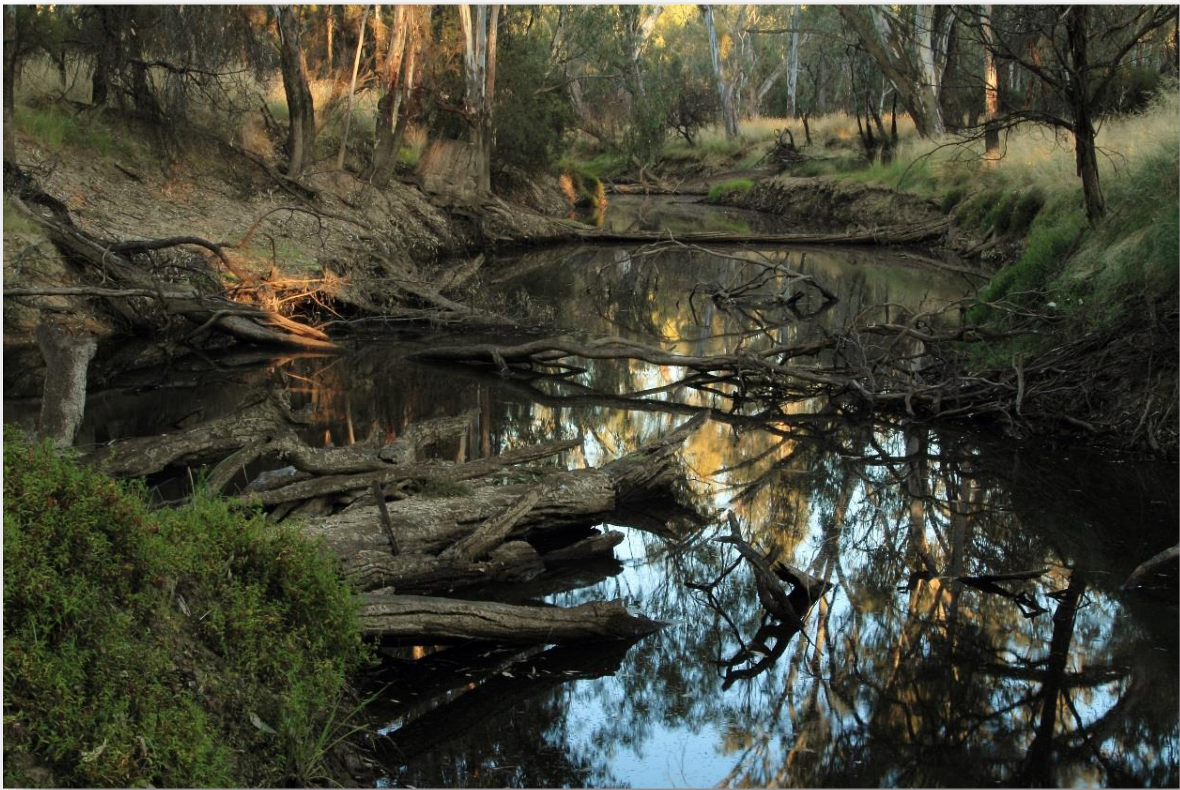
The MDBA–MDFRC Collaboration Project

Prepared by: Daryl Nielsen, Gavin Rees, Paul Brown, Darren Baldwin, Rick Stoffels, Ben Gawne and Nick Bond



Stocktake Report

MDFRC Publication 137

The MDBA–MDFRC Collaboration Project – stocktake report

Final report prepared for the Murray–Darling Basin Authority by The Murray–Darling Freshwater Research Centre.

Murray–Darling Basin Authority
Level 4, 51 Allara Street | GPO Box 1801
Canberra City ACT 2601

Ph: (02) 6279 0100; Fax: (02) 6248 8053

This strategy was prepared by The Murray–Darling Freshwater Research Centre (MDFRC). The aim of the MDFRC is to provide the scientific knowledge necessary for the management and sustained utilisation of the Murray–Darling Basin water resources. The MDFRC is a joint venture between La Trobe University and CSIRO.

For further information contact:

Daryl Nielsen

The Murray–Darling Freshwater Research Centre
PO Box 991
Wodonga VIC 3689
Ph: (02) 6024 9674

Email: d.nielsen@latrobe.edu.au
Web: www.mdfrc.org.au
Enquiries: mdfrc@latrobe.edu.au

Report Citation: D Nielsen, G Rees, P Brown, D Baldwin, Rick Stoffels, Ben Gawne and Nick Bond, (2016) The MDBA–MDFRC Collaboration Project – stocktake report. Final Report prepared for the Murray–Darling Basin Authority, MDFRC Publication 137/2016, November, 52 pp.

Cover Image: Ovens River

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Director
Communications
Murray–Darling Basin Authority
51 Allara St
Canberra ACT 2601

Email: copyright@mdba.gov.au

Document history and status

Version	Date issued	Reviewed by	Approved by	Revision type
Draft	6/10/2016	MDFRC	Daryl Nielsen	Internal
Draft	28/10/2016	MDFRC	Daryl Nielsen	Edits as suggested by investment committee
Draft	8/11/2016	MDFRC	Daryl Nielsen	Internal
Draft	13/11/2016	N. Ning	Daryl Nielsen	Copy edit
Draft	16/11/2016	N. Bond	Daryl Nielsen	Internal
Draft	24/11/2016	D. Nielsen	Daryl Nielsen	Edits as requested by JGR.

Distribution of copies

Version	Quantity	Date issued	Issued to
Draft	1 x PDF	10/10/2016	MDBA (Nadeem Samnakay)
Draft	1 x Word	24/10/2016	Investment Committee
Draft	1 X Word	21/11/2016	Joint State Governments
Draft	1 X Word	30/11/2016	Joint State Governments
Final	1 x pdf	21/12/2016	MDBA

Filename and path: G:\SHE - Life Sciences\MDFRC\Projects\MDBA\637 MDBA MDFRC Collaboration Agreement\Administration\Stocktake\MMCP project stocktake_Final.pdf

Author(s): D Nielsen[1], G Rees[1], P Brown[2], D Baldwin[1], Rick Stoffels[1], Ben Gawne[3] and Nick Bond[2]

Author affiliation(s): [1]: CSIRO/MDFRC, [2]: La Trobe University/MDFRC, [3]: University of Canberra

Project Manager: Daryl Nielsen

Client: MDBA

Project Title: The MDBA–MDFRC Collaboration Project

Document Version: Final

Project Number: 637

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1 Background

Since its inception in 1986, the Murray–Darling Freshwater Research Centre (MDFRC) has undergone numerous changes in order to adapt to the changing needs of water managers and their institutional arrangements. The Murray-Darling Basin Commission (MDBC) was a founding participant in the MDFRC, and their financial contribution, in the form of core funding from the Murray-Darling Joint Programs, provided a foundation for MDFRC operations. In 2007, the passing of the Water Act saw the incorporation of the MDBC into the Murray–Darling Basin Authority (MDBA). While the MDBA had been an independent Commission, it is subject to the Commonwealth Financial Management and Accountability Act (1997), which meant funding to another institution must be tied to tangible outputs. In response, the MDBA and MDFRC moved to transition the relationship from joint-venture participants to a collaborative arrangement governed by a contract.

The objective of the collaborative arrangement was for MDFRC to be able to continue in its role of supporting sustainable water management, while facilitating important changes in the relationship between the MDFRC, MDBA and jurisdictions required by changes in water management associated with the Basin Plan and establishment of the MDBA. It was also anticipated that the changes would lead to greater transparency and closer working relationships between MDFRC and Basin water managers.

Once the agreement was in place, a round of consultation was undertaken to identify the specific activities that would be undertaken under the collaboration agreement. The broad objective of these activities was to provide high quality scientific research and capability that are highly valued and utilised by water policy and management. Within this broad objective were the following subsidiary objectives:

- Develop predictive capacity to support environmental water management
- Maintain MDFRC capacity to respond to emerging issues/risks in environmental water delivery
- Leverage value from the large projects being led by MDFRC.

In addition to these objectives, the MDBA were keen to ensure that the:

- Proposed activities complement and do not duplicate the work being undertaken in the Commonwealth Environmental Waterholder's Long-Term Intervention Monitoring (LTIM) and the Murray–Darling Basin (MDB) Environmental Water Knowledge and Research (EWKR) Project.
- Proposed activities align with areas of strength for the MDFRC
- Activities include syntheses of our current understanding in response to questions from the Basin Officials Committee (BOC).

At a work shop in August 2015 attended by representatives from the states and commonwealth, participants agreed on four research themes to be addressed under the MMCP (Vegetation dispersal, Fish movement, Fish population and community dynamic modelling, and Linking macroinvertebrate community structural changes to ecosystem outcomes). Participants also requested that activities to be undertaken by the MMCP were mapped against existing MDFRC projects (LTIM, EWKR, TLM) to avoid duplication of activities and to assess their influence on management activities.

The MDFRC then developed a suite of activities including two questions from the BOC that were presented to a jurisdictional workshop held in Canberra on 13 August 2015. The workshop broadly endorsed the proposed program of activities, although there were two common issues raised:

1. Participants agreed there was a need to develop a stronger line of sight between the proposed activities and their influence on management decisions.
2. The relationship between the proposed activities and other activities being undertaken in the Basin needed to be clarified. This was important both in terms of avoiding duplication, but also in order to foster collaboration and value adding.

A briefing document was prepared for the Basin Officials Committee Meeting on 15 October 2015, which was accompanied by a presentation from Jane Doolan. The briefing and presentation outlined the overall structure of the MDBA–MDFRC Collaboration Project (MMCP) that included details on the BOC questions, the research components and support for students. It was recommended that the specific aspects of the BOC questions be addressed in 2015–16, to be:

1. How can information generated through a variety of activities (intervention monitoring, condition assessments and research), including understanding of ecological processes, be integrated to guide water planning and management?
2. How are previously identified water quality risks in the southern Murray–Darling likely to be affected by climate change, and how will these changes impact on ecological community composition and function?

The MMCP research components would focus on four areas: vegetation dispersal, river food webs (with an emphasis on macroinvertebrates), fish dispersal and fish population modelling. Finally, it was proposed that the MMCP should continue to support MDFRC's involvement in student supervision.

A detailed research strategy was developed and presented to the Investment Committee in November 2015, in combination with a power point presentation. A series of comments on the power point presentation and research strategy were received by the project team, which were acknowledged and the team set about addressing the specific comments. A revised version of the research strategy was subsequently presented to the Investment Committee in May 2016 and work continued on the project.

2 MMCP Governance arrangements

Figure 1 describes the governance structure for the MMCP project as of November 2016. Key features of the governance arrangements are summarised below.

- The MDBA are the administrative custodian for the Joint Government funding and review and monitor all contractual obligations for the funded activities outlined in the Research Plan, including milestone deliverables, reporting and financial acquittals. The MMCP reports directly to MDBA for all funded activities conducted under the Collaboration Agreement. The MDBA are responsible to notify and engage the Basin Officials Committee (BOC) and the Joint Government Representatives (JGR) of these activities and contractual reporting.

- The Joint Government Representatives provide advice to MDBA on the funded activities conducted by the MMC and briefs the state BOC representative on the current research plan and associated activities. To improve engagement with the JRG four research theme co-representatives will be nominated by the JRG to assist in the flow of information between the MMCP project team and the JRG and to ensure that the MMCP is addressing the needs of the States and MDBA.

- The BOC provides a nominated Joint Government Representative (JGR) as their primary point of contact.

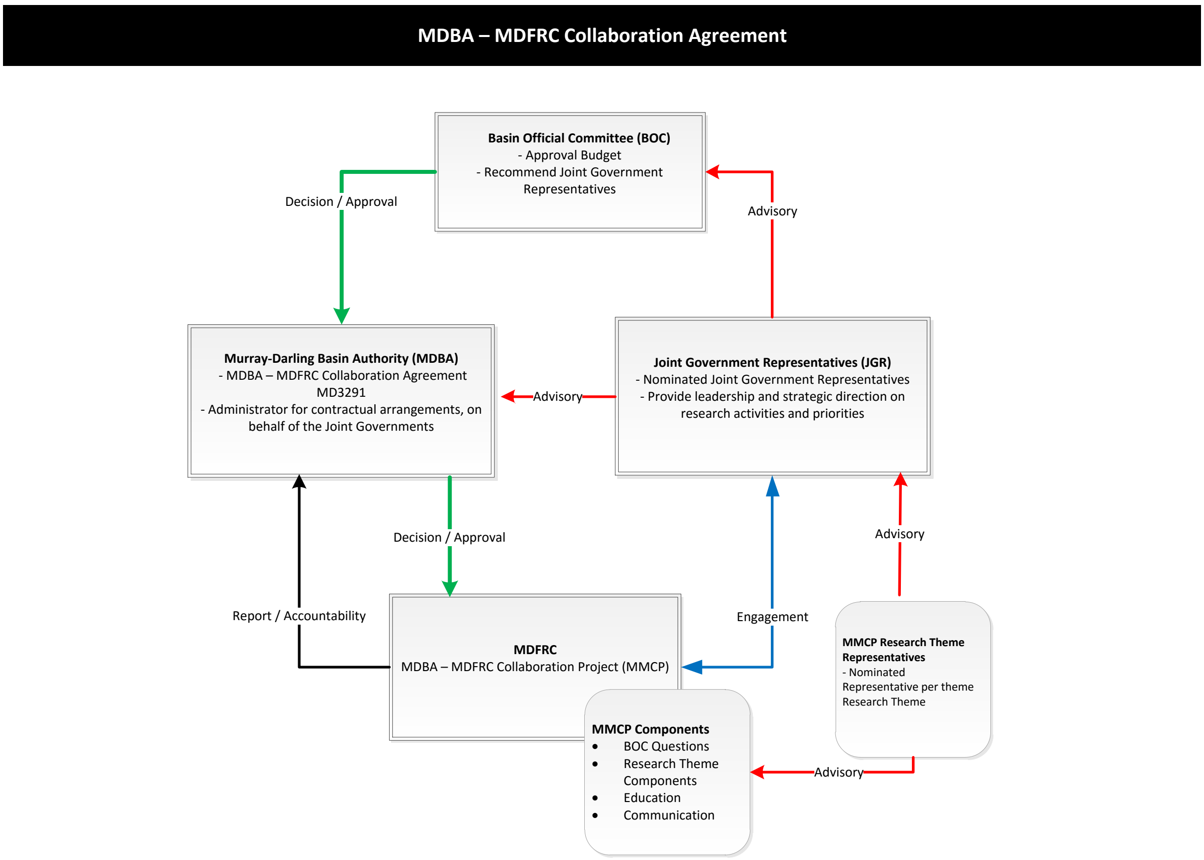

Figure 1. Governance structure for the MMCP.

2.1 Internal reporting

Internally the MMCP reports directly to the:

- The Investment Committee consists of members, who have an interest and investment in the research activities conducted at MDFRC. Current members include

CSIRO, La Trobe University, MDBA, University of Canberra and the Centre Director[1]. The Investment Committee provide. The investment committee provides

  - Advice on the MDBA strategic knowledge requirements
  - Advice on activities that are undertaken under the Collaboration Agreement
  - Advice on interaction and value adding between all major collaborative projects at MDFRC
  - Feedback of the value of MDFRC outputs
  - Assist in identifying emerging issues and concerns surrounding management of aquatic ecosystems in the MDB.

- MDFRC Governing Board consist of representatives of each participant in the MDFRC Joint Venture. This is currently CSIRO and La Trobe University, with the Centre Director reporting to the Board. The Governing Board have the overall responsibility of setting the strategic research priorities, to ensure the financial viability of the Centre and reporting on the Centre's performance to stakeholders.

- The MMCP - The project has an appointed Project Leader, four theme coordinators for the research components and two BOC Question component leaders. The project currently is required to report the Investment Committee and Governing Board via the Centre Director.

- The Project Leader is required to report all contractual and funded activities to the nominated contact at MDBA.

- The MMCP provides the MDFRC Executive with monthly updates on the status of the project. These reports provide a summary of activities, financial report and an assessment of any potential risks to the project.

- The MMCP provided updated reports to the Investment committee as required

2.2 External Reporting requirements

- Quarterly reports: The MMCP provide quarterly reports to the MDBA providing a summary of activities for the preceding three months. These report are tied to payments of $250K. Currently these reports are provided in February, May, August and November each year.

- Annual reports: The MMCP provides an annual report to the MDBA in June of each year. These reports provide an overview of the project activities and outcomes for the preceding twelve months and includes a financial acquittal for the preceding financial year

- As part of the MMCP, the MDFRC addresses two strategic questions each year that consolidate the current state of scientific knowledge relevant to those questions. In 2016 these questions were agreed upon at BOC meetings, and were reported to MDFRC through the MDBA representative for the MMCP and via the MDFRC Investment Committee. This process is being modified for the next BOC questions.

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[1] Current Centre Director – Professor Nick Bond

The MDFRC in collaboration and engagement with managers and research providers, will identify and produce a list of ten priority questions that will then be submitted to the BOC for consideration.

2.3 Communication

The communication and engagement between the MMCP and the Joint Government Representatives (JGR) has been limited in the development of the project themes since the August 2015 workshop. To address this issue the governance structure of the MMCP has been reviewed and revised in November 2016

3 MMCP budget

The agreed investment to be made by the MDBA on behalf of Joint Governments is $1m per year over five years (2015–19). Budgets for 2016–19 for each of the research themes, the education component and communication components are outlined in the sections below.

The research themes have been developed and details relating to the current status of these themes have been provided to the MDBA in the MMCP project stocktake. Future negotiation may occur relating to the research themes, and their objectives and outcomes, which may change the future year budget allocations.

Table 1. Budget summary and forecast for the MMCP for the duration of project. Detailed allocations are provided in the individual sub-project sections.

	2015-2016	2016–17	2017–18	2018–19	Total
Total salary[2]	867,978	716,139	742,379	769,642	3,096,137
Operating	32,022	63,211	38,971	33,708	167,912
Communication activities	0	20,000	20,000	20,000	60,000
Students[3]	0	200,650	98,650	76,650	375,950
MDFRC administration (indirect costs)	0	100,000	100,000	100,000	300,000
Annual project budget	900,000	1,100,000	1,000,000	1,000,000	4,000,000

4 Relationships between the major MDFRC projects

The MDFRC undertakes a range of research and monitoring throughout the southern connected basin. As well as the MMCP project the Centre is currently coordinating two additional large-scale and closely related programs, Murray–Darling Basin Environmental Water Knowledge and Research Project (MDB EWKR) and Commonwealth Environmental Water Office's Long-Term Intervention Monitoring (LTIM), and The Living Murray (TLM) which are being carried out on behalf of the Commonwealth Environmental Water Office within the Department of Environment and Energy.

[2] Salaries include an allocation to the project manager for each year.
[3] For 2016–17 there was a carry-over of student funds from the previous year.

4.1 The Commonwealth Environmental Water Office's Long-Term Intervention Monitoring

The LTIM program monitors the outcomes of environmental flow interventions (water actions) as part of the monitoring and evaluation phases of the CEWO adaptive management framework. Primary objective of the LTIM project is to monitor the outcomes of environmental flows and support evaluation of their contribution to achievement of Basin Plan objectives. The project monitors six broad indicators (hydrology, ecosystem diversity, river metabolism and water quality, vegetation, fish and generic diversity) at seven selected areas. The outcomes are evaluated at the "area" scale and an evaluation is also undertaken at unmonitored sites using a multiple lines of evidence approach. The outputs of these evaluations are then integrated to provide an evaluation at the Basin scale.

The program is focussed on monitoring outcomes that are directly relevant to Basin Plan environmental objectives such as biodiversity (e.g. ecosystems, fish) and ecosystem function (e.g. hydrological connectivity, river metabolism) (Figure 3). What the program does not do, is examine the processes that link changes in flow to changes in the indicator. For example, fish population changes may be due to changes in habitat, connectivity, food or predation, but these process lie outside the scope of the CEWO LTIM. The CEWO LTIM program also does not consider the influence of non-flow drivers on the outcomes of water actions that may be significant in some situations

4.2 The Living Murray

TLM program aims to achieve a healthy working Murray River system for the benefit of all Australians by returning water to the environment and building and upgrading infrastructure to deliver water to wetlands, floodplains and forests across six icon sites including Hattah Lakes and Lindsay- Mulcra-Wallpolla Island. The Living Murray program is undertaken within an adaptive management framework that includes both condition assessments and intervention monitoring. The MDFRC has conducted annual assessments of the condition of key ecological components of the Hattah Lakes and LMWI icon sites since 2005. These condition assessments seek to identify any changes in ecosystem condition over time but doesn't link these changes to environmental watering. Managers can make inferences/assumptions regarding outcomes but the extent to which condition monitoring can be used to inform adaptive management will be limited. Monitoring environmental responses to measures including environmental water delivery and the development of water management infrastructure (e.g. regulators and block banks), helps evaluate the extent to which management objectives are being achieved in the long-term. Annual condition assessments are conducted using permanent survey sites and comparable survey timing and methods so that the condition of key ecological components can be tracked over time

4.3 The Murray–Darling Basin Environmental Water Knowledge and Research

The MDBA-EWKR project seeks to enhance environmental water management and thereby improve environmental outcomes through the generation of new knowledge that both improves our understanding of flow responses, but also of the way that non-flow drivers (stressors) may affect the outcomes of environmental flows with the objective to "Improve our understanding of the influence of flow on the condition of the Basin's water-dependent ecosystems. THE MDB EWKR builds on the assessment and monitoring projects being undertaken by management agencies with benefits to both managers and researchers. The MDB EWKR project will identify activities that will lead to improvements in managers' capacity to predict the outcomes of environmental flows. Wherever possible, these activities will seek to build on previous work (data analysis) or complement other activities occurring throughout the Basin, including Basin Plan Monitoring and Evaluations and CEWO LTIM. It is anticipated that the project's outputs will be useful in interpreting the assessments undertaken by Basin Plan Monitoring and Evaluation, support improved planning and operational decisions around environmental flows and inform the evaluation of intervention monitoring data; helping to identify refinements to the prioritisation and design of environmental flows.

Table 2. Primary objectives of the major projects managed by the MDFRC

	MMCP	EWKR	LTIM	TLM	Other
Vegetation	How does the use of infrastructure influence the dispersal of plant species?	What are the drivers of sustainable populations and diverse communities of water-dependent vegetation?	How do species, populations, communities respond to environmental water	Condition and interventions monitoring	QLD Vegetation mapping across the Lower Balonne and Barwon-Darling systems
Fish	Modelling growth rates as a function of flows and temperature. How to effectively manage flows to promote the movement of fish through fish-ways?	What flow regimes best support the reproduction of native fish populations?	Statistical analysis of the response of population processes (spawning/recruitment) to flow.	Condition and intervention monitoring	Vic Modelling the response of populations to flow
Waterbirds		Which flow regimes best support recruitment of waterbirds?		Condition and intervention monitoring	
Food webs	Improved capacity to predict how changes in the	What flow regimes best support food-webs that	How does water quality, primary production and decomposition		

	food web structure alters fish communities	contribute to positive outcomes for native fish and waterbirds?	respond to environmental water		

4.4 Integration across major projects

The CEWO LTIM and TLM projects have quite specific objectives and questions that are appropriate to their role in adaptive management. There will be situations where TLM data will add value to CEWO LTIM evaluation of environmental flow outcomes and where CEWO LTIM data can contribute to an assessment of condition across the Basin. These synergies represent an important way in which the value and efficiency of these projects can be enhanced.

The MDB EWKR project has a much broader brief, but its relationship to the CEWO LTIM and TLM projects will be important in both improving the outputs of the MDB EWKR project and also the application of the project's outputs to key steps in the adaptive management framework, condition assessment and evaluating the outcomes of interventions.

The MMCP project seeks to generate new knowledge by undertaking targeted research on specific topics that have been identified as key knowledge gaps by the MDFRC, MDBA and the State Funding jurisdictions. Outcomes from the four research themes and response to the BOC questions will will complement activities undertaken in EWRK. Additionally, the response to the BOC questions will provide guidance to water resource managers about the effectiveness of current water resource management strategies within the Basin which will guide the ongoing adaptive management of water resources within the Basin (Figure 1)

Together the four major research projects provide a complementary suite of activities that will support management of the MDB into the future. Specific benefits to management include the following:

- Improved understanding of ecosystem flow requirements and the factors that facilitate or limit outcomes will enable more effective and efficient use of environmental water.
- Improved predictive capacity of the outcomes of environmental flows will support planning and operational decisions around environmental flows. This will be particularly important in situations where volumes of water are less then specified water requirements, for example during periods of drought.
- Increased understanding of the influence of other stressors may lead to the development of innovative and efficient restoration initiatives. This will be particularly important in systems with limited volumes of environmental water, such as some rivers in the northern Basin.
- Identification of complementary NRM management options may enhance outcomes of environmental flows. These will both enhance efficiency of environmental flows and provide a focus for engagement with regional communities.

- Capacity to rapidly respond to emerging risks such as hypoxic blackwater, salinity and blue-green algal blooms will be maintained

4.5 Relationship with external projects

The MMCP, MDB EWKR, LTIM and the Arthur Rylah Institute (ARI - Victoria) each have fish modelling projects that are addressing different facets of the relationship between flows and fish ecology.

- ARI modelling aims to bring together all available current and historical fish knowledge, publish it, update conceptual models, include it in a modelling framework, and prepare a user interface and user manuals, so that operators can have a real-time tool to guide delivery of water, based on their objectives. The parameters of the models developed will determine how the populations will respond to flow and, in the case of the ARI work, these parameters are based on expert opinion and historical data.
- LTIM modelling activities are focused on statistical analysis (time series analysis) of how certain population processes respond to flow; namely spawning, recruitment of 0+ individuals, and age-specific transition rates (proxies for survival). Within the first five years, the objective is to evaluate the outcomes of specific flow events at specific areas throughout the Basin. As such, the statistical models used in LTIM are used primarily for the purposes of flow evaluation.
- MMCP modelling is focused on understanding how the relationship between flows (natural and managed) and temperature affect the growth of fish by analysing otoliths collected as part of the LTIM program.

There are also numerous other complementary research and monitoring programs being carried out within and across the MDB. These projects can be broadly classified as falling across 4 broad groups (i) decision support, (ii) fundamental research, (iii) monitoring and (iv) modelling. **Error! Reference source not found.** maps some of these projects (and their c omponents) across these four categories, while also illustrating the relative scale of investment in each project. Such a representation provides an indication as to whether current investment strategies are being distributed across the major aspects of scientific contribution to supporting policy and management decisions.

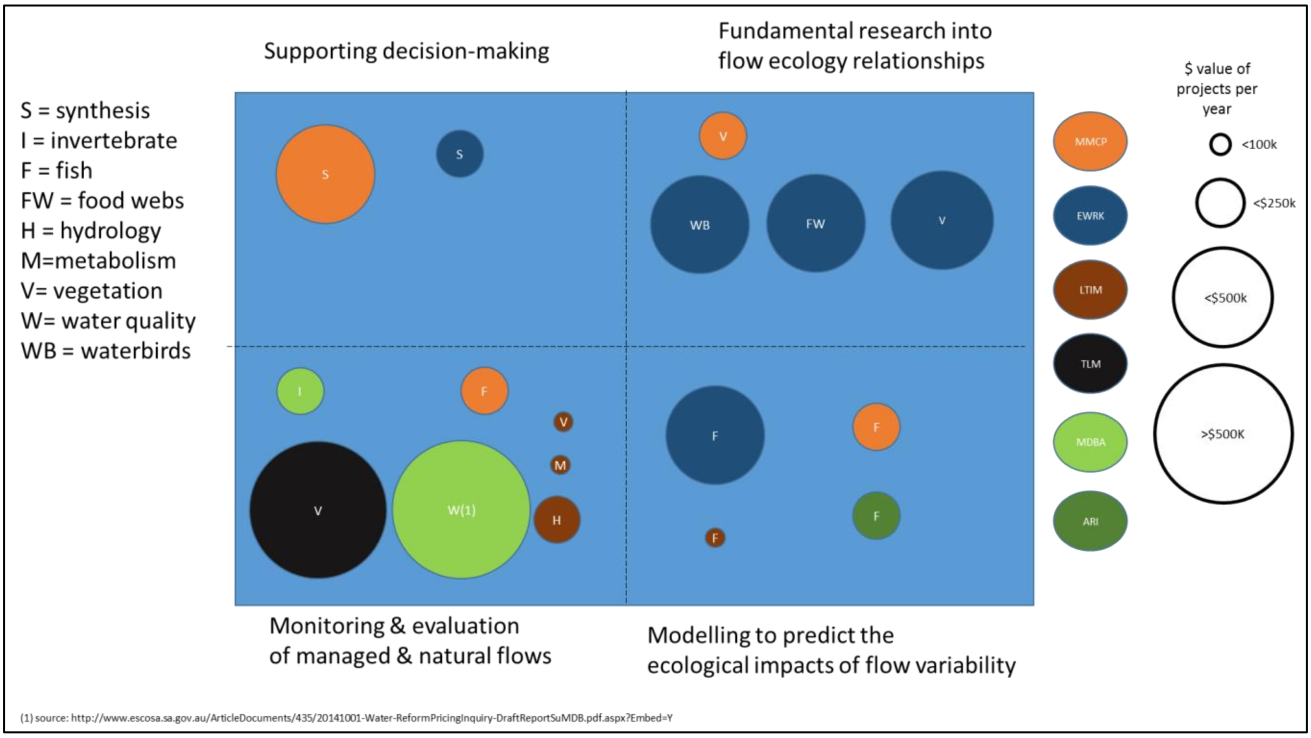


Figure 2. Relationships between the major projects within the MDFRC portfolio

5 Project stocktake

At the request of the MDBA and the Joint Government representatives (JGR), MDFRC has undertaken a review of the projects currently being undertaken as part of the MMCP.

The MDBA–MDFRC Collaboration Agreement seeks to sustain the collaboration between the MDBA and MDFRC. The agreed investment to be made by the MDBA on behalf of Joint governments is $1m per year over five years (2015–19).

The Collaboration Agreement seeks to continue the commitments from the MDBA, LTU and CSIRO to the generation and adoption of freshwater ecological knowledge through collaboration. The MDBA and MDFRC have agreed to work together to maintain research capability and contribute supporting science to underpin the Basin-Wide Watering Strategy. Specific objectives include:

- improving understanding of the relationship between flow, ecosystem function and biodiversity
- improving managers' capacity to predict the environmental outcomes of water management and complementary natural resource management.
- improved capacity to evaluate the threats to ecosystem function and diversity under a range of water management and climate scenarios
- improving capacity to assess ecosystem condition and identify the interventions most likely to effectively and efficiently achieve environmental objectives.

5.1 Management implications

The MMCP directly address the Basin Plan environmental objectives:

- Protect and restore water-dependant ecosystems
  The maintenance of connectivity both longitudinally and laterally is recognised as being important in the protection and restoration of aquatic ecosystems. The MMCP aims to provide managers with the tools to make informed decisions on (i) how effectively the creation of longitudinal connectivity from the Sea-to-Hume has restored native fish communities, and (ii) how the operation of infrastructure (pumps/regulators) to restore lateral connectivity between rivers and wetlands will lead to changes in vegetation communities by either selecting for or against seeds with specific traits.
- Protect and restore the ecosystem functions of water-dependant ecosystems
  The management and restoration of native fish populations has primarily targeted the maintenance of flows and habitats that promote recruitment and growth of larvae and juvenile fish. The success of these actions may be limited due to a poor understanding of (i) what the appropriate flow regimes are required to support the growth of native fish, and (ii) whether the appropriate food resources occur under current conditions to support the recruitment and growth of native fish. The MMCP will provide water resource managers with the knowledge on how to manipulate flow regimes to support and maintain food resources and promote the growth of native fish.
- Ensure that water-dependant ecosystems are resilient to climate change and other risks and threats
  The MMCP will provide water resource managers with the knowledge on how best to manipulate water regimes to maintain ecosystem function (including native seed dispersal and growth of aquatic organisms) and protect water-dependant ecosystems as the demand for water resources increases under climate change scenarios.

To sustain the collaboration between the MDBA and the MDFRC, the project will deliver on four themes, as well as responses to two questions posed by the BOC in the form of synthesis papers. Writing synthesis papers in response to questions raised by the BOC, the research projects will improve predictive capacity that link key ecosystem function and processes with management activities within the Murray–Darling Basin.

The research projects are based around the four themes:

- Vegetation dispersal
- Fish movement
- Fish population and community dynamic modelling
- Linking macroinvertebrate community structural changes to ecosystem outcomes.

6 Summary of projects

Research theme	Management implications	Objectives	Status	Outcomes
Vegetation dispersal	*Protect and restore water dependant ecosystems.* The maintenance of lateral connectivity is recognised as being important in the protection and restoration of aquatic ecosystems. The MMCP aims to provide managers with the tools to make informed decisions on how the operation of infrastructure (pumps/regulators) to restore lateral connectivity between rivers and wetlands will lead to changes in vegetation community by either selecting for or against seeds with specific traits. *Ensure that water-dependant ecosystems are resilient to climate change and other risks and threats* The MMCP will provide water resource managers with the knowledge on how best to manipulate water regimes to maintain ecosystem function, including native seed dispersal and protect water dependant ecosystems as the demand for water resources increase under climate change scenarios.	Describe the physical characteristics of seeds that will facilitate dispersal Understand the spatial & temporal movement patterns of wetland & riparian vegetation	On-going On-going	An improved understanding how the use of infrastructure influences the dispersal of plant species & recommendations as to how to address the associated risks
Fish movement	*Protect and restore water dependant ecosystems* By building the capacity to tag fish through the training of Lock staff thereby increasing the number of tagged fish in the system, and analysis of existing data on fish-passage, this project will provide water resource managers with knowledge on how to effectively manage flows to promote the movement of fish along the length of the Murray River and create lateral connectivity.	Develop a program for training lock staff to enable tagging of fish at up to three locks. This will provide a cost-effective means of maintaining tagged populations	On-going	Lock-staff at three sites along the Murray will be trained to trap & PIT-tag fish.
		Analyse & interpret the fish-movement data set.	Planned	The analysis of the existing data set will provide essential management information for continuous-

				improvement of best practice flow-management for river-rehabilitation
How do flows and climate affect growth dynamics of Murray-Darling Basin fishes?[4]	*<u>Improved capacity to evaluate outcomes from managed flows.</u>* The work proposed here will yield inferences that enable us to report against key Basin Plan objectives. Further, a key challenge facing the Commonwealth Environmental Watering Office (CEWO) is reporting on fish response to managed flows (a) within monitored Selected Areas of the Basin, and (b) outside monitored areas of the Basin. This study will help CEWO with both of these reporting objectives. First, we are using otoliths collected from CEWO's key monitoring areas throughout the Basin, which means we can back-calculate the growth of fishes that have been exposed to Commonwealth environmental water in recent years, and we'll also have good hydrology data from those areas; data where the managed and background components of the hydrograph have been separated. Second, we will be estimating the parameters of models that can then be used for inferring the likely range of managed flow impacts on fish growth in unmonitored areas, where good hydrology data exist, using 'predictive inference'. *<u>Increases effectiveness of flow delivery.</u>* The models generated will facilitate decision making within and across years, specifically with respect to how hydrograph features (e.g. timing, magnitude etc.) affect growth. The spatial scale of the analysis (whole-of-Basin)	This project is proposing to use otoliths obtained as part of LTIM to back-calculate the growth rates of individual fish at sites across the Basin, and to then model those growth rates as a function of flow & temperature. This will provide an empirical test of some of the conceptual models that have already been developed that hypothesize how flows & temperature affect growth of different fish species	Inception	Improved capacity to both predict and evaluate the impacts of environmental water on fish; Improved capacity to predict the effects on fish growth of the timing & magnitude of water delivery; Improved knowledge of fish-flow ecology

[4] This theme was originally called "*Fish population and community dynamic modelling*"4

	greatly broadens the generality of any inferences we make, hence its utility within the Basin. *Improved capacity to anticipate emerging risks.* As the Basin-Wide Watering Strategy evolves, we must improve our capacity to predict how changing climate will interact with flows to affect Basin Plan objectives (MDBA 2014). This study specifically aims to improve our understanding of climate-flow interactions, and generates models that enable us to forecast hence anticipate emerging threats to fish growth.			
Understanding the ecological consequences of macroinvertebrate community-structure change	*"Protect and restore the ecosystem functions of water dependant ecosystems"* The management and restoration of native fish populations has primarily targeted the maintenance of flows and habitats that promote recruitment and growth of larvae and juvenile fish. The success of these actions may be limited due to a poor understanding of how changed flow regimes have modified the occurrence of appropriate food resources that necessary support the recruitment and growth of native fish. The MMCP will provide water resource managers with the knowledge on how to manipulate flow regimes to support and maintain food resources that promote the growth of native fish	Determine how changes in the size structure within the macroinvertebrate community alters the energy distribution of Murray River foodwebs, thus affecting fish communities. Synthesise and summarise the relevant literature on key elements of fish nutrition that have the greatest ecological significance in driving fish growth and reproduction.	On-going	An improved capacity to predict how changes in the food web structure alters fish communities The improved capacity will have been obtained through improved understanding of the energetic availability and nutritional landscape of macroinvertebrate communities, as food sources for higher order consumers.

		Define the nutritional landscape in selected macroinvertebrates present in the Murray River.		
<u>BOC question 1</u> How can improved knowledge of the relationship between flows, ecological condition & response be used to guide environmental water planning & management	With the implementation of the Basin Plan, the Basin-Wide Watering Strategy (BWWS) & the Commonwealth's Long-Term Intervention Monitoring (LTIM) program, now is a good time to critically evaluate the roles that scientists must fulfil to best facilitate meeting Basin Plan objectives.	Drawing on the scientific literature, the BWWS, LTIM documentation & our experience, offer answers to the following: Given the Basin Plan objectives, the BWWS & LTIM, exactly which functions within the adaptive management of flows must scientists fulfil? Within each major function, what are the hallmarks of best-practice? Efficiency is key, so given the nation's investment in major monitoring & research	Completed	Highlighted recent achievements in the improved efficiency of scientific functions within the adaptive management of flows within the Basin. Improved complementarity of scientific activities within the Basin. Improved collaborative arrangements between scientists & managers. Improved capacity for prediction & evaluation of flow outcomes

		programs (e.g. LTIM, EWKR, MMCP), are we covering-off on the key scientific functions efficiently? How do the major research & monitoring programs of the Basin complement each other? What key functions require further capacity development &/or investment?		
<u>BOC Question 2</u> How are previously identified water quality risks in the southern Murray–Darling Basin likely to be affected by climate change, & how will these changes impact on ecological community composition & function?	In the last 15 years there have been a number of severe water quality events that have affected large areas of the Murray-Darling Basin. It has been suggested that many of these events are either directly or indirectly a consequence of climate change	To determine how known water quality issues in the MDB will be affected by a changing climate. Climate predictions for the MDB include increased temperature, reduced rainfall, increased likelihood of intense rainfall events &, a greater likelihood & intensity of fire.	Completed	Increased understanding on how changing climate will impact on known water quality issues in the basin Opportunity to develop additional research on algal blooms?

7 Vegetation dispersal

7.1 Background/Justification

The movement of propagules within the landscape is an important factor in both the replenishment of dormant propagule banks and in the diversity of extant aquatic communities (Morris 2012; Nilsson *et al.* 2010). Changes in flow regimes, or hydrological connectivity, are therefore likely to significantly impact the distribution of aquatic and riparian plants (Merritt, Nilsson & Jansson 2010). Changed connectivity may occur through the disconnection of components of the landscape caused by changes in flow regime, construction of barriers that physically impede dispersal, and the physical removal of riparian plants.

Research globally has indicated that provision of pathways for the dispersal of seeds and propagules is important in the restoration and rehabilitation of wetlands (Bischoff, Warthemann & Klotz 2009), but there is limited information on the dispersal of seeds and propagules by water in Australian landscapes (Capon *et al.* 2009; Groves *et al.* 2009).

Long-term monitoring programs throughout the southern connected basin have identified more than 700 floodplain and wetland plant species. Most plants have the capacity to disperse either as vegetative propagules or as seeds. However, there is limited information on dispersal mechanisms for individual plants and their capacity to disperse throughout the landscape. The physical characteristics of seeds will determine whether they float or sink, which is likely to influence where they are likely to be deposited.

Throughout the MDB, management agencies are watering wetlands via artificial connection pathways (i.e. pumps), which may favour the dispersal of some groups of plants over others (Jansson *et al.* 2000). Understanding the way in which managed flow regimes and infrastructure alter or facilitate the movement of aquatic and riparian plant species will be key to managing for dispersal. By understanding how and when individual plant species or groups of species move throughout the landscape, and which species are likely to or predominantly move by water, managers will be able to better target species of interest, and better understand the likely outcomes of a particular watering event.

7.2 Objective

- Determine the physical characteristics of seeds that facilitate dispersal.
  The physical characteristics of seeds will determine the distance that they drift in the water column and whether they drift on the surface or lower in the water column. Knowledge of seed morphology will enable predictions on which seeds are likely to persist in the drift and how infrastructure will influence drift.
- Understand how the operation of water delivery infrastructure (pumps, channels, regulators) may affect seed dispersal.
  This component seeks to understand how the delivery of water through infrastructure modifies the movement of propagules between different components of the riverine-floodplain landscape.

7.3 Management implications

- Protect and restore water-dependant ecosystems
  The maintenance of lateral connectivity is recognised as being important in the protection and restoration of aquatic ecosystems. The MMCP aims to improve understanding of how the operation of infrastructure (pumps, regulators, channels) to restore lateral connectivity between rivers and wetlands may select for or against seeds with specific traits, and could lead to changes in aquatic and riparian vegetation communities.

- Ensure that water-dependant ecosystems are resilient to climate change and other risks and threats
  The MMCP will improve the ability of environmental water managers to manipulate water regimes to maintain ecosystem function. By better understanding the impacts of using infrastructure to maintain lateral connectivity, managers will be able to manage connectivity to protect water-dependant ecosystems as the demand for water resources increases under climate change scenarios.

7.4 Project activities

Table 3. Timeline of activities, hold points and deliverables for the vegetation dispersal component of the MMCP.

Date	Activity	Deliverable
2016	Description of seed attributes that enable dispersal Describe the physical characteristics of floodplain and wetland plant species Determine the capacity of seeds to either float or sink	Summary of the physical characteristic of seeds
	Sampling of seeds passing through pumps and siphons	Summary of field sampling and initial finding
2017		
February 2017	Preparation of 2017 Quarter 1 Milestone Report.	Milestone report Initial analysis of the morphology and floating ability of 30 plant species Description of how the use of pumps at Speewa Creek and Wee Wee Creek and the siphon at Thegoa lagoon influence the dispersal of seeds
February 2017–May 2017	Further sampling of the movement of seeds through pumps (potential sites in the Mallee region)	

Date	Activity	Deliverable
May 2017	Preparation of 2017 Quarter 2 Milestone Report	Milestone report Updated analysis of the movement of seeds through pumps
April 2017–June 2017	Processing of samples	
June 2017	Preparation of 2017 Annual Technical Report:	Report describing the: 1. analysis of the morphology of seeds and their ability to float 2. movement of seeds through pumps.
Hold point 1	**At this point we will be able to assess if:** **1. the characteristics of a sufficiently broad range of seeds have been assessed and to identify which groups of plants are missing from the analysis that need to be targeted in future assessment** **2. sufficient data has been collected on the movement of seeds through pumps to enable predictions to be made.**	
May 2017–August 2017	Sampling the movement of seeds through regulators (potential sites within the Barmah forest) Description of seed attributes that enable dispersal	
August 2017	Preparation of 2017 Quarter 3 Milestone Report	Milestone report Preliminary analysis of the movement of seeds through regulators
August 2017–November 2017	Processing of samples	
November 2017	Preparation of 2017 Quarter 4 Milestone Report	Milestone report Updated analysis of the movement of seeds through regulators
November 2017–February 2018	Processing of samples	
2018		
February 2018	Preparation of 2018 Quarter 1 Milestone Report	Milestone report Brief report describing progress on measurement of seeds and results from sampling program
February 2018–May 2018	Description of seed attributes that enable dispersal Identification of potential sites and sampling of seeds	
May 2018	Preparation of 2018 Quarter 2 Milestone Report	Milestone report Updated analysis of the movement of seeds through pumps and regulators and seed measurements
June 2018	Preparation of 2018 Annual Technical Report	Report describing the: 1. movement of seeds through pumps and regulators

Date	Activity	Deliverable
		2. analysis of seed morphology and ability to float.
Hold point 2	**At this point we should have data on how seeds move through pumps and regulators (although further data may be required around regulators if only one set of regulator samples have been obtained).** **We should also have measured the characteristics of 50 plant species and determined their ability to float.**	
May 2018–August 2018	Description of seed attributes that enable dispersal Identification of potential sites and sampling of seeds	
August 2018	Preparation of 2018 Quarter 3 Milestone Report	Milestone report Updated analysis of the movement of seeds through pumps and regulators and seed measurements
August 2018–November 2018	Description of seed attributes that enable dispersal Identification of potential sites and sampling of seeds (if required)	
November 2018	Preparation of 2018 Quarter 4 Milestone Report	Milestone report Updated analysis of the movement of seeds through pumps and regulators and seed measurements
November 2018–February 2019	Description of seed attributes that enable dispersal Processing remaining field samples	
February 2019	Preparation of 2019 Quarter 1 Milestone Report	Milestone report Updated analysis of the movement of seeds through pumps and regulators and seed measurements
February 2019–April 2019	Analysis of data	
April 2019	Preparation of 2019 Quarter 1 Milestone Report	Milestone report Preliminary analysis of seed movement an morphology data
June 2019	**Preparation of 2019 Final Report**	**Report describing the:** **1. movement of seeds through pumps and regulators** **2. analysis of seed morphology and ability of seeds to float.**

7.4.1 Current activities

- Characterisation of physical properties of seeds
  To date, 23 plant species have been tested for buoyancy and have had their physical characteristics measured (length, width, weight). These physical characteristics are then used to calculate a range of other parameters including density, and shape. The characteristics will then be used to classify seeds into groups based on their ability to float. This may allow predictions on which groups of plants will have their dispersal ability modified by management practices, such as pumping of water.
  Seeds will continue to be collected as flowering occurs. Currently the dataset is dominated by emergent plants. Future collections will target more submerged plants. An application for a summer cadetship student has been put forward with the aim to increase the size of the current dataset. By the end of the project in 2019, it is expected that more than 100 of the 700 known plant species associated with the MDB will have had their seed properties described.
- Movement patterns
  Samples have been collected from three wetlands (Speewa Creek, Wee Wee Creek and Thegoa lagoon). Speewa and Wee Wee creeks were being filled by pumps and Thegoa was filled via a siphon. Samples were also collected from the adjacent river/weirpool. Samples are currently being processed. A second survey was planned for November 2017, but this has now been cancelled due to inundation of the wetlands by naturally occurring floodwaters. A second trip is being planned for autumn 2017 in the Mallee region.
  In 2017–18, surveys will target water delivery through regulators and levees. It is expected that water delivery through these structures will select for or against seeds with different characteristics.

7.5 Budget

Table 4. Budget summary and forecast for the vegetation theme.

Staff	Role	2015-2016	2016–17	2017–18	2018–19
Daryl Nielsen	Project leader. Responsible for project design and development. Primary person in charge of data analysis and report writing	64,082	38,147	39,559	41,023
Technical support	Technical support is required to undertake field work. Once field work is completed support is required for seed sorting and identification. Technicians will also undertake preliminary data analysis	196,199	98,834	102,494	106,339
Salary total		260,282	136,981	142,052	147,362
Operating		11,260	25,100	12,986	12,855
Project total		271,542	162,081	155,038	160,217

7.6 Risks

- A core component of this project relies on the capacity of water resource managers to deliver water. If environmental conditions changed to the extent that water was not being delivered through management structures, the project would not be able to meet Objective 2.
- Loss of key technical resources. Currently there are only two technical staff who are sufficiently skilled to identify seeds. Loss of these staff would limit the project ability to deliver on Objectives 1 and 2.

7.7 End-user

The end-users of this project will be water resource managers throughout the MDB.

7.8 Who has an interest in this project being undertaken

Staff from the MDBA, NSW Office of Environment and Heritage (OEH), The South Australian Research and Development Institute (SARDI) and the Victorian Department of Environment, Land, Water and Planning (DELWP) have expressed a strong interest in the outcomes of this project due to their substantial investment in infrastructure.

7.9 References

Bischoff A, Warthemann G, Klotz S (2009) Succession of floodplain grasslands following reduction in land use intensity: the importance of environmental conditions, management and dispersal. *Journal of Applied Ecology* **46**, 241–249.

Capon SJ, James CS, Mackay SJ, Bunn SE (2009) Literature review and identification of research priorities to address retaining floodwater on floodplains and flow enhancement hypotheses relevant to understorey and aquatic vegetation. Report to the Murray–Darling Basin Authority (project MD1252). 149pp.

Groves JH, Williams DG, Caley P, Norris RH, Caitcheon G (2009) Modelling of floating seed dispersal in a fluvial environment. *River Research and Applications* **25**, 582–592.

Jansson R, Nilsson C, Dynesius M, Andersson E (2000) Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. *Ecological Applications* **10**, 203–224.

MDBA (2014) Basin-Wide Environmental Watering Strategy (ed. Molloy K). Murray–Darling Basin Authority, Canberra.

Merritt DM, Nilsson C, Jansson R (2010) Consequences of propagule dispersal and river fragmentation for riparian plant community diversity and turnover. *Ecological Monographs* **80**, 609–626.

Morris K (2012) Wetland connectivity: understanding the dispersal of organisms that occur in Victoria's wetlands. Arthur Rylah Institute for Environmental Research Technical Report Series No. 225. Department of Sustainability and Environment, Heidelberg, Victoria.

Nilsson C, Brown RL, Jansson R, Merritt DM (2010) The role of hydrochory in structuring riparian and wetland vegetation. *Biological Reviews* **85**, 837–858.

8 Fish movement

8.1 Background/Justification

Fish are good indicators of the ecological health of river systems. They are readily identifiable, and occupy a wide range of habitats longitudinally, from alpine to estuarine waterways, and laterally, from river channels to floodplain wetlands. Fish species occupy multiple trophic levels, ranging from algaevores/detritivores to apex predators. Many species are long-lived and their populations can integrate 'river health' effects over multi-decadal timescales. Many species of native fish show dispersal or movement behaviours and, for some, these behaviours are probably critical to long-term population health. Some of the key threats to fish dispersal are flow related — directly to either the quantity or quality of the flow, or indirectly via effects of the infrastructure built to regulate flows for human use. Research on the performance and significance of fish dispersal behaviours is critical to evaluate whether river operations (flows and infrastructure) are performing in such a way as to promote healthy fish populations.

The Sea to Hume fishway construction program was a $77M program that spanned ten years — the biggest fish passage rehabilitation program ever undertaken in Australia. As such, it formed an essential component of the MDBA Native Fish Strategy, a large, long-term river restoration project that was enthusiastically supported by The Commonwealth and State Governments of South Australia, Victoria, NSW and Queensland; and was extremely popular with community stakeholders in all jurisdictions.

The Sea to Hume program included the installation of automated Passive Integrated Transponder (PIT) technology to monitor the movements of migratory fish both during and beyond the construction program. This monitoring infrastructure is an essential tool to report on, and potentially fine-tune, the effectiveness of the program in meeting its original ecological objectives — i.e. that of rehabilitation of fish-passage and native fish communities throughout the Murray–Darling Basin.

To be truly effective, the program requires a population of tagged fish being present within the river. Naturally occurring population processes dictate that the tagged fish population slowly turns-over through time. Over 40 000 tagged fish were liberated into the Murray River over the past decade, mainly by the 'Tri-state Murray River Fishway Assessment Program' (MRFAP). However, due to natural attrition, and major blackwater events, it is expected that this number of tagged fish would now be severely depleted. There is a pressing need to increase tagged fish numbers to ensure that the automated-system can optimally record fish movements. MDBA analysis has shown that tagging by lock-staff will be much more cost-effective than MRFAP after including training costs (MDBA 2016, 'Pilot Program Proposal — Fish Tagging at River Murray fishway sites'). Tagging rates during the Murray River Fishway Assessment Program ranged from 4,000 to 6,000 tags per year. This represents an aspirational target for future tagging numbers along the River Murray. Once the tagging program is operating the number of tagged fish passing each weir can be assessed and the tagging effort can be adjusted to provide a good range for all of the fishways. The cost effectiveness was analysed in the Pilot Program Proposal — Fish Tagging at River Murray fishway sites' and states "*When an estimate of training costs are included, this* *works out to be just over $5 per tag, which is considered to be very cost-effective compared to other alternative tagging methods*" (MDBA 2016). Staff at MDFRC's Lower Murray Laboratory are highly experienced in fish tagging and fish handling techniques, and are well-placed geographically (Mildura) to cost-effectively train lock-staff with necessary skills.

8.2 Objectives

8.2.1 Immediate

Develop a program for training lock staff to enable tagging of fish at up to three sites initially at Lock 10, Lock 7 (or 8 or 9) and Lock 15.

8.2.2 Planned

MDFRC will lead a collaborative process with the MDBA, ARI, Fisheries NSW, the South Australian Research and Development Institute (SARDI) Aquatic Sciences, Charles Sturt University and the State constructing authorities to:

1. Develop appropriate methodologies for the ecological-interpretation and analysis of the existing and developing fish-movement dataset
2. Generate and answer key ecological questions relating to fish movement, fishways and river rehabilitation in the southern connected system
3. Provide ongoing insight into appropriate ways to manage flows and fishways to achieve the overarching rehabilitation objectives of the Sea to Hume and Native Fish Strategy programs to the benefit of all Murray–Darling Basin States
4. Develop a plan for broader roll-out of fish tagging by lock staff at other sites along the Murray River.

8.3 Management implications

- *Protect and restore water-dependant ecosystems*
  By building the capacity to tag fish through the training of Lock staff thereby increasing the number of tagged fish in the system. Additionally analysis of existing data on fish-passage will provide water resource managers with knowledge on how to effectively manage flows to promote the movement of fish along the length of the Murray River and create lateral connectivity.

8.4 Project activities

Table 5. Timeline of activities, hold points and deliverables for the fish movement component of the MMCP.

Date	Activity	Deliverable
November 2016	Coordinate the acquisition of the necessary equipment and tags to undertake tagging-training at the three sites Develop and implement a training program for initial tagging at Lock 10 in consultation with WaterNSW and the MDBA (three training events completed)	Delivered Initial training course for Lock 10 staff (3-days) Technical Report: 'A lock keepers guide to tagging fish at Lock 10', detailing the requirements, procedures and processes for tagging fish to be provided to each of the lock staff

Date	Activity	Deliverable
	Write a brief training manual	
November 2016–February 2017	Undertake an additional training visit to Lock 10 early in the second season (2016–17)	Training day to give lock staff a refresher course. *This will be rescheduled (potentially into 2017) when present high-flows recede enough to allow fishway operations.*
	Organise and host workshop 'Focussing the ecological objectives of fish PIT tagging'	Delivered workshop, 4 November at La Trobe University in Melbourne. MDFRC coordinated the workshop and invited the MDBA, ARI, NSW Fisheries, SARDI Aquatic Sciences and Charles Sturt University to develop methodologies for the ecological-interpretation and analysis of the existing and developing fish-movement dataset.
February 2017	Preparation of 2017 Quarter 1 Milestone Report.	Quarter 1 Milestone Report An update on progress against training objectives and workshop actions.
2017		
February 2017–May 2017	Initial training Lock 15	Provide the lock staff at one additional lock (Lock 15) with the necessary training to safely undertake tagging. This involves teaching the necessary steps and procedures for safely handling and tagging fish, using the equipment, and supervising initial tagging.
	Collate available data on fish movement, flows, temperature and fish communities	Compatible collated data on fish movement, flows, temperature and fish communities
May 2017	Preparation of 2017 Quarter 2 Milestone Report.	Milestone Report An update on progress against training objectives, and we anticipate having data sets on fish movement, flow, temperature and fish-communities collated
April 2017–June 2017	Data analysis	Preliminary analysis using collated data on fish movement, flows, temperature and fish communities
Hold point 1	**By this stage we should have a good idea if Animal Ethics approval has been granted for lock staff PIT tagging, and about whether existing data will support the investigation of the role of fish movement in driving fish community change and if not, where the deficiencies may lie to target further investment.**	
May 2017–August 2017	Further data analysis	Continue analysis using collated data on fish movement, flows, temperature and fish communities
August 2017	Preparation of 2017 Quarter 3 Milestone Report.	Quarter 3 Milestone Report We anticipate having completed the data analysis to investigate the role of fish movement in fish community rehabilitation
August–November 2017	Lock 10 staff tagging independently Refresher training Lock 15	Training day to give Lock 15 staff a refresher course at the start of spring 'fish passage season', and start training program for staff at Lock 7, 8 or 9

Date	Activity	Deliverable
	Commence initial training program for staff at a third lock (Lock 7, 8 or 9 to be decided)	
November 2017	Preparation of 2017 Quarter 4 Milestone Report	Quarter 4 Milestone Report An update on progress against training objectives
November 2017–February 2018	Additional training for staff at a third lock (7, 8 or 9) Drafting report on role of fish movement in fish community rehabilitation (seek input from MRFAP)	Complete initial training for Lock 7, 8 or 9 staff
2018		
February 2018	Preparation of 2018 Quarter 1 Milestone Report	Quarter 1 Milestone Report Anticipate that a report on the role of fish movement in fish community rehabilitation will be circulated to MRFAP collaborators for comments
February 2018–June 2018	Finalise report with MRFAP collaborators	Final report on role of fish movement in fish community rehabilitation
Hold point 2	**At this stage we will have a draft collaborative report that describes the role of the restoration of fish movement in fish community rehabilitation. The next stage would be to aim to publish this in the peer-reviewed literature.** **We will also have a significant number of lock-keeper tagged fish at large. A next stage, before rolling out the training program more widely to other locks, would be to comparatively evaluate movement of fish tagged by lock-staff with those tagged by fisheries agency staff (i.e. those tagged in fishway traps, with those tagged below fishways etc.).**	
June 2018–November 2018	Refresher training Lock 7, 8 or 9 staff Evaluate lock keeper tagging using fish 'movement-performance'	Training day to give lock staff a refresher course at start of spring 'fish passage season' Comparative analysis of fish movement performance of lock-keeper tagged fish and non-lock-keeper tagged fish
November 2018	Preparation of 2018 Quarter 4 Milestone Report	Quarter 4 Milestone Report An update on progress against training objectives and the evaluation of lock-keeper tagged fish performance
November 2018–June 2019	Plan wider roll-out of cost-effective PIT tagging by lock-staff	
June 2019	**Preparation of 2019 Final Technical Report**	**Final Technical Report** **Containing a plan for wider roll-out of PIT tagging by lock-staff, a summary of all training activities and a comparative evaluation of fish-movements by fish tagged by lock-staff and others**

8.5 External collaborators

- MDBA: Greg Ringwood, Ben Dyer, Laura McCann, Stuart Little, Jack Smart

- NSW DPI: Matt Gordos
- KarlTech: Karl Pomorin
- CSU: Lee Baumgartner
- SARDI: Brenton Zampatti

8.6 Budget

Table 6. Budget for the training and tagging component of MMCP Fish Movement Project.

Staff	Role	2015-2016	2016–17	2017–18	2018–19
Paul Brown	Training lock staff Project leader. Responsible for project design and development.	30,628	14,312	2,968	3,078
Technical support	Technical support is required to undertake training of the lock staff	102,853	29,281	30,365	31,488
Salary total		133,481	43,593	33,333	34,566
Operating[5]		2,258	2,500	5,000	5,000
Total		135,739	46,093	38,333	39,566

Table 7. Budget for the Collaborative ecological interpretation of the Fish movement project

Staff	Role	2015-16	2016–17	2017–18	2018–19
Paul Brown	Liaise with state fisheries representatives and co-ordinate working groups Lead data analysis and report writing		14,312	26,715	27,703
Salary total			14,312	26,715	27,703
Operating			7,500	5,000	5,000
Total			21,812	31,715	32,703

8.7 Risks

- If the MDBA application for an Animal Care and Ethics permit for the lock-staff is unsuccessful, sign-off of training to enable lock-staff to tag independently of MDFRC cannot occur.
- If the stakeholders from the states are unwilling or unable to collaborate with MDFRC and the MDBA (e.g. due to lack of funding), methodologies for the ecological-interpretation and analysis of existing MDBA datasets may not accommodate ideas from the broad science community and may be less well supported by states.

[5] The operating component includes provision to cover travel and accommodation costs of external collaborators.

8.8 End-user

State constructing authorities, the MDBA, and state and commonwealth agencies involved in flow management and fish management within the southern connected basin.

8.9 Who has an interest in this project being undertaken?

- Ben Dyer, MDBA River Management Division; Greg Ringwood and Stuart Little (MDBA), state constructing authorities (NSW, SA and Victoria), and state and commonwealth agencies involved in flow management and fish management within the southern connected basin.
- Collaboration will be sought with Lee Baumgartner (Charles Sturt University), Matt Gordos, Jason Theim (NSW DPI), Brenton Zampatti (SARDI), and Matt Jones/Justin O'Connor (ARI)

Analyses of fish movement data and its role in river rehabilitation have transferability beyond the southern connected basin to other areas with fish species with similar traits and similar fishways.

8.10 References

MDBA (2016). Pilot program proposal: fish tagging at River Murray fishway V3.0

9 How do flows and climate affect growth dynamics of Murray–Darling Basin fishes?

9.1 Background/Justification

Due to their socio-economic importance, fish are recognised as a critical indicator of flow outcomes under the Basin Plan (Basin Plan 2012). A key objective within the Basin-Wide Watering Strategy is to manage flows to improve survival rates of fishes with medium to long life-spans (MDBA 2014). If we wish to see increases in fish population size, then meeting this objective is critical. From a scientific perspective, however, direct estimation of flow-survival relationships is a great challenge, and takes several years of quality data to establish (Walters 1997). The impact of flows on fish survival in the Basin is being studied directly as part of the Commonwealth's LTIM program. To complement LTIM's direct, long-term analyses of flow-survival relationships at the Basin-scale, there is a need for further short-term studies that take novel approaches to the problem; studies that improve our predictive understanding of how flows affect proxies of survival, and hence our ability to report on flow outcomes at the temporal scale of 1–5 years.

Individual growth rate has a strong influence on critical population processes (Sauer and Slade 1987), including survival (Jensen and Johnsen 1999). However, our understanding of how managed and natural flows affect growth of the Basin's fishes is rudimentary (Tonkin et al. 2011). Here we propose to use fish otoliths (ear bones) collected as part of LTIM to determine the effects of flows and temperature on growth histories of Murray cod (*Maccullochella peelii peelii* Mitchell), Bony herring (*Nematalosa erebi* Günther) and Golden perch (*Macquaria ambigua ambigua* Richardson) at six sites throughout the Basin (Gwydir, Lachlan, Murrumbidgee, Edward-Wakool, Goulburn and lower Murray Rivers). The approach we plan on taking has been used to study impacts of environmental change on population performance in various contexts (Morrongiello and Thresher 2015; Morrongiello et al. 2012; Morrongiello et al. 2014; Neuheimer et al. 2011), but has not been used to understand the impacts of environmental flows at any temporal scale. It follows that in addition to generating highly desirable outcomes to water managers (see Management outcomes), we are also breaking new ground from a scientific point of view.

9.2 Objectives

1. For Murray cod, Golden perch and Bony herring, use otoliths obtained as part of LTIM to back-calculate time series of the growth rates of individuals, and model those growth rates as a function of flows and temperature throughout fishes' lives.
2. Parameterise a model that facilitates forecasting of how flows and temperature affect growth of these species throughout the Basin.
3. Integrate growth models developed in Objectives 1 and 2 within a structured population model that enables us to forecast how a changing climate interacts with flows to affect the dynamics of fish populations within the Basin.

9.3 Management Implications

- *Improved capacity to evaluate outcomes from managed flows*

  The work proposed here will yield inferences that enable us to report against key Basin Plan objectives. Further, a key challenge facing water managers is reporting on fish response to managed flows (a) within river segments of the Basin where monitoring is taking place, and (b) outside monitored areas of the Basin (MDBA 2014). This study will help with both of these reporting objectives. First, we are using otoliths collected from monitored areas throughout the Basin, which means we can back-calculate the growth of fishes that have been exposed to environmental water deliveries in recent years, and we'll also have good hydrology data from those areas; data where the managed and background components of the hydrograph have been separated. Second, we will be estimating the parameters of models that can then be used for inferring the likely range of managed flow impacts on fish growth in unmonitored areas, where good hydrology data exist, using 'predictive inference'.

- *Increases effectiveness of flow delivery*

  The models generated will facilitate decision making within and across years, specifically with respect to how hydrograph features (e.g. timing, magnitude etc.) affect growth. The spatial scale of the analysis (whole-of-Basin) greatly broadens the generality of any inferences we make, hence its utility within the Basin.

- *Improved capacity to anticipate emerging risks*

  As the Basin-Wide Watering Strategy evolves, we must improve our capacity to predict how changing climate will interact with flows to affect Basin Plan objectives (MDBA 2014). This study specifically aims to improve our understanding of climate-flow interactions, and generates models that enable us to forecast and, hence anticipate emerging threats to fish growth.

9.4 Project activities

Leverage from LTIM: Note that all otoliths used by this project have already been collected as part of other projects, most notably LTIM. LTIM otoliths were collected to develop models that enable us to predict age from length, not for the purposes described above in the Objectives. Hence, we are maximising the utility of existing collections.

Table 8. Timeline of activities, hold points and deliverables for the fish modelling component of the MMCP.

Date	Activity	Deliverable
October–November 2016	Obtaining otoliths from LTIM Basin-Matter team, collating a database including detailed photographs of each otolith	
November 2016–February 2017	Measurement of increment widths from 100s of Murray cod otoliths Measurements taken and saved in database	
2017		
February 2017	Preparation of 2017 Quarter 1 Milestone Report	Milestone report We anticipate having half of the Murray cod growth data uploaded and ready for analysis.
February 2017–May 2017	Finalising all increment measurements from Murray cod otoliths collected across the Basin	
May 2017	Preparation of 2017 Quarter 2 Milestone Report	Milestone report We anticipate having all Murray cod growth data uploaded and ready for analysis.
April 2017–June 2017	Modelling growth dynamics of Murray cod, our first of three target species	
June 2017	**Preparation of 2017 Annual Technical Report:** **Impacts of flows and climate on the growth dynamics of Murray cod**	**Report describing the impact of flows on Murray cod growth dynamics; Forecasts of Murray cod growth dynamics under different climate and flow scenarios.**
Hold point 1	**At this stage we will have a good idea of whether or not the approach and outputs are useful to stakeholders. Decide whether or not to expand analyses to Golden perch and Bony herring, as outlined below.**	
May 2017–August 2017	Measurement of increment widths from hundreds of Golden perch otoliths Measurements taken and saved in database	
August 2017	Preparation of 2017 Quarter 3 Milestone Report	Milestone report

Date	Activity	Deliverable
		We anticipate having all Golden perch growth data uploaded and ready for analysis.
August–November 2017	Measurement of increment widths from hundreds of Bony herring otoliths Measurements taken and saved in database Modelling growth dynamics of golden perch, our second of three target species	
November 2017	Preparation of 2017 Quarter 4 Milestone Report	Milestone report Brief report describing progress on the modelling of Golden perch growth in response to flows and climate
November 2017 – February 2018	Measurement of increment widths from hundreds of Bony herring otoliths Measurements taken and saved in database Modelling growth dynamics of golden perch, our second of three target species	
2018		
February 2018	Preparation of 2018 Quarter 1 Milestone Report	Milestone report Brief report describing progress on the modelling of Golden perch growth in response to flows and climate
February 2018–May 2018	Modelling growth dynamics of Golden perch and Bony herring	
June 2018	**Preparation of 2018 Annual Technical Report:** ***Impacts of flows and climate on the growth dynamics of Golden perch and Bony herring***	**Report describing the impact of flows on the growth dynamics of Golden perch and Bony herring;** **Forecasts of how growth dynamics of Golden perch and Bony herring are affected by different climate and flow scenarios.**
Hold point 2	**At this stage we will have reported on how flows and climate interact to affect the growth dynamics of three large-bodied species: Murray cod, Golden perch and Bony herring. The models we will have been working with to this point describe how flows and climate affect the growth rate (change in length per unit time) of individuals within populations. The next step of the project would be to integrate these models with structure population models to describe how flows and climate affect the dynamics of entire populations (see Objectives).**	
May 2018–November 2018	Developing the approach and collating additional parameter data (e.g. size-fertility relations) for the three target species	
November 2018	Preparation of 2018 Quarter 4 Milestone Report	Milestone report We anticipate having collated all necessary parameters for modelling at the population level.
November 2018–June 2019	Population modelling: Modelling changes in population size-structure and persistence as a function of flow regimes and climate change	

Date	Activity	Deliverable
June 2019	**Preparation of 2019 Annual Technical Report:** ***Impacts of flow regimes and climate change on the dynamics of large-bodied fishes within the Murray–Darling Basin***	**Report describing the impact of flows on the population dynamics of Murray cod, Golden perch and Bony herring; Forecasts of how future flow and climate scenarios affect the dynamics of large-bodied fish populations within the Basin.**

9.5 External collaborators

- University of Melbourne: John Morrongiello — expert advice on otolith reading and analysis
- NSW Fisheries: Jason Thiem and Gavin Butler — provision of data
- Charles Sturt University: Keller Kopf and Nicole McCasker — provision of data
- Arthur Rylah Institute: Wayne Koster — provision of data
- South Australian Research and Development Institute: Qifeng Ye and Brenton Zampatti — provision of data

9.6 Budget

Table 9. Budget summary and forecast for the fish modelling theme.

Staff	Role	2015-16	2016–17	2017–18	2018–19
Rick Stoffels	Project leader. Responsible for project design and development. Primary person in charge of data analysis and report writing	12,500	100,686	104,411	108,275
Technical support	Technical support in assembling database and taking all increment measurements from otoliths and data management	25,000	65,891	68,329	70,857
Salary total		37,500	166,577	172,740	179,132
Operating			5,000	5,000	5,000
Project total		37,500	171,577	177,740	184,132

9.7 Risks

- *High noise: signal ratio for Bony herring otoliths.* The approach we are taking here has been used for Golden perch in impoundments before, so we are confident of the approach working on Golden perch otoliths. We are confident of obtaining excellent growth data from Murray cod, following a preliminary examination of the otoliths. However, having examined some Bony herring otoliths already, they are difficult otoliths to read and may be characterised by high noise-to-signal ratios. We are managing this risk by analysing these otoliths last, following extensive practice with the approach.

9.8 Who has an interest in this project being undertaken?

In addition to the above end-users, this project is a collaboration between MDFRC, University of Melbourne, Arthur Rylah Institute, NSW Fisheries, Charles Sturt University, and SARDI.

9.9 References

Jensen AJ, Johnsen BO (1999). The functional relationship between peak spring floods and survival and growth of juvenile Atlantic Salmon (Salmo salar) and Brown Trout (Salmo trutta). Functional Ecology **13**: 778-785.

MDBA. 2014. Basin-wide environmental watering strategy, Licensed from the Murray–Darling Basin Authority, under a Creative Commons Attribution 3.0 Australia Licence.

Morrongiello JR, Thresher RE (2015). A statistical framework to explore ontogenetic growth variation among individuals and populations: a marine fish example. Ecological Monographs **85**: 93-115.

Morrongiello JR, Thresher RE, Smith DC (2012). Aquatic biochronologies and climate change. Nature Climate Change **2**: 849-857.

Morrongiello JR, Walsh CT, Gray CA, Stocks JR, Crook DA (2014). Environmental change drives long-term recruitment and growth variation in an estuarine fish. Global Change Biology **20**: 1844-1860.

Neuheimer AB, Thresher RE, Lyle JM, Semmens JM (2011). Tolerance limit for fish growth exceeded by warming waters. Nature Climate Change **1**: 110-113.

Sauer JR, Slade NA (1987). Size-based demography of vertebrates. Annual Review Ecology and Systematics **18**: 71-90.

Tonkin ZD, King AJ, Robertson AI, Ramsey DSL (2011). Early fish growth varies in response to components of the flow regime in a temperate floodplain river. Freshwater Biology **56**: 1769-1782.

Walters C (1997). Challenges in adaptive management of riparian and coastal ecosystems. Ecology and Society **1**: 1-19.

10 Understanding the ecological consequences of macroinvertebrate community-structure change

10.1 Background/Justification

A healthy and productive fish community relies on the underlying food web to provide energetic and nutritional needs. Macroinvertebrates are central to those food webs. The 35-year monitoring program of macroinvertebrates in the Murray River (the River Murray Biological Monitoring Project (RMBMP), funded by the MDBA) has shown that macroinvertebrate communities in the Murray River have changed over time and at different sites. The aim of this component of the MMCP is to quantify the ecological consequences of those changes. In doing so, we will generate a conceptual model that provides information to target management activities directly towards the key elements of the food web that have the greatest effect on the productivity of fish communities. This project links with activities undertaken within the LTIM and MDB EWKR Food Web and Fish projects.

In the first instance, we propose examining two approaches:

Energetics approach

The MDB EWKR Food Web Project has recognised the need to understand the role of trophic dynamics in determining outcomes of managed hydrological regimes. Established ecological theory allows prediction of the energy distribution within different food web structures. We will use this approach to further interrogate the RMBMP long term dataset, to establish how changes in size structures within the macroinvertebrate community alters the energy distribution of Murray River food webs. The overall impact is the extent to with energy can be transferred to fish production.

Nutritional approach

Macroinvertebrates in the Murray River are an important food source for native fish and any changes that lead to alterations in macroinvertebrate communities, either abundances of all or specific organisms and/or community composition, will alter the nutritional landscape available for native fish.

As with all consumers, a ‘balanced diet’ is critical to maintaining healthy individuals and populations. Diets with balanced amounts of macronutrients are known to be important in fish communities. At the biochemical level, the aquaculture industry has identified a suite of ‘indispensable amino acid requirements (IAA)’ (also termed essential amino acids) for fish growth (Cowey 1995; Mambrini and Kaushik 1995). Understanding the overall nutritional requirements has informed the design of food sources to optimise fish growth in the aquaculture sector. While the aquaculture industry has examined nutritional needs from an industrial perspective (e.g. including growth of Murray cod ;De Silva et al. 2000), the ecological significance of changes in fish diets has not received attention. Early work at MDFRC has shown that the food sources (macroinvertebrates) can vary in the extent to which they supply a balanced diet to fish, but it remains to be shown how ecologically significant these controls are, compared to other drivers of fish populations.

10.2 Objectives

10.2.1 Immediate

- Drawing on the long-term Murry River Monitoring dataset, to quantify the extent to which changes in the size structure of the macroinvertebrate communities has lead to changes in the energy distribution, and thus energy resources available for fish.

10.2.2 Medium to long term

- Synthesise and summarise the relevant literature on the key aspects of fish nutrition that have greatest ecological significance in driving fish growth and reproduction. This will involve investigating the relative importance of macronutrients and micronutrients in generating healthy populations of higher order consumers in the river.

- The overall objective is to explore whether or not the decline in native fish can be attributed to observed shifts in the types and distributions of potential prey items and how management options can be used to optimise food resources.

10.3 Management implications

- *Protect and restore the ecosystem functions of water-dependant ecosystems*

  The management and restoration of native fish populations has primarily targeted the maintenance of flows and habitats that promote recruitment and growth of larval and juvenile fish. The success of these actions may be limited due to a poor understanding of how changed flow regimes have modified the occurrence of appropriate food resources that are necessary to support the recruitment and growth of native fish. The MMCP will provide water resource managers with the knowledge on how to manipulate flow regimes to support and maintain food resources that promote the growth of native fish.

10.4 Project activities

Table 10. Timeline of activities, hold points and deliverables for the macroinvertebrate component of the MMCP.

Date	Activity	Deliverable
October–November 2016	Re-interrogate the current long-term Murray River Monitoring program datasets. Examine which biota represent major change in food webs. Complete first method development for biochemical analysis of macroinvertebrates	Report update that describes which biota are responsible for alterations to food web Short update on methods development and successful application
November 2016–February 2017	Develop first approach to determine size structure of the modified food web	
2017		
February 2017	Preparation of 2017 Quarter 1 Milestone Report	Milestone Report Report on the progress made measuring the size structure of the food web at one site on the Murray River
February 2017–May 2017	Continue analysis on different sites Analytical routines developed for a single site will be applied to further sites Compilation of nutritional ecology literature	
May 2017	Preparation of 2017 Quarter 2 Milestone Report	Milestone report Report on the progress made measuring size structure of the food web at further sites on the Murray River
April 2017–June 2017	Finalising analysis of the size structure and energy distributions across the sites examined as part of the Murray Monitoring program Continued compilation of nutritional ecology literature	

Date	Activity	Deliverable
June 2017	**Preparation of 2017 Annual Technical Report**	**Report on the size structure of the food webs and a forecast on the potential energy differences across different sites and times** **An estimation of the key nutritional elements that need to be examined as driving forces for food web structures and fish communities**
Hold point 1	**At this stage we will decide on the most important aspect of nutritional ecology to pursue as part of the ongoing nutritional component.**	
May 2017–August 2017	Carry out nutritional analysis of key food sources for fish. Analyses are likely to include overall C:N:P analysis and biochemical analysis on macroinvertebrates.	
August 2017	Preparation of 2017 Quarter 3 Milestone Report	Milestone report Update report on a suite of nutritional elements of the fish food
August–November 2017	Continue with nutritional analysis of key food sources for fish Analyses will be as previously identified	
November 2017	Preparation of 2017 Quarter 4 Milestone Report	Milestone report Update report on a suite of nutritional elements of the fish food
November 2017–February 2018	Continue with nutritional analysis of key food sources for fish Analyses will be as previously identified	
2018		
February 2018	Preparation of 2018 Quarter 1 Milestone Report	Milestone report Brief report describing the nutritional landscape of the river food webs and their relationship to fish production
February 2018–June 2018	Finalise measurements on the nutritional landscape of the river food webs and their relationship to fish production	
June 2018	**Preparation of 2018 Annual Technical Report**	**Brief report describing the nutritional landscape of the river food webs and their relationship to fish production** **Forecasts of how growth dynamics are affected by different nutritional aspects of macroinvertebrate food sources**
Hold point 2	**We propose implementing a series of laboratory approaches that will measure growth response of consumers to the food resources described in early parts of the project. These experiments will enable a mathematical approach to be used in determining how energetics and nutrition regulate the fish community. The appropriate fish species will be chosen for the analyses. At this point, we will also consider whether other higher order consumers could, or should be included in the study. Large crustaceans (crayfish/yabby) are important freshwater biota, either as top predators, or food sources for fish such as Murray cod, and are likely to be affected by similar flow-driven events.**	

Date	Activity	Deliverable
June 2018–November 2018	Experiments that examine specific response parameters of fish history to altered food resources	
November 2018	Preparation of 2018 Quarter 4 Milestone Report	Milestone report Report on fish responses to altered food resources
November 2018–June 2019	Finalisation of the laboratory experiments, and modelling growth responses to food resources	
June 2019	**Preparation of 2019 Annual Technical Report**	**Report describing the impact of flows on the food web structures of lowland rivers and how they drive fish communities**

10.5 Budget

Table 11. Budget summary and forecast for the macroinvertebrate theme.

Staff	Role	2015-16	2016–17	2017–18	2018–19
Gavin Rees	Project leader. Responsible for project design and development. Provides biochemical and analytical expertise Primary person in charge of data analysis and report writing.	17,831	42,509	44,082	45,713
Darren Baldwin	Provides analytical chemistry and carbon metabolism expertise. Will provide scientific input into project and critical links to the MDB EWKR project	16,692	42,509	44,082	45,713
Michael Shackleton	Leads the macroinvertebrate Murray monitoring project and provides macroinvertebrate ecology expertise in data analysis and interpretations	15,939	22,289	23,114	23,969
Technical support	Technical support assists in the collection of data and analysis of the data in the analysis of samples using liquid chromatography- mass spectrometry	133,334	71,324	73,963	76,700
Salary total		183,797	178,633	185,242	192,096
Operating		18,504	30,111	17,985	12,853
Project total		202,301	208,744	203,227	204,949

10.6 Risks

While we have a clear plan for future activities, some aspects will be informed by the results from the previous year's work. For example, the outcomes of the nutritional review will inform details of the work program for years 2018–19, this there is some risk around the work plan in the last year of the project.

10.7 Who has an interest in this project being undertaken?

Management agencies who have an interest in managing fisheries. The information will contribute to existing knowledge on factors that drive current fish communities. The information will be of interest to those who have a responsibility to improve fish communities — managing fish by managing the factors that drive the current communities.

This project will also have major social and recreational benefits. In particular, the general fishing community (and community more widely) has an interest in this information as it will ultimately lead to an improved inland fishery in the MDB.

10.8 References

Cowey CB (1995) Protein and amino acid requirements: A critique of methods. Journal of Applied *Ichthyology* **11**, 199-204

De Silva SS, Gunasekera RM, Gooley G (2000) Digestability and amino acid availability of three protein-rich ingredient-incorporated diets by Murray cod (*Maccullochella peeli peeli* (Mitchell) and the Australian shortfin eel *Anguilla australis* Richardson. *Aquaculture Research* **31**, 95-205

Mambrini M, Kaushik SJ (1995) Indispensable amino acid requirements of fish: correspondence between quantitative data and amino acid profiles of tissue proteins. *Journal of Applied Ichthyology* **11**, 240-247

11 Basin Officials Committee questions

The BOC has agreed that, each year of the Agreement, the MDFRC will provide the committee with responses to two strategic questions, as considered pieces of advice representing the consolidation of the current state of scientific knowledge directly targeted to the issues of concern to BOC. The responses to these questions are in the form of reviews or synthesis papers. Discussions are currently being had with BOC in regards to what the next BOC question will be and what the end product of the responses will look like. It is not envisaged that they will be a full synthesis, which is the approach that was taken with BOC #1 and #2.

A process is currently being developed to enable the identification of the questions to be addressed. It is envisaged that a broad group of freshwater ecologists will be canvassed and a priority list of ten questions will be developed and presented to the BOC.

11.1 Budget

Table 12. Budget summary and forecast for the BOC questions.

Staff	Task	2015-16	2016–17	2017–18	2018–19
Darren Baldwin	Writing of synthesis in response to BOC questions	102,393			
Rick Stoffels		66,847			
To be identified		0	92,748	96,179	99,738
Total		169,240	92,748	96,179	99,738

In 2015–16, two topics were identified as being important to the BOC.

11.2 How can improved knowledge of the relationship between flows, ecological condition and response be used to guide environmental water planning and management?

Status: ***Completed***

11.2.1 Executive Summary

The Murray-Darling Basin Plan has seen significant volumes of water transferred away from agricultural production toward restoring and sustaining aquatic ecosystems. This shift comes at significant economic costs (both direct and indirect), and there is thus intense pressure to demonstrate the ecological benefits arising from environmental watering to the community, and to show the related social and economic benefits arising from improvements in river health.

Scientific knowledge has, and continues to, provide an important input to policy and management decisions about how best to manage environmental water to achieve a range of ecosystem targets. These decisions span a range of spatial-scales (representing different jurisdictions) and different time-frames, and many decisions are still subject to considerable uncertainty. In practical terms it is therefore important to ask “how (and where) can improved knowledge of the relationships between flows, ecological condition and responses to flow be used to guide environmental water planning and management”?

The Basin-Wide Watering Strategy explicitly recognises the need for an adaptive approach to the management of environmental water to account for the various uncertainties in terms of how ecosystems respond to water delivery. This adaptive approach operates at multiple temporal and spatial scales. For example, in the short-term, annual watering strategies will evolve over time in response to information about the effectiveness, or otherwise, of environmental watering actions. Over the longer, term periodic reviews of the Basin Plan provide an opportunity to adjust the Sustainable Diversion Limits (SDL) to account for changes in the understanding of ecosystem water requirements and the water volumes required to meet the Basin Plan objectives. This adjustment may affect water allocations at both river and whole-of basin scales.

Within this adaptive framework there are arguably three primary objectives that water managers must strive for. First, environmental watering must be effective; that is it must be demonstrated that environmental watering is achieving the desired outcomes. Secondly, those outcomes must be achieved with the greatest possible efficiencies in terms of the volumes of water required. Increased efficiency arguably will follow as knowledge refines our understanding of how to manage environmental watering for maximum effectiveness. Thirdly, these first two objectives must be met while giving due consideration to also managing risks of adverse outcomes, which may arise directly or indirectly from environmental watering actions. Most importantly a number of such risks may increase simultaneously with efforts to increase efficiency.

Here we briefly summarise these three goals, providing examples of how additional knowledge will impact on them, and suggesting a way forward in terms of bringing additional knowledge to bear on each of these challenges via research-management partnerships.

Effectiveness.

The most obvious objective for environmental watering is to be able to demonstrate that the desired ecological outcomes are being achieved; that is that environmental watering is effective. While the best available science has been used to determine environmental watering regimes across the basin, there are numerous uncertainties regarding ecological responses. Some responses are less well understood than others, and thus may require repeated experimental trials (adopting adaptive management principles) to reduce those uncertainties and achieve effective outcomes. The existence of monitoring programs such as the Commonwealth Environmental Water Office Long Term Intervention Monitoring Program (LTIM) will be critical to assessing effectiveness and reducing uncertainties over time. Local environmental water managers are also actively engaged in acquiring and utilising the most up to date information available to achieve effective environmental outcomes.

Efficiency.

There are heavy constraints on the quantity of water available to achieve Basin Plan objectives and there is thus huge pressure to achieve environmental outcomes as efficiently as possible. Efficiency can be considered in terms of delivering the maximal environmental benefit per unit investment in environmental water, and is likely to increase over time simultaneously with reductions in uncertainty and increases in effectiveness. Strong parallels can be drawn with the role that experience plays in farmers having the accumulated knowledge and experience to make good planting and watering decisions based on water availability and seasonal forecasts.

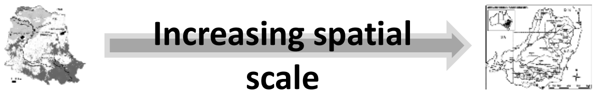
There are a number of avenues for additional research and knowledge to increase efficiencies by, for example; (i) identifying through monitoring which watering actions have been effective, (ii) identifying novel delivery strategies such as works and measures programs, and (iii) via opportunities for achieving multiple benefits, for example through the re-use of environmental and agricultural water as it is delivered downstream. Finally, efficiency and effectiveness will likely increase where environmental watering actions are modified, if they are found to be ineffective due to other constraints that cannot be lifted, or, over time from the simultaneous adoption of additional complementary measures.

Managing risks.

The benefits of environmental watering may be compromised by a range of threats that may be independent of, or directly associated with, environmental watering actions. Relevant examples include the threats and impacts associated with algal blooms and blackwater events, both of which may be linked to water management decisions. While the recent blackwater events were triggered by large natural floods, environmental water has played a role in trying to mitigate the impacts. There has also been cases where environmental watering has inadvertently triggered fish kills and other impacts in the past. Obvious examples of where such risks may arise include the risk of blackwater events from poor management of floodplain works and measures (which may pond water on the floodplain for too long), or the triggering of poor water quality (blackwater, low pH) from rewetting of dry river channels and wetlands. Because such threats may compromise ecosystem values being targeted by environmental watering (e.g. sustaining native fish populations), the ability to foresee and mitigate such risks may be critical in ensuring longer-term environmental watering goals are achieved.

Where can knowledge add value?

There are a number of readily identifiable areas where additional knowledge will provide opportunities to increase the efficiency and effectiveness of environmental watering while simultaneously reducing the risks of adverse outcomes. The Basin Wide Watering strategy includes a spatial and temporal hierarchy of decision making that geographically spans local to basin-scales, and temporally includes long-term planning, annual priority setting and intra-annual operational decision making (Figure 1).



Decreasing temporal scale

	Local	State	Southern connected basin	BASIN
Long term planning	Long term environmental plans	Water Resource Plans		Basin Environmental Watering Strategy
Annual planning	Local reach and wetland proposals	Seasonal Watering Plans	The Living Murray Priorities	MDB – Annual Basin Priorities CEWH – Annual Water Use Options
Annual operations	Delivery	Multi-site watering in tribs	Multi-site watering	

Figure 3. Table summarising the range of spatial (jurisdictional) and temporal scales over which environmental watering decisions are made

Decisions made at each of these scales have different information and knowledge requirements. Table 1 (below) provides a summary of examples of where new knowledge would assist in decision making at each of these scales, and the associated value proposition in terms of likely gains in effectiveness, efficiency and risk mitigation.

Addressing these knowledge gaps

The integration of scientific research and river management requires a shared understanding between scientists and managers of the management problems to be solved, and the effective sharing of knowledge and information in subsequently solving those problems. Increasingly these two goals are being achieved through much greater collaboration across all phases of the research cycle than has historically been the case. Under this collaborative model collaboration spans the processes of question generation, research program implementation, interpretation of findings and dissemination of results. Under such a model two-way knowledge exchange is an integral component of each step in the research cycle. As an example MDFRC is currently leading a joint activity with members of the MDFR Consortium to further refine the examples provided in Table 1, by conducting targeted surveys with local, state and commonwealth water managers to identify their critical knowledge needs. This activity builds on similar engagement efforts undertaken as part of the MDB EWKR project through a series of engagement workshops held in 2016. This information is already informing research being undertaken within several large MDFRC led research projects (including MDB EWKR and the MDBA Collaboration Project).

The additional information obtained from the current engagement activities (being undertaken by each of the consortium partners) could provide an ideal basis from which to establish locally based research-management collaborations aimed at improving the outcomes from the delivery of environmental water.

Table 13. Examples of where knowledge can add value across the spectrum of decisions being made at different spatial scales.

	Value proposition		
Where can knowledge add value?	**effectiveness**	**efficiency**	**Risk mitigation**
Local-scale			
Long term environmental plans			
Refining water regimes to meet ecological objectives during drought and dry spells	✓	✓	✓
Dependence of ecological outcomes of complementary works	✓	✓	✓
Local socio-economic benefits	✓		
Complementarity with indigenous and recreation outcomes		✓	
Annual planning (local reach and wetland proposals)			
Improved understanding of fish and bird breeding cues and vegetation thresholds	✓		
optimising timing and duration of watering at sites for multiple outcomes		✓	
Managing invasive species			✓
Understanding return flows	✓	✓	✓
Understanding failures and their cause			✓
Operational decisions (Delivery)			
Optimising use of environmental works	✓	✓	✓
Minimising risks; blackwater, salt peaks			✓
Socio-economic effects	✓		✓

State-scale			
Long-term planning (Water Resource Plans)			
Refining water regimes to meet ecological objectives	✓		
Relative significance of sites under varying climates		✓	✓
Regional socio-economic benefits		✓	✓
Annual planning (Seasonal watering plans)			
Determining relative ecological benefits	✓		✓
Annual operations (multi-site watering)			
Optimising delivery for multiple site benefits and multiple outcomes		✓	
Southern connected basin			
Annual planning (TLM priorities)			
Maximise use of consumptive water (e.g. Hume/Darmouth transfers)		✓	
Optimise with consumptive water delivery		✓	
Relative ecological benefits under varying climate	✓	✓	✓
Weir pool management and sequencing	✓		
Event management d/s; salt, blackwater, algae			✓
Sequenced use of environmental works	✓	✓	✓
Basin-scale			
Long-term (Basin Env. Watering Strategy)			
Management of basin-level refugia	✓		✓
Carp eradication implications	✓		✓
Beyond Basin ecological relationships			✓
Validating/refining hydrologic indicator sites	✓	✓	✓

Annual planning (MDB Annual Basin Priorities & CEWH Annual Water Use Options			
Relative ecological importance Northern Basin flows vs SCB	✓		

Summary

The Basin-Wide Watering Strategy explicitly recognises the need for an adaptive approach to the management of environmental water to account for the various uncertainties in terms of how ecosystems respond to water delivery. There remains considerable scope for new knowledge to further improve the effectiveness and efficiency of environmental watering, and to reduce the risks arising from unindented consequences. Improving environmental watering outcomes represents an adaptive management challenge that lends itself to close and ongoing collaboration between researchers and water managers at all stages of the adaptive management cycle, to improve the ecological outcomes associated with the substantial investment in environmental watering.

11.3 How are previously identified water quality risks in the southern Murray–Darling Basin (including eutrophication, salinity, extremes in pH, thermal pollution and hypoxia) likely to be affected by climate change (including extreme events), and how will these changes impact on ecological community composition and function?

Status: ***Completed***

11.3.1 Executive Summary

A recent study has looked at how predicted changes to the climate during this century will impact on known water quality risks in the southern Murray-Darling Basin. While the emphasis has been on the southern Basin, many of the effects will also occur in the northern Basin.

Climate change is driven by the buildup of a number of greenhouse gases (such as carbon dioxide and methane) in the atmosphere. These gases stop radiated heat from the earth leaving the atmosphere, leading to an overall increase in world temperatures. The increased temperature in turn affect climate patterns at a local, regional and global scales. For the Southern Murray-Darling Basin this will lead to hotter and drier conditions. Overall rainfall will decrease, but the rainfall will be delivered by increasingly more intense storms. The changed weather patterns will result in:

- An overall increase in water temperatures
- Some permanently flowing streams and rivers will have periods where they cease to flow or even completely dry out.
- A decline in ground cover condition leading to increased erosion
- There will be a greater number of more intense bushfires and,
- There will be more frequent and larger dust storms.

Each of these changes will impact on known risks to water quality in the southern Murray-Darling Basin including:

Increased Erosion. Erosion is an important issue in the MDB. It has been estimated that up to 28.7 million tonnes of sediment enters the river network of the MDB annually and this is likely to increase. Turbidity is a measure of how much suspended sediment there is in a waterbody. Highly turbid systems are often characterised by a low diversity of aquatic habitat types through sediment smothering. In addition, the sediment brings with it nutrients and possibly other contaminants. There are massive amounts of mine tailings in the upper catchment as a legacy of gold mining. These tailings have elevated arsenic levels and can be contaminated with mercury – both of which can be lethal to aquatic organisms. Increased fire intensity as well as increased storm intensity will most likely lead to increased erosion in the upper catchments of the southern Murray-Darling Basin.

Blue-green Algal Blooms. It has been suggested that climate change will favour both the incidence and global expansion of blue-green algal blooms because of increases in water temperature and nutrient pollution. Up until the turn of this century, there was at most 3 massive blooms of blue green algae in the Murray River; when Lake Hume was commissioned in the 1930's, during the 'war drought' in the 1940's and during the drought of the early 1980's. There have been 5 massive blooms in the Murray River in the last 13 years with up to 1000 km of the river affected. All the recent blooms started in Lake Hume and were mostly associated with low water levels in the lake. The low water levels were a result declines in inflows into the lake and increasing irrigation demand. Those pressures will only be made worse as the climate dries. In addition, greater erosion, more nutrient-rich sediment will be delivered from the upper catchment.

Periods of Low Dissolved Oxygen. Many aquatic organisms (including fish) rely solely on the dissolved oxygen in the water column to survive. They die if the oxygen level falls below a critical level (about 2mg/L for fish like Murray Cod). It is predicted that periods of low (or no) dissolved will increase into the future; at least in the medium term. Warmer temperatures together with increased frequency of times when rivers stop flowing and form pools means that oxygen consumption by microorganisms in the sediment can more often lead to oxygen depletion in the pools.

Low-oxygen blackwater events are also more likely to occur in the future. Low-oxygen blackwater events occur when carbon is leached from leaf litter that has been inundated. The carbon is used as a food source by bacteria, which in turn consumes oxygen. If the microorganisms can consume the oxygen faster than it can be replaced from the atmosphere it leads a loss of oxygen in the water. In the short term, increases in atmospheric carbon dioxide will promote the production of greater amounts of leaf litter, while extended periods of drought will allow for a greater period of time for litter to accumulate on the floodplain. Periodic storms will generate flooding which will then mobilise the carbon. However, in the longer term, a lack of periodic flooding may see an overall decline in floodplain vegetation. Lower carbon stocks on the floodplain could ultimately result in less carbon mobilisation from the floodplain during flooding events.

Salinisation: The impact of climate change on salinisation is hard to predict. Increased bushfires will increase salinity as salt is washed from the upper catchment following the fires. Ephemeral pools in river and creek channels will become more saline as they dry out, leading to a pulse of salt when they are re-flooded. However, much of the salinity in the southern Murray-Darling Basin is associated with groundwater. Decreased rainfall and increased demand should see levels of groundwater fall across the Basin, but this is far from certain.

Internationally, storm surges coupled with rising sea levels are seen as a threat to water quality in low lying areas through salinisation of freshwater environments. In the southern connected MDB the only area at risk is the Coorong and Lower Lakes. It is uncertain at this point to what extent the current barrages can protect the Lower Lakes from salinisation

12 Project administration

Tasks undertaken within the project management role include:

- general administration:
    - project reporting, internal and external
    - financial reporting and tracking
    - resource allocations
- internal and external project communications and engagement
- coordination of student activities
- tracking of all project research tasks:
    - reviewing and updating the project plan
    - tracking of milestones and deliverables
    - developing, implementing and reviewing research programs
    - coordinating project meetings
    - risk management.

12.1 Budget

Table 14. Budget summary and forecast for project administration.

Staff	Role	2015-16	2016–17	2017–18	2018–19
Daryl Nielsen	General administration (project, communication and student activities Tracking of milestones and deliverables	83,678	76,295	79,118	82,045
Total		83,678	76,295	79,118	82,045

13 Student support

13.1 Introduction

Student support is an important component of the MMCP collaboration project as students are an investment in future research and the management needs of freshwater ecology within Australia. Postgraduate students can carry out high-quality research at a reasonable cost and make an important contribution to the development of aquatic research capability. These positions will be embedded in the MDFRC at either the Albury-Wodonga or Mildura campuses of La Trobe University.

Potential research themes include:

- Plant ecology
- Floodplain fish ecology
- Food web ecology
- Invasive aquatic species.

The collaboration project allows up to 10% of the annual research funds to be used for targeted student research over the duration of the project.

13.2 Cadetships and scholarships

The following student support package has been proposed to the value of $400,000 over a four year period.

Cadetships

The MMCP will aim to support two Summer Industry Cadetships each year to the value of $5 325 each. Cadetships will be offered to second-year undergraduate students enrolled within School of Life Sciences programs/units at La Trobe University. Cadetships are targeted at students who are interested in pursuing a career in aquatic ecology. During a 10 week summer placement with the MDFRC, cadets undertake a small research project on a topic set by MDFRC staff and aligned with the objectives of the MMCP. At the end of their placement, cadets submit a project report and present their research findings at an MDFRC seminar.

Two summer cadetships were offered, but only one was accepted. Adriana Galanakis will be based at the Wodonga laboratory and supervised by Daryl Nielsen and Rebecca Durant.

Project title: *Predicting the ability of aquatic and riparian plants to disperse*
The objective of this project is to determine the ability of seeds from wetland and riparian plants to float and therefore, their ability to disperse by hydrochory. Hydrochory is the dispersal of biota in water. An understanding of how plants disperse is fundamental to how wetlands are managed and the conservation of plants in landscapes that are becoming increasingly fragmented. The objective of this project is to undertake floatation experiments to determine the duration that seeds are able to float. An understanding of which plants produce seeds that either float (or sink) will enable predictions to be made on the ability of plants to disperse throughout riverine and wetland networks.

Honours scholarships

The MMCP will aim to support three Honours scholarships each year to the value of $6 000 each ($4 000 stipend for each student and $2 000 towards project operations). These scholarships will be awarded through a merit selection process. Scholarships will be advertised nationally to attract suitably qualified candidates. Honours students will be supervised/co-supervised by MMCP researchers and will undertake a research project aligned with the objectives of the MMCP. A summary of their research will be embedded within the MMCP annual report.

Honours scholarships were advertised in September 2016. Applications for these close in December 2016. To date, no applications have been received.

PhD 'top-up' scholarships

The MMCP will offer three 'top-up' scholarships for students commencing in 2017 and a further two 'top-up' scholarships commencing in 2018. These 'top-up' scholarships will be to the value to $15 000 ($10 000 'top-up' + $5 000 operating) and will be awarded through a merit selection process. 'Top-up' scholarships will be advertised nationally and internationally to attract suitably qualified candidates. Prospective students would need to be eligible for, and obtain an Australian Postgraduate Award or an International Postgraduate Research Scholarship and enrol with La Trobe University.

The MDFRC will liaise with the Joint Government delegates to develop broad project briefs that fit within the overall aims of the MMCP collaboration project and knowledge interests of the Joint Governments, while delivering programs of suitable scope and scientific relevance that are required for a PhD program.

PhD projects will aim to have a strong interaction with a suitable industry partner, enabling students to have an industry-focused collaborative and learning experience as part of their research program. A range of approaches to achieve these goals are available. Such approaches could include, but not necessarily be limited to, project design in collaboration with a suitable industry partner, placement within agencies for 1–2 week periods and joint supervisions with appropriate staff. Students will not be required to deliver core-project outputs for industry partners. A summary of their research will be embedded within the MMCP quarterly reports.

Top-up scholarships were advertised September 2016. Applications for international students closed on 30 September and for Australian students on 31 October. The MDFRC received inquiries from two Australian students and three international students. Applications have been received from two of the international students.

13.3 Engagement

The MDBA will liaise with the JGR to provide a list of priority research areas within the above research themes. MDFRC will rank the applications based on academic merit and relevance to these research priority areas. The top ten applications will be provided to the MDBA, who will then liaise with the JGR to finalise the ranking of the applications.

Successful applicants will be given the opportunity to be mentored by state and federal water policy and management representatives with the aim of enhancing their understanding of evidence-based decision making. This will enable the recipient to acquire industry-relevant knowledge, develop industry contacts and obtain advice on career paths.

The benefits of industry mentoring for graduate researchers include:

- Acquiring a good understanding of industry operations and developing skills required for working within or collaborating with industry

- Strengthening research skills and capacity to build sustainable linkages with industry, and promote translational research
- Developing skills that enable PhD students to successfully translate research knowledge into management outcomes.

This engagement is voluntary and will occur by utilising the La Trobe University, Graduate Research Office, Industry Mentoring Program.

13.4 Budget

Table 15. Proposed allocation of funds for student support.

Type	2015-16	2016–17	2017–18	2018–19
Cadetships		15,150(1)	10,650	10,650
Honours stipends		18,000	18,000	18,000
PhD top ups		135,000	45,000	45,000
Advertising		6,000	6,000	3,000
Relocation		26,500	19,000	,
Total		200,650	98,650	76,650

[1]One cadetship was taken up in in 2016–17. The funds for the second cadetship from that year have been carried forward.

14 Communication

14.1 Budget

Table 16. Proposed communication activities.**.** Budget summary and forecast for communication.

Type		2015-16	2016–17	2017–18	2018–19
Technical support	Production of factsheets and maintenance of web-pages		7,000	7,000	7,000
Communication activities			13,000	13 000	13,000
Total		0	20 000	20 000	20,000

14.2 Proposed communication activities

Table 16. Proposed communication activities.

Activity	Deliverable	Indicative annual budget	Expenditure
Factsheets Web page	Four factsheets outlining the objects for each theme and expected management outcomes At the end of each financial year, four additional factsheets will be produced that detail the results from each theme and how they relate to the management outcomes A web-based presence for the MMCP will be created on the MDFRC website. This will include an overview of the MMCP as well as the objectives and management outcomes for each theme. This will be updated after the submission and acceptance of annual reports.	$8 000	Production and updating of factsheets and web page
Joint States Forum	Annual workshop in Canberra to that enables the MMCP to present research outcomes to the JSR and receive feedback	$4 000	Transport, catering, accommodation
MDBA seminar series	At a minimum, the MMCP will fund two MDFRC staff to present their research at the MDBA seminar series	$2 000	Transport
Stakeholder workshops	Members of the MMCP team are regularly asked to present data at stakeholder workshops. For example, Darren Baldwin and Daryl Nielsen have been participating in workshops organised by NSW OEH around blackwater benefits.	$3 000	Transport, accommodation
Presentation at Australian Limnological conference	The meeting has participation from researchers and managers and is an important forum for the exchange of new information that is directly relevant to managers.	$3 000	Conference registration, accommodation, transport

Activity	Deliverable	Indicative annual budget	Expenditure
	At a minimum the will be one presenter from the MDFRC.		

Other communication outputs may include (but not limited too):

- Social media (Facebook, Twitter, blogs, YouTube, etc.)
- Media releases
- Community events
- Articles in La Trobe University newsletters
- Publication of findings in articles submitted to peer-reviewed journals

15 Risk management

The MDFRC has a risk management framework in which all identified risks have been incorporated. The framework enables the project to track the status of the identified risk over the duration of the project to ensure project outcomes are delivered. Risk management is an iterative process and individual risks are evaluated throughout the life of the project and any emerging risks that are identified are included in the framework. The figures below show 'screen grabs' of the risk frame work, highlighting risk identification, rating and management.

Dashboard - Summary Status of Risks

Risk Summary

Low	2
Medium	1
Significant	5
High	2
Extreme	0
Total # Risks	10

Action Summary

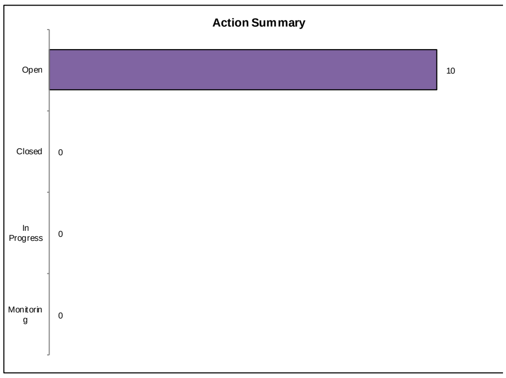
Open	10
Closed	0
In Progress	0
Monitoring	0
Total Actions	10

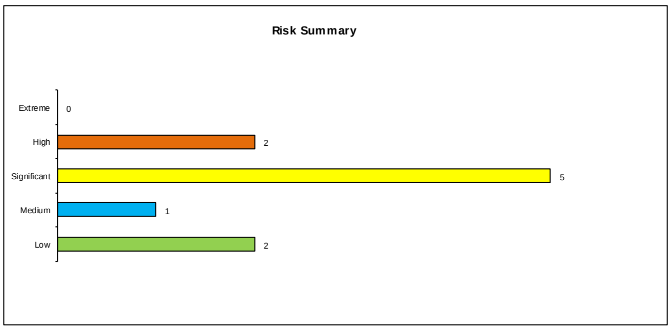
Risk Type Summary

Safety	0
Security	0
Financial	1
Business Performance	8
Stakeholder	0
Reputation	1
Regulatory / legal	0

Risk Category Summary

Internal	7
External	3





MDFRC Risk Register for Major Centre Projects

Project Name:

Project Manager: **Daryl Nielsen**

Project Lead Daryl Nielsen

Version Date **21/10/2016**

Next Register Review Date

Risk Identification					Risk Rating					Risk Management			
Risk Type	**Risk Description**	**Impact of the risk**	**Risk source category**	**Stakeholders impacted by risk**	**Likelihood Rating**	**Likelihood**	**Consequence Rating**	**Consequence**	**Risk Rating**	**Risk Management Actions**	**Responsible Officer**	**Degree of Management Activity**	**Current Status**
Business performance	Loss of key staff	Objectives not able to be complete or delayed	internal	MDBA	C	Possible	2	Minor	M	ensure key staff are retained	Daryl Nielsen	Observe for Change	Open
Business performance	No environmental water allocation	Objectives delayed	external	MDBA	A	Almost certain	2	Minor	S	Nil	Daryl Nielsen	Observe for Change	Open
Business performance	MDBA ACEC application unsuccessful	Delays will occur in traing lock staff	external	MDBA	E	Rare	1	Minimal	L	Monitor status of aplication	Paul Brown	Observe for Change	Open
Business performance	External stakeholders unwilling to collaborate	Delays in analysis & interpretation of data	internal	MDBA	C	Possible	3	Moderate	S	Maintain relationships with state authorities	Paul Brown	Active management	Open
Business performance	External stakeholders unwilling to collaborate	Delays in analysis & interpretation of data. Objects unable to be fully met	internal	MDBA	C	Possible	3	Moderate	S	Maintain relationships with state authorities	Rick Stoffels	Active management	Open
Business performance	Loss of otoliths during transport	Loss of data	external	MDBA	E	Rare	5	Catastrophic	S	Nil	Rick Stoffels	Periodic review	Open
Business performance	Specific AA not identified	Objectives not able to be complete or delayed	internal	MDBA	D	Unlikely	2	Minor	L	Review existing data	Gavin Rees	Periodic review	Open
Business performance	Ambiguity over interpretation of the question	Objectives not able to be complete or delayed	internal	MDBA	C	Possible	3	Moderate	S	Review progress	Daryl Nielsen & Nick Bond	Periodic review	Open
financial	Loss of funding	Project ceases	internal	MDFRC	C	Possible	5	Catastrophic	H	Ensure quality research specific to clint needs	Project team	Active management	Open
reputation	Resarch not aligned with client needs	Project ceases	internal	MDFRC	D	Unlikely	5	Catastrophic	H	Ensure quality research specific to clint needs	Daryl Nielsen & Nick Bond	<select>	Open
<select>			<select>		<select>		<select>		N/A			<select>	<select>