.4     | Results   | 40 |
| B.4.1   | Relevant flow components delivered to the lower Goulburn River in 2014-15   | 40 |
| B.4.2   | 2D Hydraulic model – example results  | 40 |
| B.4.2.  | 1 Detail of setup   | 40 |
| B.4.2.2 | 2 Example outputs   | 42 |
| B.4.3   | Bank condition results, observations and analysis   | 45 |
| B.5     | Discussion  | 46 |
| B.6     | Conclusion  | 50 |
| Apper   | ndix C. Detailed results for Stream metabolism  | 51 |
| C.1     | Background  | 51 |
| C.2     | Methods   | 52 |
| C.3     | Results   | 52 |
| C.4     | Discussion  | 58 |
| C.5     | Preliminary Bayesian analysis of metabolism data  | 59 |
| C.5.1   | Statistical results   | 60 |
| C.5.2   | Discussion of statistical analysis results  | 60 |
| Apper   | ndix D. Detailed results for Macroinvertebrates   | 65 |
| D.1     | Introduction  | 65 |
| D.2     | How are environmental flows expected to affect macroinvertebrate communities in the lower Goulburn River and specific evaluation questions?     | 65 |
| D.2.1   | Basin-scale evaluation questions  | 65 |
| D.2.2   | Area-specific evaluation questions  | 65 |
| D.3     | Monitoring methods  | 66 |
| D.4     | Results   | 67 |
| D.4.1   | Relevant flow components delivered to the lower Goulburn River in 2014-15   | 67 |
| D.4.2   | Monitoring results and observations   | 67 |

| D.5   | Discussion  | 79  |
|-------|---|-----|
| D.5.1 | Effects of environmental flows on macroinvertebrates  | 79  |
| D.5.2 | Assessment issues and future monitoring   | 80  |
| D.6   | Conclusion  | 81  |
| Apper | ndix E. Detailed results for Vegetation   | 82  |
| E.1   | Introduction  | 82  |
| E.2   | How are environmental flows expected to affect riparian and aquatic vegetation in the lower Goulburn River and specific evaluation questions? | 82  |
| E.2.1 | Basin-scale evaluation questions  | 82  |
| E.2.2 | Area-specific evaluation questions  | 82  |
| E.3   | Monitoring methods  | 83  |
| E.3.1 | Sampling  | 83  |
| E.4   | Results   | 84  |
| E.4.1 | Relevant flow components delivered to the lower Goulburn River in 2014-15   | 84  |
| E.4.2 | Monitoring results and observations   | 84  |
| E.5   | Discussion  | 88  |
| E.5.1 | Monitoring evaluation   | 88  |
| E.6   | Conclusion  | 89  |
| E.7   | Adaptive management of flow:  | 89  |
| Apper | ndix F. Detailed results for Fish   | 91  |
| F.1   | Introduction  | 91  |
| F.1.1 | Annual adult fish surveys   | 91  |
| F.1.2 | Larval fish surveys   | 91  |
| F.1.3 | Fish movement   | 92  |
| F.2   | How are environmental flows expected to affect native fish communities in the lower Goulburn River and specific evaluation questions?         | 92  |
| F.2.1 | Basin-scale evaluation questions  | 92  |
| F.2.2 | Area-specific evaluation questions  | 93  |
| F.3   | Monitoring methods  | 94  |
| F.4   | Results   | 94  |
| F.4.1 | Relevant flow components delivered to the lower Goulburn River in 2014-15   | 94  |
| F.4.2 | Monitoring results and observations   | 94  |
| F.5   | Discussion  | 103 |
| F.6   | Conclusion  | 104 |
| Apper | ndix G. Examples of stakeholder communications  | 105 |

## Table of Figures

## Report main body

| Figure 1-1. Map of the Goulburn River Catchment including the fiv<br>Goulburn River downstream of Lake Eildon  | e environmental flow reaches of the   |
|--|---|
| Figure 3-1. Erosion in one event can be a zone of deposition in and colonisation by bank vegetation.   | other event and this can enhance<br>12  |
| Figure 5-1. Abundance of macroinvertebrates collected from artific<br>Sweep Samples, all aquatic Chironomidae caught on yellow<br>Chironomidae excluding <i>Corynoneura australiensis</i> caught | ial substrates and Replicated Edge<br>v sticky traps and, aquatic<br>on yellow sticky traps18 |
| Appendix A. Hydrology and Hydraulics methods   |   |
| Appendix B. Detailed results for Physical habitat and Bank ero   | osion   |
| Fig. B-1. Contribution of physical habitat (hydraulic habitat) to examonitoring program.   | nple CEDs developed for the CEW<br>   |
| Fig. B-2. Contribution of bank condition monitoring to example CEI program.  | Os developed for the CEW monitoring<br>   |
| Fig. B-3. Instruments used to collect field data for development and   | d verification of the hydraulic model38   |
| Fig. B-4. Topography used to develop the hydraulic model for Mos survey  | s Rd based on LiDAR and bathymetric   |
| Fig. B-5. (left) Colour coded erosion pins inserted at each transect bank and measured by digital calipers, and (right) field place  | to indicate location/elevation on the river<br>ement  |
| Fig. B-6. Bank erosion sampling visits relative to discharge with efl  | ows (blue) and without (purple)40   |
| Fig. B-7. Comparison of velocities at low and high flows as a plot, a (observed) and modelled velocities are compared for low a  | and cross sections at which measured nd high flows43  |
| Fig. B-8. Hydraulic habitat represented by a close up of velocity m  | agnitudes and direction for Moss Rd44   |
| Fig. B–9. Low flow discharge ~850 ML/d (10 $\ensuremath{\text{m}^3\!/s}\xspace)$ and high flow di  | scharge ~3200 ML/d (37 m <sup>3</sup> /s)44   |
| Fig. B-10. Bank movement illustrated as erosion and aggradation  | 45  |
| Fig. B-11. Erosion is greater than deposition. Graphs show probab<br>function of duration of inundation at the McCoy's Bridge site   | ility of any erosion or deposition as a<br>e46  |
| Fig. B-12. Significant erosion events are rare. Graphs show the pro-<br>as a function of duration of inundation for the four sites   | bability of erosion of greater than 30mm<br>47  |
| Fig. B-13. Effect of environmental flows on erosion. Graphs show t<br>(>30mm) erosion for all sample measurements when movin<br>experienced to one that has had the environmental flows re       | he change in probability of significant<br>ng from the inundation regime<br>emoved48          |
| Fig. B-14. Drying of clay-rich sediments prepares bank materials for at the Yambuna Bridge site  | or removal during subsequent inundation<br>49   |
| Fig. B-15. An outer bank at the McCoy's Bridge site that appears to erosion activity has been recorded at the erosion pins   | be eroding but where little or no<br>49   |
| Appendix C. Detailed results for Stream metabolism   |   |
| Fig. C-1. Relationships between photosynthesis, respiration, organ   | ic matter, dissolved gases and nutrients51  |
| Fig. C-2. Mean Daily Water Temperature and Dissolved Oxygen C from October 2014 to April 2015  | oncentration for the three study sites<br>53  |
| Fig. C-3. Stream Metabolism-Flow Relationships for McCoy's Bridg<br>2015   | ge (Zone 2) from October 2014 to April<br>54  |
| Fig. C-4. Stream Metabolism-Flow Relationships for Loch Garry (Z 2015  | one 2) from November 2014 to April<br>55  |
| Fig. C-5. Stream Metabolism-Flow Relationships for Darcy's Track 2015  | (Zone 1) from November 2014 to April  |

| Fig. C-6. Effect of discharge on Gross Primary Production  | 61  |
|--|---|
| Fig. C-7. Effect of discharge on Ecosystem Respiration   |   |
| Fig. C-8. Effect of discharge on Net Primary Production  |   |
| Fig. C-9. Summed effect of environmental flows upon ecosystem  | metabolism measures64   |
| Appendix D. Detailed results for Macroinvertebrates  |   |
| Fig. D-1. Abundance, number of taxa, Shannon-Wiener diversity i<br>D captured in artificial substrates   | ndex H', and Simpson's diversity index 1-<br>   |
| Fig. D-2. Abundance of Oligochaeta caught in artificial substrates   | s in 2014-1568  |
| Fig. D-3. Abundance of common Chironomidae caught in artificial  | substrates70  |
| Fig. D-4. Total abundance of Ephemeroptera, Plecoptera and Tric<br>abundance of selected EPT taxa caught in artificial substr  | choptera (EPT), number of EPT taxa, and ates in 2014-1571   |
| Fig. D-5. The abundance, number of taxa, Shannon-Wiener diver index 1-D captured in replicated edge sweep samples  | sity index H', and (d) Simpson's diversity<br>72  |
| Fig. D-6. The abundance of common taxa caught in replicated ed   | ge sweep samples in 2014-1573   |
| Fig. D-7. Total abundance of Ephemeroptera, Plecoptera and Tric<br>caught in replicated edge sweep samples in 2014-15  | choptera (EPT) and number of EPT taxa<br>74   |
| Fig. D-8. Total abundance of crustaceans and number of crustace samples in 2014-15   | ean taxa caught in replicated edge sweep<br>75  |
| Fig. D-9. Abundance of all invertebrates caught on yellow sticky to  | raps in 2014-1575   |
| Fig. D-10. Abundance of Hymenoptera, Diptera, Hemiptera, Thys caught on yellow sticky traps in 2014-15   | anoptera, Coleoptera and (f) Araneae<br>76  |
| Fig. D-11. Abundance of all aquatic Chironomidae, abundance of<br><i>Corynoneura australiensis,</i> and number of aquatic Chirono<br>traps in 2014-15                                      | all aquatic Chironomidae excluding<br>omidae taxa captured on yellow sticky<br>77                         |
| Fig. D-12. Shannon Wiener Diversity Index H', and Simpson's Div<br>caught on yellow sticky traps in 2014-15  | versity Index 1-D of aquatic Chironomidae<br>   |
| Fig. D-13. Abundance of common taxa caught on yellow sticky tra  | aps in 2014-1578  |
| Appendix E. Detailed results for Vegetation  |   |
| Fig. E-1. Goulburn river discharge over the monitoring period for I (red line). Arrows show dates of vegetation surveys  | McCoys Bridge (blue line) and Loch Garry<br>84  |
| Fig. E-2. Number of days inundated between sampling events acr<br>and percent foliage projected cover (FPC) across the elev<br>common species before and after the delivery of spring free | ross the elevation gradient at Loch Garry<br>ration gradient for all vegetation and three<br>eshes        |
| Fig. E-3. Number of days inundated between sampling events act<br>Bridge and percent foliage projected cover (FPC) across t<br>and three common species before and after the delivery o    | ross the elevation gradient at McCoy's<br>he elevation gradient for all vegetation,<br>f spring freshes87 |
| Appendix F. Detailed results for Fish  |   |
| Fig. F-1. Length frequency of Murray cod collected in the Goulbur  | n River95   |
| Fig. F-2. Length frequency of golden perch collected in the Goulb  | urn River96   |
| Fig. F-3. Length frequency of silver perch collected in the Goulbur  | rn River96  |
| Fig. F-4. Length frequency of carp gudgeon collected in the Gould  | ourn River97  |
| Fig. F-5. Length frequency of Australian smelt collected in the Go   | ulburn River97  |
| Fig. F-6. Adjusted total density of golden perch eggs/larvae per 10<br>Goulburn River  | 000m <sup>3</sup> collected in drift nets in the<br>  |
| Fig. F-7. Adjusted total density of silver perch eggs per 1000m <sup>3</sup> co  | ollected in drift nets in the Goulburn River98  |
| Fig. F-8. Probabilities of spawning at different rates of increase in  | daily discharge at the four sites100  |

| Fig. F-9. Predicted abundances of eggs/larvae at different rates of daily discharge at the two most downstream sites           | 100 |
|--|-----|
| Fig. F-10. Weak effects of temperature on probability of any spawning, but strong effect on predicted abundance of eggs/larvae | 101 |
| Fig. F-11. Examples of movement patterns of golden perch tagged in the Goulburn River in 2014                                  | 102 |
| Appendix G. Examples of stakeholder communications   |     |
| Fig. G-1. Facebook post to the GB CMA iSpy facebook page, 24 October, 2014   | 105 |
| Fig. G-2. Facebook post to the GB CMA Facebook page, 12 June 2015  | 105 |
| Fig. G-3. Report on bank condition monitoring published in the Country News, 3 March 2015                                      | 22  |
| Fig. G-4. Report on golden perch spawning published in the Alexandra Standard, November 2014                                   | 24  |

## **Table of Tables**

| Report main body  |    |
|---|----|
| Table 1-1: LTIM monitoring sites in each zone and the monitoring activities undertaken at each site   | 4  |
| Table 1-2: Commonwealth environmental water entitlements as at 1 July 2014  | 6  |
| Table 1-3. Summary of priority environmental flow components for the Lower Goulburn River 2014-15   | 8  |
| Table 2-1: Schedule of planned and actual monitoring activities by month for 2014-15  | 9  |
| Appendix A. Hydrology and Hydraulics methods  |    |
| Table A-1. Available gauge data   | 32 |
| Table A-2. Flow data where no gauge exists  | 33 |
| Table A-3. Hydraulic models available   | 33 |
| Appendix B. Detailed results for Physical habitat and Bank erosion  |    |
| Table B-1. Goulburn River LTIM physical habitat monitoring sites for physical habitat (hydraulic modelling)           and bank condition.   | 37 |
| Table B-2. Rating curve developed for Moss Road downstream boundary   | 41 |
| Table B-3. Events used for field survey (using the ADCP) and verification of the hydraulic models   | 42 |
| Table B-4. Verification of model through comparison of measured (ADCP) and modelled velocities at 5 cross sections for two discharges   | 42 |
| Appendix C. Detailed results for Stream metabolism  |    |
| Table C-1. Summary of primary production and ecosystem respiration rates and P/R ratios for the six study sites, August 2014 - March 2014.  | 57 |
| Table C-2. Mean daily oxygen loads created by photosynthesis (GPP) and consumed by respiration (ER))  | 57 |
| Table C-3. Exploration of Linear Relationships between the metabolic parameters (GPP and ER) and,         Light and Temperature for the three study sites, Oct/Nov 2014 - Apr 2015                  | 58 |
| Table C-4. Nutrient (N, P & C) concentrations of water samples collected from the four study sites over the period October 2014 to April 2015. Long term data from McCoy's Bridge are also included | 59 |
| Appendix D. Detailed results for Macroinvertebrates   |    |
| Table D-1. Timing of macroinvertebrate sampling in the Goulburn River and Broken River during 2014-15   | 66 |
| Table D-2. List of the most commonly occurring taxa (>0.9 % of the total abundance) caught in artificial substrate samplers from Goulburn River and Broken River, 2014-15                           | 69 |
| Table D-3. List of the most commonly occurring taxa (>0.9 % of the total abundance) caught in replicated         edge sweep sampling from Goulburn River and Broken River, 2014-15                  | 74 |
| Table D-4. List of the most commonly occurring Chironomidae species (>0.9 % of the total abundance)caught on yellow sticky traps from the Goulburn River and Broken River, 2014-15                  | 78 |
| Appendix E. Detailed results for Vegetation   |    |
| Table E-1. Summary of vegetation survey dates, sampling locations and transects   | 83 |
| Table E-2. Mean percent cover of ground layer vegetation at different channel features sampled in           December 2014 at Loch Garry and McCoys Bridge   | 85 |
| Appendix F. Detailed results for Fish   |    |
| Table F-1. Numbers of individual fish species collected from the Goulburn River in electrofishing, fyke net           and bait trap surveys   | 95 |
| Table F-2. Numbers of eggs and larvae of fish species collected in drift net surveys from the Goulburn         River  | 98 |
| Table F-3. Numbers of eggs and larvae of fish species collected in light traps from the Goulburn River in   | 99 |
| Table F-4. Bayesian probabilities of effects of the rate of increase in discharge, and of the effect of temperature   | 99 |

## **Executive Summary**

The Lower Goulburn River Long-Term Intervention Monitoring (LTIM) Project is a joint venture between the University of Melbourne, Jacobs, Arthur Rylah Institute for Environmental Research, Monash University, Streamology, Goulburn Valley Water, and the Goulburn-Broken Catchment Management Authority. It combines expertise in the monitoring being undertaken by the Commonwealth Environmental Water Office; with analytical and project management skills; together with local expertise on the environments and stakeholders of the Goulburn River.

Commonwealth environmental water was delivered to the lower Goulburn River over the 2014-15 period largely as: baseflows to ensure adequate habitat provision, and two major spring freshes, delivered in October and November, which aimed to stimulate production in the system, a smaller autumn fresh, and a major winter fresh.

Monitoring in the Goulburn River LTIM project focuses on the stretch of river between the confluence of the Broken River near Shepparton to the Murray River Confluence near Echuca (Zone 2). There is also a smaller amount of monitoring being done between Goulburn Weir and the Broken River confluence (Zone 1).

| Matter   | Year 1 highlight   | Implications for Adaptive Management  |
|--|--|---|
| Physical habitat<br>quantified by 2-<br>dimensional hydraulic<br>models and bank<br>condition analysis | Rates of bank erosion and deposition are related to<br>inundation duration, but the effect of environmental flows<br>on bank condition is very minor compared to changes<br>that occur under the remainder of the regulated flow<br>regime.  | Flow delivery can proceed with confidence that it is<br>not having major adverse effects on the banks of the<br>Goulburn River. However, we note that these<br>conclusions are based upon small environmental flow<br>events only.  |
| Stream metabolism:<br>production and<br>respiration  | The in-channel environmental flows delivered to the<br>lower Goulburn River have only minor effects upon<br>stream metabolism parameters, but there is some<br>indication of a small boost in net primary productivity.  | Larger flow events, currently in planning frameworks<br>but constrained because of third party risks, may be<br>required in the future to mobilise carbon and nutrients<br>from backwaters and the floodplain. Flow events need<br>to take place when waters are relatively warm.   |
| Macroinvertebrate biomass and diversity  | Macroinvertebrate biomass in sweep samples from the river's edge increased following the spring environmental flows. However, these results were not seen with other sampling methods used, indicating that the flows were not of sufficient magnitude to cause a major response.  | The small macroinvertebrate response is consistent<br>with the small response of stream metabolism. Larger<br>flow events may be required to induce increased<br>production of macroinvertebrates.  |
| Bankside vegetation<br>abundance and<br>diversity  | Areas of the bank inundated by the spring environmental<br>flow events had improved vegetation abundance and<br>diversity pre- to post-flow, while the remainder of the<br>bank showed no effect. This demonstrates the value of<br>bank wetting as the climate grows drier over summer.                                     | We believe that benefits to bankside vegetation may<br>be greater if the first extended spring flow is delivered<br>earlier. This would allow plants to grow in response to<br>bank wetting before air temperatures increase<br>significantly as we move into summer.   |
| Fish assemblages,<br>and the spawning and<br>movement of golden<br>and silver perch                    | Golden perch exhibited a strong spawning result to<br>spring environmental flows, with eggs and larvae being<br>collected in numbers never before seen following<br>environmental flows. Golden perch also exhibited strong<br>movement responses to environmental flows, mostly<br>moving down the river to spawning areas. | While we are now able to achieve good spawning<br>outcomes for golden perch, adjusting the timing of the<br>second spring fresh will be important for determining<br>how closely spawning is tied to temperature. Future<br>data collection will improve our understanding of the<br>importance of antecedent flows on fish spawning, and<br>whether spawning responses translate to recruitment. |

Monitoring focuses on the following matters, with highlights and implications of the year-1 monitoring provided.

All matters therefore reported at least some probable benefits of Commonwealth environmental water delivered to the lower Goulburn River in 2014-15, with some matters showing strong indications of ecological response. The monitoring program has also generated favourable media attention, with stories in local newspapers, and multiple posts to social media. The results provide confidence in the value of this investment in the environment.

The Goulburn LTIM project team is currently beginning to implement monitoring for year 2 of the monitoring program, building upon the data set generated in 2014-15 and taking on board the learnings that resulted from the first year of monitoring.

## 1. Introduction

The Commonwealth Environmental Water Office (CEWO) is funding a Long-Term Intervention Monitoring (LTIM) Project in seven Selected Areas to evaluate the ecological outcome of Commonwealth environmental water use throughout the Murray-Darling Basin. The LTIM Project will be implemented over five years from 2014-15 to 2018-19 to deliver five high level outcomes:

- 1. Evaluate the contribution of Commonwealth environmental watering to the objectives of the Murray-Darling Basin Authorities (MDBA) Environmental Watering Plan;
- 2. Evaluate the ecological outcomes of Commonwealth environmental watering in each of the seven Selected Areas;
- 3. Infer ecological outcomes of Commonwealth environmental watering in areas of the Murray-Darling Basin not monitored;
- 4. Support the adaptive management of Commonwealth environmental water; and
- 5. Monitor the ecological response to Commonwealth environmental watering at each of the seven Selected Areas.

This report describes the monitoring activities undertaken in the lower Goulburn River Selected Area in 2014-15 and summarises the results and analysis outcomes of that monitoring. Detailed descriptions of results and analyses for each monitoring discipline are provided in appendices. The report has been prepared by all discipline leaders of the Lower Goulburn River Monitoring and Evaluation Provider and addresses the annual reporting requirements specified in Clause 11.2 of the head contract between UoM Commercial and the Commonwealth Department of Environment.

### 1.1 Lower Goulburn River selected area

The Goulburn River extends from the northern slopes of the Great Dividing Range north to the Murray River near Echuca (Figure 1-1). Mean annual discharge for the catchment is approximately 3,200 GL (CSIRO 2008), and approximately 50% of that is on average diverted to meet agricultural, stock and domestic demand.

The Goulburn River Selected Area includes the main river channel between Goulburn Weir and the Murray River (235 km), along with any low-lying riparian or wetland / floodplain assets that are connected to the river by in-channel flows up to bank full. The Selected Area corresponds to Reach 4 (Goulburn Weir to confluence with Broken River at Shepparton) and Reach 5 (confluence of Broken River to Murray River) described in environmental flow studies and environmental watering plans (Cottingham et al. 2003, Cottingham et al. 2007, Cottingham and SKM 2011). Environmental flows in the lower Goulburn River will not be used to deliver overbank flows or water the floodplain, therefore for the purposes of the LTIM Project, the Lower Goulburn River Selected Area is considered a Riverine System under the Australian National Aquatic Ecosystem (ANAE) classification (Brooks et al. 2013).

The environmental flow reaches in the Goulburn River were determined after an analysis of stream hydrology, morphology and regulation. The reasons for dividing the Goulburn River downstream of Goulburn Weir into two environmental flow reaches is sound and Commonwealth environmental water is used to address specific environmental flow objectives in those reaches. Previous environmental flow monitoring programs in the lower Goulburn River (e.g. the Victorian Environmental Flows Monitoring and Assessment Program, and the Commonwealth short-term environmental water monitoring program) have based their sampling design around the existing environmental flow reaches. In order to complement this historical monitoring, promote consistency in the data sets, and potentially to allow incorporation of historical data into analyses, the LTIM Project does the same.



Figure 1-1. Map of the Goulburn River Catchment including the five environmental flow reaches of the Goulburn River downstream of Lake Eildon (different colours). The LTIM project focuses on the Lower Goulburn River, which extends from Goulburn Weir to the Murray River and includes Reaches 4 and 5 shown on the map, here re-labelled as Zones 1 and 2 as per the key. Map modified from GBCMA (2014).

The zone definitions for the lower Goulburn River are:

- Zone 1 Main channel of the Goulburn River and associated wetlands and backwaters that are connected to the main channel at flows less than bankfull between Goulburn Weir and the confluence of the Broken River (i.e. Environmental Flow Reach 4).
- Zone 2 Main channel of the Goulburn River and associated wetlands and backwaters that are connected to the main channel at flows less than bankfull between the confluence of the Broken River and the Murray River (i.e. Environmental Flow Reach 5).

Zone 1 and Zone 2 are physically similar, have similar hydrology and are not separated by significant barriers. Moreover, they will be equally affected by Commonwealth environmental water, which will be controlled by the regulator at Goulburn Weir. The Monitoring Providers for the Lower Goulburn River Selected Area decided to invest effort in many monitoring activities in a single zone rather than a small number of monitoring activities in both zones. We are focussing on responses to environmental flows in Zone 2 because that is where most of the previous fish surveys in the Goulburn River have been conducted and improving native fish populations is one of the highest priority environmental flow objectives for the lower Goulburn River. High rates of golden perch spawning have previously been recorded in Zone 2, and it is closer to other LTIM selected areas including the Edward Wakool system, the Murrumbidgee System and the Lower Murray system.

We are investigating hydraulic, geomorphological, fish, vegetation, macroinvertebrate and stream metabolism responses to environmental flows in Zone 2. We are investigating some responses to environmental flows in Zone 1, but the level of effort applied in Zone 1 is less and does not necessarily meet the specified requirements for the Basin-Scale analyses. We are also investigating macroinvertebrates in the Broken River (Zone 3), using that site as a control for the Goulburn River. Specific monitoring sites within each zone and the monitoring activities undertaken at each site are detailed in Table 1-1.

| Site<br>No. | Site Name                         | ult Fish | rval fish | :h<br>vement | Model | nk<br>ndition | getation<br>ersity | eam<br>tabolism | icroinvert<br>rates |
|-------------|-----------------------------------|----------|-----------|--------------|-------|---------------|--------------------|-----------------|---------------------|
|             |                                   | Ad       | La        | Fis          | 2D    | င် Ba         | Ve<br>div          | Str<br>me       | Ma<br>ebi           |
| Zone        | 1 – Goulburn Weir to Broken River |          |           |              |       |               |                    |                 |                     |
| 1           | Moss Road                         |          |           |              |       |               |                    |                 |                     |
| 2           | Toolamba/Cemetery Bend            |          |           |              |       |               |                    |                 |                     |
| 3           | Darcy's Track                     |          |           |              |       |               |                    |                 |                     |
| Zone        | 2 – Broken River to Murray River  |          |           |              |       |               |                    |                 |                     |
| 1           | Shepparton                        |          |           |              |       |               |                    |                 |                     |
| 2           | Shepparton Weir                   |          |           |              |       |               |                    |                 |                     |
| 3           | Zeerust                           |          |           |              |       |               |                    |                 |                     |
| 4           | Loch Garry Gauge                  |          |           |              |       |               |                    |                 |                     |
| 5           | Pogue Road                        |          |           |              |       |               |                    |                 |                     |
| 6           | Kotpuna                           |          |           |              |       |               |                    |                 |                     |
| 7           | McCoys Bridge                     |          |           |              |       |               |                    |                 |                     |
| 8           | Murrumbidgee Road                 |          |           |              |       |               |                    |                 |                     |
| 9           | Yambuna                           |          |           |              |       |               |                    |                 |                     |
| 10          | Sun Valley Road                   |          |           |              |       |               |                    |                 |                     |
| 11          | Murray Junction                   |          |           |              |       |               |                    |                 |                     |
| Zone        | 3 – Broken River                  |          |           |              |       |               |                    |                 |                     |
| 1           | Central Avenue                    |          |           |              |       |               |                    |                 |                     |

Table 1-1: LTIM monitoring sites in each zone and the monitoring activities undertaken at each site.

## **1.2** Environmental values and flow regulation of the lower Goulburn River

The Goulburn Broken Regional River Health Strategy (GBCMA 2005) identifies the Goulburn River as a high priority waterway due to its significant environmental values. The river and its associated floodplain and wetland habitats support intact River Red Gum forest, and numerous threatened species such as Murray cod, trout cod, squirrel glider, and eastern great egret. The river, and its associated floodplain and wetland habitats also contain many important cultural heritage sites, provide water for agriculture and urban centres, and support a variety of recreational activities such as fishing and boating. Further description of the lower Goulburn River is included in Gawne et al. (2013).

The two major water regulation structures on the Goulburn River are Lake Eildon and Goulburn Weir. Lake Eildon has a capacity of approximately 3,334 GL, and provides water to the majority of the Shepparton, Central Goulburn, Rochester and Pyramid/Boort irrigation areas. Water is diverted at Goulburn Weir into the East Goulburn Main Channel and is harvested into Waranga Basin (capacity 432 GL).

Flow in the middle Goulburn River (i.e. Between Lake Eildon and Goulburn Weir) is higher than it would naturally be in summer and early autumn to supply irrigation needs, but is lower than natural at other times of the year. The diversion of irrigation water at Goulburn Weir and inflows from tributaries such as the Broken River and Seven Creeks have helped to retain the natural seasonal flow patterns (i.e. high winter flows and low summer flows) in the lower Goulburn River. Significant Inter-Valley Transfer (IVT) flows may also be released into the lower Goulburn River from Goulburn Weir during summer and early autumn to supply water entitlements traded from the Goulburn River system to the Murray River system. IVT flows do not persist for the whole season and therefore do not reverse the natural seasonal flow pattern nor compensate for water harvested higher in the catchment. The regulation described above has reduced the average annual flow in the lower Goulburn Weir to 1,340 GL, which is less than half of the estimated pre-regulated flow.

The sections of the Goulburn River between Lake Eildon and Shepparton (including Zone 1 of the Lower Goulburn River Selected Area) have a naturally confined floodplain (up to 4 km wide). Constructed levees confine the floodplain along the Goulburn River downstream of Shepparton (i.e. Zone 2 of the Lower Goulburn River Selected Area). Flood water leaving the Goulburn River downstream of Shepparton either returns to the channel (where blocked by levees), or flows north via the Deep Creek system that discharges to the Murray River downstream of Barmah (but upstream of the confluence of the Goulburn and Murray Rivers). The Broken River is a major tributary of the Goulburn River, discharging at Shepparton.

As well as the impact of long term flow reduction, the lower Goulburn River was heavily affected by the Millennium Drought, and the following 2010-11 and 2012 floods. During the drought, amphibious and flood tolerant bank vegetation retreated down the bank and was replaced by terrestrial vegetation. The extended floods in 2010-11 and 2012 killed off all the terrestrial vegetation leaving bare river banks, susceptible to erosion. Vegetation re-establishment is only now starting to occur. Golden perch, a flow cued spawner, also did not significantly spawn during the drought (Koster et al. 2012), making spawning a priority to rebuild populations and age classes.

### 1.3 Overview of Commonwealth environmental watering

As of the 1<sup>st</sup> July 2014, the Commonwealth held 224.5 GL of high security and 15.8 GL of low security environmental water entitlements in the Goulburn River (D. Straccione, CEWO, pers. comm.; Table 1-2). The Goulburn River receives other environmental flows through Bulk Entitlements, Environmental Entitlements held by the Victorian Environmental Water Holder, Environmental Entitlements for The Living Murray and Inter-Valley Transfers (see Gawne et al. 2013 for further details). However, the Commonwealth environmental water entitlement provides most of the water that is used to meet specific environmental flow objectives in the lower Goulburn River channel.

| Entitlement type            | Entitlement held (GL) | Entitlement held                    |
|-----------------------------|-----------------------|-------------------------------------|
|                             |                       | Long term average annual yield (GL) |
| Goulburn (high reliability) | 224.5                 | 211.2                               |
| Goulburn (low reliability)  | 15.8                  | 6.3                                 |

#### 1.3.1 What type of watering is proposed?

Watering options include increasing baseflows throughout the year, and provision of freshes in winter, spring, summer and autumn. It is expected that Commonwealth environmental water will be used to provide flows up to 9,000 ML/day, and these may rise to approximately 15,000 ML/day if timed to coincide with natural high flow events. These managed flows could be up to three quarters of bankfull flows and may connect some low lying wetlands via anabranches, but are more likely to be approximately one third to one half the magnitude of bankfull flows. Commonwealth environmental water will not be used to contribute to flows greater than 19,000 ML/day at Shepparton to avoid flooding of private property or infrastructure (Gawne et al. 2013). Commonwealth environmental water will therefore not provide overbank flows in the lower Goulburn River and will not water any parts of the lower Goulburn River floodplain or associated wetlands.

To maximise the efficient and effective use of Commonwealth environmental water, where possible return flows from the Goulburn River are traded for use downstream, providing significant environmental benefits at multiple sites including the lower River Murray channel and floodplain wetlands, Lower Lakes, Coorong and Murray Mouth (CEWO 2014).

#### 1.3.2 What are the expected watering outcomes?

Environmental flows in the lower Goulburn River are intended to achieve the following ecological outcomes:

- Baseflows aim to improve fish habitat and allow fish movement, and improve macroinvertebrate habitat (including instream vegetation) and therefore macroinvertebrate abundance.
- Freshes aim to improve spawning of golden perch, encourage fish migration/movement, encourage the recovery of bank vegetation and increase macroinvertebrate habitat and therefore abundance.

If all planned flow components are delivered, substantial volumes of Commonwealth environmental water will be invested in fish breeding and fish movement (particularly for golden perch), re-establishing bank vegetation that has been lost through drought, floods or land clearing, and increased macroinvertebrate abundance. Monitoring activities that test the effect of environmental water delivery on river fish populations, riparian bank vegetation and macroinvertebrate abundance are therefore considered the highest priorities for the lower Goulburn River Selected Area.

As the CEWO does not currently intend to contribute to bank full and overbank flows along the Goulburn River, changes in floodplain vegetation health will not occur as a result of environmental flows. The LTIM program will not specifically target floodplain habitats or biota in the lower Goulburn River Selected Area.

### 1.3.3 Practicalities of watering

Water in desirable flow patterns is released from Goulburn Weir, either by reducing water harvesting into Waranga Basin or by increasing water released from Lake Eildon. Current river flows from natural catchment runoff, normal minimum flows or irrigation releases (e.g. Inter-Valley Transfers), and environmental transfers to Murray River environmental sites are assessed to see how well they provide desirable environmental flow regimes in the lower Goulburn River. Environmental water is released when required to increase flows to desirable levels for prescribed durations. These other sources of water are more fully described in Gawne et al. (2013).

Environmental releases to maintain minimum flows are usually set as a standing order with the water authority (i.e. Goulburn-Murray Water) providing access to water to maintain the desired flow. Freshes are normally

planned and released as specified flow events, but the magnitude, duration and/or timing of these events can be modified as catchment runoff, or the risk of catchment runoff, changes.

Low flows and freshes up to approximately 3,000 ML/day are relatively easy to deliver, being well within the capacity of the water supply system. However, as targeted flows rise above 3,000 ML/day, constraints to delivery become increasingly likely. If delivered under dry conditions, the maximum release rates downstream of Lake Eildon and high rates of irrigation delivery can limit the flows downstream of Goulburn Weir to 5,000 to 6,000 ML/day. Private irrigation pumping along the lower Goulburn River can also be affected by flows above 3,000 ML/day, particularly if flows persist for longer than about seven days. Under wet conditions with catchment runoff, Eildon release capacity can be reduced (by downstream of the weir relatively easily, but only if catchment runoff is being diverted to Waranga Basin at the time. Timing releases (particularly from Lake Eildon) to augment flows from catchment runoff to achieve desired flow rates can also be difficult.

Monitoring the physical and ecological effects of environmental flows is particularly sensitive to the timing of fresh events as well as catchment runoff and irrigation releases because high flows and localised heavy rainfall can restrict access to the river or monitoring sites and sampling efficiency. These constraints can in some cases affect the capacity to reliably evaluate the effect of particular flow events, although it is not expected to be a major issue for managed environmental flow releases.

### 1.4 Environmental water delivered in 2014-15 and context

Environmental flow priorities, targeting baseflows and freshes, for 2014-15 are detailed in Table 1-3.

Table 1-3. Summary of priority environmental flow components for the Lower Goulburn River 2014-15 (modified from GBCMA 2014). Green-shaded components were high priorities for delivery, with orange-shaded components dependent upon water availability.

| _        |                 |         |          | Discharge (ML/day)  |   |  |
|----------|-----------------|---------|----------|---|---|--|
| Priority | Flow component  | Year    | Timing   | Zone 1 (Reach 4)  | Zone 2 (Reach 5)  |  |
| 1        | Baseflow        | 2014    | July-Nov | 500   | 540   |  |
| 2        | Fresh           | 2014    | Oct-Nov  | As high as possible, up to<br>15,000 ML/day, with flows above<br>5,600 ML/day for 14 days | As high as possible, up to<br>15,000 ML/day, with flows above 5,600<br>ML/day for 14 days |  |
| 3        | Baseflow        | 2014-15 | Dec-Feb  | 500   | 540   |  |
| 4        | Baseflow        | 2015    | Mar-Jun  | 500   | 540   |  |
| 5        | Baseflow        | 2015    | Jul-Sep  | 500   | 540   |  |
| 6        | Fresh           | 2015    | Feb-Apr  | Up to 5,600 ML/day for 2 days   | Up to 5,600 ML/day for 2 days   |  |
| 7        | Fresh           | 2014    | Nov-Dec  | As high as possible, up to 15,000 ML/day for 2 days                                       | As high as possible, up to 15,000 ML/day for 2 days                                       |  |
| 8        | Baseflow        | 2014    | July-Nov | 830   | 940   |  |
| 9        | Baseflow        | 2014-15 | Dec-Feb  | 830   | 940   |  |
| 10       | Fresh           | 2014    | Jun-Aug  | As high as possible, up to<br>15,000 ML/day, with flows above<br>6,600 ML/day for 14 days | As high as possible, up to<br>15,000 ML/day, with flows above<br>6,600 ML/day for 14 days |  |
| 11       | Recession Flows | 2014-15 | Any time | As required   | As required   |  |
| 12       | Baseflow        | 2015    | Mar-Jun  | 830   | 940   |  |
| 13       | Fresh           | 2015    | Jun-Aug  | As high as possible, up to<br>15,000 ML/day, with flows above<br>6,600 ML/day for 14 days | As high as possible, up to<br>15,000 ML/day, with flows above<br>6,600 ML/day for 14 days |  |
| 14       | Baseflows/fresh | 2014-15 | Jul-Jun  | Up to 5,000 ML/day  | Up to 5,000 ML/day  |  |

Baseflow components were primarily designed to provide adequate physical habitat for macroinvertebrates and fish, with freshes designed to promote movement and breeding of native fish species, particularly golden perch, and to inundate banks to promote improved bankside vegetation (GBCMA 2014).

All high-priority flow components were able to be delivered through natural and managed flows (Figure 1-2), sometimes in combination with the delivery of operational (IVT) water. Overall, over 309 GL of environmental water was delivered, with the major environmental water holders providing 226 GL (Commonwealth Environmental Water Holder), 29 GL (Victorian Environmental Water Holder), and 54 GL (The Living Murray).



Goulburn River @ McCoy's Bridge 2014/15

Figure 1-2. Summary of environmental flows delivery and compliance in the lower Goulburn River 2014-15 (GMW pers. comm. 2015). Chart shows total discharge at the McCoy's Bridge gauging station near the bottom of the system, along with managed environmental flows delivered at that point, and inter-valley transfer flows, which were also managed to deliver parts of environmental flow components (see Appendix A for explanation of the hydrological data used in this report). Superimposed numbers illustrate the delivery of priority flow components identified in Table 1-3. All high-priority flow components within the period of this chart were delivered (component 5 falls after the end of the hydrograph). Lower priority flow components 12 and 13 were also delivered. The superimposed arrow indicates the period for which monitoring data were evaluated for the 2014-15 selected area evaluation report (Sep 1 – Apr 30).

## 2. Overview of monitoring undertaken in 2014-15

We implemented all of the planned monitoring activities outlined in the Monitoring and Evaluation Plan (MEP; Webb et al. 2014) during 2014-15, although some activities were delayed by 1-2 months (see Table 2-1). Bank condition monitoring and stream metabolism are the only activities for which the overall level of effort was less than planned (see Table 2-1). The start of bank condition monitoring was delayed by scope negotiations between the CEWO, VEWH, the GBCMA and Streamology Pty Ltd. The missed sampling events are being used to provide additional resolution of sampling around major flow events (i.e. extra sampling trips). The stream metabolism monitoring was delayed because monitoring equipment could only be ordered and purchased once the CEWO approved the final MEP. There have also been some problems with setting up the stream metabolism data recorders at a water level that provides reliable results across a range of different flow magnitudes (see section 4). The Centre for Aquatic Pollution Identification and Monitoring (CAPIM) has a research student that is conducting a project to complement the macroinvertebrate component of the LTIM. This extra resource allowed us to sample macroinvertebrate communities three times between September and January, rather than two as initially planned.

The periods of monitoring for each activity are based upon the expected responses to flow variation, optimized for budgetary and logistic considerations. These reasons are given more fully in the MEP (Webb et al. 2014). More detailed discussions of monitoring activities, how they differed from planned activities and preliminary results are presented separately for each technical discipline in the following chapters.

Table 2-1: Schedule of planned and actual monitoring activities by month for 2014-15. D indicates planned/actual timing for downloading data from fish movement loggers; I indicates planned/actual deployment of artificial substrates for macroinvertebrate sampling, O indicates planned/actual retrieval of artificial substrates for macroinvertebrate sampling. The light red shading for May-June for Stream Metabolism indicates that one of the four probes (McCoy's Bridge) was left deployed over the winter to gather further information regarding fluctuation in seasonal dissolved oxygen levels, particularly at lower water temperatures.

| Monitoring activity  | No of sites | s per Zone   | Planned / | Schedule of planned and actual activities |   |    |    |   |   |   |   |   |   |   |   |
|----------------------|-------------|--------------|-----------|---|---|----|----|---|---|---|---|---|---|---|---|
|                      | Zone 1      | Zone 2       | Actual    | J   | Α | s  | ο  | Ν | D | J | F | м | Α | м | J |
| Fish River           |             | 10           | Planned   |   |   |    |    |   |   |   |   |   |   |   |   |
|                      |             |              | Actual    |   |   |    |    |   |   |   |   |   |   |   |   |
| Fish Larvae          | 1           | 3            | Planned   |   |   |    |    |   |   |   |   |   |   |   |   |
|                      |             |              | Actual    |   |   |    |    |   |   |   |   |   |   |   |   |
| Fish Movement        |             | ~20 stations | Planned   |   |   | D  |    |   | D |   |   | D |   |   | D |
|                      |             |              | Actual    |   |   |    |    |   | D |   |   |   |   | D |   |
| Vegetation Diversity |             | 2            | Planned   |   |   |    |    |   |   |   |   |   |   |   |   |
|                      |             |              | Actual    |   |   |    |    |   |   |   |   |   |   |   |   |
| Macroinvertebrates   |             | 2            | Planned   |   |   |    | I  | 0 |   | T | 0 |   |   |   |   |
|                      |             |              | Actual    |   |   | I. | OI | 0 | 1 | 0 |   |   |   |   |   |
| Stream Metabolism    | 2           | 2            | Planned   |   |   |    |    |   |   |   |   |   |   |   |   |
|                      |             |              | Actual    |   |   |    |    |   |   |   |   |   |   |   |   |
| Bank Condition       | 2           | 4            | Planned   |   |   |    |    |   |   |   |   |   |   |   |   |
|                      |             |              | Actual    |   |   |    |    |   |   |   |   |   |   |   |   |
| 2D Hydraulic Model   | 2           | 2            | Planned   |   |   |    |    |   |   |   |   |   |   |   |   |
|                      |             | Actual       |           |   |   |    |    |   |   |   |   |   |   |   |   |

## 3. Physical habitat and bank erosion

Environmental flows delivered in early 2015 provided useful conditions for fieldwork and assessment of physical habitat. Physical habitat fieldwork (for the development of hydraulic models) was undertaken in March and June. Bank condition installation was undertaken from January to August, with the freshes of February and March captured by the current data analysis and discussed in this report. Unfortunately, installation of erosion pins was only possible at the end of the January fresh so no pre-fresh data is available for this. Pin assessments must be undertaken at low flows (<1000 ML/d). The report for 2015-16 will have a complete coverage of measurements (6 per season for 2 seasons).

Bank condition monitoring including erosion pin measurement and qualitative assessments are ongoing. Some initial results form the bulk of this physical habitat report. Hydraulic habitat models are close to completion and require further collaboration with the ecological team to identify particular questions on flow-habitat relationships to be interrogated with the models. This report therefore does not provide results of the hydraulic habitat assessment, but describes the tasks required in their development and includes some example results of the type that may ultimately be delivered to the ecological team (Appendix B).

## 3.1 Evaluation

| Question   | Were appropriate flows provided?   | Effect of environmental flows   | What information was the evaluation based on?          |
|--|--|---|--|
| What did CEW<br>contribute to the<br>provision of productive<br>habitat (e.g.<br>slackwaters) for the<br>recruitment, growth<br>and survival of larval<br>and juvenile fish?                             | The provision of<br>baseflows, such as<br>provided in the 2014-15<br>season, is known to<br>contribute to productive<br>fish habitat. Freshes,<br>also provided, are also<br>known to improve<br>recruitment.                        | Baseflow provisions are known to increase<br>habitat for fish, such as through the<br>availability of slackwater habitat. Freshes<br>are known to provide triggers and depths<br>required for recruitment. This is a likely<br>outcome to be confirmed using the physical<br>habitat models developed.  | Hydraulic habitat models will be used for this purpose |
| What did CEW<br>contribute to the<br>provision of diverse<br>and productive<br>macroinvertebrate<br>habitats?  | Baseflows and freshes,<br>such as provided in the<br>2014-15 season, are<br>known to provide for<br>macroinvertebrates.  | Baseflows increase the wetted area of the<br>channel bed, and freshes increase wetting<br>on higher, often more productive features<br>such as bars and benches. This is a likely<br>outcome to be confirmed using the physical<br>habitat models developed.  | Hydraulic habitat models will be used for this purpose |
| What did CEW<br>contribute to inundating<br>specific riparian<br>vegetation zones and<br>creating hydraulic<br>habitats that favour the<br>dispersal and<br>deposition of plant<br>seeds and propagules? | Freshes and variable<br>flow levels, such as<br>achieved through flow<br>management during the<br>2014-15 season, are<br>known to increase<br>opportunities for the<br>dispersal and deposition<br>of plant seeds and<br>propagules. | Variable discharges and flow levels provide<br>greater opportunities for the recruitment,<br>transport and dispersal of seeds and<br>propagules. High flow freshes, in particular,<br>may transport the seeds and provide<br>favourable conditions (wetting, low velocity)<br>to encourage vegetation germination and<br>growth on benches and banks. This is a<br>likely outcome to be confirmed using the<br>physical habitat models developed. | Hydraulic habitat models will be used for this purpose |

#### 3.1.1 Area specific evaluation questions

| Question  | Were appropriate flows provided?  | Effect of environmental flows  | What information was the evaluation based on?  |
|---|---|--|--|
| How does CEW affect<br>bank erosion and<br>deposition?  | Yes. Rates of drawdown<br>are of particular interest<br>to bank condition and<br>these were all<br>appropriate.   | Environmental flows via inundation of<br>banks increases erosion but also<br>aggradation on the banks. However,<br>compared to the erosion and aggradation<br>that occurs under the remainder of the flow<br>regime, the effects of environmental flows<br>are very small. These episodic changes are<br>natural and can provide important niches,<br>such as for vegetation establishment. The<br>levels of erosion were higher than the<br>levels of aggradation but this may also be<br>an artefact of sensitive banks being<br>targeted for this study. No mass failure<br>(bank slumping) was observed at any of<br>the four reaches. | Bank condition is based on<br>quantitative measurements of bank<br>erosion using 200 erosion pins. At<br>each site erosion pins, located at<br>varying levels and locations, are<br>remeasured pre/post events to assess<br>bank change. Statistical models<br>compared predicted<br>erosion/deposition under actual flow<br>regime and one from which<br>environmental flows had been<br>removed. Qualitative assessments of<br>bank erosion mechanisms are also<br>made. |
| How does the amount<br>of river bank erosion<br>affect vegetation<br>responses to<br>environmental water<br>delivery? | Yes. Depth of inundation<br>reached the upper third<br>of banks and rates of<br>recession were<br>adequately low to enable<br>mud drapes and prevent<br>major bank failure. | Whilst vegetation response has not been<br>formally incorporated into the bank<br>condition assessment at this stage the<br>flows delivered maintained appropriate<br>rates of erosion and deposition and were<br>found, in some cases, to encourage<br>vegetation establishment. Low rates of<br>recession commonly left 'mud drapes' on<br>banks.  | Assessment of hydrologic conditions,<br>qualitative assessments of erosion<br>mechanisms, and observations<br>(including repeat photographs) have<br>enabled an assessment of bank<br>condition and the potential for<br>vegetation establishment.   |

## 3.2 Main findings from physical habitat and bank erosion monitoring program

Physical habitat (hydraulic habitat) models will be available by the end of 2015. These models will be used to run scenarios for ecological metrics developed in conjunction with the ecological team. These scenarios and the questions addressed may be informed by the results from the 2014-15 season to help explain the mechanisms behind responses to environmental flows. As a result the habitat modelling will be an ongoing output during the LTIM investigation.

A summary of key findings from the bank condition monitoring program include (refer to Appendix B for details):

Bank erosion is highly variable

- Erosion and deposition (soil removal and aggradation) are both ongoing processes in the Goulburn River.
- Erosion is highly variable at a site over time. For example, erosion pins experiencing erosion in one event can often be a site of deposition following another event.
- Sites of erosion in one event can induce deposition in another event and these sites can be colonised by vegetation (Figure 3-1).
- The February inter-valley transfer resulted in between 1 and 6 mm more erosion on average than the March fresh event (the February IVT was 3000 ML/d compared to the March fresh of 4000 ML/d with a slightly faster recession rate) at all sites except for Darcy's Track, where the opposite was true.
- No mass failure events (large volume slips) have occurred during the monitoring period (January to March).



Figure 3-1. Erosion in one event can be a zone of deposition in another event and this can enhance colonisation by bank vegetation.

#### Inundation matters but only marginal change can be attributed to environmental flows

- The duration of inundation of banks (the only metric assessed so far) does increase activity on the banks (both erosion and deposition).
- Erosion is increased more than aggradation, but both are increased by increased inundation (but this may be an artefact of the selection of sensitive sites).
- The probability of significant erosion (defined here as ≥ 30 mm) is low, being approximately 0.15-0.45 across the four sites if (and only if) banks are inundated almost continually between sampling trips.
- Increases in inundation caused by environmental flows have small effects; less that 7% of samples had an increased probably of significant erosion as a result of environmental flows.
- No major notching or mass failures (e.g. slumps) have been observed. Photos of before/after will be included when there are visually observable changes.
- While the results here indicate negligible impacts of environmental water on bank condition during the summer/autumn period, there are currently no data on the effect of higher magnitude environmental water deliveries in spring. This will be addressed in future years when sampling occurs throughout the year.

#### It is not just flow that affects bank condition

- Mechanisms other than those that are flow-induced can modify banks. Minor deposition on upper and lower banks may be attributed to soil creep (under gravity), particularly following heavy rainfall.
- Drying of soils between events (desiccation) is likely to contribute to preparing soils for subsequent
  erosion during flow events. Bank vegetation may play an important role in reducing the extent of drying
  of bank material. It is important to note that banks without significant vegetation have been targeted by
  this assessment to ensure the most sensitive banks are able to provide adequate change. These results
  can then be related to environmental flow deliveries.

#### Perceptions of bank erosion are not often representative of fact

• Actual changes to banks (erosion or deposition) are not perceptible by eye and visual inspections can be misleading. Banks that look to be eroding can often have undergone erosion during an event and subsequent overlaying of a veneer of fine sediments, as determined from erosion pin measurements.

Drapes (deposition) and subsequent erosion may give the perception that a bank is receding, yet cycles of deposition and erosion appear to be common.

#### Results in relation to short and long term questions

The overarching short and long term question for bank erosion is: What did environmental water contribute to sustaining bank condition as a result of flow management. Overall, based on limited data at this stage, there is evidence to suggest that flow management, and certainly the CEW contribution, were delivered without any adverse effects on the river banks. There was no significant erosion, and both erosion and deposition occurred (as would be expected). There are also some initial observations that zones of deposition resulting from mud drapes following freshes have encouraged vegetation establishment.

There are no recommendations for changes to current management. Interim recommendations for upcoming environmental flow management supports the current management approaches including:

- Maintain variability in discharges and water levels to increase opportunities for recruitment, transport and deposition of seeds and plant propogules, maintain bank wetting at varying levels on the bank, and avoid bank 'notching' (these are hypotheses still to be tested);
- Maintain high discharges (flow freshes) to encourage vegetation establishment on the upper bank to reduce the potential for desiccation (drying and cracking) of bank sediments;
- Maintain current rates of flow recession to avoid bank surcharging and erosion, and allow mud drapes to develop (no major erosion events e.g. slumping have been observed from recent environmental flow management); and
- Maintain 'piggy backing' on tributary inflows to ensure sediment from tributaries is transported and deposited at higher levels in the channel (bars, benches, upper banks) during high flow freshes.

## 4. Stream metabolism

Stream metabolism was monitored over the period October 2014 – April 2015. During this period there were two spring freshes, an inter-valley transfer, and an autumn fresh. We did not observe any major changes in stream metabolism as a result of these flows, but there were some indications of minor effects. The derivation of results and more detailed analyses are included in Appendix C)

### 4.1 Evaluation

| 4.1.1 | Basin-scale | evaluation | questions |
|-------|-------------|------------|-----------|
|-------|-------------|------------|-----------|

| Question   | Were appropriate flows provided? | Effect of environmental flows  | What information was the evaluation based on?   |
|--|----------------------------------|--|---|
| What did CEW<br>contribute to<br>patterns and<br>rates of<br>decomposition?        | Yes                              | There was a weak relationship showing that daily<br>Ecosystem Respiration (ER) rates decreased with<br>discharge, almost certainly due to the dilution effect<br>of the added water. It is expected that increases in<br>ER will follow days after a flow event as it takes<br>time for microbial populations to increase in<br>response to the larger amounts of organic carbon.  | This first statistical analysis of the<br>discharge-ER data indicated ER<br>decreased as discharge increased. This is<br>not unexpected and definitely not an<br>indication of lack of response to watering<br>events. More complex models will be<br>developed in following years (when larger<br>data sets are available) which include<br>looking at lag phases post flow event for<br>ER increases .i.e. the ER increases e.g. 7<br>days after a flow event |
| What did CEW<br>contribute to<br>patterns and<br>rates of primary<br>productivity? | Yes                              | The results suggested an immediate suppression<br>of gross primary production (GPP) through simple<br>dilution effects. At one site there was an indication<br>of post-flow increases over subsequent weeks, but<br>without further data for the no-flow counterfactual, it<br>is difficult to determine whether the increase was<br>flow related or simply due to warmer temperatures<br>and longer days (more light). There was some<br>indication of overall positive effect on net primary<br>productivity. It is expected that any positive<br>responses of GPP to discharge events will occur in<br>the timeframe of 1-3 weeks post event. This is<br>based on the hypothesis that flow events introduce<br>nutrients which can then fuel algal and biofilm<br>growth. Growth rates of algae mean effects take a<br>week or more to be manifest. | Analyses indicated weak positive effects<br>of discharge on Net primary productivity.<br>More complex models will be developed in<br>subsequent years which include looking at<br>lag phases post flow event for GPP<br>increases.  |

#### 4.1.2 Area specific evaluation questions

| Question  | Were appropriate<br>flows provided? | Effect of environmental flows   | What information was the evaluation based on?   |
|---|-------------------------------------|---|---|
| How does the timing<br>and magnitude of CEW<br>delivery affects rates of<br>Gross Primary<br>Productivity and<br>Ecosystem Respiration<br>in the lower Goulburn<br>River?   | Yes                                 | As noted in 4.1.1, the immediate effect of<br>flow increases (including those from CEW<br>delivery) was to suppress GPP and ER. It<br>is expected that if flows introduce nutrients<br>there will be a post-flow lag of perhaps 10-<br>20 days for significant increases in GPP to<br>occur (shorter response times are expected<br>for ER as bacterial populations increase in<br>size much faster than algal populations).<br>The key point is that rates of both GPP and<br>ER were in the lower range of normal<br>behaviour for river systems worldwide and<br>all variability observed occurred within<br>these low ranges. | Based on daily estimates of gross primary<br>production and Ecosystem Respiration<br>regressed with daily discharge in a model<br>using Bayesian linear regression. More<br>complex models will be developed in<br>subsequent years which include looking at<br>lag phases post flow event for GPP and ER<br>increases. In addition, we will be able to<br>follow individual packets of water as each<br>travels downstream from logger to logger.<br>This requires excellent hydrological<br>modelling and data regarding water<br>velocities and transit times between each of<br>the logger sites. This will be greatly assisted<br>when meaningful data is obtained from the<br>most upstream site. |
| How do stream<br>metabolism responses<br>to CEW in the lower<br>Goulburn River differ<br>from CEW responses<br>in the Edward Wakool<br>system where the<br>likelihood of overbank<br>flows is higher and<br>nutrient concentrations<br>are generally much<br>lower? | Yes                                 | Stream metabolism rates were slightly<br>lower in the Goulburn River. The actual<br>CEW and natural flows in the Edward-<br>Wakool prevented determination of flow-<br>metabolism relationships. In neither system<br>did flows get out of the river channel. Both<br>systems had very low bioavailable nutrient<br>concentrations (especially P) which was<br>significant constraint on GPP (and affected<br>ER too). Very low bioavailable P (and N) is<br>the reason metabolic parameters are at the<br>low end of international values.   | Based on daily estimates of gross primary<br>production and Ecosystem Respiration<br>regressed with daily discharge,<br>Photosynthetically active radiation (PAR)<br>(GPP only), and temperature. Monthly<br>nutrient sampling was assumed to be<br>representative of nutrient concentrations<br>most/all of the time.  |

### 4.2 Main findings from stream metabolism monitoring program

The main findings from the first year of stream metabolism data (Oct/Nov 2014 through to Apr 2015):

- The flow patterns experienced during this period meant that water was always retained within the river channel, rather than reconnecting major backwaters or accessing the floodplain. Hence there was no significant introduction of nutrients and organic carbon into the river. Higher flows are required, and while they are allowed for in environmental flows planning, are currently constrained by third party risks.
- Stream metabolism and hence the energy base of the aquatic foodwebs was almost certainly constrained by very low bioavailable nutrient concentrations, most notably phosphate which was typically only 0.003 mg P/L. These concentrations are marginally lower than median values measured over the last decade at McCoy's Bridge.
- Rates of Gross Primary Production (GPP) and Ecosystem Respiration (ER) vary with flow but within a small range at the lower end of rates observed in river systems around the world. Both GPP and ER were initially suppressed during and after flow events.
- Statistical analyses indicated negative effects of discharge on GPP and ER once the structure of the daily data had been accounted for. There was some indication of an overall increase in Net Primary Productivity (NPP) with discharge. Although detectable, the decreases in GPP and ER, along with the increases in NPP are small. Such changes are unlikely to have any significant effects (positive or negative) on either the water quality in the Goulburn River or on ecosystem health.

## 5. Macroinvertebrates

Macroinvertebrate objectives were measured in relation to Commonwealth environmental water, which was delivered as spring freshes in 2014, with sampling occurring before (September to October, 2014), during (October to November 2014), and after the freshes (December, 2014, to January, 2015). The samples taken during the fresh were over and above the program described in the monitoring and evaluation plan (Webb et al. 2014), and we do not at present have resources to process the samples. It is hoped that during-fresh sample results will be able to be presented in future annual evaluation reports, but here we present results based upon the before-fresh and after-fresh samples. The freshes were delivered to promote the recovery of bank vegetation, stimulate fish reproduction, and were also expected to increase macroinvertebrate diversity, abundance (biomass), and adult macroinvertebrate emergence. These effects were predicted through the provision of suitable instream habitat, improving riparian habitat through bank wetting and promoting riparian vegetation, improving water quality, and enhancing colonisation and drift of macroinvertebrates. Although we did not find strong evidence from the 2014-15 survey period that environmental flows provided beneficial effects for macroinvertebrates, neither did we find negative effects. It should be noted that seasonal differences among macroinvertebrate assemblages may affect responses (e.g. macroinvertebrate communities present in spring will react differently to flow events than those present in summer). The generality of the year-1 finding, along with effects of flow timing will be better elucidated with repeated, long-term monitoring.

### 5.1 Evaluation

| Question   | Were appropriate flows provided?  | Effect of environmental flows   | What information was the evaluation based on?   |
|--|---|---|---|
| What did CEW contribute to<br>macroinvertebrate diversity in<br>the lower Goulburn River?                            | Unknown. As this is only the first<br>year of sampling, the data are<br>only preliminary and future<br>monitoring will help answer this<br>question with more confidence. | There was no obvious increase<br>in taxonomic richness or<br>diversity due to the<br>environmental flows. However,<br>environmental flows may have<br>helped sustain richness and<br>diversity in the Goulburn River<br>during the dry conditions within<br>the region (as described in<br>Section 6.2) | This was based on a qualitative<br>analysis of monitored results<br>from the 2014-15 survey period.<br>Statistical analyses were not<br>performed as the data are only<br>preliminary. More<br>comprehensive analyses can be<br>conducted once a second year<br>of data have been acquired. |
| What did CEW contribute to<br>macroinvertebrate biomass<br>(abundance) in the lower<br>Goulburn River?               | Possibly. Some of the data are<br>consistent with this<br>interpretation, but further long-<br>term monitoring is required to<br>more definitely answer this<br>question. | An increase in some measures<br>of the macroinvertebrate<br>abundances in the Goulburn<br>River indicate environmental<br>flows in spring were having an<br>effect, especially as similar<br>increases were not seen in<br>Broken River (which does not<br>receive environmental flows).                | This was based on a qualitative<br>analysis of monitored results<br>from the 2014-15 survey period.<br>Statistical analyses were not<br>performed as the data are only<br>preliminary. More<br>comprehensive analyses can be<br>conducted once a second year<br>of data have been acquired. |
| What did CEW contribute to<br>macroinvertebrate emergence<br>(and hence recruitment) in the<br>lower Goulburn River? | Yes   | Macroinvertebrate emergence,<br>measured by abundance of adult<br>Chironomidae, appeared to be<br>stimulated by environmental<br>flows in Goulburn River.   | This was based on a qualitative<br>analysis of monitored results<br>from the 2014-15 survey period.<br>Statistical analyses were not<br>performed as the data are only<br>preliminary. More<br>comprehensive analyses can be<br>conducted once a second year<br>of data have been acquired. |

#### 5.1.1 Area specific evaluation questions

## 5.2 Main findings from macroinvertebrate monitoring program

Three methods were employed to assess the effects of environmental flows on macroinvertebrates in the Goulburn River. Each method was employed before and after the Commonwealth environmental watering events (pre- and post-CEW) in spring/summer, 2014-2015. Two sites were assessed using these methods: the Goulburn River at McCoys Bridge, which received environmental flows, and the Broken River at Central Avenue, Shepparton East, which did not receive environmental flows (and was thus used as a reference site for comparisons). The following is a summary of results from each method; a more detailed description of the methods, results and discussion are given in Appendix D.

#### Artificial substrates

- In both pre- and post-CEW sampling, the average abundance of macroinvertebrates occupying the
  artificial substrates was marginally higher in the Goulburn River than in the reference site (Figure 5a).
  Macroinvertebrate abundance was substantially lower at both sites in the post-CEW sampling event, so
  it appears factors other than environmental flows were affecting macroinvertebrate colonisation.
- More taxa were present in substrates from the reference site than the Goulburn River in both pre- and post-CEW sampling, but there was no evidence environmental flows affected the number of taxa. Diversity was unaffected by Commonwealth environmental water and remained similar in the Goulburn River during both sampling events, but increased in the reference site post-CEW.
- Not every taxon responded to site or sampling events similarly, and there was evidence environmental
  water may have affected the abundances of some common taxa. For example, the environmental flow
  appeared to have a positive effect on the mayfly *Atalophlebia* sp. AV6 and chironomid *Paracladopelma*sp., with abundances increasing post-CEW in the Goulburn River, but not the reference site. Similarly,
  the chironomids *Procladius* sp. and *Djalmabatista* sp. showed greater increases in abundance in the
  Goulburn River post-CEW than in the reference site.
- The total abundance and taxa richness of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) taxa (EPT) decreased at both sites in the post-CEW sampling event.

#### Replicated Edge Sweep Sampling

- Macroinvertebrate abundance decreased at both sites post-CEW, but this was more pronounced in the reference site (Figure 5-1b), indicating that the effects of factors that reduced macroinvertebrate abundance in edge habitats may have been reduced by environmental flows in the Goulburn River.
- Slightly more taxa were caught in the reference site than in the Goulburn, but at both sites this decreased post-CEW. Diversity also decreased at both sites post-CEW, and did not seem to be affected by environmental flows.
- There was evidence environmental flows had a positive effect on individual taxa, with the abundance of the chironomid *Nanocladius* sp. substantially increasing in the Goulburn River post-CEW while decreasing in the reference site.
- The abundance and number of EPT taxa was always higher in the reference site than the Goulburn River, with no apparent effect of the environmental flow in the Goulburn River on EPT taxa.
- The abundance and taxa richness of crustaceans in the Replicated Edge Sweep Samples (RESS) samples was always greater in the Goulburn River than in the reference site; however at both sites the number of taxa declined post-CEW. Crustacean abundance also decreased post-CEW in the Goulburn River, which may be caused by environmental flows.

#### Yellow sticky traps

- Of the 22,659 invertebrates caught on the yellow sticky traps, most were terrestrial. However, 2,666 individuals were from the dipteran family Chironomidae, and most of these were species with aquatic larval life stages.
- The total abundance of aquatic chironomids was higher in the reference site than the Goulburn River, and abundances increased at both sites post-CEW (Figure 5c). However, this was due to large numbers of the most common species, *Corynoneura australiensis*, at Broken River, and exclusion of this species showed a different result (Figure 5-1d). Here, abundances again increased at both sites post-CEW, but this increase was much greater in the Goulburn River, indicating environmental flows could be stimulating emergence.
- Environmental flows appeared to have a beneficial effect on several common species. *Paratrichocladius pluriserialis* abundances increased more in the Goulburn River than in the reference site post-CEW, indicating environmental flows at this site could be improving survival, providing better larval habitat and conditions to support more individuals, or stimulating adult emergence. *Cladotanytarsus bilinearis* and *Microcricotopus parvulus* abundances also increased in the Goulburn River during post-CEW sampling; however, as these species were absent from the reference site, it is difficult to attribute this to environmental flows.
- Species richness did not appear to respond to environmental flows, with the number of taxa captured increasing similarly at both sites post-CEW. Measures of chironomid diversity were not informative and did not show any obvious response to environmental flows. Diversity indices were lower in the reference site than the Goulburn River, particularly in the post-CEW event, indicating the dominance of *Corynoneura australiensis* at the reference site.



Figure 5-1. Abundance of (a) macroinvertebrates collected from artificial substrates (average ± standard error), (b) macroinvertebrates collected from Replicated Edge Sweep Samples (average ± standard error), (c) all aquatic Chironomidae caught on yellow sticky traps and (d) aquatic Chironomidae excluding Corynoneura australiensis caught on yellow sticky traps in 2014. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows in the study.

#### Summary

The three sampling methods were effective at capturing a large and diverse number of macroinvertebrates from the Goulburn and Broken Rivers. All three methods showed some macroinvertebrate taxa were responding to environmental flows in the Goulburn River, perhaps as a result of the slight increase in daily Ecosystem Respiration (indicative of increased organic carbon in the river channel) as a result of the flows. As well as responses observed in aquatic macroinvertebrates, terrestrial invertebrates in the riparian zone also increased in abundance after spring freshes; it is hypothesised that environmental flows improved riparian habitat quality for these animals. However, it was also evident that differences between sites as well as other factors, such as differences in the pre- and post-CEW sampling periods, could also be contributing to macroinvertebrate responses. Repeated monitoring will help to separate environmental flow effects from other factors that affect macroinvertebrate abundance, diversity and emergence. They may also allow us to further focus on particular species that respond consistently to environmental flows.

## 6. Vegetation diversity

Bankside vegetation was measured at two sites (Loch Garry and McCoys Bridge) before and after the spring freshes delivered in 2014. The first fresh was designed primarily to improve vegetation outcomes by wetting banks and providing opportunities for germination and growth of inundation-adapted native species. Determining the before-after effects of environmental flows is made difficult by the fact that the post-fresh samples are taken in summer when temperatures are much hotter and bankside vegetation may be dried out. Nevertheless, the gradient of inundation duration up the bank allows some inference as to the likely benefit of environmental flows.

## 6.1 Evaluation

#### 6.1.1 Basin-scale evaluation questions

| Question   | Were appropriate flows<br>provided?  | Effect of environmental flows   | What information was the evaluation based on?   |
|--|--|---|---|
| What did CEW contribute to vegetation species diversity?   | The spring fresh flows delivered<br>are of the type expected to be of<br>benefit to species diversity.   | Abundance of several species<br>increased on the portion of the<br>bank inundated by the spring | Qualitative examination of<br>species cover plots versus<br>elevation and inundation profiles.                              |
| What did CEW contribute to vegetation community diversity? | The spring fresh flows delivered<br>are of the type expected to be of<br>benefit to community diversity. | flow events, but not on higher<br>portions of the bank that were<br>not inundated.              | We propose to confirm these<br>conclusions with statistical<br>analyses once more data have<br>been collected (i.e. year 2) |

#### 6.1.2 Area specific evaluation questions

| Question  | Were appropriate flows provided?  | Effect of environmental flows   | What information was the evaluation based on?   |
|---|---|---|---|
| Long-term evaluation  | on questions  |   |   |
| What has CEW<br>contributed to the<br>recovery of riparian<br>vegetation<br>communities on the<br>banks of the Lower<br>Goulburn River that<br>were impacted by<br>drought and flood? | While the current flow delivery is<br>appropriate it is not known if<br>adjustments to the timing,<br>magnitude or rates of flows delivery<br>would enhance vegetation<br>recovery.<br>For example, the earlier delivery of<br>the spring fresh may provide a<br>longer window for plant growth<br>following the recession of freshes<br>because climate conditions are<br>likely to be more favourable than<br>when freshes are delivered later in<br>the season.<br>(see Appendix E for further<br>discussion of flow management) | Several native plant species with an affinity for<br>wet habitats only occurred in regions of the<br>bank inundated by spring freshes. In contrast,<br>the native grass <i>Poa labillardierei</i> preferred<br>locations at or above the level inundated by<br>spring freshes.<br>Within the region of the bank inundated by<br>spring freshes, the cover of vegetation was<br>greatest at higher elevations and declined at<br>lower elevations where deeper and more<br>frequent inundation was experienced.<br>The recruitment of woody species ( <i>Acacia</i><br><i>dealbata</i> and <i>Eucalyptus camaldulensis</i> ) was<br>rare and restricted to higher areas of the bank<br>which experience shallow and less frequent<br>inundation. | Patterns of changes in<br>vegetation cover and<br>recruitment were<br>qualitatively assessed along<br>the elevation gradient,<br>together with patterns of<br>inundation produced by<br>spring freshes. |

| Question  | Were appropriate flows provided?                                 | Effect of environmental flows   | What information was the evaluation based on?  |
|---|--|---|--|
| How do vegetation<br>responses to CEW<br>vary between sites<br>with different<br>channel features<br>and different bank<br>conditions?  | Yes but see comments above and<br>in Appendix E                  | The cover of vegetation in regions of the bank<br>inundated by spring freshes increased following<br>spring freshes at Loch Garry but not at McCoys<br>Bridge where vegetation cover did not change.<br>Although spring freshes are likely to have<br>contributed to the increase in vegetation cover,<br>it was not possible to distinguish flow effects<br>from natural variation in cover. Further<br>monitoring is needed to determine if patterns<br>persist. It is unclear why responses of<br>vegetation to the spring fresh differed among<br>sites, but one possibility is that these sites are<br>at different points along their recovery<br>trajectories after drought and floods. The cover<br>of vegetation tended to be lower on outside<br>bends of the river compared with straight<br>sections or inside bends. This pattern is<br>consistent with typical distributions of bank<br>stability in rivers with inner bends generally<br>being most stable and thereby providing<br>suitable conditions for vegetation<br>establishment. | Based on patterns of<br>changes in percent cover of<br>vegetation along the<br>elevation gradient pre and<br>post fresh at each site.<br>Mean cover of vegetation at<br>transects located on<br>outside, inside and straight<br>sections of the stream                                 |
| Short-term evaluati   | on questions   | 1   | 1  |
| Does the CEW<br>contribution to<br>spring freshes and<br>high flows trigger<br>germination and<br>new growth of<br>native riparian<br>vegetation<br>communities on the<br>banks of the lower<br>Goulburn River? | Yes but see comments in row 1 of<br>this table and in Appendix E | The elevation reached by spring freshes<br>represents a boundary in the distribution of<br>some species along the bank. Several species<br>with an affinity for wet habitats were limited to<br>regions inundated by the fresh, whereas the<br>native perennial grass <i>Poa labillardierei</i><br>preferred elevations at or above the inundation<br>level.<br>Vegetation cover within the region of the bank<br>inundated by spring freshes was higher<br>following the spring fresh at Loch Garry but not<br>at McCoys Bridge.<br>Woody recruits represented by <i>Acacia dealbata</i><br>and <i>Eucalyptus camaldulensis</i> were rare and<br>limited to higher elevation that experience<br>shorter and more shallow inundation.   | Based on patterns of<br>change in vegetation cover<br>and inundation along the<br>elevation gradient resulting<br>from spring freshes<br>Presence of woody recruits<br>along the elevation gradient<br>along with the upper<br>elevation inundated by<br>spring freshes at both sites. |
| How does CEW<br>delivered as low<br>flows and freshes<br>contribute to<br>maintaining new<br>growth and<br>recruitment of<br>native vegetation<br>on the banks of the<br>lower Goulburn<br>River?               | Unknown as yet, requires 2015 surve                              | ey data   |  |

## 6.2 Main findings from vegetation monitoring program

- The distribution and cover of vegetation along the bank varied with the extent and duration of inundation provided by spring freshes. Several native plant species that have an affinity for wet habitats only occurred in regions of the bank inundated by spring freshes. This suggests that e-flows are likely to be contributing to maintaining the distribution of flood tolerant vegetation on the bank.
- The area of bank that was inundated by the spring freshes was limited by the peak magnitudes of those freshes (~7,000 ML/d). Higher spring freshes (up to the 15,000 ML/d proposed in the seasonal watering proposal (GBCMA 2014) may promote a greater vegetation response. However the delivery of higher flows is currently constrained by both third party risks and the volume of water available for delivery as environmental flows.
- Within the region of the bank inundated by spring freshes, the cover of vegetation is greatest at higher elevations and declines at lower elevation where deeper and more frequent inundation is experienced.
- Woody recruits represented by Acacia dealbata and Eucalyptus camaldulensis were rare on the banks and restricted to higher elevations that experience shorter and more shallow inundation. This indicates that e-flow are achieving their objective of limiting the encroachment of terrestrial vegetation down the bank by maintaining sufficient duration of inundation above the threshold for woody plant establishment.
- The cover of vegetation increased following spring freshes at Loch Garry but not at McCoys Bridge, where cover did not change. Species that contributed to the increase in cover only occurred at elevations inundated by spring freshes and it was not possible to distinguish flow responses from natural variation in cover. It is unclear why responses of vegetation to the spring fresh differed among sites. One possibility is that these sites are at different points along their recovery trajectories.
- Higher than average temperatures and lower than average rainfall in December 2014 may have limited vegetation responses to freshes. When plants were surveyed in December 2014 the banks were observed to be extremely dry. The depletion of soil moisture with the onset of hotter and drier conditions may have constrained vegetation responses to spring freshes.
- Vegetation cover tended to be higher on banks located on inside bends, followed by straight sections and lowest on outside bends. This pattern is consistent with typical distributions of bank stability in rivers with inner bends generally being most stable and thereby providing suitable conditions for vegetation establishment. In evaluating vegetation responses to environmental flows the influence of channel features needs to be considered.

## 7. Fish

In spring 2014, environmental water was delivered to the lower Goulburn River over 3 weeks from mid-November to early December in accordance with seasonal watering plans. The primary aim of this flow event was to trigger spawning and movement of golden perch. A maximum discharge of about 6300 ML/d was released. Immediately prior to this event there was also an environmental water release from mid-October to early November over 3 weeks for vegetation objectives. A maximum discharge of about 7600 ML/d was released. Observed effects on fish are summarized below, with detail provided in Appendix F.

## 7.1 Evaluation

#### 7.1.1 Basin-scale evaluation questions

| Question  | Were appropriate flows provided?           | Effect of environmental flows   | What information was the evaluation based on?  |  |  |  |  |
|---|--|---|--|--|--|--|--|
| Long-term evaluation questions                              |  |   |  |  |  |  |  |
| What did CEW<br>contribute to native fish<br>populations?   | Possibly                                   | Spawning and spawning associated<br>movement of golden perch observed<br>during environmental flow events                                     | Qualitative and statistical analysis of larval survey and fish tracking data.  |  |  |  |  |
| What did CEW<br>contribute to fish<br>species diversity?    | Unknown at this stage                      | Unknown at this stage   | There is only a single data point from the first annual survey   |  |  |  |  |
| Short-term evaluation questions                             |  |   |  |  |  |  |  |
| What did CEW<br>contribute to fish<br>community resilience? | Unknown at this stage                      | Unknown at this stage   | There is only a single data point from the first annual survey   |  |  |  |  |
| What did CEW<br>contribute to native fish<br>survival?      | Unknown at this stage                      | Unknown at this stage   | There is only a single data point from the first<br>annual survey. Size frequency data from target<br>species may answer this question in future |  |  |  |  |
| What did CEW<br>contribute to native fish<br>reproduction?  | Yes (for golden perch<br>and silver perch) | Golden perch exhibited a strong<br>spawning response to increased<br>flows. Silver perch also spawned in<br>association with increased flows. | Quantitative observations based on drift netting<br>data. Peak egg abundances were collected<br>coinciding with an environmental flow release    |  |  |  |  |
| What did CEW<br>contribute to native fish<br>dispersal?     | Yes (for golden perch)                     | Long-distance movements coincided<br>with increases in flow associated with<br>environmental flow releases                                    | Qualitative observations based on telemetry data   |  |  |  |  |

### 7.1.2 Area specific evaluation questions

| Question   | Were appropriate flows<br>provided? | Effect of environmental flows   | What information was the evaluation based on?  |  |  |  |  |
|--|-------------------------------------|---|--|--|--|--|--|
| Long-term evaluation questions   |                                     |   |  |  |  |  |  |
| What did CEW contribute to the<br>recruitment of golden perch in<br>the adult population in the lower<br>Goulburn River? | Unknown                             | Population surveys revealed no<br>strong relationships between<br>golden perch spawning and<br>recruitment of juvenile fish,<br>suggesting that spawning may<br>not necessarily translate into<br>recruitment of juveniles into the<br>local population | Qualitative observations based<br>on comparisons between<br>electrofishing and drift netting<br>data |  |  |  |  |

| Question  | Were appropriate flows provided? | Effect of environmental flows  | What information was the evaluation based on?   |  |  |  |
|---|----------------------------------|--|---|--|--|--|
| Short-term evaluation questions   |                                  |  |   |  |  |  |
| What did CEW contribute to<br>Golden Perch spawning and in<br>particular what magnitude,<br>timing and duration of flow is<br>required to trigger spawning? | Yes                              | Golden perch exhibited a strong<br>spawning response to the<br>environmental flow event<br>described at the beginning of this<br>chapter. Silver perch also<br>spawned in association with<br>increased flows.   | Quantitative observations based<br>on drift netting data. Peak egg<br>abundances were collected<br>coinciding with an environmental<br>flow release. There was a very<br>strong statistical association<br>between both probability of<br>spawning and abundance of<br>eggs/larvae and the rate of flow<br>increase and temperature |  |  |  |
| What did CEW contribute to the survival of Golden Perch larvae in the lower Goulburn River?   | Unknown                          | Although golden perch spawned<br>in 2014, no young-of-year fish<br>were collected. Thus, whilst<br>increased flows can promote<br>golden perch spawning, this may<br>not necessarily lead to<br>immediate <i>in situ</i> recruitment of<br>juvenile fish | Quantitative observations based<br>on electrofishing and netting<br>data  |  |  |  |
| What did CEW contribute to the<br>movement of golden perch in<br>the lower Goulburn River and<br>where did those fish move to?                              | Yes                              | Long-distance movements<br>coincided with increases in flow<br>associated with environmental<br>flow releases. Long-distance<br>movements occurred primarily<br>downstream into the lower<br>reaches.  | Qualitative observations based<br>on telemetry data. No statistical<br>analysis of these data<br>undertaken as yet.   |  |  |  |

## 7.2 Main findings from fish monitoring program

Annual surveys (electrofishing and netting)

- The golden perch population consisted of mostly larger fish, with few individuals below the minimum legal size of 300 mm. There was no evidence of recent recruitment with no young-of-year fish collected.
- Silver perch were only collected in low numbers, and there was no evidence of recent recruitment with no YOY fish collected.
- Given that golden perch and silver perch lay semi-buoyant eggs that drift downstream on river currents, potentially over large distances, it is possible that eggs drift downstream into the Murray River, and that any recruitment into the Goulburn River occurs at a later stage by older fish and also potentially by fish from other river systems.
- A number of species of conservation significance were collected, namely Murray cod, trout cod and silver perch. A range of introduced fish species, namely carp, goldfish and eastern gambusia, were also collected.
- The annual surveys will be useful for the assessment of long term-changes in fish assemblage structure (species composition and abundance), and analyses conducted at the basin scale may be able to relate these changes to changes in flow regimes. This would answer the long-term and short-term evaluation questions related to the contribution of CEW to native fish populations in the standard monitoring protocol document. However, it should be recognized that such an analysis would not directly elucidate cause and effect.

Surveys of eggs and larvae (drift nets and light traps)

- Golden perch exhibited a strong spawning response to increased flows. Peak egg abundances were collected in late November coinciding with a spring fresh flow release that caused an increase in flow from about 964 to 6309 ML/d associated with an environmental flow release.
- Low numbers of golden perch eggs were also collected in late October coinciding with an increase in flow from about 1448 to 7673 ML/d associated with an earlier environmental flow release (for vegetation objectives).
- Statistical analysis showed a strong association of both probability of spawning and abundance of eggs/larvae with the rate of increase of flows from day to day during the sampling period. There was also a positive effect of water temperature on probability of spawning and on egg/larvae abundance.
- Similar to golden perch, peak egg abundances of silver perch were collected in late November coinciding with an increase in flow from about 964 to 6309 ML/d associated with an environmental flow release.

#### Movement of golden perch

- Movement activity of golden perch was greatest during increased flow in the spawning season.
- Many of the tagged fish undertook long-distance (> 15-20 km) movements (predominantly downstream) associated with environmental flow releases (e.g. from 1448 to 7673 ML/d in late October, and from 964 to 6309 ML/d in late November) targeted at promoting golden perch spawning and movement.
- Three tagged fish also visited the Murray River coinciding with environmental flow releases, before returning to the Goulburn River.

## 8. Adaptive management

What are the implications of the monitoring results for future environmental water delivery and monitoring in the Lower Goulburn River?

- Bank condition assessments indicate at this stage that additional erosion and deposition caused by environmental flows are small compared to those that occur under the remainder of the regulated flow regime. Therefore flow delivery can proceed with confidence that it is not having major adverse effects on the banks of the Goulburn River. However, these conclusions are based upon small flow events.
- Stream metabolism monitoring does not indicate any strong effects of environmental flows at this stage, although there are some indications of an improvement in net primary productivity associated with spring discharge events. The strong association between metabolism parameters and temperature implies that any events specifically aimed at improving stream primary productivity should take place when water temperatures are warm (i.e. late spring or summer). The results highlight the need for larger flows in the future to mobilise carbon and nutrients from major backwaters and the floodplain. Current flows are always retained within the river channel and appear to have limited ability to mobilise sufficient carbon and nutrients to provide an energy base to support a health aquatic foodweb. Higher flows (e.g. 15,000 ML/d) are included in environmental flows plans (GBCMA 2014), but delivery of such flows is currently constrained by third party risks. The constraints project currently being undertaken by the Goulburn-Broken Catchment management authority may allow the release of higher flows in future.
- Macroinvertebrate monitoring found a weak correlation between biomass of macroinvertebrates
  collected using edge sweep sampling and the spring environmental flow events. This is consistent with
  the idea that flow events bring more organic carbon into the system to act as a stimulant to
  macroinvertebrate productions. However, the relatively weak macroinvertebrate response may reflect
  the limited input of carbon into the river channel as suggested by the stream metabolism results. With
  only one year of monitoring, we do not yet have any recommendations regarding 'optimising' spring
  flows for macroinvertebrate production.
- Vegetation monitoring demonstrated benefits of environmental flows for promoting vegetation on those
  parts of the banks inundated by spring freshes. However, we believe that benefits may be greater if the
  first extended spring flow is delivered slightly earlier than in 2014. This would allow plants to grow in
  response to bank wetting before air temperatures raise significantly as we move into summer. Plants
  that have grown better by the time summer arrives may be better able to cope with the extreme heat
  and dryness of summer. Higher peaks in spring freshes (e.g. 15,000 ML/d; GBCMA 2014) may promote
  further plant growth, but delivery of such flows is constrained by third party risks and water availability.
- Fish spawning monitoring demonstrated a strong association between the rate of rise in discharge and spawning success, mediated by effects of water temperature. The second spring fresh induced spawning in numbers not previously seen, other than following the 2010 floods, and so can be regarded as an outstanding example of managed flows achieving their aim. However, we cannot claim to have full knowledge of the spawning requirements for golden perch yet, and future 'negative' results (reduced or absent spawning) will also inform adaptive management. Adjusting the timing of the second spring fresh will be important for determining how closely spawning is tied to temperature (e.g. if flows are delivered in cooler water, will we see spawning?), and also data collection over the remainder of the LTIM project will improve our understanding of the importance of antecedent winter flows on preparing fish for spawning.
- Adult golden perch moved in response to environmental flow events; mostly migrating downstream to
  areas where spawning took place. The non-detection of golden perch young-of-year in the annual
  electrofishing survey may indicate that larvae produced in the Goulburn river are exported from the
  system, only recruiting back into the Goulburn as larger sub-adults in later years. Incorporating
  consideration of connectivity at larger spatial scales (i.e. among rivers) for fish should be a key
  component of future environmental flow regime developments.
# 9. Stakeholder communications

The following planned communication and engagement actives were undertaken over the last twelve months to inform stakeholders and the broader community about the aims and results of the Goulburn River LTIM Project and the role of the Commonwealth Environmental Water Office in environmental water management. Selected examples of communications are included in Appendix G.

# 9.1 Media Releases and Articles

Five media releases between March 2014 and February 2015 promoted the Goulburn River LTIM Project, Commonwealth environmental water use in the Goulburn River, fish monitoring including Golden Perch breeding responses to environmental flows and bank condition monitoring.

The media releases resulted in corresponding articles in the Seymour Telegraph, Alexandra Standard, Country News and Shepparton News. Articles were also included in the March 2015 edition of the GB CMA electronic newsletter 'Connecting Community and Catchment', which has over 892 subscribers.

# 9.2 Social Media

4 posts to the GB CMA iSpy Facebook page and 3 posts to the GB CMA Facebook page on fish monitoring including Golden Perch breeding responses to environmental flows. These posts were viewed by over 1,500 people, shared with 37 people, liked by 44 people and generated 5 comments.

https://www.facebook.com/gbcmaispyfish

https://www.facebook.com/gbcma

7 tweets promoting the Goulburn River LTIM project, Commonwealth environmental water use in the Goulburn River and fish monitoring including Golden Perch breeding responses to environmental flows. Over 500 people currently follow GB CMA twitter feeds.

## 9.3 Fact sheets

Draft Goulburn River LTIM project fact sheets have been developed incorporating feedback from all environmental water holders, waterway managers and delivery partners. One outlining the overall project and one for each of the key monitoring activities (fish, vegetation, macroinvertebrates, stream metabolism and bank condition). The final fact sheets will be ready for distribution and posting shortly.

# 9.4 Videos

Short web videos (3-5 minutes) are being developed on each of the key monitoring activities (fish, vegetation, macroinvertebrates, stream metabolism and bank condition). The videos are expected to be completed by the end of 2015.

## 9.5 Radio

GB CMA staff discussed and promoted the Goulburn River LTIM project on 3SR FM and UG FM interviews.

## 9.6 **Presentations**

On the 10th December GB CMA Staff and David Papps, the Commonwealth Environmental Water Holder, presented at the Goulburn Broken Environmental Watering Forum in Shepparton. They discussed the role of the Commonwealth Environmental Water Holder, how Commonwealth environmental water is used and how the outcomes of Commonwealth environmental water use are being assessed through the LTIM project. Sixty people from various stakeholder groups attended the forum, including representatives from local governments,

water authorities, land holders and community members, and interest groups including Environment Victoria and Field and Game Australia.

On the 21st May Dr Wayne Koster presented on the fish monitoring been undertaken as part of the Goulburn River LTIM project at a Research Forum run by the GB CMA. The forum showcased the aquatic and terrestrial research and monitoring work undertaken in the Goulburn Broken Catchment over the past 18 months. The forum was attended by approximately 105 community members and agency staff.

GB CMA staff presented/provided updates to a number of community and agency groups throughout the year on the Goulburn River LTIM project. These groups included:

- the Wyuna Landcare Group;
- GB CMA Indigenous Consultation Group;
- GMW Water Resource Group;
- Shepparton fishing groups;
- Local Government Biodiversity Reference Group;
- RiverConnect (an initiative of the Shepparton-Mooroopna community to promote the protection and enhancement of the Goulburn and Broken rivers);
- GB CMA partnership group
- Dookie College
- Kotupna Farmers Group;
- U3A;
- Broken Environmental Water Advisory Group; and
- Fairley Leadership Group.

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# Appendix A. Hydrology and Hydraulics methods

# A.1 Introduction

There are five established flow gauges in the lower Goulburn River that provide high quality data over a long period and have good rating curves. The gauges at Goulburn Weir and Murchison provide good information about flows in Zone 1, and the gauges at Loch Garry and McCoys Bridge provide good flow information for Zone 2. The fifth gauge is at Shepparton, which is close to the boundary between Zone 1 and Zone 2 and can be used to check flow conditions and assumptions for either Zone. An additional established gauge in the lower Broken river is being used to provide flow data for the macroinvertebrate analysis.

Reliable daily and instantaneous flow records are critical to determine whether the environmental water released from storages meets the target flows throughout the river. These hydrological data are critical to analysing the results of all of the biological and physical monitoring activities that are proposed in this M&E Plan. The existing flow gauge network in the lower Goulburn River and the small number of large tributaries that flow into it, provide a reliable measure of flow at most points along the river from Goulburn Weir to the Murray River and therefore meet the hydrological monitoring requirements for the LTIM Project.

## A.2 What hydrological data have been used for the analysis?

Verified hydrology data have been drawn from the Victorian Water Measurement Information System <DELWP, 2015>. Data were obtained for the sites outlined in Table A-1. Where data were unavailable, unverified (or operational) data were obtained from Goulburn-Murray Water, and the verified data sequence infilled with the operational data. Both flow and level data were available at each gauge for verified data, but only flow data were available from the operational data.

| Gauge Number | Gauge Name                      |
|--------------|---------------------------------|
| 405204       | Goulburn River at Shepparton    |
| 405232       | Goulburn River at McCoys Bridge |
| 405253       | Goulburn River at Goulburn Weir |
| 405276       | Goulburn River at Loch Garry    |
| 405200       | Goulburn River at Murchison     |
| 404222       | Broken River at Orrvale         |
| 409215       | Murray River at Barmah          |

Table A-1. Available gauge data

Loch Garry flows were unavailable for several lengthy periods of the record, and therefore a regression was developed to infill flows with the McCoys Bridge flows. The regression equation used was:

Loch Garry = 0.9297 x McCoys (next day) +91.781,

R<sup>2</sup> of 0.9702

McCoys (next day) represents the flow at McCoys on the next day to account for travel time

There are several sites where flow data were not available; these are listed in Table. A-2, and the method to derive flows at each location summarized.

An environmental flow series is available from Goulburn Murray Water, based on flows that are accounted as environmental flow. This series is only available at McCoys Bridge gauge, and is adopted to other locations by adopting a delay. This series allowed for flow time series to be adopted that excluded environmental flows, and were also converted to level using rating tables at each of the sites.

Table A-2. Flow data where no gauge exists.

| Site          | Method for deriving a flow series   |
|---------------|---|
| Darcy's Track | Flows at Shepparton the next day. This represents the correct magnitude and pattern of flows, when compared to the next downstream site, McCoys Bridge. |
| Moss Road     | Adopt flow series from Goulburn Weir  |
| Yambuna       | Adopt flow series from McCoy's Bridge   |
| Cable Hole    | Adopt Goulburn Weir data (same as Moss Road)  |

1-Dimensional Hydraulic models are available for several sites, and were adopted as part of the VEFMAP monitoring. A summary of these models is in Table A-3. Many of these models will be superseded in future years by the 2-dimensional hydraulic models being adopted for the physical habitat assessments.

Table A-3. Hydraulic models available.

| Site                   | Model reference |
|------------------------|-----------------|
| Loch Garry             | VEFMAP site 34  |
| McCoys                 | VEFMAP site 36  |
| Moss Road              | VEFMAP site 26  |
| Broken River at Orvale | VEFMAP site 9   |
| Darcy Track            | VEFMAP site 32  |

To determine a time series of velocity values, a representative cross section was selected, which reflected the typical shape of the channel throughout the reach. From this, a velocity v flow rating table was adopted for each reach, which then enabled the flows to be converted to velocity. In reality, the velocity will vary as water passes through different cross section features, but this provides a representation of velocity typical in the reach.

# Appendix B. Detailed results for Physical habitat and Bank erosion

# **B.1** Introduction

Physical habitat in the form of hydraulic conditions and the condition of the river banks (including sediment dynamics) are important determinants of fish and macroinvertebrate population dynamics, yet the relationships to flow are poorly understood. Therefore, in the physical monitoring program we are developing hydraulic models to quantify flow-habitat relationships and what CEW may contribute, and monitoring bank condition to assess the influence of CEW flows on erosion and deposition.

When we refer to hydraulic conditions we mean specifically metrics such as velocity and depth, rather than flow volume. We often refer to flow volume as river managers, but it is the hydraulic conditions that influence the biota. For example, slackwater habitats have been shown to be important nursery areas for fish larvae and juvenile fish, and are also areas of high productivity for zooplankton and some macroinvertebrates. Flows that maximise the quality and quantity of slackwater habitats at critical times in a particular river system are most likely to trigger a significant ecological response. Measuring changes in the distribution and quality of hydraulic habitats under different flow conditions is therefore critically important in determining whether specific flow management actions are providing the conditions required for an intended ecological outcome. Such information will improve the interpretation of ecological monitoring results. Specifically they will increase our ability to attribute good ecological outcomes to the delivery of CEW.

To understand physical habitat in the Goulburn River, hydraulic modelling is being used to quantify the relationships between flow and ecologically relevant hydraulic metrics. This is the most efficient way to assess how Commonwealth environmental water delivery affects physical habitats. Model results can be used to produce discharge-habitat curves enabling prediction of the quality, quantity and distribution of specific hydraulic habitats under a wide range of flow magnitudes.

River banks influence the velocity of flow, depth of water, and provide the sediment conditions for biota including flora and fauna. River bank condition can alter conditions for biota, and this is often related to the extent of bank activity and river flow. For example, appropriate levels of erosion provide niches for vegetation establishment, yet, excessive erosion can lead to sediment smothering of bed habitat (as well as concerns for riparian infrastructure such as bridges and property). Quantifying the relationship between CEW and bank condition can assist with understanding flows that enhance the ecological objectives sought (i.e. bank vegetation establishment) and reduce any potential unintended consequences.

# B.2 How are environmental flows expected to affect physical habitat and bank erosion in the lower Goulburn River and specific evaluation questions?

#### B.2.1 Basin-scale evaluation questions

Nearly all environmental flow recommendations are predicated on the assumption that changes in flow magnitude will alter hydraulic habitats within the river channel, and that the specific quality, quantity and distribution of these habitats as well as the timing of when they are provided will influence ecological processes and ecological responses to particular flow regimes. The importance of physical habitat change is explicitly described in the great majority of Cause and Effect Diagrams presented in MDFRC (2013b) and referred to in Section 3.3 of the lower Goulburn River monitoring and evaluation plan.

Most river channels are geomorphologically diverse and therefore discharge will affect habitat availability in a non-linear way. The relationship between discharge and habitat quality and quantity is arguably more explicit and more quantifiable than biotic responses to flow. Quantifying change in hydraulic habitat with discharge will be vital for explaining biotic responses (of lack thereof) to environmental flows. This is particularly relevant for larval fish, riparian bank vegetation, and macroinvertebrate abundances that are closely associated with specific hydraulic habitats such as slackwaters. For these reasons detailed two dimensional hydraulic modelling has been included as part area-specific monitoring.

Monitoring and modelling of physical habitat relative to CEW contributions will:

- Enable the benefit of all types of Commonwealth environmental water deliveries to be determined,
- Provide evidence of how Commonwealth environmental water supports ecological values (e.g. Ecosystem diversity objectives),
- Produce explanatory variables for population dynamics (e.g. retention of larval and juvenile fish) thereby reducing risks of 'false negatives', and
- Allow adaptive management of Commonwealth environmental water delivery patterns to better support ecological objectives.

Specific evaluation questions that relate to physical habitat responses to flow include:

- What did CEW contribute to the provision of productive habitat (e.g. slackwater habitats) for the recruitment, growth, and survival of larval and juvenile fish?
- What did CEW contribute to the provision of diverse and productive macroinvertebrate habitats?
- What did CEW contribute to inundating specific riparian vegetation zones and creating hydraulic habitats that favoured the dispersal and deposition of plant seeds and propagules?

Despite the provision of explicit questions relating to physical habitat, we see the main value of this monitoring activity as providing critical data for understanding responses of fish, macroinvertebrates and vegetation.

#### B.2.2 Area-specific evaluation questions

#### Hydraulic habitat

The two-dimensional hydraulic model protocol addresses the following Selected Area specific questions:

- What discharge is required to establish productive habitat for larval juvenile recruitment, growth, and survival?
- What discharge is required to inundate habitat and facilitate seed dispersal for re-establishment of vegetation on the banks of the Goulburn?
- What discharge is required to create habitat for enhanced macroinvertebrate biomass?

#### Bank condition

There is currently a perception by some members of the community that environmental flow releases in the lower Goulburn River have contributed to erosion of the river bank. Riverbank erosion is a natural process, but if excessive erosion occurs there can be significant implications for the survival and recruitment of riparian vegetation, water quality and sediment deposition on the streambed. Direct measurements of the river bank may be used to determine whether managed flow releases are contributing to the observed erosion and if so, how flow delivery may be altered to reduce impacts. Bank erosion will also be an important explanatory variable for interpreting the results of the riparian vegetation diversity assessment.

The short term and long term question for bank erosion is:

• What did environmental water contribute to sustaining bank condition as a result of flow management?



Fig. B-1. Contribution of physical habitat (hydraulic habitat) to example CEDs developed for the CEW monitoring program.



Fig. B-2. Contribution of bank condition monitoring to example CEDs developed for the CEW monitoring program.

# B.3 Monitoring methods

Four sites are used for each of the hydraulic habitat and bank condition monitoring (Table B-1). The sites correspond with the exception of Moss Road only being used for hydraulic habitat, and Yambuna Bridge only being used for bank condition. This variation is to maximise the value of the specific questions being posed for each of these monitoring programs.

The methods for monitoring hydraulic habitat and bank condition are described in detail in the SOPs (Webb et al. 2014). The methods are summarised here.

#### B.3.1 Hydraulic habitat

Hydraulic habitat (i.e. velocity, depth etc.) is assessed by using a hydraulic model that can be used to characterise hydraulic conditions for particular flows. The model is two-dimensional (velocity in both x and y directions) and requires bed topography as an input. This is obtained from two sources. LiDAR has been made available by the GBCMA which provides topography of the Goulburn River with an accuracy of +/-15cm. LiDAR, however, cannot obtain data through water. To capture bathymetry standard survey techniques were proposed (using a Total Station). This approach, however, was modified from the SOP (as approved February 2015) to achieve greater resolution of the bed by using considerably more advanced technology. Austral Research was engaged to use a remote controlled Sonar boat (Z-Boat 1800, Fig. B-3, left). This instrument increased the number of points on the stream bed from approximately 800-1000 over the reach, to approximately 15000-20000 depending on the accuracy required. In addition, field velocities were measured using an Acoustic Doppler Current Profiler (ADCP) at a range of discharges for model verification (Fig. B-3, right). The LiDAR topographic data was joined to the bathymetric data in GIS to produce the topographic surface (Fig. B-4). The model River2D is being used to construct hydraulic models for each reach, with verification of results against field measured ADCP data. The hydraulic models will be run to quantify changes in hydraulic habitat once metrics are selected in consultation with ecologists. Example results for the Moss Rd site are provided below.

|   | Site  | Coordinates                  | Image |
|---|---|------------------------------|-------|
| _ | (Component)   |                              |       |
| 1 | Moss Road<br>(physical habitat)                           | E 337458.08<br>N 5936838.35  |       |
| 2 | Darcy's Track<br>(physical habitat and<br>bank condition) | E 351721.99, N<br>5966032.91 |       |

Table B-1. Goulburn River LTIM physical habitat monitoring sites for physical habitat (hydraulic modelling) and bank condition.

|   | Site<br>(Component)  | Coordinates                 | Image |
|---|--|-----------------------------|-------|
| 3 | Loch Garry<br>(physical habitat and<br>bank condition)     | E 345932.83 N<br>5987637.56 |       |
| 4 | McCoy's Bridge<br>(physical habitat and<br>bank condition) | E 330801.78 N<br>5994732.86 |       |
| 5 | Yambuna Bridge<br>(bank condition)                         | E 360741.50 N<br>1450010.78 |       |



Fig. B-3. Instruments used to collect field data for development and verification of the hydraulic model: (left) Sonar bathymetric survey boat, (right) Acoustic Doppler Current Profiler (tethered to a rope to obtain velocities across fixed cross sections).



**Fig. B-4**. Topography used to develop the hydraulic model for Moss Rd based on LiDAR and bathymetric survey. The main channel (represented here in green) has path of the bathymetric survey overlain in black to demonstrate coverage. This includes some verification runs of the boat into the backwater section (already covered by LiDAR).

#### B.3.2 Bank condition

Equipment used for this monitoring program consists of 200 erosion pins (50 pins at each of the four sites). Erosion pins are 300 mm long bicycle spokes with colour coded heat shrink (Fig. B-5, left). Erosion pins are inserted so that 25 mm is exposed. Erosion pins are located five different elevations on the bank at 10 transects at each site, up to approximately bankfull (Fig. B-5, right). Measurements of the erosion pins are made using digital calipers. Qualitative assessments are also made at each transect on erosion process, failure mechanism, and weakening process (see proforma in the SOP; Webb et al. 2014).



Fig. B-5. (left) Colour coded erosion pins inserted at each transect to indicate location/elevation on the river bank and measured by digital calipers, and (right) field placement.

Recordings with positive values (relative to starting position) indicate bank retreat (erosion) and negative values indicate bank aggradation (deposition). Assessment of bank condition is being conducted 6 times per year (first

two years). Data presented in this report is from the earlier period (to March 2015) and as such only includes the installation and two measurement deployments. Qualitative assessments are repeated at the end of each year (visual changes are not evident from event to event).

#### B.4 Results

#### B.4.1 Relevant flow components delivered to the lower Goulburn River in 2014-15

Flow management for the period was well suited to capturing data on bank condition for freshes (pre and post), and low flow periods (Fig. B-6). Climatic conditions were not sufficiently out of the ordinary so as to influence bank erosion, with no large flood events and near-average rainfall. Flow is considered the main driver of bank activity during the period, but as discussed, not the only driver of bank activity. Conditions were well suited to capture velocities at a range of discharges and bathymetry for the development of the hydraulic models to be used to assess physical habitat.



Fig. B-6. Bank erosion sampling visits relative to discharge with eflows (blue) and without (purple). Data for McCoys streamgauge.

#### B.4.2 2D Hydraulic model – example results

#### B.4.2.1 Detail of setup

The same procedure for model development and verification is followed for each of the four sites, only the Moss Rd model development, verification and results are presented here.

The bathymetry XYZ file (from field survey) was triangulated in ArcGIS and converted to a 1 m resolution grid. The bathymetry TIN (Triangulated Irregular Network) was compared to the LiDAR grid in the areas where they overlapped. The area of overlap was based on visual matching and the unwanted water surface in LiDAR was clipped and removed.

The mean difference between the two datasets was 0.22 m (LiDAR was on average higher than bathymetry). The standard deviation of differences was 0.36 m, indicating noise in one or both datasets, but most likely the bathymetry dataset, as the LiDAR data is rated to an accuracy of 0.15 m.

The bathymetry TIN dataset was extended upstream and downstream by approximately 15 m by inserting manually extrapolated points. The TIN was also smoothed to meet the LiDAR on the banks by adding a 3D line

draped on the LiDAR as a breakline. The TIN was clipped to this extent. The TIN exhibited a significant amount of noise, likely due to some points representing non-bed surfaces such as snags. The TIN was smoothed via conversion to a 3 m grid with natural neighbour interpolation, then to a 1 m grid with cubic convolution interpolation. This removed most problem noise from the bathymetry. The smoothed bathymetry grid was joined with the LiDAR data by mosaic, with preference given to the bathymetry in areas of overlap. The final LiDAR/bathymetry grid is shown below with the raw bathymetry survey overlaid (Fig. B-4).

The 2-dimensional hydraulic model River2D was used for all four sites. The 1m LiDAR/bathymetry grid provided the topography for model development. The R2DMesh program was used to create a triangular mesh of the following approximate resolution:

- In-channel (bank to bank): 1 m
- Floodplain: 4 m
- Transition: 2 m

The upstream boundary condition was set to a constant inflow. The downstream boundary condition was set to a water level elevation, based on a rating curve developed from the HEC RAS models for each site (Table B-2).

Table B-2. Rating curve developed for Moss Road downstream boundary.

| Flow (ML/d) | Flow (m3/s) | DS water level (m AHD) |
|-------------|-------------|------------------------|
| 500         | 6           | 111.38                 |
| 1000        | 12          | 111.79                 |
| 2000        | 23          | 112.36                 |
| 3000        | 35          | 112.80                 |
| 4000        | 46          | 113.13                 |
| 5000        | 58          | 113.47                 |
| 6000        | 69          | 113.75                 |
| 7000        | 81          | 114.02                 |
| 8000        | 93          | 114.28                 |
| 9000        | 104         | 114.51                 |
| 10000       | 116         | 114.75                 |
| 11000       | 127         | 114.95                 |
| 12000       | 139         | 115.17                 |

Most form roughness was already included in the bathymetry data, which included submerged wood (this represents the roughness experienced by the flow). The bed file was set up with variable roughness including the following values:

- Background: 0.2 m
- Wood not in bathymetry: 1 m
- Island vegetation: 0.3 m
- Riparian Vegetation: 0.5 m

Two calibration events were available from the field survey using the ADCP (Table B-3).

| Date      | Average Q from<br>ADCP data | Gauged Q at<br>Murchison | Observed data   | Adopted<br>Q | Adopted<br>tailwater |
|-----------|-----------------------------|--------------------------|---|--------------|----------------------|
| 12/6/2015 | 9.4                         | 10.0                     | ADCP velocity (x, y, magnitude and direction) at 5 sections | 9.4          | 112.8                |
| 25/6/2015 | 37                          | 46                       | ADCP velocity (x, y, magnitude and direction) at 5 sections | 37           | 111.6                |

Table B-3. Events used for field survey (using the ADCP) and verification of the hydraulic models.

The events were run through the model using the average flow from the ADCP profiles. Velocity magnitude results were extracted at each ADCP observation point for comparison (Table **B-3** and Fig. B-7).

Table B-4. Verification of model through comparison of measured (ADCP) and modelled velocities at 5 cross sections for two discharges.

| Date      | Section | Average difference (modelled – measured) | St. dev. of differences | Max difference |
|-----------|---------|--|-------------------------|----------------|
|           | 4       | -0.003                                   | 0.08                    | -0.18          |
|           | 6       | 0.01                                     | 0.08                    | -0.17          |
| Low flow  | 8       | -0.04                                    | 0.15                    | -0.32          |
| 12/6/2015 | 9       | -0.04                                    | 0.04                    | -0.15          |
|           | 10      | -0.02                                    | 0.03                    | -0.12          |
|           | Total   | -0.02                                    | 0.09                    | -0.32          |
|           | 4       | 0.03                                     | 0.07                    | 0.20           |
|           | 6       | 0.05                                     | 0.13                    | 0.27           |
| High flow | 8       | -0.02                                    | 0.19                    | -0.90          |
| 25/6/2015 | 9       | 0.01                                     | 0.05                    | 0.11           |
|           | 10      | -0.01                                    | 0.09                    | -0.22          |
|           | Total   | 0.01                                     | 0.12                    | -0.90          |

#### **B.4.2.2 Example outputs**

The hydraulic habitat models have been developed to be run at a range of discharges from essentially zero ( $\sim 0.1 \text{ m}^3$ /s) up to bankfull discharge. The models display velocity magnitude and direction and can be used to characterise hydraulic habitat including velocity and depth (Figure B–8). The low and high flow discharges at which the models are verified are presented in Figs. B–9a,b, respectively. The hydraulic habitat metrics to be assessed are to be based on year-1 results from the LTIM and will be defined in conjunction with the ecological team.



Fig. B-7. a) and b) Comparison of velocities at low and high flows as a plot, and c) and d) cross sections at which measured (observed) and modelled velocities are compared for low and high flows, indicating differences by colour shading.



Fig. B–8. Hydraulic habitat represented by a close up of velocity magnitudes (red as high velocity) and direction (arrows) for Moss Rd (for a discharge of approximately 850 ML/d).



Fig. B–9. a) Low flow discharge ~850 ML/d (10 m<sup>3</sup>/s) and b) high flow discharge ~3200 ML/d (37 m<sup>3</sup>/s).

#### B.4.3 Bank condition results, observations and analysis

Quantitative measurements from erosion pins demonstrated that more than 55% of points on the banks experienced no change, and more than 80% of points experienced less than 5 mm of erosion. Both erosion and deposition are occurring on the banks of the Goulburn River, albeit with erosion (positive erosion pin values) being greater than deposition (negative erosion pin values) (Fig. B-10). There were only 5 erosion pins removed entirely during the sampling period (assigned as >175 mm erosion), with these pins including 2 that did not experience inundation. No mass failure events occurred at the erosion pin sites, or were observed at the sites more generally.

Relationships to discharge are currently only quantified for 2 sampling events. With installation in late January these events are the February fresh and the March fresh. With inundation there are more events with erosion > 30 mm, but also more deposition (Fig. B-10).



Fig. B-10. Bank movement illustrated as erosion (+ values) and aggradation (- values) highlighting some significant erosion where pins where entirely removed (in these cases given 175 cm maximum values), a considerable number of sites where sediment was deposited (include where pins where covered and given a value of -25 cm) and that the most significant number of points had no change (i.e. 0 cm values). These changes occurred for sites that were both inundated (1) or not inundated (0).

The data were analysed using a hierarchical Bayesian logistic regression. The probability of erosion and deposition was assessed as a function of the duration of inundation experienced by the pin during each of the two deployment periods.

$$y_{ijk} \sim \text{Bern}(p_{ijk})$$
$$\log it(p_{ijk}) = int + \text{eff.D}_k + D_{ijk} + \text{eff.site}_k + \text{eff.pin}_{jk}$$

The occurrence of erosion (y) for pin j at site k during deployment i is driven by a global average across all sites and in the absence of inundation (int), plus the effect of duration of inundation (eff.D) for each site and the duration of inundation experienced by the pin during the deployment. There is a random effect of site (eff.site) that acknowledges that local conditions may enhance or retard erosion overall, plus a random effect of pin (eff.pin) to account for the repeated measures taken for each pin). The random effects were considered to be drawn from a normal distribution with mean zero. The site-level estimates of eff.D were modelled hierarchically and drawn from a hyper-distribution. All prior distributions for parameters were assigned as minimally informative.

The model was implemented separately for four different thresholds of 'significant' erosion (>0, >10, >30, >70 mm) and for deposition (>0 mm). Selected results are presented below.

Bank erosion and deposition are both positively correlated with inundation (the only hydrologic metric assessed at this stage) (Fig. B-11).



Fig. B-11. Erosion is greater than deposition. Graphs show probability of any erosion (a) or deposition (b) as a function of duration of inundation at the McCoy's Bridge site. Solids lines are the median of the predicted probability from the fitted model, with dotted lines encompassing the 95% credible interval of the estimate. Similar patterns were observed at other sites.

Significant erosion events are relatively rare, occurring with low probability (Fig. B-12). They are much less likely than erosion of any kind (compare Fig. B-11a to Fig. B-12c). Moreover, while they grow increasingly likely with increasing duration of inundation, there is non-zero probability of significant erosion with zero inundation (Fig. B-10 and extreme left of panels in Fig. B-12).

Similarly, the effects of environmental flows on top of normal erosion/deposition processes are extremely minor. We used the fitted model to estimate probabilities of erosion for all samples (i.e. each erosion pins measured twice) under a flow regime from which environmental allocations had been removed. We compared these results to those from the model fitted to the data, quantifying the change in probability of erosion for all samples. Probabilities of significant erosion changed very little for the vast majority of samples, and all samples that did show a change were very low down on the bank, where inundation profiles were maximally impacted by the removal of environmental flows from the hydrograph (Fig. B-13). For erosion of >30 mm, only 4%, 7%, 4% and 3% of samples saw an increase in probability of significant erosion of more than 0.1.

#### B.5 Discussion

Does CEW water contribute to sustaining bank condition?

To answer this question we highlight that erosion and deposition of river banks is a natural process. We consider 'sustaining' as not significantly exacerbating the level of erosion or deposition on the river banks. The overarching answer to this question, then, is that there was no significant negative effects from environmental water management, based on evidence so far. As such we consider at this stage that CEW and the management of flow conditions is likely to be adequate to sustain bank condition. There are three items of evidence for this.

Firstly, quantitative measurements demonstrated that more than 55% of points on the banks experienced no change, and more than 80% of points experienced less than 5 mm of erosion. Both erosion and deposition are occurring on the banks of the Goulburn River, albeit with erosion (positive erosion pin values) being greater than deposition (negative erosion values) (Fig. B-10). There were only 5 erosion pins removed entirely during the sampling period (>175 mm erosion). No mass failure events occurred at the erosion pin sites, or were observed at the sites more generally.



Fig. B-12. Significant erosion events are rare. Graphs show the probability of erosion of greater than 30mm as a function of duration of inundation for the four sites. Interpretation of graphs is the same as for Fig. B-11.

Secondly, while erosion and deposition increased with duration of inundation (Fig. B-11), they also both occurred when erosion pins were not inundated (Fig. B-10, 0 = not inundated). These initial results highlight that while flow is a central driver, other mechanisms can influence erosion and deposition. In particular, sub-aerial preparation, e.g. drying of clay-rich soils leading to cracking (desiccation), is likely to contribute to preparing soils for subsequent removal during inundation (Fig. B-14). Soil creep, enhanced in this case by rainfall, is also a mechanism by which bank activity occurs, mostly deposition on the lower slopes. It is important to note that banks without significant vegetation have been targeted by this assessment to ensure the most sensitive banks are able to provide adequate change and enable relationships to be drawn with flow deliveries. We would expect greater activity (erosion and deposition) at the monitoring transects than anywhere else at the sites.



Fig. B-13. Effect of environmental flows on erosion. Graphs show the change in probability of significant (>30mm) erosion for all sample measurements (i.e. each erosion pin sampled twice) when moving from the inundation regime experienced to one that has had the environmental flows removed. A positive change is an reduction in probability of erosion when environmental flows are not delivered. X-axis is the elevation of pins on the bank.

Thirdly, the contribution of CEW is a small component of the flows delivered. The proportion of CEW water, and how flows would have been managed without this water, are an important consideration for future analysis. In particular, the appropriate rates of flow recession may be attributed to CEW water. Figure 1-2 illustrates that environmental water was used in addition to regulated and unregulated flows that would have otherwise occurred regardless. The statistical analysis demonstrated that the additional effect of this water on probabilities of significant erosion is very small, and certainly well within the bounds of our uncertainties on the predictions. Large-volume environmental flow events (e.g. the two spring freshes provide) provide temporary inundation of portions of the bank that might otherwise have been exposed at that time. The erosion pin placement deliberately targets those areas of the bank for which inundation profiles will change by the most, and yet probabilities of erosion were little different with and without environmental flows for almost all pins (Fig. B-13).

One caveat should be made for these conclusions, however. While the results here indicate negligible impacts of environmental water on bank condition during the summer/autumn period, there are currently no data on the effect of higher magnitude environmental water deliveries in spring. This will be addressed in future years when sampling occurs throughout the year.



Fig. B-14. Drying of clay-rich sediments prepares bank materials for removal during subsequent inundation (note erosion pin exposed in the centre of the right panel, at the Yambuna Bridge site, with 54 mm of erosion measured following the first fresh of 3000 ML/d as desiccated sediment was removed).

The two specific questions for the bank condition monitoring are:

- Does CEW contribute to or increase the risk of bank erosion in the lower Goulburn River?
- How does the amount of river bank erosion affect vegetation responses to environmental water delivery?

The risk of bank erosion from environmental flows is present. The initial evidence, however, suggests that management of the freshes so far has prevented erosion beyond that that would have occurred under the regulated flow regime. This will be further investigated as more data are collected and analysed. Importantly, the perception of risk, and the perception of erosion occurring in the Goulburn River, may be greater than the actual erosion measured. For example, sediment drapes deposited in one event may be subsequently eroded by another and as such the bank appears to be eroding (Fig. B-15, left). Some banks that appeared to be undergoing significant erosion were found by erosion pins to have surprisingly little or no erosion when measured (Fig. B-15, right). This may demonstrate the importance of community education on the dynamics of rivers and how appearance may differ from actual erosion.



Fig. B-15. (left) Sediment drapes (deposition) may be subsequently eroded giving the perception of wholesale bank erosion, but this is episodic, (right). An outer bank at the McCoy's Bridge site that appears to be eroding but where little or no erosion activity has been recorded at the erosion pins.

The role of bank erosion relative to bank vegetation has yet to be investigated. Zones of deposition did provide niches for vegetation colonisation (Figure 3-1, right). Anecdotally, vegetation plays an important role in the resistance of banks to erosion. Sub-aerial preparation of banks as a result of drying and cracking is exacerbated

when vegetation is not available to shade soils. In addition root wads enhance structural integrity. Deposition is also enhanced by vegetation through increased roughness, encouraging further vegetation establishment. Data from bank condition and riparian vegetation assessments will be synthesised to understand relationships in future reporting.

There are no major issues associated with the development of the physical habitat or bank condition monitoring program. The physical habitat models are currently being verified and will be run through scenarios in conjunction with the ecological team's interests. There was a slight delay in the placement of erosion pins for bank condition as it relied on appropriately low flow conditions and availability of key staff. The program commenced in January 2015. The six field visits required will, however, be easily achieved by incorporating the 2015 spring fresh into the first year's campaign, enabling all subsequent events in the 2015/16 to be captured. Further hydrologic analysis will investigate a range of flow characteristics other than merely inundation, including flow magnitude and the rate of recession and these will be related to bank condition and erosion and deposition mechanisms.

# B.6 Conclusion

There are no recommendations for changes to flow management at this stage until further bank condition data are analysed against specific hydrologic metrics, and hydraulic models have been run through ecological habitat scenarios. There is no foreseen risk of the CEWO operating flow freshes as currently planned, ensuring that rates of flow recession are appropriate.

Ongoing science-management collaborations are a critical component to the physical habitat program. Some of the early observations by the main researcher on the bank condition monitoring program have been incorporated in planning future events both for the Goulburn River and other rivers within the MDB. Active monitoring appears to have led to extensive communication and a great awareness of flow-bank condition relationships, and management that has appropriately led to no excessive erosion. Numerous organisations (CEWO, GBCMA, GMW) have also provided valuable information on flow deliveries and assistance that has enabled successful monitoring. These inputs are greatly appreciated.

# Appendix C. Detailed results for stream metabolism

# C.1 Background

Whole stream metabolism measures the production and consumption of dissolved oxygen gas (DO) by the key ecological processes of photosynthesis and respiration (Odum 1956). Healthy aquatic ecosystems need both processes to generate new biomass (which becomes food for organisms higher up the food chain) and to break down plant and animal detritus to recycle nutrients to enable growth to occur. Hence metabolism assesses the energy base underpinning aquatic foodwebs. The relationships between these processes are shown in Fig. C-1.





Metabolism is expressed as the increase (photosynthesis) or decrease (respiration) of DO concentration over a given time frame; most commonly expressed as (change in) milligrams of dissolved oxygen per Litre per day (mg  $O_2/L/Day$ ). Typical rates of primary production and ecosystem respiration range over two orders of magnitude, from around 0.2 to 20 mg  $O_2/L/Day$  with most measurements falling between 0.5 and 10 mg  $O_2/L/Day$ .

If process rates are too low, this will limit the amount of food resources (bacteria, algae and water plants) for consumers. This limitation will then constrain populations of larger organisms including fish and amphibians. Rates *are* expected to vary on a seasonal basis as warmer temperatures and more direct, and longer hours of, sunlight contribute to enhancing primary production. Warmer temperatures and a supply of organic carbon usually result in higher rates of ecosystem respiration (Roberts and Mulholland 2007).

In general, there is concern when process rates are too high. Greatly elevated primary production rates usually equate to algal bloom conditions (or excessive growth of plants, including duckweed and azolla), which may block sunlight penetration ,killing other submerged plants, produce algal toxins and large diel DO swings - overnight, elevated respiration rates can drive the DO to the point of anoxia (no dissolved oxygen in the water). When an algal bloom collapses, the large biomass of labile organic material is respired, often resulting in extended anoxia. Very low (or no) DO in the water can result in fish kills and unpleasant odors. Bloom collapse often coincides with release of algal toxins; hence the water becomes unusable for stock and domestic purposes as well.

Sustainable rates of primary production will primarily depend on the characteristics of the aquatic ecosystem. Streams with naturally higher concentrations of nutrients (e.g. arising from the geology), especially those with very open canopies (hence lots of sunlight access to the water) will have much higher natural rates of primary production than forested streams, where rates might be extremely low due to heavy shading and low concentrations. Habitat availability, climate and many other factors also influence food web structure and function. Uehlinger (2000) demonstrated that freshes with sufficient stream power to cause scouring can 'reset'

primary production to very low rates which are then maintained until biomass of primary producers is reestablished.

# C.2 Methods

The stream metabolism and water quality measurements were performed in accordance with the LTIM Standard Operating Procedure.

Water temperature and dissolved oxygen were logged every ten minutes with one ZebraTech DO logger placed in each of the four sites in zones 1 (Moss Rd, Darcy's Track) and 2 (McCoy's Bridge, Loch Garry). Data were downloaded and loggers calibrated approximately once per month depending on access. In some months, downloads were delayed by high water levels preventing access to the loggers (too far underwater). Light (PAR) loggers were also deployed in open fields at Shepparton and Nagambie (Tahbilk); these data were downloaded every few months. The data collected by the DO loggers was also used to calculate daily average temperature (Fig. C-2 upper) and dissolved oxygen concentrations (Fig. C-2 lower) for each of the rivers from October/November 2014 to mid-April 2015.

In accord with the LTIM Standard Protocol, water quality parameters (temperature (°C), electrical conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU)) were also measured as spot recordings at two sites within each river reach during deployment and maintenance of the DO loggers.

Water samples were collected from the same two sites within each zone used for the metabolism measurements, to measure:

- Total Organic Carbon (TOC)
- Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC)
- Nutrients (Ammonia (NH<sub>4</sub><sup>+</sup>), filtered reactive phosphorus (FRP), dissolved nitrate + nitrite (NOx), Total Nitrogen (TN) and Total Phosphorus (TP))

Acceptance criteria for inclusion of daily results from the BASE model (Grace et al. 2015) in the data analysis presented here were established at the July 2015 LTIM Workshop in Sydney. These criteria were that the fitted model for a day must have both an  $r^2$  value of at least 0.90 *and* a coefficient of variation for the GPP parameter of < 50%.

Subsequent data analysis using the BASE model showed that the Moss Road site consistently produced extremely poor (and unusable) fits to the data. This is almost certainly due to the close proximity of the site to the outflow from Goulburn Weir at Nagambie. Metabolism typically integrates an upstream distance of  $3 \times v / K$  where v is the water velocity in km/day (derived from m/s) and K is the reaeration rate in /day. This equates to integration distances of between 5 and 15 km given typical values of K and v for the Goulburn River. Consequently, the Moss Rd site is being moved much further downstream for the 2015-16 season (and beyond), and those data are not considered further in this report.

# C.3 Results

Estimates of Gross Primary Production and Ecosystem Respiration for the 3 viable sites were produced using the BASE model (Grace et al. 2015). Data loggers were in place from mid-October (McCoy'sBridge) or November (Loch Garry, Darcy's Track) 2014 until late-April 2015. Regular maintenance and occasional problems with some loggers meant that there were less than the respective maximum number of daily results for each site. Using the acceptance criteria for each day's diel DO curve, the acceptance rates were: McCoy's Bridge 66% (128 of 195 possible days), Darcy's Track 72% (101 of 141) and Loch Garry 38% (51 of 134).

Fig. C-3 to Fig. C-5display the daily rates of GPP, ER and then P/R ratio at all 3 sites. The daily flow data are also plotted in each figure.



Fig. C-2. Mean Daily Water Temperature and Dissolved Oxygen Concentration for the three study sites from October 2014 to April 2015.



Fig. C-3. Stream Metabolism-Flow Relationships for McCoy's Bridge (Zone 2) from October 2014 to April 2015: a) Gross Primary Production; b) P / R ratio.



Fig. C-4. Stream Metabolism-Flow Relationships for Loch Garry (Zone 2) from November 2014 to April 2015: a) Gross Primary Production; b) P / R ratio.



Fig. C-5. Stream Metabolism-Flow Relationships for Darcy's Track (Zone 1) from November 2014 to April 2015: a) Gross Primary Production; b) P / R ratio.

Table C-1 summarizes the daily metabolism results portrayed in Fig. C-3 to Fig. C-5. Each metabolic parameter is expressed as a median with minimum and maximum values also included. The median provides a more representative estimate without the bias in the mean arising from a relatively few much higher values. The median GPP values for all three sites fall within a narrow range of 1.20 to 1.45 mg O<sub>2</sub>/L/Day. This closeness in these median GPP rates is unsurprising given the similarity in the biogeochemical environment and being in the same river channel. Similarly, all three median ER values fell within the range 1.02 to 1.40 mg O<sub>2</sub>/L/Day. The P/R ratios (medians 1.03 to 1.10) indicate that there is typically an extremely close balance between gross primary production and ecosystem respiration. Such a relationship occurs in the absence of both large sources of allochthonous organic matter (which can drive high respiration rates) and of significant nutrient limitation which may constrain primary production (as discussed below). These median GPP and ER values are slightly low in comparison to many other world rivers but certainly not of concern.

Table C-1. Summary of primary production (GPP) and ecosystem respiration (ER) rates and P/R ratios for the six study sites, August 2014 - March 2014.

|                                | McCoy's Bridge (n = 128) |      |      | Loch Garry (n = 51) |      |      | Darcy's Track (n = 101) |      |      |
|--------------------------------|--------------------------|------|------|---------------------|------|------|-------------------------|------|------|
| Parameter                      | Median                   | Min  | Max  | Median              | Min  | Max  | Median                  | Min  | Max  |
| GPP (mg O <sub>2</sub> /L/Day) | 1.32                     | 0.38 | 3.17 | 1.20                | 0.55 | 2.56 | 1.45                    | 0.49 | 3.43 |
| ER (mg O₂/L/Day)               | 1.02                     | 0.16 | 5.71 | 1.15                | 0.39 | 2.55 | 1.40                    | 0.45 | 3.82 |
| P/R                            | 1.03                     | 0.15 | 8.76 | 1.10                | 0.39 | 2.11 | 1.05                    | 0.26 | 2.78 |

The total amount of oxygen (and hence organic carbon) created by photosynthesis or consumed by respiration is determined by the daily load. This load is simply the product of the metabolic rate in mg  $O_2/L/Day$  multiplied by the flow in L/Day. The result is in mass of  $O_2$  produced or consumed on that day. The most convenient unit is kg  $O_2$ . Table C-2 summarizes the GPP and ER loads for each of the sites. The table shows that although the rates of GPP and ER were not the highest at McCoy's Bridge, this site produced (and consumed) the largest amounts of oxygen due to the higher flow rates. Given the high variability around these similar load values, no specific importance is therefore drawn to inter-site differences.

Table C-2. Mean daily oxygen loads created by photosynthesis (GPP) and consumed by respiration (ER). Median values are provided in parentheses. All values are  $\pm$  1 standard deviation (sd).

| Zone & Site            | n   | GPP Load (kg O <sub>2</sub> ) | sd GPP | ER Load (kg O <sub>2</sub> ) | sd ER |
|------------------------|-----|-------------------------------|--------|------------------------------|-------|
| McCoy's Bridge, Zone 2 | 128 | 2900 (2560)                   | 1400   | 3000 (2940)                  | 1800  |
| Loch Garry, Zone 2     | 51  | 2400 (2160)                   | 1500   | 2200 (2280)                  | 1000  |
| Darcy's Track, Zone 1  | 101 | 2500 (2500)                   | 1100   | 2500 (2500)                  | 900   |

Primary production is expected to depend upon temperature and light (PAR) while respiration is also expected to increase with increasing temperature. Consequently, linear regressions were performed between the two metabolic parameters and these expected explanatory variables. The results of these regressions are presented in Table C-3.

As expected, both GPP and ER daily rates were positively correlated with mean daily water temperature (Table C-3), with the exception of GPP at Loch Garry where no significant relationship was found. There was a large degree of variability (scatter) in these regression plots, partially due to the effects of discharge and light (for GPP). GPP was strongly correlated with light at each site although the plots again showed a very large scatter.

As the sampling period progressed from spring into summer, GPP rates generally increased due to a combination of longer days (more sunlight) and warmer temperatures. Rates then declined during March and into April. A key point is that although the GPP rates varied with time (season) and location, the magnitude of the variability was very small. Rates were constrained within a narrow range (Table C-1).

Table C-3. Exploration of Linear Relationships between the metabolic parameters (GPP and ER) and, Light and Temperature for the three study sites, Oct/Nov 2014 - Apr 2015. Statistical significance was inferred at p < 0.05.

| Site           |                | GPP vs Temp | GPP vs Light | ER vs Temp |  |
|----------------|----------------|-------------|--------------|------------|--|
| Loch Garry     | r <sup>2</sup> | 0.05        | 0.256        | 0.169      |  |
|                | р              | 0.15        | 0.0002       | 0.0046     |  |
|                | slope          | -           | 1.01         | 0.155      |  |
| McCoy's Bridge | r <sup>2</sup> | 0.42        | 0.26         | 0.39       |  |
|                | р              | < 0.0001    | < 0.0001     | < 0.0001   |  |
|                | slope          | 0.173       | 1.01         | 0.323      |  |
| Darcy's Track  | r <sup>2</sup> | 0.05        | 0.44         | 0.24       |  |
|                | р              | 0.016       | < 0.0001     | < 0.0001   |  |
|                | slope          | 0.040       | 1.45         | 0.124      |  |

Nutrient concentrations from the four sites were determined on the samples that were collected approximately monthly during the DO probe deployment, downloading and maintenance. These data are presented in Table C-4. Also included in the table are data from the long term monitoring program at McCoy's Bridge (DELWP 2015). Dating back to 1990, data was collected weekly up until December 2013, when monthly sampling was instituted.

# C.4 Discussion

The mean daily DO data for the three sites shown in Fig. C-2 (lower) ranged between ca. 6.5 and 10.5 mg/L. Of equal importance, at no stage over the study period at any site did DO drop below 4 mg/L or 60% saturation: the minimum measured DO and % DO values were Loch Garry 6.4 mg  $O_2/L$  and 66% saturation, McCoy's Bridge 6.6 mg  $O_2/L$  and 79% saturation and Darcy's Track 5.8 mg  $O_2/L$  and 78% saturation.

The data presented in Fig. C-3 to Fig. C-5 and the linear regressions with flow shown in Table C-3 did not demonstrate a significant correlation between GPP and flow events. Primary production is expected to respond on a perhaps 10-20 day time frame following flow events (this time frame is based on typical algal doubling rates of 1-2 days), as this corresponds to sufficient time post nutrient addition to generate a significantly higher biomass of primary producers. The key assumption is that an increase in flow will introduce nutrients into the river channel which will then stimulate biomass growth and hence higher rates of GPP. It is extremely likely that the absence of significant growth is due to the extremely low bioavailable nutrient concentrations, especially the extremely low levels of filterable reactive phosphorus (which essentially equates to bioavailable phosphate). Two of the nutrient sampling dates listed in Table C-4 corresponded to periods of higher flow (November and January) yet there was no consistent increase in FRP at all. The observed tripling in GPP at McCoy's Bridge in Dec 2014-early Jan 2015 (from ca.  $1 - 3 \text{ mg O}_2/L/Day$ ) may be in response to the preceding flow event in late November or simply due to higher water temperatures and more sunlight. Respiration rates did seem to increase slightly in the days to weeks following discharge events. A flow-based influx of organic matter will enhance respiration although the quality/palatability of that organic matter is just as important as the increase in concentration.

Higher flows that remain within the river channel are unlikely to introduce significant amounts of nutrients which in turn will constrain primary production.

Comparison with the long term data set from McCoy's Bridge shows that the 6 sample sets collected at the 4 sites during DO logger deployment displayed nutrient concentrations slightly lower than the corresponding long term median results (ammonia and total nitrogen were not measured in the long term monitoring).

Table C-4. Nutrient (N, P & C) concentrations of water samples collected from the four study sites over the period October 2014 to April 2015. Long term data from McCoy's Bridge are also included.

| Site             | Date       | Total P | Total N | NPOC measured | NH <sub>3</sub> | FRP    | NOx    |
|------------------|------------|---------|---------|---------------|-----------------|--------|--------|
|                  |            | mg/L P  | mg/L N  | as TOC mg/L-C | mg/L N          | mg/L P | mg/L N |
| Darcy's Track    | 6/10/2014  | 0.03    | 0.34    | 6.6           | 0.004           | 0.002  | 0.090  |
|                  | 21/11/2014 | 0.03    | 0.31    | 3.0           | 0.006           | 0.002  | 0.071  |
|                  | 10/12/2014 | 0.03    | 0.29    | 5.8           | 0.001           | 0.002  | <0.001 |
|                  | 22/01/2015 | 0.03    | 0.34    | 6.4           | <0.001          | 0.002  | 0.041  |
|                  | 24/03/2015 | 0.03    | 0.31    | 3.5           | <0.001          | 0.001  | 0.038  |
|                  | 24/04/2015 | 0.02    | 0.29    | 2.3           | 0.011           | 0.002  | 0.090  |
| Moss Rd          | 6/10/2014  | 0.02    | 0.29    | 3.8           | 0.004           | 0.002  | 0.088  |
|                  | 19/11/2014 | 0.03    | 0.30    | 3.3           | 0.004           | 0.002  | 0.071  |
|                  | 10/12/2014 | 0.03    | 0.33    | 3.2           | 0.002           | 0.002  | 0.012  |
|                  | 22/01/2015 | 0.03    | 0.39    | 4.2           | 0.007           | 0.007  | 0.077  |
|                  | 25/03/2015 | 0.02    | 0.35    | 3.9           | 0.005           | 0.002  | 0.076  |
|                  | 24/04/2015 | 0.02    | 0.30    | 2.5           | 0.007           | 0.002  | 0.097  |
| Loch Garry       | 6/10/2014  | 0.04    | 0.38    | 4.7           | 0.002           | 0.002  | 0.071  |
|                  | 21/11/2014 | 0.04    | 0.36    | 3.1           | 0.001           | 0.002  | 0.085  |
|                  | 10/12/2014 | 0.04    | 0.31    | 8.1           | <0.001          | 0.002  | <0.001 |
|                  | 22/01/2015 | 0.04    | 0.34    | 8.5           | <0.001          | 0.003  | 0.001  |
|                  | 25/03/2015 | 0.04    | 0.32    | 3.4           | <0.001          | 0.001  | <0.001 |
|                  | 24/04/2015 | 0.04    | 0.36    | 2.9           | 0.004           | 0.008  | 0.066  |
| McCoy's Bridge   | 6/10/2014  | 0.04    | 0.40    | 6.0           | 0.002           | 0.002  | 0.029  |
|                  | 21/11/2014 | 0.05    | 0.35    | 4.1           | <0.001          | 0.002  | <0.001 |
|                  | 11/12/2014 | 0.04    | 0.33    | 1.9           | <0.001          | 0.003  | 0.003  |
|                  | 19/01/2015 | 0.05    | 0.33    | 14            | 0.002           | 0.002  | 0.002  |
|                  | 25/03/2015 | 0.04    | 0.28    | 3.3           | <0.001          | 0.002  | <0.001 |
|                  | 24/04/2015 | 0.05    | 0.44    | 3.1           | 0.005           | 0.004  | 0.054  |
| Long Term Mean   | Oct 2004   | 0.067   | -       | 6.9           | -               | 0.008  | 0.133  |
| Long Term Median | to         | 0.059   | -       | 5.0           | -               | 0.004  | 0.050  |
| n                | Apr 2015   | 493     | -       | 456           | -               | 493    | 493    |

## C.5 Preliminary Bayesian analysis of metabolism data

Relationships between discharge and gross primary production (GPP), ecosystem respiration (ER) and net primary production (GPP – ER = NPP) were analysed using a hierarchical Bayesian linear regression of the metabolism endpoint against discharge (log transformed) and temperature. First-order auto-regressive terms in the model tested for (and compensated for) the lack of temporal independence in the daily data.

$$y_{ij} \sim N(\mu_{ij}, \sigma)$$
  

$$\mu_{ij} = \operatorname{int}_{j} + \operatorname{eff.Q}_{j} \cdot \log(Q_{ij}) + \operatorname{eff.Te}_{j} \cdot Te_{ij}$$
  

$$+\operatorname{ac} \cdot e^{-\operatorname{eff.d} \cdot (d_{ij} - d_{i-1,j})} \left( y_{i-1,j} - \left( \operatorname{int}_{j} + \operatorname{eff.Q}_{j} \cdot \log(Q_{i-1,j}) + \operatorname{eff.Te}_{j} \cdot Te_{i-1,j} \right) \right)$$

The metabolism endpoint (y) on day i at site j is a linear function of logged discharge (Q) and temperature, with separate parameter values for the intercept (int), effect of discharge (eff.Q) and temperature (eff.Te) for each site. The second line of the model equation is the first-order regressive component. The term ac is the autocorrelation term, which quantifies the extent to which a data point can be estimated from the point immediately preceding it (autocorrelation). This term is multiplied by a weighted exponential function parameterized by the term eff.d, which is the extent to which autocorrelation breaks down with increasing temporal separation of data points ( $d_i - d_{i-1}$ ). This term was necessary because of the relatively large number of data points that had been deleted from the metabolism time series because of poor fit to the expected value from the BASE model. The bracketed component is simply the residual of the previous data point in the time series.

The regression parameters were all modelled hierarchically, with int, eff.Q, and eff.Te for each site assumed to be drawn from a larger distribution of possible values. All prior distributions were assigned as minimally informative. There was one exception to this. The fully hierarchical model for ecosystem respiration would not run. As an alternative, the model above was coded but with totally separate intercepts for each site (i.e. there was no hyperprior distribution for the site-level regression intercepts).

The effect of environmental flows was estimated by predicting ecosystem metabolism values from the fitted model, but with a synthetic flow series from which environmental allocations had been removed. This resulted in daily ecosystem metabolism values that were then compared to the fitted values from the full model. The total effect of environmental flows over the sampling period was computed as the sum of daily values.

#### C.5.1 Statistical results

There was noticeable suppression of GP with higher discharge at Darcy's Track and McCoy's Bridge, with little effect at Loch Garry (Fig. C-6). ER was suppressed by increasing discharge at all three sites (Fig. C-7). When these two data streams were combined, there were small positive effects of discharge on NPP at Loch Garry and McCoy's Bridge, with little effect at Darcy's Track (Fig. C-8).

In terms of the effect of environmental flows, the probability distributions of most estimates encompassed the zero line, which means it is difficult to draw any strong conclusions (Fig. C-9). Exceptions to this were a reduction in ecosystem respiration rates at McCoy's Bridge, and an increase in net primary productivity at the same site.

#### C.5.2 Discussion of statistical analysis results

Examination of the raw data plots (Fig. C-3 to Fig. C-5) suggests a delay between flow events and corresponding changes in GPP and ER. This is also conceptually consistent with current understanding (see above). The cyclical nature of the high flow and low flow events during the sampling period, coupled with not yet including a lag in the statistical model could have led to spurious results interpretations of responses for GPP and ER. However, because NPP is the difference in GPP and ER rates, it may have been more robust to such inadequacies in model structure.

For the next analysis of data, we intend to attempt to model a temporal lag in ecosystem metabolism measures and their relationship to discharge and temperature. We believe this will need to be done using a computationally intensive approach that runs the models many times with an increasing temporal lag on each model run. The Deviance Information Criterion would be used to identify the optimal lag time (i.e. the lag time that maximizes fit of the model to the data), and then inferences and predictions would be made from that model. It is likely that the lag phase between introduction of new organic matter and nutrients will itself be dependent on temperature and light (for GPP).



Fig. C-6. Effect of discharge on Gross Primary Production. Solid line is the median predicted gpp at different discharge levels, with the dotted lines encompassing the 95% credible interval for the estimate.



Fig. C-7. Effect of discharge on Ecosystem Respiration. Solid line is the median predicted er at different discharge levels, with the dotted lines encompassing the 95% credible interval for the estimate.


Fig. C-8. Effect of discharge on Net Primary Production. Solid line is the median predicted npp at different discharge levels, with the dotted lines encompassing the 95% credible interval for the estimate.



Fig. C-9. Summed effect of environmental flows upon ecosystem metabolism measures. Dots are the median summed effect of environmental flows delivered over the monitoring period on GPP (green), ER (red) and NPP (blue) for each site. Error bars encompass the 95% credible interval for the estimate. Abbreviations: DT – Darcy's Track, LG – Loch Garry, MB – McCoy's Bridge.

# Appendix D. Detailed results for Macroinvertebrates

## D.1 Introduction

One objective within the SEPP Waters of Victoria is to ensure that Victorian rivers have a diverse fauna. Environmental flows can help achieve this target. In addition to their inherent value, macroinvertebrates are an important source of food for fish and other vertebrates, and therefore it is important to know whether environmental flow events increase macroinvertebrate diversity, abundance and biomass. Understanding the effects of environmental flows on macroinvertebrates has been thwarted by their high spatial and temporal variability in streams, as well as the use of Rapid Bioassessment methods that are unable to measure important variables such as abundance. Another important aspect that is often neglected is macroinvertebrate emergence. Many aquatic macroinvertebrates have a terrestrial adult life stage, which is significant for reproduction and macroinvertebrate recruitment. Adult macroinvertebrates may also be a valuable food resource for other organisms, including fish. Macroinvertebrate emergence could be affected by environmental flows, which may trigger emergence from the stream.

To measure the effects of environmental flows on macroinvertebrates in the lower Goulburn River, three different methods were employed, each of which would contribute to monitoring the above aspects of macroinvertebrate condition in response to environmental flows. Artificial substrates and Replicated Edge Sweep Samples (RESS) were employed in this project to provide quantitative, replicated measures of macroinvertebrate diversity and abundance, while yellow sticky traps were used to collect emerging insects. These methods were used before and after the Commonwealth environmental flow events in spring 2014, to determine the effects of environmental flows on macroinvertebrates in the Goulburn River at McCoys Bridge. In addition, the same methods were used at a reference site which does not experience environmental flows, the Broken River at Central Avenue in Shepparton East, so comparisons of the macroinvertebrate fauna could be made, and the effects of environmental flows could be distinguished from other factors such as seasonal changes.

# D.2 How are environmental flows expected to affect macroinvertebrate communities in the lower Goulburn River and specific evaluation questions?

#### D.2.1 Basin-scale evaluation questions

• Nil

Following submission of the draft monitoring and evaluation plan, macroinvertebrates were revised from a category II indicator to category III. It appears likely that no other Selected Areas will be monitoring macroinvertebrates, eliminating the possibility of basin-scale (or even multi-Area) evaluation.

#### D.2.2 Area-specific evaluation questions

The M&E Advisor originally prescribed a standard monitoring method that used a combination of artificial substrates, sweep samples and decapod traps. With the change in macroinvertebrates to a category III indicator, we have made modifications to the standard method described below that will address the following evaluation questions:

#### Long-term and short-term questions:

• What did CEW contribute to macroinvertebrate diversity?

Macroinvertebrate assessment in previous environmental flow monitoring programs has been thwarted by a focus on diversity and the use of standard Rapid Bioassessment sampling procedures. In large lowland rivers, such as those targeted by the LTIM Project, the macroinvertebrate communities tend to be dominated by species that favour relatively simple habitats and are able to tolerate moderate to poor water quality. Environmental flows delivered to these rivers are more likely to influence macroinvertebrate abundance and biomass than diversity. Such effects are important, because macroinvertebrates are an important component of

riverine food webs, and therefore changes in abundance will have cascading effects on other organisms such as fish.

The environmental flow recommendations for the lower Goulburn River include low flows and summer freshes to maintain habitat and provide food for macroinvertebrates. Part of the revised standard method monitors macroinvertebrate emergence rates to see if environmental flows influence macroinvertebrate breeding and reproduction. This additional monitoring is being structured as a PhD project. In addition, the future PhD project will build on current monitoring by measuring macroinvertebrate biomass. Greater emergence would lead to breeding and recruitment of new aquatic invertebrates to the river. This would be expected to increase the amount of food available to fish.

Overall, our monitoring program aims to answer the following questions in the lower Goulburn River:

- What did CEW contribute to macroinvertebrate diversity and abundance in the lower Goulburn River? Specifically what combination of freshes and low flows are required to maximise macroinvertebrate abundance and biomass in the river?
- What did CEW contribute to macroinvertebrate emergence in the lower Goulburn River?

## D.3 Monitoring methods

The methods used for monitoring macroinvertebrates are given in Webb et al. (2014). A brief summary is given here. Three methods were used to monitor the effects of Commonwealth environmental water on macroinvertebrates in the lower Goulburn River at McCoys Bridge. The same methods were also used in the Broken River at Shepparton East, which is a lowland tributary of the Goulburn River that does not receive environmental flows and is thus considered a reference site. In spring, 2014, environmental water was delivered as two freshes to stimulate fish spawning. Each method was used prior to environmental flow delivery and also after the flow events. The timing of the each sampling method is given Table D-1.

The first method used artificial substrate samplers, adapted from Cook et al. (2011), which consist of a cylinder of black plastic mesh containing commercially available onion bags as a substrate for macroinvertebrates to colonise. Originally ten substrates were to be deployed at each site during each sampling event, but instead 15 were deployed to account for the fact that substrates often go missing after deployment. The artificial substrates were left at each site for 4 to 6 weeks, allowing macroinvertebrates to colonise them. Upon retrieval, five of these artificial substrates were randomly selected, and the macroinvertebrates within these were identified and counted in the laboratory.

The second method was Replicated Edge Sweep Sampling (RESS), which involves using a hand net to sample edge habitats. The method was developed by the Murray Irrigation Limited Aquatic Ecosystem Monitoring Program (Gigney et al. 2007a, b), and involves sampling the major edge habitat types within a reach (bare ground, snags, macrophyte beds and leaf litter deposits). The method is quantitative, replicated within a site and comparable between sites because of the sweeping technique described. Five replicate samples were collected at each site during each sampling event, and the macroinvertebrates from these were identified and counted in the laboratory.

| Method              | Site           | Pre-environmental flow |                | Post-environmental flow |                |  |
|---------------------|----------------|------------------------|----------------|-------------------------|----------------|--|
|                     |                | Date deployed          | Date retrieved | Date deployed           | Date retrieved |  |
| Artificial          | Goulburn River | 08/09/2014             | 13/10/2014     | 10/12/2014              | 27/01/2015     |  |
| Substrates          | Broken River   | 08/09/2014             | 14/10/2014     | 11/12/2014              | 28/01/2015     |  |
| Replicated Edge     | Goulburn River | 13/10/2014             | -              | 10/12/2014              | -              |  |
| Sweep samples       | Broken River   | 14/10/2014             | -              | 11/12/2014              | -              |  |
| Yellow sticky traps | Goulburn River | 09/09/2014             | 18/09/2014     | 10/12/2014              | 19/12/2014     |  |
|                     | Broken River   | 09/09/2014             | 18/09/2014     | 11/12/2014              | 19/12/2014     |  |

Table D-1. Timing of macroinvertebrate sampling in the Goulburn River and Broken River during 2014-2015.

The third method is the use of yellow sticky traps to capture flying macroinvertebrates. The technique is based upon that described in Townsend (2013) and involves the deployment of 15 yellow, adhesive coated plastic cards at each site. The traps are tied to a metal stake or vegetation and surrounded by a wire cage to prevent interference by birds. The traps are deployed for around one week and are then retrieved from the site. Insects stuck on the traps are identified and counted back in the laboratory.

## D.4 Results

#### D.4.1 Relevant flow components delivered to the lower Goulburn River in 2014-15

It was hypothesised that the flow components with the greatest effect on macroinvertebrates would be freshes and bankfull flows. Bankfull flows were not delivered in the 2014-2015 survey period; the effects of two spring freshes on macroinvertebrates, consisting mostly of Commonwealth environmental water but also inter-valley transfers, were assessed during this survey period. Here, macroinvertebrate monitoring was conducted before and after the spring freshes.

The 2014-15 survey period was considered a dry year across much of Victoria, including the study area, with temperature above average and below average rainfall (BOM 2015). During spring, minimum temperatures were warmer than average by up to 1°C, while rainfall was equal to or below average. As such, some stress may have been experienced by the macroinvertebrate community, which would have been alleviated by the spring freshes.

#### D.4.2 Monitoring results and observations

The results are presented for each of the three monitoring methods.

#### Artificial substrates

A total of 16,368 macroinvertebrates belonging to approximately 155 taxa were captured in the artificial substrates at the two sites across the survey period. Macroinvertebrate abundance decreased at both sites post-Commonwealth environmental water (CEW) flows (Fig. D-1a). In contrast, taxonomic richness increased at both sites post-CEW, although more taxa were present in the Broken River reference site than in the Goulburn River during both pre- and post-CEW sampling events (Fig. D-1b). Species diversity, as measured by the Shannon-Wiener Index, increased slightly at both sites post-CEW (Fig. D-1c), whereas Simpson's Diversity Index decreased slightly in the Goulburn River post-CEW, but increased in the reference site (Fig. D-1d).

Twenty five taxa contributed to the majority of the abundance (with each individual taxon comprising more than 0.9% of the total abundance), and most of these taxa occurred at both sites and in both sampling events (Table D-2). These were examined further. There was no evidence of an effect of environmental flows on the worms *Chaetogaster* sp. or other Oligochaeta (Fig. D-2); the abundance of other Oligochaeta was greater at both sites pre-CEW, and a similar response was observed for *Chaetogaster* sp., although here abundances were much greater pre-CEW in the reference site. Genera from Chironomidae were among the more common taxa captured; the responses of these to site and sampling event were not consistent among genera, although some genera did seem sensitive to environmental flows (Fig. D-3). For example, *Procladius* sp., *Paracladopelma* sp. and *Djalmabatista* sp. experienced a much greater increase in abundance in the Goulburn River than the reference site post-CEW (Fig. D-3b,g,m). Other taxa seemed to experience a negative response to environmental flows, with a decrease in abundance observed in the Goulburn River but not the reference site for *Nanocladius* sp. and *Tanytarsus manleyensis* (Fig. D-3a, c). Some taxa appeared to show a greater response to season than flows, and were more abundant during certain sampling events than at particular sites (Fig. D-3f,h,i,j,k,I). Others appeared to have a preference for particular sites regardless of sampling event (Fig. D-3a, c).



Fig. D-1. The (a) abundance, (b) number of taxa, (c) Shannon-Wiener diversity index H' and (d) Simpson's diversity index 1-D captured in artificial substrates (average ± standard error) that were deployed in the Goulburn River and Broken River (reference site) pre- and post-Commonwealth environmental flows (spring/summer 2014-15). Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event.



Fig. D-2. Abundance of Oligochaeta (average ± standard error) (a) other Oligochaeta and (b) *Chaetogaster* sp. caught in artificial substrates in 2014-15. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.

Table D-2. List of the most commonly occurring taxa (>0.9 % of the total abundance) caught in artificial substrate samplers from Goulburn River and Broken River (reference site) pre- and post-Commonwealth environmental water (CEW) flows, 2014-15.

|    | Taxon                   | Family          | Abundance | % total<br>abundance | Sites present | Events<br>present |
|----|-------------------------|-----------------|-----------|----------------------|---------------|-------------------|
| 1  | Oligochaeta             |                 | 4,147     | 25.3                 | All           | All               |
| 2  | Nanocladius sp.         | Chironomidae    | 1,445     | 8.8                  | All           | All               |
| 3  | Procladius sp.          | Chironomidae    | 940       | 5.7                  | All           | All               |
| 4  | Ecnomus pansus          | Ecnomidae       | 665       | 4.1                  | All           | All               |
| 5  | Tanytarsus manleyensis  | Chironomidae    | 528       | 3.2                  | All           | All               |
| 6  | Tasmanocoenis arcuata   | Caenidae        | 505       | 3.1                  | All           | All               |
| 7  | Nilotanypus sp.         | Chironomidae    | 443       | 2.7                  | All           | All               |
| 8  | Rheotanytarsus sp.      | Chironomidae    | 373       | 2.3                  | All           | All               |
| 9  | Caenidae Genus C sp. D  | Caenidae        | 360       | 2.2                  | All           | Pre-CEW           |
| 10 | Rheocricotopus sp.      | Chironomidae    | 302       | 1.8                  | All           | All               |
| 11 | Paracladopelma sp.      | Chironomidae    | 289       | 1.8                  | All           | All               |
| 12 | Tanytarsus sp.          | Chironomidae    | 231       | 1.4                  | All           | All               |
| 13 | Thienemanniella sp.     | Chironomidae    | 227       | 1.4                  | All           | Pre-CEW           |
| 14 | Caenidae Genus C sp. A  | Caenidae        | 223       | 1.4                  | Broken        | All               |
| 15 | Tasmanocoenis sp.       | Caenidae        | 214       | 1.3                  | All           | All               |
| 16 | Paratanytarsus sp.      | Chironomidae    | 211       | 1.3                  | All           | All               |
| 17 | Chaetogaster sp.        | Naididae        | 20        | 1.3                  | All           | All               |
| 18 | Parakiefferiella sp.    | Chironomidae    | 203       | 1.2                  | All           | All               |
| 19 | Cladotanytarsus sp.     | Chironomidae    | 180       | 1.1                  | All           | Post-CEW          |
| 20 | Tasmanocoenis tonnoiri  | Caenidae        | 174       | 1.1                  | All           | Pre-CEW           |
| 21 | Tasmanocoenis tillyardi | Caenidae        | 166       | 1.0                  | All           | All               |
| 22 | Atalophlebia sp. AV6    | Leptophlebiidae | 163       | 1.0                  | All           | All               |
| 23 | Djalmabatista sp.       | Chironomidae    | 146       | 0.9                  | All           | All               |
| 24 | Cryptochironomus sp.    | Chironomidae    | 144       | 0.9                  | All           | All               |
| 25 | Ecnomus continentalis   | Ecnomidae       | 144       | 0.9                  | All           | All               |

There was no obvious effect of environmental flows on the abundance or richness of Ephemeroptera, Plecoptera and Trichoptera (EPT) (Fig. D-4a,b). The Ephemeropteran, *Atalophlebia* sp. AV6, was the only taxon with a response that might be caused by environmental flows, with an increase in abundance post-CEW in the Goulburn River but a decrease in the reference site (Fig. D-4i). Other taxa showed effects that indicated a strong temporal difference between the pre- and post-CEW sampling events (Fig. D-4d,f,h,j,k) and site differences (Fig. D-4e,f,g), but with no strong response that might indicate either negative or beneficial effects of environmental flows.

As crustaceans are important prey species for many fishes, the abundance and taxonomic richness of these was also investigated separately. Crustaceans were not common in the artificial substrates, with between 0 to 5 individuals caught per substrate. *Cherax* sp. was the most commonly occurring taxon, but *Macrobrachium australiense crassum*, *Paratya australiensis* and *Paratya* sp. were also captured. More crustaceans were present in artificial substrates from the Goulburn River than the Broken River, but both sites experienced an increase in crustacean abundance in post-CEW sampling.



Fig. D-3. Abundance (average ± standard error) of common Chironomidae (a) *Nanocladius* sp., (b) *Procladius* sp., (c) *Tanytarsus manleyensis*, (d) *Nilotanypus* sp., (e) *Rheotanytarsus* sp., (f) *Rheocricotopus* sp., (g) *Paracladopelma* sp., (h) *Tanytarsus* sp., (i) *Thienemanniella* sp., (j) *Paratanytarsus* sp., (k) *Parakiefferiella* sp., (l) *Cladotanytarsus* sp., (m) *Djalmabatista* sp. and (n) *Cryptochironomus* sp. caught in artificial substrates in 2014-15. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.



Fig. D-4. (a) Total abundance of Ephemeroptera, Plecoptera and Trichoptera (EPT), (b) number of EPT taxa, the abundance of the Ephemeroptera (c) *Tasmanocoenis arcuata*, (d) Caenidae Genus C sp. D, (e) Caenidae Genus C sp. A, (f) *Tasmanocoenis* sp., (g) *Tasmanocoenis tonnoiri*, (h) *Tasmanocoenis tillyardi*, (i) *Atalophlebia* sp. AV6, and the Trichoptera (j) *Ecnomus pansus* and (k) *Ecnomus continentalis* (average ± standard error) caught in artificial substrates in 2014-15. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event is a reference site that did not receive environmental flows during the study.

#### Replicated edge sweep samples (RESS)

The types of edge habitat available differed between sites but were fairly consistent between sampling periods. Edge habitat in the Goulburn River appeared to be more degraded, with an estimated 50% of the habitat bare and the rest consisting of woody debris. In the Broken River reference site, it was also estimated that 40-50% of the edge habitat was woody debris, but here only 30% was bare and 20% was macrophytes. Instream habitat did not change in the Goulburn River after the environmental flows.

A total of 7,207 macroinvertebrates belonging to 84 taxa were captured from edge habitats in the Goulburn and Broken Rivers during the 2014-15 sampling period. Macroinvertebrate abundance decreased at both sites during the post-CEW sampling period (Fig. D-5a); however, this was more pronounced in the reference site, and possibly indicates environmental flows ameliorated the effects of factors that caused decreased macroinvertebrate abundance. More macroinvertebrate taxa were collected from the Broken River than Goulburn River, and while the number of taxa was relatively unchanged pre- and post-CEW in the Goulburn River, the number of taxa did reduce in the Broken River post-CEW (Fig. D-5b). Both the Shannon-Wiener Diversity Index and Simpson's Diversity Index showed diversity decreased at both sites post-CEW (Fig. D-5c,d), not because species richness decreased at these sites, but because some taxa became much more abundant.



Fig. D-5. The (a) abundance, (b) number of taxa, (c) Shannon-Wiener diversity index H' and (d) Simpson's diversity index 1-D captured in replicated edge sweep samples (average ± standard error) that were deployed in the Goulburn River and Broken River (reference site) pre- and post-Commonwealth environmental flows (spring/summer 2014-15). Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event.

There were 13 commonly occurring taxa that comprised over 0.9% of the total abundance each, with most of these occurring at both sites and in both sampling events (Table D-3). *Nanocladius* sp. appeared to respond to environmental flows in the Goulburn River, with an increase in abundance post-CEW, whereas abundance decreased post-CEW in the reference site (Fig. D-6f). Responses to environmental flows were less clear for other taxa (Fig. D-6). Environmental flows did not affect the abundance and richness of EPT taxa as much as site did, with abundances and richness higher in edge habitats from the reference site than the Goulburn (Fig. D-7). Crustacean abundance and taxonomic richness was greater in the Goulburn River than the reference site on both sampling occasions (Fig. D-8). Crustacean abundance did decline in the Goulburn River post-CEW, which was also evident for the species *Macrobrachium australiense crassum* (Fig. D-6j), but at this stage it is difficult to attribute these declines to an effect of environmental flows as the number of crustacean taxa also declined at both sites regardless of environmental flow.



Fig. D-6. The abundance of (a) *Micronecta* sp., (b) Oligochaeta, (c) *Offadens confluens*, (d) *Micronecta annae annae*, (e) *Offadens* sp., (f) *Nanocladius* sp., (g) *Tasmanocoenis rieki*, (h) *Cricotopus* sp., (i) Ceratopogonidae, (j) *Macrobrachium australiense crassum*, (k) *Thienemanniella* sp., (l) *Microvelia* sp. and (m) Oribatida (average ± standard error) caught in replicated edge sweep samples in 2014-15. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.

Table D-3. List of the most commonly occurring taxa (>0.9 % of the total abundance) caught in replicated edge sweep sampling from Goulburn River and Broken River (reference site) pre- and post-Commonwealth environmental water (CEW) flows, 2014-15.

|    | Taxon                                 | Family          | Abundance | % total<br>abundance | Sites present | Events<br>present |
|----|---------------------------------------|-----------------|-----------|----------------------|---------------|-------------------|
| 1  | Micronecta sp.                        | Corixidae       | 1,643     | 22.8                 | All           | All               |
| 2  | Oligochaeta                           |                 | 1,300     | 18.0                 | All           | All               |
| 3  | Offadens confluens                    | Baetidae        | 807       | 11.2                 | Broken River  | All               |
| 4  | Micronecta annae annae                | Corixidae       | 539       | 7.5                  | All           | All               |
| 5  | Offadens sp.                          | Baetidae        | 247       | 3.4                  | Broken River  | All               |
| 6  | Nanocladius sp.                       | Chironomidae    | 201       | 2.8                  | All           | All               |
| 7  | Tasmanocoenis rieki                   | Caenidae        | 160       | 2.2                  | All           | Pre-CEW           |
| 8  | Cricoptopus sp.                       | Chironomidae    | 123       | 1.7                  | All           | Pre-CEW           |
| 9  | Ceratopogonidae                       | Ceratopogonidae | 120       | 1.7                  | All           | All               |
| 10 | Macrobrachium australiense<br>crassum | Palaemonidae    | 118       | 1.6                  | All           | Pre-CEW           |
| 11 | Thienemanniella sp.                   | Chironomidae    | 84        | 1.2                  | All           | All               |
| 12 | <i>Microvelia</i> sp.                 | Veliidae        | 64        | 0.9                  | All           | All               |
| 13 | Oribatida                             |                 | 62        | 0.9                  | All           | Post-CEW          |



Fig. D-7. (a) Total abundance of Ephemeroptera, Plecoptera and Trichoptera (EPT) and (b) number of EPT taxa (average  $\pm$  standard error) caught in replicated edge sweep samples in 2014-15. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.



Fig. D-8. (a) Total abundance of crustaceans and (b) number of crustacean taxa (average ± standard error) caught in replicated edge sweep samples in 2014-15. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.

#### Yellow sticky traps

A total of 22,659 invertebrates were caught on the yellow sticky traps during the 2014-15 survey period. The majority of these were from the insect orders Hymenoptera (43.3% of the total abundance), followed by Diptera (36.7%), Hemiptera (8.6%), Thysanoptera (5.7%), Coleoptera (3.1%) and the Arachnida Araneae (1.3%). Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa were uncommon on the sticky traps (<0.2%). The total abundance of invertebrates captured was greater post-CEW than pre-CEW at both sites, and tended to be higher at Broken River than the Goulburn River (Fig. D-9). An examination of the most common insect Orders showed a similar trend, with Hymenoptera, Hemiptera, Thysanoptera and Coleoptera much more abundant on the sticky traps post-CEW (Fig. D-10a,c,d,e). However, with the exception of the Hymenoptera, these Orders were much more abundant in the Goulburn River than Broken River reference site post-CEW. The spiders also showed a similar result (Fig. D-10f). The Diptera, in contrast, were always more abundant in the reference site than the Goulburn, with only a small difference in abundance observed pre- and post-CEW at each site (Fig. D-10b).



Fig. D-9. Abundance of all invertebrates caught on yellow sticky traps in 2014-15. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.



Fig. D-10. Abundance of (a) Hymenoptera, (b) Diptera, (c) Hemiptera, (d) Thysanoptera, (e) Coleoptera and (f) Araneae caught on yellow sticky traps in 2014-15. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.

Most invertebrates from these families have terrestrial larval life stages, although some may be aquatic or semiaquatic. While environmental flows could still benefit these animals through bank wetting and increasing the quality of riparian vegetation, subsequent analyses were focussed on a group of insects with immature life stages more directly impacted by environmental water: the Dipteran family Chironomidae (chironomids). Of the 2,666 chironomids caught on the yellow sticky traps, 2,628 were species with aquatic or semi-aquatic larvae and pupae, and only these were considered further. The total abundance of aquatic chironomids caught on the traps increased at both sites post-CEW, and was substantially higher at the reference site than at the Goulburn River (Fig. D-11a). However, this was because of the dominance of single species, *Corynoneura australiensis*, which was only present at Broken River (Fig. D-13a); exclusion of this species instead showed that while chironomid abundance did increase at both sites post-CEW, this was much greater in the Goulburn River (Fig. D-11b).

The number of aquatic chironomid taxa caught on the sticky traps was greater post-CEW than pre-CEW at both sites, particularly at Broken River (Fig. D-11c). Chironomid diversity, whether measured by Shannon's Diversity Index or Simpson's Diversity Index, did not appear to respond to environmental flows (Fig. D-12). Regardless of sampling event, diversity was always greater at Goulburn River, while in the reference site it declined in post-CEW sampling. This is due to the dominance of a single species, *C. australiensis*, at this site post-CEW. Seven species were commonly captured on the sticky traps, and while most of these were present in both pre- and post-CEW sampling, four occurred at only one site (Table D-4). Commonwealth environmental water seemed to stimulate the emergence of one species, *Paratrichocladius pluriserialis*, with a substantially larger increase in abundance in the Goulburn River post-CEW than in the reference site (Fig. D-13d). *Microcricotopus parvulus* and *Cladotanytarsus bilinearis* also increased in abundance post-CEW in the Goulburn River (Fig. D-13b,g), however it is difficult to attribute this to an effect of environmental flows as these species were not present in the reference site. In contrast, environmental flows may have had an adverse effect on *Limnophyes vestitus*, which

had a relatively consistent abundance pre- and post-CEW in the Broken River but was absent from sticky traps post-CEW in the Goulburn River (Fig. D-13c).



Fig. D-11. (a) Abundance of all aquatic Chironomidae, (b) abundance of all aquatic Chironomidae excluding *Corynoneura australiensis* and (c) number of aquatic Chironomidae taxa captured on yellow sticky traps in 2014-15. Blue bars indicate before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.



Fig. D-12. (a) Shannon Wiener Diversity Index H' and (b) Simpson's Diversity Index 1-D of aquatic Chironomidae caught on yellow sticky traps in 2014-15. Blue bars indicate before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.

Table D-4. List of the most commonly occurring Chironomidae species (>0.9 % of the total abundance) caught on yellow sticky traps from the Goulburn River and Broken River (reference site) pre- and post-Commonwealth environmental water (CEW) events, 2014-15.

|   | Species                         | Subfamily      | Abundance | % of total<br>abundance | Sites present  | Events<br>present |
|---|---------------------------------|----------------|-----------|-------------------------|----------------|-------------------|
| 1 | Corynoneura australiensis       | Orthocladiinae | 1,747     | 66.5                    | Broken River   | All               |
| 2 | Microcricotopus parvulus        | Orthocladiinae | 254       | 9.7                     | Goulburn River | All               |
| 3 | Limnophyes vestitus             | Orthocladiinae | 128       | 4.9                     | All            | All               |
| 4 | Paratrichocladius pluriserialis | Orthocladiinae | 97        | 3.7                     | All            | All               |
| 5 | Cricotopus parbicinctus         | Orthocladiinae | 65        | 2.5                     | All            | All               |
| 6 | Cladotanytarsus australomancus  | Chironominae   | 55        | 2.1                     | Broken River   | Post-CEW          |
| 7 | Cladotanytarsus bilinearis      | Chironominae   | 54        | 2.1                     | Goulburn River | All               |



Fig. D-13. Abundance of (a) *Corynoneura australiensis*, (b) *Microcricotopus parvulus*, (c) *Limnophyes vestitus*, (d) *Paratrichocladius pluriserialis*, (e) *Cricotopus parbicinctus*, (f) *Cladotanytarsus australomancus* and (g) *Cladotanytarsus bilinearis* caught on yellow sticky traps in 2014-15. Blue bars indicate abundance before a Commonwealth environmental flow event; red bars indicate abundance after a Commonwealth environmental flow event. The Broken River is a reference site that did not receive environmental flows during the study.

# D.5 Discussion

The three different macroinvertebrate monitoring methods provided a large amount of data pre- and post-CEW. The most useful parameters for measuring an effect of environmental flows were total macroinvertebrate abundance and the abundances of individual common taxa. In contrast, species richness (measured as the number of taxa) and diversity were less useful indicators of an effect of environmental flow.

#### D.5.1 Effects of environmental flows on macroinvertebrates

The environmental flows in spring would be considered to have a positive effect on macroinvertebrates if measured parameters increased in the Goulburn River post-CEW, but parameters decreased, remained unchanged or had a much lower increase in the Broken River reference site post-CEW. Numerous endpoints across the different sampling methods indicated environmental flows were possibly stimulating macroinvertebrate abundance. There are several mechanisms by which this may occur. For example, environmental flows could potentially increase food availability through redistributing and depositing fine sediments, organic matter and detritus, which would benefit detritivores such as Atalophlebia (MDFRC 2013a). This was demonstrated in the Short Term Intervention Monitoring (STIM) Program in the Goulburn River, with spring freshes increasing phosphorus and nitrogen concentrations in the water, enhancing riverine productivity by increasing primary production, increasing suspended organic matter in the water column, moving woody debris and adding terrestrial organic matter to the river channel, all of which potentially translate into increased food for consumers such as macroinvertebrates (Webb et al. 2015). Indeed, macroinvertebrate abundance was shown to increase with environmental flows. Similarly, in the current program a weak positive relationship was observed between daily Ecosystem Respiration rates and stream discharge, which could indicate organic carbon was being added to the stream channel (Section 4. Stream metabolism), which could benefit macroinvertebrates. It was also expected that after a lag period, environmental flows would increase gross primary production, which would also provide a food source for macroinvertebrates. The flows could also create more favourable habitats, and in the STIM, environmental water did increase the availability of deep water habitat, prevent benthic habitat smothering, increase slackwater habitats by inundating benches, and mobilise woody debris (Webb et al. 2015). Improvements in habitat availability and quality would benefit some taxa, such as the genus Procladius, which prefer muddy substrates and have species that inhabit deep water (Cranston undated). Environmental flows can benefit macroinvertebrates by maintaining water guality and keeping nuisance algal species below harmful levels (Webb et al. 2015).

An important aspect of how an environmental flow can benefit macroinvertebrate communities is through its effect on the riparian zone. Riparian vegetation at the reach-scale can have a greater impact on macroinvertebrate community structure and function than regional-scale factors such as land use (Rios and Bailey 2005). Through submersion of banks and bank wetting, environmental flows can increase the habitat available for semi-aquatic taxa, such as the Oribatida mites (MDFRC 2013a), flush silt, organic material and woody debris from the riparian zone into the river channel (providing food and habitat for many species), and increase vegetative growth in the riparian zone. Riparian vegetation tends to be more species rich than surrounding habitats, with ecological processes and community structure determine by flow regime (Nilsson and Svedmark 2002). Flows can therefore have important consequences for riparian vegetation, and this was evident in the STIM, where environmental flows in the Goulburn River returned riparian vegetation to a more natural regime, with gradual zonation of vegetation types and increasing the presence of species adapted to regular inundation (Webb et al. 2014). Improved riparian vegetation can have subsequent effects macroinvertebrates. Some of the beneficial effects the riparian zone can have on macroinvertebrates include:

- Providing a source of food and habitat for instream macroinvertebrates through deposition of organic terrestrial material (e.g. leaf litter, woody debris);
- Providing habitat for aquatic species with terrestrial life stages (such as winged adults) and corridors between reaches, enhancing colonisation;
- Stabilising the bank habitat, reducing erosion and subsequent riverbed scouring or smothering;
- Increasing entrapment of materials within the river channel, including organic matter and fine sediments;

- Affecting the microclimate of streams (including stream temperature, light exposure and evapotranspiration) through shading;
- Acting as a buffer between the stream and surrounding landscape, protecting the stream from nutrients, sediments and other pollutants (Naiman and Decamps 1997).

Riparian composition is an important determinant of terrestrial invertebrate communities around a waterbody, which in turn are a significant source of food for aquatic organisms, including fish (e.g. Allan et al. 2003). Beneficial effects on invertebrates in the riparian zone were evident when yellow sticky traps were used to examine the terrestrial and emergent invertebrates in the current survey. Several invertebrate orders, largely consisting of terrestrial species, increased in abundance in the Goulburn post-CEW. The abundance of aquatic Chironomidae adults (excluding the most dominant species) also increased in the Goulburn post-CEW, suggesting environmental flows benefited this group. Flows can have a significant impact on chironomid development, and in one study, snag-dwelling chironomids from a blackwater river developed more slowly when discharges were below average (Hauer and Benke 1991). Similarly, increased food availability due at higher water velocities was thought to be the reason chironomid emergence increased at outlets of barrage lakes (Čmrlec et al. 2013). Some chironomid taxa may be opportunistic and increase in abundance with disturbance events like environmental flows; for example, heavier summer rainfall events and late summer flooding resulted in increased winter chironomid emergence (Anderson and Ferrington 2013). Increased flows can thus create conditions favouring more rapid development and survival of certain chironomid species.

While many macroinvertebrates appeared to benefit from the environmental flows, the conditions caused by the spring freshes may have adversely affected some taxa. This was evident with a decrease in the abundance of some taxa such as Tanytarsus manleyensis and Micronecta annae annae in the Goulburn post-CEW, whereas abundances remained unchanged or even increased in the Broken River. Environmental flows can have a negative impact on water quality by increasing turbidity, reducing light penetration, and increasing erosion and sedimentation (especially in a large flow event after a long period of base flows) (Webb et al. 2015). Flows can also cause mortality in some taxa (Shafroth et al. 2010). Mortality due to environmental flows may have occurred with one chironomid species, Limnophyes vestitus. The abundance of L. vestitus adults remained relatively unchanged between pre- and post-CEW sampling at Broken River, but post-CEW adults were no longer present on sticky traps at the Goulburn River. Limnophyes vestitus prefers shallow water around the margins of water bodies, feeding on algae and detritus, and in the laboratory pupae will fail to emerge and die in water deeper than 5mm (Edward and Colless 1968). The shallow water habitat in Broken River reference site probably provided a more favourable environment for L. vestitus development. In contrast, the relatively rapid increase in water levels from the spring freshes in the Goulburn River would have inundated existing suitable shallow edge habitats and decreased the availability of these, while rapid water declines after flow delivery would have dried out any newly created shallow habitats before L. vestitus colonisation and successful development could be achieved. Conditions created during and after the flows potentially increased L. vestitus mortality or made edge habitats unsuitable for the species to successfully develop and emerge.

It should also be noted that life history traits and behavioural characteristics of some taxa can affect their response to environmental flows. For example, an experimental flood in Bill Williams River, Arizona, caused mortality in Ephemeroptera and Gomphidae, however the Ephemeroptera population rapidly recovered after the flood through recruitment from aerial adults, while Gomphidae abundance also recovered as individuals actively moved back into the stream channel after being displaced by the flows (Shafroth et al. 2010).

#### D.5.2 Assessment issues and future monitoring

Environmental flows were not the only factors at play that could affect macroinvertebrate abundances, and for some taxa it was obvious that other factors were indeed driving presence and abundance. Some invertebrates showed a clear preference for site, consistently occurring at one site but not at the other (or at least not at as high abundances). For example, crustaceans were more abundant in the Goulburn River than the Broken River, whereas several EPT taxa showed a preference for the Broken River. While both sites are in lowland reaches of the Goulburn-Broken catchment, there are numerous differences between the sites that could contribute to differences in the fauna present, including surrounding land use, river regulation and hydrological regime (recent and longer term), riparian vegetation type, connectivity to other aquatic ecosystems, geology and substrate, and so on. In addition, temporal factors could also affect the macroinvertebrates, and this was evident with some taxa only occurring (or occurring at much higher numbers) in one sampling event but not the

other at both sites. For example, the Chironomidae *Tanytarsus* sp. and *Thienemanniella* sp., and the Caenidae *Tasmanocoenis tillyardi* were much more abundant at both sites pre-CEW, whereas the Chironomidae *Cladotanytarsus* sp., *Djalmabatista* sp., *Cricotopus parbicinctus* and the Veliidae *Microvelia* sp. were much more abundant at both sites post-CEW. The composition of macroinvertebrate communities can vary substantially across seasons (e.g. Šporka et al. 2006, Bouchard and Ferrington 2011), so it should be expected that the macroinvertebrate communities pre-CEW (early to mid-spring) would differ from those post-CEW (early to mid-summer). As such, it can be difficult to determine the effects of Commonwealth environmental flows on macroinvertebrates when other factors, such as site and temporal differences, are also having a strong effect. Repeated monitoring over the next four years will aid in the analysis of the data and give more clarity as to how much of the variance in macroinvertebrate responses can be explained by environmental flows.

Finally, there are plans to incorporate some of this research into a PhD project. These plans include expanding the macroinvertebrate research to other catchments, extend monitoring to include other environmental flow events across different seasons; and to build upon existing methods by including endpoints that may be more ecologically relevant and sensitive to environmental flows, such as biomass. Some of the outcomes of the PhD project will provide more certainty regarding the effects of environmental flows on macroinvertebrates.

## D.6 Conclusion

Macroinvertebrates in the Goulburn River were responding to environmental flows. This was evident with the increased abundance of some taxa in the artificial substrates and the replicated edge sweep samples, indicating environmental flows were making conditions within the Goulburn River more favourable for these taxa, potentially by improving or maintaining water quality and habitat, increasing food and habitat availability, and affecting the colonisation and recruitment of these taxa. In addition, monitoring in the riparian zone with yellow sticky traps showed that for the aquatic Dipteran family, Chironomidae, environmental flows may have increased the abundance and survival of larvae to adulthood. Other invertebrates in the riparian zone also increased after the spring freshes in the Goulburn River, and as these are largely terrestrial organisms, it is hypothesised that the environmental flows improved riparian habitat for these animals. While other factors, such as site and temporal differences between the sampling locations and sampling events, might also contribute to the results observed, further monitoring will help to separate the effects of these factors from Commonwealth environmental flows. At this stage, the macroinvertebrate monitoring results do not have any implications for adaptive management in the lower Goulburn River.

# **Appendix E. Detailed results for Vegetation**

# E.1 Introduction

Riparian and aquatic vegetation underpins aquatic systems by: (1) supplying energy to support food webs, (2) providing habitat and dispersal corridors for fauna, (3) reducing erosion and (4) enhancing water quality. In the Goulburn River drought and floods have reduced the quantity, quality and diversity of riparian and bankside vegetation over the last 10-15 years. Minimum summer and winter low flows and periodic freshes are recommended to help rehabilitate and maintain vegetation along the lower Goulburn River. The recommended flow components shape aquatic plant assemblages by influencing (1) inundation patterns in different elevation zones on the bank and hence which plants can survive in each zone; (2) the abundance and diversity of plant propagules dispersing in water; and (3) where those propagules are deposited and germinate.

Vegetation diversity has been monitored at four sites in the lower Goulburn River every two years since 2008 as part of the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP), and has been assessed for the Commonwealth Short Term Monitoring Project. Including vegetation diversity monitoring in the LTIM Project for the lower Goulburn River will extend those data sets and allow the effect of different flow components to be assessed in wet and dry climatic conditions. The results will be used to identify what flows are needed to maintain or rehabilitate riparian vegetation in the lower Goulburn River depending on its current condition and state of recovery. The results will also be used to broadly inform appropriate water management in other systems recovering from extreme events.

# E.2 How are environmental flows expected to affect riparian and aquatic vegetation in the lower Goulburn River and specific evaluation questions?

#### E.2.1 Basin-scale evaluation questions

#### Short-term (one-year) and long-term (five year) questions:

- What did Commonwealth environmental water contribute to vegetation species diversity?
- What did Commonwealth environmental water contribute to vegetation community diversity?

These questions are being addressed by quantitatively measuring the abundance of different plant species on the banks of the channel (i.e. between the low flow water level and mid-way up the bank) on multiple occasions over the term of the LTIM Project. The vertical elevation of each monitoring point will be recorded to link the vegetation data with short and long term inundation patterns. Repeat measurements will be taken every year of the program to assess long term changes in the composition and distribution of bankside vegetation. Monitoring is also being done before and after planned spring high flows to determine the more immediate effects of those flows on vegetation.

#### E.2.2 Area-specific evaluation questions

Prolonged drought, followed by record breaking floods has significantly altered the vegetation community on the banks of the lower Goulburn River. Particular effects include the loss of some plant species that were not able to tolerate the extreme conditions, and the physical removal of virtually all plants in some sections of the river that experienced severe bank erosion. The GBCMA is delivering a combination of summer low flows and freshes throughout the year to try to promote the rehabilitation of native riparian vegetation communities.

We aim to use the vegetation diversity monitoring to address the following Area-specific evaluation questions:

#### Long-term evaluation questions

• What has CEW contributed to the recovery (measured through species richness, plant cover and recruitment) of riparian vegetation communities on the banks of the lower Goulburn River that have been impacted by drought and flood and how do those responses vary over time?

 How do vegetation responses to CEW delivery vary between sites with different channel features and different bank conditions?

#### Short-term evaluation questions

- Does the CEW contribution to spring freshes and high flows trigger germination and new growth of native riparian vegetation on the banks of the lower Goulburn River?
- How does CEW delivered as low flows and freshes at other times of the year contribute to maintaining new growth and recruitment on the banks of the lower Goulburn River?

Vegetation diversity monitoring is being done at sites with different physical forms and different bank conditions; we aim to determine how these factors influence riparian vegetation responses to environmental watering. Moreover, the program aims to determine whether responses to environmental watering events in the first few years of the LTIM Project are repeated in subsequent years, or whether responses are primarily determined by the condition and 'maturity' of vegetation communities when specific flows are delivered. This monitoring will help the GBCMA determine appropriate ways to modify their environmental watering programs to either facilitate post-disturbance recovery or to maintain riparian communities that are in good condition.

The vegetation monitoring program will be enhanced by physical habitat assessments including 2-D hydraulic modelling and bank erosion. Two dimensional hydraulic modelling will help predict the sheer forces that particular parts of the river bank experience under different flow conditions and allow vegetation responses in different environments to be compared. Bank condition monitoring will help explain any gross differences in vegetation responses to flow at different sites. Monitoring vegetation and physical habitat parameters concurrently may also help to determine the extent to which different types of vegetation buffer the river banks from erosion during floods and high flows.

## E.3 Monitoring methods

#### E.3.1 Sampling

Vegetation was sampled on both banks at Loch Garry and McCoys Bridge, pre and post the delivery of spring freshes (Table E-1, Fig. E-1). Vegetation was surveyed along transects that ran perpendicular to stream flow. Sampling initially aimed to survey regions of the bank that had previously been surveyed by other programs (i.e. VEFAMP and CEWH STIM). However, many quadrats sampled by these programs were at elevations well above the level expected to be inundated by spring freshes. As such, sampling did not attempt to match the spatial extent of these previous programs. Instead, surveys extended from around base flow to just above the level inundated by spring freshes (nominally a change in elevation of approximately 3 m). As transect elevation data were not available in the first year of sampling, a 3 m change in height from base flow was estimated visually. To support more targeted monitoring in the future, elevation profiles using a high-precision RTK GPS were obtained at 1 m intervals along all transects in December 2014.

| Sampling<br>event | Date                         | Sites sampled | Transects sampled<br>North bank | Transects sampled<br>South bank |
|-------------------|------------------------------|---------------|---------------------------------|---------------------------------|
| Pre-fresh         | 23 Sept 2014 and 3 Oct 2014* | Loch Garry    | 1,3,5,8,9,10,12,13,15           | 9,10,11,12,13                   |
|                   | 24 Sept 2014                 | McCoys Bridge | 1,2,3,6,8,10,12,13,15           | 1,2,3,5,10,12,13,15             |
| Post-fresh        | 16 Dec 2014                  | Loch Garry    | 1,3,5,8,9,12,13,15              | 1,3,5,9,10,12,13,15             |
|                   | 17 Dec 2014                  | McCoys Bridge | 1,2,3,6,10,12,13,15             | 1,2,3,6,10,12,13,15             |

Table E-1. Summary of vegetation survey dates, sampling locations and transects

\*A return visit on the 3 Oct 2014 by CMA staff was required to sample the South bank at Loch Garry.

#### Vegetation indicators

Vegetation indices were assessed using the line point intercept method at 1 m intervals along each transect line until a change in elevation of approximately 3 m was reached. At each sampling interval a 2 m measuring tape

was placed perpendicular to the transect (i.e. parallel to streamflow) and all species that intercept a rod placed vertically through the vegetation every 10 cm was recorded. This gave a total of 20 sampling points at each sampling location. Foliage projected cover (%) for each species was calculated by dividing the number hits per species by the total number of points sampled. Soil surface cover type(s) were assessed in the same manner. Overstorey vegetation cover was assessed applying the same sampling approach but using a crosswire sighting periscope held vertically at each pointing location. The density of woody recruits was initially assessed within 1m x 1m quadrats positioned at the bottom, middle and top of the bank profile. Due to the very low number of recruit this approach was modified for the December 2014 survey and recruitment was assessed in 1m x 1m quadrats every 2 m.

### E.4 Results

#### E.4.1 Relevant flow components delivered to the lower Goulburn River in 2014-15

In spring 2014, Commonwealth environmental water was delivered to the Goulburn River for vegetation objectives over 3 weeks from mid-October to early November in accordance with seasonal watering plans. A maximum discharge of about 7700 ML/d was released. A further release of Commonwealth environmental water occurred over 3 weeks, from mid-November to early December, in accordance with seasonal watering plans, primarily to meet fish objectives and with a secondary objective of maintaining bank soil moisture stores.

Releases of up to 3000 ML were also delivered for TLM from late September to early October 2014, and again at the start of January 2015 as inter-valley-transfers. These releases have the potential to constrain vegetation sampling by limiting access to the lower banks.



Fig. E-1. Goulburn river discharge (ML/d) over the monitoring period for McCoys Bridge (blue line) and Loch Garry (red line). Arrows show dates of vegetation surveys.

Despite the delivery of the October and November freshes in 2014, the soils were extremely dry when surveyed in December 2014. The climatic conditions recorded at Shepparton Airport indicate that December 2014 was hotter (mean max air temp of 30.2 °C cf 28.8°C) and drier (17.4 mm vs 31.8 mm) compared with the long term average (1996-2015). These drier conditions may have limited the responses of vegetation to spring freshes.

#### E.4.2 Monitoring results and observations

#### Patterns of inundation

The duration and depth of inundation experienced by vegetation along the river bank is determined by their position along the elevation gradient and by patterns of river discharge. Spring freshes delivered in 2014 extended to elevations of approximately 102 AHD m and 96.5 AHD at Loch Garry and McCoy's Bridge, respectively. Both the upper extent of water delivery on the banks, and the depth and duration of inundation

experienced along the elevation gradient appears to influence the distribution and abundance of vegetation (Fig. E-2, Fig. E-3).

#### Vegetation cover

The cover and distribution of ground layer vegetation along the elevation gradient at Loch Garry and McCoys bridge pre and post the delivery of spring freshes is shown in Fig. E-2b and Fig. E-3b, respectively. In some cases the cover of all vegetation was greater 100%, this occurs when two layers of vegetation are present such as a prostrate ground cover (e.g. *Persicaria prostrata*) and a taller herb (e.g. *Cyperus eragrostis*).

At both sites, the total cover of vegetation in the ground layer increased with increasing elevation, reaching maximum values around the upper elevation reached by spring freshes (blue vertical line on graphs). Patterns in the cover of vegetation differed among species. *Alternanthera denticulata* and *Persicaria prostrata* both native species and *Cyperus eragrostis* an introduced species were restricted in their distribution to elevations inundated by spring freshes. In contrast *Poa labillardierei*, a native perennial grass, preferred drier locations and had minimal cover at elevations inundated by the spring fresh and highest cover at elevation at or above the level of inundation.

Within the region of the bank inundated by spring freshes, the total cover of vegetation was greatest at higher elevations where short periods of shallow inundation were experienced, and was minimal at lower elevations that experienced permanent or long periods of inundation, and the deepest inundation depths. Species differed in their sensitivity to inundation; for example, the cover of *P. prostrata* was very sensitive to change in elevation.

Vegetation cover within the region of the bank inundated by spring freshes was higher following the spring fresh at Loch Garry but not at McCoys Bridge where cover did not change. At Loch Garry increases in the cover of ground layer vegetation along the elevation gradient was largely attributed to an increase in cover of *A. denticulata* and to a lesser extent *C. eragrostis*.

#### Recruitment

Woody recruits represented by *Acacia dealbata* and *Eucalyptus camaldulensis* were rare at both Loch Garry and McCoy Bridge and were limited to higher elevations along the bank that experience shorter and more shallow inundation.

#### Influence of channel features on vegetation cover

Surveyed transects were categorised as occurring on inside bends, outside bend or straight sections of the river channel. These channel features appear to influence the cover of ground layer vegetation. Cover was highest on banks located on inside bends, followed by straight sections and lowest on outside bends (Table E-2). These differences were more evident at Loch Garry than at McCoy's Bridge but the same patterns were present.

Table E-2. Mean percent cover of ground layer vegetation at different channel features sampled in December 2014 at Loch Garry and McCoys Bridge. Data are means  $\pm$  S.E. The number of locations sampled (n) is given in parentheses.

| Site          | Channel feature | Percent cover of ground layer vegetation |
|---------------|-----------------|--|
| Loch Garry    | Inside bend     | 81 ± 12 (12)                             |
|               | Straight        | 57± 9 (n=34)                             |
|               | Outside bend    | 33 ±10 (21)                              |
| McCoys Bridge | Inside bend     | 49 ± 13 (n=17)                           |
|               | Straight        | 30 ± 6 (n=66)                            |
|               | Outside bend    | 22 ± 11 (n=22)                           |



Fig. E-2. Number of days inundated between sampling events across the elevation gradient at Loch Garry (a) and percent foliage projected cover (FPC) across the elevation gradient for (b) all vegetation, (c) *Poa labillardierei*, (d) *Alternanthera denticulata* and (e) *Persicaria prostrata* before (red open circles) and after (green filled circles) the delivery of spring freshes.



Fig. E-3. Number of days inundated between sampling events across the elevation gradient at McCoy's Bridge (a) and percent foliage projected cover (FPC) across the elevation gradient for: (b) all vegetation, (c) *Persicaria prostrata*, (d) *Alternanthera denticulata* and (e) *Cyperus eragrostis* before (red open circles) and after (green filled circles) the delivery of spring freshes.

# E.5 Discussion

Vegetation responses to water regime, particularly spring freshes are summarised below.

- The extent and duration of inundation provided by spring freshes was correlated with the distribution and cover of vegetation along the bank. A number of plant species associated with wet habitats including *Alternanthera denticulata*, *Persicaria prostrata* and *Cyperus eragrostis* were restricted to elevations inundated by spring freshes. In contrast, the perennial native grass *Poa labillardierei* preferred elevations at or above the level inundated by spring freshes.
- Within the region of the bank inundated by spring freshes, the cover of vegetation is greatest at higher elevations and declines at lower elevations as the depth and frequency of inundation increases.
- The cover of vegetation within the region inundated by spring freshes increased following spring freshes at Loch Garry, but not at McCoys Bridge where cover remained unchanged. Species that contributed to the increase in cover only occurred at elevations inundated by spring freshes and it was not possible to distinguish flow responses from natural variation in cover. It is unclear why responses of vegetation to the spring fresh differed among sites. One possibility is that these sites are at differ points along their recovery trajectories.
- When plants were surveyed in December 2014 the banks were observed to be extremely dry. The depletion of soil moisture with the onset of hotter and drier conditions may have constrained vegetation responses to spring freshes. Climate data from the Bureau of Meteorology (BOM) for Shepparton Airport show that December 2014 was hotter and drier than the long term average.
- The recruitment of woody species was restricted to higher elevations that experienced shallow and less frequent inundation.
- Cover was highest on banks located on inside bends, followed by straight sections and lowest on outside bends. These differences were more evident at Loch Garry than at McCoys Bridge but the same pattern was observed.

While patterns of vegetation cover and extent appear to be correlated with spring freshes, further monitoring is needed to: (i) determine if these patterns persist over time, (ii) understand trajectories of change at both sites, and (iii) assess how sensitive vegetation is to changes in the timing, duration, magnitude and/or rate of flow delivery.

#### E.5.1 Monitoring evaluation

Monitoring programs should be adjusted through a continuous process of evaluation. A number of aspects of the vegetation monitor program have been refined based on the experience of delivering the program in 2014 and are detailed below.

Sampling effort: As elevation data was not available to guide sampling in 2014 it was difficult to gauge how far up the bank vegetation surveys should extend. Elevation data along all transect was collected in December 2014 will allow more targeted and consistent sampling effort for the remainder of the LTIM Project.

*Overstorey cover*. As the cover of the overstorey was not a key flow response indicator in the Goulburn, assessment of cover has been reduced to annual surveys.

*Recruitment*: As woody recruits were very rarely observed, the sampling strategy has been changed to increase sampling effort. Future surveys will assess the density of woody recruits in 2m x 1m quadrats every 1 m along transects.

Soil wetness: Soil wetness is also now recorded including: dry, saturated or muddy, inundated (approx. depth).

Seedling recruitment: The CEWH SOP for vegetation only specifies monitoring woody recruits. While the presence of seedlings of non-woody species was often recorded during assessment of ground layer cover, it has not been clearly specified in the SOP or on the field sheets, and there may have been inconsistency among assessors in recording seedlings. We have revised the program to ensure assessors record the cover of seedlings. At sites where large numbers of seedlings are observed, this will be noted along with their location so they can be followed over time.

# E.6 Conclusion

- The extent and duration of inundation provided by spring freshes was correlated with the distribution and cover of vegetation along the bank. Several native plant species that have an affinity for wet habitats only occurred in regions of the bank inundated by spring freshes.
- The recruitment of woody species, specifically *Acacia dealbata* and *Eucalyptus camaldulensis* was restricted to higher areas of the bank which experience shallow and less frequent inundation.
- Within the region of the bank inundated by spring freshes, the cover of vegetation is greatest at higher elevations and declines at lower elevation where deeper and more frequent inundation is experienced.
- Channel features appear to influence vegetation cover on the banks. Cover was highest on banks located on inside bends, followed by straight sections and lowest on outside bends.
- The cover of vegetation increased following spring freshes at Loch Garry but not at McCoy's Bridge, where cover did not change. Higher than average temperatures and lower than average rainfall in December 2014 may have limited vegetation responses to freshes.

#### E.7 Adaptive management of flow:

While the current flow delivery is appropriate, it is not known if adjustments to the timing, magnitude or rates of flow delivery would enhance vegetation recovery. Possible responses of vegetation to changes in components of the flow regime are discussed below.

#### Timing of spring freshes

Delivering the October spring fresh earlier may provide a longer window for plant growth following the recession of these flows, as climatic conditions are likely to be more favourable for growth than when flows are delivered later in the season.

#### Receding flows

Experiments carried out in flumes have shown that more plant propagules are deposited on the receding arm of flows when they are stepped (Merritt and Wohl 2002). Adopting this strategy for the spring fresh may facilitate the deposition of plant progagules at different elevations along the bank and enhance vegetation recovery at lower elevations. However, the retention of propagules may be limited as many areas of the bank lack any woody litter or surface roughness to promote propagule retention.

#### Height of spring freshes

Although the upper extent of the spring fresh is correlated with higher vegetation cover, cover declines down the elevation gradient. Lowering the level of the spring fresh may provide a more favourable inundation regime for vegetation at lower elevations, provided vegetation establishment and growth is not constrained by other non-flow variables (e.g. erosion, propagule availability or retention) and that soil moistures stores are maintained.

If drought conditions are likely in the future, there may be merit in gradually lowering the height of spring freshes to allow vegetation to track down the profile where water delivery under drought conditions may be more sustainable. It is also possible, however, that reducing the height of the spring may have adverse effects on vegetation by reducing soil moisture stores held in the bank. A better understanding of the soil moisture stores

achieved by spring freshes, and how long this is sustained following freshes will help evaluate the potential consequences of lowering the height of spring freshes on vegetation. Developing a program to assess bank soil moisture stores would require additional resourcing. Without constraints on the availably of water, periodically varying the height of the freshes may promote greater vegetation cover across the elevation gradient but requires testing.

#### Research needs

The re-establishment of vegetation on the banks of the Goulburn River is limited, with many locations having no vegetation. The limited recovery of vegetation at some location may be due to a number of factors and warrant investigation through field based experimental manipulations. Field based experimental manipulations should aim to assess if vegetation recovery is limited by:

- The availability of propagules.
- Poor retention of propagules on the banks due to the lack of wood/litter, soil surface roughness or erosion.
- The depth and duration of inundation experienced during early plant establishment.
- The availability of microclimates required for establishment.

# Appendix F. Detailed results for Fish

# F.1 Introduction

Supporting native fish populations is a key element of the Basin Plan's goal to protect biodiversity. The Goulburn River supports a diverse native fish fauna with high conservation and recreational angling value. Species of conservation significance include trout cod, Murray cod, silver perch, golden perch and freshwater catfish. Conservation of the fish fauna of the Goulburn River has been recognised as a high priority by fisheries management and natural resource management agencies. In particular, the provision of environmental flows to support native fish populations has been identified as a key environmental watering objective for the Goulburn River (Cottingham and SKM 2011). Indeed, in terms of Commonwealth water being invested for environmental objectives, flow allocation for native fish represents a major investment of water (e.g. 58 GL for fish habitat maintenance, 138 GL for fish breeding/movement). Given this investment, it is critical that the LTIM Project evaluates the effect that CEW has on native fish populations in the lower Goulburn River. Quantifying relationships between fish populations (e.g. abundance, distribution, population structure) and environmental flows in the lower Goulburn River will help the GBCMA adaptively manage environmental flows in the Goulburn River and support decisions regarding environmental flows for fish throughout the Murray-Darling Basin.

The fish monitoring being carried out in this program builds upon 10 years' worth of monitoring and research assessing the status of fish populations in the Goulburn River (Koster et al. 2012) as well as monitoring undertaken since 2006 as part of the Victorian Environmental Flows Monitoring and Assessment Program. When complete, the Goulburn River fish LTIM Project will represent one of the longest continuous sets of fish monitoring data collected in the Murray Darling Basin. Moreover, it will cover a wide range of climatic conditions including record drought, record floods, and a major blackwater event that contributed to widespread fish kills. The next five years' monitoring will be particularly important in assessing the ongoing recovery of fish populations from those extreme disturbances.

The Goulburn River fish LTIM Project is also crucial to informing and interpreting the results of monitoring in other areas of the Basin. Golden perch have the capacity to disperse throughout the Basin and there is potentially a high level of connectivity between population in the lower Goulburn River, lower Murray River, Edwards-Wakool system and Murrumbidgee River. Co-ordinated monitoring across these four regions may be used to assess the influence environmental flows in one area (e.g. spawning in the Goulburn River) have on fish populations in other areas (e.g. recruitment in lower Murray).

The fish monitoring methods (annual adult fish surveys, larval surveys, fish movement) complement each other, increase the number of evaluation questions and associated research questions that can be answered through the program.

#### F.1.1 Annual adult fish surveys

Annual fish surveys in the river channel is a Category I monitoring activity that will provide critical information for the Basin-scale assessment. When added to the existing fish survey data for the lower Goulburn River it will provide a record of how the fish community has changed over a period of 15 years and how those changes relate to river flow. Moreover annual surveys will help to determine whether fish spawning (detected through larval surveys) or fish movement that may be triggered by environmental flow releases result in successful recruitment.

#### F.1.2 Larval fish surveys

The larval surveys for the lower Goulburn River are collecting larvae of all fish species, but will be designed more specifically to detect golden perch spawning. Golden perch is one of only two fish species (along with silver perch) in the Murray Darling Basin thought to require increased discharge to initiate spawning. Indeed, environmental flows in the Goulburn River are explicitly used to promote spawning and recruitment of Golden perch (Cottingham and SKM 2011) and, as part of environmental water delivery for the Goulburn River, one of the key flow objectives is to deliver freshes to promote the spawning of golden perch (Cottingham and SKM 2011).

The annual adult fish surveys can be used to identify any young-of-year golden perch in the lower Goulburn River, but given Golden Perch can move long distances, direct egg/larval surveys are required to determine whether high flows released into the lower Goulburn River actually trigger fish spawning.

The larval fish program will build on and add to an existing 10 year data set monitoring the spawning responses of fish to flows in the Goulburn River (Koster et al. 2012) and will represent one of the longest continuous sets of larval fish data collected in the Murray Darling Basin. Relatively few spawning events have been recorded in the lower Goulburn River to date. That is mainly thought to be due to the lack of large flows during the drought. The managed flow releases in spring 2013 and 2014 (which used Commonwealth environmental water) triggered the most significant Golden perch spawning that has been recorded in the lower Goulburn River in recent years. Ongoing monitoring as part of the LTIM Project should aim to more reliably determine the specific timing, magnitude and duration of flows that are needed to trigger significant spawning events. That information can then be used to help the Goulburn Broken CMA actively manage environmental flows in the future.

The larval fish program will also inform and complement monitoring in other Selected Areas. Fish have the capacity to disperse throughout the Basin and there is potentially a high level of connectivity between regions, particularly the Goulburn, lower Murray, Edwards-Wakool and Murrumbidgee rivers. That connection means that environmental flows in one area (e.g. spawning in the Goulburn River) has the potential to strongly influence outcomes in other areas (e.g. recruitment in lower Murray). In other words, monitoring of fish spawning responses in the Goulburn River may help to explain changes in recruitment and abundance in other selected areas. Thus, the Goulburn River larval fish LTIM Project will contribute to a comparison and contrast of spawning and recruitment responses of golden perch at sites across much of the Murray Darling Basin, thereby informing Basin-level responses.

#### F.1.3 Fish movement

Biotic dispersal or movement is critical to supporting connectivity of native fish populations, which is a key element of the Basin Plan's goal to protect Ecosystem Function. In particular, movement within and between water-dependent ecosystems (i.e. connectivity) can be crucial for sustaining populations by enabling fish to recolonise or avoid unfavourable conditions. For some fish species, movement also occurs for the purposes of reproduction and therefore contributes to the Basin Plan's goal to protect Biodiversity.

The Goulburn River fish movement program targets golden perch and will build on the existing six-year acoustic telemetry project (currently funded by CEWO) monitoring movement of native fish in the Goulburn River and Murray River (Koster et al. 2012). The Goulburn River fish movement program complements monitoring of fish movement proposed as part of the LTIM Project in the Murrumbidgee, Edward-Wakool and Gwydir rivers. In particular, it will enable a comparison and contrast of the movements of native fish at sites across much of the Murray Darling Basin thereby informing Basin-level responses. The Goulburn River fish movement program will also be crucial to informing and interpreting the results of monitoring within the other selected areas. Fish have the capacity to disperse throughout the Basin and there is potentially a high level of connectivity between regions, particularly the Goulburn, lower Murray, Edward-Wakool and Murrumbidgee Rivers. Therefore the influence of environmental flows in one area has the potential to strongly influence outcomes in other areas. In other words, monitoring of fish movement within the Goulburn River might help to explain changes in fish abundance within other selected areas.

The LTIM Project represents a unique opportunity to co-ordinate fish movement monitoring across the southern connected Murray-Darling Basin. We are specifically investigating whether individual golden perch move between any of the selected areas over the course of the LTIM Project and consider whether particular flow events triggered or facilitated that movement.

# F.2 How are environmental flows expected to affect native fish communities in the lower Goulburn River and specific evaluation questions?

#### F.2.1 Basin-scale evaluation questions

The M&E Advisor has prescribed three different fish monitoring methods for river channels. These include annual surveys of adult fish populations within the river channel, targeted egg/larval surveys between spring

and late summer, and tracking the movement of tagged fish throughout the year. These three monitoring techniques provide data that will be variously used to address long-term and short-term evaluation questions at the Basin-scale:

#### Long-term (five year) questions:

- What did CEW contribute to native fish populations? (annual fish surveys, larval surveys, movement)
- What did CEW contribute to species diversity? (annual fish surveys, larval surveys)

#### Short-term (one year) questions:

- What did CEW contribute to fish community resilience? (annual fish surveys, larval surveys)
- What did CEW contribute to native fish survival? (annual fish surveys, larval surveys)
- What did CEW contribute to native fish reproduction? (annual fish surveys, larval surveys, movement)
- What did CEW contribute to native fish dispersal? (movement)

Questions relating to population structure and species diversity will be assessed by measuring the abundance and age structure of different populations, richness of species within the community and the distribution of species within Selected Areas and across different Selected Areas throughout the Basin. Native fish community resilience and survival will be assessed through species distribution and age composition (e.g. species that are widespread and have a wide range of age classes are likely to be more resilient). Fish reproduction will be directly assessed through egg/larval surveys and indirectly through annual surveys that check for a mix of age cohorts within the population. Fish tracking or movement will be specifically used to determine whether fish (golden perch) move in response to certain environmental flows, but will also be linked to questions about reproduction for species that migrate to preferred spawning areas to breed.

#### F.2.2 Area-specific evaluation questions

One of the main objectives of Commonwealth environmental water delivery in the lower Goulburn River is to maintain or improve the health of native fish communities. This is particularly important now because the Millennium Drought and then blackwater events that were associated with the 2010 and 2011 floods significantly reduced native fish populations in the lower Goulburn River. Golden perch, and to a lesser extent silver perch, are the main targets for environmental water in the lower Goulburn River because their spawning and recruitment is linked to flows. The GBCMA delivers high flows or freshes during spring to trigger golden perch spawning. The area specific questions for fish monitoring in the lower Goulburn Area include:

#### Long-term (five year) questions

• What did CEW contribute to the recruitment of golden perch in the adult population in the lower Goulburn River? (annual fish surveys, larval surveys, movement)

#### Short-term (one year) questions

- What did CEW contribute to golden perch spawning and in particular what magnitude, timing and duration of flow is required to trigger spawning? (larval surveys and movement)
- What did CEW contribute to the survival of golden perch larvae in the lower Goulburn River? (annual fish surveys and larval surveys)
- What did CEW contribute to the movement of golden perch in the lower Goulburn River and where did those fish move to? (movement)

These assessments, particularly assessments of larval survival and recruitment, will benefit from complementary 2-D Hydraulic Modelling that will quantify the distribution, quantity and quality of slackwater habitats within the channel under different flow conditions. Much of the fish monitoring described above will also be conducted in the lower Murray Selected Area and the Edward Wakool Selected Area. Golden perch are likely to move between the lower Goulburn River and those other two selected areas and co-ordinated monitoring across all three areas throughout the LTIM Project will provide a unique opportunity to understand

that movement and how flow regimes and other factors in one area can affect Golden perch populations in other areas.

# F.3 Monitoring methods

A detailed description of the sampling methods can be found in the Standard Operating Procedures. Briefly, electrofishing was conducted at 10 sites in the Goulburn River during April and May 2015. Sampling was conducted at each site during daylight hours using a Smith–Root model 5 GPP boat–mounted electrofishing unit. At each site the total time during which electrical current was applied to the water was 2880 seconds. Ten fyke nets were also set at each site. In addition, ten bait traps were set at each site to comply with VEFMAP data collection requirements. Nets were set in late afternoon and retrieved the following morning.

At the time of writing, annual ageing of a sample of the selected target equilibrium (Murray cod) and periodic (golden perch, silver perch) species collected was being undertaken using otoliths. Samples of short-lived opportunistic species (carp gudgeon, Australian smelt, Murray river rainbowfish) were collected, but have not yet been aged, with the idea being to choose two species which are abundant across different selected areas to make results more broadly applicable (R. Stoffels, Monitoring Advisor, pers. comm.). The value of annual ageing of short-lived species is also questionable as only one or two size classes would generally be expected in the population and this issue needs to be resolved.

Golden perch (n = 30) collected during autumn 2015 were tagged with acoustic transmitters. In addition, golden perch (n = 29) were tagged with acoustic transmitters as part of surveys conducted for GBCMA in autumn 2014. Twenty one acoustic listening stations were deployed in the Goulburn River between Goulburn Weir and the Murray River junction. Four listening stations were also deployed in the Murray River one and two km upstream and one and three km downstream of the Goulburn River junction.

Drift nets were used to sample fish eggs and larvae in the Goulburn River at four sites (Pyke Road, Loch Garry, McCoys Bridge, Yambuna) every week from October to December 2014 using 3 nets set at each site. Light traps were also set at three sites (Loch Garry, McCoys Bridge, Yambuna) every 1-2 weeks from October to December 2014 using 10 light traps set at each site. The nets and light traps were set in late afternoon and retrieved the following morning.

# F.4 Results

#### F.4.1 Relevant flow components delivered to the lower Goulburn River in 2014-15

In spring 2014, environmental water was delivered to Goulburn River from mid-November to early December over 3 weeks in accordance with seasonal watering plans, and with the aim of triggering spawning and migration of golden perch. A maximum discharge of about 6300 ML/day was released. There was also an environmental water release to the Goulburn River immediately prior from mid-October to early November over 3 weeks for vegetation objectives. A maximum discharge of about 7700 ML/day was released.

#### F.4.2 Monitoring results and observations

#### Annual surveys (electrofishing and netting)

A total of 631 individuals representing seven native and three exotic species were collected from the annual electrofishing surveys (Table F-1). Australian smelt was the most abundant species, comprising 42% of the total abundance for all species. Murray River rainbowfish and carp were the next most abundant species, comprising 20% and 17% respectively. These three species were also the most abundant in electrofishing surveys conducted in the Goulburn River from 2003 to 2013 (Koster et al. 2012, Koster unpubl. data).

A total of 239 individuals representing four native species were collected from the annual netting surveys (Table F-1.). Carp gudgeon was the most abundant species, comprising 71% of the total abundance for all species. Murray River rainbowfish was the next most abundant species, comprising 24%. A total of 6 individuals representing one native species (carp gudgeon) were collected from the bait trap surveys.

A number of species of conservation significance were collected, namely Murray cod, trout cod and silver perch. A range of introduced fish species, namely carp, goldfish and eastern gambusia, were also collected.

Table F-1. Numbers of individual fish species collected from the Goulburn River in electrofishing, fyke net and bait trap surveys in 2015.

| Species   | Electrofishing | Fyke Netting | Bait Traps | Total |
|---|----------------|--------------|------------|-------|
| Silver perch Bidyanus bidyanus                    | 2              |              |            | 2     |
| Goldfish Carassius auratus                        | 8              |              |            | 8     |
| Carp Cyprinus carpio                              | 107            |              |            | 107   |
| Eastern gambusia Gambusia holbrooki               | 1              |              |            | 1     |
| Carp gudgeon Hypseleotris spp.                    | 9              | 170          | 6          | 185   |
| Trout cod Maccullochella macquariensis            | 1              |              |            | 1     |
| Murray cod Maccullochella peelii                  | 79             |              |            | 79    |
| Golden perch Macquaria ambigua                    | 29             | 2            |            | 31    |
| Murray River rainbowfish Melanotaenia fluviatilis | 128            | 58           |            | 186   |
| Australian smelt Retropinna semoni                | 267            | 9            |            | 276   |
| Total number of individuals                       | 631            | 239          | 6          | 876   |

Length frequency histograms are presented for five of the six selected target species: Murray cod, golden perch, silver perch, carp gudgeon, Australian smelt. One of the target species, river blackfish, was not collected.

#### Murray cod

The size of Murray cod collected in the surveys ranged from 52 mm in length and 1 g in weight to 800 mm in length and 8.9 kg in weight (Fig. F-1). The majority of Murray cod collected were 50-400 mm in length. A broad range of sizes of fish, including YOY (approximately < 100 mm in length) were collected, indicating recent recruitment.



Fig. F-1. Length frequency of Murray cod collected in the Goulburn River

#### Golden perch

The size of golden perch collected in the surveys ranged from 140 mm in length and 32 g in weight to 492 mm in length and 1.8 kg in weight (Fig. F-2). The golden perch population consisted of mostly larger fish, with few individuals below the minimum legal size of 300 mm. There was no evidence of recent recruitment with no YOY fish collected.



Fig. F-2. Length frequency of golden perch collected in the Goulburn River

#### Silver perch

Only 2 Silver perch were only collected, and there was no evidence of recent recruitment with no YOY fish collected (Fig. F-3).



Fig. F-3. Length frequency of silver perch collected in the Goulburn River

#### Carp gudgeon

The majority of carp gudgeon collected were 20-40 mm in length (Fig. F-4). These fish likely represent 0+ year old individuals. Carp gudgeon are a short-lived species (e.g. 1-2 years) and only one or two size classes would generally be expected in the population.



Fig. F-4. Length frequency of carp gudgeon collected in the Goulburn River

#### Australian smelt

The majority of Australian smelt collected in the Goulburn River were 30-60 mm in length (Fig. F-5). These fish likely represent 0+ year old individuals. Australian smelt are a short-lived species (e.g. 1-2 years) and only one or two size classes would generally be expected in the population.





#### Surveys of eggs and larvae (drift nets and light traps)

A total of 2839 individuals representing six native species were collected in the drift net surveys (Table F-2). Golden perch was the most abundant species collected, comprising 57% of the total abundance for all species. Golden perch eggs/larvae were collected at all 4 sites, but the majority were collected from Yambuna (47%) and McCoys Bridge (30%).

Golden perch eggs/larvae were collected from late October to late November in water temperatures ranging from 18–23° C. Peak egg abundances were collected in late November coinciding with an increase in flow from about 964 to 6309 ML/day associated with an environmental flow release (Fig. F-6). Low numbers of eggs were also collected in late October coinciding with an increase in flow from about 1448 to 7673 ML/day associated with an environmental flow release (Fig. F-6).

Murray cod was the next most abundant species comprising 33%. Murray cod larvae were collected from late October to early December under a range of flow conditions. This finding is consistent with those of previous studies of Murray cod spawning (Humphries 2005, King et al. 2009, Koster et al. 2012).

Table F-2. Numbers of eggs (e) and larvae (I) of fish species collected in drift net surveys from the Goulburn River in 2014.

| Species                                 | Pyke Rd     | Loch Garry       | McCoys Bridge | Yambuna | Total |
|---|-------------|------------------|---------------|---------|-------|
| Silver perch Bidyanus bidyanus          |             |                  | 47e           |         | 47    |
| Murray cod Maccullochella peelii        | 20/         | 282/             | 136/          | 504/    | 942   |
| Golden perch Macquaria ambigua          | 54 <i>e</i> | 314e             | 490e, 1/      | 770e    | 1629  |
| Australian smelt Retropinna semoni      | 5e          | 99 <i>e</i> , 2/ | 54e, 2l       | 46e, 5/ | 213   |
| Flathead gudgeon Philypnodon grandiceps | 1/          | 5/               | 1/            | 1/      | 8     |
| Total number of individuals             | 80          | 702              | 731           | 1326    | 2839  |



Fig. F-6. Adjusted total density of golden perch eggs/larvae (grey bar) per 1000m<sup>3</sup> collected in drift nets in the Goulburn River. Red dashed line represents water temperature and blue line represents daily mean discharge in the Goulburn River at McCoys Bridge.

Silver perch eggs were collected in low numbers at McCoys Bridge from late November to early December in water temperatures ranging from 21–23° C. Similar to golden perch, peak egg abundances were collected in late November coinciding with an increase in flow from about 964 to 6309 ML/day associated with an environmental flow release (Fig. F-7).



Fig. F-7. Adjusted total density of silver perch eggs (grey bar) per 1000m<sup>3</sup> collected in drift nets in the Goulburn River. Red dashed line represents water temperature and blue line represents daily mean discharge at McCoys Bridge
A total of 343 individuals representing five native species were also collected in the light trap surveys (Table F-3). Australian smelt was the most abundant species, comprising 64% of the total abundance for all species. Murray cod was the next most abundant species comprising 31%. Murray cod larvae were collected from late October to early December under a range of flow conditions.

| Species                                 | Loch Garry        | McCoys Bridge           | Yambuna                      | Total |
|---|-------------------|-------------------------|------------------------------|-------|
| Carp gudgeon Hypseleotris spp.          |                   | 1 <i>j</i> , 1 <i>a</i> | 8 <i>I</i> , 4 <i>j</i> , 4a | 18    |
| Australian smelt Retropinna semoni      | 38 <i>e</i> , 14/ | 15/                     | 141 <i>I</i> , 10 <i>j</i>   | 218   |
| Murray cod Maccullochella peelii        | 42/               | 42/                     | 221                          | 106   |
| Flathead gudgeon Philypnodon grandiceps |                   | 1/                      |                              | 1     |
| Total number of individuals             | 94                | 60                      | 189                          | 343   |

Table F-3. Numbers of eggs (e) and larvae (I) of fish species collected in light traps from the Goulburn River in 2014.

The golden perch spawning data were analysed with a hierarchical logistic regression (probability of spawning) and a hierarchical log-Poisson regression (abundance of eggs/larvae). The two models had the same structure for the underlying linear model, with the expression for the logistic regression being:

 $y_{ijk} \sim \text{Bern}(p_{ijk})$  $\log_{ijk} = \text{int} + \text{eff.del.}Q_k + del.Q_{ijk} + \text{eff.Te} + Te_{ijk}\text{eff.site}_k + \text{eff.net}_{jk}$ 

The occurrence of spawning (y) for drift net j at site k during deployment i is driven by a global average across all sites (int), plus the effect of the rate of rise in discharge from the day before the sample to the day of the sample (eff.del.Q) for each site and the effect of water temperature (eff.Te) on the day of sampling. There is a random effect of site (eff.site) that acknowledges that local conditions may enhance or retard spawning overall, plus a random effect of each drift net location (eff.net) to account for the repeated measures taken for each net location).

The random effects were considered to be drawn from a normal distribution with mean zero. The site-level estimates of eff.del.Q were modelled hierarchically and drawn from a hyper-distribution. All prior distributions for parameters were assigned as minimally informative.

The abundance data were analysed using the same model structure, but with the data being modelled as a Poisson distribution, and with the link function on the linear model being log rather than logit.

Rate of increase in discharge and water temperature had very strong effects on both the probability of any spawning and on the abundance of eggs/larvae observed (Table F-4).

Table F-4. Bayesian probabilities of effects of the rate of increase in discharge (eff.del.Q) modelled hierarchically across the four times, and of the effect of temperature (eff.Te). Values close to 1 support the hypothesis of a positive effect.

| Term         | Site           | Spawning analysis | Abundance analysis |  |  |
|--------------|----------------|-------------------|--------------------|--|--|
| P(eff.del.Q) |                |                   |                    |  |  |
|              | Pyke Road      | 0.93              | 1.00               |  |  |
|              | Loch Garry     | 1.00              | 1.00               |  |  |
|              | McCoy's Bridge | 1.00              | 1.00               |  |  |
|              | Yambuna        | 0.99              | 1.00               |  |  |
| P(eff.Te)    |                | 0.88              | 1.00               |  |  |

Fig. F-8 shows how probability of spawning increased with the rate of increase in discharge, with spawning highly likely at the Zone 2 sites (Loch Garry, McCoy's Bridge, Yambuna) at rates of increase in discharge of > 800 ML/d and at 20°C. Spawning probabilities and abundances were higher at the Zone 2 sites compared to the Pyke Rd site in Zone 1, even once effects of increasing temperature with distance downstream had been accounted for in the analysis.



Fig. F-8. Probabilities of spawning at different rates of increase in daily discharge at the four sites. Solid line is the median estimated probability of spawning, with dotted lines encompassing the 95% credible interval of the estimate. These plots are for 20°C, the temperature at which most spawning was observed in the field.

Predicted abundances off eggs/larvae display an exponentially increasing trend as rate of discharge increases. However, this is accompanied by large increases in the uncertainties in abundance estimates (Fig. F-9).



Fig. F-9. Predicted abundances of eggs/larvae at different rates of daily discharge at the two most downstream sites. Other details and interpretation are as for Fig. F-8

There was a weak effect of the probability of any spawning with temperature, but a strong increase in abundance of eggs/larvae (Fig. F-10). The data show that golden perch did spawn on the first environmental flow event in October Fig. F-6), but only in very low numbers. The analyses corroborate the role of temperature in inducing significant spawning.



Fig. F-10. Weak effects of temperature on probability of any spawning, but strong effect on predicted abundance of eggs/larvae. Graphs show predictions for probability of spawning (a,b) and abundance (c,d) at McCoy's Bridge and at 16°C and 20°C.

We were surprised by the strength of the statistical results from a single year of monitoring data. The models produced here provide a basis for quantitatively predicting the effects of environmental flow pulses in spring on golden perch spawning. We have not provided such predictions here, as it is difficult to conceive of how they should be expressed (for example, is it peak probability of spawning or average). Through conversations with principal stakeholders, we aim to bring such predictions into the analysis of data after year 2 of the LTIM Project. Nevertheless, it is worth noting that days of high rate of change in discharge are enhanced by the delivery of environmental flows. Over the sampling period for larvae (1/10/14 - 8/12/14), there were 7 days at McCoy's Bridge where the change in discharge was > 800 ML/d. With the environmental flows removed, this drops to 4, halving the chances for successful golden perch spawning.

#### Movement of golden perch

Of the 29 golden perch tagged in 2014, 22 were detected by the listening stations. Almost half (14 out of 29) of the fish undertook long-distance (i.e. > 15-20 km) movements, while about half (15 out of 29) displayed little detectable movement.

Long-distance movements were most common during late October and late November, which coincides with the spawning season of golden perch. Long-distance movements coincided with increases in flow (e.g. from 1448 to 7672 ML/day in late October, and from 964 to 6309 ML/day in late November) associated with environmental flow releases (Fig. F-11).

Long-distance movements during the spawning season occurred primarily downstream into the lower reaches of the river (i.e. downstream of Shepparton) and corresponded with the occurrence of eggs/larvae in this reach. Most fish that moved downstream returned upstream, usually within several weeks.

Three of the fish also visited the Murray River coinciding with environmental flow releases, before returning to the Goulburn River (Fig. F-11).



Fig. F-11. Examples of movement patterns of golden perch tagged in the Goulburn River in 2014. Black circles show date and location of tagging, and grey circles show detections of tagged fish on the listening stations. Red dashed line represents water temperature and blue line represents daily mean discharge in the Goulburn River at McCoys Bridge.

# F.5 Discussion

## Annual surveys (electrofishing and netting)

A particular focus of this component of the monitoring program is on whether spring freshes to promote spawning translate into increased recruitment (i.e. presence of young-of-year fish) and a broader range of size classes, and potentially an increase in abundance, of golden perch and silver perch. The results of the 2015 electrofishing and netting surveys show that the golden perch population in the Goulburn River consisted of mostly large, older fish, while few silver perch were collected. These findings are consistent with those of previous surveys in the Goulburn River (Koster et al. 2012, Koster unpubl. data).

Although golden perch and silver perch spawned in the Goulburn River in 2014, no young-of-year fish were collected in the 2015 electrofishing and netting surveys. Similarly, golden perch spawned in the Goulburn River each year between 2010 and 2013, but no young-of-year fish were collected in electrofishing surveys (Koster et al. 2012, Koster unpubl. data). Thus, whilst increased flows can promote spawning of these species in the Goulburn River, it appears that this may not necessarily lead to immediate *in situ* recruitment of juvenile fish.

Given that golden perch and silver perch lay semi-buoyant eggs that drift downstream on river currents, potentially over large distances, it is possible that eggs drift downstream into the Murray River, and that any recruitment into the Goulburn River occurs at a later stage by older fish and also potentially by fish from other river systems. Under this scenario, the presence of a broader range of size classes and an increase in abundance, might not become evident (if at all) until subsequent years. Determining the origin and migratory history of golden perch and silver perch in the Goulburn River using techniques such as otolith microchemistry would be a valuable area for future monitoring.

The annual surveys will be useful for the assessment of long term-changes in fish assemblage structure (species composition and abundance), but have limited power to elucidate cause and effect relationships and hence contribute to answering the long-term and short-term evaluation questions related to the contribution of CEW to native fish populations in the standard monitoring protocol document.

#### Surveys of eggs and larvae (drift nets and light traps)

The results of this study add to knowledge of the influence of particular components of the flow regime on golden perch and silver perch spawning. In particular, golden perch and silver perch spawned in association with within-channel pulses (or 'freshes') in late spring (at temperatures ≥18° C), whilst during lower and stable flows, no spawning was detected. These findings support suggestions that golden perch and silver perch require increased discharge to initiate spawning, coupled with appropriate water temperature (King et al. 2009), and serves to demonstrate the benefit of restoring critical components (e.g. spring freshes) of the natural flow regime for golden perch and silver perch reproduction in regulated rivers.

Densities of golden perch eggs/larvae were substantially higher in 2014 than in surveys conducted from 2003-2013 (Koster et al. 2012, Koster unpubl. data). The magnitude of flow associated with spawning in 2014 was similar to flow magnitudes associated with spawning in recent years, as was water temperature around these times (about 18–21° C) (Koster et al. 2012, Koster unpubl. data). Despite these similarities, levels of spawning were much higher in 2014 compared to other years. A possible explanation for the higher levels of spawning in 2014 might be higher flows associated with an earlier environmental flow release (for vegetation) in late October/early November prior to the peak spawning period, which could for example, improve the pre-spawning condition of fish resulting in increased spawning activity (Chee et al. 2009).

Further assessment in more years is needed to more reliably determine the role of specific flow conditions on spawning success. For example, future environmental water allocation and monitoring could target the effect of antecedent flow conditions, and larger flow magnitudes, to more reliably understand the flow conditions that are needed to promote spawning.

### Movement of golden perch

The results of this study also add to understanding of the influence of flow conditions on golden perch movement behaviour. In particular, the study revealed that many adult golden perch move long-distances during the spawning season (predominantly downstream) during within-channel freshes associated with environmental flows. Of particular significance is that long-distance movements during the spawning season corresponded with the occurrence of eggs/larvae. These results suggest that long-distance movements of golden perch during the spawning season are related to reproductive behaviour.

A small proportion of tagged fish also moved downstream into the Murray River associated with environmental flows. This result adds to growing evidence that tributary and mainstem connections represent important links for the movement of fish throughout river networks (Koster et al. 2014). Flow recommendations are generally developed only for single rivers and there is presently little or no consideration of ecological linkages between rivers in these recommendations. The finding of movement between the Goulburn and Murray rivers during increased flows highlights how incorporating consideration of connectivity at relevant spatial scales should also be a key component of environmental flow regime developments.

Movement patterns of fish are often variable and the results to date should only be treated as preliminary. The transmitters implanted into fish in 2014 should continue to transmit until 2017. Additional fish were also tagged in 2015, while more fish will be tagged in 2016, providing data through to 2019. This will enable more conclusive analysis regarding golden perch movement patterns to be undertaken and improve our capacity to develop and implement targeted management strategies for the species.

# F.6 Conclusion

- Elevated flows are a key driver of golden perch spawning and migration. In particular, high flow 'freshes' targeted towards late October/November
- Monitoring in more years with different flows is needed to more reliably understand the role of particular flow components in promoting spawning
- Future environmental water allocation and monitoring could target the effect of antecedent flow conditions, and larger flow magnitudes, to more reliably understand the flow conditions that are needed to promote spawning. For example, high flow freshes around October to potentially improve prespawning condition of golden perch
- Spawning may not necessarily translate into recruitment of juveniles into the local population. The origin
  and migratory history of golden perch and silver perch is a knowledge gap and represents an important
  area for future research.
- Incorporating consideration of connectivity at relevant spatial scales (i.e. among rivers) should be a key
  component of environmental flow regime developments
- The annual surveys have limited power to elucidate cause and effect relationships

# Appendix G. Examples of stakeholder communications



Fig. G-1. Facebook post to the GB CMA iSpy facebook page, 24 October, 2014 (https://www.facebook.com/gbcmaispyfish).



Fig. G-2. Facebook post to the GB CMA Facebook page, 12 June 2015 (https://www.facebook.com/gbcma).

# Banking on program

## Researchers have monitor bank erosion along the lower Goulburn River.

The monitoring program is funded by the Commonwealth and Victorian Environmental Water Holders for five years and aims to assess whether there is any influence from environmental flow deliveries on rates of bank erosion.

Dr Geoff Vietz from Streamology, which is conducting the monitoring, said the information collected from the program would help determine if environmental flow deliveries contributed to bank erosion by accelerating natural rates of erosion, and if so how they might be modified to reduce their impact.

"Bank erosion is a dynamic and natural process that helps to create a diverse range of physical habitats for native vegetation, fish and bugs," Mr Vietz said.

"However, accelerated rates of bank erosion can have an impact on water quality and result in the loss of valuable riparian and agricultural land."

A total of 200 erosion pins have been inserted into the bank at four locations along the lower Goulburn River between Murchison and the Murray River. The erosion pins are remeasured up to six times a year to quantify rates of bank recession.

Qualitative visual assessments of bank erosion are also made to determine the main mechanisms of erosion:

Simon Casanelia from Goulburn Broken Catchment Management Authority said the CMA was hopeful the results of the monitoring program would identify opportunities for further refinement of the



Simon Casanelia from the Goulburn Broken Catchment Management Authority assisting researchers with monitoring recently on a Goulburn River bank.

planning and delivery of environmental water.

"Currently, the height of environmental deliveries down the Goulburn River are varied and their rate of rise and fall are controlled to reduce their potential impact on bank erosion," Mr Casanelia said.

"The Goulburn Broken CMA is delivering environmental water down the lower Goulburn River to promote the growth and establishment of bank vegetation, which will help reduce the potential for erosion.

"The loss of bank vegetation through overgrazing, drought and floods has weakened the ability of the river bank to resist the erosive forces of high flows."

The river bank condition monitoring is part of a broader monitoring program funded by the Commonwealth and state governments that is also evaluating the impact of environmental water deliveries on native fish, instream metabolism, riparian vegetation and macro-invertebrates along the lower Goulburn River.

The Victorian Environmental Water Holder prioritises environmental water releases in the Goulburn River as part of its Seasonal Watering Plan 2014-15, which aims to improve river and wetland health across the state.



Golden perch eggs collected during monitoring in the Goulburn River. -S

# Flows stimulate fish breeding

THE second of two spring environmental flow releases in the lower Goulburn River has triggered hundreds of Golden perch (Yellow belly) to spawn from Murchison to the Murray.

Goulburn Broken Catchment Management Authority environmental water co-ordinator Meegan Judd said the flow commenced at Goulburn Weir on Saturday, November 15, and rose to approximately 7,800 ML/day at Murchison on Thursday, November 20.

"This very successful breeding response builds on the achievement of last year's environmental flow that triggered Golden perch spawning, and it will complement last month's environmental flow, which also resulted in some Golden perch spawning," Ms Judd said.

The flows used Commonwealth environmental water and transfers of water trade to the Murray River.

Part of a federal government long term environmental water monitoring program that has recently commenced is measuring the breeding response of Golden perch and other fish species to the environmental flows.

Monitoring occurs in spring and focuses on larvae, and then again in autumn to detect any new recruits.

Native fish, including Golden perch, have been in decline for many years now, making it important to see whether well timed flows improve conditions throughout the Goulburn so fish are able to move through the system to breed and grow.

The environmental flows are planned by the GBCMA and managed by Goulburn Murray Water in line with the Victorian Environmental Water Holder's Seasonal Watering Plan 2014-15 which aims to improve river and wetland health across the state.

Environmental water delivery also takes into consideration delivery orders by irrigators and other water users.

For more information, visit gbcma.vic. gov.au.