Australian Government

Government of South Australia

Ngarrindjeri Regional Authority

MURRAY FUTURES
Riverine Recovery

Murrundi Recovery

Sugar Shack Complex Management Plan
December 2015

WATER FOR GOOD

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This is Version 15 of the *Sugar Shack Complex Management Plan*.

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The Ngarrindjeri Regional Authority has developed this draft through agreement with the South Australian Government. This contribution extends the ongoing process of including Indigenous knowledge and traditions in wetland management planning as part of looking after the lands and waters.

PREPARED: DATE:___/___/___

(for acceptance) (<name> – <position>)

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Acknowledgements

The South Australian Government has entered into Kungun Ngarrindjeri Yunnan (Listen to what Ngarrindjeri are saying) agreements and project agreements with the Ngarrindjeri people that commit to respectful acknowledgement of Ngarrindjeri interests in lands and waters. The Sugar Shack Complex Management Plan is an important step in this new approach to natural resource management. The development of this management plan has been funded by the Riverine Recovery Project (RRP), also known by Ngarrindjeri as the Murrundi Recovery Project (MRP), a component of South Australia's $610 million *Murray Futures* Program, which is funded by the Australian Government's Water for the Future initiative. It has also been funded by contributions from the Ngarrindjeri Regional Authority, its regional member organisation the Mannum Aboriginal Community Association Incorporated (MACAI) and Sugar Shack Aboriginal Corporation (SSAC).

The Ngarrindjeri Regional Authority's Murrundi Recovery Project Team oversaw the preparation of this document. The NRA seconded Ben Taylor from the Department of Environment, Water and Natural Resources (DEWNR) to work as part of the team and he made significant contributions to the development of the document and contributed much of the ecological and hydrological text. Isobelle Campbell as Chair of the Mannum Aboriginal Community Association Incorporated (MACAI) and Rick Hartman as Coordinator of the NRA's Murrundi Project Team and Steve Hemming of Flinders University ensured that Ngarrindjeri, Nganguraku and Ngaiawang cultural knowledge and protocols are respected. The Sugar Shack Complex is part of the Ngurunderi Creation story of the Ngarrindjeri Nation.

The Ngarrindjeri Regional Authority pay respects to the Ngarrindjeri, Nganguraku and Ngaiawang ancestors, elders, and young people who have cared for this part of Ruwe/Ruwar since creation.

The NRA's engagement in this process has been supported through its partnership with Flinders University Office of Indigenous Strategy and Engagement, and further informed by research partnerships with the Goyder Institute for Water Research.

Jem Tesoriero and Kate Mason from the SAM-DBNRM Board, in association with the MACAI and Sugar Shack Corporation, authored a draft plan for one wetland of the Sugar Shack Complex (Wetland 10). Sean Robinson and Matt Gibbs provided assistance with the interpretation and use of the Robinson model.

Ngarrindjeri Acknowledgement

Ngarrindjeri, Nganguraku and Ngaiawang (referred to as Ngarrindjeri at some points in this plan) are the descendants of the original Indigenous inhabitants of the lands and waters of the Murray River, Lower Lakes and Coorong and adjacent areas. Ngarrindjeri have occupied, enjoyed, utilised and managed these traditional homelands since the Kaldowinyeri (Ngarrindjeri Creation). The NRA pay respects to the Ngarrindjeri Creators, ancestors, elders, and young people who have cared for this part of Ruwe/Ruwar since creation.

Ngarrindjeri Creation stories outline that Murrundi, including Sugar Shack Complex, was created by Ngarrindjeri Creation Ancestors such as Ngurunderi, Pondi (Murray Cod) and Thukabi (Macquarie Tortoise) and has been cared for by generations of Ngarrindjeri people. Sugar Shack Complex is part of the living body of Murrundi and Creation Ancestors such as Ngurunderi and Pondi.

For Sugar Shack Complex to continue to give life to the Ngarrindjeri nation it must be healthy and cared for in a culturally respectful manner. The initial inclusion of Ngarrindjeri knowledge and interests in this wetland plan is a preliminary step towards recognising Ngarrindjeri understanding of the relationship between healthy lands and waters and all living things. These Ngarrindjeri values are expressed through the philosophy of being recognised as Ngarrindjeri Ruwe/Ruwar. Ngarrindjeri note it is important that this plan and future management recognises Ngarrindjeri cultural obligations to Ruwe/Ruwar and their role in caring for the wetlands overall health.

Abbreviations

DEM	Digital Elevation Model - a digital, high-resolution map of topography
DEWNR	South Australian Government Department of Environment, Water and Natural Resources
KNYA	Kungun Ngarrindjeri Yunnan Agreement (see Glossary of Terms)
MACAI	Mannum Aboriginal Community Association Incorporated
mAHD	metres Australian Height Datum – height above sea level
MDB	Murray Darling Basin
ML	megalitre – a million litres
MMLAP	Mid-Murray Local Action Planning
MRP	Murrundi Recovery Project (Riverine Recovery Project)
NRA	Ngarrindjeri Regional Authority
NYR	Ngarrindjeri Regional Authority Yarluwar-Ruwe Program
RRP	Riverine Recovery Project
SAMDB NRM Board	South Australian Murray-Darling Basin Natural Resources Management Board
SSAC	Sugar Shack Aboriginal Corporation
UNDRIP	*United Nations Declaration of the Rights of Indigenous Peoples*, 2007

Glossary of Terms

Kungun Ngarrindjeri Yunnan Agreement (KNYA)

A negotiation and contract (agreement) making methodology known as Kungun Ngarrindjeri Yunnan (listen to what Ngarrindjeri people have to say). Ngarrindjeri use this methodology in significant interactions with government and other non-Indigenous interests that may impact on Ngarrindjeri Ruwe/Ruwar.

Miwi

Ngarrindjeri inner spiritual connection to our lands, waters, each other and all living things, and which is passed down through our mothers since Creation.

Murrundi

Ngarrindjeri word for River Murray.

Ngarrindjeri Regional Authority (NRA)

Ngarrindjeri contemporary governing organisation recognised by State and Federal governments as the peak governing body for the Ngarrindjeri nation. The NRA Board includes representation from the Ngarrindjeri Native Title Management Committee, the Ngarrindjeri Heritage Committee, the Ngarrindjeri Tendi and the Mannum Aboriginal Community Association Incorporated (MACAI).

Ngarrindjeri Yarluwar-Ruwe Program (NYR Program)

Ngarrindjeri Regional Authority, Yarluwar-Ruwe Program coordinates Ngarrindjeri Caring for Country programs.

Ngartji

For Ngarrindjeri people birds, animals, plants and all living things are spiritually connected – they are considered Ngartjis. A Ngartji is often referred to as a close friend and relative.

Ngarrindjeri Yannarumi

Ngarrindjeri maintaining the health of Ngarrindjeri Ruwe/Ruwar (lands, waters, body, spirit and all living things).

Ngurunderi

Ngarrindjeri Creation Ancestor: Ngurunderi creation story is a primary account of creation in the River Murray, Lower Lakes, Coorong and Murray Mouth Region.

Pondi

Ngarrindjeri word for Murray Cod. Also a Creation Ancestor.

Ruwe/Ruwar

Ngarrindjeri philosophy of being: represents the interconnectedness between lands, waters, body, spirit and all living things.

Tendi

The traditional Ngarrindjeri governing body – a founding member of the NRA.

Wuri/Karrarru

Ngarrindjeri words for River Redgum (*Eucalyptus camaldulensis*).

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1. Introduction

1.1 Context

Ngarrindjeri philosophies of being are based on an interconnection between country, body and spirit and this interconnection is fundamental to wellbeing. The Ngarrindjeri nation in southern South Australia use the term *Ruwe/Ruwar* to encapsulate this concept, and argue that healthy lands and waters are critical to healthy Ngarrindjeri people and culture.

The Sugar Shack Complex is part of the living body of Murrundi (River Murray) and was created by Creation Ancestors such as Ngurunderi, Pondi (Murray Cod) and Thukabi (Macquarie Tortoise) and cared for by generations of Ngarrindjeri. Ngarrindjeri people past, present and future are part of the living body of Murrundi. For this part of Murrundi to continue to give life to Ngarrindjeri people it must be healthy and cared for in a culturally respectful manner. The inclusion of Ngarrindjeri knowledge and interests in this wetland plan is a preliminary step towards recognising Ngarrindjeri understanding of the relationship between healthy lands and waters and all living things and Ngarrindjeri responsibility for the overall health of the Sugar Shack Complex.

Prior to European colonisation the lower River Murray was notable for its highly variable hydrology, driven by climatic cycles and significant weather events. Environmentally, the river and associated wetlands provided a highly productive and diverse range of habitats that supported biota well adapted to both flooding and drought. River regulation, i.e. the construction of weirs, locks and barrages for navigation and irrigation in the 1920s and 30s, combined with water resource development upstream, has led to relatively stable water levels in the main river channel in South Australia. The frequency of flooding has been reduced resulting in a greatly reduced exchange of water between the river channel and the floodplain. Locks and barrages also prevent the low river levels that would have occurred regularly under natural low flow conditions (Robinson 2013).

As a result of operating the river at a relatively fixed level, about 30% of riparian and floodplain wetland area in the South Australian Murray Valley has been isolated and now only receives water irregularly during very high flows. Conversely, the other 70% of wetland area is now effectively permanently connected to the river at or below its operational level and are therefore permanently inundated (Walker 2006). This increased permanence has changed the ecological character of wetlands, reduced productivity and reduced species diversity (Walker and Thoms 1993). The reinstatement of a more natural cycle of wetting and drying has been recommended as a means of improving the condition of wetlands on the lower River Murray (e.g. Jensen *et al.* 1996).

The Riverine (Murrundi) Recovery Project (RRP) is a major component of 'Murray Futures' - South Australia's priority program under the Australian Government's Water for the Future initiative. Among other outcomes, the RRP aims to restore variability in water level to lower River Murray wetlands by managing individual wetlands and investigating management at a reach scale.

One of the key requirements preceding any managed change to the water regime of a wetland on the River Murray in South Australia is the preparation of a wetland management plan, such as this one for the Sugar Shack Complex. Wetland management plans document and summarise the wetland's ecological character, identify management opportunities, assess management risks, and describe management objectives and monitoring targets to determine the effectiveness of any management actions.

The Sugar Shack Complex is a rare example on the lower River Murray of an entire floodplain complex able to be managed as a single system. This is due to the consistency of tenure and land use throughout the Complex. This plan identifies the opportunities to reintroduce a more variable water regime to selected wetlands of the Complex and to enhance flows through anabranch creeks. These improvements will occur during periods of regulated river flows.

A companion program, the Integrated Operating System, will coordinate management of all wetlands in the South Australian Murray Darling Basin to optimise environmental benefits and to enhance the benefits of any flood flows. This program will need to take into account Indigenous values and uses through appropriate engagement with the Ngarrindjeri Regional Authority (NRA).

This plan continues the process of bringing Ngarrindjeri cultural understandings, values and interests into water and natural resource management (NRM) planning (see Birckhead *et al.* 2011). It also takes into account Aboriginal heritage issues [as defined in the *Aboriginal Heritage Act* (SA) 1988] and highlights the need to consider these in wetland planning. This plan is also a preliminary attempt to address the requirements for the inclusion of Indigenous values, uses and requirements under the Murray Darling Basin Plan 2012. Ngarrindjeri have been working with the South Australian Government through the *Kungun Ngarrindjeri Yunnan* (KNY) agreement strategy to bring Ngarrindjeri interests into natural resource management planning more broadly and this includes water planning. The NRA has emphasised that Australia's commitment to the *United Nations Declaration of the Rights of Indigenous Peoples 2007* (UNDRIP) provides important guidelines for a just recognition. In accordance with Articles 19, 25 and 32 Indigenous people must have a central role in the development, implementation and evaluation of policy and legislative or administrative measures that concern water. Importantly, the NRA (2012: 3) makes the following point regarding *a priori* rights to water in its submission to the Murray Darling Basin Authority (MDBA):

> Ngarrindjeri consider they have the first right, a right attached to the exercise of their cultural rights, interests and responsibilities, that precedes all other rights including but not limited to the legislative function of the MDBA to allocate water for particular uses. The rights and interests of the Ngarrindjeri require that water flows into, through, and from, their country from up river. This is a right *a priori* to all others and the MDBA should commence their consideration of allocations without interference or diminishment of these rights.

In 2009, the Ngarrindjeri nation in South Australia negotiated an agreement with the State of South Australia that recognised Ngarrindjeri traditional ownership and established a process for negotiating and supporting Ngarrindjeri rights and responsibilities for country (see Hemming *et al.* 2011). The agreement takes the form of a whole-of-government contract agreement between the Ngarrindjeri nation and the State of South Australia, called a *Kungun Ngarrindjeri Yunnan* agreement (KNY – Lit: "Listen to what Ngarrindjeri have to say"). It provides for a resourced, formal structure for meetings and negotiations between the Ngarrindjeri Regional Authority and government, universities and other non-Indigenous organisations (see Ngarrindjeri Nation 2006).

In recent years the Ngarrindjeri KNY strategy has provided the platform for South Australian Government support for building Ngarrindjeri capacity to take a leading role in caring for Ngarrindjeri country, including conducting research to better inform Ngarrindjeri programs (see DEH 2010). Underpinning these negotiations is a long-term Ngarrindjeri educational strategy that seeks to explain the Ngarrindjeri principle that the lands and waters are a living body and it must be healthy for Ngarrindjeri to be healthy. When Ngarrindjeri undertake 'Caring for Country' activities, cultural heritage assessments, or other forms of research and planning associated with the lands, waters people and all living things, the principle of Ruwe/Ruwar remains paramount.

The following set of principles has been developed by the NRA to provide governments and other non-Indigenous organisations with an understanding of the requirements of just and appropriate engagement:

1. Respectful processes, time and support to Ngarrindjeri to care for country (that means caring for people, past, present and future).

2. Ngarrindjeri actively involved in research, planning, management and monitoring activities on Ngarrindjeri Ruwe / Ruwar.

3. Cultural knowledge and intellectual property protected across Ngarrindjeri engagements with government and research organisations.

4. Ngarrindjeri cultural values integral to all planning and future management arrangements.

5. Active Ngarrindjeri participation in planning and future management arrangements through employment, education and training opportunities.

This developing Indigenous capacity provides an opportunity for collaborative research aimed at supporting new strategies for NRM and water management in the MDB. Recital E (KNY 2009 in Hemming *et al.* 2011: 110) provides an indication of the intentions of the agreement:

> E. By this Agreement the Ministers wish to provide support and resources to the Ngarrindjeri Regional Authority Inc. and enter into negotiations and consultations with the Ngarrindjeri about the maintenance and protection of Ngarrindjeri culture and cultural sites and the natural resources of the Land [lands and waters].

A proper relationship and role in the management of the lands and waters is a fundamental platform in building and maintaining Ngarrindjeri culture and self-respect. Ngangurаku and Ngaiawang, being part of the Ngarrindjeri Nation believe that their future involvement in the management of the land and waters would be positive and beneficial to all members of the community, both Indigenous and non-Indigenous, and would represent a significant step in the process of reconciliation (see Ngarrindjeri Ramsar Working Group 1998, Ngarrindjeri Nation 2006, KNY 2009). The strengthening of Ngarrindjeri people and their culture requires a serious involvement in the management of their traditional lands and waters.

1.2 Development of this Management Plan

This plan is a first step towards the development of a Ngarrindjeri wetland management plan that privileges cultural knowledge, Ngarrindjeri aspirations, and a Ngarrindjeri understanding of the relationship between healthy lands, waters and all living things. These Ngarrindjeri values are expressed through the philosophy of being known as Ngarrindjeri Ruwe/Ruwar. Ngarrindjeri have worked with non-Indigenous environmental scientists and others to develop this management plan for the Sugar Shack Complex. It is important to recognise that the language, style and structure of this plan still largely reflects a non-Indigenous perspective. As the local Ngarrindjeri organisations, the Mannum Aboriginal Community Association Incorporated (MACAI) and the Sugar Shack Aboriginal Corporation (SSAC) develop more experience with wetland planning, and a healthier future for the Sugar Shack Complex, the Wetland Management Plan will become increasingly Ngarrindjeri -focussed. This planning-future will incorporate the best Ngarrindjeri and non-Indigenous science, maintain and build strong partnerships between Ngarrindjeri and non-Indigenous organisations.

In 2009, the NRA developed a Murray Futures plan to inform negotiations with the South Australian Government regarding future State plans to address the degradation of Ngarrindjeri lands and waters due to extended drought conditions and the over-allocation of water in the MDB. At this time the NRA was negotiating with the State Government to become formally part of the RRP and argued strongly that a formal project agreement in alignment with the 2009 KNY agreement needed to be finalised to provide acceptable engagement between the NRA and SA government.

The formal Riverine Recovery Project agreement between DEWNR and the NRA was finalised in 2012, which means that NRA input into the RRP was delayed. The NRA established a Murrundi Recovery Program (MRP) team and developed an appropriate research and management structure for the project. This included strong representation from MACAI, which is as a member organisation of the NRA and a key local organisation with a central interest in the RRP. The NRA was able to employ Ngarrindjeri cultural heritage rangers, a cultural heritage specialist, create employment for MACAI and provide other resource, planning and research support. Funding also supported the secondment of an environmental scientist (Ben Taylor) to the NRA team. The NRA's heritage team, the Ngarrindjeri Heritage Committee, and MACAI's heritage team developed a program strategy to support the work of the NRA's MRP (coordinated by Rick Hartman).

During the period that the NRA was not formally part of the RRP, wetland management planning was taking place through the South Australian Murray Darling Basin Natural Resources Management Board (SAMDB NRM Board). Initially this Wetland Management Plan was developed for just one of the wetlands of the Sugar Shack Complex, Wetland 10 (Sugar Shack Pangki). A Draft Plan for the 2012 – 2017 period was developed to replace the Plan for the preceding five year period (Bjornsson 2006). Development of the 2012 – 2017 Plan was undertaken by the SAMDB NRM Board, in collaboration with the MACAI/SSAC. A draft version of the resultant Plan was reviewed by Luke Ireland (DEWNR) and Kelly Marsland (DEWNR). The draft management objectives and target hydrograph were also reviewed by Kane Aldridge (DEWNR). A near-final version of the Plan was then prepared (Tesoriero and Mason 2012).

At this time the NRA were dissatisfied with the process of engagement for the development of the wetland plans being undertaken as part of the RRP. As a result, the NRA negotiated a 'draft' status for all existing plans and developed a process for NRA/MACAI's review of these plans and the preliminary cultural heritage assessments of works proposed under the RRP. Implementation of the draft Sugar Shack Plan had already commenced when the NRA re-negotiated the South Australian government's process for Indigenous engagement via the 2012 RRP funding agreement.

In mid-2013 the NRA (with MACAI as a member organisation) nominated the wetlands of the Sugar Shack Complex for on-ground works and management under the Riverine Recovery Project. This decision was made to support the broader, long-term Ngarrindjeri objective of best-practice Indigenous engagement with water, wetland and NRM planning. The nomination of the Sugar Shack Complex was intended to provide the opportunity for MACAI/SSAC to develop a sustainable and leading role in managing Ruwe, as the Sugar Shack complex is owned and managed by the SSAC. It is hoped that Sugar Shack Complex will become a 'best-practice' example of Indigenous management of a wetland complex in the MDB. This nomination required the development of a Wetland Management Plan for the entire Complex (this Plan). This Plan for the Sugar Shack Complex has been developed by the NRA and MACAI in association with DEWNR. The proposed registration is aligned with the Ngurunderi Creation Story – Ngurunderi and Pondi created Murrundi's wetlands during their travels.The Sugar Shack Complex Wetland Management Plan has been developed in accord with the Ngarrindjeri Yarluwar-Ruwe Plan and seeks to restore the cultural health of this part of Murrundi.

A central part of this Plan is the recommendation that the Sugar Shack Complex is registered as a 'site' under the Aboriginal Heritage Act, SA (1988), although it is understood that this aspiration is beyond the direct scope of a wetland management plan such as this one.

For simplicity this single Plan for the entire Complex has been developed, making the draft Plan for Sugar Shack Pangki redundant. This plan has been lead and developed by the NRA working in conjunction with DEWNR to align with the principles of the KNY agreement and a Ngarrindjeri Yannarumi (Speaking as Country) approach. However, the research and planning that informed the draft Plan have not been lost and are largely incorporated within this plan.

2. Description of Sugar Shack Complex

2.1 Indigenous Cultural significance

Ngang uraku and Ngaiawang, being part of the Ngarrindjeri Nation, are the descendants of the original Indigenous inhabitants of the lands and waters of the Murrundi (Murray River), Lower Lakes and Coorong and adjacent areas. They have occupied, enjoyed, utilised and managed these traditional homelands since the Kaldowinyeri (Ngarrindjeri Creation). The River Murray, Lower Lakes, Kurangk (Coorong) and Murray Mouth are central to Ngarrindjeri culture and spiritual beliefs. This association is expressed through Creation stories about Ruwe/Ruwar, which reveal the significance of the relationship between the country and the people, both practically and spiritually. As Ngarrindjeri Elder Tom Trevorrow (deceased) said:

> *The land and waters is a living body. We the Ngarrindjeri people are a part of its existence. The land and waters must be healthy for the Ngarrindjeri people to be healthy.*

(Trevorrow in Hemming *et al*. 2002)

Ngarrindjeri philosophies of being are based on an interconnection between country, body and spirit that is fundamental to wellbeing. The Ngarrindjeri nation in southern South Australia use the term *Ruwe/Ruwar* to encapsulate this concept and argue healthy lands and waters are critical to healthy Ngarrindjeri people and culture. The Sugar Shack Complex is part of the living body of Murrundi (River Murray) and was created by Creation Ancestors such as Ngurunderi, Pondi (Murray Cod) and Thukabi (Macquarie Tortoise) and cared for by generations of Nganguraku and Ngaiawang, being part of the Ngarrindjeri Nation. For this wetland to continue to give life to Ngarrindjeri it must be healthy and cared for in a culturally respectful manner. The initial inclusion of Ngarrindjeri knowledge and interests in this wetland plan is a preliminary step towards recognising Ngarrindjeri understanding of the relationship between healthy lands and waters and all living things, and Ngarrindjeri responsibility for the overall health of the Sugar Shack Complex. Ngarrindjeri people, past, present and future are part of the living body of Murrundi.

The following Ngarrindjeri Creation Story is reproduced from the *Ngarrindjeri Nation Yarluwar-Ruwe Plan* (2006). It provides an account of the cultural connections (Ruwe/Ruwar) between Ngarrindjeri and Yarlwuar-Ruwe (all Ngarrindjeri lands and waters):

> *Ngurunderi the Creator*
>
> A long, long time ago Ngurunderi our Spiritual Ancestor chased Pondi, the Murray Cod, from the junction where the Darling and Murrundi (River Murray) meet. Back then, the River Murray was just a small stream and Pondi had nowhere to go. As Ngurunderi chased him in his bark canoe he went ploughing and crashing through the land and his huge body and tail created the mighty River Murray. When Ngurunderi and his brother-in-law Nepele caught Pondi at the place where the fresh and salt water meet they cut him up into many pieces, which became the fresh and salt water fish for the Ngarrindjeri people. To the last piece Ngurunderi said—you keep being a Pondi (Murray Cod). As Ngurunderi travelled throughout our Country, he created landforms, waterways and life. He gave to his people the stories, meanings and laws associated with our lands and waters of his creation. He gave each Lakalinyeri (clan) our identity to our *Ruwe* (country) and our *Ngartjis* (animals, birds, fish and plants) - who are our friends. Ngurunderi taught us how to hunt and gather our foods from the lands and waters. He taught us, don't be greedy,

> don't take any more than what you need, and share with one another. Ngurunderi also warned us that if we don't share we will be punished.
>
> Ngarrindjeri respect the gifts of Creation that Ngurunderi passed down to our Spiritual Ancestors, our Elders and to us. Ngarrindjeri must follow the Traditional Laws; we must respect and honour the lands, waters and all living things. Ngurunderi taught us our *Miwi*, which is our inner spiritual connection to our lands, waters, each other and all living things, and which is passed down through our mothers since Creation. Our Great Grandmothers, Grandmothers and mothers fought to protect our Spiritual waters from desecration when a bridge to Kumarangk (Hindmarsh Island) was to be built.
>
> Ngurunderi taught us how to sustain our lives and our culture from what were our healthy lands and waters. Our lands and waters must be managed according to our Laws to make them healthy once again. As the Ngarrindjeri Nation we must maintain our inherent sovereign rights to our *Yarluwar-Ruwe*. Ngarrindjeri people have a sovereign right to make our living from the lands and waters in a respectful and sustainable way.
>
> *We are asking non-Indigenous people to respect our traditions, our rights and our responsibilities according to Ngarrindjeri laws.*

Freshwater flows down the Murray-Darling system are understood by Ngarrindjeri as the lifeblood of the living body of the River Murray, Lower Lakes and Coorong. Maintaining connectivity between parts of the living body is a Ngarrindjeri cultural priority. When Ngurunderi travelled down the River Murray chasing Pondi, wetlands were created from the splashes of the giant cod's tail. These wetlands are understood by Ngarrindjeri as nurseries and the lungs of the river. The Wuri (River Redgum, *Eucalyptus camaldulensis*) are Ngurunderi's trees. The following excerpt from a 1999 public speech by Ngarrindjeri Elder Tom Trevorrow helps to explain the significance of the Wuri:

> This old *Wuri* was born upon this ground and has stood here for many, many years, tall and proud.
>
> If it could speak it would have so many stories to tell us, stories like:
>
> *My roots grow deep in the earth.*
>
> *My heritage goes back a long, long time.*
>
> *Over the years I have provided shelter for mother earth.*
>
> *Over the years I have provided food and shelter for all creatures who wish to live under me or upon me.*
>
> *I have provided shelter and my branches for fire, for the people who camped alongside of me.*
>
> *I have provided my skin for the people to make their canoe.*
>
> *I have shared myself with all living things.*
>
> Maybe through what has happened and what is happening today this old *Wuri* is speaking to us. Maybe it's telling us to come together and respect each other and respect and acknowledge each other's cultural and spiritual beliefs.
>
> Maybe we could also call this old *Wuri* a reconciliation tree …

Since the arrival of Europeans, the Ngarrindjeri have witnessed the draining of their wetlands along the rivers and in the south east of South Australia, and the disconnection of the living body of the River Murray, Lower Lakes and Coorong through the installation of locks, levee banks and barrages. They have watched their Ngartjis diminish, their lands cleared and the degradation of their Country. A proper relationship and role in the management of the lands and waters is a fundamental platform in building and maintaining Ngarrindjeri culture and self-respect (Ngarrindjeri Yannarumi). Ngarrindjeri believe that their future involvement in the management of the land and waters would be positive and beneficial to all members of the community, both Indigenous and non-Indigenous, and would represent a significant step in the process of reconciliation (see Ngarrindjeri Ramsar Working Group 1998, Ngarrindjeri Nation 2006, KNY 2009).

In 2009, the South Australian Government and the Ngarrindjeri people entered into the Kungun Ngarrindjeri Yunnan Agreement (KNY) whereby the relevant Ministers on behalf of the Crown expressed a desire for a new relationship between the State of South Australia and Ngarrindjeri. This is based on mutual respect and trust, acknowledging that Ngarrindjeri consider protection and maintenance of culture and cultural sites upon its land and waters central to Ngarrindjeri community wellbeing and existence. Through the KNY, the Government provides support to the Ngarrindjeri Regional Authority and enters into negotiations and consultations with the Ngarrindjeri about the maintenance and protection of Ngarrindjeri culture and cultural sites and the natural resources of the land. The KNY Taskforce meets monthly and provides an important opportunity for engagement between Ngarrindjeri and South Australian Government agencies regarding a range of programs and projects. Ngarrindjeri use this methodology in significant interactions with government and other non-Indigenous interests impacting on Ngarrindjeri *Ruwe/Ruwar.* This approach has been adopted by the Ngarrindjeri nation's peak body, the Ngarrindjeri Regional Authority (NRA) (see Hemming and Trevorrow 2005 , Hemming *et al.* 2011).

The Ngarrindjeri Regional Authority (NRA) is the peak body for the Ngarrindjeri nation. It is the lawful Ngarrindjeri body put in place by Ngarrindjeri to ensure that Ngarrindjeri Ruwe/Ruwar is healthy and life giving to Ngarrindjeri and includes the Mannum Aboriginal Community Association Inc. (MACAI) as a founding member organisation. The MACAI, under the *Aboriginal Heritage Act 1988* (SA), has responsibility for the care and protection of Aboriginal heritage along the River Murray from Morgan to Mypolonga, an area that includes the Swan Reach Complex. The MACAI is supported by the NRA's heritage team and the Ngarrindjeri Yarluwar-Ruwe Program. As the former Chair of MACAI, Ngarrindjeri Elder Richard Hunter (deceased) argued in 1994:

> Well, my dream, which is one that I have been involved with for quite a long time now and hope to be for a long time into the future, is that eventually with all the projects that I am involved with: the Devon Downs site, Swan Reach Mission site, and all the site recording through Mannum and Morgan and all the appropriate archaeological finds and stuff that we do, that we will eventually build up a big dossier that will make the Aboriginal people especially the children aware of where their roots are - who they are so they can walk straight ahead instead of looking down to the ground. So they can look people in the eye and not be ashamed of what they are, who they are. The other good plus out of this is it is also educating the white society making them understand or giving them the opportunity to understand us the Aboriginal people.
>
> (Hunter in Hemming *et al*. 2000)

Importantly, Indigenous traditions and interests have also been recognised by the Australian government through ratification of The *Declaration on the Rights of Indigenous Peoples (UNDRIP)*. The Declaration sets out the individual and collective rights of indigenous peoples, as well as their rights to culture, identity, language, employment, health, education, lands, waters and other issues.

Ngarrindjeri Yannarumi – assessing the cultural health of Murrundi

Ngarrindjeri support the sustainability of diverse and healthy wetland habitats and the restoration and maintenance of connectivity between habitats. Fundamental to this however is the connection between the health of Murrundi and Ngarrindjeri culture which must inform management responses.

Nganguraku and Ngaiawang, being part of the Ngarrindjeri Nation are developing a Ngarrindjeri Yannarumi (cultural health) process for assessing the cultural health of Sugar Shack complex – Ngarrindjeri maintaining the health of Ngarrindjeri Ruwe/Ruwar (land, body and spirit). This process is complex and ongoing, beginning with this preliminary input into wetland management planning processes. Ngarrindjeri seek to further incorporate this process into future wetland management planning and implementation. The following values, statements and objectives are guiding the development of the Ngarrindjeri Yannarumi program:

- Ngarrindjeri support actions that return the River Murray and wetlands to the healthy, life giving form that Ngurunderi and Pondi created.
- Ngarrindjeri Ruwe/Ruwar requires that the lands and waters are healthy for Ngarrindjeri to be healthy.
- Ngarrindjeri need to exercise their cultural responsibility to care for Country.
- The KNY Agreement (2009) provides the framework for a respectful and culturally appropriate management of Ngarrindjeri lands and waters.
- The commitments and undertakings contained in the KNY agreement are reflected in the Riverine Recovery Project Funding and Service Agreement (this agreement includes cultural knowledge protection).
- The NRA has set up the Ngarrindjeri Yarluwar-Ruwe Program to coordinate Caring for Country activities.
- MACAI is a founding member of the NRA and is supported by the NRA to care for the cultural heritage of lands and waters north of Mypolonga.
- The Ngarrindjeri Heritage Committee (also an NRA founding member) has responsibility for lands and waters south of Mypolonga.
- The cultural health assessment will not separate the cultural, social, spiritual, ecological and economic significance of Sugar Shack Complex for Ngarrindjeri. These are all connected through the Ngarrindjeri concept of Ruwe/Ruwar.
- That water allocation planning at the national, state and regional scale should be consistent with Ngarrindjeri aspirations and responsibilities, as set out in the Ngarrindjeri Nation Yarluwar-Ruwe Plan (Ngarrindjeri Nation 2006) and that Ngarrindjeri are centrally involved in such planning.

2.2 Location

The Sugar Shack Complex is a floodplain complex of wetlands and anabranch creeks located on lower Murrundi (the River Murray) immediately upstream of Swan Reach, South Australia (Figure 1). The complex lies within the River Murray Gorge geomorphic zone, which extends from Overland Corner downstream to Mannum (Walker and Thoms 1993). This geomorphic zone is characterised by a narrow river valley bordered on both sides by cliffs of varying height. The main channel of Murrundi meanders within the river valley, typically bound on both sides by a floodplain featuring wetlands, anabranches and related features. In some locations one bank of the main channel directly abuts the cliff base and the floodplain is absent. Such locations define the upstream and downstream extent of discrete areas of floodplain. The Sugar Shack Complex is one such discrete floodplain area. The complex occupies 10.7 km of river distance on the left bank of Murrundi between 250.5 and 261.2 river kilometres upstream of the Murray Mouth. The complex is bordered by the Murrundi main channel to the west and cliffs of approximately 25 m height to the east.

2.3 Climate

2.3.1 Local climate

The South Australian Murray-Darling Basin (SAMDB) region experiences hot dry summers and cool winters. The climate is generally described as warm and persistently dry. The average maximum daily temperature for Murray Bridge (the closest Bureau of Meteorology (BOM) weather station to Sugar Shack Complex, located 70 km to the south west) is 22.9˚C, ranging between 29.3˚C in February and 16.2˚C in July. The average annual rainfall at Murray Bridge is 348.8 mm with most falling during the winter months. Mean annual potential evaporation is some 2303 mm per annum and is highest during the warmer summer months, but in no month does average rainfall exceed average evaporation. Local climatic conditions are not the main driver of inundation of the Sugar Shack Complex, which is primarily influenced by flow rates and water levels in Murrundi.

2.3.2 Climate change

Warming of the global climate system is likely to continue over coming decades (Kirtman *et al.* 2013). The Murray Darling Basin is likely to experience continued increases in average temperature, changes in rainfall (likely reductions in winter and spring), an increase in daily rainfall intensity but longer dry spells between rainfall events, an increase in evapotranspiration, an increase in very hot days and nights, a reduction in the frequency of frosts, and a likely increase in the number of extreme fire danger days (Suppiah *et al.* 2006). These shifts in atmospheric (and related oceanic) trends are expected to produce flow on effects to water resources, ecological systems, agriculture, forestry, fisheries, human settlements, and human health (Balston *et al.* 2012). Ecosystems will need to be able to adapt or migrate in tandem with their suitable climatic zone or sea level, or will face local extinction. New biosecurity hazards and increased impact due to extreme events is also likely (Balston *et al.* 2012). The implication of the combined temperature, rainfall and pan evaporation trends and projections (combined with the level of water extraction from Murrundi) is an ongoing management challenge to make adequate environmental water available to meet the needs of the wetlands of the SAMDB region.

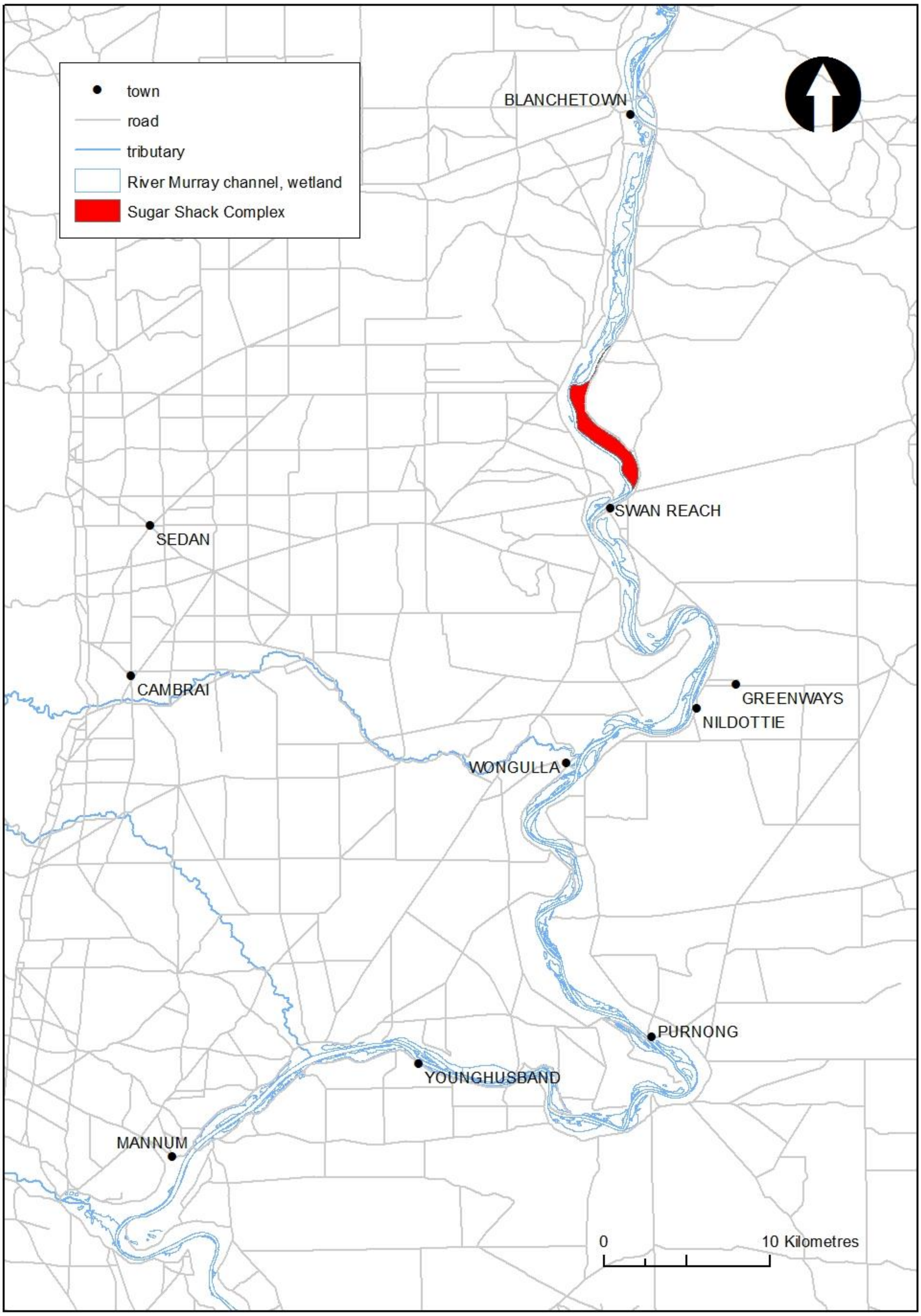

Figure 1. Sugar Shack Complex location map.

2.4 Tenure and Land Use

2.4.1 Tenure

The Sugar Shack Complex lies completely within the Hundred of Nildottie. The land parcels that cover the area, their tenure and ownership are listed in Table 1 and their spatial arrangement is shown in Figure 2. An adjacent highland parcel is also shown due to its relevance to this plan. The property known as Sugar Shack, owned and managed by the Sugar Shack Aboriginal Corporation, partly as freehold title and partly as crown leasehold, comprises sections S1, S2, S423 and S424 (floodplain area) and S435 (highland area) (Figure 2). The remaining land parcels of the Sugar Shack Complex, being unallotted Crown land, are administered by the Crown lands branch of DEWNR under the South Australian Crown Land Management Act 2009. Section 426, which covers the southern third of the floodplain, is known locally as “McAuley’s”.

Table 1. Tenure and ownership details for land parcels of the Sugar Shack Complex.

Parcel ID	Tenure	Lease Type	Owner
S1	Freehold		Sugar Shack Aboriginal Corporation
S376	Unallotted Crown Land		Minister for Environment and Conservation
S375	Unallotted Crown Land		Minister for Environment and Conservation
S379	Unallotted Crown Land		Minister for Environment and Conservation
S380	Unallotted Crown Land		Minister for Environment and Conservation
S382	Unallotted Crown Land		Minister for Environment and Conservation
S191	Unallotted Crown Land		Minister for Environment and Conservation
S423	Crown Leasehold	Ordinary Perpetual	Sugar Shack Aboriginal Corporation
S424	Crown Leasehold	Ordinary Perpetual	Sugar Shack Aboriginal Corporation
S2	Freehold		Sugar Shack Aboriginal Corporation
S383	Unallotted Crown Land		Minister for Environment and Conservation
S426	Unallotted Crown Land		Minister for Environment and Conservation
S142	Unallotted Crown Land		Minister for Environment and Conservation
S362	Unallotted Crown Land		Minister for Environment and Conservation
S435	Freehold		Sugar Shack Aboriginal Corporation

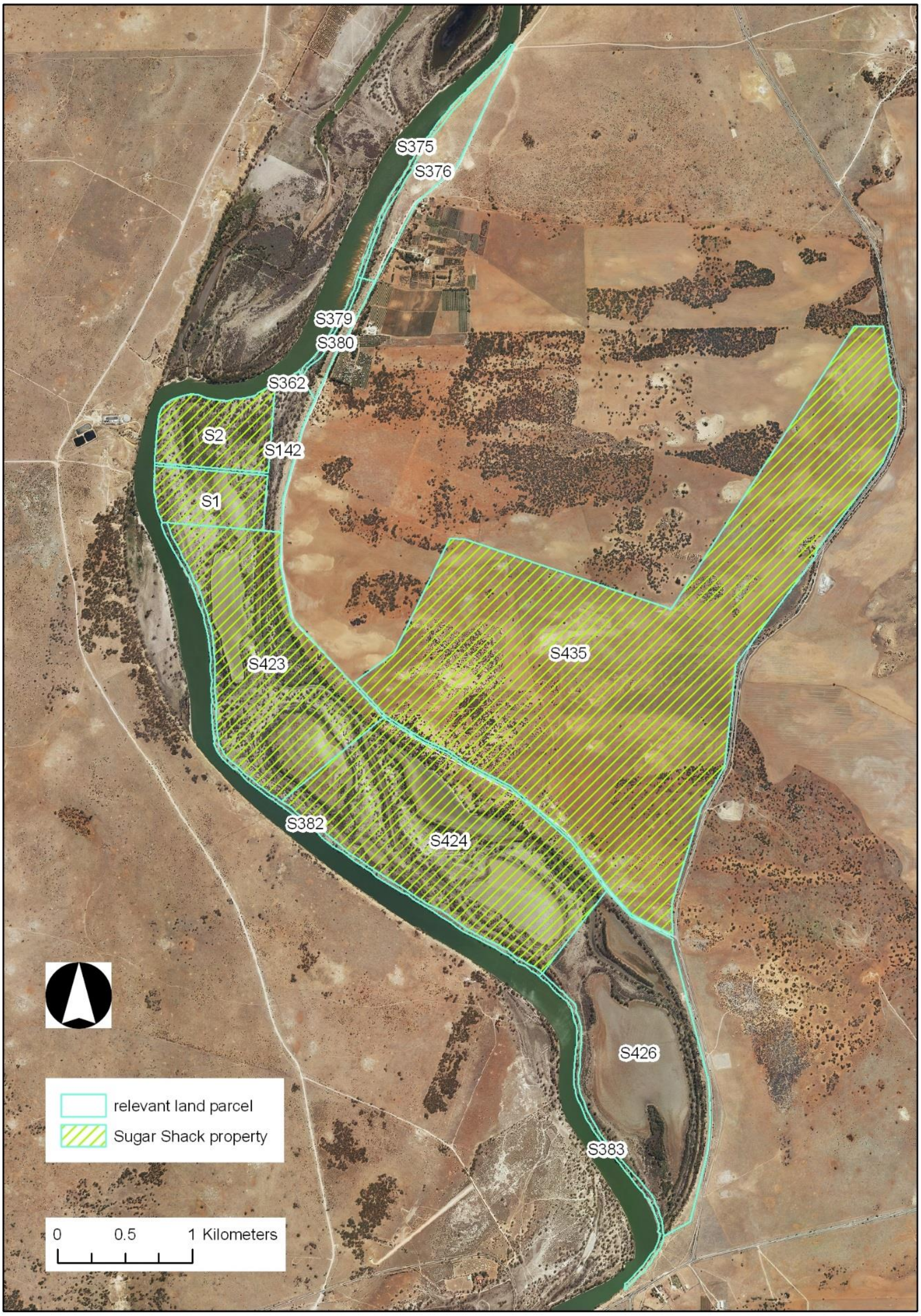

Figure 2. Map of Sugar Shack Complex and adjacent area showing land parcels (numbered). The land parcels that comprise the Sugar Shack property are highlighted (green cross-hatching).

2.4.2 Land use

Ngarrindjeri land use and traditional ownership of the Sugar Shack Complex over millennia is discussed in Section 2.3. This stewardship is ongoing and is facilitated by the prescriptions of this Plan.

The beds of several wetlands in the Complex have in the past been used for cropping, with shallow channels around wetland margins created to assist with irrigation (AWE 2005, Bjornsson 2006). These channels are clearly visible around the margins of Wetlands 2 and 13 (Figure 3, below). It is also likely, based on their shape and location, that several deeper channels connecting wetlands to anabranches and the main channel of Murrundi were excavated in association with cropping, to allow the flood irrigation of crops. These channels have effectively lowered the natural sills of Wetlands 2, 5, 10 and 13.

Although there are no specific records of vegetation clearance at Sugar Shack Complex, there has been significant harvesting of floodplain trees along Murrundi in South Australia. From the 1860's to the 1920's. River Redgums were harvested extensively for fuel, wharves and jetties to support the paddle steamer transportation industry (Sharley 2003) and for railway sleepers (Marsden 1989). River Redgums were also harvested as firewood for the Adelaide market (Sim 2012). Regulations under the *Planning Act 1982*, followed by the *Native Vegetation Act 1985* ended the large-scale logging of River Redgums in South Australia (Marsden 1989).

The grazing history of the Sugar Shack Complex has not been thoroughly researched, however it is likely that sheep and cattle grazing commenced soon after European colonisation. Stocking rates were reduced in 2002 when the Sugar Shack property was purchased by the Sugar Shack Aboriginal Corporation. At present the floodplain is lightly grazed and is stocked with approximately 15 cattle and 40 goats. Wetland 10 (Sugar Shack Pangki) has been fenced for several years to exclude stock, although periodic stock incursions do occur. The Crown reserve known as McAuley's (Section 426) is also fenced from the remainder of the property. There are various fences, two creek crossings and cattle yards on the floodplain for livestock management.

Limited timber harvesting occurs to support the firewood requirements of the SSAC. Native plants and animals are occasionally harvested by the owners and invited members of the wider Aboriginal community. Water is pumped from the creek (Wetland 7) for domestic use on the Sugar Shack property.

In the past camps have been held on Yatco Creek and around the wetlands of the Complex as part of the Duke of Edinburgh awards youth program (Mooney and Tan 2010).

2.4.3 Ngarrindjeri vision for Sugar Shack Land and Management

The Nganguraku and Ngaiawang, as part of the Ngarrindjeri Nation have identified a vision for Ngarrindjeri involvement and management of the Sugar Shack Complex that the NRA, MACAI and SSIC will take responsibility for:

1. That the Sugar Shack Complex become a best-practice example of Indigenous wetland management, incorporating Indigenous knowledge, practices, objectives and visions.
2. That water allocation planning for the site (and other's within the area) becomes consistent with Ngarrindjeri aspirations and responsibilities, as set out in the Ngarrindjeri Nation Yarluwar-Ruwe Plan (Ngarrindjeri Nation 2006) and that Ngarrindjeri are centrally involved in such planning.
3. That the tourism potential of the Complex be developed, such as:
    - A bush tucker path be developed to introduce tourists to Ngarrindjeri bush foods;

  - The hessian huts, that were the dwellings of Ngarrindjeri people on the Complex for many years, be reconstructed in their original locations;
  - Bird hides be constructed and the outstanding bird watching opportunities of the Complex be promoted; and
  - Facilities be established to encourage kayaking within the Complex.

4. That primary production opportunities within the Complex be developed, including:
    - Potential for Aquaculture including the harvesting of blue yabbies *Cherax destructor*; and a variety of native fish species (subject to appropriate licencing)
    - The harvesting of Common Carp *Cyprinus carpio* (subject to appropriate licencing), potentially in association with wetland drying events; and
    - The harvesting of quandongs *Santalum* spp. (high ground adjacent to Complex).
5. That Ngarrindjeri through MACAI and Sugar Shack Corporation are supported to assume greater responsibility for the management of the Complex, including:
    - operating regulating structures and undertaking ecological and cultural condition assessments.
6. That the Sugar Shack Indigenous Corporation apply for a licence over the McAuley's block (Section 426) for the purposes of cultural and ecological management as part of the Sugar Shack Complex.

2.5 Hydrology and Aquatic Features

The Sugar Shack Complex is located in the weir pool created by the barrages separating Lake Alexandrina from the Coorong. This weir pool includes the Goolwa Channel, Lake Alexandrina, Lake Albert and Murrundi from Wellington to Blanchetown. Typical pool level below Lock 1 is 0.75 mAHD. Under typical pool level conditions, the inundated habitat of the Sugar Shack Complex comprises (Figure 3):

- Two anabranches (creeks):
    - Yatco Creek (Creek 4), 5.85 km in length, which diverges from the River Murray main channel at 259.3 river km and re-enters it at 252.4 river km; and
    - A secondary creek (Creeks 11 and 14), 5.03 km in length, which diverges from Yatco Creek and follows the base of the cliffs on the eastern side of the complex, re-entering the River Murray main channel at the downstream end of the complex (250.5 river km). A short channel connects this creek to Wetland 13, into which it flows. Note immediately downstream of its connection to Wetland 13 a 300 m long section of this creek has a bed invert slightly above pool level (approximately 0.85 mAHD) and is therefore often dry.
- Six permanently inundated or regulated wetlands:
    - Wetland 2, which is 29.8 hectares in size and has a single artificially created (excavated) inlet/outlet channel to Yatco Creek with a sill elevation of approximately 0.1 mAHD;

- Wetland 5, which is 37.8 hectares in size and has an single artificially created inlet/outlet channel to the Murrundi main channel with a sill elevation of approximately 0.7 mAHD;

- Wetland 7, which is 23.8 hectares in size and is connected to Yatco Creek via Creek 11;

- Wetland 10 (Sugar Shack Pangki), which is 29.8 hectares in size and has a single artificially created inlet/outlet channel to Yatco Creek with a sill elevation of approximately 0.1 mAHD. This channel features a regulator and the wetland is currently managed to a target hydrograph (Bjornsson 2006, Tesoriero and Mason 2012);

- Wetland 12, which is 11.1 hectares in size and has a wide connection to Creek 11; and

- Wetland 13, which is 66.2 hectares in size and has an artificially created inlet channel from Creek 14 and an artificially created outlet channel to the River Murray with a sill elevation of approximately 0.3 mAHD.

In addition to the habitat inundated at pool level there are five temporary wetlands with sill elevations above pool level:

- Wetland 1, which is 0.7 hectares in size and has a sill elevation of 1.35 mAHD;

- Wetland 3, which is 2.5 hectares in size and has a sill elevation of 2.57 mAHD;

- Wetland 6, which is 7 hectares in size and has an artificially lowered sill elevation of 1.30 mAHD, and a natural sill elevation of approximately 2.60 mAHD;

- Wetland 8, which is 2.7 hectares in size and has a natural sill elevation of 1.35 mAHD, but this has been artificially raised by a vehicle crossing to 1.60 mAHD; and

- Wetland 9, which is 2.0 hectares in size and has a sill elevation of 0.99 mAHD.

The remainder of the complex comprises shedding floodplain habitat.

The water regime of permanent wetlands in the Sugar Shack Complex reflects water levels in the main channel of Murrundi. The six permanently inundated (or regulated) wetlands of the complex are all connected to the Murrundi main channel by smaller channels and/or anabranches at normal pool level.

Under natural River conditions the wetlands of the Sugar Shack Complex experienced considerable seasonal fluctuations in water level and regular floods of significant height and duration, which would have inundated the riparian zone and the surrounding floodplain (Robinson 2013). Additionally, all wetlands of the Complex would have disconnected from the River in most years, in some years more than once, but typically in autumn, as river levels fell below natural wetland sills (Robinson 2013).

A close examination of the digital elevation model (DEM) reveals that the inlet channels to several of the permanent wetlands of the complex have been excavated and are artificial. This is supported by the local knowledge of MACAI members. These artificially lowered sills provide permanent connection between such wetlands and the River under pool level conditions. River regulation has resulted in relatively stable water levels that rarely fall below pool level (0.75 mAHD), the Millenium Drought being an exception. Additionally, under today's regulated conditions, the frequency, magnitude and duration of floods in lower Murrundi have been reduced (Maheshwari *et al.* 1995). Although water levels in Murrundi at Sugar Shack Complex still fluctuate, these fluctuations are minor and short-term compared to natural conditions. They are due mainly to wind influence (Webster *et al.* 1997) and result in river levels between approximately 0.45 and 0.90 mAHD in the Swan Reach area. These short term fluctuations can expose relatively large areas of wetland bed in some wetlands (Figure 4), although the erratic and short-term nature of this exposure appears not to be conducive to the establishment of littoral zone vegetation.

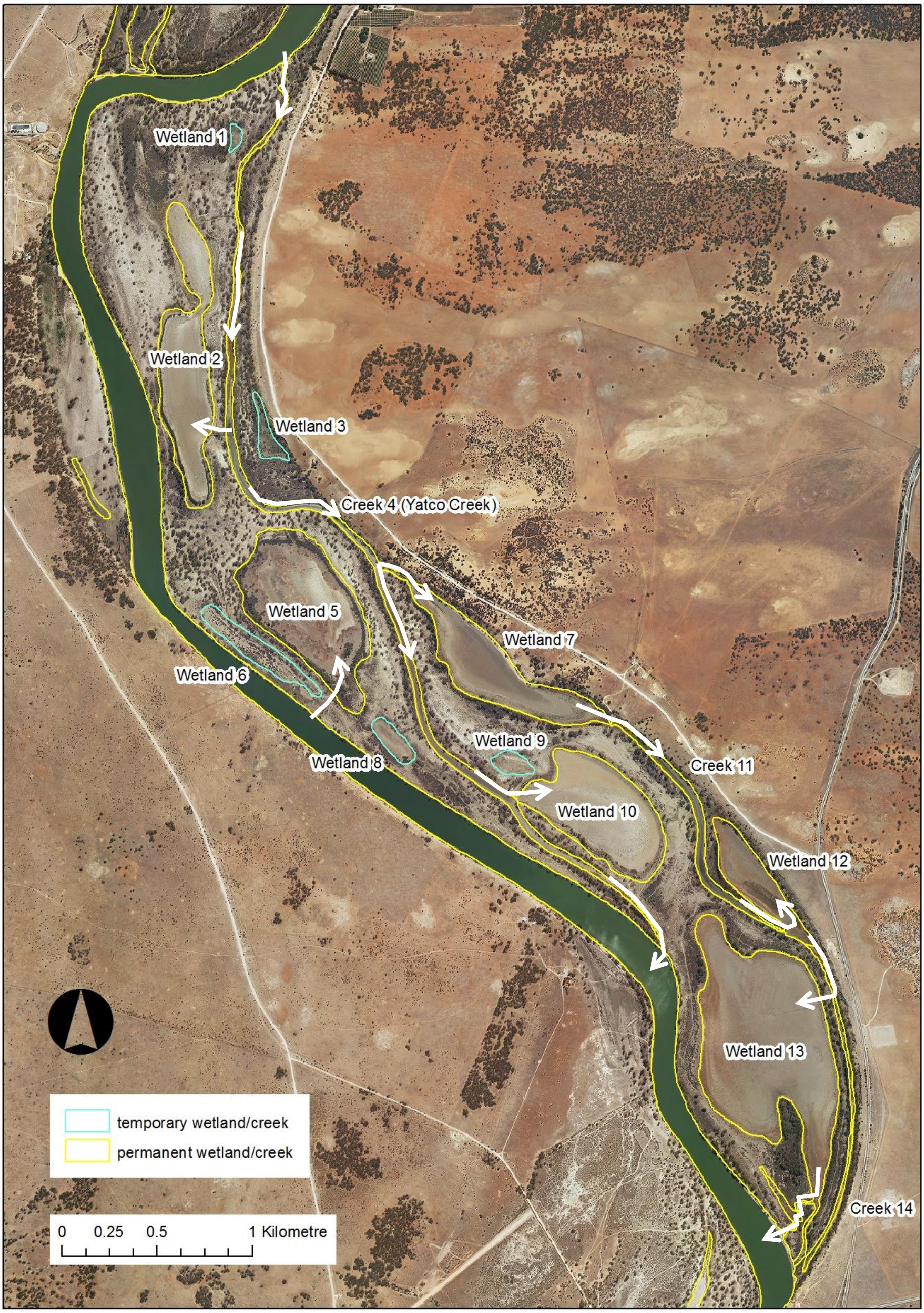

Figure 3. Map of Sugar Shack Complex showing wetlands and anabranch creeks (numbered) and flow paths under typical weir pool water level conditions (white arrows).

Figure 4. Partially exposed bed on the margin of Wetland 5 on 19 July 2013, corresponding to a low water level (0.45 mAHD) in Murrundi caused by wind set up. Note the absence of littoral zone emergent vegetation.

2.6 Regulating Structures

One regulating structure is currently in place on the Sugar Shack Complex (Figure 5). Constructed in 2007, the inlet structure to Wetland 10 (Sugar Shack Pangki) regulates inflows to this wetland from Yatco Creek. Its design details are listed in Table 2. Priority maintenance works for this structure are earthworks to reinforce eroded material around the concrete side walls (a result of high flows) and an upgrade of the locking mechanism. The structure could be improved with an upgrade of carp screens to current best-practice 'jail bar' 31 mm spacing design.

Table 2. Design details for Sugar Shack inlet structure.

Name	Location Description	Coordinates (GDA 1994, Zone 54)	Structure type and operation	Invert	Crest height	CTF when closed
Sugar Shack inlet structure	Inlet channel between Sugar Shack Pangki and Yatco Creek	E371191, N6177822	Two box culverts (1200 mm) with stop-logs and rotatable Carp exclusion screens (Alu-tread series 13)	0.10 mAHD	1.52 mAHD	Approx. 37,000 ML/day

Figure 5. Sugar Shack inlet structure (wetland to left).

Four additional regulating structures are proposed to enable the implementation of this Plan. These are described in Section 5.6.1 on page 102.

2.6.1 Ecological Values and general condition

Thompson (1986) classified the Sugar Shack Complex as high conservation value due to the variability of wetland types and the two creeks, the relative ease of management of the complex and the diversity of its avifauna including both water and forest birds. At the time of Thompson's survey there was a significant regeneration of River Redgums at Wetland 10, however most of this regeneration does not remain (AWE 2005).

Lloyd and Balla (1986) also classified Sugar Shack Complex as high conservation value based on the aquatic biota, overall condition and special features of the Complex. Jensen *et al*. (1996) confirmed Lloyd and Balla's classification and recommended that "high priority … be given to the protection of riparian vegetation and the investigation of hydrological management options".

The Complex is also listed as a Key Environmental Asset in the *Guide to the Basin Plan* (MDBA 2010a), meeting all five criteria for listing, that is it:

- is formally recognised in, and/or is capable of supporting species listed in, relevant international [migratory bird] agreements;

- is natural or near-natural, rare or unique;
- provides vital habitat;
- supports Commonwealth-, state- or territory-listed threatened species and/or ecological communities; and
- supports, or is capable of supporting, significant biodiversity.

A baseline survey conducted in 2003 – 04 (AWE 2005) focussed on Wetland 10 and the immediately surrounding area. The fish, bird and amphibian community of the area was found to be typical of lower Murrundi wetlands, with the exception of two threatened species, which add considerably to its conservation value; the Southern Bell Frog (*Litoria raniformis*) and Regent Parrot (*Polytelis anthopeplus*). Floodplain vegetation was considered to be in poor condition due to historic and ongoing livestock grazing, although it was suggested that livestock numbers had recently been reduced. AWE (2005) recommended improved grazing management and control of exotic fish species as the highest management priorities for the area.

An obvious example of ecological degradation within the Complex is the presence of dead mature River Redgums. The death of old trees is a natural process, however stands of dead old trees without living trees suggests environmental factors, rather than age alone, are at play. Several such stands occur within the Sugar Shack Complex such as the north-western perimeter of Wetland 2 and the periphery of temporary Wetlands 3, 8 and 9. These locations are all distant from surface water under normal pool level conditions, suggesting reduced floodplain inundation has contributed to tree death (see also Section 4.4).

Terrestrialisation, that is the displacement of inundation-tolerant vegetation with dryland species, is likely to have occurred in some areas, for example the bed of temporary Wetland 6, which has a ground layer dominated by the Chenopod shrub *Enchyleana tomentosa* var. *tomentosa* (Kloeden 2013). Terrestrialisation is a response to reduced frequency of inundation. The reduced frequency of floodplain inundation due to river regulation is likely to have contributed to terrestrialisation of the Sugar Shack Complex floodplain broadly post-colonisation. Many of the inundation intolerant plant species present within the Complex are introduced, including a number of annual and perennial grasses and forbs that are ubiquitous in lower Murrundi (AWE 2005, Kloeden 2013).

The margins of permanently inundated wetlands and creeks within the Complex feature a diverse suite of sedges, forbs and shrubs that are typical of lower Murrundi (Kloeden 2013). Below normal pool level the aquatic habitats of the complex generally lack vegetation or feature sparse cover and low floristic diversity (AWE 2005, Kloeden 2013), which is also typical of lower Murrundi but is a symptom of degradation arising from excessively stable river levels and the impact of Common Carp (DEWNR 2012a).

As is typical of lower Murrundi, the permanently inundated habitats of the Sugar Shack Complex at times support a high abundance of introduced fish species, particularly Common Carp and Gambusia (Hammer and Wedderburn 2004, Thwaites and Fredberg 2014). Introduced fish species may impact negatively upon native fish and amphibian populations via predation, competition, habitat modification and the introduction of diseases and parasites (Lintermans 2007). The abundance of native aquatic fauna within the Sugar Shack Complex is likely suppressed by these pest species.

In summary, the Sugar Shack Complex, while not pristine and featuring many of the symptoms of degradation common on lower Murrundi, retains important ecological values and is formally regarded as a high conservation value area.

2.6.2 Culturally Important Biota

The plant and animal species listed in Table 3 and Table 4 below have complex cultural significance that has been passed down from generation to generation by Ngarrindjeri ancestors. It should be noted that all tables in this plan that identify cultural uses and meanings associated with lands and waters and all living things provide a very basic interpretation for initial management planning.

Ngarrindjeri name(s)	Common name	Scientific name
Manangkeri, Kongi	*Bulrush, Cumbungi*	*Typha* spp.
Pangki	*Common Reed*	*Phragmites australis*
	Nardoo	*Marsilea* spp.
	Black Box	*Eucalyptus largiflorens*
Patcheroo	*River Cooba, Native Willow*	*Acacia stenophylla*
Wuri, Karrarru	*River Redgum*	*Eucalyptus camaldulensis* ssp. *camaldulensis*
Yalkari	*Spiny Flat-sedge*	*Cyperus gymnocaulous*

Table 3. Some animal species found at Sugar Shack Complex with complex cultural significance for Ngarrindjeri as part of the living body of Murrundi

Ngarrindjeri name(s)	Common Name	Scientific name
Mrayi (birds)		
Ngo:ri	Australian Pelican	*Pelecanus conspicillatus*
Kungari	Black Swan	*Cygnus atratus*
Nakari	Pacific Black Duck	*Anas superciliosa*
Ritjaruki	Willie Wagtail	*Rhipidura leucophrys*
Ma:mi (fish)		
Thukeri	Bony Herring	*Nematalosa erebi*
Pilalki	Golden Perch, Callop	*Macquaria ambigua ambigua*

Ngarrindjeri name(s)	Common Name	Scientific name
Reptiles		
Malinthaipari	Eastern (Common) Long-necked Tortoise	*Chelodina longicollis*
Thukubi	Macquarie Tortoise	*Emydura macquarii*
Invertebrates		
Kaltuwarri, Morrokun	Yabby	*Cherax destructor*

Table 4. Some plant species found at Sugar Shack Complex with complex cultural significance for Ngarrindjeri as part of the living body of Murrundi

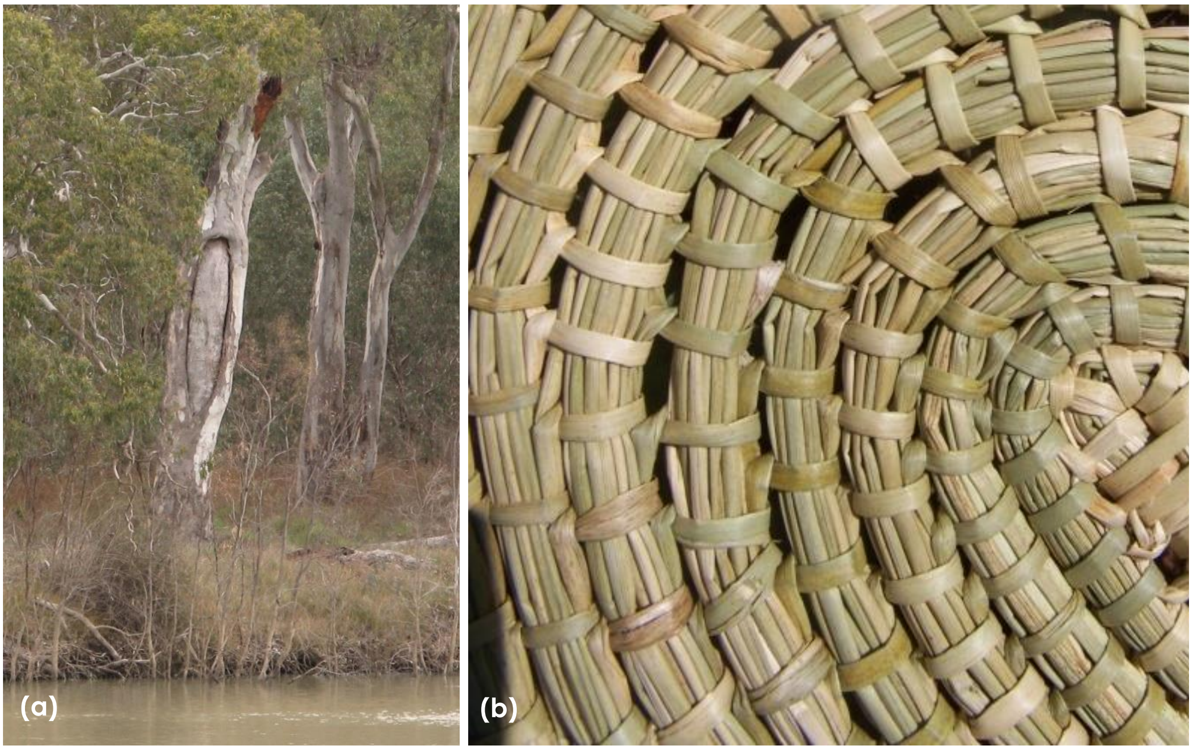

Figure 6. (a) Wuri / Karrarru (River Redgum) Yuki-Ancestor tree in the Swan Reach area, and (b) Yalkari (Spiny Flat-sedge, *Cyperus gymnocaulous*) weaving (photo: Chris Koolmatrie).

2.6.3 Vegetation

In January to March 2013, the vegetation of the Sugar Shack Complex was mapped using the standardised methodology of the National Vegetation Information System (NVIS) (Kloeden 2013). Areas inundated at typical pool water level (wetlands, creeks) were mapped as unvegetated. Of the remaining area, approximately 80%, or a total of 318.4 ha, was mapped (Figure 7). Mapping indicates that River Redgum woodlands of various tree density and understorey composition occupy about 134 ha, or 22% of the complex. Lignum (*Duma florulenta*) shrublands occupy 102 ha, or 17%, Black Box (*Eucalyptus largiflorens*) woodlands occupy 47 ha (7.6%) and mixed Red Gum/Black Box woodlands 8 ha (1.3%).

Areas inundated at typical pool water level (creeks, wetlands) occupy 227 ha, or 37% of the total complex. These features are largely unvegetated, although Wetland 5 contains some stands of emergent vegetation (Kloeden 2013). The margins of these wetlands currently support a range of littoral zone species typical of the lower River Murray (Kloeden 2013), providing a source of propagules for the future natural dispersal and establishment onto currently unvegetated wetland sediments.

2.6.4 Threatened flora

Fifteen plant species of conservation significance are known to occur at Sugar Shack Complex (Table 5). Most are located on the damp margins of the permanent wetlands, or at higher elevations on the floodplain.

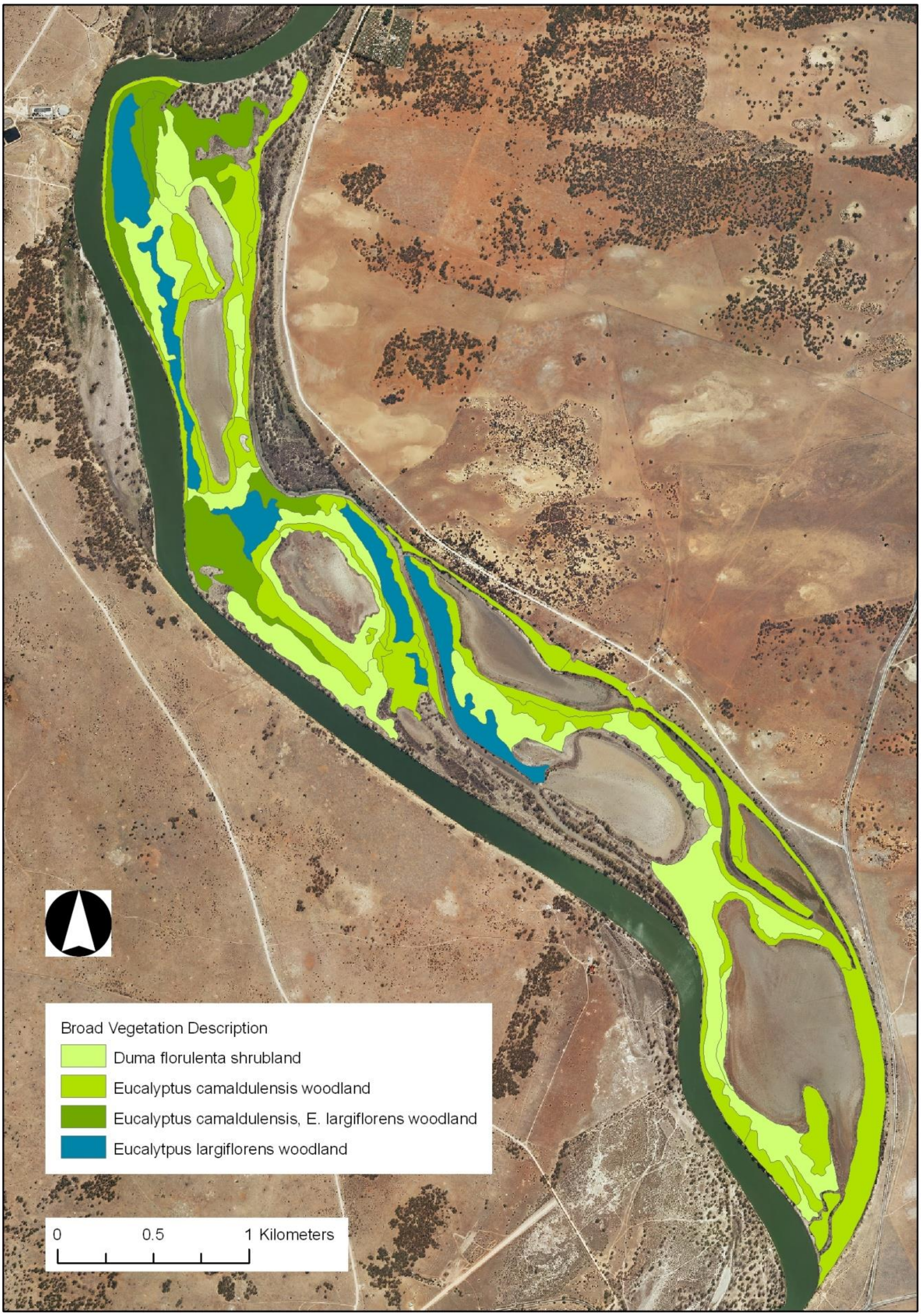

Figure 7. Map of the broad vegetation types at Sugar Shack Complex (source: Kloeden 2013).

Table 5. Plant species of conservation significance known to occur at Sugar Shack Complex.

Species	Common Name	Status*	Where Recorded	Source
Brachyscome basaltica var. *gracilis*	Swamp Daisy	SA(r), Region(r)	Damp margins of Wetland 2, Wetland 5, Wetland 7, Wetland 12 and Wetland 13	Kloeden (2013)
Callistemon brachyandrus	Prickly Bottlebrush	SA(r), Region(r)		Tesoriero and Mason (2012)
Calotis scapigera	Tufted Burr Daisy	SA(r), Region(r)	Damp margins of Wetland 2	Kloeden (2013)
Cotula vulgaris var. *australasica*	Slender Cotula	Region(r)	Damp margins of Wetland 10	AWE (2005)
Cullen australasicum	Tall Scurf-pea	Region(r)	Riverbank approx. 2 m above normal pool level E369226, N6181461 (GDA 1994 MGA Zone 54)	Aimee Linke, MMLAP, pers. com., Sept. 2013
Elatine gratioloides	Waterwort	SA(v)	Damp margins of Wetland 2, Wetland 5, Wetland 7, Wetland 12 and Wetland 13	Kloeden (2013)
Eragrostis australasica	Cane-grass	Region(r)	Floodplain adjacent Wetland 10	AWE (2005)
Lythrum salicaria	Purple Loosestrife	SA(r), Region(v)		Tesoriero and Mason (2012)

Species	Common Name	Status*	Where Recorded	Source
Maireana rohrlachii	Rohrlach's Bluebush	SA(r), Region(nt)	Floodplain NW of Wetland 10	AWE (2005)
Muehlenbeckia horrida ssp. *horrida*	Spiny Lignum	SA(r), Region(v)	50 m west of Wetland 10	AWE (2005)
Myoporum parvifolium	Creeping Boobialla	SA(r)	Between Wetland 10 and Yatco Creek	AWE (2005)
Picris squarrosa	Squat Picris	SA(r), Region(r)	NW of Wetland 10	AWE (2005)
Sclerolaena muricata var. *villosa*	Five-spine Bindyi	SA(r), Region(r)	Amongst Blackbox adjacent Wetland 10	AWE (2005)
Setaria jubiflora	Warrego Summer-grass	Region(r)	Floodplain adjacent Wetland 10	AWE (2005)
Stellaria palustris var. *tenella*	Swamp Starwort	SA(r), Region(e)		Tesoriero and Mason (2012)

*Status:

SA = rare or threatened with extinction within the state of South Australia and listed as such in the Schedules of the *National Parks and Wildlife Act 1972*.

Region = rare or threatened with extinction within the Murraylands region of South Australia and listed as such in Gillam and Urban (2010).

Codes:

e = endangered

v = vulnerable

r = rare

nt = near threatened (unofficial category)

2.6.5 Threatened fauna

Thirty-one fauna species of conservation significance have been recorded in the Sugar Shack Complex, as well as an additional eleven regarded as "near threatened" (Table 6). All of these species are wetland-dependent to varying degrees and affected by the condition of floodplain and wetland habitats.

Of particular note is the Regent Parrot (*Polytelis anthopeplus*), which is known to breed in the Complex. Nesting sites for this nationally vulnerable species are rare in the lower River Murray. Successful breeding requires large old hollow-bearing River Redgums, generally within 120 m of water, mallee woodlands within 20 km and ideally within 5 km of nest sites for foraging, and treed flight corridors between these two habitats (Baker-Gabb and Hurley 2011). The Sugar Shack Complex is located at the south-western edge of the known distribution of the species. The population of Regent Parrots occurring at the Complex is therefore considered an important population (DoE 2013).

Another notable threatened species of the Complex is the Southern Bell Frog (*Litoria raniformis*). This nationally vulnerable frog (*EPBC Act 1999*) was recorded in low abundance (<5 individuals) calling at two locations in Wetland 10 during the 2004 baseline survey (AWE 2005). Tadpoles of the species were recorded in Wetland 10 in November 2010. The species has not been detected at any other time within the Complex despite a number of frog monitoring surveys being conducted (see Section 4.6).

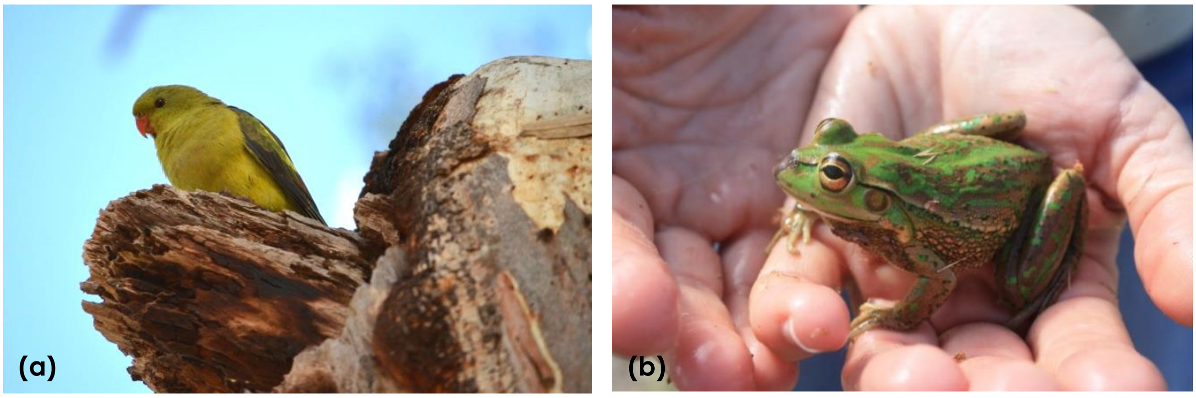

Figure 8. Two iconic threatened species of the lower River Murray known to occur at Sugar Shack Complex: (a) Regent Parrot (photo Irene Wegener) and (b) Southern Bell Frog (photo Callie Nicolai).

Table 6. Fauna species of conservation significance known to occur at Sugar Shack Complex.

Species	Common name	Status*	Where Recorded	Source
Mrayi (birds)				
Anas rhynchotis	Australasian Shoveler	SA(r), Region(r)	In vicinity of E372450, N6175964 (between Wetland 13 and River)	Michael Dolan, MMLAP, pers. com., Aug. 2013
Pelicanus conspicillatus	Australian Pelican	Region(nt)	In vicinity of E372450, N6175964 (between Wetland 13 and River)	Michael Dolan, MMLAP, pers. com., Aug. 2013
Tadorna tadornoides	Australian Shelduck	Region(nt)	In vicinity of E372450, N6175964 (between Wetland 13 and River)	Michael Dolan, MMLAP, pers. com., Aug. 2013
Threskiornis molucca	Australian White Ibis (Sacred Ibis)	Region(v)	In vicinity of E372450, N6175964 (between Wetland 13 and River)	Michael Dolan, MMLAP, pers. com., Aug. 2013
Porzana pusilla	Baillon's Crake	Region(cr)	Wetland 10	SA MDB NRM Board routine monitoring
Elseyornis melanops	Black-fronted Dotterel	Region(r)	Wetland 10	SA MDB NRM Board routine monitoring
Himantopus himantopus	Black-winged Stilt	Region(v)	In vicinity of E372450, N6175964 (between Wetland 13 and River)	Michael Dolan, MMLAP, pers. com., Aug. 2013
Oxyura australis	Blue-billed Duck	SA(r), Region(e)	Wetland 10	SA MDB NRM Board routine monitoring
Hydroprogne caspia	Caspian Tern	AUS(m), CAMBA, Region(r)	Wetland 10	SA MDB NRM Board routine monitoring

Species	Common name	Status*	Where Recorded	Source
Anhinga melanogaster	Darter	SA(r), Region(r)	Wetland 10	SA MDB NRM Board routine monitoring
Stagonopleura guttata	Diamond Firetail	SA(v), Region(e)		SA MDB NRM Board routine monitoring
Fulica atra	Eurasian Coot	Region(nt)	Wetland 10	SA MDB NRM Board routine monitoring
Petrochelidon ariel	Fairy Martin	Region(r)	In vicinity of E372450, N6175964 (between Wetland 13 and River)	Michael Dolan, MMLAP, pers. com., Aug. 2013
Stictonetta naevosa	Freckled Duck	SA(v), Region(v)	Wetland 10	SA MDB NRM Board routine monitoring
Plegadis falcinellus	Glossy Ibis	SA(r), Region(r)	Wetland 10	SA MDB NRM Board routine monitoring
Phalacrocorax carbo	Great Cormorant	Region(r)	Wetland 10	SA MDB NRM Board routine monitoring
Ardea alba	Great Egret	Region(v)	Wetland 10	SA MDB NRM Board routine monitoring
Aythya australis	Hardhead	Region(nt)	Wetland 10	SA MDB NRM Board routine monitoring
Poliocephalus poliocephalus	Hoary-headed Grebe	Region(nt)	Wetland 10	SA MDB NRM Board routine monitoring

Species	Common name	Status*	Where Recorded	Source
Ardea intermedia	Intermediate Egret	SA(r), Region(r)	In vicinity of E372450, N6175964 (between Wetland 13 and River)	Michael Dolan, MMLAP, pers. com., Aug. 2013
Phalacrocorax sulcirostris	Little Black Cormorant	Region(nt)	Wetland 10	SA MDB NRM Board routine monitoring
Egretta garzetta	Little Egret	SA(r), Region(r)	Wetland 10	SA MDB NRM Board routine monitoring
Megalurus gramineus	Little Grassbird	Region(nt)	Wetland 10	SA MDB NRM Board routine monitoring
Microcarbo melanoleucos	Little Pied Cormorant	Region(nt)	Wetland 10	SA MDB NRM Board routine monitoring
Biziura lobata	Musk Duck	SA(r), Region(v)	Wetland 10	SA MDB NRM Board routine monitoring
Nycticorax caledonicus	Nankeen Night-heron	Region(v)	Wetland 10	SA MDB NRM Board routine monitoring
Ardea pacifica	Pacific Heron	Region(r)	Wetland 10	SA MDB NRM Board routine monitoring
Phalacrocorax varius	Pied Cormorant	Region(r)	Wetland 10	SA MDB NRM Board routine monitoring
Erythrogonys cinctus	Red-kneed Dotterel	Region(r)	Wetland 10	SA MDB NRM Board routine monitoring

Species	Common name	Status*	Where Recorded	Source
Recurvirostra novaehollandiae	Red-necked Avocet	Region(r)	In vicinity of E372450, N6175964 (between Wetland 13 and River)	Michael Dolan, MMLAP, pers. com., Aug. 2013
Polytelis anthopeplus monarchoides	Regent Parrot	AUS(v), SA(v), Region(e)	River Redgums peripheral to Wetland 10	SA MDB NRM Board routine monitoring
Platalea flavipes	Yellow-billed Spoonbill	Region(v)	In vicinity of E372450, N6175964 (between Wetland 13 and River)	Michael Dolan, MMLAP, pers. com., Aug. 2013
Ma:mi (fish)				
Bidyanus bidyanus	Silver Perch	SA(e), Region (e)	Yatco Creek	Thwaites and Fredberg (2014)
Maccullochella peelii	Murray Cod	AUS(v), SA(e), Region (e)	Yatco Creek	Richard Hunter/Cynthia Hutchinson
Tandanus tandanus	Freshwater Catfish	SA(e), Region (e)	Yatco Creek	Thwaites and Fredberg (2014)
Macquaria ambigua ambigua	Golden Perch	SA(nt), Region (v)	Wetland 10 monitoring sites	SA MDB NRM Board routine monitoring
Melanotaenia fluviatilis	Murray-Darling Rainbowfish	SA(nt)	Wetland 10 monitoring sites	SA MDB NRM Board routine monitoring
Menpuri (Amphibians)				
Litoria raniformis	Southern Bell Frog	AUS(v), SA(v), Region(nt)	Wetland 10 fish monitoring sites	SA MDB NRM Board routine monitoring

Species	Common name	Status*	Where Recorded	Source
Reptiles				
Emydura macquarii	Macquarie Tortoise	SA(v), Region(nt)	Wetland 10	AWE (2005)
Chelodina expansa	Broad-shelled Tortoise	SA(v), Region(r)	Not recorded in the Complex but known to occur in this section of Murrundi	
Chelodina longicollis	Eastern (Common) Long-necked Tortoise	Region(nt)	Wetland 10	SA MDB NRM Board routine monitoring

*Status:

AUS = threatened with extinction in Australia or migratory and listed as such under the *Environment Protection and Biodiversity Conservation Act 1999*.
CAMBA = species protected under the China-Australia Migratory Bird Agreement.
SA = rare or threatened with extinction within the state of South Australia and listed as such in the Schedules of the *National Parks and Wildlife Act 1972* or for fishes Hammer *et al*. (2009).
Region = rare or threatened with extinction within the Murraylands region of South Australia and listed as such in Gillam and Urban (2010)
Codes:

cr = critically endangered
e = endangered
v = vulnerable
r = rare
m = migratory
nt = near threatened (unofficial category)

3. Threats to Sugar Shack Complex

3.1 Threats Addressed by this plan

3.1.1 Threats to Cultural Health

This plan aims to address threats resulting in poor cultural health consequences for Ruwe/Ruwar. Nganguraku and Ngaiawang are part of the Ngarrindjeri Nation, and Ngarrindjeri philosophy of Ruwe/Ruwar asserts that the lands, waters, body, spirit and all living things are connected and that this interconnection is fundamental to Ngarrindjeri wellbeing. To mitigate these threats, and to improve the cultural health of Murrundi, Ngarrindjeri are currently developing a Ngarrindjeri Yannarumi (cultural health) assessment process. Current strategies identified to mitigate threats to cultural health prioritise the following:

- The development and ongoing implementation of a Ngarrindjeri Yannarumi cultural health assessment
- Aboriginal heritage registration of the wetland as a 'site' under the *Aboriginal Heritage Act, SA 1988* as part of the Ngurunderi/Pondi Creation story.
- Aligning wetland management objectives with Ngarrindjeri cultural health objectives through ongoing liaison with DEWNR and further input into wetland management planning
- Conducting further Ngarrindjeri research into the importance of this part of the body of Murrundi.
- Recognition of Ngarrindjeri cultural interests in any environmental water licences associated with the Sugar Shack Complex.
- Ngarrindjeri (MACAI/SSAC) management of the Sugar Shack Complex in-line with improved cultural and ecological health.
- Ngarrindjeri training, economic development and employment developed to support Ngarrindjeri management of the Sugar Shack Complex – includes contracting for monitoring programs.

DEWNR will support Ngarrindjeri as part of their commitment under the KNY agreement to improve the cultural health of the wetland.

3.1.2 Threats created by the Millennium Drought

The Millennium Drought (1995 – 2009) led to unprecedented conditions in Murrundi in South Australia. By mid-2006 river flows were insufficient to offset evaporation in the lower River and Lower Lakes between Lock 1 and the Barrages, and flows were limited over weir one. As a consequence, river levels dropped well below normal pool level and all aquatic habitat within the Sugar Shack Complex dried completely for a continuous period of approximately 48 months between 2007 and 2010. A range of impacts resulted including a decline in the condition of mature River Redgums and a reduced abundance and diversity of a range of amphibious and aquatic biota (see Section 4). The value of the Complex as a meeting place for the local Aboriginal community was also significantly affected during this time, which reduced the site's ability to support community well-being and the intergenerational transfer of cultural knowledge and skills.

Although many are difficult to measure, a range of cultural and ecological health measures are likely still recovering from the extreme perturbation of the Millennium Drought. Tree health is one straightforward ecological measure for which pre-, during- and post-drought data exist. Tree health declined in response to the drought but has subsequently improved following the return of pool level (or higher) conditions in September 2010 (see Section 4.4). Other measures such as frog diversity and abundance and waterbird diversity and abundance do not appear to have recovered to pre-drought levels as yet, however waterbird abundance observed in Wetland 10 following the first managed drying event and subsequent refilling event in January 2014 exceeded pre-drought numbers.

Actions:

- Water management within the Sugar Shack Complex must be sensitive to the recovering nature of the ecosystem following the unprecedented perturbation of the Millennium Drought.

3.1.3 Stable, unnaturally high water levels

River regulation has greatly reduced water level fluctuations in Murrundi. The barrages typically hold water levels at 0.75 mAHD. Although some water level fluctuations do occur, outside of flood events levels typically remain within the range 0.45 – 1.05 mAHD (DEWNR 2012a, DEWNR 2014b). Water levels within this range never fall to the very low levels (possibly as low as 0.0 mAHD) that would have occurred pre-regulation. Additionally, because fluctuations in water level are typically caused by wind setup (DEWNR 2012a), water levels below pool level are usually short term (days) rather than the extended periods of disconnection (months) that likely characterised wetland hydrology pre-regulation (Robinson 2013). As a consequence, many wetlands that would have dried regularly, either partially or completely, under pre-regulation conditions are now permanently inundated. This change has likely been further exacerbated by the artificial lowering of most wetland sills in the Sugar Shack Complex. Relatively stable, unnaturally high water levels and the absence of a dry phase cause a number of ecological problems (DEWNR 2012a):

- a narrowing and reduced diversity of wetland littoral zone vegetation, which in itself leads to secondary impacts including:
  - reduced habitat extent and quality for cryptic waterbirds;
  - reduced habitat extent and quality for native fish;
  - reduced habitat extent and quality for frogs;
- reduced wetland productivity;
- reduced habitat extent and quality for wading birds;
- unconsolidated sediments, which can increase turbidity, reduce light penetration and reduce the diversity and abundance of submerged aquatic vegetation;
- decline in tree health due to permanent waterlogging of the root zone of trees located at or near pool level.

Actions:

- install structures to enable the regulation of flows between Murrundi main channel and permanently inundated floodplain wetlands. Operate structures to recreate pre-regulation wetland water regimes as closely as possible.

3.1.4 Restrictions to flow and fish passage in anabranch habitat

River regulation has converted Murrundi into a series of weir pools within which the water surface is relatively flat from upstream to downstream most of the time. As a consequence, flow rates within anabranches have been reduced because the water level difference between upstream and downstream ends of these features has been reduced. Exceptions occur where an anabranch straddles two weir pools, for example Pike River. However, overall the extent of fast flowing anabranch habitat in Murrundi has been greatly reduced (Bice *et al.* 2013).

Flowing (lotic) waters are favoured over still (lentic) waters by a number of culturally and ecologically important species that have declined in Murrundi including some large-bodied native fish species (DEWNR 2012a), the River Mussel (*Alathyria jacksoni*) and the Murray crayfish (*Euastacus armatus*) (Walker 1981, Walker 1985).

The anabranches of the Sugar Shack Complex, Yatco Creek and its offshoot, have both their inlet and outlet within the Barrages weir pool. Due to the relatively long distance between the inlet and outlet of this anabranch system, 9 river km in total, the water level difference between upstream and downstream ends is regularly sufficient to generate flows. However, there are two causeways across these creeks that restrict flow due to the inadequate capacity of their associated culverts. Both currently feature pipe culverts of approximately 900 mm diameter and 4 m length. In addition to restricting flow, these culverts may also act as barriers to upstream fish passage due to high flow velocities, lack of resting habitat for fish and lack of light penetration.

Actions:

- Upgrade causeways with culverts featuring:
    - sufficient capacity to not restrict flows; and
    - appropriate flow velocity, fish resting habitat and light penetration to maximise potential fish passage.

3.1.5 Reduced flood frequency: impacts upon temporary wetlands

The Sugar Shack Complex features a number of temporary wetlands (see Section 2.5), i.e. wetlands with a sill elevation above typical pool level that are therefore typically dry. River regulation, by reducing the frequency of floods in lower Murrundi, has greatly reduced the frequency of inundation of these basins. As a consequence, the ecology of temporary wetlands has changed in a number of ways:

- the vegetation of temporary wetlands has likely "terrestrialised" (see DEWNR 2012a);
- habitat for aquatic fauna, e.g. frogs, waterbirds, turtles has likely been degraded or lost; and
- tree health around the margins of these basins is likely to have declined.

The reinstatement of a more natural water regime to temporary wetlands in the Complex would:

- reverse the process of terrestrialisation, leading to an increase in amphibious and aquatic plants, potentially including culturally important species (e.g. Yalkari (*Cyperus gymnocaulous*)) and threatened species;

- restore or reinstate lost habitat for aquatic fauna including frogs, waterbirds and turtles and likely increase the abundance of such fauna, with cultural and ecological benefits; and

- improve tree health around the margins of such wetlands.

At workshops to develop this Plan the MACAI nominated two temporary wetlands of the Complex for water regime restoration; Wetlands 1 and 3. It was thought that other temporary wetlands of the Complex, i.e. Wetlands 6, 8, 9 and 15, are inundated with sufficient frequency under current arrangements.

The frequency and duration of connection between Murrundi main channel and Wetlands 1 and 3 under natural (pre-regulation) conditions has been determined by the Robinson model (Robinson 2013) and is shown in Appendix 5. This information provides a guide to water management in these basins.

The Basin Plan for the Murray-Darling Basin may increase the frequency of floods in lower Murrundi, however it is several years away from full implementation and, even when fully implemented, will not restore a natural flow regime to the River. Weir pool manipulation is another tool to restore a more natural pattern of river stage fluctuations, however this approach has logistical difficulties, particularly in the Barrages weir pool. The only way to reinstate a natural frequency of inundation to temporary wetlands at Sugar Shack Complex is to artificially pump water into these areas. This provides reduced ecological benefits compared to natural flooding for a variety of reasons including limitations to the exchange of materials and biota between the wetlands and the main channel, and pumping has its own ecological risks (see Wallace *et al.* 2011). However, if artificial pumping is carefully managed, the ecological benefits described above are anticipated to occur

Actions:

- Regularly pump water into the three temporary wetlands nominated by MACAI, Wetlands 1, 3 and 6, to mimic the natural (pre-regulation) water regime of these areas.

3.1.6 Exotic Ma:mi

The exotic ma:mi (fish) species Common Carp (*Cyprinus carpio*), Eastern Gambusia (*Gambusia holbrooki*), Redfin Perch (*Perca fluviatilis*), Goldfish (*Carassius auratus*) and Oriental Weatherloach (*Misgurnus anguillicaudatus*) have all been recorded in Sugar Shack Complex wetlands (Tesoriero and Mason 2012, Thwaites and Fredberg 2014). Large, adult Carp in particular have a range of deleterious ecological impacts that can be minimised by the installation of carp screens in association the wetland regulators, and the inclusion of complete dry phases into the target hydrograph (DEWNR 2012a). Carp screens do not exclude juvenile Carp from wetlands, therefore a complete dry phase leads to only a temporary (1 – 2 year) absence of large-bodied, adult Carp. Research indicates that juvenile Carp of a size able to pass through carp screens are approximately two years from sexual maturity (Brown *et al.* 2005). Complete drying of wetlands every two to three years will help reduced Carp breeding within wetlands and reduce the abundance of large-bodied adults.

Oriental Weatherloach (*Misgurnus anguillicaudatus*) were detected at Sugar Shack Complex for the first time in March 2014, with two juveniles captured during monitoring in Wetland 10 (K. Mason, SA MDB NRM Board, pers. com.). Although little is known about the impacts of this species, it has significant dietary overlap with some native species, may predate upon the eggs of native species, carries a range of parasites not previously recorded from Australia, can depress macroinvertebrate numbers, and increase turbidity and nitrogen levels (Lintermans 2007).

Actions:

- Include two dry phases in the 5 year target hydrograph for all managed wetlands to extirpate large-bodied Common Carp.

- Include carp screens on regulators to prevent the immigration of large-bodied Common Carp into refilling wetlands.

3.1.7 Kanatji (Fox)

Kanatji (European Red Fox, *Vulpes vulpes*) are present at Sugar Shack Complex and have been identified as causing impacts to a range of culturally and ecologically significant species (Mooney and Tan 2010). Kanatji are known to prey on waterbirds (Scott 1997) and have been found to take over 93% of Thukubi (Macquarie Tortoise) and Malinthaipari (Long-necked Tortoise) eggs along Murrundi in South Australia (Thompson 1983). They are a major predator of Valaki (Carpet Python (*Morelia spilota*)) (Treilibs 2006). Reducing fox abundance and maintaining low levels via management would have benefits for the local populations of these and other native fauna.

Action:

- Develop and implement a Fox control program throughout the Complex that is coordinated with fox management at the district-scale.

3.1.8 Rabbits

Rabbits (*Oryctolagus cuniculus*) are known to occur at Sugar Shack Complex. Rabbit populations can increase rapidly under favourable conditions leading to degradation of native vegetation. The health of the river-floodplain ecosystem at Sugar Shack depends upon the maintenance of a low abundance of rabbits via management.

Action:

- Develop and implement a Rabbit control program throughout the Complex that is coordinated with Rabbit management at the district-scale.

3.1.9 Domestic Stock

Both the long and short-term negative impacts of domestic stock on vegetation and soil condition at Wetland 10 were identified in the initial baseline survey (AWE 2005). Although the SSAC have reduced the stocking rate on the property and have fenced Wetland 10, domestic stock, specifically cattle (*Bos taurus*) and goats (*Capra aegagrus hircus)*, will continue to be a threat to the wetland and floodplain and will require careful management into the future.

Wetland habitats are particularly susceptible to damage via the grazing and trampling activities of livestock. Grazing has been shown to change wetland seedbanks and the composition of wetland vegetation through time (Jutila 1998, Jutila 2001, Nicol *et al.* 2007). Grazing of juvenile macrophytes can reduce above ground biomass (Hayball and Pearce 2004) with implications for the structure of fringing emergent vegetation and its suitability as habitat for fauna such as cryptic waterbirds. During drawdown the changing conditions lead to the germination and establishment of plants adapted to the dry phase of the hydrological cycle and also to the clonal expansion of fringing macrophytes down the elevation gradient (DEWNR 2012a). Livestock grazing may interfere with this response of the vegetation to drying and reduce the benefits of drying (DEWNR 2012a).

Recently germinated or established plants may be more susceptible to damage because livestock may remove the entire plant, rather than removing a part of a larger plant. Damp, exposed sediment can be pugged by livestock, leading to poor water quality, particularly high turbidity, upon subsequent re-inundation. Additionally, the inundation of livestock manure that has accumulated on a wetland bed during the dry phase may lead to eutrophication and associated algal blooms (Croel and Kneitel 2011). During the wet phase, if submerged aquatic plants establish, these are particularly susceptible to damage by cattle, which wade into deep water and may dislodge entire plants from soft sediments.

Action:

- Construct new fencing to exclude domestic livestock from managed wetlands.
- Maintain as fit for purpose all existing and proposed fencing within the Complex on an ongoing basis.

3.1.10 Pest Flora

The Sugar Shack Complex appears to be completely free of Weeping Willow (*Salix babylonica*), a major weed of permanent watercourses in the SAMDB. Declared weeds such as Prickly Pear (*Opuntia* spp.) and African Boxthorn (*Lycium ferocissimum*) are present but in low abundance. It is important for both cultural and ecological reasons that these and other exotic large shrub and tree species be prevented from establishing and/or proliferating within the Complex. A number of smaller exotic herbs, grasses and small shrubs are present, several in very high abundance (e.g. Stinkwort, *Dittrichia graveolens*). Control of these species presents considerable challenges and may be of limited ecological benefit. For further information regarding weed management on the Sugar Shack see Barron (2008).

During wetland drying events it is anticipated that dry phase plant species will establish upon exposed wetland beds. It is possible that the dry phase plant community will be dominated by exotic herbs and grasses, in terms of both species richness and total biomass. This need not trigger a management response. The re-inundation of dry phase vegetation will cause most of these plants to die and decompose, providing a productivity boost to the aquatic ecosystem. The productivity boost is a key benefit of wetland drying and will occur irrespective of the native/exotic status of dry phase vegetation. In time, dry phase vegetation may become more native-dominated as native species secure a greater proportion of the propagule bank within the sediments of managed wetlands.

Action:

- Develop and implement a pest flora control program throughout the Complex.

3.2 Threats Beyond the Scope of This Plan

3.2.1 Reduced Flood Frequency: Impacts upon Floodplain Habitat

The reduction in flood frequency, level and duration at Sugar Shack Complex is a consequence of the upstream impoundment and diversion of water. Floods are fundamental to the health of the riverine ecosystem (Junk *et al.* 1989, Walker and Thoms 1993). Departures from the natural flooding regime can have impacts upon tree health, vegetation condition, tree recruitment, fish recruitment, and indeed virtually all aspects of the riverine ecosystem.

Possible Actions:

- Enactment of a Murray-Darling Basin Plan that returns flows to lower Murrundi sufficient to restore flood frequency, level and duration to a degree that maintains the riverine ecosystem over the long term.

- Development of a barrage operating strategy that aims to manage water levels in lower Murrundi in a way that mimics natural seasonal fluctuations.

- The minimisation of climate change, which is likely to lead to increased temperature, reduced rainfall and thus reduced runoff in the Murray-Darling Basin (Hobday and Lough 2011), via global Greenhouse gas emission reductions.

4. Ecological Monitoring Results

4.1 Overview

A range of biotic and abiotic parameters have been measured and/or monitored at Sugar Shack Complex by the SAMDB NRM Board with assistance from the SSAC since implementation of the first Management Plan in 2006. This monitoring has focussed on measuring the outcomes of management of Sugar Shack Pangki (Wetland 10), the only wetland subject to hydrological management during that period. Monitoring locations for all parameters for this ongoing SAMDB NRM Board monitoring program are shown in Figure 9. Additionally, DEWNR commissioned baseline flora and fauna surveys of the greater Sugar Shack Complex as part of the MRP. These baseline surveys focussed on the unmanaged wetlands and were undertaken in early 2013. A summary of monitoring undertaken to date, including both SAMDB NRM Board ongoing monitoring and DEWNR MRP baseline surveys, is presented in Table 7.

Ngangurаku and Ngaiawang's (being part of the Ngarrindjeri Nation) understanding of baseline data is that which exists as a result of many generations of occupation, use, management and care, passed down by Ngarrindjeri Creation ancestors. Ngarrindjeri were not engaged in the collection and collation of baseline survey data for much of the information that has informed this wetland management plan.

Through the first stage of the Ngarrindjeri Yannarumi cultural health assessment process Ngarrindjeri will determine the processes needed for Ngarrindjeri to be involved in all aspects of management and planning, including wetland monitoring and developing baselines that are more aligned with Ngarrindjeri understandings of their lands and waters. This creates a case study that can "provide end users with additional guidance on managing and assessing water quality in a manner that accounts for indigenous cultural and spiritual values. (Collings 2012) DEWNR will support Ngarrindjeri, as part of their commitment under the KNY agreement, to improve the cultural health of the wetland.

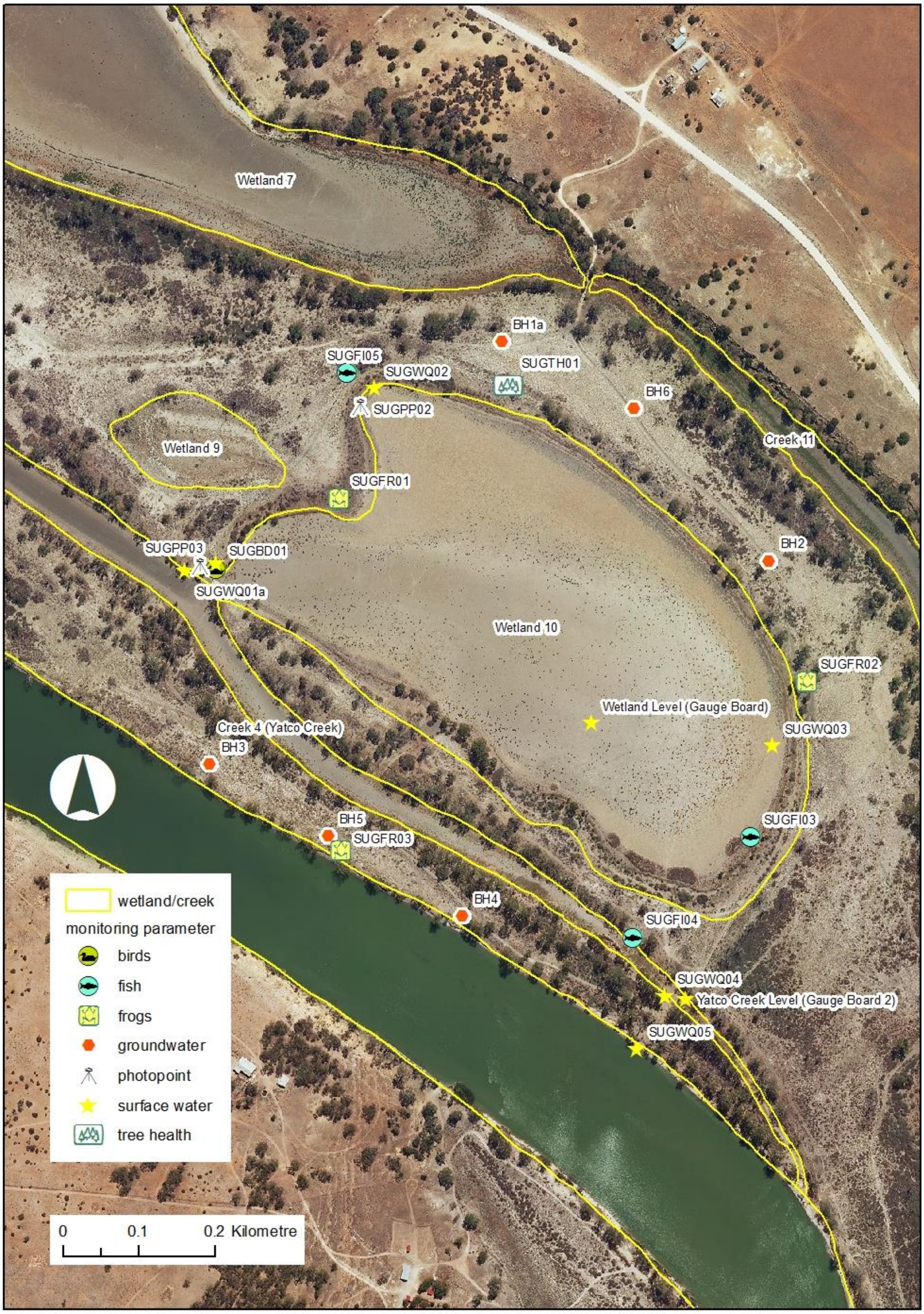

Figure 9. Location of SAMDB NRM Board monitoring at Sugar Shack Complex.

Table 7. Summary of previous and ongoing biotic and abiotic monitoring at Sugar Shack Complex.

Parameter	Project	Location(s)	Frequency and Timing	Responsibility Of	Data Custodian
FAUNA					
Regent Parrot active nest abundance and flight path assessment	Regent Parrot Recovery Project	Entire Sugar Shack Complex	Biannual in spring	Regent Parrot Recovery Team	DEWNR
Fish abundance and species richness	SAMDBNRMB Ongoing	Wetland 10 (2 locations) Yatco Creek (1 location)	Twice annually in March and October	SAMDBNRMB	SAMDBNRMB
	MRP Baseline	Wetland 13 (3 locations) Wetland 7 (3 locations) Wetland 2 (3 locations)	April – May 2013, October 2013	DEWNR Major Projects	DEWNR Major Projects
Frog abundance and species richness	SAMDBNRMB Ongoing	Wetland 10 (2 locations)	Twice annually in September and November	SAMDBNRMB	SAMDBNRMB
Waterbird abundance and species richness	SAMDBNRMB Ongoing	Wetland 10 (2 transects)	Annually in September	SAMDBNRMB	SAMDBNRMB
	MRP Baseline	Wetland 2 (southern half) Wetland 5 Wetland 7 Creek 11 Wetland 12 Wetland 13	Feb – March 2013	DEWNR Major Projects	DEWNR Major Projects
Bush bird abundance and species richness	SAMDBNRMB Ongoing	In vicinity of Wetland 10	Opportunistic	SAMDBNRMB	SAMDBNRMB
	MRP Baseline	Within 100m of the edge of: Wetland 2 (southern half) Wetland 5 Wetland 7 Creek 11 Wetland 12 Wetland 13	Feb – March 2013	DEWNR Major Projects	DEWNR Major Projects

Parameter	Project	Location(s)	Frequency and Timing	Responsibility Of	Data Custodian
FLORA					
Tree Condition	SAMDBNRMB Ongoing	Wetland 10 (10 trees)	Variable, typically twice yearly in February and November	SAMDBNRMB	SAMDBNRMB
	MRP Baseline	Wetland 2 (35 trees) Wetland 5 (30 trees) Wetland 7 (25 trees) Wetland 12 (9 trees) Wetland 13 (37 trees)	March 2013	DEWNR Major Projects	DEWNR Major Projects
Vegetation photopoints	SAMDBNRMB Ongoing	Wetland 10 (3 photopoints)	Four times annually in January, April, July and October.	SAMDBNRMB	SAMDBNRMB
Quantitative Vegetation Monitoring	SAMDBNRMB Ongoing	Wetland 10 (3 transects, 1 quadrat)	Annually in November	SAMDBNRMB	SAMDBNRMB
Gradient Based Quantitative Assessment	MRP Baseline	Wetland 2 (9 transects) Wetland 5 (9 transects) Wetland 7 (6 transects) Wetland 12 (3 transects) Wetland 13 (9 transects)	March 2013	DEWNR Major Projects	DEWNR Major Projects
Vegetation Community Mapping	MRP Baseline	Most of the floodplain above typical pool level	March 2013	DEWNR Major Projects	DEWNR Major Projects
ABIOTIC PARAMETERS					
Groundwater elevation	SAMDBNRMB Ongoing	Wetland 10 (6 piezometers)	4 times annually in Jan, Apr, Jul and Oct	SAMDBNRMB	SAMDBNRMB
Groundwater salinity	SAMDBNRMB Ongoing	Wetland 10 (6 piezometers)	4 times annually in Jan, Apr, Jul and Oct	SAMDBNRMB	SAMDBNRMB
Surface water elevation	SAMDBNRMB Ongoing	Wetland 10 (1 gaugeboard)	4 times annually in Jan, Apr, Jul and Oct	SAMDBNRMB	SAMDBNRMB

Parameter	Project	Location(s)	Frequency and Timing	Responsibility Of	Data Custodian
Surface water quality (EC, pH, NTU, DO, °C)	SAMDBNRMB Ongoing	Wetland 10 (3 locations) Yatco Creek (2 locations) River Murray main channel (1 location)	4 times annually in Jan, Apr, Jul and Oct	SAMDBNRMB	SAMDBNRMB
	MRP Baseline (collected during fish monitoring)	Wetland 13 (3 locations) Wetland 7 (3 locations) Wetland 2 (3 locations)	April – May 2013, October 2013	DEWNR Major Projects	DEWNR Major Projects

4.2 Surface Water Quality

Surface water quality monitoring at Sugar Shack Complex to date has been undertaken by the SAMDB NRM Board in collaboration with the MACAI. Monitoring has been focused in and around the currently managed Wetland 10. Since 2010 regular surface water quality monitoring has occurred at Wetland 10 (monitoring site codes SSWQ1b, SSWQ2, SSWQ3) and adjacent sites on Yatco Creek (SSWQ1a, SSWQ4) and Murrundi main channel (SSWQ5) (Figure 9). Surface water quality measurements were undertaken at additional sites throughout the Complex in April/May 2013 and October 2013 as part of baseline fish monitoring for the MRP. Under this Plan, surface water quality monitoring, and monitoring generally, is proposed to be expanded to support the long term adaptive management of the Complex as a whole (see Section 5.7, page 106).

4.2.1 Salinity

Surface water salinity is assessed using the surrogate measure of electrical conductivity (EC), utilising the units microsiemens per centimetre (µS/cm). The salinity of surface water has a strong influence on the character and condition of aquatic ecosystems (Hart *et al.* 1991, Hart *et al.* 2003, Nielsen *et al.* 2003). EC is expected to vary predictably during the wetting and drying phases of a wetland. Lower surface water EC, reflecting EC in the River, is expected when regulators are open and wetlands are full and connected to the River. EC is anticipated to increase as wetland water levels fall following the closure of inlet regulators, due to the evapo-concentration of salt. This is a natural phenomenon. Inputs of groundwater derived salt into a disconnected wetland can also elevate surface water EC. Again, this is a natural phenomenon, however it may be exacerbated if a saline groundwater table is elevated due to land use changes, such as irrigated horticulture on high ground adjacent to the floodplain (MDBA 2010b). Although this appears to be a low risk at Sugar Shack Complex, the monitoring of surface water EC is undertaken to inform management.

Salinity monitoring to date has focussed on Wetland 10. Prior to the construction of the regulator, surface water EC was measured on four occasions in 2003/2004 (AWE 2005). No obvious trend was observed with salinity ranging between 678 and 1090 µs/cm. The highest result of 1090 µs/cm was recorded in March 2004.

Since 2010 regular EC monitoring has occurred at Wetland 10 (monitoring site codes SSWQ1b, SSWQ2, SSWQ3) and adjacent sites on Yatco Creek (SSWQ1a, SSWQ4) and Murrundi main channel (SSWQ5) (Figure 9). These data are presented in Figure 10. During this period, and at times when the wetland has been connected to Yatco Creek and the river, EC has generally been marginally higher in Wetland 10 (185 to 670 µs/cm) than in Yatco Creek (145 to 597 µs/cm), and higher in Yatco Creek than in the Murrundi main channel (131 and 480 µs/cm). These data suggest that surface water EC increases as it flows through the Sugar Shack Complex, although the increase is relatively minor and EC remains low.

Surface water EC was higher than previously recorded during the flood of mid-2011, when river levels peaked at 3.09 mAHD, and again in early 2012, when levels peaked at 2.17 mAHD. These peaks in EC are likely due to the mobilisation of salts from floodplain soils. As river levels receded surface water EC decreased. In May 2012, immediately following the flood, EC was very similar in the wetland, creek and River, ranging between 258 and 267 µs/cm.

On 15 March 2013 the regulator was closed and Wetland 10 was disconnected from Yatco Creek; the commencement of the first managed drying event at Sugar Shack Complex. By 10 January 2014 a near complete drying of the wetland had occurred and the regulator was opened and the wetland refilled. During disconnection surface water EC in Wetland 10 increased (Figure 10), likely due to the evapoconcentration of salt. Following refilling EC in the wetland dropped rapidly but as at June 2014 was yet to fall to its pre-drying level. Through mid-2014 wetland EC remained relatively constant at approximately 550 µs/cm, whereas prior to the managed drying event it had typically been approximately 350 µs/cm. However river EC has at times also been marginally higher post-refilling and the difference between river and Wetland 10 EC has not changed markedly post-refilling. It is anticipated that surface water EC in Wetland 10 will gradually return to its pre-drying level but will remain marginally higher than river EC.

In late April/early May 2013 surface water EC measurements were taken during MRP baseline fish surveys at three other wetlands within the Sugar Shack Complex (Thwaites and Fredberg 2014). These wetlands had marginally higher ECs than Wetland 10 at the same time. Data for these wetlands were:

- Wetland 7: 570 µs/cm;
- Wetland 2: 480 µs/cm; and
- Wetland 13: 485 µs/cm.

Wetland 7 is situated on the floodplain edge, further from the River than the other wetlands. The slightly higher salinity in this wetland may suggest a positive correlation between distance from the River and rate of salt input to surface water at Sugar Shack Complex. However, even if such a relationship exists, it appears to have only a weak effect upon surface water salinity.

In summary, surface water salinities of waterbodies within the Sugar Shack Complex generally reflect salinity in the River, but are often slightly higher than the river. The risk of excessive inputs of salt from groundwater appears to be low under current management Surface water salinity monitoring will remain a priority under the new management proposals herein.

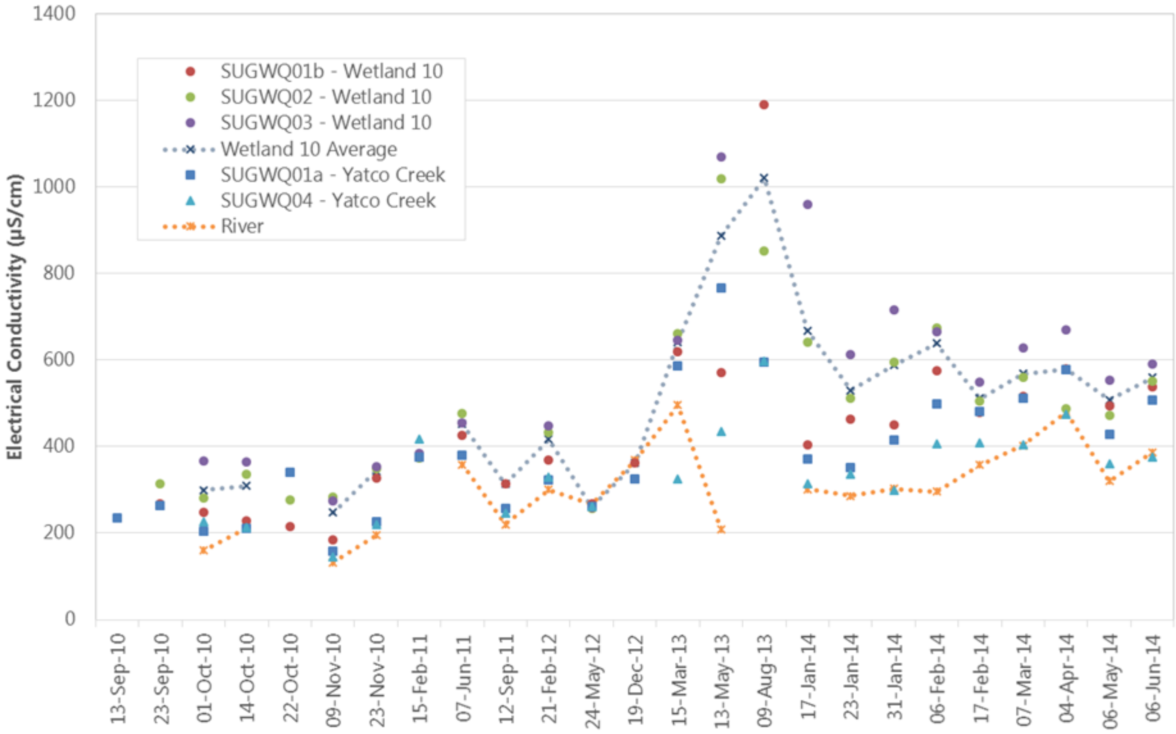

Figure 10. EC in and around Wetland 10, Sept. 2010 to June 2014 (Note that the time axis is not to scale).

4.2.2 Turbidity

Turbidity is a measure of the cloudiness of water due to suspended particles and has an important influence on light penetration and thus rates of primary production in aquatic ecosystems. Turbidity is a significant driver of biota in various types of Lower River Murray wetlands including permanent lakes, temporary wetlands and floodplains (Souter 2009). Baseline surveys show that the turbidity of permanently inundated lower Murrundi wetlands is quite variable, but typically high, with a mean value of 114 NTU (Nephelometric Turbidity Units), and can reach extreme values (>400 NTU; Blanch *et al.* 1999). The euphotic depth of a waterbody is the depth above which light penetration is sufficient for net photosynthesis and thus growth of photosynthetic organisms is possible (Moss 1988). Turbidity greater than 250 NTU generally equates to a euphotic depth of only a few centimetres.

The reintroduction of drying regimes to wetlands is anticipated to increase the abundance of submerged aquatic plants, in part due to reduced turbidity. By allowing wetland sediments to dry and consolidate, turbidity is anticipated to be lower upon rewetting than it would be under static, permanent inundation (DEWNR 2012a). A positive feedback as then established as aquatic plants reduce the resuspension of sediments upon rewetting, thereby helping maintain a lower turbidity and facilitating further increases in aquatic plant cover (DEWNR 2012a). Additionally, drying is also anticipated to reduce the abundance of Common Carp in wetlands, albeit temporarily, and therefore lead to reduced bioturbation and reduced turbidity (DEWNR 2012a). These links between turbidity, management actions and management objectives make necessary the monitoring of turbidity.

The baseline survey of Wetland 10 in 2003/2004 recorded turbidity between 190 and 700 NTU. Turbidity was initially highest during December 2003, during a period of high river flows, and decreased as flows receded. As the wetland dried following disconnection in September 2006, turbidity increased. Likely causes were wind action, shoreline disturbance by stock and an increase in phytoplankton abundance. Large numbers of Common Carp were captured in the wetland at this time, which likely also contributed to a high turbidity.

Since 2010, regular turbidity monitoring has occurred at Wetland 10 (monitoring site codes SSWQ1b, SSWQ2, SSWQ3) and adjacent sites on Yatco Creek (SSWQ1a, SSWQ4) and Murrundi main channel (SSWQ5) (Figure 9). These data are presented in Figure 11. During the first two months of re-inundation (September, October 2010), wetland turbidity was generally low (8.6 – 46 NTU) in areas furthest from the inlet (SSWQ2 and SSWQ3), even though incoming flows from the river and Yatco Creek were higher (75 – 116 NTU) (Figure 11). The consolidated sediments and sheltered aspect of these locations likely influenced the results. By November 2012 high river levels were observed and turbidity within the Creek and Murrundi ranged between 210 and 271 NTU. Wetland turbidity during this time had increased to between 66.8 and 109.3 NTU. Turbidity results across monitoring sites had decreased and became more uniform when high flows declined.

Extremely high turbidity was observed during February 2012 ranging between 321 and 551 NTU in the wetland and 220 and 309 NTU in the creek and river. This was due to a high abundance of cyanobacteria (blue-green algae) in the water column. The highest result of 551 was observed at SSWQ2, located on the sheltered northern side of the wetland where cyanobacteria were concentrated. By May 2012 turbidity had reduced to 46.1 to 65.3 NTU within the wetland.

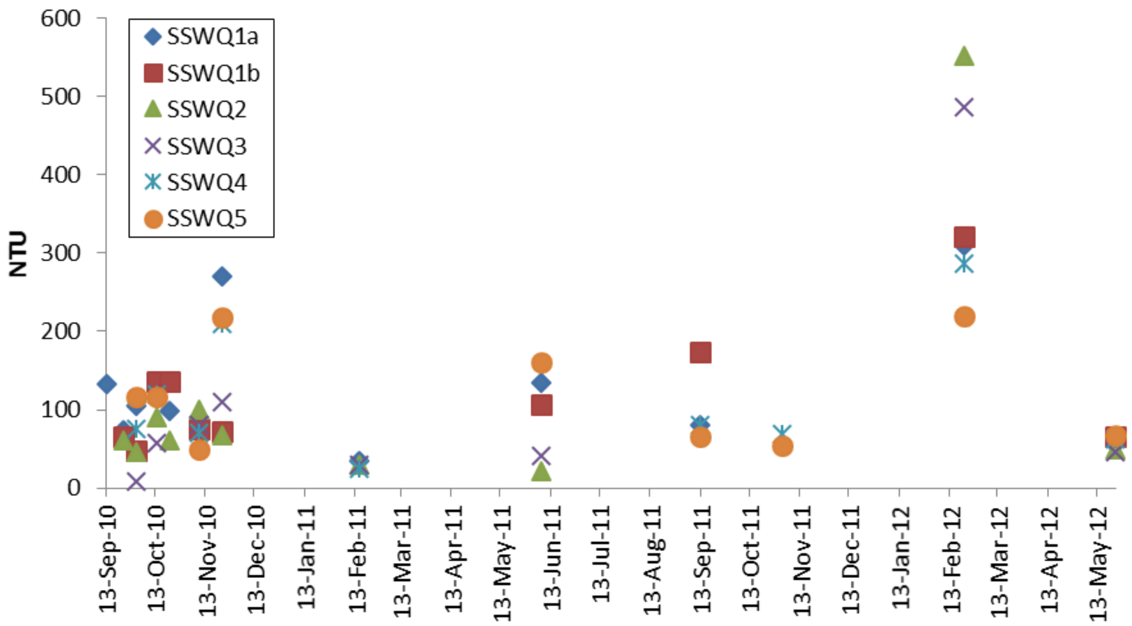

Figure 11. Turbidity in and around Wetland 10, Sept. 2010 to May 2012.

4.2.3 Dissolved Oxygen

Aquatic organisms, including both plants and animals, require oxygen. The concentration of dissolved oxygen (DO) in a waterbody must remain adequate for the needs of resident organisms. The mass death of aquatic organisms, e.g. mass fish deaths, can result if DO falls too low (Tucker *et al.* 2003, Baldwin *et al.* 2005). DO typically displays a daily pattern, being lowest in the early morning and highest in the mid afternoon as a result of the photosynthetic activities of aquatic plants and algae (Tucker *et al.* 2003). DO levels typically fall between 7-10 mg/L depending on surface water temperature, with colder water able to contain more DO (Baldwin *et al.* 2005). Most fish species (even juveniles) can tolerate DO levels as low, or possibly lower than 3 mg/L for short periods (McNiel and Closs 2007). However, persistently low DO levels are a cause of concern for management.

The reinstatement of wetting and drying regimes in wetlands has implications for DO. The rewetting of a wetland following a dry phase can result in low DO due to the decomposition of plant material that has grown or accumulated on the wetland bed during the dry phase (DEWNR 2012a). Due to its importance to aquatic biota and its potential to be influenced by management, dissolved oxygen is a parameter that is monitored at Sugar Shack Complex.

Since 2010, regular DO monitoring has occurred at Wetland 10 (monitoring site codes SSWQ1b, SSWQ2, SSWQ3) and adjacent sites on Yatco Creek (SSWQ1a, SSWQ4) and Murrundi main channel (SSWQ5) (Figure 9). These data are presented in Figure 12. DO levels were highly variable during the first months after re-wetting between September and November 2010. These results were likely influenced by the preceding extended dry period. In October 2010, DO levels fell as low as 0.49 mg/L in Wetland 10 (Figure 12). However levels did not persist this low for long and subsequently returned to levels more typical and favourable for aquatic organisms.

Occasionally low DO is possible in wetlands under the management regime proposed in this Plan. In the latter stages of a drying event, when water levels are low and temperature possibly high, low DO would be expected, with potentially deleterious effects upon fish and other biota. Similarly, low DO levels are possible when dry wetland beds are re-wetted. These low DO events are likely to have occurred under natural wetting and drying patterns. It is persistently low DO at unexpected times that may suggest a change to the management regime is required.

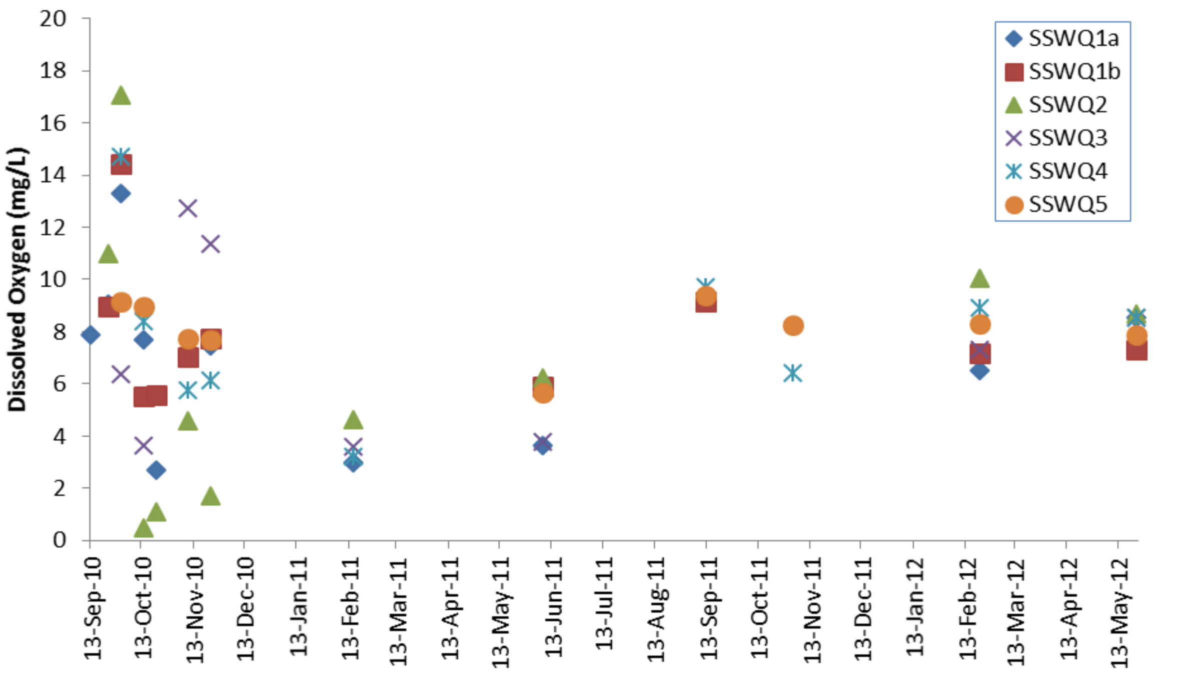

Figure 12. Dissolved oxygen in and around Wetland 10, Sept. 2010 to May 2012.

4.2.4 pH

Surface water pH is a measure of the acidity or alkalinity of water. Typically, surface water pH ranges between 6 and 9. Outside of this range pH may indicate unusual processes occurring within a wetland (Baldwin *et al.* 2005). Higher surface water pH may be recorded as a result of abundant aquatic macrophyte growth (Cronk and Fennessy 2001). Surface water pH may also be increased through some bacterial processes (Baldwin *et al.* 2005). Low pH may be caused by high organic loads, bacterial processes or the oxidisation of sulfidic sediments (Baldwin *et al.* 2005). The latter process occurs when acid sulphate soils (ASS) that have been permanently submerged become exposed and subsequently re-wetted. Highly acidic surface water harmful to aquatic biota can result (Fitzpatrick *et al.* 2009b). This phenomenon has occurred in Murrundi wetlands and lakes both upstream and downstream of Sugar Shack Complex (e.g. McCarthy *et al.* 2002, Fitzpatrick *et al.* 2009a). The Sugar Shack Complex appears to be a low risk area in relation to acid sulphate soils because the extended drying event of the Millennium Drought was not followed by low pH upon re-wetting of the wetlands of the Complex. However, pH is a simple parameter to measure and it is prudent to include it in ongoing monitoring.

Since 2010, regular pH monitoring has occurred at Wetland 10 (monitoring site codes SSWQ1b, SSWQ2, SSWQ3) and adjacent sites on Yatco Creek (SSWQ1a, SSWQ4) and Murrundi main channel (SSWQ5) (Figure 9). These data are presented in Figure 13. Following wetland refill due to increased River levels in 2010, wetland surface water pH has generally followed that of pH within Yatco Creek and the River. Within the wetland, pH has ranged between 6.76 and 9.31 and between 5.58 and 8.48 within Yatco Creek and the River combined. The highest pH result of 9.31 was recorded in October 2010 as water levels were rising and inundating parts of the floodplain. Generally, the results obtained during this period have remained within the range expected and optimal for aquatic ecosystem health.

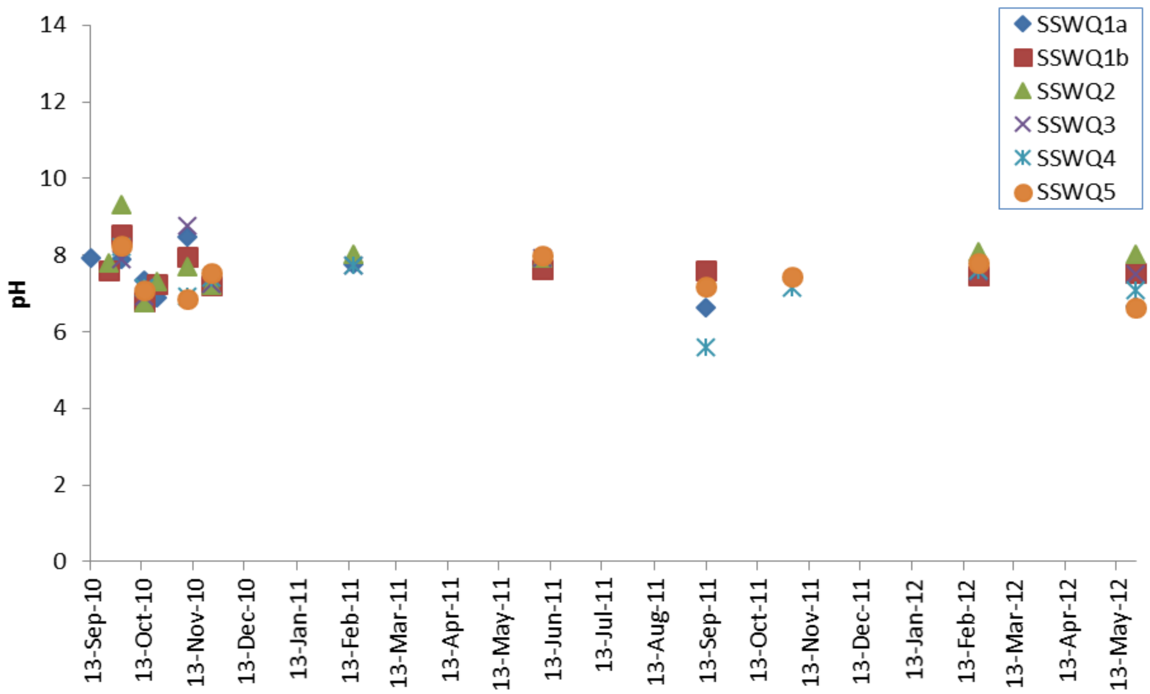

Figure 13. Surface water pH in and around Wetland 10, Sept. 2010 to May 2012.

4.3 Groundwater

The interaction between ground- and surface waters can have important implications for waterbodies. This is particularly the case at Sugar Shack Complex and other areas on lower Murrundi, with highly saline groundwater. There are six groundwater monitoring bores at Sugar Shack Complex, all in the vicinity of Wetland 10 (Figure 9). The bores are arranged to detect gradients both along the River channel and perpendicular to it, across the floodplain. Groundwater levels are measured in reference to sea level using the units mAHD.

4.3.1 Groundwater Level

Groundwater levels have been monitored in the six bores at Sugar Shack Complex since August 2004 (Figure 14). The data indicate that through time, in general, groundwater levels are correlated with surface water levels in the river, although fine scale departures from this trend are apparent. Spatial trends are more difficult to discern. In general, surface water levels in the river are as high as or higher than groundwater levels. However there is no obvious relationship between groundwater level and distance from the river channel. The ongoing monitoring of the existing observation bores, and the installation of additional bores proposed under this Plan, is recommended to gain an improved understanding of the spatial patterns of groundwater level and their implications for management.

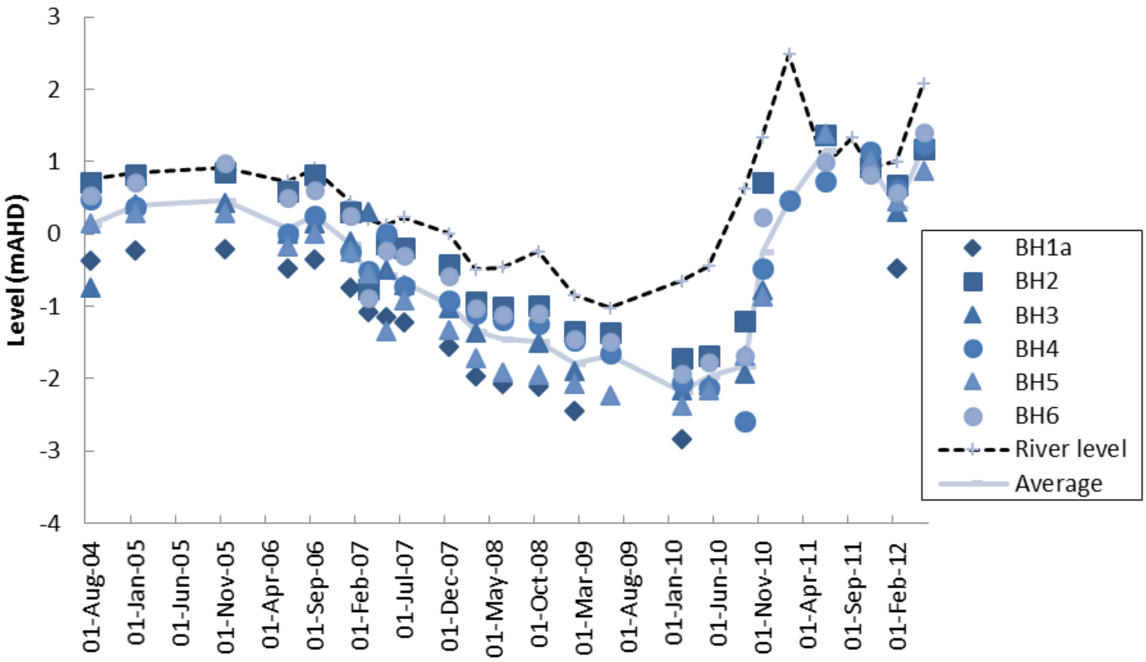

Figure 14. Groundwater and surface water (river) levels in the vicinity of Wetland 10 since 2004.

4.3.2 Groundwater Salinity

Groundwater salinity has been monitored since January 2005 at the same six monitoring bores at which groundwater levels are monitored (Figure 9), which are located to inform implications for Wetland 10. The spatial patterns of groundwater salinity in these bores are challenging to interpret. Bores located close to the river channel show both the lowest (BH3) and highest (BH4) salinities, which suggests groundwater salinity is not related to distance from the river at Sugar Shack Complex, at least in the vicinity of Wetland 10. A possible explanation for the higher salinity in BH4 is that it may access a deeper, more saline regional aquifer than the other bores. Temporally, a noticeable pattern is apparent in the three bores located furthest from the river (BH2, BH1a and BH6). During the extended dry (September 2006 to August 2010) groundwater salinity in these bores increased markedly (e.g. from approximately 10,000 to 40,000 µs/cm in BH1a) and then returned to approximately pre-drought levels following the flood of early 2011. High river levels occurred again in autumn/winter 2012, triggering a similar response in groundwater salinity. This suggests the presence of surface water in wetlands or floodwaters acts to freshen groundwater in the mid-floodplain. The implication for management is that groundwater salinity may increase in response to wetland drying. Groundwater will therefore require careful monitoring during the drying phases of managed wetlands at Sugar Shack Complex and an appropriate management response initiated should groundwater related risks begin to manifest (see Section 5.5.1).

From January 2006 to September 2006 groundwater EC ranged between 2780 and 49,900 µs/cm. The lowest salinity results (2780 – 3040 µs/cm) were recorded in BH3, which is located directly adjacent the river channel (Figure 9) and is likely to be influenced by this. EC was higher, ranging between 34 700 and 49 900 µs/cm, in piezometers located in low-lying floodplain between the river and Yatco Creek (BH4 and BH5 – excluding BH3) (Figure 15).

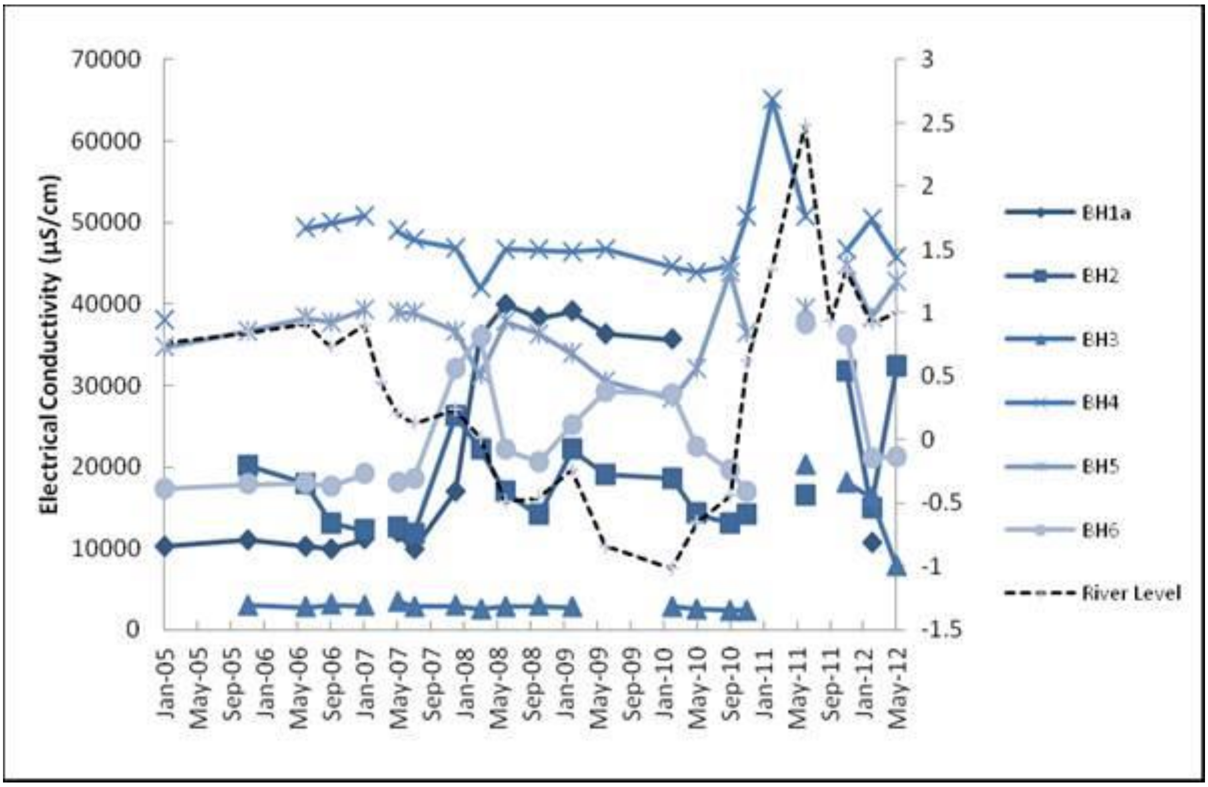

Figure 15. Groundwater salinity in the vicinity of Wetland 10 since 2005.

4.4 Wuri/Karrarru (River Redgum) Tree Condition

Tree health monitoring at Sugar Shack Complex to date has focussed on the area close to Wetland 10. Between 2006 and September 2010, a transect of ten River Redgums were assessed using the tree health monitoring method of Tucker (2004). This method uses a scoring between 0 and 5 for each tree which is based on an assessment of canopy cover, presence of dead limbs and epicormic growth. From November 2010, trees were assessed using both the above method and an alternative method developed by Souter *et al*. (2010). The Souter method assesses different features of the tree's condition individually (crown extent and density, epicormic growth, new tip growth, presence of mistletoe and bark condition), providing more information on which to assess how the trees respond to changing conditions.

November 2003 to September 2006 – wetland connected at pool to drawing down

One survey was done during this period, in which four trees had a condition score of four or higher (healthy trees) and an average score of all trees was 3.5 (Figure 16).

September 2006 to August 2010 – dry

Initially tree health score increased to an average of 3.8 (Figure 16) with six trees scoring four or higher. By August 2010, tree health had dropped to an average of 3.4, showing signs of stress likely due to the extended dry conditions, lower groundwater levels and higher groundwater salinity.

August 2010 onwards – re-wetting and high flows (connected at pool)

Initially, tree health score averaged 2.85, showing poor health after the dry period. Tree health scores improved following re-wetting and increased to an average of 3.9 by February 2012, with three trees having a score of five (excellent health). Since rewetting, minimal change has been seen in reproduction, epicormic growth, tip growth, leaf die-off and leaf damage. It should be noted that the ten trees within the transect are not necessarily indicative of overall tree health at Sugar Shack Complex. During the extended dry period, a number of trees in the Complex were observed to be showing symptoms of high stress and several trees died. Since rewetting, overall tree health within the Complex has improved.

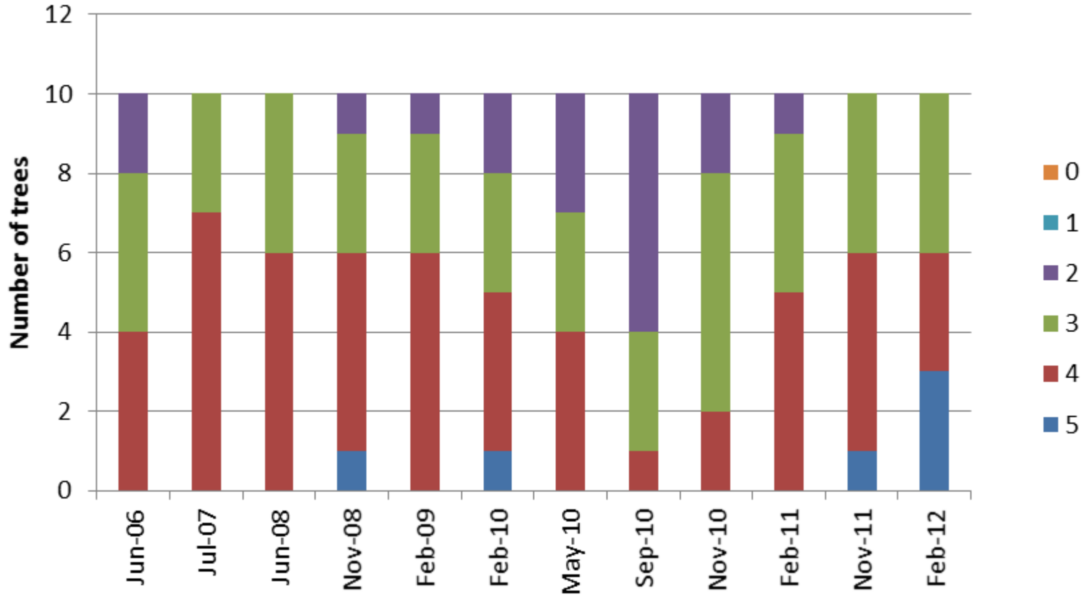

Figure 16. Tree health results for ten River Redgums in the vicinity of Wetland 10, 2006-2012, using the method of Tucker (2004).

4.5 Ma:mi (Fish)

Ma:mi (fish) surveys were undertaken during the baseline survey of Wetland 10 and Yatco Creek in 2003/2004 (Hammer and Wedderburn 2004, AWE 2005). Regular fish monitoring of Wetland 10 and Yatco Creek (see Figure 9 for locations) by the SAMDB NRM Board, in association with the MACAI, commenced in June 2006. There are two monitoring sites in Wetland 10 and one in Yatco Creek (Figure 9). Each site consists of two fyke nets and five bait traps, which are set overnight. Seine netting has occasionally been undertaken. No surveys were undertaken between 2007 and late 2010 as Wetland 10 was dry. Regular monitoring re-commenced on a bi-annual basis when the wetland was re-inundated in August 2010.

Baseline fish surveys of five other waterbodies of the Complex were undertaken for the MRP in April/May 2013 and again in October 2013 (Thwaites and Fredberg 2014). Wetlands 2, 5, 7 and 13 and Yatco Creek were surveyed. Each waterbody was surveyed at three sites. Each site consisted of three bait traps, three fyke nets and a gill net. Gear was set in the afternoon and hauled the following morning.

A total of 14 fish species have been recorded in Sugar Shack Complex, including nine native and five non-native species (Table 8). Appendix 1 provides a summary of fish monitoring and baseline survey results for the Complex.

Table 8. Ma:mi (fish) species recorded at Sugar Shack Complex.

Species	Common Name	Wetland 2	Wetland 5	Wetland 7	Wetland 10	Wetland 13	Yatco Creek
Native species							
Bidyanus bidyanus	Silver Perch						✓
Craterocephalus stercusmuscarum fulvus	Un-specked Hardyhead	✓	✓	✓	✓	✓	✓
Hypseleotris spp.	Carp Gudgeon complex	✓	✓	✓	✓	✓	✓
Macquaria ambigua ambigua	Golden Perch, Callop	✓	✓	✓	✓	✓	✓
Melanotaenia fluviatilis	Murray-Darling Rainbowfish				✓		
Nematalosa erebi	Bony Bream	✓	✓	✓	✓	✓	✓
Philypnodon grandiceps	Flat-headed Gudgeon	✓		✓	✓		✓
Philypnodon macrostomus	Dwarf Flat-headed Gudgeon	✓			✓	✓	✓
Retropinna semoni	Australian Smelt	✓	✓	✓	✓	✓	✓
Alien species							
Carassius auratus	Goldfish	✓	✓		✓	✓	✓
Cyprinus carpio	Common Carp	✓	✓	✓	✓	✓	✓
Gambusia holbrooki	Eastern Gambusia	✓		✓	✓		✓
Misgurnus anguillicaudatus	Oriental Weatherloach				✓		
Perca fluviatilis	Redfin Perch				✓	✓	

The following discussion pertains to the monitoring of Wetland 10 and adjacent Yatco Creek only.

November 2003 to September 2006 – wetland connected at pool to drawing down

Wetland 10 was connected at pool level during these monitoring events with slightly elevated water levels in November 2003 and lower levels during April 2004. Eight native species were recorded across the combined baseline survey events. The catch was dominated by Australian Smelt (*Retropinna semoni*), constituting 21% of total abundance, Bony Bream (*Nematalosa erebi*), 27% and Carp Gudgeons (*Hypseleotris* spp.), 13%. Large numbers of the non-native fish, particularly Common Carp (*Cyprinus carpio*) were captured within the wetland (12% of the total abundance). Non-native Eastern Gambusia (*Gambusia holbrooki*) dominated the fish assemblage captured within Yatco Creek, representing 25% of the total abundance over the two sampling events combined. Overall the suite of species recorded was characteristic of general wetland communities along the Murray (AWE 2005).

In 2006, river levels declined and the wetland fringes became exposed with minimal fringing habitat available for fish. Low abundances of both native and non-native fish were captured. Seven native species and one alien species were recorded, with the catch dominated by Unspecked Hardyhead (*Craterocephalus stercusmuscarum fulvus*), 27.5% of total abundance, and Australian Smelt, 27%.

September 2006 to August 2010 – dry

No fish surveys were undertaken during this time.

August 2010 onwards – re-wetting and high flows (connected at pool)

Following re-inundation of the wetland in mid-2010 after the Millenium Drought, only two native fish species were captured in low abundances in Wetland 10; Carp Gudgeon (n= 3) and Bony Bream (n=19). The total catch was dominated by Common Carp and tadpoles which constituted 36% and 61.5% of total abundance respectively. The absence of native fish in the wetland during this time was likely due to water quality. Low dissolved oxygen levels (as low as 0.49 mg/L) were experienced in the months immediately following re-wetting (see Section 4.2.3). Similar results were seen in many wetlands below Lock 1 following re-wetting after the extended dry of the Millennium Drought.

Fish monitoring conducted in November 2011 occurred when water levels were still elevated but much of the floodplain had dried. A total of seven native and four non-native fish species were captured. Non-native fish species (predominantly Common Carp and Eastern Gambusia) represented only 5% of total abundance. The native fish assemblage was dominated by Carp Gudgeon (45%) and Australian Smelt (44%).

Water levels were still elevated above pool level during fish surveys in February 2012. Although much of the fringe of Wetland 10 had emergent vegetation, predominantly Spiny Flat-sedge, Splendid Flat-sedge (*Cyperus exaltatus*) and Lignum, small-bodied native fish represented only 19.6% of the total abundance. Bony Bream and Common Carp, both large-bodied species, dominated the fish assemblage in both the wetland and creek constituting 30% and 39% of total abundance respectively. Elevated water temperatures during summer and availability of algae and detritus provide favourable conditions for Bony Bream and would likely have contributed to their increased presence in Wetland 10 in February 2012.

4.6 Menperi (Frogs)

Menperi (frog) monitoring is undertaken using a digital voice recorder and handheld microphone after dark, as described by Tucker (2004). Each species of frog has a unique call (only males call) enabling identification of the species. Abundance classes are used to estimate the number of frogs calling (Table 9) as it is difficult to count individual frogs when abundance is high. Frog monitoring has been conducted at Wetland 10 during the baseline survey in 2004 and routinely since 2008. In December 2013 baseline frog monitoring of Wetland 2 (3 sites), Wetland 5 (2 sites), Wetland 7 (3 sites) and Wetland 13 (2 sites) was undertaken. Monitoring and baseline survey activities have recorded six frog species at Sugar Shack Complex (

Table 10). Detailed frog monitoring data are shown in Appendix 2.

Table 9. Abundance classes used to score frog abundance.

Score	Frog Abundance
0	0
1	1
2	2-9
3	10-50
4	>50

Table 10. Menperi (frog) species recorded at Sugar Shack Complex.

Species	Common Name	Wetland 2	Wetland 5	Wetland 10
Crinia signifera	Common Froglet			✓
Limnodynastes dumerilii	Eastern Banjo Frog		✓**	✓
Crinia parinsignifera	Eastern Sign-bearing Frog	✓	✓	✓
Litoria peronii	Peron's Tree Frog			✓
*Litoria raniformis**	Southern Bell Frog			✓
Limnodynastes tasmaniensis	Spotted Grass Frog			✓

* Listed nationally vulnerable (*EPBC Act 1999*)
** Opportunistic call identification, B. Taylor, 19/7/2013.

The following discussion pertains to the monitoring of Wetland 10 only.

November 2003 - September 2006 – wetland connected at pool to drawing down

Five frog species were recorded calling at Wetland 10 during the baseline survey in 2004, including the nationally vulnerable Southern Bell Frog (*Litoria raniformis*). Bell Frogs were detected in low abundance (2 - 9) within reed beds on the southern fringes of the wetland (AWE 2005). Water levels were higher than pool level at this time; 0.95 mAHD at Swan Reach.

September 2006 - August 2010 – dry

One frog survey was conducted at Wetland 10 in November 2008 when all wetlands and creeks in the Sugar Shack Complex were dry. No frogs were recorded calling.

August 2010 onwards – re-inundation and high flows

Four frog species were recorded at Wetland 10 in November 2010, approximately three months after the wetland refilled following the Millennium Drought. Water levels were above pool at the time of monitoring (1.34 mAHD at Swan Reach) and some over-bank flooding was occurring. Frogs were observed in relatively low abundance but were more abundant in densely vegetated areas. The dominant species was the Eastern Sign-bearing Froglet (*Crinia parinsignifera*). Although a low abundance of frogs was observed In Wetland 10, high numbers (>50) of the same species were heard calling in adjacent wetlands of the Complex during September 2010 (although no survey took place at this time). At this time frog abundance appeared to be highest in dense inundated vegetation, predominantly Lignum (*Duma florulenta*) shrublands.

No Southern Bell Frogs were observed calling in November 2010, however four Southern Bell Frog tadpoles were captured in fish nets set on the same monitoring event. Fish nets were dominated by tadpoles (and Common Carp). This is indicative of successful breeding events and higher abundances of frogs earlier in spring.

Much of the floodplain became inundated in late 2010 due to high river levels which remained high for approximately seven months. Fringing vegetation did not withstand the long period of inundation and after water levels receded there was little habitat available for frogs, only exposed mud. This lack of habitat is likely to have contributed to the low frog abundances recorded in September 2011, December 2011 and December 2012. A total of three species were recorded during this period; Common Froglet, Eastern Sign-bearing Frog and Spotted Grass Frog.

4.7 Mrayi (Birds)

Bird surveys have been conducted at Wetland 10 since the baseline survey in 2004. The approach involves a count of the entire wetland by walking two transects that combined have a total length equal to approximately 1/3 of the wetland perimeter (K. Mason, SA MDB NRM Board, pers. com.). One transect begins at the existing regulator end ends at water quality monitoring location SUGWQ02. The other is in the vicinity of SUGWQ03. Opportunistic observations are also recorded. Monitoring is undertaken by the SA MDB NRM Board with assistance from the MACAI. Data are presented in Figure 17 using the functional group classification system used for the National Waterbird Assessment (Kingsford *et al.* 2012).

A baseline survey of additional wetlands and fringing floodplain habitat of the Complex was commissioned under the MRP and was undertaken in March 2013 (Bailey and Paton 2013). Fixed area searches, comparable with the approach used at Wetland 10, were undertaken at Wetlands 2, 5, 7, 12 and 13 and Creek 11. Complete waterbird monitoring and baseline survey data for the Complex are presented in Appendix 3. In March 2013, the MRP baseline surveyed for terrestrial birds on the Sugar Shack floodplain within an area defined by a 100 m radius from the edge of the same six waterbodies. For the results see (Bailey and Paton 2013).

The following discussion pertains to waterbird monitoring of Wetland 10 only.

November 2003 - September 2006 – connected at pool to drawing down

Nineteen species of waterbird comprising a maximum of 326 individuals were recorded at Wetland 10 during the baseline survey conducted in September 2004. The most dominant species recorded were the Australian Wood Duck (*Chenonetta jubata*) and Australian Pelican (*Pelecanus conspicillatus*) (AWE 2005).

September 2006 - August 2010 – dry

One bird survey was conducted at Wetland 10 during this period when the wetland was completely dry in November 2008. No waterbird species were recorded utilising the wetland or surrounding floodplain.

August 2010 – mid 2011 – re-inundation and high flows

Overbank flooding in 2010 inundated much of the Swan Reach Complex floodplain. In June 2011, nine months after the wetland was reconnected, 206 water birds from 13 species were recorded in Wetland

10. At the time of the survey, river levels had receded from a peak of 3.09 mAHD in March 2011 to 0.94 mAHD at Swan Reach (DEWNR 2014b), i.e. typical pool level conditions (0.75 mAHD) had almost returned. The survey was dominated by the piscivorous (fish-eating) species, Australian Pelican, Little Black Cormorant (*Phalacrocorax sulcirostris*) and Little Pied Cormorant (*Microcarbo melanoleucos*), the majority of which were resting on exposed mud.

September 2011 – mid 2013 – connected at pool

In September 2011, less than half the abundance of waterbirds (120) was observed when compared to abundances recorded in September 2004 (326). The species assemblage was dominated by dabbling ducks, namely Grey Teal (*Anas gracilis*) and Australian Wood Duck, all foraging in the water.

Wetland 10 was not surveyed again until 14 March 2013. On this occasion total waterbird abundance was similar (282) to the 2004 baseline survey result but the composition of functional groups was quite different. Dabbling ducks were dominant, with a particularly high abundance (169) of Grey Teal observed.

March 2013 – Jan 2014 – first managed drying event

The regulator on Wetland 10 was closed on 15 March 2013 and the wetland began to draw down. A waterbird survey was conducted on 6 September 2013 when the area inundated had shrunk by approximately 30%. Total waterbird abundance was approximately half it had been in March but more notably the composition of the community had changed considerably. The greatest abundance of shorebirds yet observed in Wetland 10 was recorded, due to a flock of 69 Red-necked Avocet (*Recurvirostra novaehollandiae*). This aligns with the theory that permanently full wetlands can disadvantage this guild of birds and that providing open, shallow habitat can temporarily increase their abundance. Piscivorous birds also formed a large proportion of the community at this time, with 63 Australian Pelicans present, presumably to take advantage of fish stranded in the drying wetland.

Jan 2014 – refilling and connected at pool

The regulator was opened on 10 January 2014 and the wetland refilled relatively quickly over approximately one week. A waterbird survey on 17 January recorded a similar total abundance to the preceding survey, however the composition had shifted back to a more dabbling duck dominated community. This is likely a reflection of a reduction in shallowly inundated, open habitat and an increase in more deeply inundated habitat.

Subsequent surveys conducted two weeks (23/1/2014) and three weeks (31/1/2014) after regulator opening show a remarkable increase in waterbird abundance and strongly support the ecological value of managed drying events. Total waterbird abundance increased to 1000, over three times the highest abundance previously recorded. This increase was driven by very high abundances of dabbling ducks, mainly Grey Teal (*Anas gracilis*), Pink-eared Duck (*Malacorhynchus membranaceus*) and the important Ngartji Pacific Black Duck (Nakari). Highest ever recorded abundances of herbivorous waterbirds were also observed, particularly Eurasian Coot (*Fulica atra*). Submerged aquatic vegetation had not developed when these surveys were conducted (Kate Mason, SAMDBNRMB, pers. com., 26/2/2014), so these waterbirds are likely to have been attracted by detritus and a boom in macroinvertebrate abundance in the water column and/or sediments stimulated by the drying event.

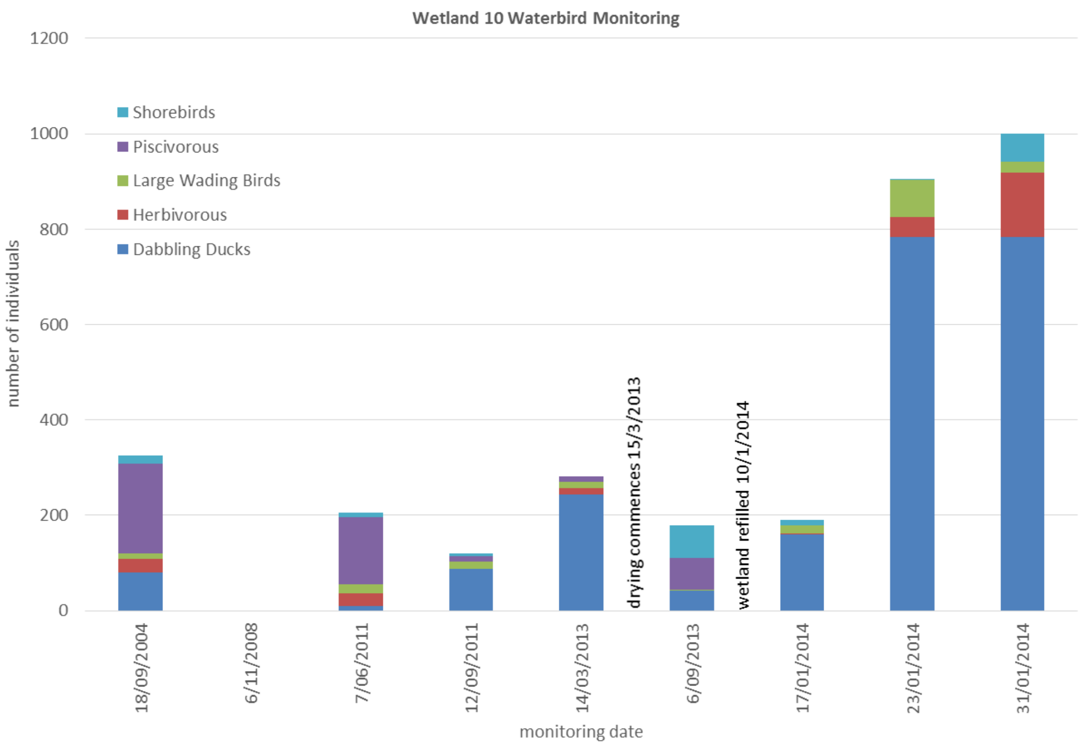

Figure 17. Waterbird monitoring results for Wetland 10.

5. Management Plan for Sugar Shack Complex

5.1 Vision

The collective vision of the MACAI is that the hydrological and ecological conditions of the wetlands of the Sugar Shack Complex resemble, as closely as possible, those experienced by the Ancestors.

5.2 Past Hydrological Management

Wetland 10 (Sugar Shack Pangki) is the only aquatic feature in the Sugar Shack Complex that has been subject to hydrological management to date. The regulator and associated carp screen that control inflows to this wetland was completed in 2007 (Tesoriero and Mason 2012). The wetland was also fenced at this time to exclude livestock. The first Management Plan for Wetland 10 (Bjornsson 2006) covered the first five year period following regulator construction, 2007 - 2012. This first plan was prepared in collaboration with the MACAI, in particular its Chair, the late Richard Hunter, and Secretary Isobelle Campbell. The key management actions recommended by this plan were to:

- operate the regulator to implement a target water regime (Figure 18); and
- exclude livestock from the wetland.

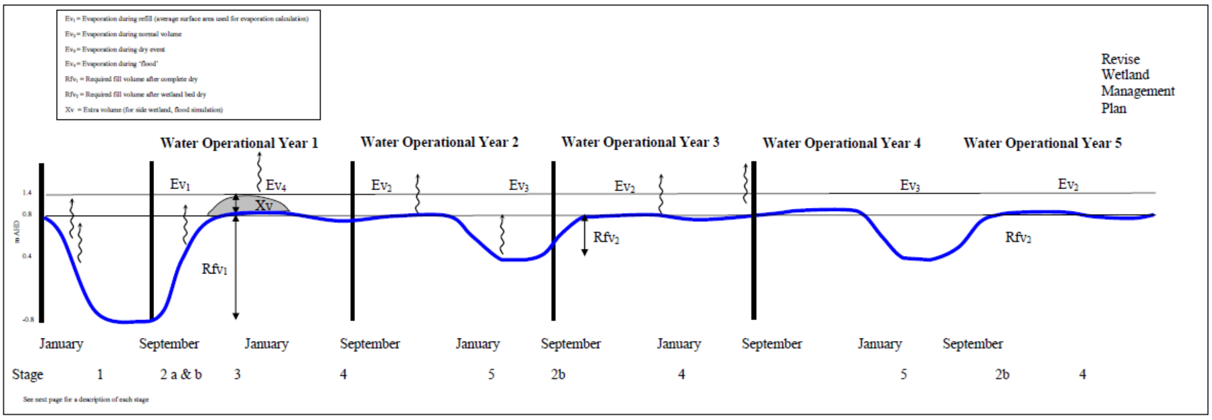

Figure 18. Target water regime for Sugar Shack Pangki, 2007 – 2012 (Bjornsson 2006).

Wetland 10 was initially disconnected from Murrundi using an earth and rock embankment in late 2006, in order to construct the regulator. However, due to the Millenium Drought the water regime of Sugar Shack Pangki could not thereafter be managed in accordance with the 2007 - 2012 Management Plan. Extremely low river levels below Lock 1 resulted in a continuous dry phase of approximately 48 months from January 2007 to August 2010. This unprecedented event was followed by floods in the summer of 2010 – 2011. The actual water regime experienced at Sugar Shack Pangki for the period January 2006 – December 2011 is shown in Figure 19.

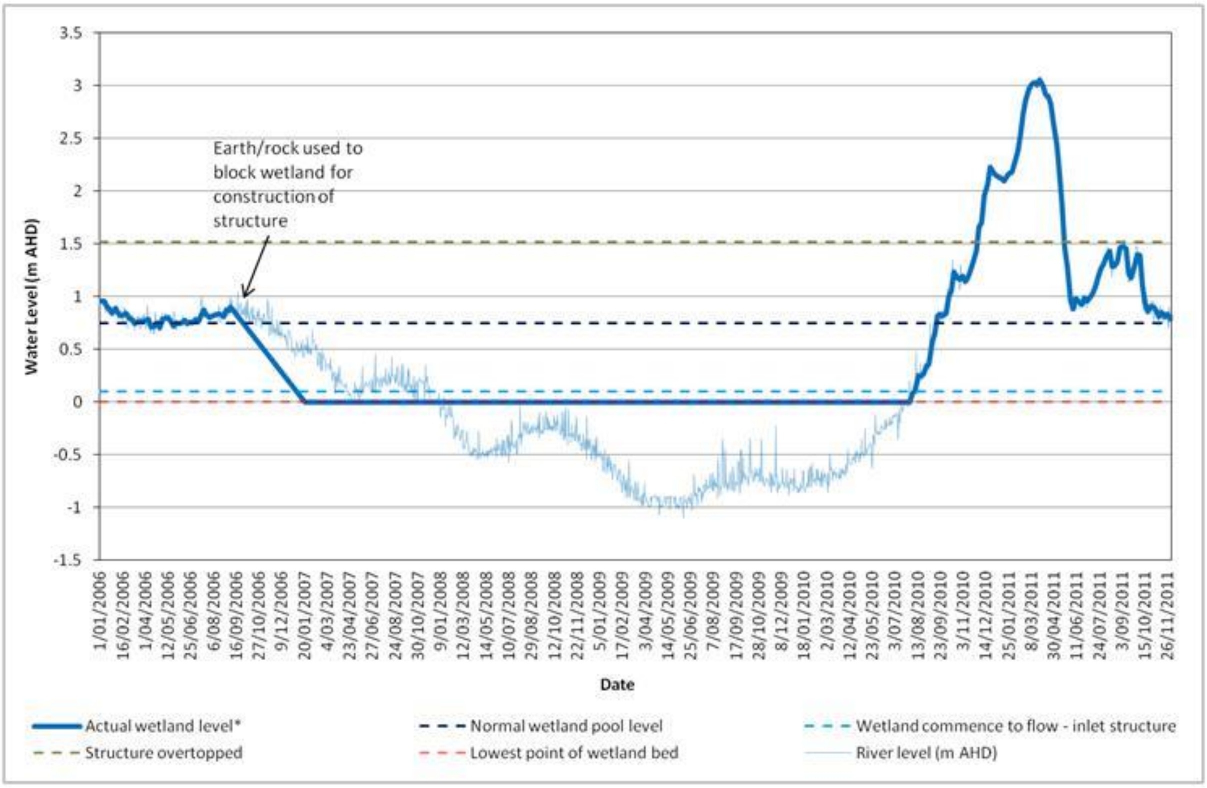

Figure 19. Actual water levels in Wetland 10, January 2006 to December 2011.

5.3 Management Objectives and Targets

The section describes the ecological objectives and targets for the Sugar Shack Complex. An objective is an expression of something that should be achieved through management of the Complex. Objectives should have the following characteristics:

- An objective must be quantified and measurable. If it is not measurable, it will be difficult to assess through monitoring whether it is being achieved.
- An objective should be achievable, at least in the long term.
- Objectives must not be prescriptive. They define the condition required of a feature and not the actions necessary to obtain or maintain that condition.

Each of the objectives in this Plan have one or more associated targets. Targets that are specific, measurable, achievable, realistic and time bound (SMART) have been developed to enable monitoring to track progress (Wilkinson *et al.* 2007).

Nganguraku and Ngaiawang, being part of the Ngarrindjeri Nation, support the sustainability of diverse and healthy wetland habitats and the restoration and maintenance of connectivity between habitats. However, Ngarrindjeri stress that the fundamental connection between the overall health of the Sugar Shack complex and Ngarrindjeri culture underpins all 'ecological' objectives. Ngarrindjeri therefore support the objectives below, and seek ongoing involvement in the care of this part of the body of Murrundi through the targets associated with each objective. DEWNR have an obligation to work with the Ngarrindjeri on the best ways to achieve these objectives, as per their commitment under the KNYA.

5.3.1 Objective 1: Increased cover/abundance, extent and diversity of littoral zone vegetation in managed wetlands during wet phase

Littoral zone vegetation is comprised of the floating, submerged and emergent plants that occur in inundated wetlands, typically around shallow wetland margins but often extending throughout. Littoral zone vegetation includes a number of culturally significant plant species including Manangkeri/Kongi (Bulrush, *Typha* spp.), Pangki (Common Reed, *Phragmites australis*), Nardoo (*Marsilea drummondii*) and Yalkari (Spiny Flat Sedge, *Cyperus gymnocaulous*). A central objective of this Plan is that, as predicted by scientific understanding (DEWNR 2012a), both the extent and floristic diversity of littoral zone vegetation will increase in all managed wetlands, mainly by expanding down the elevation gradient. This includes both wetlands connected under pool level conditions (Wetlands 2, 5, 10 and 13) and temporary wetlands (Wetlands 1 and 3). In the absence of major unforeseen perturbations (e.g. extreme and prolonged drought or flood), clear, measurable progress towards this objective is anticipated to be observed within the five year lifespan of this Plan.

The proposed tools for the measurement of this objective are photopoint monitoring (see Section 5.7.5) and vegetation transect monitoring (see Section 5.7.6). The cultural health of the Complex is strongly linked to this objective.

Targets relating to Objective 1 are described in Table 11.

Table 11. Targets relating to Objective 1.

Wetland	Objective 1 Targets
Wetland 1	Target 1: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Emergent plants present in at least 3 of 15 cells at +1.05 mAHD. Target 2: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Amphibious plants detected in at least 3 of 15 cells at +1.05 mAHD. Target 3: During wet phase monitoring after the third year of management and for at least 1 of the 3 transects, mixed assemblages of native Emergent, Amphibious Fluctuation Tolerator and Amphibious Fluctuation Responder plant functional groups detected at +1.05 mAHD (i.e. across the 15 cells). Target 4: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects native Submergent plants present in at least 3 of 15 cells at +0.80 mAHD. Target 5: During wet phase monitoring after the third year of management, record greater overall mean plant species richness and abundance below +1.35 mAHD at Wetland 1 than at Wetland 8 control site.
Wetland 2	Target 1: During wet phase monitoring after the third year of management and on average across the 9 vegetation transects, native Emergent plants present in at least 3 of 15 cells at +0.45 mAHD. Target 2: During wet phase monitoring after the third year of management and on average across the 9 vegetation transects, native Amphibious plants detected in at least 3 of 15 cells at +0.45 mAHD. Target 3: During wet phase monitoring after the third year of management and for at least 3 of the 9 transects, mixed assemblages of native Emergent, Amphibious Fluctuation Tolerator and Amphibious Fluctuation Responder plant functional groups detected at +0.45 mAHD (i.e. across the 15 cells). Target 4: During wet phase monitoring after the third year of management and on average across the 9 vegetation transects native Submergent plants present in at least 3 of 15 cells at +0.15 mAHD. Target 5: During wet phase monitoring after the third year of management, record greater overall mean plant species richness and abundance below +0.75 mAHD at Wetland 2 than at Wetland 7/12 control site.

Wetland	Objective 1 Targets
Wetland 3	Target 1: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Emergent plants present in at least 3 of 15 cells at +1.40 mAHD. Target 2: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Amphibious plants detected in at least 3 of 15 cells at +1.40 mAHD. Target 3: During wet phase monitoring after the third year of management and for at least 1 of the 3 transects, mixed assemblages of native Emergent, Amphibious Fluctuation Tolerator and Amphibious Fluctuation Responder plant functional groups detected at +1.40 mAHD (i.e. across the 15 cells). Target 4: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects native Submergent plants present in at least 3 of 15 cells at +1.10 mAHD. Target 5: During wet phase monitoring after the third year of management, record greater overall mean plant species richness and abundance below +1.70 mAHD (FSL) at Wetland 2 than at Wetland 8 control site.
Wetland 5	Target 1: During wet phase monitoring after the third year of management and on average across the 9 vegetation transects, native Emergent plants present in at least 3 of 15 cells at +0.45 mAHD. Target 2: During wet phase monitoring after the third year of management and on average across the 9 vegetation transects, native Amphibious plants detected in at least 3 of 15 cells at +0.45 mAHD. Target 3: During wet phase monitoring after the third year of management and for at least 3 of the 9 transects, mixed assemblages of native Emergent, Amphibious Fluctuation Tolerator and Amphibious Fluctuation Responder plant functional groups detected at 0.45 mAHD (i.e. across the 15 cells). Target 4: During wet phase monitoring after the third year of management and on average across the 9 vegetation transects, native Submergent plants present in at least 3 of 15 cells at +0.15 mAHD. Target 5: During wet phase monitoring after the third year of management, record greater overall mean plant species richness and abundance below 0.75 mAHD at Wetland 5 than at Wetland 7/12 control site.

Wetland	Objective 1 Targets
Wetland 6	Target 1: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Emergent plants present in at least 3 of 15 cells at +1.65 mAHD. Target 2: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Amphibious plants detected in at least 3 of 15 cells at +1.65 mAHD. Target 3: During wet phase monitoring after the third year of management and for at least 1 of the 3 transects, mixed assemblages of native Emergent, Amphibious Fluctuation Tolerator and Amphibious Fluctuation Responder plant functional groups detected at 1.65 mAHD (i.e. across the 15 cells). Target 4: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Submergent plants present in at least 3 of 15 cells at +1.35 mAHD. Target 5: During wet phase monitoring after the third year of management, record greater overall mean plant species richness and abundance below 1.95 mAHD (FSL) at Wetland 6 than at Wetland 8 control site.
Wetland 10	Target 1: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Emergent plants present in at least 3 of 15 cells at +0.45 mAHD. Target 2: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Amphibious plants detected in at least 3 of 15 cells at +0.45 mAHD. Target 3: During wet phase monitoring after the third year of management and for at least 1 of the 3 transects, mixed assemblages of native Emergent, Amphibious Fluctuation Tolerator and Amphibious Fluctuation Responder plant functional groups detected at 0.45 mAHD (i.e. across the 15 cells). Target 4: During wet phase monitoring after the third year of management and on average across the 3 vegetation transects, native Submergent plants present in at least 3 of 15 cells at +0.15 mAHD. Target 5: During wet phase monitoring after the third year of management, record greater overall mean plant species richness and abundance below 0.75 mAHD at Wetland 10 than at Wetland 7/12 control site.

Wetland	Objective 1 Targets
Wetland 13	Target 1: During wet phase monitoring after the third year of management and on average across the 9 vegetation transects, native Emergent plants present in at least 3 of 15 cells at +0.45 mAHD. Target 2: During wet phase monitoring after the third year of management and on average across the 9 vegetation transects, native Amphibious plants detected in at least 3 of 15 cells at +0.45 mAHD. Target 3: During wet phase monitoring after the third year of management and for at least 3 of the 9 transects, mixed assemblages of native Emergent, Amphibious Fluctuation Tolerator and Amphibious Fluctuation Responder plant functional groups detected at 0.45 mAHD (i.e. across the 15 cells). Target 4: During wet phase monitoring after the third year of management and on average across the 9 vegetation transects, native Submergent plants present in at least 3 of 15 cells at +0.15 mAHD. Target 5: During wet phase monitoring after the third year of management, record greater overall mean plant species richness and abundance below 0.75 mAHD at Wetland 13 than at Wetland 7/12 control site.

5.3.2 Objective 2: Increased cover/abundance, extent and diversity of native plant species on wetland bed during dry phase

When wetlands that have been permanently inundated are first dried, the exposed sediments are likely to have a low abundance and diversity of native "amphibious" plants (DEWNR 2012a). During the first few drying events wetland beds may remain relatively bare or become colonised by terrestrial weed species with excellent dispersal mechanisms. However, as more wetting and drying cycles are applied, native amphibious species are likely to establish in greater diversity and extent and to create a propagule bank that persists during the wet phase (DEWNR 2012a). By the end of the five year lifespan of this Plan the dry phase plant community of managed wetlands should be more diverse, more abundant (greater total biomass), include more native species and cover a larger proportion of the bed of all managed wetlands than at the commencement. This is anticipated to have flow-on benefits for other biota. Terrestrial fauna will benefit from increased habitat extent and resource availability during the dry phase, while aquatic biota will benefit from the productivity boost that accompanies re-inundation of wetland sediments with a cover of dry-phase plants.

The proposed tools for the measurement of this objective are photopoint monitoring (see Section 5.7.5) and vegetation transect monitoring (see Section 5.7.6).

Targets relating to Objective 2 are described in Table 12.

Table 12. Targets relating to Objective 2.

Wetland	Objective 2 Targets
Wetland 1	Target 1: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Floodplain plants present in at least 3 of 15 cells at +1.05 mAHD. Target 2: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Terrestrial (Dry and/or Damp) plants present in at least 3 of 15 cells at +1.05 mAHD. Target 3: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Amphibious Fluctuation Tolerator plants present in at least 1 of 15 cells at 0.80 mAHD and 3 of 15 cells at +1.05 mAHD. Target 4: During dry phase monitoring after the third year of management and for at least 1 of the 3 transects, mixed assemblages of native Floodplain, Terrestrial (Dry and/or Damp) and Amphibious Fluctuation Tolerator plant functional groups detected at 1.05 mAHD (i.e. across the 15 cells) Target 5: During dry phases after the third year of management record greater overall mean plant species richness and abundance at Wetland 1 than at Wetland 8 control site.
Wetland 2	Target 1: During dry phase monitoring after the third year of management and on average across the 9 vegetation transects, native Floodplain plants present in at least 3 of 15 cells at +0.45 mAHD. Target 2: During dry phase monitoring after the third year of management and on average across the 9 vegetation transects, native Terrestrial (Dry and/or Damp) plants present in at least 3 of 15 cells at +0.45 mAHD. Target 3: During dry phase monitoring after the third year of management and on average across the 9 vegetation transects, native Amphibious Fluctuation Tolerator plants present in at least 1 of 15 cells at 0.15 mAHD and 3 of 15 cells at +0.45 mAHD. Target 4: During dry phase monitoring after the third year of management and for at least 3 of the 9 transects, mixed assemblages of native Floodplain, Terrestrial (Dry and/or Damp) and Amphibious Fluctuation Tolerator plant functional groups detected at 0.45 mAHD (i.e. across the 15 cells) Target 5: If drought leads to drawdown of Wetland 7/12 control site, record greater overall mean plant diversity and abundance at Wetland 2 than at control site during dry phases after the third year of management.

Wetland	Objective 2 Targets
Wetland 3	Target 1: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Floodplain plants present in at least 3 of 15 cells at +1.40 mAHD. Target 2: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Terrestrial (Dry and/or Damp) plants present in at least 3 of 15 cells at +1.40 mAHD. Target 3: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Amphibious Fluctuation Tolerator plants present in at least 1 of 15 cells at 1.10 mAHD and 3 of 15 cells at +1.40 mAHD. Target 4: During dry phase monitoring after the third year of management and for at least 1 of the 3 transects, mixed assemblages of native Floodplain, Terrestrial (Dry and/or Damp) and Amphibious Fluctuation Tolerator plant functional groups detected at 1.40 mAHD (i.e. across the 15 cells). Target 5: During dry phases after the third year of management record greater overall mean plant diversity species richness and abundance at Wetland 3 than at Wetland 8 control site.
Wetland 5	Target 1: During dry phase monitoring after the third year of management and on average across the 9 vegetation transects, native Floodplain plants present in at least 3 of 15 cells at +0.45 mAHD. Target 2: During dry phase monitoring after the third year of management and on average across the 9 vegetation transects, native Terrestrial (Dry and/or Damp) plants present in at least 3 of 15 cells at +0.45 mAHD. Target 3: During dry phase monitoring after the third year of management and on average across the 9 vegetation transects, native Amphibious Fluctuation Tolerator plants present in at least 3 of 15 cells at +0.45 mAHD. Target 4: During dry phase monitoring after the third year of management and for at least 3 of the 9 transects, mixed assemblages of native Floodplain, Terrestrial (Dry and/or Damp) and Amphibious Fluctuation Tolerator plant functional groups detected at 0.45 mAHD (i.e. across the 15 cells) Target 5: If drought leads to drawdown of Wetland 7/12 control site, record greater overall mean plant diversity and abundance at Wetland 5 than at control site during dry phases after the third year of management

Wetland	Objective 2 Targets
Wetland 6	Target 1: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Floodplain plants present in at least 3 of 15 cells at +1.65 mAHD. Target 2: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Terrestrial (Dry and/or Damp) plants present in at least 3 of 15 cells at +1.65 mAHD. Target 3: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Amphibious Fluctuation Tolerator plants present in at least 1 of 15 cells at 1.35 mAHD and 3 of 15 cells at +1.65 mAHD. Target 4: During dry phase monitoring after the third year of management and for at least 1 of the 3 transects, mixed assemblages of native Floodplain, Terrestrial (Dry and/or Damp) and Amphibious Fluctuation Tolerator plant functional groups detected at 1.65 mAHD (i.e. across the 15 cells) Target 5: During dry phases after the third year of management record greater overall mean plant diversity species richness and abundance at Wetland 6 than at Wetland 8 control site.
Wetland 10	Target 1: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Floodplain plants present in at least 3 of 15 cells at +0.45 mAHD. Target 2: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Terrestrial (Dry and/or Damp) plants present in at least 3 of 15 cells at +0.45 mAHD. Target 3: During dry phase monitoring after the third year of management and on average across the 3 vegetation transects, native Amphibious Fluctuation Tolerator plants present in at least 1 of 15 cells at 0.15 mAHD and 3 of 15 cells at +0.45 mAHD. Target 4: During dry phase monitoring after the third year of management and for at least 1 of the 3 transects, mixed assemblages of native Floodplain, Terrestrial (Dry and/or Damp) and Amphibious Fluctuation Tolerator plant functional groups detected at 0.45 mAHD (i.e. across the 15 cells) Target 5: If drought leads to drawdown of Wetland 7/12 control site, record greater overall mean plant diversity and abundance at Wetland 10 than at control site during dry phases after the third year of management.

Wetland	Objective 2 Targets
Wetland 13	Target 1: During dry phase monitoring after the third year of management and on average across the 9 vegetation transects, native Floodplain plants present in at least 3 of 15 cells at +0.45 mAHD. Target 2: During dry phase monitoring after the third year of management and on average across the 9 vegetation transects, native Terrestrial (Dry and/or Damp) plants present in at least 3 of 15 cells at +0.45 mAHD. Target 3: During dry phase monitoring after the third year of management and on average across the 9 vegetation transects, native Amphibious Fluctuation Tolerator plants present in at least 1 of 15 cells at 0.15 mAHD and 3 of 15 cells at +0.45 mAHD. Target 4: During dry phase monitoring after the third year of management and for at least 3 of the 9 transects, mixed assemblages of native Floodplain, Terrestrial (Dry and/or Damp) and Amphibious Fluctuation Tolerator plant functional groups detected at 0.45 mAHD (i.e. across the 15 cells) Target 5: If drought leads to drawdown of Wetland 7/12 control site, record greater overall mean plant diversity and abundance at Wetland 13 than at control site during dry phases after the third year of management.

5.3.3 Objective 3: Maintain health of mature Wuri / Karrarru (River Redgum)

Mature Wuri/Karrarru (River Redgums) are highly significant in Ngarrindjeri culture (see Section 2.1) and play a central role in the river-floodplain ecology of Murrundi. Ensuring that proposed management does not harm mature Wuri is an important cultural and ecological objective of this Plan. Wetland management may affect the health of mature Wuri by (DEWNR 2012a):

- Relieving oxygen stress caused by permanent inundation of the root zone, potentially improving tree health (permanent wetlands only);
- Causing oxygen stress by inundating the root zone of trees that are rarely subjected to inundation (temporary wetlands only);
- Excessively dehydrating the root zone during wetland dry phases, potentially reducing tree health (permanent wetlands only);
- Causing saline groundwater to rise and contact the root zone, potentially reducing tree health.

Death of mature Wuri is a natural process, however a well-designed monitoring program should enable the discrimination between the impacts of management and natural processes upon tree health.

The proposed tool for the measurement of this objective is tree health monitoring (see Section 5.7.4). Groundwater monitoring (see Section 5.7.3) will also provide information of relevance to this objective.

Targets relating to Objective 3 are described in Table 13.

Table 13. Targets relating to Objective 3.

Wetland	Objective 3 Targets
Wetland 1	Target 1: Record Medium to Maximum crown density scores for all 8 monitoring river red gum trees by the end of the first five-year cycle. Target 2: For all monitoring river red gums, obtain an average "positive future trend indicators" category that is equal to or better than that of Wetland 8 control site by the end of the first five year period. Target 3: At least 1 of the 3 vegetation transects record successful recruitment (at least 20 mm trunk diameter) of river red gum seedlings at +1.35 mAHD by the end of the first five year period.
Wetland 2	Target 1: Record Medium to Maximum crown density scores for all 32 monitoring river red gum trees by the end of the first five-year cycle. Target 2: For all monitoring river red gums, obtain an average "positive future trend indicators" category that is equal to or better than that of Wetland 7/12 control site by the end of the first five year period. Target 3: At least 2 of the 9 vegetation transects record successful recruitment (at least 20 mm trunk diameter) of river red gum seedlings at 0.75 mAHD by the end of the first five year period.
Wetland 3	Target 1: Record Medium to Maximum crown density scores for all 8 monitoring river red gum trees by the end of the first five-year cycle. Target 2: For all monitoring river red gums, obtain an average "positive future trend indicators" category that is equal to or better than that of Wetland 8 control site by the end of the first five year period. Target 3: At least 1 of the 3 vegetation transects record successful recruitment (at least 20 mm trunk diameter) of river red gum seedlings at 1.70 mAHD by the end of the first five year period.
Wetland 5	Target 1: Record Medium to Maximum crown density scores for all 28 monitoring river red gum trees by the end of the first five-year cycle. Target 2: For all monitoring river red gums, obtain an average "positive future trend indicators" category that is equal to or better than that of Wetland 7/12 control site by the end of the first five year period. Target 3: At least 2 of the 9 vegetation transects record successful recruitment (at least 20 mm trunk diameter) of river red gum seedlings at 0.75 mAHD by the end of the first five year period.

Wetland	Objective 3 Targets
Wetland 6	Target 1: Record Medium to Maximum crown density scores for all 8 monitoring river red gum trees by the end of the first five-year cycle. Target 2: For all monitoring river red gums, obtain an average “positive future trend indicators” category that is equal to or better than that of Wetland 8 control site by the end of the first five year period. Target 3: At least 1 of the 3 vegetation transects record successful recruitment (at least 20 mm trunk diameter) of river red gum seedlings at 1.95 mAHD by the end of the first five year period.
Wetland 10	Target 1: Record Medium to Maximum crown density scores for all 10 monitoring river red gum trees by the end of the first five-year cycle. Target 2: For all monitoring river red gums, obtain an average “positive future trend indicators” category that is equal to or better than that of Wetland 7/12 control site by the end of the first five year period. Target 3: At least 1 of the 3 vegetation transects record successful recruitment (at least 20 mm trunk diameter) of river red gum seedlings at 0.75 mAHD by the end of the first five year period.
Wetland 13	Target 1: Record Medium to Maximum crown density scores for at least 30 of the 37 monitoring river red gum trees by the end of the first five-year cycle. Target 2: For all monitoring river red gums, obtain an average “positive future trend indicators” category that is equal to or better than that of Wetland 7/12 control site by the end of the first five year period. Target 3: At least 2 of the 9 vegetation transects record successful recruitment (at least 20 mm trunk diameter) of river red gum seedlings at 0.75 mAHD by the end of the first five year period.

5.3.4 Objective 4: Increased abundance and breeding success of culturally significant fauna

The re-introduction of wetting and drying cycles to wetlands that have been permanently inundated due to river regulation is anticipated to boost ecological productivity (DEWNR 2012a). Increased biomass of vegetation within wetlands will provide increased food and structural habitat for higher trophic organisms including a range of culturally important species. Improved flows through anabranch creeks within the Complex, and the removal of barriers to fish passage, is anticipated to improve habitat quality and accessibility in those areas. Increased frequency of inundation of temporary wetlands will greatly increase ecological productivity in these areas, with likely benefits for a suite of waterbirds and aquatic reptiles. Overall, increased abundance is anticipated for:

- large-bodied native fish including Pilalki (Callop) and Thukeri (Bony Herring);
- waterbirds including Nori (Australian Pelican), Kungari (Black Swan) and Nakari (Pacific Black Duck);

- aquatic reptiles including Malinthaipari (Long-necked Tortoise) and Thukubi (Macquarie Tortoise); and
- aquatic invertebrates including Kaltuwarri/Morrokun (Yabby).

The proposed tools for the measurement of this objective are Ma:mi (fish) monitoring (see Section 0) and Mrayi (bird) monitoring (see Section 5.7.9).

Targets relating to Objective 4 are described in Table 14.

Table 14. Targets relating to Objective 4.

Wetland	Objective 4 Targets
Whole Complex	Target 1: Across the wetland complex, observe increased incidence of breeding activity by culturally significant waterbirds, in particular Kungari (Black Swan, *Cygnus atratus*), compared to baseline levels by the end of the first five year period. Target 2: Across the wetland complex, MACAI members observe increased abundance of Thukubi (Macquarie Tortoise), *Emydura macquarii*) and Broad-shelled Tortoise (*Chelodina expansa*) compared to pre-management abundance by the end of the first five year period.
Wetland 2	Target 1: Record an increase in the proportion (indicative of improved spawning and recruitment conditions) of <100 mm Total length (i.e. Year-of-Young) Bony Herring between Year 1 and Year 5. Target 2: Record increases in relative abundances of Bony Herring compared to baseline levels and Wetland 7/12 control site.
Wetland 5	Target 1: Record an increase in the proportion (indicative of improved spawning and recruitment conditions) of <100 mm Total length (i.e. Year-of-Young) Bony Herring between Year 1 and Year 5. Target 2: Record increases in relative abundances of Bony Herring compared to baseline levels and Wetland 7/12 control site.
Wetland 13	Target 1: Record an increase in the proportion (indicative of improved spawning and recruitment conditions) of <100 mm Total length (i.e. Year-of-Young) Bony Herring between Year 1 and Year 5. Target 2: Record increases in relative abundances of Bony Herring compared to baseline levels and Wetland 7/12 control site.

5.3.5 Objective 5: Increased Menperi (Frog) abundance

As discussed above in relation to culturally significant fauna, the management proposed in this Plan is anticipated to lead to increased ecological productivity in all six wetlands proposed for hydrological management. This productivity boost is likely to have flow-on benefits for frogs, with abundances of all species anticipated to increase. Of particular note is the nationally vulnerable Southern Bell Frog (*Litoria raniformis*), which has been recorded occasionally in low abundance within the Complex. In Murrundi, breeding of this species is triggered by flooding of ephemeral waterbodies during spring or summer, and the larval period can be as short as two months (Clemann and Gillespie 2012). The hydrological management proposed in this Plan may greatly increase the frequency and success of Southern Bell Frog breeding within the Complex. The drying and subsequent re-inundation of permanent wetlands in late winter or spring, and filling of temporary wetlands at similar times, with water persisting for several months over spring and summer in all managed wetlands (see Section 5.3.2), provides the duration and timing of inundation considered optimal for successful breeding of the species in lower Murrundi (Schulz 2008, Clemann and Gillespie 2012).

The proposed tool for the measurement of this objective is Menperi (frog) monitoring (see Section 5.7.8).

Targets relating to Objective 5 are described in Table 15.

Table 15. Targets relating to Objective 5.

Wetland	Objective 5 Targets
Whole Complex	Target 1: During the first five year period record the presence of all six frog species previously recorded at the Complex.
Wetland 1	Target 1: Record 3 or more frog species, each with an abundance score of at least 3 (2-9 individuals), during a single monitoring event by the end of the first five year period. Target 2: Record the presence of Southern Bell Frog on at least one occasion during the first five year period.
Wetland 2	Target 1: Record 3 or more frog species, each with an abundance score of at least 3 (2-9 individuals), during a single monitoring event by the end of the first five year period. Target 2: Record the presence of Southern Bell Frog on at least one occasion during the first five year period.
Wetland 3	Target 1: Record 3 or more frog species, each with an abundance score of at least 3 (2-9 individuals), during a single monitoring event by the end of the first five year period. Target 2: Record the presence of Southern Bell Frog on at least one occasion during the first five year period.

Wetland	Objective 5 Targets
Wetland 5	Target 1: Record 3 or more frog species, each with an abundance score of at least 3 (2-9 individuals), during a single monitoring event by the end of the first five year period. Target 2: Record the presence of Southern Bell Frog on at least one occasion during the first five year period.
Wetland 6	Target 1: Record 3 or more frog species, each with an abundance score of at least 3 (2-9 individuals), during a single monitoring event by the end of the first five year period. Target 2: Record the presence of Southern Bell Frog on at least one occasion during the first five year period.
Wetland 10	Target 1: Record 3 or more frog species, each with an abundance score of at least 3 (2-9 individuals), during a single monitoring event by the end of the first five year period. Target 2: Record the presence of Southern Bell Frog on at least one occasion during the first five year period.
Wetland 13	Target 1: Record 3 or more frog species, each with an abundance score of at least 3 (2-9 individuals), during a single monitoring event by the end of the first five year period. Target 2: Record the presence of Southern Bell Frog on at least one occasion during the first five year period.

5.3.6 Objective 6: Increased abundance of large waders and shorebirds

Large waders (e.g. Spoonbills, Stilts, Avocets) and shorebirds (e.g. Sandpipers, Dotterels) forage in shallowly inundated open areas, with the optimal water depth for foraging differing between species (Paton 2010). Stable, unnaturally high water levels make wetlands less favourable for these species in two key ways:

- Water depth throughout most of the wetland is too deep for these species to forage in. Shallow areas close to wetland margins still occur, however these tend to be densely vegetated, e.g. with Lignum or Managkeri (Bulrush), and therefore unsuitable as foraging habitat for these birds.

- Permanent inundation decreases ecological productivity, reducing food availability for large waders and shorebirds.

The re-introduction of drying phases to permanent wetlands addresses both of these problems. The increased frequency of inundation of temporary wetlands will have similar benefits. In both cases a much larger area of open, shallowly inundated habitat should be present during drawdown and refilling events than is the case under the unmanaged scenario. The increased frequency of drying of permanent wetlands, and wetting of temporary wetlands, should increase wetland productivity and therefore food availability for these bird species. An increase in their abundance, particularly during periods of drawdown and refilling, is therefore likely.

The proposed tool for the measurement of this objective is Mrayi (bird) monitoring (see Section 5.7.9).

Targets relating to Objective 6 are described in Table 16.

Table 16. Targets relating to Objective 6.

Wetland	Objective 6 Targets
Whole Complex	Target 1: Record success of at least one large wader (e.g. Spoonbill, Heron, Ibis, Egret) breeding event in first five year period.
Wetland 1	Target 1: Record 6 or more large wader /shorebird species during a single monitoring event by the end of the first five year period. Target 3: Record greater large wader / shorebird mean diversity and abundance during wet phases than at Wetland 8 control site over first five year period.
Wetland 2	Target 1: Record 6 or more large wader /shorebird species during a single monitoring event by the end of the first five year period. Target 2: Record greater large wader / shorebird mean species richness and abundance during drawdown periods than during bank-full periods over first five year period. Target 3: Record greater large wader / shorebird mean diversity and abundance during wet phases than at Wetland 7/12 control site over first five year period.
Wetland 3	Target 1: Record 6 or more large wader /shorebird species during a single monitoring event by the end of the first five year period. Target 3: Record greater large wader / shorebird mean diversity and abundance during wet phases than at Wetland 8 control site over first five year period.
Wetland 5	Target 1: Record 6 or more large wader /shorebird species during a single monitoring event by the end of the first five year period. Target 2: Record greater large wader / shorebird mean species richness and abundance during drawdown periods than during bank-full periods over first five year period. Target 3: Record greater large wader / shorebird mean diversity and abundance during wet phases than at Wetland 7/12 control site over first five year period.
Wetland 6	Target 1: Record 6 or more large wader /shorebird species during a single monitoring event by the end of the first five year period. Target 3: Record greater large wader / shorebird mean diversity and abundance during wet phases than at Wetland 8 control site over first five year period.

Wetland	Objective 6 Targets
Wetland 10	Target 1: Record 6 or more large wader /shorebird species during a single monitoring event by the end of the first five year period. Target 2: Record greater large wader / shorebird mean species richness and abundance during drawdown periods than during bank-full periods over first five year period. Target 3: Record greater large wader / shorebird mean diversity and abundance during wet phases than at Wetland 7/12 control site over first five year period.
Wetland 13	Target 1: Record 6 or more large wader /shorebird species during a single monitoring event by the end of the first five year period. Target 2: Record greater large wader / shorebird mean species richness and abundance during drawdown periods than during bank-full periods over first five year period. Target 3: Record greater large wader / shorebird mean diversity and abundance during wet phases than at Wetland 7/12 control site over first five year period.

5.3.7 Objective 7: Reduced impacts of Common Carp

The impacts of Common Carp are discussed in Section 3.1.6. Common Carp >25 mm in length feed benthically (Vilizzi 1998) and cause impacts to aquatic habitats through bioturbation and nutrient excretion (Matsuzaki *et al.* 2007), competition (Cadwallader 1978) and direct damage to submerged plants (Fletcher *et al.* 1985, King 1995, Roberts *et al.* 1995). Large adult Carp may be particularly problematic. Reducing the abundance Common Carp, particularly of large adults, within the wetlands of the Sugar Shack Complex is likely to have ecological benefits. In combination with the reinstatement of more natural wetting and drying patterns, Carp control would greatly assist with the achievement of Objectives 1, 2, 4, 5 and 6 above. In particular, the re-establishment of submerged aquatic littoral zone vegetation (Objective 1) would benefit from a reduced abundance of large adult Common Carp in managed wetlands (see Matsuzaki *et al.* 2007).

Carp are known to make movements between river and wetland habitats where they spawn (Stuart and Jones 2006, Jones and Stuart 2009). In lower Murrundi, Carp lateral movements from river to wetlands peak in Spring as water temperatures approach 16°C, a temperature which coincides with spawning (Conallin *et al.* 2012). It is believed that carp then return from the wetlands, to the more thermally stable river, in autumn to overwinter as water temperature decreases. This behaviour follows a movement model seen in North America (Penne and Pierce 2008). The South Australian Research and Development Institute (SARDI) has developed a carp screen that takes advantage of Carp behaviour to allow Carp movement in one direction only (Thwaites *et al.* 2007, Thwaites *et al.* 2010). These one-way carp screens can be installed on the inlet/outlet channels of managed wetlands such that Carp ≥ 250 mm in length can only move out of the wetland, not into the wetland.

Following refilling after the first managed drying event of Wetland 10 at Sugar Shack Complex (March 2013 – January 2014) an aggregation of large adult Carp was observed attempting to enter the wetland, prevented from doing so by the existing carp screens. With SARDI's one-way carp screens installed on other managed wetlands, as is proposed under the MRP, the seasonal movement of Carp from wetland to river channel will occur but movement back into the wetland will be prevented for fish larger than 250 mm. This should effectively exclude large adult Carp from managed wetlands except under flood conditions (see Section 5.4.3).

Complete drying events for managed wetlands provide an additional form of Carp management that is also consistent with other management objectives, in particular Objectives 1, 2, 4, 5 and 6.

The proposed tool for the measurement of this objective is Ma:mi (Fish) monitoring (see Section 0).

Targets relating to Objective 7 are described in Table 17.

Table 17. Targets relating to Objective 7.

Wetland	Objective 7 Targets
Wetland 2	Target 1: Over the first five year management period, record a decrease in the ratio of Common Carp to all fish (total count). Target 2: Over the first five year management period, record a decrease in the ratio of Common Carp measuring more than 250 mm to total carp caught during late Spring-early Summer monitoring.
Wetland 5	Target 1: Over the first five year management period, record a decrease in the ratio of Common Carp to all fish (total count). Target 2: Over the first five year management period, record a decrease in the ratio of Common Carp measuring more than 250 mm to total carp caught during late Spring-early Summer monitoring.
Wetland 10	Target 1: Over the first five year management period, record a decrease in the ratio of Common Carp to all fish (total count). Target 2: Over the first five year management period, record a decrease in the ratio of Common Carp measuring more than 250 mm to total carp caught during late Spring-early Summer monitoring.
Wetland 13	Target 1: Over the first five year management period, record a decrease in the ratio of Common Carp to all fish (total count). Target 2: Over the first five year management period, record a decrease in the ratio of Common Carp measuring more than 250 mm to total carp caught during late Spring-early Summer monitoring.

5.3.8 Objective 8: Increased management responsibility for MACAI/SSAC

Until recently Ngarrindjeri cultural values and interests have been historically overlooked in wetland management planning and implementation. Ngarrindjeri seek better recognition of their cultural values in the ongoing management of Murrundi, including Sugar Shack Complex, through mechanisms such as the KNY agreement. Ngarrindjeri are currently developing a process for assessing the Cultural Health of Murrundi including wetlands such as Sugar Shack Complex. This process will support Ngarrindjeri in identifying and then monitoring specific cultural values that support the wetland management objectives found in this plan. As both the traditional and legal owners of the Sugar Shack Complex, the MACAI and SSAC are seeking to take increased responsibility for management. Management activities that should ultimately be entrusted to the MACAI/SSAC include (but are not limited to):

- Development and implementation of the Ngarrindjeri Yannarumi program
- The operation of regulators and carp screens;
- The operation of pumps including the filling of temporary wetlands and the draining of permanent wetlands as required;
- Abiotic monitoring including surface water quality and groundwater;
- Biotic monitoring including tree health, photopoints, vegetation transects, ma:mi (fish), menperi (frogs) and mrayi (birds).

Ngarrindjeri intend that the operation and monitoring activities currently undertaken at Sugar Shack Complex by the SA MDB NRM Board are to be expanded under this Plan, and will be transitioned to the MACAI/SSAC over the first five year management period. This transition is likely to require government support, both during an initial capacity building transition phase and thereafter on an ongoing basis. Ngarrindjeri and DEWNR will continue to discuss these aspirations through the KNYA consultation process.

Targets relating to Objective 8 are described in Table 18.

Table 18 . Targets relating to Objective 8.

Whole Complex	Target 1: MACAI/SSAC fully responsible for regulator and carp screen operations by the end of the first five year management period Target 2: MACAI/SSAC fully responsible for the operation of pumps, including the filling of temporary wetlands and the draining of permanent wetlands, by the end of the first five year management period Target 3: MACAI/SSAC fully responsible for abiotic monitoring, including surface water quality and groundwater, by the end of the first five year management period Target 4: MACAI/SSAC fully responsible for biotic monitoring including tree health, photopoints, vegetation transects, ma:mi (fish), menperi (frogs) and mrayi (birds) by the end of the first five year management period Target 5: MACAI/SSAC will continue to develop and implement the Ngarrindjeri Yannarumi (cultural health) assessment program

5.4 Proposed Hydrological Management

5.4.1 Target Hydrograph Methodology

Timing and Duration of Connection

This Plan proposes hydrological management for four permanent (Wetlands 2, 5, 10 and 13) and two temporary (Wetlands 1 and 3) wetlands of the Sugar Shack Complex. The natural patterns of connection (to Murrundi main channel) and disconnection of the six wetlands proposed for management were determined using the model described by Robinson (2013). The Robinson model requires the input of a wetland's distance from the Murray mouth in river km and natural sill elevation in mAHD. The model simulates the timing and duration of all periods of connection between the River and the wetland (i.e. periods when river level was greater than natural sill elevation) for the period 1/7/1895 to 30/6/2009 (114 years) assuming natural river level fluctuations, i.e. no barrages, locks or dams and no upstream diversions. The four permanent wetlands of the Sugar Shack Complex proposed for management all appear to have artificially lowered sill elevations. The estimation of the natural sill elevations of wetlands proposed for management was required. The locations and elevations of natural sill elevations were determined from the digital elevation model (DEM) (Austin and Gallant 2010) for this area and are shown in Appendix 4. The model outputs for each of the six wetlands proposed for management are shown in Appendix 5.

The Robinson model shows that, for a given wetland, the timing and duration of connection varies from year to year. In some years multiple, short connection events occur, while in other years a wetland can remain connected for the entire year or several years. However, in most years most wetlands of the Sugar Shack Complex, under natural conditions, become connected once and remain connected for several months. It is these more typical events that the managed wetting and drying events described in this plan aim to mimic. For these typical events, percentiles for connection timing and connection duration have been calculated by the Robinson model and are presented in Appendix 5. It is these numbers that have been used to set the opening and closing dates for regulators on managed wetlands.

SWET Models

When River Murray wetlands are permanently inundated, a large volume of water is lost from the river system by evaporation from the open water surface in the wetland. When the wetland connection to the river is closed by a regulator, wetland water level and inundated area start to decrease as evaporative and other water losses in the wetland are no longer balanced by river inflows. The decreasing inundated area results in decreasing volumes of water lost to evaporation in the wetland and in some cases the wetland completely dries out, at which point the maximum rate of water savings occurs. The water savings can thus be calculated by comparing the volume of water lost to evaporation, for the case where the wetland is temporarily disconnected from the river, to the case where the wetland remains permanently inundated. The agreed model to calculate wetland water budgets for the MRP is the spreadsheet model SWET (Gippel 2005). This spreadsheet uses climate data, the wetland's hydrological operating regime, and the wetland's physical characteristics (e.g. bathymetry, hydraulic structures, and sediment bed parameters). From these data, the model calculates the flow into the wetland, water losses due to evaporation, and the wetland water level at a daily time-scale (DEWNR 2014a). The SWET model has been used to determine the hydrographs and water savings for Wetlands 2, 5 and 13 at Sugar Shack Complex.

Refill and Drawdown Rates

A refill rate of 3-5 cm/day is proposed when refilling managed wetlands, both permanent and temporary, of the Sugar Shack Complex. This refill rate is standard for managed wetlands in lower Murrundi. Drawdown rates in managed wetlands are based on the seasonally adjusted evaporation and seepage rates incorporated into the SWET models (DEWNR 2014a) and are therefore likely to resemble natural rates.

Dry Phases to Control Common Carp

The management vision for Sugar Shack Complex is that the hydrological conditions of the Complex resemble, as closely as possible, those experienced by the ancestors. However, Common Carp pose a serious threat to wetland condition in Murrundi and Carp were not present during the time of the ancestors. The threats posed by Carp are discussed elsewhere (see Section 3.1.6). Effective tools for the management of Carp are wetland drying and carp screens. Wetland drying eliminates large-bodied adult Carp, which cause the greatest impacts upon wetland condition (DEWNR 2012a). Carp screens prevent the immigration of large-bodied adult Carp upon refilling. Although small-bodied juvenile Carp are not excluded by carp screens, a period of 2 – 3 years without large-bodied Carp is likely following the refilling of a wetland with carp screens in place. Frequent and regular wetland drying, i.e. every 2 – 3 years, combined with carp screens, therefore largely excludes large-bodied Carp from wetlands, as well as minimising Carp breeding, leading to reduced Carp impacts.

For that reason the five year target hydrographs for each of the managed wetlands in the Sugar Shack Complex include two dry phases. For managed wetlands, dry phases are only achievable when natural (pre-regulation) river conditions in dry years are mimicked, i.e. the depth of these wetlands would prevent them from drying in median or wet years under natural conditions. Thus, the five year target hydrographs proposed represent a slight departure from the conditions experienced by the ancestors in order to manage Carp. Without this requirement, the dry years of the target hydrographs would only occur once every five to ten years, depending upon the sill elevation of the wetland.

In years when complete drying events are planned it is possible that weather conditions may prevent this. Lower than anticipated evaporation rates and/or unseasonal rainfall may result in a wetland remaining inundated to a sufficient depth to support large, adult Common Carp at the end of the planned drying phase. To extirpate any remaining Carp in this situation, the drying phase could be extended. However, given that the drying phases in this Plan typically end in late autumn/early winter (see Section 5.4.2) when evaporation rates are relatively low and rainfall likely, the drying phase may need to be extended considerably to completely dry the wetland. This would involve a significant departure from the planned patterns of wetting and drying, the timings of which have important ecological implications.

It is therefore proposed that mechanical pumps be deployed to rapidly remove any water remaining at the end of a planned complete drying event if large, adult Common Carp are still present in the wetland. The bathymetry of permanent wetlands planned for management (Austin and Gallant 2010) indicates that the locations of proposed and existing (Wetland 10) regulating structures correspond with the deepest areas. Therefore complete drying can be achieved if pumps are located at regulating structures.

Inter-annual Variability

The Robinson model clearly indicates the high degree of inter-annual variability in the behaviour of Murrundi under natural (pre-regulation) conditions. To recreate the hydrological conditions experienced by the ancestors it is necessary to mimic that natural variability through management. The five year target hydrograph for each wetland therefore aims to mimic wet, median and dry years under natural conditions. Wet years have been defined as those occurring 1 year in 5 (20th percentile), median years as those occurring 1 year in 2 (50th percentile).

As discussed above in relation to Carp control, the definition of a dry year for the purposes of this Plan is a year in which complete or near-complete drying of a wetland occurs. Due to the different sill elevations and depths of wetlands proposed for management, the natural return frequency of a complete drying event differs between wetlands. For Wetland 5 a complete drying would have occurred 1 year in 5 under natural conditions (80th percentile). For Wetland 13 the figure is 1 year in 10 (90th percentile) and for Wetland 2 one year in 20 (95th percentile).

Synchronisation

The key question regarding management synchronisation asks whether it is better to apply a dry (or median or wet) year scenario to all managed wetlands simultaneously, or is it better to stagger management such that different wetlands experience different conditions (dry, median or wet) at the same time? The only advantage in staggering management is that there will be a greater extent of inundated refugia habitat available for aquatic species able to migrate within the Complex at any given time. However, permanently inundated refugia habitat will remain throughout the Complex even if all managed wetlands are dry simultaneously. Yatco Creek, Creeks 11 and 14, Wetlands 7 and 12 and the main channel of Murrundi will remain unmanaged and therefore permanently inundated. Synchronised management of all managed wetlands more closely aligns with the MACAI vision for the Complex. For this reason it is proposed to synchronise the management of wetlands. All managed wetlands will be subjected to the following conditions over the five year life of this Plan:

Year 1	Year 2	Year 3	Year 4	Year 5
Dry	Median	Wet	Dry	Median

The exception to this rule is Wetland 10, which had a five year target hydrograph developed by a separate process (Tesoriero and Mason 2012). However, at the end of the five year period covered by this Plan it is proposed, subject to review of monitoring results, that hydrological management of Wetland 10 be synchronized with the other managed wetlands of the Complex.

Adaptive Management

All hydrographs proposed in this Plan will be subject to an adaptive management approach and therefore flexible. All aspects of proposed water regimes are subject to ongoing review including the timing, duration, full supply level (temporary wetlands only) and rate of refill. Adaptive management will be informed by the results of cultural, ecological and chemico-physical monitoring.

5.4.2 Target Hydrographs for Managed Wetlands

Wetland 1

Wetland 1 is a temporary wetland that is dry under typical pool level conditions. The application of its target hydrograph will therefore require the pumping of water from adjacent Yatco Creek. With a bed elevation of 0.80 mAHD at its deepest point and a sill elevation of 1.35 mAHD (Table 25), Wetland 1 can be filled by pumping to a maximum depth 0.55 m. It is proposed that 1.35 mAHD (sill elevation) be adopted as full supply level (FSL) for this wetland. The timing and duration of connection (filling) and disconnection (commencement of drawdown) (Table 19) have been determined from the Robinson model (see Appendix 5).

Table 19. Proposed dates of pumping to enable five year target hydrograph for Wetland 1.

Year Mimicked	Date*	Management Action
80th percentile (dry)	Year 1	Do not pump
50th percentile (med)	27-Jun-Yr 1	Pump to FSL and maintain
50th percentile (med)	19-Jan-Yr 2	Allow drawdown to commence
20th percentile (wet)	5-May-Yr 2	Pump to FSL and maintain
20th percentile (wet)	10-Feb-Yr 3	Allow drawdown to commence
80th percentile (dry)	Year 4	Do not pump
50th percentile (med)	27-Jun-Yr 4	Pump to FSL and maintain
50th percentile (med)	19-Jan-Yr 5	Allow drawdown to commence

*Note years refer to “water years”, which commence on 1 July and end on 31 June.

Wetland 2

Wetland 2 is a permanent wetland that is connected to the Murrundi main channel via Yatco Creek under typical pool level conditions. The application of its target hydrograph will require the construction and operation of a regulator. Wetland 2 has an elevation of approximately 0.04 mAHD at its deepest point (Table 25), although some deeper areas of small surface area may exist. Although the target hydrograph does not dry the wetland completely (Figure 20), the surface water remaining at the end of the drying phase in a mimicked dry year will be very shallow and small in area (Figure 21). Complete extirpation of Carp during a mimicked dry year, either naturally or with minimal active intervention, should be readily achievable. The timing and duration of connection (regulator opening) and disconnection (regulator closure) (Table 20) have been determined from the Robinson model (see Appendix 5).

Table 20. Proposed dates of regulator operation to enable five year target hydrograph for Wetland 2.

Year Mimicked	Date*	Management Action
unmanaged	1-Jul-Yr 1	Open regulator
95th percentile (dry)	15-Nov-Yr 1	Close regulator
50th percentile (med)	5-Jun-Yr 1	Open regulator
50th percentile (med)	7-Feb-Yr 2	Close regulator
20th percentile (wet)	15-Apr-Yr 2	Open regulator
20th percentile (wet)	8-Feb-Yr 3	Close regulator
95th percentile (dry)	2-Aug-Yr 4	Open regulator
95th percentile (dry)	15-Nov-Yr 4	Close regulator
50th percentile (med)	5-Jun-Yr 4	Open regulator
50th percentile (med)	7-Feb-Yr 5	Close regulator
50th percentile (return)	5-Jun-Yr 5	Open regulator

*Note years refer to "water years", which commence on 1 July and end on 31 June.

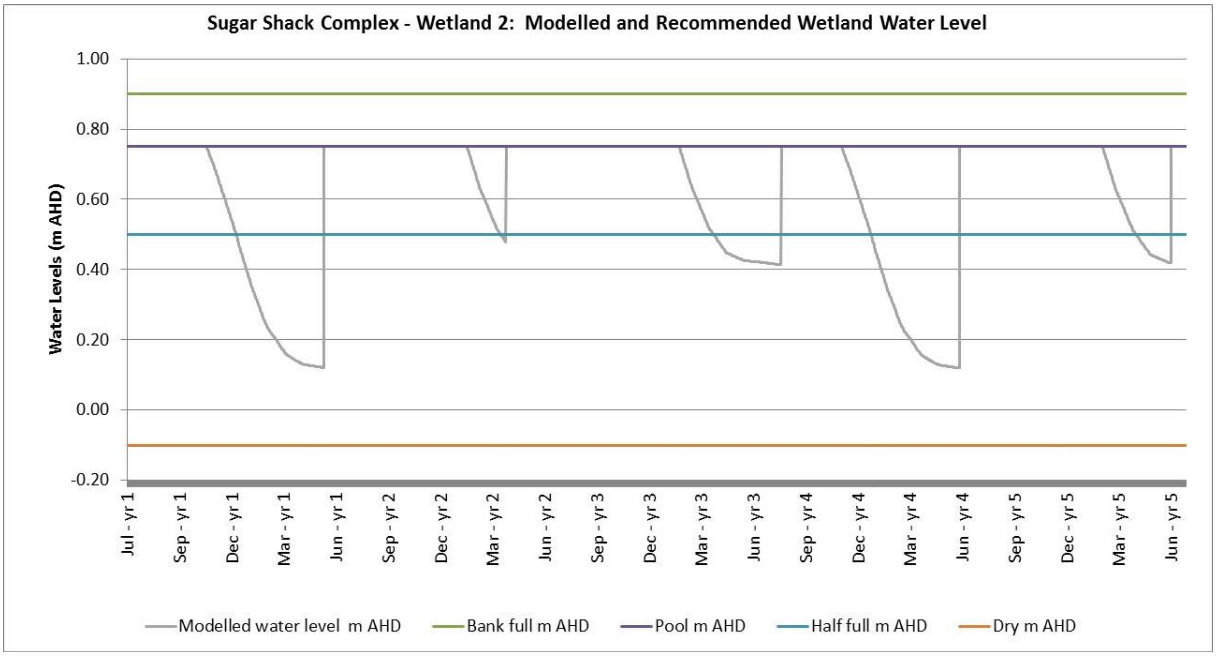

Figure 20. Five year target hydrograph for Wetland 2 based on SWET model.

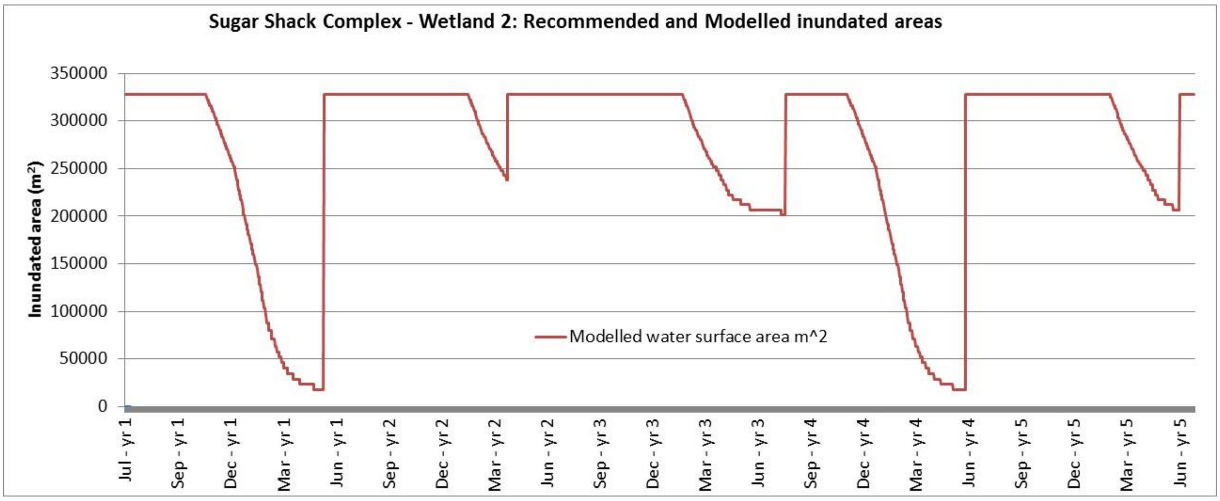

Figure 21. Five year target inundation extent for Wetland 2 based on SWET model.

Wetland 3

Wetland 3 is a temporary wetland that is dry under typical pool level conditions. The application of its target hydrograph will therefore require the pumping of water from adjacent Yatco Creek. With a bed elevation of 0.70 mAHD at its deepest point and a sill elevation of 2.57 mAHD (Table 25), Wetland 3 can be filled by pumping to a maximum depth of 1.87 m. Such a depth would make this wetland approximately two times deeper than the other managed wetlands of the Complex at FSL. Although the wetland would have filled to this depth on a near annual basis under natural conditions (see Appendix 5), filling the wetland to a lower level is likely to achieve a suite of ecological and cultural benefits with a smaller volume of water and a shorter duration of pumping, and therefore a lower cost.

Pumping from the river into temporary wetlands imports dissolved salt. When pumped wetlands drawdown through evaporation the imported salt remains. Repeated pumping and drying events can lead to the accumulation of salt in temporary wetlands, with potential impacts upon floodplain trees, other vegetation and aquatic fauna. Natural flood events connect temporary basins with the river and can remove accumulated salt, however river regulation has reduced the frequency of these events. Therefore pumping into temporary wetlands should be undertaken cautiously. A frequency of filling that is less than the natural frequency is ecologically justified to balance risks and benefits. For Wetland 3 pumping is proposed for years when median or wet conditions are being mimicked throughout the Complex, not dry years (see Section 5.4.1 above). This means pumping is proposed in three of the five year life of this Plan.

Wetland 3 has a band of peripheral Wuri (River Redgum) (Figure 22) and Black Box trees that extend down to an elevation of approximately 1.7 mAHD. Most of these trees are relatively young. There are also older, mature Wuri within this peripheral band of trees. The health of the older trees is variable. On the eastern side, at the base of the cliff that borders the floodplain, tree health appears good. However on the western side the older trees appear to be in poorer health (Figure 22). More regular inundation of Wetland 3 would likely improve the health of older Wuri and Black Box and help maintain the stand of younger trees through to maturity. Adoption of 1.7 mAHD as full supply level for regular watering (via pumping) of Wetland 3 will:

- water peripheral young and mature Wuri and Black Box trees, thus improving tree health and survivorship;
- create a wetland of approximately 1.3 hectares with a maximum depth of 1 m at FSL;
- create approximately 0.8 hectares of shallow (<0.5 m depth) littoral zone habitat at FSL, an area likely to become colonised by littoral zone emergent vegetation, providing cultural and ecological benefits, should the proposed frequency of inundation be maintained.

Figure 22. Wetland 3 showing (a) Relatively young peripheral Wuri and (b) an older peripheral Wuri in poor health (24 February 2014).

The timing and duration of connection (filling) and disconnection (commencement of drawdown) (Table 21) have been determined from the Robinson model (see Appendix 5).

Table 21. Proposed dates of pumping to enable five year target hydrograph for Wetland 3.

Year Mimicked	Date*	Management Action
80th percentile (dry)	Year 1	Do not pump
50th percentile (med)	27-Jun-Yr 1	Pump to FSL and maintain
50th percentile (med)	19-Jan-Yr 2	Allow drawdown to commence
20th percentile (wet)	5-May-Yr 2	Pump to FSL and maintain
20th percentile (wet)	10-Feb-Yr 3	Allow drawdown to commence
80th percentile (dry)	Year 4	Do not pump
50th percentile (med)	27-Jun-Yr 4	Pump to FSL and maintain
50th percentile (med)	19-Jan-Yr 5	Allow drawdown to commence

*Note years refer to "water years", which commence on 1 July and end on 31 June.

Wetland 5

Wetland 5 is a permanent wetland that is connected to the Murrundi main channel under typical pool level conditions. The application of its target hydrograph will require the construction and operation of a regulator. Wetland 5 has an elevation of approximately 0.33 mAHD at its deepest point (Table 25), although some deeper holes with small surface area may exist. Although the target hydrograph does not dry the wetland completely (Figure 23), the surface water remaining at the end of the drying phase in a mimicked dry year will be very shallow and small in area (Figure 24) and volume and readily pumped out to achieve a complete dry. The timing and duration of connection (regulator opening) and disconnection (regulator closure) (Table 22) have been determined from the Robinson model (see Appendix 5).

Table 22. Proposed dates of regulator operation to enable five year target hydrograph for Wetland 5.

Year Mimicked	Date*	Management Action
Unmanaged	1-Jul-Yr 1	Open regulator
80th percentile (dry)	16-Dec-Yr 1	Close regulator
50th percentile (med)	26-Jun-Yr 1	Open regulator
50th percentile (med)	24-Jan-Yr 2	Close regulator
20th percentile (wet)	16-Apr-Yr 2	Open regulator
20th percentile (wet)	23-Jan-Yr 3	Close regulator
80th percentile (dry)	5-Aug-Yr 4	Open regulator
80th percentile (dry)	16-Dec-Yr 4	Close regulator
50th percentile (med)	26-Jun-Yr 4	Open regulator
50th percentile (med)	24-Jan-Yr 5	Close regulator
50th percentile (return)	26-Jun-Yr 5	Open regulator

* Note years refer to “water years”, which commence on 1 July and end on 31 June.

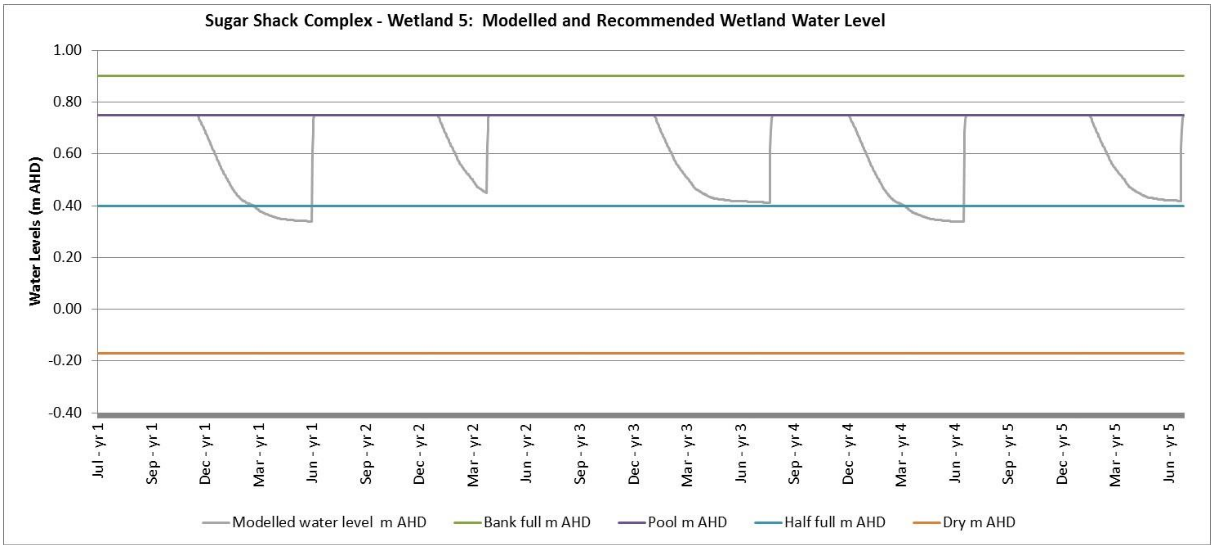

Figure 23. Five year target hydrograph for Wetland 5 based on SWET model.

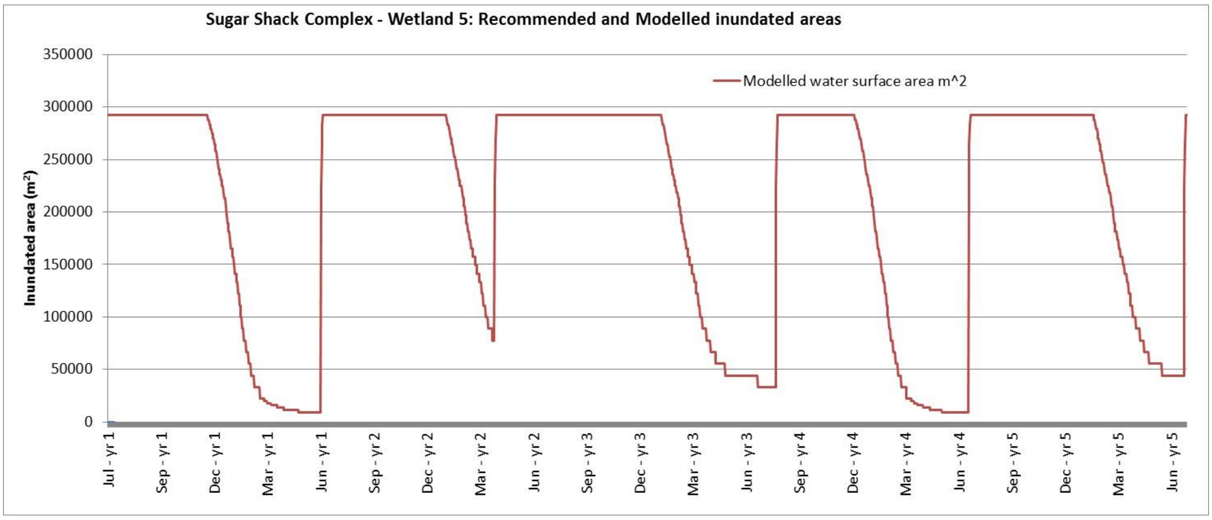

Figure 24. Five year target inundation extent for Wetland 5 based on SWET model.

Wetland 6

Wetland 6 is a temporary wetland that is dry under typical pool level conditions. The application of its target hydrograph will therefore require the pumping of water from the adjacent main channel of Murrundi (or inlet channel to Wetland 5). Minor works to temporarily or permanently block two artificial channels that have lowered the sill of this wetland to 1.3 mAHD will be required during inundation.

The salt accumulation risks associated with pumping discussed above for Wetland 3 apply equally to Wetland 6. To manage these risks while facilitating the benefits of inundation, pumping into Wetland 6 is proposed for years when median or wet conditions are being mimicked throughout the Complex, not dry years (see Section 5.4.1 above). This means pumping is proposed in three of the five year life of this Plan.

With a bed elevation of 0.95 mAHD at its deepest point and a sill elevation of 2.50 mAHD (Table 25), Wetland 6 can be filled by pumping to a maximum depth of 1.55 m. Although the wetland would have filled to this depth on a near annual basis under natural conditions (see Appendix 5), filling the wetland to a lower level is likely to achieve a suite of ecological and cultural benefits with a smaller volume of water and a shorter duration of pumping, and therefore a lower cost. It will also better support the existing vegetation.

Wetland 6 has a band of peripheral Wuri (River Redgum) and fringing sedges including Yalkari (*Cyperus gymnocaulous*) and *Juncus* sp., with the main body of the basin dominated by open stands of Lignum (*Duma florulenta*) and a groundlayer of low Chenopod shrubs and annual forbs (Kloeden 2013). The inundation of this vegetation type will not occur via hydrological management at any other managed wetland in the Complex and is likely to provide ecological benefits unique within the Complex including:

- provision of exceptional frog breeding habitat, particularly Southern Bell Frog (see Clemann and Gillespie 2012, DEWNR 2012a); and
- provision of breeding and feeding habitat for cryptic waterbirds.

Schulz (2007) recommended three months of inundation during late spring and early summer to promote Bell Frog breeding in lower Murrundi wetlands.

Maintaining the Lignum shrubland on the bed of Wetland 6 is an objective of water regime management. Excessive or insufficient inundation potentially threaten this vegetation. For optimal Lignum growth Roberts and Marston (2011) recommended:

- a frequency of inundation of once every one to five years;
- an inundation duration of three to seven months;
- a depth of inundation up to 1 m;
- a timing of inundation aligning with what is typical for the location.

A full supply level of 2 mAHD is proposed for Wetland 6. At this level the wetland is approximately 1 m deep at its deepest point and the fringing band of sedges is shallowly inundated, promoting vigour. This depth is optimal for Lignum and the health and recruitment of peripheral Wuri (River Redgum) may also be promoted. This depth may also encourage the use of inundated Lignum as nesting habitat for cryptic waterbirds.

The target hydrograph for Wetland 6 (Table 23) aims to strike a balance between the following objectives:

- restore the natural hydrology, using the Robinson model as a guide (see Appendix 5);
- minimise the risk of salt accumulation;
- protect and enhance the existing vegetation, particularly Lignum shrubland and fringing sedgeland and Wuri (River Redgum);
- promote frog breeding, particularly Southern Bell Frog.

Table 23. Proposed dates of pumping to enable five year target hydrograph for Wetland 6.

Year Mimicked	Date*	Management Action
80th percentile (dry)	Year 1	Do not pump
50th percentile (med)	12-Aug-Yr 2	Pump to FSL and maintain
50th percentile (med)	8-Jan-Yr 2	Allow drawdown to commence
20th percentile (wet)	6-Jul-Yr 3	Pump to FSL and maintain
20th percentile (wet)	6-Jan-Yr 3	Allow drawdown to commence
80th percentile (dry)	Year 4	Do not pump
50th percentile (med)	12-Aug-Yr 5	Pump to FSL and maintain
50th percentile (med)	8-Jan-Yr 5	Allow drawdown to commence

*Note years refer to "water years", which commence on 1 July and end on 31 June.

Wetland 10

A target hydrograph for Wetland 10 was developed via an alternative process to the other managed wetlands of the Complex (Tesoriero and Mason 2012). It is proposed that this target hydrograph (Figure 25) be adhered to for the current five year period. The implementation of this target hydrograph, unlike those for the other managed wetlands of the Complex, has already commenced. Wetland 10 was dried completely during spring and summer 2013/14 and refilling commenced on 10 January 2014. This was the first managed drying and refilling event for Wetland 10; the previous managed event in 2006 was interrupted by the Millenium Drought and the drought-breaking floods that followed. An excellent ecological response was observed following the 2014 refill with water birds being abundant across the wetland during January and February 2014, along with significant re-growth of aquatic and emergent native vegetation throughout riparian zone. For a full report see Adams *et al*.(2014).

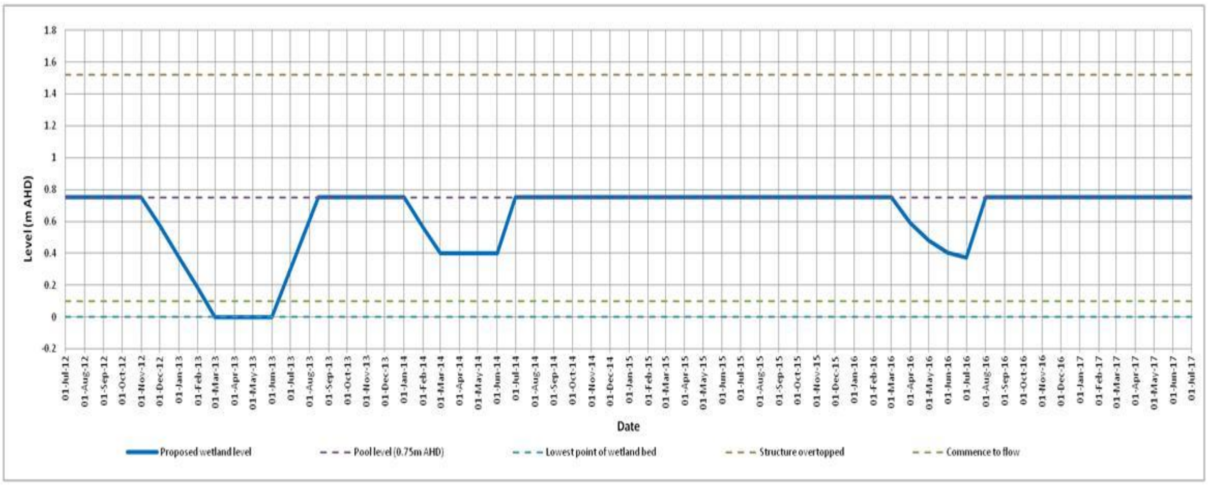

Figure 25. Five year target hydrograph for Wetland 10.

Wetland 13

Wetland 13 is a permanent wetland that is connected to the Murrundi main channel and Creek 14 under typical pool level conditions. The application of its target hydrograph will require the construction and operation of two regulators. Wetland 13 has an elevation of approximately 0.10 mAHD at its deepest point (Table 25), although some deeper areas with small surface area may exist. Although the target hydrograph does not dry the wetland completely (Figure 26), the surface water remaining at the end of the drying phase in a mimicked dry year will be very shallow and small in area (Figure 27). Complete extirpation of Carp during a mimicked dry year, either naturally or with minimal active intervention, should be readily achievable. The timing and duration of connection (regulator opening) and disconnection (regulator closure) (Table 24) have been determined from the Robinson model (see Appendix 5).

Table 24. Proposed dates of regulator operation to enable five year target hydrograph for Wetland 13.

Year Mimicked	Date*	Management Action
Unmanaged	1-Jul-Yr 1	Open regulator
90th percentile (dry)	13-Nov-Yr 1	Close regulator
50th percentile (med)	23-May-Yr 1	Open regulator
50th percentile (med)	9-Jan-Yr 2	Close regulator
20th percentile (wet)	4-Apr-Yr 2	Open regulator
20th percentile (wet)	17-Jan-Yr 3	Close regulator
90th percentile (dry)	25-Jul-Yr 4	Open regulator
90th percentile (dry)	13-Nov-Yr 4	Close regulator
50th percentile (med)	23-May-Yr 4	Open regulator
50th percentile (med)	9-Jan-Yr 5	Close regulator
50th percentile (med)	23-May-Yr 5	Open regulator

* Note years refer to "water years", which commence on 1 July and end on 31 June.

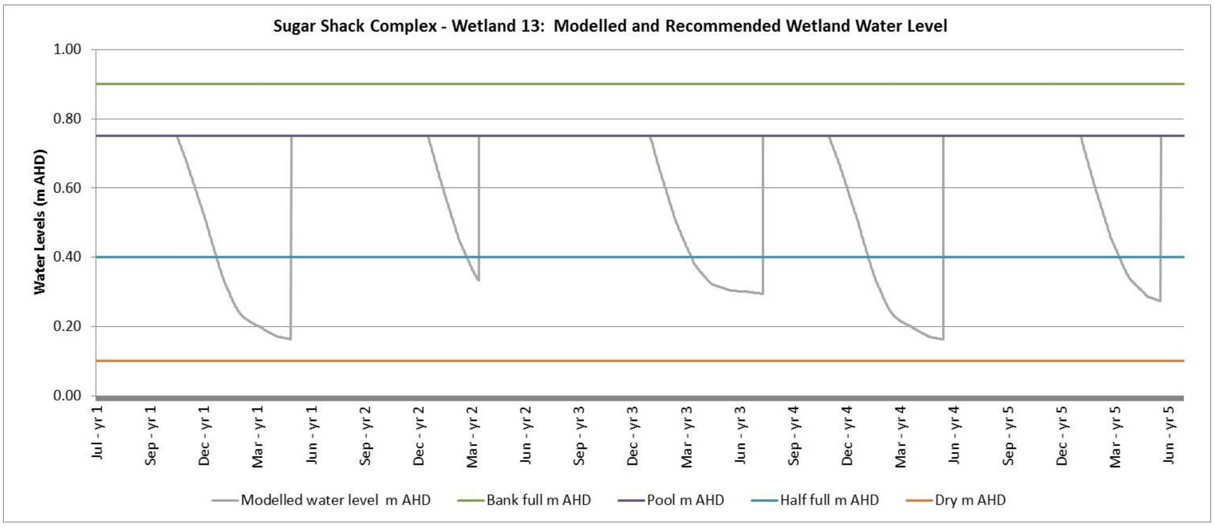

Figure 26. Five year target hydrograph for Wetland 13 based on SWET model.

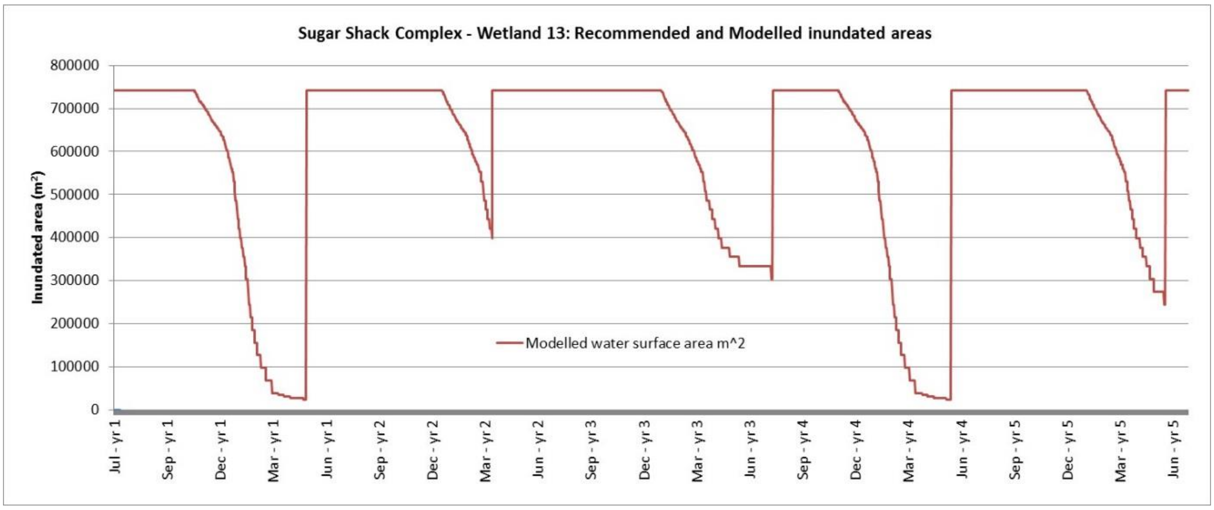

Figure 27. Five year target inundation extent for Wetland 13 based on SWET model.

Table 25. Summary of physical attributes of wetlands proposed for management.

Wetland ID	Sill Elev.* (mAHD)		Wetland Type	River Distance from Mouth (km)	Deepest Elev* (mAHD)	Full Supply Level** (mAHD)	Surface area when full** (ha)	Volume when full** (ML)
	Existing	Natural						
Wetland 1	1.35	1.35	temporary	259	0.80	1.35	0.6	1.7
Wetland 2	0.1	1.05	permanent	257	0.04	0.75	28.2	159.8
Wetland 3	2.57	2.57	temporary	257	0.70	1.70	1.7	6.3
Wetland 5	0.7	1.5	permanent	255	0.33	0.75	37.8	95
Wetland 6	1.3	2.5	temporary	255	0.95	1.95	7.3	45.8
Wetland 10	0.1	1.65	permanent (managed)	253	-0.17	0.75	26	120.4
Wetland 13	0.3	0.9	permanent	252	0.10	0.75	66.2	370.7

*estimated from DEM (see Appendix 4)

**FSL = typical pool level (0.75 mAHD) for permanent wetlands and as specified for temporary wetlands (Wetlands 1, 3 and 6).

5.4.3 Implications of High Flows

In the event of a flood during the five year period of this Plan the target hydrographs of affected wetlands may be temporarily interrupted. As flood conditions approach and while they persist it is recommended that both regulating structures and carp screens be opened. This is intended to reduce the likelihood of damage to the structures. Opening is also proposed for the ecological purpose of allowing exchange of materials (biota, nutrients, carbon) between the river and the wetlands during the flood pulse, an exchange that is central to the health of the riverine ecosystem (Junk *et al.* 1989).

Pilalki (*Macquaria ambigua ambigua*), a large bodied native fish, has been recorded in wetlands of the Sugar Shack Complex (Thwaites and Fredberg 2014) and it is possible that other large bodied species including Silver Perch and Freshwater Catfish may at times utilise the wetland habitats of the Complex (DEWNR 2012a). While carp screens are removed it is possible that adult large bodied native fish species may move into wetland habitats. Unlike Carp, these fish may be unable to move through carp screens back into river or anabranch habitats. Caution should therefore be used when reinstalling carp screens following their removal during a flood. It is recommended that the current practice of monitoring for fish and frogs in managed wetlands as soon as practicable following flood recession be maintained. Using an adaptive management approach, monitoring results will inform appropriate management following the flood, for example:

- Delaying the reinstallation of carp screens until adult large bodied native fish have emigrated from the wetland;

- Delaying the commencement of the next managed drawdown (if imminent) to allow the completion of frog breeding cycles;

- Bringing forward the commencement of drawdown and implementing a complete dry if Carp management is deemed a priority and weather conditions are appropriate (i.e. adequate rates of drawdown are anticipated).

If monitoring does not suggest otherwise, the default management approach is to recommence the target five year managed hydrograph where (and if) it was interrupted. Given the target hydrographs are based on natural flow patterns, it is likely that most floods will occur during proposed periods of connection (open regulator) and will therefore not require any departure from the proposed five year hydrographs.

5.5 Risk Management

The following risks have the potential to impact the cultural health of the Sugar Shack Complex. Nganguraku and Ngaiawang, being part of the Ngarrindjeri Nation will incorporate the following risks and associated mitigation strategies into the development and implementation of the Ngarrindjeri Yannarumi (cultural health) assessment program.

5.5.1 Salinisation

Salinisation, in the context of Murrundi, is the process by which saline groundwater moves upwards and into the root zone of floodplain vegetation, causing vegetation condition to decline (e.g. Wallace and Rengasamy 2011). In extreme cases, salty groundwater is expressed at the surface, increasing the salinity of surface waters and causing degradation of the aquatic ecosystem. Groundwater salinities of up to 65,100 µS/cm have been recorded in groundwater monitoring bores located on the floodplain of the Sugar Shack Complex (see Section 4.3.2), and groundwater depths are typically within 1 m of the surface (see Section 4.3.1). There has been some decline in tree health, and the death of some old River Redgums, in recent years within the Complex (AWE 2005). Salinisation may have contributed, however it is difficult to separate its effects from those of dehydration generally.

Managed drying events in floodplain wetlands present an increased risk of salinisation compared to the maintenance of permanent pool level conditions. When wetland water levels fall below river level, the hydraulic pressure of surface water is reduced, which may cause saline groundwater to enter wetlands (DEWNR 2012a). During the recent extended drying of Sugar Shack Complex associated with the Millennium Drought, groundwater levels in the vicinity of Wetland 10 fell (see Section 4.2), thus salinisation was avoided. However, this event was not representative of the drying events proposed under this Plan because the river level was also extremely low. Groundwater may be more likely to rise during wetland drying under typical pool level conditions in the river (DEWNR 2012a).

Salinisation threatens a range of Aboriginal cultural values at Sugar Shack Complex. The impacts of salinity can include direct damage to heritage sites (e.g. burials), indirect damage to heritage sites through salinity-induced erosion, death of significant trees such as scar trees, death of other culturally significant plant species and loss of habitat for culturally significant fauna (English and Gay 2005).

Mitigation:

- Install groundwater bores at strategic locations and monitor groundwater response to hydrological management. Adaptively manage to prevent vegetation degradation and the surface expression of saline groundwater, e.g. re-inundate dry wetland earlier than planned if salinisation appears imminent. Adjust the duration of future drying events accordingly.
- Monitor tree health in proximity to drying wetlands during drawdown/dry phase. If signs of stress are observed re-inundate wetland earlier than planned. Adjust the duration of future drying events accordingly.

5.5.2 Acidification

The exposure of previously permanently inundated sediments in some areas of Murrundi (e.g. the Lower Lakes) has caused problems associated with acid sulphate soils. The re-inundation of exposed acid sulphate soils can cause surface waters to become highly acidic and toxic to most aquatic species. The risk of this occurring at Sugar Shack Complex appears low. The recent complete drying of all wetlands in the Complex during the Millenium Drought, and subsequent re-inundation, did not lead to acidification.

It appears that sulfidic sediments are not present in the Complex. However, given the potentially severe ecological degradation that acidification can cause, this risk should be monitored.

Mitigation:

- Regularly monitor surface water pH in managed wetlands and adjust management accordingly should large, unanticipated shifts in pH occur.

5.5.3 Dehydration of Long-Lived Vegetation

Extended drying of wetlands may excessively dehydrate long-lived perennial plants in and around the wetlands of the Complex leading to poor health or death. Species of potential concern include Wuri (River Redgum), Black Box, Patcheroo (River Coobah) and Lignum. Although the frequency and duration of drying events proposed in this Plan are well within the tolerance range for these species (Roberts and Marston 2011), given their cultural and ecological significance, a cautious approach is recommended.

Mitigation:

- Do not dry for "unnaturally" long periods, as indicated by the natural patterns of connection and disconnection (see Appendix 5) and empirically derived water regime recommendations for these long-lived plants (Roberts and Marston 2011). For Wuri (River Redgum), the least drought tolerant of the four species mentioned, this equates to a maximum duration of drying no greater than two years.

- Monitor tree health in the vicinity of managed wetlands and adjust management in response to data (adaptively manage).

5.5.4 Common Carp Impacts

Large-bodied adult Common Carp could undo the benefits wetland drying and refilling by damaging or even preventing the return of submerged aquatic and littoral zone vegetation (see Section 3.1.6).

Mitigation:

- Include two dry phases in the five year target hydrograph for each managed wetland to extirpate Carp;

- Install carp screens on all regulating structures to prevent the immigration of large-bodied adult Carp into wetlands; and

- Monitor fish in managed wetlands and revise management according to learnings.

5.5.5 Prevention of Native Fish Movement

The movement of adult large-bodied fish between managed wetlands and the main channel or anabranches is prevented by carp screens. While wetlands are typically favoured by small-bodied native species that are not restricted by carp screens (DEWNR 2012a), adult large-bodied natives do occasionally enter wetlands. Pilalki (Callop) up to 38 cm in length have been recorded in wetlands at Sugar Shack Complex (Thwaites and Fredberg 2014). It is possible that some adult large-bodied native fish species could be disadvantaged by the prevention of their movement into and out of wetlands, particularly during high flows.

Mitigation:

- As high flows/floods approach and persist, and for a period following flood recession, open all regulators and carp screens until large-bodied native species are known to have emigrated, as determined via post-flood fish survey (see Section 5.4.3).

5.5.6 Biota Trapped in Disconnected Wetlands

Amphibious fauna (e.g. turtles, frogs) can survive wetland drying by moving to suitable refugia during the dry phase. However, obligate aquatic species (e.g. fish) are unable to emigrate when regulators are closed and become more susceptible to predation, poorly oxygenated water and dehydration. This is a natural process and provides benefits for the larger ecosystem such as food resources for predators (e.g. piscivorous waterbirds) and nutrient cycling. Under natural conditions permanently inundated refugia were likely important for the maintenance of populations of amphibious and aquatic fauna during periods of low river level. Refugia remain important under regulated conditions.

Mitigation:

- Retain some unmanaged (permanent) waterbodies adjacent to managed waterbodies throughout the Complex. These refugia will be the main channel of Murrundi, Yatco Creek, Wetland 7, Creek 11, Wetland 12 and Creek 14

5.5.7 Excessive Reed Growth

The re-introduction of a dry phase to the wetlands of the Complex may advantage reed species (*Phragmites australis*, *Typha* sp.) and result in dense stands of reeds dominating the beds of managed wetlands. Thus other habitat types, such as open water with submerged aquatic plants, may in time be excluded, reducing habitat diversity and biodiversity more generally.

Mitigation:

- Monitor wetland vegetation in managed wetlands and adjust hydrological management accordingly (adaptive management).

5.5.8 Blue-green Algal Blooms

Blue-green algal blooms can occur in lentic (non-flowing), warm, nutrient enriched waters. Some species of algae are toxic to fauna. The implementation of drying regimes may increase the likelihood of algal blooms because the inundation and decomposition of dry phase vegetation may temporarily increase the nutrient concentration of surface waters. Additionally, the closure of proposed Regulator 3 (see Figure 29) could convert Wetland 7, Creek 11 and Creek 14 from lotic (flowing) to lentic waterbodies, increasing the algal bloom risk.

Mitigation:

- Lower bed elevation and increase capacity of Creek 14 downstream of inlet to Wetland 13 to retain flows through this creek when Regulator 3 is closed under typical pool level conditions.

5.6 MRP Proposed On Ground Works

5.6.1 New Regulators

In addition to the existing regulator (to manage Wetland 10), the following new regulators are proposed to enable management of additional wetlands (Figure 29):

- New regulator 1: to manage the water regime of Wetland 2;
- New regulator 2: to manage the water regime of Wetland 5;
- New regulators 3 and 4: to manage the water regime of Wetland 13 (McAuley's).

Design criteria for the new regulators:

- The most cost effective, durable and environmentally benign materials (e.g. concrete box culverts) should be used;
- SARDI-designed one-way carp screens should be included;
- All regulators should double as channel crossings trafficable by 4WD vehicles.

5.6.2 Pumping into Wetlands

A number of wetlands in the Sugar Shack Complex have sill elevations above typical pool level and therefore, due to river regulation, are inundated far less frequently than would be the case without river regulation. Regular pumping into the following such wetlands is proposed to restore a more natural water regime:

- Wetland 1;
- Wetland 3; and
- Wetland 6.

5.6.3 Removal of Flow Restrictions

Flow in the two creeks of the Sugar Shack Complex is restricted in several locations (e.g. Figure 28). Removal of flow restrictions should lead to increased flow velocity in the creeks, with benefits for flow dependent biota including large-bodied native fish. Proposed locations for the removal of flow restrictions are (see Figure 29):

- Location 1: possible restriction associated with a tree fallen across Yatco Creek near Wetland 1;
- Location 2: sedimentation at upstream end of Wetland 7 near junction with Yatco Creek;
- Location 3: culverts under causeway near house need to be upgraded;
- Location 4: culverts under causeway over Yatco Creek need to be upgraded;
- Location 5: sedimentation in downstream end of Yatco Creek could be dredged;

- Location 6: rock weir on Creek 14 needs to be removed;
- Location 7: Creek 14 bed could be lowered for approximately 300 m. Creek bed is currently 0 – 10 cm above typical pool level in this location;
- Location 8: sedimentation in downstream end of Creek 14 could be dredged and narrow connection to river widened: and
- Location 9: sedimentation in Yatco Creek immediately upstream of causeway (Location 4) could be dredged.

Figure 28. Existing causeway across Yatco Creek (Location 4), which restricts flow.

5.6.4 Fencing

Existing fencing on the Sugar Shack Complex enables the management of livestock grazing including the exclusion of livestock from wetlands during drawdown events. Some of the existing fencing is in need of upgrading in some locations. With the proposal to regulate additional wetlands in the Complex comes the need to erect additional fencing for appropriate livestock management. The planning and installation of new fencing will need to be completed prior to the commencement of the first drying event if the benefits of drying are to be fully realised. Existing fencing is shown in Figure 29.

5.6.5 Track Upgrade

An existing vehicle track leading from high ground to the east down to the Sugar Shack Complex has been damaged by erosion and is in poor condition. It is envisaged that this track will require upgrading to enable large vehicles required for regulator construction to access the floodplain. The upgrading of this track will serve the dual purpose of improving vehicular access for ongoing future management of Sugar Shack Complex by SSAC and/or DEWNR. These future requirements should be taken into account when the track is upgraded.

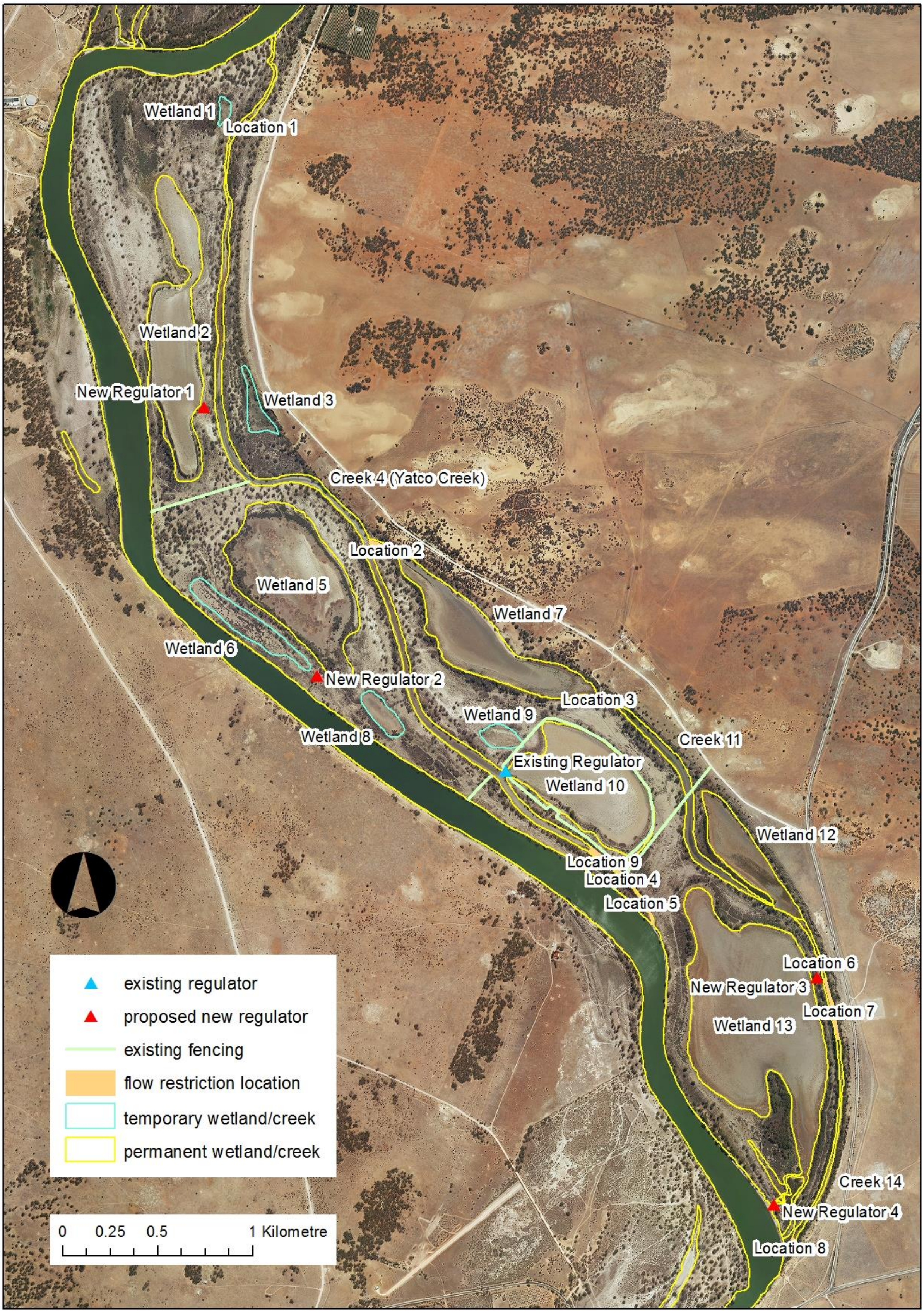

Figure 29. Map of Sugar Shack Complex showing locations of existing and proposed new regulators and other on-ground works.

5.7 Monitoring Plan

5.7.1 Ngarrindjeri Yannarumi (Cultural Health)

Nganguraku and Ngaiawang, being part of the Ngarrindjeri Nation, will monitor specific cultural health indicators as part of the ongoing cultural health assessment of Murrundi. Through the first stage of the Ngarrindjeri Yannarumi cultural health assessment process Ngarrindjeri will determine the processes needed for Ngarrindjeri to be involved in all aspects of wetland research and monitoring. Ngarrindjeri will have responsibility for this, and will continue to work with DEWNR to embed the practice in the ongoing management of Sugar Shack Complex.

5.7.2 Surface Water Quality

Surface water quality (EC, DO, turbidity and pH) has been monitored quarterly since September 2010 at three sites in Wetland 10, two sites on adjacent Yatco Creek and one site on the main channel of Murrundi (see Section 4.2, Figure 9). Additionally, baseline fish monitoring undertaken for the MRP measured water quality on two occasions in several wetlands (Thwaites and Fredberg 2014). It is proposed that existing monitoring locations and quarterly frequency be maintained and that additional sites be added to measure the water quality response in the additional wetlands proposed for, or likely to be influenced by, hydrological management: Wetlands 1, 2, 3, 5, 6 and 13 and Creek 14 (Table 26). For logistical simplicity water quality monitoring sites should correspond with frog and/or monitoring sites where possible. Monitoring in waterbodies not proposed for management (Murrundi main channel, Yatco Creek, Wetland 7 and Wetland 12) should also continue or be initiated as these are control sites that enable a before-after-control-impact (BACI) experimental design approach to monitoring. To enable the statistical analysis of water quality data, e.g. the calculation of mean and variance, it is proposed that a minimum of three sites be monitored in each waterbody on each occasion.

Table 26. Existing and proposed surface water quality monitoring at Sugar Shack Complex.

Wetland ID	Surface Water Quality Monitoring	
	existing	proposed new
Wetland 1		3 sites
Wetland 2	3 sites	
Wetland 3		3 sites
Wetland 5	3 sites	
Wetland 6		3 sites
Wetland 7 (control)	3 sites	
Wetland 10	3 sites	
Wetland 12 (control)		3 sites
Wetland 13	3 sites	
Creek 4 (Yatco Creek)	3 sites	
Creek 14		3 sites
Murrundi main channel	1 site	2 sites

5.7.3 Groundwater

Ngarrindjeri have cultural values and uses associated with groundwater. Groundwater depth and EC have been monitored quarterly since August 2004 at six sites in proximity to Wetland 10 (see Section 4.2, Figure 9). It is proposed that existing monitoring locations and frequency be maintained and that additional monitoring bores be installed to assess the groundwater response to proposed hydrological management of additional wetlands. Approximately 12 new bores will need to be installed throughout the Complex, with optimal locations determined according to cultural and ecological considerations, accessibility and predicted responsiveness of groundwater to surface water management. This will require negotiation between the MACAI, NRA and DEWNR.

5.7.4 Wuri/Karrarru (River Redgum) and other Tree Health

Tree health has been monitored in the vicinity of Wetland 10 since 2006 (Tesoriero and Mason 2012) and baseline tree health assessments have been undertaken for a number of other wetlands in the Complex (Kloeden 2013) (Table 27). Tree health monitoring enables the measurement of progress towards Objective 3 of this Plan: Maintain health of mature Wuri/Karrarru (River Redgum). It also enables the monitoring of the identified management risks of salinisation, acidification and dehydration of long-lived vegetation.

Additional tree health monitoring will be required at Wetlands 1 and 3. The lesser number of trees proposed for monitoring at these wetlands reflects their small size compared to other wetlands of the Complex. The frequency of past monitoring has varied between once and four times per year. It is recommended that a monitoring frequency of twice annually (in autumn and spring) be adopted to allow seasonal influences to be separated from management influences whilst not overburdening the monitoring program.

The health of monitored trees has been assessed using the methodology described by Souter *et al*. (2010) and it is recommended this approach continue. Wetlands 7 and 12 are not proposed for management but do have existing tree health monitoring. It is important that monitoring of these two wetlands continue as they are control sites that enable a before-after-control-impact (BACI) experimental design approach to monitoring. Additionally, tree health monitoring is proposed for temporary Wetland 8 to act as a control site for the response of tree health in temporary wetlands.

Table 27. Existing and proposed tree health monitoring at Sugar Shack Complex.

Wetland ID	Tree Health Monitoring	
	existing	proposed new
Wetland 1	-	6 trees
Wetland 2	35 trees	
Wetland 3	-	8 trees
Wetland 5	30 trees	
Wetland 6		8 trees
Wetland 7 (control)	25 trees	
Wetland 8 (control)		8 trees
Wetland 10	10 trees	
Wetland 12 (control)	9 trees	
Wetland 13	37 trees	

5.7.5 Photopoints

Photopoints provide a qualitative indication of vegetation change through time that can be a powerful communication tool for non-specialists. Given the ease with which they are obtained, regular photographs should be taken of all managed and control wetlands. The photopoints already established at Sugar Shack Complex are of two types; 'wetland photopoints' and 'transect photopoints'.

Wetland photopoints follow the "permanent photopoint" methodology described by Tucker (2004). The objective is to observe changes to wetland vegetation through time in response to management. Locations most likely to exhibit change are selected and the emphasis is on change at the wetland scale. Wetland photopoints have been established at Wetland 10. Wetland photopoint monitoring at Wetland 10 occurs four times annually in January, April, July and October. This timing and frequency should be maintained and applied at all wetlands listed in Table 19.

Transect photopoints were established by Kloeden (2013) at each of the vegetation transects established throughout the Complex in March 2013 (see Section 5.7.6 below). A single digital photograph was taken of each transect in the direction of its compass bearing, from a permanent photopoint star picket located 10 metres inland of the transect marker (Kloeden 2013). Transect photopoints aim to document vegetation change at the scale of individual transects. Transect photopoints should be re-photographed whenever transects are monitored. Existing and proposed new transect photopoints are listed in Table 29.

Photographs should also be taken of trees whenever tree health monitoring occurs.

Table 28. Existing and proposed new photopoint monitoring at Sugar Shack Complex.

Wetland ID	Wetland Photopoints		Transect Photopoints	
	existing	proposed new	existing	proposed new
Wetland 1	-	2 photopoints	-	3 photopoints
Wetland 2	-	3 photopoints	9 photopoints	
Wetland 3	-	2 photopoints	-	3 photopoints
Wetland 5	-	3 photopoints	9 photopoints	
Wetland 6		2 photopoints		3 photopoints
Wetland 7 (control)	-	3 photopoints	6 photopoints	
Wetland 8 (control)		2 photopoints		3 photopoints
Wetland 10	3 photopoints		3 photopoints,	
Wetland 12 (control)	-	2 photopoints	3 photopoints	
Wetland 13	-	4 photopoints	9 photopoints	

5.7.6 Vegetation Transects

Vegetation transects measure changes to the diversity, cover/abundance and extent of littoral zone vegetation in wetlands. Monitoring of vegetation transects enables the measurement of progress towards two objectives of this Plan:

- Objective 1: Increased extent and diversity of littoral zone vegetation; and
- Objective 2: Increased cover/abundance and diversity of native plant species on wetland bed during dry phase.

Vegetation transects also enable the monitoring of the identified management risks of salinisation, acidification, Common Carp impacts and excessive reed growth.

Transects have been established in several wetlands (Kloeden 2013) and additional transects will need to be established in others (Table 29) to comprehensively measure progress towards these management objectives. Wetlands 7 and 12 are not proposed for management but do have existing vegetation transects. It is important that monitoring of these two wetlands continue as they are control sites that enable a before-after-control-impact (BACI) experimental design approach to monitoring. Vegetation transects should be monitored twice annually, in late spring/early summer (high wetland water levels) to measure progress towards Objective 1, and in autumn at low water to measure progress towards Objective 2.

Table 29. Existing and proposed new vegetation transects at Sugar Shack Complex.

Wetland ID	Vegetation Transects	
	existing	proposed new
Wetland 1	-	3 transects
Wetland 2	9 transects	
Wetland 3	-	3 transects
Wetland 5	9 transects	
Wetland 6		3 transects
Wetland 7 (control)	6 transects	
Wetland 8 (control)		3 transects
Wetland 10	3 transects, 1 quadrat	
Wetland 12 (control)	3 transects	
Wetland 13	9 transects	

5.7.7 Ma:mi (Fish)

Regular fish monitoring at Sugar Shack Complex has to date focussed on Wetland 10 (2 sites) and nearby Yatco Creek (1 site). Baseline fish monitoring for the MRP has also been undertaken in Wetlands 2, 5, 7, 13 and Creek 4 (Yatco Creek) (3 sites each) (Thwaites and Fredberg 2014). Fish monitoring will enable the measurement of progress towards Objective 4 of this Plan: increased abundance and breeding success of culturally significant fauna.

Existing sites are largely adequate to measure the Complex-scale response of fish to management However, an additional site is proposed for Creek 14 near its junction with the main channel of Murrundi. Monitoring of this additional site will measure the effectiveness of the excavation works proposed for Creek 14 at providing habitat for flow-dependent fish species. Wetland 12 also requires monitoring. Wetlands 7 and 12 are not proposed for management and therefore provide comparable control sites, enabling a before-after-control-impact (BACI) experimental design approach to monitoring. Wetland 7 has existing sites monitored for the MRP baseline survey while Wetland 12 has not been surveyed to date. Monitoring of all new sites should commence prior to the on-ground works proposed in this Plan. A complete list of existing and proposed new fish monitoring sites is provided in Table 30.

The frequency of past monitoring has been variable. It is proposed that future monitoring occur annually in spring, when managed wetlands will be inundated and usually connected to the main channel of Murrundi, i.e. regulators will be open.

Opportunistic fish monitoring should be undertaken at all or a sub-set of wetlands following the recession of floods to inform post-flood regulator operations and the recommencement of hydrological management (see Section 5.4.3).

To enable quantitative comparison with existing data, monitoring techniques should be consistent with those employed at Sugar Shack Complex to date. Monitoring techniques should also be consistent with other managed wetlands in lower Murrundi, particularly those with management initiated by the MRP, to enable broader scale comparisons. Therefore, sites in Wetland 10 should be monitored with two fyke nets and five bait traps, set overnight. All other sites should be monitored using the standard technique developed for the MRP (DEWNR 2012b) and employed for the MRP baseline survey (Thwaites and Fredberg 2014), i.e. three bait traps, three fyke nets and a gill net, set overnight. Fish monitoring is not proposed for temporary wetlands to be filled via pumping.

Table 30. Existing and proposed fish monitoring at Sugar Shack Complex.

Wetland ID	Fish Monitoring	
	existing	proposed new
Wetland 2	3 sites	
Wetland 5	3 sites	
Wetland 7 (control)	3 sites	
Wetland 10	2 sites	
Wetland 12 (control)		3 sites
Wetland 13	3 sites	
Creek 4 (Yatco Creek)	3 sites	
Creek 14		1 site (downstream end)

5.7.8 Menperi (Frogs)

Regular frog monitoring at Sugar Shack Complex has to date focussed on Wetland 10 (2 sites) and nearby Yatco Creek (1 site). The monitoring program was expanded in December 2013 to include Wetlands 2, 5, 7 and 13. Frog monitoring will enable the measurement of progress towards Objective 5 of this Plan: increased frog abundance.

Monitoring should be expanded to include Wetlands 1, 3 and 6, which are temporary wetlands proposed for watering in part to stimulate frog breeding. Wetland 12 should also be monitored for frogs. Wetlands 7, 8 and 12 are not proposed for management and therefore provide comparable control sites, enabling a before-after-control-impact (BACI) experimental design approach to monitoring. Wetland 7 has existing sites first monitored in December 2013 while Wetlands 1, 8 and 12 have not been surveyed to date. Wetland 13 has two sites established in December 2013, however it is a large wetland and the habitat at its southern end is quite different from that at its northern end where the existing sites are located. An additional site in Wetland 13 is proposed at its southern end. Monitoring of all new sites should commence prior to the on-ground works proposed in this Plan. A complete list of existing and proposed new frog monitoring sites is provided in Table 31.

Past monitoring has generally occurred annually in spring/early summer. It is proposed that this frequency and timing of future monitoring be maintained to coincide with the inundation of managed wetlands and peak frog calling activity. Standardised techniques employed previously at Sugar Shack Complex and throughout lower Murrundi should continue to be used (see Tucker 2004, DEWNR 2012b).

Table 31. Existing and proposed frog monitoring at Sugar Shack Complex.

Wetland ID	**Frog Monitoring**	
	existing	**proposed new**
Wetland 1		1 site
Wetland 2	3 sites	
Wetland 3		1 site
Wetland 5	2 sites	
Wetland 6		2 sites
Wetland 7 (control)	3 sites	
Wetland 8 (control)		1 site
Wetland 10	2 sites	
Wetland 12 (control)		2 sites
Wetland 13	2 sites	1 site (southern end)
Creek 4 (Yatco Creek)	1 site	

5.7.9 Mrayi (Birds)

Waterbird monitoring at Sugar Shack Complex enables the quantitative measurement of progress towards Objective 4: Increased abundance and breeding success of culturally significant fauna, and Objective 6: Increased abundance of large waders and shorebirds. Monitoring of both managed and unmanaged (control) wetlands will enable a before-after-control-impact (BACI) approach to the assessment of management outcomes.

Regular waterbird monitoring has to date focussed on Wetland 10. In March 2013, baseline waterbird surveys of Wetlands 2, 5, 7, 12 and 13 and Creek 11 were conducted (Bailey and Paton 2013). It is proposed that temporary Wetlands 1, 3 and 6 (managed) and Wetland 8 (control) also be included in the monitoring program. Monitoring of all new sites should commence prior to the on-ground works proposed in this Plan. A complete list of existing and proposed new waterbird monitoring sites is provided in Table 32.

Waterbird monitoring techniques should follow the standard approach described by Tucker (2004), which is recommended for all wetlands under the MRP (DEWNR 2012b). All wetlands of the Sugar Shack Complex are small enough to enable a total count of waterbirds present to be made, i.e. they are less than 100 ha in size (Tucker 2004). The number and location of monitoring sites should be selected to ensure the entire wetland is surveyed and birds are counted once only. Bailey and Paton (2013) used a more intensive methodology for the 2013 baseline surveys, i.e. 12 consecutive five minute counts over a one hour period, with the abundance of each species averaged across all counts. If resources are sufficient the Bailey and Paton methodology should be used at all sites due to its greater accuracy.

Tucker (2004) recommended waterbird surveys be conducted during the spring months (September to October) when birds are likely to be breeding and towards the end of summer (February to March), to record birds using the wetland as a drought or summer refuge. It is also important to consider the hydrological cycle, as waterbird abundance, diversity and community composition will change in response to wetting and drying (DEWNR 2012a). At Sugar Shack Complex it is recommended that as a minimum waterbird surveys be conducted two to five weeks after the refilling of managed wetlands (i.e. in winter/spring) and again during drawdown when water levels have fallen sufficiently to expose 20 – 50% of the wetland bed (i.e. in late summer/autumn). These times are anticipated to correspond with peak overall waterbird abundance (post refilling) and peak diversity of large wader and shorebirds (drawdown). To permit a comparison between managed and control sites all monitoring sites should be monitored whenever monitoring is undertaken.

Surveys should occur in the morning and evening to provide the greatest likelihood of detecting all species (Tucker 2004). Cryptic species such as Rails and Crakes are most likely to be seen at these times.

Table 32. Existing and proposed waterbird monitoring at Sugar Shack Complex.

Wetland ID	Waterbird Monitoring	
	existing	proposed new
Wetland 1		1 site
Wetland 2	1 site	
Wetland 3		1 site
Wetland 5	1 site	
Wetland 6		2 sites
Wetland 7 (control)	2 sites	
Wetland 8 (control)		1 site
Wetland 10	2 sites	
Wetland 12 (control)	1 site	
Wetland 13	2 sites	
Creek 11	1 site	

5.8 Evaluation, Review and Reporting

The on-going management of Sugar Shack Complex requires regular review of the success of this Plan, evaluation of monitoring data and adaptation of actions as required. This process should be conducted through the NRA's KNY agreement process and incorporating the appropriate NRA programs and organisations (e.g. MACAI). Changes to the distribution and abundance of biota, ecological processes and services are likely to unfold during individual and successive wetting and drying phases and are difficult to predict. River conditions, and thus water availability and flow regime, are also difficult to predict more than a few months in advance and thus wetland operations may have to respond to changing river conditions at any time. This makes data integrity, storage and analysis critical, as it does effective communication between data analysts and wetland managers (if they are not one and the same).

An annual review of monitoring data and Complex condition should be undertaken to assess progress towards targets, determine if active mitigation of risks is required and update the conceptual understanding of the system if necessary. A full review of the Plan should be conducted at the end of the proposed five year hydrological regime and a revised Plan for the following five year period should be prepared.

For the annual reviews to be effective they need to potentially update the following:

- target hydrograph, based on new knowledge and understanding;
- values, threats, objectives and risk management based on the evaluation of monitoring data; and
- monitoring schedule to reflect any changes to the above.

A reporting element is required to comply with Government requirements. The South Australian Government is required to be informed of any changes to the management objectives, wetland operational plan or the monitoring program. This requirement ensures that any changes are in agreement with wetland management plan guidelines, the scope of this project and to ensure water allocation arrangements for the wetland are still appropriate.

Records of all monitoring data and management actions, indicating dates, actions carried out and results will be retained by the wetland manager as well as provided to the Government. Ngarrindjeri must be involved in the adaptive management evaluation review process and will be responsible for the review of the cultural health of the wetland. Ngarrindjeri also seek a joint-management arrangement for the Sugar Shack Complex (excluding the area already managed by SSAC – this does not exclude existing and future partnerships).

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Appendix 1

Fish survey and baseline monitoring results for Sugar Shack Complex

Species	Common Name	Wetland 10								Wetland 2		Wetland 5	Wetland 7		Wetland 13		Yatco Creek	
		Jun-06	Nov-10	Nov-11	Feb-12	Dec-12	Mar-13	Dec-13	Mar-14	May-13	Oct-13	Oct-13	May-13	Oct-13	May-13	Oct-13	Apr 13	Oct 13
Native Fish																		
Bidyanus bidyanus	Silver Perch																	1
Craterocephalus stercusmuscarum fulvus	Un-specked Hardyhead	30		51		5	9	2	2	1	1	2		18		1	17	3
Hypseleotris spp.	Carp Gudgeon complex	32	3	248	45	107	63	59	30	40	295	24	88	401	11	500	437	43
Macquaria ambigua ambigua	Golden Perch, Callop	1			14	13	6	2			8	3		6		14	1	42
Melanotaenia fluviatilis	Murray-Darling Rainbowfish	1		1														
Nematalosa erebi	Bony Bream	14	19	9	131	18	34	26	12	29	74	27	22	29	21	20	27	33
Philypnodon grandiceps	Flat-headed Gudgeon	4		38	43	29	2	1	2		1		1				2	1
Philypnodon macrostomus	Dwarf Flat-headed Gudgeon			1	2	1			1		1				6	5	2	
Retropinna semoni	Australian Smelt	48		128	9			21	1	1	8	16	20	99	8	202	3	50
Alien Fish																		
Carassius auratus	Goldfish			1	2	58		1		1	3	5			1	2	5	12
Cyprinus carpio	Common Carp		51	29	168	87	33	13	2	11	1118	3851	14	103	2	137	21	26
Gambusia holbrooki	Eastern Gambusia	31		42	2	65	120	6	31	150			61	14	93		120	

Species	Common Name	Wetland 10								Wetland 2		Wetland 5	Wetland 7		Wetland 13		Yatco Creek	
		Jun-06	Nov-10	Nov-11	Feb-12	Dec-12	Mar-13	Dec-13	Mar-14	May-13	Oct-13	Oct-13	May-13	Oct-13	May-13	Oct-13	Apr 13	Oct 13
Misgurnus anguillicaudatus	Oriental Weatherloach								2									
Perca fluviatilis	Redfin Perch			11	14	3										1		
Opportunistic																		
Limnodynastes sp. tadpoles						2												
Litoria raniformis tadpoles	Southern Bell Frog		4															
Cherax destructor	Yabby	6			1	4												
Chelodina longicollis	Long-neck Tortise					1												

Appendix 2

Frog survey and baseline monitoring results for Sugar Shack Complex

<table>
<tr><th rowspan="2">Common name</th><th rowspan="2">Species name</th><th colspan="7">Wetland 10</th><th>Wetland 2</th><th>Wetland 5</th><th>Wetland 7</th><th>Wetland 13</th></tr>
<tr><th>Sep-04</th><th>Nov-08</th><th>Nov-10</th><th>Sep-11</th><th>Dec-11</th><th>Dec-12</th><th>Jan-14</th><th>Dec-13</th><th>Date</th><th>Date</th><th>Dec-13</th></tr>
<tr><td>Common Froglet</td><td>Crinia signifera</td><td>10-50</td><td rowspan="6">NO FROGS HEARD</td><td></td><td>2-9</td><td></td><td rowspan="6">NO FROGS HEARD</td><td></td><td></td><td></td><td rowspan="6">NO FROGS HEARD</td><td rowspan="6">NO FROGS HEARD</td></tr>
<tr><td>Eastern Banjo Frog</td><td>Limnodynastes dumerilii</td><td>10-50</td><td>2-9</td><td></td><td></td><td>2-9</td><td></td><td></td></tr>
<tr><td>Eastern Sign-bearing Frog</td><td>Crinia parinsignifera</td><td>10-50</td><td>10-50</td><td>2-9</td><td></td><td>10-50</td><td>2-9</td><td>10-50</td></tr>
<tr><td>Peron's Tree Frog</td><td>Litoria peronii</td><td></td><td>2-9</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>*Southern Bell Frog</td><td>Litoria raniformis</td><td>2-9</td><td>4†</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Spotted Grass Frog</td><td>Limnodynastes tasmaniensis</td><td>10-50</td><td>2-9</td><td></td><td>2-9</td><td>>50</td><td></td><td></td></tr>
</table>

*Listed nationally vulnerable (*EPBC Act 1999*)

†Tadpoles captured during fish monitoring

Appendix 3

Waterbird survey and baseline monitoring results for Sugar Shack Complex

Species	Wetland 10*												Wetland 2**	Wetland 5**	Wetland 7**	Creek 11**	Wetland 12**	Wetland 13**	Flood plain* **
	Sep-04	Nov-08	Jun-11	Sep-11	Mar-13	Sep-13	17-Jan-14	23-Jan-14	31-Jan-14	6-Mar-14	4-Apr-14	6-May-14	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13
Australasian Grebe				7													0.8		
Australasian Shoveler								8	7	16	2							0.5	
Australian Pelican	170		71		10	63				12		7	65	0.5	27.7		6.4	108.5	
Australian Shelduck	8			6		2	3		19				1.4	98.1	0.2			0.7	
Australian Wood Duck	20			38		40						20				109.5	34.6		
Baillon's Crake								1											
Black Swan									3										
Black-fronted Dotterel	1												4	5				1.5	
Black-tailed Native Hen	30				7		3							60				5.7	
Black-winged Stilt							2	80	49	30									
Blue-billed Duck				1															

Species	Wetland 10*												Wetland 2**	Wetland 5**	Wetland 7**	Creek 11**	Wetland 12**	Wetland 13**	Flood plain* **
	Sep-04	Nov-08	Jun-11	Sep-11	Mar-13	Sep-13	17-Jan-14	23-Jan-14	31-Jan-14	6-Mar-14	4-Apr-14	6-May-14	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13
Caspian Tern	15					2													
Chestnut Teal	30				16					2				25					
Clamorous Reed-warbler	1																		
Darter				1						1						0.5	0.2		
Dusky Moorhen																1			
Eurasian Coot			26		6			42	131	28	2					3.7	8	6.3	
Freckled Duck										2	1								
Glossy Ibis									1										
Great Cormorant	2														4.2			0.1	
Great Egret			9	13	1								0.3		0.8	2.2	1.5	1.9	
Grey Teal	3		2	32	169		101	495	436	359	209	71	113.1	290	52.3		56.5	224.1	
Hardhead							6	13		5									
Hoary-headed Grebe									20	20	1								
Little Black Cormorant	2		43	8									39.4		0.6		1.5		

Species	Wetland 10*												Wetland 2**	Wetland 5**	Wetland 7**	Creek 11**	Wetland 12**	Wetland 13**	Flood plain* **
	Sep-04	Nov-08	Jun-11	Sep-11	Mar-13	Sep-13	17-Jan-14	23-Jan-14	31-Jan-14	6-Mar-14	4-Apr-14	6-May-14	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13
Little Egret			8																
Little Grassbird	1																		
Little Pied Cormorant			26													0.2			
Masked Lapwing	2						14	8	10	4				1.5				1.1	
Musk Duck			2							6									
Nankeen Night Heron																			6
Pacific Black Duck	18		6	4	40		49	37	154		7	5	28.5	10.8	6.6	2	2.9	3.4	
Pacific Heron								1	1										
Pied Cormorant				3											7.4	0.2	1.5		
Pink-eared Duck					19			219	148	103	138	2						0.9	
Red-kneed Dotterel			10	6			12						5.8	41.6					
Red-necked Avocet	16					69				6									
Royal Spoonbill					3														1

Species	Wetland 10*											Wetland 2**	Wetland 5**	Wetland 7**	Creek 11**	Wetland 12**	Wetland 13**	Flood plain* **
	Sep-04	Nov-08	Jun-11	Sep-11	Mar-13	Sep-13	17-Jan-14	23-Jan-14	31-Jan-14	6-Mar-14	4-Apr-14	6-May-14	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13	Mar-13
Sacred (Australian White) Ibis	3		1		2				5	3				4	0.5		0.8	1.7	
Silver Gull	1					2												0.5	
Straw-necked Ibis														1					
White-faced Heron	1		1	1				1	7	4	2			0.2	1.5	0.3	0.3	0.8	
Yellow-billed Spoonbill	4		1		9	1			9	6	6	1	1.2		0.2			6.2	

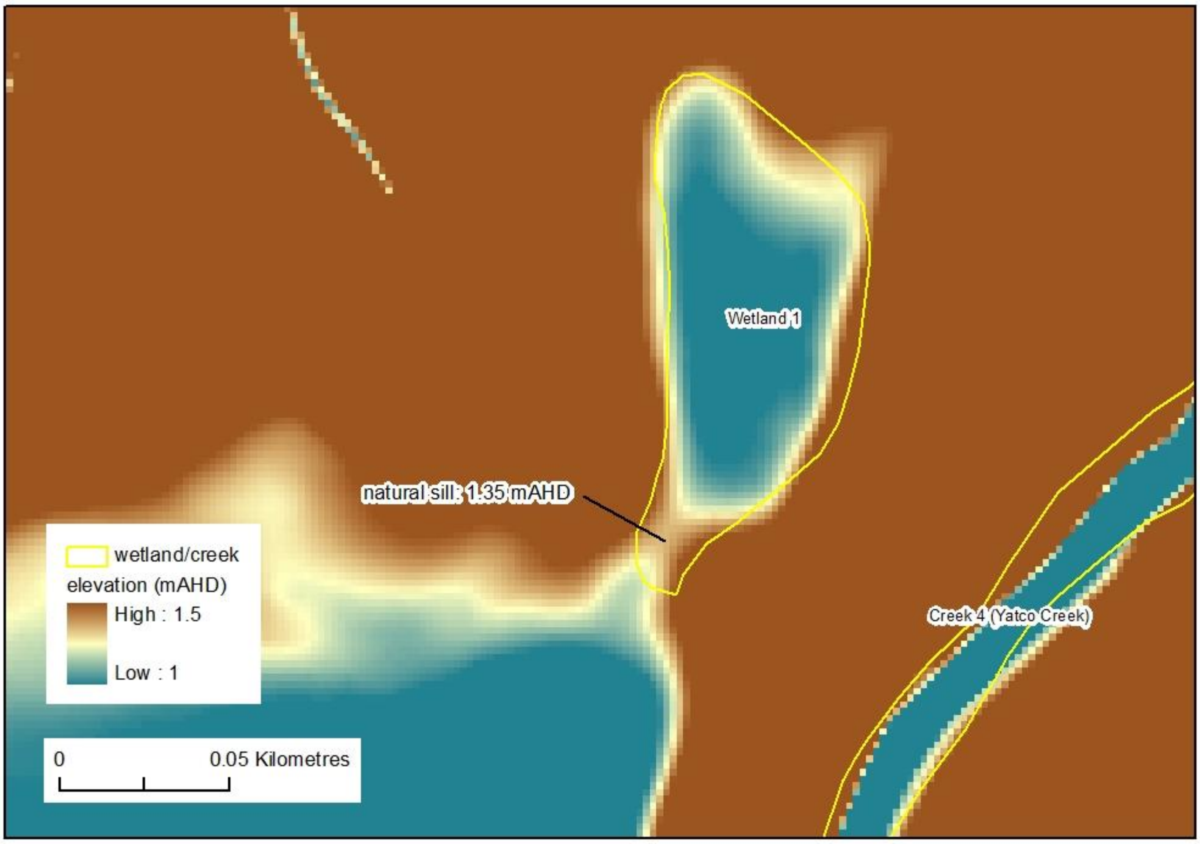
* Data based on a single count using technique described by Tucker (2004).

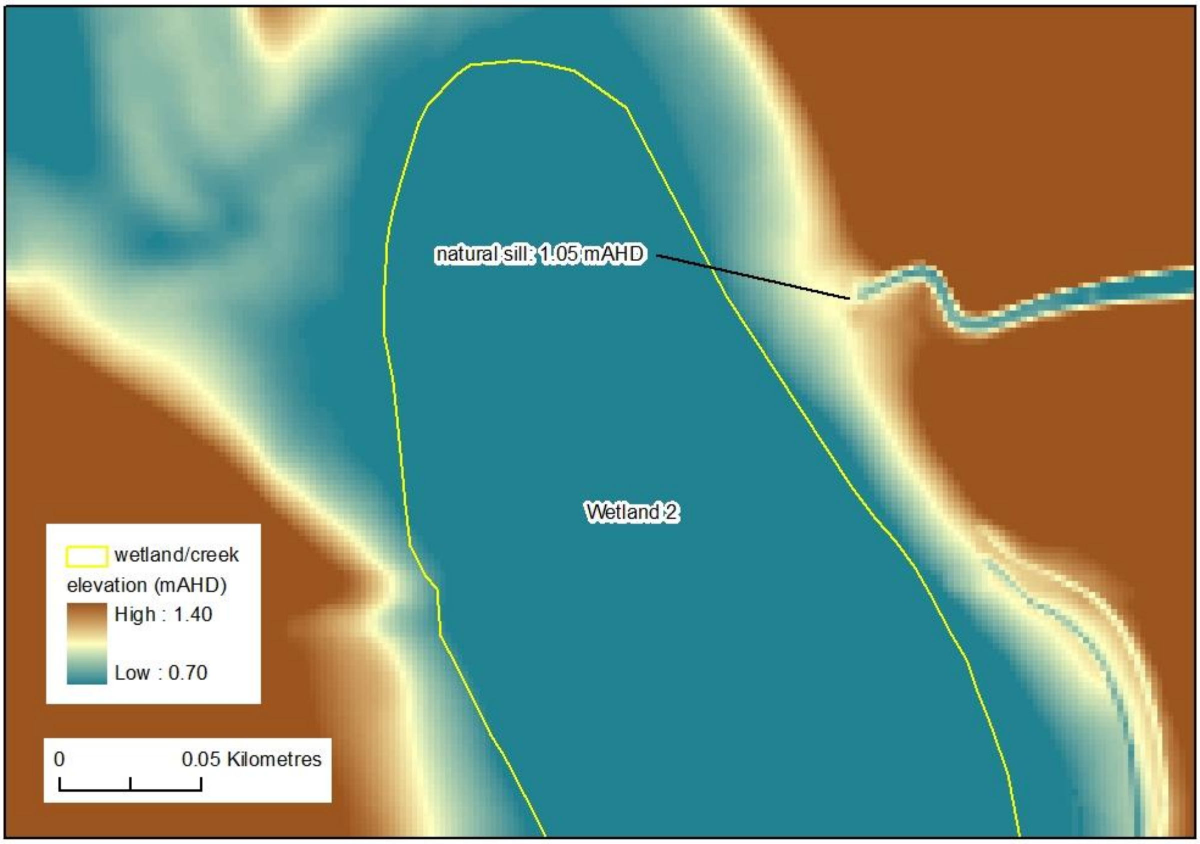
** Data based on average of 13 counts of 5 minutes each over 1 hour (Bailey and Paton 2013), hence decimal component.

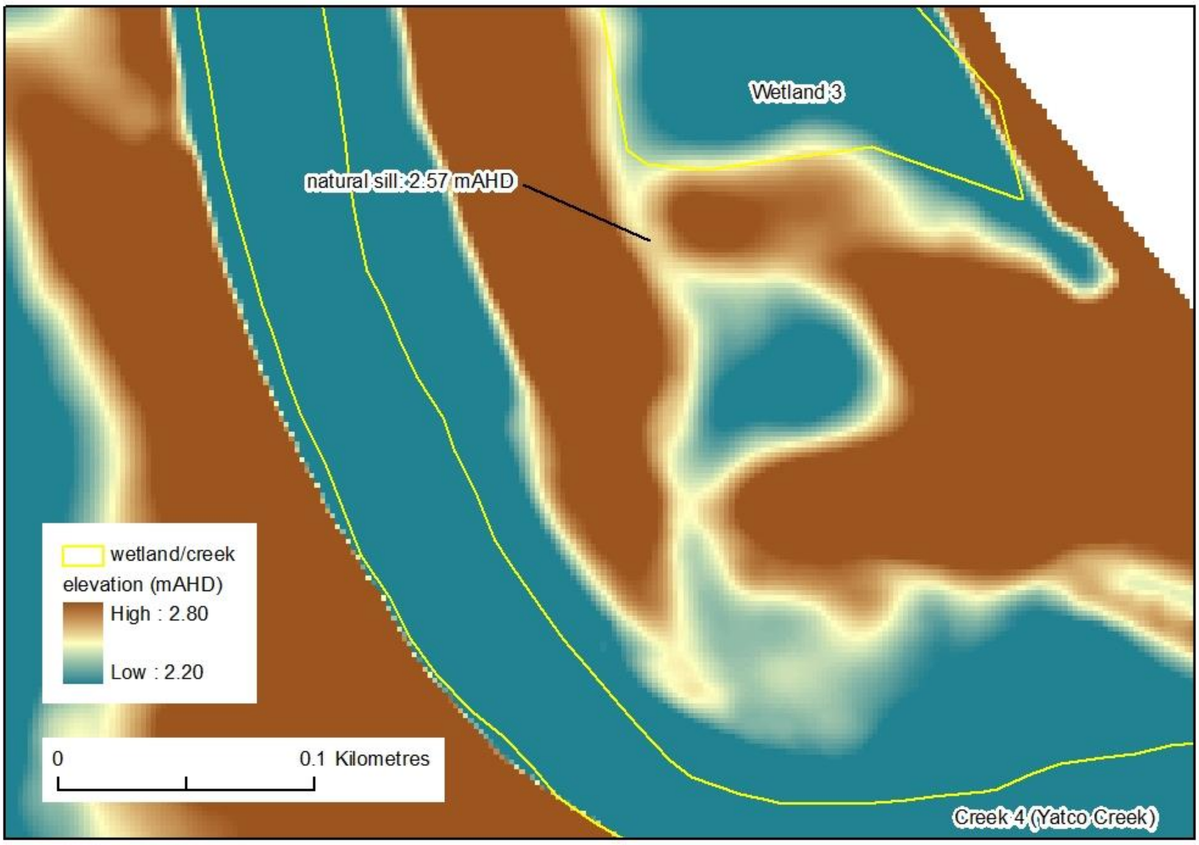
*** Species recorded for the first time during survey of floodplain habitat in March 2013 (Bailey and Paton 2013). These data are not amenable to quantitative comparison.

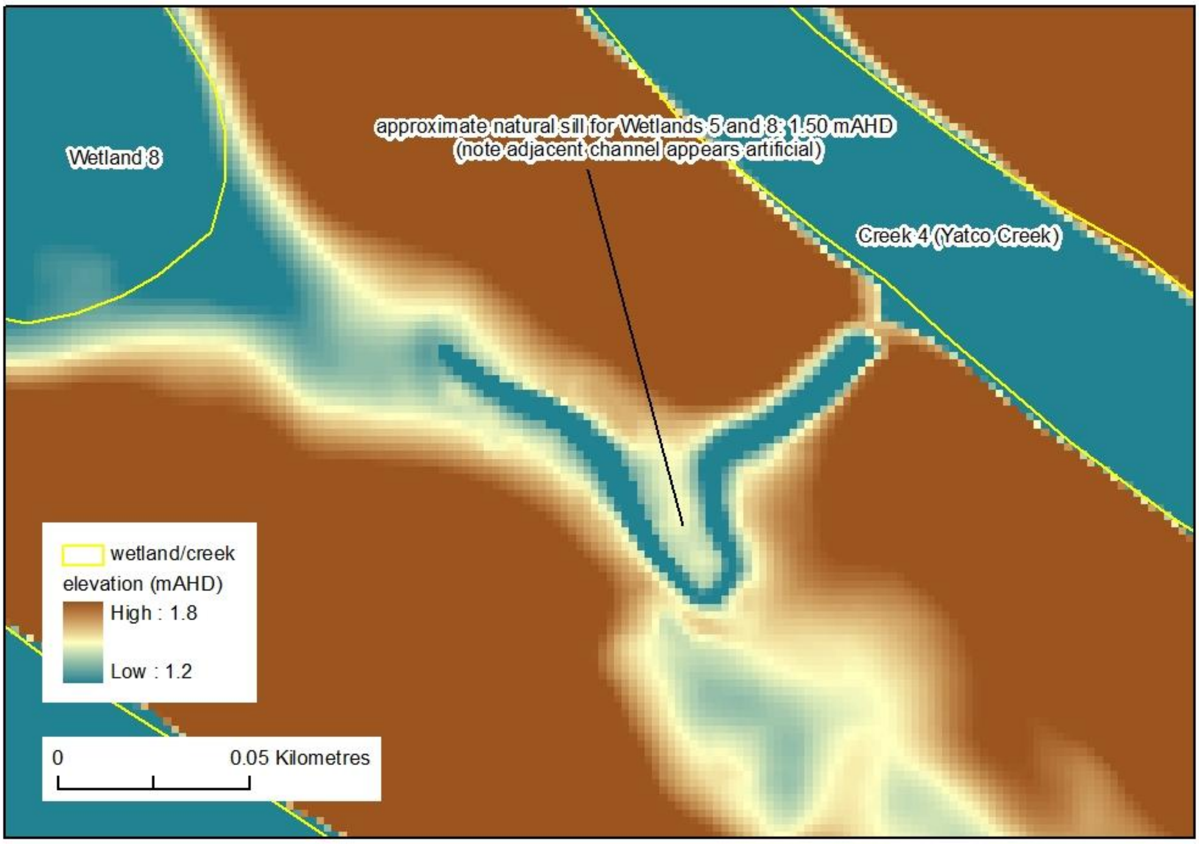
Appendix 4

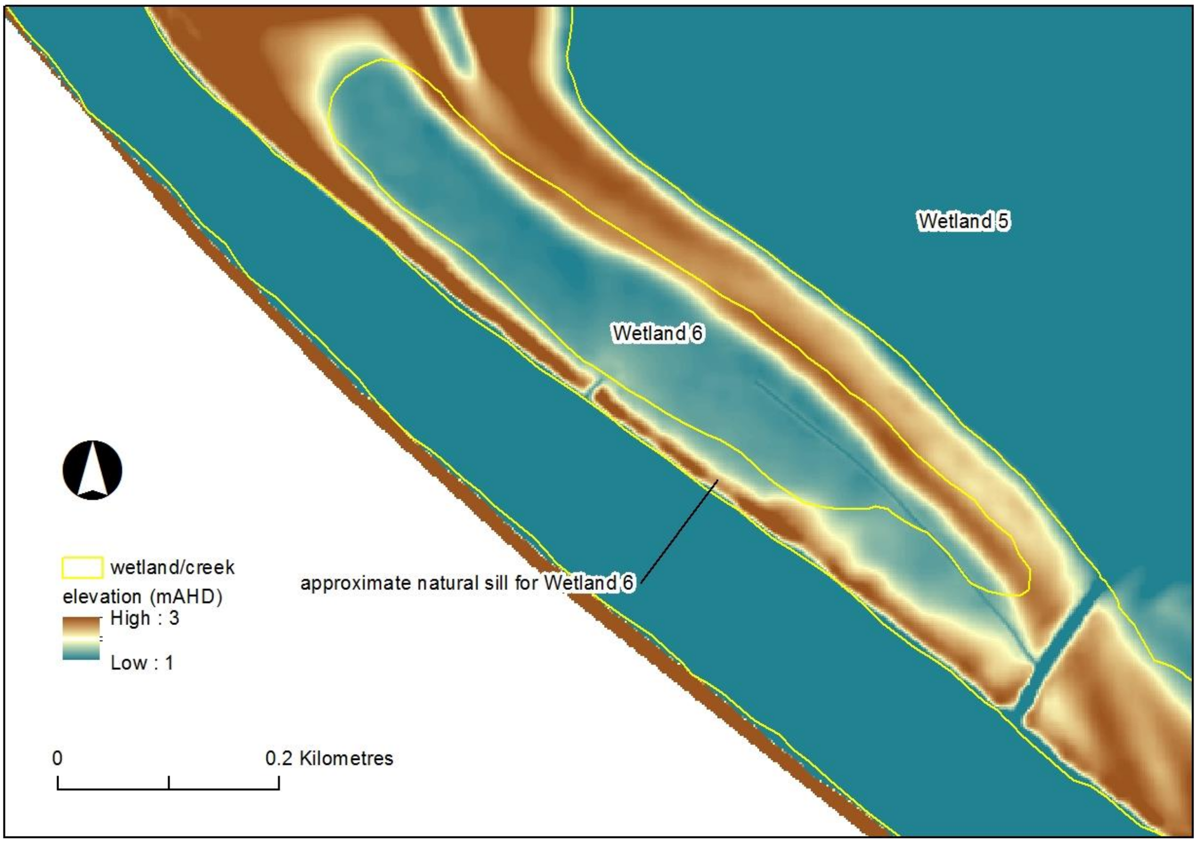
Estimated Locations and Elevations of Natural Sills for Wetlands Proposed for Management

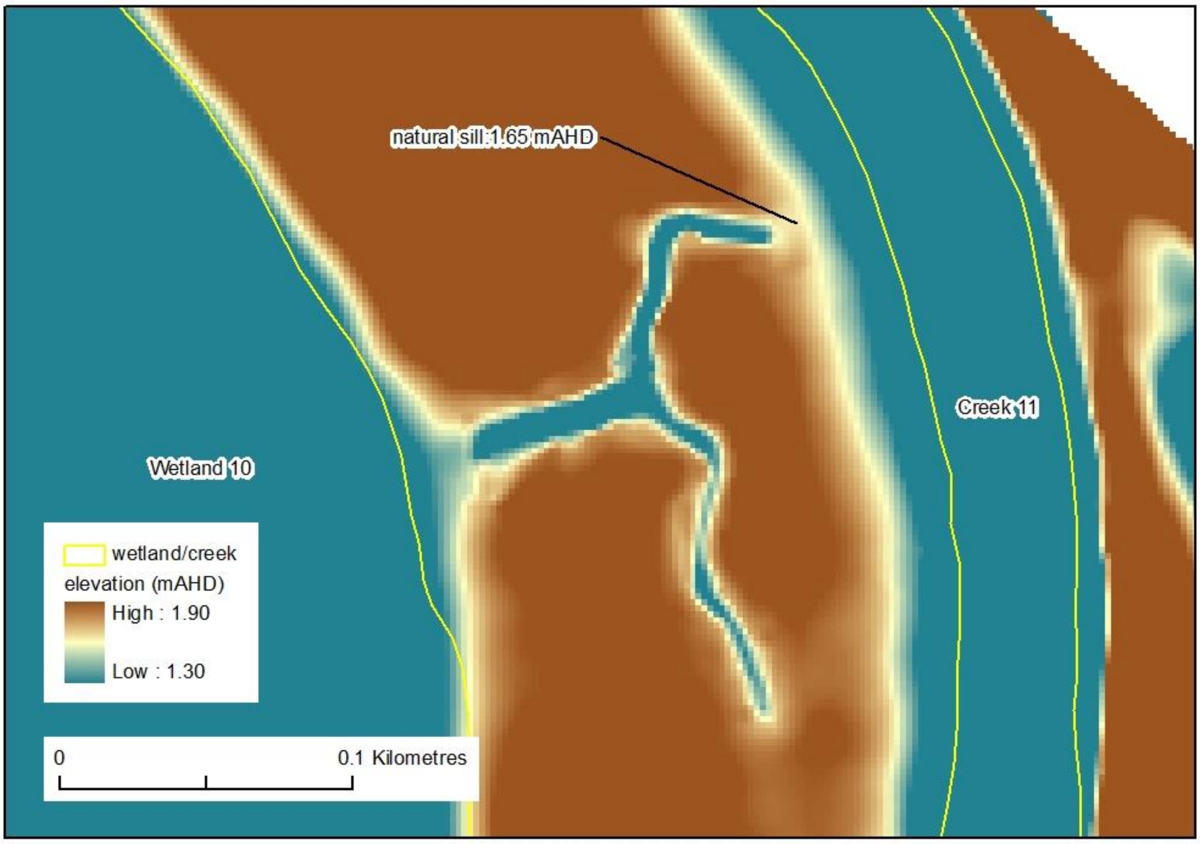


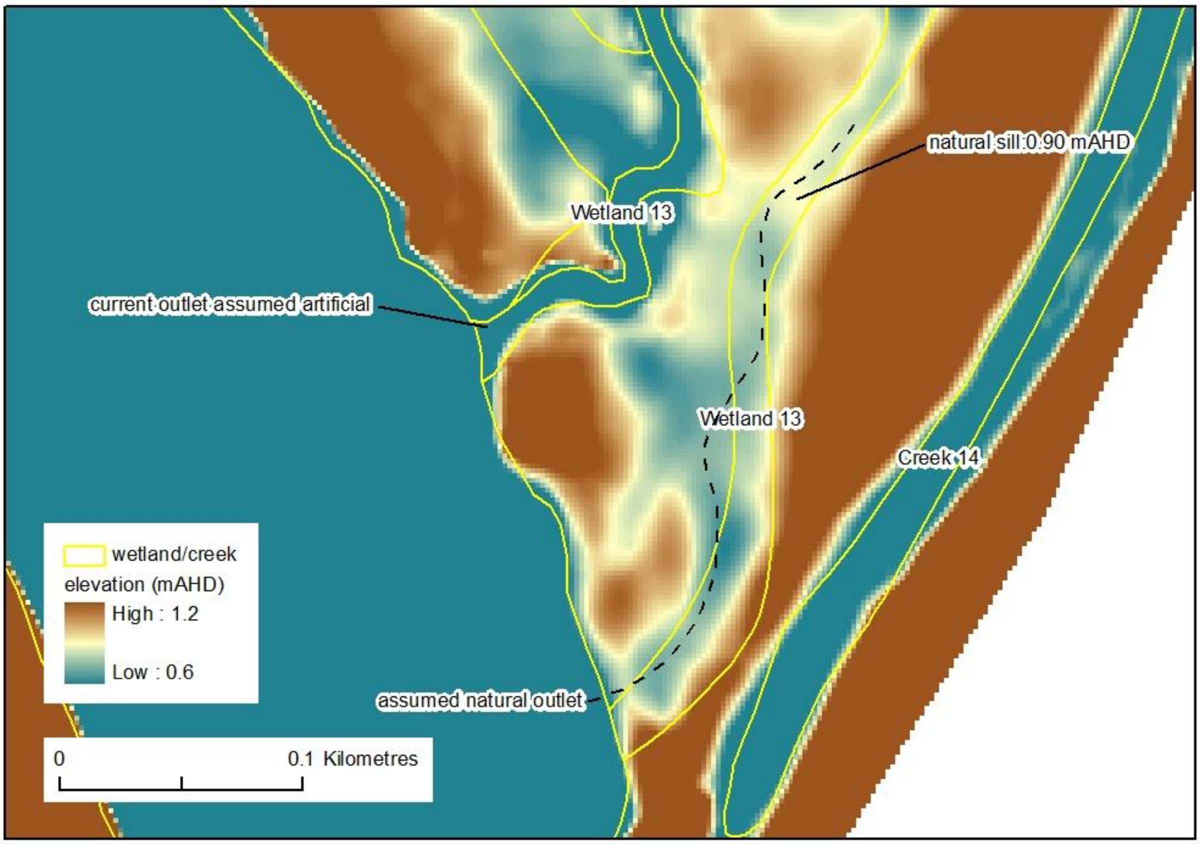

natural sill: 1.05 mAHD
Wetland 2
wetland/creek
elevation (mAHD)
High : 1.40
Low : 0.70
0
0.05 Kilometres


Wetland 3
natural sill: 2.57 mAHD
wetland/creek
elevation (mAHD)
High : 2.80
Low : 2.20
0
0.1 Kilometres
Creek 4 (Yatco Creek)


approximate natural sill for Wetlands 5 and 8: 1.50 mAHD
(note adjacent channel appears artificial)
Wetland 8
Creek 4 (Yatco Creek)
wetland/creek
elevation (mAHD)
High : 1.8
Low : 1.2
0
0.05 Kilometres


Wetland 5
Wetland 6
approximate natural sill for Wetland 6
wetland/creek
elevation (mAHD)
High : 3
Low : 1
0
0.2 Kilometres


natural sill 1.65 mAHD
Creek 11
Wetland 10
wetland/creek
elevation (mAHD)
High : 1.90
Low : 1.30
0
0.1 Kilometres


natural sill 0.90 mAHD
Wetland 13
current outlet assumed artificial
Wetland 13
Creek 14
wetland/creek
elevation (mAHD)
High : 1.2
Low : 0.6
assumed natural outlet
0
0.1 Kilometres

Appendix 5

Outputs of the Robinson Model (Robinson 2013)

Wetland 1

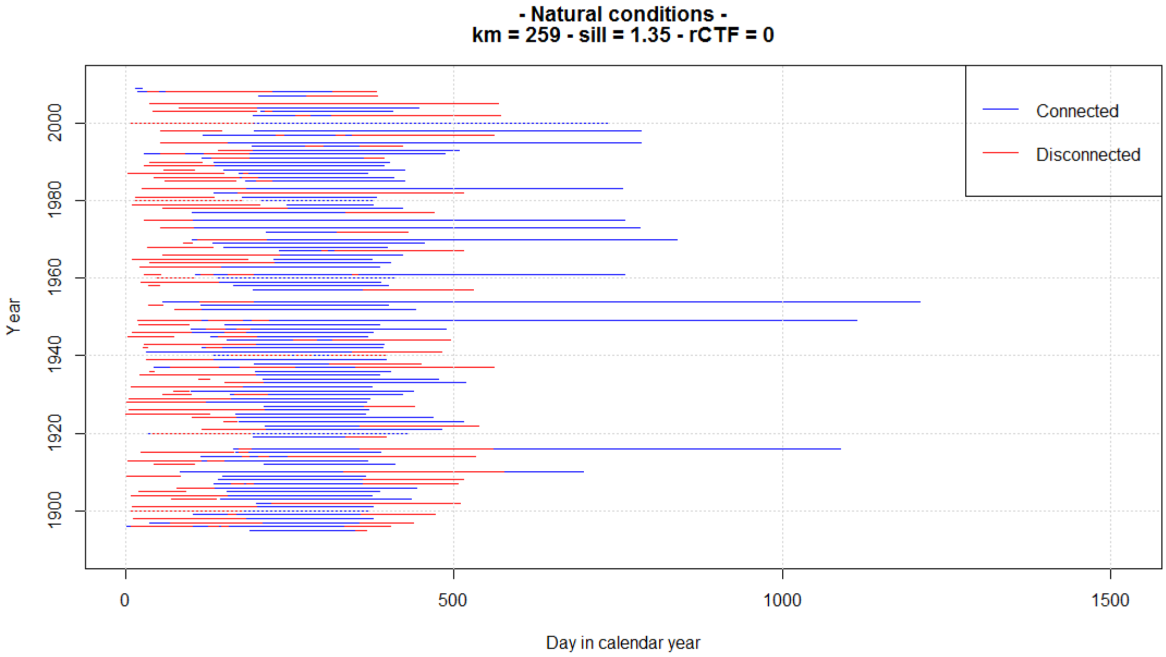
Wetland-River connectivity for Wetland 1, km = 259, natural sill = 1.35 mAHD

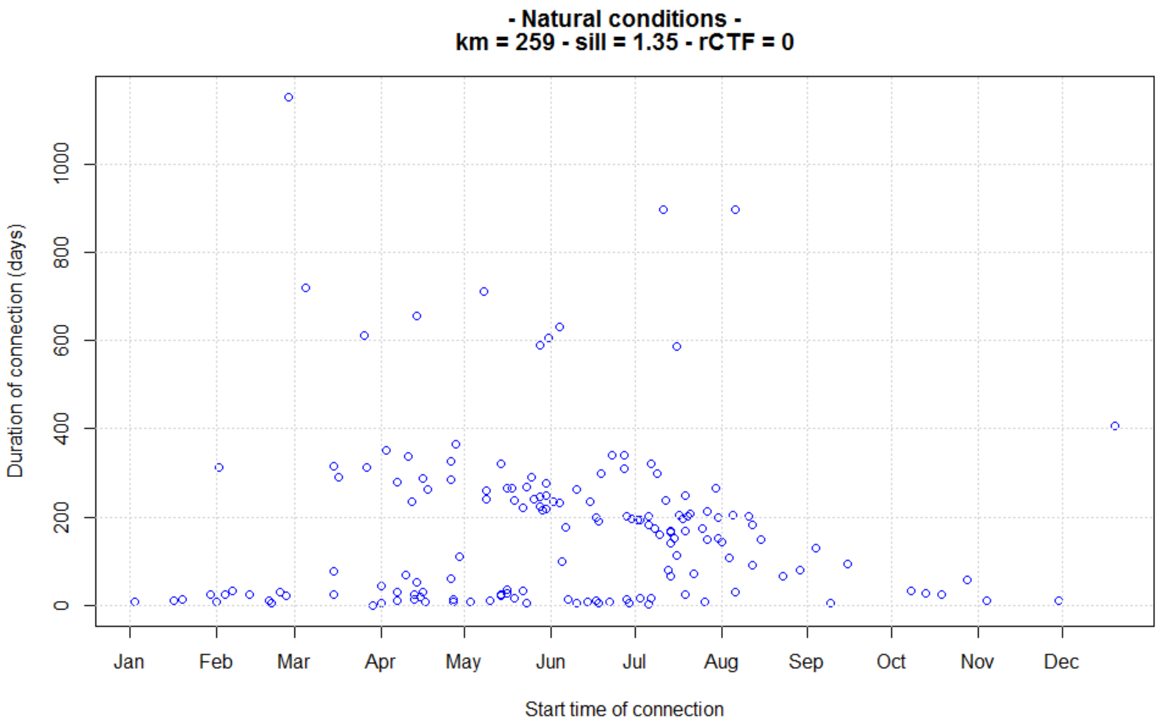
proportion of time connected under natural conditions: 0.6737

average number of connections per year under natural conditions: 1.3596

	Wetland 1-River connection events, all events								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	74	103	120	142	155	178	191	200	221
Start date	15 Mar	12 Apr	29 Apr	22 May	04 Jun	27 Jun	09 Jul	19 Jul	09 Aug
Duration (days)	339	277	235	200	161	79	30	16	8
End date	17 Feb	15 Jan	11 Dec	8 Dec	12 Nov	14 Sep	9 Aug	3 Aug	17 Aug

	Wetland 1-River connection events, excluding durations <50 days and >400 days								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	102	125	145	155	178	189	196	204	218
Start date	11 Apr	05 May	25 May	04 Jun	27 Jun	07 Jul	14 Jul	23 Jul	06 Aug
Duration (days)	313	281	255	235	206	196	171	143	80
End date	19 Feb	10 Feb	4 Feb	25 Jan	19 Jan	20 Jan	2 Jan	13 Dec	25 Oct


- Natural conditions -
km = 259 - sill = 1.35 - rCTF = 0
Connected
Disconnected
Year
1900
1920
1940
1960
1980
2000
0
500
1000
1500
Day in calendar year


- Natural conditions -
km = 259 - sill = 1.35 - rCTF = 0
Duration of connection (days)
0
200
400
600
800
1000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start time of connection

Wetland 2

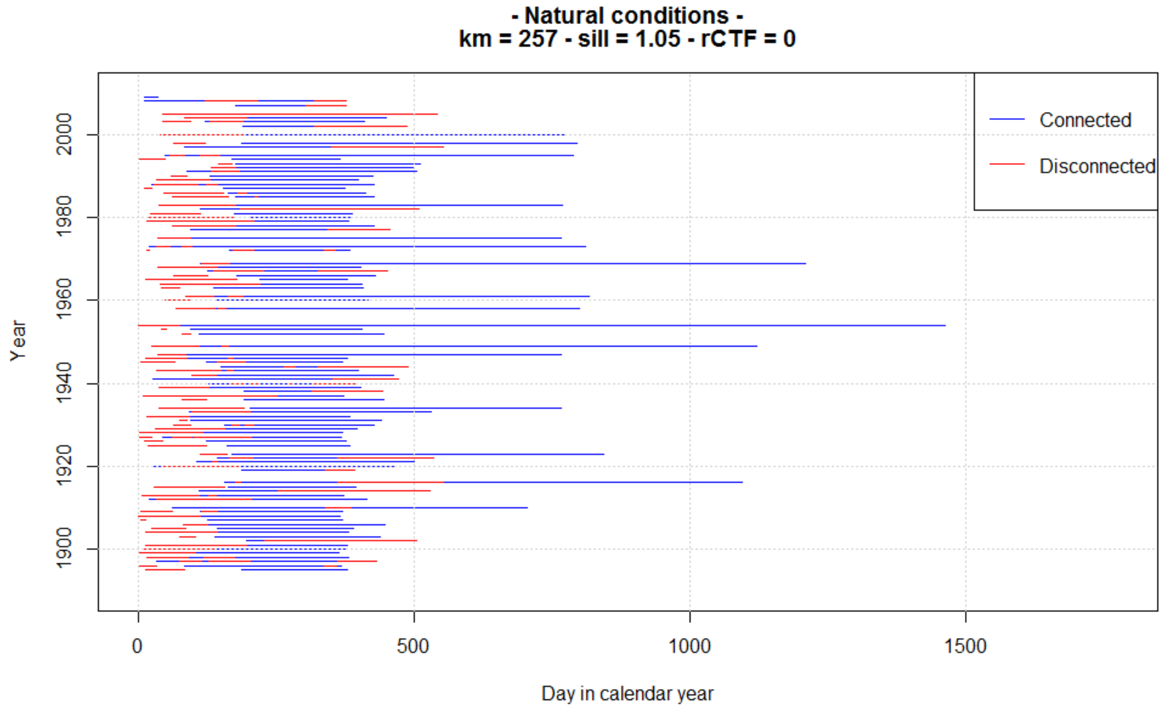
Wetland-River connectivity for Wetland 2, km = 257, natural sill = 1.05 mAHD

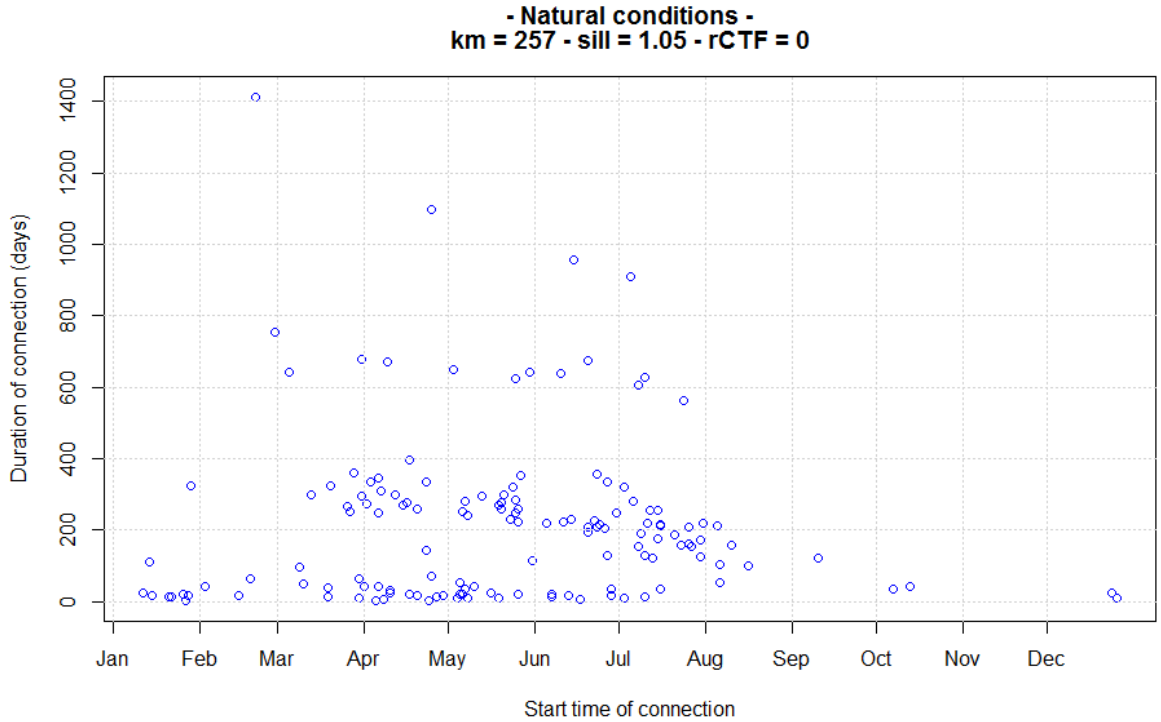
proportion of time connected under natural conditions: 0.7502

average number of connections per year under natural conditions: 1.2456

	Wetland 2-River connection events, all events								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	65	91	106	125	141	158	176	191	207
Start date	05 Mar	01 Apr	16 Apr	05 May	20 May	07 Jun	25 Jun	10 Jul	26 Jul
Duration	603	309	264	226	194	122	42	22	13
End date	30 Oct	4 Feb	5 Jan	17 Dec	1 Dec	7 Oct	6 Aug	1 Aug	8 Aug

	Wetland 2-River connection events, excluding durations <100 days and >450 days								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	90	105	128	144	156	174	188	196	208
Start date	31 Mar	15 Apr	7 May	23 May	5 Jun	23 Jun	6 Jul	15 Jul	26 Jul
Duration	332	299	276	258	247	221	209	174	133
End date	26 Feb	8 Feb	7 Feb	5 Feb	7 Feb	28 Jan	31 Jan	5 Jan	6 Dec


- Natural conditions -
km = 257 - sill = 1.05 - rCTF = 0
Year
Day in calendar year
Connected
Disconnected
0
500
1000
1500
1900
1920
1940
1960
1980
2000


- Natural conditions -
km = 257 - sill = 1.05 - rCTF = 0
Duration of connection (days)
Start time of connection
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0
200
400
600
800
1000
1200
1400

Wetland 3

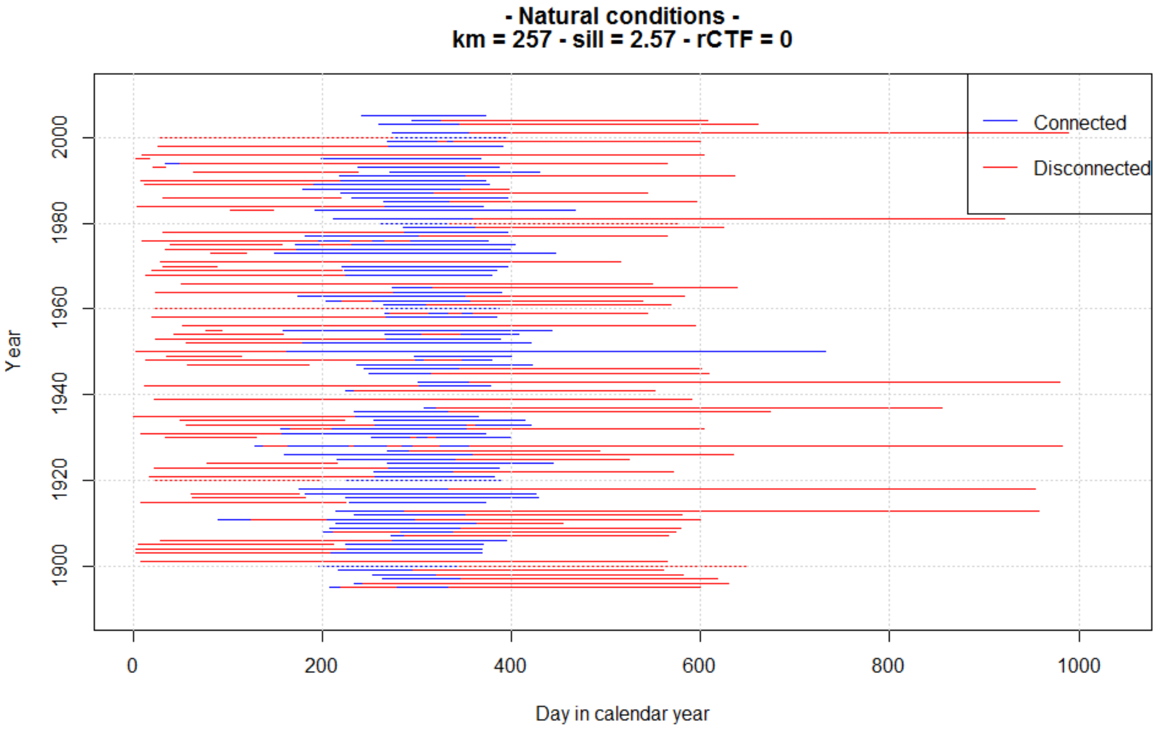
Wetland-River connectivity for Wetland 3, km = 257, natural sill = 2.57 mAHD

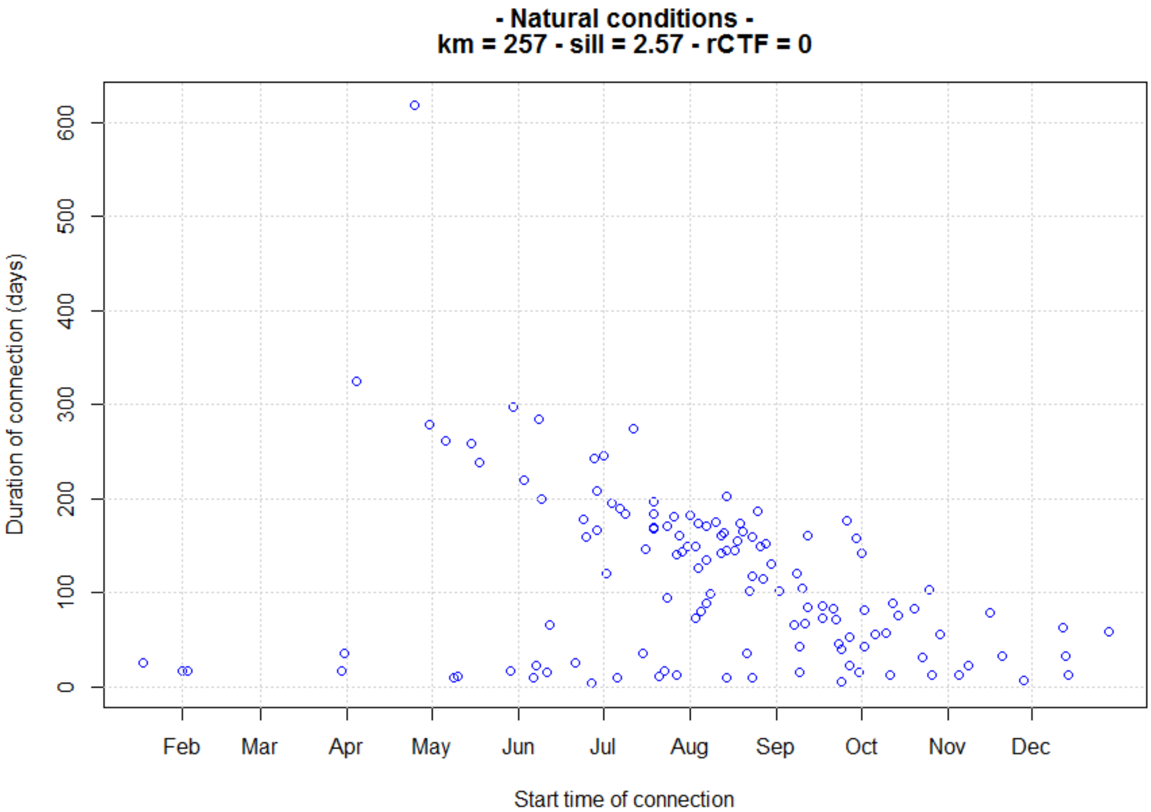
proportion of time connected under natural conditions: 0.3451

average number of connections per year under natural conditions: 1.1053

	Wetland 3-River connection events, all events								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	144	178	199	210	223	235	252	270	295
Start date	23 May	27 Jun	17 Jul	29 Jul	11 Aug	23 Aug	09 Sep	27 Sep	21 Oct
Duration	205	175	160	142	101	76	49	23	13
End date	15 Dec	19 Dec	25 Dec	18 Dec	20 Nov	7 Nov	28 Oct	20 Oct	4 Nov

	Wetland 3-River connection events, excluding durations <30 days and >365 days								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	162	188	205	216	225	235	252	267	286
Start date	10 Jun	07 Jul	24 Jul	04 Aug	13 Aug	23 Aug	09 Sep	23 Sep	12 Oct
Duration	227	183	169	159	144	116	86	71	50
End date	24 Jan	6 Jan	9 Jan	10 Jan	4 Jan	17 Dec	4 Dec	4 Dec	2 Dec


- Natural conditions -
km = 257 - sill = 2.57 - rCTF = 0
Connected
Disconnected
Year
1900
1920
1940
1960
1980
2000
0
200
400
600
800
1000
Day in calendar year


- Natural conditions -
km = 257 - sill = 2.57 - rCTF = 0
Duration of connection (days)
0
100
200
300
400
500
600
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start time of connection

Wetland 5

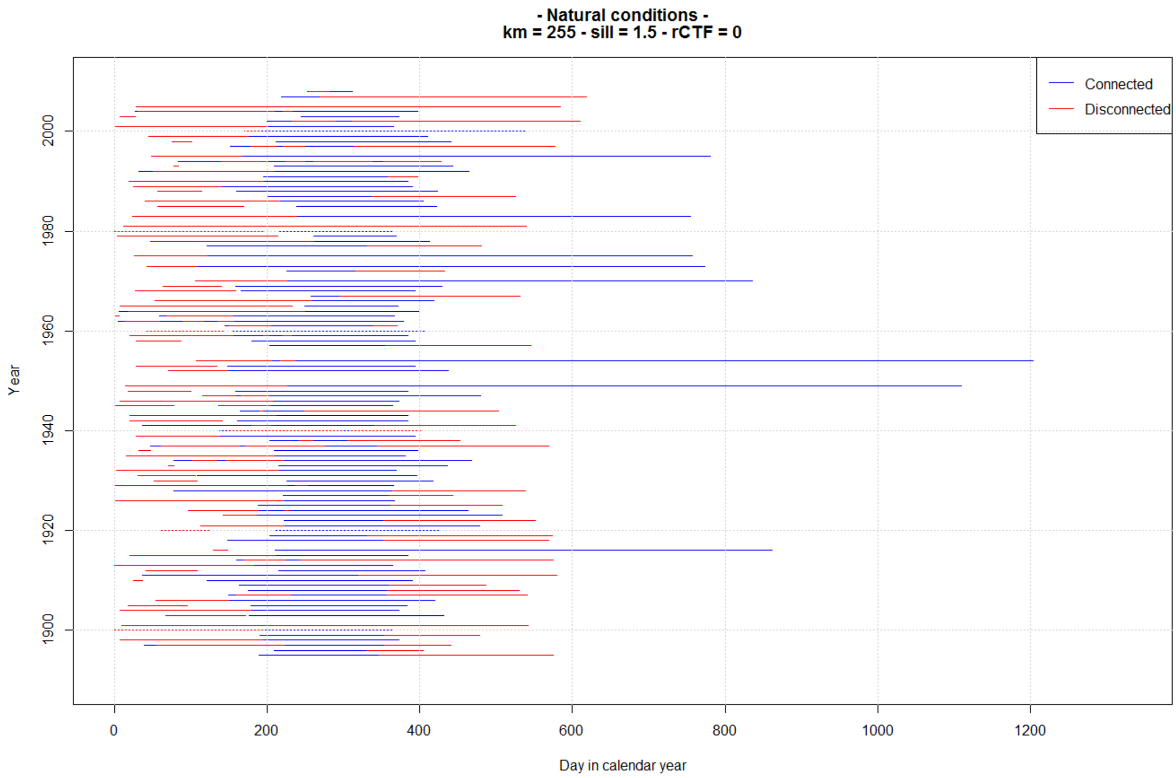
Wetland-River connectivity for Wetland 5, km = 255, natural sill = 1.5 mAHD

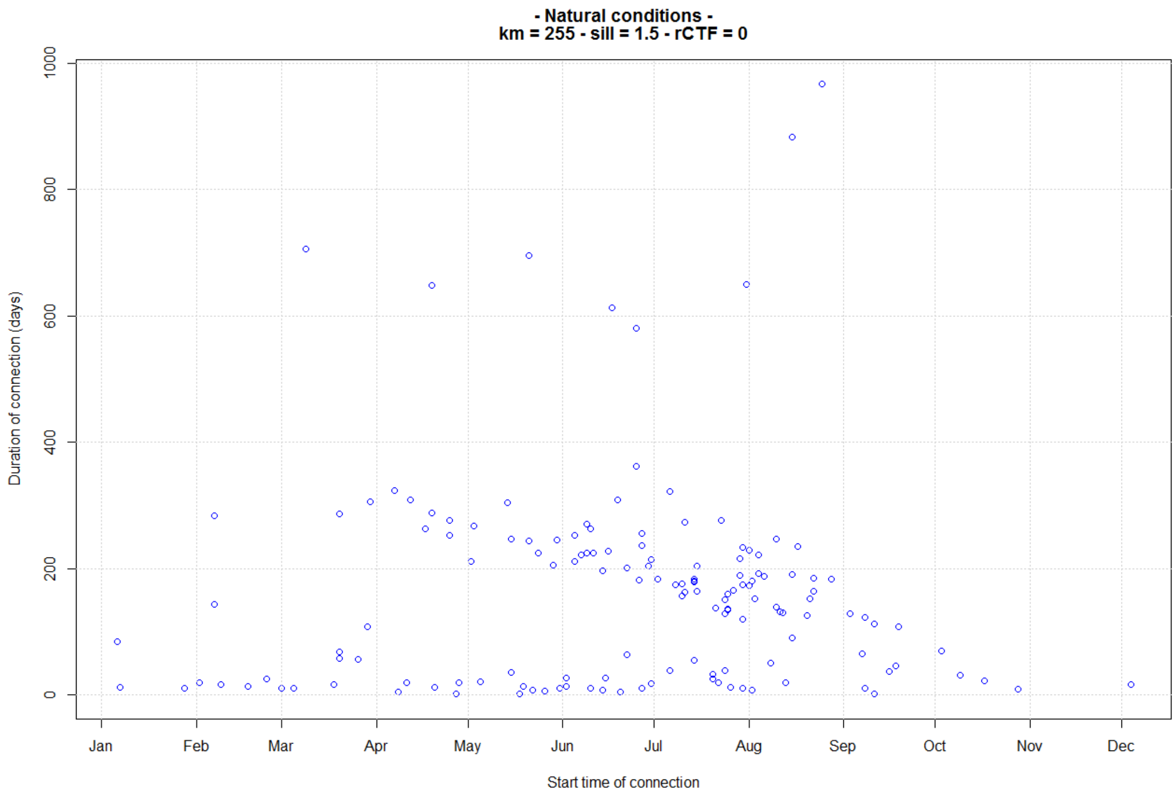
proportion of time connected under natural conditions: 0.5873

average number of connections per year under natural conditions: 1.2895

	Wetland 5-River connection events, all events								
	← wetter year		percentiles			drier year →			
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	79	117	148	165	181	196	210	220	238
Start date	20 Mar	27 Apr	28 May	14 Jun	30 Jun	15 Jul	29 Jul	07 Aug	26 Aug
Duration	294	247	212	183	153	116	38	19	11
End date	8 Jan	30 Dec	26 Dec	14 Dec	30 Nov	8 Nov	5 Sept	27 Aug	6 Sept

	Wetland 5-River connection events, excluding durations <50 days and >400 days								
	← wetter year		percentiles			drier year →			
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	98	136	160	177	192	203	211	218	233
Start date	7 Apr	16 May	9 Jun	26 Jun	10 Jul	22 Jul	29 Jul	5 Aug	20 Aug
Duration	282	252	229	212	189	177	158	132	108
End date	15 Jan	23 Jan	24 Jan	24 Jan	16 Jan	15 Jan	4 Jan	16 Dec	7 Dec


- Natural conditions -
km = 255 - sill = 1.5 - rCTF = 0
Connected
Disconnected
Year
1900
1920
1940
1960
1980
2000
0
200
400
600
800
1000
1200
Day in calendar year


- Natural conditions -
km = 255 - sill = 1.5 - rCTF = 0
Duration of connection (days)
0
200
400
600
800
1000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start time of connection

Wetland 6

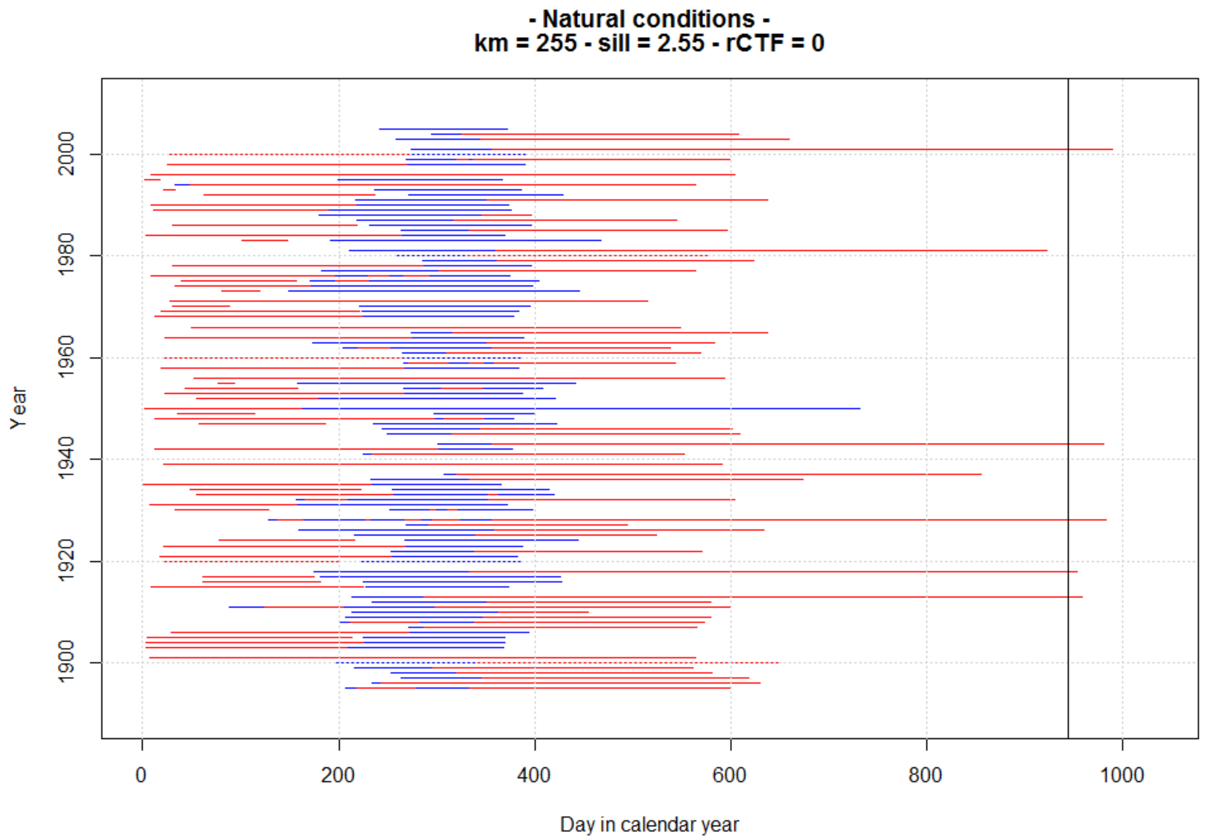
Wetland-River connectivity for Wetland 6, km = 255, natural sill = 2.5 mAHD

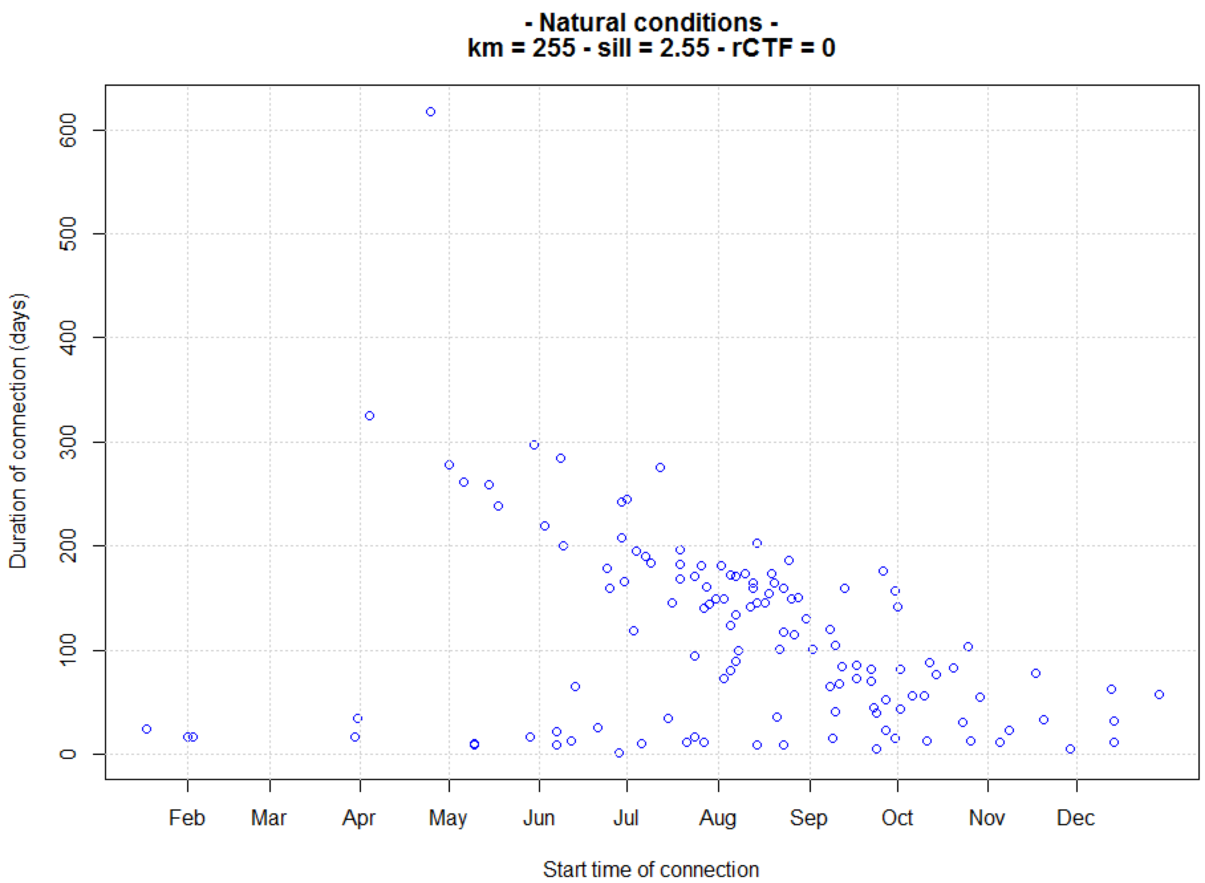
proportion of time connected under natural conditions: 0.3442

average number of connections per year under natural conditions: 1.1053

	Wetland 6-River connection events, all events								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	144	179	199	210	223	235	253	270	295
Start date	23 May	28 Jun	17 Jul	29 Jul	11 Aug	23 Aug	10 Sep	27 Sep	21 Oct
Duration	206	174	159	142	101	76	49	23	13
End date	16 Dec	19 Dec	24 Dec	18 Dec	20 Nov	7 Nov	29 Oct	20 Oct	4 Nov

	Wetland 6-River connection events, excluding durations <40 days and >400 days								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	164	187	205	216	225	234	251	265	279
Start date	12 Jun	6 Jul	24 Jul	4 Aug	12 Aug	22 Aug	8 Sep	22 Sep	6 Oct
Duration	239	184	171	159	148	128	100	82	65
End date	7 Feb	6 Jan	11 Jan	10 Jan	8 Jan	28 Dec	17 Dec	13 Dec	10 Dec


- Natural conditions -
km = 255 - sill = 2.55 - rCTF = 0
Year
1900
1920
1940
1960
1980
2000
0
200
400
600
800
1000
Day in calendar year


- Natural conditions -
km = 255 - sill = 2.55 - rCTF = 0
Duration of connection (days)
0
100
200
300
400
500
600
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start time of connection

Wetland 10

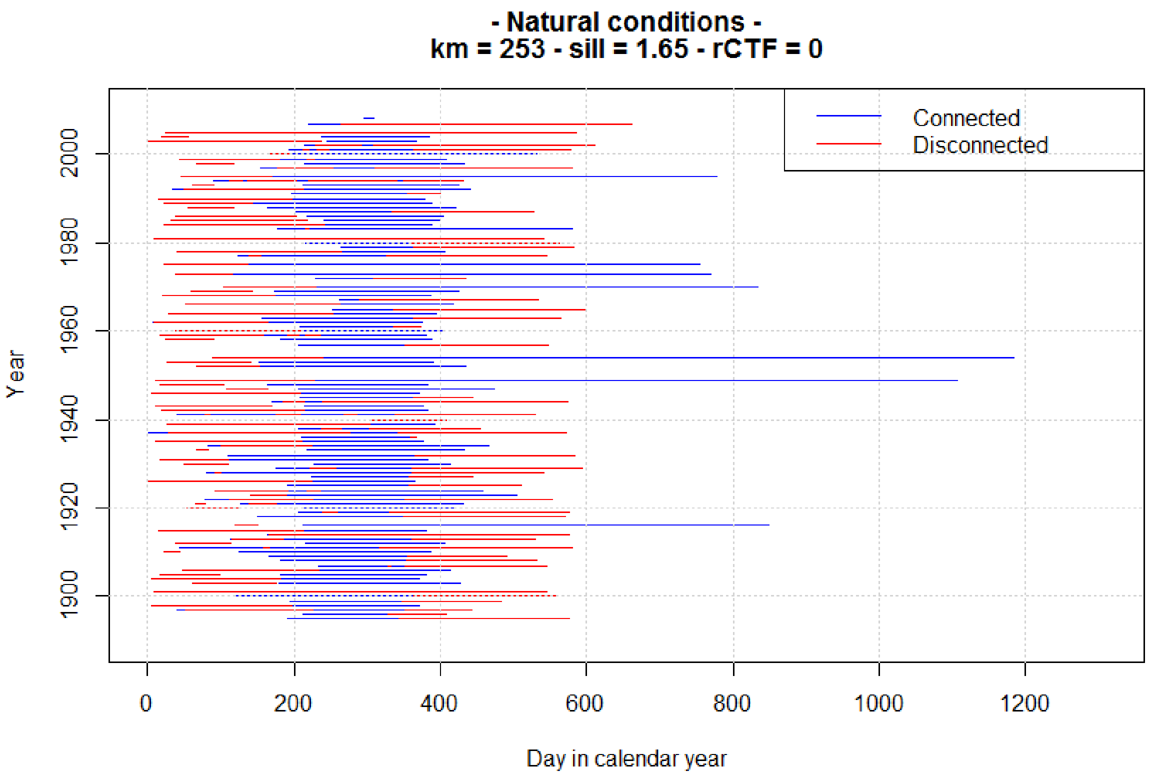
Wetland-River connectivity for Wetland 10, km = 253, natural sill = 1.65 mAHD

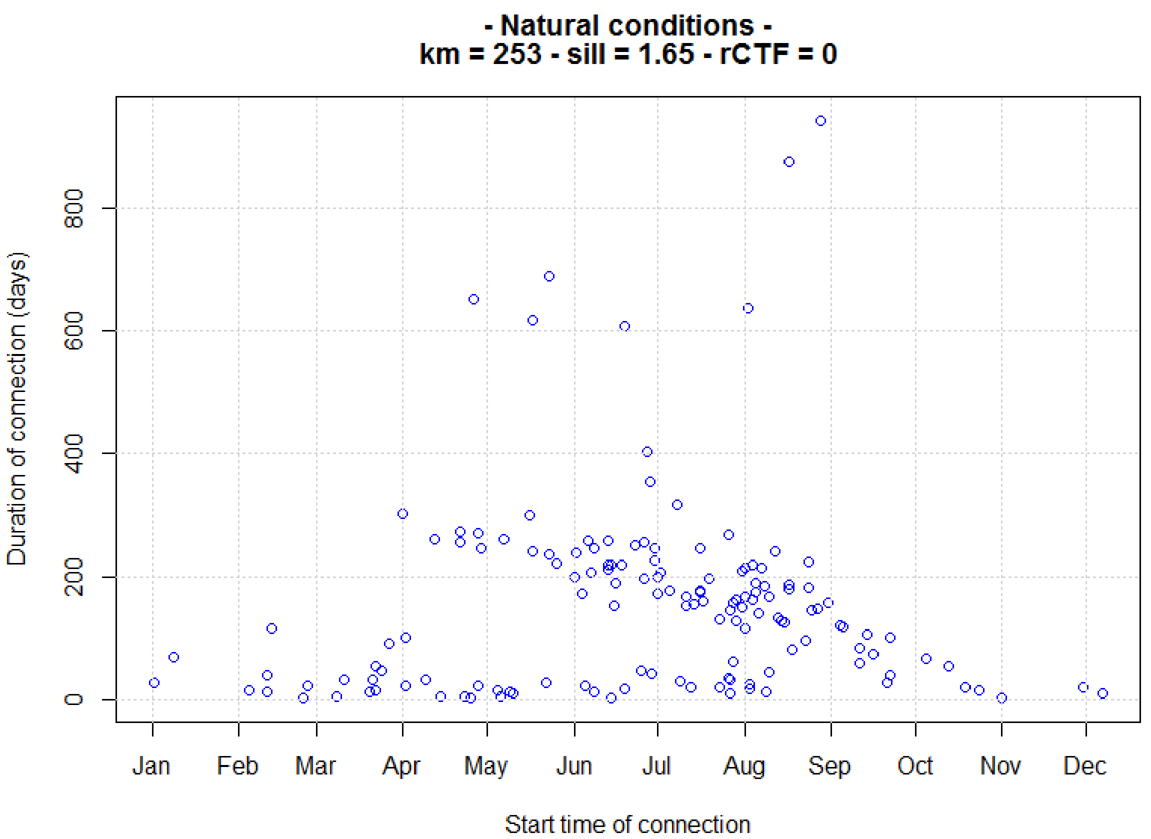
proportion of time connected under natural conditions: 0.55

average number of connections per year under natural conditions: 1.27

	Wetland 10-River connection events, all events								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	84	119	153	170	186	205	214	225	248
Start date	25 Mar	28 Apr	2 Jun	18 Jun	5 Jul	24 Jul	1 Aug	13 Aug	4 Sep
Duration	265	237	200	173	146	100	44	22	11
End date	15 Dec	22 Dec	19 Dec	8 Dec	28 Nov	1 Nov	15 Sep	4 Sep	16 Sep

	Wetland 10-River connection events, excluding durations <60 days and >400 days								
	← wetter year			percentiles			drier year →		
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	119	156	167	182	197	209	216	226	238
Start date	28 Apr	4 Jun	16 Jun	1 Jul	16 Jul	28 Jul	4 Aug	13 Aug	25 Aug
Duration	259	244	219	201	181	168	153	129	100
End date	12 Jan	3 Feb	21 Jan	18 Jan	13 Jan	12 Jan	4 Jan	10 Jan	4 Dec


- Natural conditions -
km = 253 - sill = 1.65 - rCTF = 0
Connected
Disconnected
Year
1900
1920
1940
1960
1980
2000
0
200
400
600
800
1000
1200
Day in calendar year


- Natural conditions -
km = 253 - sill = 1.65 - rCTF = 0
Duration of connection (days)
0
200
400
600
800
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start time of connection

Wetland 13

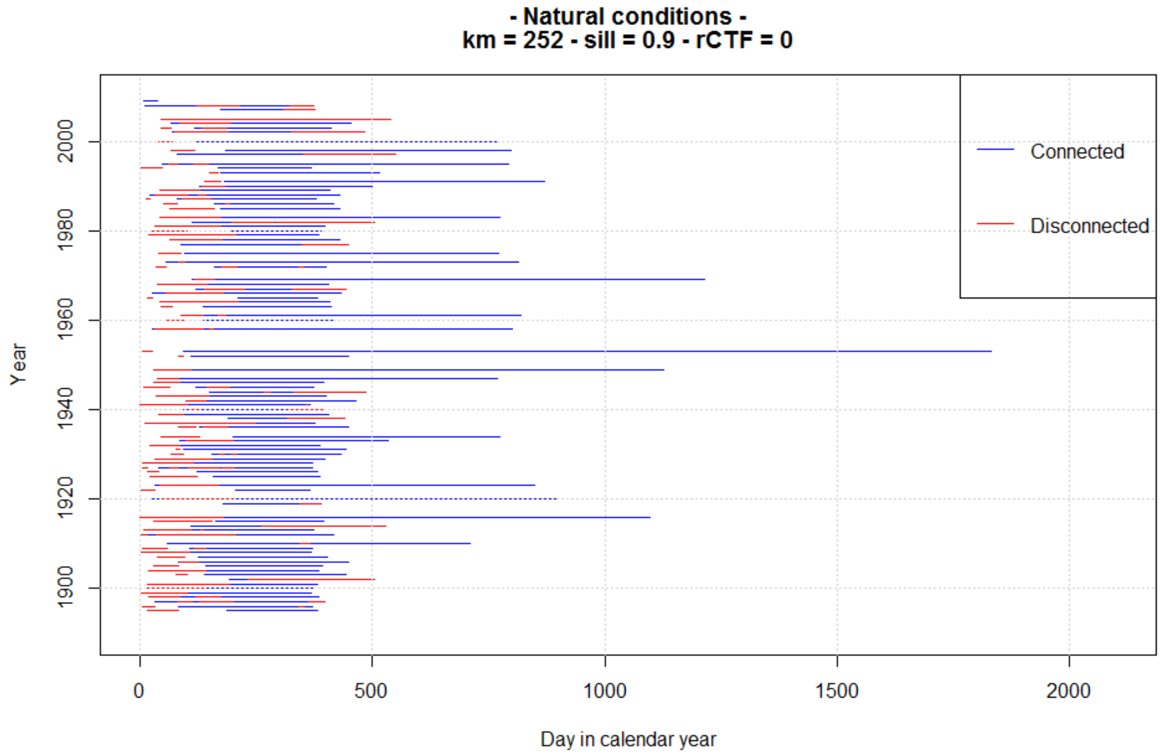
Wetland-River connectivity for Wetland 13, km = 252, natural sill = 0.9 mAHD

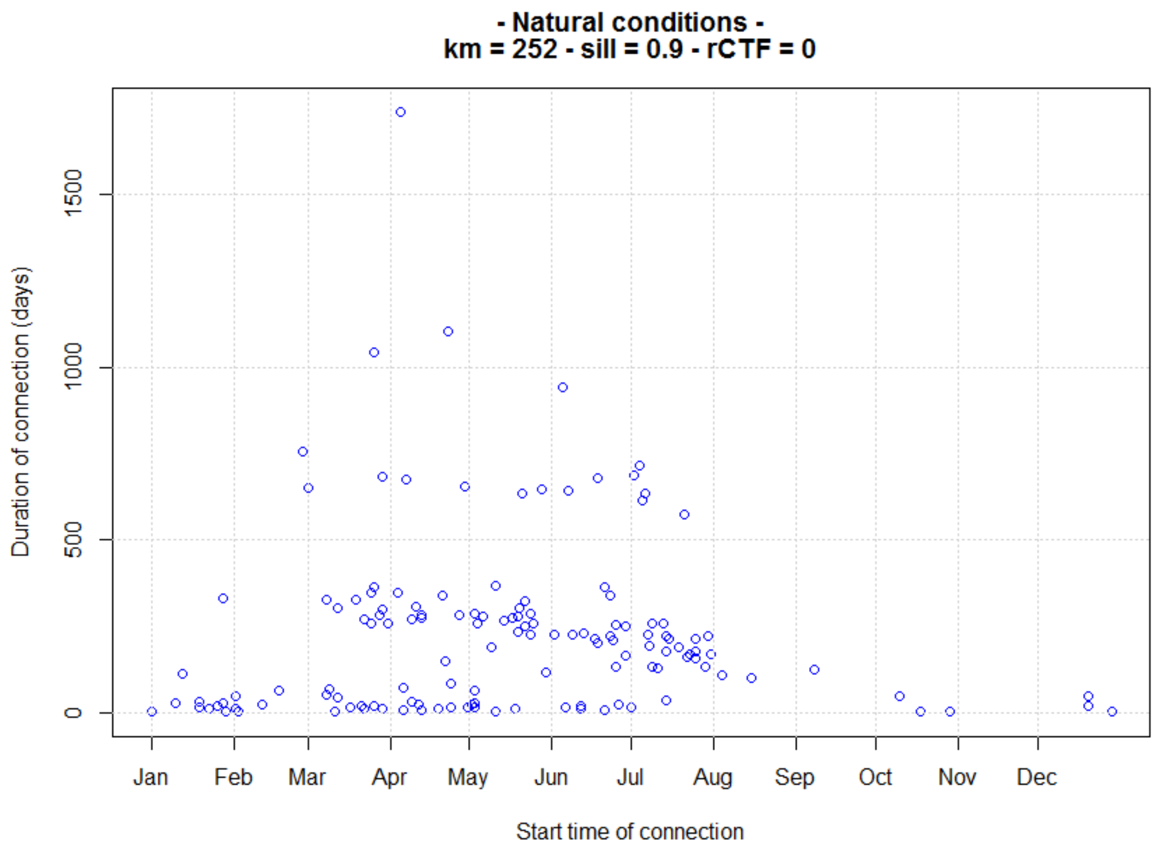
proportion of time connected under natural conditions: 0.78

average number of connections per year under natural conditions: 1.22

	Wetland 13-River connection events, all events								
	← wetter year		percentiles			drier year →			
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	48	83	96	114	131	150	173	188	206
Start date	16 Feb	23 Mar	6 Apr	24 Apr	11 May	29 May	22 Jun	7 Jul	25 Jul
Duration (days)	636	326	274	232	192	127	47	22	12
End date	15 Nov (+1 yr)	13 Feb	5 Jan	12 Dec	19 Nov	4 Oct	8 Aug	29 Jul	6 Aug

	Wetland 13-River connection events, excluding durations <50 days and >500 days								
	← wetter year		percentiles			drier year →			
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Start day no.	80	94	113	131	143	168	178	194	206
Start date	20 Mar	4 Apr	23 Apr	11 May	23 May	17 Jun	27 Jun	13 Jul	25 Jul
Duration (days)	331	288	275	260	231	216	186	151	111
End date	15 Feb	17 Jan	23 Jan	26 Jan	9 Jan	19 Jan	30 Dec	11 Dec	13 Nov


- Natural conditions -
km = 252 - sill = 0.9 - rCTF = 0
Year
2000
1980
1960
1940
1920
1900
0
500
1000
1500
2000
Day in calendar year
Connected
Disconnected


- Natural conditions -
km = 252 - sill = 0.9 - rCTF = 0
Duration of connection (days)
1500
1000
500
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Start time of connection

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