

Supplementary Materials: Adaptation tipping points of a wetland under a drying climate

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Table S1. Overview legislation framework.

International Agreements/Treaties	
Ramsar Convention (1971)	The Convention on Wetlands of International Importance; intergovernmental treaty for the protection and wise use of wetlands.
Bonn Convention (1979)	The Convention on the Conservation of Migratory Species of Wild Animals; aims to conserve avian, marine and terrestrial migratory species. For Australian purposes, many of these species are migratory birds. The species listed in the Convention are of a matter of national environmental importance under the Environment Protection and Biodiversity Conservation Act assessment and approval provisions
JAMBA (1974)	Japan-Australia Migratory Bird Agreement; cooperation to protect migratory birds
CAMBA (1986)	China-Australia Migratory Bird Agreement; cooperation to protect migratory birds
ROKAMBA (2006)	Republic of Korea-Australia Migratory Bird Agreement; cooperation to protect migratory birds
National Legislation and Policy	
Environment Protection and Biodiversity Conservation Act (1999)	Establishes a legislative framework for biodiversity conservation and environmental protection, including species and Ramsar site listing, management plans, recovery plans, assessment and approvals of proposed actions. Establishes standards for the management of Ramsar sites through the Australian Ramsar Management Principles.
Native Title Act (1993)	The act requires that when a management plan is being prepared or important public works are taking place on a conservation estate, representative bodies and native title claimants ought to be advised.
Wetlands Policy of the Commonwealth Government of Australia (1997)	Provides strategies to ensure that the activities of the Australian Government promote the conservation, ecologically sustainable use and where possible, enhancement of wetland functions, keeping in mind aims of the Ramsar Convention.
Western Australia State Legislation and Policy	

Wildlife Conservation Act (1950)	Principal Western Australia legislation directly concerned with biodiversity conservation being administered by the Department of Environment and Conservation (DEC) of Western Australia. Administers the approvals needed to take declared rare flora and threatened fauna. It also provides for the protection and conservation of wildlife, including rare/ threatened flora and fauna.
Conservation and Land Management Act (1984)	Another Act also being administered by Department of Environment and Conservation. It sets the framework for the creation and management of terrestrial and marine parks, management and reserve areas in Western Australia. Deals with the protection of flora and fauna within reserve systems. DEC is required to prepare management plans for these areas in accordance with the legislative specifications of this Act. The specified objectives of these plans are to maintain and restore the natural environment and to protect, care for, and promote the study of indigenous flora and fauna, and to preserve any feature of archaeological, historic or scientific interest.
Environmental Protection Act (1986)	Provides for the creation of the Environmental Protection Authority, which was established as an independent authority with the broad objective of protecting Western Australia's environment. Provides for the prevention, control and abatement of pollution, and for the conservation, preservation, protection, enhancement and management of the environment. Provides authorisation to activities (such as mining, draining, discharging effluent) that could impact wetlands.
Aboriginal Heritage Act (1972)	All registered sites within Forrestdale Lake and Thomson's Lake Nature Reserves are protected under this Act. Ensures the protection of places and objects customarily used by or traditional to, the original inhabitants of Australia. A Register of Aboriginal Sites is maintained under the Act, as a record of places and objects of significance to which the Act applies. The presence of an Aboriginal site places restrictions on what can be done to the land. Anyone who wants to use land for research, development or any other cause, must investigate whether there is an Aboriginal heritage site on the land.
Wetlands Conservation Policy for Western Australia (1997)	Outlines the Government's commitment to identify, maintain and manage the State's wetland resources and values on long term. Provides broad objectives for wetlands, waterways, estuaries and shallow marine areas. Provides an implementation strategy specifically for the management of wetlands in Western Australia. Identifies the agencies involved and their responsibilities.

Table S2. Participants of stakeholder workshop 1.

Abbreviation	Actor	Role
FOF	Friends of Forrestdale	Community conservation group: responsible for ecological monitoring, revegetation and rehabilitation works
COA	City (council) of Armadale	Council: land allocation, drainage, groundwater use for irrigation
DOW	Department of Water	Water regulator: groundwater allocation and surface water monitoring of the wetland
DPAW	Department of Parks and Wildlife	Conservation authority: protecting biodiversity, visitor access, and coordinating local wetland management
	positive statement	
	negative statement	
	no positive or negative statement	

Exercise 1 – Problem statement, objectives, drivers and performance metrics

Table S3. All problem statements that are mentioned by the different management authorities which they commonly agree on (green); disagree (red); and not mentioned by the representative institution, or no indication of agree/disagree, neutral statement (grey).

Objective	FOF	COA	DOW	DPAW
Increase water levels	Green	Grey	Grey	Green
Have water for longer periods in the lake	Green	Green	Red	Green
Higher spring peaks	Grey	Grey	Grey	Green
Try to follow criteria set in Ramsar (wading bird habitat values) such as control of weed invasion	Green	Grey	Grey	Green
Maintenance of ecological character according to descriptions in Bush Forever 345	Green	Green	Grey	Green
Implementing deep sewerage (closed system) to substitute septic tanks in the township of Forrestdale	Green	Green	Green	Green

Table S4. All problem objectives that are mentioned by the different management authorities which they commonly agree on (green); disagree (red); and not mentioned by the representative institution, or no indication of agree/disagree, neutral statement (grey).

Objective	FOF	COA	DOW	DPAW
Increase water levels	Green	Grey	Grey	Green
Have water for longer periods in the lake	Green	Green	Red	Green
Higher spring peaks	Grey	Grey	Grey	Green
Try to follow criteria set in Ramsar (wading bird habitat values) such as control of weed invasion	Green	Grey	Grey	Green
Maintenance of ecological character according to descriptions in Bush Forever 345	Green	Green	Grey	Green
Implementing deep sewerage (closed system) to substitute septic tanks in the township of Forrestdale	Green	Green	Green	Green

Table S5. All drivers of change to the wetland system that were proposed by all institutions which they agree on (green).

Driver	FOF	COA	DOW	DPAW
Climate change (leading to decrease rainfall and recharge)	Green	Green	Green	Green
Change in hydrology in broader catchment by: land-use change, abstraction of water, drainage, borefield on Taylor Rd (Jandakot borefield; abstraction conditions breaching in Forrestdale Townsite), private backyard bores	Green	Green	Green	Green

Table S6. All performance metrics for wetland management or ecological change that are proposed by the different management authorities which they commonly agree on (green); disagree (red); and not mentioned by the representative institution, or no indication of agree/disagree, neutral statement (grey).

Driver	FOF	COA	DOW	DPAW
weed invasion	Green	Grey	Grey	Green
weed encroachment (extend from lake edge to water perimeter)	Green	Green	Grey	Green
wading bird numbers / breeding numbers (now suits swans)	Green	Grey	Red	Green
constant spread of <i>Typha orientalis</i>	Green	Green	Green	Green
water quality / nutrient loading of phosphorus and nitrogen	Green	Green	Green	Green
amount of bore licenses and bore use	Green	Grey	Red	Green
estimate the exempt use of groundwater	Grey	Grey	Green	Green
estimates of use around Lake Forrestdale	Grey	Green	Green	Green
the risk of increased use (difference between actual use and allocation limit)	Grey	Green	Green	Green
number of macro-invertebrates	Green	Grey	Red	Green
condition of wetland vegetation	Green	Grey	Green	Green

Table S7. Proposed performance metrics for wetland management or ecological change.

Ecological objectives	Water level (mAHD)	Threshold definition	Remarks
1. protect vegetation and mammals; definition of drought	SW < 21.5	3 consecutive months; 1 in 5 years	surface water available at depth of >21.5
2. prevent mosquitoes	SW < 21.5 SW > 21.7	1 month per year; 1 in 1 year	Spraying of wetland between 21.5-21.7
3. protect waterbirds	SW < 21.6	6 consecutive months; 1 in 5 years	
4. protect frogs	SW < 21.6	8 months; 1 in 5 years	
5. protect tortoises	SW < 21.6	6 months; 1 in 5 years	tortoises aestivate when depth is <21.5 in summer
6. protect macro-invertebrates	SW < 21.6	6 consecutive months; 1 in 5 years	macro-invertebrates sustain surface water depth of >21.6
7. prevent exposure of Acid Sulphate Soils	GW < 21.1	3 consecutive months; 1 in 5 years	
8. maintain sediment processes	GW < 21.1	3 consecutive months; 1 in 5 years	

Exercise 2 - Identify measures to postpone ATPs

Table S8. Potential actions and indicated tipping points that already have occurred with indicated consensus to implement the action.

ALL ACTIONS	Consensus
Recoup unused entitlements (especially in groundwater capture zone of wetland)	No
Restrict exempt use (especially in groundwater capture zone of wetland)	No
Improve metering of licenses around the lake	Yes
Recover licenses through land-use change	No
Reduce Leederville aquifer abstraction	Yes
Implementing WSUD to redirect stormwater to lake from new developments around the lake	Yes
Sewer system to replace septic tanks	Yes
Get local community support to change the negative perception of management authorities	Yes
DPaW to manage the lake by reducing the threat of fires and water draw downs	Yes
Ramsar criteria should be applied and ecological water requirements implemented as when originally studied	No
Monitor water quality from surrounding land-use and include as a condition of subdivision of lots.	No
Work closely with DPaW and DoW to achieve measurable outcomes of management	Yes
Reporting to Commonwealth of possible change in ecological character could result in an intra-agency committee with the community	Yes
Response plan: work with development proponents in drainage design; review limits of acceptable change as preliminary assessment; work with CoA to direct drainage through James Drain	No
Review the limits of acceptable hydrological change	No