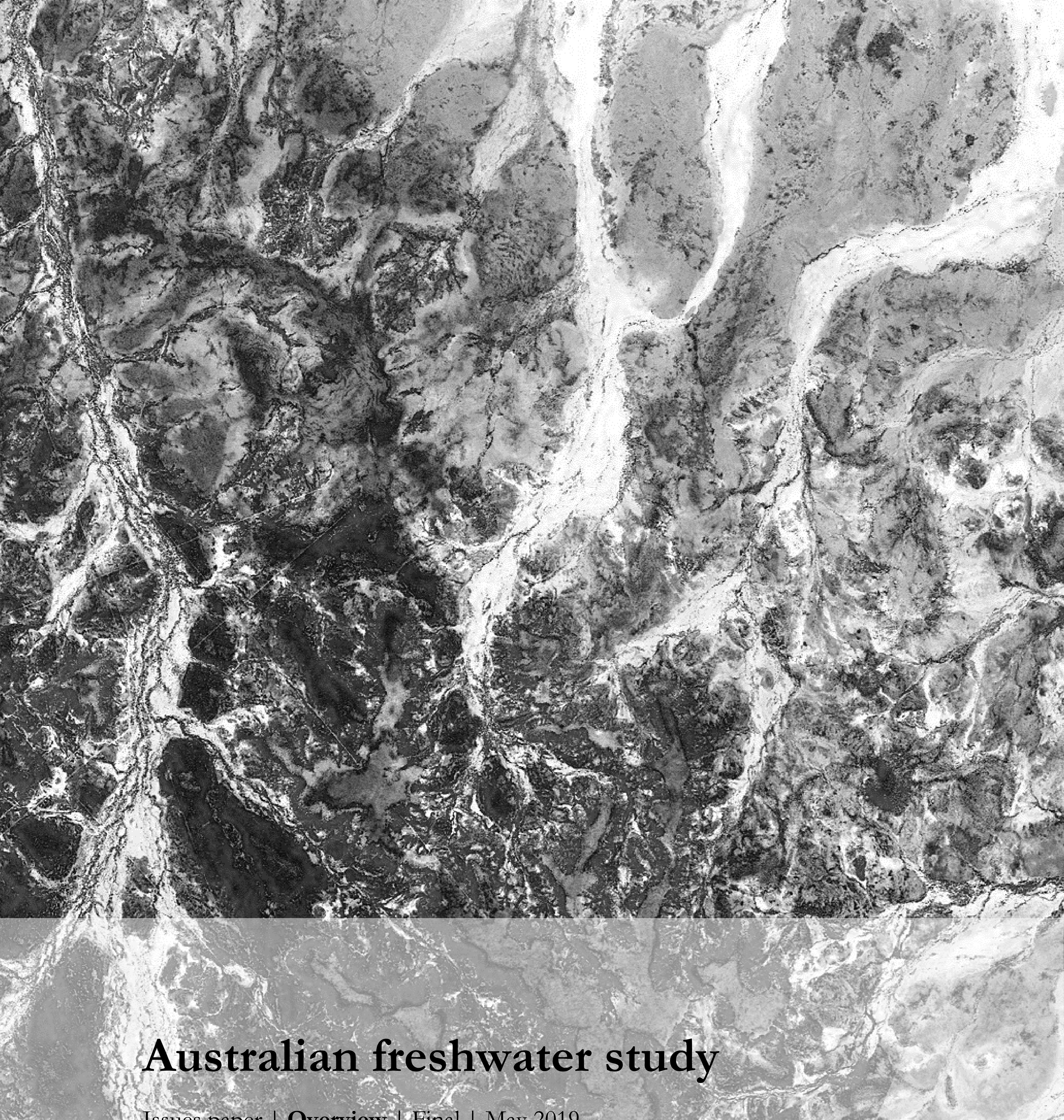

Australian freshwater study

Issues paper | **Overview** | Final | May 2019

The Ian Potter Foundation

The Myer Foundation

Point. Advisory

alluvium

Outline

This paper provides a brief overview of Australia's freshwater systems, their management and use, and future challenges to their long-term integrity and in turn Australia's water security. It is the first of six papers produced for the Ian Potter and Myer Foundations' Australian Freshwater Mapping Study.

This overview provides a brief introduction to the hydrology of Australia's freshwater systems, a short history of their management and use, and an assessment of their health along with a review of major threats and stressors. Future policy and decisions about water are not made against a "blank canvas". Consequently, it is essential to understand both the hydrology and the history of water in Australia to grasp the possibilities and options available in the present as well as future challenges.

The paper concludes by identifying two major pressures on Australia's freshwater system alongside a set of challenges that must be addressed to deliver a sustainable future for freshwater systems in Australia.

About the Australian Freshwater Study

The Ian Potter Foundation and The Myer Foundation have funded a study of major issues affecting Australia's freshwater systems. The Foundations want to better understand the ways philanthropic investment might catalyse changes to the management of Australia's freshwater resources that will protect their ecological integrity, make access to them more equitable, and ensure Australia's long-term water security.

The consulting firms Point Advisory and Alluvium have been commissioned to undertake the study and have prepared a set of short issues papers covering water governance, economics, freshwater ecosystems, First Peoples' water rights, and social values. The issues papers are the first step in the project. They provide a "long list" of major issues facing the management of fresh water in Australia as well as a general indication of options for philanthropic intervention. In parallel, Point Advisory and Alluvium are working on identifying more detailed options for philanthropy to intervene to catalyse change. Both work streams will be consolidated into a final report that matches issues with options and recommends a short list of specific future interventions to the Foundations for more detailed review.

Acknowledgements

Point Advisory and Alluvium would like to thank the Expert Panel Members for the project who gave time to be interviewed and provided references, advice, insights and review that benefited this paper including:

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- Professor Sarah Wheeler, University of Adelaide

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We would also like to thank the respondents to the public consultation process who provided feedback, which has contributed to the final paper. While we are very grateful for all of the assistance provided by our Expert Panel, responsibility for the final product and any errors rests with Point Advisory and Alluvium.

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Acknowledgement of First Peoples and Country
We acknowledge Australia's First Peoples and pay respect to the past, present and future Elders of Australia's First Peoples' communities. We honour the deep spiritual, cultural and customary connections of Australia's First Peoples to their lands and waters.

Contents

Old, flat, dry and nothing like Britain

Key messages:

Australia is the Earth's driest inhabited continent and Australian rainfall and runoff are highly variable, geographically and over time. Some Australian catchments have the most variable rainfall in the world.

Variations in rainfall and runoff patterns in Australia are long-standing and visible in the palaeoclimatic record. Australia's ecosystems are well-adapted to this variability.

Australia's unique hydrology and its significant differences from other world agricultural regions presents ongoing challenges to modern agricultural systems.

Australia cannot be "drought-proofed". Instead, we must come to terms with our continent's highly variable rainfall patterns as well as the likely impacts of climate change on rainfall and runoff if we are to sustainably manage our freshwater resources over the long term.

Australia is a low-lying, ancient continent. It straddles a mid-latitude, dry climatic zone marked by continental deserts on either side of the equator and is the driest inhabited continent on Earth. While average continental rainfall is low, Australia has wide spectrum of hydroclimates from the wet tropics in the north through the dry centre to temperate rainforests of Tasmania.[1] Australia lacks the high mountain ranges that feed major river systems with permanent snowmelt on other continents.[1] It shares only a small proportion of the Earth's fresh water resources—while the nation has around 5% of the Earth's land area, it has less than 1% of global river runoff.[2] Australia's biggest river system, the Murray-Darling, ranks among the 20 largest in the world measured by river length and catchment area (it drains roughly a seventh of the country), yet the Murray carries less water in a year than the Amazon does in a day.[3]

Rainfall is concentrated in Australia's coastal zones—particularly in the north, east, south-west and south-east—which receive far more rain than the dry interior.[2], [4] Travelling inland from the coast, average annual rainfall can drop by an inch per mile (15mm/km).[5] Consequently, annual precipitation averages in individual catchments vary from below 150mm to over 3000mm.[2] Most rain that falls in Australia returns to the atmosphere through evapotranspiration—runoff ranges from less than 1% of rainfall in the Western Plateau to over 40% in Tasmania and parts of Northern Australia.[4] Roughly two-thirds of Australia's runoff occurs in northern catchments, while more than half the continent produces almost none at all (see ***Figure 1***).[6] Rainfall's high spatial variability is apparent even at subcontinental scales—for example, rainfall in the small state of Victoria varies widely between the dry western districts and Gippsland. [7]

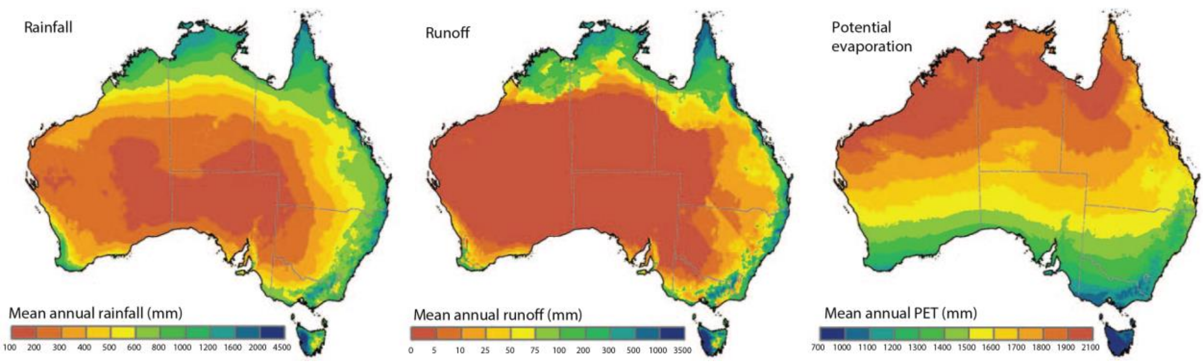

Figure 1*: Australian rainfall, runoff and potential evaporation (maps from CSIRO see [4])*

Australia's also has some of the most variable year-to-year freshwater flows in the world, with average variation between wet and dry years in Australia's temperate catchments more than twice that found in temperate regions of the northern hemisphere. Some Australian catchments exhibit even more rainfall variance.[2], [4],

[8], [9] Palaeoclimatic reconstructions of rainfall in Australia show a long-standing pattern of high temporal variability, with significant changes in rainfall patterns visible over 800 years (***Figure 2***). [10], [11]

Figure 2: *Palaeoclimatic reconstruction of rainfall by NRM region from 1200 to 1900 combined with instrument rainfall data from 1900 to 2018 presented as a relative rainfall anomaly (created from data presented in [11]). The red bars show periods of lower than average rainfall, the light blue, periods of higher than average rainfall. The vertical dotted line shows the break between reconstructed and instrument data. Reconstructed data is not available for all regions for all time periods.*

As ***Figure 2*** illustrates, over much of Australia, what can be predicted about rainfall is its high variability—there are very few "normal" years.[5] As a consequence, Australia's inland rivers have over 1000 times more variation in average annual discharge than similar rivers in North America or Europe. Rivers and streams in almost half of Australia provide no runoff to the ocean—much of their flow is taken up by the flat, arid landscape and many rivers end in closed ephemeral lake systems or flood plains. Most Australian rivers that do reach the ocean are slow flowing, intermittently flooding their banks and becoming "distributaries" to surrounding flood plains in wet years and retreating in the dry.[1], [5] Australia's river and wetland ecosystems are well attuned to this high variation, requiring intermittent flooding and dry periods to flourish.[12]

The Murray-Darling Basin, where much of Australia's high-value irrigated agriculture is located, has the most unpredictable and variable rainfall of the world's large river systems.[13] Recent settlers have found adapting to this characteristic of Australia's hydrology difficult.[2] As a grazier said to an agricultural researcher in the early 1990s in the middle of another "drought": "All the things I'm trying to farm—sheep and cattle—just want to die out here and all the things that I'm trying to kill just want to live out here."[14] The differences between total rainfall and its year-to-year variability between Australia's dominant area of agricultural development and the United Kingdom are well illustrated by ***Figure 3***, which shows annual rainfall (***Figure 3***(a) and(b)) and the relative regional rainfall anomaly (***Figure 3***(c) and (d)) for the UK and the Murray Darling Basin from 1901 to 2015. As we shall see in the following sections, these differences have shaped settler management of landscapes and rivers and attempts to re-engineer Australia's freshwater systems to fit a style of agriculture not always well-suited to Australia's rainfall patterns; attempts which have left an ongoing legacy of environmental damage.

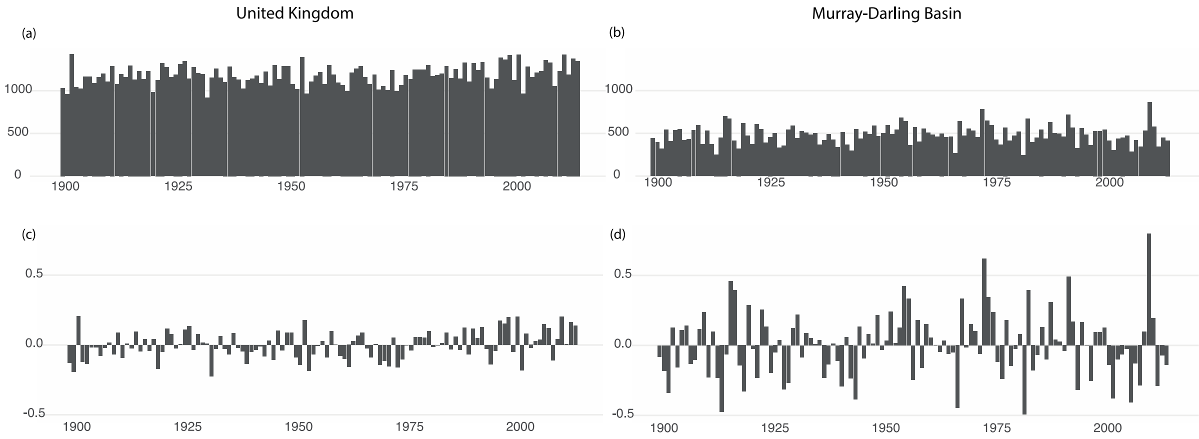

Figure 3: *Comparison between average regional rainfall and relative rainfall anomaly across the UK and the Murray-Darling Basin (MDB). Average annual rainfall across the MDB is less than half that of the UK, while variability between years is twice as high. (Created from data presented in [15] and [16])*

Groundwater aquifers in Australia contain many times the volume of water than is found in surface freshwater systems. Complex relationships exist between surface and ground water systems. Groundwater recharge rates from surface water tend to be small compared to the total volume of water stored in aquifers. Aquifer recharge rates also vary widely over space and time.[4], [17] Groundwater discharge supports river flows in many parts of Australia—for example, the Northern Territory's Daly River flows year-round fed by groundwater despite receiving nearly no runoff during the driest quarter of the year.[2], [4] Most of Australia's groundwater systems are poorly understood compared to surface water systems. Their distribution is quite different from surface water drainage divisions and catchments.[18]

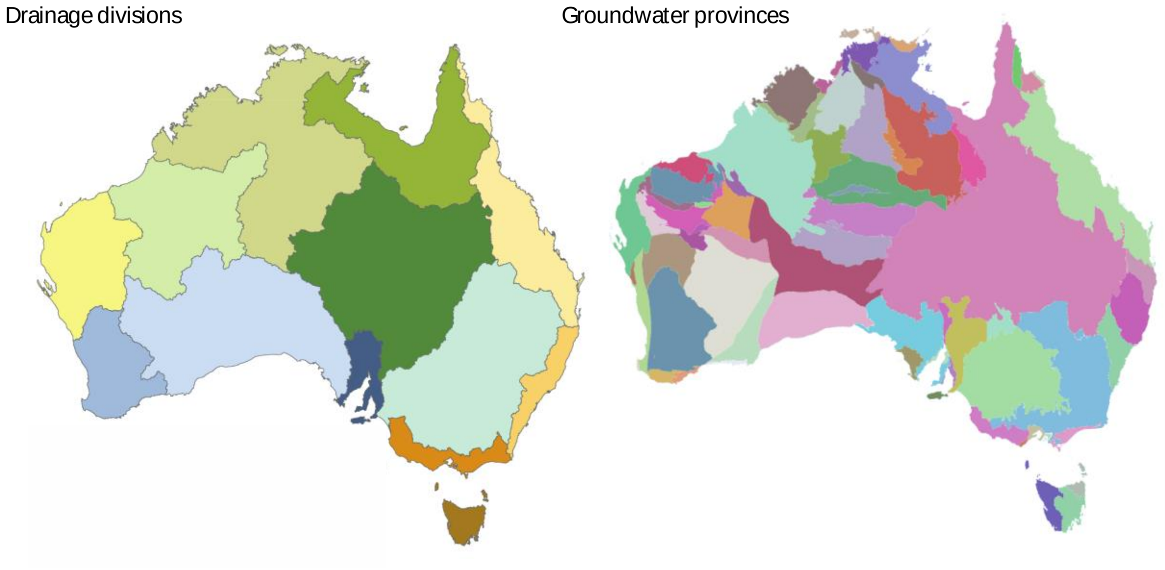

Figure 4: *These maps show how Australia's surface water drainage divisions and ground water provinces are quite differently distributed. The map on the left shows drainage divisions for surface water, while the one on the right shows the ground water provinces (maps from Bureau of Meteorology see [19]).*

Water use in Australia and its environmental impacts

Key messages:

Freshwater is a critical economic input for agriculture, industry, urban society and electricity production. Healthy freshwater ecosystems also have immense social and cultural value.

The economic and social benefits from freshwater consumption are often accompanied by negative impacts on Australia's freshwater ecosystems. Agricultural and urban systems are the major users of water in Australia and their use is highly correlated with freshwater system damage.

Australia's river basins vary in the human withdrawal and use of freshwater. Consequently, some Australian river and groundwater systems are highly-utilised, while others vary little from their natural flow regimes.

The characteristics of Australian hydrology (low rainfall and runoff, high variability) have a substantial impact on the way water has been used in Australia since European settlement.

The way landscapes are managed also affects Australia's freshwater systems. Land use and management are as important for long-term water security as direct water system management.

Introduction

Water is essential for all life on Earth. It has a crucial place in all human societies and is needed for food production and human welfare. It has immense social and cultural value. (See ***Water and Society*** and ***First Peoples' Water Rights Issues Papers***.) In advanced, industrialised economies like Australia's it is a critical economic input for agriculture, industry, urban development and electricity production. Yet in almost all nations, human activities directly impact freshwater systems and as a result the future viability of the activities and societies that depend on them.[20] Such threats are clearly visible in Australia.

Many of Australia's freshwater systems have been radically changed since European settlement.[3] Settler land-clearing, swamp draining and other changes in landscape management, have altered water's place in the landscape. Early explorers in the south-east often described shallow streams connecting "a chain of ponds" where water flowed slowly over substantial floodplains during wet periods. By the late 19th century, observers in the same areas complained of fast-running water eroding hillsides and cutting deep channels in the landscape. [5], [21] Water availability shaped European settlement patterns in Australia—determining the location of towns and cities and areas of intensive agricultural activity—and in turn European settlement patterns have shaped water availability and ecosystem damage.[2], [5], [21] Water remains an indispensable input into Australia's current economy and its use for agricultural and industrial activities has generated substantial wealth and economic growth.

Economic development has transformed many of Australia's freshwater systems. Direct water extractions are only one factor in this transformation. Another major factor is water infrastructure investments like dams and irrigation channels designed and built in attempts to capture water and smooth the high seasonal and year-to-year variability in Australia's rainfall and runoff. Land use change, predominantly land-clearing, and pasturing stock have also made major alterations to the water-cycle in many catchments. It is becoming increasingly clear that everything we do in the landscape affects Australia's freshwater systems.[5], [21], [22]

Good ecological health of Australia's freshwater systems is essential if they are to continue to support Australian agriculture, cities and industry. The economic and social impacts of damage to freshwater systems can be severe. Freshwater system changes caused by poor land and water management include increasing salinity, turbidity, eutrophication and changes to water PH. These changes reduce the capacity of freshwater systems to provide the supporting and regulating ecosystem services that all water users depend on. [23] Substantial reductions in these services can lead to events with major economic consequences. For example, NSW declared a state of emergency after a 1000km-long stretch of the Barwon-Darling system was contaminated by a toxic algal bloom in 1990. As UN work on nature-based solutions for water demonstrates, healthy river systems support healthy and productive communities and economies.[24]

Where water is used in Australia

Australia's river basins vary substantially in human withdrawal and use of freshwater. Consequently, some Australian river and groundwater systems are highly-utilised, while others vary little from their natural flow regimes.[2], [4], [17], [25] *Figure 5* (a, b) compares the surface water runoff with the proportion of surface water used for human activities across Australia's 224 river basins. The maps show how areas of high (>40%) water use are concentrated in basins supplying capital cities and in those, like the Murray-Darling Basin, where water is used for agriculture.[4] As can be seen in *Figure 5* (c, d), the most intensively settled areas of the continent are in the south-east and a small part of the south-west. Agricultural areas fill the hinterlands in the southern half of the continent. Consequently, many areas with relatively low rainfall experience high demand pressures.[26]

Differences in rainfall between the highly populated south and the north of Australia have caused Australian policy-makers to look to northern catchments for future agricultural investment for over a century.[2], [27] Dreams of abundant, reliable water for agriculture based on major infrastructural investments to capture the north's larger flows have periodically engaged Australian politicians and communities. However, dreaming does not make for successful investments or new agricultural systems as was found at considerable cost in the failure of the Ord River scheme in northern Western Australia. [28], [29] Future development of water resources in northern Australia faces substantial hydrological, environmental, political and economic hurdles, which are discussed in the Future Challenges section below.

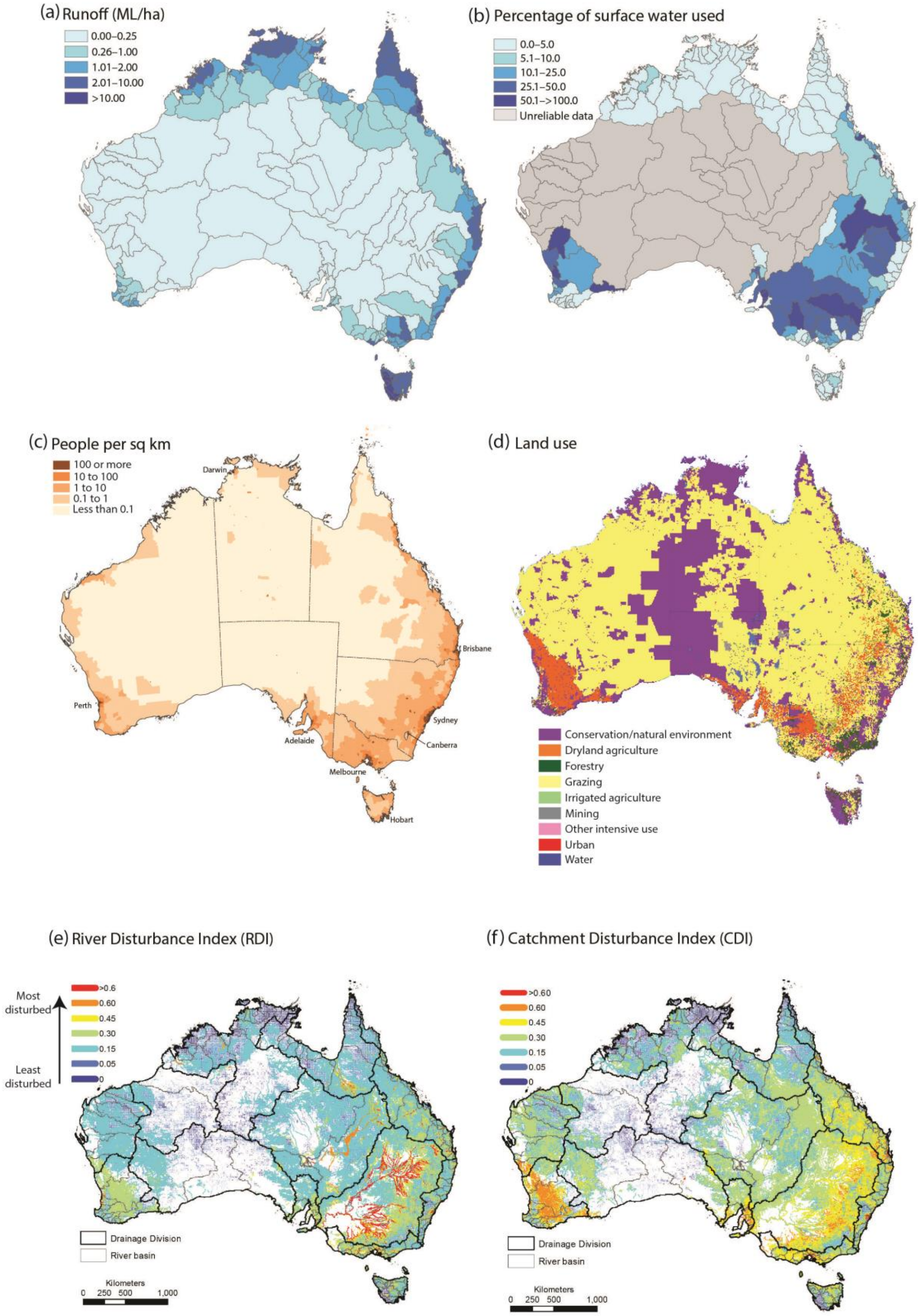

Figure 5*: Comparing runoff, water use, population, land-use and river and catchment disturbance (maps from Bureau of Meteorology, CSIRO, ABARES and the Australian Rivers Institute, Griffith University[4], [28]-[31])*

How water is used in Australia

Agriculture is Australia's major water consumer. Agriculture consumes between 50 and 70 per cent of all water taken for consumptive use (70 per cent in 2016-2017) depending on water available from rainfall and storage systems. Urban water is the next largest consumer, taking up 20–25 per cent of consumption (20% in 2016-2017). Manufacturing, mining and other industrial uses constitute the remaining 10–15 per cent (***Figure 6***). [17], [19], [32]

Figure 6: *Water consumption in Australia 2016-2017 (data from Bureau of Meteorology[17])*

In 2016-2017, 83 per cent of water for agriculture was taken from surface water sources, with the remainder from groundwater. Nearly 30 per cent less groundwater was used in 2016-2017 than in 2015-2016 because of the increased availability of surface water. This magnitude of change is not unusual as users adjust to variations in annual surface supply. Broken down by state, agriculture remains the dominant consumer in all states except Western Australia, where mining is the major consumer, and the Northern Territory and the ACT, where urban water dominates consumption. Of total water extracted in Australia, hydroelectricity is by far the greatest user of water, but almost all of this water is returned to the environment. However, the timing, temperature and other qualities of water returned by hydroelectric generators can have adverse effects on freshwater ecosystems.

Box 1: The significance of water in the Australian economy—facts and figures

Total revenue from sales of water and the provision of water services in 2015-16 was $17.2 billion. Of this amount, households spent $10.1 billion, industry spent $6.9 billion and primary industries spent $689 million.

The gross value of irrigated agricultural production in 2016-17 was $15.5 billion, which was approximately 25% of the gross value of all agricultural production. Around half of the gross value of irrigated agricultural production was produced in the Murray-Darling Basin. In this period, irrigated agriculture used around 70% or 11,300GL of Australia's total water extractions of 15,600GL, however this amount varies from year to year and also varies substantially between the states.

The value of allocation (temporary) water trades across Australia in 2016-17 was about $131 million. The value of entitlement (permanent) water trades across Australia in 2016-17 was about $1.06 billion

Australia's urban water industry had assets of $160 billion as at 1 July 2015. The urban water industry receives over $15 billion revenue per annum and directly accounts for 0.75% of Australia's GDP. It spends between $3.5 and $4.5 billion on capital works every year. Total urban water and wastewater capital expenditure in 2016-17 was $3.45 billion—this has reduced from the $6.0 billion spent in 2008-09 and $5.5 billion spent in 2009-10 in response to the drought. The capital cost of Australia's six desalination plants installed between 2006-12 to redress water security problems was $10.2 billion.

Australia has 108 hydroelectric power stations with a total installed capacity of 7.8GW. Over 50% of the installed capacity is in NSW, almost 30% in Tasmania and the remainder spread across Qld, SA, Victoria and WA. Note that Tasmania's smaller capacity generates more electricity than NSW (8.4GWh vs 6.1GWh). Hydropower stations generated 16,285 GWh of electricity in 2016-2017, around 6% of all electricity generated in Australia, but around 40% of all electricity generated from renewable sources. The amount of electricity generated from hydropower stations varies from year to year, during the Millennium drought generation dropped to 11,869 GWh. [32], [33], [34], [35], [38], [149] Where it is used intensively, as in irrigated agriculture, water increases yields and the value of agricultural production. Between 1920 and 2000 the area of irrigated agricultural land in Australia increased 10-fold, with the majority of the growth occurring before 1990.[32] Even with this growth, irrigated land represented less than 1% of Australia's total agricultural land area in 2016-17, although it delivered more than a quarter of the gross value of total agricultural production. Around half of this value is generated in the Murray-Darling Basin.[32]

Australia's per capita water resources are moderate to high in a global context. However, Australia's low population density means that the nation uses a relatively small proportion of its available surface runoff.[4] While such national averages can be misleading for practical policy and decision-making purposes, which need to occur at catchment and basin scales, Australia's largely urban population uses water as though it were not particularly scarce, although usage declined during the Millennium Drought, per capita urban domestic water use in Australia remains moderate to high by international standards. Indoor use in Australia is comparable with countries with similar living standards and much of the difference in urban use is a result of low housing density, greater areas of parkland and sporting fields and the predominance of the Australian backyard.[4] Urban water in Australia predominantly comes from surface water in all major cities with the exception of Perth where it is sourced in almost equal parts from ground water and desalination (see *Figure 7*).

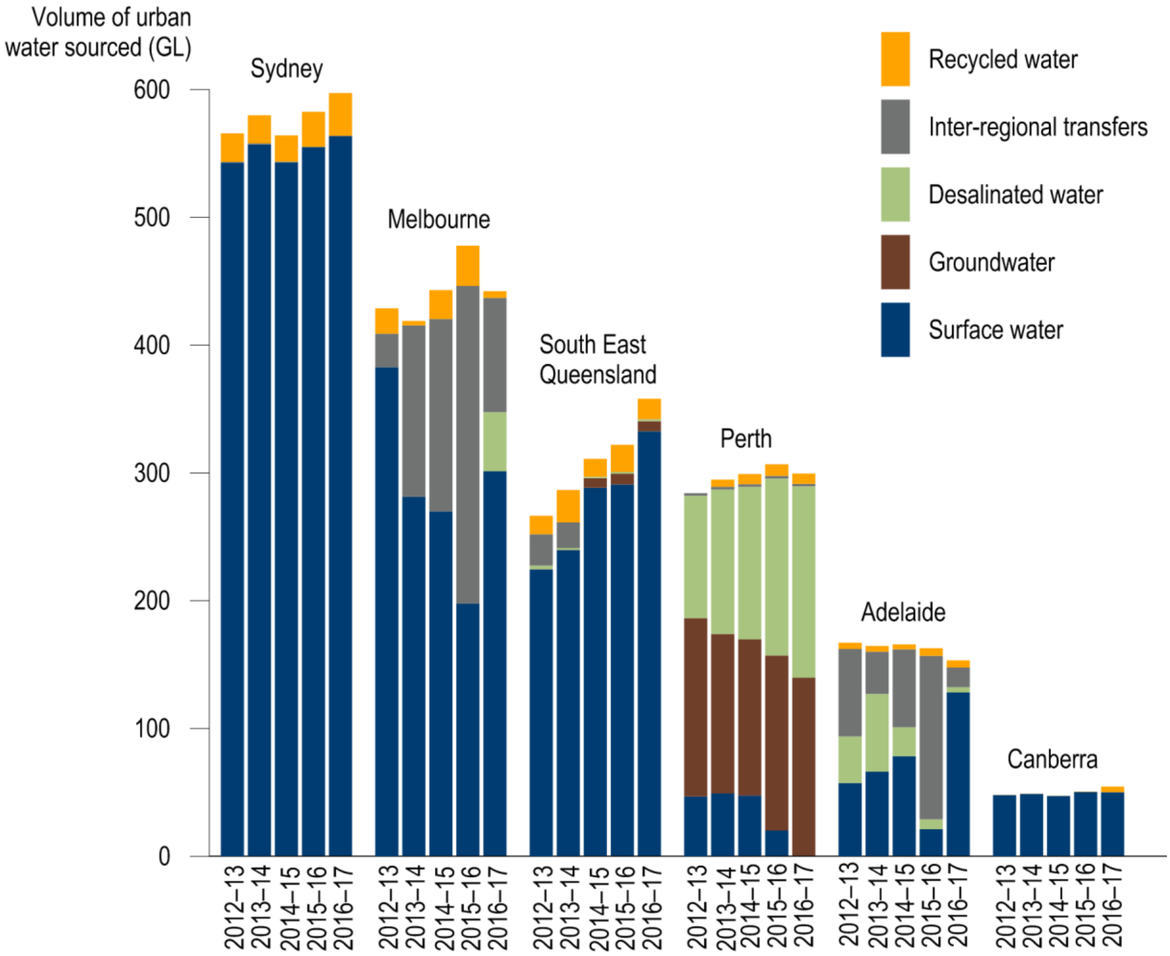

Figure 7: *Water sources for Australia's major cities (chart from Bureau of Meteorology[17])*

The groundwater component of Australia's water resource is often used to smooth supply/demand imbalances. It is estimated that groundwater supplies at least a third of Australia's total water consumption (as a long-term annual average). This is likely to be an underestimate of the actual total as limited monitoring and metering and inconsistent reporting regimes mean that accurate groundwater use records are not available for most of Australia. Groundwater usage by sector roughly parallels that of surface water use with around 70% of groundwater used in agriculture with the remainder used for urban water supply and industrial uses. The exception to this distribution of uses is in Western Australia where agriculture accounts for around 21% of groundwater use and mining accounts for another 38% with the remainder being used for urban water. *Figure 8* shows the level of over-extraction in groundwater resources and the areas of Australia dependent on groundwater.[18]

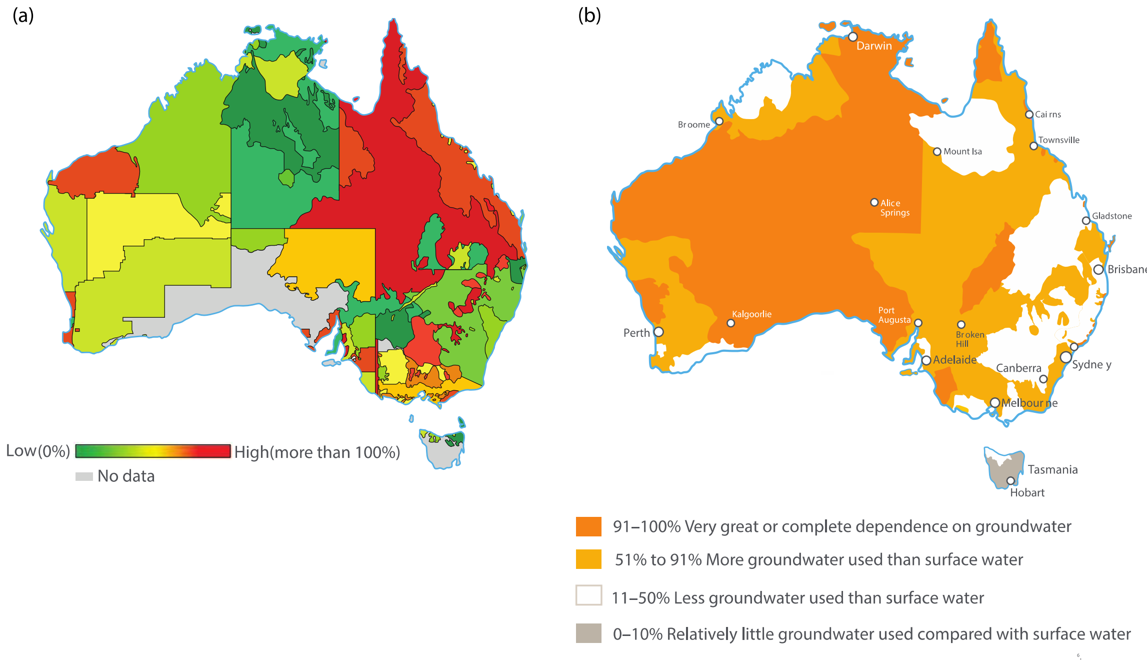

Figure 8: *Map (a) shows the ratio of groundwater use to sustainable yield for Australian groundwater management units; Map (b) shows areas of groundwater use as a percentage of total water use as a measure of groundwater dependence (charts from the National Centre for Groundwater Research and Training, Flinders University[18])*

Consequences of Australia's high rainfall and runoff variability

All Australian water users are exposed to Australia's high evapotranspiration rates and rainfall and runoff variability. Australian agriculturalists face much greater year-to-year variability than most of their international counterparts. Both Australia's interior and northern rangelands, where much pastoral agriculture occurs, and Australia's temperate areas where dryland cropping and irrigated agriculture takes place, have year-to-year rainfall variability more than twice that of comparable areas in many other countries.[26] In the Murray-Darling Basin, 94% of rainfall is returned to the atmosphere through evapotranspiration and historical aggregate water inflows in the Basin (i.e. all runoff entering the river network) range from less than 7,000GL (in 2006) to 118,000 GL (in 1956). [36]

The high variability of inflows and Australia's high evaporation rates mean that water storage dams in Australia need to have a much greater relative capacity than those in other countries—for example, Sydney can store 25 times more water per person than can London.[2], [26] However, interannual variability and evaporation are high enough in many basins that even large storage systems are not a simple solution to providing long-term reliable supply—an equivalent amount of water is lost to evaporation from Australia's dams as is withdrawn for use.[4] Supply uncertainties have led to water storages being augmented in high-use catchments by water transfers, groundwater use or, more recently, desalination of seawater.[4], [26]

Evaporation and returns to groundwater also cause substantial reductions in the river flow over large distances meaning that only a small proportion of runoff is available when water is moved through systems like the Murray-Darling Basin for use far from its source.[4]. Some highly productive irrigated agriculture exists in areas where potential evapotranspiration is up to eight times rainfall. In these areas, the pressure on water resources that occurs in low rainfall years can require substantial adjustments to water allocations and management of the transmission of water through the system to maximise agricultural use and environmental benefits.

Demand for freshwater in Australia varies far less seasonally and year-to-year than do rainfall and runoff. Runoff variability often causes supply/demand imbalances that lead to water scarcity. Such imbalances are particularly pronounced in catchments with high water use where the uncertainty arising from unpredictable seasonal and year-by-year variations in runoff is more consequential than long-term averages.[2], [4] The rainfall elasticity of streamflow (or runoff) in Australia is between 2–3.5, which is high by global standards. This means that a 10% drop in mean annual rainfall is amplified as a 20–35% drop in mean annual runoff.[145] Australia's water allocation reforms respond to this unpredictability by providing water entitlement holders with a share of available water rather than a fixed volume each year. [37] During the Millennium Drought there was so little available water that many irrigators were allocated little or no water.

The Millennium Drought presented most mainland urban centres with a water crisis and led to severe water restrictions to manage demand. In major capital cities, water restrictions were combined with supply augmentation through the construction of six desalination plants at a cost of over $10 billion. The drought demonstrated the limitations of traditional approaches to supplying urban water—dam storage and inter-basin water transfers—in the face of growing urban populations and rainfall variability.[4] Variable supply also affects Australia's National Electricity Market where periods of low rainfall reduce output from hydro-electric generators and coal-fired generators that require fresh water for cooling. This increases electricity prices and the risk of unserved demand in the system.[38]

The environmental impacts of water use

Australian freshwater systems have been transformed through land clearing, agricultural production, urbanisation, withdrawals from surface and groundwater systems, the introduction of pests and invasive species, and engineering works including dams, reservoirs and irrigation channels. These transformations have reversed the natural pattern of river flows[1] and left an ongoing legacy of increased nutrient runoff, sedimentation and salinity. They have profoundly altered the ecology of many riparian and wetland areas. [3], [6], [19], [39], [40] As ***Figure 5*** (e, f) makes clear, stark differences exist between the environmental status of freshwater systems in areas of low population not yet subject to the alterations of settler agricultural and urban systems and those areas where settler agriculture and urbanisation have a longer history.

Regular high diversions for agriculture have had substantial negative impacts on riparian ecosystems like those of the Murray-Darling Basin. [2], [4], [25] Agricultural water requirements in some areas have limited flexibility, which means that dry periods can cause considerable competition for water between the environment and human consumptive uses in high-use catchments. For example, in the Murray-Darling Basin, more than 70% of available water is used in the driest 30% of years, whereas in the wet years a much smaller proportion of the total is diverted for use (see ***Figure 9***).[4]

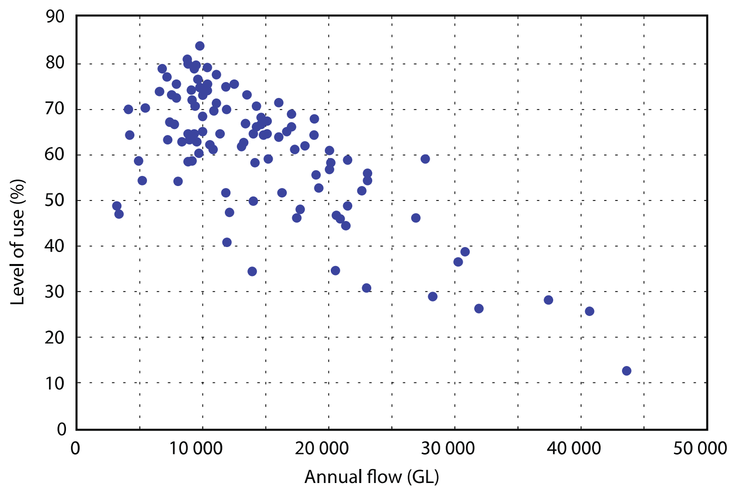

Figure 9: *Proportion of annual flow extracted for use by level of flow in the Murray-Darling Basin (chart from CSIRO, see [4])*

[1] This "reversal" arises from low flows in wet seasons as water is captured in dams and high flows in dry seasons when irrigation water is delivered.

As *Figure 9* shows, the environment tends to lose the competition for water in dry years in high-use catchments and it was the "big loser" during the Millennium drought in the Murray-Darling Basin.[23] Towards the end of the drought, river health audits in the Basin showed that 2 of 62 zones in 23 valleys were rated as being in "Good" ecological health. The majority (49) were in "Poor" (19), "Very poor" (27) or "Extremely poor" (3) health. While the remaining 11 were in "Moderate" health. By the end of the drought, only one zone was in "Good" health and one in "Moderate" health.[23]

As Figures 6 and 9 make clear, environmental pressures and impacts are strongly correlated with the:

- level of extraction for human consumption
- total available water in the system (droughts are a significant stressor)
- extent of alteration of the system's natural flow regime through infrastructural change and management (e.g. building and operation of dams, levees, irrigation channels and associated temperature changes, removal of both low- and high-flow events or the reversal of seasonal flows etc.)
- the alteration and management of surrounding landscapes (e.g. land clearing and subsequent erosion, pasture and livestock management practices) [12], [23], [41]

For the most part, highly-allocated freshwater systems in dry years are subject to greater pressures and suffer greater ecological impacts than they do in wet years. Highly managed systems with substantial infrastructural change in landscapes with a long history of human alteration suffer greater ecological stressors than those where little alteration has been made to land and waterscapes. [12], [23], [41] The one major exception to this general rule is rivers in remote areas of Australia that have been contaminated by toxic runoff from mines (for example the McArthur River mine in the Northern Territory's Roper River region). Recent research also suggests that available water in the system in any single year may be less important than the sequencing of wet and dry periods, particularly preceding and during drought periods.[42]

Understanding the health of Australian freshwater systems requires a broader, integrated focus on land and water management practices.[26] Water quality and ecosystem health is affected by land clearing, which increases sediment loads and salinity; agricultural fertiliser and pesticide use, which can increase nutrient (nitrogen and phosphorus) and chemical loads through runoff; poor management of animal wastes, which also increase nutrient loads; irrigation and replacement of deep-rooted native vegetation with shallow-rooted pasture and crops, which increase salinity in soil and water; and, point sources of pollution from industrial and urban activities. [2], [26] Poorly managed water quality has additional impacts on marine ecosystems where freshwater runoff flows into the sea—for example, the Great Barrier Reef's ecosystems are negatively affected by increased sediment, nutrient, pathogen and herbicide loads from Queensland grazing and cane farming.[43]

Current state of Australia's inland waters

Australia's national State of the Environment Report has assessed the state of Australia's inland waters every five years since the first report in 1996. [3] The reports document pressures on Australia's inland water systems as well as the consequences of these pressures. From 1996 to the latest report in 2016, the reports have documented the considerable human impacts on freshwater systems across Australia, particularly in high-utilised southern catchments.

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Table 1 and 2 are taken from the most recent 2016 Australian State of the Environment Report and consider the changes occurring in the period since the previous 2011 report.[19]

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Table 1: *State of Australia's inland waters 2016—pressures affecting inland water environments[19]*

Pressure	Assessment grade since last report	Comments
Climate variability and climate change	High impact and trend deteriorating	Rainfall deficiencies in Qld, Vic, Tas, NSW, SA and WA; warmest, assessment period included third warmest and fifth warmest years on record; water storages decreasing.
Water resource development	High impact and trend stable	Urban water use has increased, but demand met through demand-management desalination and other climate resilient sources; agricultural water use stable, but small dam construction continues to increase resource pressures and management challenges.
Land use and management	High impact and comparable to 2011 assessment	Land clearing continues, particularly in Queensland; other land management practices improving run-off and nutrient load pressures.
Pests and invasive species	High impact and deteriorating from 2011	Weeds of National Significance and vertebrate pests affecting mainland waterways.

Error! Not a valid bookmark self-reference. provides a detailed assessment of each drainage division across four major assessment areas and identifies trends based on a comparison between the 2016 status and that identified in the 2011 State of the Environment Report.

Table 2: *State of inland waters by drainage division[19]*

Drainage division	Flows and levels		Groundwater		Water quality		Ecological processes	
Carpentaria coast	—	VG	↙	P	?	G	—	G
Lake Eyre Basin	—	G		G	?	G	—	G
Murray-Darling Basin	—	P	↙	P	↗	VP	↙	VP
North East Coast	—	G	↙	P	↗	P	—	VP
North Western Plateau	—	VG	?	VG	*Not assessed*	*n/a*	?	G
Pilbara-Gascoyne	—	VG	—	VG	*Not assessed*	*n/a*	*Not assessed*	*n/a*
South Australian Gulf	↙	P	↙	P	?	P	—	P
South East Coast (NSW)	↙	P	—	P	?	P	—	G
South East Coast (Vic)	↙	P	—	P	—	P	?	G
South West Coast	↙	P	↙	P	—	VP	?	P
South Western Plateau	?	VG	—	G	*Not assessed*	*n/a*	*Not assessed*	*n/a*
Tanami-Timor Sea Coast	↗	G	↙	G	—	G		G
Tasmania	↙	G	?	P	—	G		G

Key

Recent trends		*Grade*	
↗	Improving	VG	Very good
↙	Deteriorating	G	Good
—	Stable	P	Poor
?	Unclear	VP	Very poor

Trends documented above compare 2016 status with that documented in the 2011 *State of the Environment* report.

A brief history of water management in Australia

Key messages:

British settlement dispossessed Australia's First Peoples' of their lands and waters (see **First Peoples' Water Rights** issues paper).

Settler water management in Australia has a long history of ignoring biophysical constraints in land and water systems. Current problems with freshwater systems arise from "an unfortunate collision of biophysical and economic reality, cultural values and public policy". [44]

Managing water is primarily a social and governance process that involves reconciling the conflicting values and water demands of different interest groups.

The National Water Initiative and the Commonwealth *Water Act 2007* delivered bold reforms of water management in Australia. However, under the stress of droughts, governments continue to bow to interest group pressure and have often prioritised infrastructure spending over resolving thorny issues.

Water politics and management in Australia remains subject to the "hydro-illogical cycle" in which change in water management is often crisis driven by drought, and wet years bring apathy and a failure to properly plan for the next supply challenge.

Introduction

Different commentators have divided the history of water management in Australia into various periods.[2], [45] In this section, the history has been organised into five periods corresponding to the dates in brackets. The periods sometimes overlap because of the complex processes of social change and the different phases of development across different regions of Australia:

- First Peoples' dispossession and British establishment (1788–1886): First Fleet to the passing of the Victorian Irrigation Act
- *State intervention and engineering expansion (1886–1987)*: the passing of the Victorian Irrigation Act to the completion of the Burdekin Dam.
- Economic suspicions, emerging environmental values and the beginnings of water reform (1967–1994): the publication of Bruce Davidson's Australia Wet or Dry to the COAG Water Reform Framework
- *Working as a Federation, the COAG Water Reforms (1994–2014)*: the COAG Water Reform Framework to the dissolution of the National Water Commission
- *The return of the "hydro-illogical" cycle? (2014 to the present)*: the dissolution of the National Water Commission to the present.

This section ends with a case study following the development and finalisation of the Murray-Darling Basin Plan (Box 2).

First Peoples' dispossession and British establishment

Australia's First Peoples have used, modified and managed Australia's fresh water systems over the last 65,000 years.[46] Indigenous Australians engineered sophisticated stone-walled fish trapping complexes,[47] modified rivers and wetlands with cuttings, scaffolding and weirs for aquaculture. [5], [48] Contemporary accounts suggest that many of the "snags" removed from rivers to clear passages for paddle steamers were Aboriginal fish traps and weirs. [49] First Peoples' also engaged in integrated land and water management practices based around "an established body of laws that allocate rights and interests among particular people" that shaped terrestrial and aquatic ecosystems. [5], [28], [50]-[53] [54] [55] Freshwater systems remain central to Aboriginal and Torres Strait Islander cultures and societies. [55], [56] ***(See First Peoples' Water Rights Issues paper)***

The arrival of European settlers in Australia led to the violent dispossession of First Peoples' lands and waters by settlers for urban and agricultural development.[57]-[60] Land was cleared of native vegetation, swamps and wetlands were drained and hoofed grazing animals compressed and hardened soils altering runoff patterns and increasing erosion and consequent sedimentation in watercourses—an historical legacy and ongoing issue with continuing impacts on freshwater ecosystems. [2], [5], [41], [45] The forced cessation of Indigenous land and water management practices alongside the introduction of European agricultural practices irrevocably changed Australia's land and waterscapes in many places. [5], [48]

Site selection for settler cities and towns was determined by water availability from rivers and streams.[2] In addition to providing water for urban and agricultural development, rivers became important transport corridors with negative impacts on aquatic life. [2], [41], [45] Towards the end of the nineteenth century steam-powered stationary engines and pumps accelerated land-clearing and the growth of irrigated agriculture in major river systems like the Murray-Darling.[41] Human water use and associated ecological impacts remained closely correlated to European settlement patterns. Impacts were high in southern catchments, while many northern catchments remained relatively undisturbed.[2]

The settlement of Australia by the British Imperial Government vested sovereign title to all Australia's land and waters in the British Crown. This legal fiction linked private rights to land with access rights to water resources under British common law riparian doctrine.[28] These rights could only be obtained by a grant from the Crown and Australia's First Peoples were legally, as well as physically, dispossessed of their lands and waters—[61], [62] *terra nullius* was also "*aqua nullius"*.[63], [64] Since settlement, First Peoples have actively resisted colonisation and participated in ongoing struggles for recognition of their sovereign rights to lands and waters including making multiple petitions to the British Crown seeking redress and legal recognition of their rights to land and water.[61] None were granted.

Over the course of the 19th Century, the common law riparian approach to water rights proved an inadequate framework to manage the sometimes fierce conflicts that surrounded access to water in Australia's relatively arid and highly variable climate. The rapid expansion of the Victorian goldfields in the 1850s led to significant changes to local water systems through the building of infrastructure and mining pollution. Up to 75% of Victoria's catchments were affected.[148] A legal framework developed in a climate of water abundance was a barrier to the larger-scale resource planning needed to manage the needs of urban, agricultural and mining development in the much drier and more variable climate of south-eastern Australia. [28], [45], [65]

State intervention and engineering expansion

In a pattern that would continue to be repeated through the 20th and 21st centuries, a low rainfall period (1877-1881) galvanised major government intervention in water resources management. New legislation was passed in Victoria in 1881 and the then Victorian Attorney General, Alfred Deakin was appointed to chair a Royal Commission on water supply. [2], [28], [45]. Deakin's work resulted in the *Victorian Irrigation Act 1886*, which constrained riparian rights and gave legislative form to Deakin's recommendation that "the State should exercise the supreme control of ownership over all the rivers, lakes, streams and sources of water supply".[28] The Victorian Act vested the use and control of freshwater in the Crown and established a water licensing scheme and irrigation districts. Deakin's work spurred similar legislative developments, with variations, in the remaining Australian states. [28], [66]

Deakin's reforms helped resolve issues arising from competing extractive uses, but had no framework for considering longer-term environmental impacts of water use or other social and cultural values for water.[45] They also made no mention of First Peoples' interests in water in Victoria. State control led to the creation of water bureaucracies focussed on managing water for increasing agricultural output and accelerating the settlement of inland areas. State governments sponsored irrigation and urban water infrastructure from the late 19th century with direct funding and by writing off the debts of private irrigation developments. [2], [45]

Salinity problems from irrigation had arisen in the Victorian Mallee and parts of southern Western Australia by the 1920s. [40], [66] However, optimism about engineering investments' ability to "drought-proof" the continent and overcome the high variability in Australia's hydrological cycle saw governments press forward as major water developers for much of the 20th century alongside private investment in farm dams to harvest floodwaters. The financing and construction of water infrastructure was a pre-eminent nation-building activity. The states and the Commonwealth funded, built and owned infrastructure including major dams, irrigation works, hydroelectric schemes, large-scale urban and rural reticulated water supply, drainage and sewage systems. [2], [45], [65], [67] Between 1950 and 1959 more dam storage was constructed in Australia than the combined capacity of all dams built in the previous 100 years. Dam construction peaked in the 1970s and the last major dam, the Burdekin in North Queensland, was completed in 1987 (see Figure 10).[2]

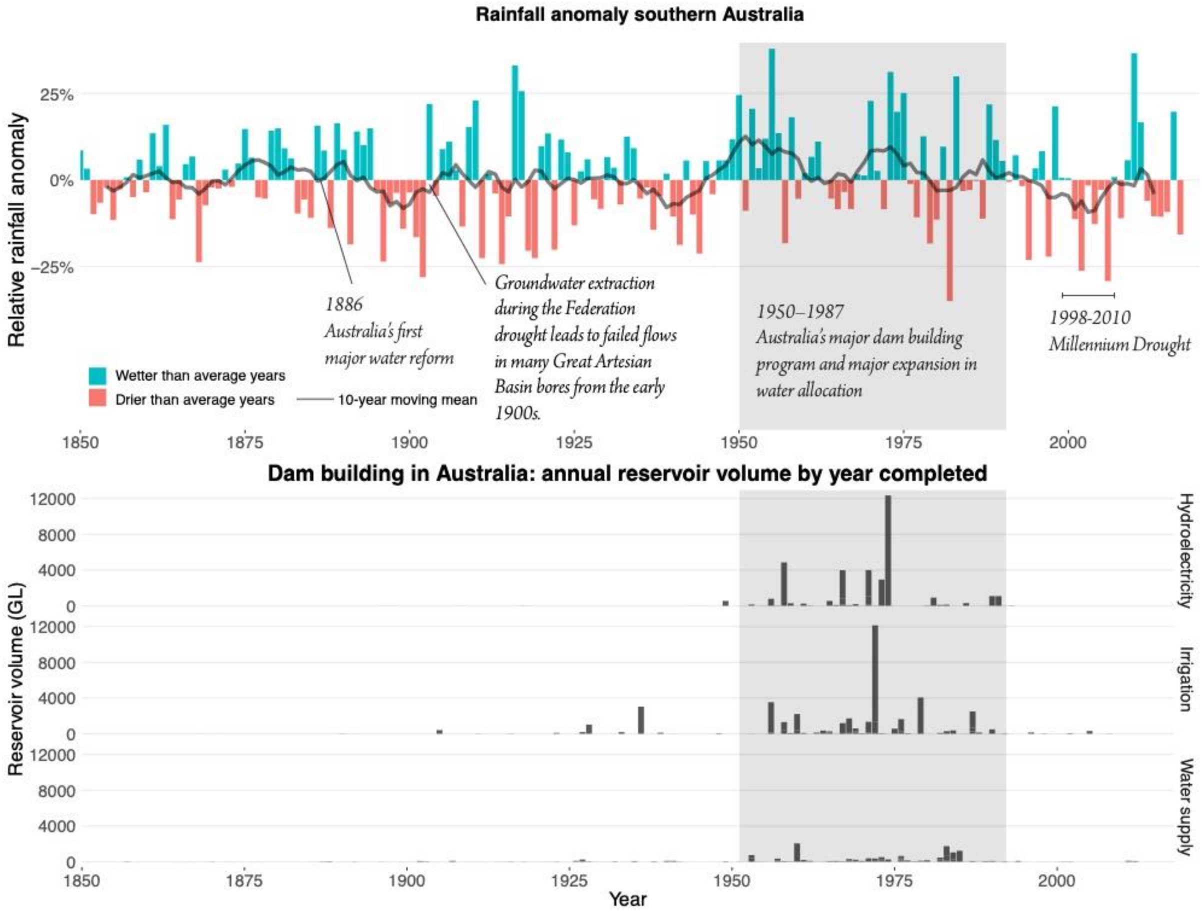

Figure 10: Dam building in Australia, note that the major period of dam construction coincides with an unusually wet period in the rainfall record. (created from data presented in [11]). The red bars show periods of lower than average rainfall, the light blue, periods of higher than average rainfall. The trend-line is a 10-year simple moving mean. Dams data only shows large dams (more than 15m in height or with a reservoir capacity greater than 1,000ML) from data in [146].

During this period the objective of water managers was, in the 1971 words of the NSW Water Conservation and Irrigation Commission, "maximum supplies with minimum waste". "Wasted" water included water running to the sea, into aquifers or across floodplain wetlands; infrastructure was designed to minimise "surplus flows" and "lost water" to creeks, streams, wetlands and floodplains.[12] Little regard was paid to the value of such water to the environment or to the ecological consequences of changes to flow regimes.[12]

Growth in extractions from groundwater systems paralleled the development of surface water infrastructure during the 20th century. The first bores to tap the Great Artesian Basin were sunk in the late 19th century in NSW and Queensland, with the water used primarily for stock watering. Rapid development of this resource led to drops in pressure and while most States vested control of ground water in the Crown. Decades of debate on how ground water should be managed continued through the 20th century and the integrated management of ground and surface water resources was a late development that still struggles with limited understanding of the connectivity between these two water sources. [2], [18], [28], [68] Water infrastructure investments increased short-term extractions from surface and groundwater systems, provided considerable storage during drier years and helped drive both agricultural and urban growth.[2] However as early as the 1960s, economists raised concerns that major state-funded irrigation infrastructure projects were uneconomic and the investment costs would never be recovered from the beneficiaries.[45], [69] Experience with larger dams also demonstrated that they could not "drought-proof" the country.

Extensive land clearing paralleled the development of water resources in all Australian States from the 1860s, with the highest clearance rates in catchments with soils most amenable to agricultural development.[70] Legislation passed in Australian States in the late-1800s penalised landholders for failing to "develop" their lands through clearing. Substantial land clearing occurred in NSW, Victoria and South Australia before the 1920s, with land clearing in south-western WA and Queensland accelerating between 1920s and the 1980s. Land clearing remains an issue, particularly in Queensland, but also in other states.[70]

Economic suspicions, emerging environmental values and the beginnings of water reform

Major water engineering projects from the mid-20th century combined with the growth of irrigated agriculture and widespread land clearing and other settler land management practices (e.g. draining wetlands, altering floodplains) led to serious environmental degradation of freshwater systems across much of the southern half of Australia.[12] By the 1970s, economic concern about the value of massive state investment in water management infrastructure was joined by growing concerns about its environmental impacts. [2], [41], [45]

By the 1980s, funding "nation-building" water infrastructure had left governments with debts as well as an ongoing legacy of maintenance and refurbishment expenses. It became increasingly clear to policy-makers: (a) that a narrow, engineering and supply-side focus would remain inadequate to meet water demands; and (b) that existing water rights systems were inadequate for Australia's variable climate because they provided entitlements that did not vary with water availability.[28], [67]

At the same time, public and policy-maker awareness of the serious environmental problems caused by Australia's approach to developing and using water resources was growing. Global concerns about an emerging ecological crisis[71]-[73] began to be reflected in Australian political discourse from the 1970s. Public outrage at the construction of the Gordon River Dam in Tasmania, which submerged Lake Pedder in an already gazetted national park, coalesced in the successful struggle over the Franklin Dam, which became a national election issue in 1983. [2] The struggle for the Franklin River grew into a broader community concern for the state of Australia's fresh water systems and the failure to account for the environmental damage of previous instrumentalist, "nation-building" investments. [74] The closing of the Murray River mouth in 1981—the first time since European settlement—with consequent ecological impacts in the Coorong became a potent symbol for the over-allocation of the Murray-Darling system. [75]

As a result of these concerns, the 1980s also saw the first "experimental" release of water for the Macquarie Marshes from the Burrendong Dam on the Macquarie River, [23] the creation of Greening Australia, the Commonwealth Government's creation of the Land and Water Resources Research and Development Corporation (LWRRDC) (Land & Water Australia (LWA) from 1990), and the launch of the Decade of Landcare in 1989 with the joint support of the Australian Conservation Foundation and the National Farmers' Federation. [14] By the 1990s, "sustainable development" had entered formal political discourse with the Council of Australian Governments (COAG) endorsing the *National Strategy for Ecologically Sustainable Development* in 1992. [76]

Working as a Federation—the COAG Water Reforms

Economic and environmental concerns about the management of Australia's fresh water systems coalesced in the Council of Australian Government's (COAG) 1994 *Water Reform Framework* and the inclusion of water reform in its 1995 National Competition Reforms. [67], [75], [77] Consistent with the broader national policy agenda, the framework required an end to cross-subsidies in the water sector, implementation of full-cost recovery and user-pays principles, consumption-based pricing, unbundling of land titles and water rights and the adoption of market-based water trading. Governments also committed to recognising the environment as a "legitimate user of water" and allocating enough water to the environment "to maintain the health and viability of river systems and groundwater basins". Environmental allocation decisions were to be based on the best available science. [28] However, First Peoples' interests in water continued to be ignored in national policy making for the next 10 years.[61]

COAG initially considered that a five-to-seven year period was required to implement these reforms. [78] States and Territories making acceptable progress would be eligible for special National Competition Policy payments.[28] At around the same time, the Murray-Darling basin states agreed to an interim cap for withdrawals from the basin in 1995. The cap was made permanent for New South Wales, Victoria and South Australia in 1997 and in the early 2000s for Queensland. [28], [67]

The Water Reform Framework was reviewed in 2004. Against a backdrop of slow implementation progress and the early years of the Millennium Drought (1997-2010), COAG recommitted to the 1994 agenda with a more ambitious National Water Initiative (NWI). The NWI extended the Framework with a focus on implementing "a nationally-compatible, market, regulatory and planning-based system of managing surface and ground water resources for rural and urban use that optimises economic, social and environmental outcomes". [79] The National Water Commission (NWC) was established as an independent statutory authority in 2004 to oversee the states' implementation of the NWI and drive the national water agenda.[80]

The NWI provided a reform agenda that required states and territories to implement policies including:

- *Reform of water access entitlement and environmental allocation systems*—water access entitlements should be separated from land and defined as tradable shares of a consumptive pool determined by a water plan, which should provide for management arrangements to deliver secure ecological outcomes; environmental water allocations should be given statutory recognition and over-allocations should be returned to "environmentally-sustainable levels of extraction"; water entitlement holders should bear the risks of reductions to the consumptive pool arising from climate changes.
- *Measures to facilitate efficient water markets*—states and territories should ensure compatible regulatory and institutional arrangements for water entitlements that maximise opportunities for trading in hydrologically connected systems and remove barriers to trade water out of irrigation areas. Markets for tradable salinity and pollution (e.g. nitrogen) credits should be explored to drive the efficient management of environmental externalities.
- *Water pricing reforms*—urban and rural water pricing should be based on full cost-recovery and user-pays principles with the costs of water planning and management as well as environmental externalities transparently recovered from users.
- Facilitating increases in water use efficiency and innovation in urban and rural water systems.
- *Effective water resource accounting including measurement, monitoring and reporting systems* able to accurately track water being traded, extracted for consumptive use and recovered and managed for environmental outcomes within and across jurisdictions. Accounting systems should be able to produce a national water balance for all significant water use in all managed systems, integrate accounting for ground and surface water use in linked systems, and account for the impacts of land use change and climate change on water balances. [79]
- *Initial, but very limited recognition of First Peoples' interests*: the NWI's reference to First Peoples' interests was "narrowly prescribed in an ahistorical and weak attempt to accommodate native title"[61]

The NWI provided a set of clear policy principles to improve water management in Australia. Its aspirational goals recognised that the major challenges were not managing variability and scarcity through the "drought-proofing", build-and-supply model of the mid-twentieth century. Instead, the NWI principles arise from an understanding that social and governance challenges are at the centre of water management and water policy requires legitimate institutional mechanisms to coordinate and resolve the competing demands of different water users and the environmental needs of freshwater systems. [81]

The NWI and work done by Australian states, territories and the Commonwealth under its influence gained considerable international acclaim as an example of policy innovation and leadership in water management.[75] Reforms introduced as a result of the NWI have ensured that urban and rural water are used more efficiently; prices paid by urban water users recover the costs of infrastructure; water authority finances have improved; more transparent institutional frameworks are now in place for water entitlements, planning, trading accounting and environmental water in most states and territories; water trading has driven water to higher value uses, improved the efficiency of use and given irrigators greater choice and flexibility; some issues with over-allocation of surface and groundwater have been resolved; and, volumes of environmental water have increased. [75], [76] It is likely that water trading ameliorated some of the worst impacts of the Millennium drought. [82], [83]

The NWI was not without flaws. Five areas for future development stand out:

- Although it agreed "Indigenous needs" should be recognised "where possible", the NWI's protection of the rights of existing entitlement holders and focus on separating water rights from land failed to guarantee First Peoples any substantive rights to water. [61], [63], [64], [84]
- The NWI was optimistic about implementing "environmentally-sustainable levels of extraction". However, the NWI's approach downplays the substantial scientific and political challenges to determining and then realising the required changes to water use and its objectives have not been fully realised in practice. [23], [85]-[87] The definitions of "key environmental assets, or ecosystem functions and the productive base of the resource" remain unclear and contested. As do the mechanisms for establishing which assets and functions are key and what it might mean to "compromise" them. [23] The focus on a "sustainable level of extraction" also obscured the other elements essential to providing water for ecosystem health beyond volume (e.g. timing, variability, duration, temperature) [23], [88]
- The NWI was also too optimistic about the potential for good policy principles to resolve the political conflicts likely to arise as a result of attempts to reduce extractions in over-allocated systems, even where entitlement holders would be fully compensated. The NWI did not focus enough on the importance of establishing the broad legitimacy of politically independent institutions tasked with understanding and resolving water management conflicts. [81]
- Although mentioned, the impacts of climate change on freshwater systems was not adequately dealt with in the NWI. In particular, the need to understand changing "environmentally-sustainable levels of extraction" in the context of a changing climate. [23]
- The NWI does not adequately reflect the importance of integrated land and water management for the long-term ecological health of freshwater systems.

Three years after COAG agreed to the NWI, the Commonwealth passed the *Water Act 2007*. Commonwealth entry into what is constitutionally a state matter was triggered by tardy NWI implementation, [89] the tenth year of the Millennium drought and indications of an environmental crisis in the Murray-Darling basin, particularly in its 16 Ramsar-listed wetlands.[77], [82], [90] Although it provided for a number of national water priorities, the *Water Act* had a specific focus on the Murray-Darling basin and established the Murray Darling Basin Authority (MDBA) and the Commonwealth Environmental Water Holder (CEWH). The Act captured many of the NWI principles, particularly those relating to environmental outcomes because the primacy of the environment under the Act was essential to the Commonwealth's constitutional assertion of power.[87], [91] The Act required the MDBA to produce a Basin Plan that would set limits on water extractions in the Basin via "long-term average sustainable diversion limits"(SDLs) and establish and manage environmental water flows "to protect, restore and provide for the ecological values and ecosystem services of the Murray-Darling Basin." [92] Further discussion on the challenges faced by MDBA in implementing NWI reforms in the Basin can be found in Box 2 below.

The return of the "hydro-illogical cycle"?

In the autumn of 2010, a wet La Niña weather pattern led to record-breaking rainfall in the Murray-Darling Basin accompanying above average falls across the rest of south-eastern Australia. Surface water storages filled, and NSW and Victoria received record spring rains and flooding. Heavy storms caused flooding across south-east Queensland in the summer of 2010-2011 and Brisbane's Wivenhoe Dam, which was almost empty by 2009 refilled quickly.[4] Western Australia received additional rain through 2011 and ecological pressures eased across many highly stressed Australian catchments.

Before the 1997-2010 Millennium drought broke, however, there had been a return to a focus on infrastructure building as the primary solution to rainfall variability. Billions of dollars of large-scale desalination plants were approved despite the potential for lower cost alternatives, modular builds on a smaller scale, or the value to be gained by delaying a build decision. NWI full-cost recovery principles have, however, ensured that urban communities will pay close to $4 billion in additional costs over a 20 year period in just Melbourne and Perth. [93], [94]

The breaking of the drought also eased many of the political pressures surrounding the implementation of water reforms that had built up during the in drought. On 24 November 2014, the National Water Commission was dissolved as there was "no longer adequate justification for a stand-alone agency to monitor Australia's progress on water reform". Many of the NWC's specialist roles were transferred to the generalist Productivity Commission. By 2015, research and development funding to drive improvements in Australia's water knowledge base and capacity building in institutions and communities, which were central to the NWI, dropped to its lowest levels in 20 years.

In 1990, the Drought Policy Review Task Force identified what it referred to as a "hydro-illogical cycle" in Australian water policy-making (**Figure 11,** p. 23). Over the last two decades, Australian water policy appears to have travelled from the "crisis" phase of the "hydro-illogical" cycle identified by during the Millennium drought, returned to the "apathy" stage after 2010 and is now in some parts of Australia is returning to "crisis". (***See*** *Governance Issues Paper*.)

In 2017, major water entitlement compliance problems including water theft in the northern Murray-Darling Basin were revealed by investigative journalists rather than by the institutions tasked with overseeing water use and water markets. [95], [96] The Productivity Commission's 2017 review of the national water reform process warned of "backsliding" and the "erosion of hard-won reforms". [97]

Box 2: The Murray-Darling Basin Plan—a "testbed" for the implementation of water reform in a contested, highly-allocated system

With the Water Act's Murray-Darling Basin focus and the MDBA's work on implementing the NWI, the Murray-Darling Basin could be seen as a "testbed" for Australia's water reform process. The Act required the MDBA to prepare a plan for the long-term management of the Basin, which would itself become law in 2012. However, when the MDBA published its *Guide to the Proposed Basin Plan* in 2010 it became clear that the process of reconciling an "environmentally sustainable level of take" (ESLT)—a level of water extraction that, if exceeded, would compromise ecosystem functions, environmental assets or environmental objectives[92]—with the objective to "optimise economic, social and environmental outcomes" would be both politically contentious and highlight the very real challenges in turning the policy prescriptions of the NWI into effective, publicly-legitimate, long-term water management practice.[87] This tension remains unresolved and is central to the South Australian Royal Commission into the Murray-Darling Basin ongoing in 2018. [99]

The MDBA's *Guide to the Proposed Basin Plan* identified a range of possible total Basin surface water diversion reductions based on hydrologic modelling and estimations of environmental water requirements. The MDBA's best estimates were that environmental requirements could be met with a high level of uncertainty (i.e. high risk) with a 3,856 GL/year (+/- 20%) Basin-wide reduction in diversions; environmental requirements could be met with a low level of uncertainty (i.e. low risk) with a 6,983 GL/year (+/- 10%) Basin-wide reduction in diversions. [100] MDBA rejected any attempt to meet the environmental objectives of the Water Act with a high level of certainty because this "would not optimise economic, social and environmental outcomes" and determined that reductions in diversions should not be greater than 4,000 GL/year. [100] However, no formal social-economic-environmental modelling was done to identify why meeting objectives with a high level of certainty was not optimal.

The proposal that the Basin Plan include reductions in diversions of somewhere between 3,000–4,000 GL/year caused considerable controversy. Many scientists and environmentalists judged the resulting environmental water allocation to be insufficient, [101] while many irrigators and Basin communities relying on irrigated agriculture judged them too onerous—even though the chief mechanism for achieving the diversion reductions was meant to be water entitlement buybacks from willing sellers. [82], [87] One of the major concerns of irrigation communities was that buybacks would have negative flow-on effects to regional communities leading to a negative spiral of job-loss, population reductions and accompanying loss of community services. [82], [87] The Murray-Darling Basin contains a highly diverse range of agricultural production types, farm sizes and communities and the impacts of buy backs have varied widely across the Basin over the last decade. The full impact of buy backs continues to be debated, with many economists suggesting that while there have been both benefits and costs from the buy backs, the negative impacts are unlikely to have justified the legislative cap imposed in 2015 (see below) and that buy backs are a far more cost-effective approach to recovering water for the environment (see ***Economics Issues Paper***). [87], [102], [103] Recent reviews of the evidence on buy-back impacts by the Murray-Darling Basin Authority has found that "while agricultural output and employment may decline from water recovery, unemployment in total declined and mean household incomes rose because of outmigration of people from the basin to be employed in expanding non-agricultural sectors of a diversified economy."[147]

The Commonwealth response to the controversy was to return to a focus on public investment in irrigation infrastructure in the Basin, this time with the objective of driving "irrigation efficiencies". [82], [87], [90] Alongside the *Water Act*, the Commonwealth made around $13 billion available in its Water for the Future (WFF) Program begun in 2008. Almost half the WFF funding ($5.8Bb) was provided for water infrastructure subsidies to provide grants for irrigation water efficiency projects, while less than a quarter ($3.1b) was made available to purchase water entitlements for the environment from voluntary sales from entitlement owners. [82]

At the same time, evidence given at the South Australian Royal Commission suggests that considerable government pressure may have been exerted on MDBA officials to ensure that the quantum of reductions in the final Basin Plan was lower than that proposed in the Guide. [104]-[106] When the Basin Plan became law the average, Basin-wide diversion reduction had been lowered to 2,750GL/year and this level did not need to be achieved until 2019. [107] A further 450GL/year was to be made available to the environment by 2024 through additional irrigation expenditure of $1.77 billion bringing total water for the environment to 3200 GL/year by 2024. These levels have been reduced by legislation implementing the Northern Basin Review and the SDL Adjustment Supply Measures. Irrigator and regional community concerns about the volume of water buybacks were addressed by a 2015 legislative cap on buybacks of 1,500 GL. [82]

The current Basin Plan, the focus on irrigation efficiencies and the legislative cap on buybacks have all attracted criticism. [67], [77], [82], [88], [103], [108], [109] Agreeing to the NWI has not reduced the lure for governments of spending on infrastructure to demonstrate a commitment to action during a drought. It is not clear that the environmental water benefits claimed for irrigation efficiencies will be realised and considerable controversy surrounds measurement of these benefits, particularly when their impact on return flows is concerned. [82], [110]-[113] However, it is clear that any environmental benefits from irrigation efficiencies are more expensive than those purchased through water buybacks, that the Water for the Future "water saving" infrastructure investments have not conformed to the NWI principles of user-pays and full-cost recovery and that the benefits of this expenditure were actively sought and largely captured by irrigators, perhaps to an average of $750,000 per irrigator. [67], [87], [110]

The 2018 draft Productivity Commission review of the Basin Plan identifies "major shortcomings in current institutional and governance arrangements [which] pose a significant risk to successful implementation." The Commission identified "major challenges and risks" to delivering SDLs on time.

Four issues relevant to the future management of freshwater systems in Australia are visible in the development and finalisation of the Basin Plan:

- Limiting extractions and setting "environmentally sustainable levels of take" in over-allocated systems is extremely difficult and subject to considerable political pressure from interest groups.
- While high quality scientific and technical input is important, managing water is primarily a social and governance process that involves reconciling the conflicting values and water demands of different interest groups with the ecological requirements of the freshwater system. Under current management frameworks, the ecological requirements of the system are unlikely to be met in any attempt to "optimise" environmental, social and economic outcomes.
- Under the stress of droughts governments are likely to bow to interest group pressure and prioritise infrastructure spending over resolving thorny issues. There is a need for water governance to be more independent from the government of the day.
- Water markets are institutions and will only deliver improved environmental outcomes and water security if their constraints (e.g. SDLs) are well-matched to underlying hydrology and ecology of the freshwater systems in which they operate. Compliance, monitory and enforcement play an essential role in maintaining market integrity and the reliability of outcomes. [111]

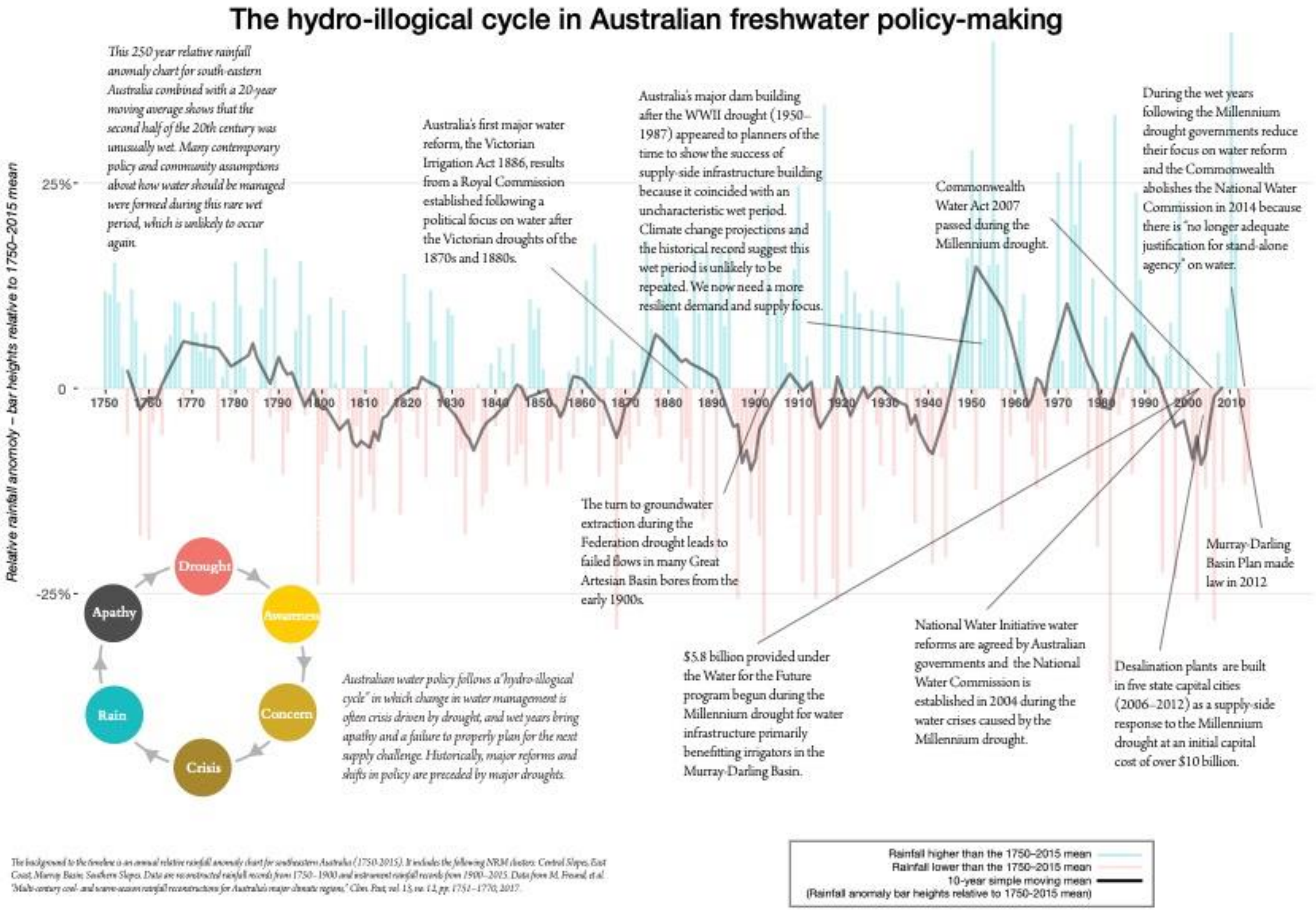

Figure 11: The hydro-illogical cycle in Australian freshwater policy-making [2], [82], [98]

Future challenges for freshwater management in Australia

Managing freshwater systems in Australia has presented major challenges since European settlement. Responding to these challenges has led to considerable changes in water policy over the last 130 years. Water policy across Australia is now more attuned to the unique hydrology of Australia's freshwater systems than it has been in the past. In particular, the water policy reforms instituted since 1994 have made considerable advances. However, as outlined above, there remain significant opportunities for further development. The Productivity Commission's recent inquiry into national water reform and its five-year assessment of the Murray-Darling Basin Plan both confirm that further improvement to Australia's water resource policy, planning and management is required. [97], [112] Ongoing reform of water policy will be important to maintaining the long-term sustainability of Australia's use of its freshwater systems—despite the value of Australia's considerable water reforms to date, a "set and forget" approach is not workable for water policy.

Enthusiasm for the development of irrigated agriculture in northern Australia to "unlock the north's vast potential" is a particular concern. The Australian Government's 2015 White Paper, *Our North, Our Future*,[140] suggests a worrying return to the policy of large capital investments in water storage in the second half of the 20th century. The focus on large-scale expansion of irrigated agriculture in the north appears to disregard the ongoing failure of the Ord River scheme—the Western Australian Auditor General's review of the 2010 second stage points to the extent to which this investment has "fallen short of targets".[141] Even the recent CSIRO assessment of the Fitzroy region states that "farm revenue from broadacre agriculture is unlikely to cover the cost of infrastructure for an irrigation scheme under current farming systems."[142][143]

Australian freshwater systems and their users face challenges from multiple pressures that will severely test existing water policy frameworks and any future northern development. Two of these pressures—climate change and population growth—will further highlight the need to resolve Australia's primary and long-standing coordination challenges—determining and instituting robust principles for allocating finite and diminishing water. These challenges are outlined below.

Pressure challenge 1—Climate change

Australia is already experiencing the effects of climate change. [113], [114] Australia's climate has warmed by an average of 1.0°C since 1910, with warming accelerating since 1950. The years 2013–2015 are three of the five warmest years on record. Heatwaves have increased in duration, frequency and intensity across much of Australia since 1950 and this has been paralleled by a longer fire season and an increase in extreme fire weather since 1970. Rainfall patterns have varied across the continent, but there have been declines in autumn and winter rainfall in the south-east since 1990 and in the winter in the south-west. [114]

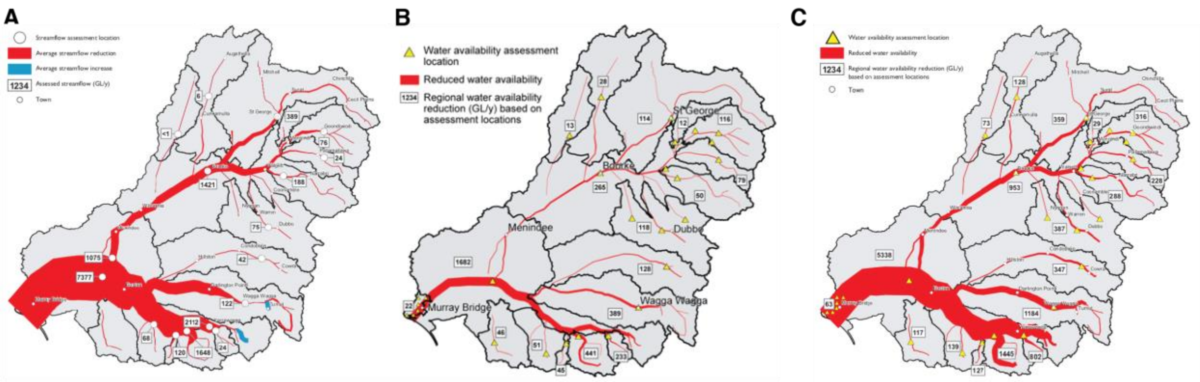

Figure 12: Climate change impacts on surface water availability in the Murray-Darling Basin. Map A shows changes in average annual streamflow as a result of current water resource development (red lines show streamflow reductions, blue lines increases), this change represents approximately half of all average streamflow; Map B shows reductions in surface water availability under a median 2030 climate; Map C shows reductions in surface water availability under a dry extreme 2030 climate. Maps from CSIRO [150].

Climate change projections suggest with very high confidence that average temperatures will continue to increase in all seasons across the whole continent along with more hot days and an increased intensity of extreme rainfall events. Sea levels are projected to rise around Australia's coasts and the heights of extreme sea-level events will also increase. Australia's high-use water catchments in the south-east and the south-west are likely to experience total annual rainfall declines and reductions in average annual streamflow. The Australian Academy of Science's review of the 2019 fish kill event at Menindee stated that "the root cause of the fish kills is that there is not enough water in the Darling system to avoid catastrophic decline of condition through dry periods". [151] As Figure 12 shows, even the median 2030 climate is projected to see a decrease in streamflow in the Murray-Darling Basin equivalent to almost one-quarter of the current changes in streamflow resulting from water resources development. Projections for an extreme-dry 2030 climate show decreases in streamflow of almost three-quarters of current reductions. Climate change projections also show greater bushfire risk, with the south-west also likely to experience more time in drought. Experiments in south-eastern Australian catchments show that bushfires can reduce runoff from catchments for at least 50 to 80 years after a fire. [115] In Australia's north, while rainfall intensity is very likely to increase, other changes to rainfall patterns remain unclear. [114]

The likelihood of lower rainfall in catchments already stressed by existing demands on limited water resources along with increased temperatures (and associated increases in evapotranspiration) will present significant challenges for water resource managers seeking to balance the competing demands of human consumptive use and the environment. [111] Lower rainfall has a nonlinear relationship with runoff with relatively small reductions in rainfall leading to substantially higher reductions in runoff, particularly in drier catchments.[145] [116] Lower rainfall may also increase pressure on groundwater resources. Increased bushfire occurrence and intensity along with climate change induced vegetation changes will alter runoff, streamflows and water quality with impacts for urban and rural water systems. [117] Increases in the intensity of extreme rainfall events will increase pressures on urban and rural water infrastructure, increase the challenges for urban storm water management and the impacts of over-bank flows in rural and urban areas. Sea-level rise increases risks for coastal water infrastructure, particularly in urban areas. Rising seas may also inundate coastal groundwater resources. Increased scarcity will increase conflict and tension surrounding decision-making over competing water uses putting pressure on existing decision-making processes and institutions.

Some future climate change impacts can be forecast with confidence (e.g. temperature increases), particularly where past greenhouse gas emissions have "locked-in" a level of change. Other climate impacts, however, remain subject to considerable uncertainty. More uncertain impacts include those which can still be influenced by global decisions on reducing greenhouse gases. Other uncertainties arise from the difficulties in "down-scaling" climate models to smaller regional areas. Still others arise from the difficulties in separating the anthropogenic climate change signal from existing climate variability. [118] At a basin or catchment scale, forecasts of changes to Australia's extremely variable rainfall and runoff patterns remains subject to considerable uncertainty. As the CSIRO and the Bureau of Meteorology make clear, "on an annual and decadal basis, natural variability in the climate system can act to either mask or enhance any long-term human induced trend, particularly in the next 20 years and for rainfall." [114] This uncertainty creates significant challenges for water policy-makers, planners and managers.

A particular challenge is the potential for climate change to magnify or alter existing patterns of variability—climate change researchers suggest that future climate change may not be experienced as gradual changes to temperature or rainfall patterns, but may rather occur as "step changes" or "regime shifts".[113], [118] This has already been observed in south-western Australia. The relationship between such changes and existing drivers of climate variation in Australia including the El Niño-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) is not well understood. [10], [119] However, as the long-term, palaeoclimatic records make clear major decadal shifts in Australia's rainfall patterns are not unusual (see Figure 2) and previous patterns of variation may be being altered by climate change-for example towards "longer and stronger El Niño events".[119] [120] Much water resources and environmental water management planning still relies on assumptions of a stationary climate for statistical analysis of historical flow regimes. [121], [122] Climate change is likely to cause future flow regimes to differ from the historical record adding an additional layer of uncertainty on Australia's already variable climate complicating planning and management cycles. [123]

Pressure challenge 2—Population growth

Population growth is a significant source of uncertainty for urban water managers. Australia is expected to remain a highly urbanised population and the majority of the projected growth will occur in major cities. [124] Australia's population is projected to grow to between 36.8 and 48.3 million by 2061 and 42.4 and 70.1 million by 2101. These ranges are broad and uncertain as population growth in Australia is tightly coupled to government policy because a major source of growth is net overseas migration. [124]

Uncertainties surrounding population growth combine with climate change pressures to present significant challenges for long-term investment planning for urban water managers. For example,

- lower rainfall in many high-use catchments that support urban water supplies along with increased demand pressures from a growing population requires urban water managers to diversify their water sources, increase water use efficiencies and reduce waste[111], [117]
- extreme rainfall events can add to population pressures on waste-water treatment plant capacity[111]
- urban expansion in coastal areas puts local water reticulation and drainage assets at risk from sea-level rise.

Evidence about the pressures an increasing population may exert on agricultural production and agricultural water needs is mixed. Some commentators suggest that a growing population's increased demands for food and fibre production in a drying climate may increase agricultural production for local markets putting pressure on agricultural water supplies. [117] While others suggest this is unlikely because most of the food and fibre produced in Australia's major agricultural areas is for export (e.g. 70% in the Murray-Darling Basin) and population growth at the levels projected is unlikely to increase the pressures already exerted by world markets. [87]. Analysis of agricultural production in the Murray-Darling Basin during the Millennium drought suggests that reductions in water supply have much smaller impacts on the average gross value of agricultural production. [102]

Coordination challenges—Institutions, principles and tools for allocating finite and diminishing water resources

Much of Australia's water policy over the last 130 years has aimed to provide security to water users and coordinate the use of a limited resource in the context of Australia's highly variable rainfall and runoff. Deakin's constraints of riparian rights, government attempts to "drought-proof" the continent with infrastructure, and the development of water markets all shared this aim—although the solutions they offered to achieve it were radically different. Each solution, however, has privileged agricultural and urban users over others. Although there have been improvements, Australia's First Peoples, the environment, and Australia's future citizens have not yet been as well-served by Australia's water policy.

Climate change will increase pressures on Australia's water resources, particularly in high-use catchments. This pressure is likely to increase conflicts over water use and demand trade-offs be made between alternative uses and value systems. The history of such decision-making in Australia suggests that we still lack a broadly legitimate, robust and transparent approach to inform how trade-offs are to be made and to equitably balance competing interests. Australia's future water allocation decisions require:

- *Effective principles for ensuring water planning processes are robust in the face of future uncertainty*—no Australian jurisdiction has successfully incorporated the likely range of climate change impacts into decisions around water diversions[111] and current hydro-economic modelling used to inform water planning and policy decisions does not yet incorporate best-practice approaches to dealing with uncertainties. [125] Deterministic approaches relying on simplifying assumptions like stationarity dominate Australian water planning. [123] Future pressures on Australian water resources require the use of adaptive management approaches and modelling and decision making tools that explicitly acknowledge and incorporate uncertainty. [126] [127], [128] A broader range of values needs to be included in water management decisions including economic, sociocultural, First Peoples', and ecological. The uncertainties associated with determining these values need to be transparently incorporated into decisions along with a clear articulation of the trade-offs.[139] Managing uncertainties will be particularly important with regard to decisions with long-term implications for

Australia's groundwater resources. Not enough is known about these resources and their connectivity with surface water systems. Yet it is likely that decisions will need to be made about the use of these resources or about other activities that may have negative impacts on them (e.g. unconventional gas extraction) before existing uncertainties are resolved. The speed of current environmental and demographic change may also require reconsideration of water planning horizons.

- *Environmental water decisions that manage for resilience*—much of the debate around environmental water in Australia has focussed on the quantity of water available to the environment and the impact of water flows on identified habitat reserves and threatened species. [23] However, there is no linear relationship between volumes of environmental water and ecosystem benefits and the long-term impacts of human activities have led to many of Australia's high-use catchments already being significantly altered from their "natural" state. [88] Aquatic ecosystems in these catchments are unlikely to ever be returned to an historical reference condition. Instead they are likely to require ongoing, active management to maintain and improve their resilience in the face of future climate change and human pressures.[137][138] This requires a focus on system-wide properties rather than individual species or habitats. [122] It will also require a focus on a wider set of challenges than levels of water extraction and environmental water provision. For example, improving the condition of riparian zones is another long-term challenge. Aquatic ecosystems in undeveloped catchments are likely to remain more resilient to climate change pressures than those in developed and highly-allocated catchments because undeveloped catchments are likely to retain more of their capacity to respond to change arising from temperature, rainfall and runoff variability. However, many freshwater species have low tolerances for temperature and hydrological changes, making aquatic ecosystems highly vulnerable to climate changes that occur more rapidly than can be adapted to by evolutionary processes. [129] We are likely to be faced with difficult social choices in some catchments where climate change is likely to cause substantial changes to ecosystem function and any future balance between extractive use and environmental values will be very difficult to maintain. Maintaining this existing resilience should be an important criterion for decision-makers considering expansion of human activities in relatively undisturbed catchments like those found in Australia's north. A resilience focus also allows water planning processes to adapt as aquatic systems and our knowledge of them changes. [123], [130]
- *Institutional capacity and legitimacy in water policy development and management*—As the Productivity Commission makes clear in its recent reports, "water reform requires perseverance, continuity and long-term commitment from governments". [97] Institutions capable of developing and implementing long-term plans independent of shorter-term political cycles are an essential component of any commitment to achieving stable, long-term policy goals. For example, operational independence has characterised the success of the modern reserve bank system in maintaining price stability. [131] Given the likely pressures on water decision-making in Australia, water management institutions need the independence to resist the crisis-driven planning of the hydro-illogical cycle. Water policy decisions requires long-term engagement from communities and interests affected by water management decisions and the cultivation of a broader, shared commitment to equity between users and the common good. [132], [133] It is critical that future water management decisions include a strong focus on delivering First Peoples' water rights and creating processes to include First Peoples in water planning and management processes. This requires more than top-down processes of community and stakeholder "consultation", which need to be replaced by opportunities for First Peoples to have direct, ongoing participation in decision-making (see **First Peoples' Water Rights issues paper)**. There is a long-standing tension in Australian water policy between centralised decision-making and broader subsidiarity that exists alongside tensions between the states and the Commonwealth. A balance will have to be struck if water policy institutions are to retain their legitimacy.
- *A broader suite of policy and management tools that integrate with existing markets*—water markets have added an important dimension to Australian water management and they have been successful in providing entitlement holders with flexibility in decision-making during droughts and driving water to higher-value uses. [82] "Marketcraft" will remain an important component in long-term water policy. [134] However, additional approaches to managing resources through local coordination and self-organisation should be explored. In some cases, these may be better suited to conditions of high uncertainty or significant pressure on scarce resources or where considerations of equity and institutional legitimacy are paramount. [135], [136],[144]

Glossary

Adaptive management	An iterative process of learning from experience and using new information to improve environmental management.
Drainage Division	Representation of the catchments of major surface water drainage systems, generally comprising a number of river basins.
Environmental flow	A flow regime applied to a river, wetland or floodplain to improve or maintain environmental outcomes (and other public benefit outcomes, where possible).
Environmental water	The water provided to achieve environmental outcomes (and other public benefit outcomes, where possible), which may derive from surface water or groundwater and be provided as planned environmental water or held environmental water.
Evapotranspiration	The sum of evaporation and plant transpiration from the earth's land surface to the atmosphere.
Freshwater system	A system that is hydrologically connected and described at the level desired for management purposes, such as a catchment, basin or aquifer, or sub-components of these.
Gigalitre (GL)	One billion (1 000 000 000) litres.
Groundwater	Water located underground in permeable soil or rock. It includes both naturally occurring water and water pumped underground for storage. However, it does not include water held in underground tanks, pipes or other works.
Groundwater province	A groundwater province is a major area having a broad uniformity of hydrogeological and geological conditions, with reasonably uniform water-bearing characteristics, and identified as either predominantly sediment or fractured rock.
Megalitre	One million (1 000 000) litres.
Overallocation	Where the total volume of water able to be extracted by entitlement holders at a given time exceeds the environmentally sustainable level of extraction for that system.
Riparian	Relating to wetlands adjacent to rivers and streams or relating to or situated on the banks of a river
Surface water	Water that flows over or collects on land and in natural or artificial waterways.
Water accounting	Identifying, recognising, quantifying, reporting and assuring information about water, the rights or other claims to that water and the obligations against that water.
Water allocation	The specific volume of water allocated to water access entitlements in a given season, defined according to rules established in the relevant water plan.
Water entitlement	A perpetual or ongoing entitlement to exclusive access to a share of water from a specified consumptive pool as defined in the relevant water plan (properly a 'water access entitlement')

Definitions from the Productivity Commission and the Bureau of Meteorology.

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