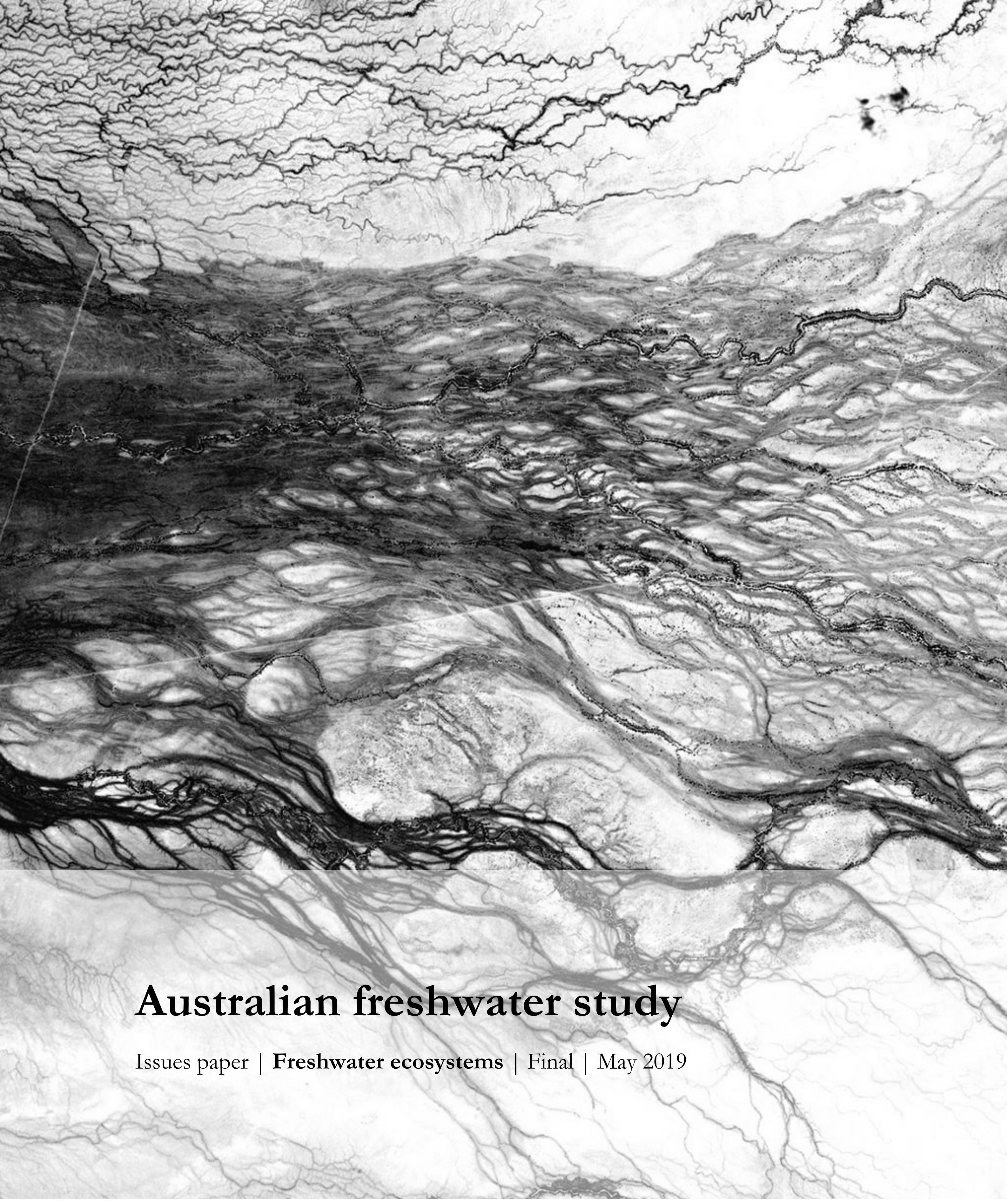

Australian freshwater study

Issues paper | **Freshwater ecosystems** | Final | May 2019

The Ian Potter Foundation

The Myer Foundation

Point. Advisory

alluvium

Outline

This paper considers the impact of human endeavour and water use on freshwater ecosystems in Australia, highlighting regions and issues of importance across Australia’s 13 drainage divisions. Views on why we should care about these issues and what might be done to address them are also outlined in the paper.

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.

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Image credit: Scott Kelly/NASA, taken 12 October 2015, photo of Australia taken from the International Space Station "#EarthArt A single pass over the #Australian continent. Picture 11 of 17. #YearInSpace". posted to Twitter <https://twitter.com/StationCDRKelly>, accessed via <https://www.flickr.com/photos/nasa2explore/22231721261/in/album-72157659515819800/>

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.

Context

The rivers of Australia have naturally irregular flow regimes with long periods of drought punctuated with substantial floods. Native flora and fauna have adapted to these variable flows over thousands of years. Periods of low and high flow support a rich diversity of organisms and habitats and have important ecological functions.

Freshwater ecosystems are some of the most important resources in the replenishment and purification of water resources needed by all biota, including humans. Unfortunately, the health and sustainability of a large proportion of these ecosystems is being negatively affected by human use and land development. Land clearing and erosion, creation of water-diversion systems, increased use of groundwater, industrial and household waste water contamination, and the eradication of wetlands and marsh areas all pose a threat to these ecosystems that help to provide us with fresh water.

Managing freshwater ecosystems presents different challenges to those faced by land-based natural resources managers. The differences are well detailed in the *Guidelines for Applying Protected Area Management Categories* [1] and can be summarised as follows:

Flow regimes:	Water is critical for maintaining freshwater biodiversity, including the volume, timing, frequency and quality of surface water flows as well as surface water–groundwater dynamics.
Longitudinal and lateral connectivity:	Protecting water flows along rivers and from channels onto floodplains is essential. This involves preventing or removing artificial physical and chemical barriers and providing bypass facilities for aquatic wildlife.
Groundwater–surface water interactions:	Protection of groundwater flows is needed since most surface waters depend to some extent or at some times on aquifers (the water table) and groundwater systems rely on surface waters for recharge.
Relationship to the broader landscape:	Wetland systems in a protected area cannot usually be "fenced off" from impacts arising in the wider terrestrial landscape of their catchments and will normally require integrated threat management at the catchment scale.
Multiple management authorities:	Different government agencies usually have overlapping and often conflicting responsibilities concerning freshwater management, including mismatches between administrative and catchment boundaries. Conservation is complicated by the need to coordinate management activities among government agencies with diverse mandates (*see also* ***Governance Issues Paper***).

Issues identified

The following issues have been identified for consideration to improve the sustainable management of freshwater ecosystems in Australia:

1. Catchment management: Catchment modification has dehydrated freshwater ecosystems and reduced resilience
2. Stream flow management: Over-allocation of water resources and the regulation of rivers fundamentally changes the water regimes which support freshwater ecosystems
3. Waterway management: Altered habitats and infrastructure barriers are reducing ecological connectivity up and down rivers

4. Weed and pest management: Invasive weeds and pests have become established in and continue to colonise our freshwater ecosystems leading to loss, or threat of loss, of native species
5. Climate change adaption and management: Planning and enforcement is inadequate for a changing climate that magnifies pressures on freshwater ecosystems

These issues are outlined in further detail in this paper.

Key issues

1 Catchment management: Catchment modification has dehydrated freshwater ecosystems and reduced resilience

The changes made to our catchments – clearing, draining, compacting – have dehydrated freshwater ecosystems. Continuing degradation has affected the resilience of catchments with sometimes devastating consequences on agricultural landscapes, biodiversity, water and soil quality.

Prior to European settlement, south east Australia's upland catchments were characterised by small streams and wetlands with flood waters regularly inundating their adjoining floodplains. These pre-European stream systems have been fundamentally changed as a result of the clearing and drainage of landscapes over the past 200 years. As the population grew, clearing and drainage was primarily undertaken to allow for human settlement and to increase landscape productivity for agriculture. However, this has resulted in the gullying of these stream systems, which has subsequently caused a disconnection between stream flow and floodplain inundation and the dehydration of catchments. [2] [3]

River and stream instability (erosion) issues are present across the urban, agricultural and mining landscapes of Australia including, the unconfined and partly confined alluvial stream systems of the Great Barrier Reef, the upper catchments of the Murray-Darling Basin, Tasmania, and the coastal catchments of Victoria, NSW and southeast Queensland. [4] Gully erosion is a major source of sediment during high-rainfall events. Erosion from stream and gully banks can generate up to 90 percent of the total sediment yield from a catchment. [5]

Financial constraints have slowly eroded opportunities for land custodians to manage land degradation. Many hard lessons have been learnt about the limitations of Australian soils and significant degradation of soils has occurred over the last two centuries. [6] However, outside highly productive agricultural land, there is little incentive for individuals to maintain the long-term health of environmental resources such as soils. There is even less incentive to maintain water quality and the health of freshwater ecosystems and biodiversity.

The challenge for policymakers in Australia lies in establishing an appropriate balance between protection of natural resources and the maintenance of viable agricultural industries. Historically, natural resource management policy has tended to preserve individual property rights, achieved to a varying extent through diverse and often competing policy approaches, and coupled with a coordinating (arm's length) role for government. However, the underlying assumption – that well-informed land managers will deliver favourable environmental outcomes – belies the pressure on land managers to innovate and intensify production in the face of declining terms of trade and the deregulation of marketing arrangements for agricultural commodities. [7]

Landscape rehydration is a key priority in agricultural areas around Australia. Dehydrated landscapes have resulted in reductions in biodiversity, soil erosion and compaction, reductions in water and soil quality and quantity, decreased resilience of landscapes in the face of climatic change, reductions in the productivity of agricultural landscapes, reduced drought resilience and increased susceptibility to risk of more intense, more frequent fires, reductions in natural fertility and diminishing resistance to weed invasion. [8] [9]

Continuing degradation of streams and riparian and adjacent floodplains, as well as land clearing and hillslope erosion, farm dams and reduced flooding, has affected the resilience of catchments with sometimes devastating consequences on agricultural landscapes, biodiversity, water and soil quality.

Planning and management at inappropriate scales (too small, too short-term) has failed to address systems holistically, with proper attention to catchment connectivity and the influence of upstream actions on downstream resources. This has often resulted in elevated levels of salinity, nutrients, metals, pathogens, and organic contaminants (e.g. pesticides). These pollutants can be derived from a wide range of sources including industry and urban areas as well as agricultural landscapes [10].

What can be done

An opportunity exists to stabilise and reconnect stream systems to their floodplains as a part of current and future stream rehabilitation programs. In urban areas, this can mean increasing connection of stormwater with groundwater to protect water quality. Such programs have the potential to significantly increase the resilience of these landscapes and associated communities to the adverse aspects of climate change, such as increasingly intense rainfall and flood events and more frequent and extended dry periods. A holistic approach, integrating biophysical and ecological factors with the social factors influencing rural communities and the economic returns of landholders and society, can potentially produce the necessary large-scale landscape change required.

In Australia, there has traditionally been a prescriptive regulatory approach to the protection of shared natural resources, sometimes described as "command and control". [11] More recent policy initiatives conceptualise and respond to environmental degradation as a form of market failure. Market-based mechanisms have emerged over the past 20 years as an alternative, harnessing the profit-motive to improve ecological outcomes. [11]

Some progress is being made in landscape re-hydration in Australia. Initiatives such the ANU Sustainable Farms Project and types of natural sequence farming that promote native species, integrate environmental, economic and health outcomes and actively regenerate landscapes. The Jeffery report [12] recommends combined soil and water conservation management. Aligning public policies and programs and private investment is needed to maximise landscape-scale change. [13] This is because many recommended landscape conservation practices, such as fencing remnant vegetation and riparian zones, are beyond the financial capabilities of many typical farms. [14] The Commonwealth government, in partnership with the states and territories, has moved towards a business approach for investing in NRM, using market-based instruments (MBIs) and stewardship payments to landholders to incentivise delivery of favourable environmental outcomes. [7] However, protecting water quality needs both enabling and incentive instruments and restrictive instruments.

There is opportunity to invest further in market mechanisms in Australia to improve the state of freshwater resources and associated ecosystems. A study simulating a nitrogen cap-and-trade scheme in the Tully catchment in the Wet Tropics found that nitrogen trading is a cost-effective method to reduce the load of dissolved inorganic nitrogen and improve water-quality. [15] An annual nitrogen load limit is set for each river catchment and permits are allocated and traded for the application of fertiliser. It is expected that farmers on good soil would buy permits to increase profitability of production and farms with poor soil will convert their farming area into wetlands for a greater profit than sugarcane production, leading to ecosystem health improvement. [15] There is also a salinity trading scheme in the Hunter River Basin in NSW. [16] In the Delaware River catchment in north-east USA, farmers in the upstream catchment are being paid to switch from agricultural use to managing native bushland to secure high-quality run-off for New York City's water supply, in order to avoid the much more expensive option of a water filtration plant at the downstream end of the system.

Philanthropic organisations could assist in supporting pilots or trials of these land management practices and incentive schemes to bring further supporting evidence and make the case to governments to implement the schemes more broadly. Related approaches could involve strategically purchasing land and engaging in rehabilitation activities directly and/or establishing or supporting environmental trusts (water, wildlife, conservation or restoration) or investing in the in the development of innovations such as virtual fencing.

2 Flow management: Over-allocation of water resources and the regulation of rivers fundamentally changes the water regimes that support freshwater ecosystems

The historical over-allocation of water resources and regulation of rivers, particularly in the east and south east of Australia, has fundamentally changed the condition of many freshwater ecosystems. Connectivity between our surface water and groundwater resources means that the impacts of these issues are felt beyond the boundaries of human development or areas of extraction.

Over the past century, there has been an allocation of water to consumptive human uses which exceeds that required to maintain healthy aquatic ecosystems in the Murray-Darling Basin. [17] Water extraction from many other major rivers and aquifers along the north, east and southwest coasts of Australia are significant and there have been concerns these systems are also over-allocated. [18] [19] [20] In the Murray-Darling Basin in particular, trade-offs have been established in surface water stream systems to enable ongoing consumptive use with some level of degraded, but functioning instream aquatic and riparian ecosystems. However, elements of water use and management continue to impact aquatic and riparian ecosystem health. These include:

1. Groundwater extractions from systems with groundwater / surface water connections (e.g., shallow aquifers in connected alluvial / gravel bed systems)

2. River regulation, including the use of river systems to supply consumptive water, which can result in undesirable water quality (e.g., saline or cold-water pollution), over-supply of water (e.g., drowning of platypus burrows) and significant changes in flow regimes (the seasonal timing of when water is available, particularly to wetlands and floodplains)

3. Continued over-extraction of water from some surface water systems, and

4. Exacerbation of impacts from saline intrusion into floodplains and watercourses.

In their natural state, surface and groundwater sources may be connected or unconnected, or have variable connectivity over time and space. In most cases, surface water is connected to groundwater and vice versa, although the degree of interaction and the spatial and temporal impacts of the interaction vary widely. The development or contamination of one connected resource usually affects the other. [21] [22] [23] [24] Pumping too much groundwater reduces river flows, and excessive diversion of rivers reduces groundwater recharge.

The interactions between surface water and groundwater influence not only streamflow and recharge, but also water quality, riparian zone character and composition, and ecosystem structure and function. [25] [26] Surface to groundwater interactions can also affect energy use and greenhouse gas emissions. For example, in the Goulburn Broken catchment in Victoria irrigation leads to a rising water table that needs to be pumped away, using energy and increasing emissions. [27]

The National Water Initiative seeks "recognition of the connectivity between surface and groundwater resources and connected systems managed as a single resource". [28] The development of integrated surface water and groundwater management, especially in the Murray-Darling Basin, has been constrained by the focus on surface water during the development of water governance and management regimes; gaps in knowledge about surface water and groundwater connectivity; and, to a lesser extent, the development of a comprehensive, flexible and balanced system of water entitlements and rules. [29]

The diversion of surface water for human consumptive use can have a range of adverse impacts including reduced water quality and harm to riparian ecosystems and wetlands. Water diversions can lead to significant changes in river flow regimes and water available for river-dependent ecosystems [30]. Increased demand for water resources from future expansion of agriculture, in northern Australia in particular, will impact natural flow regimes of spring-fed rivers, including the Daly and Roper Rivers. [31] Water extraction from these rivers will reduce river baseflow, interrupt the flow regime and potentially impact river functions and ecological processes. These impacts include an increase in the frequency of fish kill events, diminished connectivity within the river and disruption of fish migration, reduced recruitment events, changed light environments and associated effects on benthic primary producers and loss of productive flow-dependent habitat such as riffles. [31]

Development on floodplains is also preventing water managers from delivering environmental water over bank to water low to mid-level wetlands and floodplain. The reliance on environmental infrastructure works that pond water is problematic as this unnatural flooding does not provide the flow velocities that are a cue for fish to breed and creates risks of blackwater and salinity.

The diversion of water for coal-seam gas and coal mining pose additional risks to freshwater resources and their dependent ecosystems. Impacts include drawdown and changes to flow regimes due to reduced baseflow, increased river leakage and subsidence related to tributaries, groundwater drawdown resulting in changes to groundwater availability to dependent ecosystems and direct land subsidence effects to the riparian zone; destabilising root systems, increasing land elevation angles and changing surface-soil drainage patterns.

What can be done

This issue needs to be understood as both a technical and social problem needing both technical and social innovation. As a start, integrated management is required to minimise or avoid the impacts described. [29] Improvements are needed in governance arrangements, rules and management organisation(s) in order to develop surface and groundwater plans that are integrated through time as well across resource boundaries (see the Governance Issues Paper). Water entitlements need to be well defined to provide security and confidence to water users, and flexible to adjust to changing conditions and new knowledge. [29]

Where river infrastructure and regulation are retained, four key measures will reduce, though not fully compensate, for, their impact on freshwater ecosystems:

1. Modifying infrastructure to:
    a. eliminate thermal pollution
    b. restore of fish passage
2. Provision for release of environmental water allocations and appropriate flows
3. Removal of constraints that prevent or limit delivery of environmental flows or block overbank flows in high flow events
4. Conservation of the river corridors to both limit and offset impacts of water and waterway use below the dam—for example, by restoring riparian vegetation. [32] [33]

It is important that measures to return water to river environments are based on the whole flow regime and not just annual volumes. Screening water diversion intakes to prevent loss of fish and other aquatic wildlife may also help. [34]

Dam structures can be retrofitted to improve environmental flow outcomes (e.g., release valves, pipes, channels, spillways). During delivery of water for human and environmental objectives, pulse flow releases can be used where possible and appropriate to mimic natural flow variability. [35] River operations that allow for environmental flow releases to enhance natural flood flows or releases for human use, may need to be established, thereby providing increased flow over banks and into floodplains and wetlands. [36]

Connectivity in fragmented landscapes should be maintained and enhanced to help native biota escape from uninhabitable conditions and enable colonization of new sites. The implementation of structural modifications, including pumping of environmental water and adjustments to weir levels and regulators, to focus and enhance flooding of specific wetland areas and floodplains, should be considered (e.g., management of levee banks, acquisition of floodplain easements, establishment of floodplain hazard versus utility zones, restoration of floodplain vegetation and absorption capacities). However, risks associated with the spread of invasive species and other perverse outcomes need to be recognised. [37] [38] The ecological benefits of low-flow periods and flow intermittency in dryland rivers also needs to be recognised and unnaturally elevated low flow levels in such systems avoided. [35]

To achieve these measures, governance responsibilities at the regional and catchment scale need to be identified to ensure a coherent approach to legislation, policy, governance, and environmental flow management linked to monitoring. Conservation legislation that supports biodiversity and resilience of rivers and wetlands – for example, wild rivers legislation, endangered species legislation, adequate environmental impact assessment for new water infrastructure, provisions for environmental flows, and other mechanisms to enhance ecosystem resilience, such as floodplain management – needs to be reviewed and/or implemented. Considerable land planning and infrastructure redesign is required so such flows may be actively delivered. This investment in communities in terms of upgraded roads and bridges can both create wealth and result in much larger areas of water dependent ecosystems being protected than through environmental works.

Environmental flow monitoring integrated with river health monitoring in a framework for adaptive management involving all stakeholders (e.g., [39]) must also be established. In addition, efforts to engage Australia's First Peoples and to incorporate Indigenous value systems and beliefs into existing or new environmental flow frameworks should be increased. [40] At the highest level, efforts to make ecologically sustainable development and resilience a guiding integrative policy framework and higher-order social goal must be enhanced.

Philanthropic organisations could play a role in the synthesis of scientific and Indigenous knowledge generated from place-based studies into a wider body of knowledge, principles, and management "rules" for rivers of contrasting hydrologic and geomorphic character and socioeconomic setting. Similarly, river ecosystem science, education, and knowledge dissemination could and should be encouraged and supported. The sustainable development of water resources in northern Drainage Divisions in particular will require information on the relationships between river flow and the ecology of key aquatic and riparian species, in order to ensure that the ecological requirements of these species are not compromised.

There is possibly also a role in advocating for the modification of structures in highly regulated systems to create flow regimes that support strategic freshwater ecosystem and ecological objectives. This could go as far as exploring the concept of 'legal personhood' for rivers in Australia and whether this could help establish the concept of a river being entitled to a fair share of its own water.

3 Waterway management: Altered habitats and infrastructure barriers are reducing ecological connectivity up and down rivers

Disruption and loss of biophysical habitat (or the "home" for freshwater biota) continue to impact on ecosystem function. The science in this area is not necessarily new – managers already have the confidence that physical barriers and quality and volume of habitat are priority issues. However, the ability to resolve the issue at a meaningful scale remains an ongoing challenge.

Riparian (streamside) zones are degraded over a broad area of Australia. [41] [9] The extent and the structural, age and floristic diversity of instream, streambank, floodplain and wetland vegetation has been lost from most waterways and floodplains across Australia's agricultural and urban landscapes. Loss of vegetation occurs as a result of both riparian clearing and through ongoing access to riparian zones by grazing stock. [42] An Assessment of River Condition (ARC) was conducted in 2001 to determine the aggregate impact of human resource use on Australian waterways in order to prioritise management strategies for their improvement. [43] The ARC found that greater than 80 percent of Australian river and riparian length is affected by human-generated catchment disturbance. In Victoria, 79% of the area assessed by the ARC had moderately to severely modified environmental features (quantified by indices of catchment disturbance, hydrological disturbance, habitat and nutrient/suspended sediment load) and 23 % had significantly to extremely impaired aquatic biota. [43] The major issues identified were delivery of sediment, nutrients and water to waterways, which has occurred as a result of land use change in surrounding catchments.

The importance of intact riparian zones is universally acknowledged as critical to aquatic-terrestrial ecosystem function and, ultimately, to waterway health. [41] Native instream and riparian vegetation is an essential element of stream systems, providing, among other things, a stabilising role, habitat for avian, riparian and aquatic species, migration corridors, a source of carbon and instream habitat (large wood), and its own aquatic values. In addition, riparian corridors support human settlements by limiting mitigating flood impacts and taking up excess nutrients. [44] [45] [46]

De-snagging (instream woody habitat removal), channelisation (stream and river straightening) and wetland drainage have also resulted in the direct loss of habitat and initiated stream network instabilities that have accelerated erosion and sedimentation of aquatic ecosystems. Accelerated erosion and sedimentation processes are ongoing and continue to result in the loss of aquatic habitat and the native species that depend on the systems.

Programs have commenced to address these issues across Australia. However, the large scale of the issues and the limited scale of responses mean that they will take many decades to address. In the meantime, there are continuing declines in ecosystem health and native species abundance and distributions. Significant investment has been expended in addressing water availability for the environment in catchments such as the Murray Darling Basin, including approximately $2.5 billion by governments in water buy-back schemes, [47] but these investments will not fully yield the intended ecosystem outcomes without these complementary issues being resolved. [41]

In addition, physical barriers (e.g., weirs, locks, barrages, dams) have been constructed across rivers throughout Australia. Australian native fish require unimpeded access along waterways in order to survive and reproduce. [48]. Both fresh and saltwater fish move within waters at different times to access food and shelter, to avoid predators, and to seek out mates. Water management structures and other infrastructure, such as roads on floodplains, block flows and connectivity vital to maintaining freshwater biodiversity. [49]

Artificial barriers and flow alteration affect fish populations by reducing habitat connectivity and disrupting movement cues. [50] Freshwater species often can't adapt to these changes and are at increased risk of extinction. [51] The cumulative effect of barriers to fish passage has been identified as a key threatening process to the continuing survival of several species of native fish in Australia. [48]

Impacts resulting from the installation and operation of instream structures include:

- Disruption to natural environmental cues necessary for reproductive cycles
- Impaired spawning, growth, recruitment, feeding and other life cycle processes of native fish resulting from the release of cold water from low level dam outlets
- Impairment of native fish movement and migration
- Reduction of available habitat and reduced breeding and regeneration events due to changes in the area, frequency and duration of floodplain and wetland inundation
- Reduction of the total water available for riverine ecosystems resulting from consumptive extraction
- Destruction of bottom habitats, changes in natural flows and decreased water clarity from extraction and dredging activities
- Alteration to the natural processes of sediment erosion, transport and deposition, leading to loss of fish habitat
- Changes to biota as a result of altering instream physical, chemical and biological conditions
- Creation of environments more suited to exotic species such as carp and redfin perch. Weir pool environments and reduced flows also provide ideal conditions for harmful algal blooms. [52]

The constructions of these structures have been widely implicated in widespread declines of native fish. [53] Dams also curtail invertebrate drift which is an essential mechanism connecting communities. In many cases, this infrastructure, often initially erected for agriculture or mining, fails to be decommissioned following the termination of industry activity. [54] [55] The structures can continue to alter flows and block connectivity without any benefit to industry, although there may be potential to operate existing flow control structures for environmental benefits. There is a lack of ownership for decommissioning unused infrastructure on public and private land, which receives little prioritisation or funding from government.

What can be done

The technologies required for stream habitat rehabilitation programs, including fish passage and stream stability management (vegetation establishment and accompanying structural interventions if and as required) are well established and can be successfully implemented with appropriate governance and funding arrangements. Key to this however is establishing forward-looking, achievable ecological objectives rather than 'ecological restoration goals' derived from pre-European benchmarks.

There are technologies available for effective riparian vegetation re-establishment and management; however, such programs require funding for both the establishment and the ongoing management of vegetated corridors. Riparian rehabilitation programs require the "buy in" of all levels of government and adjoining land managers to protect remnant riparian vegetation from grazing and clearing pressure and to establish and maintain plantings. For example, farmers retiring cropland from production to allow the planting of native vegetation and streambank repair. A suite of vegetation types is required to fulfil various roles, and should include instream vegetation, streambank groundcovers, shrub species and trees. In addition, in some places, a range of engineering solutions might need to be implemented to assist native vegetation establishment, e.g., bank toe protection, bank re-profiling, alignment training and grade control.

Accelerated programs to re-establish stability in stream systems and programs to prevent further sediment mobilisation by locking down existing sediment into stream beds, are required. Policy and legislation could be enacted to regulate and prevent sediment extraction from stream systems, except where necessary to protect aquatic ecosystems from elevated sediment loads, as part of an agreed plan and backed by research.

Accelerated programs of waterway restoration and barrier removal are also required, including the removal of old infrastructure, reconstruction and modification of existing infrastructure (e.g. road culverts) and fish ladder construction. Wherever possible, redundant water storages in protected areas should be decommissioned. There are a number of manuals available for removing dams. [56] [57] In the United States, two large dams have been removed on the Elwha River to enable migratory salmon to recolonise habitat within Olympic National Park in Washington State. [58] Dam removal has commenced in eastern Australia with the decommissioning of Lake Mokoan and the Honeysuckle Reservoir as recent examples.

There are opportunities in riverine environments such as the Murrumbidgee, Werribee, Warrego and Yanco rivers to upgrade infrastructure to serve environmental objectives such as diverting water to tributaries in need. Threat Abatement Plan development, and their implementation with adequate funding, provide an opportunity to assess where all the barriers to fish passage are, and to guide barrier removal.

Opportunities in waterway management for philanthropic organisations, as in catchment management, could include strategically purchasing land and engaging directly in stream and riparian rehabilitation activities and/or establishing or supporting environmental trusts (water, wildlife, conservation, restoration). There are also opportunities to generate positive ecosystem function outcomes through the restoration of flows from the decommissioning of defunct infrastructure. A good example is in the Lake Eyre Basin where disused roads act as an impediment to overland flow in very flat country [54]. Philanthropic organisations could investigate opportunities where the adaptation or removal of unused infrastructure would achieve positive freshwater ecosystem outcomes and ascertain whether they may be able to directly finance or co-fund these actions. The cost effectiveness of different solutions should be carefully analysed and put to the public and politicians for debate. The scale of the benefits for each solution also needs to be determined mapped and compared.

4 Weed and pest management: Invasive weeds and pest animals have become established in and continue to colonise our freshwater ecosystems, leading to loss, or threat of loss, of native species

Invasive weeds and pests have become established in, and continue to colonise, our freshwater ecosystems. Willow, once used for stream stability programs, is now taking over and blocking some waterways. Pest animals can promote soil erosion, stream turbidity, the spread of weeds, and can threaten native plant species and animals through competition, habitat destruction and predation. They also have the potential to act as reservoirs for diseases that affect native wildlife, domestic stock or people. [59]

Weeds affect the structure and function of land-based and aquatic ecosystems, and impact negatively on native fauna and flora. They can displace native plant species and harbour pests and diseases. Weeds can also increase the biomass of ecosystems leading to more intense bushfires, changing the composition and structure of native vegetation.

Weeds can threaten the integrity of nationally and globally significant sites, species and ecological communities, such as Ramsar-listed wetlands, cultural heritage sites and declared World Heritage areas. National parks and nature reserves, multi-use forest lands, urban and peri-urban public land all require ongoing weed control and monitoring. [60]

Pest species are commonly recognised as a threat to wetlands. They compete for resources needed by native freshwater biota; Carp can outcompete native fish for food resources for example. Aquatic pests also compete with native species important to our economy and conservation and reduce the attractiveness and social enjoyment of aquatic areas by damaging these environments. They can also pose health risks.

Pest animals can have a range of negative impacts on wetlands, including:

- habitat degradation (e.g. spreading weeds and reduced amount and quality of water)
- competition with native fauna for food and shelter
- direct predation on native fauna
- poisoning native animals (e.g. by cane toads) and spreading disease
- altering ecosystem function.

Aquatic weeds can affect freshwater ecosystems by:

- impeding waterflow and increasing flooding and erosion
- reducing water quality, creating health hazards
- displacing natural vegetation and destroy aquatic life
- reducing fish habitat

Pest and weed management, including in freshwater ecosystems, has long been a central responsibility of Landcare programs and focus of initiatives. While in the past Landcare programs have been a significant contributor to controlling and managing the spread of invasive species, there is a view that the development of regional NRM delivery models and the early achievements made through Landcare have been forgotten and that the stocks of human and social capital that were developed during earlier times have been degraded and lost. [61]

Evidence has emerged of declining membership in community Landcare groups in parts of Western Australia, Victoria and New South Wales. Volunteer burn out has been reported in many places, with many community Landcare groups in sleeper mode or ceasing to exist. [62] Funding uncertainty and high turnover of support staff contribute to the problem.

In addition, existing planning and management is not synchronised or optimised enough for effective pest and weed management at catchment scale to maintain freshwater ecosystem outcomes. For example, Threatened Species Recovery Plans (TSRPs, a conservation mechanism under the *Environmental Protection and Biodiversity Conservation Act 1999*) address the recovery of individual species, but are not adequate to reverse declines in ecosystem health at larger ecological and spatial scales.

Threat Abatement Plans (TAPs) are arguably a more suitable mechanism for managing threats from aquatic pest and weed management. Focussing on managing the threats common to many threatened species might be a more effective approach than individual species recovery planning. For example, creating habitats that favour natives over weed or introduced species; a more variable flow regime will favour cod over carp for instance.

However, neither TSRPS nor TAPs generally receive adequate funding to support their effective implementation. [63] [64]

Irrespective of the need to move towards integrated landscape management of weeds or to implement targeted responses, mitigation of weeds is costly and not always effective. There will continue to be a demand for a range of weed control options that can be used alone or in combination. Chemical (herbicide) options have been pursued commercially by industry for agricultural related application, while classical biological control options have received support from government and industry for agricultural and environmental outcomes. Technological advances in cognate areas of science and engineering are also becoming available as options for weed management. Refining and adapting technologies such as robotics / drones so they are fit for purpose in weed detection and control will require ongoing research and development. [65]

What can be done

A focus on incursions overcomes the historic tendency for skewing investment to established weed problems. The proportional under-investment in prevention, where the greatest returns can be achieved, was highlighted as a matter of concern by the independent review of Australia's biosecurity system. [66] The development and deployment of best practice tools and systems for early detection and prevention through the use of risk-based surveillance systems is required to ensure investment targeted to understanding and applying techniques focused on prevention of new weed introductions, movements within Australia or establishment. This will reduce the impacts of weeds through adoption of best practice incursion management systems, risk-based surveillance systems and deployment of rapid and cost-effective responses. [65]

Secondly, moving from a focus on species or specific control techniques to approaches based on integrated management, and focused on outcomes rather than problems, helps to deal with many weeds (and even other issues) by combining different techniques simultaneously or in sequence. Such approaches try to have managers across different land uses within a catchment or region coordinate actions to reduce the impacts of weeds. As such, management at this scale depends upon community, industry and NRM organisation led solutions. [65]

Control technologies, including biocontrol, should be nested within a wider network of land managers and practitioners involved in applying, monitoring and managing these technologies. These investments will be enhanced by industry and community engagement and delivery, and deploying control options within integrated programs of landscape management. [65]

We know action must be taken on invasive species quickly. The longer we ignore an invasive species, the harder and more expensive the battle for control becomes. [67] We all can help stop the introduction and spread of invasive species by starting with informed, responsible stewardship of our own little pieces of Australia, however large or small they may be. Technologies are available for effective aquatic pest and weed control, but coordinated and targeted programs of management are required with significant and ongoing funding.

Planned, ongoing weed management strategies have high initial and ongoing costs. Yet, this approach is also likely to deliver long-term benefits with reduced weed incursions and impacts. The Australian Weeds Strategy 2017–2027 and the Australian Pest Animal Strategy 2017–2027 both contain independent sets of principles for effective invasive species management. Both sets of principles reflect that prevention and early intervention to avoid the establishment of new pest species is generally more cost-effective than ongoing management of established populations, that pest species management is a shared responsibility between landholders, community, industry and government that requires all parties to have a clear understanding of their roles, and that the management of pest species requires a coordinated approach among all levels of government in partnership with industry, land and water managers and the community, across a range of scales and land tenures. The Australian Weeds Strategy also states that sustaining capability and capacity across landholders, community, industry and government is fundamental to effective weed management.

Philanthropic opportunities are probably most appropriate and effective in supporting the responsibilities of natural resources management bodies, which include:

- helping monitor invasive species impacts and playing a regional surveillance role for detecting high risk invasive species that pose risks to their region or could spread to other regions
- working with landholders and government to develop effective regional invasive species management programs The connection between discovery and action is often not there. Philanthropy could assist this connection.
- playing a role in coordinating and implementing regional and catchment-based invasive species management plans
- representing community interests in pest animal management
- assisting with data collection and information exchange
- supporting and building public awareness about invasive species issues
- supporting Landcare and other volunteer efforts to strengthen on-ground groups and avoid burnout.

5 Climate change adaption and management: Planning and enforcement is inadequate for a changing climate that magnifies pressures on freshwater ecosystems

Many of Australia's rivers and wetlands are increasingly threatened by catchment processes that affect overland flows, flow regime alterations by dams and diversions, and excessive groundwater pumping. Their flow regimes already require remediation to restore and sustain ecological resilience. Predicted climate change scenarios are likely to exacerbate the risks associated with existing flow regime alterations through altered rainfall, temperature, and runoff patterns; increased vulnerability to drought damage; loss of connectivity; and cumulative disruptions to biogeochemistry, biological communities, and ecosystem processes.

In this context, maintaining freshwater ecosystem health will be a challenge for national, state and regional governments. Governments need to respond to the challenges posed by climate change, population growth and changing community expectations. [68] Planning for Australia's freshwater resources is currently inadequate to address the effects of climate change on water availability for both ecosystem function and consumptive use.

Climate change implications challenge the science and practice of water management and environmental flows and make ecosystem protection and restoration even more urgent as well as more complex. [69] Free-flowing rivers in largely undeveloped catchments are expected to be more resilient in the face of climate change than regulated and degraded rivers because they retain their inherent capacities to respond to, and recover from, disturbances associated with historical regimes of flow variability, sediment, nutrient and energy inputs, and water quality. [70] [71] Regulated and degraded rivers, however, tend to lack this adaptive capacity. [72]

In general, freshwater ecosystems, their biota, functions and services, are highly vulnerable to climate change due to high levels of exposure and sensitivity to projected changes and extreme events. [37] [73] [74] Ecological responses to climate change will be complex, dynamic and variable and are very likely to involve shifts in the composition and structure of freshwater ecosystems which, in turn, will affect the ecological functions, goods and services these provide. [37] [75] In particular, significant shifts in the distribution of freshwater taxa can be expected in response to projected climatic change. [76] Ecological responses to hydrology are also likely to change. Warmer temperatures, for instance, may make ecosystems and biota "thirstier" and potentially less tolerant of past drying regimes. [73] Shifts in ecological functions and ecosystem services can be similarly anticipated. The capacity of freshwater ecosystems to retain flood waters, for example, may become more variable in space and time. [37] [75] Freshwater ecosystems will furthermore be sensitive to climate change effects in the surrounding landscape which may exacerbate direct impacts. [37] [77]

The National Water Initiative set a blueprint for water reform in Australia, [28] but there remain gaps in planning to address the impact of climate change and other threats to freshwater ecosystems at national and river basin scales. Insufficient planning for the effects of climate change on water availability and ecosystem health is evident in the absence of meaningful reference to climate change in the Murray Darling Basin Plan.

[78] Poor planning or failure to plan for the effects of climate change puts fresh water and the ecosystems that depend on it at risk. It can result in reactive responses to water issues and missed opportunities to consider mitigation and adaptation responses in advance.

Climate change prompts a need to systematically develop multiple integrated objectives for Environmental Water Management (EWM) that incorporate socio-economic, cultural and ecological aspects. [79] In particular, adaptive EWM goals might have a greater emphasis on ecosystem functions and services valued by society, e.g., water filtration, bank stability, shading, cultural values etc. [80] Specific objectives relating to the resilience or adaptive capacity of particular ecological functions or values may also be appropriate, especially in catchments which are characterized by high levels of climate variability and extreme events. [81] Transformative EWM objectives might even include over-restoration of wetland ecosystems (e.g., [82]) such that certain ecological functions are enhanced beyond their historical limits, for example, creation of new aquatic refuges where climate change has negatively impacted historical ones. Such designer EWM objectives may become the norm as natural environments are replaced by novel and/or managed systems that are valued for their particular benefits to ecosystems and people. [83]

What can be done

For river and water systems, restoration will be crucial to resilience. Strategies to defend and advance restoration agenda and methods are multi-fold. They need to encompass on-ground restoration, law and policy that effectively compel protective and restorative agenda, and (perhaps as the MDB attests) capacity to advocate for and enforce laws. The premises of legal and normative regimes, such as the Commonwealth Water Act, provide key foundations for climate response, for instance in the primacy of environmental considerations and actions and socio-economic approaches to be shaped and conformed to those norms. Additionally, climate action provides scope for regulatory and normative approaches and schemes emphasising restoration, specifically via concepts such as ‘carbon sinks’. Nevertheless, anthropogenic sources of climate change, as well as eco-hydrological change to water systems, needs to be expressly understood as leading to managed systems.

Much of the recent climate change literature suggests the following suite of strategies, options, and processes are priorities for climate change adaption and management (e.g., [84] [85] [72]):

- Systematic conservation planning approaches (principles of comprehensiveness, adequacy, representativeness, and efficiency), need to be applied from catchment to river basin scales, to identify priority habitats and water bodies (e.g., drought refugia) for designation and management as protected areas, to mitigate threats and establish priorities for environmental flow delivery [86]
- Biological databases and predictive models that provide spatial and temporal information for conservation planning are needed. Conservation attention should be focussed on species where management actions can reduce vulnerability rather than focusing attention on the species that are most vulnerable per se
- Sound assessment is required of proposed dams or plans to commence or increase diversions from rivers or extractions from groundwater
- The potential effects of climate change need to be incorporated into scenario modelling to help forecast environmental flow requirements under changing thermal and flow regimes. Melbourne Water’s Healthy Waterways Strategy provides a good example of this kind of modelling [87]
- The science and modelling of hydro-ecological scenarios that demonstrate trade-offs between deleterious alterations to flow regimes and environmental costs versus benefits needs to be improved [88]
- Multiple stressors on species and ecosystems need to be identified and addressed to give additional resilience and flexibility in adapting to climate change [69]
- Long-term drought-management strategies are required to reduce water demand, increase efficiency, and increase recycling and re-use
- Landscape and stream rehabilitation programs should be planned to perform under future rather than past climate states
- Legislated conservation obligations need to be met, and ecological values protected or rehabilitated, by providing flow regimes to meet defined ecosystem targets. Natural flow regimes need to be restored, or more suitable environmental flows provided, to meet conservation obligations for endangered species and key habitats and processes. The flow regimes of rivers and tributaries that remain largely free-flowing should be protected.

The philanthropic opportunities in the above may be limited, but successful natural resources management reforms rely on more than just the skilful selection and implementation of policy instruments and strategies. Major policy and management reforms like those associated with climate change have the potential for significant transitional impacts on communities. Policy development and implementation will therefore generally be improved by active participation of affected communities, so they are involved in the co-creation of their future. [89]

Community involvement alone may not be sufficient to address systemic issues; however, community engagement models that aim to mobilise and motivate people can be meaningfully applied to climate-change adaptation challenges. [90] There are opportunities for philanthropy to assist with case studies for stewardship programs or other community land & water management projects – for example, Indigenous Ranger projects or Council-led renewable energy projects.

In addition, philanthropy can assist in synthesising science, advocacy and practice. This approach has been used effectively in response to shortcomings of MDB management and in cultural flows research project.

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