Development of conceptual models of wetland and drain systems to support water policy and planning in the South East NRM region

DEWNR Technical note 2014/23

Government of South Australia
Department of Environment, Water and Natural Resources

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December, 2014

DEWNR Technical note 2014/23

Government of South Australia
Department of Environment, Water and Natural Resources

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Abbreviations

DEWNR	Department of Environment, Water and Natural Resources (South Australia)
GDE	Groundwater Dependent Ecosystem
GIS	Geographic Information System
IAN	Integration and Application Network
SEDWS	South East Drainage and Wetland Strategy
SE NRM	South East Natural Resource Management
SEWCDB	South East Water Conservation and Drainage Board
SMK	Science, Monitoring and Knowledge (Branch of DEWNR)
TLA	Tertiary Limestone Aquifer

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- Integration and Application Network (IAN), through the University of Maryland, Centre for Environmental Science, whose IAN Symbol Library was used to source and adapt icons and bases for the development of conceptual diagrams.
- Report review and suggestions by Jen Schilling (Natural Resources South East, DEWNR), Brad Page (SMK, DEWNR), Andy Harrison (SMK, DEWNR), and Colin Cichon (SMK, DEWNR).

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Summary

The South East Natural Resources Management (NRM) region landscape is dominated by a series of roughly parallel dune ranges, separated by interdunal corridors which form the region's extensive wetlands, watercourses and floodplains. The low gradient topography along with shallow regional groundwater levels, and relatively high rainfall, contributed to vast areas of permanently and seasonally inundated wetlands which prior to European settlement, covered an estimated 45% of the region (Harding 2007). An estimated 2600 kilometres of government managed drains have been established in the South East region since settlement (SEWCDB 1980; Farrington and Slater 2010). The drains were designed to relieve surface water inundation in the Lower South East, and control saline groundwater levels in the Upper South East, allowing the development of agricultural enterprises. The drains have brought about a major landscape change across the South East, removing over 93% of the original wetland extent (Harding 2012; Taylor 2006). Currently less than 6% of the original wetland area remains, albeit fragmented and in an altered hydrological state. Less than 10% of the remaining wetland area is considered to be in intact hydrological condition (Harding 2007).

The South East Natural Resource Management (SE NRM) Board has begun the preparation of a *South East Drainage and Wetland Strategy* (SEDWS), which will provide an overarching strategy for how surface waters are managed in the region, including the management of drains and environmental surface water delivery for remnant wetlands. Concurrent to the preparation of the SEDWS, the Minister for Sustainability, Environment and Conservation has asked the SE NRM Board to convene a community panel to provide recommendations on a sustainable funding regime for the future operation of the drainage network. Common to both of these processes was the need to collate and present information to support community understanding and awareness of the complex interactions between climate and landscape processes, groundwater and surface water, land use, and the impacts of drains and drain management on wetlands in the SE NRM region. Conceptual models and diagrams provide a visual way to communicate complex interactions and, along with supporting documentation, assist in summarising the major drivers, values, processes, threats and ecosystem responses to change, and have been identified as a valuable communication tool (Imgraben et al. 2014; Wiebkin 2014).

This technical note details the development of conceptual diagrams for four priority wetland systems of the SE NRM region, including both pre-European and present day scenarios. Each of the wetland system conceptual diagrams are supported by box-line conceptual model, and reference list evidence base, as well as summarised information about important hydrological processes and key elements of the conceptual models.

Conceptual diagrams were produced for the following priority wetland systems:

1. Inland interdunal wetlands and watercourse
2. Coastal dune lakes and permanent freshwater in drains
3. Karst rising springs and coastal peat swamps
4. Freshwater grass and sedge marshes

1 Introduction

1.1 Background

Australian Bureau of Statistics data indicates that in 2013 the SE NRM region supported approximately $1.0 billion of South Australia's $5.6 billion gross value agricultural industry – notably dryland and irrigated agriculture and horticulture, dairy, and forestry. The region has over 16000 extant mapped wetlands formed as a result of low gradient topography, poor natural drainage, shallow regional groundwater aquifer, and relatively high annual rainfall. Wetlands provide a wide range of ecosystem services, by supporting soil formation and biogeochemical cycling, providing food, fresh water and habitat, regulating climate and flood attenuation, as well as providing a range of cultural, educative and tourism services (Mitsch and Gosselink 2000).

The main water supply for industry, agriculture and town water supplies is sourced from groundwater, with the relatively flat topography characteristic of the region supporting limited exploitable surface water resources (SE NRMB 2010). The hydrogeology of the SE NRM region consists of an upper Tertiary Limestone Aquifer (TLA), which are separated from an underlying Tertiary Confined Sand Aquifer (TCSA) by a clay aquitard. Overlying the TLA throughout much of the region is a series of north–west trending Quaternary beach-dune ridge systems, separated by a series of interdunal flats which form the region's watercourses and floodplains (Wood 2009). Depth to groundwater in the TLA is typically shallow, with the majority (77%) of the regions wetland ecosystems supported by the interaction of groundwater and surface water (SKM 2009). The majority of water for economic and domestic activity is also allocated from the TLA.

In the SE NRM region watercourses historically flowed from south to north along broad interdunal flats between roughly parallel, ancient dune ranges (Figure 1.1). The construction of a drainage network in the lower catchment areas has broken the connectivity of this flow, diverting water directly into the sea. An estimated 2600 km of government managed drains have been established in the South East region since settlement, commencing in the 1860s (SEWCDB 1980; DFW 2010; Slater and Farrington 2010) (Figure 1.1). The drains were designed to reduce surface water inundation in the Lower South East, and control saline groundwater levels in the Upper South East, improving the agricultural productivity of the region. Extensive vegetation clearance followed the construction of the drains, with only 13% of original native vegetation cover remaining (SE NRMB 2010), along with a considerable reduction in water availability to remaining wetland vegetation (Heneker 2006).

The drains have brought about a major landscape change across the South East, removing over 93% of the original wetland extent (Harding 2012; Taylor 2006). An estimated 45% of the South East landscape was subject to inundation either permanently or seasonally prior to drainage. Currently less than 6% of the original wetland area remains, albeit fragmented and in an altered hydrological state (Figure 1.1). Less than 10% of remaining wetland area is considered to be in intact hydrological condition (Harding 2007).

In recent times, drains primarily designed for increasing agricultural productivity have included infrastructure that is managed and designed to convey water for environmental purposes (Taylor et al. 2014), utilising a system of regulators and a decision support system to seek a balance between productive and environmental values (Slater and Farrington 2010; Denny et al. 2014). This infrastructure provides an opportunity for mitigation against some of the impacts of regional drainage by connecting some wetlands and floodplains to drain flows, or utilising the placement of regulators to aid retention of water in the landscape. The operation of the drainage network infrastructure has also been identified for its potential to mitigate against the impacts of climate change for high value wetland assets (Denny et al. 2014).

As part of a now highly modified and engineered environment, many wetlands are now reliant on the operation of drainage infrastructure for the delivery of environmental water flows, and as a result of the success of drainage in drying out the landscape, in many cases the drains themselves are viewed as environmental assets (Slater and Farrington 2010; Anderson et al. 2013). Drains now provide some of the only remaining permanent freshwater refuge habitat for key species in the region, particularly native fishes and frogs (Anderson et al. 2013). However, often the management of drains to maximise agricultural productivity and the ecosystem values of wetlands are incompatible, with the need to maintain the relatively small amount of remnant wetland habitat and the need for inundation relief on agricultural land conflicting.

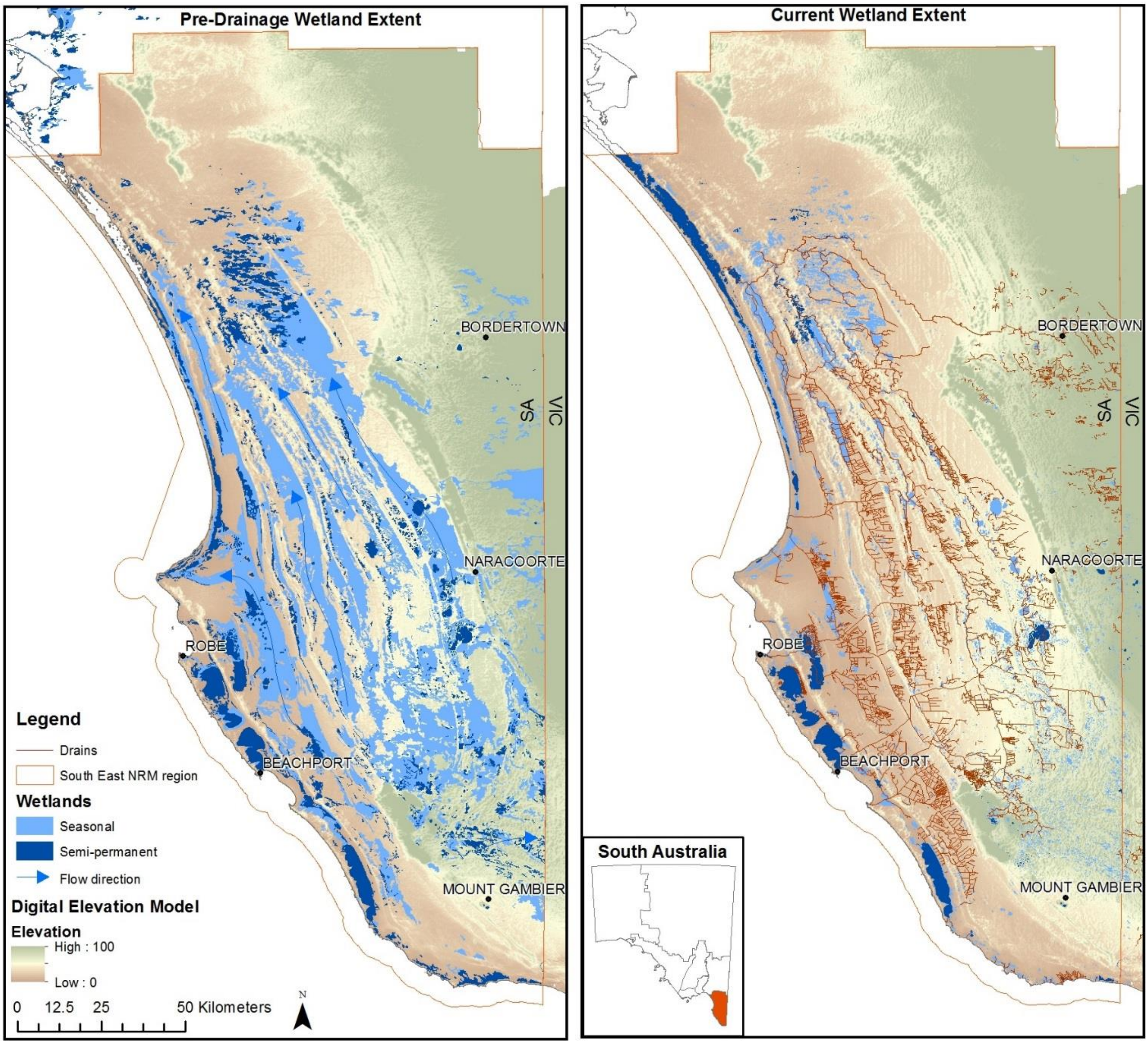


Figure 1.1 Wetland extent in the SE NRM region: pre-drainage and current

1.2 Communicating complex hydrological and landscape processes

The SE NRM Board has begun the preparation of a *South East Drainage and Wetland Strategy* (SEDWS), which will provide an overarching strategy for how surface waters are managed in the SE NRM region. Concurrent to the preparation of the SEDWS, the Minister for Sustainability, Environment and Conservation has asked the SE NRM Board to convene a community panel to provide recommendations on a sustainable funding regime for the future operation of the drainage network. Members of the community panel will be drawn from the South East population and may not necessarily have an understanding of issues associated with drainage nor the management of water in the SE NRM region.

Common to both of these processes is the need to collate and present information to support community understanding and awareness of the complex interactions between climate and landscape processes, groundwater and surface water, land use, and the impacts of drains and drain management on wetlands in the SE NRM region. Conceptual models and diagrams provide a visual way to communicate complex interactions and, along with supporting documentation, assist in summarising the major drivers, values, processes, threats and ecosystem responses to change (Imgraben et al. 2014; Wiebkin 2014). They have been identified as a valuable communication tool for both the community panel and development of the SEDWS.

Conceptual models provide a simplified representation of the current knowledge of a system, and they integrate current understanding of system dynamics with the important processes and functions (Gross 2003). Natural systems are inherently complex, and conceptual models can help organise and integrate disparate information and data, and make sense of system components and interactions. Fundamentally, they are working hypotheses about system form and function, resting on clearly stated assumptions that are open to review (Wilkinson et al. 2007).

1.3 Objectives

The objective of this project was to develop conceptual models for identified priority wetland and drain systems in the SE NRM region to:

- Collate, synthesise, and simplify the current understanding of interactions of drivers, processes, ecosystem and social values, threats, and ecosystem responses of wetlands and drains
- Illustrate the differences between priority wetland systems across the region

At the request of the SE NRM Board the conceptual models also needed to be at a scale and level of detail which could be used for multiple regional planning and policy related purposes and be useful as communication and education tools for the public.

A concurrent project engaging with the South East Aboriginal Focus Group has documented the traditional cultural values of wetlands (Auricht and Imgraben 2014) and has refined the wetland conceptual models produced in this report to include the values of Indigenous Australians, both historically and currently.

2 Methods

The development of the conceptual models and diagrams followed the process shown in Figure 2.1 and the guidelines for facilitating conceptual model workshops provided by Wiebkin (2014). The following sections describes each of the conceptual model development steps.

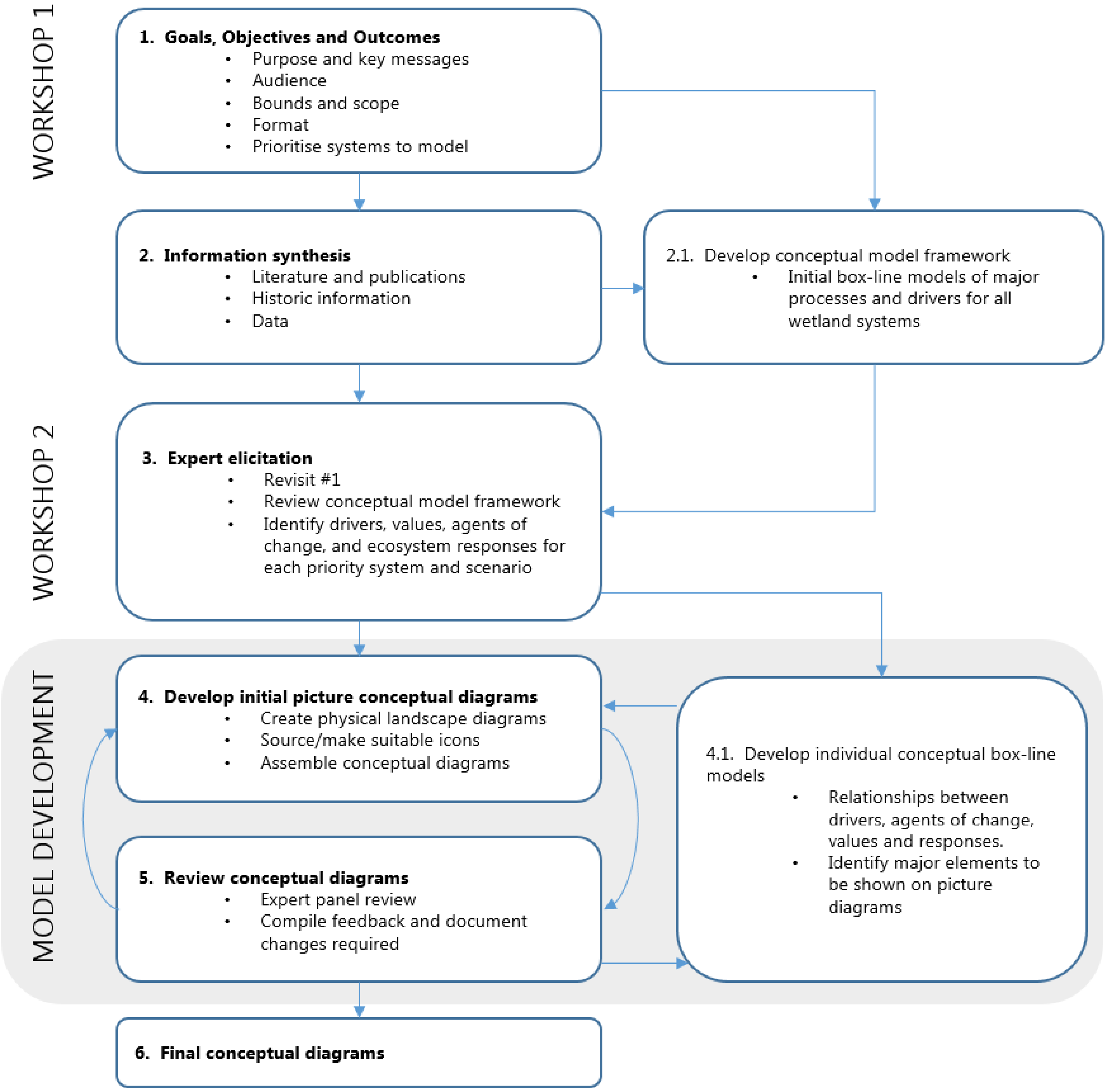


Figure 2.1 Work flow diagram illustrating the steps involved in the development of conceptual models for wetland systems in the SE NRM region (adapted from Imgraben et al. 2014)

2.1 Step 1: Setting goals, objectives and outcomes

The first of two workshops was held on the 25 September 2014 where staff from SE NRM region DEWNR policy, community engagement, land management, South East Water Conservation and Drainage Board (SEWCDB) and Science, Monitoring and Knowledge (SMK) staff agreed upon the purpose, style, and presentation of the conceptual diagrams, and identified priority systems to be modelled. Workshop 1 participants are listed in Appendix 1.

2.1.1 Agreed purpose and audience of the conceptual models and diagrams

There were multiple purposes of the conceptual models/diagrams identified by workshop participants, including short-term (e.g. community panel) and longer term uses for documenting drivers, processes and values of wetlands and drains for the SEDWS, future climate change modelling (predicting future states), defining environmental water requirements, and as general communication and education tools. The development of conceptual models and diagrams also offered an opportunity to compile all the current science and expert understanding on wetland systems and drivers at a scale useful for multiple purposes.

The workshop group identified a primary purpose of the models to be developed, as well as documenting secondary purposes. The final conceptual models were to meet the primary purpose, however be specifically designed with consideration to secondary purposes (i.e. could be used as a framework for more quantitative analysis of relationships between drivers and values).

Primary purpose: communication products for the community panel. The primary purpose was to communicate to the community panel in a simplified way, the complex hydrological and landscape processes effecting wetlands and drains.

The conceptual diagrams were required to:

- Be useful as communication and education tools
- Illustrate the differences and values of systems across the region
- Illustrate connectivity of wetlands and drains, and other drivers and threats
- Be easily identifiable (recognisable, relatable) as South East landscape features by the community
- Depict consequences to values from agreed scenarios
- Clearly identify the evidence base (literature or expert opinion) for model relationships
- Be developed in a way that can be added to and developed further for secondary purposes

Secondary purposes: to improve water planning and policy, including:

- Contributing to the identification of issues outlined within the SEDWS concept statement, including supporting documentation (qualitative and quantitative) of relationships between driving processes and values in wetland and drain systems
- Contributing to future risk assessment processes for water planning
- Identifying potential scenarios and management actions that mitigate the impacts of climate change
- Identifying environmental water requirements

2.1.2 Priority wetland systems, scale, and scenarios

Seven unique and representative wetland-drain-landscape systems, which are typical of the SE NRM region, were identified and prioritised by the workshop participants (Table 2.1). The top four wetland systems were identified as the deliverables for this project within the project scope. The final three systems (Table 2.1) were identified as priorities for additional conceptual modelling should further opportunities become available.

The conceptual diagrams aimed to illustrate representative and stylised wetland systems, sections of drains, and adjacent landscape features and land use. The scale was chosen to show landscape processes and threats, groundwater and surface water interactions, impacts associated with land use, and ecosystem values and responses.

Table 2.1 Wetland systems for conceptual model development (in order of priority)

Wetland system	Examples
1. Inland interdunal wetlands and watercourse with groundwater drain and associated infrastructure	West Avenue; Bakers Range; Marcollat Watercourses
2. Coastal dune lakes and permanent freshwater in drains	Lake George and Drain M; Lake Bonney; Lake Frome
3. Karst rising spring with drain and peat swamp	Ewens Ponds and Eight Mile Creek; Piccaninnie Ponds; Stratmans Pond and Deep Creek; Cress Creek
4. Freshwater marsh GDE (both drained and un-drained), including perched systems in same model	Dismal Swamp area; The Marshes; Honans
5. Cross-border creek into freshwater lake. Including permanent pools and floodplain and off-stream wetlands*	Mosquito, Morambro, Tatiara, and Nalang Creeks
6. Terminal saline lake / inland interdunal (northern outlet drain)*	Morella Basin; Messant; Duck Island
7. Freshwater meadows, non-groundwater dependent*	Seasonal Herbaceous Wetlands (e.g. Bangham; Swede Flat)

*not included in this project

The conceptual models aimed to present an historic (pre-European), present, and a range of future scenarios (e.g. climate change impacts, impacts of no drainage management vs. management intervention). Difficulties in developing conceptual future scenario diagrams was discussed by the workshop attendees, including the lack of data to support predictive models and the requirement of clearly defining and justifying the changes in drivers modelled. As such, this project produced pre-European and present conceptual diagrams for each of the four priority wetland systems identified (Table 2.1).

2.2 Step 2: Information synthesis

All publications and data sources used to inform the development of the conceptual models were referenced within each individual box-line model for each of the priority systems. Information sourced and reviewed in the development of the conceptual diagrams included:

- Published peer-reviewed literature
- Unpublished reports
- Data (e.g. groundwater level monitoring)
- Spatial datasets (e.g. LiDAR Digital Elevation Model, Aerial photography, Wetlands mapping, Pre-European vegetation mapping)
- Current and historic photographs and drawings
- Historic land survey mapping
- Expert opinion from the workshop participants

In total, 66 data sources/publications (see references for each conceptual model in Appendix 2) were used to inform the development of conceptual models and diagrams, and 15 workshop participants (Appendix 1) provided additional expert knowledge. The pre-European scenario models were based on the sourcing of historic land surveys (circa 1880 - 1890's), historic photos (e.g. Figure 2.2), physical setting, and anecdotal and expert opinion. Present scenarios were based as much as possible on published literature and expert knowledge.

2.2.1 Conceptual model framework

As part of the synthesis of available information to develop conceptual models for wetlands systems, a generic conceptual model framework for wetlands in the South East was developed based on existing models (Butcher et al. 2011; Department of Environment and Heritage Protection 2013; Nicol et al. 2012). The conceptual model framework identified the broad major drivers (physical setting, hydrology, climate, and water quality) which interact with and determine wetland values. Agents of change are components that operate to alter the natural drivers of the system (e.g. drainage, climate change, groundwater extraction etc.) (Table 2.2 and Figure 2.3).

The drivers identified in the conceptual model were expanded to identify their significant components, and the linkages and relationships between drivers, agents of change and values for wetlands in the SE NRM region (Figure 2.4). This framework was then used to develop the more detailed individual conceptual box-line models for each of the four priority systems documented in this report and are provided as Appendix 2.

The box-line conceptual models (Appendix 2) are considered preliminary, with the project timeframe and scope limiting the ability to fully identify and test/verify all relationships for each system. It was the intention of this project that the box-line conceptual models produced were an initial compilation of literature, data, and knowledge from regional experts. These were used to identify the major components (drivers, processes, values and agents of change) to be illustrated in the picture conceptual diagrams, however the box-line models require further refinement for use for other purposes.

Table 2.2 Terms used to describe wetland system functions

Term	Definition
Values	The components and character of the ecosystem that result from the interaction of drivers and processes (e.g. animals, plants, vegetation communities, social and cultural uses, biophysical processes).
Processes	A process relates to the interaction between different values, drivers and agents of change (e.g. rainfall recharges and aquifer which seasonally discharges into a wetland). Interactions between different processes can also occur (e.g. two different chemical processes interacting with each other).
Drivers	Drivers can be a component of process that causes a change in an ecosystem, community, organism or other component or process. A driver (e.g. physical setting, hydrology, climate, water quality) causes a process (e.g. hydrological or chemical) to interact with and determine wetland values.
Agents of change	Human related alteration of natural drivers (e.g. landscape and land use changes, climate change).
Ecosystem response	The outcome of the interaction between drivers, processes and agents of change on an ecosystem value (e.g. drainage causing loss of permanent water results in loss of habitat for permanent water dependent fauna causing species population local extinction)

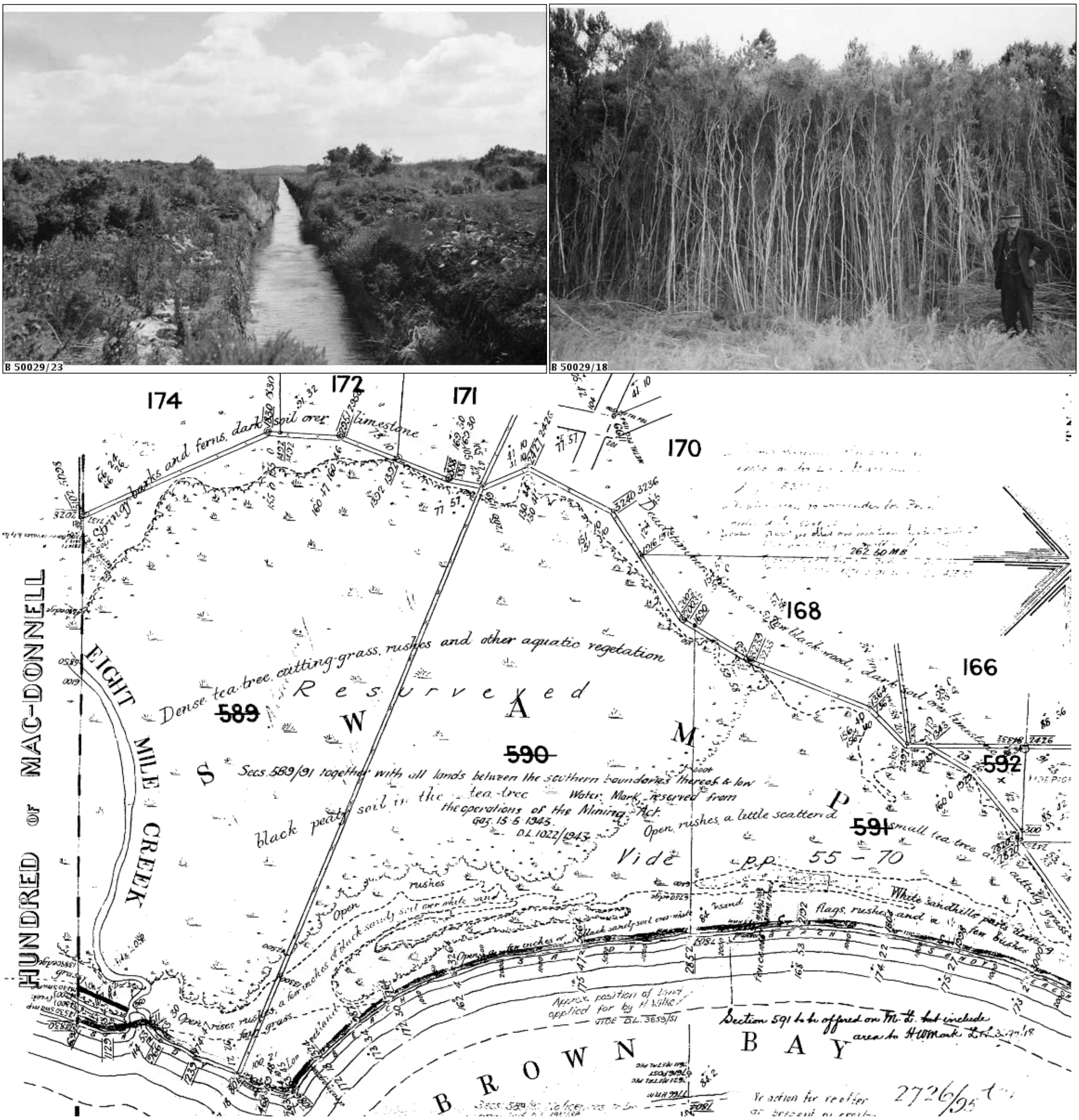


Figure 2.2 Example of historic photos and land survey mapping sourced for each system: Karst rising springs and peat swamp. Photos of draining and clearing of Eight Mile Creek area (circa 1930), and land survey mapping (1896). Source: National Library of Australia.

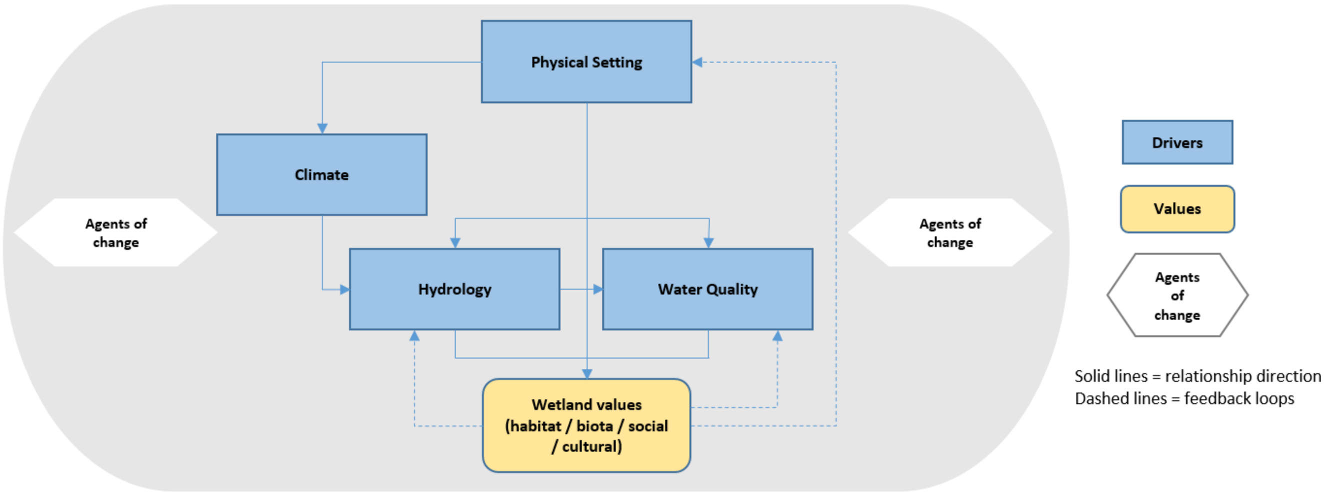


Figure 2.3 Natural wetland system major drivers conceptual model framework

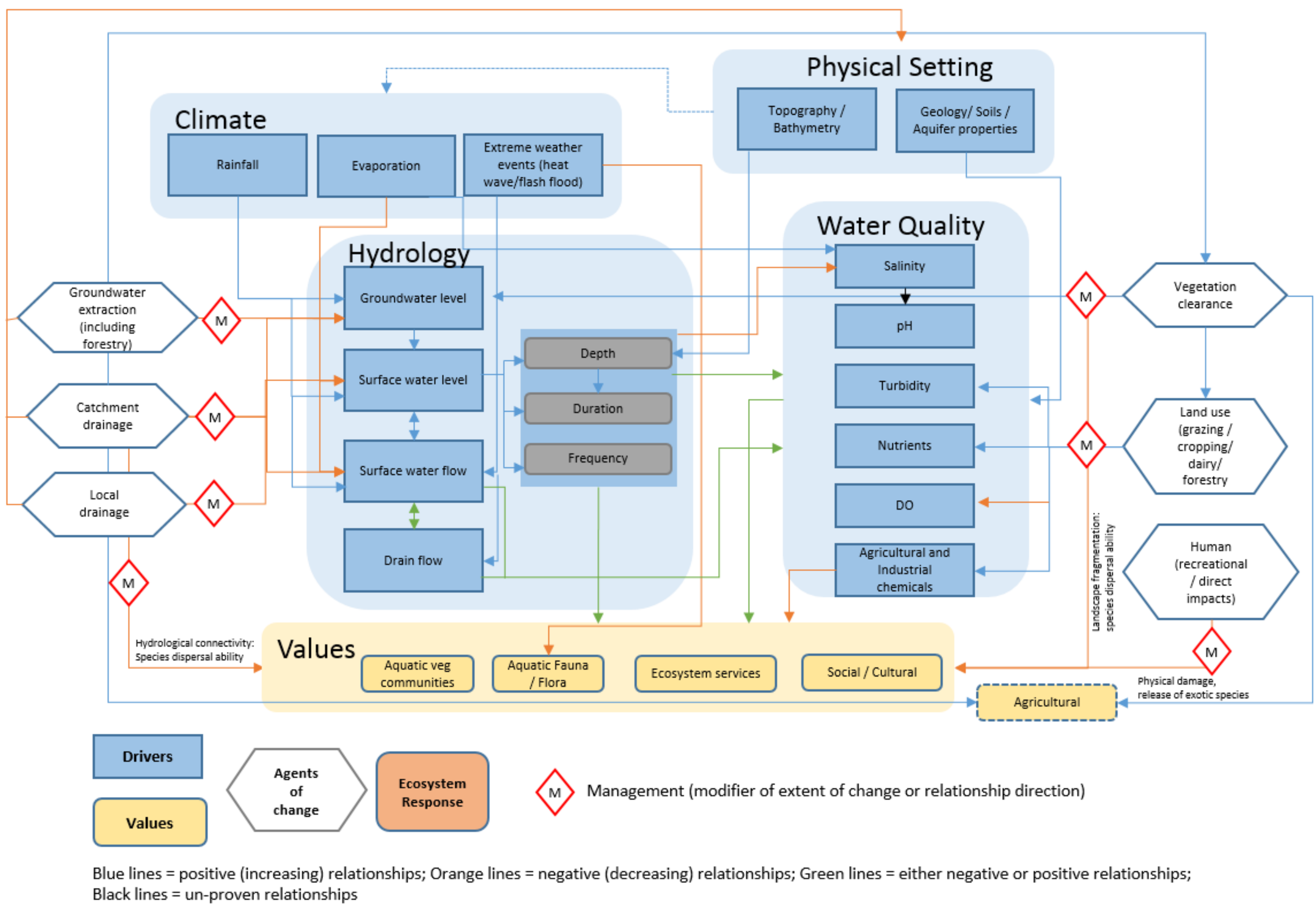


Figure 2.4 Generic conceptual model framework for wetland systems in the South East

2.3 Step 3: Expert elicitation

Information on wetland systems was elicited from regional experts (Appendix 1) at a workshop on the 22nd October 2014. The workshop participants identified drivers, values, agents of change and ecosystem responses for the identified priority wetland systems identified in Table 2.1 for both the pre-European and present case scenarios within the framework of the conceptual models already prepared (Figures 2.3 and 2.4). A geographic information system (GIS) displaying aerial photographs and a digital elevation model, along with example photos and any existing conceptualisations of the wetland systems to be modelled assisted in directing the discussions.

The workshop participants drew each of the priority wetland systems in both a pre-European and current case scenario (Appendix 3). Drawing of individual participants understanding of landforms, geology, hydrogeology, surface water hydrology, drain infrastructure, ecological values, social and cultural values, and known ecosystem responses were able to be discussed and relationships (cause and effect) were identified and subsequently summarised (supported by literature or data where possible) in detailed box-line conceptual models (refer to Appendix 2).

2.4 Step 4: Develop conceptual models

Conceptual diagrams were developed in Adobe Illustrator®, with use of symbols and landscape scenes available from the Integration and Application Network (IAN 2004). Box-line models were developed in MS Powerpoint®.

The conceptual diagrams were supported with summarised information from the box-line models (refer to Appendix 2). Major hydrological drivers and processes were summarized in text to add clarity and explanation to complex interactions in relation to the purpose of the diagrams.

2.5 Steps 5 and 6: Review of models and conceptual diagrams

Both the box-line conceptual models and pictorial conceptual diagrams were reviewed by the workshop participants (Appendix 1), and community engagement staff from the SE NRM region. All comments and additional information were collated and synthesised, and used to refine the final conceptual diagrams presented in this technical note, along with the accompanying descriptive information.

The final versions presented in this report have captured expert input and supporting science as closely as possible. We recognise that further editing could be undertaken to refine the diagrams and the box-line models, and Aboriginal values will be added to these models as a separate consultative process (Auricht and Imgraben 2014).

3 Project output

Each conceptual diagram was formatted to be printed on A3 size paper or larger. The conceptual diagrams were designed to stand-alone and be used in the absence of this report as required. The supporting preliminary box-line conceptual models for each diagram are provided in Appendix 2 and are also required to be printed on minimum A3 size paper. Citations referred to in the box-line models are listed individually for each system in Appendix 2.

Electronic copies of the conceptual diagrams have been provided in Adobe Illustrator® format to the SE NRM Board.

3.1 Inland interdunal wetland and watercourse conceptual diagram

INLAND INTERDUNAL WETLANDS AND WATERCOURSE

DESCRIPTION

Watercourse flow in the South East has historically moved from south to north, along broad flats between north-westerly aligned, roughly parallel, ancient dune ranges. Inland interdunal wetlands are formed in the lowest part of the flats at the base of the range, and flood out onto vast floodplain flats, before flowing northwards. These wetlands and floodplains (occuring mostly in the Upper South East) are known as watercourses, and (prior to drainage) were up to 10 km wide and over 70 km long.

MAJOR DRIVERS

Climate: Rainfall (Temperate: Winter-Spring rainfall 500-600mm/year average); Evaporation; Extreme weather events
Physical Setting: Topography (Quaternary marine origin dunes; low topographic relief); Geology (shallow unconfined limestone/marl aquifer); Soil type
Hydrology: Groundwater level; Surface water level; Watercourse flow; Drain flow
Water Quality: Salinity (increasing); pH (increasing); Turbidity; Nutrients; Dissolved Oxygen; Agricultural chemicals; Sediment

INFLUENCES

Regional surface water drains
Groundwater interception drains
Local surface water drains
Native vegetation clearance
Landuse (grazing/cropping)
Recreational (deer/duck hunting)
Pests (foxes/deer/spiny rush)
Reduced fire frequency
Climate change

IMPACTS

Reduced hydrological connectivity
Reduced depth and duration of inundation
Reduced frequency of flow
Loss of permanent water
Increasing salinity
Increasing alkalinity
Agricultural pollutants
Decreasing Dissolved Oxygen
Overgrazing

LOCATION

MANAGEMENT

Managed wetland hydrology through manipulation of drain infrastructure

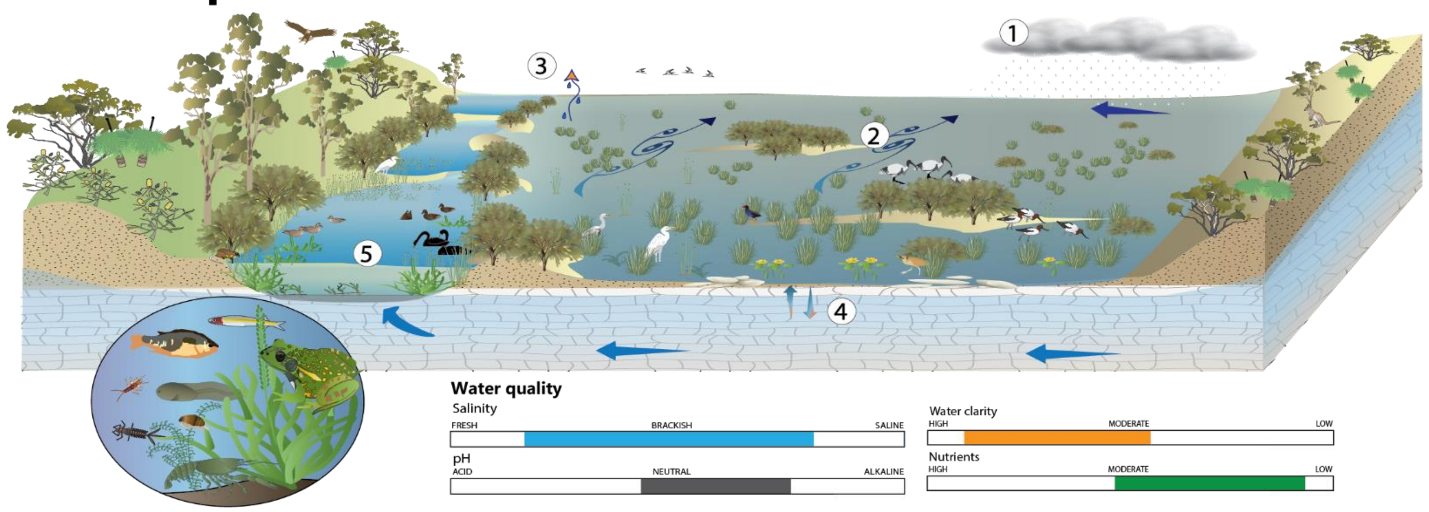
ECOSYSTEM RESPONSES

Decrease in aquatic biodiversity
Loss of salt sensitive species
Loss of native fish (permanent water refuges)
Decline in waterbird breeding success
Decline in waterbird diversity and abundance
Increase in Swamp Paperbark shrubland

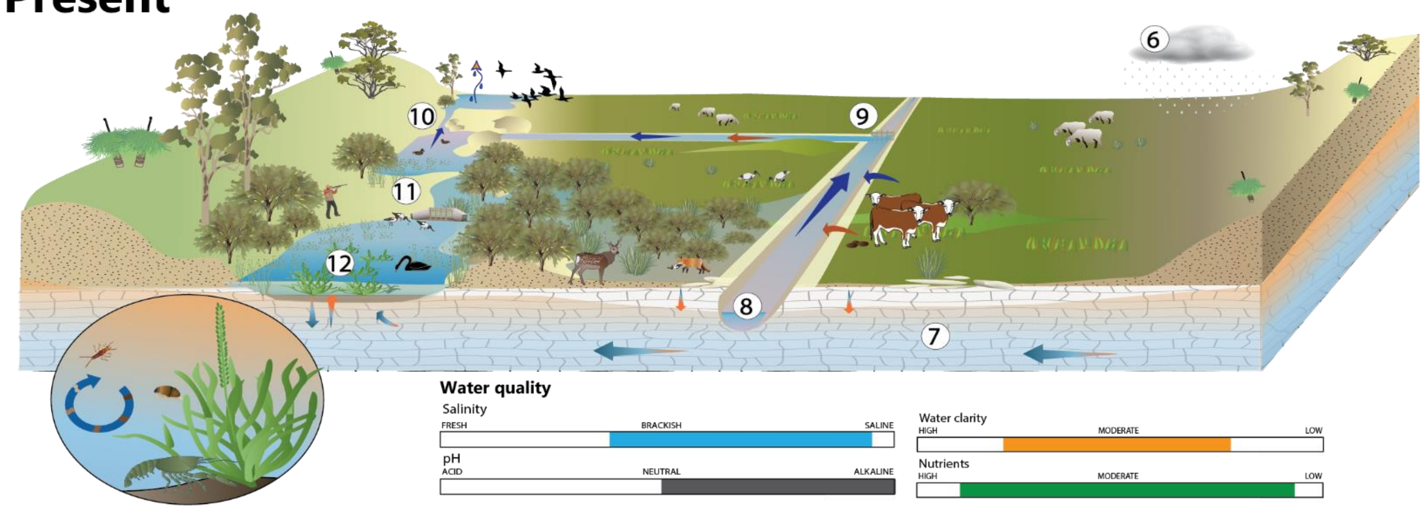
EXAMPLES

West Avenue , Taratap, Tilley Swamp, Bakers Range, and Marcollat Watercourses; Mandina Marshes; Kungari Conservation Park.

Pre-European



Present



PHYSICAL SETTING

Calcrete
Tertiary limestone aquifer
Calcareous sand (Bridgewater formation)
Brackish groundwater

VALUES

Wetland Vegetation Communities

Floodplain: open Chaffy Saw-sedge sedgeland
Floodplain: dense Swamp Paperbark shrubland
Wetland: Fresh - brackish aquatic plants (Water Ribbons; Water Milfoil with fringing sedges and rushes)

Aquatic Fauna and Flora

Waders
Colonial nesting waterbirds (e.g. ibis; herons; egrets)
Waterfowl (ducks; swans)
Diving ducks
Diverse waterbirds
Raptors (e.g. Swamp Harrier)
Cryptic waterbirds (bitterns; rails; crakes)
Wetland dependent mammals (Toolache Wallaby; Water-rat)
Diverse freshwater insects and crustaceans
Specialist habitat requirement frogs (e.g. Southern Bell Frog)
Salt sensitive native fish (Yarra Pygmy Perch; Dwarf Galaxias)
Freshwater aquatic herbs, sedges and rushes (e.g. Running Marsh-flower; Twig-rush)

Ecosystem services

Water purification / Carbon storage
Biological pest control

Social / Cultural

Recreation (deer and duck shooting; yabbying)

Agricultural

Grazing (beef cattle; sheep) / cropping

OTHER THREATS

Predation (fox)
Over-grazing / trampling (deer)

MAJOR HYDROLOGICAL DRIVERS AND PROCESSES

Pre-European

1. Freshwater enters the watercourse through rainfall in the local catchment & overland flow from large upstream catchments.
2. Surface water flows in a north-westerly direction filling the wetland basins against the dune range, and spilling out onto vast shallowly inundated floodplains, before flowing in a northerly direction. The low topographic relief produces slow water movement and permanent waterlogging.
3. Water is lost through transpiration and evaporation and the evapoconcentration produces seasonally brackish conditions.
4. Shallow brackish groundwater in the regional unconfined aquifer and fresh - brackish surface water interchange on the floodplain, and permanently discharge into wetland basins at the base of the range. Groundwater flows in a westerly direction .
5. Permanent inundation of wetland basins with predominantly fresh to slightly brackish water. Seasonal flooding of large floodplain.

Present

6. Significantly reduced volumes of freshwater entering the watercourse as a result of upstream drainage (e.g. Drain M) which removed large flooding flows originating in the Lower South East. Freshwater entering the watercourse is restricted to rainfall in reduced local catchments.
7. Loss of large freshwater flows from upstream catchment results in reduced recharge and flushing and contributes to rising groundwater salinity.
8. Increased recharge from cleared land on the dune ranges causes episodic rising of saline groundwater. Drains intercepting the local aquifer are designed to lower local groundwater levels and reduce seasonal flooding, resulting in improved agricultural productivity. Local catchment runoff , including agricultural pollutants and sediments enter the drain.
9. Managed drain infrastructure allows manipulation of groundwater levels (e.g. weirs). Diversion of drain waters into wetlands occurs when salinity levels are suitable for recieving wetland ecosystems . Agricultural pollutants and sediments are delivered to the wetlands directly by drain inputs, and diffusely from the landscape.
10. Local drainage of surface water from the floodplain, along with drains cut between wetlands at the base of the dune range result in reduced levels and duration of inundation in wetlands and complete loss of the floodplain.
11. Restoration and management of wetland water levels through weir and levy installations allow for re-instated depth and duration of inundation in some wetlands.
12. Wetlands are now seasonally inundated with brackish to saline water. Brackish groundwater discharges into the wetlands seasonally, and groundwater and surface water interchange .
Changed hydrology and water quality has resulted in aquatic biodiversity loss, however wetlands and remnant floodplains provide important habitat for diverse waterbirds and provide ecosystem services supporting healthy landscapes.

Natural Resources South East
Government of South Australia Department of Environment, Water and Natural Resources

Published by: Science Monitoring and Knowledge, December 2014

3.2 Coastal dune lakes and permanent freshwater in drains conceptual diagram

COASTAL DUNE LAKES AND PERMANENT FRESHWATER IN DRAINS

DESCRIPTION

Several large permanently inundated coastal lakes are formed behind modern coastal dunes south of Robe to Carpenters Rocks. The lakes are major groundwater discharge points for the unconfined aquifer, and prior to drainage were land-locked, with no direct connection to the sea. Water quality varies from fresh to hypersaline depending on the balance between marine and regional groundwater interaction, evaporation, and rainfall . Some coastal lakes are now also the terminus of regional surface drainage networks, with artificial outlets to sea, and are significantly ecologically altered.

MAJOR DRIVERS

Climate: Rainfall (Temperate: Winter-Spring rainfall 600-700 mm/year average); Evaporation; Extreme weather events
Physical Setting: Topography (modern coastal dunes and interdunal flat); Geology (shallow unconfined limestone aquifer); Soils (sand / marine)
Hydrology: Groundwater level; Surface water level; Drain flow; Sea water level / Tidal influences
Water Quality: Salinity; pH; Turbidity; Nutrients; Dissolved Oxygen; Agricultural and industrial chemicals; Sediment; Marine inputs

INFLUENCES

Regional drainage network inflow
Artificial sea outlet
Local surface water drains
Native vegetation clearance
Landuse (grazing/crops/forestry)
Irrigated agriculture
Industrial wastewater input
Recreational (boating / fishing)
Climate change
Sea level rise

IMPACTS

Increased hydrological connectivity
Reduced depth and duration of inundation
Reduced volume of flow
Increasing salinity
Increasing nutrients and sedimentation
Increasing turbidity
Agricultural and industrial pollutants
Decreasing dissolved oxygen
Increased marine connectivity
Habitat fragmentation

LOCATION

MANAGEMENT

Groundwater use policy
Manipulation of outlet drains
Regional drainage network
Exclusion of stock
Re-vegetation of buffer zones

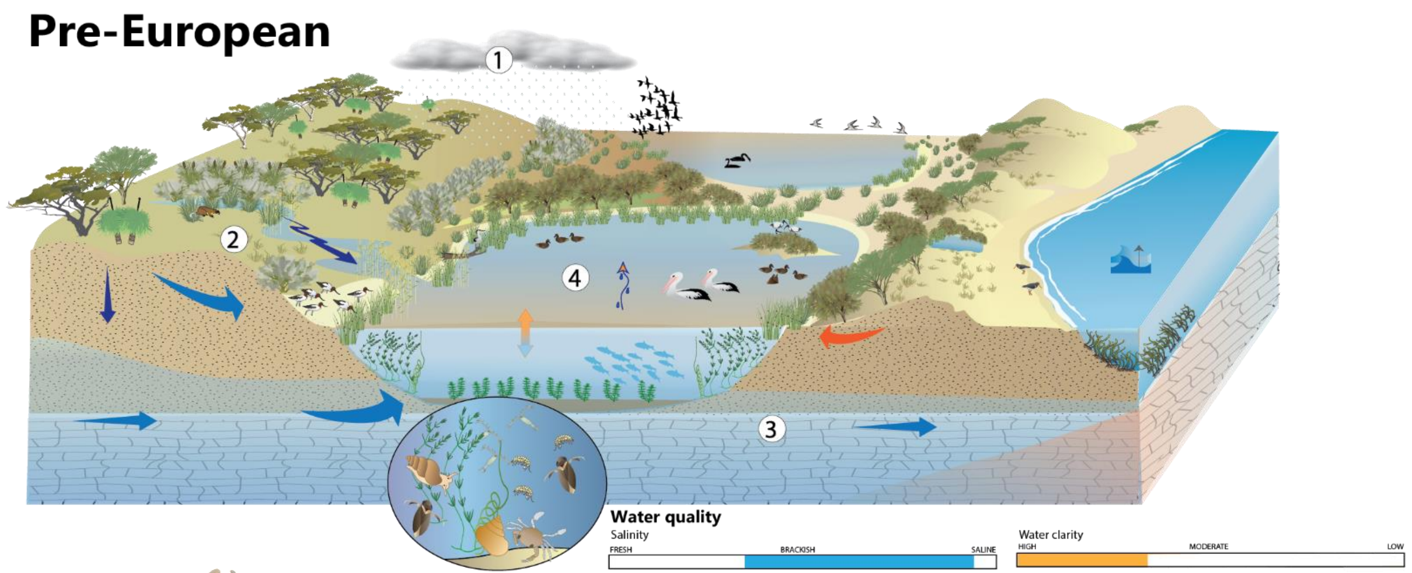
ECOSYSTEM RESPONSES

Decrease in aquatic biodiversity
Loss of aquatic plants
Risk of algal blooms and fish deaths
Loss of native fish species
Addition of marine and migrating fish species
Decline in waterbird breeding success
Decline in waterbird diversity and abundance

EXAMPLES

Coastal Lakes: Lake George; Lake Eliza; Lake St Clair; Lake Bonney, Butchers Gap
Drains: Drain M, Drain L, Bevilaqua; Bray

Pre-European



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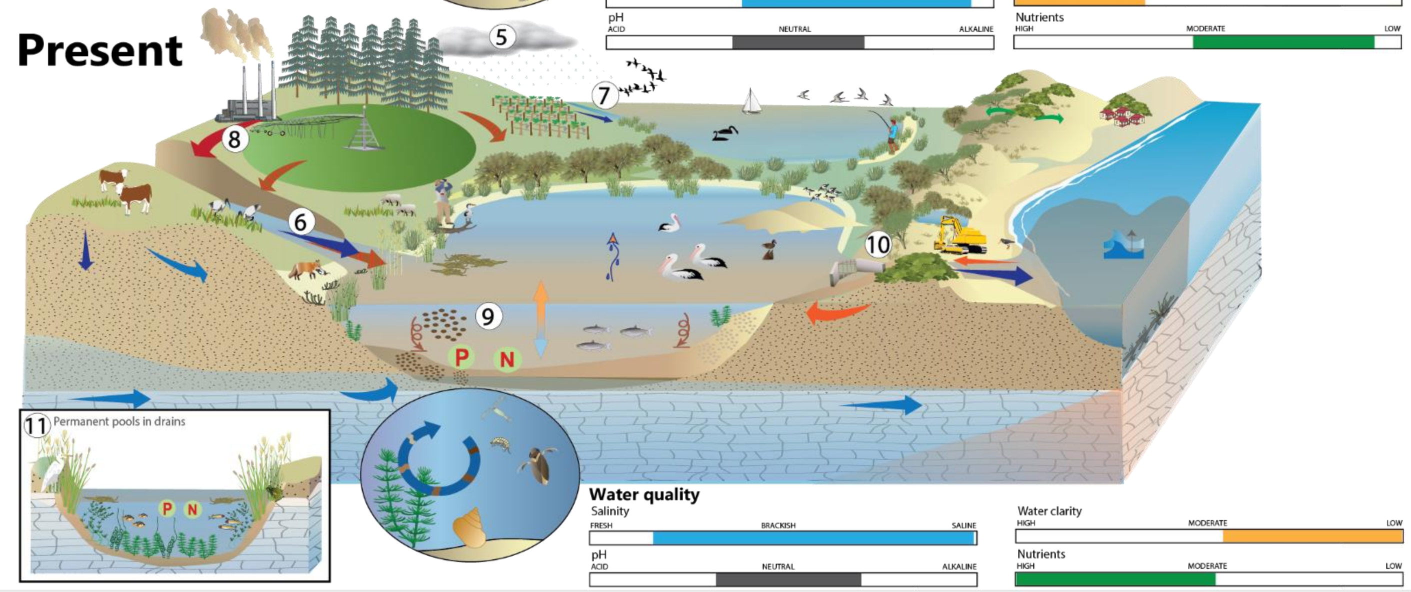

PHYSICAL SETTING

Tertiary limestone aquifer
Sand
Fresh groundwater
Sea water interface

VALUES

Wetland Vegetation Communities

Chaffy Saw-sedge sedgeland
Swamp Paperbark shrubland
Silky Tea-tree shrubland (groundwater seeps and springs)
Fringing sedges
Submerged aquatic plants

Aquatic Fauna and Flora

Diverse waders / Internationally significant numbers
Colonial nesting waterbirds (e.g. ibis; herons; egrets)
Waterfowl (ducks;swans)
Diving ducks
Fish-eating waterbirds
Wetland dependent mammals (Water-rat)
Brackish insects, snails and crustaceans
Diverse and abundant native fish
Marine and fishes that migrate between sea and fresh water
Threatened native freshwater fish species
Specialist habitat requirement frogs (e.g. Southern Bell Frog)
Seagrass

Ecosystem services

Water purification / Carbon storage
Biological pest control

Social / Cultural

Fishing / Boating
Coastal townships / Tourism
Nature based tourism

Agricultural / Industry

Grazing (beef cattle; sheep)
Irrigated agriculture
Horticulture (vineyards)
Industrial (pulp mill)
Forestry (pines)

OTHER THREATS

Predation (fox)
Invasive species (Coastal Wattle)

MAJOR HYDROLOGICAL DRIVERS AND PROCESSES

Pre-European

1. Rainfall rapidly recharges into sand dune ranges and the regional limestone unconfined aquifer via infiltration.
2. Freshwater enters the land-locked lake via local groundwater discharge at the base of the dunes , spring fed creeks and surface water runoff. Silky Tea-tree communities form where fresh groundwater seeps beneath the dune range.
3. Groundwater in the regional unconfined aquifer permanently discharges into coastal lakes, maintaining permanent water. Groundwater in the unconfined aquifer flows towards the sea . Marine groundwater infiltration is influenced by tidal action .
4. Coastal lakes exhibit large seasonal changes in salinity ranging from brackish in the winter (due to higher freshwater inputs) to saline in the summer as a result of evapoconcentration and accumulated salts from the marine environment. The open water lakes were abundant in waterbird and fish, with submerged aquatic plants.

Present

5. Reduced recharge to groundwater due to interception by plantation forestry and declining rainfall, along with groundwater extraction for irrigation, result in decreased local and regional groundwater discharge and levels.
6. Regional surface water drainage networks input large quantities of fresh water seasonally into some coastal lakes (e.g. Lake George as the terminus of Drain M).
7. Local surface water drains remove water from surrounding flats and seeps, allowing development of the flats for agriculture.
8. Agricultural pollutants and sediments from landuses within the catchment of regional drainage networks flow into drains via runoff and accumulate in high concentrations in drain water.
Treated wastewater from pulp and paper mills are discharged into drains terminating in coastal lakes, including quantities of suspended solids, nutrients, chemicals and heavy metals.
9. Pollutants P N (e.g. nitrogen and phosphorous) and sediments within drain waters flow into and accumulate in receiving coastal lakes . Interactions between sediment, nutrient flux and water levels within the lakes result in high turbidity , higher likelihood of algal blooms , and subsequent loss of aquatic plants and reduction in fauna diversity. Lake levels and salinity fluctuate from slightly brackish to hypersaline with drain inflows.
10. Outlet channels are cut to allow the regional drainage network to discharge to sea. Outlet structures are managed (usually accompanied with dredging) to reduce sand sedimentation and manage lake levels. Discharge of nutrient rich, relatively fresh water to the marine environment results in seagrass loss . Sea water inflows into the lake, driven by tidal influences and sand sediment builds up in the lake basin .
11. Permanent pools within the regional drainage network provide important refuge habitat for threatened aquatic species (e.g. native fish populations) due to the loss of natural wetland habitats.

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3.3 Karst rising springs and coastal peat swamp conceptual diagram

KARST RISING SPRINGS AND COASTAL PEAT SWAMP

DESCRIPTION

Karst rising springs are formed by dissolution of the limestone aquifer and occur along the coast of the Lower South East. They are characterised by having permanent open deep freshwater habitat as a result of direct surface expression of groundwater. In a natural state, karst springs fed large densely vegetated peat swamps which occurred behind the coastal foredunes, and largely flowed towards the Glenelg River mouth. Drainage of karst spring discharge out to sea began in the late 1800s, allowing development of the peat swamps for agriculture. Karst rising springs support more threatened species than any other ecosystem in the South East, are unique to the region, and extremely rare world-wide.

MAJOR DRIVERS

Climate: Rainfall (Temperate: Winter-Spring rainfall 700-750 mm/year average); Evaporation; Extreme weather events
Physical Setting: Topography (modern coastal dunes and flat); Geology (karstic limestone aquifer); Soils (peat)
Hydrology: Groundwater level; Groundwater flow; Surface water level; Sea water level / Tidal influences
Water Quality: Salinity; Turbidity; Nutrients; Dissolved Oxygen; Agricultural chemicals; Sediment

INFLUENCES

Drains (sea outlets)
Native vegetation clearance
Irrigated agriculture (dairy)
Landuse (grazing/cropping)
Forestry
Mechanical management of drains
Recreational (snorkelling / diving)
Pests (foxes / coastal wattle)
Climate change
Sea level rise

IMPACTS

Loss of hydrological connectivity
Reduced depth and duration of inundation
Reduced flow / spring discharge
Increasing salinity
Increasing nutrients / pollutants
Decreasing water clarity
Habitat fragmentation
Increased marine connectivity

LOCATION

MANAGEMENT

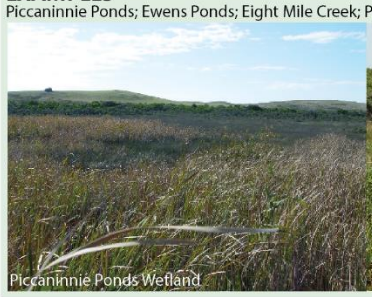
Groundwater use policy
Hydrological restoration
Establishment of buffer zones
Stock exclusion

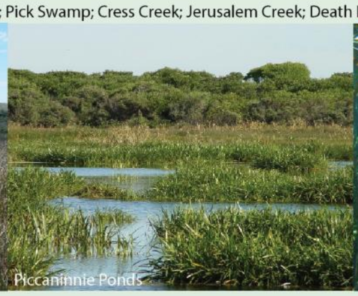
ECOSYSTEM RESPONSES

Decrease in aquatic biodiversity
Loss of genetic diversity (isolated populations)
Loss of aquatic vegetation in karst springs
Decline in waterbird diversity and abundance
Decline in waterbird breeding success
Loss of water dependent mammals
Increase in terrestrial and invasive species
Local extinction of vulnerable aquatic species

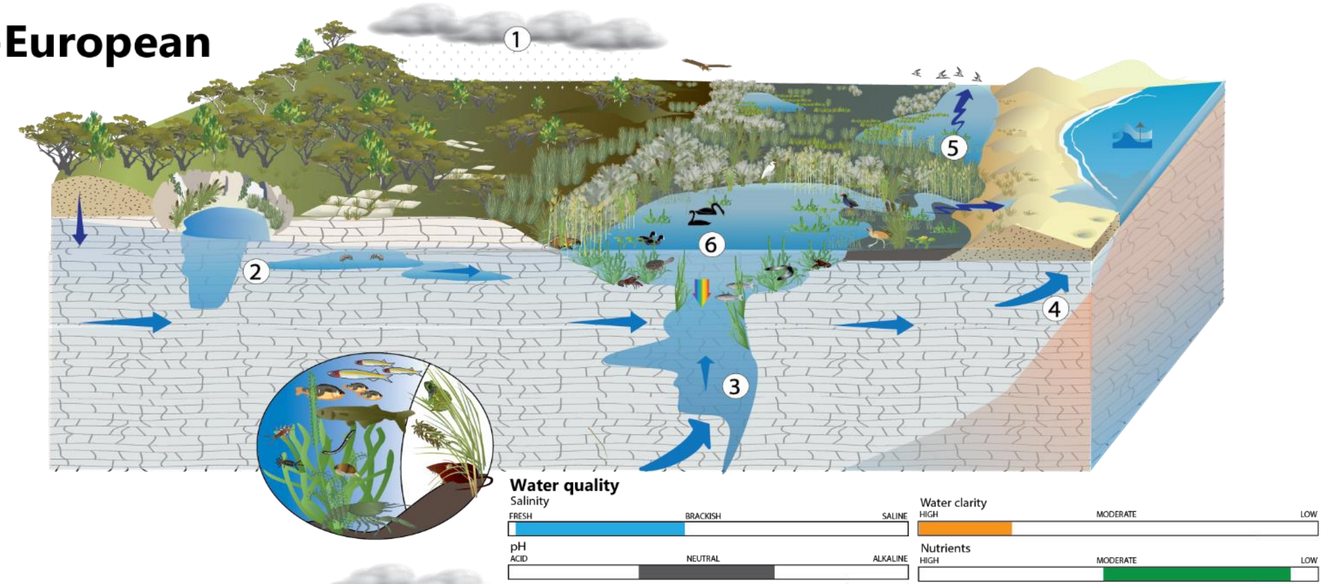
EXAMPLES

Piccaninnie Ponds; Ewens Ponds; Eight Mile Creek; Pick Swamp; Cress Creek; Jerusalem Creek; Death Hole; Stratmans Pond; Crescent Pond; Bones Pond.





Pre-European



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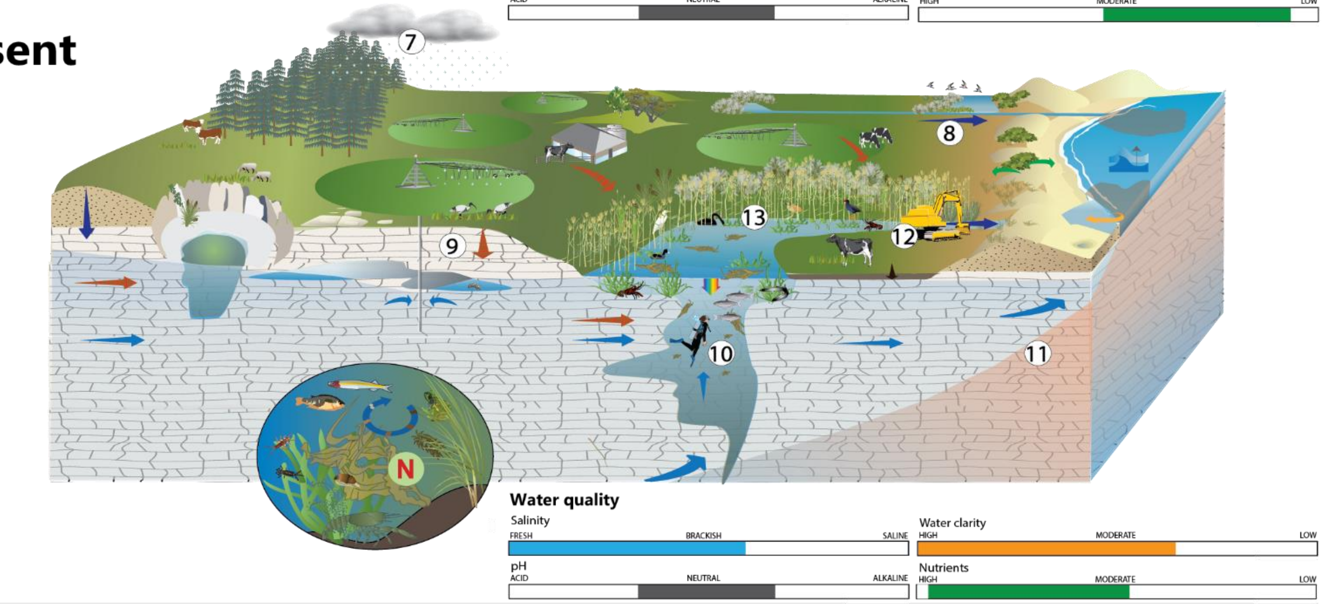

PHYSICAL SETTING

Tessellated karst pavement
Tertiary limestone aquifer
Sand
Peat soils
Fresh groundwater
Sea water interface

VALUES

Wetland Vegetation Communities

Aquatic plants (Water Ribbons; Pennywort; River Buttercup)
Fringing sedges (Common Reed; Cumbungi; Twig-rush)
Peat swamp shrubland (Silky Tea-tree; Saw-sedges)

Aquatic Fauna and Flora

Waterfowl (ducks; swans; coots)
Diverse waterbirds
Cryptic waterbirds (bitterns; rails; crakes)
Raptors (e.g. Swamp Harrier)
Wetland dependent mammals(Water-rat; Swamp Antechinus)
Diverse freshwater insects and crustaceans
Specialist habitat requirement frogs / turtles
Native freshwater fish
Fishes that migrate between sea and fresh water
Nationally endangered fauna (e.g. Glenelg Spiny Crayfish)
Groundwater crustaceans (Stygofauna)

Ecosystem services

Water purification / Carbon storage
Biological pest control

Social / Cultural

Recreation / tourism (e.g. snorkelling; diving)

Agricultural

Irrigated agriculture
Dairy
Forestry (Pines)

OTHER THREATS

Predation (fox)
Invasive species (Coastal Wattle)

MAJOR HYDROLOGICAL DRIVERS AND PROCESSES

Pre-European

1. High rainfall rapidly recharges into transmissive limestone regional unconfined aquifer via infiltration .
2. Karst features including sinkholes (e.g. Little Blue Lake) and cavities within the limestone aquifer act as conduits to groundwater flow. Groundwater flows towards the coast .
3. Groundwater permanently discharges at karst spring features along the coast , with enough head pressure to cause permanent flowing springs (e.g. Piccaninnie Ponds; Ewens Ponds), which spill out onto vast coastal peat swamps behind the foredunes.
4. Groundwater discharges on the beach, forming beach springs , and also out to sea. Significant groundwater flow supresses the salt water interface of the marine environment.
5. Densely vegetated peat swamps, fed by large karst springs and local groundwater discharge, flow towards the Glenelg River . Open water permanently inundated sedge wetlands are formed behind the foredunes.
   Outlets to sea were few, although included the natural state Eight Mile Creek , and the Glenelg River estuary.
6. Unique freshwater aquatic flora and fauna communities form to depths of over 15m due to the clarity of the water . Wetland ecosystems are diverse and abundant.

Present

7. Reduced recharge to groundwater due to interception by plantation forestry and declining rainfall.
8. Drains are cut from major karst springs, through peat swamp, directly out to sea . The drains allow for clearing of the peat swamps for agricultural development, and has resulted in isolation and fragmentation of a small number of remnant karst and peat wetlands.
9. Groundwater is extracted for irrigation, resulting in further lowering of groundwater levels in the regional unconfined aquifer and reduced flow . Agricultural pollutants infiltrate into groundwater .
10. Decreased groundwater flow and discharge into springs , along with agricultural pollutant inputs via groundwater and directly from surrounding landuse result in an increase in nitrogen concentration N . High nitrogen contributes to increased algal growth , and episodes of blue-green algae blooms (e.g. Little Blue Lake, Ewens Ponds). Reduced water clarity results in reduced diversity and abundance of aquatic plants and animals and loss of deeper water communities.
11. Tidal influences along with decreased groundwater level and flow causes the sea water interface to extend inland. Vulnerable karst features (e.g. Piccaninnie Ponds / Spencers Pond) begin to increase in salinity due to greater marine water influence. Higher tides cause greater incursion of sea water into drain outlets. Coastal irrigation is also vulnerable to sea water intrusion of the regional unconfined aquifer.
12. Outlet drains are managed to maintain a drainage service to surrounding agricultural land. The removal of water from peat swamps has over time resulted in subsistence (compression) of the peat soils, resulting in increased flooding potential. The outlet drains provide some of the only remnant habitat for several threatened species , whose habitat requirements are often incompatible with drain management for agriculture.
13. Remaining karst springs are fragmented and isolated, resulting in contraction of aquatic plant and animal communities, loss of genetic diversity, and high susceptibility to agents of change and further decline.

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3.4 Freshwater grass and sedge marshes conceptual diagram

FRESHWATER GRASS AND SEDGE MARSHES

DESCRIPTION

Sedge, grass, and herb dominated marshes occur on elevated flats between Mount Burr to Naracoorte and north of Mount Gambier to the Victorian border. The slightly undulating land surface and shallow groundwater produced a mosaic of shallow freshwater wetlands in depressions and adjacent wet heath and River Red Gum woodland. The formation of the landscape resulted from tectonic uplift in the Pliocene, with remnants (e.g. Dismal Swamp area) of the historic course of the Glenelg River. The majority of freshwater marshes are seasonally inundated, containing water for 6 to 8 months/year.Perched wetlands occur in association with volcanic origin landscapes (e.g. Mount Burr, Lake Leake and Edward) and as localised perched sand aquifers, generally supporting more permanent distinct biodiverse freshwater ecosystems and associated wet heath.

MAJOR DRIVERS

Climate: Rainfall (Temperate: Winter-Spring rainfall 650-800mm/year average); Evaporation; Extreme weather events
Physical Setting: Topography (Pliocene - Quaternary volcanics and dune deposits; low relief plateau); Geology (shallow freshwater unconfined limestone aquifer, volcanics and sand); Soils (sand and clay)
Hydrology: Groundwater level; Surface water level; Surface water flow
Water Quality: Salinity (fresh); pH (neutral); Turbidity; Nutrients; Dissolved Oxygen; Agricultural chemicals; Sediment

INFLUENCES

- Local surface water drains
- Native vegetation clearance
- Forestry
- Irrigated agriculture
- Landuse (grazing/cropping)
- Pests (foxes / mosquito fish)
- Climate change

IMPACTS

- Reduced / altered hydrological connectivity
- Reduced depth and duration of inundation
- Reduced / altered frequency of flow
- Loss of permanent water
- Large scale loss of wetland extent
- Agricultural and Forestry pollutants
- Decreasing Dissolved Oxygen
- Overgrazing / pugging
- Habitat fragmentation

LOCATION

MANAGEMENT

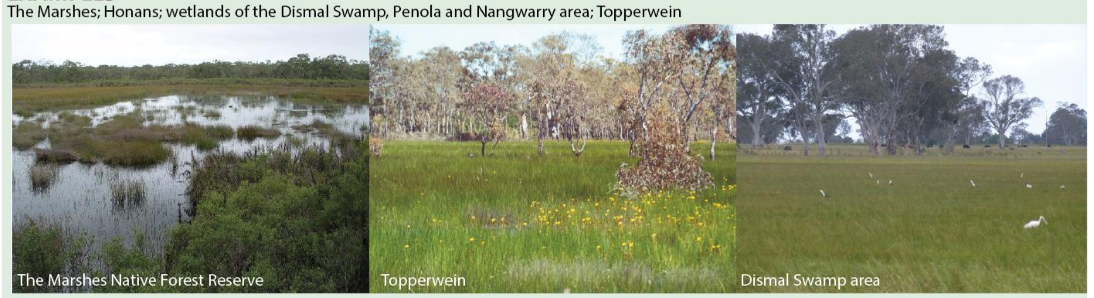
- Protection from overgrazing
- Managed grazing regimes
- Vegetation buffer zones
- Groundwater use policy
- Forest management policy
- Hydrological restoration

ECOSYSTEM RESPONSES

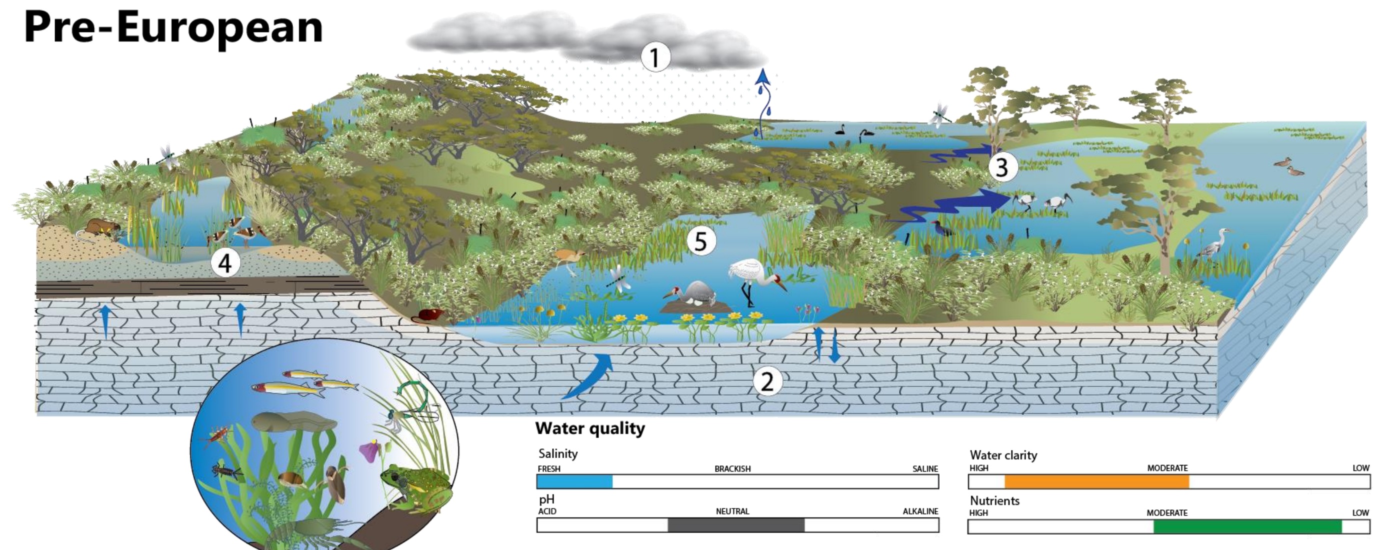
- Decrease in aquatic biodiversity
- Decline in native fish
- Loss of permanent water refuges
- Decline in waterbird breeding success
- Decline in waterbird diversity and abundance
- Loss of genetic diversity
- Encroachment of wet heath shrubs

EXAMPLES

The Marshes; Honans; wetlands of the Dismal Swamp, Penola and Nangwarry area; Topperwein



Pre-European



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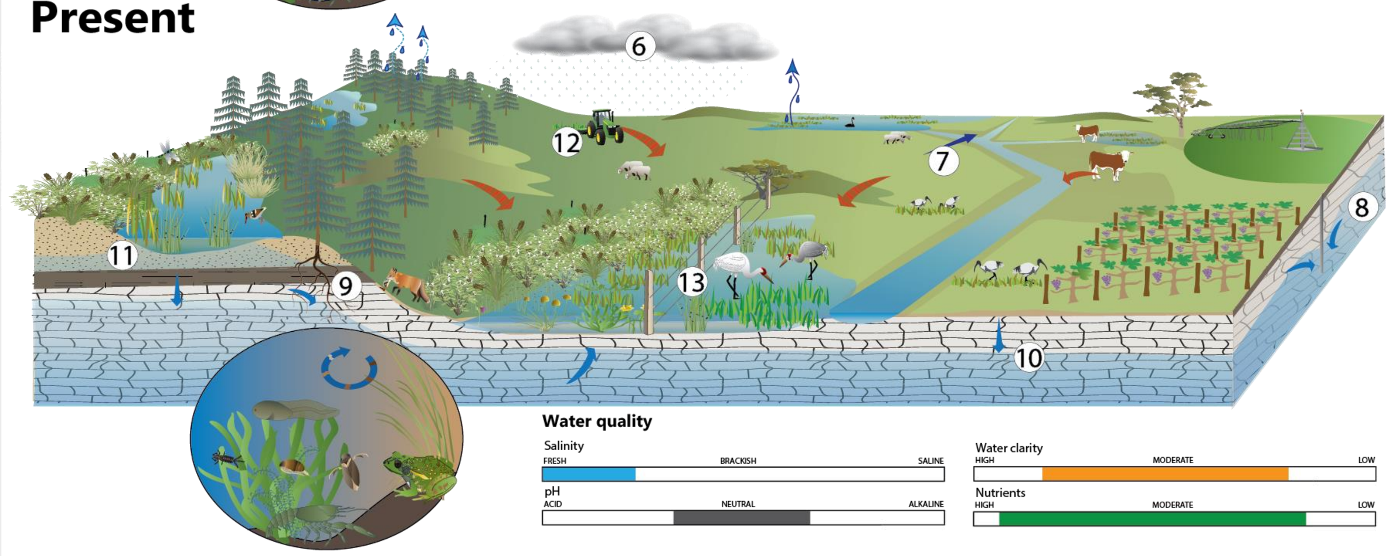

PHYSICAL SETTING

- Clay (semi-confining aquitard)
- Tertiary limestone aquifer
- Sand perched aquifer
- Fresh groundwater

VALUES

Wetland Vegetation Communities

- Wet heath (Prickly Tea-tree; Saw-sedges; Yacca)
- River Red Gum woodland
- Freshwater sedges and herbs (Water Ribbons; Twig-rush; Common Spikerush)
- Freshwater sedges and rushes (Tassel Cord Rush; Sedges; Twig-rush)

Aquatic Fauna and Flora

- Nesting waterbirds (e.g. Brolga; ducks;, swans)
- Waterfowl (Ducks; Swans)
- Diverse waterbirds
- Cryptic waterbirds (bitterns; rails; crakes; snipe)

Aquatic Fauna and Flora

- Wetland dependent mammals (Water-rat; Swamp Antechinus)
- Diverse freshwater insects and crustaceans
- Specialist habitat requirement frogs (e.g. Southern Bell Frog)
- Salt sensitive native fish (e.g. Dwarf Galaxias)
- Specialist insects (Ancient Greenling; dragonfly)
- Diverse freshwater aquatic herbs (e.g. Running Marsh-flower; Fairy Aprons; Billy Buttons)

Ecosystem services

- Water purification / Carbon storage
- Biological pest control

Agricultural

- Grazing (beef cattle; sheep) / cropping
- Horticulture (vinyards)
- Irrigation (pasture/cropping)
- Forestry (pines)

OTHER THREATS

- Predation (fox)

MAJOR HYDROLOGICAL DRIVERS AND PROCESSES

Pre-European

1. High rainfall delivers large quantities of fresh surface water to low lying, poorly draining, flat landscape. Water is lost through transpiration and evaporation .
2. Shallow fresh groundwater in the regional unconfined aquifer and surface water interact , and groundwater discharges into wetland basins permanently.
3. Wetlands were typically isolated, however periodic flood events produce slow, meandering flow between depressions. Periodic connections are important for dispersal of aquatic flora and fauna.
4. Localised perched sand freshwater aquifers, with semi-confining clay layers above the regional unconfined aquifer support wetland ecosystems in higher elevation areas. The regional unconfined aquifer influences the level of the perched aquifer.
5. A mosaic of permanently and seasonally inundated sedge and herb dominated freshwater wetlands and seasonally inundated wet heath, and River Red Gum woodlands support diverse and abundant aquatic flora and fauna. Wetland soils permanently waterlogged.

Present

6. Reduced rainfall from a drying climate contributes to declining groundwater levels and reduced surface water runoff.
7. Regional drainage networks further reduce freshwater inputs, and permanently drains surface water from large areas of former wetland habitat. Local drainage of wetlands alters wetland water levels, alters connectivity, flow direction and speed. Removal of surface water enables the establishment of agricultural values.
8. Groundwater is extracted for irrigation, resulting in locally lowered groundwater levels in the regional unconfined aquifer .
9. Plantation forests intercept rainfall and extract groundwater via root uptake and transpiration .
10. Reduced groundwater level in the regional unconfined aquifer due to intensive landscape scale extraction for agriculture and forestry, and decling rainfall, resulting in decreased discharge into wetlands or complete disconnection from groundwater sources.
11. Reduced groundwater level in the unconfined aquifer results in lowering of groundwater levels in perched aquifers via increased leakage through semi-confining clays . Plantation forests may also extract water from local perched aquifers and reduce recharge.
12. Agricultural and forestry pollutants and sediments enter wetland systems from local runoff, spray drift, drains, and diffusely through groundwater .
13. Significant loss of wetland area has resulted from drainage and reduced groundwater levels. The majority of remnant freshwater marshes are now seasonally inundated, and dominated by sedges and grasses. Where protected , encroachment of wet heath shrubs results from declining water levels.
Seasonal freshwater marshes and meadows remain important sources of biodiversity in the region, and contribute important ecosystem services at the landscape scale.

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5 Appendices

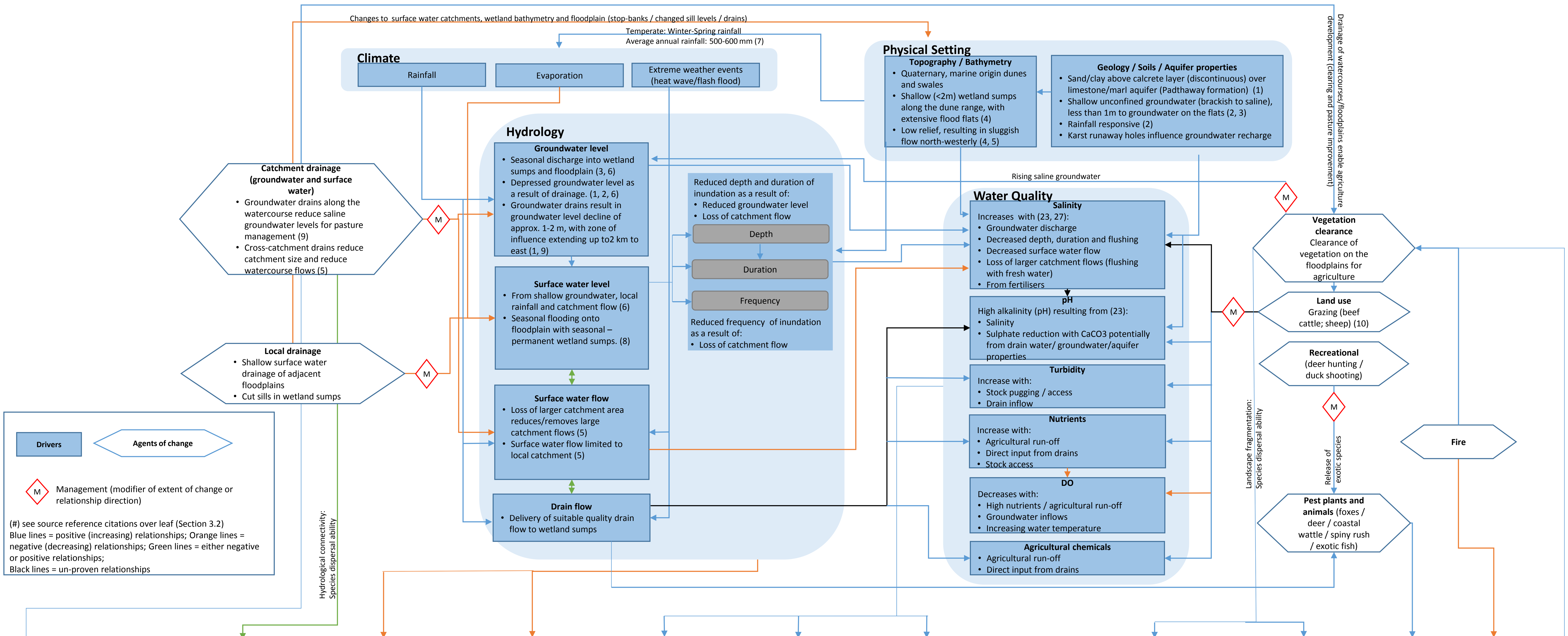
Appendix 1: Workshop participants

Project scoping workshop 1: 25 September 2014		
Name	**Expertise / Position title**	**Affiliation**
Claire Harding	Aquatic Ecologist	SMK, DEWNR
Jen Schilling	Senior Planning Officer	SE NRM, DEWNR
Mark De Jong	Senior Environmental Officer	SEWCDB, DEWNR
Melissa Herpich	Landscape Ecologist	SE NRM, DEWNR
Tim Bond	Manager, Planning and Evaluation	SE NRM, DEWNR
Abigail Goodman	Bush Management Advisor	SE NRM, DEWNR
Brad Page	Principal Advisor Evaluation and Reporting	SMK, DEWNR
Jan Newport	Senior Project Officer	SE NRM, DEWNR
Peter Whiting	Communication / Media Officer	SE NRM, DEWNR

Expert elicitation workshop 2: 22 October 2014		
Name	**Expertise / Position title**	**Affiliation**
Claire Harding	Aquatic Ecologist	SMK, DEWNR
Jen Schilling	Senior Planning Officer	SE NRM, DEWNR
Mark De Jong	Senior Environmental Officer	SEWCDB, DEWNR
Melissa Herpich	Landscape Ecologist	SE NRM, DEWNR
Abigail Goodman	Bush Management Advisor	SE NRM, DEWNR
Saad Mustafa	Senior Hydrogeologist	SMK, DEWNR
Ross Anderson	District Manager	SE NRM, DEWNR
Mark Bachmann	Principal Ecologist and Manager	Nature Glenelg Trust
Bryan Haywood	Senior Ecologist	Nature Glenelg Trust
Steve Clarke	Wetland Restoration Ecologist	SE NRM, DEWNR
Contributors outside of workshop		
Cath Dickson	Flora and Threatened Species Ecologist	Nature Glenelg Trust
Ben Taylor	Coordinator, Wetland Ecology	Major Projects, DEWNR
David New	Aboriginal Engagement Officer	SE NRM, DEWNR
Chris Auricht	Managing Director	Auricht Projects
Don Mount	Senior Ranger	SE NRM, DEWNR

Appendix 2: Preliminary box-line conceptual models for priority wetland systems

Inland interdunal wetlands and watercourse preliminary box-line conceptual model



Values (22, 23, 24)	Ecosystem Responses to Impacts										
	Reduced hydrological connectivity	Reduced depth and duration of inundation	Reduced frequency of flow	Increasing salinity	Increasing pH	Agricultural pollutants (nutrients, sediments, chemicals)	Decreasing DO	Vegetation clearance	Overgrazing	Pest plants and animals	Reduced Fire frequency
Vegetation communities											
Floodplain Vegetation: Open brackish Gahnia sp. sedgeland	Loss of propagule source. Loss of soil water store and freshwater flushing, resulting in salinisation and terrestrialisation (terrestrial native species or pasture grasses) (14, 23)	Invasion by Melaleuca halmaturorum. Loss of micro-environment for aquatic herbs (14)	Reduced opportunity to replenish soil water store, extending dry periods which allow for establishment of Melaleuca halmaturorm and terrestrial species (pasture grasses / Coastal Wattle) (14)	Gahnia filum tolerant of high salinities, resulting in potential increase in cover. (14) Reduction in Gahnia trifida. Loss of understorey diversity, and salt sensitive aquatic herbs (14)	Unknown	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs). Excessive nutrients may favour exotic species over native species (14)	Unknown	Floodplain cleared for agriculture post drainage resulting in loss of large percentage of Gahnia tussock sedgeland. Fragmentation of landscape, with some remnant floodplain vegetation . Transition to pasture. (23)	Formation of bare/pugged patches and/or tracks fragmenting the sedgeland. Suppressed regeneration. (14)	Habitat for foxes. *Juncus acutus (Spiny Rush) dispersed via drain/watercourse flow. Encroachment of Coastal Wattle (23)	Probable decrease in open Gahnia sedgelands (23)
Floodplain Vegetation: Melaleuca halmaturorum / brevifolia shrubland	Loss of propagule source. Loss of soil water store and freshwater flushing, resulting in salinisation and terrestrialisation (terrestrial native species or pasture grasses) (14, 23)	Little impact on canopy species where there is access to groundwater. Probable expansion of community unless grazed. Loss of aquatic understorey species. Transition to terrestrial ecosystems with prolonged drying. (14, 16)	Fewer opportunities for mass germination events. Loss of aquatic understorey species (14)	Tolerant of high salinities, resulting in expansion of community (unless under grazing pressure). Loss of understorey diversity (14)	Unknown	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs). Excessive nutrients may favour exotic species over native species (14)	Unknown	Floodplain cleared for agriculture . Fragmentation of landscape, with some remnant floodplain vegetation. (23) Transition to pasture. (23)	Reduced understorey diversity and cover.Increased bare ground. Senescence of canopy species with limited survival of seedlings to replace mature canopy. Increased exotic understorey species including species transported by stock and adventive species able to colonise bare ground. (14)	Habitat and cover for feral deer and foxes (23)	Probable increase in M. halmaturorum (23)
Wetland Vegetation: Fresh – brackish semi-permanent macrophytes (herbland – Triglochin / Myriophyllum) with fringing sedges (Baumea arthrophylla)	Loss of propagule source (23)	Wetlands become seasonal – episodic. Downwards colonisation of fringing vegetation from higher elevations (exotic or native). If wetland dries before fledging, adults may abandon nests. Transition to seasonal brackish herbland (14)	Wetlands become seasonal – episodic. Loss of permanent water refugia (23)	Transition to brackish herbland species. Loss of salt sensitive species (e.g. B. arthrophylla /Triglochin sp.). Osmotic stress leading to loss of vigour and dieback. Impacts to primary productivity (changes in abundance and/or composition of zooplankton, phytoplankton) (14)	Unknown	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs). Excessive nutrients may favour exotic species over native species. Algal blooms may occur with secondary effects to macrophytes (14)	Any loss of aquatic plants (producers of DO via photosynthesis) has the potential to reduce DO. (23)	Transition to pasture (23)	Pugging. Lowered biomass, supressed flowering and vegetative reproduction, reduced regeneration. (14)	Mosquito fish. Dry basins provide summer grazing /water supply for feral deer (23)	Unknown
Localised dune springs/soaks: Leptospermum lanigerum freshwater soaks	Loss of propagule source (23)	Little impact on canopy species if waterlogged conditions remain. Transition to terrestrial ecosystems (native or pasture) with prolonged dry periods (e.g. drying of spring/soaks). Loss of aquatic herbs species from understorey (14)	Fewer opportunities for mass germination events for canopy species. Loss of aquatic understorey species (14)	Dieback of mature canopy species. Impaired recruitment of canopy, low germination due to soil salinity (14, 23)	Unknown	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs). Excessive nutrients may favour exotic species over native species. Algal blooms may occur with secondary effects to macrophytes (14)	Unknown	Fragmentation of landscape, with very few spring/soak vegetation communities remaining in Inland Interdunal wetland systems. Transition to pasture (23)	Reduced understorey diversity and cover. Increased bare ground. Senescence of canopy species with limited survival of seedlings to replace mature canopy. Increased exotic understorey species including species transported by stock and adventive species able to colonise bare ground. (14, 23)	Mosquito fish (23)	Unknown
Aquatic fauna / flora											
Colonial nesting waterbirds (egrets / herons / ibis)	Decrease in spatial and temporal habitat availability (23)	Colonial nesting waterbirds (ibis / egrets) will only breed successfully if water surrounds their nest sites. If wetland dries before fledging, adults may abandon nests. Ibis tend to be most sensitive species (15)	Infrequent breeding and feeding habitat availability. Loss of 'traditional' nesting sites (23)	Decline in invertebrates and fish resulting in loss of diversity and abundance of colonial nesting species (13, 17) Salinity exceeds thresholds for waterbird broods (19).	Loss or reduction of fish and macro-invertebrate species resulting in decline in food resources of colonial nesting species. Very high pH (>9) may impact brood survival (19).	Unknown, pesticides potentially have a decreasing effect on macro-invertebrates and fish (23)	Decrease in fish / macro-invertebrates resulting in reduced food for colonial nesting species (23)	Loss of nesting habitat (e.g. M. halmaturorum shrublands) (17)	Stock disturbance of nesting sites (23) Loss of nesting habitat (15)	Foxes prey on eggs / juveniles (23)	Unknown
Diverse waterfowl populations / breeding habitat (ducks / swans)	Decrease in spatial and temporal habitat availability (23)	Loss of diving ducks / waterbirds (cormorants / grebes / pelican / Musk Duck / Blue-billed Duck). (23) Reduced breeding season length and habitat. Increase in teal / black duck. (23)	Infrequent breeding and feeding habitat availability (23)	Decline in invertebrates and fish resulting in loss of diversity and abundance of waterfowl (13) Salinity exceeds thresholds for waterbird broods (19).	Loss of fish and macro-invertebrate species resulting in decline in waterbirds. Very high pH (>9) may impact brood survival (19).	Unknown, pesticides potentially have a decreasing effect on macro-invertebrates and fish (23)	Decrease in fish / macro-invertebrates resulting in reduced food for waterbirds (23)	Loss of habitat (23)	Loss of nesting habitat. Pugging of wetlands (declining water quality). Nest disturbance (23)	Foxes / cats (23)	Unknown
Waders (e.g. sandpipers / stilts / snipe)	Decrease in spatial and temporal habitat availability (23)	Decrease in mud flat / shallow inundation on floodplains (habitat loss). (23) Increase in mud flat / shallow inundation in wetland basins. (23)	Infrequent feeding habitat availability (23)	Decline in invertebrates. Generally tolerant of a wide range of salinities (23)	Loss of macro-invertebrate species resulting in decline in waders (23)	Unknown, pesticides potentially have a decreasing effect on macro-invertebrates and fish (23)	Decrease in fish / macro-invertebrates resulting in reduced food for waders (23)	Loss of habitat (23)	Loss of nesting habitat. Pugging of wetlands (declining water quality). Nest disturbance (23)	Foxes / cats (23)	Unknown
Cryptic waterbird species (bitterns / crakes / rails)	Habitat fragmentation may impede dispersal and population numbers (23)	Loss of suitable habitat (tussock / sedge / reed) cover resulting in reduced occurrence (17, 23)	Loss of suitable habitat (tussock / sedge / reed) cover resulting in reduced occurrence (17, 23)	Decline in invertebrates and fish resulting in loss of diversity and abundance of cryptic species (13) Salinity exceeds thresholds for bitterns / crakes broods (19)	pH exceeds thresholds for bitterns and crakes broods (19)	Unknown, pesticides potentially have a decreasing effect on macro-invertebrates and fish (23)	Decrease in fish / macro-invertebrates resulting in reduced food for cryptic waterbirds (23)	Loss of habitat (23)	Loss of nesting habitat. Pugging of wetlands (declining water quality). Nest disturbance (23)	Foxes / cats (23)	Potentially contributed to loss of open Gahnia sedgelands (habitat loss) (23)
Southern Bell Frog (recent local extinctions in Inland Interdunal wetland systems)	Loss of species dispersal ability (23)	Loss of permanent water refugia / suitable habitat (23)	Loss of permanent water refugia / suitable habitat (23)	Salinity exceeding species thresholds (23)	pH exceeding species thresholds (23)	Pesticides potentially have a decreasing effect on food availability: macro-invertebrates. (23) Pesticides and herbicides have been shown to be toxic to frog species – particularly in the larval phase (25)	Decrease in macro-invertebrates resulting in reduced food for Southern Bell Frog (23)	Loss of habitat (23)	Pugging of wetlands (declining water quality and trampling of aquatic vegetation) Direct nutrient inputs from manure (23)	Exotic fish prey on tadpoles (23)	Unknown
Native fish (Yarra Pygmy Perch – recently locally extinct in Inland Interdunal wetland systems)	Loss of species dispersal ability (23)	Loss of permanent water refugia resulting in loss of native fish species (23)	Loss of permanent water refugia resulting in loss of native fish species. Loss of species dispersal ability (23)	Salinity (>5000 EC) exceeding species thresholds resulting in loss of native fish species / failed recruitment (20)	Highly alkaline events(e.g. > 9.6), may induce in fish: death, damage to outer surfaces like gills, eyes, and skin and an inability to dispose of metabolic wastes. High pH may also increase the toxicity of other substances (23)	Agricultural runoff containing fertilizers can increase the likelihood of algal booms which can increase water temperatures and create low dissolved oxygen conditions beyond the survival tolerance of native fish species. (23) Pesticides and herbicides directly and indirectly toxic to fish (26)	DO below tolerance range for native fish, resulting in hypoxia (20)	Loss of habitat (23)	Pugging of wetlands (declining water quality and trampling of aquatic vegetation). Direct nutrient inputs from manure (23)	Exotic fish prey on and out-compete native fish species (e.g. mosquito fish) (23)	Unknown
Toolache Wallaby (extinct) Water-rat (in decline)	Loss of species dispersal ability (23)	Habitat loss (Gahnia sedgelands) Loss of permanent water habitat (23)	Habitat loss (Gahnia sedgelands) (23)	Unknown	Unknown	Unknown	Unknown	Habitat loss (Gahnia sedgelands) (23)	Habitat loss (Gahnia sedgelands) (23)	Foxes / hunting. (18)	Unknown
Ecosystem services											
Retention of water in landscape / flushing of salts	Loss of freshwater flows, and freshwater recharge to aquifer (23)	Drier, more drought prone landscape. Reduction in summer grazing opportunities (23)	Drier, more drought prone landscape. Reduction in summer grazing opportunities. (23)	Declining pasture quality. Reduced stocking rate (23)	Unknown – possible negative effect on pasture (23)	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Carbon storage	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (21)	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (21)	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (21)	Salinity inhibits production of methane in coastal wetlands (21)	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Natural pest and waste control	Fewer ibis and other biological control values (23)	Fewer ibis and other biological control values (23)	Fewer ibis and other biological control values (23)	Loss of species diversity for biological pest control. (23) Salinisation causes changes in light and mixing properties, which has an impact on the cycling of energy and nutrients (27)	Loss of wetland ecosystem services: nutrient and sediment balancing / biofilters / removal of toxic substances. Accumulation of toxins / nutrients in the landscape / drains (23)	Unknown	Unknown	Accumulation of toxins / nutrients in the landscape /drains (23)	Unknown	Unknown	Unknown
Health of receiving systems	N/A	N/A	Reduced flow to upstream systems, resulting in increased salinization/terrestrialisation (23)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Social / cultural											
Recreational (deer / duck hunting / yabbying)	Decreased duck hunting / yabbying opportunities (23)	Increased deer habitat and population. Decreased duck hunting / yabbying opportunities. (23)	Decreased duck hunting / yabbying opportunities (23)	Loss of yabbies (exceed species tolerance thresholds) Decreased duck hunting / yabbying opportunities (23)	Loss of yabbies (exceed species tolerance thresholds) (23)	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Intrinsic / Spiritual		Emotional impact of loss (23)	Emotional impact of loss (23)	Unknown	Unknown	Unknown	Unknown	Emotional impact of loss (23)	Unknown	Unknown	Unknown
Agricultural											
Grazing pastures (beef cattle and sheep)	Increased grazing land (23)	Increased grazing land / establishment of improved pasture (23)	Increased grazing land. Reduced salt flushing (23)	Declining pasture quality. Reduced stocking rate (23)	Unknown – possible negative effect on pasture (23)	Unknown	Unknown	Increased grazing land (23)	Unknown	Stock losses to foxes (23)	Unknown
Hay / cropping	Increased hay/cropping (23)	Increased hay/cropping (23)	Increased hay/cropping (23)	Declining pasture/ cropping quality (23)	Unknown – possible negative effect on pasture (23)	Unknown	Unknown	Increased cropping land (23)	Unknown	Deer grazing pasture /crops (23)	Unknown

Inland interdunal wetlands and watercourse box-line conceptual model references

Evidence Base: Inland interdunal wetlands and watercourse

Reference No.	Citation
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(2)	Observation well groundwater level data sourced from: Groundwater Data (https://www.waterconnect.sa.gov.au/Systems/GD/Pages/default.aspx#Unit Number)
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(21)	Wetlands and Waterbirds Taskforce (2012). Issues Paper: The Role of Wetlands in the Carbon Cycle. Australian Government, Department of Sustainability, Environment, Water, Population and Communities, Canberra.
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(23)	South East Wetland Conceptual Model workshop panel (this project)
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(25)	Relyea, R.A. (2011). Chapter 9: Amphibians are not ready for Roundup®. In Wildlife Ecotoxicology: Forensic Approaches. Elliot, J.E., Bishop, C.A. & Morrissey, C.A. Eds. Springer Science.
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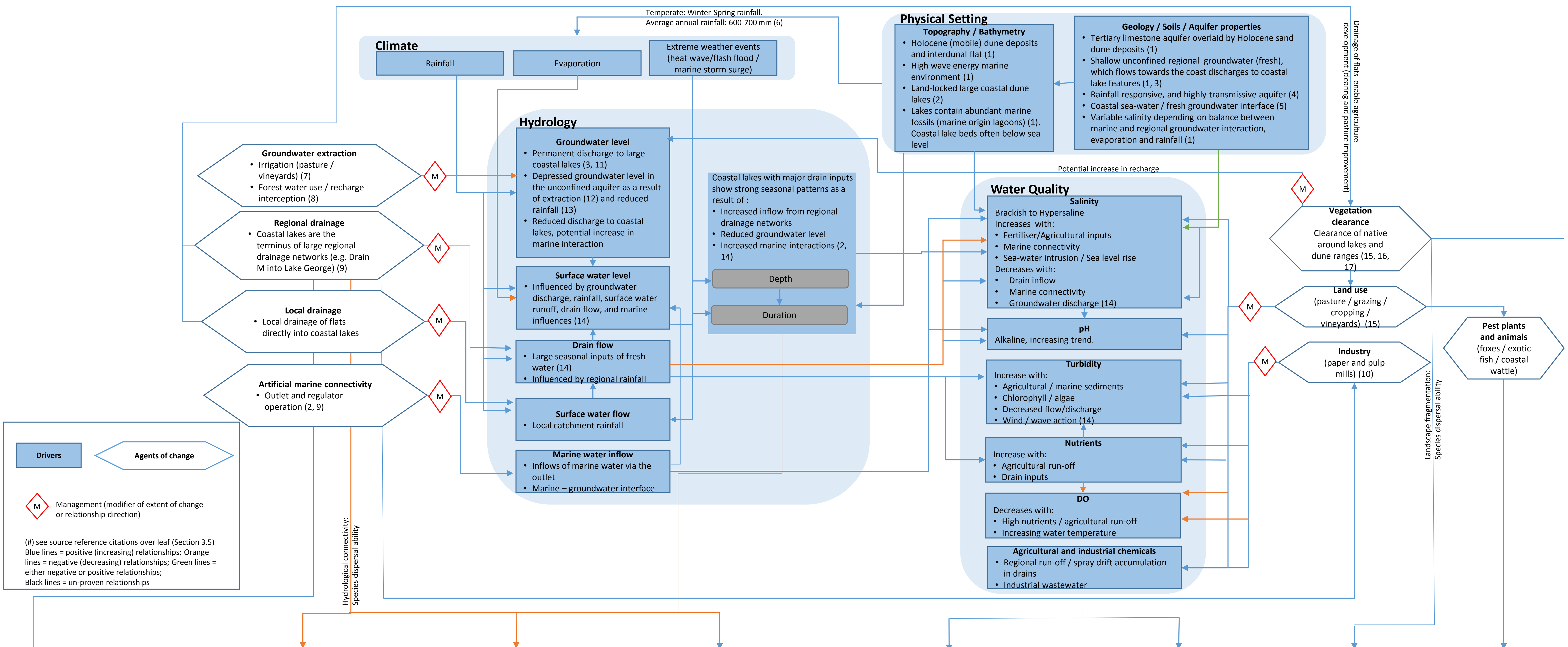
Coastal dune lakes and permanent freshwater in drains preliminary box-line conceptual model



Values (10,14,18)	Ecosystem Responses to Impacts						
	Changed hydrological connectivity	Reduced (variable) depth and duration of inundation	Increased marine connectivity	Agricultural and industrial pollutants (nutrients, sediments, agricultural chemicals, wastewater)	Increasing (variable) salinity	Vegetation clearance	Pest plants and animals
Vegetation communities							
Surrounding flats/floodplain: Gahnia filum sedgeland	Lake margins and adjacent flats drained for agriculture Loss of propagule source Loss of dispersal habitat for aquatic species (18)	Reduced depth and duration (drained for agriculture) Invasion by Melaleuca halmaturorum or transition to pasture. Loss of micro-environment for aquatic herbs (19)	Little impact on canopy species (18)	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs). Excessive nutrients may favour exotic species over native species (19)	Gahnia filum tolerant of high salinities, resulting in potential increase in cover (19) Reduction in Gahnia trifida Loss of understorey diversity, and salt sensitive aquatic herbs (19)	Floodplain and lake margins cleared for agriculture post drainage resulting in loss of large percentage of Gahnia tussock sedgeland. Fragmentation of landscape, with some remnant floodplain vegetation Transition to pasture (18)	Habitat and cover for foxes (18) Coastal Wattle invasion (18)
Surrounding flats/floodplain: Melaleuca halmaturorum shrubland	Loss of propagule source Loss of soil water store and freshwater flushing, resulting in salinisation and terrestrialisation (terrestrial native species or pasture grasses) (18)	Little impact on canopy species where there is access to groundwater Probable expansion of community unless grazed or cleared Loss of aquatic understorey species Transition to terrestrial ecosystems with prolonged drying. (19)	Little impact on canopy species (18)	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs). Excessive nutrients may favour exotic species over native species (19)	Tolerant of high salinities, resulting in expansion of community (unless under grazing pressure) Loss of understorey diversity (19)	Floodplain and lake margins cleared for agriculture post drainage resulting in loss of large percentage of Melaleuca halmaturorum shrubland (18) Fragmentation of landscape, with some remnant floodplain vegetation (18) Transition to pasture (18)	Habitat and cover for foxes (18) Coastal Wattle invasion (18)
Lake margins: Leptospermum lanigerum shrubland / freshwater seeps and springs	Majority of Leptospermum lanigerum shrubland has been permanently drained for agriculture (no hydrological connectivity, complete loss of vegetation community) (15, 16) Loss of propagule source Loss of soil water store Loss of dispersal habitat for aquatic species (19) Loss of springs due to groundwater level decline (18)	Majority of Leptospermum lanigerum shrubland has been permanently drained and cleared for agriculture (complete loss of vegetation community) (15, 16) Protected remnants: Little impact on canopy species where access to groundwater and waterlogged condition remain. Loss of aquatic understorey species (18) Transition to terrestrial ecosystems with prolonged drying. (19) Invasion of woody weed species (e.g. coastal Wattle) (18)	Increase in salinity (18) Dieback of mature canopy species, no recruitment (18)	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs). Excessive nutrients may favour exotic species over native species (19)	Dieback of mature canopy species. Impaired recruitment of canopy (19)	Majority of Leptospermum lanigerum shrubland has been permanently drained and cleared for agriculture (complete loss of vegetation community). (15, 16) Large scale conversion to agricultural land. (15)	Habitat and cover for foxes (18) Coastal Wattle invasion (18)
Lake margins: Fringing sedges (Juncus sp., Schoenoplectus pungens, Ficinia nodosa)	Change in seasonal water levels from drain inflows Little change to fringing sedges (18)	Downwards colonisation of fringing vegetation from higher elevations (exotic or native) (13) Transition to fringing shrubland (where buffered by native vegetation) or pasture grasses Permanent transition to pasture grasses where loss of waterlogged soils has occurred (19)	Little impact, high salinity tolerance of sedge species (18)	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs) (19) Low herbs susceptible to smothering by sediment loads (19) Excessive nutrients may favour exotic species over native species. Algal blooms may occur with secondary effects to macrophytes (19)	Loss of salt sensitive species (19) Increase in salt tolerant species (eg. Sarcocornia sp.) (18)	Reduced width of sedgeland perimeter of coastal lakes (18)	Habitat and cover for foxes (18)
Aquatic macrophytes / charophytes (Ruppia sp., Potamogeton sp., Lepilaena sp., Lamprothamnium sp.)	Increased connectivity as a result of drain inputs, and artificial marine connection results in changes in water quality and flow. Freshwater flows from drains are now important for maintaining aquatic macrophyte communities (which are likely to have established as a result of changed hydrological connectivity) (18)	Loss (desiccation) of aquatic macrophytes. Loss of Ruppia sp., then loss of / reduction in Myriophyllum sp. and charaphytes. Significant implications for bird species with reduction in Ruppia (19)	Loss of salt sensitive species Smothering as a result of sand sedimentation (18)	Smothering by sediment loads. Maximum colonisation depth of submergent plants effected by turbidity and sediment chemistry (14) Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs) Excessive nutrients may favour exotic species over native species Algal blooms may occur with secondary effects to macrophytes and subsequent water quality (19) Transition to phytoplankton, zooplankton, and benthic cyanobacteria (14)	Loss of salt sensitive species. Severe decline in the abundance of aquatic macrophytes without significant freshening (from drain inputs) (14) Transition to salt tolerant phytoplankton, zooplankton, and benthic cyanobacterial blooms (14)	Community not a target for physical vegetation clearance (18)	Unknown
Artificial freshwater stream: habitat within drains (Phragmites australis / Chara sp., Nitella sp. Potamogeton sp. Ruppia sp. / Myriophyllum sp.)	Drains remove large amounts of water from the landscape, and create artificial stream habitat and refugia (18)	Variable depth, duration and flow in drains as a result of regional rainfall runoff and groundwater discharge (18) Loss or retraction of permanent pools within drains which provide important refugia for aquatic species (18) Loss (desiccation) of aquatic species. Downwards colonisation of fringing vegetation from higher elevations (exotic or native) (13)	N/A	Regional drains accumulate nutrients and pollutants from agricultural runoff, over-spray, spray drift, direct wastewater input, pugging, and stock access (18, 19) Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs) Excessive nutrients may favour exotic species over native species (19) Algal blooms may occur with secondary effects to macrophytes and subsequent water quality (19)	Loss of salt sensitive species (19) Increase in salt tolerant species (eg. Sarcocornia sp.) (18)	Artificial stream habitat created as a result of drainage and vegetation clearance. Absence of buffering (shading) native vegetation (21) Bank erosion and sedimentation (21)	Water supply and habitat for foxes and deer. Conduit for aquatic weeds (e.g. Spiny Rush) and exotic fish (Mosquito fish). (21)
Seagrass beds	Artificial drain outlet discharges into marine environment, including important seagrass beds. Drain discharge results in plumes of turbid water released into the sea (20)	N/A	N/A	Health of seagrass impacted by water quality of drain discharges, including elevated nutrient concentrations and associated epiphyte growth, increased turbidity, sedimentation, and herbicides and pesticides (20) Level of impact directly related to the volume of discharge Major losses in seagrass extent has resulted, causing seabed instability (20)	Generally relatively tolerant of varied salinities (20)	N/A	N/A
Aquatic fauna / flora							
Diverse waterbird populations (ducks / swans /coots/ herons / egrets / spoonbills / pelicans /)	Drains remove large amounts of water from the landscape, resulting in reduced habitat for waterbirds. Increased connectivity and permanency of coastal lakes provides important summer drought refuge in a drier landscape. (18)	Summer drought refuge for diverse waterbirds. (14) Reduction in depth and duration results in loss/reduction in refuge habitat. Loss of aquatic macrophytes (e.g. Ruppia sp.) may cause significant decline in waterbird diversity and abundance (reduction in number of herbivorous and omnivorous waterbirds). (18) Loss of suitable nesting / feeding / roosting habitat (18) Reduced breeding season length and habitat (18) Decrease in species diversity and abundance (18)	Potential increase in piscivorous waterbirds (e.g. pelicans) which feed on marine and diadromous fish (18) Loss of freshwater native fish species (18)	Pesticides / herbicides potentially have a decreasing effect on macro-invertebrates, aquatic plants and fish (18) Loss of aquatic macrophytes (e.g. Ruppia sp.) due to increased turbidity and algae may cause significant decline in waterbird diversity and abundance (reduction in number of herbivorous and omnivorous waterbirds) (14)	Decrease in fish / macro-invertebrates / macrophytes resulting in reduced food for waterbirds (18) Decrease in species diversity and abundance (18)	Loss of habitat on surrounding flats (e.g. loss of sedgelands, resulting in loss of cryptic waterbird species (18) Reduced diversity and abundance (18)	Foxes / cats (18)
Diverse waders / internationally significant numbers	Drains remove large amounts of water from the landscape, resulting in reduced habitat for waterbirds. Increased connectivity and permanency of coastal lakes provides important summer drought refuge in a drier landscape (18)	Summer drought refuge for diverse and significant numbers of waders. (22) Possible increase in mud-flats results in more habitat for waders. Significant water level decline may reduce wader species to resident hypersaline specialists (e.g. Banded Stilt, Silvergulls). (14)	Increase in estuarine /coastal migratory waders occurrence (eg. Great Knot, Red Knot) (14)	Pesticides / herbicides potentially have a decreasing effect on macro-invertebrates, aquatic plants and fish (18) Turbidity and nutrients impacts on macro-invertebrate populations. Probable decline in wader species diversity and abundance (18)	Decline in wader species diversity and abundance. Populations my be reduced to hypersaline resident specialists (e.g. Banded Stilt, Silvergulls) (18)	Loss of habitat and dispersal ability (18) Reduced diversity and abundance (18)	Foxes / cats (18)
Colonial nesting waterbirds (e.g. Ibis / herons / egrets)	Drains remove large amounts of water from the landscape, resulting in reduced habitat for colonial nesting waterbirds (18)	Colonial nesting waterbirds (ibis/egrets) will only breed successfully if water surrounds their nest sites. If wetland dries before fledging, adults may abandon nests. Ibis tend to be most sensitive species (23) Water level drops resulting in lake islands (eg. Ibis Island) connection with the shore, resulting in predation (foxes) on traditional colonial nesting sites (18)	Increase in salinity resulting in decreased diversity and abundance of colonial nesting species (23, 24) Salinity exceeds thresholds for waterbird broods (25)	Pesticides / herbicides potentially have a decreasing effect on macro-invertebrates, aquatic plants and fish (18) Turbidity and nutrients impacts on macro-invertebrate populations (18) Probable decline in colonial nesting waterbird species diversity and abundance and brood survival (18)	Decrease in fish / macro-invertebrates / macrophytes resulting in reduced food for colonial nesting waterbirds. (18) Salinity exceeds thresholds for waterbird broods (25)	Loss of nesting habitat (e.g. M. halmaturorum shrublands) (18)	Foxes / cats (18)
Native obligate freshwater fish (eg. Yarra Pygmy Perch; Southern Pygmy Perch) (14) (in drains)	Drains remove large amounts of water from the landscape, and create artificial stream habitat and refugia for native freshwater fish (18) Loss of species dispersal ability, resulting in isolated populations and limited genetic diversity (18)	Reduction in permanent and seasonal freshwater habitat resulting in reduced diversity and abundance of native freshwater fish (18) Habitat for freshwater fish largely restricted to permanent pools within drains (18)	Loss of native freshwater fish in coastal lake ecosystems (18)	Agricultural runoff containing fertilizers can increase the likelihood of algal booms which cause reduced water clarity and aquatic vegetation loss, resulting in decreased habitat suitability (reduced diversity and abundance) (26) Pesticides and herbicides directly and indirectly toxic to fish (27)	Freshwater fish species with low tolerance of high salinity (>5000 EC) Increasing salinity can result in loss of native freshwater fish species and failed recruitment (26, 28)	Native freshwater fish species occur in permanent pools in drains as isolated and fragmented populations as a result of drainage and vegetation clearance for agriculture (18) Loss of habitat and dispersal ability (18) Reduced diversity and abundance (18)	Exotic fish prey on / out-compete native fish species (18)
Marine / estuarine (Yellow-eye Mullet, Sea Mullet, Greenback Flounder, Australian Salmon) and diadromous native fish (Congolli / Common Galaxias) (14)	Increased connection to sea (via drains) likely to have resulted in marine estuarine and diadromous fish entering coastal lakes (14)	Desiccation / habitat loss caused be major drying event Reduced connection to sea (e.g. operation of outlet regulator / reduced water levels) could result in impacts on marine fish populations within coastal lakes (18) Decreased diversity and abundance (18)	Artificial connection with the sea has resulted in marine fish populations in previously land-locked coastal lakes (18) Marine connection required for diadromous and marine fish migration and recruitment (18) Increased sedimentation (due to marine connection) may restrict fish passage (14)	Agricultural runoff containing fertilizers can increase the likelihood of algal booms which cause reduced water clarity and aquatic vegetation loss, resulting in decreased habitat suitability (reduced diversity and abundance) (28) Major fish kill (e.g. Lake George 1999) (14) Pesticides and herbicides directly and indirectly toxic to fish (27)	Generally high/moderate tolerance of variable salinity, although some species require freshwater flowing habitat as part of their lifecycle (28) Potential increase in marine and diadromous fish species with the loss of freshwater fish (18)	Marine and diadromous fish species occur in permanent coastal lakes and associated drains connected to the sea as a direct result of drainage and vegetation clearance for agriculture (18)	Exotic fish prey on / out-compete native fish species (18)
Wetland dependent mammals (Water-rat / Swamp Antechinus)	Loss of species dispersal ability. Fragmentation of landscape (29)	Reduction in permanent freshwater aquatic habitat (30) Loss of Leptospermum lanigerum shrublands, freshwater springs and seeps (29) Reduction in suitable habitat (18)	Reduction in permanent freshwater aquatic habitat and food sources. (28)	Unknown. Pesticides/herbicides potentially have a decreasing effect on invertebrates, frogs and fish (18)	Low salinity tolerance (18) Decrease in habitat suitability (18)	Loss of habitat and dispersal ability (18) Clearance of Leptospermum lanigerum shrubland/springs and seeps for agriculture, resulting in reduced and fragmented habitat for Swamp Antechinus (29)	Foxes/cats/rats (29, 30)
Southern Bell Frog (in drains)	Drains remove large amounts of water from the landscape, and create artificial stream habitat and refugia for specialist habitat frogs such as Southern Bell Frog Loss of species dispersal ability (18)	Reduction in permanent freshwater refugia / suitable habitat (18)	Loss of Southern Bell Frog in coastal lake ecosystems and surrounding freshwater springs (18)	Pesticides potentially have a decreasing effect on food availability: macro-invertebrates (18) Pesticides and herbicides have been shown to be toxic to frog species – particularly in the larval phase (31)	Decrease in macro-invertebrates resulting in reduced food for Southern Bell Frog (18) Low salinity tolerance (18) Decrease in habitat suitability and loss of populations (18)	Loss of habitat and dispersal ability (18) Reduced diversity and abundance (18)	Exotic fish prey on tadpoles (18)
Ecosystem services							
Retention of water in landscape	Reduction of freshwater recharge to aquifer (18)	Drier, more drought and fire prone landscape (18) Reduction in summer grazing opportunities (18)	N/A	Accumulation of toxins / nutrients in the landscape /drains / marine environment (18)	N/A	N/A	N/A
Carbon storage	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (32)	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (32)	Salinity inhibits production of methane, so coastal wetlands may have lower methane emissions than freshwater wetlands (32)		N/A	N/A	N/A
Natural pest and waste control	Fewer ibis and other biological control values (18)	Fewer ibis and other biological control values (18)	Fewer ibis and other biological control values (18)	Accumulation of toxins / nutrients in the landscape /drains / marine environment (18)	N/A	N/A	N/A
Social / cultural							
Intrinsic / Spiritual	Emotional and cultural impact of loss (18)	Emotional and cultural impact of loss	Changed character of ecosystem (18)			Emotional and cultural impact of loss (18)	
Recreation / tourism (boating/fishing/nature based tourism)		Declining recreational fish (e.g. Yellow-eye Mullet, Black Bream) Loss of recreational and commercial fishery. (e.g. Lake George) (14) Reduced boating opportunities / reduced experience value (18) Less tourism (18)	Large-bodied marine fish established in coastal lakes results in development of recreational and commercial fishing (18)	Declining recreational fish (eg. Yellow-eye Mullet, Black Bream) Loss of recreational and commercial fishery. (e.g. Lake George) (14) Less tourism (18)			
Agricultural							
Agriculture (pasture / grazing / vineyards / irrigation)	Increased agricultural land. Increasing requirement for irrigation in a drier landscape. (18)	Increased agricultural land (18) Increasing requirement for irrigation in a drier landscape (18)	Increased agricultural land as a result of regional drainage network outlet (18)				
Forestry (pines)	Increased forestry (18)	Increased forestry (18)	Increased forestry (18)			Increased forestry (18)	
Industry (paper pulp mills)	Ability to discharge wastewater (18)		Ability to discharge wastewater (18)				

Coastal dune lakes and permanent freshwater in drains box-line conceptual model references

Evidence Base: Coastal dune lakes and permanent freshwater in drains	
Reference No.	**Citation**
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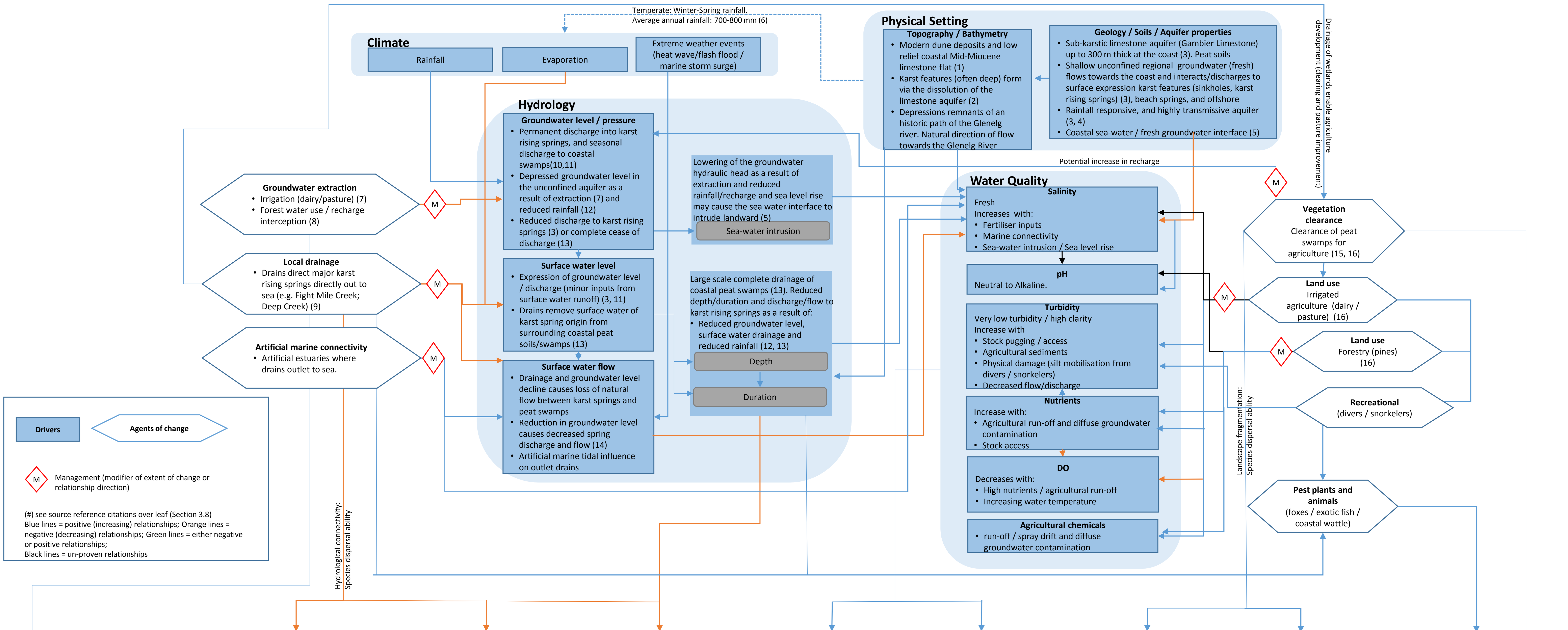
Karst rising springs and coastal peat swamp preliminary box-line conceptual model



Feedback loops between values

Values (2, 13, 17, ,18, 19, 25)	Ecosystem Responses to Impacts							
	Reduced hydrological connectivity	Reduced depth and duration of inundation	Reduced flow / spring discharge	Agricultural pollutants (nutrients, sediments, agricultural chemicals)	Increasing salinity	Vegetation clearance	Overgrazing / Pugging	Pest plants and animals
Vegetation communities								
Karst spring aquatic macrophytes (large Triglochin procerum / Hydrocotyle sp. / Ranunculus sp. / Myriophyllum sp.)	Loss of propagule source (17) Loss of dispersal habitat for aquatic species (17)	Exposure and desiccation of fringing wetland vegetation adapted to permanent presence of water (20) Shallow karst springs / pools may completely or seasonally dry out resulting in loss of permanent freshwater aquatic macrophytes vegetation and associated biota. Invasion of sedges / terrestrial species (17)	Decrease in flow reduces flushing (dilution) of sediments, nutrients, and phytoplankton, contributing to the growth of epiphytic algae and episodes of cyanobacterial blooms Reduced water clarity (light attenuation) and smothering of macrophyte vegetation from high algae concentrations results in death of aquatic macrophytes at depth (21) Loss of permanent discharge (spring becomes seasonal) resulting in loss of permanent freshwater aquatic macrophytes (13)	An environment that may concentrate residual herbicides / surfactants / pesticides, resulting in reduced biological productivity (20) High nutrients (nitrate / phosphorous) result in increased epiphytic algae growth, and episodes of cyanobacterial blooms (17) Reduced water clarity (light attenuation) and smothering of macrophyte vegetation from high algae concentrations results in death of aquatic macrophytes at depth (21)	Impacts to primary productivity (changes in abundance and/or composition of zooplankton / phytoplankton). Loss of salt sensitive aquatic macrophytes (20)	Vegetation community reduced to the boundaries of the karst spring/pool (usually associated with a drain), with little or no buffering native vegetation (17) Results in isolated ecosystems, decreased dispersal habitat for aquatic species, and loss of propagule source and genetic diversity (17)	Not a target for grazing, however if the surrounding landscape is heavily grazed, smaller pools may be impacted by sedimentation (17)	Exotic fish (potential) (17)
Artificial freshwater stream / estuary: habitat within drains associated with karst rising springs (Phragmites australis / Triglochin procerum / Myriophyllum sp. etc.)	Drain reduces natural connectivity of the karst springs with surrounding peat swamp (17) Increased direct (artificial) connectivity with the sea (17)	Exposure and desiccation of fringing wetland vegetation adapted to permanent presence of water (20) Formation of dense reedbeds (Phragmites australis) (17)	Decrease in flow reduces flushing (dilution) of sediments, nutrients, and phytoplankton, contributing to the growth of epiphytic algae and episodes of cyanobacterial blooms Reduced water clarity (light attenuation) and smothering of macrophyte vegetation from high algae concentrations results in death of aquatic macrophytes (21) Increased sedimentation, and formation of dense reedbeds (Phragmites australis) (17) Increased marine water surges into the drain outlet, resulting in rise in salinity and associated changes in aquatic macrophytes and biota (17)	An environment that may concentrate residual herbicides / surfactants / pesticides, resulting in reduced biological productivity (20) High nutrients (nitrate/phosphorous) result in increased epiphytic algae growth, and episodes of cyanobacterial blooms. Reduced water clarity (light attenuation) and smothering of macrophyte vegetation from high algae concentrations results in death of aquatic macrophytes (21)	Impacts to primary productivity (changes in abundance and/or composition of zooplankton / phytoplankton). Loss of salt sensitive aquatic macrophytes (20)	Artificial stream habitat created as a result of drainage and vegetation clearance (17) Absence of buffering native vegetation (17) Drain management (dragging and excavation of sediment and aquatic plants) to improve the drainage service to adjacent agricultural land results in increased turbidity and removal of aquatic macrophytes (17)	Not a target for grazing, however if the surrounding landscape is heavily grazed, stream habitat may be impacted by sedimentation (17)	Exotic fish (potential) (17)
Peat swamp shrubland (Leptospermum lanigerum / Gahnia clarkei / Gahnia trifida) (13, 18)	Majority of peat swamp shrubland has been permanently drained for agriculture (no hydrological connectivity, complete loss of vegetation community) (13, 15) Loss of propagule source Loss of soil water store Loss of dispersal habitat for aquatic species (20)	Majority of peat swamp shrubland has been permanently drained and cleared for agriculture (complete loss of vegetation community) (13, 15) Protected remnants: Little impact on canopy species where access to groundwater and waterlogged condition remain Loss of aquatic understorey species Transition to terrestrial ecosystems with prolonged drying (20) Invasion of woody weed species (e.g. Coastal Wattle) (17)	Reduced inundation (depth and duration) from reduced flows from karst springs (17) Fewer opportunities for mass germination events (senescence of canopy species). Loss of aquatic understory species (17) Transition to terrestrial ecosystems with prolonged loss of karst spring discharge (20) Invasion of woody weed species (e.g. Coastal Wattle) (17)	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs) (17) Excessive nutrients may favour exotic species over native species (20)	Dieback of mature canopy species. Impaired recruitment of canopy (20)	Majority of peat swamp shrubland has been permanently drained and cleared for agriculture (complete loss of vegetation community) (13, 15) Large scale conversion to pasture grasses / dairy / irrigated pastures (16)	Reduced understorey diversity and cover Senescence of canopy species with limited survival of seedlings to replace mature canopy (17) Increased exotic understorey species including species transported by stock and adventive species able to colonise bare ground (20)	Habitat and cover for foxes. (17) Coastal Wattle invasion (17)
Peat swamp sedgeland (Baumea arthrophylla / Typha sp./ Phragmites australis / Baumea articulata / Cladium procerum / Triglochin sp.)	Majority of peat swamp shrubland has been permanently drained for agriculture (no hydrological connectivity, complete loss of vegetation community) (15,16) Loss of propagule source (17) Loss of dispersal habitat for aquatic species (17)	Remnant sedgelands become seasonal to episodic Downwards colonisation of fringing vegetation from higher elevations (exotic or native) (12) Transition to peat shrubland(where buffered by native vegetation) or pasture grasses Permanent transition to pasture grasses where loss of waterlogged soils has occurred (20)	Reduced inundation (depth and duration) from reduced flows from karst springs (17) Transition to terrestrial ecosystems with prolonged loss of karst spring discharge (20)	Loss / reduced vigour of species sensitive to herbicides (eg. understorey herbs) (17) Low herbs susceptible to smothering by sediment loads (17) Excessive nutrients may favour exotic species over native species. Algal blooms may occur with secondary effects to macrophytes (20)	Loss of salt sensitive species (20)	Transition to pasture / dairy / irrigated pastures (17, 18)	Pugging, low plant cover (17) Lowered biomass, supressed flowering and vegetative reproduction, reduced regeneration (20)	Habitat and cover for foxes (17) Coastal Wattle invasion (17)
Aquatic fauna / flora								
Diverse waterbird populations (ducks / swans /coots/ herons / egrets / spoonbills)	Decrease in spatial and temporal habitat availability (17) Decrease in species diversity (17)	Loss of suitable nesting / feeding / roosting habitat (17) Reduced breeding season length and habitat (17) Decrease in species diversity and abundance (17)	Loss of suitable nesting / feeding / roosting habitat (17) Reduced breeding season length and habitat (17) Decrease in species diversity and abundance (17)	Unknown. Pesticides / herbicides potentially have a decreasing effect on macro-invertebrates, aquatic plants and fish (17)	Decrease in fish / macro-invertebrates resulting in reduced food for waterbirds (17)	Loss of habitat (17) Reduced diversity and abundance (17)	Loss of nesting habitat (17) Pugging of wetlands (declining water quality) (17) Nest disturbance (17)	Foxes / cats (17)
Cryptic waterbird species (bitterns / crakes / rails / snipe)	Habitat fragmentation may impede dispersal and population numbers (17)	Loss of suitable habitat (tussock/sedge/reed) cover resulting in reduced occurrence (22)	Loss of suitable habitat (tussock/sedge/reed) cover resulting in reduced occurrence (22)	Unknown. Pesticides potentially have a decreasing effect on food availability: macro-invertebrates, frogs, fish (17)	Decrease in fish / frog / macro-invertebrates resulting in reduced food for cryptic waterbirds (17)	Loss of habitat and dispersal ability (17) Reduced diversity and abundance (17)	Loss of nesting / feeding / cover habitat. Pugging of wetlands (declining water quality) (17) Nest disturbance (17)	Foxes / cats (17)
Southern Bell Frog	Loss of species dispersal ability (17)	Reduction in permanent water refugia / suitable habitat (17)	Reduction in permanent water refugia / suitable habitat (17)	Pesticides potentially have a decreasing effect on food availability: macro-invertebrates (17) Pesticides and herbicides have been shown to be toxic to frog species – particularly in the larval phase (23)	Decrease in macro-invertebrates resulting in reduced food for Southern Bell Frog (17)	Loss of habitat and dispersal ability (17) Reduced diversity and abundance (17)	Pugging of wetlands (declining water quality and trampling of aquatic vegetation) (17) Direct nutrient inputs from manure (17)	Exotic fish prey on tadpoles (no exotic fish in these systems at present) (17)
Native obligate freshwater fish (e.g. Dwarf Galaxias / Yarra Pygmy Perch / Ewens Pygmy Perch / Southern Pygmy Perch) (24)	Loss of species dispersal ability, resulting in isolated, fragmented populations and limited genetic diversity (17) Hybridisation between pygmy perch species (24) Increased connection to sea (via drains) may have altered native fish population dynamics (with increased numbers of marine and diadromous fish) (17)	Reduction in permanent and seasonal freshwater habitat resulting in reduced diversity and abundance of native freshwater fish (17)	Reduced spring/drain flow required for spawning, resulting in declining recruitment (24, 25, 27) Reduced water quality (clarity), quantity, and aquatic vegetation in permanent karst springs resulting in decreased habitat suitability (reduced diversity and abundance) Reduced spring/drain flow required for spawning, resulting in declining recruitment (24, 25)	Agricultural runoff containing fertilizers can increase the likelihood of algal booms which cause reduced water clarity and aquatic vegetation loss, resulting in decreased habitat suitability (reduced diversity and abundance) (24) Pesticides and herbicides directly and indirectly toxic to fish (26)	Freshwater fish species with low tolerance of high salinity (>5000 EC) (24) Increasing salinity can result in loss of native freshwater fish species as a result of failed recruitment (24, 27)	Native freshwater fish species occur in permanent karst springs and associated drains as isolated and fragmented populations as a result of drainage and vegetation clearance for agriculture (17) Regular dredging of drains creates intense disturbance to in-stream habitat (27) Removal of riparian vegetation reduces shading, and structural in-stream habitat (27) Loss of habitat and dispersal ability (17) Reduced diversity and abundance (17)	Pugging of wetlands (declining water quality and trampling of aquatic vegetation) (17) Direct nutrient inputs from manure Removal of riparian vegetation reduces shading, and structural in-stream habitat (27)	Exotic fish prey on / out-compete native fish species (no exotic fish in these systems at present) (17)
Marine (bream / mullet) and diadromous native fish (Congolli / lamprey / eels / Climbing Galaxias)	Increased connection to sea (via drains) likely to have resulted in an increase in marine and diadromous fish in karst springs (17)	Occurrence in permanently flowing karst springs with drain connection to sea (17) Reduced connection to sea (e.g. drain flow becomes seasonal) could result in impacts on marine fish populations within inland springs (17)	Reduced connection to sea (e.g. drain flow becomes seasonal) could result in impacts on marine fish populations within inland springs Reduced water flow, quality, and aquatic vegetation resulting in decreased habitat suitability (24, 25)	Agricultural runoff containing fertilizers can increase the likelihood of algal booms which cause reduced water clarity and aquatic vegetation loss, resulting in decreased habitat suitability (reduced diversity and abundance) (24) Pesticides and herbicides directly and indirectly toxic to fish (26)	Generally high to moderate tolerance of variable salinity, although some species require freshwater flowing habitat as part of their lifecycle (27) Potential increase in marine / diadromous fish species with the loss of freshwater fish	Marine and diadromous fish species occur in permanent karst springs and associated drains connected to the sea as a direct result of drainage and vegetation clearance for agriculture (17) Regular dredging of drains creates intense disturbance to in-stream habitat, and loss of shading riparian vegetation (27)	Pugging of wetlands (declining water quality and trampling of aquatic vegetation) (17) Direct nutrient inputs from manure (17)	Exotic fish prey on / out-compete native fish species (no exotic fish in these systems at present) (17)
Wetland dependent mammals (Water-rat / Swamp Antechinus)	Loss of species dispersal ability (17) Fragmentation of landscape (29)	Reduction in permanent aquatic habitat. (28) Loss of peat swamp shrublands (29) Reduction in suitable habitat (17)	Reduction in permanent aquatic habitat and food sources (28)	Unknown. Pesticides/herbicides potentially have a decreasing effect on invertebrates, frogs and fish (17)	Low salinity tolerance (17) Decrease in habitat suitability (17)	Loss of habitat and dispersal ability (17) Damage to banks of drains from dredging Clearance of peat swamp shrubland for agriculture, resulting in reduced and fragmented habitat for Swamp Antechinus (29)	Trampling of vegetation, secondary impacts to food chain (17) Direct vegetation removal (17) Loss of habitat (17)	Foxes /cats / rats (17)
Glenelg Spiny Crayfish	Dramatic reductions in distribution and abundance as a result of loss of hydrological connectivity (30) Isolated populations remain in 9 karst springs. Reduced genetic diversity, resulting in skewed sex-ratio and gonopore aberrations Loss of species dispersal ability and reduced recruitment (30)	Requirement for permanent, flowing, clear freshwater (30) Desiccation results in mortality of juveniles (30) Adults may be able to burrow, however long-term persistence in dry wetlands is unlikely (30)	Reduced water quality (clarity), quantity, and aquatic vegetation in permanent karst springs resulting in decreased habitat suitability (reduced recruitment ability and abundance) (30)	Agricultural runoff containing fertilizers can increase the likelihood of algal booms which cause reduced water clarity and aquatic vegetation loss, resulting in decreased habitat suitability (reduced abundance) (17) Pesticides and herbicides directly and indirectly toxic to crayfish (30) Potential impact of hormone disrupters (contributing to gonopore aberrations) (17)	Low tolerance to rises in salinity (17) Loss of populations (17)	Loss of habitat and dispersal ability (17) Regular dredging of drains creates intense disturbance to in-stream habitat (17) Removal of riparian vegetation reduces shading, and structural in-stream habitat (30)	Pugging of wetlands (declining water quality and trampling of aquatic vegetation) (17) Direct nutrient inputs from manure (17)	Human (illegal fishing) (17)
Stygofauna	Reductions in groundwater level can reduce the hydrological connectivity of subterranean cavities (31)	Reductions in groundwater level can reduce the hydrological connectivity of subterranean cavities. (31)	Reductions in groundwater flow can reduce the hydrological connectivity of subterranean cavities (31)	Stygofauna potentially have functional roles in groundwater quality maintenance. (31) Potentially negatively effected by infiltration of agricultural chemicals and pollutants (17)	Low tolerance to rapid salinity change, due to long in-situ evolutionary history (31)	Increased recharge, infiltration of agricultural chemicals and pollutants (17)	N/A	Unknown
Ecosystem services								
Retention of water in landscape	Reduction of freshwater recharge to aquifer (17)	Drier, more drought and fire prone landscape (17) Reduction in summer grazing opportunities (17)	Drier, more drought and fire prone landscape. Reduction in summer grazing opportunities (17)	Accumulation of toxins / nutrients in the landscape /drains / marine environment (17)	N/A	N/A	N/A	N/A
Carbon storage	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (32)	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (32)	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (32)		Salinisation causes changes in light and mixing properties, impacts on the cycling of energy and nutrients (33)	N/A	N/A	N/A
Natural pest and waste control	Fewer ibis and other biological control values (17)	Fewer ibis and other biological control values (17)	Fewer ibis and other biological control values (17)	Accumulation of toxins / nutrients in the landscape /drains / marine environment (17)	N/A	N/A	N/A	N/A
Social / cultural								
Intrinsic / spiritual	Emotional and cultural impact of loss (17)	Emotional and cultural impact of loss (17)	Emotional and cultural impact of loss (17)			Emotional and cultural impact of loss (17)		
Recreation / tourism (snorkelling and diving)			Reduced water clarity and aquatic flora/fauna reducing dive/snorkel experience value (17) Less tourism (17)	Reduced water clarity and aquatic flora/fauna reducing dive/snorkel experience value (17) Less tourism (17)				
Agricultural								
Irrigated agriculture (dairy / pasture)	Increased agricultural land (17) Increasing requirement for irrigation in a drier landscape (17)	Increased agricultural land (17) Increasing requirement for irrigation in a drier landscape (17) Subsidence of peat soils (drying and compression), resulting in increased flooding potential (9)	Increased agricultural land (17) Increasing requirement for irrigation in a drier landscape (17)		Sea water intrusion and sea level rise have potentially serious consequences for irrigated and near shore agriculture (17)			
Forestry (pines)	Increased forestry (17)	Increased forestry (17)	Increased forestry (17)			Increased forestry (17)		

Karst rising springs and coastal peat swamp box-line conceptual model references

Evidence Base: Karst rising springs and coastal peat swamp	
Reference No.	**Citation**
(1)	Drexel, J.F. & Preiss, W.V. (1995). The geology of South Australia – Volume 2: The Phanerozoic. South Australia Geological Survey. Bulletin 54.
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(10)	SKM (2009). Classification of Groundwater – Surface Water Interactions for Water-dependent Ecosystems in the South East, South Australia. Report for the Department of Water, Land and Biodiversity Conservation. Sinclair Knight Merz, Hobart.
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(12)	Harding, C., Deane, D. Green, G. & Kretschmer, P. (2014). Impacts of Climate Change on Water Resources in South Australia: Predicting the impacts of climate change to groundwater dependent ecosystems - an application of a risk assessment framework to a case study site in the South East NRM region: Middlepoint Swamp. Department of Environment, Water and Natural Resources.
(13)	Bachmann, M. R. (2002). Silky Tea-tree and Cutting Grass Wetland Rehabilitation Project 1999-2002. (Nature Conservation Society of South Australia: Adelaide).
(14)	DEWNR Coastal spring flow monitoring (sourced from Hydstra database)
(15)	Land survey mapping (1883 - 1885), Hundred of Caroline
(16)	DEWNR 2013 Aerial photography (spatial dataset)
(17)	South East Wetland Conceptual Model workshop panel (this project)
(18)	Historic photos – clearing of native vegetation at Eight Mile Creek circa 1930s. Sourced from National Library of Australia.
(19)	Butcher, R., Hale, J., and Cottingham, P. (2011). Ecological character description for Piccaninnie Ponds Karst Wetlands. Prepared for the Department of Environment and Natural Resources, Mt Gambier.
(20)	Denny, M. & Fisher, G. (2011). South East Wetland Condition Assessment: Conceptual wetland state and transition models. Nature Conservation Society of SA, Adelaide.
(21)	Rigosi, A. (2014 in prep). Determining environmental risks to high priority wetlands in the South East – Goyder Institute Research Project. The University of Adelaide.
(22)	O'Connor, J., Rogers, D., Pisanu, P. (2013). Cryptic and colonial-nesting waterbirds in the Coorong, Lower Lakes and Murray Mouth: distribution, abundance and habitat associations. DEWNR Technical Report 2013/20. Department of Environment, Water and Natural Resources, Adelaide.
(23)	Relyea, R.A. (2011). Chapter 9: Amphibians are not ready for Roundup®. In Wildlife Ecotoxicology: Forensic Approaches. Elliot, J.E., Bishop, C.A. & Morrissey, C.A. Eds. Springer Science.
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(25)	Butcher, R., Hale, J., and Cottingham, P. (2011). Ecological character description for Piccaninnie Ponds Karst Wetlands. Prepared for the Department of Environment, Water and Natural Resources.
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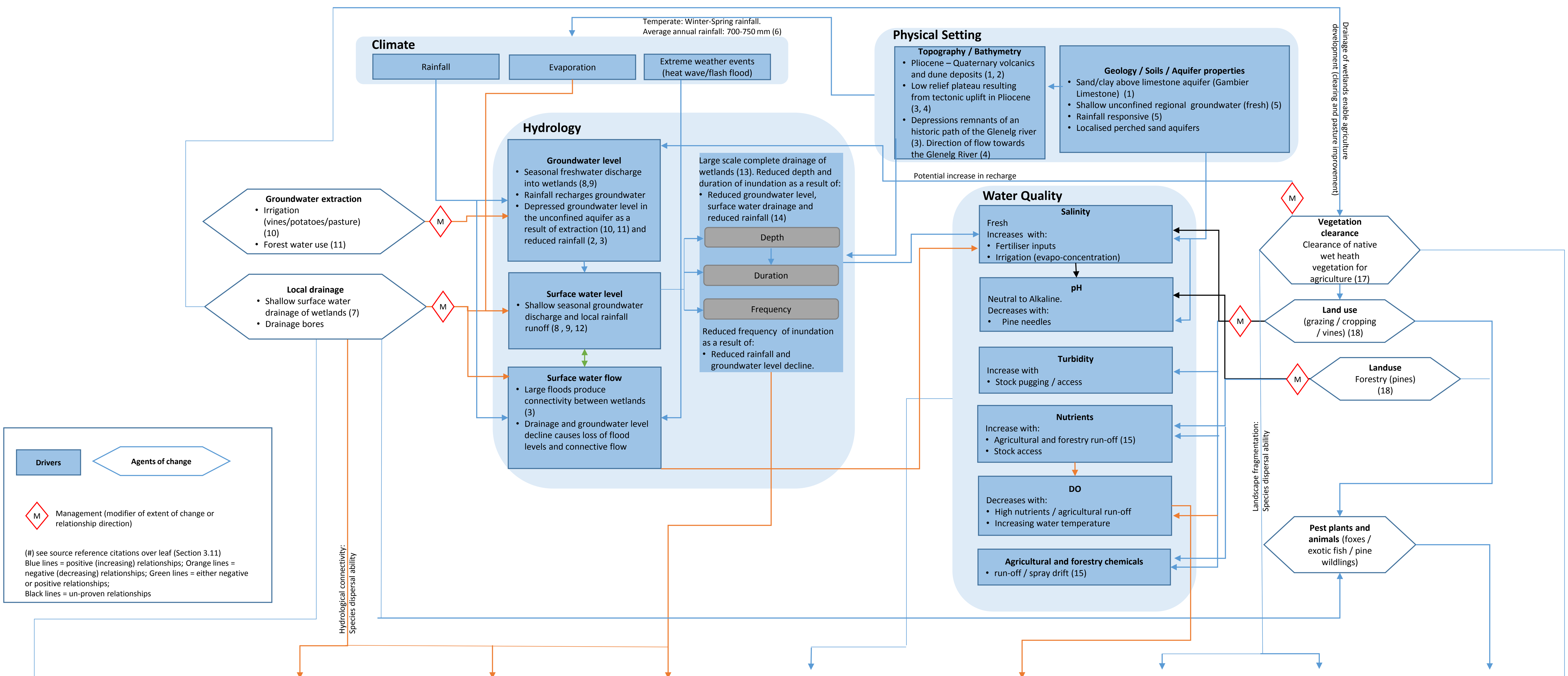
(32)	Wetlands and Waterbirds Taskforce (2012). Issues Paper: The Role of Wetlands in the Carbon Cycle. Australian Government, Department of Sustainability, Environment, Water, Population and Communities, Canberra.
(33)	Nielsen, D.L., Brock, M.A., Rees, G.N. and Baldwin, D.S. (2003). Effects of increasing salinity on freshwater ecosystems in Australia. Australian Journal of Botany 51:655-665.

Freshwater grass and sedge marshes preliminary box-line conceptual model



Feedback loops between values

Values (13, 16, 17,18)	Ecosystem Responses to Impacts							
	Reduced hydrological connectivity	Reduced depth and duration of inundation	Reduced frequency of flow	Agricultural pollutants (nutrients, sediments, agricultural and forestry chemicals)	Decreasing DO	Vegetation clearance	Overgrazing / Pugging	Pest plants and animals
Vegetation communities								
River Red Gum woodland	Fewer opportunities for mass germination events. Transition to pasture grass understorey (19) Loss of dispersal habitat for aquatic species (16)	Shift from sedge / aquatic herb understorey to terrestrial species. Transition to pasture grass understorey (19) Decreased vigour and health of mature trees (16)	Fewer opportunities for mass germination events (19) Transition to pasture grass understorey (19)	Loss/reduced vigour of species sensitive to herbicides (eg. understorey herbs) (19) Excessive nutrients may favour exotic species over native species (19)	Unknown	Vegetation community reduced to scattered mature trees in paddocks with pasture grass understorey (17, 18)	Reduced understorey diversity and cover Senescence of canopy species with limited survival of seedlings to replace mature canopy (19) Increased exotic understory species including species transported by stock and adventive species able to colonise bare ground (19) Stock camping and cultivation result in damage to feeder roots in canopy zone of trees Impaired health and resilience (eg. ability to withstand Mundulla Yellows) (16)	Pasture weeds (16)
Wet heath (Leptospermum continentale / Gahnia sp. / Xanthorrea sp.)	Loss of propagule source (19) Loss of soil water store (19) Loss of dispersal habitat for aquatic species (19)	Little impact on canopy species where there is access to groundwater and waterlogged condition remain. Probable expansion of community into wetland basins unless grazed (16, 19) Loss of aquatic understorey species (19) Transition to terrestrial ecosystems with prolonged drying (19)	Fewer opportunities for mass germination events (19) Loss of aquatic understorey species (19) Transition to terrestrial species (19)	Loss/reduced vigour of species sensitive to herbicides (e.g. understorey herbs) Excessive nutrients may favour exotic species over native species (19)	Unknown	Vegetation community reduced to narrow buffer zones around remnant wetlands or conserved in Native Forest Reserves (eg. Honans / The Marshes) (16) Large scale conversion to pasture grasses (17, 18)	Reduced understorey diversity and cover (19) Senescence of canopy species with limited survival of seedlings to replace mature canopy (19) Increased exotic understory species including species transported by stock and adventive species able to colonise bare ground (19)	Habitat and cover for foxes (16) Coastal Wattle invasion (16)
Freshwater sedges and herbs (Triglochin / Baumea arthrophylla / Eleocharis acuta / /Glyceria australis / Utricularia sp. / Ornduffia sp. / Craspedia sp.)	Loss of propagule source (19) Loss of dispersal habitat for aquatic species (16) Local extinction of aquatic plants if water requirements are not met for recruitment within the timeframe that propagules remain viable (16)	Wetlands become seasonal to episodic. Downwards colonisation of fringing vegetation from higher elevations (exotic or native) (14) Transition to wet heath (where buffered by native vegetation) or pasture grasses Permanent transition to pasture grasses where loss of waterlogged soils has occurred (19) Loss of permanent water refugia Local extinction of aquatic plants if water requirements are not met for recruitment within the timeframe that propagules remain viable (16)	Loss of propagule source (16) Loss of dispersal ability for aquatic species (16) Local extinction if water requirements are not met for recruitment within the timeframe that propagules remain viable (16)	Loss/reduced vigour of species sensitive to herbicides (e.g. understorey herbs). Low herbs susceptible to smothering by sediment loads (19) Excessive nutrients may favour exotic species over native species (19) Algal blooms may occur with secondary effects to macrophytes (19)	Any loss of aquatic plants (producers of DO via photosynthesis) has the potential to reduce DO (16)	Transition to pasture (17, 18) Loss of buffer vegetation exposing aquatic vegetation to higher incidence of spray drift and stock pugging (16)	Pugging, low plant cover (16, 19) Lowered biomass, supressed flowering and vegetative reproduction, reduced regeneration (19)	Mosquito fish (16) Habitat for foxes (16)
Freshwater perched sedge wetlands (Baloskion sp. / Carex sp. / Baumea arthrophylla / Sphagnum)	Loss of propagule source (16) Loss of dispersal habitat for aquatic species (16)	Wetlands become seasonal to episodic. Downwards colonisation of fringing vegetation from higher elevations (exotic or native) (14) Transition to wet heath (where buffered by native vegetation) or pasture grasses / pine wildlings Permanent transition to pasture grasses / terrestrial vegetation / pines where loss of permanently waterlogged soils has occurred (19) Loss of permanent water refugia (16) Increased dry periods increase the risk of mounding and planting with pines in future rotations (16)	Loss of propagule source (16) Loss of dispersal ability for aquatic species (16)	Loss/reduced vigour of species sensitive to herbicides (e.g. understorey herbs). Low herbs susceptible to smothering by sediment loads (19) Excessive nutrients may favour exotic species over native species (19) Algal blooms may occur with secondary effects to macrophytes. (19)	Any loss of aquatic plants (producers of DO via photosynthesis) has the potential to reduce DO (16)	Transition to pasture or pine plantation (17, 18) Loss of buffer vegetation exposing aquatic vegetation to higher incidence of spray drift and stock pugging (16)	Pugging, low plant cover (16) Lowered biomass, and diversity supressed flowering and vegetative reproduction, reduced regeneration (19)	Mosquito fish (16) Habitat for foxes (16) Invasion of pine wildlings (16)
Aquatic fauna / flora								
Brolga	Decrease in spatial and temporal habitat availability (16)	Loss of suitable nesting habitat (shallow open freshwater grass sedge meadows and marshes) and 'traditional' nesting sites (16) Reduced breeding season length (16) Decreased breeding success and reduced population (20, 21)	Loss of suitable nesting habitat (shallow open freshwater grass sedge meadows and marshes) and 'traditional' nesting sites (16) Reduced breeding season length (16) Decreased breeding success and reduced population (20, 21)	Unknown. Pesticides and herbicides potentially have a decreasing effect on major diet components (aquatic plants, frogs etc.) (16)	Decrease in fish / macro-invertebrates resulting in reduced food for Brolga (16)	Loss of habitat – conversion to pasture grass or plantation forestry (16) Potential that establishment of crops / irrigation provide food source for Brolga, and open pastures more suitable than dense shrubland (16)	Stock disturbance of nesting sites – reduced nesting success (16) Loss of nesting habitat (20,21)	Foxes prey on eggs / juveniles (16)
Diverse waterbird populations / breeding habitat (ducks / swans / herons / egrets / spoonbills)	Decrease in spatial and temporal habitat availability (16) Decrease in species diversity (16)	Loss of suitable nesting / feeding / roosting habitat (16) Reduced breeding season length and habitat (16) Decrease in species diversity and numbers (16)	Infrequent breeding and feeding habitat availability (16)	Unknown. Pesticides/herbicides potentially have a decreasing effect on macro-invertebrates, aquatic plants and fish (16)	Decrease in fish / macro-invertebrates resulting in reduced food for waterbirds (16)	Loss of habitat and dispersal ability (16)	Loss of nesting habitat (16) Pugging of wetlands (declining water quality). Nest disturbance (16)	Foxes / cats (16)
Cryptic waterbird species (bitterns / crakes / rails / snipe)	Habitat fragmentation may impede dispersal and population numbers (16)	Loss of suitable habitat (tussock / sedge / reed) cover resulting in reduced occurrence (22)	Loss of suitable habitat ((tussock/sedge/reed) cover resulting in reduced occurrence (22)	Unknown. Pesticides potentially have a decreasing effect on food availability: macro-invertebrates and fish (16)	Decrease in fish / macro-invertebrates resulting in reduced food for cryptic waterbirds (16)	Loss of habitat and dispersal ability (16)	Loss of nesting / feeding / cover habitat (16) Pugging of wetlands (declining water quality) (16) Nest disturbance (16)	Foxes / cats (16)
Southern Bell Frog	Loss of species dispersal ability (16)	Loss of permanent water refugia / suitable habitat (16)	Loss of permanent water refugia / suitable habitat (16)	Pesticides potentially have a decreasing effect on food availability: macro-invertebrates (16) Pesticides and herbicides have been shown to be toxic to frog species – particularly in the larval phase (23)	Decrease in macro-invertebrates resulting in reduced food for Southern Bell Frog (16)	Loss of habitat and dispersal ability (16)	Pugging of wetlands (declining water quality and trampling of aquatic vegetation) (16) Direct nutrient inputs from manure (16)	Exotic fish prey on tadpoles (16)
Native fish	Loss of species dispersal ability, resulting in isolated populations and limited genetic diversity (16)	Loss of permanent water refugia resulting in loss of native fish species (16)	Loss of permanent water refugia resulting in loss of native fish species (16) Loss of species dispersal ability (16) Loss of species which require flow for reproduction (16)	Agricultural runoff containing fertilizers can increase the likelihood of algal booms which can increase water temperatures and create low dissolved oxygen conditions beyond the survival tolerance of native fish species (16) Pesticides and herbicides directly and indirectly toxic to fish (24)	Low DO can result in hypoxia (16) Decrease in macro-invertebrates (16)	Loss of habitat and dispersal ability (16)	Pugging of wetlands (declining water quality and trampling of aquatic vegetation) (16) Direct nutrient inputs from manure (16)	Exotic fish prey on / out-compete native fish species (e.g. Mosquito fish) (16)
Wetland dependent mammals (Water-rat / Swamp Antechinus)	Loss of species dispersal ability (16) Fragmentation of landscape (16)	Loss of habitat (16)	Loss of habitat (16)	Unknown. Pesticides / herbicides potentially have a decreasing effect on invertebrates, frogs and fish (16)	Unknown. Potential secondary impacts (16)	Loss of habitat and dispersal ability (16)	Loss of habitat through direct trampling, grazing, and pugging (16)	Foxes / cats (16)
Specialist insects (Ancient Greenling) (26)	Loss of species dispersal ability (feeble flight and dispersal capabilities) Fragmentation of landscape (26)	Loss of habitat – freshwater Baumea sedgelands. Encroachment of woody shrubs decreases habitat suitability (26)	Loss of habitat – freshwater Baumea sedgelands (16) Loss of species dispersal ability (16)	Unknown. Pesticides / herbicides highly likely to have a detrimental effect on larval stages (16)	Unknown. Highly likely to have a detrimental effect on larval stages (16)	Loss of habitat and dispersal ability (26)	Loss of habitat through direct trampling, grazing, and pugging (16)	
Ecosystem services								
Retention of water in landscape	Reduction of freshwater recharge to aquifer (16)	Drier, more drought prone landscape (16) Reduction in summer grazing opportunities (16)	Drier, more drought prone landscape (16) Reduction in summer grazing opportunities (16)					
Carbon storage	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (25)	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (25)	Frequent wetting and drying is likely to lead to lower carbon storage and greater greenhouse gas emissions (25)					
Natural pest and waste control	Fewer ibis and other biological control values (16)	Fewer ibis and other biological control values (16)	Fewer ibis and other biological control values (16)			Accumulation of toxins / nutrients in the landscape / drains (16)		
Social / cultural								
Intrinsic / Spiritual		Emotional impact of loss (16)	Emotional impact of loss (16)			Emotional impact of loss (16)		
Agricultural								
Grazing pastures (beef cattle and sheep)	Increased grazing land (16)	Increased grazing land and establishment of improved pasture (16)	Increased grazing land (16) Reduced salt flushing (16)			Increased grazing land (16)		Stock losses to foxes (16)
Hay / cropping	Increased hay/cropping (16)	Increased hay/cropping (16)	Increased hay/cropping (16)			Increased cropping land (16)		
Irrigated agriculture (vines / potatoes/pasture)	Increasing requirement for irrigation in a drier landscape (16)	Increasing requirement for irrigation in a drier landscape (16)	Increasing requirement for irrigation in a drier landscape (16)					
Forestry (pines)	Increased forestry (16)	Increased forestry (16)	Increased forestry (16)			Increased forestry (16)		

Freshwater grass and sedge marshes box-line conceptual model references

Evidence Base: Freshwater grass and sedge marshes	
Reference No.	**Citation**
(1)	Drexel, J.F. & Preiss, W.V. (1995). The geology of South Australia – Volume 2: The Phanerozoic. South Australia Geological Survey. Bulletin 54.
(2)	Dodson, J.R. (1974). Vegetation history and water fluctuations at Lake Leake, South-eastern Australia: 10000 BP to Present. Australian Journal of Botany 22: 719-741.
(3)	Dodson, J.R. & Wilson, I.B. (1975). Past and present vegetation of Marshes Swamp in South-eastern South Australia. Australian Journal of Botany 23: 123 – 150.
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(5)	Observation well groundwater level data sourced from: Groundwater Data (https://www.waterconnect.sa.gov.au/Systems/GD/Pages/default.aspx#Unit Number)
(6)	Bureau of Meteorology (http://www.bom.gov.au). Rainfall isohyets for South Australia.
(7)	South East Drainage Board (1980). Environmental impact study on the effect of drainage in the South East of SA. South Eastern Drainage Board, Adelaide, SA.
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(10)	Harding C. (2012). Extension of the Water-dependent Ecosystem Risk Assessment Framework to the South East NRM Region, DFW Technical Report 2012/10, Government of South Australia, through Department for Water, Adelaide.
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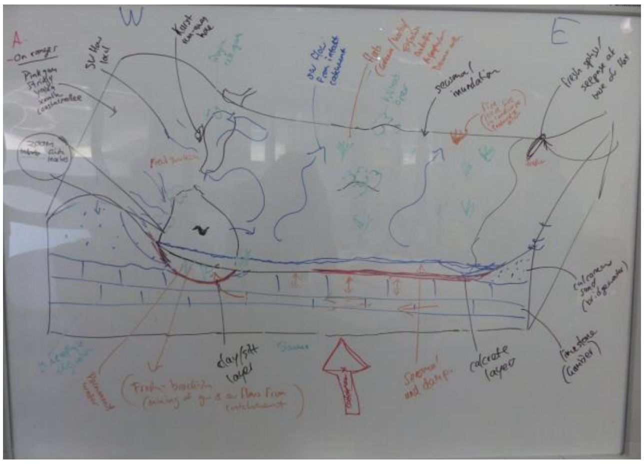
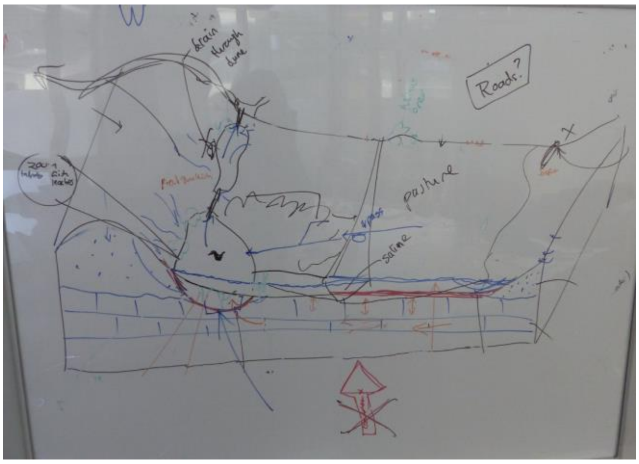
(14)	Harding, C., Deane, D. Green, G. & Kretschmer, P. (2014). Impacts of Climate Change on Water Resources in South Australia: Predicting the impacts of climate change to groundwater dependent ecosystems - an application of a risk assessment framework to a case study site in the South East NRM region: Middlepoint Swamp. Department of Environment, Water and Natural Resources.
(15)	Houlahan, J.E. and Findlay, C.S. (2004). Estimating the 'critical' distance at which adjacent land-use degrades wetland water and sediment quality. Landscape Ecology 19: 677-690.
(16)	South East Wetland Conceptual Model workshop panel (this project)
(17)	Land survey mapping (1883 - 1885), Hundreds of Mingbool, Young, Hindmarsh.
(18)	DEWNR 2013 Aerial photography (spatial dataset)
(19)	Denny, M. & Fisher, G. (2011). South East Wetland Condition Assessment: Conceptual wetland state and transition models. Nature Conservation Society of SA, Adelaide.
(20)	Bransbury, J. (1991). The Brolga in South-eastern South Australia. Department of Environment and Planning, Government of South Australia.
(21)	Harding, C. (2001). The use of remote sensing and geographic information systems to predict suitable breeding habitat for the Brolga (Grus rubicunda) in south-western Victoria. Honours thesis. University of Ballarat.
(22)	O'Connor, J., Rogers, D., Pisanu, P. (2013). Cryptic and colonial-nesting waterbirds in the Coorong, Lower Lakes and Murray Mouth: distribution, abundance and habitat associations. DEWNR Technical Report 2013/20. Department of Environment, Water and Natural Resources, Adelaide.
(23)	Relyea, R.A. (2011). Chapter 9: Amphibians are not ready for Roundup®. In Wildlife Ecotoxicology: Forensic Approaches. Elliot, J.E., Bishop, C.A. & Morrissey, C.A. Eds. Springer Science.
(24)	Rand, G.M. (Ed) (2003). Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment – Second Edition.
(25)	Wetlands and Waterbirds Taskforce (2012). Issues Paper: The Role of Wetlands in the Carbon Cycle. Australian Government, Department of Sustainability, Environment, Water, Population and Communities, Canberra.
(26)	Haywood, B. & Richter, R. (2013). The Ancient Greenling Hemiphlebia mirabilis (Odonata: Hemiphlebiidae) in South Australia. The South Australian Naturalist 87:1.

Appendix 3: Workshop 2 white-board outputs

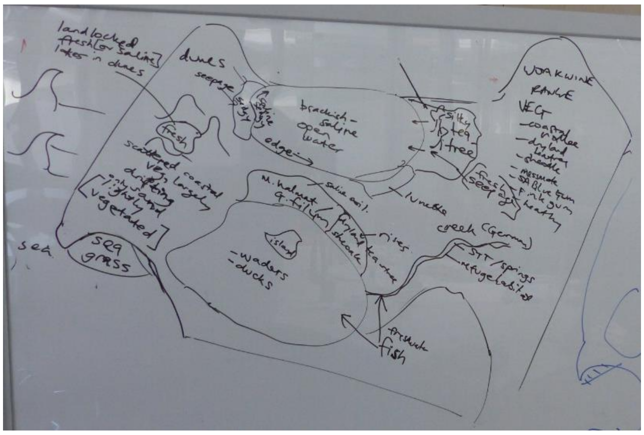
Pre-European scenario	Present scenario

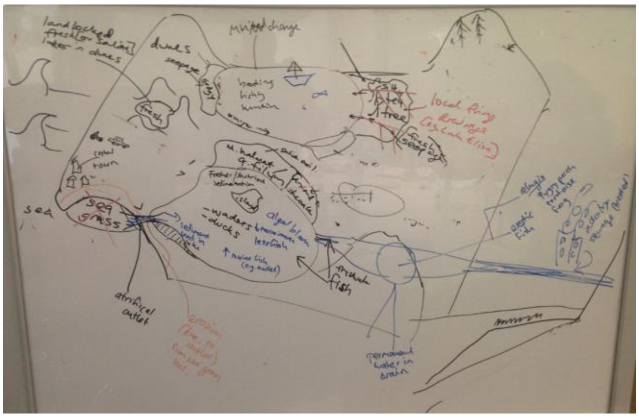
Inland interdunal wetlands and watercourse



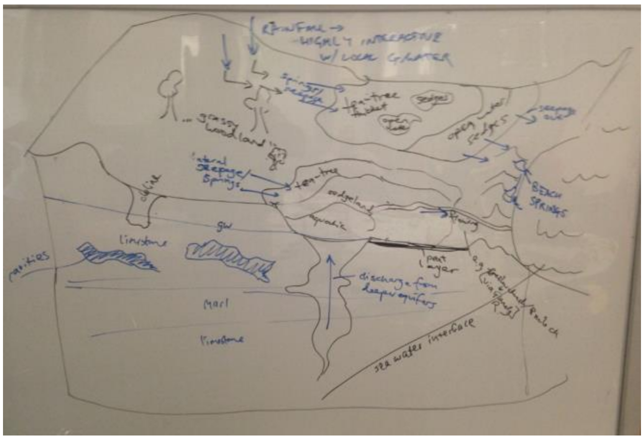


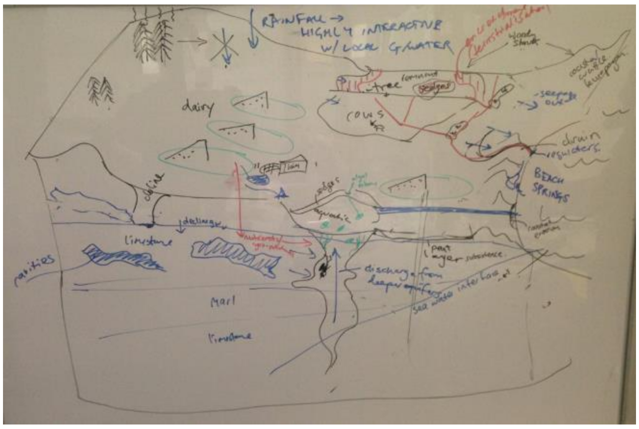
Coastal dune lakes and permanent pools in drains





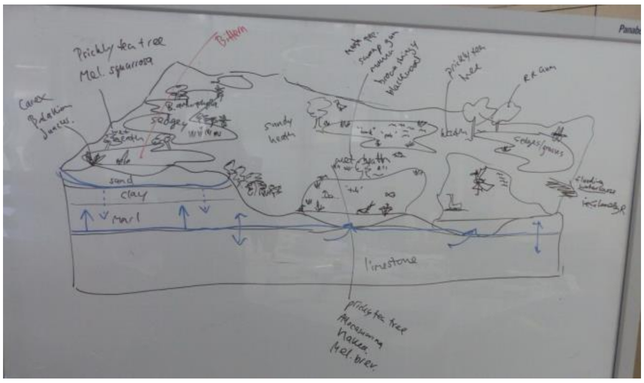
Karst rising springs and coastal peat swamp

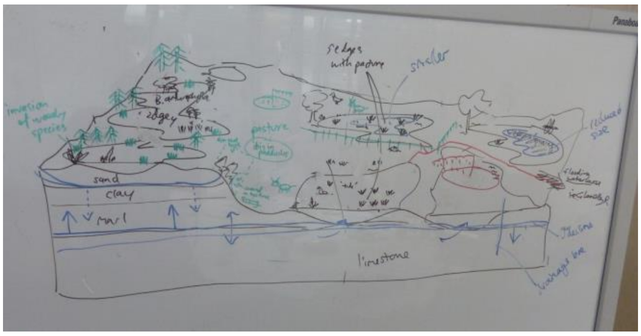




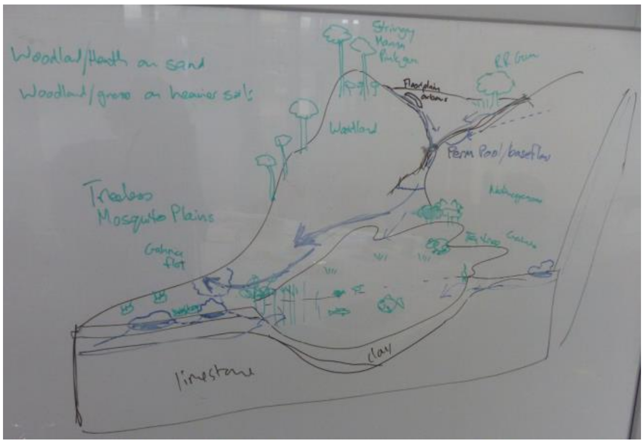
Pre-European scenario	Present scenario

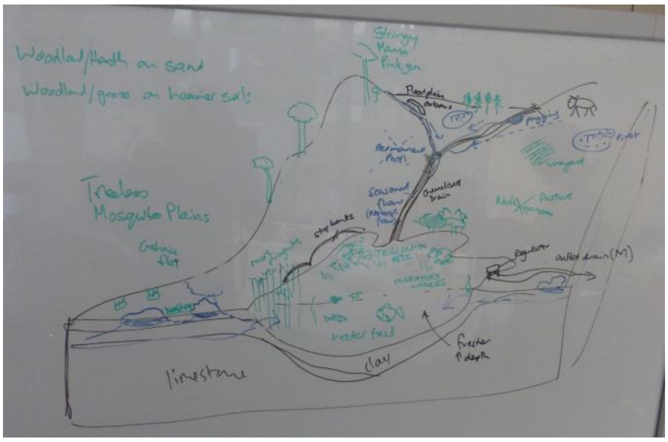
Freshwater grass and sedge marshes





Cross-border creeks





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Department of Environment,
Water and Natural Resources