Native Fish Recovery Plan – Gunbower and Lower Loddon

Martin Mallen-Cooper, Ivor Stuart & Clayton Sharpe

August 2014

FISHWAY CONSULTING SERVICES

KINGFISHER RESEARCH

CPS ENVIRONMENTAL RESEARCH

Produced for: North Central Catchment Management Authority

NORTH CENTRAL
Catchment Management Authority
Connecting Rivers, Landscapes, People

Document Review & Authorisation

Document Version	Draft	Date	Authors	For	Copies	Comments
1.0	Draft	20/09/2013	M. Mallen-Cooper I. Stuart C. Sharpe	A. Chatfield	1e	
1.2	Draft	22/04/2014	M. Mallen-Cooper I. Stuart C. Sharpe	A. Chatfield	1e	
1.3	Draft	30/6/2014	Reviewed by J Leevers	B Gregory	1e	
1.4	Updated Draft	9/8/2014	Reviewed by J Leevers	B Gregory	1e	

Note: (e) after number of copies indicates electronic distribution

Acknowledgement of Country

The North Central Catchment Management Authority acknowledges Aboriginal Traditional Owners within the region, their rich culture and spiritual connection to Country. We also recognise and acknowledge the contribution and interest of Aboriginal people and organisations in land and natural resource management.

Citation:
Mallen-Cooper M, Stuart I.G., Sharpe C. 2014. The Native Fish Recovery Plan - Gunbower & Lower Loddon. Report prepared for the North Central Catchment Management Authority. 156p.

All photo credits, unless otherwise indicated, are attributed to the authors.

Cover photographs clockwise from top: Murray cod
Silver perch juvenile
Golden perch juvenile

For further information contact:

MARTIN MALLEN-COOPER
FISHWAY CONSULTING SERVICES
8 TUDOR PLACE ST IVES NSW 2075
TEL: (02) 9449 9638
FAX: (02) 9943 6249

VISION

*Greatly increased native fish populations,
recovered threatened species,
improved natural values,
integrated with vibrant and productive
irrigation and agriculture.*

FOREWORD

The *Native Fish Recovery Plan - Gunbower and Lower Loddon* (from here on referred to as The Plan) provides an opportunity to restore native fish populations and waterway health in the Torrumbarry Irrigation District. The Plan provides a unique opportunity by recognising irrigation systems as a component of aquatic ecosystems and developing approaches to using irrigation infrastructure to assist in building the numbers and resilience of native fish populations.

The Plan focuses on key the waterways within the Torrumbarry Irrigation District – Gunbower Creek, Taylors Creek, Kow Swamp, Box and Pyramid creeks and the lower Loddon River. It also encompasses the wetlands and floodplain of the Gunbower Forest.

The Plan addresses three key factors on the decline of native fish populations and species: loss of connectivity for fish movement and migration, alteration of natural flows regimes and loss of habitat.

The Plan has an implementation horizon of 20 years and when fully delivered will:

- create a connected fish passage between the River Murray and waterways in the project area,
- utilise flows to optimise conditions for native fish whilst maintaining water delivery for irrigation needs,
- improve habitat, migration and breeding conditions for native fish and platypus,
- reduce the incidence of native fish entrainment into irrigation channels,
- reintroduce threatened fish species, and
- reduce the impact of non-native fish species.

The Plan addresses the challenge of balancing ecological outcomes with water use for irrigation needs and recreational uses. A key aspect of the Plan is to utilise water from the River Murray to support fish habitat and migration needs, however this water is not used it is only borrowed. Water taken from the River Murray flows through the project area and is returned to the River Murray via either the Gunbower Creek or lower Loddon River with minimal losses.

In this way the project demonstrates the intent of the Basin Plan – the irrigation industry and the environment working together.

The Plan has a strong emphasis on gaining input and guidance from the local community, Aboriginal groups, irrigators, water managers, government agencies and the scientific community. It is built on sound science and local knowledge.

In supporting the growth of native fish communities and the re-establishment of threatened species the plan will support increased recreational fishing and eco-tourism with associated benefits to the regional economy. It also has the potential to lead to the development of a world class Trophy Fishery for large Murray cod in the Cohuna region.

I encourage you to read, and become involved with, the *Native Fish Recovery Plan – Gunbower and Lower Loddon*, a plan that supports the fundamental human need to be involved with and connected to rivers.

EXECUTIVE SUMMARY

Water is the lifeblood of the Murray-Darling Basin. It has supported Aboriginal communities for over 40,000 years and for over 130 years it has supported an irrigation industry that has provided Australians with food, prosperity and wealth, but at the now-recognised cost of declining river health. Water reforms over the last 20 years, culminating in the Basin Plan, have sought to balance cultural values with industry and the environment.

The Basin Plan aims to provide more environmental water to rivers, wetlands and floodplains; the recovery paradigm associated with this is that bringing flows or flooding frequencies closer to natural will improve river and floodplain health. This is based on sound science but it overlooks one of the most significant opportunities; acknowledging that irrigation systems are an integral part of the aquatic ecosystem of the Basin.

The Draft *Native Fish Recovery Plan - Gunbower and Lower Loddon* (The Plan) directly addresses an irrigation system and answers the question: "What is the best that can be done for native fish while meeting irrigation needs?" The philosophy differs from the more traditional approach of returning the ecosystem to as close to natural conditions as possible. The rationale is that more can be achieved on a regional scale by collectively utilising the potential of the creeks, wetlands, forests and irrigation systems. A key component is embedding fish restoration flows into irrigation flows; that is, using the water twice.

The Plan uses the Gunbower - lower Loddon River area in northern Victoria to develop a strategy that is tailored to the region, with a methodology that is applicable to irrigation areas Basin-wide. The region is a watershed with public and private land that includes Gunbower Forest (a large Ramsar wetland) and most of the Torrumbarry Irrigation District, a large irrigation area that makes over $130 million of produce a year. Irrigation in the Murray-Darling Basin started here in the 1880's and it is now one of the most modern irrigation systems in the Basin. The region is supplied by 280 km of streams that are largely managed for water delivery through a system of weirs and channels. The streams have little or no flow in winter when there is no irrigation demand; the lower Loddon, Pyramid Creek and Gunbower Creek do receive an environmental flow allocation delivered according to a seasonal watering plan.

Native fish populations in this area are in extremely low numbers, with some species locally extinct. The poor numbers are due to three main factors:

- Connectivity
  - Weirs prevent fish entering the system to recolonize from the River Murray
  - Weirs also prevent fish from leaving the system to complete spawning migrations.
  - Fish are lost from creeks and streams into irrigation channels.
- Flow
  - Zero and low winter flow provides very poor habitat.
  - Little end-of-system flow back to the River Murray, so there is no stimulus for fish to enter.
  - Hydrodynamic diversity (fast and slow-flowing reaches) is reduced by lack of flow in winter and weirpools.
  - Loss of small permanent wetlands (habitat for key threatened species).
- Habitat

- Snags have been removed in the past.
- Stream edges and riparian vegetation are degraded by cattle.

All of these impacts can be readily addressed by proven techniques such as fishways, screens on irrigation channels (common overseas and self-cleaning), providing flow, and habitat rehabilitation. Importantly, because this is an anabranch system, the key opportunity is that any additional flow directed through the system for the benefit of fish is returned to the River Murray. The net flow in the River Murray over 200 km would remain largely the same, with less stream channel losses in winter and potentially topping up of small wetlands in summer. Hence, these recovery actions do not depend on large water allocations and can be integrated into the existing water delivery schedule.

Applying the last decade of research on fish biology of the River Murray reveals that the streams and associated habitats that are used to deliver irrigation water in this system have, in fact, immense potential to support thriving populations of native fish and become a functioning part of the River Murray ecosystem.

The flow-on benefits of thriving native fish communities include: increased recreational fishing, including the creation of a “Trophy Fishery” for catch-and-release of large Murray cod; increased biodiversity, including re-established threatened species; and improved opportunities for ecotourism.

The irrigation area would not only be an adjunct to the River Murray ecosystem but it would become a critical component. The streams and wetlands would act as refuges during droughts and during ‘blackwater’ events in the main river that can kill high numbers of fish. The region would then provide source populations of common and threatened species to recolonize the River Murray.

A broad 10-year cost estimate is $30-35 million, of which two-thirds is for infrastructure (5 fishways and 4 irrigation screens). The project is value for money because of the potential to improve fish populations over a wide area (over 280 km of streams) and contribute more broadly to regional populations, while maintaining irrigation and using very little additional water. It also builds on existing programs; of the 11 weirs in the project area, 6 already have fishways and The Living Murray program is rehabilitating the Ramsar wetland.

The Draft *Native Fish Recovery Plan – Gunbower and Lower Loddon* would enable the region to move from one that is focused on agriculture to having a greater emphasis on its emerging multifaceted role, of irrigation, conservation, recreation and broader economic benefits. The Plan is being issued as a Draft to seek comment and support from stakeholders. The objective is to issue a final report that has the support of all key stakeholders. The Plan presents a new approach in viewing irrigation as part of sustainable healthy rivers, providing a unique opportunity to unify the water debate and clarify the common values and goals of stakeholders. The Gunbower - lower Loddon region is an agricultural hub and, as the birthplace of irrigation, it can become the birthplace of riverine recovery with sustainable irrigation.

Abbreviations

ANCOLD	Australian National Committee on Large Dams
AWA	Australian Water Association
CMA	Catchment Management Authority
COAG	Council of Australian Governments
DEPI	Department of Environment and Primary Industries
DPI	Department of Primary Industries
GL	Gigalitre (1,000 megalitres)
G-MW	Goulburn-Murray Water
MDBA	Murray Darling Basin Authority
ML	Megalitre (1 million litres)
NVIRP	Northern Victoria Irrigation Renewal Project
O&M	Observations and Measurements
PIT	Passive Integrated Transponder
s.d.	standard deviation
SEWPAC	Department of Sustainability, Environment, Water, Population and Communities
SRA	Sustainable Rivers Audit
TLM	The Living Murray
VEFMAP	Victorian Environmental Flows Monitoring and Assessment Program
VEWH	Victorian Environmental Water Holder

CONTENTS

LIST OF APPENDICES

1 INTRODUCTION

1.1 Historical Background

Aboriginal people have lived in the Murray-Darling Basin for 40,000 years and as traditional owners their Nations have a deep cultural, social, environmental, spiritual and economic connection to rivers and surrounding lands. European settlement in the Murray-Darling Basin has been relatively recent, starting in the Murray Valley in the mid-1800's. In the late 1880's the Gunbower region of northern Victoria became the birthplace of irrigation in Australia. This enabled a rapid expansion of European settlement along the Murray Valley, with consequent dispossession of land from Aboriginal people. For over 130 years irrigation has provided Australians with food, prosperity and wealth but at the now-recognised cost of declining river health.

1.2 Water Reform

The need for more strategic use of water to balance cultural values with industry and the environment led to the COAG 1994 Water Reform Framework, the 1995 Murray-Darling Cap, the 2004 National Water Initiative, the 2004 Living Murray Initiative and the 2007 federal Water Act which provides for the Basin Plan. The latter is the biggest potential change in water management of the Basin since the River Murray Waters Agreement in 1915; it involves setting Sustainable Diversion Limits for each river system, building new and improved infrastructure, and buying back water licences to increase the volume of water available for the environmental water.

1.3 The Basin Plan and New Opportunities

The Basin Plan aims to provide more environmental water to rivers, wetlands and floodplains; the recovery paradigm associated with this is that bringing flows or flooding frequencies closer to natural will improve river and floodplain health. This is based on sound science but it overlooks one of the most significant opportunities, acknowledging that irrigation systems are an integral part of the aquatic ecosystem of the Basin. Working alongside rehabilitated natural areas, irrigation areas have major potential to improve regional populations of fish and aquatic biota, not only contributing to regional river health but also becoming key spawning areas and climate change refugia.

Irrigations systems are often not considered "natural" systems but where water goes, so too do fish and other aquatic biota; at present these biota are lost from the river system to the irrigation system where they either die or cannot return to the river system. The present approach in managing natural resources is to partition irrigation systems and focus on managing rivers, floodplains and wetlands. This report outlines the logic, science and practical need of a new approach that integrates these two areas so that irrigation areas become functioning parts of the aquatic ecosystem and contribute to the Basin Plan objectives.

1.4 The proposed "*Native Fish Recovery Plan - Gunbower and Lower Loddon*"

The Plan uses the Gunbower - lower Loddon River area in northern Victoria to develop a strategy that is tailored to the region, with a methodology that is applicable to irrigation areas Basin-wide.

The Gunbower - lower Loddon River region is a watershed with public and private land that includes Gunbower Forest (a large Ramsar wetland) and most of the Torrumbarry Irrigation District, a large irrigation area that produces over $130 million of food, fibre and economic wealth per year. Implementing the Plan in Gunbower and lower Loddon region has the advantage of building on existing remediation actions, including initiatives under The Living Murray program and numerous initiatives from the North Central Catchment Management Authority and the bulk water distributor, Goulburn–Murray Water.

The Plan uses scientific findings on aquatic ecology of the last decade that have not yet been integrated or applied to irrigation areas. The science provides a conceptual and practical framework, which is used to develop an action plan of on-ground works that can be applied now. The science reveals that native fish populations will greatly improve with these measures, with very low risk.

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* is intended to provide an investment framework. Annual review of the Plan is proposed with the provision for updates, if required. This approach enables the prioritisation of actions and the flexibility to adapt to new inputs, including knowledge, funds, industry changes, conservation priorities and climate change.

1.5 Philosophy and Principles

Rehabilitation of anabranch creek and floodplain systems is occurring along the length of the River Murray (notably The Living Murray projects) in response to reduced flooding frequency and changed seasonality of flows. The main methods are to restore more natural wetting and drying regimes of floodplains and ephemeral streams through the use of infrastructure and allocation of environmental water.

Restoration of past flow regimes, or components of the regime, on a local scale, is often a common goal of river rehabilitation and is the present recovery paradigm for aquatic systems of the Murray Darling Basin. An additional option or adjunct, which is proposed in this Plan, is to optimise ecological values at a regional scale. In this context it is pooling ecological values and examining the optimum outcome for the whole regulated system rather than relying on incrementally trying to reinstate past flow regimes in localised areas.

The philosophy of the Plan is to enhance the present ecological values and exploit the potential ecological values, using the latest scientific knowledge, whilst working in partnership with a modern irrigation system. This differs from the more traditional approach of returning the ecosystem to as-close-to-natural conditions as possible. The reasoning is that in the Gunbower - lower Loddon region, more can be achieved on a local and regional scale by utilising the potential of the streams, anabranches and wetlands that are part of existing and irrigation systems.

The ecological principles of riverine recovery also apply to irrigation areas in the Plan: flow, habitat, connectivity – so that biota can move between habitats to spawn, disperse, etc. - and managing pest species. In the following Plan, changes to management and improved infrastructure provide most of the recovery benefits with negligible impacts to the maintenance of flow for irrigation. The Gunbower - lower Loddon region, as the birthplace of irrigation, can also become the birthplace of riverine recovery and sustainable irrigation.

1.6 Stakeholder Support

The Draft Plan is being distributed to inform stakeholders, seek their comments and support. Once comments are received and the Plan modified, this section of the Final Plan will describe the extent that stakeholders support the Plan.

1.7 Unifying the Basin

The proposed *Native Fish Recovery Plan – Gunbower and Lower Loddon* is a first for the Murray-Darling Basin and a potential model for irrigation and the Basin Plan. It presents an opportunity to unify communities and demonstrate that irrigation and the environment, using fish as a catalyst for change, can co-exist and prosper equally. The project has the following attributes:

- Highly achievable with outcomes potentially realised over 10 years
- Low risk, with a very high probability of achieving the goals.
- High benefit at low cost at local and regional scales.
- Benefits realised in the short, medium and long-term.
- Low operating costs.
- High likelihood of attracting funding partners.
- High likelihood of stakeholder support.
- Compatible with irrigation developments and present operations.
- Compatible with Basin-wide water management objectives, especially the Basin Plan.
- Compatible with Basin–wide conservation priorities.
- Links and builds on existing programs and infrastructure (River Murray fishways; Living Murray Program at Gunbower Island, Gunbower Creek fishways, Loddon Stressed River Project).
- Consistent with the Victorian Waterway Management Strategy and the North Central Waterway Management Strategy.

Importantly the project has a clear goal: greatly increased native fish populations, recovered threatened species, improved natural values, integrated with vibrant and productive irrigation and agriculture.

2 FISH AND THE COMMUNITY

2.1 Aboriginal Culture

Kow Swamp is one the two most important Aboriginal archaeological sites with human remains in Australia (Thorne 1971), the other being Lake Mungo. Recent studies have dated the Kow Swamp remains at approximately 20,000 years (Stone and Cupper 2003), about the same time as humans were crossing the land bridge from Asia to North America for the first time. Evidence of ongoing Aboriginal occupation is throughout the district, including scar trees, earthen mounds, artefact scatters, shell middens and burial sites (SKM 2009). Many of the archaeological sites have become fragmented and damaged by past land use including stock grazing and timber harvesting. The majority of remaining scarred trees are on box trees which are outside the area of forest presently managed for timber harvesting (SKM 2009).

Local Aboriginal communities have strong ongoing cultural links with Gunbower Forest and the adjacent region. The traditional owner groups of Gunbower Forest are the Yorta Yorta Nations Aboriginal Corporation, and the Wamba Wamba, Barapa Barapa and Wadi Wadi Native Title Claimants.

Historically, the river and forest provided a concentration of food resources year-round including fish, waterbirds, eels, crustaceans, possums, kangaroos, emus and various reptiles. These resources provided reliable sources of protein, an essential connection of Aboriginal peoples with the rivers, forests and wetlands of the region (SKM 2009).

2.2 Catchment Management, Fish and the Community

Catchment management incorporates all aspects of use of a catchment, integrating natural, cultural and social values for the mutual benefit of present and future generations. The formation of the Catchment Management Authorities (CMA) and Natural Resource Management Groups in Victoria, NSW and Queensland acknowledges that - as a watershed - catchments form natural geographical management units. All land uses of catchments are eventually reflected in the condition of waterways; hence, river health reflects catchment health, which has been the basis for numerous monitoring programs.

The Gunbower - lower Loddon region is within the North Central region of Victoria and the Regional Catchment Strategy (North Central CMA 2013) reflects these views of catchment management. There are thirteen themes and sub themes in the Regional Catchment Strategy (Fig. 1), ranging from biodiversity to land to Aboriginal heritage. Fish are part of Biodiversity and Waterways but link to all components of the Strategy (Fig. 1).

For catchment management and communities, fish are particularly important for a number of specific reasons:

- For Aboriginal people in the North Central region, fish are an important cultural value, especially for those groups that have lived and still live in the Murray Valley.
- Recreational fishing contributes to the well-being and mental health of the broader community (McManus *et al.* 2011).

- Knowledge that there are abundant and rare native fish species in the catchment contributes to pride and ownership of the catchment within the community.

- Fish are powerful indicators of catchment and river health, because they are a high trophic level in the aquatic ecosystem. Hence, all other aspects of the aquatic ecosystem need to be functioning to provide for healthy and abundant native fish populations. Land management directly affects waterways (especially through vegetation management, erosion and siltation) and water quality. Hence, fish overlap with management of public land, dryland, irrigated land, water resources, streams and wetlands (Fig. 1).

- Fish are likely to be sensitive indicators for climate change, partly because spawning and migration are cued to temperature and also because of possible changes toward a drier climate which would result in less flow in rivers and creeks.

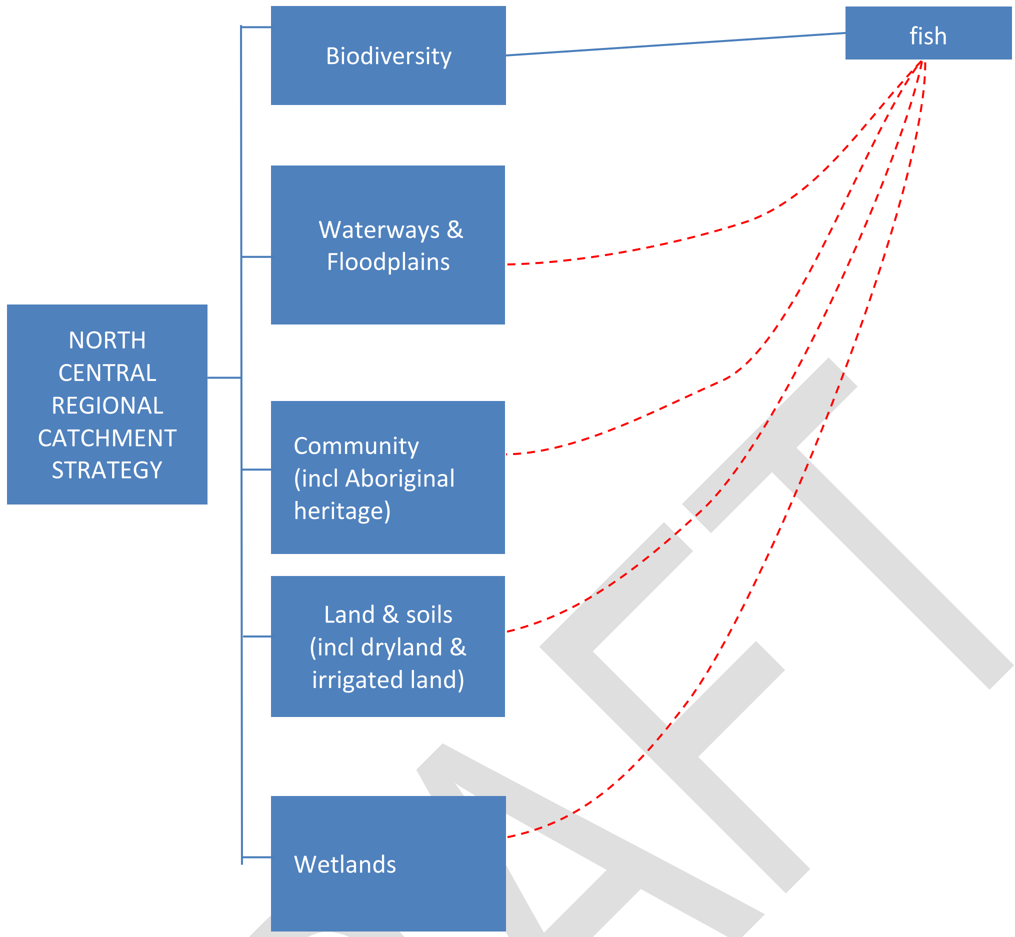


Fig. 1. The relationship of fish in the North Central Regional Catchment Strategy. The dashed red lines from 'fish' show the interrelationships with other aspects of the catchment strategy.

3 BIOPHYSICAL BACKGROUND

3.1 Project Area

The Project Area incorporates the River Murray floodplain and anabranch flow paths from Gunbower Creek to the lower Loddon River (Fig. 2), which:

- Enter from the inlets of:
  - National Channel–Gunbower Creek intake,
  - proposed upper forest channel in the Torrumbarry weirpool, and
  - other minor forest inlets from the River Murray along Gunbower Forest.
- Pass through:
  - Gunbower Creek, an 144 km-long anabranch;
  - Irrigation channels that are connected to Gunbower Creek, Taylors Creek and Kow Swamp (Nos 1, 2, 3 and 4 [including 4/1, 6/1, Leitchville Channel, 5])
  - Gunbower Forest, a large 19,450 ha Ramsar–listed forest floodplain that lies between the Gunbower Creek anabranch and the main channel of the River Murray; it includes numerous wetlands (off-channel habitats);
  - Kow Swamp, Box Creek and Pyramid Creek, lower Loddon River.
- Leave the system and re-enter the River Murray at:
  - Gunbower Creek and,
  - lower Loddon River.

These habitats and lands form a natural geographic and management unit for the purposes of the *Native Fish Recovery Plan – Gunbower and Lower Loddon*. Flow also passes into the Kerang Lakes and the Little Murray River from the flow paths above but we have excluded them from the Project Area, as they are sufficiently different to require separate plans.

Gunbower Forest is a key ecological asset of the River Murray. It is part of the Gunbower-Koondrook-Perricoota Forest, one of six Living Murray Icon Sites and listed as a Wetland of International importance under the Ramsar Convention. The Gunbower Forest comprises Gunbower National Park (8892 ha) and Gunbower State Forest. Kow Swamp is a 2,721 ha lake which receives water from River Murray via Gunbower Creek and Taylors Creek, and is used as a storage to re-regulate flow for irrigation.

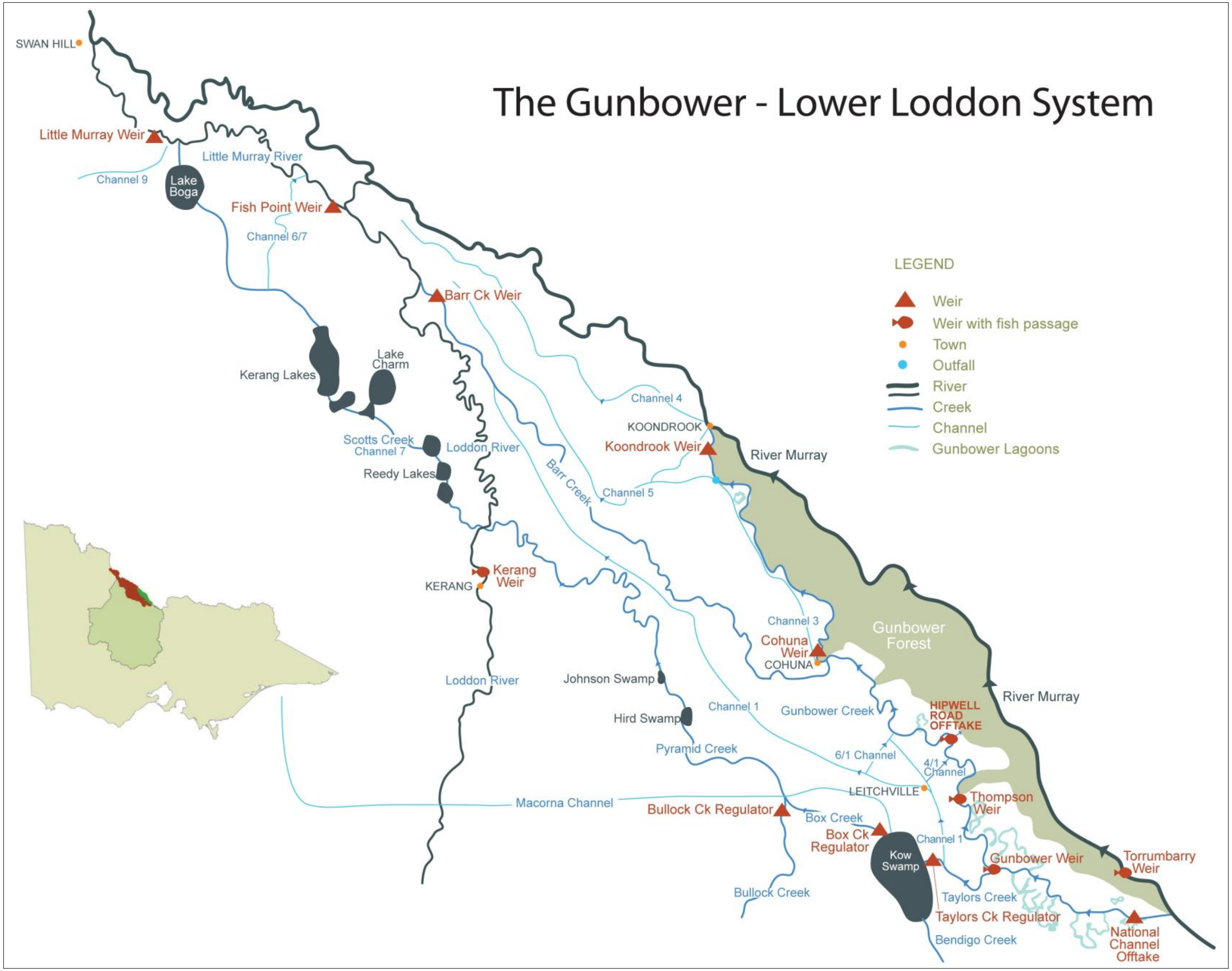


Fig. 2. Map of area proposed for *Native Fish Recovery Plan – Gunbower and Lower Loddon* showing waterways, waterbodies and major infrastructure.

3.2 Geomorphology of Aquatic Habitats

The geomorphology of the Project Area can be broadly grouped into streams, lakes, wetlands and floodplains. There are three main streams habitats: Gunbower Creek, Box Creek and Pyramid Creek (hereafter Box-Pyramid Creek) and the lower Loddon River (Fig. 2). Prior to irrigation Gunbower Creek and Box-Pyramid Creek were ephemeral streams that flowed for many months each year but stopped in the dry season of late summer and autumn. Gunbower Creek is 144 km long running roughly parallel with the River Murray, varying from 2 km to 8 km apart, with the forest floodplain located between these two streams (Fig. 3). Gunbower Creek varies in width from 30-60 m at bankfull to 10-30 m at low flows. Depth varies from up to 5 m at high flows to approximately 1.5-3 m at low flows. The creek generally has a U-shaped low-flow channel with some high shallow benches (Fig. 4), and has a relatively uniform gradient, dropping 6 m over 100 km. The channel has a capacity of approximately 1650 ML/d downstream of Gunbower Weir and is less than 900 ML/d downstream of Cohuna (Ross Stanton, G-MW, pers. comm.). The present capacity of the creek downstream of the National Channel is considered similar to pre-irrigation, as the channel profile has not changed substantially though it has been dredged in the past.

Box-Pyramid Creek system connects Kow Swamp to the Loddon River at Kerang Weir. It has a similar gradient to Gunbower Creek but is narrower at 7-15 m wide, when bankfull. It is approximately 69 km long and halfway along its length it passes through two wetlands, Johnson Swamp and Hird Swamp. The channel has higher banks than Gunbower Creek and has a higher capacity of 2500 ML/d. Pyramid Creek has very little instream woody habitat [“snags”] instream (Kitchingman *et al.* 2012), which are a key component of fish habitat.

The lower Loddon River is 10-20 m wide from Kerang Weir to Barr Creek, a distance of 50 km, widening to 40 m wide between Barr Creek and the River Murray, a distance of 29 km. It has a much lower gradient than Box-Pyramid Creek and Gunbower Creek, but has a high flood capacity. It is mainly a single channel but there is short braided section 10 km downstream of Kerang Weir and water can flow into wetlands near this area as well as into Dartagook Nature Reserve. Sheepwash Creek forms an ephemeral anabranch from the Kerang weirpool that includes creek, wetland and flooded forest habitat.

Today much of the lower Loddon River is shallow (0.5 m deep) at low flows with only a few deep holes. The major cause is thought to be sedimentation and siltation from dredging of Pyramid Creek in the 1960s and reduced flow (Sharpe *et al.* 2010).

Kow Swamp is the only permanent waterbody in the Project Area, although the Kerang lakes are adjacent to the lower Loddon and receive flow from this catchment. It is a shallow lake, with a maximum depth of approximately 5 m and gradually receding shallow edges.

Gunbower Forest is the main forest floodplain and wetland complex. Benwell and Guttrum forests are alongside the River Murray, downstream of Koondrook but are not part of the Gunbower catchment or flow paths and are not included in this Plan. Gunbower Forest can be divided into the Upper and Lower Landscapes (Fig. 3). The Upper Landscape is at a higher elevation, which is flooded less frequently, and is dominated by grey box (*Eucalyptus macrocarpa*) and black box (*Eucalyptus largiflorens*) woodlands. The Lower Landscape forms large red gum (*Eucalyptus camaldulensis*) forests, which are frequently flooded directly from the River Murray.

The aquatic habitats of the Upper Landscape are the channel habitat of Gunbower Creek and the numerous lagoons (also called billabongs or ox-bow lakes) connected to the channel of the creek, including Turner, Phyland, Longmore, Upper Gunbower, Gum, Cockatoo, and Taylor lagoons. These habitats are either natural lagoons, which are old disconnected river channels, or they have been created by construction of the National Channel for irrigation development. Most of these lagoons have regulators for controlling flow and most provide terminal supplies for irrigation or stock.

The Upper Landscape of Gunbower Forest also contains wetland habitat within the forest itself, for example Black Charlie Lagoon and Pig Swamp, as well as a diverse mosaic of smaller unnamed wetlands. These wetlands provide different aquatic habitats from the lagoons along Gunbower Creek because they are forest wetlands and not old river channels. They also differ from the wetland complexes in the lower landscape because they are smaller and more diverse in size, shape and aquatic plant assemblages.

The Lower Landscape also has the channel habitat of Gunbower Creek and contains lagoons (billabongs) directly associated with the creek, including Horseshoe, Reedy and Black Swamp lagoons (Fig. 3). Within the red gum forest are large complexes of permanent and semi-permanent wetlands (Fig. 3) and in large floods the whole forest is inundated transforming it into a large semi-permanent wetland. The permanent forest wetlands, characterised by Little Gunbower and Little Reedy wetland complexes, are created by the forest floodplain draining to low points at the downstream end. Compared with the lagoons, the forest wetlands are geomorphologically distinct and more complex, providing a range of different habitats, which are also larger than those in the Upper Landscape.

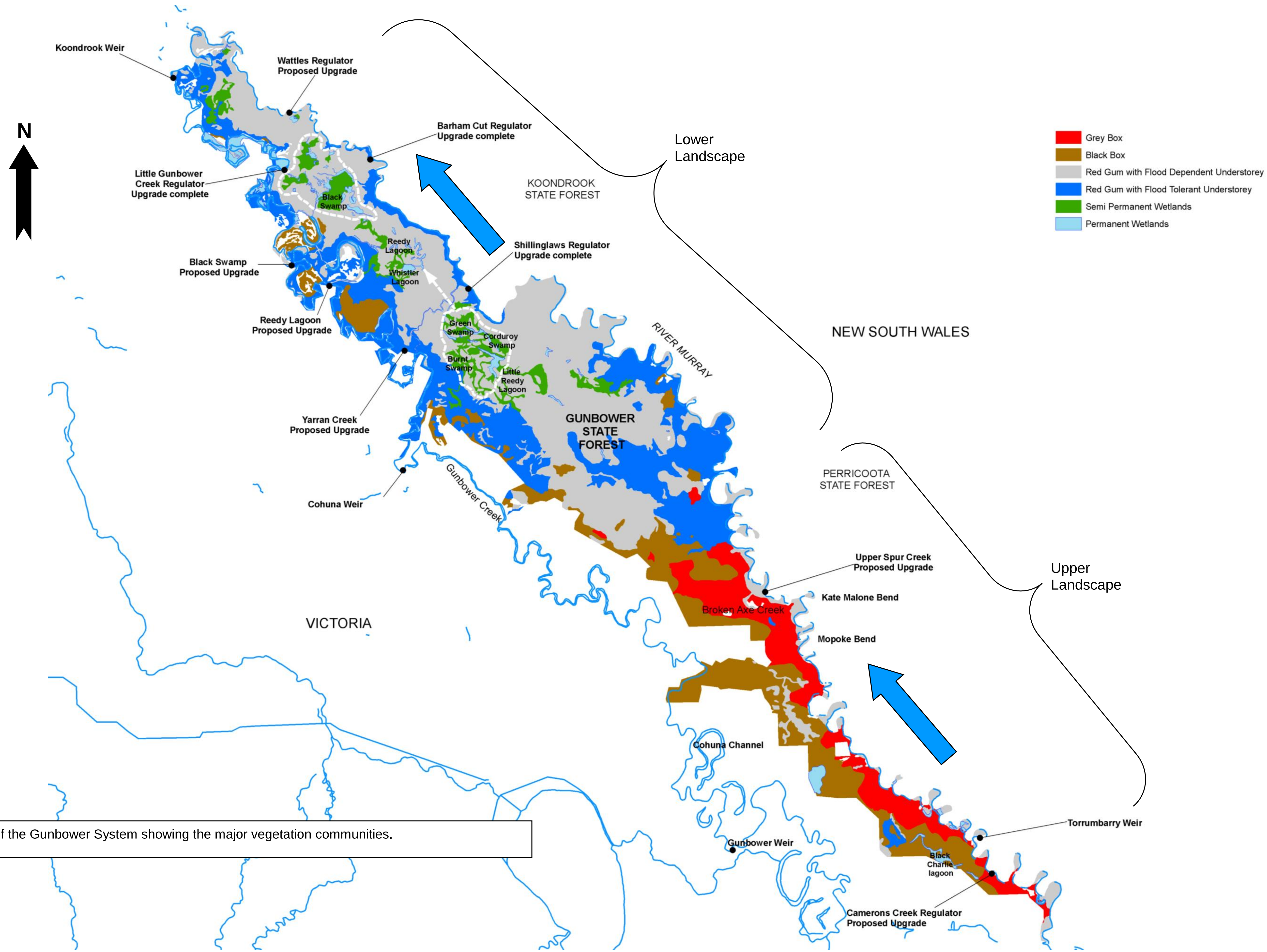


Fig. 3. Map of the Gunbower System showing the major vegetation communities.

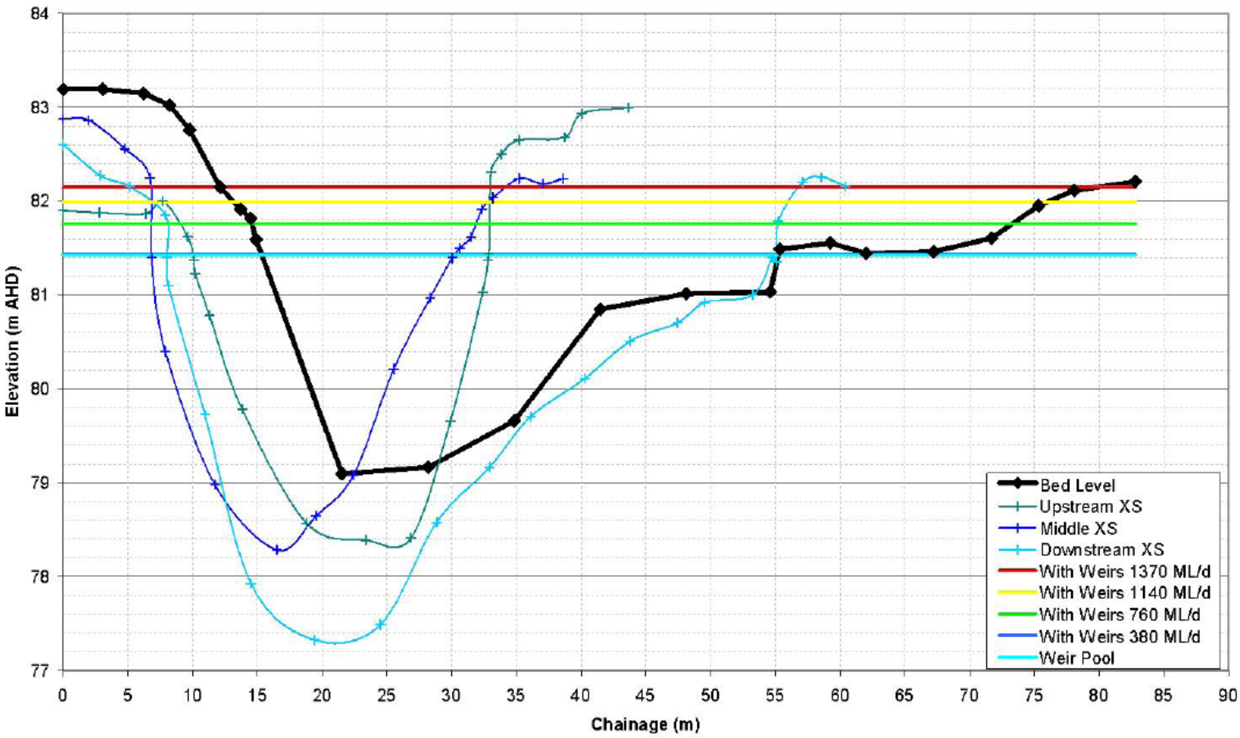


Fig. 4. Example of four cross-sections of Gunbower Creek (at Holmes Bridge) and varying flow levels, showing the U-shaped low-flow channel and high flow benches (Anderson *et al.* 2007a).

3.3 Irrigation Infrastructure

Irrigation started in the Gunbower district in the mid-1880's with water pumped directly from the River Murray and Gunbower Creek. Pumps stations were established on the River Murray for Cohuna (Fig. 5) and Murrabit. Cohuna also had a gravity-fed inlet at Deep Creek which operated at moderate river flows. The main gravity-fed channel for irrigation was Gunbower Creek which passed water to the Macorna Channel and Kow Swamp (Davis *et al.* 1902).

Fig. 5. Cohuna headworks pumphouse in 1914, on the banks of the River Murray close to the Deep Creek inlet. The river is behind the building and the irrigation channel is in the foreground. Photo used with permission: State Library of New South Wales, At Work and Play – 06314.

Originally Gunbower Creek only flowed when there were moderate flows in the river but in 1882 the inlets of Gunbower Creek and Taylors Creek were deepened, the latter to enable more water to enter Kow Swamp[1]. In 1890 the National Channel (10’ by 45’, 4 miles long (3m by 13.7m, 6.4 km long)) and Inlet Regulator (later upgraded) were built[2, 3] (Fig. 6). This straightened and enlarged the upper channel of Gunbower Creek. The channel enabled Gunbower Creek to flow when there was only “4 feet” [3] (1.2 m) of water in the River Murray, rather than 13 feet (4 m) with the natural Gunbower Creek inlet[4]. The channel averaged “in depth about 10 ft., and 45 ft. in width in the bottom of the channel” [3] enabling gravity-fed water, instead of pumped water, to be used for irrigation and to be diverted and stored in Kow Swamp, much as it is today. The National Channel has a capacity of approximately 4,000 ML/day.

Torrumbarry Weir was built in 1924 to provide a weirpool in the River Murray for the inlet of the National Channel, which provided a permanent source of water for Gunbower Creek, which allowed for the establishment of the irrigation industry.

Today the Torrumbarry Irrigation Area diverts approximately 500,000 ML of water to 120,000 ha of irrigated land annually. Farming activities utilising irrigation include dairy farms, fat lambs, beef cattle, stone fruit, grapes and vegetables. The annual gross value of the local agricultural products is approximately $130 million.

---

1 The Argus (Melbourne, Vic.: 1848-1954), Thursday 5 October 1882, page 9.
2 The Argus (Melbourne, Vic.: 1848-1954), Tuesday 21 April 1891, page 10.
3 The Argus (Melbourne, Vic.: 1848-1954), Tuesday 9 September 1890, page 7.
4 The Argus (Melbourne, Vic.: 1848-1954), 1 April 1887, Page 9.

The National Channel and Gunbower Creek are presently regulated as a water supply channel for the Torrumbarry Irrigation Area by Goulburn-Murray Water, with five weirs controlling flow; these are, from upstream to downstream: the National Channel Inlet Regulator, controlling all inflows; and Gunbower, Thompsons, Cohuna and Koondrook weirs providing headwater level for gravity-fed irrigation channels (Fig. 2, Fig. 7).

Fig. 6. Original National Channel Inlet Regulator ("Kow Swamp Headworks") built in 1890.
Original photo by State Rivers and Water Supply Commission photographer. Sourced online from State Library of Victoria collection. Out of copyright.

Gunbower Weir provides headwater for the offtake of Taylors Creek which flows to Kow Swamp (Fig. 2, Fig. 7), which is used as an off-stream storage. Taylors Creek has two regulators to provide headwater for diversion to Channel No. 1 and Macorna Channel (Channel No.2), which flows around Kow Swamp. A further intake for the Macorna Chanel is adjacent to the Kow Swamp outlet at Box Creek Weir.

The storage level of Kow Swamp is regulated by Box Creek Weir. From Kow Swamp, water is diverted to either the Macorna Channel (Channel No. 2) which flows westward to the Loddon River, or into Box Creek which passes into Pyramid Creek; water then flows into the Kerang weirpool in the Loddon River and either continues onto the Kerang Lakes or passes into the lower Loddon River.

There are three existing fishways on structures within the system. In 2008 Gunbower Weir was replaced as the old structure had become unstable. As part of this upgrade, fish passage was constructed. Thompsons Weir has a recent rock-ramp fishway which needs modification to meet fish passage requirements. Kerang Weir has a vertical-slot fishway which needs minor modification to adjust turbulence in the pools and operate at low flows. Box Creek Weir is in the process of being replaced (tenders for construction were being considered as of June 2014) and will include a fish lock.

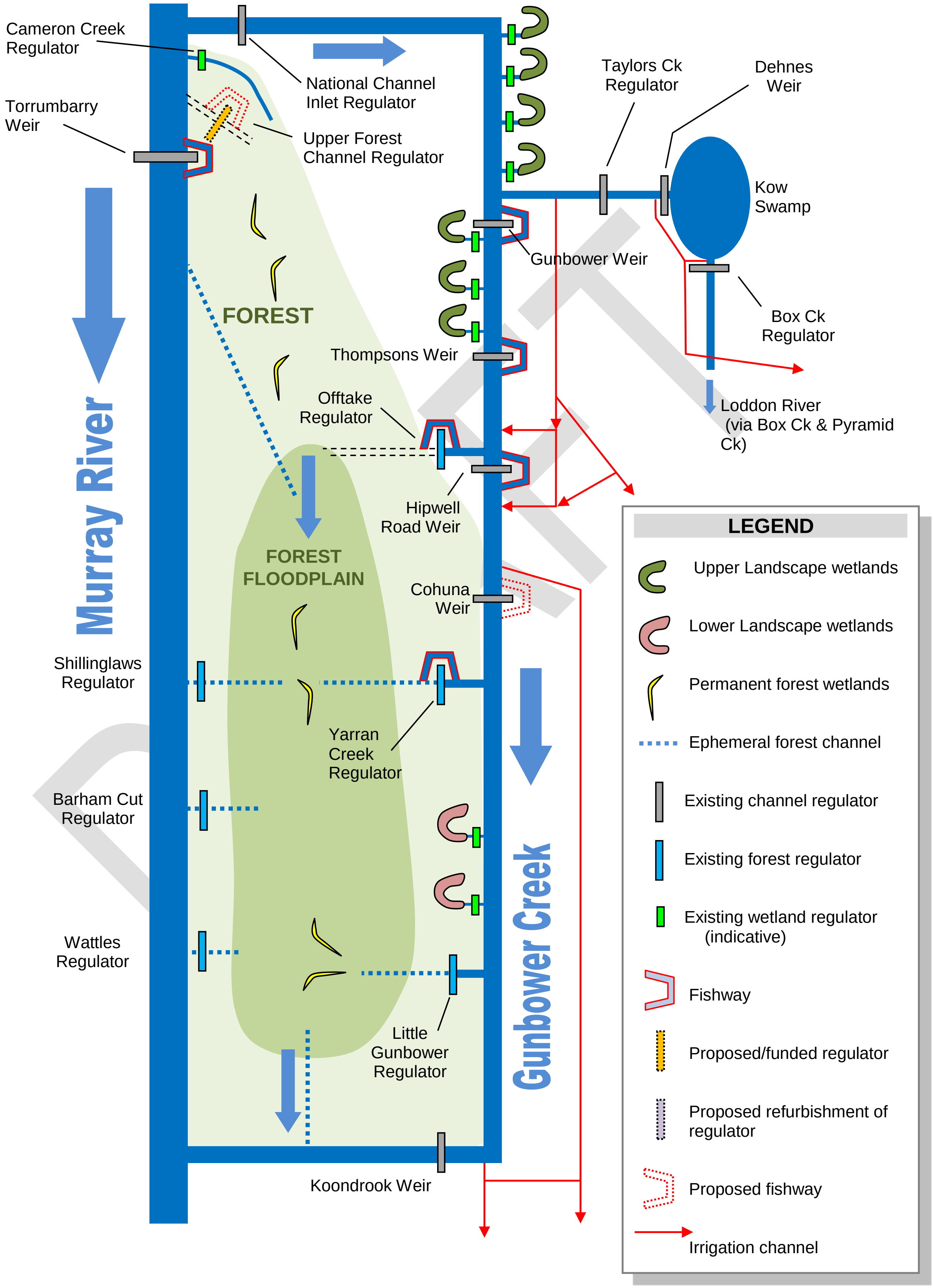


Fig. 7. Schematic of Gunbower Forest showing existing and proposed infrastructure and fish habitats.

Downstream of Gunbower Weir the creek has a capacity of 1650 ML/d. In the irrigation season, Gunbower Creek is maintained at channel capacity for long periods whilst regulators on the edges of Gunbower Creek prevent water flowing laterally into Gunbower Forest. Below Cohuna Weir the capacity of Gunbower Creek is about 900 ML/d. The most downstream weir on Gunbower Creek is Koondrook Weir. Gunbower Creek is presently operated as a terminal system and only excess water is passed over Koondrook Weir to the River Murray via the lower reach of Gunbower Creek.

The lagoons in the upper reaches of Gunbower Creek are regulated and used for irrigation, stock and domestic supply. In some cases the inlet sills of the lagoons have been modified to maintain an effective connection with the creek.

Torrumbarry Irrigation Area has been the focus of modernisation of much of the irrigation infrastructure through the Northern Victoria Irrigation Renewal Project (NVIRP) and the Goulburn-Murray Water Connections Project. Stage 1 of NVIRP was funded by the Commonwealth through a $1 billion Federal and Victorian agreement and Stage 2 is funded through a $1.216 billion agreement. Through NVIRP and the Food Bowl Modernisation Project the region is arguably one of the most modern and efficient irrigation regions in the country.

3.4 Forests and Wetlands Infrastructure

Gunbower Forest (19,450 ha) and Benjeroop-Dartagook Nature Conservation Reserve (1179 ha) are the main forest floodplains in the Project Area. The lower and middle landscapes of Gunbower Forest are State Forest and used for commercial timber harvesting and firewood collection. The upper landscape of was recently declared a National Park (8892 ha). The Benjeroop-Dartagook Nature Conservation Forest Reserve is presently managed for conservation. Benjeroop-Dartagook Nature Conservation Reserve does not have any infrastructure to control water but Gunbower Forest and associated wetlands have numerous regulators, many of which have been upgraded, built, or are under construction as part of The Living Murray (TLM) program to provide more control of flow for conservation objectives.

There are three major regulators that control flow into the forest from the River Murray: Shillinglaws (upgraded), Barham Cut (upgraded) and Wattles (poor condition) (Fig. 7). In the past these were used to control flooding and watering of the forest for logging but are now used to meet conservation objectives. Cameron Creek Regulator (poor condition) is at the upstream end of the forest and receives water from the Torrumbarry weirpool, providing eight irrigators with water and supplying Black Charlie Lagoon. The Upper Channel Forest Regulator is proposed (funding by Commonwealth Department of Sustainability, Environment, Water, Population and Communities [SEWPAC]) at the upstream end of the forest; it would receive up to 800 ML/d from the Torrumbarry weirpool to water the upper forest.

On the Gunbower Creek side of the forest are Yarran Creek Regulator and Fishway (upgraded, TLM) and Little Gunbower Regulator (TLM) which provide water to the lower forest. The Hipwell Road Weir and Regulator, both with fishways, are part of a major Living Murray initiative. They are designed to provide up to 1650 ML/d to water the forest and construction was completed in mid 2014. .

On the smaller wetlands of Gunbower Creek in the lower reaches, downstream of Cohuna, there are regulators on Black Swamp Creek Regulator (upgraded), Black Swamp Creek Regulator No. 2 (upgraded), and Reedy Lagoon Regulator (upgraded). These wetlands are all managed for conservation values.

As mentioned in the previous section, the lagoons/wetlands in the upper reaches of Gunbower Creek, upstream of Thompsons Weir, are presently managed for irrigation and stock supply. The presence of the threatened freshwater catfish, however, is changing the management to meet both conservation and irrigation objectives, particularly under the G-MW Connections Program. The upper wetlands include Splatt, Turner, Phyland, Longmore, Upper Gunbower, Gum, and Cockatoo; each has regulators that control flow from the creek.

3.5 Past and Present Hydrology

3.5.1 Gunbower Creek

Past Hydrology

Prior to irrigation development Gunbower Creek was not permanently connected to the River Murray. In this state the creek was reported to start flowing when there was 13 feet of water (approx. 4 m or 13,700 ML/d) in the River Murray[1]. Modelling of daily natural river levels (MDBA BIGmod, unpublished data) for 100 years (1900-2000) shows that Gunbower Creek would likely have flowed for months every year in winter and spring and did not flow in only three years in 100 (Appendix 1); examples of a 'dry' decade and 'wet' decade are shown in Fig. 8 and Fig. 9. The 13 feet figure may have been underestimated but the graphs show that this estimate is not sensitive. In the months between flows and in the odd years without flow Gunbower Creek would very likely have retained deep pools as it is deeply incised in some reaches (Anderson *et al.* 2007b).

When Gunbower Creek had high flows it would have provided overflow to Taylors Creek, which was not formally connected prior to irrigation, and this would have flowed to Kow Swamp which also has its own catchment of Mt Hope Creek, Bendigo Creek and surrounding lands. Gunbower Creek was an anabranch system, so any water that did not flow into wetlands and natural distributaries would have flowed back to the River Murray.

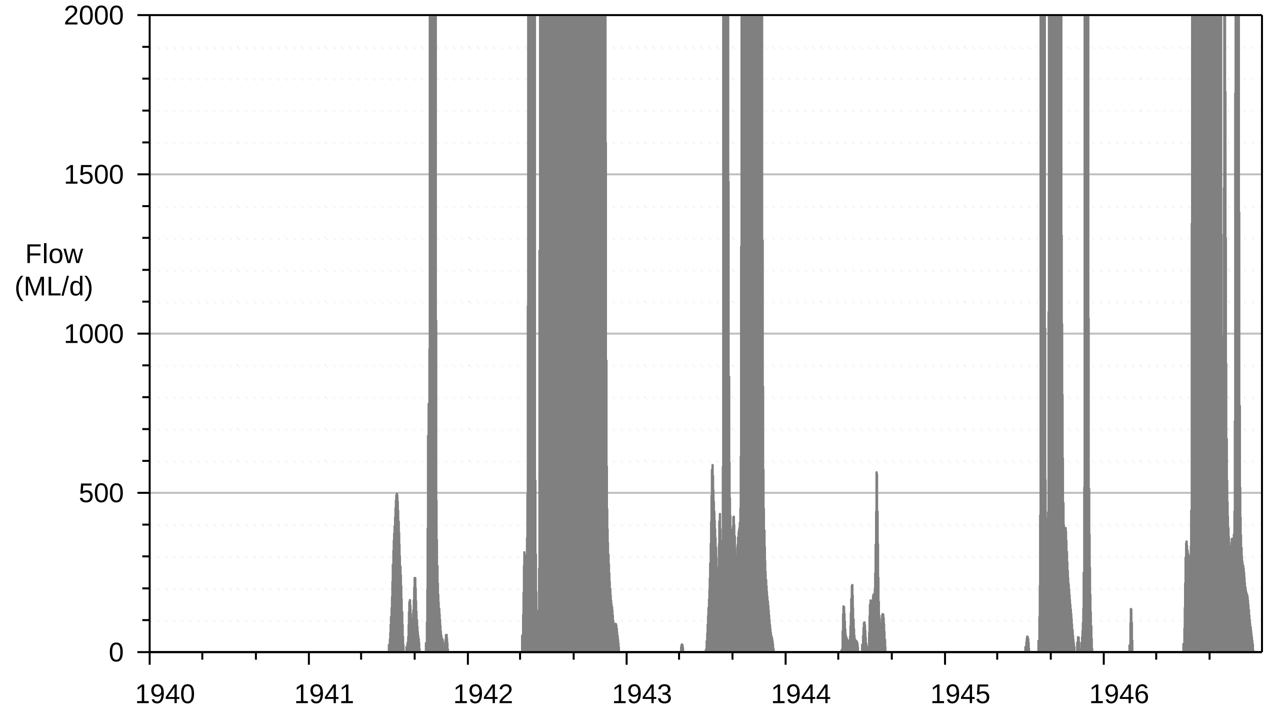
The seasonality and magnitude of flows in Gunbower Creek would have mirrored the River Murray, with flows increasing in early winter, peaking from late-winter to early spring and decreasing in early summer (Fig. 8, Fig. 10, Appendix 1). Modelled data suggests there was no flow in the creek from mid-summer to the end of autumn.

Present Hydrology

With the construction of the National Channel and Torrumbarry Weir the flow in Gunbower Creek became completely regulated, even with large floods as the National Channel Inlet Regulator is designed to hold back high water levels rather than be overtopped. Under present regulated conditions there is still high flow in late winter and spring but this flow continues through summer and early autumn and the low to zero flows now occur in early to mid-winter (Fig. 10). In Kow Swamp most of the flow is also completely regulated from Gunbower Creek but the catchment can flood on rare occasions, although it generally has very low rainfall.

[1] The Argus (Melbourne, Vic.: 1848-1954), 1 April 1887, Page 9.

a) Flows into Gunbower forest.



b) Modelled natural flows in the River Murray.

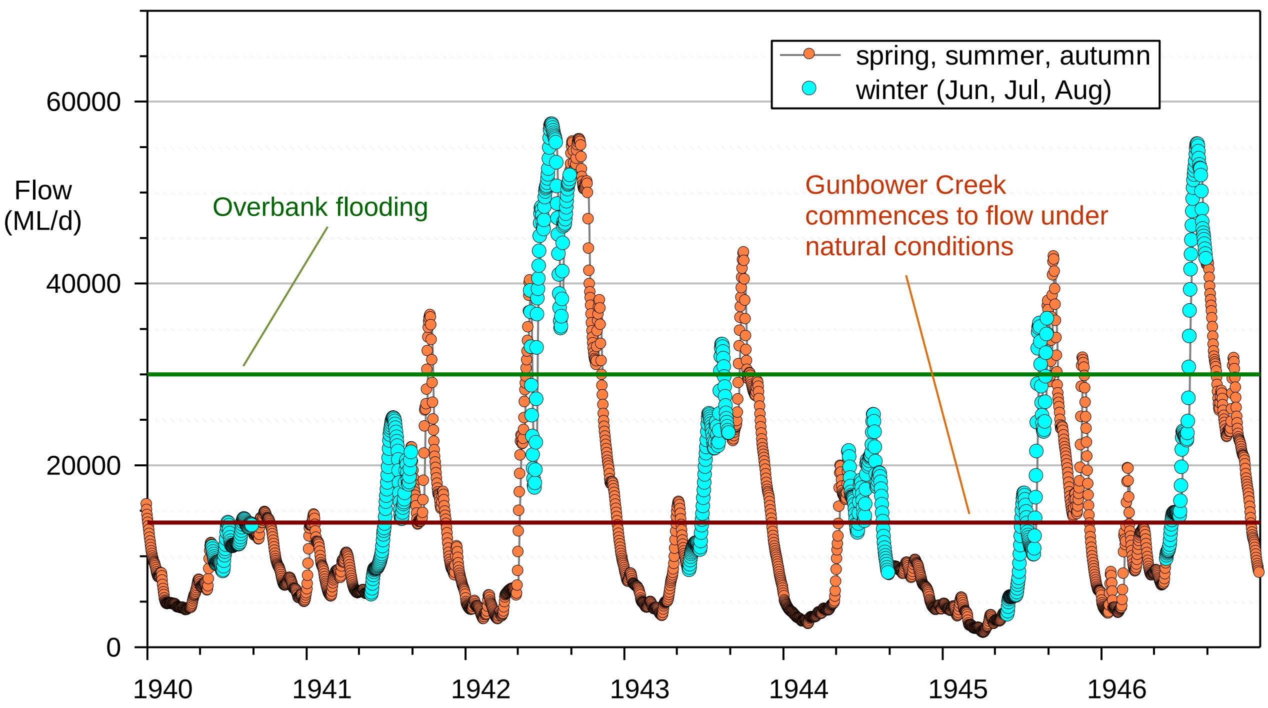
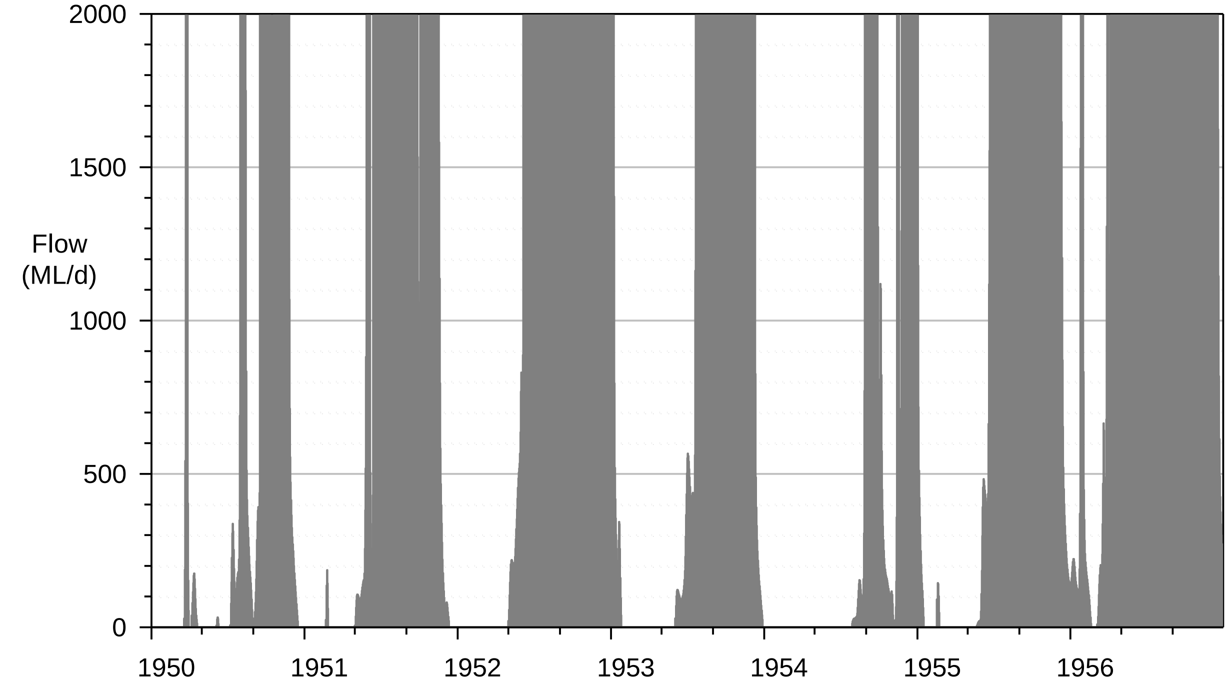


Fig. 8. Example of flows in 'dry' years: a) into Gunbower Forest and b) modelled natural flows in the River Murray at Torrumbarry. The lower graph show the flows for overbank flooding and estimated commence-to-flow for Gunbower Creek, prior to irrigation development, and the seasonality of flows.

a) Flows into Gunbower forest.



b) Modelled natural flows in the River Murray.

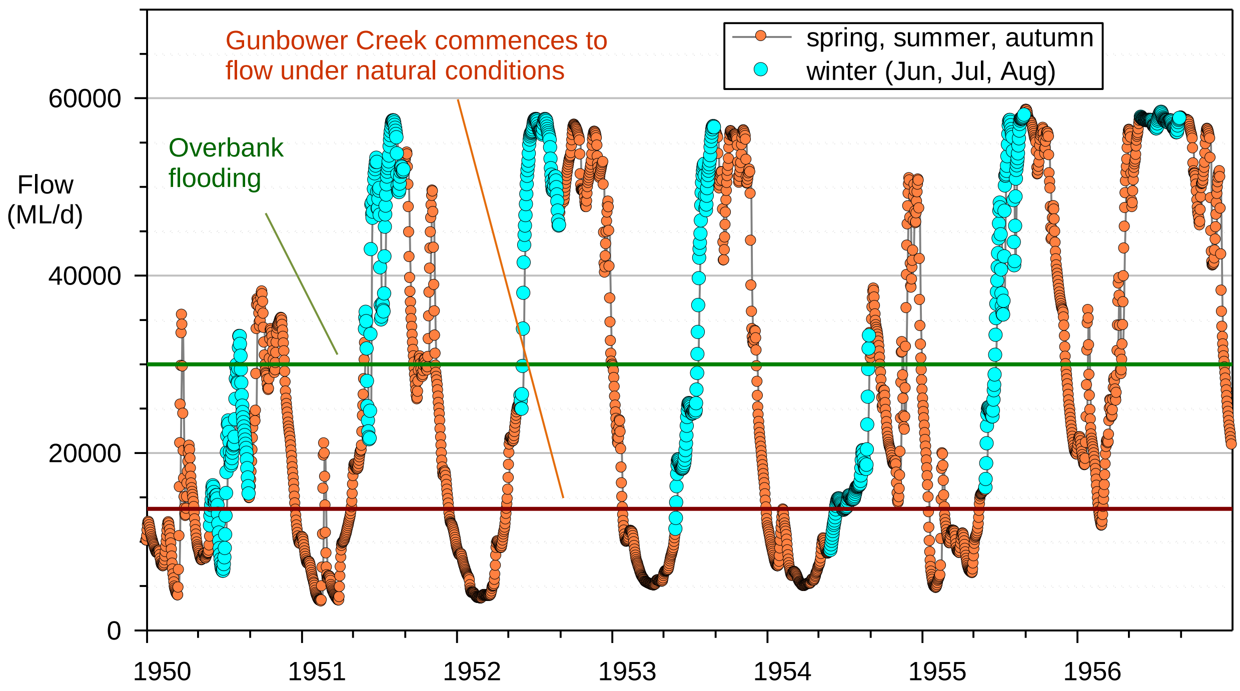
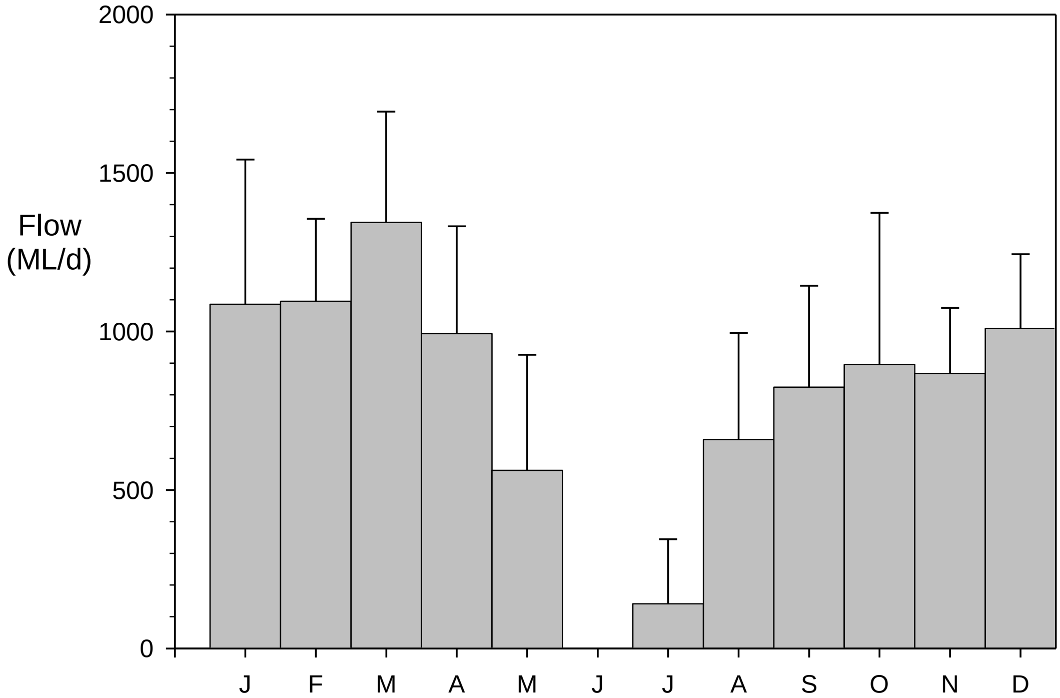


Fig. 9. Example of flows in 'wet' years: a) into Gunbower Forest and b) modelled natural flows in the River Murray at Torrumbarry. The lower graph show the flows for overbank flooding and estimated commence-to-flow for Gunbower Creek, prior to irrigation development, and the seasonality of flows.

a) Flows in Gunbower Creek at Gunbower Weir (1987-2006).



b) Modelled natural flows in the River Murray (1987-2006).

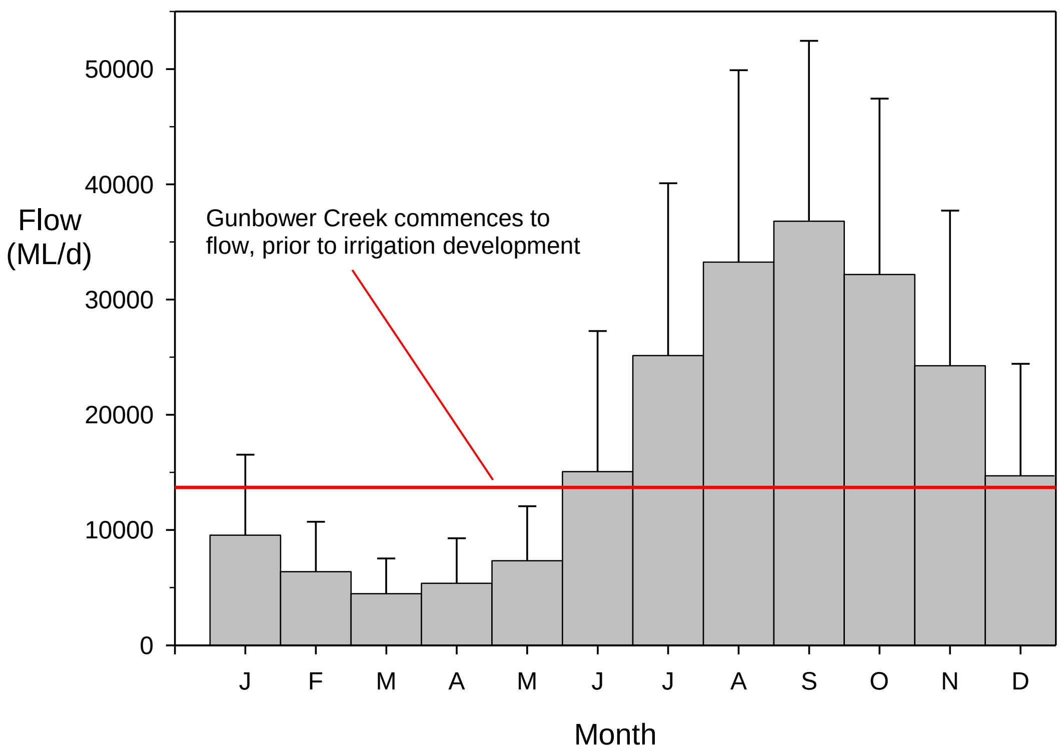
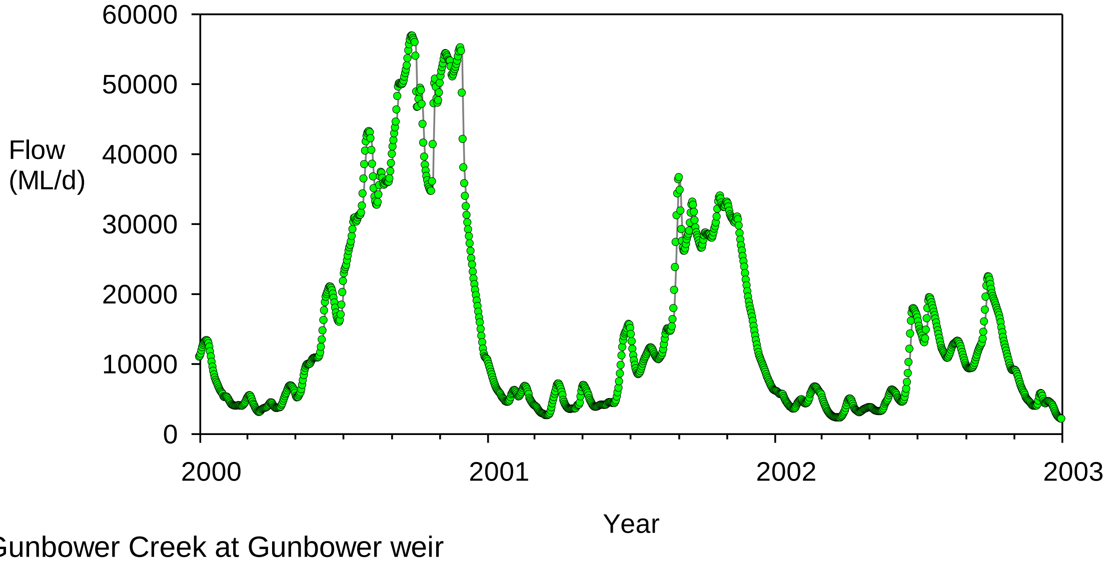


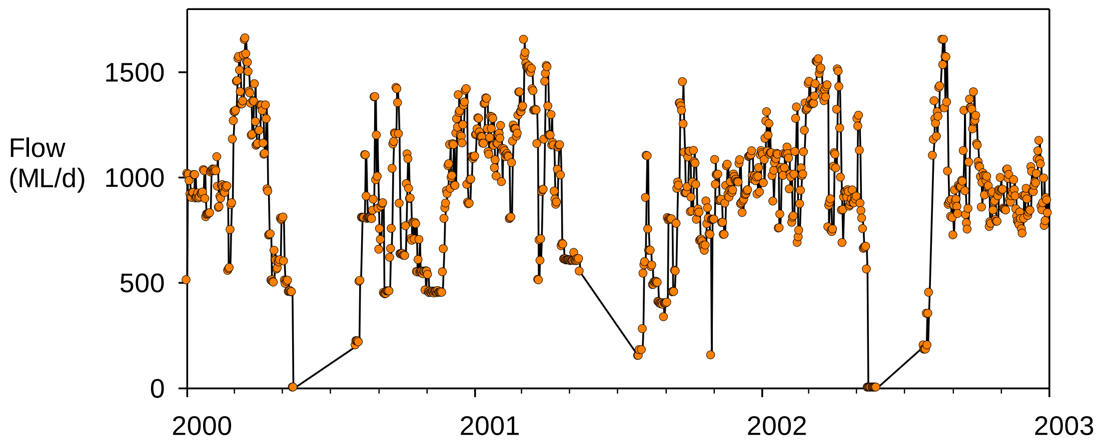
Fig. 10. Comparison of mean (+ s.d.) monthly flows in Gunbower Creek and modelled natural flows in the River Murray, which would reflect the hydrology of Gunbower Creek without regulation of flow. The horizontal red line represents the commence–to-flow of Gunbower Creek prior to irrigation development.

Gunbower Creek is managed to meet irrigation demands and hence can have wide daily oscillations in flow (Fig. 11). Under natural conditions the River Murray, which would be supplying Gunbower creek as an anabranch, has less oscillation between rising and falling river levels, but is still within the range expected under natural conditions (Fig. 12).

a) River Murray - modelled natural



b) Gunbower Creek at Gunbower weir



c) Box Creek

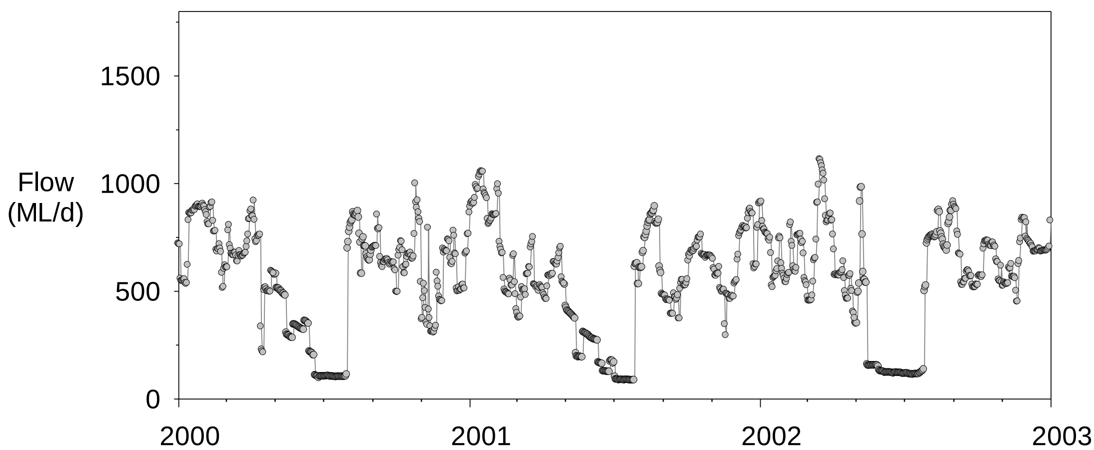


Fig. 11. Daily flow in the River Murray (modelled natural) compared with daily flow (not continuous data) in Gunbower creek and Box-Pyramid Creek, showing wide daily variation.

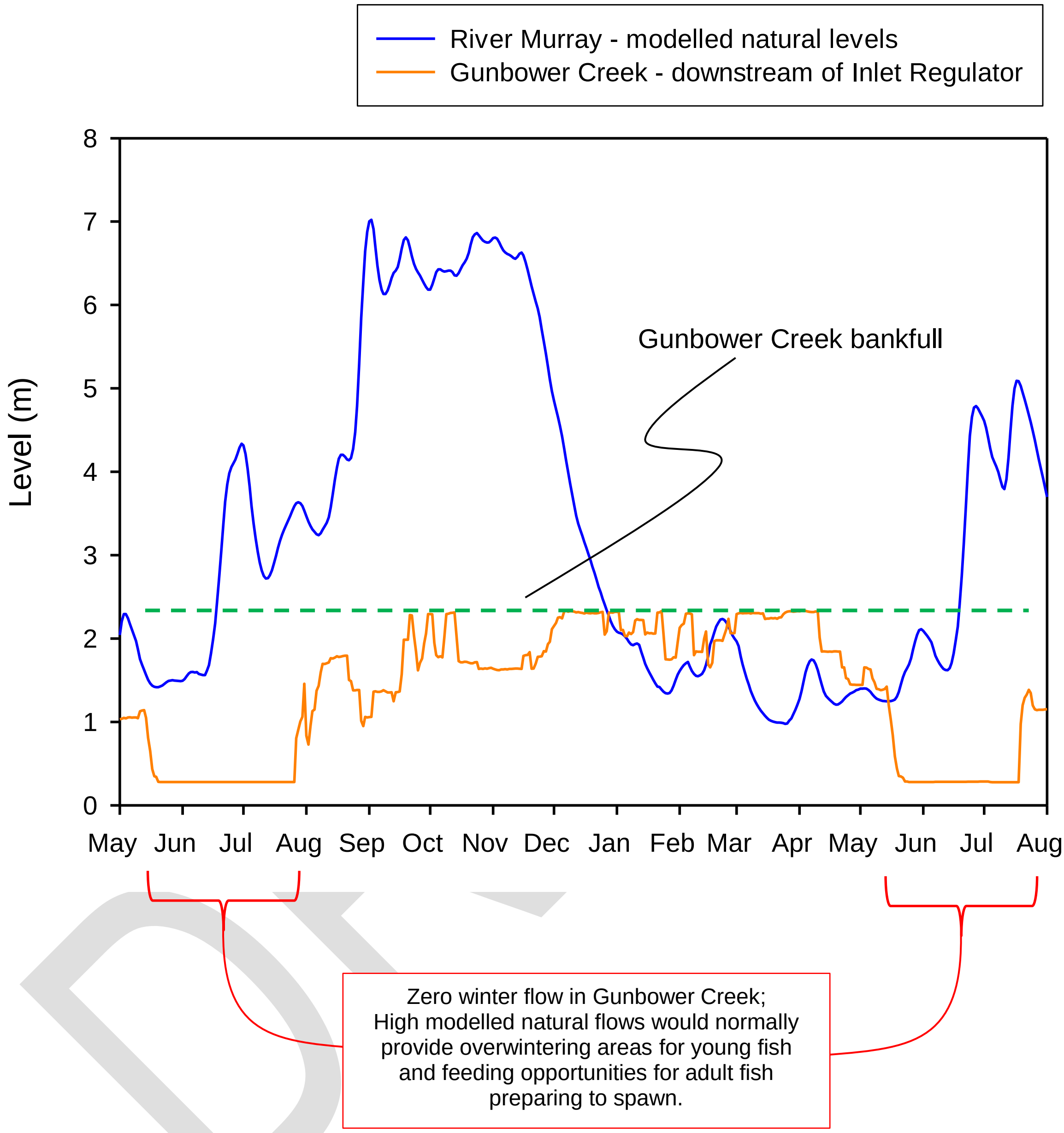


Fig. 12. Daily level in the River Murray (modelled natural for 2002) compared with daily level in Gunbower Creek for 2002, showing zero winter flow and frequent oscillation in summer but within the expected range of natural. Under natural conditions Gunbower Creek would be running high throughout September to early December, a key spawning period for many species, including Murray cod.

There are four weirs along Gunbower Creek at Thompsons, Gunbower, Cohuna and Koondrook. These change the creek from a flowing stream habitat at high flows to a series of weirpools at low flows (Fig. 13).

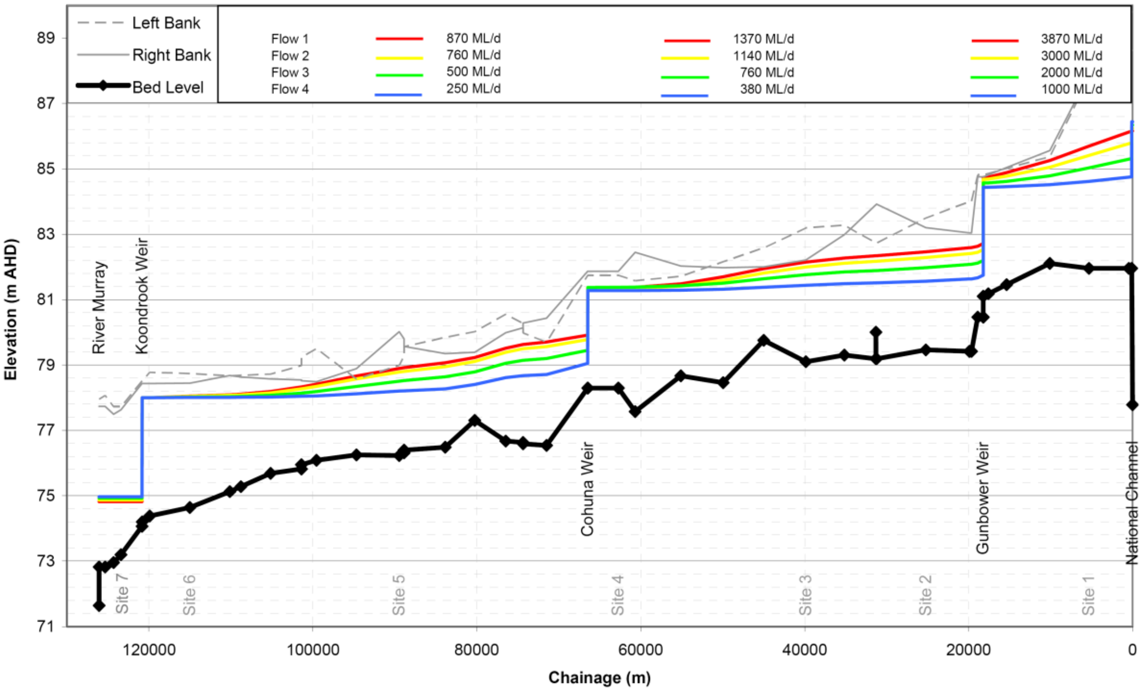


Fig. 13. Modelled water surface profiles of Gunbower Creek under present conditions, showing the four major weirs of the system (Anderson 2007a).

3.5.2 Gunbower Forest floodplain

Past Hydrology

The Gunbower forest floodplain receives most of its water directly from the River Murray via inlets which break from the river bank. The principle forest inlets are Broken Axle at Kate Malone Bend, Yarran Creek at Shillinglaws Regulator and Barham Cut (Ecological Associates 2003). These inlets start to flow at 13,700 ML/d and gradually increase up to 27,800 ML/d (Atkins *et al.* 1991; Ecological Associates 2003):

- at 18,300 ML/d of River Murray flow the forest inflows are low, at 95 ML/d;
- at 25,200 ML/d forest inflows increase to 520 ML/d, and
- at 27,800 ML/d forest inflows increase to 1780 ML/d.

When the River Murray is over 30,000 ML/d there is widespread inundation of the forest and at the maximum flows in the River Murray, of 55,000–60,000 ML/d, almost the entire forest is inundated (Ecological Associates 2003).

Comparing the above data of forest inflows in a regression with the modelled natural flow data from the River Murray (MDBA, BIGmod, unpublished data), shows that low flows into the forest wetlands occurred every year except two (1940 and 1982) in 100 years (1900-2000) (Appendix 1, Fig. 8, Fig.

9). Under modelled natural conditions, overbank flows (> 30,000 ML/d) occurred nine out of ten years but extended events occurred six out of ten years with each event lasting up to 4.2 months (Appendix 1, Fig. 8, Fig. 9). Hence, the forest wetlands were topped up almost every year, at least for those wetlands close to the River Murray, and had significant inflows nine in ten years.

Present Hydrology

Regulation of flow in the River Murray by headwater dams has resulted in a reduction in the magnitude, frequency and duration of floods as shown in Table 1 below.

The frequency of large floods that exceed 36,000 ML/day, which result in overbank flows and widespread flooding of the River Red Gum areas, has fallen by 58% since regulation, although the duration of events is much the same. Overbank flows (>27,800 ML/day) now only occur in 34% of years and last 3.1 months each time.

The frequency of intermediate floods (18,000 ML/day – 30,000 ML/day) has not declined as dramatically but the event duration has been reduced by almost 50%. Prior to regulation, flows greater than 18,000 ML/day had a duration of five and half months. These same flow events now have a duration of only three and half months (Ecological Associates 2003).

Table 1. The effect of river regulation on flows in the River Murray at Torrumbarry Weir (Ecological Associates, 2003)*

River Murray Flow	Duration[1] (Months/event)		Frequency[2] (Events/100years)	
ML/day	Natural	Current	Natural	Current
<13,700	N/A	N/A	3	45
≥13,700	6.2	3.9	98	55
>15,200	6.0	3.7	96	53
>18,300	5.5	3.6	94	46
>25,200	4.4	3.2	91	37
>27,800	4.2	3.1	84	34
>36,000	3.4	2.6	68	27
>46,000	2.8	2.6	42	8
>56,500	1.8	2.5	11	2

* Data is based on modelled monthly flows from MDBA – Monthly Simulation Model for flows between 1891 and 1990

1. Duration is the average number of months per event that monthly flow exceeds the threshold values shown in ML/day column

2. Frequency is the number of years, in the 100 years modelled, in which one or more months had flows exceeding the threshold values shown in ML/day column

For the smaller floods (<15,000 ML/day), which would have topped up wetlands without inundating the forest floodplain, both the frequency and duration have more than halved under regulation. Flood events of 15,000 ML/day previously lasted for about 6 months, whereas now they only last for 3 months. The frequency and duration of these smaller flow events is critical in ensuring that the lower flows into the forest are sufficient to sustain permanent and semi-permanent wetlands in the forest (Ecological Associates 2003). Many of the smaller wetlands, such as Smith Swamp and Barton Swamp that may be key habitats for some small-bodied threatened fish species, would very likely have been permanent and now regularly dry out.

The changed water regime has had significant impact on vegetation communities throughout the forest with poorer health of many adult trees, and plant species tolerant of drier conditions becoming more abundant. The permanent wetlands would have been surrounded by a semi-permanent wetland fringe which would have been maintained by higher elevation inlets which flowed in 91% of years. Under current conditions, these effluents flow in only 37% of years. It is believed that semi-permanent wetlands have consequently reduced in extent and contracted to the lowest parts of the forest, replacing the permanent wetland areas. The degradation of the forest ecosystem has led to a decline in the number of fish, waterbirds and frogs.

In summary, the frequency and duration of floods under current conditions are insufficient to meet the water requirements of the forest ecosystem. The significant alteration to the water regime of Gunbower Forest has caused:

- the loss of permanent wetlands and a large reduction in the extent of other wetland types,
- a reduction in the frequency and size of breeding events of colonial nesting waterbirds,
- a reduction in the temporarily flooded wetland and forest habitats, and a decline in the number and diversity of associated flora and fauna,
- a decline in the condition of Black Box and Grey Box woodlands,
- reduced connectivity between the river and floodplain forest limiting access to food and habitat for aquatic fauna.

3.5.3 Kow Swamp

Past Hydrology

Kow Swamp is filled from Gunbower Creek but prior to irrigation development the connection was less well developed and high flows were needed in Gunbower Creek to pass into Kow Swamp. It is reported to have received floodwaters from the River Murray one year in three and was considered to be a large permanent waterbody[1]. It would also have received inflows from its catchment, which includes Mt Hope Creek and Bendigo Creek. Without the present outlet regulator at Box Creek, which raises the water level of Kow Swamp, the lake would naturally drain away via Box-Pyramid Creek. A report of timber in the middle of the lake during the 1915 drought suggests that it was a floodplain of red gums[2]. Given the hydrology, it is likely it was a seasonal shallow lake in winter and spring, and a swamp in summer and autumn, probably with some permanent water in the centre.

Present Hydrology

With irrigation development, the National Channel and Taylors Creek were enlarged and Gunbower Weir built to raise the water level in Gunbower Creek so that flow could be diverted at any time into Kow Swamp. The construction of Box Creek Weir at the outlet of the swamp in 1969 raised the operating water level in Kow Swamp up to a maximum of 5.2 m, which enabled it to be operated as an off-stream storage for irrigation. Kow Swamp can hold approximately 50 GL and is generally filled at the beginning of the irrigation season in mid-August and reduces toward the end of the irrigation season in mid-May (Fig. 14). The lake level varies widely within months (Fig. 14), as it is topped up to meet water demands, and between years (Fig. 15) when droughts occur. Within the fish migration season of September to April it mostly varies within 2 m.

Interestingly, although this hydrology is largely a managed one and does not drain seasonally as it did in the past, it has some features that resemble a natural off-stream lake of the River Murray.

[1] Kerang Times and Swan Hill Gazette (Vic.: 1877 - 1889), Tuesday 10 March 1885, page 3.
[2] Bendigo Advertiser (Vic.: 1855-1918), 14 Dec 1914, page 5.

Comparing the natural river hydrology (Fig. 10) with lake levels (Fig. 14) shows that filling in late winter, peaking in spring and declining in late autumn would be natural features of a lake connected to the river. The hydrology differs from natural in extending the peak or high lake level throughout summer and early autumn, and extending the low lake level to early winter.

The increase in lake level in late winter and spring would inundate ground and would likely increase productivity, which generally results in an increase in phytoplankton and zooplankton that aids survival of fish larvae. This is the basis of the flood recruitment model for fish and suggests that Kow Swamp could have potential as a nursery area for native fish.

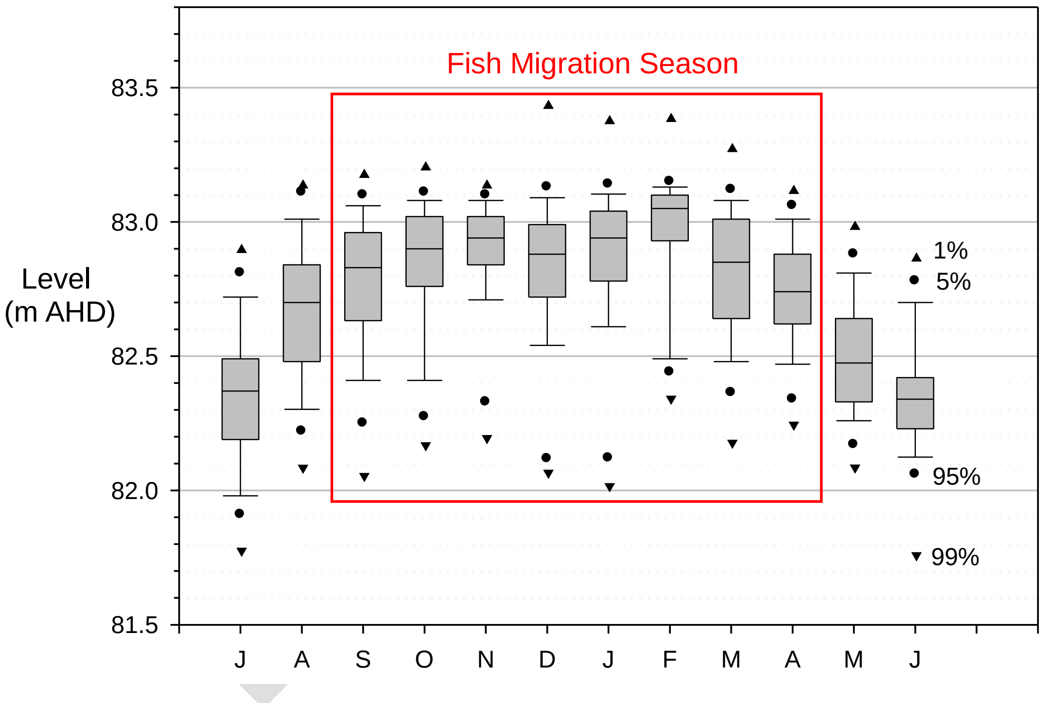


Fig. 14. Box plot of monthly levels of Kow Swamp with percentiles (data from 1975-2012), shown with the fish migration season.

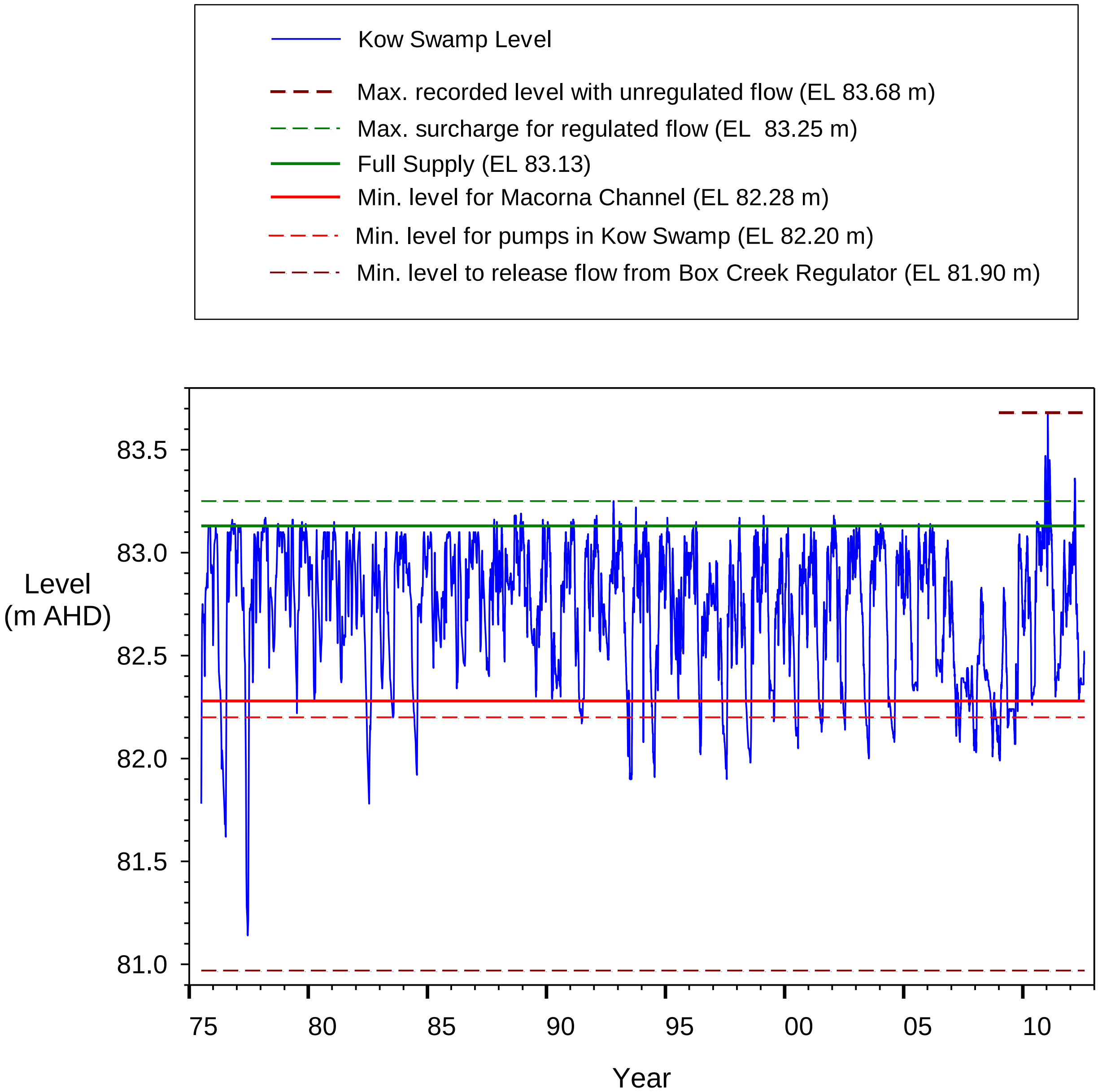


Fig. 15. The lake level of Kow Swamp from 1975 to 2012, shown with the operating levels for irrigation systems.

3.5.4 Box Creek – Pyramid Creek

Past Hydrology

Box Creek drains Kow Swamp and becomes Pyramid Creek at the confluence with Bullock Creek, approximately 9 km downstream. The past hydrology of Box Creek would have directly reflected inflows to Kow Swamp; hence, it would have flowed one year in three and fluctuations would have been buffered by Kow Swamp. Local rainfall, either in the catchment of the creek or in the catchment of Kow Swamp, would have caused rapid rises and falls of high flows as they still do (e.g. January 2010 in Fig. 15).

Present Hydrology

Box Creek is operated as an irrigation delivery channel releasing water from Kow Swamp for irrigators downstream and delivery of flows to the Kerang Lakes. This function delivers a regime of high flows in the irrigation season (Mid-August to mid-May) that fluctuates frequently as irrigator demands vary over a season and very low flows in winter (Fig. 16). The high irrigation flows overlap with the main fish migration season but as for Gunbower Creek, the very low flows in winter would not have been the natural regime.

The seasonal watering plan for the Loddon system 2014-15 sets a priority watering action for Pyramid Creek for a spring fresh of up to 800 ML per day for 7 days during September or November to improve native fish migration. Completion of an environmental flow study for Pyramid Creek is anticipated in 2014-15 (VEWH 2014).

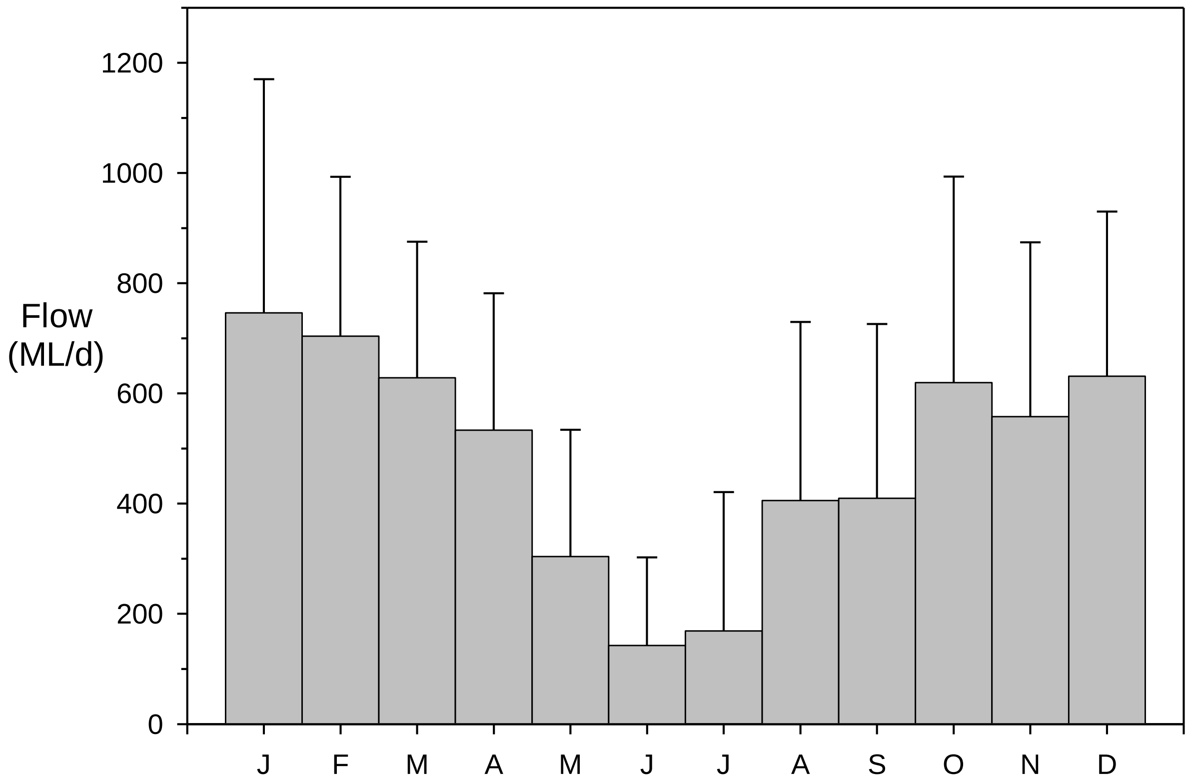


Fig. 16. Monthly flows (mean + s.d., data 1987 to 2012) in Box Creek, showing high flows in the irrigation season (Mid-August to mid-May) and low flows in winter, similar to Gunbower Creek (Fig. 10) and differing from modelled 'natural' flows (Fig. 10).

3.5.5 Lower Loddon River

Past Hydrology

The Loddon River had a widely fluctuating flow prior to any dams or irrigation. The river has a relatively short length for Murray-Darling Basin rivers and without upstream dams to capture flows, was very responsive to catchment rainfall. There were higher flows in winter and spring and very low flows in summer, following the pattern of most southern Murray-Darling rivers prior to regulation (Loddon River Environmental Flows Scientific Panel 2002).

Present Hydrology

The present hydrology has been strongly altered by upstream dams capturing flow and mid-stream weirs diverting flows for irrigation (Loddon River Environmental Flows Scientific Panel 2002). End-of system flows are reduced by half on average but in droughts up to 93% of flows can be diverted (MDBA 2006, North Central CMA 2012).

The regulation of flow has led to: reduced frequency of small floods, which are captured by upstream dams; changed seasonality and less low flow periods in the middle regulated reaches, which are used to pass irrigation flow; retained seasonality in the lower reaches (downstream of Kerang Weir) but severely reduced low flows in summer as all major abstractions of flow are upstream of this point (Fig. 17). In all reaches there is less variability of flow, due to capture and re-regulation of flow.

The Loddon River downstream of Kerang Weir currently has no specific environmental flow allocation however it benefits from flows delivered to the upstream reach 4 of the river, as well as irrigation flows through Pyramid Creek (VEWH 2014).

Environmental Water Management Plans are due to be completed for the Loddon River (including Pyramid and Serpentine creeks) and Gunbower Creek in 2015 (Louissa Rogers, North Central CMA, pers. comm.).

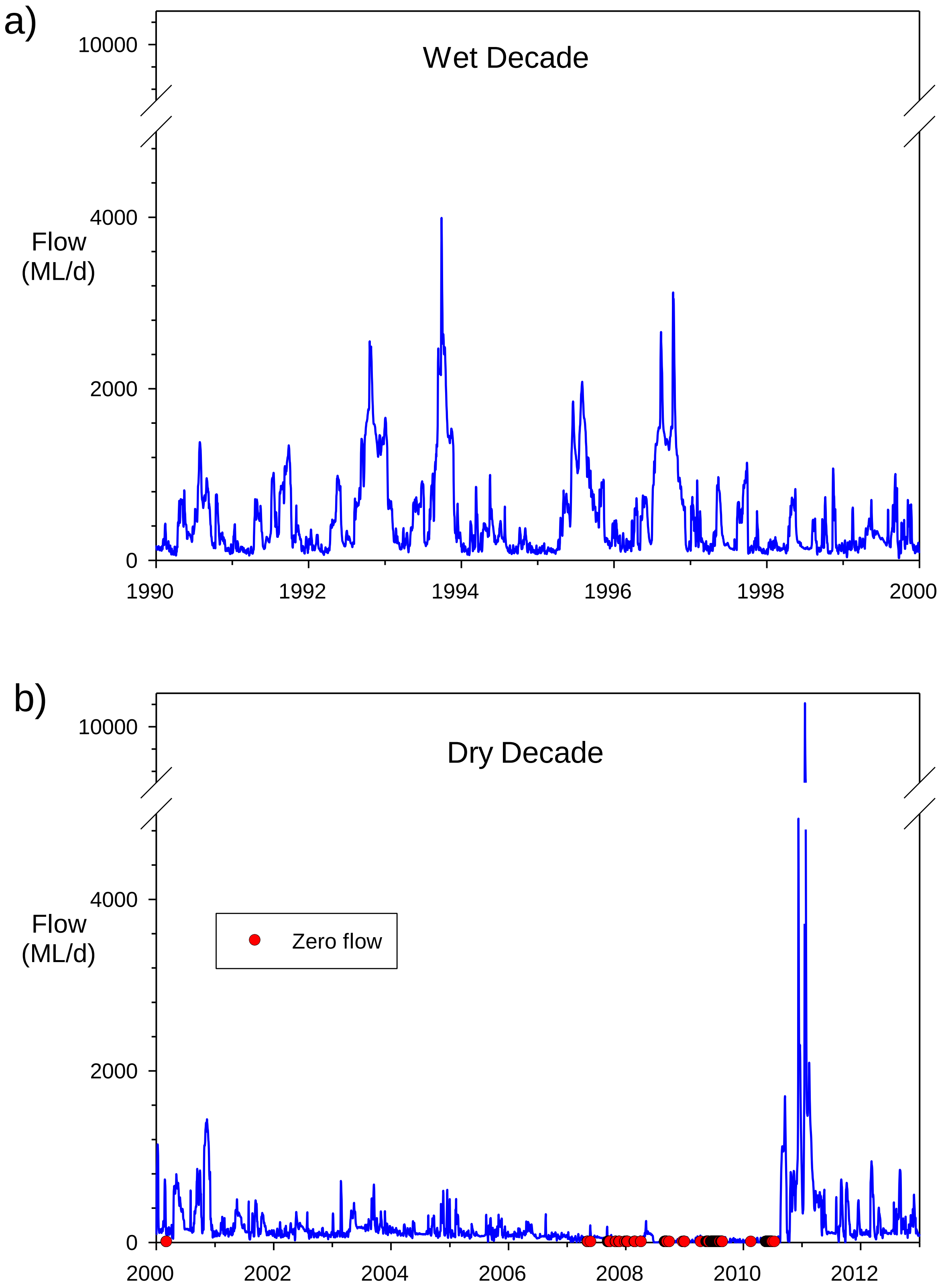


Fig. 17. Daily flows in the Loddon River passing Kerang Weir in a) a wet decade, and b) a dry decade (Millennium drought). Zero flows are shown as red symbols.

4 HABITATS

The presence and abundance of native fish is directly related to habitat, not only the physical attributes such as hydrodynamic complexity (depth, width, velocity, turbulence), substrate (rocks, sand, silt etc.) and vegetation (aquatic and riparian), but also the spatial distribution and connectivity among habitats. Different species and life stages use different habitats and a greater diversity of habitats leads to a greater diversity in fish assemblages. The creeks, wetlands and floodplains in the Gunbower to lower Loddon region are particularly diverse within a relatively small geographical range, forming a complex mosaic of:

i) *permanent channel habitats* (Gunbower, Box-Pyramid creeks and lower Loddon River);

ii) *ephemeral channel habitat*s (forest flood-runners and irrigation channels);

iii) *permanent lakes* (Kow Swamp);

iv) *permanent wetlands, comprising forest wetland complexes*, *billabongs,* and *small off-channel wetlands*;

v) *semi-permanent wetlands;* and

vi) *forest floodplain of river red gums*.

Of the permanent channel habitats, Gunbower Creek has a high diversity of habitat for the majority of its length, including variable depth and width (as described in sec 3.2), instream woody debris ('snags'), riparian vegetation and aquatic vegetation (Fig. 18). However, some areas of cleared land adjacent to the creek have less riparian habitat and some reaches have also been de-snagged in the past. A key habitat feature of Gunbower Creek is its hydrodynamic diversity; that is, it has a variety of still-water habitats (billabongs, weirpools etc.), slow-flowing reaches and fast-flowing reaches in the upper weirpools, as well as local variation in water velocity and turbulence (e.g. around instream woody habitat). This hydrodynamic diversity, when provided with other habitat features, is a key to a diverse native fish community and Gunbower Creek has potential for greater hydrodynamic diversity (see sec. 7.3.2).

Fig. 18. Gunbower Creek downstream of Cohuna Weir, showing excellent fish habitat of instream woody habitat (snags), littoral (edge) vegetation, and streamside (riparian) vegetation.

Box-Pyramid Creek, in contrast, has very poor habitat diversity for much of its length (Kitchingman *et al*. 2012). It has little instream woody debris ("snags") as well as little aquatic vegetation or riparian vegetation (Fig. 19). These features, however, can be rehabilitated and "re-snagging" programs have been very successful.

Fig. 19. Pyramid Creek, showing poor fish habitat with no instream woody habitat (snags) and little streamside (riparian) vegetation. The littoral zone has inundated *Lignum* and *Phragmites,* but has no aquatic macrophytes such as *Vallisneria*.

The lower Loddon River is a river channel, widening from 10-20 m near Kerang to 40 m downstream of Barr Creek (Fig. 20, Fig. 21). It has a riparian zone varying from bordering red gums with intermittent instream woody debris to reaches with wider riparian forest and dense woody debris, and some adjacent wetlands/forest floodplain in Benjeroop-Dartagook Nature Conservation Reserve. Sheepwash Creek is an ephemeral floodplain anabranch of the Loddon River which receives water at high river levels via an auxiliary concrete spillway in the Kerang weirpool.

Gunbower Creek, Box-Pyramid Creek and the lower Loddon River have a managed hydrology, which has a major impact on the habitat values. Gunbower Creek and Box-Pyramid Creek are operated for irrigation delivery and hence flow is stopped in winter when there is no irrigation demand, differing from the natural regime of higher flows in winter (Fig. 10). In Gunbower Creek the habitats are then reduced to the remaining weirpools of Gunbower, Thompsons and Cohuna weirs. In Box-Pyramid Creek, which has no weirs, the stream habitats are reduced to very shallow pools and, in the lower reaches, backwater from the Kerang weirpool. The lower Loddon River has a small allocation for environmental flow but at these flows the depth of the river channel is shallow, especially between Kerang and Barr Creek, although there are a few deep holes. In all three streams hydrodynamic complexity in winter is reduced to stillwater (lentic) habitats with no flowing (lotic) habitats.

The irrigation channels can be *ephemeral channel habitats* where they are drained each winter or *permanent* where they hold water all year. They are designed to optimise hydraulic efficiency so they have a uniform cross-section and are as straight as possible. They generally do not have roughness, habitat complexity or riparian vegetation, which would reduce hydraulic efficiency, increase maintenance and pose a structural risk. They do, however, have native fish present which enter with water each season.

There are *ephemeral channel habitats* of forest floodrunners in Gunbower Forest (Fig. 22). These are deeper channels through the forest which are used by large-bodied and medium-bodied fish in floods.

Fig. 20. The lower Loddon River channel during a low flow.

Fig. 21. The lower Loddon River channel during a high flow.

Fig. 22. An ephemeral forest floodrunner at Shillinglaws Regulator during high river flow.

Kow Swamp (Fig. 23) is the only *permanent lake*. It is shallow, mostly less than 3 m but up 5 m in deeper sections. There are numerous dead red gums in the lake due to permanent inundation; they extend 200 m from the shore and up to 600 m where Bendigo Creek enters the lake. These dead trees provide habitat for fish, especially when limbs fall off and become submerged. There are large beds of *Phragmites* in the northeast end of the lake near the outlet, which extend up to 800 m from the shoreline. Numerous willows also line the banks in this area. The remaining littoral (edge) zone of the lake is much narrower but can extend up to 100 m from shore. It is mainly a mix of Phragmites, introduced grasses (kikuyu) and spike rush (*Eleocharis*) interspersed with mudflats, while near the inlets of Picanniny Creek and Mt Hope Creek there is more cumbungi (*Typha*) and the emergent *Ludwidgia*.

Of the *permanent wetlands*, the *forest wetland complexes* are of diverse habitat (Fig. 24), supporting a range of small-bodied fish species as well as low numbers of medium-bodied native fish species, which may include freshwater catfish, bony herring and individuals of golden perch that remain after a flood. For these medium-bodied fish species, these *wetland complexes* are not considered primary habitat.

The *permanent billabongs* are adjacent to channel habitat and are isolated sections of the old creek channel. They include billabongs such as Turner and Phyland lagoons in the Upper Landscape, and Black Swamp and Reedy lagoons in the Lower Landscape. They are generally deeper than the wetland complexes with a discrete littoral zone, often with aquatic vegetation. They have a similar fish assemblage to the forest wetland complexes but three of these (Turners, Phyland and Cockatoo (Fig. 25)) also have freshwater catfish (Rehwinkel and Sharpe 2009), reflecting the different habitat type.

Fig. 23. Kow Swamp.

Fig. 24. A large, permanent forest wetland with a well-developed littoral (edge) zone.

Fig. 25. Cockatoo Lagoon – a billabong of Gunbower Creek that contains freshwater catfish.

The *permanent small off-channel wetlands* are in the red gum and box forests, not adjacent to channel habitats (hence "*off-channel*"). They are usually shallower than other wetlands (e.g. Smith Swamp and Barton Swamp) and are not favoured by medium-bodied fish species but small-bodied native fish species specifically use these habitats when other fish species cannot. Therefore the *permanent small off-channel wetlands*, which have declined and were completely dry in the last drought, are likely to be critical refuges for these species.

A significant characteristic of the *off-channel wetlands* in the Gunbower Forest is their diversity in size, morphology, aquatic macrophytes, permanence and riparian zone (Fig. 26 to Fig. 24). It is this diversity that provides opportunities for sustaining populations of small-bodied fish species, especially those with specific habitat requirements, such as threatened species (e.g. southern pygmy perch, southern purple-spotted gudgeon).

The *permanent small off-channel wetlands* have been more affected by river regulation and reduced flooding frequency than the other categories of permanent wetlands, as they would be the first to dry out with reduced inflows. The modelling shows that these wetlands probably received inflows 98 years in the last 100 (see sec. 3.5.2). Not only was there more frequent watering of the forest under natural conditions but evaporation rates of a healthy and complete forest canopy would also have been lower. These wetlands, being highly affected by flow regulation and a potential habitat for threatened species, are key habitats for restoration that will require specific management.

The *forest floodplain* is an aquatic habitat only in floods. It is mainly river red gum in the Lower Landscape (north-western two-thirds of Gunbower forest) and grey box/black box in the Upper Landscape (south-eastern third of Gunbower Forest). Depths in the forest are general shallow in floods but widely used by small-bodied fish and non-native fish species, such as carp. Medium-bodied fish species, such as golden perch, would use the floodplain in large floods, whilst the large-bodied fish would generally remain in the deeper flood-runners.

Fig. 26. Small forest wetland (upper Gunbower forest) with dense aquatic macrophytes.

Fig. 27. A small forest wetland (upper Gunbower forest) with steep sides, woody debris and few aquatic macrophytes. A high water mark can be seen from the previous flood, showing that this was a deep pool at high flows.

Fig. 28. A medium-sized, permanent forest wetland (upper Gunbower forest) with a dense riparian zone.

5 FISH ECOLOGY AND CONCEPTUAL MODELS

5.1 Introduction

The following information on fish aims to describe the fish community and provide conceptual models to guide the fish recovery strategy. Conceptual models are representations of complex systems that use available data and the present understanding of causal factors to show links, interactions and processes. They are usually pictorial or diagrammatic but can also be a concise description in text. The strength of conceptual models is that they link components of a system together to present a holistic view. The model, and the process of constructing the model, can highlight knowledge gaps, identify research and monitoring priorities, and clarify and synthesise thinking.

A potential weakness of conceptual models is that the relative strengths of various links, based on the data, are often not explicit and the model can sometimes be viewed as having more validity than the data suggests. Conceptual models need to be viewed as a tool that needs constant review and updating, rather than an absolute explanation. They are presented in this report as a resource to describe the present understanding and to be constantly refined.

Conceptual models are useful in natural resource management as they attempt to provide an understanding of why biota are present or absent in different habitats (i.e. reasons or causes), rather than only a description of distribution (i.e. effects). A good example of these differences is the area of fish passage. Providing fishways enable fish to move past a barrier (i.e. effect) but the conceptual model behind it may be that fish are moving to spawning habitat, feeding habitat, or countering downstream displacement as larvae. The conceptual model would then provide guidance for complementary actions, such as improving spawning habitat.

5.2 Species Diversity and Abundance

Twelve native fish species have been collected in Gunbower Forest wetlands and Gunbower Creek, and the area is within the range of an additional nine native fish species (PIRVic 2007; Rehwinkel and Sharpe 2009; Richardson *et al.* 2005; Sharpe 2009; Sharpe *et al* 2013) (Table 2). The Sustainable Rivers Audit (Davies *et al.* 2008) listed shortfinned eel, congolli and spangled perch as expected species within the middle River Murray catchment and thus the Gunbower Region. Shortfinned eel would be considered rare in the middle Murray but is included in Table 2. Congolli and spangled perch are not included in Table 2, as the former is only found in the lowlands of coastal streams near the estuary and the latter is mainly found in the Darling and occasionally the Murrumbidgee catchments.

The most common species in Gunbower Creek and the adjacent permanent wetlands are the small-bodied species that are also common elsewhere in the lowlands of the River Murray catchment (Lintermans 2007). Murray-Darling rainbowfish is the only small-bodied species that is common elsewhere in the River Murray catchment but is in very low abundance in the Gunbower habitats (Rehwinkel and Sharpe 2009; Sharpe *et al* 2013)); the reasons for this are not apparent.

The large- and medium- bodied fish species generally have low abundance but notably include four threatened species, Murray cod (Fig. 29), silver perch, trout cod (Fig. 30) and freshwater catfish, although the latter three have only been recorded in very low numbers in recent surveys (Rehwinkel and Sharpe 2009). Of the six non-native species, carp and gambusia are the most abundant.

A review of recent fish surveys show similar fish species present in the lower Loddon River and Pyramid Creek (Hale & Sharpe 2014, Stuart et al 2010) with ten native fish species in these two waterways. Small bodied fish, in particular Carp Gudgeon and Australian Smelt, are the most abundant species with notable numbers of Golden Parch recorded in Pyramid Creek (Hale and Sharpe 2014). In 2014 VEFMAP surveys, two Murray cod were recorded at each of the survey sites in Pyramid Creek and the Loddon River downstream of Kerang Weir. There are no records of Trout cod in the lower Loddon. Exotic species are the same as for Gunbower Creek with addition of Tench which are present in the lower Loddon.

Table 2. Fish species present or within range of Gunbower - lower Loddon system. An asterisk indicates a threatened species.

Abundance: ✓✓✓✓ Very abundant, ✓✓✓ Abundant, ✓✓ Common, ✓ Rare, - Absent

	Present abundance	**Channel specialists**	**Generalists**	**Off-channel Specialists**
NATIVE				
Large-bodied (500-1000 mm)				
Murray cod*	✓✓	▲		
Trout cod*	✓	▲		
Medium-bodied (90-500mm)				
Golden perch	✓✓	▲		
Silver perch*	✓	▲		
Freshwater catfish	✓		▲	
Bony herring	✓		▲	
River blackfish	-	▲		
Macquarie perch*	-	▲		
Short-headed lamprey	-	▲		
Shortfinned eel	-		▲	
Small-bodied (20-90 mm)				
Carp gudgeons	✓✓✓✓		▲	
Flat-headed gudgeon	✓✓✓		▲	
Un-specked hardyhead	✓✓✓		▲	
Australian smelt	✓✓		▲[1]	
Dwarf flat-headed gudgeon	✓✓		▲	
Murray–Darling rainbowfish	✓	▲?		
Southern pygmy perch*	-			▲
Southern purple-spotted gudgeon*	-			▲
Flat-headed galaxias*	-			▲
Olive perchlet	-		▲?	
Murray hardyhead*	-			▲
NON-NATIVE				
Carp	✓✓✓		▲	▲[2]
Eastern gambusia	✓✓✓✓			▲
Goldfish	✓✓		▲	
Redfin perch	✓		▲	
Oriental weatherloach	✓✓			▲
Tench	-		▲	

[1] Although not abundant in wetlands in Gunbower, it is common in other wetland habitats along the River Murray.
[2] Can complete their life cycle within channel habitat but high recruitment can occur on floodplains.

Fig. 29. Example of a Murray cod collected in Gunbower Creek.

Fig. 30. A trout cod angled from Kow Swamp, below the Taylors Creek regulator, in spring 2012. Photo courtesy Gary Hodges, Fisheries Victoria.

5.3 Model of Habitat Use

5.3.1 Generalists and specialists

Understanding fish use of floodplain (wetlands and forests) and channel habitats (Gunbower Creek, River Murray) is important to optimise outcomes for native fish. The fish species listed in Table 2 can be grouped into three functional guilds which relate to their preferred habitats and life history strategy. The *generalists* can complete their life cycle in disconnected wetlands or in channel habitats, which usually include areas of stillwater and slackwater. The *channel specialists* are not considered able to complete their life cycle in disconnected wetlands. The *off-channel specialists* specifically prefer wetland habitats that are isolated from the main channel but can also complete their life cycle in slackwater habitats that are part of channel habitats.

5.3.2 Use of channel habitats

The channel specialist species, which are most of the large- and medium-bodied native fish (Table 2), all spawn in channel habitats. Spawning of golden perch and silver perch occurs in spring and early summer (King *et al.* 2009) and is considered to be related to an increase in flow (i.e. a flow pulse) at a broad spatial scale, although some larvae have been collected in a range of flows. Murray cod spawn during spring/summer (October-December) in response to an increase in water temperature, independently of prevailing flows (Koehn and Harrington 2005). The generalist species also spawn in channel habitats and, like Murray cod, do so in response to warmer temperatures in spring and summer.

Murray cod, trout cod, golden perch and silver perch have a drifting larval stage, as do many of the generalist species. Larval drift is a specific life history strategy of many native and non-native fish species (Humphries *et al.* 1999). It aids dispersal from spawning areas to feeding and nursery areas. For the channel specialists much of this drift is along the channel, and larvae are likely to settle in slack-waters along the channel margins and where floodplains meet channels, but some larvae are also likely to drift onto floodplains. Where there are channel offtakes for forest watering, this drift onto floodplains is accentuated, depending on the proportion of flow that is diverted. Irrigation offtakes would also receive drifting larvae, depending on the proportion of flow that was diverted, as well as the season and localised hydraulics of the inlet.

Channel habitats are used for feeding by channel specialists and generalists, and are an important refuge and overwintering habitat. Winter is a critical period for young-of-year fish (i.e. fish that are less than one year old and the result of spawning in the previous spring) as their fat resources are much less than adult fish. Hence, diverse aquatic habitats are important to provide shelter and a productive food web, so these fish can feed in winter.

5.3.3 Direct use of the floodplain

In non-flood years the pools, lakes, and billabongs on floodplains (floodplain wetlands) serve as refuge habitats for off-channel specialist and generalist fish species, which can spawn, recruit and maintain populations in these habitats. Notably, there are four threatened species considered to benefit from wetland habitats in non-flood years: freshwater catfish, southern pygmy perch, southern purple-spotted gudgeon and flat-headed galaxias. The latter three species have not been recorded for many years in the Gunbower region and may require reintroduction to re-establish their populations (see sec. 8.8).

In flood years, when floodplain wetlands are connected to channel habitats, the off-channel specialists and generalist fish species spawn and recruit, as well as actively move between floodplain and channel habitats (Lyon *et al.* 2010). Almost all the channel specialist species have also been recorded using floodplain habitats during floods to some degree (Jones and Stuart 2008). These movements appear to be for feeding and not for spawning; there are no records of these channel specialists spawning on floodplains and recent studies collecting larvae of these species find them consistently in channel habitats and not on floodplains (King *et al.* 2003; King *et al.* 2009). Freshwater catfish use permanent off-channel habitats as well as pools in channel habitats to spawn, but there is no direct evidence that they actively seek ephemeral floodplain habitats to spawn.

The other direct use of floodplains is by larvae that have drifted with inflows, as described above. The abundance of larvae and the extent these drift onto floodplains will be dependent on timing and upon the scale of hydrological changes. Many small-bodied fish species respond to small-scale changes, such as inundation of a small wetland, as well as broad-scale flooding. Medium-bodied fish species generally respond to broader landscape-scale changes such as major increases in channel flow that is usually occurring over 10s or 100s of kilometres.

5.3.4 Indirect use of the floodplain

Recruitment of fish is dependent on the survival of larvae, which have a naturally high mortality. Inundated floodplains are very productive with high densities of phytoplankton and zooplankton that provide food of appropriate size and density for fish larvae. For the fish species that spawn within channel habitats, such as Murray cod, golden perch and silver perch, high survival of larvae may occur as floodwaters recede back into channels. This would be an indirect use of the floodplain by channel specialists and it may occur at a small scale of 10s of kilometres or in large floods over scales of 100s of kilometres. The body of research at present indicates that the channel specialists, which are mostly the large-bodied fish species listed in Table 2, can spawn and recruit in absence of floods, especially where there are flowing water habitats without barriers to fish passage, but it is likely that floods significantly enhance recruitment.

5.4 Model of Fish Migration and Movement

5.4.1 Introduction

Migration involves a significant proportion of the population and is usually cyclic with upstream and downstream movement along rivers and streams, or movement on and off floodplains. It is usually seasonal and occurs within the life cycle of an individual but in Australian rivers that have variable flows, with floodplains that have variable inundation and permanence, it can also be opportunistic, varying between years and between generations of fish. The following models describe the present understanding of migration in the Murray Valley and its application to the Gunbower - lower Loddon system.

5.4.2 Longitudinal fish movements

5.4.2.1 Generic movements in the River Murray

In the lowlands of the River Murray all riverine species are highly mobile, with upstream and downstream migrations. A major downstream migration occurs with drifting larvae. As discussed earlier, all of the channel specialists and most of the generalist species (Table 2) have larvae that drift; this is unlikely to be entirely passive and it is probable that larvae are migrating vertically or laterally in the current, seeking near-bottom (epi-benthic) habitats or channels edges (littoral). This downstream migration has a reciprocal migration upstream of either adult fish, often prior to spawning, or juvenile fish.

There has been considerable research on these aspects of migration in the River Murray and some recent work in the Gunbower – lower Loddon system, which confirms some trends and responses of fish. In general, the main cues for both upstream and downstream migration are: i) water temperature, or ii) water temperature and flow. Both conditions produce a strong seasonality of fish movements (Table 3).

Of the large-bodied fish species, adult golden perch, silver perch, Murray cod and bony herring move upstream in spring and summer. For the first three species this movement is considered to be related to spawning and is strongly cued by rising flow with much less migration in stable flow. However, there can also be considerable variation in migration within and between populations; for example, adult golden perch can also move downstream in spring (O'Connor *et al.* 2005) and Murray cod can migrate in stable flow and not all Murray cod in a population may migrate. In anabranches Murray cod can have a different pattern again, migrating to spawning areas in autumn or winter rather than spring (Saddlier *et al.* 2008).

Adult and juvenile bony herring migrate upstream in response to warmer temperatures and are not specifically cued to move by changes in flow. For both life stages these appear to be dispersal migrations and this species is one of the early colonisers of ephemeral lakes and flooded habitats.

Immature golden perch and silver perch, that are one year and older, migrate upstream in a similar pattern to the adult fish, responding to increased flow, but their upstream season appears to extend to early autumn. Mature and immature fish may aggregate for days or weeks at a migration barrier such as a weir, if flows provide sufficient stimulus, or they may return downstream to seek alternative migration pathways. Aggregations below barriers can quickly disperse downstream as flows recede.

Small-bodied fish species, which also have drifting larvae, dominate the migratory population numerically. Adults and juveniles tend to migrate upstream from mid-summer and early autumn, generally during low flows. Australian smelt can migrate earlier, from late winter, and will also migrate during higher flows.

The scale of migration is very important in these species and fragmentation of habitats by weirs affects them differently. Despite the large size of Murray cod their cyclic seasonal migrations, where they occur, are often over the scale of 25 to 100 km and are between slow-flowing habitats and fast-flowing habitats. Golden perch migrations are usually over the scale of 100’s of kilometres although some can be over 10’s of kilometres (Reynolds 1985, O’Conner *et al*. 2005). Silver perch is considered to be similar to golden perch and both species seek flowing water in channel habitats in which to spawn, so their eggs and larvae can drift downstream.

The scale of movement of bony herring is unknown but their rapid colonisation of habitats in floods suggests they move at least over 10s of kilometres and probably much greater distances. Freshwater catfish are considered to move over small scales of hundreds of metres up to 10 km, but dispersal of some individuals is likely to be greater. For small-bodied fish species, tagging of adult fish suggests the scale of migration is less than 10 km (Hutchison *et al* 2008). Larval drift of any of these small or large-bodied species could be hundreds of kilometres in a flood.

Table 3. Model of longitudinal migrations of fish in the Gunbower lower-Loddon region. Movement upstream is indicated by blue lines and movement downstream by green lines. Solid coloured lines represent predicted responses based on available data, and dotted lines are less certain and have little data.

Key to Migration Cues

- (orange) migrate in response to water temperature only
- (blue) migrate on water temperature and flow
- (green) migrate on either condition

		WINTER	SPRING	SUMMER	AUTUMN
NATIVE					
Large-bodied (500-1000 mm)	Adult				
Murray cod	Juvenile				
	Larvae				
Trout cod	Adult				
	Juvenile				
	Larvae				
Medium-bodied (90-500 mm)	Adult				
Golden perch, silver perch	Juvenile				
	Larvae				
Bony herring	Adult				
	Juvenile				
	Larvae				
Freshwater catfish, river blackfish, Macquarie perch	Adult				
	Juvenile				
	Larvae				
Small-bodied (20-90 mm)	Adult				
Australian smelt	Juvenile				
	Larvae				
Carp gudgeons, flat-headed gudgeon	Adult				
	Juvenile				
	Larvae				
Unspecked hardyhead	Adult				
	Juvenile				
	Larvae				
Pygmy perch, flat-headed galaxias, olive perchlet, southern purple-spotted gudgeon, dwarf flat-headed gudgeon, Murray hardyhead					
NON-NATIVE					
Carp	Adult				
	Juvenile				
	Larvae				
Redfin perch, oriental weatherloach, Eastern gambusia, goldfish					

Carp can complete their life cycle over scales of hundreds of metres to 10 km, moving from riverine or permanent wetland habitats to localised spawning areas of shallow vegetated habitats, which is commonly a lateral movement (see next section). They also make long distance movements of hundreds of kilometres, which enables them to rapidly colonise river systems or flooded areas.

5.4.2.2 Movement in the Gunbower – lower Loddon system

The generic movement patterns above for the mid-Murray system can be applied to develop a model of longitudinal fish movements in the Gunbower – lower Loddon system. A detailed model is provided in Memorandum No. 2 (Appendix 2) and a brief summary is presented here:

- **Regulated flows**
  - Characterised by:
    - low to zero flows in winter in Gunbower Creek and Box-Pyramid Creek,
    - low flows in the Loddon River below Kerang Weir,
    - moderate fluctuating flows (for irrigation) in spring, summer and autumn, in Gunbower Creek and Box-Pyramid Creek,
    - moderate fluctuating flows in the lower Loddon in spring, summer and autumn,
    - no end-of-system flow from Gunbower Creek (Koondrook Weir) to the River Murray and very low flows in the lower Loddon River.
  - Upstream migration: *temperature-cued species* (bony herring, some Murray cod, most small-bodied fish species and carp) move upstream in spring and summer, accumulating at weir/regulators without fishways; these include Box Creek Weir, Taylors Creek Regulator, National Channel Inlet Regulator and Cohuna Weir, although fish numbers at the latter site are low due to the migration barrier of Koondrook Weir and the poor habitat downstream of this weir during winter caused by low winter flows. (Note: no fish accumulate below Koondrook Weir as there is no flow under regulated conditions)

    Temperature & flow-cued species (golden and silver perch) move upstream in response to some fluctuating irrigation flows that simulate a sudden increase in river flow. These fish accumulate at the same weir/regulators without fishways. A recent study in the lower Loddon – Pyramid system identified tagged Golden perch as moving upstream to Box Creek Weir and then returning downstream to either move further up the Loddon River or entering Washpen Creek and possibly moving into the Kerang Lakes system (O'Connor et al 2013).
  - Downstream migration: drifting larvae from the River Murray have high mortality through Torrumbarry Weir and the National Channel Inlet Regulator (depending on gate opening and head differential). Larvae that pass into the irrigation channels have high mortality due to poor habitat and drying of channels where this occurs. Larvae that pass into Kow Swamp or remain in Gunbower Creek may have reasonable survival but no data is available.

- **High unregulated flows**
  - Characterised by:
    - high flows in Box-Pyramid Creek from the Kow Swamp catchment and high flows in the lower Loddon River.
    - zero flow passing the National Channel Inlet Regulator (to mitigate flooding) but high end-of-system flow from Gunbower Creek (Koondrook Weir) to the River Murray due to flows coming from the River Murray via flooded forest channels and local rain.

- Upstream migration: these flows provide a major stimulus for *temperature & flow-cued* species (golden and silver perch, Murray cod) to enter the area from the River Murray. High numbers of these species move upstream and mainly accumulate at Koondrook Weir and Box Creek Weir. There is little or no accumulation of fish at the National Channel Regulator as there is no flow.

- Downstream migration: if high flows are in spring, drifting larvae would be present. Larvae in the River Murray would mostly pass down the river, as there are no inflows at the National Channel Inlet Regulator. Depending on the gate openings of Torrumbarry Weir there could be high mortality of larvae. Some larvae would drift into the forest and across to Gunbower Creek.

5.4.3 Lateral fish movements

During flows that are sufficient to connect floodplain and channel habitats, there is active movement on and off floodplains of all fish species to some extent (Table 4). This movement is important for feeding, dispersal, gene flow and re-colonisation of areas desiccated following droughts (Balcombe *et al.* 2006).

In the past, there have been important commercial fisheries in floodplain lakes, mostly for golden perch and to a lesser extent Murray cod and catfish (Reid et al 1997). More recent, radio-tracking has shown that in the middle reaches of the River Murray the large-bodied fish species (Murray cod and trout cod) generally stay in deeper flood-runners and do not usually access the shallow floodplain (Koehn 2009; Koehn *et al.* 2009; Koehn *et al.* 2008). The medium-bodied golden perch will move extensively onto inundated floodplains but often remain in the deeper flood-runners (Jones 2006), whilst little is known of the use of floodplains by silver perch. Golden perch will access a floodplain with the current, as the floodplain fills, but they can also enter the floodplain where it flows back to the river, or enter the floodplain directly during large overbank floods where there is no flow cue. Freshwater catfish (Cadwallader 1977), Macquarie perch (Cadwallader 1977) and river blackfish (Lyon *et al.* 2010) have been recorded on floodplains but little is known of their behaviour and specific habitat use.

All fish species are more likely to utilise floodplains during spring and summer (October - February) rather than during winter (June–August). Spawning of native and non-native fish can occur from late August (winter) through to autumn (April) so that larvae can be expected to drift onto floodplains should inundation occur during this period.

Large- and medium-bodied native fish appear cued to leave the floodplain by a significant drop in water level (Jones 2006); for example, 0.3 m over 48 hours. The generalist, small-bodied native fish species (Table 2) enter and leave the floodplain freely while there is a connection to the main channel, with an increase in numbers leaving the floodplain as the level drops (Lyon *et al.* 2010). There is very little data, however, on the behaviour of the small-bodied off-channel specialists. Active dispersal is expected for this group of fishes, as has been reported elsewhere for the non-native Gambusia which is a small-bodied off-channel specialist (Lyon *et al.* 2010). These movements are essential to enable the use of recently accessible or inundated habitats and for recolonisation following droughts.

Adult carp migrate onto floodplains to spawn upon recently inundated vegetation during spring (Stuart and Jones 2006a). Of the large-bodied fish species they are considered to be the ‘first on’ and ‘last off’ the floodplain.

These generic movement data for the River Murray can be used to develop a model of lateral fish movements in the Gunbower forest floodplain. Table 4 provides a list of expected lateral movements of native and non-native fish into, and out of, the Gunbower Forest floodplain when it is connected to the River Murray and Gunbower Creek. In summary, the major expected trends in lateral fish movements are:

- **Large-bodied native fish** (Murray cod and trout cod):
  - Adult fish will enter the forest flood-runners and channels from the River Murray, mainly from mid-winter (August) to the end of spring (November) and likely leave throughout spring.
  - Larvae can be swept into the forest from channel spawning sites in the River Murray from late spring (October) to mid-summer (December) (Note: these species spawn at this time every year, independently of flow).
  - Juveniles would likely leave the forest floodplain from mid/late-spring and possibly throughout summer.
- **Medium-bodied native fish** (mainly golden perch and possibly other species):
  - Adult fish will enter the forest mainly from mid/late-winter to early summer and likely leave from early spring to late summer.
  - Larvae will drift into the forest from channel spawning sites, from mid-spring (October) to mid-late summer (March). (Note: these species generally require an increase in river flow and water temperature to stimulate spawning and do not necessarily spawn every year)
  - Juveniles will likely leave the forest from mid-spring to late summer.
- **Small-bodied native fish - Generalists** (mainly carp gudgeons, Australian smelt, unspecked hardyhead):
  - Adult fish will enter and leave the forest throughout spring and summer.
    - These fish will move between the channel and floodplain habitats over a wide range of hydrological conditions, with varying responses among species.
  - Larvae will drift into the forest from late winter to summer.
  - Juveniles will likely exit the forest from mid-spring to late summer.
    - These fish will move between the channel and floodplain habitats over a wide range of hydrological conditions, with varying responses among species.
- **Small-bodied native fish - Off-channel specialists** (most likely species are flat-headed galaxias and pygmy perch):

  Little is known of this group but dispersal between off-channel habitats, and therefore also along channel habitats, is considered part of their life history strategy, as they have been recorded recolonising temporary off-channel habitats.

  - Adult fish
    - *Dispersal*. Some proportion of the population will disperse from off-channel habitats, which is likely to occur from late-winter to late summer. The preferred flows or hydrological cues for dispersal are unknown and they may be a broad or narrow range of either high or low inflows.

Table 4. Model of lateral migrations of fish in Gunbower Forest, if floodplain is inundated. Movement onto the forest floodplain is indicated by blue lines and out of the forest floodplain by orange lines. Solid coloured lines represent predicted responses based on available data and dotted lines are less certain and have little data.

		WINTER	SPRING	SUMMER
NATIVE				
Large-bodied (500-1000 mm)	Adult			
Murray cod, trout cod	Juvenile			
	Larvae			
Medium-bodied (90-500 mm)	Adult			
Golden perch	Juvenile			
	Larvae			
Silver perch	Adult			
	Juvenile			
	Larvae			
Freshwater catfish, Bony herring, river blackfish, Macquarie perch	Adult			
	Juvenile			
	Larvae			
Small-bodied (20-90 mm)	Adult			
Australian smelt	Juvenile			
	Larvae			
Carp gudgeons, flat-headed gudgeon	Adult			
	Juvenile			
	Larvae			
Unspecked hardyhead	Adult			
	Juvenile			
	Larvae			
Pygmy perch, flat-headed galaxias, southern purple-spotted gudgeon, dwarf flat-headed gudgeon, olive perchlet, Murray hardyhead				
NON-NATIVE				
Carp	Adult			
	Juvenile			
	Larvae			
Redfin perch, oriental weatherloach	Adult			
	Juvenile			
	Larvae			
Eastern gambusia, goldfish	Adult			
	Juvenile			
	Larvae			

    - *Residency.* The greater proportion of the population is more likely to remain permanently in wetland refuges in the forest.

  - Larvae – as the life cycle is completed within wetlands the dispersal of larvae from these habitats is likely to be minimal, except in floods.

  - Juveniles – movements unknown.

- **Non-native fish**

  - Adult fish, particularly carp, will enter and leave the forest from late winter to the end of autumn, with particularly high abundance entering wetlands in spring.

  - Larvae, particularly of carp, will drift into the forest from late winter to summer.

  - Juveniles will likely leave the forest from mid-spring to late summer.

5.5 Models of Spawning and Recruitment

Spawning

The native fishes of the Murray-Darling Basin demonstrate five types of spawning; reflecting the duration of spawning, spawning style and time, cues for spawning, fecundity (number of eggs per female) and parental care:

1) *Circa-annual spawners, parental care, low fecundity* (relates to Humphries *et al.* (1999) Mode 1).

   Two large-bodied species (e.g. Murray cod, freshwater catfish) and one small-bodied species (purple-spotted gudgeon), which spawn in spring/early summer, and at the same time each year. Spawning is circa-annual and temperature related, from thousands to tens of thousands of eggs are laid demersally and subject to parental care.

2) *Circa-annual spawners, no parental care, high fecundity.*

   Represented by only one species, the large-bodied bony herring, which spawns in early summer and has litho-pelagic (i.e. demersal, then pelagic) larvae. Females spawn once but males may spawn multiple times.

3) *Circa-annual spawners, no parental care, low fecundity (Humphries et al. (1999) Mode 3b).*

   These are small-bodied species, with a single spawning event from late winter through summer. Mostly small-bodied species, including carp gudgeons and Murray rainbowfish.

4) *Flow-cued spawners, no parental care, high fecundity (Humphries et al. (1999) Mode 2).*

   Large-bodied species (e.g. golden perch, silver perch) that may spawn at any time between spring and autumn. Spawning is linked to a rise in flow and is related to temperature. Hundreds of thousands of semi-buoyant eggs are laid and no parental care is exhibited.

5) *Protracted spawners, no parental care, low fecundity (Humphries et al. (1999) Mode 3a).*

Mostly small-bodied species (e.g. Australian smelt, flat-headed gudgeon) that have protracted, repeat or serial spawning from spring to autumn. Spawning cues are uncertain; from hundreds to thousands of pelagic or demersal eggs are laid and no parental care is exhibited

In general, the only species that require a rise in flow or a flood to spawn are the flow-cued spawners, golden perch and silver perch. All other species reliably spawn each year in response to rising temperatures in spring and summer.

Recruitment

In biology *recruitment* simply means the survival of young to maturity and successful breeding; that is, the population continues and the individual's genes continue. It is a term that is often misused and misunderstood in aquatic science. In fecund animals (high number of young per female), such as fish, which have high mortality of young, *recruitment* is used to refer to a size or age when mortality is dramatically reduced; however, this still remains a surrogate measure of biological recruitment which assumes young fish will survive to maturity. In fish there is high mortality of larvae and much less mortality after the first year. The presence of larvae is proof of spawning but is not *recruitment* as these larvae still need to survive the period of high mortality over the first year of life, especially their first winter. In this project we use the biological definition of *survival to maturity*, as the basis of the project is recovering native fish populations, which requires recruitment. We have also used the presence of yearlings (1+) and older fish of other studies to show regular survival of year classes from larvae and a high probability of future recruitment.

There are four major patterns of recruitment of wholly freshwater fish (i.e. excluding diadromous) in the lowlands of the Murray-Darling Basin:

1) *Off-channel recruitment (off-channel specialists and generalists)*

Survival of young to maturity occurs entirely within off-channel habitats. Includes off-channel specialists such as pygmy perch and flat-headed galaxias, and generalists such as carp gudgeon and freshwater catfish.

2) *Low-flow channel recruitment (generalists)*

Recruitment occurs within channel habitats at low stable flows. Presently only applies to generalist species which, apart from freshwater catfish and olive perchlet, remain common in regulated rivers in the Murray-Darling Basin (Table 2).

3) *Variable flow channel recruitment (channel specialists)*

Recruitment occurs when there is variation of within-channel flows. Applies to golden perch, silver perch, and possibly Murray cod and trout cod.

4) *Flood recruitment (channel specialists, off-channel specialists and generalists)*

Recruitment occurs when floodplains are inundated increasing productivity and larval survival. Applies to the large- and medium-bodied channel specialists, off-channel specialists and generalists. Likely applies to all species to some degree.

In the southern Murray-Darling Basin there are only four native species that appear to be off-channel specialists specifically using floodplain or wetlands to complete their life cycle and recruit: southern purple-spotted gudgeon, southern pygmy perch, flat-headed galaxias and Murray hardyhead. These species are all small-bodied and use permanent wetland habitats. They are also all threatened species, which probably reflects the degradation of these habitats.

The basis of *low-flow channel recruitment* is that slow-flowing streams with dense plankton enhance survival of fish larvae. The evidence for *low-flow channel recruitment* was evident in the last drought where the generalist small-bodied species remained abundant in the River Murray. There is also evidence for low-flow recruitment of a range of fish species from the more arid inland river systems (Ebner *et al.* 2009; Kerezsy *et al.* 2011).

In the River Murray *variable flow channel recruitment* is known to occur for golden perch and silver perch and may be related to increased productivity associated with inundated riverine banks and benches (Mallen-Cooper and Stuart 2003; Zampatti and Leigh 2013). In the Darling River golden perch can spawn during low variable flows (Balcombe *et al.* 2006; Ebner *et al.* 2009).

Flooding is often a stimulus for reproduction of fish in floodplain rivers (Junk *et al.*, 1989) and this has been applied in the *flood recruitment* model in the Murray -Darling Basin (Ye, 2004). In the Murray system there is no evidence of large-bodied native species using ephemeral floodplains directly for spawning and recruitment in the Murray-Darling Basin (Humphries *et al*., 1999; King *et al*., 2003) it is highly likely that increased productivity from floodplain inundation benefits recruitment in the river system generally. There is, however, some evidence for floodplain spawning and recruitment in the Darling system, where small golden perch are frequently collected on the floodplain (Balcombe *et al.* 2006; Rolls and Wilson 2010; Sharpe 2011b).

Strong recruitment in some circa-annual and flow-cued spawners (i.e. Murray cod and golden perch) has been associated with overbank flows (Ye 2004; Rowland 1998; Ye and Zampatti, 2007) and, if floods coincide with spawning, food from the floodplain may be transported back into the river channel, enhancing recruitment directly. Nevertheless, the role of the floodplain and overbank flows in the recruitment ecology of large-bodied fish in the River Murray remains little explored and requires further investigation.

The one medium to large-bodied species that does use ephemeral floodplains directly for spawning and recruitment is the non-native common carp (Stuart and Jones 2006b). Spawning occurs on freshly inundated ground and recruitment is enhanced by flooding.

5.6 Using the Models to Explain the Present Abundance of Fish

Applying the models described above to the Gunbower - lower Loddon system, the present abundance and distribution of fish is largely determined by:

- scales of migration,
- fragmentation of habitats by weirs/regulators,
- connectivity,
- flow management, and
- habitat quality.

The *scale of migration* determines the extent that *fragmentation* and *connectivity* influence fish abundance. Gunbower Creek is "bookended" at the downstream and upstream ends with weirs that have no fishways (Fig. 7) which for fish disconnects the creek from the River Murray. Within Gunbower Creek the fragmentation of habitats is reduced by fishways at Gunbower Weir and Thompsons Weir which creates two connected reaches, of 55 km in the lower section and 105 km in the upper section. The most abundant native fish species at present – carp gudgeons, flat-headed gudgeon, and unspecked hardyhead - are species that appear to have small scales of movement/migration that are completed within these reaches, and have *generalist* (Table 2) habitat requirements.

The reaches of Gunbower Creek are not long enough to support self-sustaining populations of golden perch or silver perch, which have large scales of migration potentially to spawning aggregation sites (O'Connor *et al.* 2005); hence their populations are dependent on connectivity with the River Murray. At present Koondrook Weir has no fishway and is managed to have no end-of-system flow to the River Murray. Hence, the lower Gunbower Creek cannot be recolonized by fish migrating upstream from the River Murray. Fish that are migrating downstream from the River Murray can potentially enter the system via the inlet at the National Channel Regulator but this has undershot gates which cause high mortalities of larvae of golden perch, Murray cod and other species (Baumgartner *et al*. 2006). The low numbers of these species that are presently in Gunbower Creek are probably individuals that have come from upstream or entered during floods, rather than residents completing their life cycle.

Gunbower Creek has flowing (lotic) and stillwater (lentic) habitats in these reaches and has potential to support abundant self-sustaining populations (with spawning and recruitment) of small-bodied fish, catfish and possibly Murray cod and trout cod; however, in the non-irrigation season of winter, flow is stopped (Fig. 10) which results in overwintering habitats reduced to a small number of pools - many of which are shallow - with no littoral zone of macrophytes and no flowing habitats. In these conditions survival of young fish (i.e. recruitment) is poor.

The lower Loddon River to Box Creek Weir at Kow Swamp is the longest unfragmented reach in the Project Area, although Kerang Weir fishway needs modifications to operate optimally. The limitations for fish populations in this reach are that Pyramid Creek has very poor instream habitat and it has extremely low flows in winter; these two factors result in very poor overwintering habitat. The limitation for fish populations in the lower Loddon River is generally low flows so there is little attraction for fish to enter from the Murray; most flow passing down Pyramid Creek in the irrigation season passes through the Kerang weirpool and onto the Kerang Lakes irrigation system. The lower Loddon River has mainly pool-type (lentic) habitat with little hydrodynamic diversity, due to the low flows.

The absence of the native *off-channel specialists* – pygmy perch, flat-headed galaxias and southern purple-spotted gudgeon – is largely due to the reduced flooding frequency of the River Murray. This has led to the desiccation of small permanent wetlands, which are a key habitat.

6 IMPACTS ON FISH

6.1 Introduction

In the previous section the ecology of fish is described to identify the specific aspects that presently determine fish abundance. In this section this knowledge is used to identify the negative impacts on fish. Clarifying the impacts and threats enables the assessment of recovery potential and possible mitigation, providing the basis for the broader recovery strategy. It also enables opportunities to be identified and these are stated in each section where they occur.

6.2 Blocked Migrations

As described in the conceptual models all fish species move to some degree and it is a key life history trait that ensures high survival of young, dispersal and recolonisation. In the Gunbower lower-Loddon system there are impacts on longitudinal migrations along Gunbower Creek, Box-Pyramid Creek, into and out of Kow Swamp; and impacts on lateral migrations, into and out of wetlands, the forest floodplain, and out of irrigation channels. Barriers to migrations and movements limit connectivity which is a key characteristic of healthy aquatic ecosystems.

The scale of fish movements and migrations differs; for some species and life stages it may be only metres or kilometres but for many species it is over tens or hundreds of kilometres. If fish are moving over a small scale and those habitats are between barriers and within weirpools, then they are less impacted; examples of these species are carp gudgeons and un-specked hardyhead. However, some fish with small-scale movements which are between habitats that have barriers, such as regulators, can be severely impacted. Freshwater catfish may be an example of this type of movement, where juveniles dispersing from wetland habitats may be restricted by regulators. This would then reduce survival of these fish due to competition and reduce the opportunity for dispersal and population recovery of other sites.

Fish species with large-scale movements include the key species of golden perch, silver perch and Murray cod. These species are severely impacted by systems with multiple weirs. Golden perch and silver perch regularly move over hundreds of kilometres, usually to spawn and for recolonisation of upstream areas as yearlings; both species also have a drifting larvae stage. Murray cod shows varied movement - frequently moving over scales of kilometres and tens of kilometres, usually upstream before the spawning season and downstream afterwards. Some fish occasionally move over hundreds of kilometres whilst some fish remain within a small home range. Murray cod also have a drifting larvae stage.

Fishways have been constructed on Thompsons, Gunbower in Gunbower Creek and Kerang Weir on the lower Loddon River. However, barriers to migration remain at Koondrook Weir, Cohuna Weir and the National Channel Inlet Regulator in Gunbower Creek, Dehnes Weir and Taylors Creek Weir in Taylors Creek between Gunbower Creek and Kow Swamp, and at Box Creek Weir at the outlet of Kow Swamp (Fig. 7), which is currently funded under the G-MW Connections Project to have a new weir and fish lock constructed.

The cumulative effect of the weirs without fishways is to fragment creeks and other habitats into reaches that are at a scale where golden perch and silver perch cannot complete spawning migrations or recolonise from downstream areas, and dispersal of a range of species cannot occur. Murray cod movements are restricted, both for spawning and dispersal, and general connection with the River Murray is very poor, limiting dispersal and recolonisation from the larger riverine populations. Juveniles of these large-bodied species and many small-bodied fish species have active upstream dispersal migrations and accumulate below weirs which cause other impacts of increased competition and higher rates of predation.

Disconnection with the River Murray is one of the significant impacts on longitudinal migrations. In Gunbower Creek the downstream end has Koondrook Weir, which prevents fish entering from the river, but it is also has little or no end-of-system flow (see sec. 6.4.2) so there is little water and no stimulus for fish to enter. The lower Loddon system does not have a physical barrier downstream of Kerang Weir but it is highly regulated and there are long periods of low flow so, again, there is little stimulus for fish to enter this system.

Impacts on upstream migration are often considered at weirs but downstream migration is just as important and involves larval, juvenile and adult fish. Many native fish species have larvae that drift which is deliberate strategy to ensure young fish are distributed along a stream and into nursery habitats.

For fish moving downstream in the Gunbower - lower Loddon system there are three potential impacts: i) passage through undershot gates which causes high mortalities of larvae of golden perch, silver perch and Murray cod (Baumgartner *et al.* 2006) and adults of small-bodied species (Baumgartner pers. comm.), ii) diversion to irrigation channels, and iii) diversion to forests and stranding on the drying floodplain.

The main undershot gates that could impact on fish larvae are at the National Channel Inlet Regulator. Fish larvae have been detected drifting into the National Channel system (O'Connor *et al.* 2008a) and since all flow into the Gunbower system, under non-flood conditions, is via the National Channel Inlet Regulator this represents a major impact on native fish; but one that can be mitigated (see sec. 8.4.2.2). Cohuna and Koondrook weirs also have undershot gates that need to be evaluated. Other weirs in the system are low-level overshot designs with sufficient depth on the downstream side so the impact on downstream drifting larvae at these sites is likely to be minimal. Box Creek Weir has a shallow tailwater with potential impact for downstream-migrating fish but this is presently being re-designed to incorporate downstream fish passage.

Diversion of native fish into irrigation channels is a significant impact and is a specific area of fish passage with specific mitigation techniques (see sec. 6.3). It is of particular importance in this Plan as a significant aim is to integrate fish recovery with the existing irrigation infrastructure.

The impact of fish diverted onto flooded forests and blocked migrations is a complex issue. Larval drift onto forest floodplains is a natural process as there is a potentially high abundance of food for larvae. Adult fish also actively seek these flooded habitats for food. The risk for larvae and adult fish, however, is that they can become stranded as waters recede (Jones and Stuart 2008). Some level of mortality of fish in drying floodplains is natural and would contribute to carbon cycling on the floodplain. Managed inundations are the only situation where water levels on the floodplain and the response of fish can be controlled; for these a fish exit strategy has been developed to minimize fish stranding, particularly of adult fish (Mallen-Cooper M. *et al.* 2011).

The permanent wetlands (forest wetlands, billabongs and small off-channel wetlands) would have been isolated from the stream channel, under natural conditions, for many months each year. However, almost every year in spring they were connected and fish could move between these habitats and young fish could disperse. At present regulators are used to control flow to these wetlands and most of these, particularly in the upper Gunbower Creek system, are not designed for fish passage and thus block migration.

In summary, fish are highly mobile and the Gunbower - lower Loddon system needs to have connectivity within the system and with the River Murray to be productive for native fish. Providing fish passage, usually through fishways, is a key mitigation for blocked migrations.

Opportunity: Restoring blocked migrations through the use of fishways is very well established in Australia in the last 25 years, and has already been applied at sites in the Project Area.

6.3 Loss of fish into irrigation channels

Diversion of native fish into irrigation channels can include larval, juvenile and adult fish. Fish that are moving downstream with the current can pass passively into irrigation channels, as there is no specific cue that provides them with the information that one path leads to the irrigation channel and one path leads further down the stream. The exception to this may be adult fish that have migrated upstream, as these could follow the same track downstream.

Water usually enters a channel via a regulator with a flume gate, which does not provide for the return movement of fish upstream from the channel. The irrigation network diverts most of the water in Gunbower Creek and Box-Pyramid Creek, which passes to Kerang Lakes. In this diverted water there is a significant loss of downstream-migrating fish into these systems from which there is little chance of return. There are, however, established techniques to mitigate this impact (see sec. 8.5).

Opportunity: Loss of fish into channels is a worldwide issue in irrigation areas where freshwater fish are present. The technology to address this issue, mainly simple self-cleaning screens, is well established.

6.4 Flow

6.4.1 Low winter flow

Under natural conditions there was high flow in winter in Gunbower Creek and Box-Pyramid Creek and zero to low flows occurred in late summer and autumn. Under present irrigation practices, zero to low flows now occur in winter (see sec. 3.5.1). Water levels during winter are held at high levels in the Koondrook and Cohuna weirpools with no passing flow. The objective is to manage loss of water from the system and use less water in filing the weirpools at the start of the irrigation season. Operationally this means that Koondrook and Cohuna Weirs are held at 10-30 cm below the full supply level. The absence of passing flow results in some reaches of the creek, especially downstream of Gunbower and Cohuna weirs, being almost empty in winter. In addition, water from Gunbower Weir can be drained into Kow Swamp to reduce loss to the Gunbower Creek system, leaving this weir pool at approximately 50% of full supply depth (Anderson et al. 2007). In Box-Pyramid Creek there are only very shallow pools along most of its length at the low winter flows, with the deeper Kerang weirpool at the downstream end.

Minimising flow in Gunbower and Box-Pyramid creeks in winter has a detrimental impact on the native fish population. The first winter for juveniles of native fish, especially large-bodied fish, is a stressful period which, under natural conditions with high flow, had more habitats available and more access to food. With the creek reduced to pools in winter and little or no passing flow, the habitats are fewer, have poorer quality and less diversity, including an unvegetated littoral zone (Fig. 31, Fig. 32).

Fig. 31. Gunbower Creek downstream of Cohuna with typical spring/summer flow.

Fig. 32. Gunbower Creek downstream of Cohuna with zero flow in winter.

The low winter flows increases the risk of fish being concentrated or stranded in pools of a drying reach. Fish are then exposed to high mortality from anglers and avian predators, while there is also increased competition for less food and increasing risks of poor water quality and disease.

In these conditions young fish have high mortality. Even if there is successful spawning and larvae initially survive the spring and summer, the present winter conditions in Gunbower Creek and Box-Pyramid Creek do not favour survival of these young fish and ongoing population growth. Winter is also the time when large-bodied fish are beginning to develop ovaries for spring spawning and hence continuity of food supply is important for optimal gonad production.

Opportunities: i) Providing a base flow in winter would have little conflict with irrigation use.

ii) A particular opportunity for the Gunbower - lower Loddon system is that providing winter flow would not use much water. Water is not lost to the River Murray system but returns to the River Murray either via Gunbower Creek or the lower Loddon River; the only water used would be channel losses in winter.

iii) Providing flow in winter has the added benefits of contributing to longitudinal connectivity (i.e. improving *blocked migrations* [sec. 6.2], *end-of-system flow* [sec 6.4.2]) and *hydrodynamic diversity* (sec. [6.4.6]).

6.4.2 End-of-system flow

Gunbower Creek is operated as a terminal system to deliver water for irrigation so there is rarely any end-of-system flow past Koondrook Weir to the River Murray. The exceptions are when there is high local rainfall or "rain rejections" (when irrigation water is ordered but not needed due to local rain). Hence, for the vast majority of the time is no stimulus for fish to enter the lower Gunbower Creek and continue into the system. As discussed earlier, there is also no fishway at Koondrook Weir so even if flow is present fish cannot migrate past the weir.

The reach of Gunbower Creek downstream of Koondrook Weir that has backwater from the River Murray is noted for its populations of large-bodied fish species, which is likely due to fish having direct access to the main river and the high density of complex, instream woody habitat and riparian vegetation (Anderson *et al.* 2007b).

The lower Loddon River also suffers from a lack of end-of-system flow due to storage and diversion upstream for irrigation. Unlike Gunbower Creek, it generally has continuous low flow in summer, except in the last drought. The minimum environmental flow entitlements for the lower Loddon River are 7-12 ML/d and up to 61 ML/d if the upstream storages are above 61,000 ML (Sharpe *et al.* 2010). The low flows in spring in a wet decade are frequently 100 to 200 ML/d but this is still a very low flow in a river channel that is 40 m wide and provides poor attraction for fish to enter the system.

Providing end-of-system flow with fish passage in Gunbower Creek is a key to the recovery of native fish populations in the Project Area and providing more flow in the lower Loddon River will provide much greater opportunity for fish to enter the system.

Opportunities: i) As for *low winter flow* above, providing *end-of-system flow* would not use much water because it would be returned to the River Murray system; again, only channel losses would be used.

ii) Providing *end-of-system flow* has the added benefits of contributing to longitudinal connectivity (i.e. improving *blocked migrations* [sec. 6.2]), *low winter flow* [sec 6.4.1]) and *reduced hydrodynamic diversity* (sec. [6.4.56]).

iii) Maintaining a passing flow would help maintain water quality in the channel and promote productivity and macroinvertebrate populations, which are the basis of a healthy ecosystem.

iv) Maintaining flow in Gunbower Creek would add 5 km of stream habitat between Koondrook Weir and the River Murray.

v) Re-routing water to the lower Loddon River, via the National Channel, Kow Swamp and Box Creek, would greatly improve river health of the lower Loddon River and help meet a range of river health objectives that cannot be met with the available storage in the upper Loddon catchment.

6.4.3 Reduced Flooding Frequency

As described earlier (sec. 3.5.2) the frequency of flooding in the River Murray has been reduced due to storage and regulation of flow. Overbank flooding is associated with an increase in primary productivity and zooplankton, which provides suitable conditions for high survival of fish larvae and subsequent recruitment; this is often referred to as the *flood recruitment model* (see sec. 5.5). Floodplains have degraded as a result of reduced flooding and they now provide a less productive environment, with subsequent impacts on the survival of young native fish.

Opportunities: i) The new Living Murray infrastructure in Gunbower Island will enable the forest floodplain to be rehabilitated and become more productive in natural floods. Infrastructure can also be used to extend the flood duration in the forest, on a local scale, which may benefit native fish species.

ii) Improving flow to the forest has the added benefits of contributing to lateral connectivity (i.e. improving *blocked migrations*) [sec. 6.2], *loss of small permanent wetland habitats* (6.4.4), and *end-of-system* flow (6.4.2).

6.4.4 Loss of small permanent wetland habitats

Apart for the large wetlands and large forest floodplain there are small permanent wetlands, such as Smith Swamp and Barton Swamp, that only require river flows of 13,700 ML/d to be “topped-up” (see sec. 3.5.2). Modelled flow data suggests that under natural conditions these flows occurred 49 out of 50 years but these habitats were permanently dry for many years in the Millennium Drought (2000-10). Despite the severity of the drought these wetlands would have received water every year except one, if there were no abstraction or storage of water (data from MDBA).

These small wetlands were confirmed habitats of pygmy perch in the 1990s (Michael Hammer, University of Adelaide, pers. comm., Tarmo Raadik, Victorian Department of Environment and Primary Industries pers.comm.) and likely habitats of flat-headed galaxias and possibly purple-spotted gudgeon; these are all small-bodied, threatened species. The loss of these habitats has had a direct impact on these species.

Opportunities: i) Some of these small permanent wetland habitats have already been identified.

ii) New Living Murray infrastructure of forest regulators provides the opportunity to re-create these habitats.

iii) Low environmental flows are required to re-create and maintain these small permanent habitats.

iv) Breeding programs for most of the threatened species (southern pygmy perch, olive perchlet and purple-spotted gudgeon) have recently been established (Martin Asmus, NSW DPI Fisheries, pers. com., Michael Hammer, University of Adelaide, pers. comm.) and flat-headed galaxias be easily translocated from other populations.

6.4.5 Management of permanent billabongs (lagoons)

The permanent billabongs or lagoons (also called ox-bow lakes) in the upper Gunbower Creek are known habitats of freshwater catfish, which is a threatened species (Rehwinkel and Sharpe 2009). Flows into these billabongs are controlled through regulators which also restrict movement of catfish, especially dispersal to other habitats.

Some of the billabongs are used for irrigation and their management is presently being reviewed in the light of water savings. One option is to not provide flow to specific lagoons that do not have catfish, and let them dry out. This management option also needs to consider:

i) surveys of catfish may not have detected all the populations, and
ii) the potential habitat of billabongs that may not have catfish, and whether they could expand the present catfish population, acknowledging that dispersal between them is presently highly restricted by the regulators.
iii) in billabongs with catfish provide a managed spring spawning hydrograph, with a small rise and a stable flat peak to initiate nesting, spawning and recruitment. Increasing localised recruitment will aid the other recovery actions.

Opportunity: The existing freshwater catfish populations can be source populations for recovery of this species in the region.

6.4.6 Reduced hydrodynamic diversity

Hydrodynamic diversity generally refers to the range of fast- and slow-flowing reaches along a stream length; it is created by flow, variation in channel shape, structural complexity (e.g. woody debris, rocks, gravels, aquatic plants) and stream gradient. More flow creates more complexity and based on the natural seasonality of River Murray flow there was more hydrodynamic complexity in winter and spring.

Prior to weirs and regulation of flow, the River Murray and most anabranches had diverse hydrodynamics, with fast-flowing sections interspersed with slow-flowing reaches with large amounts of woody debris and well-developed littoral zones. Weirs reduce this diversity by creating pools, which decrease fast-flowing reaches and create still or very slow flowing habitats. This favours some common small-bodied native fish species such as carp gudgeons and un-specked hardyhead, as well as non-native fish, but is poor habitat for most large- and medium-bodied native fish.

Adult Murray cod will use and spawn in a range of habitats, including weirpools, but survival of larvae and young fish is far greater where there are fast-flowing reaches with hydrodynamic diversity. Where these conditions occur in the River Murray and they are combined with connectivity, so that migrations and movements are not blocked, there are usually abundant Murray cod populations. Where there is hydrodynamic diversity and connectivity over a large scale (100s of km) golden perch and silver perch are more abundant.

In the Gunbower - lower Loddon system the loss of hydrodynamic diversity is caused by weirpools, particularly in Gunbower Creek, low flows in winter, and past desnagging, especially in Box-Pyramid Creek.

Opportunities: i) The upper reaches of weirpools in Gunbower Creek retain some hydrodynamic diversity (Fig. 13).

ii) Hydrodynamic diversity can be enhanced in Gunbower Creek by increasing passing flows through the system (Fig. 13), which would also improve *end-of-system flows* (6.4.2).

iii) Lowering weirpools, whilst maintaining or increasing flow would create hydrodynamic diversity. This could be done in the non-irrigation season or at other times depending on irrigation demands.

iv) It may be possible to operate Gunbower Creek passing higher, more stable, flows and meet all irrigation demands by regulating the offtakes; then as irrigation demand fluctuated the balance would be released to the River Murray, along with a base *end-of-system* flow.

The same strategy might apply to Box-Pyramid Creek: passing higher, more stable, flows and meeting all irrigation demands by regulating the Washpen Creek Offtake to the Kerang Lakes; and passing the balance from irrigation via Kerang Weir to provide *end-of-system* flow in the lower Loddon.

v) Re-snagging would improve hydrodynamic diversity, especially in Box-Pyramid Creek, and is a complementary mitigation for *loss and degradation of habitat* (sec 6.5).

6.4.7 Changed seasonality

The analysis of hydrology (Sec. 3.5) showed that under natural conditions the River Murray and adjacent anabranches had high winter/spring flows and low summer/autumn flows. Flows in Gunbower Creek and Box-Pyramid Creek show a different trend with low winter flows and high spring/summer/autumn flows. As discussed earlier, the low winter flows (sec. 6.4.1) are detrimental to fish. The higher spring flows coincide with natural seasonality but the absence of low summer flows probably reduces productivity and larval survival as the natural low flows would concentrate food resources. Of the two impacts, the low winter flow is likely to be more severe.

Opportunities: The component of *changed seasonality* that potentially can be readily restored are the low winter flows. As discussed earlier (6.4.1), restoration of these flows would:

- have little conflict with irrigation use;
- be returned to the River Murray;
- have added benefits of improving *blocked migrations* [sec. 6.2], *end-of-system flow* [sec 6.4.2]) and *hydrodynamic diversity* (sec. [6.4.6]).

6.4.8 Short-term hydrological variation

The analysis of hydrology (Sec. 3.5) showed that under natural conditions the water levels of the River Murray and anabranches like Gunbower Creek and Box-Pyramid Creek rose or fell over days and weeks. There are now short-term oscillations in these two streams to meet irrigation needs. This would inhibit growth of the littoral zone and aquatic plants, which are nursery areas for fish larvae.

Opportunities: i) Providing a more natural variation, which could be done winter, when there is no irrigation demand.

ii) As discussed for improving *hydrodynamics diversity* (6.4.6), it may be possible to operate Gunbower Creek and Box-Pyramid Creek by passing higher, more stable, flows and meet all irrigation demands by regulating the offtakes and passing the surplus as *end-of-system* flow.

iii) A more natural hydrological variation would help improve the littoral zone and reduce *degradation of habitat* (sec. 6.5).

6.5 Loss and Degradation of Habitat

Loss and degradation of habitat in the Project Area is a result of past and present management practices in three main areas:

i) Removal of instream woody habitat or 'snags' to improve channel capacity.

This has occurred over a long period of time in the past, especially in Box-Pyramid creek where most of the instream woody habitat has been removed (Kitchingman *et al.* 2012) and also in the lower Loddon River (Sharpe *et al.* 2010). Instream woody habitat is currently rarely removed from waterways.

ii) Degradation of the littoral and riparian zone.

The main past and ongoing impact on the littoral or stream-edge zone is grazing by cattle, whilst a past impact has been clearing of riparian vegetation.

iii) Siltation.

Siltation of deep holes and channels in streams is a partly a result of over a century of land clearing. A particular impact in the Project Area has been siltation of the lower Loddon River due to the dredging of Pyramid Creek in the 1960s, and reduced flow.

Instream woody habitat provides hydrodynamic diversity by breaking up the flow pattern, creating areas of different velocities and making more turbulent flow rather than more laminar flow. This diversity encourages a wide range of native fish species, but appears particularly important for large- and medium-bodied fish species such as Murray cod and golden perch. Instream woody habitat creates velocity refuges where small-bodied fish can harbour and equally where predators can wait for prey. Instream woody habitat is also directly used for spawning by Murray cod.

The littoral or edge zone often has aquatic macrophytes and emergent plants, forming an important nursery zone for larvae of many native fish species. Clearing of riparian vegetation has an indirect impact on fish and habitat. Dense overhanging vegetation is a source of terrestrial food for fish (e.g. insects, juvenile birds, etc.) as well as providing shade. Riparian vegetation is a periodic source of instream woody habitat and a constant source of carbon, which underpins stream productivity.

Siltation reduces depth, channel variability and produces uniform fine streambed material. As different species have different habitat preferences, a reduction in habitat variability reduces biodiversity. Some native fish species have specific spawning requirements for streambed material and siltation can bury spawning sites. A variety of substrate also produces a variety of invertebrates and plankton, providing a diverse food source for different life stages of fish.

Opportunity: i) Re-snagging programs have been successful in the River Murray, the upper Loddon and nearby Broken Creek and could be readily applied to the Project Area.

ii) Reducing grazing of littoral zones through fencing and providing alternative watering points are established techniques of river rehabilitation.

iii) Improving end-of-system flows and winter flows, combined with re-snagging, would help re-create some channel (geomorphic) variability where channels have become silted.

6.6 Non-native species

Six species of non-native fish have invaded and formed self-sustaining populations in Gunbower - lower Loddon system. This includes redfin perch which were introduced to Victoria almost 150 years ago to more recent invaders, such as Oriental weatherloach which began their invasion into Victoria in the 1980s. Perhaps the best-known non-native fish are carp, which inhabit all aquatic habitats at Gunbower and commonly use the floodplain for breeding. Gambusia are another pest fish which are commonly found and whose impacts on native fish are only recently being understood (Macdonald and Tonkin 2008; Macdonald *et al.* 2012). Two other non-native fish are in very low abundance (brown trout and tench) and are unlikely to significantly increase in biomass. The last non-native species is goldfish, which are common but much less destructive than carp.

The success of non-native fish in Australia is due to competitive aspects of their biology (long life-span, such as 30 years for carp), human-made habitat changes (i.e. regulated rivers) that provide them with good conditions and poorer conditions for native fish, combined with few diseases and relatively few predators. Most non-native fish produce large numbers of eggs and can breed several times a year. Hence they can rapidly recover their numbers following drought or control operations. Non-native fish very probably damage the health of the native fish fauna of the Murray-Darling Basin and the Gunbower - lower Loddon system but the extent of the impacts are often unclear.

Opportunities: i) Providing fishways (see *blocked migrations,* sec. 6.2) provides the opportunity to harvest carp using carp-selective traps (Stuart *et al.* 2006).

ii) Managed inundations of the forest using Living Murray infrastructure could be used to inhibit carp movements or recruitment (although this is also a risk).

6.7 Illegal fishing

The extent and impact of illegal fishing in the Kow Swamp and Box-Pyramid Creek areas is not known. Reports from DEPI Fisheries officers do, however, indicate that these areas are poaching 'hot spots', particularly when there is a high flow release in Box-Pyramid Creek and the fish are moving upstream (Gary Hodges, Victorian DEPI Fisheries, pers. com.). Poachers often deploy illegal drum nets or traps to take Murray cod out of season, or to exceed bag limits (DPI 2004). Many illegal traps were observed during a recent high definition sonar study to map fish habitat in Pyramid Creek (Zeb Tonkin, Arthur Rylah Institute, pers. comm.).

Opportunity: A regional *Native Fish Recovery Plan – Gunbower and Lower Loddon* led by the community would increase community awareness of this issue and may increase reporting.

6.8 Stocking

DEPI Fisheries heavily stock Kow Swamp. In April 2012 100,000 Murray cod were released and another 100,000 will follow in both 2013 and 2014. In addition, 20,000 Murray cod and 30,000 golden perch are released annually in the Gunbower system. In Kow Swamp, DEPI Fisheries have targeted a stocking rate of 36 fish/ha, which is the greatest density in Victoria (DPI 2011).

Stocking is important for recreational fishing, where natural populations are not self-sustaining, and for recovery of threatened native fish, but it can also have a significant negative impact. Stocking can reduce the genetic diversity of the population by using too few parent stock. It can also dilute the genes in the naturally occurring population, which may be lost over time with repeated stocking. If broodstock are not chosen from local populations, stocking can also bring in genes that are not native to the area, potentially changing the local gene pool.

A reduction in genetic diversity can also occur naturally because of mixing of distinct populations or by using too few parent stock (Moore et al. 2010). The effects of this introgression are largely unknown but at least Murray cod appear not to be impacted (Rourke et al 2007). Hatchery management protocols, therefore, aim to prevent loss of genetic diversity but there is little pre-stocking genetic information for Gunbower Creek, Kow Swamp or Box-Pyramid creek. There has been some recent genetic study of freshwater catfish in Gunbower Creek lagoons and other sites in Victoria which suggest there is differentiation between sites (Louissa Rogers, North Central CMA, pers.comm.), although this differs from other findings suggesting that catfish genetics in the Murray-Darling Basin were relatively uniform (Rourke *et al.* 2010). To be prudent, stocking of freshwater catfish should not be done until the genetics are clarified.

In the nearby Kerang Lakes, chemically marked golden perch fingerlings contributed to the lake populations by 47 ± 9% (mean ± SE) at Reedy Lake, 55 ± 9% at Kangaroo Lake, and 90 ± 5% at Lake Charm (Hunt *et al.* 2010). The contribution of stocked fish appeared to decline with increasing connection to the Loddon River. There are too few data for golden perch or Murray cod in Kow Swamp to form a reliable estimate of the proportion of stocked fish in the population.

Despite considerable uncertainty, the larval and fish survey data for Gunbower Creek indicate that golden perch populations are maintained by stocking but it is unclear to what degree stocking or natural spawning maintains Murray cod. Fish recovery programs for fish often highlight the fact that stocking masks the natural recruitment rate and can prevent or make difficult long-term population recovery. New research is underway to mass mark fingerling native fish to help evaluate stocking programs and understand natural recruitment dynamics (Crook et al 2009; Hunt et al. 2010).

Opportunity:	The aim of the *Native Fish Recovery Plan – Gunbower and Lower Loddon* is to have self-sustaining native fish populations. The present high stocking rate is a reflection of the present impacts on native fish that the Plan aims to address. As native fish populations recover, reliance on stocking would be reduced.

6.9 Overlapping Impacts – Overlapping Opportunities

Many of the impacts above are interlinked and addressing one impact does not necessarily mitigate the impact. For example, restoring blocked migrations at Koondrook Weir with a fishway would do little to restore fish migration without end-of-system flow to stimulate fish to enter Gunbower Creek. Equally, restoring winter flow to Box-Pyramid Creek would provide some benefit but this would multiplied many times by adding habitat (e.g. snags and riparian vegetation). Hence, there are dependencies among the impacts and cumulative benefits.

The flip side to these dependencies is that mitigating one impact can have multiple benefits as well. Table 5 shows that in all cases except *stocking*, addressing an impact also contributes to addressing other impacts. The dependencies and how these affect the recovery strategy are discussed in Section 8.

Table 5. Interdependencies of impacts showing multiple benefits when an action is addressed.

IMPACT ADDRESSED	**COMPLEMENTARY IMPACT ADDRESSED**													
	Blocked migrations	Loss of fish in irrigation channels	Low winter flow	End-of-system flow	Reduced flooding frequency	Loss of small permanent wetlands	Management of permanent billabongs	Hydrodynamic diversity	Changed seasonality	Hydrological variability	Degradation of habitat	Non-native fish	Illegal Fishing	Stocking
Blocked migrations			■	■	■	■	■	■	■			■	■	
Loss of fish in irrigation channels														
Low winter flow	■			■				■	■	■	■		■	
End-of-system flow	■		■		■			■	■	■	■	■		
Reduced flooding frequency	■			■		■	■	■	■	■	■			
Loss of small permanent wetlands	■				■				■		■			
Management of permanent billabongs	■				■									
Hydrodynamic diversity	■		■	■	■				■	■	■	■		
Changed seasonality	■		■	■	■	■		■				■		
Hydrological variability			■	■	■			■			■			
Degradation of habitats			■	■	■	■		■		■		■		
Non-native species	■			■				■	■		■			
Illegal fishing	■		■											
Stocking														

7 POTENTIAL FOR RECOVERY OF FISH POPULATIONS

7.1 Introduction

The previous sections have described a region that is typical of an irrigation area that has developed over the last 130 years and has become depauperate in native fish due to several impacts, most of which were unknown during the intensive phases of development. The question now is: “to what extent can these fish populations be recovered?” This section describes the recovery potential by examining: the fish ecology of the species that are present, threatened and locally extinct; regional populations of fish; unique features of the habitats; and opportunities to control non-native species. The section concludes with an assessment of predicted population changes for each species, if all impacts were addressed.

7.2 Fish Ecology

7.2.1 Present native species

The present native fish species assemblage provides an indication of what the existing habitats and flow regime can support and of the potential to support greater fish abundances and diversity. Of the 22 native fish species that were historically present or expected to occur in the past, 13 species are still present, whilst the remaining nine species are considered locally extinct (Table 6). Some small-bodied fish species are still common but the abundance of the medium- and large-bodied native fish are low for most of the Project Area but moderate in Kow Swamp, which is heavily stocked.

Kow Swamp had abundant native fish in the past[1] and supported a commercial fishery based on natural populations for many years. It is often cited as the location where the largest golden perch (50 pounds, 22.6 kg) ever recorded was collected in 1938. Presently Kow Swamp still supports a strong golden perch, redfin and carp angling fishery with reasonable numbers of silver perch and small numbers of Murray cod (Hunt *et al*. 2010). However, the extent that the golden perch are natural populations or a result of stocking is unknown.

In late 2010 during drought-breaking flows, abundant golden perch and silver perch were observed below the Kow Swamp outlet (Box Creek Weir) (I. Stuart, pers. comm.). These fish were very likely migrating upstream from the River Murray, lower Loddon River or Kerang Lakes, indicating the abundance of these fish on a regional scale and the recolonisation potential if fish passage was present at Box Creek Weir. Similar observations of high densities of native fish below Koondrook Weir were made during high flow releases (Sharpe 2011a), showing the same recolonisation potential for those species that are highly migratory.

There are six threatened species present in the Project Area, which are extremely valuable assets, and these are discussed in detail in the next section (sec. 7.2.2).

Recovery Potential:	The existing populations of native fish and the accumulations of fish trying to get into the system during high flows show that: i) there is major potential to support high abundance of native fish and that, ii) recovery of some species could be rapid.

1 Bendigo Advertiser (Vic.: 1855-1918), 14 Dec 1914, page 5.

Table 6. Fish species presence in the Gunbower - lower Loddon Region, and in adjoining systems, based on recent records. Species shaded in orange are threatened (*[N] Nationally threatened species, *[V] Victorian threatened species).

	PROJECT AREA					ADJOINING SYSTEMS		
	NOW ABSENT	**Gunbower Creek and wetlands**	**Kow Swamp**	**Pyramid Creek**	**Lower Loddon River**	**Kerang Lakes**	**Little River Murray**	**Mid-River Murray**
NATIVE								
Large-bodied (500-1000 mm)								
Murray cod*[N]		•	•	•	•	•	•	•
Trout cod*[N]		•	•					
Medium-bodied (90-500mm)								
Golden perch		•	•	•	•	•	•	•
Silver perch*[V]		•	•	•	•	•	•	•
Freshwater catfish*[V]		•				•	•	•
Bony herring		•	•	•	•	•	•	•
River blackfish	X							
Macquarie perch*[N]	X							
Short-headed lamprey	X							•
Shortfinned eel	X							•
Small-bodied (20-90 mm)								
Carp gudgeons		•	•	•	•	•	•	•
Flat-headed gudgeon		•	•	•	•	•	•	•
Un-specked hardyhead*[V]		•	•		•	•	•	•
Australian smelt		•	•		•	•	•	•
Dwarf flat-headed gudgeon		•	•		•	•	•	•
Murray–Darling rainbowfish*[V]		•	•		•	•	•	•
Southern pygmy perch*[V]	X							•
Southern purple-spotted gudgeon*[V]	X							
Flat-headed galaxias*[V]	X							•
Olive perchlet*[V]	X							
Murray hardyhead*[N]	X					•		
Obscure galaxias (*Galaxias* sp1)					•			
NON-NATIVE								
Carp		•	•	•	•		•	•
Eastern gambusia		•	•	•	•		•	•
Goldfish		•	•	•	•		•	•
Redfin perch		•	•	•	•		•	•
Oriental weatherloach		•			•			•
Tench		•		•	•		•	•
Brown trout					•			•

7.2.2 Residual populations of threatened species

Despite the impacts of flow regulation on reduced flooding, habitat changes and barriers to migration, the Gunbower - lower Loddon River retain some key populations of six threatened fish species. Two of these are nationally threatened and four are listed as threatened in Victoria (Table 6). Most are in very low abundance and can be considered residual populations which are under significant threat within the Project Area. They do, however, indicate the suitability and diversity of habitats present in the Project Area and the recovery potential if present impacts are mitigated.

The following is a summary of their status in the Project Area:

Trout cod. Recorded in lower Gunbower Creek in 2008 and more recently in the River Murray near Koondrook and below Taylors Creek Weir (in Kow Swamp) (Fig. 30, Gary Hodges, Fisheries Victoria, pers. com.). Trout cod are very rarely collected in the adjacent River Murray, having only a few strongholds where populations remain intact. The population in the Project Area is extremely fragmented, with only a few individuals having been collected in past decades. There is a relatively robust population in the River Murray upstream of Barmah, approximately 200 km away. Trout cod have not been recorded in the lower Loddon River.

Murray cod. Present at very low abundance compared to historical levels. Has recently been recorded in Gunbower Creek, River Murray, Kow Swamp, Pyramid Creek and the Loddon River downstream of the Kerang Weir. Populations are fragmented with limited size classes present. The population in Gunbower Creek has low numbers and only a few individuals were recorded in the most recent 2013 survey (Sharpe et al. 2013). It is present in the River Murray, although in low abundance.

Silver perch. Present at low abundance relative to historical levels. Populations are fragmented in size and age structure. Has only been found in Box-Pyramid Creek, Kow Swamp, Gunbower Creek and the lower Loddon; not recorded in Forest wetlands or Gunbower Lagoons. Large aggregations of juveniles have been observed below Koondrook Weir during a spring/summer spill event (Sharpe 2011a). Population in the adjacent River Murray is one the most robust in the Murray - Darling Basin. High potential for recolonisation of the Project Area.

Freshwater catfish. Present at very low abundance relative to historical levels. Populations are restricted to a few of the Gunbower Lagoons (e.g. Turner, Phyland, Cockatoo) and has never been recorded in Gunbower Creek, Pyramid Creek or the lower Loddon from monitoring surveys. The populations in Turner and Phyland lagoons appear to be recruiting, although abundances are overall very low relative to other areas (Rehwinkel and Sharpe 2009; Sharpe *et al* 2013)). Their localised distribution makes them highly vulnerable to disturbance such as pollution, drying of a lagoon ore recruitment failure. These freshwater catfish populations have high conservation value. They are particularly significant as a breeding population that may act as a source for repopulating broader areas, either by adult movement or by juvenile dispersal. Catfish are also present in the Little Murray River and River Murray, and are occasionally recorded ascending Torrumbarry fishway (Mallen-Cooper 1999).

Un-specked hardyhead. Are common in Gunbower Creek and lagoon (billabong) habitats where the species has increased in abundance since 2009. Common in forest wetlands until 2010 but now absent there after flooding and poor water quality (blackwater). Creek and lagoon populations are robust and will serve as important source populations for recolonisation of wetlands. It is common in the adjacent River Murray. In the 2014 VEFMAP survey a single Un-specked hardyhead was recorded in the Loddon River downstream of the Kerang Weir, a first record for this species in the Loddon catchment (Hale and Sharpe 2014).

Murray-Darling rainbowfish. Infrequently encountered, but most common in lagoons relative to other habitats. Lagoon populations appear to be stable, albeit fragmented in population structure and with relatively low abundances compared to other regions where the species is common. Can be common in some areas of the River Murray. It has also been recently recorded in the lower Loddon, however not in Pyramid Creek.

Recovery Potential:

i) The existing populations of threatened native fish show that there is presently suitable habitat in some locations.

ii) The analysis of fish ecology (sec. 5) shows that the suitable habitat attributes – connectivity, overwintering flows, habitats and flow regimes for the survival of larvae and young-of-year - can be significantly enhanced to improve these populations.

iii) The existing populations can provide source populations for rehabilitation.

iv) Rehabilitated populations of threatened species could provide source populations for the region.

7.2.3 Locally extinct species with potential for recovery

Examining the past fish diversity and comparing it to the present provides a perspective on the potential of the habitats in the Project Area. In the past 60 years the Gunbower - lower Loddon region, like most other areas of the Murray-Darling Basin, has suffered a serious decline in the distribution and abundance of native fish. Of the 22 native fish species predicted to occur in the Project Area, nine are now no longer found and of these, six are threatened species (Table 6).

Shortheaded lamprey prefer the main channel habitat of the River Murray and were possibly always uncommon in the Project Area. Up to the 1950s Macquarie perch were common upstream of Echuca, including the anabranches and creeks of Barmah Forest, and present at Cohuna and along the River Murray near Gunbower (Trueman 2012). Shortfinned eel migrate upstream from the sea; their abundance prior to the locks and weirs on the River Murray is uncertain but they were not known in the area in 1950 (Cadwallader 1977). River blackfish were also not known or recorded in Gunbower Creek or the lower Loddon River in 1950, but were abundant at Barmah Forest upstream (Cadwallader 1977) and presently remain in the upper Loddon River and the upper River Murray upstream of Yarrawonga.

There are five small-bodied species that are locally extinct. Murray hardyhead has a specific habitat requirement of more saline waters. It is found in the Kerang Lakes system but is unlikely to have been common in the Project Area.

Olive perchlet was not known upstream of the junction with the Murrumbidgee River but is likely to have been present as the habitats are similar. Olive perchlet is now rarely recorded in the southern Murray-Darling Basin and is extremely rare in the Murray drainage. Olive perchlet were recently re-discovered in the Lachlan catchment but appears extinct in Victoria and South Australia (Lintermans

2007). Re-introduction of the Lachlan River olive perchlet in southern NSW waterways alongside the Murray drainage appears to have been largely successful (Martin Asmus, NSW DPI, pers. com.). This suggests that reintroduction into the Project Area would have a high probability of success.

The other three small species (southern pygmy perch, flat-headed galaxias, and southern purple-spotted gudgeon) could have been common. In 1950 Langtry (Cadwallader 1977) reported “Pigmy perch [sic], which move in shoals, appear to abound throughout the whole Murray system”. He also stated that “galaxids . . . have been taken throughout the system”; these were reported as common galaxias but are much more likely to be flat-headed galaxias as the former species is coastal, not migrating far from the sea. The Project Area is within the historical range of purple-spotted gudgeon; although it was never recorded as common along this reach of the River Murray, it is a cryptic species. In the southern Murray-Darling Basin purple-spotted gudgeon is now found only in small isolated habitats in South Australia and in some rivers of NSW (Lintermans 2007).

Southern pygmy perch and flat-headed galaxias are presently uncommon in the middle Murray. Southern pygmy perch are present upstream in Barmah Forest (Tonkin *et al.* 2008) but not in the adjacent Millewa Forest where they recorded up till 2009 (Sharpe and Wilson 2012), whilst flat-headed galaxias can be found in billabongs and slow-flowing streams upstream of Barmah. The habitats in the Project Area are similar to these other sites and hence there is high potential to establish self-sustaining populations of these species through initial reintroductions. Less is known of the habitat requirements of purple-spotted gudgeon on the River Murray but they have been found in adjacent lagoons and there is also potential to reintroduce this species.

Recovery Potential:

i) Macquarie perch, shortheaded lamprey, shortfinned eel, and river blackfish appear not to have been abundant in the Project Area in the past and hence, do not to have significant potential for establishing new populations or recovery.

ii) Olive perchlet, southern pygmy perch and flat-headed galaxias have high potential for recovery, while less is known about southern purple-spotted gudgeon

iii) Breeding programs of southern pygmy perch and southern purple-spotted gudgeon are established and these species can be easily reintroduced.

iv) Flat-headed galaxias can be easily translocated (Llewellyn 2005) and reintroduced.

7.2.4 Nearby fish populations; potential for recolonisation

Rehabilitation of depleted fish populations depends on the presence of nearby populations that can recolonise or alternatively, a source of fish that can be translocated or stocked. Recolonising by providing connectivity and habitat is preferable as it provides diverse wild genetics of all species and is a permanent sustainable solution.

A perspective of the regional fish populations provides an insight into the recovery potential of fish populations through recolonisation. If they are present regionally but not in the Project Area then there is potential for recolonisation if the impacts that caused the original declines are addressed.

The Murray Valley region has a fish assemblage of eighteen native fish species and seven exotic fish species (Table 6). As described above, the native fish species of the region include four nationally threatened fish species and eight species listed in Victoria as threatened. In the upper Loddon system there are also significant populations of river blackfish and obscure galaxias (Galaxias sp1) (Data courtesy of the Victorian Sustainable Rivers Audit Project Fish. Freshwater Ecology, Arthur Rylah Institute for Environmental Research, Melbourne). The nearby Kerang Lakes have the nationally threatened Murray hardyhead but, as described above, the habitat in the Project Area is generally unsuitable.

The River Murray is a source of juvenile silver perch and golden perch, fish that move and recruit at landscape scales. The Basin Plan also proposes to restore a greater frequency of small to medium floods (i.e. 20,000 to 40,000 ML/d) which may greatly enhance recruitment of riverine and floodplain fish species.

The Murray Fishway Program restores fish passage to the River Murray at 14 weirs and was competed in 2014 (Barrett and Mallen-Cooper 2006). It is likely that this will also influence fish in the Gunbower - lower Loddon system, with much greater passage rates of fish travelling between feeding and spawning habitats. One of these will be lampreys, moving from the southern ocean, upstream to find the sandy substrates and clear fast flowing waters of the upper Murray to complete their once in a life-time spawning effort.

The River Murray below Torrumbarry is one of few river reaches where the nationally listed silver perch are still common (Mallen-Cooper and Stuart 2003). This river reach is the longest unfragmented river reach in the Murray-Darling Basin and it retains a natural seasonality of flows, albeit with reduced total flow, as well as relatively intact in-stream habitat. Freshwater catfish and Murray cod are reasonably common in this reach, as well as the same species complement of small-bodied fish that occur in the Project Area. The highly mobile golden perch, silver perch and Murray cod populations would likely form the source for future enhancement of fish populations in the Gunbower - lower Loddon system (O'Connor *et al*. 2013).

There are two main connections into the Project Area for upstream-migrating fish: Gunbower Creek and the lower Loddon River. The latter connection is complex because at low flows the Loddon River flows into the Little Murray which, functionally, becomes the lower Loddon River but at high flows the Loddon River passes directly to the River Murray. To optimize outcomes for native fish future management of the Little Murray would need to be compatible with the Plan.

Recovery Potential:

i) The nearby populations of native fish in the River Murray would provide a ready source for recolonisation and recovery of populations.

ii) The accumulations of fish at Box Creek Weir and Koondrook Weir during high flows (sec. 7.2.1) show that fish are "knocking on the door" trying to get into the Project Area.

iii) To optimize recolonisation, management of the Little Murray would need to be compatible with the Recovery Plan.

iv) Once abundant populations of native fish are established in the Project Area, these would provide robustness for the regional populations. Significantly, the Project Area could then serve for recolonisation of the River Murray if was a catastrophic event such as the 2011 blackwater which killed many fish.

7.3 Habitats

7.3.1 Diversity of habitats

The habitats of the Gunbower – lower Loddon system are described individually in Section 4. At a biogeographical level there is a high diversity of aquatic habitats that form a unique mosaic within a relatively small geographic range. The creeks have slow and fast-flowing reaches which vary in discharge, depth, width, instream woody debris, riparian vegetation and aquatic vegetation; and have numerous adjacent wetlands, billabongs and backwater areas. The wetlands and floodplains have particularly high biodiversity. The wetlands that have retained some of their natural wetting and drying cycles are considered close-to-natural condition compared to other wetlands along the Murray Valley.

The proximity of these diverse habitats to each other is a particular feature that provides opportunities to support a range of life stages (e.g. larvae, juveniles, adults) and a range of species that have different habitat requirements. To utilize this potential these habitats need to be connected, as they have been in the past, so fish can move between them.

The reaches that have poor diversity or poor habitat values, such as Pyramid Creek, have high potential to be rehabilitated with proven techniques. Providing instream woody habitat, winter flows and restricting cattle access would provide a large part of the rehabilitation.

Recovery Potential:

i) The diversity of habitats over a relatively small geographic range and the ease of rehabilitating degraded habitats provide high potential for recovery of fish populations.

ii) Providing connectivity and flow between the habitats so that different life stages and species of fish can access them increases the recovery potential.

7.3.2 Stream gradient and geomorphology

One of the key impacts on fish habitats is reduced hydrodynamic diversity (see sec. 6.4.6) – mainly from the reduction in complex faster flowing habitats, as there are abundant slow-flowing and stillwater habitats. This impact can be mitigated with additional flow and additional complexity (such as snags) but it also requires stream gradient and a geomorphology that creates faster flows. A low gradient and a wide channel would produce low water velocities even with increased flow.

Two significant features of the Project Area are the high stream gradients (compared to other streams in the lowlands of the Murray valley) in Gunbower Creek and Pyramid Creek, combined with a geomorphology that includes a relatively narrow cross-section, so that additional flow creates fast-flowing water. The Loddon River between Kerang and Barr Creek may also offer the same opportunities because of the braided reaches and a few areas that have narrower cross-sections. These features enable hydrodynamic diversity to be recreated and add considerably to the recovery potential of the system.

Recovery Potential:	The relatively high stream gradients and narrow stream cross-sections provide the hydraulic and geomorphic features that, with added flow or reduced weirpool heights, increase hydrodynamic diversity and fish habitat.

7.4 Non-native fish control opportunities

Management of non-native fish species in the Murray-Darling Basin is now usually part of an integrated pest management plan which can be local or regional (Braysher and Barrett 2000). A plan is defined by: (i) setting clear goals which address non-native fish impacts rather than killing as many as possible, (ii) identify and evaluate all management options and develop a plan, (iii) implement the plan, (iv) monitor progress and evaluate against the objectives.

It is usually unrealistic that any established pest fish can be eradicated, that is, every last animal removed. The possible exception is in some local situations where the populations are isolated and in relatively low numbers but no established widespread pest has ever been eradicated from Australia. Pest fish control should only be undertaken in the context of broader initiatives of native fish recovery.

The Project Area offers several potential ways to control pest fish because the system is fully regulated and therefore can be controlled to enhance native fish populations but also to impact on non-native fish. For example, reducing summer inundations of floodplains can limit spawning/recruitment of carp and gambusia. In addition, managed drying of floodplains can trap and destroy large numbers of carp. There are also intervention techniques such as the Williams carp separation cage for fishways, which is discussed below. Importantly, control options should be carefully considered for potential impacts on native fish. In summary, control of non-native fish, like carp, should probably be part of an integrated plan which includes the River Murray and other nearby Icon sites.

Williams Carp Separation Cage

The Williams carp separation cage is used within fishways to trap carp and release native fish. It uses the behaviour of carp in confined spaces where they tend to jump, while native fish in the southern Murray-Darling Basin do not. This enables the carp to be separated. These separation cages are usually employed at fishways to trap carp as they are migrating.

Within the Project Area there are eight new or proposed fishways, including: Gunbower Weir vertical-slot, Thompsons Weir rock-ramp fishway, Box Creek Weir fish lock (funded for construction in 2014), Hipwell Road vertical-slot (construction completed in 2014), Hipwell Road Off-channel Regulator fish lock (construction completed in 2014), Yarran Creek fishway, Kerang Weir vertical-slot fishway and Torrumbarry Weir vertical-slot fishway (just outside the Project Area but an important link in carp control).

For the stakeholders, particularly the water and land managers (Goulburn-Murray Water, North Central CMA), fishways present an opportunity to reduce the migratory biomass of carp. Prioritisation of the potential sites in the Project Area, by carp potential biomass, would enable pilot trials to determine the feasibility and cost-effectiveness of carp removal. There are also opportunities for cost sharing with similar initiatives in southern NSW (e.g. Murray CMA, Lachlan CMA) to utilise existing infrastructure and carp disposal mechanisms.

Recovery Potential:	Fishways not only provide connectivity for native fish to move into the Project Area and between habitats, but also provide the opportunity to reduce the population of carp, which improves the recovery potential for native fish.

7.5 Assessment of Recovery Potential by Species

A qualitative assessment of the recovery potential of each species can be made using present knowledge of fish ecology of each species, particular the habitat preferences. These can be compared with the quality of the remaining habitat, potential to improve habitats that are suitable, potential to reconnect habitats through fish passage and flows, presence of remnant populations or potential to stock with translocated local populations.

Table 2 provides an estimate of: i) past abundance, within each body-size grouping (large, medium, small), based on records (Lintermans 2007) and assessment of past habitat; ii) present abundance; iii) population change to the present; and iv) predicted population change with all impacts addressed.

Of the 21 native species in the Project Area, 18 have declined or become locally extinct. Fourteen of these species can be significantly rehabilitated but four of these are unlikely to improve because the area is not their primary habitat or their habitat requirements are unknown. For three species (golden perch, silver perch and bony herring) their recovery is partly dependent on landscape-scale recruitment that is much larger than the Project Area. There is also uncertainty about the response of purple-spotted gudgeon, olive perchlet and river blackfish because of knowledge gaps about microhabitat requirements and the extent that these can be rehabilitated.

Four of the medium- and large-bodied fish species have potential for major population increases, including Murray cod, golden perch and silver perch.

Four of the small-bodied threatened species that have not been recently detected in the Project Area have high potential for population recovery. Significantly, three of these species appear to be off-channel (wetland) specialists, probably using the *permanent small off-channel wetlands*; thus re-establishing and maintaining such habitats as permanent refuges would be important. Although southern pygmy perch has not been recorded recently on Gunbower Island it was recorded in Smiths Swamp in December 1990 (Michael Hammer, University of Adelaide, pers. comm.) and Black Charlie Lagoon in December 1997 (Tarmo Raadik, Victorian Department of Sustainability and the Environment, pers. comm.), demonstrating that the habitat is suitable for the recovery of this species.

Recovery Potential:	Based on habitat requirements and the potential for habitat rehabilitation, 14 of the 18 native fish species that have declined or become locally extinct, can be significantly rehabilitated. Five species can be expected to have major population increases including Murray cod, golden perch and silver perch.

Table 7. Past and predicted fish populations in the Project Area with Recovery Actions implemented (see Sec. 8). Threatened species are shaded in light orange.

KEY

Abundance: ✓✓✓✓ Abundant, ✓✓✓ Common, ✓✓ Uncommon, ✓ Rare, - Absent

Population Trend in Project Area:

↑	Slight increase	↓	Slight decline
↑↑	Moderate increase	↓↓	Moderate decline
↑↑↑	Major increase	↓↓↓	Major decline
▬	No Change		

	Past abundance	Present abundance	Estimated Population Change	Predicted Population Change with all Impacts addressed (see Sec. 8)
Large-bodied (500-1000 mm)				
Murray cod	✓✓✓✓	✓✓[S]	↓↓	↑↑↑
Trout cod	✓✓	✓	↓↓	↑↑
Medium-bodied (90-500mm)				
Golden perch	✓✓✓✓	✓✓[S]	↓	↑↑↑ L
Silver perch	✓✓✓✓	✓	↓↓	↑↑↑ L
Freshwater catfish	✓✓✓	✓	↓↓	↑↑
Bony herring	✓✓✓	✓	↓	↑↑↑ L
River blackfish	✓✓	-	↓↓	↑↑ ?
Macquarie perch	✓✓	-	↓↓	▬ ?
Short-headed lamprey	✓	-	↓	▬
Shortfinned eel	✓	-	↓↓↓	▬
Small-bodied (20-90 mm)				
Carp gudgeons	✓✓✓	✓✓✓✓	↑	▬
Flat-headed gudgeon	✓✓✓	✓✓✓	▬	▬
Un-specked hardyhead*	✓✓✓	✓✓✓	▬	▬
Australian smelt	✓✓✓	✓✓	↓	↑↑
Dwarf flat-headed gudgeon	✓✓✓	✓✓	↓	↑↑
Murray–Darling rainbowfish	✓✓✓	✓	↓↓	↑↑
Southern pygmy perch	✓✓✓	-	↓↓↓	↑↑↑
Southern purple-spotted gudgeon	✓✓	-	↓↓↓	↑ ?
Flat-headed galaxias	✓✓✓	-	↓↓↓	↑↑
Olive perchlet	✓	-	↓↓↓	↑ ?
Murray hardyhead	✓	-	↓↓↓	▬
Non-Native Species				
Carp		✓✓✓	↑↑↑	↓
Eastern gambusia		✓✓✓✓	↑↑↑	↓
Goldfish		✓✓	↑↑↑	↓
Redfin perch		✓	↑↑	▬
Oriental weatherloach		✓	↑	▬
Tench		-	↑	▬

L = depends on landscape-scale recruitment. ? = uncertain population response. S = Present abundance supplemented by stocking.

8 RECOVERY STRATEGY

8.1 Introduction

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* provides a strategy and an investment framework to improve native fish populations, including recreational species and threatened species. The Recovery Strategy uses conceptual models to identify ecological processes (e.g. fish migration) and habitats (e.g. small off-channel wetlands, fast-flowing water) that are keys to the recovery of freshwater fish in this system. From these models, the impacts on fish can be clarified, knowledge gaps recognised, and suitable recovery actions identified. These steps are shown in a flow chart in Fig. 33, which includes monitoring to provide assessment of the recovery action and feedback to conceptual models to refine actions.

The three keystones of rehabilitation that apply to rivers – connectivity (i.e. providing passage), flow and habitat – also apply to irrigation areas because they are intrinsically linked to river systems. An overlying principle in restoration science is that all three are interlinked and addressing only one impact would provide little benefit. For example, providing fish passage only will not attract fish into the Project Area if there is unsuitable flow; providing flow only does not allow access of fish into the Project Area; and providing habitat only would still not enable fish into the area.

The Recovery Strategy is centred on addressing these three rehabilitation themes with the additional targeted actions of the *reintroduction of threatened species* and *non-native fish control*. At a higher level is the long-term management of the project, acknowledging that the recovery of fish populations would take many years with new infrastructure, project management, assessment and adaptive management.

8.2 A new recovery paradigm for working rivers

Rehabilitation of rivers in the Murray-Darling Basin follows a paradigm of improving flow regimes and focusing on rivers and streams that are not wholly regulated for irrigation. The Plan is proposing an additional approach that:

i) Directly uses irrigation areas, viewing them as ecological assets with high potential value and,

ii) Optimises ecological values at a regional scale.

In the present context this means pooling ecological values (e.g. flowing water habitat, fish nursery areas) and examining the optimum potential outcome for the whole regulated system, as a working river.

This accepts that some changes to the river system are permanent, if there are shared users of the river, and that some areas can serve a more productive ecosystem role by adopting a new function (e.g. spawning area) rather than returning to a previous more-natural state.

The philosophy differs from the more traditional approach of returning the ecosystem to as close to natural conditions as possible. The rationale is that more can be achieved on a regional scale by utilising the potential of the creeks, wetlands, forests and irrigation systems.

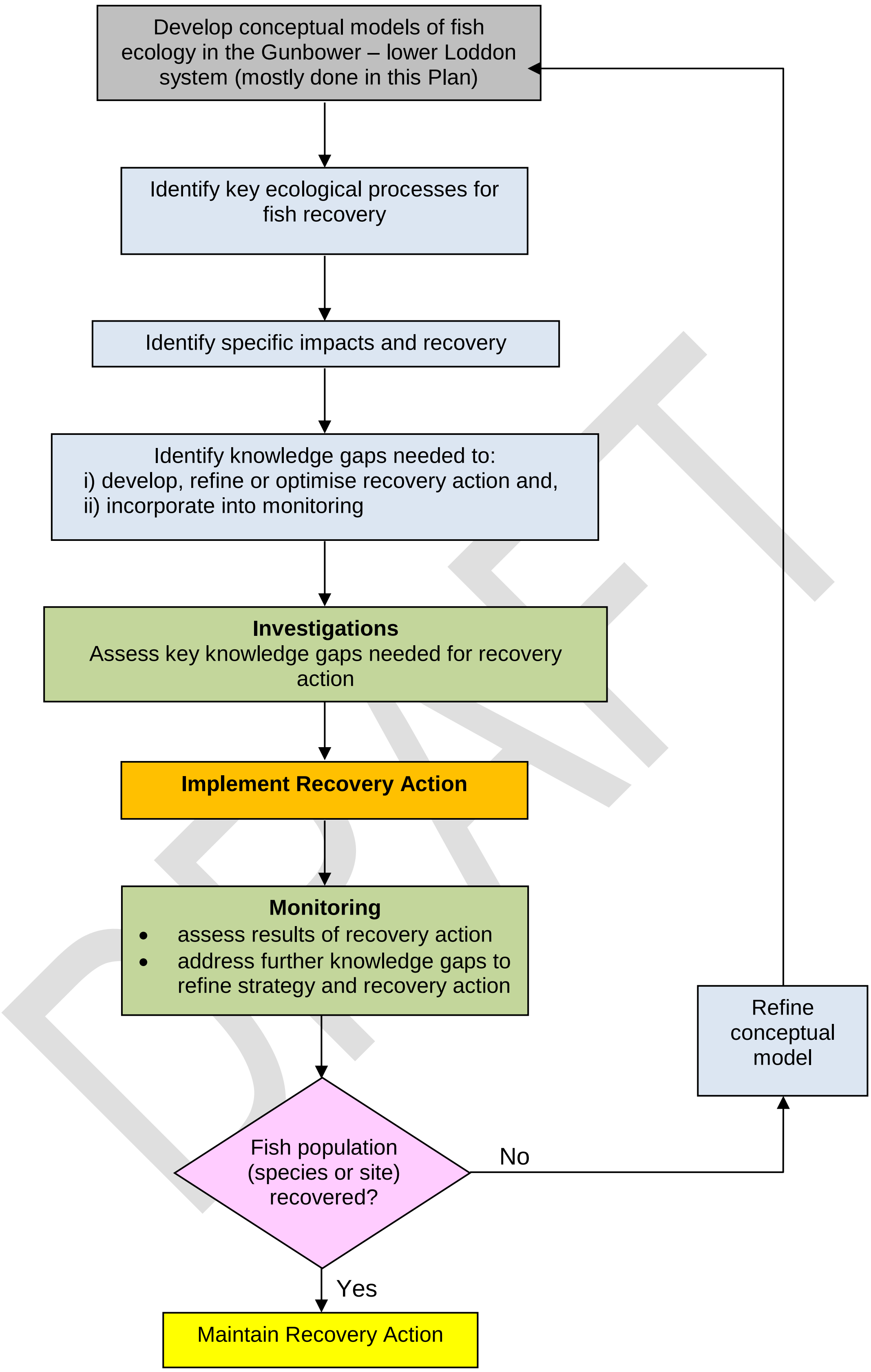


Fig. 33. Flow chart for recovery actions.

The background to this approach starts with the present rehabilitation of rivers at various sites in the Murray-Darling Basin. The most notable examples are the anabranch creek and floodplain systems along the length of the River Murray (in The Living Murray and Murray Futures programs) which are being rehabilitated in response to reduced flooding frequency and changed seasonality of flows. The main methods are to restore wetting and drying cycles of floodplains and ephemeral streams through the use of infrastructure and allocation of environmental water.

Rehabilitation of natural flow regimes on a local scale is often a common goal of river rehabilitation and the change in hydrology from past flows is used as a measure of impact. For example, the comprehensive Sustainable Rivers Audit assesses the hydrological impacts of rivers in the Murray-Darling Basin by various measures of deviations from a modelled natural condition (Davies *et al*. 2008). These measures are useful to broadly assess and compare rivers, and they have a direct bearing on impacts to fish populations. The management view that stems from this is that *incrementally changing flows, or parts of the flow regime, to be closer to natural will improve the aquatic ecosystem*; this has become the dominant rehabilitation paradigm for aquatic systems of the Murray-Darling Basin.

The paradigm, however, has several constraints, some of which are obvious and some less so. An obvious one is that the flow regime cannot ultimately return to natural because there are a range of water users. The issue this raises is whether the increments of an improved flow regime can achieve a threshold to improve the ecosystem. In a regulated and modified system only monitoring can provide the answer.

Less obvious constraints are that in many cases the geomorphology and hydrodynamics have changed; sediment has filled deep holes that were drought refugia in the past and in some reaches flowing, dynamic rivers have become weirpools. Restoring a more natural flow regime in these conditions may not necessarily make any ecological improvements. For example, restoring 'natural' low flow periods may be harmful to fish populations if deep hole refugia are absent, whilst adding flow to a weirpool may be insufficient to create flowing water and hydrodynamic complexity.

Overlaid on these constraints of flow are the recognised factors of habitat and connectivity. Rehabilitation of habitat is often done through re-snagging and riparian re-vegetation but there is less emphasis on littoral zones and benthic zones (e.g. cobble substrates and riffles). The issue of connectivity for fish is well known through fishway programs, although the links with different scales of movement - enabling dispersal, recolonisation and connecting ecosystems – and with flows to stimulate fish movement are often overlooked.

The Plan proposes to integrate these factors into a new paradigm for working rivers which dovetails with the present approach in the Murray-Darling Basin and presents new opportunities, *using irrigation areas* and *optimising ecological values at a regional scale*. The Plan uses the Torrumbarry Irrigation District, which includes Gunbower Creek, Kow Swamp and Box-Pyramid Creek that are wholly used for irrigation, so that there is no flow in non-demand periods such as winter.

Although Gunbower Creek and Box-Pyramid Creek were originally ephemeral they provide greater ecological value regionally as permanent flowing-water habitats connected to the River Murray and adjacent wetlands, which provides an integrated mosaic of habitats. With habitat rehabilitation these streams would become spawning and nursery areas for native fish, as well as migration pathways. Hence, for these streams, flow, connectivity and habitat become key actions.

Kow Swamp under natural conditions filled approximately every third year and drained to a much lower point without Box Creek Weir. It is now filled every year and held at a higher level but the seasonality of filling and draining is similar to natural. Kow Swamp is critical infrastructure for irrigation but because of the seasonality of water levels it also presents the opportunity to be managed for littoral productivity and become a nursery for native fish.

Rehabilitation of the large forest wetland of Gunbower Forest is part of The Living Murray program but management of the small permanent wetlands are also a key action for recovery of threatened fish species. In this case the action is restoring these habitats, conforming to the present rehabilitation paradigm, rather than creating new ones.

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* presents a new approach in viewing irrigation as part of sustainable healthy rivers, while providing emphasis on the support and input of the local community, irrigators, water managers, government and Aboriginal community. In this way, the Plan aims to clarify the common values and goals of stakeholders, using the recovery of native fish populations.

8.3 Project Continuity and Momentum

The Plan is anticipated to take over 10 years for the intensive phase of capital investment and 20 years of monitoring and adaptive management, which would likely become progressively less intensive over this time. A significant risk to the project is that intellectual property largely resides with one or a few project officers and with staff turnover during the lengthy project period, continuity of ideas and processes is diluted. Funding could also be diluted over this timeframe and more than one source of funding would be needed.

The North Central Waterway Strategy details action plans and targets for specific program areas in the North Central region (North Central CMA 2014). The strategy includes programs of works and activities for Gunbower Creek, Box – Pyramid creeks and the lower Loddon River, which are consistent with the activities and intent of the Plan. Project planning and delivery should be consistent with, and supportive of, activities and outputs detailed in the Waterway Strategy. The strategy also includes works programs for the Little Murray River and Kerang Lakes, environmental assets adjacent to the Gunbower – lower Loddon project area.

To address these issues, three initiatives are proposed:

i) ongoing steering committee (Gunbower – Lower Loddon Native Fish Recovery Committee)
ii) Technical Memorandum Series, and
iii) Annual or Biannual forum.

The objectives of the Committee would be to:

- Maintain project continuity and momentum;
- Assist new staff become established and familiar with the project;
- Develop a broad network for the project that attracts funding and research through contacts;
- Ensure latest findings from other projects are applied to Gunbower - lower Loddon system;
- Review priorities in the light of new data;
- Provide peer review;
- Ensure accountability (best value for money) of research, monitoring and capital expenditure.

Potential Membership of the Committee includes:

- North Central CMA
- Goulburn-Murray Water
- Irrigators
- Indigenous representatives
- Department of Environment and Primary Industries, other government departments
- Murray Darling Basin Authority
- Independents (fish biologists, scientist, engineer, other CMA representatives)

The project should aim for an annual review with the Committee, with the main emphasis on participants bringing networks and opportunities to the Project.

The Technical Memorandum Series is aimed at providing another level of detail to the Plan, which is intended to: i) directly feed into present management and investment, ii) identify knowledge gaps to target and iii) capture corporate knowledge as it develops. The Memorandums are intended to be short, but their subject matter is very broad and may include:

- Conceptual models, which capture present thinking,
- Technical guidelines
- Recommended processes
- Initial results of trials or experiments,
- Ecological observations (e.g. migrating fish observed below a regulator under certain flows or conditions; fish kills)
- Summary of community consultations
- Changes in irrigation industry that directly affect the project.

Examples are included in appendices of this report. Although technical and targeted to the Gunbower – lower Loddon Region, the intent is that they are public domain and posted on a corporate website, so that stakeholders are kept informed of developments. Reports of larger projects still retain their role.

Each memorandum would have the format of:

- Objective
- Subject
- Knowledge Gaps, and
- Management Implications.

The Annual or Biannual forum would follow the successful Fish Forums that the North Central CMA has hosted in the last two years. It would be held in the region for one day with the community as the main focus, with scientists and managers speaking on developments. It would be an opportunity to disseminate results and provide a forum to receive feedback and new ideas.

8.4 Infrastructure – Fish Passage

8.4.1 Introduction

What is fish passage?

All fish and aquatic biota move to some degree and it is an essential ecological process. Fish passage is the term used to describe providing for the free movement (upstream, downstream or lateral) of fish within aquatic environments. It has increasingly been used to describe providing for the movement all aquatic biota, such as turtles and crustaceans; hence, the recent term *biopassage*.

Fish passage is interrupted by barriers such as weirs, dams and road causeways. These barriers interrupt critical ecological processes and have a profound effect on upstream and downstream fish communities.

Providing for fish passage can include barrier removal, providing flows to improve depth and submerge barriers, weir management (lifting gates to provide passage when a structure is not in use), or more commonly - providing fishways. A fishway is a water passage around or through a stream barrier, designed to provide hydraulic conditions suitable for fish to pass the barrier without undue stress, delay or injury. Fishways are one of the most widely used methods for rehabilitating freshwater fish populations worldwide. Over 250 fishways have been built in eastern Australia over the last 25 years and they have proved to be very successful.

Fish passage objectives

The broad ecological objective of fish passage is to maintain fish populations or, in the case of depleted populations, rehabilitate them. All fishways have ecological objectives, although these are sometimes not articulated; from these, fish passage objectives can be established, followed by hydrological and hydraulic design criteria. Clarifying and documenting these objectives enables the performance of a fishway to be evaluated and action taken if the performance standard is not met.

As an example, from the broad ecological objective the fish passage objective might be:

> "provide upstream and downstream passage for the whole migratory fish community (fish 30-1000 mm long) from low flows (e.g. 30 ML/d) through to weir drown-out flows".

For each specific weir and fishway this objective could be refined to take into account site specific factors, such as: presence of threatened species, presence of species with specific migratory requirements, unique site hydrology, unique site geography or the operating requirements of the weir.

Need for fish passage

The need for fish passage in the Project Area stems firstly from the migratory nature of fish in this region and secondly from the existing barriers. As described in Section 5, upstream migration of juvenile, sub-adult and adult fish is a widespread life history trait in the middle and lower reaches of the River Murray, along with downstream drift of larvae. This is evidenced in the high numbers of fish collected in fishways and the diverse range of species collected in larvae drift studies.

Flow in the waterways of the Gunbower – lower Loddon region is regulated by a series of barriers and restoring fish passage along the waterways is an essential component for recovery of native fish populations in the region. This has been recognised for some time and the North Central CMA and Goulburn–Murray Water have constructed fishways at Gunbower, Thompsons and Kerang weirs, with a new fishway planned for construction with the new weir at Box Creek. All new Living Murray infrastructure also has fish passage provisions, most with specific fishways. The present need for fish passage stems from the existing five barriers without fishways in Gunbower Creek and Taylors Creek and at the Box Creek Weir. Essentially without complete connection to the River Murray fish cannot move in or out of the Project Area and as a result key ecological processes have been affected and fish populations have declined.

8.4.2 Methods of providing fish passage

8.4.2.1 Upstream

The most effective upstream fish passage is barrier removal, which has proved to be the most cost-effective solution at a number of sites in eastern Australia where the function of the barrier has changed over time and its role in regulation is no longer warranted. More commonly a dedicated fishway is built providing a channel of water around the barrier. At low-level weirs the designs include pool-type fishways (designs include vertical-slot, cones), rock-ramp fishways (including full-width, partial-width and bypass channels), Denil fishways, trapezoidal weirs and fish locks.

Each of these designs has strengths and limitations which are often site specific and not generic. Importantly, there are two major components of all these designs:

i) ensuring fish locate the entrance, and
ii) passage through the fishway.

To achieve the first component an important part of all these fishway designs is ensuring that the broader design of weir crests, gates and abutments, as well as operation of the structure, all guide fish to the fishway entrance.

In the Gunbower – lower Loddon region the designs that have been used are the vertical-slot (Kerang, Gunbower, Yarran Creek [modified slots], Hipwell Road Weir, Upper Gunbower Forest Channel [under construction]), rock-ramp (Thompsons Weir) and fish lock (Box Creek Weir [construction imminent], Hipwell Road Offtake Regulator. A review of these is provided in Section 8.4.3.

8.4.2.2 Downstream

There has been considerable research on downstream fish passage in the last decade, which has included live fish trials in different weir designs (Baumgartner *et al.* 2006), physical modelling and computer (CFD) modelling. From this work a few generic design themes have developed:

- Undershot gates provide poor passage for fish and can cause high mortalities of fish, particularly larval stages.
- Overshot gates provide good passage of fish with high survival, if tailwater depth is sufficient.
- Tailwater depth should be the greater of: 0.5 m or 40% of the maximum differential head (difference in upstream and downstream water).
- There should preferably be a gradual acceleration of water velocity at a gate or weir crest to not inhibit downstream movement.

These have been applied to develop generic criteria for Gunbower Forest regulators (Appendix 3). A special case of downstream passage is irrigation offtakes where the preferred outcome is to *prevent* passage of fish into the channels, which is discussed below in Section 8.5.

8.4.2.3 Lateral

Lateral passage refers to passage between channel habitats and the off-channel habitats of wetlands, billabongs and flooded forests. Essentially this is still passage *downstream*, with the flow, or *upstream*, against the flow, depending on whether fish are moving in or out of the off-channel habitat as it fills or drains. Hence, in principle, the same approaches to fish passage can be used. However, because the ecology of migrations differ, particularly when small and large fish may be moving, the ecological and fish passage objectives can be very different to longitudinal passage along stream channels. These differing objectives usually lead to very different applications of the fishway designs used for longitudinal migrations.

There are also unique risks and opportunities with lateral passage. A significant risk is stranding of large- and medium-bodied fish, some of which may be threatened species, as water levels recede; in Gunbower Forest this has led to a fish exit strategy to manipulate flows to encourage fish to leave the floodplain (Mallen-Cooper M. *et al.* 2011). A significant opportunity is that during watering events the head difference at regulators used to manage flows is often close to equal with very low water velocities, so that fish can move directly through the regulator, in some cases without a dedicated fishway. The other unique challenge for lateral passage sites is that water can run in both directions, as the regulator fills and then drains the floodplain.

In the Project Area there are three areas of lateral passage to consider in further development of the Plan:

1. Flooded forest
    - Issue: Passage through forest regulators during natural floods and managed floods.
    - Presently part of a fish exit strategy that includes water management and fishways at Yarran Creek Regulator, Hipwell Road Offtake Regulator and Gunbower Upper Forest Channel Regulator.
2. Permanent Lagoons/Billabongs
    - Issue: Passage of juvenile and adult catfish between habitats.
    - Presently no strategic view of fish passage at these sites.
3. Off-channel permanent wetlands
    - Issue: Passage of threatened species between habitats.
    - Passage at these sites would need to be considered after re-introduction of native fish.
    - Part of Ramsar site, with potential to provide water and passage with present infrastructure being proposed and built.

8.4.3 Review of existing fish passage

There has already been substantial work on restoring fish passage in the region, which the present project would build upon. In this section the existing fishways and fish passage in the Project Area are reviewed to identify the structures remaining that require fishways, and the existing fishways that require updating or modification (Table 8, Fig. 34). Torrumbarry Weir fishway and weirs in the Little Murray are included in the review for regional context, although they are just outside the Project Area.

Upstream Passage

The Torrumbarry vertical-slot fishway is effective for passage of a wide range of fish species and sizes from 120-1000 mm long (Mallen-Cooper 1999). In Gunbower Creek, the new vertical-slot fishway at Gunbower Weir is effective for medium and large-bodied fish (>120 mm in length), based on hydraulic specifications, but not for smaller fish (Stuart and Sharpe 2012). The latest research on the hydraulics of vertical-slot fishways has shown that minor modifications to the baffles can reduce turbulence and enable this design to pass smaller fish (Mallen-Cooper *et al.* 2008). Kerang Weir vertical-slot fishway has high turbulence and can be modified, similar to Gunbower Weir, to pass smaller fish and meet the ecological objectives (Stuart *et al*. 2009). Thompsons Weir rock-ramp fishway presently has poor fish passage and requires significant rectification (Stuart and Sharpe 2012).

Table 8. Existing fishways in the Gunbower – lower Loddon region and the adjacent River Murray.

Site	Waterway	Design	Constructed	Efficacy	Photograph
Torrumbarry Weir	River Murray	Vertical-slot	1990 (old fishway) 1997 (new fishway)	Meets fish passage objective, passing fish >120 mm. (Mallen-Cooper 1999)	
Gunbower Weir	Gunbower Creek	Vertical-slot	2009	Effective for fish > 120 mm, based on hydraulic specs. Does not presently meet fish passage objective of passing small fish 30-90 mm. Requires minor rectification (Stuart and Sharpe 2012)	
Thompsons Weir	Gunbower Creek	Rock-ramp	2010	Ineffective. Requires significant modification. (Stuart and Sharpe 2012)	
Hipwell Rd Weir	Gunbower Creek	Vertical-slot	Constructed 2014	To be assessed.	

Site	Waterway	Design	Constructed	Efficacy	Photograph
Hipwell Rd Offtake Regulator	Gunbower Creek forest offtake	Fish lock	Constructed 2014	To be assessed.	
Yarran Creek Regulator	Gunbower Creek/ Forest Regulator.	Vertical-slot	Data required	To be assessed.	
Box Creek Weir	Pyramid Creek	Fish lock	Funded for 2014-15	To be assessed.	
Kerang Weir	Loddon River	Vertical-slot	2008	Requires minor rectification. (Stuart *et al.* 2009)	

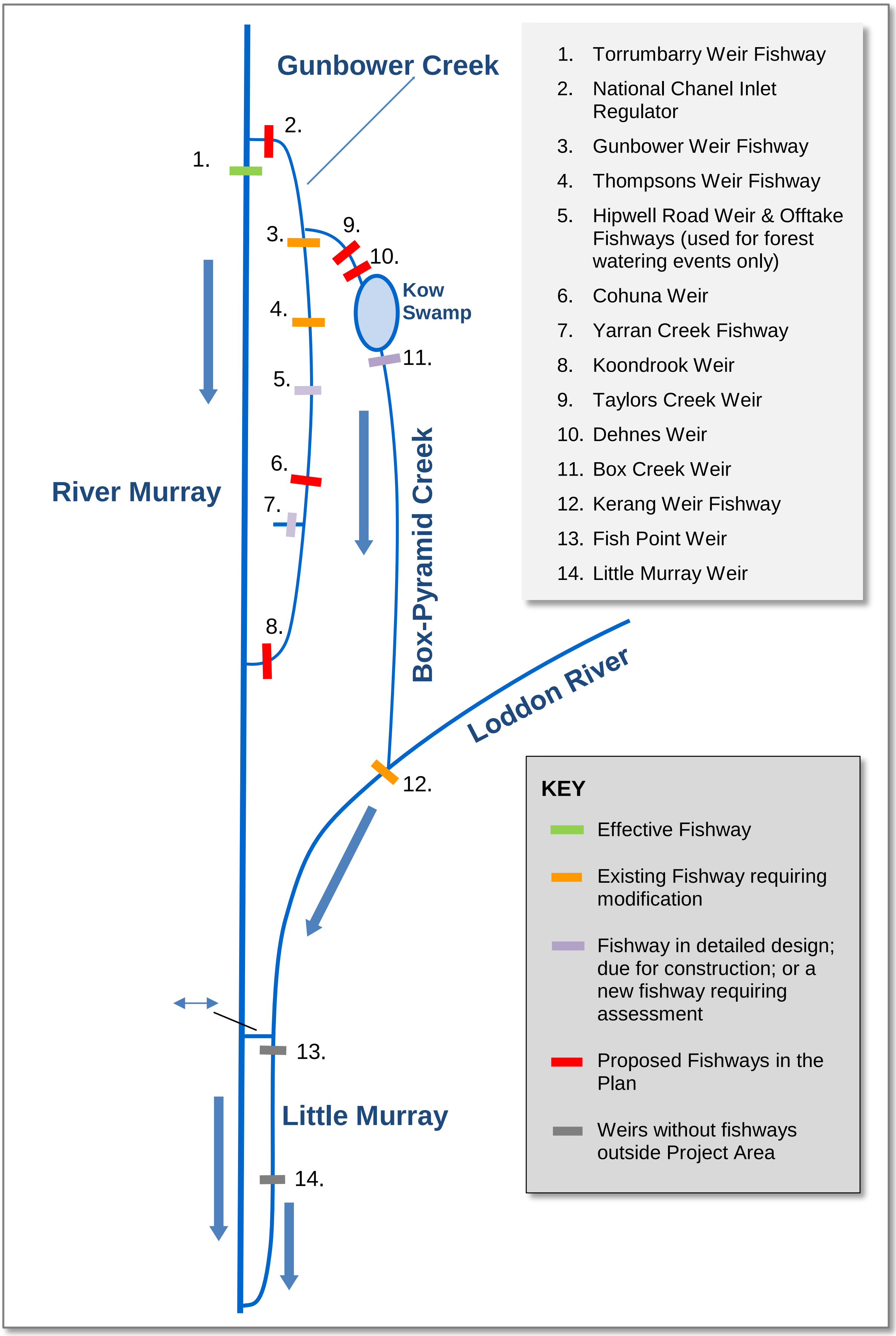


Fig. 34. Schematic map of Project Area with present and proposed fish passage along creeks.

It is noteworthy that the effective fishways were part of a consultative design process that has developed for fishways in eastern Australia (Appendix 4). There are three fishways with recent detailed designs and constructed, or about to begin construction, including Hipwell Road Weir, Hipwell Road Off-take and Box Creek Weir. All of these projects had a consultative design phase with engineers, fish biologists and river managers on the design teams.

The Hipwell Road structures were being constructed under The Living Murray program. The new weir in Gunbower Creek incorporates a vertical-slot fishway and the new offtake regulator, which diverts environmental water from Gunbower Creek to Gunbower Forest, incorporates a fish lock. The new fishways provide passage for temporary weirs that are used during a managed inundation of the forest but they retain, rather than improve connectivity along Gunbower Creek.

The new Box Creek Weir is to replace an ageing asset. The soon to be constructed fishway is a fish lock and will improve connectivity into and through Kow Swamp.

Downstream

No purpose-built downstream fish passage is provided but most of the existing weirs provide suitable conditions for downstream passage; the exceptions are the National Channel Inlet Regulator and Cohuna Weir, which have undershot gates and are a priority to address. For Cohuna Weir there is an opportunity to simply modify the gates from undershot to overshot. All inflows to Gunbower Creek and most inflows to Box-Pyramid Creek come from the River Murray via the National Channel Inlet Regulator. Hence, all drifting fish larvae, which could be a major source of population recovery, pass through this structure and likely suffer high mortalities. Addressing downstream passage at this structure, along with upstream passage, would provide an important link in the Plan.

The existing Box Creek Weir has poor downstream passage because of shallow tailwater. However, downstream passage is specifically addressed in the new design.

Lateral

Yarran Creek Fishway (Fig. 34) is designed for lateral movement of large, medium and small fish between a major creek within Gunbower Forest and Gunbower Creek. The fishway is designed to operate with flow in both directions but has yet to be assessed when operating.

The forest regulators between the River Murray and Gunbower Forest (Fig. 7) provide free passage of fish when they are fully open and lateral fish movements are an integral part of managed inundations of the Gunbower Forest (Mallen-Cooper *et al.* 2011). The inlet regulators of lagoons of the upper Gunbower Lagoons (Fig. 7) are small and even when open are unlikely to provide much passage of fish; as discussed earlier these habitats contain the threatened freshwater catfish and improving passage would improve dispersal and recolonisation of this species.

8.4.4 Remaining barriers

The weirs that remain as blockages to upstream migration are Koondrook, Cohuna, National Channel Inlet Regulator, Taylors Creek Weir and Dehnes Weir (red sites in Fig. 34). These ultimately limit the recolonisation and rehabilitation of fish populations and are a priority to address. There are two barriers outside the study area in the Little Murray (Fig. 34); consideration of the future of these weirs is part of an existing project but needs to be linked with the objectives of this Plan so that fish passage is considered. When there are low flows in the lower Loddon River, most of these pass into the Little Murray, which is then the major migration pathway, while high Loddon flows pass directly to the River Murray.

8.4.5 Recovery Actions and Implementation

There are two important perspectives to the consideration and implementation of fish passage:

i) Fish passage is only as strong as the weakest link.

That is, one weir without a fishway breaks the movement pathway and prevents fish from completing migrations and life cycles.

ii) Fishways do not provide for movement if there is insufficient flow.

Flow is essential to simply provide the habitat and depth in which to move and also to provide cues for migration.

Given these two aspects, the proposed strategy and recovery actions of the Plan are:

1) Optimise existing fishways at:
   - Gunbower Weir,
   - Thompsons Weir, and
   - Kerang Weir.
2) Design and construct five fishways at the remaining weirs [red sites in Fig. 34]):
   - National Channel Inlet Regulator (incl. downstream passage),
   - Cohuna (incl. downstream passage),
   - Koondrook,
   - Taylors Creek Weir (may be a combination of operation and fishway),
   - Dehnes Weir (may be a combination of operation and fishway).
3) Provide flow, including end-of-system flows and flow during winter. The flow components are addressed separately in Section 8.6, but are noted here to show the critical dependent links between actions.
4) Assess new fishways (hydraulics and biology) to optimise designs.
5) Support lateral fish movement actions in managed inundations of Gunbower Forest.
6) Improve lateral passage between lagoon habitats and Gunbower Creek, including through operation and/or improved infrastructure.

The action with the highest capital cost is providing five new fishways; this is also a fundamental building block of the Plan. The ecological objective of addressing all five migration barriers in the Project Area is that fish can move freely in and out - to recolonise, use nursery areas, enable spawning migrations - so that the irrigation system becomes part of the River Murray ecosystem and increases local and regional fish populations

8.5 Infrastructure - Screening Irrigation Offtakes

Irrigation offtakes are a special case of downstream fish passage. As water is diverted into irrigation channels there is downstream movement of all life-stages of fish and these are lost to the river population. There are two approaches to this issue: i) allow fish to enter the channel system, provide habitat in the main channels and fishways at the inlet regulators so that fish can return to the river; or ii) screen the inlet regulators to prevent fish entering the channel system. The second approach is the one that is almost universally taken because managing fish populations in irrigation channels using habitat, managing flows and installing fishways limits the function of the channels.

The Torrumbarry Irrigation System provides a good case study to assess and implement solutions to this problem because water flowing into the National Channel carries significant numbers of native fish (O'Connor *et al.* 2008b). These fish losses into irrigation networks, with some channels now plastic-lined which provide very poor habitat, is likely to have population level impacts.

Loss of fish passing into irrigation channels is a world-wide issue (Carlson and Rahel 2007; King and O'Connor 2007; Post *et al.* 2006; Roberts and Rahel 2008) but has well-established solutions (Gale *et al.* 2008). The solutions are diverse and the Project Area provides a good demonstration site for this technology and for sustainable irrigation practice.

In the USA and Europe, screens are used in many rivers to limit fish entrainment into irrigation channels, hydroelectric power stations and pump houses. In some US states there is legislation that requires any person abstracting water to have a screen to prevent fish entrainment; this has resulted in innovation of numerous designs of screens for different sizes of fish, discharges, head differentials and sites configurations. Rotary drum screens (Fig. 35) are one type of screen that is commonly used, particularly for early life-stages, such as fish eggs and larvae. The advantage of this design is that it is self-cleaning and mechanically simple.

In Australia large rotary drum screens are used at tidal power stations to exclude fish. In the Mareeba-Dimbulah Irrigation Area in north Queensland a very fine screen (approximately 0.5 mm aperture) has been used on the water supply to prevent the spread of *Tilapia*, a pest species. Experimental research in Australia on irrigation screens with Murray-Darling fish species has developed some design criteria that are readily applicable (Boys *et al.* 2013a; Boys *et al.* 2013b). The Torrumbarry Irrigation System, with a known population of native fish and high recovery potential, provides an excellent opportunity for testing and implementation.

A strategic approach is needed to the assessment and application of screening. The extent that fish are drawn into irrigation channels needs to be evaluated to assess the impact, which may vary between sites, and a staged application is needed, with a pilot installation, followed by assessment and refinement of the design, if needed.

There are four main irrigation offtakes within the Project Area for Channels No. 1, 2 (Macorna), 3 and 4, which may all require screening if assessment shows there are significant losses of native fish. The discharges and capacity of these channels are well within the existing technology of readily available screen designs.

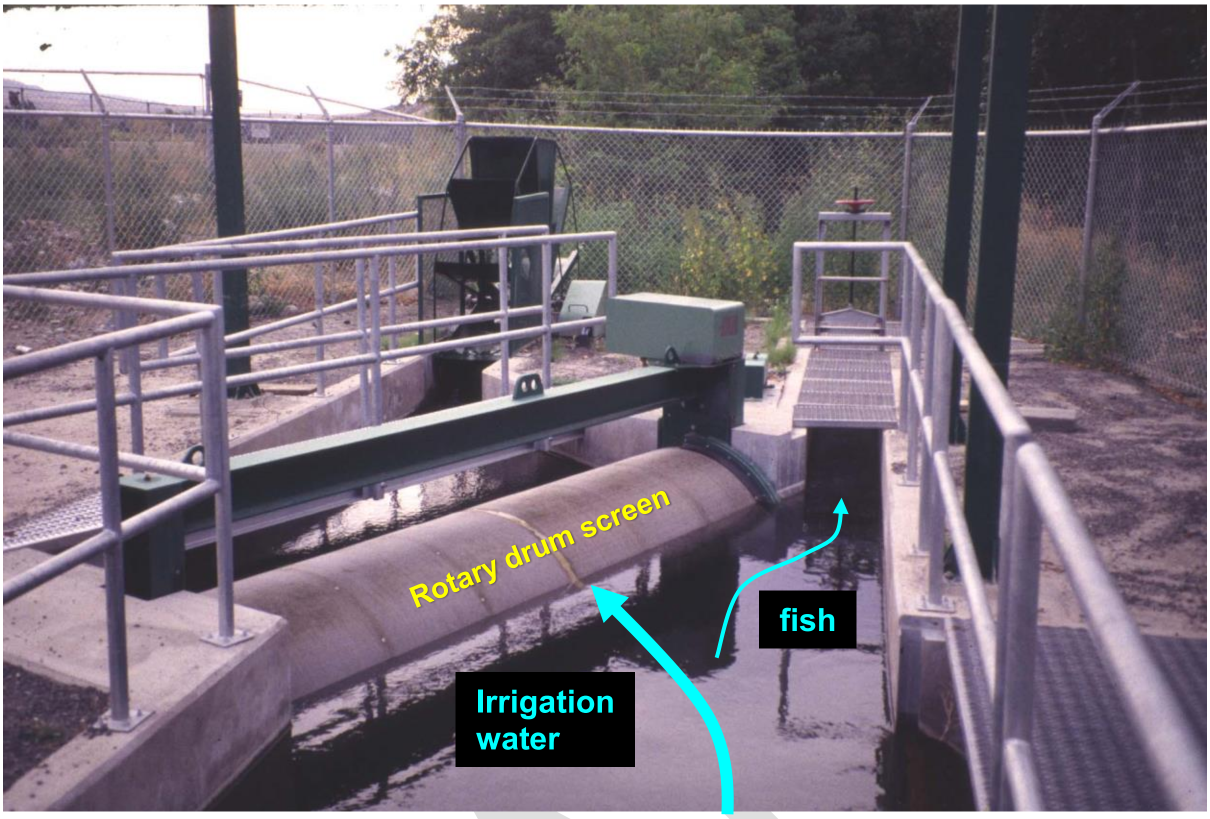


Fig. 35. Example of a rotary drum screen for diverting fish from irrigation water.

8.5.1 Recovery Actions and Implementation

The proposed strategy and recovery actions of the Plan are:

1) Assess proportion of the fish population that is entrained into each of the four main irrigation channels and the need for screening.

2) Assess larval drift patterns (such as diel and vertical movement) that could influence screen design and operation.

3) Design a pilot installation of screening at one irrigation offtake.

4) Evaluate screen effectiveness for preventing entry of native fish (including all life stages detected in Step 1) and reliability. Refine design, if needed, and reassess.

5) Following prototype assessment, finalise screen design and implement at the other three offtakes.

8.6 Flow Management

8.6.1 Creeks

8.6.1.1 Base flow

Increasing permanent baseflows in Gunbower Creek and Box-Pyramid Creek are key recovery actions and linked with end-of-system flows. Flows of 300-1000 ML/d need to be considered. The exact flow that is required to maintain and improve habitats can be refined with hydrodynamic modelling of habitats and field trials. Increasing these flows in winter, in particular, is likely to have very positive effects for native fish populations. Significantly, these flows can be returned to the River Murray and potentially re-credited, less channel losses.

8.6.1.2 End-of-system flow

Providing end-of-system flow is essential to provide connectivity with the River Murray. Linked with the provision of fish passage this action would support a major increase in the recovery of native fish.

Providing end-of-system flow would also improve base flow. Combined with the provision of fish passage, flow would restore movements of fish along the two major pathways of Gunbower Creek and Loddon River - Pyramid Creek - Kow Swamp – Taylors Creek.

8.6.1.3 Seasonal and daily variation in flow

Analysis of historical and modelled natural River Murray flows (sec. 3.5) shows that there were high flows in winter and spring with low flows in summer. Gunbower Creek and Box-Pyramid Creek are presently operated to have close to no flow in winter, when there is little or no irrigation demand, and have high flows in summer.

The winter flows are a priority to restore because they provide overwintering habitat for young fish and provide opportunities for feeding for adult fish, which are rapidly converting body stores of fat and muscle to gonads for spring breeding. Under natural conditions Gunbower Creek was bankfull or higher in winter and spring which suggests that a similar condition, or close as practical, run continuously through winter and spring would benefit native fish.

The high flows in summer are a key output of the irrigation system and have little scope to be modified. However, these flows are unlikely to have a large negative ecological impact because floods that extended to summer were not uncommon (Appendix 1).

Daily variation of flow in spring and summer is much higher now than under natural conditions, due to daily variation in irrigation demands (Fig. 12). These sudden variations could affect food supplies along the stream edge (littoral zones) which could affect developing larvae and fry. Sudden drops in water height may also impact on nesting fish species (Murray cod and catfish) as these fish may abandon nests. There may be opportunities to buffer this variation through utilising end-of-system flow, while providing all irrigation needs, and these are proposed to be investigated.

A model of a hydrograph for Gunbower Creek that restores fish habitats and meets irrigation demand is shown in Fig. 36. The key features are that it is high, close to bankfull, and relatively stable from winter to early summer, and more variable flow in summer/autumn but with less short-term oscillation. The summer/autumn flow does not drop below half of bank-full. The same generic hydrograph applies to Box-Pyramid Creek.

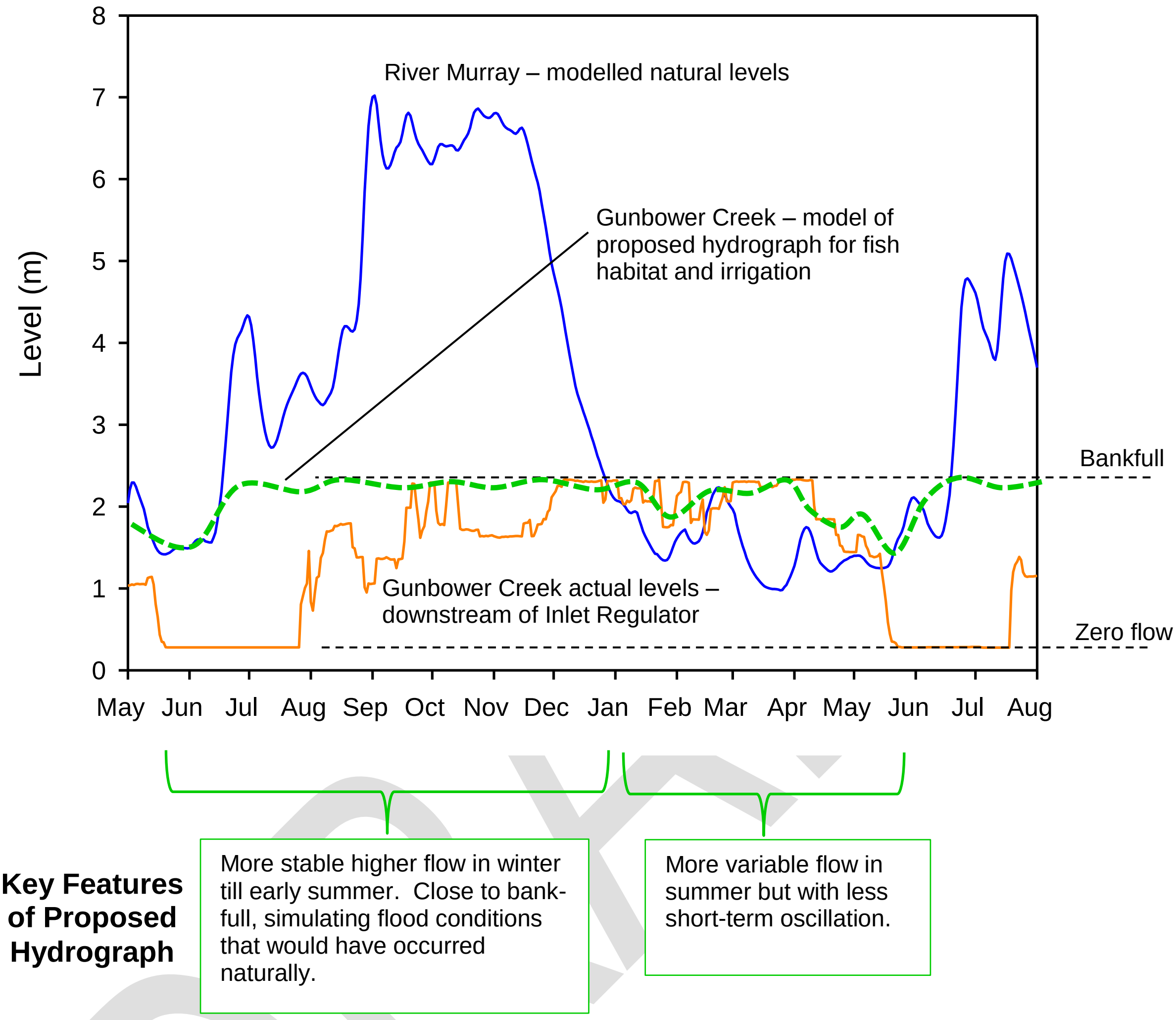


Fig. 36. A model of a hydrograph (green dashed line) for Gunbower Creek that restores fish habitats and meets irrigation demand. The model is compared with data from Fig. 12 showing daily level in Gunbower Creek for 2002 and natural (modelled) daily level in the River Murray for the same period.

8.6.1.4 Hydrodynamic diversity

Hydrodynamic diversity is the variation of fast- and slow-reaches reaches along a stream. Creating weirpools reduces the fast-flowing areas, which are critical habitats for many species including spawning Murray cod (see sec. 6.4.6).

A significant opportunity for the Project is the relatively high stream gradient in Gunbower Creek and Box-Pyramid creek; hence, increasing flow would immediately increase the fast-flowing reaches and hydrodynamic diversity. All the actions above, which increase flow, would help achieve this objective. Additional mechanisms for increasing hydrodynamic diversity are lowering of weirpools which creates flowing reaches in the upper weirpools, and re-snagging which creates complexity of flow paths. The lower weirpools would need to be compatible with irrigation demand but could be done in the non-irrigation season. Alternatively, weirs could be lowered with pumping as an adjunct for irrigation.

8.6.2 Wetlands

The wetlands offer particular opportunities for fish recovery because of the presence and potential of threatened species. The permanent lagoons/billabongs adjacent to Gunbower Creek have freshwater catfish, while the off-channel permanent wetlands within the forest have potential to support four small-bodied threatened species. Flow into these wetland habitats would be targeted mainly at maintaining minimum levels and water quality. These habitats would naturally have lower levels in late summer and autumn so some reduction in level could be managed at this time, ensuring that water quality was maintained. Because these habitats are small the flow requirements to maintain them would be small.

8.6.3 Forest floodplain

Providing flow to the forest floodplain and the forest wetlands mentioned above is part of The Living Murray program; setting flow and inundation targets and managing this flow is part of an existing process aimed at improving inundation frequency and duration (MDBA 2012). These flows could be natural events, part of specific environmental allocations, or a combination of both.

The managed flows are targeted at improving floodplain health as well as optimising these for native fish (Mallen-Cooper *et al.* 2011). Specific objectives for fish are included in the management plans, including the passage of large and small fish into, and out of, the forest floodplain. A specific exit strategy has been developed and is part of an adaptive management approach to: maximise passage of fish back to the river, minimise stranding of fish, and optimise recruitment (survival of young fish) to the river and regional populations (Mallen-Cooper *et al.* 2011).

Because a process for project management and flow management of Living Murray projects has been established it is not dealt with specifically in the Plan. It is, however, a major improvement in the environment and a synergy that the Plan would build upon.

8.6.4 Opportunities

Managing flows is one of the three keystones – flow, habitat, connectivity - that underpin recovery of native fish populations. A major opportunity for the Plan is that the key actions of increasing base flows, winter flows, end-of-system flow, and increasing hydrodynamic diversity can be done with water that can be returned to the River Murray, so that the only water used would be channel losses.

As described above, an additional opportunity is the inherent gradient of Gunbower Creek and Box-Pyramid Creek which produces hydrodynamic diversity with fast-flowing reaches, simply with increased flow.

Managing water is a sensitive issue and it directly interacts with operation of the irrigation system. The principle of the Plan is to optimise flows for fish and meet irrigation demand. However, changing operation would require significant liaison; all stakeholders and interdependencies would need to be identified and feedback, including the response of fish populations, would be essential.

Completion of an environmental flow study for Pyramid Creek is anticipated in 2014-15 (VEWH 2014) and Environmental Water Management Plans are due to be completed for the Loddon River (including Pyramid and Serpentine creeks) and Gunbower Creek in 2015 (Louissa Rogers, North Central CMA, pers. comm.).

8.6.5 Recovery Actions and Implementation

The proposed strategy and recovery actions of the Plan are:

Investigations

1) Liaise with Goulburn-Murray Water on options to manage flows for fish and irrigation demands; assess opportunities such as rain rejections.

2) Develop flow management plan covering each waterway and providing for a seasonal hydrograph and variation in flow that is more suitable for fish, while meeting irrigation requirements. The flow management plan should include:

- Flow volumes
- Timing
- Seasonality
- How flows will be measured and assessed
- How losses will be estimated and accounted for.

3) Develop a communications strategy – keep all stakeholders well informed, especially the community.

4) Use hydrodynamic model (1D) of velocity to assess most effective options to increase hydrodynamic diversity. This will also help prioritise habitat rehabilitation, especially areas for snags and littoral zones for nursery areas.

5) Develop operational arrangements to optimise environmental values of small permanent forest wetlands (e.g. enhancement of Freshwater catfish populations in Phyland, Turners lagoons). (Covered under TLM program).

Actions

6) Provide base flow / winter flow.

7) Provide end-of-system flow; target range of 300-1000 ML/d.

8) Provide seasonal hydrograph and variation in flow that is more suitable for fish, while meeting irrigation requirements:

- High flow with low variation from winter to early summer.
- Lower flows with more variation but less short-term oscillation from mid-summer to autumn.

9) Increase hydrodynamic diversity, which is largely achieved by the flow actions above, but also by re-snagging and lowering weirpools where possible (e.g. non-irrigation season). Explore alternatives to irrigation supply with lowered weirpools.

10) Provide flow to small permanent wetlands within the forest (most of these were dry in the last drought) and billabongs along Gunbower Creek. [Note: there is likely to be overlap with The Living Murray program for some of these wetlands].

11) Support Living Murray Gunbower Forest project to optimise outcomes for native fish.

Monitoring

12) Validate hydrodynamic model in the field.

13) Monitor and quantify response of fish to changed flow management; provide feedback for adaptive management.

8.7 Habitat Management

8.7.1 Channel habitats

8.7.1.1 Littoral habitat

The littoral zone is the aquatic edge zone of waterways and the bank is the riparian zone. The littoral zone is a complex habitat where aquatic plants, leaf litter and shallow water with low velocity provide diverse habitat for small fish, particularly larvae and juvenile fish. Hence, they are important nursery areas. Structural complexity of littoral zones also needs to be part of hydrodynamic complexity on a broader scale; for many species the complex littoral edges need to be adjacent to flowing water in the middle of the channel which would constantly bring drifting food into these habitats.

Larvae of numerous native fish species are drifting into the Project Area via the National Channel (O'Connor *et al.* 2008b) but, from the abundance of adult fish, survival of these larvae appears poor. Larvae are the most critical stage in the life cycle of a fish. They hatch with a yolk sac that provides short-term nutrition and energy but once this is used – usually 2 to 8 days – larvae need to feed within 24 hours. If the right type and size of food is not present the larvae dies. Nursery habitats, like littoral zones, provide that access to food at this critical time as well as protection from predators.

There are some excellent examples of high quality littoral zones in Gunbower Creek but much of these areas are degraded in all three main channel habitats. The main impact is cattle, which trample and eat aquatic vegetation, as well as introduce nutrients and resuspend sediment and silt. The recovery action is to manage their access, usually through fencing, and provide alternative watering points and crossings.

Short-term, frequent oscillations of water level in summer and low flows in winter also restrict the development of the littoral zone and limits diversity to hardy plant species.

8.7.1.2 Instream habitat

The main instream habitat that has degraded over a long period of time is instream woody habitat or 'snags.' Snags provide one of the fundamental elements of aquatic habitats in Murray-Darling streams and numerous studies (and numerous fishers!) have shown native fish, particularly Murray cod, use snags as primary habitat.

Historically, snags have been removed to improve channel capacity throughout the Murray Darling Basin. Recent studies have shown the impact on channel capacity is dependent on the density and placement of snags, and whether the snags completely cross the channel in high local densities (a "log jam"). Where placed along the stream edges and oriented partly with the flow, the impact on channel capacity is minimal and can be designed to have no practical impact.

Re-snagging is an established method of stream rehabilitation and it is a proposed action of the Plan, particularly in Pyramid Creek which has very few snags. Modelling of channel capacity with different levels of snag density, or roughness, would be part of this action to ensure that water delivery for irrigation remains unaffected. Hydrodynamic modelling would also be used to identify the reaches that have the fastest flow and hence would produce the more complex hydrodynamics with the addition of snags.

The channel provides an overwintering habitat which, as discussed in Section 8.6 on flow management, would be greatly improved with the provision of winter flow. It would be further enhanced with re-snagging and an improved littoral zone.

8.7.1.3 Geomorphic variability

Land clearing and channelization, such as in the National Channel and Box Creek, inevitably leads to transport of sediment and siltation of streams, which reduces geomorphic variability and in particular, the loss of deep holes. Often this is a permanent change of the channel morphology and dynamics but in streams the size of Gunbower Creek and Box-Pyramid Creek rehabilitation techniques such as rock groynes and drop structures have been used to recreate deeper holes. A proposed action of the Recovery Plan is to investigate the use of channel rehabilitation techniques to assess their potential in the Project Area.

8.7.1.4 Riparian habitat

Although not directly part of the aquatic habitat, the riparian zone is intimately linked, providing shelter, food, carbon and woody debris. Some areas of Gunbower Creek that are adjacent to Gunbower Forest have an excellent riparian zone but Box-Pyramid Creek is essentially cleared land and has few trees or shrubs along the banks. The riparian zone of the lower Loddon is poor to moderate with some dense patches of lignum and in some areas widely spaced red gums (Sharpe et al 2010). Recent works by the North Central CMA have seen significant lengths of the river fenced from stack access. The proposed action in the Plan is to investigate links with land management programs to improve these habitats.

8.7.2 Off-channel habitats

The off-channel habitats include the forest floodplain, the forest wetlands and the billabongs along Gunbower Creek; as discussed earlier the first two are part of a Living Murray project to improve inundation frequency and duration. A major overlap with the present project is the small permanent wetlands within the forest, which are a specialised habitat of at least two threatened species – southern pygmy perch and flat-headed galaxias. The permanency of these habitats has been underestimated in the past (sec. 3.5.2) and the loss of these habitats parallels a decline in these species along the River Murray.

Recreating these habitats, by providing flow to prevent them drying, is a proposed recovery action of the Plan, overlapping with the previous actions on flow. This recovery action is also now part of Living Murray planning for using the new infrastructure in Gunbower Forest. A complementary action that is integral to this habitat rehabilitation is the re-introduction of threatened species (see next section 8.8).

The Gunbower Creek lagoons are a specific off-channel habitat that has the threatened freshwater catfish and they require specific management. Maintaining water quality through flow and the littoral zone by managing cattle access are two recovery actions. An overlapping action is also providing fish passage so freshwater catfish can move out of the lagoons and repopulate other areas.

For both the forest wetlands and the lagoons there is also the complementary action of managing the two non-native pest species, carp and Gambusia, to minimise negative interactions with threatened species (refer to Section 8.9 below on *Non-Native Fish Control*).

8.7.3 Recovery Actions and Implementation

The proposed strategy and recovery actions of the Plan are:

Investigations

1) Identify larval drift and settlement areas to prioritise littoral zones for rehabilitation; also part of monitoring.

2) Modelling of channel capacity with different levels of snag density to ensure that water delivery for irrigation remains unaffected.

3) Hydrodynamic modelling to optimise re-snagging locations.

4) Investigate the use of channel rehabilitation techniques to re-create geomorphic variability, including deep pools.

Actions

5) Manage cattle access to littoral zones.

6) Re-snag (replace instream woody habitat) in streams where necessary; Pyramid Creek is a high priority.

7) Link with land management programs to improve riparian zones.

8) Restore small permanent forest wetlands with flow; part of Living Murray and the present Plan.

9) Improve billabong habitats through managing cattle access, flow and fish passage

10) Rehabilitate large forest wetland complexes.

Monitoring

11) Monitor plant response in littoral zones; provide feedback on species and structure diversity to refine management.

12) Monitor fish response to improved habitats; quantify plankton and fish larvae assemblage at various sites to refine management and identify nursery areas to target rehabilitation.

13) Evaluate spatial variability and connectivity of habitats (e.g. spawning habitats with nursery habitats), to refine management.

Overlapping Actions

14) Littoral zone: Flow Management – reduce short-term oscillations and provide winter flow.

15) Overwintering habitats: Flow Management – provide winter flow.

16) Instream habitat: Flow Management - increase hydrodynamic diversity

8.8 Reintroduction of Threatened Species

Analysis of the fish species that are present or expected in the Project Area and the habitats that can be rehabilitated, show that over half the species have high potential for recovery (Sec. 7.5, Table 7). Of these species some will recover as habitat recovers and connectivity is re-established, because they have active large-scale dispersal migrations and would rapidly recolonise. However, other species have small-scale dispersal migrations and no nearby source populations; for these, an initial stocking or translocation would be the most effective method to re-establish populations.

The species that have potential for recovery and have small-scale dispersal movements are the small-bodied threatened species - southern pygmy perch, olive perchlet, flat-headed galaxias and southern purple-spotted gudgeon – and freshwater catfish. The first three species would almost certainly benefit from reintroduction, either via stocking or translocation, because they are known to use similar habitats. Freshwater catfish would also be likely to benefit from translocation because their movements are presently restricted in the Gunbower Lagoons. For southern purple-spotted gudgeon the habitat requirements in the Project Area are less well–known and success is less certain.

Southern pygmy perch, southern purple-spotted gudgeon and olive perchlet breed easily in captivity and there are presently government breeding programs for these species at Narrandera Fisheries Centre in NSW. In South Australia there is a breeding program for southern purple-spotted gudgeon and translocation of southern pygmy perch to farm dams that had wetland characteristics (as refuges during the last drought) has been very successful.

Southern pygmy perch have been successfully reintroduced into wetland habitats at Deniliquin, Washpen Creek (near Euston), and Thurgoona NSW (John Conallin, Murray CMA pers. comm., 2012; Dean Gilligan, NSW Fisheries pers. comm., 2012).

Olive perchlet have also been re-introduced into Deniliquin town lake, Thurgoona lagoon and Washpen Creek in southern NSW. This has either been successful or failed but the underlying causal factors are unknown (Martin Asmus, NSW I&I, pers. comm. 2014).

Flat-headed galaxias can be easily transported but appear difficult to breed in captivity (Llewellyn 2005), so direct translocation of fish from healthy populations would likely be the most effective method.

Re-introduction of threatened fish is a strong management option but one that needs to be planned. Importantly, if the causes (e.g. alteration of flows) and impacts of non-native fish (e.g. competition with Gambusia) for the decline of the species are not addressed then a self-sustaining population from the re-introduction is unlikely to succeed.

In Victoria there are "Guidelines for the Translocation of Aquatic Organisms in Victoria" which provide a risk management framework for approval to move fish, which might require approval under the relevant Acts (e.g. Fisheries Act 1995 & Flora and Fauna Guarantee Act 1988). For species with conservation significance, such as southern pygmy perch which were once found in Gunbower Forest, there is a reasonable expectation that re-introduction would be positively considered by the relevant authorities. If risks (e.g. stocked fish negatively impact on another species) can be mitigated then re-introduction remains a very effective management option. For the small-bodied threatened species considered here, the risks appear very low. Translocating threatened fish from one population to another commonly occurs for species such as catfish into the Wimmera and stocking of trout cod and Macquarie perch occur each year.

More information in stocking and translocating in Victoria can be found at the DEPI website:

http://www.depi.vic.gov.au/fishing-and-hunting/fisheries/moving-and-stocking-live-aquatic-organisms/guidelines-for-assessing-translocations/translocation-administration

If approval is granted then the logistics of re-introduction can be investigated, including:

- Nearest source of fish for genetic integrity (e.g. Barmah Forest for southern pygmy perch).
- Number of fish required.
- Locations and habitats to be prioritised for re-introduction
- Monitoring program.

The habitat preferences and ecology of threatened species is usually not as detailed as common species, simply due to the difficulty of studying species with low abundance. For the species discussed here, there are a number of specific knowledge gaps which are described below in *Investigations* and *Monitoring*. It would be essential to address these with the reintroduction of species to ensure that self-sustaining populations establish.

In summary, the authors consider that with habitat rehabilitation as described in this Plan, mitigation of direct and indirect threats and a reintroduction plan with monitoring, the likelihood of recovery is very high for four threatened species (southern pygmy perch, olive perchlet, flat-headed galaxias, freshwater catfish) and possible for a fifth (southern purple-spotted gudgeon).

8.8.1 Recovery Actions and Implementation

The proposed strategy and recovery actions of the Plan are:

Investigations

1) Undertake comprehensive study to determine benefits or disbenefits, and to prioritise, reintroduction or translocation of fish species.

2) Identify habitat characteristics associated with robust threatened fish populations (e.g. size, geomorphology, density and types of aquatic plants, flow regimes).

3) Identify specific wetlands/sites in Gunbower Forest that contain optimum habitat characteristics and where water delivery can be easily managed to support reintroduced fish populations.

4) Identify direct and indirect threatening processes associated with the fish species' decline (e.g. competition or predation associated with non-native species; effects of regulated flow regimes on recruitment and dispersal).

Actions

5) Proceed with Victorian DEPI approvals for reintroductions.

6) Identify and apply management options at specific sites to remove direct and indirect threats (e.g. drying of particular wetlands to remove exotic species; reintroduction of indigenous aquatic plants; management options to maintain drought refuges [e.g. pumping]; dispersal pathways).

7) Reintroduce southern pygmy perch, olive perchlet and flat-headed galaxias into a selected range of habitats including: a) large and small forest wetlands and b) optimal, sub optimal, and poor habitats. It would be preferable to replicate these habitats in a well-designed experiment to enable rapid feedback to adaptively manage populations and ensure efficient use of future resources.

8) Translocate freshwater catfish to other lagoons and habitats.

9) Trial reintroduction of southern purple-spotted gudgeon.

Monitoring

10) Monitor status of reintroduced populations, including:

- In different habitats in experiment.
- Assessment of hydrological regimes that favour native fish over non-native fish (esp. carp and Gambusia).
- Dispersal to new habitats.
- Assess interactions with Gambusia and carp to determine the maximum densities tolerated by reintroduced native species and, hence, determine when management intervention is required.

Overlapping Actions

11) Flow, habitats, fish passage.

12) Restore small permanent wetlands (part of Living Murray, but need to be separated from large forest complexes)

13) Non-native fish control (carp and Gambusia)

8.9 Non-Native Fish Control

There are six non-native fish species known in the Project Area - carp, Gambusia, goldfish, redfin perch, oriental weatherloach and tench - of these, carp, Gambusia and redfin perch are likely to have the greatest negative impact on habitats and native fish. Management of these species requires an Integrated Pest Management Plan; this can include localised actions but needs to be viewed in the regional context with nearby forest floodplains, including Living Murray Icon sites. Rather than eliminating pest species the objective would be to reduce their abundance to a level that has acceptable impacts on habitats and enables native fish populations to recover.

The Project Area offers several potential ways to control pest fish, largely through flow management and using Williams Carp Separation Cages on fishways. These efforts would need to be applied with monitoring in an adaptive management framework, to refine their application and assess potential impacts on native fish.

8.9.1 Recovery Actions and Implementation

The proposed strategy and recovery actions of the Plan are:

Investigations

1) Prioritise fishways in the Project Area for the Williams Carp Separation Cage, by potential biomass of carp and migration pathways.

2) Explore opportunities for cost sharing of carp harvesting with similar initiatives in southern NSW (e.g. Murray CMA, Lachlan CMA) to utilise existing infrastructure and carp disposal mechanisms.

3) Assess densities of non-native fish species in wetlands that have potential for reintroduction of threatened species.

4) Develop a carp management plan for Gunbower Forest, including flow management regimes for select wetlands.

Actions

5) Williams Carp Separation Cage.

- Initiate pilot trials to determine feasibility and cost-effectiveness of carp removal.

6) Manage flow:

- Reduce summer inundations of floodplains to limit spawning/recruitment of carp and Gambusia.

7) Dry floodplains to trap and destroy large numbers of carp.

Monitoring

8) Assess efficacy of actions and refine application.

9) Assess impacts on native fish.

Overlapping Actions

10) Flow, fish passage.

11) Restore small permanent wetlands.

9 MONITORING AND INVESTIGATION

9.1 Introduction

As our knowledge of fish population dynamics in Gunbower – lower Loddon waterways is imperfect, appropriate monitoring can help to address some of these gaps in knowledge. In other words, management can be used as an experiment to obtain relevant information to refine actions. This is often called "*adaptive management*". It is a strategy that helps to cope with the problem that there will always be missing information and unexpected responses to actions taken during a management intervention, such as this Native Fish Recovery Plan. Monitoring programs require clear timelines and check points when results are reviewed and changes to the program are made, if necessary.

Monitoring is the systematic collection of information on the progress of a project. *Evaluation* is the comparison of the results from the monitoring against the objectives of the program. Monitoring and evaluation are invaluable tools for the program manager, enabling a feedback loop to constantly refine, improve and optimise methods and actions.

Most funding agencies require some form of monitoring and evaluation so they can determine whether the funds have been well spent. Clearly, if there is no hard evidence that the program objectives are being achieved, it is difficult to make a case for continued funding. For the Plan some reasons for monitoring and evaluation include:

- To determine whether the recovery actions are meeting the objectives (e.g. improved native fish recruitment).
- To determine what other factors are significant or more important in the Plan.
- To increase understanding of fish population dynamics, to change or refine management actions.
- To provide feedback to those involved in the program and to maintain their engagement.
- To determine the efficiency of the program and how it might be improved.
- To demonstrate outcomes and thus meet the requirements of funding agencies, justify continued funding and to seek additional funds.

Much care needs to be given to the design of a monitoring program and to data collection. It is important to determine what data to collect, when, where and exactly how to collect the data.

Involving a biometrician early in the scientific design phase is an important component. Much of the data will require specialised methods and trained staff, and will be difficult to integrate into other long-term programs (e.g. Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) (Chee *et al.* 2009)). Determining how fish populations change as a result of management actions will likely require specific funds. By contrast, some monitoring might be able to be incorporated into the existing management framework, particularly if the support of major stakeholder such as recreational fishers and G-MW is gained.

Indicators of population change need to be SMART (Specific, Measurable, Attainable, Relevant and Time-bound). Applying this principle results in some aspects not needing to be monitored every year and it may be better to put resources into: i) less frequent but intensive recovery monitoring and ii) other targeted species-specific monitoring (e.g. surveillance monitoring to see if southern pygmy perch are surviving). The *Time-bound* aspect is important to consider in fish populations as some will recover quickly while others that are long-lived (30-50 years) and have low fecundity (low number of eggs per female) may take a decade or more to recover.

Lastly, integration of *operational monitoring*, or how, where and when G-MW manages operational aspects and at what cost, can also be used to assess management objectives. By integrating operational monitoring and fish monitoring there will be increased cost effectiveness of management.

9.2 Measuring Change

Collecting field data to demonstrate improvements to fish populations in Gunbower - lower Loddon waterways requires a well-structured and robust scientific program. It is important to recognise that the waterways in the Project Area are smaller than the River Murray so that the logistics of quantifying fish abundance and dynamics are more straightforward. When measuring parameters of fish populations (e.g. species composition, relative abundance, year-class strength, recruitment) sampling should be replicated and stratified by habitat (e.g. ephemeral and permanent wetlands, flood runners, permanent creeks) and time (e.g. sampling in spring and summer) using techniques appropriate for the Project aim.

It is important the experimental design (the way sampling is conducted) is carefully planned with a clear objective or hypothesis. For hypothesis testing, bio-statistical support is integral and guidance on appropriate sampling techniques, tailored to the local conditions and objectives, from existing programs (e.g. VEFMAP) would be useful. Very often it is the inherent variation in relative fish numbers that controls how sampling will be conducted and here, the VEFMAP data would be useful for a biometrician to analyse before designing a sampling regime. The optimal level of sampling effort is one that allocates field sampling in a way that maximises statistical power.

Power analysis (from existing data) is useful for determining the appropriate sample size before the monitoring begins to determine what power is in the study as calculated from the sample and effect size (the level of change in fish populations that the hypothesis expects). Hence, the power analysis would be used to determine the probability of a statistically significant difference between fish populations.

In the case of low statistical power there are several ways to increase power:

- Increase sampling
- Increase (weaken) the significance level (e.g. α from 0.05 to 0.1)
- Increase the reliability of the sample data (data variation)

The results of power analyses are dependent on the magnitude of the sampling variance as quantified by VEFMAP or other existing data. It enables the risk of a project investment to be objectively judged and any changes made with a greater degree of certainty; for example, a small extension in sampling period might enable much smaller population changes to be detected. Power analysis also enables the information to be clearly communicated to all stakeholders so that the rationale for the time periods of sampling, which are often many years, are understood.

There is also an opportunity to sample fishways to gain long-term quantitative fish movement data and a better understanding of migration rates and the influence of different flows. This type of information is often less resource intensive than standard fish sampling techniques (e.g. electro-fishing) if it can be incorporated into G-MW operations similar to the Torrumbarry Weir monitoring. An existing cage trap suitable for Kerang and Gunbower weirs is presently stored at Torrumbarry Weir and might be used to quantify fish migration regularly (e.g. two days per fortnight) in spring and summer. Alternatively, Passive Integrated Transponder (PIT) tag readers, DIDSON sonar or other technologies are increasingly being employed to measure and quantify improvements to fish passage. A PIT tag reader is installed at Kerang Weir.

9.3 Measuring improvements in fish populations

A variety of methods have been used to sample fish in the Loddon River and nearby waterways and these are summarised for the more recent surveys in Table 9. The methods utilised by each study are dependent on the objectives but usually include boat electrofishing which is one of the more cost effective sampling techniques for large-bodied fish (Growns *et al.* 1996). Bait traps (usually unbaited) have also been used in the system to capture small-bodied fish, such as carp gudgeons that are rarely sampled by boat electrofishing techniques. Fyke nets have also been used to capture a number of medium- to small-bodied fish species that undertake local or upstream movements, such as river blackfish and catfish, but may also be harder to sample by boat electrofishing techniques.

Table 9. Fish sampling methods used in some recent fish assessment work in the Loddon River and nearby waterways.

Survey	**Broad Aim**	**Fishing Method**								
		Gill nets	**Fyke nets**	**Bait traps**	**Backpack electrofishing**	**Boat electrofishing**	**Bank electrofishing**	**Light traps**	**Larval nets**	**Seine net**
McGuckin 2000	Fish upstream and downstream of Kerang Weir	✓	✓		✓			✓		
Richardson *et. al.* 2005	Fish community restoration		✓			✓				
DPI 2007	Assess small fish communities		✓	✓		✓		✓	✓	✓
SKM 2007	Fish community monitoring		✓	✓	✓	✓	✓			
SKM 2007 (Hannon)	Investigate fish communities		✓	✓	✓	✓	✓			
SRA 2007	Baseline fish community assessment		✓	✓	✓	✓	✓			
SKM annually from 2008 (VEFMAP)	Fish community monitoring		✓	✓	✓	✓	✓			
Rehwinkel and Sharpe 2009	Fish community change		✓	✓		✓				

Integration of multiple techniques is an appropriate way to sample a broad range of fish species and sizes but again the methods, sample efficiency, site selection and replication all need to be suitable for providing data in regard to the study aim. The most important factor to consider when selecting a survey method is that the results are as objective as possible, are repeatable and the potential for bias is minimised.

The VEFMAP and Sustainable Rivers Audit (SRA) sampling programs use similar sampling techniques (electrofishing, fyke nets, bait traps) for sampling fish in the Loddon, Pyramid and Gunbower systems. The VEFMAP and SRA projects aim to provide an ongoing 'snapshot' of fish communities, their composition and relative abundance. The sample frequency and site selection are not directly relevant to the potential objectives of the Plan, which aims to measure improvement in the fish populations of the Gunbower region. Nevertheless, VEFMAP and SRA surveys are broadly useful and could detect long-term changes in fish species and abundance in the Gunbower/Pyramid and lower Loddon systems.

9.4 Knowledge Gaps

9.4.1 Introduction

Identifying knowledge gaps enables monitoring to be targeted and prioritised, and enables assessment of risk and certainty associated with each recovery action. The Plan has identified some knowledge gaps where investigation could significantly improve outcomes of recovery actions. These relate to quantifying threats to refine mitigation strategies, identifying key areas for habitat rehabilitation, and fish behaviour.

9.4.2 Downstream movement and survival of fish

There are two areas of downstream movement and survival that require investigation: i) movement into irrigation channels and, ii) survival through the National Channel Inlet Regulator. The first issue has been described in the Recovery Actions (section 8.5) and is part of a staged approach to the loss of fish irrigation channels. Specifically, the knowledge gaps are:

- Fish movement (larvae, juveniles and adults) in and out of the four major irrigation channels.

  Data would include fish movement rates, biomass, life-stages, sizes and timing. Assessing this and comparing it to fish, particularly larvae, which do not enter the irrigation channels would: i) enable the impact on fish populations to be quantified and ii) guide the extent and type of screening required at each site.

- Diel (day/night) movement of larvae.

  This data would be useful to assess whether operational regimes of channels can improve fish survival (e.g. if larvae are active at night then water delivery at the intakes could be prioritised for day use).

The second knowledge gap is survival through the National Channel Inlet Regulator which has undershot gates; it is significant because almost all water that passes into the Project Area passes through this structure. Studies have shown that fish larvae drift into the National Channel (O'Connor *et al.* 2008b) and that fish larvae have high mortality passing through undershot gates (Baumgartner *et al.* 2006). However, specific survival of larvae at this site has not been quantified and it may vary depending on the flow and head differential. Quantifying this would enable action at this site to be refined and prioritised. It would also aid in understanding the contribution of wild fish versus stocked fish to the Kow Swamp fish populations.

9.4.3 Identification of spawning and nursery habitats

Murray cod appear to spawn in Gunbower Creek, in high quality snag habitats between Cohuna and Koondrook weirs. Identification of these spawning sites is important to protect and restore these areas and thus maximise larval survival. As discussed in previous sections the early life stages (larvae, fry) of all fish species are vulnerable and suffer high mortality even under natural conditions. If nursery habitats are also degraded or inaccessible the mortality of young fish reaches a point where the population is not sustained and declines.

Identification of nursery habitats, some of which will be littoral zones of streams, would be important to optimise rehabilitation. Nursery habitats will not be uniformly distributed so all littoral zones, for example, will not have equal ecological value. The location in the landscape and relationship to fast- and slow-flowing reaches will influence settlement of larvae, survival of larvae and the value of different nursery habitats.

9.4.4 Rehabilitation of fast-flowing reaches

Restoring hydrodynamic diversity (fast- and slow-flowing reaches) is a specific recovery action, acknowledging that weirpools and low flows reduce this diversity and create more stillwater and slow-flowing habitats. Hydrodynamic modelling of channel profiles, flow, water velocity and depth is a very effective tool in predicting the outcomes of increased flow and has been used extensively on Living Murray projects. For the present project it would enable:

- Flow thresholds to be established for optimised water management that meets fish habitat objectives and irrigation demands.
- Identification of reaches where re-snagging would provide the greatest habitat benefit.
- Options to be explored for weirpool management and water delivery (e.g. operating the weirpools at lower levels re-establishes fast-flowing reaches upstream).

9.4.5 Rehabilitation of deep holes in streams

Techniques for rehabilitating geomorphic diversity, particularly deep holes, using drop structures and rock groynes in streams, are well established. Other options for the recreation of deep holes include use of high flows to create scour, judicious placement of instream woody habitat and excavation of silt and sediment. Their application, however, to the streams in the Project Area are unknown. The proposed approach is:

- Investigate the various techniques for restoring geomorphic diversity.
- Evaluate the effect of interventions on channel capacity and water delivery of irrigation.
- Establish a pilot trial.
- Monitor, refine the application, and apply elsewhere, if appropriate.

9.4.6 Habitats of threatened species

There is considerable knowledge of the general habitats of threatened species that are in the Project Area or proposed to be re-introduced. However, briefly determining which habitat features (e.g. aquatic plants) support threatened fish would enable recovery actions to be more targeted and have a greater probability of success. These actions are described in Section 8.8.1 and involve identifying habitat characteristics associated with robust threatened fish populations outside the Project Area, as well as an experimental approach to re-stocking into variations of suitable habitats.

9.4.7 Survival of stocked fish

Both Kow Swamp and Gunbower Creek are regularly stocked with native fish but the proportion of these fish that survive is unknown. Kow Swamp may be a natural nursery area and Gunbower Creek, with more flow, connectivity and habitat management, could become a major nursery area for native fish. As recovery actions are implemented, wild fish populations are certain to increase and there can be less reliance on stocking. Techniques for identifying stocked fish are well established and have been applied in the Kerang Lakes. Understanding the survival of stocked fish and the contribution of wild populations would be part of quantifying the population recovery and part of practical management of fish populations.

9.4.8 Response of fish in forest floodplains

In the last decade there has been substantial research on the behaviour of fish on floodplains which is summarised in Section 5. The response of fish, however, is less certain in forest floodplains during managed inundations where the floodplain and river hydrology are not synchronised. Predictions can be made on fish behaviour, based on the models presented in Section 5, but the certainty around these is variable.

The approach to address these knowledge gaps and uncertainty is to use adaptive management. The objectives are to: i) maximise opportunities for fish to access new spawning/feeding habitats and leave at the end of the inundation cycle, and ii) minimise opportunities for carp. The response of fish will be totally reliant on the inundation regime and may not be fully planned for until the event is underway. Hence, adaptive management as the event unfolds would be the most effective method to minimise risks and optimise outcomes.

This adaptive management will require real-time data on fish response to provide guidance on flow management in particular, timing and duration of watering to give fish appropriate access and exit pathways. Real-time data is also needed to provide advice on the need for manual collection and rescue of stranded large-bodied native fish or harvest/destruction of carp aggregations. These aspects require responsive management and co-operation with fish biologists and the asset operators, Goulburn-Murray Water.

9.4.9 Response of fish to flows

Flow recommendations for Gunbower Creek and Box-Pyramid Creek are a major Recovery Action. Again, there has been considerable research on flows and fish, which is summarised in Section 6. The complexity for the present project is that water delivery is also used for irrigation so micromanagement (daily) of flow is as important as broad, seasonal flow objectives. Understanding the response of fish to flow at temporal and spatial scales appropriate to the Project Area would considerably help management.

9.4.10 Knowledge wealth

A discussion of *knowledge gaps* can tend to suggest there is less certainty of the outcomes of actions. It is worth noting that in fact the present project comes at a time of increased *knowledge wealth* on native fish in the River Murray and anabranch systems over the last decade. It is this knowledge that has provided the fish recovery potential to be realised, the momentum to initiate the Plan and appreciate that the outcomes have extremely high certainty.

10 OPPORTUNITIES AND RISKS

10.1 Opportunities

The Native Fish Recovery Plan – Gunbower and Lower Loddon provides three major and unique opportunities to demonstrate a new paradigm of water management:

1. **Recovery Potential**.

   The recovery potential of fish for over 280 km of streams (Gunbower creek, Box-Pyramid Creek, lower Loddon River), 190 km of which are solely used for irrigation delivery, is extremely high (see Section 7).

2. **Water Use.**

   All flow recommendations use water that is returned to the River Murray, so the actual water used is channel losses in winter, which are very low.

3. **Existing Programs.**

   The building blocks for the Plan are presently laid, through two initiatives:

   - 4 of the 8 fishways required are built or funded,
   - Rehabilitation of the forest floodplain and wetland is being done through the Living Murray program.

Additional opportunities include:

4. **Infrastructure and constructability is not complex.**

   - The remaining weirs requiring fishways are not high (< 2.5 m difference in upstream and downstream water level).
   - The irrigation channels that are likely to require screening do have high discharge, so screens are a practical solution.
   - A large part of the cost of instream structures is dewatering and managing the risk of flooding. For the fishways and irrigation screens proposed in Gunbower Creek, there is a very high degree of flow control because the National Channel Inlet Regulator is the main source of flow and this is built to a very high flood level.

     The depth of Gunbower Creek is much less than River Murray and hence, also favours simple dewatering and construction.

     The National Channel Inlet Regulator is an old asset, which are often more costly to modify for fish passage, with potentially more complex dewatering. Both these issues could potentially be addressed by using the existing regulator for dewatering and building a new regulator and fishway immediately downstream; similar solutions have proven to be more cost-effective and simpler to build at other sites in the Murray-Darling Basin, with the advantage of a new regulator with a 100 year life.

5. **Ecotourism**

   - Recreational fishing would increase in the region.

- Provision of flow, connectivity and habitat would provide a major increase in the Murray cod population that would not have occurred without these measures. This provides the opportunity for a "Trophy Fishery", where anglers have a high chance of catching a large trophy-sized fish and all fish are released alive. The Trophy Fishery would likely be centred adjacent to the town of Cohuna.
- Recreational fishing improvements would link with Living Murray improvements in the wetlands and floodplains, providing combined opportunities for ecotourism.

6. Social

- Potential to depolarise the water debate and clarify common social, economic and environmental goals.

7. Policy

- Potential to show that irrigation areas can be active parts of achieving river management and conservation goals.

8. Program / Institution Links

- The project presents opportunities to link between institutions for cooperative sub-projects. Organisations include:
  - Indigenous groups.
  - The Living Murray Program.
  - Goulburn–Murray Water Connections Project.
  - Parks Victoria. A section of Gunbower Forest was recently gazetted as a National Park.
  - Universities and research institutes. The Plan would provide an excellent case study of river rehabilitation and irrigation, providing wide scope for research students. The research would be linked with the knowledge gaps and monitoring objectives, providing feedback to recovery actions and further refining management.

10.2 Risks

There are two applications of risk to the Plan: i) program risks and ii) risks of a 'do nothing' scenario. The program risks fall into three categories of program continuity, infrastructure and fish responses; these are listed in Table 10, alongside mitigations. They represent high-level risks rather than detailed risks of individual on-ground works.

Table 10. Risks and mitigations of the Native Fish Recovery Plan – Gunbower and Lower Loddon.

RISK	MITIGATION
Program Continuity	
Funding incomplete. • Interlinked actions not achieved (e.g. not all fishways completed, or end-of-system	Communicate: • Links between actions in funding applications.

RISK	MITIGATION
flow not provided).	• Value for money of whole program to avoid "cherry-picking" of selected actions.
Staff changes. • North Central CMA (program coordinators), G-MW (operators). • Conceptual framework and program objectives are diluted.	• Present Plan provides conceptual framework. • Technical Memorandum Series intended to capture corporate knowledge. • Steering Committee to provide oversight and continuity.
Lack of monitoring • On-ground works can often receive priority as they are at the beginning of the program.	• Ensure funding for monitoring tracks alongside capital works. • Communicate the value of monitoring and continue updates and reporting through the website, Technical Memorandums and the Plan Forums.
Lack of stakeholder engagement	• Ensure Communications Strategy runs in parallel with recovery actions. • Request annual feedback from stakeholders and be responsive to changing communication needs.
Infrastructure and Operation	
Poor fishway design.	• Use a consultative design process (Tech. Memo. No. 4). • Include peer review at various design stages. • Ensure wet commissioning occurs.
Operation not optimised of: • Fishways, including regulator gates for fish attraction. • Screens.	• Observations & Measurements to include operation for fish objectives. • Provide on-site training of operators. • Liaison with operating staff; include annual meeting to receive feedback from operators.
Managed inundations trap and strand native fish.	• Real-time fish monitoring of managed inundations. • Plan availability of required resources to rescue stranded fish.
Fish Responses	
Non-native fish species. • Carp and gambusia establish in new permanent wetlands and compromise habitat for small threatened species (e.g.	• Ongoing low-level (e.g. annual) monitoring to assess carp populations. • Active management of non-native fish

RISK	MITIGATION
southern pygmy perch and flat-headed galaxias).	species.
Knowledge Gaps. • Unknown aspects of fish biology; impacts and threats that impacted on past populations are unknown and may still be present (e.g. redfin predation of juvenile native fish; disease).	• Monitoring of populations, with scope for more detailed investigations if population response of native fish is poor. • Experimental approach to re-introductions to understand underlying reasons for the improvement or otherwise of populations.

The risks of a 'do nothing' scenario are not likely to become apparent in the short term of one to five years but in the medium term of 10 years or longer they would likely become apparent. Many of these have previously been identified in this Plan; nevertheless some of the most significant and likely risks over 10 years are summarised below:

Native fish

- High conservation value species, such as freshwater catfish and trout cod, will continue to decline or even disappear from the Project Area.
- Species already lost (e.g. southern pygmy perch) will not re-establish.
- Golden perch and silver perch will remain in very low numbers because they cannot complete spawning and overwintering habitats remain poor.
- Golden perch and Murray cod populations largely dependent on continued stocking. The low genetic diversity of stocked fish further reduces genetic diversity of remnant natural populations, reducing their viability.
- Lost opportunities to improve spawning, migration, and enhance fish populations.
- Lost opportunity to fill key knowledge gaps, improve conceptual understanding and improve regional fish populations.

Non-native fish

- Carp populations increase regionally due to the managed inundation regime of the forest floodplain and lack of native fish predators.
- Carp establish in more habitats and higher densities.
- Carp negatively impact on habitat (e.g. aquatic vegetation, turbidity) preventing natural recolonisation of threatened species (e.g. flat-headed galaxias and southern pygmy perch).
- Gambusia and weatherloach become widespread throughout floodplain habitats further impacting native fish and conservation values.
- Lost opportunity to control pest fish, such as aggregations of carp.

Monitoring

- Little or no monitoring undertaken; the status of fish populations is unknown so declines or loss could continue unnoticed.

Stakeholders

- North Central CMA, G-MW, DEPI and MDBA staff unaware of native fish issues or framework of priorities; opportunities lost to enhance fish populations cost-effectively and mitigate risks of water and floodplain management.
- Broader community stakeholders unengaged and support for initiatives lost.

The mitigation for the above risks is the present Recovery Plan.

There are additional specific risks for the Living Murray project in Gunbower Forest, such as the risk of native fish stranding in managed inundations and increased carp populations, which are listed under program risks above (Table 10). However, the Living Murray project will continue independently and will have monitoring and risk management for these items.

11 COMMUNICATIONS STRATEGY

A communications strategy is essential to ensure:

- that stakeholders are engaged,
- funding agencies are kept informed of progress,
- project support grows,
- significant findings are disseminated to the water industry so that uptake of results is rapid,
- project profile is maintained to attract future funding sources and good staff,
- that institutions are attracted to cooperative projects.

Only a broad framework of a communications strategy is presented here and it would need more detail before implementation:

1. Identify stakeholders and funding sources; establish strategic links.

Groups include:

- Community
- Aboriginal Groups: Yorta Yorta, Wamba Wamba, Barapa Barapa and Wadi Wadi
- Irrigators: local and Basin-wide
- Shires of Gannawarra and Campaspe
- Recreational Fishing: Recfish Australia, VRFish, regional angling clubs
- North Central Catchment Management Authority

- Bulk water delivery: Goulburn-Murray Water
- Irrigation modernisation programs, Goulburn-Murray Connections Program
- Murray-Darling Basin Plan
- National Irrigators Council
- Australia Water Association
- Water Industry Operators Association

- Murray-Darling Basin Authority
- Department for Sustainability, Environment, Water, Population, and Communities
- Victorian Department of Environment and Primary Industries
- Parks Victoria
- Universities
- Research institutes

2. Indigenous engagement

Aboriginal people in northern Victoria have strong cultural associations with waterways, fish and other aquatic species. In recognition of this cultural association, and of the aspiration of Traditional Owners to be actively involved in natural resource management, a particular focus could be made in engaging with Traditional Owners groups. The traditional owner groups in the Project Area include Yorta Yorta Nations Aboriginal Corporation, Wamba Wamba, Barapa Barapa and Wadi Wadi.

Each of these groups should be actively engaged as primary stakeholders in order to:

- gain support for the Plan,
- incorporate traditional Aboriginal knowledge into the Plan as appropriate,
- foster opportunities for Aboriginal groups to be involved in project delivery where suitable,
- respect and strengthen cultural connections and practices.

3. Media

YouTube. These videos can introduce the project and have regular updates.

Radio. Similar frequency and objectives to YouTube but different audience.

Television. The project would aim for a segment on Landline and Catalyst after approximately 5 years when major rehabilitation elements are completed and some before/after data is available. Two potential newsworthy angles are that: i) clever use of flow (end of system flow and winter flow) and targeted fish passage improves fish populations, and ii) irrigation screens, which will be innovative for Australia. These prevent loss of fish; again this is a gain with no water cost.

Press Releases. Quarterly for local and state; annually for national print media.

Articles for magazines. RipRap. Finterest. Fishing magazines.

4. Native Fish Recovery Forum (annual or biannual, see Section 8.3)

5. Technical Memorandum Series (see Section 8.3 and examples in Appendices)

6. Conference Presentations

The objective of conference presentations is to keep other professions informed, maintain professional networks and maintain a high profile to attract future funding, research and employees. Examples include:

- ANCOLD (water engineers – major national conference),
- AWA conference (water engineers and managers – major national conference),
- RiverSymposium (water managers, natural resource managers – major national and international conference).
- Australian Stream Management Conference
- Australian Society for Limnology Congress

12 VALUE FOR MONEY

12.1 Cost Estimate

Detailed costings would be part of the next stage but a broad estimate, based on recent projects along the River Murray, shows the value for money of the Plan. The capital for infrastructure represents the largest item, with five fishways, up to four screens on irrigation channels, and re-snagging. The fishways are all low-level weirs (<2.5 m) and would cost in the order of $2 million each; this is less than the River Murray fishways because the dewatering costs are much lower (see Sec. 10.1 on Opportunities). The National Channel Inlet Regulator is more complex because it has very high abutments and banks with road access across the structure; the fishway cost is estimated to be approximately $5.6 million (URS 2011); as discussed earlier (Sec. 10.1) this may include a new regulator with a 100 year life to service the irrigation district. In summary, the fishway component of the Plan is likely to be in the order of $15.5 million.

The cost of screening irrigation offtakes is dependent on the discharge passing through them. In the USA screens cost AUD $200,000 to $350,000 per cumec ($m^3/s$). The transferability of these figures is unknown and would be evaluated in the feasibility stage, but $0.75 to $1.5 million per screen in the present project is possible; hence an initial estimate for screening is $3.0 to $6.0 million.

The cost of re-snagging depends on the length of stream, density of snags and availability of snags. From other projects the cost of re-snagging Pyramid Creek, using a snag every 50 m on average (but variable distance in practice), would be approximately $0.7 to $1.0 million. The costs of habitat rehabilitation of littoral zones and riparian zones are likely to be similar.

Monitoring and evaluation is likely to be $0.75 million per year, although this would vary between years. Over the projected 10 years of the project, these costs are likely to be $5 million. The Plan would need two or three full-time project staff, which would add $0.3 - $0.45 million per year with on-costs, or $3 – $4.5 million for the life of the project. These staff would be based in the North Central CMA and Goulburn-Murray Water. The budget for the communications strategy would be part of the project staff budget as they are likely to produce and coordinate the material. Environmental water is not costed at this stage, although it is likely to be a minimal project cost.

In summary, a high-level cost estimate is $30 to $35 million (Table 11), which is similar in scope to the individual Total Living Murray projects.

Table 11. High-level 10-year budget for the Plan. These figures would need to be quantified in the next stage.

Item	Provisional Cost Estimate ($ million)
Fishways	$15.5
Screens	$3.0 to $6.0
Re-snagging and habitat rehabilitation	$0.7 to $1.0
Monitoring and Evaluation	$7.5
Project Staff and Communications Strategy	$3.0 to $4.5

Total	**$30 to $35 million**

12.2 Value for Money

How does the *Native Fish Recovery Plan – Gunbower and Lower Loddon* represent value for money? Primarily, it is rehabilitating 280 km of streams (Gunbower Creek and Box-Pyramid Creek) – that have very few native fish and are presently used for irrigation delivery - and converting it to a productive part of the River Murray ecosystem that will flourish with native fish. In doing so it will showcase how the community, irrigation, and conservation can achieve mutual objectives and, in this case, do so using very little environmental water.

The other major rehabilitation projects along the River Murray, which are comparable cost, are from the Total Living Murray program. These are mainly focused on rehabilitating floodplains. They have general objectives for native fish populations but are not targeted directly at improving native fish populations. Because these are managed inundations where the floodplain can be inundated separately from flows in the river there are also risks for fish – of stranding and favouring non-native species – that need to be managed. These projects are dependent on receiving significant volumes of environmental water in non-flood years, as the major environmental impact over the last 75 years has been reduced flooding.

The Hume to Sea fishways program, which provides fishways on the weirs along the river, is a Living Murray program which is directly targeted at improving native fish populations and specifically addressing the issue of connectivity. Re-snagging of the River Murray between Yarrawonga and Hume Dam is a National Heritage Trust and Living Murray program which is specifically addressing the issue of habitat.

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* is the only approach which addresses all three major impacts on native fish populations: flow, habitat and connectivity. Rather than improving natural areas with moderate impacts the Plan is directly targeting a highly impacted irrigation area, with a correspondingly high potential to improve fish populations. It would add substantially to the natural values of the area; providing refugia from droughts and blackwater events as well as more resilience to climate change.

The project is value for money because of this immense potential to improve local and regional fish populations, which maintains irrigation and uses very little additional water. The flow-on effects include improving recreational fishing, re-establishing threatened species and improved opportunities for ecotourism. The water management of the region would then move from one that is focused on irrigation to having a greater emphasis on its emerging multifaceted role, of irrigation, conservation, recreation and broader economic benefits.

13 CONCLUSION

Water is the lifeblood of the Murray-Darling Basin. It has supported Aboriginal communities for over 40,000 years and for over 130 years it has supported an irrigation industry that has provided Australians with food, prosperity and wealth, but at the now recognised cost of declining river health. There are various programs addressing this decline but they overlook one significant opportunity; acknowledging that irrigation systems are an integral part of the aquatic ecosystem of the Basin.

Synthesising the research on native fish and hydrology of the River Murray reveals that the Gunbower - lower Loddon region, which is wholly managed for irrigation, has in fact, huge potential to support thriving populations of native fish and become a functioning part of the River Murray ecosystem. The flow-on benefits are increased recreational fishing, including the creation of a “Trophy Fishery” for catch-and-release of large Murray cod, and increased ecotourism.

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* achieves this through water management, providing fishways (so that fish can complete migrations) and improving habitats. It is not proposing any changes to the present volumes for irrigation but small changes to the existing water delivery. The Draft Plan is presently seeking comments and support of stakeholders.

The project is value for money because of the potential to improve fish populations over a wide area (over 280 km of streams) and contribute more broadly to regional populations, while maintaining irrigation and using very little additional water.

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* presents a new approach in viewing irrigation as part of sustainable healthy rivers, providing emphasis on the support and input of the local community, irrigators, water managers, government and Aboriginal community. In this way, the Plan aims to unify the water debate and, using recovery of native fish populations, provide a unique opportunity to clarify the common values and goals of stakeholders.

The Gunbower - lower Loddon region is an agricultural hub and, as the birthplace of irrigation, it can become the birthplace of riverine recovery with sustainable irrigation.

14 REFERENCES

Anderson, B.G., Gippel, C.J., Cooling, M.P., Lloyd, L.N., and Kerr, G. (2007a) Gunbower Creek Environmental Flows Study, Flow Recommendations Report. *Report for North Central Catchment Management Authority, Huntly.*

Anderson, B.G., Gippel, C.J., Cooling, M.P., Lloyd, L.N., and Kerr, G. (2007b) Gunbower Creek Environmental Flows Study, Issues Paper. In Report by Water Technology in association with Fluvial Systems, Lloyd Environmental and Ecological Associates for North Central Catchment Management Authority, Huntly. pp. 97.

Atkins, B.P., Lloyd, L.N., and Nikolaou, N. (1991) The Hydrological Characteristics of Gunbower Forest: Draft Report of the Integrated Watering Strategy (Ed. DfCa Environment).

Balcombe, S., Arthington, A., Foster, N., Thoms, M., Wilson, G., and Bunn, S. (2006) Fish assemblages of an Australian dryland river: abundance, assemblage structure and recruitment patterns in the Warrego River, Murray–Darling Basin. *Marine and Freshwater Research* **57**(6), 619-633.

Barrett J. and Mallen-Cooper M. (2006) The Murray River's 'Sea to Hume Dam' fish passage program: Progress to date and lessons learned. *Ecological Management & Restoration* **7**, 173-183.

Baumgartner, L., Reynoldson, N., and Gilligan, D. (2006) Mortality of larval Murray cod (*Maccullochella peelii peelii*) and golden perch (*Macquaria ambigua*) associated with passage through two types of low-head weirs. *Marine and Freshwater Research* **57**(2), 187-191.

Boys, C., Baumgartner, L., and Lowry, M. (2013a) Entrainment and impingement of juvenile silver perch, Bidyanus bidyanus, and golden perch, Macquaria ambigua, at a fish screen: effect of velocity and light. *Fisheries Management and Ecology*.

Boys, C.A., Robinson, W., Baumgartner, L.J., Rampano, B., and Lowry, M. (2013b) Influence of Approach Velocity and Mesh Size on the Entrainment and Contact of a Lowland River Fish Assemblage at a Screened Irrigation Pump. *PloS one* **8**(6), e67026.

Brayshер, M. and Barrett, J. (2000) Ranking Areas for Action: A Guide for Carp Management Groups. Carp Control Coordinating Group and the Murray-Darling Basin Commission. 56 pp.

Cadwallader, P.L. (1977) J. O. Langtry's 1949-50 Murray River Investigations. *Fisheries and Wildlife Paper, Victoria* **13**, 70.

Carlson, A.J., and Rahel, F.J. (2007) A basinwide perspective on entrainment of fish in irrigation canals. *Transactions of the American Fisheries Society* **136**(5), 1335-1343.

Chee, Y.E., Webb, A., Stewardson, M., and Cottingham, P. (2009) Victorian environmental flows monitoring and assessment program: Monitoring and evaluation of environmental flow releases in the Loddon River. *Report prepared for the Goulburn Broken Catchment Management Authority and the Department of Sustainability and Environment by eWater Cooperative Research Centre, Canberra.*

Crook, D.A., O'Mahony, D.J., Sanger, A.C. and Munro, A.R. (2009). Development and evaluation of methods for osmotic induction marking of golden perch Macquaria ambigua with calcein and alizarin red S. North American Journal of Fisheries Management, 29, 279-287

Davies, P.E., Harris, J.H., Hillman, T.J., and Walker, K.F. (2008) Sustainable Rivers Audit: A report on the ecological health of rivers in the Murray-Darling Basin, 2004–2007. In Prepared by the

Independent Sustainable Rivers Audit Group for the Murray–Darling Basin Ministerial Council. pp. 396. (Murray-Darling Basin Commission: Canberra, ACT)

Davis, J., Murray, S., and Burchell, F. (1902) Interstate Royal Commission on the River Murray. pp. 359. (Sands and McDougall Limited Printers: Melbourne)

DPI (2004) Fish 'N' (Micro) Chips Lead To A Substantial Fine. . *http://franklin.dpc.vic.gov.au/domino/Web_Notes/newmedia.nsf/798c8b072d117a01ca256c8c0019bb01/87272b2b2b4f5c8fca256f0f000fe0f2!OpenDocument*.

DPI (2011) More to celebrate than Murray cod season opening this December. *Angler Diary* **12**(http://www.dpi.vic.gov.au/fisheries/about-fisheries/newsletters-and-updates/angler-diary-newsletter/issue-12).

Ebner, B., Scholz, O., and Gawne, B. (2009) Golden perch Macquaria ambigua are flexible spawners in the Darling River, Australia. *New Zealand Journal of Marine and Freshwater Research* **43**(2), 571-578.

Ecological Associates (2003) Flooding Enhancement of Gunbower Forest - Investigation of Priority Options - Part A.

Gale, S.B., Zale, A.V., and Clancy, C.G. (2008) Effectiveness of Fish Screens to Prevent Entrainment of Westslope Cutthroat Trout into Irrigation Canals. *North American Journal of Fisheries Management* **28**(5), 1541-1553.

Growns, I., Pollard, D., and Harris, J. (1996) A comparison of electric fishing and gillnetting to examine the effects of anthropogenic disturbance on riverine fish communities. *Fisheries Management and Ecology* **3**(1), 13-24.

Hale, J. & Sharpe, A. (2014) Monitoring response to environmental flows in the Loddon and Campaspe Rivers: Fish survey 2013/2014. Report by Jacobs Group for North Central CMA, Huntly.

Humphries, P., King, A., and Koehn, J. (1999) Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray-Darling River system, Australia. *Environmental Biology of Fishes* **56**(1), 129-151.

Hunt, T.L., Allen, M.S., Douglas, J., and Gason, A. (2010) Evaluation of a Sport Fish Stocking Program in Lakes of the Southern Murray–Darling Basin, Australia. *North American Journal of Fisheries Management* **30**(3), 805-811.

Hutchison, M., Butcher, A, Kirkwood, J, Mayer, D, Chikott, K Backhouse, S. (2008) Mesoscale movements of small and medium-sized fish in the Murray-Darling Basin. pp. 118. (Murray-Darling Basin Commission)

Jones, M.J. (2006) Effects of Environmental Flow Allocations on the lateral movements of native fish in the Barmah-Millewa Forest. pp. 89. (Final report to the Murray-Darling Basin Authority. Arthur Rylah Institute for Environmental Research)

Jones, M.J., and Stuart, I.G. (2008) Regulated floodplains – a trap for unwary fish. *Fisheries Management and Ecology* **15**(1), 71-79.

Junk WJ, Bayley PB, Sparks RE. 1989. The flood pulse concept in river-floodplain systems. Canadian Special Publication of Fisheries and Aquatic Sciences 106: 110-127.

Kerezsy, A., Balcombe, S.R., Arthington, A.H., and Bunn, S.E. (2011) Continuous recruitment underpins fish persistence in the arid rivers of far-western Queensland, Australia. *Marine and Freshwater Research* **62**(10), 1178-1190.

King, A., Humphries, P., and Lake, P. (2003) Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Sciences* **60**(7), 773-786.

King, A., Tonkin, Z., and Mahoney, J. (2009) Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. *River Research and Applications* **25**(10), 1205-1218.

King, A.J., and O'Connor, J.P. (2007) Native fish entrapment in irrigation systems: A step towards understanding the significance of the problem. *Ecological Management & Restoration* **8**(1), 32-37.

Kitchingman, A., Tonkin, Z., Lyon, J., and Ayres, R. (2012) Loddon River and Pyramid Creek Habitat Mapping. Report for the North Central Catchment Management Authority (Ed. DoSa Environment) pp. 15. (Arthur Rylah Institute)

Koehn, J. (2009) Multi-scale habitat selection by Murray cod *Maccullochella peelii peelii* in two lowland rivers. *Journal of Fish Biology* **75**(1), 113-129.

Koehn, J., and Harrington, D. (2005) Collection and distribution of the early life stages of the Murray cod (*Maccullochella peelii peelii*) in a regulated river. *Australian Journal of Zoology* **53**(3), 137-144.

Koehn, J., Nicol, S., McKenzie, J., Lieschke, J., Lyon, J., and Pomorin, K. (2008) Spatial ecology of an endangered native Australian Percichthyid fish, the trout cod *Maccullochella macquariensis*. *Endangered Species Research* **4**(1-2), 219-225.

Koehn, J., McKenzie, J., O'Mahony, D., Nicol, S., O'Connor, J., and O'Connor, W. (2009) Movements of Murray cod (*Maccullochella peelii peelii*) in a large Australian lowland river. *Ecology of Freshwater Fish* **18**(4), 594-602.

Lintermans, M. (2007) 'Fishes of the Murray-Darling Basin: an introductory guide.' (Murray-Darling Basin Commission Canberra, ACT)

Llewellyn, L. (2005) Breeding biology, and egg and larval development of Galaxias rostratus Klunzinger, the Murray Jollytail from inland New South Wales. *Australian Zoologist* **33**(2), 141.

Loddon River Environmental Flows Scientific Panel (2002) Environmental Flow Determination of the Loddon River Catchment. Part a - Final Report.

Lyon, J., Stuart, I., Ramsey, D., and O'Mahony, J. (2010) The effect of water level on lateral movements of fish between river and off-channel habitats and implications for management. *Marine and Freshwater Research* **61**(3), 271-278.

Macdonald, J., and Tonkin, Z. (2008) A review of the impact of eastern gambusia on native fishes of the Murray-Darling Basin. (Ed. DoSaE Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria.).

Macdonald, J.I., Tonkin, Z.D., Ramsey, D.S.L., Kaus, A.K., King, A.K., and Crook, D.A. (2012) Do invasive eastern gambusia (Gambusia holbrooki) shape wetland fish assemblage structure in south-eastern Australia? *Marine and Freshwater Research* **63**(8), 659-671.

Mallen-Cooper, M. (1999) Developing fishways for non-salmonid fishes: a case study from the Murray River in Australia. *Innovations in fish passage technology*, 173-195.

Mallen-Cooper, M., and Stuart, I. (2003) Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. *River Research and Applications* **19**(7), 697-719.

Mallen-Cooper M., Stuart I.G., and Sharpe C. (2011) Optimising Outcomes for Native Fish in Managed Inundations of the Gunbower Forest. Report prepared for the North Central Catchment Management Authority. 31 p.

McManus, A., Hunt, W., Storey, J., and White, J. (2011) Identifying the health and well-being benefits of recreational fishing. *FRDC Project*(2011/217).

MDBA (2012) Gunbower Forest: Environmental Water Management Plan 2011. Murray–Darling Basin Authority, Canberra.

Moore, A., Ingram, B.A., Friend, S., King Ho, H., Robinson, N., McCormack, R., Coughran, J. and Hayes, B. (2010). Management of genetic resources for fish and crustaceans in the Murray-Darling Basin. Bureau of Rural Sciences, Canberra.

NCCMA (2010). Loddon River Environmental Watering Plan, Prepared for the Northern Victoria Irrigation Renewal Project, North Central Catchment Management Authority, Huntly, Victoria.

North Central CMA (2013) North Central Regional Catchment Strategy 2013 - 2019. North Central Catchment Management Authority, Huntly.

North Central CMA (2014) North Central Waterway Strategy 2014 - 2022. North Central Catchment Management Authority, Huntly.

O'Connor, J.P., O'Mahony, D.J., and O'Mahony, J.M. (2005) Movements of Macquaria ambigua, in the Murray River, south-eastern Australia. *Journal of Fish Biology* **66**(2), 392-403.

O’Connor, J., King, A., Tonkin, Z., Morrongiello, J., and Todd, C. (2008a) Fish in the Murray Valley and Torrumbarry Irrigation Areas In Arthur Rylah Institute for Environmental Research Technical Report Series No. 176. . (Ed. H Department of Sustainability and Environment, Victoria) pp. 65.

O’Connor, J., King, A., Tonkin, Z., Morrongiello, J., and Todd, C. (2008b) Fish in the Murray Valley and Torrumbarry Irrigation Areas. *Arthur Rylah Institute for Environmental Research Technical Report Series* **176**, 65.

O'Connor, J., Jones, M, and Hackett, G. (2102) Kerang Weir PIT Reader Installation. Report by Arthur Rylah Institute for Environmental Research for North Central CMA, Huntly.

O’Connor, J., Amtstaetter, F., Jones, M. and Mahoney, J. (2013). Golden perch Movement in the Loddon River and Pyramid Creek: Pilot Study. Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria.

PIRVic (2007) Report of a Fish Survey of the Gunbower Creek. In A report prepared for the North Central Catchment Management Authority. pp. 38. (Primary Industries Research Victoria (PIRVic))

Post, J.R., van Poorten, B.T., Rhodes, T., Askey, P., and Paul, A. (2006) Fish entrainment into irrigation canals: an analytical approach and application to the Bow River, Alberta, Canada. *North American Journal of Fisheries Management* **26**(4), 875-887.

Rehwinkel, R., and Sharpe, C. (2009) Status of freshwater catfish populations in Gunbower Creek 2009. *A report prepared for the North Central Catchment Authority by the Murray-Darling Freshwater Research Centre. 36 p.*, 36.

Reid DD, Harris JH, Chapman DJ. 1997. NSW inland commercial fishery data analysis. Fisheries Research and Development Council 94/027: 60.

Richardson, A., Meredith, S., Conallin, A., and Sharpe, C. (2005) Status of the Gunbower Island Fish Community. In A Report prepared for the North Central Catchment Management Authority. (Murray-Darling Freshwater Research Centre)

Roberts, J.J., and Rahel, F.J. (2008) Irrigation canals as sink habitat for trout and other fishes in a Wyoming drainage. *Transactions of the American Fisheries Society* **137**(4), 951-961.

Rolls, R., and Wilson, G. (2010) Spatial and Temporal Patterns in Fish Assemblages Following an Artificially Extended Floodplain Inundation Event, Northern Murray-Darling Basin, Australia. *Environmental Management* **45**(4), 822-833.

Rourke M, Nheu J, Mountford H et al. (2007) Isolation and characterization of 102 new microsatellite loci in Murray cod, Maccullochella peelii peelii (Percichthyidae), and assessment of cross-amplification in 13 Australian native and six introduced freshwater species. Molecular Ecology Notes, 7, 1258–1264.

Rourke, M.L., McPartlan, H.C., Ingram, B.A., and Taylor, A.C. (2010) Biogeography and life history ameliorate the potentially negative genetic effects of stocking on Murray cod (Maccullochella peelii peelii). *Marine and Freshwater Research* **61**(8), 918-927.

Rowland SJ. 1998. Aspects of the reproductive biology of Murray cod, Maccullochella peelii peelii. Proceedings of the Linnean Society of New South Wales 120, 147-162.

Saddlier, S., O'Mahony, J., Ramsey, D., and Murray, L. (2008) 'Protection and enhancement of Murray cod populations.' (Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment)

Sharpe, A., Sandercock, P., Boon, P., Atkinson, B., Murrihy, E., Baldwin, D., and Morden, R. (2010) 'Review of environmental flow requirements for the lower Loddon River system.' (Sinclair Knight Merz: Armadale) 145

Sharpe, C. (2009) Aquatic fauna investigation of the Gunbower Creek at Chinamans Bend and the area of influence of the proposed Gunbower Forest Outfall. . In Flora and Fauna Investigation of the proposed Gunbower Forest Outlet. (Eds. K Bennets, D Cook, K Jolly and C Sharpe). (Murray-Darling Freshwater Research Centre Final Report for Australian Ecosystems)

Sharpe, C. (2011a) Fish surveys in Gunbower Creek downstream of Koondrook Weir in association with Environmental Flows, December 2011. pp. 15.

Sharpe, C., Campbell-Brown, S. and Vilizzi, L. (2013) Gunbower Island Annual Fish Surveys: 2013. . *Report for the North Central Catchment Management Authority by CPS Environmental. 79pp.*

Sharpe, C., and Wilson, E. (2012) Fish surveys at 39 sites throughout Millewa Forest, NSW, with focus on the distribution of Southern pygmy perch (Nannoperca australis). Report for the NSW Office of Environment and Heritage. 17 p.

Sharpe, C.P. (2011b) Spawning and recruitment ecology of golden perch (Macquaria ambigua Richardson 1845) in the Murray and Darling Rivers. . *PhD Thesis. Griffith School of Environment, Griffith University, Brisbane.*

SKM (2009) Gunbower Forest - Hipwell Road Option, near Leitchville, Victoria. Indigenous Cultural Heritage Assessment. *Report to the North Central Catchment Managment Authority. 84 p.*

Stone, T., and Cupper, M.L. (2003) Last Glacial Maximum ages for robust humans at Kow Swamp, southern Australia. *Journal of Human Evolution* **45**(2), 99-111.

Stuart, I., and Jones, M. (2006a) Large, regulated forest floodplain is an ideal recruitment zone for non-native common carp (*Cyprinus carpio* L.). *Marine and Freshwater Research* **57**(3), 333-347.

Stuart, I., and Jones, M. (2006b) Movement of common carp, Cyprinus carpio, in a regulated lowland Australian river: implications for management. *Fisheries Management and Ecology* **13**(4), 213-219.

Stuart, I., Ryan, T., and McGuckin, J. (2009) Assessment of Kerang Weir fishway and design of a fish monitoring program. *Report for North Central Catchment Management Authority. 64 p.*

Stuart, I., and Sharpe, C. (2012) Monitoring and assessment of Gunbower and Thompsons weir fishways *Report for the North Central Catchment Management Authority. 45 pp.*

Stuart, I., Williams, A., McKenzie, J., and Holt, T. (2006) Managing a migratory pest species: a selective trap for common carp. *North American Journal of Fisheries Management* **26**, 888-893.

Thorne, A. (1971) Mungo and kow swamp: morphological variation in Pleistocene Australians. *Mankind* **8**(2), 85-89.

Tonkin, Z., King, A.J., and Mahoney, J. (2008) Effects of flooding on recruitment and dispersal of the Southern Pygmy Perch (Nannoperca australis) at a Murray River floodplain wetland. *Ecological Management & Restoration* **9**(3), 196-201.

Trueman, W. (2012) 'True Tales of the Trout Cod: River Histories of the Murray–Darling Basin-Central Murray River catchment booklet.' (Murray–Darling Basin Authority (MDBA): Canberra, ACT).

Victorian Environmental Water Holder (2014) Seasonal Watering Plan 2014 - 15. Victorian Environmental Water Holder, East Melbourne.

Ye, Q. (2004). Golden perch (Macquaria ambigua): Fishery Assessment Report to PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Ye, Q. and Zampatti, B. 2007. Murray cod stock status: the Lower River Murray, South Australia. Stock Status Report to PIRSA Fisheries.. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007-000211-1.

Zampatti, B.P., and Leigh, S.J. (2013) Within-channel flows promote spawning and recruitment of golden perch, Macquaria ambigua ambigua–implications for environmental flow management in the River Murray, Australia. *Marine and Freshwater Research*.

APPENDIX 1

NATIVE FISH RECOVERY PLAN – GUNBOWER AND LOWER LODDON

TECHNICAL MEMORANDUM No. 1

Past hydrology of the River Murray, Gunbower Creek and Gunbower Forest

NATIVE FISH RECOVERY PLAN - GUNBOWER AND LOWER LODDON

TECHNICAL MEMORANDUM No. 1

Past hydrology of the River Murray, Gunbower Creek and Gunbower Forest

1. INTRODUCTION

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* provides a conceptual and strategic framework for management and investment to recover native fish populations and maintain a robust irrigation sector.

This brief report is the first of the Technical Memorandum series which is aimed at providing another level of detail to the Plan. These are intended to: i) directly feed into present management and investment, ii) identify knowledge gaps to target and iii) capture corporate knowledge as it develops. The Memorandums are intended to be short, but their subject matter is very broad and may include:

- conceptual models, which capture present thinking,
- technical guidelines
- recommended processes
- initial results of trials or experiments,
- ecological observations (e.g. migrating fish observed below a regulator under certain flows or conditions; fish kills)
- summary of community consultations
- changes in irrigation industry that directly affect the project.

Although technical and targeted to the Gunbower – lower Loddon region, the intent is that they are public domain and posted on a corporate website, so that stakeholders are kept informed of developments. Reports or larger project still retain their role.

Each memorandum will have the format of:

- Objective
- Subject
- Knowledge Gaps, and
- Management Implications.

2. OBJECTIVE

To describe the pattern of flows in Gunbower Creek and Gunbower Forest under natural conditions.

3. HYDROLOGY

3.1. Gunbower Creek

Prior to irrigation development Gunbower Creek was not permanently connected to the River Murray. In this state the creek was reported to start flowing when there was 13 feet of water (approx. 4 m or

13,700 ML/d) in the River Murray[1]. Modelling of daily natural river levels (MDBA BIGmod, unpublished data) for 100 years (1900-2000) shows that Gunbower Creek would likely have flowed for months every year in winter and spring and did not flow in only three years in 100 (Fig.1). The 13 feet figure may have been underestimated but the graphs show that this estimate is not sensitive. In the months between flows and in the odd years without flow Gunbower Creek would very likely have retained deep pools as it is deeply incised in some reaches (Anderson *et al*. 2007).

When Gunbower Creek had high flows it would have provided overflow to Taylors Creek, which was not formally connected prior to irrigation, and this would have flowed to Kow Swamp which also has its own catchment of Mt Hope Creek, Bendigo Creek and surrounding lands. Gunbower Creek was an anabranch system, so any water that did not flow into wetlands and natural distributaries would have flowed back to the River Murray.

The seasonality and magnitude of flows in Gunbower Creek would have mirrored the River Murray, with flows increasing in early winter, peaking from late-winter to early spring and decreasing in early summer (Fig. 1). Modelled data suggests there was no flow in the creek from mid-summer to the end of autumn and the creek would have been a series of pools.

3.2. Gunbower Forest

The forest floodplain receives most of its water directly from the River Murray via inlets which break from the river bank. The principle forest inlets are Broken Axle at Kate Malone Bend, Yarran Creek at Shillinglaws Regulator and Barham Cut (Ecological Associates 2003). These inlets start to flow at 13,700 ML/d and gradually increase up to 27,800 ML/d (Atkins *et al.* 1991; Ecological Associates 2003):

- at 18,300 ML/d of River Murray flow the forest inflows are low, at 95 ML/d;
- at 25,200 ML/d forest inflows increase to 520 ML/d, and
- at 27,800 ML/d forest inflows increase to 1780 ML/d.

When the River Murray is over 30,000 ML/d there is widespread inundation of the forest and at the maximum flows in the River Murray, of 55,000–60,000 ML/d, almost the entire forest is inundated (Ecological Associates 2003).

Comparing the above data of forest inflows in a regression with the modelled natural flow data from the River Murray (MDBA, BIGmod, unpublished data), shows that low flows into the forest wetlands occurred every year except two (1940 and 1982) in 100 years (1900-2000) (Fig. 1). Under modelled natural conditions, overbank flows (> 30,000 ML/d) occurred nine out of ten years but extended events occurred six out of ten years with each event lasting up to 4.2 months (Fig. 1). Hence, the forest wetlands were topped up almost every year, at least for those wetlands close to the River Murray, and had significant inflows nine in ten years.

4. KNOWLEDGE GAPS

- The geomorphology of Gunbower Creek prior to regulation and hence the depth of holes and extent of flowing habitats is less certain.

- The geomorphology of forest channels and hence the extent that low inflows reached wetlands.

[1] The Argus (Melbourne, Vic.: 1848-1954), 1 April 1887, Page 9.

5. MANAGEMENT IMPLICATIONS

- Under natural conditions the seasonality of Gunbower Creek followed the River Murray with high flows in winter and spring and low flows in summer and autumn. Under regulated conditions it has almost the opposite regime with low flows in winter, high flows in spring, summer and autumn.

- The low flows in winter may be very damaging for fish populations as food would become scarce and juvenile fish, with limited body resources could have high mortality, as well as suffer predation.

- A management priority is to restore winter flows in Gunbower Creek.

- The forest inflows show that small wetlands were likely permanent habitats in the forest. These are key habitats of four threatened small-bodied fish species: southern pygmy perch, southern purple-spotted gudgeon, olive perchlet and flat-headed galaxias.

- A management priority is to restore small permanent wetlands in Gunbower Forest.

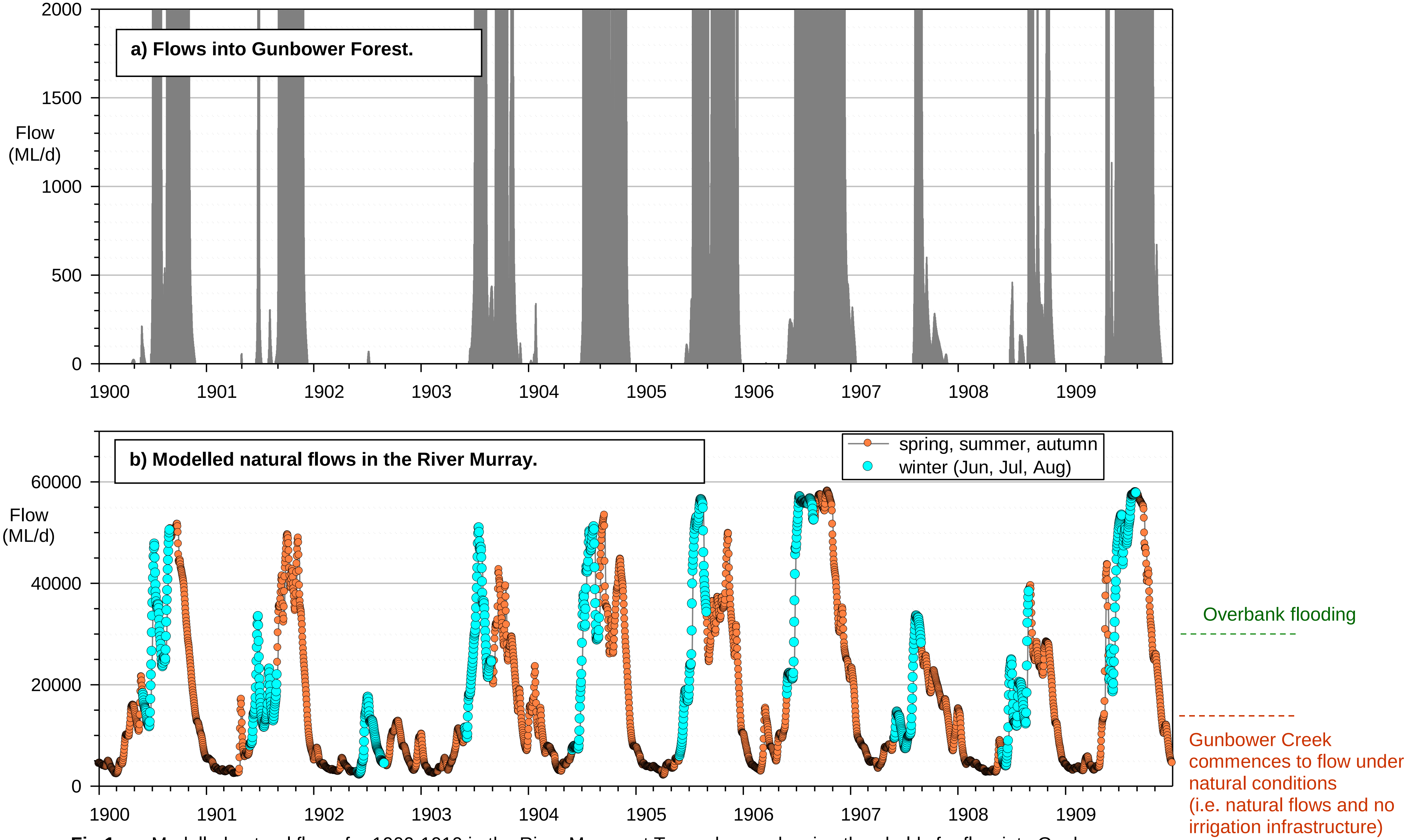


Fig.1. Modelled natural flows for 1900-1910 in the River Murray at Torrumbarry, showing thresholds for flow into Gunbower Creek and overbanks flow, and total flow into Gunbower Forest (a).

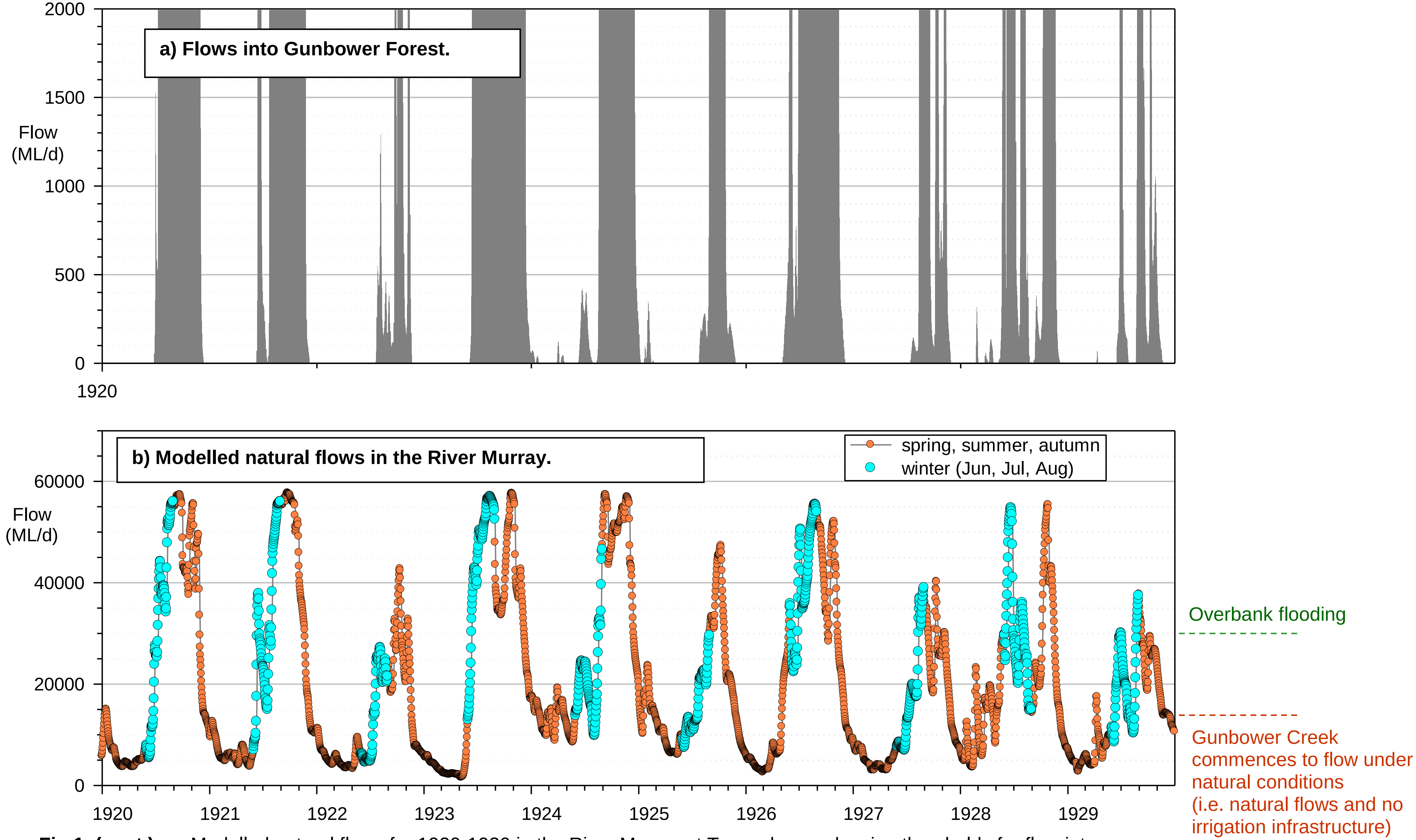


Fig.1. (cont.) Modelled natural flows for 1920-1930 in the River Murray at Torrumbarry, showing thresholds for flow into Gunbower Creek and overbanks flow, and total flow into Gunbower Forest (a).

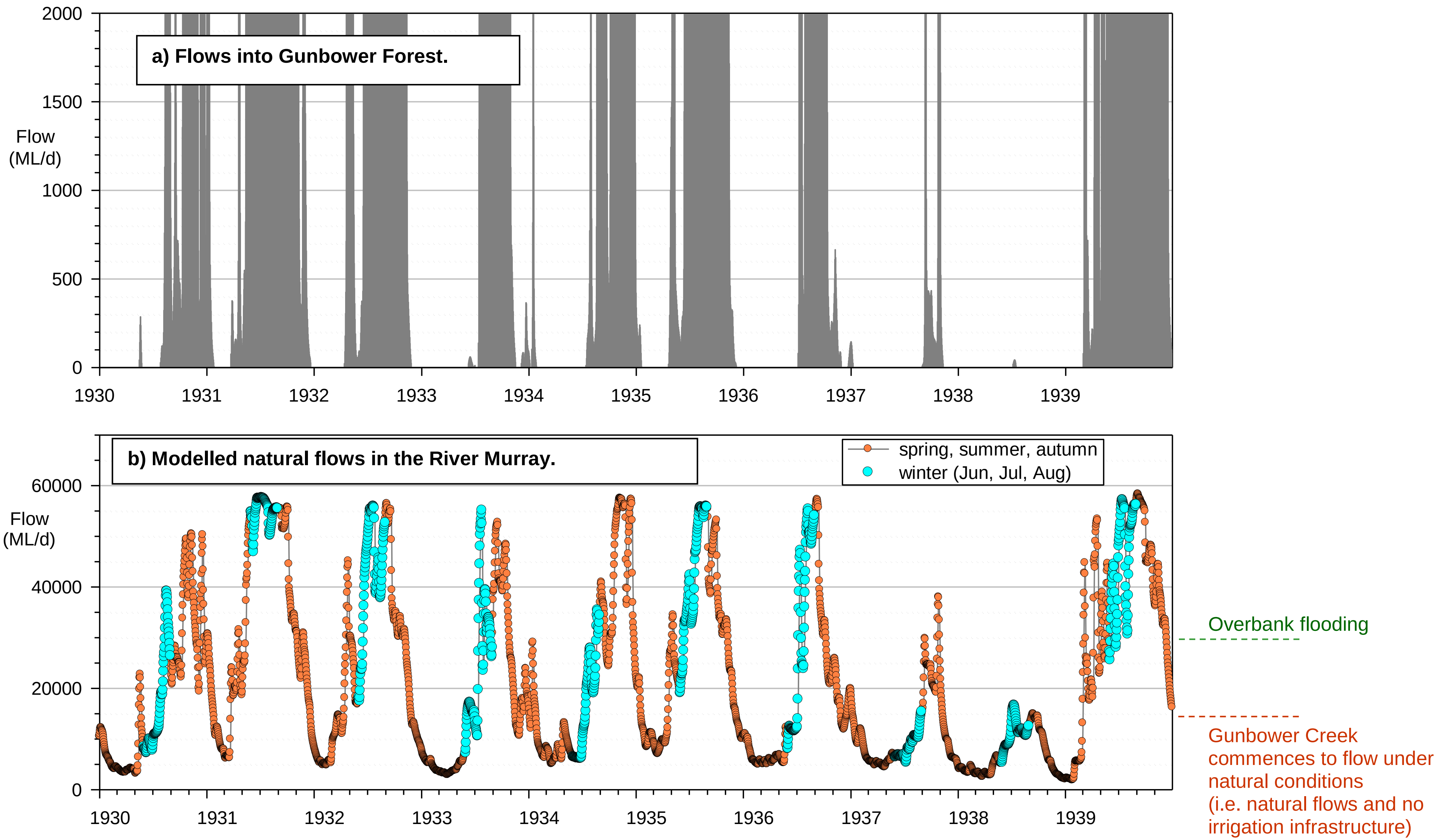


Fig.1. (cont.) Modelled natural flows for 1930-1940 in the River Murray at Torrumbarry, showing thresholds for flow into Gunbower Creek and overbanks flow, and total flow into Gunbower Forest (a).

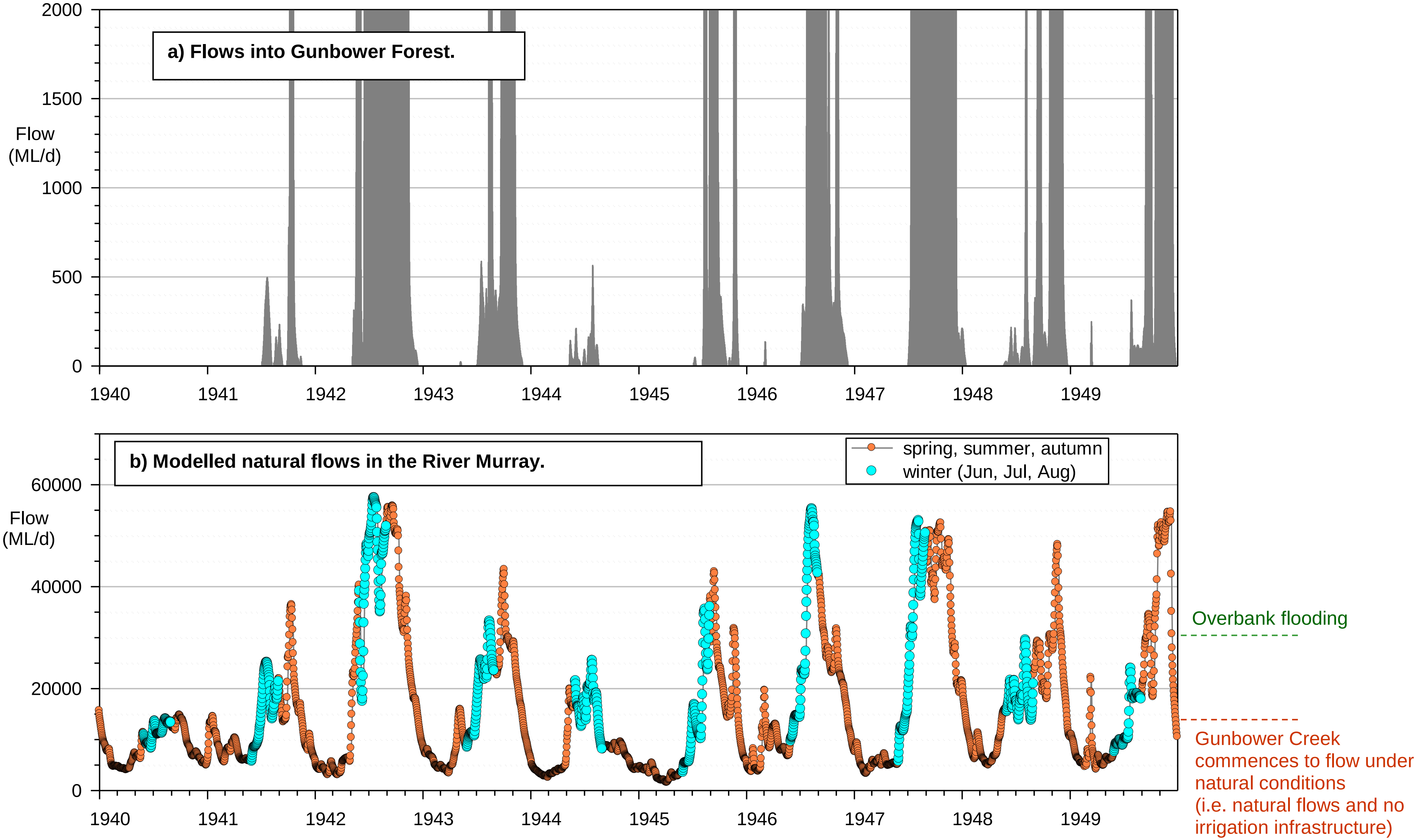


Fig.1. (cont.) Modelled natural flows for 1940-1950 in the River Murray at Torrumbarry, showing thresholds for flow into Gunbower Creek and overbanks flow, and total flow into Gunbower Forest (a).

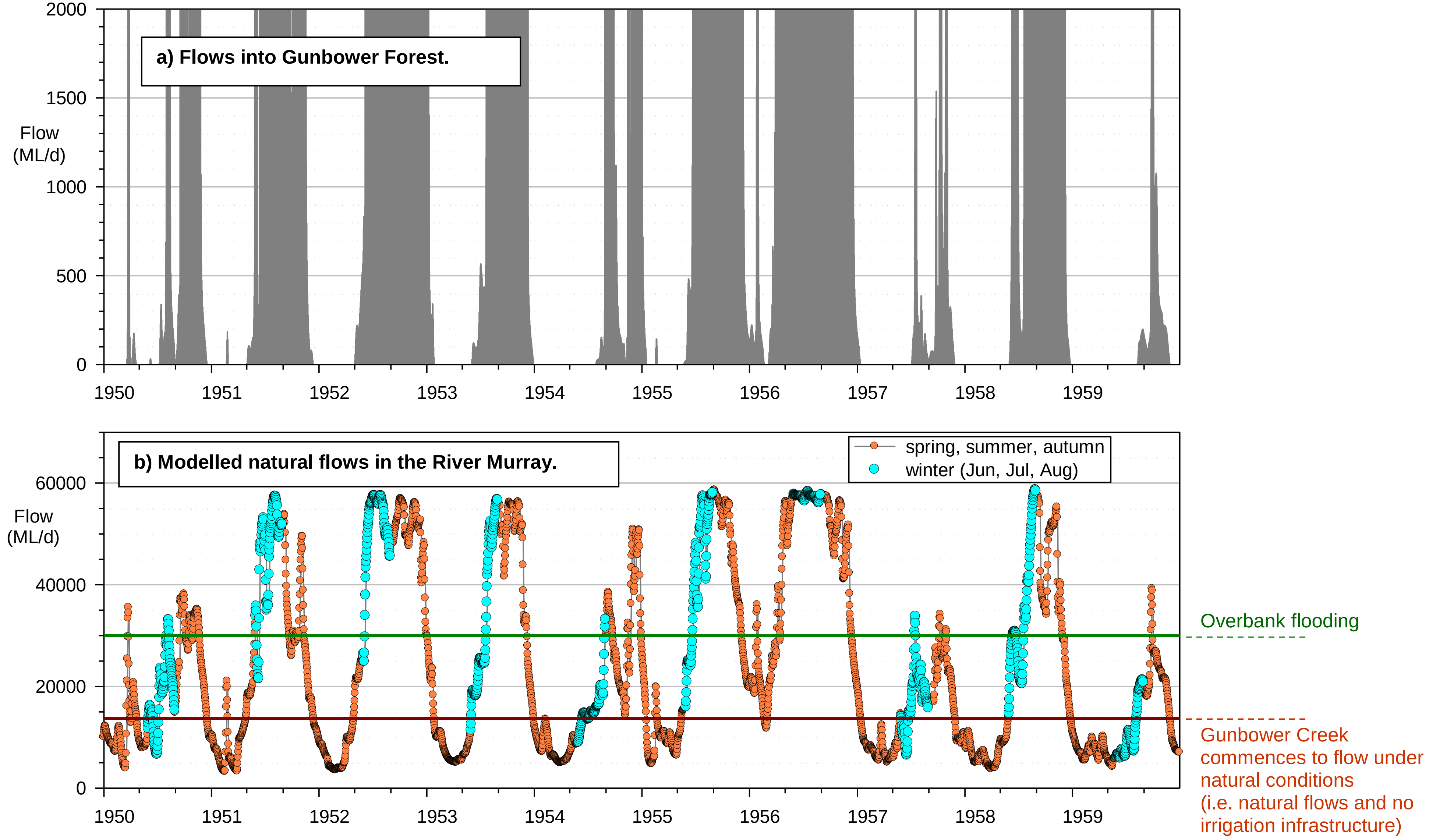


Fig.1. (cont.) Modelled natural flows for 1950-1960 in the River Murray at Torrumbarry, showing thresholds for flow into Gunbower Creek and overbanks flow, and total flow into Gunbower Forest (a).

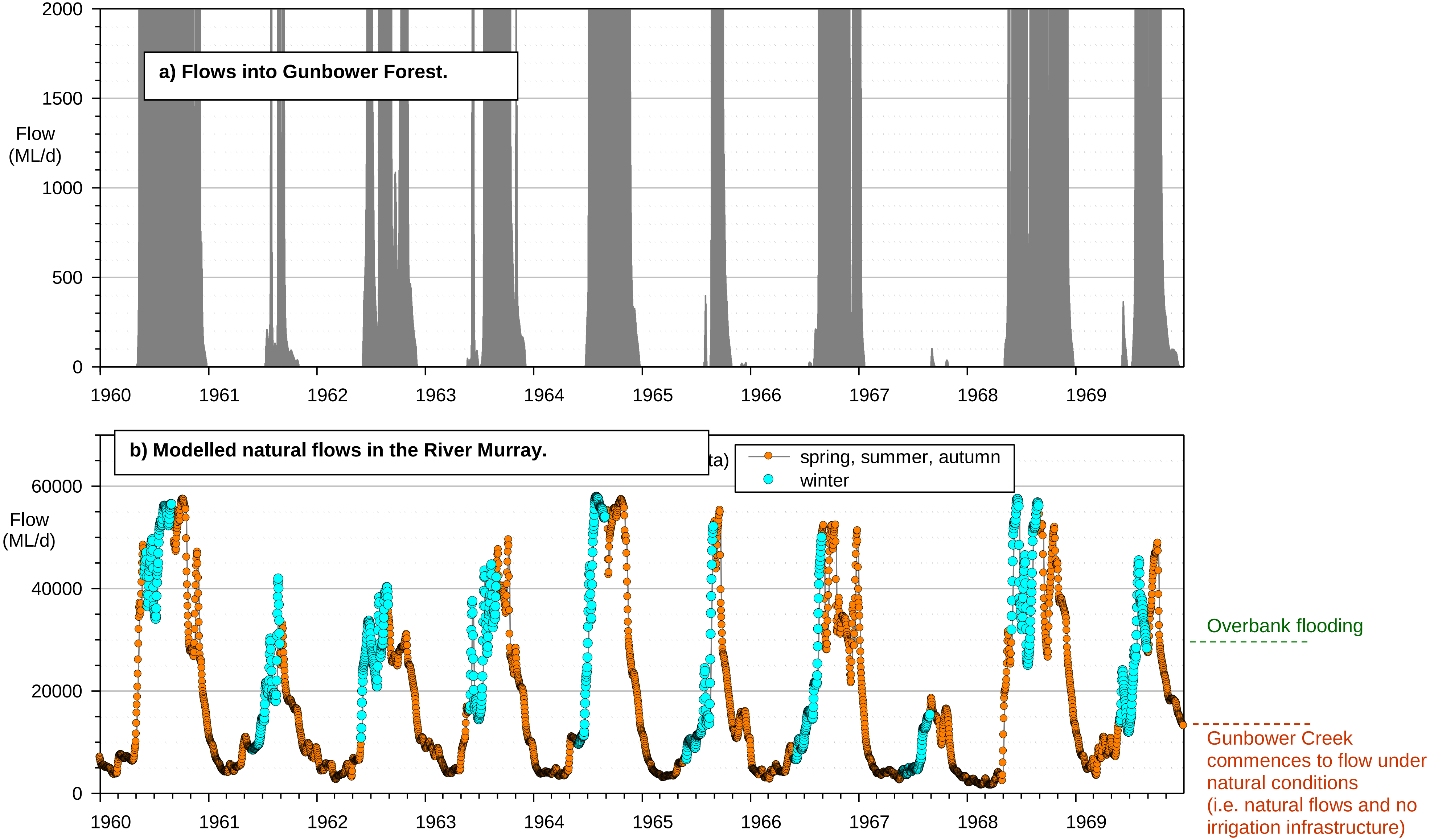


Fig.1. (cont.) Modelled natural flows for 1950-1960 in the River Murray at Torrumbarry, showing thresholds for flow into Gunbower Creek and overbanks flow, and total flow into Gunbower Forest (a).

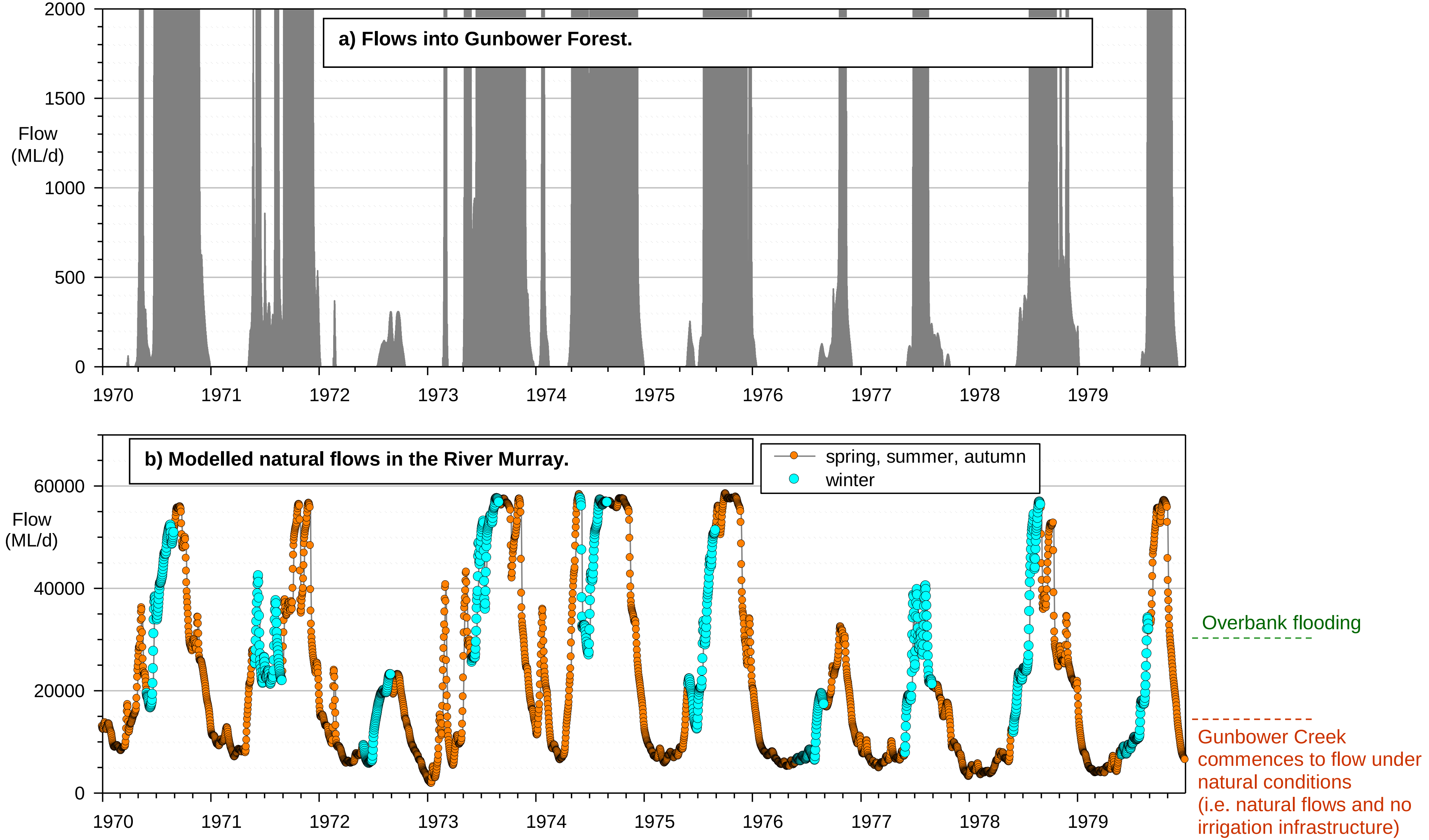


Fig.1. (cont.) Modelled natural flows for 1970-1980 in the River Murray at Torrumbarry, showing thresholds for flow into Gunbower Creek and overbanks flow, and total flow into Gunbower Forest (a).

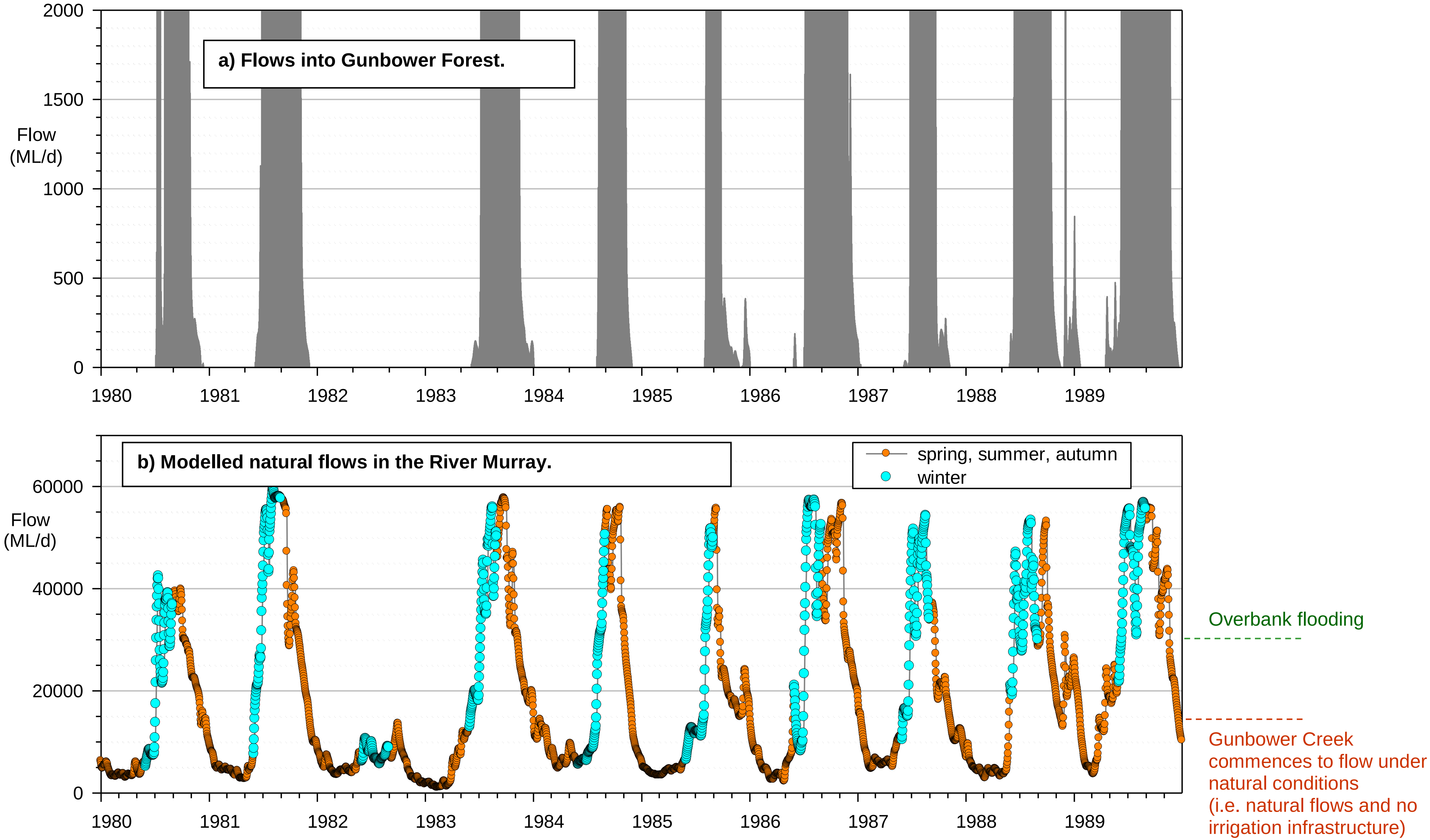


Fig.1. (cont.) Modelled natural flows for 1980-1990 in the River Murray at Torrumbarry, showing thresholds for flow into Gunbower Creek and overbanks flow, and total flow into Gunbower Forest (a).

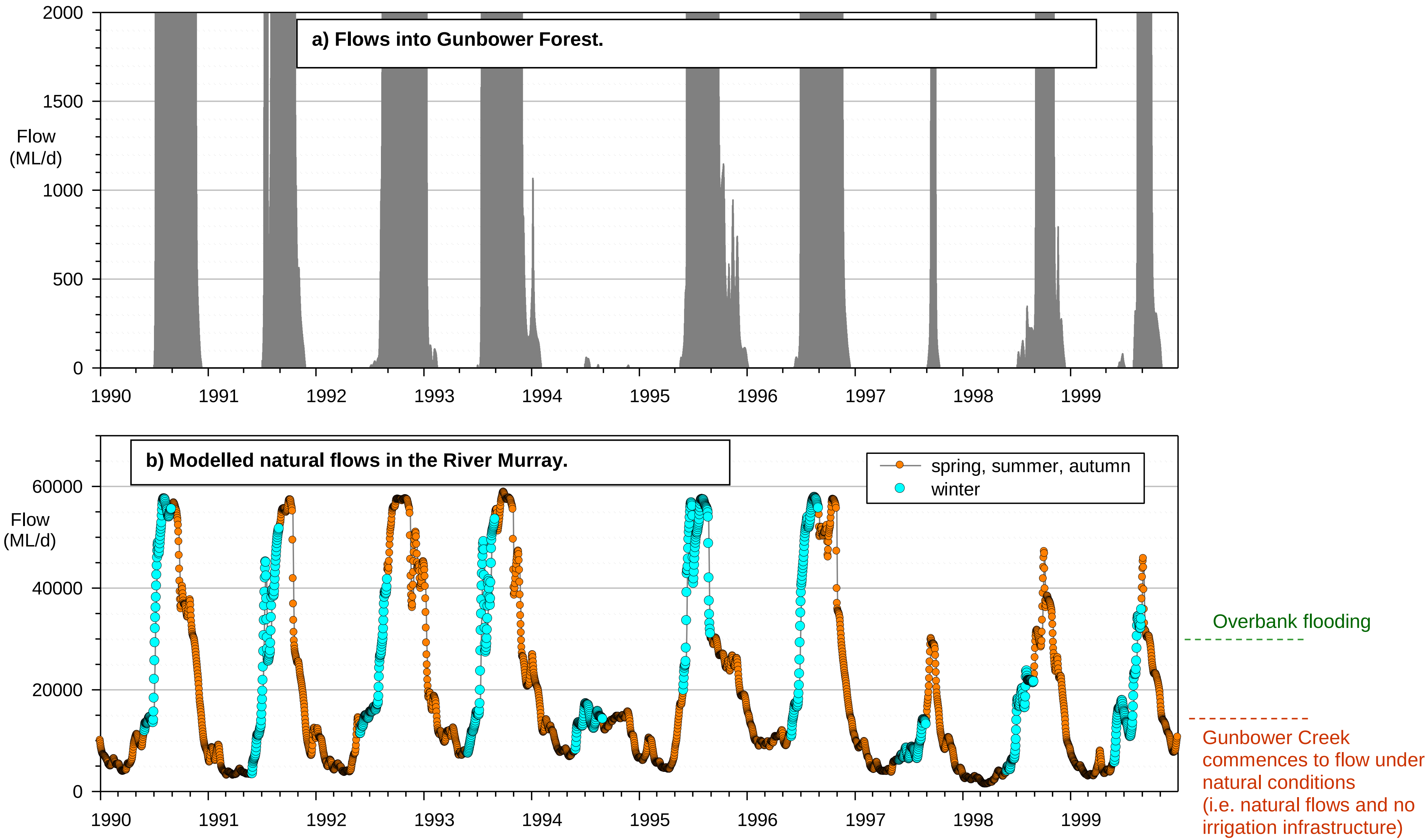


Fig.1. (cont.) Modelled natural flows for 1990-2000 in the River Murray at Torrumbarry, showing thresholds for flow into Gunbower Creek and overbanks flow, and total flow into Gunbower Forest (a).

APPENDIX 2

NATIVE FISH RECOVERY PLAN – GUNBOWER AND LOWER LODDON

TECHNICAL MEMORANDUM No. 2

Conceptual Model of Present Fish Movements and Recruitment

NATIVE FISH RECOVERY PLAN – GUNBOWER AND LOWER LODDON

TECHNICAL MEMORANDUM No. 2

Conceptual Model of Present Fish Movements and Recruitment

1. INTRODUCTION

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* provides a conceptual and strategic framework for management and investment to recover native fish populations and maintain a robust irrigation sector.

This brief report is the second of the Technical Memorandum series which is aimed at providing another level of detail to the Plan. These are intended to: i) directly feed into present management and investment, ii) identify knowledge gaps to target and iii) capture corporate knowledge as it develops. The Memorandums are intended to be short, but their subject matter is very broad and may include:

- conceptual models, which capture present thinking,
- technical guidelines
- recommended processes
- initial results of trials or experiments,
- ecological observations (e.g. migrating fish observed below a regulator under certain flows or conditions; fish kills)
- summary of community consultations
- changes in irrigation industry that directly affect the project.

Although technical and targeted to the Gunbower – lower Loddon Region, the intent is that they are public domain and posted on a corporate website, so that stakeholders are kept informed of developments. Reports or larger project still retain their role.

Each memorandum will have the format of:
- Objective
- Subject
- Knowledge Gaps, and
- Management Implications.

2. OBJECTIVE

To describe a conceptual model of fish movement in the Project Area to aid: management of flow and habitat; prioritise fish passage; and identify knowledge gaps.

3. CONCEPTUAL MODEL OF PRESENT FISH MOVEMENTS AND RECRUITMENT

3.1. Biological Background

The background to fish migration and recruitment in the Project Area (Fig. 1) is presented in the *Native Fish Recovery Plan – Gunbower and Lower Loddon*. The key points are repeated here:

Migration

- All fish move to some degree, even those that have small home ranges require dispersal movements to maintain their distribution following droughts and floods
- Fish mainly migrate from August to April inclusive
- The migratory response of fish is cued to either: water temperature or a combination of water temperature and increases in flow.
- Most riverine fish in the mid-Murray region have larvae that drift with the current, which is a downstream migration.
- Juvenile and immature fish often migrate upstream, probably to counter their downstream displacement as larvae.
- Adult fish will mostly have cyclic migrations often, but not always, upstream to spawn followed by a downstream migration.

Recruitment

- In biology *recruitment* simply means the survival of young to maturity and successful breeding. In this project we use the biological definition of survival to maturity as well as the presence of yearlings (1+) and older fish to show regular survival of year classes from larvae.
- Spatial scales of recruitment vary. Some species can spawn and recruit over a small scale such as a wetland while some species, like golden perch and silver perch, likely need 100s of kilometres. Murray cod likely needs 10s of kilometres but also move over larger distances.
- There are four major patterns of recruitment of wholly freshwater fish (i.e. excluding diadromous) in the lowlands of the Murray-Darling Basin:

    1) *Off-channel recruitment (off-channel specialists and generalists)*

       Survival of young to maturity occurs entirely within off-channel habitats. Includes off-channel specialists such as pygmy perch and flat-headed galaxias, and generalists such as carp gudgeon and freshwater catfish.

    2) *Low-flow channel recruitment (generalists)*

       Recruitment occurs within channel habitats at low stable flows. Presently only applies to generalist species which, apart from freshwater catfish and olive perchlet, remain common in regulated rivers in the Murray-Darling Basin (Table 2).

    3) *Variable flow channel recruitment (channel specialists)*

       Recruitment occurs when there is variation of within-channel flows. Applies to golden perch, silver perch, and possibly Murray cod and trout cod.

    4) *Flood recruitment (channel specialists, off-channel specialists and generalists)*

       Recruitment occurs when floodplains are inundated increasing productivity and larval survival. Applies to the large- and medium-bodied channel specialists, off-channel specialists and generalists. Likely applies to all species to some degree.

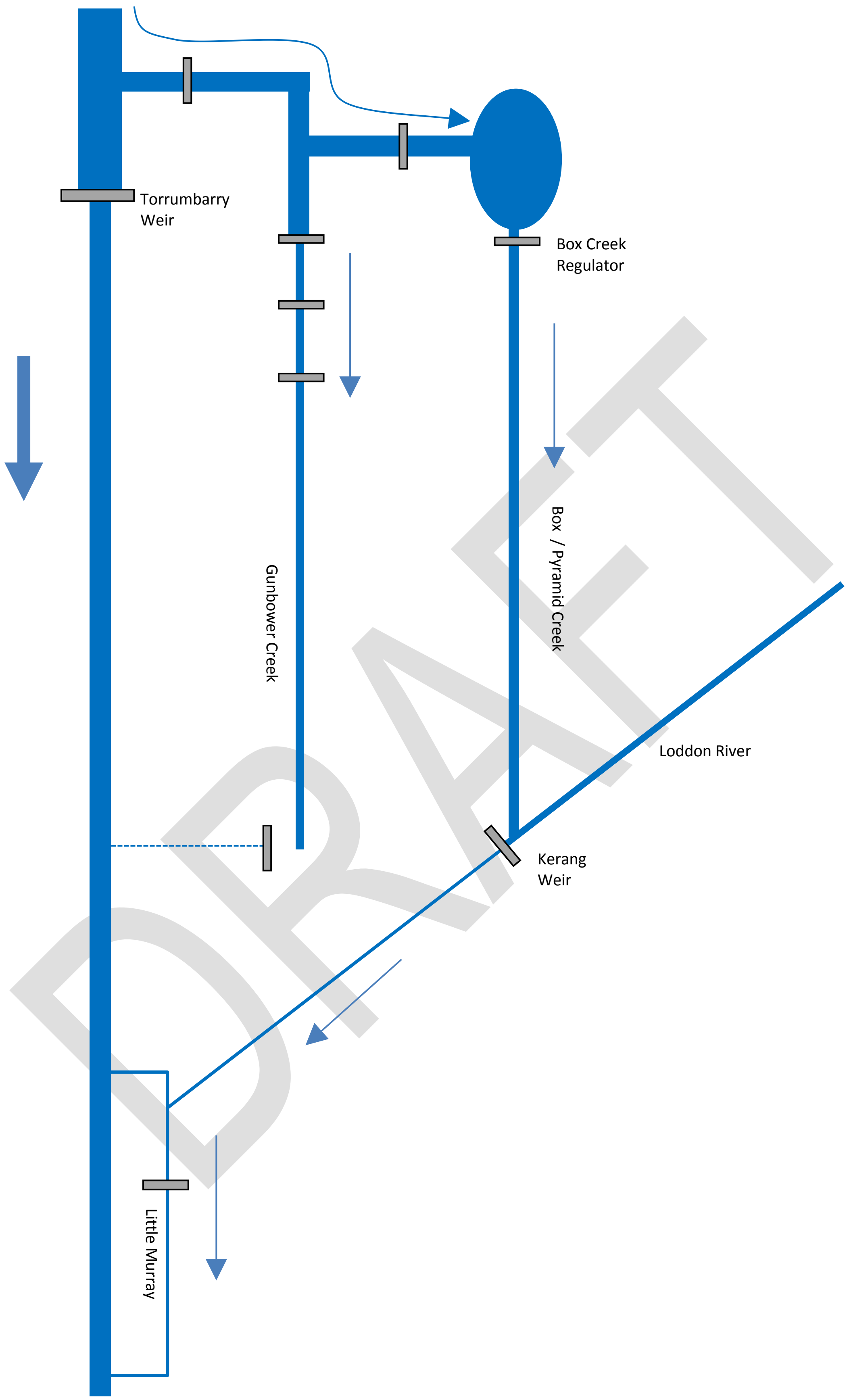


Fig. 1. Schematic of flow to illustrate migration pathways in the region (irrigation offtakes not shown).

4. CONCEPTUAL MODEL

The conceptual models are presented under five flow regimes of:

1) Spring, stable flows; typical regulated flows for irrigation,
2) Spring or summer, increased regional flows (greater than regulated flows for irrigation)
3) Spring or summer flood flows,
4) Winter (May - July), greatly reduced flows (typical regulated flows)

4.1. Spring, stable flows; typical regulated flows for irrigation

Upstream migration

- Temperature-cued spring migrations active.
- Bony herring and carp migrate up the lower Loddon River and Box-Pyramid Creek; presently accumulate at Box Creek Weir.
- No flow at Koondrook Weir; no fish migration up to weir.
- At the National Channel Regulator and Box Creek Weir variation in irrigation demands and flow provides some stimulus for fish that have flow-cued migrations (e.g. golden perch and silver perch adults and juveniles, some Murray cod) and small numbers of these fish accumulate at these structures.
- Within Gunbower Creek carp move to nearby spawning areas on channel edges or off-channel wetlands that are accessible.

Downstream migration

- Larvae of species that spawn annually in response to rising temperature, drift downstream (e.g. Murray cod, bony herring, freshwater catfish, small-bodied species, carp) [These fish do not include the species that spawn in response to flow and temperature, such as golden perch and silver perch]. The larvae of freshwater catfish or small-bodied species that spawn in billabongs would not drift but remain close to adult habitats.
- Numerous larvae drift into the National Channel from the River Murray, passing through the Regulator; the undershot gates cause high mortality at small openings and low mortality at large openings (the latter is a knowledge gap but assumed from hydraulics).
- Larvae that survive the National Channel Regulator, enter Gunbower Creek or Kow Swamp, where some would survive, although nursery habitats are variable and overwintering habitats poor in Gunbower Creek; or enter the irrigation channels with very high mortality with very limited chance of survival overwinter.
- Larvae that are present in Gunbower Creek would drift into weirpools, where initial survival would be reasonable or irrigation channels, where survival would be poor.
- Larvae that are present or enter Kow Swamp are very unlikely to drift to the Outlet Regulator at Box Creek in regulated flows.
- Larvae in Box-Pyramid Creek would drift to littoral zones, which has poor habitat, and the Kerang weirpool, which some variable littoral habitat

Lateral migration

- Small-bodied fish and catfish move between channel and wetland habitats depending on operation of local regulators.

Recruitment

- Of larvae that enter Gunbower Creek and Kow Swamp the initial survival of larvae that pass the National Channel Regulator is potentially reasonable but recruitment (survival to a life stage with low mortality; usually one-year-old or sub-adult) depends on overwintering conditions, which are very limited in Gunbower Creek.

4.2. Spring or summer, increased regional flows (greater than regulated flows for irrigation)

Regional flows in: the River Murray in the lower Loddon from Loddon catchment; in Box-Pyramid Creek from Kow Swamp catchment; at return of Gunbower Creek to the Murray at Koondrook Weir, due to rain rejections or local catchment rainfall.

Upstream migration

- Temperature-cued migrations remain active.
- Major stimulus for flow-cued migrations of golden perch, silver perch and Murray cod
- High numbers of these fish aggregate at migration barriers near end-of-system flows (Koondrook and Box Creek weirs), migrating from >100 km downstream.
- Within Gunbower Creek, small aggregations of adult and sub-adult native fish congregate below weirs without fishways at Cohuna Weir, Taylor's Creek Weir, Dehnes Weir [Kow Swamp Inlet], and National Channel Regulator or pass through weirs with fishways at Thompson, Gunbower and Kerang weirs).
- At weirs without fishways, fish may aggregate for days or weeks, if flows continue, or they may return downstream to seek alternative migration pathways in other tributaries.
- Aggregations of fish quickly disperse downstream as flows recede.

Downstream migration

- Larvae of species that spawn annually, as above, and those that are flow-cued (golden and silver perch) drift into the National Channel, passing through the Regulator; undershot gates cause high mortality at small openings and low mortality at large openings (the latter is a knowledge gap but assumed from hydraulics).

Lateral migration

- Small-bodied fish and catfish move between channel and wetland habitats depending on operation of local regulators.

Recruitment

- Initial survival of larvae potentially high but recruitment (survival to a life stage with low mortality; usually one-year-old or sub-adult) depends on overwintering conditions.
- Larvae that survive enter Gunbower Creek or Kow Swamp, possibly with reasonable survival, or enter the irrigation channels with very limited chance of survival overwinter.
- Within Kow Swamp, adult golden perch are in relatively high abundance; this may be due to annual stocking, survival of larvae from the River Murray, or both.

4.3. Spring or summer, flood flows

National Channel Regulator closed to prevent high inflows to Gunbower Creek; high Murray flows enter Gunbower Forest and some pass into Gunbower Creek; Koondrook Weir passing excess flows from Gunbower system; flows at Box-Pyramid Creek can be high from Kow Swamp catchment, although National Channel closed.

Upstream migration

- Fish responses as above for *increased regional flows*, with less attraction at the National Channel Regulator due to no flow, but greatly increased attraction and accumulations occurring at Box Creek Weir and Koondrook Weir.

Downstream migration

- Larvae of species that spawn annually and those that are flow-cued (golden and silver perch) do not drift into the National Channel or pass through the Regulator, due to Regulator closure.
- Larvae from upstream mainly enter the system via the forest channels (see lateral movement below).

Lateral

- Larvae enter the forest floodplain and associated wetlands directly from the River Murray.
- Most young fish of large-bodied fish species, or enter the irrigation channels with very limited chance of survival overwinter.

Recruitment

- Larvae that enter the floodplain potentially have good survival due to high productivity, if water quality remains good and young fish can leave the floodplain and not get trapped. Most young fish of large-bodied fish species which enter the irrigation channels have very limited chance of survival overwinter.
- Initial survival of larvae in channel habitats is potentially good but recruitment (survival to a life stage with low mortality; usually one-year-old or sub-adult) depends on overwintering conditions and is expected to be low.
- Larvae that survive enter Gunbower Creek or Kow Swamp, possibly with reasonable survival, or enter the irrigation channels with very limited chance of survival overwinter.

4.4. Summer, stable flows

Upstream migration

- Temperature-cued migrations active; mainly small-bodied fish within Gunbower Creek and mainly small-bodied fish and bony herring in Pyramid Creek and the lower Loddon.
- Accumulations of these fish below upstream weirs /regulators without fish passage, Cohuna weir in Gunbower Creek and Box Creek Weir in Box Creek.

Downstream migration

- Larvae of small-bodied fish drift downstream from the River Murray and from within Gunbower Creek.
-

Lateral migration

- Small-bodied fish and catfish move between channel and wetland habitats depending on operation of local regulators

4.5. Winter (May - July), greatly reduced flows (typical regulated flows)

- Little upstream, downstream or lateral movement, even with increased flow from local rain.
- Poor survival of young fish in Gunbower Creek and Box-Pyramid Creek, due to low flow in both systems to overwintering
- Limited overwintering habitats for adult fish; minimum flows have low productivity producing less food for adult and juvenile fish; fish are in poorer condition with lower fecundity (eggs per fish),
- Overwintering may occur effectively in Kow Swamp
- Within Kow Swamp, adult golden perch are in relatively high abundance; this may be due to annual stocking, survival of larvae from the River Murray, or both.
- Within Gunbower Creek, adult golden perch and silver perch are in low abundance because they cannot complete landscape-scale movements (over 100's kilometres) to spawn.
- Within Gunbower Creek there will be some movement of sub-adult, large-bodied fish onto the floodplain during a managed inundation and return movements (through fishways) post inundation event. During natural flooding, when the River Murray laterally inundates the floodplain, large-bodied fish may also temporarily move onto the floodplain.
- Most spawning of large bodied fish appears to occur in the River Murray with larval drift into Gunbower Creek resulting in no significant recruitment. There is some potential for fish larvae from the River Murray to survive and recruit in Kow Swamp.

5. KNOWLEDGE GAPS

- Are larvae drifting into the National Channel and Gunbower Creek in significant numbers to recolonise?
- Is there spawning and recruitment of Murray cod within Gunbower Creek?
- Settlement zones of larvae. Are larvae settling in littoral or benthic zones in Gunbower Creek in lotic or lentic reaches? Are larvae settling in Kow Swamp?
- Migratory response to short-term variations in flow that are typical of summer regulated conditions.

6. MANAGEMENT IMPLICATIONS

- There is potential to manipulate and enhance golden perch and silver perch re-colonisation of Gunbower Island by providing a flow event (e.g. 900 ML/d) from the terminal weirs (e.g. Koondrook and Box Creek) in spring or summer.

- There is potential to operate weirs to facilitate downstream fish movement and survival larvae by maximising gate settings and operating weirs in overshot rather than undershot mode where possible.

- Re-colonisation of Box-Pyramid Creek by Murray cod is likely to be by low numbers of sub-adult fish (150-700 mm long) and is likely to take 10 years or more. Stocking will likely reduce the time lag to create stronger population numbers.

- Re-colonisation of Gunbower Creek by Murray cod could be by drift of larvae from the River Murray and could take less than 10 years. Stocking may also be necessary.

- Following installation of fishways on the terminal weirs (Koondrook Weir and Box Creek Weir) annual (spring/summer) re-colonisation migrations by juvenile golden perch and silver perch (80-280 mm long) from the River Murray can be expected. Adult fish (280-600 mm long) can be expected to steadily re-colonise Gunbower Creek but these move in large numbers during a high flow event.

APPENDIX 3

NATIVE FISH RECOVERY PLAN – GUNBOWER AND LOWER LODDON

TECHNICAL MEMORANDUM No. 3

Generic Design Criteria for Gunbower Forest Regulators: Downstream Fish Passage

FISH RECOVERY PLAN – GUNBOWER AND LOWER LODDON

TECHNICAL MEMORANDUM No. 3

Generic Design Criteria for Gunbower Forest Regulators: Downstream Fish Passage

1 INTRODUCTION

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* provides a conceptual and strategic framework for management and investment to recover native fish populations and maintain a robust irrigation sector.

This brief report is the third of the Technical Memorandum series which is aimed at providing another level of detail to the Plan. These are intended to: i) directly feed into present management and investment, ii) identify knowledge gaps to target and iii) capture corporate knowledge as it develops. The Memorandums are intended to be short, but their subject matter is very broad and may include:

- conceptual models, which capture present thinking,
- technical guidelines
- recommended processes
- initial results of trials or experiments,
- ecological observations (e.g. migrating fish observed below a regulator under certain flows or conditions; fish kills)
- summary of community consultations
- changes in irrigation industry that directly affect the project.

Although technical and targeted to the Gunbower – lower Loddon Region, the intent is that they are public domain and posted on a corporate website, so that stakeholders are kept informed of developments. Reports or larger project still retain their role.

Each memorandum will have the format of:

- Objective
- Subject
- Knowledge Gaps, and
- Management Implications.

2 OBJECTIVE

Provide guidance on design of forest regulators for downstream fish passage.

3 DESIGN CRITERIA

Gate design

Passage of fish through undershot gates causes high mortalities of larvae of golden perch, silver perch and Murray cod (Baumgartner *et al.* 2006) and adults of small-bodied species (Baumgartner pers. comm.). Overshot gates or stoplogs are recommended for safe downstream fish passage with a suitable plunge pool (see below).

If downstream fish passage is to be encouraged, such as fish leaving a drying floodplain, then gradual acceleration of the water as it approaches the gate is preferred, which is achieved in sloping flume gates. If downstream fish passage is being discouraged, such as an entry to an irrigation channel, then a sudden acceleration of the water is preferred, which is achieved with a sharp crest (e.g. aluminium stoplogs).

Sidewinder gates may also be applicable for fish passage but there is no data on fish passage and it is possible that there is a pressure differential that could harm fish, so they are not recommended at this stage.

Plunge pool design

Plunge pool depth.

The plunge pool depth needs to be 40% of the total differential head (e.g. a 2 m difference in upstream and downstream water level would require a 0.8 m deep plunge pool) with a minimum depth is 0.5 m. At regulators that do not have continuous flow and a stable tailwater, such as wetland sites that dry out, the plunge pool needs to be filled on initial flows; this is done with an endsill that is the same height as the plunge pool so that low flows fill the plunge pool. The endsill needs a drain slot (typically 0.3-1.0 m wide) so that it drains at low flows and does not become a trap for fish; the width of the slot is sized to pass less flow than the minimum expected discharge through the regulator so that flow is restricted and the plunge pool on the apron fills quickly. The invert of the drain slot is the same as the downstream apron and the downstream channel bed, which enables the plunge pool to drain completely when flows cease.

Plunge pool length and volume.

There are no specific criteria for energy dissipation and downstream fish passage that can be used to quantitatively determine the pool volume and length, but there are observations of hydraulic modelling for the Gunbower Weir Fishway (Mallen-Cooper 2008). These indicate that with small forest regulators, which have a low head differential and low flows (< 100 ML/d) on initial filling, an endsill located 5 m from the downstream edge of the gate should provide a sufficient pool for gradual energy dissipation for fish.

As the wetland fills and the tailwater rises above the level of the endsill there is a greater tailwater volume to absorb the energy of the flowing water.

Endsill shape.

The endsill shape requires a chamfer of 45^{O} or greater to minimise the risk of injury for fish. A vertical endsill on a short apron that is close to a gate creates intense energy dissipation and turbulence which increases the risk of injuries for fish.

3 KNOWLEDGE GAPS

- Mortality of larvae through undershot gates with low head differential (e.g. 0.5m) and wide opening.
- Field data on effectiveness of plunge pool and larval survival.
- Survival of fish through sidewinder gates.

4 MANAGEMENT IMPLICATIONS

- The only undershot gates in Gunbower – lower Loddon project area are on the National Channel Inlet Regulator, Cohuna Weir, and Koondrook Weir, all in Gunbower Creek. These structures can be retrofitted with overshot gates.
- There is potential to operate weirs to facilitate downstream fish movement and survival larvae by maximising gate settings and operating weirs in overshot rather than undershot mode where possible.

APPENDIX 4

NATIVE FISH RECOVERY PLAN – GUNBOWER AND LOWER LODDON

TECHNICAL MEMORANDUM No. 4

Design Process for Fish Passage

NATIVE FISH RECOVERY PLAN – GUNBOWER AND LOWER LODDON

TECHNICAL MEMORANDUM No. 4

Design Process for Fish Passage

1 INTRODUCTION

The *Native Fish Recovery Plan – Gunbower and Lower Loddon* provides a conceptual and strategic framework for management and investment to recover native fish populations and maintain a robust irrigation sector.

This brief report is the fourth of the Technical Memorandum series aimed at providing another level of detail to the Plan. They are intended to: i) directly feed into present management and investment, ii) identify knowledge gaps to target and iii) capture corporate knowledge as it develops. The Memorandums are intended to be short, but their subject matter is very broad and may include:

- conceptual models, which capture present thinking,
- technical guidelines
- recommended processes
- initial results of trials or experiments,
- ecological observations (e.g. migrating fish observed below a regulator under certain flows or conditions; fish kills)
- summary of community consultations
- changes in irrigation industry that directly affect the project.

Although technical and targeted to the Gunbower – lower Loddon Region, the intent is that they are public domain and posted on a corporate website, so that stakeholders are kept informed of developments. Reports on larger projects are separate and still retain their role.

Each memorandum will have the format of:
- Objective
- Subject
- Knowledge Gaps, and
- Management Implications.

2 OBJECTIVE

To clarify the design process for fish passage and fishways.

3 DESIGN PROCESS

A flow chart of the design process for fish passage or a fishway is shown in Fig. 1. Providing fish passage can include barrier removal, operational changes (e.g. seasonal removal of stoplogs) or a fishway. The following flow charts relate mainly to the design of fishways but also apply to the other fish passage options.

The flow chart in Fig. 1 shows the process from conceptual design to completion and acceptance of a functioning fishway. Quite often a fishway project is considered completed when all construction is complete and the project meets all the specifications as tendered and all engineering standards. Three additional steps are shown in the flow chart that are essential to ensure the new asset performs its intended function of passing fish:

- Wet Commissioning
- Implement Fishway Management Plan, including Observations & Measurements, and
- Biological assessment.

The biological assessment then has a feedback loop to ensure the fishway meets its design objectives.

The first step of concept design is expanded in Fig. 2 to provide more detail. If all these steps are followed then all the critical design decisions have been made and detailed design can proceed with very little change. Often the distinction between the stages of Feasibility, Concept, Detailed Concept and Detailed Design are unclear; the flow chart covers the first three stages which may be one concept stage in smaller projects. These preliminary stages need to be thorough to avoid revisiting the concepts in detailed design. Early estimates of costs should be taken in context and contingencies of even 40% are not useful if the concept is not well workshopped and agreed upon. As well as engineering and biological function, the aspects that greatly influence cost are: constructability, dewatering, risk of flooding, access, foundation, the extent of geotechnical investigation, and land tenure. A Detailed Concept Design needs to have considered these aspects before Detailed Design proceeds.

In the concept design stage there are two fundamental components to consider in fishway design:

i) attracting fish to the fishway and
ii) passage through the fishway.

Frequently there is as much design work in the first component as there is in the second.

4 MANAGEMENT IMPLICATIONS

Three themes emerge from the flow charts:

i) An effective design process is consultative and requires engineers and fish biologist from the start, and

ii) Continuity of designers, with peer review, ensures quality control and that the intent of the design is followed through all stages.

iii) Each fishway is unique, despite often having similar design criteria, hence biological assessment and feedback is required to ensure that the fishway is optimised.

From experience on other projects Design and Construct (D & C) tenders are a poor process for fishways. Theoretically it should deliver the same result if the tender is well written, however commercial pressures result in less consultation and the functional intent of early concepts can be diluted.

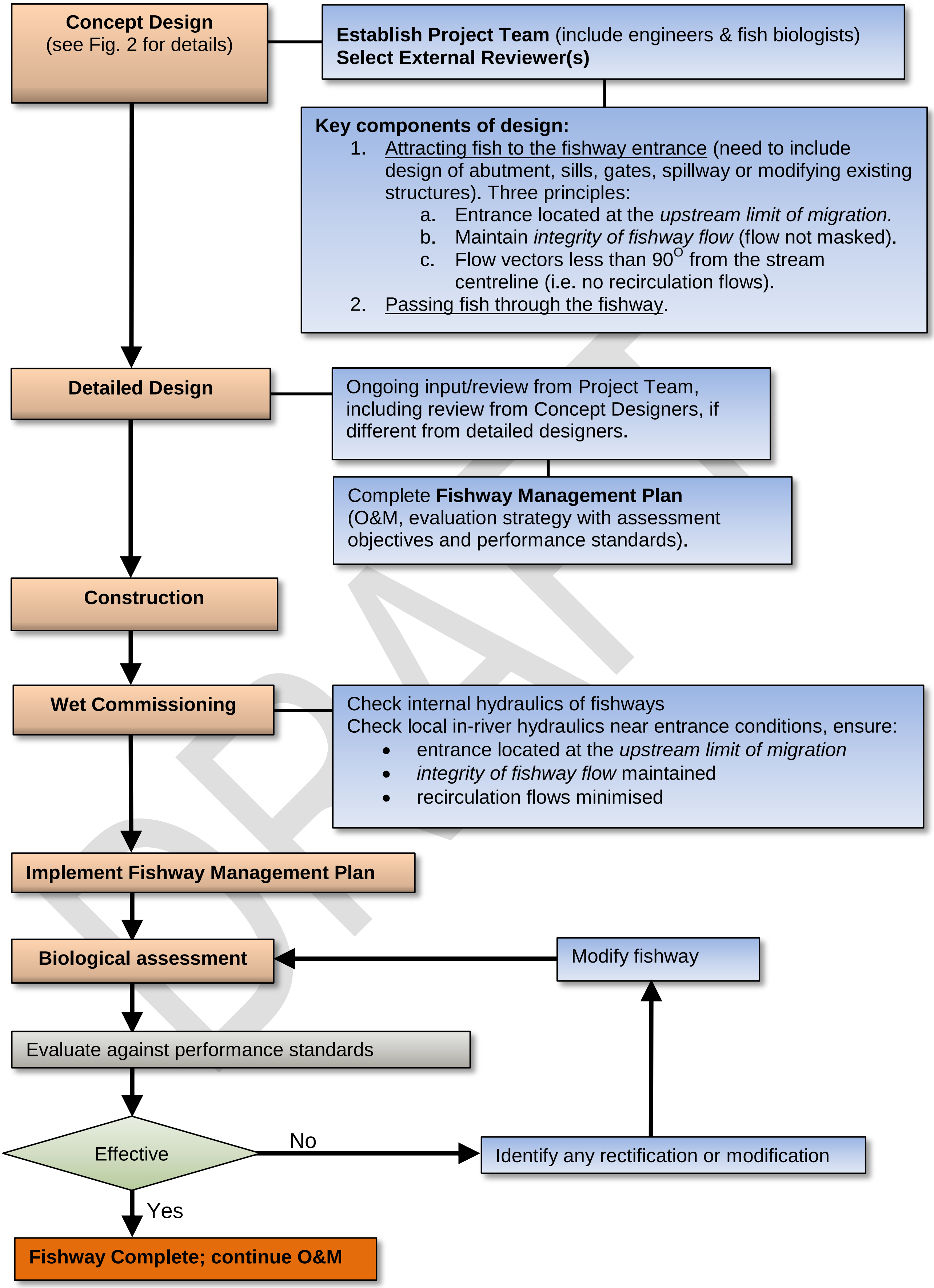


Fig. 1. Fishway Design and Evaluation Process. Concept Design Phase is expanded in Fig. 2.

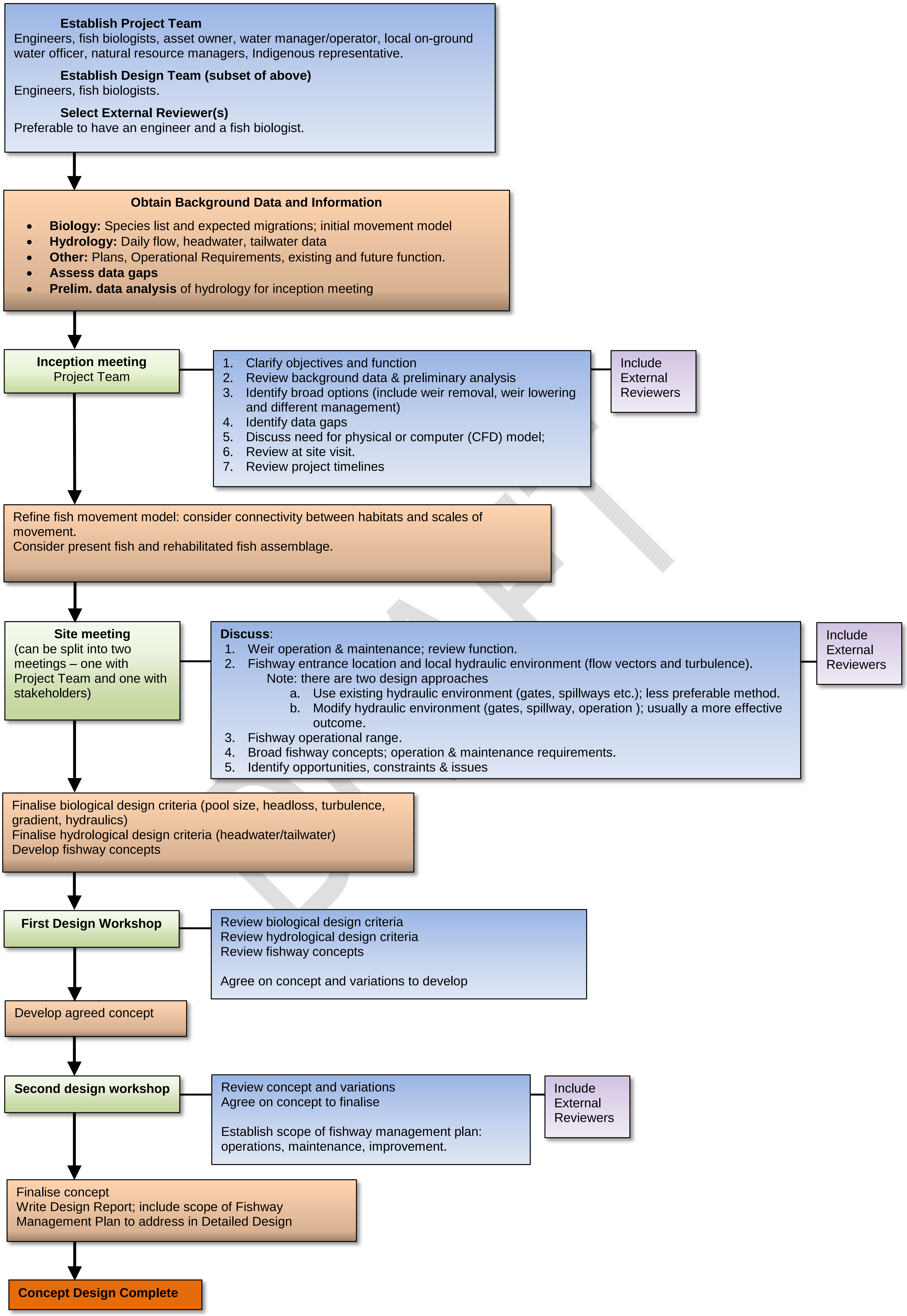


Fig. 2. A consultative model of fishway concept design development.