SELECTED ANNOTATED BIBLIOGRAPHY OF PEER-REVIEWED, PUBLISHED LITERATURE (2009 TO 2019) ON THE MURRAY-DARLING BASIN, AUSTRALIA

Prepared as a useful reference for publication by the Peter Cullen Trust by Jason Alexandra, Daniel Connell, Matt Colloff, James Horne, Jamie Pittock, Quentin Grafton, Richard Kingsford, Sarah Wheeler and John Williams

28 May 2019

2019

Alexandra J., 2019. Losing the authority – what institutional architecture for cooperative governance in the Murray Darling Basin? Australasian Journal of Water Resources, (Published online: 12 Mar 2019) DOI: 10.1080/13241583.2019.1586066

https://doi.org/10.1080/13241583.2019.1586066

Water governance strongly depends on the institutional arrangements in place. The plethora of recent inquiries into the adequacy and integrity of governance arrangements in the Murray Darling Basin (MDB) indicates a crisis of trust, legitimacy and public confidence – in short, a loss of authority. With the prospect that current arrangements are losing the authority and legitimacy needed to govern the Basin, pressure is mounting for further reforms due to scandals exposed in the media throughout 2017 and 2018. These and subsequent inquiries have revealed serious concerns about probity, integrity, maladministration and the adequacy of compliance and enforcement regimes. The productive potential of this crisis is that draws attention to the need for reforms to governance institutions. This paper aims to explore the redesign of the institutional architecture in the MDB. Given the profound challenges of social and climate change that are demanding reconsideration of the underlying models used in adaptively governing large complex socio-ecological systems, the paper asks what arrangements are suited to the challenges of governing the Basin in the 21st century? This paper explores the nature of the redesign challenge, exploring principles, practices and features of MDB governance. The need for institutions with capacity for strategic navigation, goal seeking and the cultural co-construction of authority are suggested in the interests of cultivating debate about prospective reorganisation.

de Bonviller, S., Zuo, A., Wheeler, S. 2019. Is there evidence of insider trading in Australian water markets? Australian Journal of Agricultural and Resource Economics 63(2), pp. 307-327.

Insider trading is a much-studied form of market manipulation in the financial market literature. However, studies addressing the issue of insider trading in resource markets, and in particular water markets, are rare. This study investigates the occurrence of insider trading practices around important water market allocation announcements in the Goulburn temporary water market trading zone in the Murray-Darling Basin, Australia, which is one of the largest and longest operating water market districts in the world. Nine years of daily water allocation volume and price transactions between 2008 and 2017 are modelled, with some evidence found of abnormal price movements in the 3 or 5 days preceding water allocation announcements, and especially before the introduction of insider trading rules in 2014. However, although the results do suggest some very weak statistically significant evidence that insider trading may still be present in Goulburn water markets post-2014, it is just as feasible that our results may also reflect an increased sophistication of trader behaviour over time.

Grafton, R.Q. 2019. Policy Review of Water Reform in the Murray-Darling Basin, Australia: The "Do's" and "Do Nots". Australian Journal of Agricultural and Resource Economics 63(1): 116-141.

The water reforms undertaken in the Murray–Darling Basin, Australia since 2007 have been viewed as a model for other countries seeking to respond to water insecurity. Here, a policy review is provided of this water reform and whether it delivers on key environmental objectives in the 2007 Water Act (the Act). The evaluation includes a review of the 2012 Basin Plan, a key instrument of the Act, and complementary policies associated with the acquisition of water entitlements for the environment via direct (reverse tenders) and indirect (infrastructure subsidies) means. Using the objects of the Act as a benchmark, an evaluation is provided of the following: (i) planned reductions in irrigation water extractions in the 2012 Basin Plan; (ii) risks associated with the 2018 amendments to the Basin Plan that, collectively, allow for an increase in irrigation water extractions of some 22 per cent, relative to the sustainable diversion limits specified in the 2012 Basin Plan; (iii) Basin-scale environmental outcomes achieved, as of the end of 2018; and (iv) economic effects of direct and indirect methods of acquiring water for the environment. Findings from the review generate the "Do's" and "Do Nots" of water reform for Australia, and possibly other countries, when managing the trade-offs between water for irrigation and the environment.

Grafton, R.Q., Garrick, D., Manero, A. and Do, T.N. 2019 The Water Governance Reform Framework: Overview and Applications to Australia, Mexico, Tanzania, U.S.A and Vietnam. Water 2019, *11*, 137; doi:10.3390/w11010137.

The world faces critical water risks in relation to water availability yet water demand is increasing in most countries. To respond to these risks, some governments and water authorities are reforming their governance frameworks to achieve a convergence between water supply and demand and ensure freshwater ecosystem services are sustained. To assist in this reform process, the Water Governance Reform Framework (WGRF) is proposed that includes seven key strategic considerations: (1) well-defined and publicly available reform objectives; (2) transparency in decision-making and public access to available data; (3) water valuation of uses and non-uses to assess trade-offs and winners and losers; (4) compensation for the marginalized or mitigation for persons who are disadvantaged by reform; (5) reform oversight and 'champions'; (6) capacity to deliver; and (7) resilient decision-making. Using these reform criteria, we assess current and possible water reforms in five countries: Murray-Darling Basin (Australia); Rufiji Basin (Tanzania); Colorado Basin (USA and Mexico); and Vietnam. We contend that the WGRF provides a valuable approach to both evaluate and to improve water governance reform and, if employed within a broader water policy cycle, will help deliver both improved water outcomes and more effective water reforms.

Haensch, J., Wheeler, S., Zuo, A. 2019. Do neighbors influence irrigators' permanent water selling decisions in Australia? Journal of Hydrology 572, pp. 732-744.

There has been increasing emphasis by scholars in trying to understand how neighbors influence farmers' decision-making. In Australia, historically there has always been strong anecdotal evidence of peer pressure on irrigators' decisions to not sell permanent

water entitlements. This local pressure increased with the advent of the federal government into the Murray-Darling Basin water market to purchase permanent water for the environment from voluntary sellers from 2008 onwards. Selling permanent water entitlements is associated with perceptions about rural community decline. This article formally tests whether a neighborhood effect can be detected in permanent water entitlement selling decisions, using farm survey data across a number of years from the southern Murray-Darling Basin (n=1,462). Irrigators' locations were geocoded and locational characteristics (regional socio-economic characteristics, land and water quality) were linked to the survey data covering farm, farmer and water trade characteristics. There was significant evidence of a farmer neighborhood effect, with higher likelihood of permanent water sales occurring in areas where more neighbors had sold permanent water, holding other locational and spatial influences constant.

Horne, J. and Grafton, R.Q..2019. The Australian Water Markets Story: Transformation Incrementally, in J. Luetjens, M. Mintrom and P. 't Hart (Eds.) ***Successful Public Policy: Lessons from Australia and New Zealand,*** **ANU Press, Canberra, pp. 38-60.**

The chapter provides a historical review of how water markets developed in the Murray-Darling Basin and highlights the impediments to water market reform and the challenges that remain.

Pittock, J. 2019. Are we there yet? The Murray-Darling Basin and sustainable water management. Thesis Eleven 150(1), pp. 119-130. Pay per view with link: https://journals.sagepub.com/doi/abs/10.1177/0725513618821970

In 2007, then Australian Prime Minister Howard said of the Murray-Darling Basin's rivers that action was required to end the 'The tyranny of incrementalism and the lowest common denominator' governance to prevent 'economic and environmental decline'. This paper explores the management of these rivers as an epicentre for three key debates for the future of Australia. Information on biodiversity, analyses of the socio-ecological system, and climate change projections are presented to illustrate the disjunction between trends in environmental health and the institutions established to manage the Basin sustainably. Three key debates are considered: (1) conflict over the allocation of water between irrigated agriculture versus a range of other ecosystem services as the latest manifestation of the debate between adherents of the pioneering myth versus advocates of limits to growth in Australia; (2) cyclical crises as a driver of reactive policy reform and the prospects of the 2008 Water Act forming the basis of proactive, adaptive management of emerging threats and opportunities; and (3) subsidiarity in governance of the environment and natural resources in the Australian federation. Implementation of the 2012 Basin Plan as promised by the Federal Government 'in full and on time' is a key sustainability test for Australia. Despite Australian claims of exceptionalism, the Murray-Darling Basin experience mirrors the challenges faced in managing rivers sustainably and across governance scales in federations around the world.

Wheeler, S.A., Marning, A. 2019. Turning water into wine: exploring water security perceptions and adaptation behaviour amongst conventional, organic and biodynamic grape growers. Land Use Policy 82, pp. 528-537.

Australian irrigators regularly experience drought conditions, placing water security as a critical issue facing agriculture, especially for permanent plantings such as grapes. This study explores irrigators' water security perceptions and their water management adaptation behaviour using in-depth interviews and surveys with 37 conventional, organic and biodynamic grape growers in South Australia. Conventional growers' water adaptation behaviour was primarily reliant on activities external to the vineyard (e.g. upgrading irrigation infrastructure); whereas alternative (i.e. certified organic/biodynamic) growers' water security actions were based largely on internal vineyard activities (e.g. agro-ecological methods). Conventional growers often named governance and district physical capital as influencing their adaptive capacity to water scarcity, while alternative growers focussed more on the role of human, social, and farm soil and land capital in influencing their farm adaptive capacity. Two-thirds of surveyed alternative growers converted away from conventional production at the end of the Millennium Drought, naming water security issues as their main reason. Overall alternative growers perceived higher water security and less water vulnerability due to higher soil water retention. Findings suggest a need for current Murray-Darling Basin water policy to seriously reconsider the approach of primarily investing money in irrigation infrastructure to save water and to focus more on agro-ecological methods.

Williams, J. and Grafton, R.Q. 2019. Missing in Action: Possible effects of water recovery on stream and river flows in the Murray–Darling Basin, Australia. Australasian Journal of Water Resources, https://doi.org/10.1080/13241583.2019.1579965.

We use published water balance data from irrigated cropping to show that water entitlements acquired for environmental purposes through water infrastructure subsidies in the Murray–Darling Basin, Australia, have resulted in smaller increases in net stream and river flows than is estimated by the Australian Government, and may even have reduced net stream and river flows. Two key policy implications arising from our results are: (1) subsidies to improve irrigation efficiency so as to increase stream and river flows must employ water accounting so that the effects on return flows are known and the volume of water extracted for irrigation is adjusted to achieve desired stream and river flows; and (2) if the net increases in stream and river flows in the MDB are much less than estimated by the Australian Government, water infrastructure subsidies to increase irrigation efficiency may have compromised the delivery of key objects of the Water Act (2007).

2018

Alexandra J., 2018 Evolving Governance and Contested Water Reforms in Australia's Murray Darling Basin Water 2018, 10, 113; doi:10.3390/w10020113 MDPI

This paper explores the ways water governance adapts to changing sociavalues and political imperatives by examining the case of water policy reforms in Australia's Murray Darling Basin. Over more than two decades, Australia's water reforms have explicitly aimed to promote ecological sustainability and economic efficiency, attempting to balance pro-market, micro-economic reforms with broader social and sustainability goals. Despite the formality of Australia's intergovernmental agreements, water reforms have been expensive and heavily contested, experiencing many implementation challenges. However, water market reforms have generally been regarded as successful, enabling the reallocation of water for environmental and extractive uses, contributing to flexibility and adaptive capacity. Recognising that discursive contestation is central to policy development, the paper documents the way the reform processes have attempted to broker compromises between three competing policy paradigms—national development, economic rationalism and environmentalism. These inherent tensions resulted in prolonged contests for influence over policy directions long after formal statements of policy intent by Governments. Given that climate change is driving the need for water governance reforms, the paper looks to what lessons can be learnt about the redesigns of meta-governance arrangements, including through structured commitments to independent audits and evaluations that can provide the feedback needed for adaptive governance and policy learning.

Bino, G., Wassens, S., Kingsford, R. T., Thomas, R. F., & Spencer, J. 2018. Floodplain ecosystem dynamics under extreme dry and wet phases in semi-arid Australia. *Freshwater Biology*, *63*(2), 224-241. doi:10.1111/fwb.13056

Ecological networks are a cornerstone of ecological theory, offering an integrated approach to understanding food webs and ecosystem dynamics required for restoration and conservation ecology.

We investigated ecological network dynamics in a large floodplain undergoing extreme variation in water availability, with drought and subsequent flooding representing a resource pulse. We used structural equation models to quantify ecological network dynamics for the Lowbidgee floodplain (Australia), based on surveys over 5 years while the floodplain transitioned from extremely dry (2009, 2010) to wet (2011) and post-wet (2013, 2014) conditions.

We identified significant associations of species and trophic guilds with inundation at the site and floodplain scale, which allowed us to quantify the strength of biotic interactions within the network and the stability of interactions under differing patterns of resource availability. At the floodplain scale, most taxa responded strongly in distribution and abundance to the 2011 resource pulse, a widespread flood, but this response did not persist during subsequent years of moderate floods. In contrast, fish species, both native and exotic, responded strongly only in the post-wet period. At the fine spatial scale (i.e., sites), complex responses were observed, with only waterbirds,

frogs and tadpoles positively associated with inundation, while fish species showed a range of associations with fine-scale inundation. Biotic interactions within sites, across all trophic guilds, were predominately overridden by inundation and water temperature, mediated by strong associations with aquatic vegetation.

Stratifying the ecological network to dry, wet and post-wet periods highlighted varying associations of taxa with fine-scale inundation, generally responding synchronously to resource pulses, with relatively weak biotic interactions. Associations with site-scale inundation were strongest during the post-wet period for fishes and frogs. Only *Litoria* spp. (Hylidae) tadpoles, waterbirds and aquatic vegetation had positive associations with site-scale inundation during the dry period.

We conclude that responses of trophic guilds are largely dependent on the way they interact with their environment at particular spatial and temporal scales. Our investigation of this ecological network reinforced the importance of hydrological drivers over biotic interactions, with clear implications for the management of environmental flows, particularly in systems recovering from long-term flow alteration. Management efforts should focus environmental flows to promote specialist species (e.g., southern bell frog, *Litoria raniformis)* and Murray hardyhead (*Craterocephalus fluviatilis*: Atherinidae), waterbirds and aquatic vegetation over the more generalist fish species that have established because of the loss of the natural flow regime.

Chu, H.L., Grafton, R.Q. and Stewardson, M. 2018. Resilience, Decision-making and Environmental Water Releases. Earth's Future 6(6), pp. 777-792.

The paper develops a stochastic resilience optimisation model to assist decision-makers optimally determine water releases from storages for environmental purposes and to measure the resilience of the system for given risk tolerances. The model, with sensitivity analyses is calibrated to the Murray-Darling Basin and the Goulburn-Broken Basin to highlight its potential to improve decision-making across multiple spatial scales and over time.

Colloff, M.J., Overton, I.C., Henderson, B., Roberts, J., Reid, J.R.W., Oliver, R.L., Arthur, A.D., Doody, T.M., Sims, N.C., Ye, Q. and Cuddy, S.M. 2018. The use of historical environmental monitoring data to test predictions on cross-scale ecological responses to alterations in river flows. Aquatic Ecology 52, 133–153. https://doi.org/10.1007/s10452-018-9650-y

Determination of ecological responses to river flows is fundamental to understanding how flow-dependent ecosystems have been altered by regulation, water diversions and climate change, and how to effect river restoration. Knowledge of ecohydrological relationships can support water management and policy, but this is not always the case. Management rules have tended to be developed ahead of scientific knowledge. The lag between practice and knowledge could be addressed by using historical monitoring data on ecological responses to changes in flows to determine significant empirical ecohydrological relationships, as an adjunct to investigating responses prospectively.

This possibility was explored in the Murray–Darling Basin, Australia. We assessed 359 data sets collected during monitoring programs across the basin. Of these, only 32 (9%) were considered useful, based on a match between the scale at which sampling was done and ecological responses are likely to occur, and used to test flow–ecology predictions for phytoplankton, macroinvertebrates, fishes, waterbirds, floodplain trees, basin-scale vegetation and estuarine biota. We found relationships between flow and ecological responses were likely to be more strongly supported for large, long-lived, widespread biota (waterbirds, basin-scale vegetation, native fishes), than for more narrowly distributed (e.g. estuarine fishes) or smaller, short-lived organisms (e.g. phytoplankton, macroinvertebrates). This pattern is attributed to a mismatch between the design of monitoring programs and the response time frames of individual biota and processes, and to the use of local river discharge as a primary predictor variable when, for many biotic groups, other predictors need to be considered.

Grafton, R.Q., Williams, J., Perry, C.J., Molle, F., Ringler, C., Steduto, P., Udall, B., Wheeler, S.A., Wang, Y., Garrick, D. and Allen, R. 2018. The Paradox of Irrigation Efficiency. Science 361 (issue 6404), pp.748-750.

The paper outlined five steps to respond to the paradox of irrigation efficiency, namely, that water saved at a farm scale typically does not reduce water consumption at a watershed or basin scale. The first step is centered on water accounting and research advances, that promote more effective policy actions. First, physical water accounts need to be developed from the farm-scale to the basin scale to make transparent "who gets what and where" to support decision-making in the public interest. This requires measurement or estimation of all inflows, water consumption, recoverable return flows, and nonrecoverable flows to sinks. Developments in remote sensing offer the possibility of estimates of water inflows and outflows at a much lower cost and a greater scale than previously available. Second, reductions in water consumption are achievable by decreases in water extractions through a direct cap on water offtakes or on the irrigated area. By contrast, in Australia, where water rights are denominated in gross extractions, actions to reduce extractions to reallocate water to the environment have to date, been neither sufficient nor cost effective. To meet environmental flow goals, incentives may be used to make irrigators account for return flows, such as water charges on the reductions in recoverable flows, or financial benefits to maintain such flows by reducing consumption

Grafton, R., Wheeler, S. 2018. Economics of Water Recovery in the Murray-Darling Basin, Australia. Annual Review of Resource Economics 10(1), pp. 487-510.

We review recent water reforms and the consequences of water recovery intended to increase stream flows in the Murray-Darling Basin (MDB), Australia. The MDB provides a natural experiment of water recovery for the environment that includes (a) the voluntary buy-back of water rights from willing sellers and (b) the subsidization of irrigation infrastructure. We find that (a) the actual increase in the volumes of water in

terms of stream flows is much less than claimed by the Australian government; (b) subsidies to increase irrigation efficiency have reduced stream and groundwater return flows; (c) buy-backs are much more cost effective than subsidies; (d) many of the gains from water recovery have accrued as private benefits to irrigators; and (e) more than a decade after water recovery began, there is no observable basin-wide relationship between volumes of water recovered and flows at the mouth of the River Murray.

Loch, A., Wheeler, S., Settre, C. 2018. Private transaction costs of water trade in the Murray-Darling Basin. Ecological Economics 146, pp. 560-573.

High transaction costs can prevent the efficient allocation of resources towards socially-desirable outcomes. Water is a classic example of a resource with private and public socially-desirable benefits, which depend on its efficient allocation. Public and private institutions thus fulfil an important function by seeking to lower transaction costs in water markets. Where transaction costs are reduced, those same institutions may benefit from positive economic outcomes. However, in spite of their importance for policy performance evaluation, very few studies have investigated the impacts of transaction costs over time on the success or failure of public policy implementation and compliance. This study identifies important transaction costs and their rate of change in the world's leading water market: the southern Murray–Darling Basin in Australia. It was found that some progress towards lowering transaction costs in water markets has been achieved, particularly in respect to water allocation (temporary) transfers. However, some water entitlement (permanent) transaction costs have increased in the time-period, which may be justifiable given the inherent complexities associated with individual entitlement transfer assessments. Overall, the analysis suggests that institutional investment in water markets have improved irrigator private gains from trade.

Thompson, R. M., King, A. J., Kingsford, R. T., Mac Nally, R., & Poff, N. L. R. 2018. Legacies, lags and long-term trends: Effective flow restoration in a changed and changing world. In *Freshwater Biology* Vol. 63 (pp. 986-995). doi:10.1111/fwb.13029

Human impacts on natural ecosystems are pervasive and will play out more severely as human populations and per capita resource use increase. Freshwater ecosystems are critical for human well-being and experience a diverse range of human-induced pressures. Most river systems throughout the world have much-altered flow regimes.

The Murray–Darling Basin in southeastern Australian has been the focus of an extensive water reform process to address the over-allocation of water for human uses. This has included many scientific investigations, hydrological modelling and the development of institutional and market structures to reallocate water. Substantial recovery of water has been achieved, which has been used to restore aspects of the natural flow regime.

We reviewed recent papers on responses to flow restoration in the Murray–Darling

Basin and complemented this with inferences from the global literature. Ecological responses to flow restoration are often inconsistent, site and taxon specific and difficult to detect.

By combining ideas from mainstream thinking in restoration ecology with the insights from our review, we propose a conceptual model for understanding responses to flow restoration. This model incorporates key factors that influence the size of ecological responses to restoration, including existing ecological condition, legacy impacts of past change, interactions with other variables, life-history traits of taxa and broad-scale and long-term trends due to climate or land-use change.

Wheeler, S., Haensch, J., Edwards, J., Schirmer, J., Zuo, A. 2018. Quantifying an integral ecology framework: a case study of the Riverina, Australia. American Geophysical Union 6(2), pp. 192-212.

Communities in Australia's Murray-Darling Basin face the challenge of trying to achieve social, economic, and environmental sustainability; but experience entrenched conflict about the best way to achieve a sustainable future, especially for small rural communities. Integral ecology is a philosophical concept that seeks to address community, economic, social, and environmental sustainability simultaneously. Its inclusive processes are designed to reduce stakeholder conflict. However, to date the application of the integral ecology concept has been largely qualitative in nature. This study developed a quantitative integral ecology framework, and applied this framework to a case study of the Riverina, in the Murray-Darling Basin. Seventy-seven community-focused initiatives were assessed, ranked, and quantified. The majority of the community-focused ranked initiatives did not exhibit all aspects of integral ecology. Initiatives typically prioritized either (1) economic and community development or (2) environmental health; rarely both together. The integral ecology framework developed here enables recommendations on future community initiatives and may provide a pathway for community leaders and other policy-makers to more readily apply integral ecology objectives. Further research refining the framework's operationalization, application and implementation to a wider-scale may enhance communities' capacity to develop and grow sustainably.

Wheeler, S., Zuo, A., Loch, A. 2018. Water torture: unravelling the psychological distress of irrigators in Australia. Journal of Rural Studies 62, pp. 183-194.

Water institutional and property right reform in the food bowl of Australia, the Murray–Darling Basin (MDB), has generated both benefits and costs for irrigators. Water allocation uncertainty along with the increased risk of recurring drought has been gradually placed back on irrigators to manage, and in the last decade there has been considerable reallocation of water from consumptive to environmental use in the MDB, which has caused much angst within rural communities. In the face of such change this study provides, for the first time, a large-scale profile (n=1000) of irrigators' mental health in the MDB. Our point estimates suggest some irrigation industries in 2015-16

recorded some of the highest levels of psychological distress nationally; higher than dryland farmers or the Australian population. Financial difficulties were most associated with this distress, but it was intertwined and underpinned by the ongoing threat of water scarcity, which irrigators often incorrectly associate with the implementation of the Basin Plan. Psychological distress varied by industry and location: horticulturists reported the highest levels of distress, followed by broadacre, dairy and livestock. Future national water policy must consider the real impacts of water recovery, and recognize that so-called 'socially neutral' water recovery policies can actually cause significant community harm where they hamper farm exit and adaptation to a hotter future. We recommend that future water policy must focus on i) encouraging farmer adaptation (hence supporting water entitlement buy-back and eliminating on-farm irrigation infrastructure subsidies); and ii) removing farm exit barriers.

2017

Alexandra J., 2017 Risks, uncertainty and climate confusion in the MDB reforms –Water Economics and Policy, Vol. 3, No. 3 (2017) 1650038 DOI: 10.1142/S2382624X16500387

Risks and uncertainties arising from climate change are increasingly recognised as significant challenges for water governance. To support adaptive approaches critical examinations of water policy practices and rationalities are needed. This paper focuses on the treatment of climate change in Australia's Murray Darling Basin reforms over the past decade. While the MDB faces potentially significant drying trends due to climate change, no reductions in future water availability due to climate change were formalised in the 2012 Basin Plan – a regulatory instrument agreed to by Australia's National Parliament. The background, key dimensions and possible reasons for this decision are examined. Possible reasons for not formally reducing water deemed available in the future include the complexity and uncertainty of climate science, the cultural construction of "climate normal" based on long-term averages, and institutional settings that reinforce dominant "hydro-logical" approaches and rationalities. Minimising the political, legal and financial consequences of attributing reductions in water allocations to climate change are also potential reasons. The case of the Murray Darling Basin, as outlined in this paper, demonstrates some of the ways climate change is a causing systemic challenges for adaptive water governance, and that innovative approaches need to be embraced, including better processes for institutionalising science/policy integration.

Capon, S. J. and T. R. Capon (2017). An Impossible Prescription: Why Science Cannot Determine Environmental Water Requirements for a Healthy Murray-Darling Basin. Water Economics and Policy 03(03), 1650037. Pay per view with link: https://www.worldscientific.com/doi/10.1142/S2382624X16500375

The concept of environmental water requirements (EWRs) is central to Australia's present approach to water reform. Current decision-making regarding environmental water relies strongly on the notion that EWRs necessary to meet targets associated with ecological objectives for asset sites can be scientifically defined, thus enabling the ecological outcomes of alternative water management scenarios to be evaluated in a relatively straightforward fashion in relation to these flow thresholds or targets. We argue, however, that the ecological objectives and targets currently underpinning the development of EWRs in the Murray-Darling Basin are insufficient to permit the identification of exact water requirements or flow thresholds. Because of the dynamic and heterogeneous nature of the Murray-Darling Basin and the myriad ways in which it is valued by people, we also assert that it is unlikely that adequate ecological objectives and targets from which to determine EWRs could ever be formulated. We suggest that the current emphasis on the concept of EWRs in environmental water planning conflates science and values, perpetuating a "how much is enough?" myth whereby the significance of the social, cultural and political dimension in environmental decision-making is diminished. We support an alternative paradigm in which the contribution of ecological science to water policy and management decisions focuses on understanding ecological responses of water-dependent ecosystems and their biota to alternative management scenarios and linking these responses to the ecosystem services and human values which they support.

Connell, D., 2017. Arguing the case to include a wider range of stakeholders in the Murray-Darling policy process Water Economics and Policy, 03, 1650040 (2017) [20 pages] https://doi.org/10.1142/S2382624X16500405

Implementation of water reform in the Murray–Darling Basin has stalled. The principles remain in legislation, but government priorities are increasingly focused on irrigation-based agriculture rather than the comprehensive range of stakeholders with a legitimate interest in decisions about the future of the MDB. The negotiations required to gain parliamentary approval of the MDB Basin Plan in 2012 resulted in extensive concessions. Some have seriously damaged its integrity as a reform package. Within this now fragmented policy framework, the utility of important individual components has been eroded. These include acceptance of the need for a comprehensive analytical framework able to take full account of costs and benefits, the precautionary principle, the beneficiary pays principle, consistent policies for assigning public benefit from public investment, the importance of a comprehensive whole-of-catchment framework for managing social and biophysical processes and the understanding that serious water reform requires change in the cultural values related to the water-human relationship. As a result of these compromises, the capacity of the Basin Plan framework to manage future climate change challenges and development pressures is in doubt. Can this trend be reversed? The paper argues for a revitalization of the public policy process to bring in a wider range of stakeholders and expose decision making to more rigorous assessment. To help achieve this goal, control over a substantial proportion of the environmental water entitlements acquired by the national government should be devolved to elected regional bodies (who would have to work within auditing guidelines). This would stimulate community involvement by providing a substantial activity that would make engagement worthwhile.

Horne, J. 2017. The politics of water reform and environmental sustainability in the Murray–Darling Basin. Water International, 42:8, 1000-1021, DOI: 10.1080/02508060.2017.1412201

This paper examines three actions by national and state governments – the role of the Cap, the Living Murray (TLM) and the National Action Plan for Water Security/Water for the Future, embodying the Murray–Darling Basin (MDB) Plan – in the Murray–Darling Basin over a 20-year period. The three actions sought to address declining environmental conditions through water policy reform. All were significant in their own way, but only the third offers the prospect of improving environmental outcomes. Taken together, the case studies illustrate that in real life and in complex, multilevel policy-making, politics is central to water policy decision-making.

Nauges, C., Wheeler, S. 2017. The complex relationship between households' climate change concerns and their water and energy mitigation behaviour. Ecological Economics 141, pp. 87-94.

This study analyses household survey data on water and energy climate change mitigation behaviour from eleven OECD countries, and provides new evidence of a complex relationship between climate change concerns and mitigation behaviour. Results confirm other studies that climate change concerns positively influence specific mitigation actions. However we also find evidence that this relationship may be more complex in the sense that adoption of mitigation behaviour may negatively feedback on households' climate change concerns. This effect more likely occurs in 'environmentally-motivated' households. Conversely, economic incentives in driving energy and water mitigation work better in non-environmentally-motivated households. This highlights that a portfolio of policies is needed to drive mitigation behaviour.

Settre, C., Connor, J., Wheeler, S.A. 2017. Reviewing the Treatment of Uncertainty in Hydro-economic Modeling of the Murray–Darling Basin, Australia. Water Economics and Policy 03(03), pp. 1650042.

Hydro-economic modeling is the combination of economic principles and hydrological modeling to achieve a more integrated representation of water resource management. In the Murray–Darling Basin (MDB), hydro-economic modeling has been widely used to analyze and inform basin-wide water policy. A growing but uneven literature base has prompted this review of MDB hydro-economic studies published over the past three decades to identify innovations and avenues for advancement. We focus particularly on the treatment of uncertainty, which is inherent in all modeling. While consideration of uncertainty is increasing in prominence, our review indicates the robust treatment of epistemic and stochastic uncertainty have not been fully integrated in the hydro-economic modeling literature. When hydro-economic modeling results are used to inform policy, treatment of uncertainty has both technical and political implications. We conclude that the methodological rigor of MDB hydro-economic modeling can be vastly improved with greater attention to quantifying, reducing and communicating uncertainties inherent in the modeling of water resources.

Settre, C., Wheeler, S. 2017. A century of intervention in a Ramsar wetland - the case of the Coorong, Lower Lakes and Murray Mouth. Australasian Journal of Environmental Management 24(2), pp. 163-183.

Coastal wetlands are among the more valuable ecosystems on the planet. Managing wetlands to maintain ecosystem function is physically and politically challenging, especially during drought. Management of the Coorong, Lower Lakes and Murray Mouth has been characterised by a sequence of active and reactive infrastructure interventions, first as active interventions to supply consumptive water demands and more recently as reactive emergency drought responses. However, infrastructure solutions are not necessarily synonymous with achieving sustainability. Infrastructure

interventions have occurred at significant public expenditure and high opportunity cost. Greater attention to demand-based management strategies including time-limited environmental water acquisitions and state-based environmental water holdings provides an alternative to future infrastructure reliance. There is also considerable scope for greater provision of cultural flows and engagement with traditional owners to improve ecological condition.

Wheeler, S., Hatton MacDonald, D., Boxall, P. 2017. Water policy debate in Australia: understanding the tenets of stakeholders' social trust. Land Use Policy 63, pp. 246-254.

The increasing physical and economic scarcity of water due to increasing societal demands and climate change will require worldwide water policy reform. Water reform is an area of public policy fraught with polarised positions regarding community and environmental welfare. As opposition to water policy reform becomes entrenched, transaction costs increase. Nowhere is this more evident than the controversy surrounding, and irrigators' opposition to, the Murray-Darling Basin Plan in Australia. This study sought to understand irrigators' trust issues and why they feel the way they do towards water reform, though a best-worst survey methodology and regression analysis. The results suggest that irrigators believe they are shouldering a fair share of the water reform burden. Lack of trust in the national water agency and the federal government is associated with irrigator location, age and climate change disbelief. Findings support the recent push for more localised water decision-making to promote social trust.

Wheeler, S., Loch, A., Crase, L., Young, M., Grafton, R. 2017. Developing a water market readiness assessment framework. Journal of Hydrology 552, pp. 807-820.

Water markets are increasingly proposed as a demand-management strategy to deal with water scarcity. Water trading arrangements, on their own, are not about setting bio-physical limits to water-use. Nevertheless, water trading that mitigates scarcity constraints can assist regulators of water resources to keep water-use within limits at the lowest possible cost, and may reduce the cost of restoring water system health. While theoretically attractive, many practitioners have, at best, only a limited understanding of the practical usefulness of markets and how they might be most appropriately deployed. Using lessons learned from jurisdictions around the world where water markets have been implemented, this study attempts to fill the existing water market development gap and provide an initial framework (the water market readiness assessment (WMRA)) to describe the policy and administrative conditions/reforms necessary to enable governments/jurisdictions to develop water trading arrangements that are efficient, equitable and within sustainable limits. Our proposed framework consists of three key steps: 1) an assessment of hydrological and institutional needs; 2) a market evaluation, including assessment of development and implementation issues; and 3) the monitoring, continuous/review and assessment of future needs; with a variety of questions needing assessment at each stage. We apply

the framework to three examples: regions in Australia, the United States and Spain. These applications indicate that WMRA can provide key information for water planners to consider on the usefulness of water trading processes to better manage water scarcity; but further practical applications and tests of the framework are required to fully evaluate its effectiveness.

Wheeler, S., Zuo, A. 2017. The impact of drought and water scarcity on irrigator farm exit intentions in the Murray-Darling Basin. Australian Journal of Agricultural and Resource Economics 61(3), pp. 1-20.

Drought and future water scarcity in the Murray–Darling Basin (MDB) will continue to restructure the irrigation industry in the coming decades. There has been little work conducted in Australia that has modelled farm exit or exit intention. ABARES farm survey data were used to model irrigators' farm exit intentions across the southern MDB from 2006 to 2013. In particular, we examined the hypotheses that drought and water scarcity positively impacted on farm exit intentions and that it is the poorest performing farms that intend to exit in times of drought. Results revealed that water scarcity impacts varied considerably. There was only weak evidence to suggest that irrigators' exit intentions were higher in times of drought, but there was stronger evidence to support the influence of a lagged water scarcity impact on farm exit intentions during periods of nondrought (e.g. intending to exit at times when the property market was less depressed). There was also strong evidence that poorer performing farms (measured by rates of return and higher debt over a certain level) were more likely to have exit intentions in drought periods, but not necessarily so in nondrought periods. Older age is the most consistent predictor of farm exit intentions across all industries, though it was most significant in drought periods.

Williams, J. 2017. Water reform in the Murray–Darling Basin: a challenge in complexity in balancing social, economic and environmental perspectives. Journal and Proceedings of the Royal Society of New South Wales 150: 68–92.

The Murray–Darling Basin is a very good example of a complex system. It is a complex system of environmental function in which snow melt and winter rain feed the south, while subtropical summer dominant rainfall feeds the northern rivers. It is a complex system of re-engineering and readjustment of the natural and built infrastructure. It is also a complex system of human endeavour facilitating community adjustment and development, strongly driven by extremely high climatic variability and thus agricultural productivity, which is exposed to highly variable prices and demand for its produce. Then across the top of all this complexity is climate change, which is expected to impact further on increased climate variability. Thrust upon these complex interacting, biophysical, economic and social systems has been public policy in water reform to address the large over-extraction of water for agriculture from the rivers and groundwater aquifers of the Basin. Amidst all this complexity, public policy sought to return stressed rivers and groundwater systems to healthy conditions where floodplains, wetlands and riverine ecosystems regain a significant part of their ecological and

hydrological function. Over $11 billion will be spent on the Basin Plan—a complex system in public policy and we are only in the middle of it. Despite this huge expenditure, the policy choices and processes are yet to show evidence that public benefit in a healthy river will be achieved.

2016

Abel, N., Wise, R.M., Colloff, M.J., Walker, B.H., Butler, J.R.A., Ryan, P., Norman, C., Langston, A., Anderies, J.M., Gorddard, R., Dunlop, M. and O'Connell, D. 2016. Building a resilient pathway towards transformation when "no-one is in charge": insights from Australia's Murray-Darling Basin. Ecology and Society 21(2), 23. http://dx.doi.org/10.5751/ES-08422-210223

Climate change and its interactions with complex socioeconomic dynamics dictate the need for decision makers to move from incremental adaptation toward transformation as societies try to cope with unprecedented and uncertain change. Developing pathways toward transformation is especially difficult in regions with multiple contested resource uses and rights, with diverse decision makers and rules, and where high uncertainty is generated by differences in stakeholders' values, understanding of climate change, and ways of adapting. Such a region is the Murray-Darling Basin, Australia, from which we provide insights for developing a process to address these constraints. We present criteria for sequencing actions along adaptation pathways: feasibility of the action within the current decision context, its facilitation of other actions, its role in averting exceedance of a critical threshold, its robustness and resilience under diverse and unexpected shocks, its effect on future options, its lead time, and its effects on equity and social cohesion. These criteria could potentially enable development of multiple stakeholder-specific adaptation pathways through a regional collective action process. The actual implementation of these multiple adaptation pathways will be highly uncertain and politically difficult because of fixity of resource-use rights, unequal distribution of power, value conflicts, and the likely redistribution of benefits and costs. We propose that the approach we outline for building resilient pathways to transformation is a flexible and credible way of negotiating these challenges.

Baldwin, D.S., Colloff, M.J., Mitrovic, S., Bond, N.R. and Wolfenden, B. 2016. Restoring dissolved organic carbon subsidies from floodplains to lowland river food webs: a role for environmental flows? Marine and Freshwater Research 67, 1387–1399. http://dx.doi.org/10.1071/MF15382

Environmental flows are managed events in river systems designed to enhance the ecological condition of aquatic ecosystems. Although not traditionally seen as important in lowland rivers, such as those of the southern Murray-Darling Basin, there is mounting evidence that terrestrial subsidies can be an important energy source in aquatic metazoan food webs. We argue that the apparent lack of importance of terrestrial subsidies to many lowland river food webs may reflect an artefact resulting from historical anthropogenic changes to lowland river–floodplain ecosystems, including the loss of lateral connectivity between rivers and their floodplains, changes in floodplain land use and carbon stores, and loss of sites of transformation within the main channel. The loss of floodplain subsidies to the main river channel can be partially redressed using environmental flows; however, this will require mimicking important aspects of natural high-flow events that have hitherto been overlooked when targeting environmental flows to a limited suite of biota. We suggest that key biotic targets for environmental flow releases may not be achievable unless river–floodplain subsidies are sufficiently restored. Environmental flows can go some way to addressing this shortfall, but only if floodplain subsidies to river channels are explicitly included in the design and management of

environmental flows.

Bark, R., Colloff, M.J., Hatton MacDonald, D., Pollino, C.A., Jackson, S. and Crossman, N.D. (2016) Integrated valuation of ecosystem services obtained from restoring water to the environment in a major regulated river basin. *Ecosystem Services* 22, 381–391. http://dx.doi.org/10.1016/j.ecoser.2016.08.002

Evaluating different environmental policy options requires extensive modelling of biophysical outcomes linked with metrics to measure the magnitude and distribution of societal impacts. An integrated ecosystem services (ES) assessment has potential to provide salient, credible and legitimate information for environmental policy- and decision-makers. Here we present an ecosystem services assessment of the Murray-Darling Basin Plan, an Australian Government initiative to restore aspects of river flow regimes to improve the ecological condition of floodplains, rivers and wetlands in south-eastern Australia. We link the effect of policy intervention – reduced limits on water diversions for irrigation – to modeled changes in river flow and flood regimes, then to changes in ecological responses of flow-dependent ecosystems, assessed against a Baseline scenario. The final steps link changes in ecosystem condition and responses to marginal changes in the supply of ES and the monetary valuation of those services at the whole-of-basin scale. We show that the supply of most ES improves as a consequence of increases in water availability for the environment. For each ES assessed we assign a confidence category for both the ecological response modelling and the economic valuation steps and discuss other tools (review and outreach) to enhance legitimacy and credibility.

Colloff, M.J., Lavorel, S., Wise, R.M., Dunlop, M., Overton, I.C. and Williams, K.J. 2016. Adaptation services of floodplains and wetlands under transformational climate change. Ecological Applications 26, 1003–1017. http://dx.doi.org/10.1890/15-0848

Adaptation services are the ecosystem processes and services that benefit people by increasing their ability to adapt to change. Benefits may accrue from existing but newly used services where ecosystems persist or from novel services supplied following ecosystem transformation. Ecosystem properties that enable persistence or transformation are important adaptation services because they support future options. The adaptation services approach can be applied to decisions on trade-offs between currently valued services and benefits from maintaining future options. For example, ecosystem functions and services of floodplains depend on river flows. In those regions of the world where climate change projections are for hotter, drier conditions, floods will be less frequent and floodplains will either persist, though with modified structure and function, or transform to terrestrial (flood-independent) ecosystems. Many currently valued ecosystem services will reduce in supply or become unavailable, but new options are provided by adaptation services. We present a case study from the Murray-Darling Basin, Australia, for operationalizing the adaptation services concept for floodplains and wetlands. We found large changes in flow and flood regimes are likely under a scenario of +1.6°C by 2030, even with additional water restored to rivers under the proposed Murray-Darling Basin Plan. We predict major changes to floodplain ecosystems, including contraction of riparian forests and woodlands and expansion of terrestrial, drought-tolerant vegetation communities. Examples of adaptation services under this scenario include substitution of irrigated agriculture with dryland cropping and floodplain grazing; mitigation of damage from

rarer, extreme floods; and increased tourism, recreational, and cultural values derived from fewer, smaller wetlands that can be maintained with environmental flows. Management for adaptation services will require decisions on where intervention can enable ecosystem persistence and where transformation is inevitable. New ways of managing water that include consideration of the increasing importance of adaptation services requires major changes to decision-making that better account for landscape heterogeneity and large-scale change rather than attempting to maintain ecosystems in fixed states.

Douglas, E., Wheeler, S., Smith, D., Overton, I., Gray, S., Doody, T., Crossman, N. 2016. Using mental-modelling to explore how irrigators in the Murray-Darling Basin make water-use decisions. Journal of Hydrology Regional Studies 6, pp. 1-12.

Study region: Water stress and over-allocation are at the forefront of water management and policy challenges in Australia, especially in the Murray–Darling Basin (MDB). Because irrigated agriculture is a major social and economic component of the MDB, farmer decision-making plays a major role in water sustainability in the region. Study focus: This study used a fuzzy cognitive mapping methodology, 'mental modeling', to understand the perceived constraints of irrigator water-use decisions in the MDB, for two different types of irrigation: permanent and annual crops. The approach elicits and documents irrigator insights into the complex and networked nature of irrigation water use decisions in relation to farm-based dynamics. New hydrological insights for the region: Results suggest support for greater local and irrigator involvement in water management decisions. Many, if not most, of the irrigators understood the need for, or at least the inevitability of, governmental policies and regulations. However, a lack of accountability, predictability, and transparency has added to the uncertainty in farm-based water decision-making. Irrigators supported the concept of environmental sustainability, although they might not always agree with how the concept is implemented. The mental modelling approach facilitated knowledge sharing among stakeholders and can be used to identify common goals. Future research utilizing the mental modelling approach may encourage co-management and knowledge partnerships between irrigators, water managers and government officials.

Grafton, R.Q. 2016. Water Reform and Planning in the Murray-Darling Basin, Australia. Water Economics and Policy 3, pp. 1702001.

The paper reviews key findings from a special issue on the Murray-Darling Basin that includes an overview of water planning in the Basin, a critical evaluation of key aspects of water reform, the science behind Basin planning decisions and the challenges of policy making. The paper concludes with six key insights for water reform and water planning at a basin scale.

Marshall, G.R. and Alexandra, J. 2016. Institutional path dependence and environmental water recovery in Australia's Murray-Darling Basin. Water Alternatives 9(3): 679-703.

The concept of institutional path dependence offers useful ways of understanding the trajectories of water policy reforms and how past institutional arrangements, policy paradigms and development patterns constrain current and future choices and limit institutional

adaptability. The value of this concept is demonstrated through an analysis of environmental water recovery in Australia's Murray-Darling Basin, where while significant water volumes have been reallocated to the environment, the costs have also been significant. While there are significant lessons from the Australian experience, attempts to emulate the approach involve substantive risks and may be prohibitively costly for less wealthy nations. Context-specific institutional analysis is emphasised as fundamental to water reform and critical for reform architecture and sequencing. A key finding is that while crisis can provide powerful catalysts for institutional innovation, institutional path dependence in the absence of active and disruptive policy entrepreneurs fosters a strong tendency to reinforce the status quo and limit innovation, potentially exposing social-ecological systems to greater shocks due to climate change and other sources of escalating uncertainty.

Grafton, R.Q., Horne, J., Wheeler, S. 2016. On the marketisation of water: evidence from the Murray-Darling Basin, Australia. Water Resources Management 30(3), pp. 913-926.

Policy makers will increasingly have to turn to water demand management in the future to respond to greater water scarcity. Water markets have long been promoted as one of the most efficient ways to reallocate water by economists, but have also been subject to much criticism due to their possible social, economic and environmental impacts. We engage with common critical perceptions of water markets by presenting first-hand evidence of their effects in the Murray-Darling Basin (MDB), Australia. Water markets in the MDB, as developed within an appropriate institutional framework and coupled with comprehensive water planning, have: (1) helped deliver improved environmental outcomes; (2) assisted irrigators' adaptation responses to climate risks, such as drought; (3) increased the gross valued added of farming; and (4) been regulated in ways to meet social goals. If water markets are embedded within fair and effective meta-governance and property right structures, the potential exists for marketisation to increase efficiency, promote fairness in terms of initial water allocations, and to improve environmental outcomes.

Haensch, J., Wheeler, S., Zuo, A., Bjornlund, H. 2016. The Impact of water and soil salinity on water market trading in the Southern Murray-Darling Basin. Water Economics and Policy 02(01), pp. 1-26.

Irrigators in the Murray–Darling Basin (MDB) of Australia face a salinity triple threat, namely: dryland salinity, surface-water, and groundwater salinity. Water trading has now been adopted to the point where it is a common adaptation tool used by the majority of irrigators in the Basin. This study uses a number of unique water market and spatial databases to investigate the association between the severity and extent of areas which suffer from salinity and permanent trade over time, holding other regional characteristics constant. It was found that larger volumes of permanent water were likely to be sold from areas suffering from higher dryland salinity. In addition, increases in the concentration of groundwater salinity was found to decrease volumes of surface-water entitlements sold, providing evidence that groundwater entitlements (where they

are viable substitutes) have been increasingly used as substitutes for surface-water entitlements in recent years. Other key influences on water sales included water market prices and net rainfall.

Hart, B.T. 2016. The Australian Murray–Darling Basin Plan: challenges in its implementation (part 1). International Journal of Water Resources Development 32:6, 819-834, DOI: 10.1080/07900627.2015.1083847

The latest in a set of major water reforms in the Australian Murray–Darling Basin occurred in November 2012 with completion of a new integrated water resources plan for the region (the Basin Plan). This occurred over a four-year period (2009–12) and was not without controversy. However, perhaps the most challenging part of this reform is occurring now with the implementation of the Basin Plan between 2012 and 2024. This paper discusses the key tasks to be undertaken by June 2016 and the main challenges in their implementation. A companion paper discusses the challenges in implementing the other tasks that need to be settled by 2024.

Hart, B.T. 2016. The Australian Murray–Darling Basin Plan: challenges in its implementation (Part 2). International Journal of Water Resources Development 32(6) , 835-852, DOI: 10.1080/07900627.2015.1084494

The most recent major water reform in the Australian Murray–Darling Basin occurred in November 2012 with the development of a new integrated water resources plan for the region (the Basin Plan). This occurred over a four-year period (2009–12). An equally challenging part of this reform is occurring now with the implementation of the Basin Plan between 2012 and 2024. This paper discusses the challenges in implementing the key tasks that must be completed in the longer term by 2024. A companion paper discusses the challenges in implementing the more immediate tasks that must be completed by June 2016

Horne, J. 2016. Water policy responses to drought in the MDB, Australia. Water Policy, 18 (S2): 28-51. https://doi.org/10.2166/wp.2016.012

This article reviews water policy responses to drought in Australia, focusing on the Murray-Darling Basin (MDB) during the two decades from 1997. This period, which includes the decade long Millennium drought, brought a much sharper focus to discussions of scarcity and value of water. The drought initially focused attention on rising salinity and environmental water availability, as action on both was supported by strong science, and resonated politically. The drought became a crisis in 2006. Short-term planning focused on ensuring communities did not run out of water. For the longer term, the national government responded by announcing a major package of reform measures addressing sustainability and underlying scarcity, and recognising climate change. The package strengthened MDB water market infrastructure, upgraded water resource planning and the ability of irrigators to manage their water assets more flexibly,

established new sustainable diversion limits and provided funding to ensure the environment received a larger share of basin water resources. But its completeness as a package can be attributed not only to the severity of drought, but also to political leadership, a disrupting strategy in the form of national legislation and a strong national budget that provided financial resources. The drought provided a crisis, but other ingredients were necessary to ensure effective action.

McGregor, H.M., Colloff, M.J. and Lunt, I.D. 2016. Did early logging or changes in disturbance regimes promote high tree densities in river red gum forests? Australian Journal of Botany 64, 530–538. http://dx.doi.org/10.1071/BT16025

Density of woody plants is thought to have increased in many ecosystems in Australia since European colonisation. Globally, there has been much debate as to whether this phenomenon is driven by the process of post-disturbance recovery – whereby historical logging resulted in the replacement of large, mature trees with smaller, younger trees – or by the process of encroachment – whereby cessation of disturbance events reduced the mortality of seedlings and saplings. We examined the extent to which historical changes in forest structure are compatible with each of these models. The study was conducted in river red gum *Eucalyptus camaldulensis* Dehnh. floodplain forest on the River Murray at Millewa Forest, southern New South Wales. We compared 'historical' (~1860s) stand structure to 'current' structure in 45 one-hectare quadrants randomly stratified between three forest productivity classes. Historical trees were determined by stumps or stags likely to have been cut during the late 1800s. Size and position of each historical and current tree was recorded, and used to calculate stem density, basal area, canopy cover and the area of the 'zone of influence' (the peripheral extent of the root zone). Current stand structure was vastly different from historical structure. Stem density has increased 9-fold, from a mean of 17 (historical) to 147 (current) trees ha^{-1}. However, basal area increased only slightly, from 13.0 to 15.3 m 2 ha^{-1}. Canopy cover increased substantially from 22.1 to 33.5% cover, as did zone of influence, from 55 to 81% cover. Evidence for both the post-disturbance recovery and encroachment hypotheses was found. The 9-fold increase in stem density between historical and current stands was attributable largely to the replacement of large trees with small trees, because basal area had increased only slightly (by 18%). However, the increase in basal area was associated with a substantial increase in canopy cover and area of the zone of influence, supporting the encroachment hypothesis. Regardless, the post-disturbance recovery hypothesis accounts for the bulk of changes in this river red gum forest.

Loch, A., Boxall, P., Wheeler, S. 2016. Using proportional modeling to evaluate irrigator preferences for market-based water reallocation. Agricultural Economics 47(4), pp. 387-398.

Irrigators' policy preferences for water reallocation programs usually take the form of proportional data, where one option will be relatively more or less favored than another in the composition of a government's total budget apportionment to address water reform. This study applies a zero-one inflated beta regression to model Murray–Darling

Basin irrigators' preferences for market-based water policy programs. Market-based arrangements are more likely to provide efficient solutions to water reallocation problems, particularly where future uncertainty and appropriate pricing induce irrigator preferences for such programs. Our modeling of drivers of irrigator preferences for government expenditure on market-based programs identified different determinants of zero (a corner solution) and proportional outcomes for the reallocation of Murray–Darling Basin water. In addition, the proportional modeling identifies some variables (namely, state regional influences, the type of farm production and recent debt, low income, or water allocation stressors) that increase engagement with market-based programs. Interestingly, while price variables are important and statistically significant, they appear to be less relevant to program engagement than other influences.

Nauges, C., Wheeler, S., Zuo, A. 2016. Elicitation of irrigators' risk preferences from observed behaviour. Australian Journal of Agricultural and Resource Economics 60(3), pp. 442-458.

Water trading in the Murray–Darling basin of Australia has developed to the point where it is a common adaptation tool used by irrigators, making it an apt case study to elicit the marginal value of irrigation water and irrigators' risk preferences in two key industries with differing levels of water dependence. Our data come from large-scale and representative surveys of irrigated broadacre and horticultural farms in the Murray–Darling basin over a 6-year period. The marginal contribution of irrigation water to profit is estimated at $547 and $61 on average in horticulture and broadacre, respectively. Horticultural irrigators are found to be averse to the risk of large losses (downside risk) while broadacre irrigators are averse to the variability (variance) of profit.

Wen, L., Saintilan, N., Reid, J.R.W. and Colloff, M.J. 2016. Changes in the distribution of waterbirds following the breaking of prolonged drought reflect habitat availability in coastal and inland regions. Ecology and Evolution 6, 6672–6689. http://dx.doi.org/10.1002/ece3.2091

Provision of suitable habitat for waterbirds is a major challenge for environmental managers in arid and semi-arid regions with high spatial and temporal variability in rainfall. It is understood in broad terms that to survive waterbirds must move according to phases of wet–dry cycles, with coastal habitats providing drought refugia and inland wetlands used during the wet phase. However, both inland and coastal wetlands are subject to major anthropogenic pressures, and the various species of waterbird may have particular habitat requirements and respond individualistically to spatiotemporal variations in resource distribution. A better understanding of the relationships between occurrence of waterbirds and habitat condition under changing climatic conditions and anthropogenic pressures will help clarify patterns of habitat use and the targeting of investments in conservation. We provide the first predictive models of habitat availability between wet and dry phases for six widely distributed waterbird species at a large spatial scale (NSW Murray-Darling Basin and wetlands east of the Great

Dividing Range). We first test the broad hypothesis that waterbirds are largely confined to coastal regions during a dry phase. We then examine the contrasting results among the six species, which support other hypotheses erected on the basis of their ecological characteristics. There were large increases in area of suitable habitat in inland regions in the wet year compared with the dry year for all species, ranging from 4.14% for Australian White Ibis to 31.73% for Eurasian Coot. With over half of the suitable habitat for three of the six species was located in coastal zones during drought, our study highlights the need to identify and conserve coastal drought refuges. Monitoring of changes in extent and condition of wetlands, combined with distribution modeling of waterbirds, will help support improvements in the conservation and management of waterbirds into the future.

2015

Colloff, M.J., Caley, P., Saintilan, N., Pollino, C.A. and Crossman, N.C. 2015. Long-term ecological trends of flow-dependent ecosystems in a major river basin. Marine and Freshwater Research 66, 957–969. http://dx.doi.org/10.1071/MF14067

The case for restoring water to the environment in the Murray–Darling Basin, Australia is based mainly on condition assessments, although time series provide valuable information on trends. We assessed trends of 301 ecological time series (mean 23 yrs., range 1905-2013) in two categories: (1) 'population' (abundance/biomass/extent) and (2) 'non-population' (condition/occurrence/composition). We analysed trends using log.-linear regression, accounting for observation error only, and a state-space model that accounts for observation error and environmental 'noise'. Of the log-linear series (n = 239), 50 (22%) showed statistically significant decline, but 180 (78%) showed no trend. For state-space series (n = 197) one increased, but others were stable. Distribution of median exponential rates of increase (r) indicated a small, declining trend, though 35-39% of the series were positive. Our analysis only partly supports prevailing assumptions of recent ecological decline in the Murray-Darling Basin. The pattern is of fluctuating stability, with declines during droughts and recovery post-flood. The overall trend from our meta-analysis is consistent with a pattern of historical decline to a hybrid ecosystem followed by slow, recent decline for some components and stability for others, with considerable variation in trends of specific ecological components: in short, there are ecological 'winners' and 'losers'.

Doody, T.M., Colloff, M.J., Davies, M., Koul, V., Benyon, R.G. and Nagler, P.L. 2015. Quantifying water requirements of riparian river red gum (Eucalyptus camaldulensis) in the Murray-Darling Basin, Australia – implications for environmental water allocations. Ecohydrology 8, 1471–1487. http://dx.doi.org/10.1002/eco.1598

Water resource development and drought have altered river flow regimes, increasing average flood return intervals across floodplains in the Murray-Darling Basin, Australia, causing health declines in riparian river red gum (*Eucalyptus camaldulensis*) forests and woodlands. Environmental flow allocations helped to alleviate water stress during the recent Millennium Drought (1997–2010), however, quantification of the flood frequency required to support healthy *E. camaldulensis* communities is still needed. We quantified water requirements of *E. camaldulensis* for two years across a flood gradient (trees inundated at frequencies of 1:2, 1:5 and 1:10 years) at Yanga National Park, New South Wales to help inform management decision-making and design of environmental flows. Sap flow, evaporative losses and soil moisture measurements were used to determine transpiration, evapotranspiration and plant-available soil water before and after flooding. A formula was developed using plant-available soil water post-flooding and average annual rainfall, to estimate maintenance time of soil water reserves in each flood frequency zone. Results indicated that soil water reserves could sustain 1:2 and 1:5 trees for 15 months and six years, respectively. Trees regulated their transpiration rates, allowing them to persist within their flood frequency zone, and showed reduction

in active sapwood area and transpiration rates when flood frequencies exceeded 1:2 years. A leaf area index of 0.5 was identified as a potential threshold indicator of severe drought stress. Our results suggest environmental water managers may have greater flexibility to adaptively manage floodplains in order to sustain *E. camaldulensis* forests and woodlands than has been appreciated hitherto.

Kingsford, R.T., Mac Nally, R., King, A., Walker, K.F., Bino, G., Thompson, R., Wassens, S., and Humphries, P. (2015) Opinion. A commentary on 'Long-Long-term ecological trends of flow-dependent ecosystems in a major regulated river basin' by Mathew J. Colloff, Peter Caley, Neil Saintilan, Carmel A. Pollino and Neville D. Crossman. *Marine and Freshwater Research*. 66, 970-980. doi:10.1071/MF15185

Colloff et al. in Marine and Freshwater Research (http:dx.doi.org/10.1071/MF14067) examined time-series data for flow-dependent vegetation, invertebrates, fish, frogs, reptiles and waterbirds in the Murray–Darling Basin, 1905–2013. They concluded that temporal patterns fluctuated, declining during droughts and recovering after floods. They suggested that major changes in land use in the late 19th century permanently modified these freshwater ecosystems, irretrievably degrading them before major water diversions. Restoring water to the environment might then be interpreted as not addressing biotic declines. We argue that their conclusions are inadequately supported, although data quality remains patchy and they neglected the influence of hydrology and the timing and extent of water resource development. We are critical of the lack of adequate model specification and the omission of statistical power analyses. We show that declines of native flow-dependent flora and fauna have continued through the 20th and early 21st centuries, in response to multiple factors, including long-term changes in flow regimes. We argue that flow-regime changes have been critical, but not in isolation. So, returning water to the environment is a prerequisite for sustained recovery but governments need to improve monitoring and analyses to adequately determine effectiveness of management of the rivers and wetlands of the Murray–Darling Basin.

Lavorel, S., Colloff, M.J., McIntyre, S., Doherty, M., Murphy, H., Metcalfe, D., Dunlop, M., Williams, R., Wise, R.M. and Williams, K. 2015. Ecological mechanisms underpinning climate adaptation services. Global Change Biology 21, 12–31. http://dx.doi.org/10.1111/gcb.12689

Ecosystem services are typically valued for their immediate material or cultural benefits to human wellbeing, supported by regulating and supporting services. Under climate change, with more frequent stresses and novel shocks, 'climate adaptation services', are defined as the benefits to people from increased social ability to respond to change, provided by the capability of ecosystems to moderate and adapt to climate change and variability. They broaden the ecosystem services framework to assist decision makers in planning for an uncertain future with new choices and options. We present a generic framework for operationalising the adaptation services concept. Four steps guide the identification of intrinsic ecological mechanisms that facilitate the maintenance and

emergence of ecosystem services during periods of change, and so materialise as adaptation services. We applied this framework for four contrasted Australian ecosystems (tropical & sub-tropical littoral rainforests, Murray-Darling Basin floodplains, temperate grassy woodlands and south-eastern montane forests). Comparative analyses enabled by the operational framework suggest that adaptation services that emerge during trajectories of ecological change are supported by common mechanisms: vegetation structural diversity, the role of keystone species or functional groups, response diversity and landscape connectivity, which underpin the persistence of function and the reassembly of ecological communities under severe climate change and variability. Such understanding should guide ecosystem management towards adaptation planning.

Nikolakis, W. and Grafton, R.Q. 2015. Indigenous communities and climate change: a Recognition, Empowerment and Devolution (RED) framework in the Murray-Darling Basin, Australia. Journal of Water and Climate Change 7(1), pp. 169-183.

This study draws on in-depth interviews with Indigenous leaders and elders across the Murray-Darling Basin in relation to climate variability and over-extraction of water resources. Interviewees identified systematic barriers that entrench vulnerability of Indigenous Peoples. Building on the insights of respondents, a Recognition-Empowerment-Devolution framework is developed to support pathways for climate adaptation.

Steinfeld, C. M. M., Kingsford, R. T., Webster, E. C., & Sharma, A. 2015. A simulation tool for managing environmental flows in regulated rivers. *Environmental Modelling and Software, 73,* 117-132. doi:10.1016/j.envsoft.2015.08.006

Environmental flows provide river flow regimes to restore and conserve aquatic ecosystems, creating considerably different demands compared to conventional water extraction. With increasing incorporation of environmental flows in water planning worldwide, governments require decision support tools to manage these flows in regulated rivers. We developed the Environmental Water Allocation Simulator with Hydrology (eWASH), a fast, flexible and user-friendly scenario-based hydrological modelling tool, supporting environmental flow management decisions for single- or multi-reservoir systems. Environmental flow demands and management rules are easily specified via the graphical user interface, and batch processing functions aid in uncertainty assessment. eWASH modelled main processes of complex regulated rivers and the tool is widely applicable. We calibrated eWASH for the Gwydir and Macquarie Rivers of Australia's Murray–Darling Basin. Modelled monthly environmental flow allocations exhibited Nash–Sutcliffe efficiencies of 0.55 for the Gwydir and 0.72 for the Macquarie catchments respectively when validated.

Thomas, R.F., Kingsford, R.T., Lu, Y., Cox, S.J., Sims, N.C. and Hunter, S.J. 2015. Mapping inundation in a heterogeneous floodplain wetland, the Macquarie Marshes, using Landsat Thematic Mapper. *Journal of Hydrology* 524: 194-213.

Flood dependent aquatic ecosystems worldwide are in rapid decline with competing demands for water. In Australia, this is particularly evident in the floodplain wetlands of semi-arid regions (e.g. the Macquarie Marshes), which rely on highly variable flooding from river flows. Environmental flows mitigate the impacts of river regulation, inundating floodplains, thereby rehabilitating degraded habitats. Mapping flooding patterns is critical for environmental flow management but challenging in large heterogeneous floodplains with variable patterns of flooding and complex vegetation mosaics. We mapped inundation in the Macquarie Marshes, using Landsat 5 TM and Landsat 7 ETM+ images (1989–2010). We classified three inundation classes: water, mixed pixels (water, vegetation, soil) and vegetation (emergent macrophytes obscuring inundation), merged to map inundated areas from not-inundated areas (dry land). We used the Normalised Difference Water Index ($NDWI_{B2/B5}$), masked by the sum of bands 4, 5, and 7 (sum457), to detect water and mixed pixels. Vegetation was classified using an unsupervised classification of a composite image comprising two dates representing vegetation senescence and green growth, transformed into two contrasting vegetation indices, NDVI and $NDI_{B7/B4}$. We assessed accuracy using geo-referenced oblique aerial photography, coincident with Landsat imagery for a small and large flood, producing respective overall accuracies of inundated area of 93% and 95%. Producer's and user's accuracies were also high (94–99%). Confusion among inundation classes existed but classes were spectrally distinct from one another and from dry land. Inundation class areas varied with flood size, demonstrating the variability. Inundation extent was highly variable (683–206,611 ha). Floods up to 50,000 ha were confined to the north and south wetland regions. Connectivity to the east region only occurred when flooding was greater than 51,000 ha. Understanding the spatiotemporal dynamics of inundation is critical for quantifying the environmental flow requirements across the suite of biota in the Ramsar-listed Macquarie Marshes.

Wheeler, S.A., Zuo, A., Loch, A. 2015. Watering the farm: comparing organic and conventional irrigation water use in the Murray-Darling Basin, Australia. Ecological Economics 112, pp. 78-85.

This study investigates the role that certified-organic farming systems play in irrigation water-use in the Murray–Darling Basin, where large-scale government policy has focussed on returning water from irrigation to key ecological sites. Information from Australia's agricultural census in 2011, as well as a specialized irrigation farm survey sample of 1499 observations, compared certified-organic and conventional irrigation water-use. Census and survey results found some evidence for some industries that organic irrigation farms are less water-use efficient (i.e. water use divided by tonne of output), but little significant difference in water-used per irrigated hectare was found overall (although for some industry sectors—notably horticulture—organic farms use less water on a per-hectare basis). After controlling for self-selection, regression model results also indicated that organic irrigation farms use less absolute water than

conventional farms; use a smaller percentage of water received; and are more water-use productive (i.e. water use divided by net farm income). A lack of significance for the importance of irrigation infrastructure adoption, plus the importance of water-use charges in reducing water demand, suggests a need for governments to reorientate irrigation policy towards more multi-layered and inclusive practices that promote better soil conditions and water management, rather than focussing on providing subsidies for technology adoption.

Zuo, A., Nauges, C., Wheeler, S. 2015. Farmers' exposure to risk and their temporary water trading. European Review of Agricultural Economics 42(1), pp. 1-24.

In this article, the role of water markets in helping farmers manage the risk of water shortage is studied. Using farm survey data from Australia's southern Murray–Darling Basin, one of the most active water markets in the world, we tested the relationship between farmers' exposure to risk and their decisions to purchase and sell water allocations (temporary water) on the market. Farmers experiencing higher variability in profit and facing more downside risk purchased greater volumes of water allocations in general. Purchasing water allocations on the market is found to be a risk-reducing strategy, in particular for farmers in the horticultural sector. There is only very weak evidence to support the notion that selling water allocations is associated with reduced risk exposure.

Zuo, A., Wheeler, S., Adamowicz, W., Boxall, P., Hatton-MacDonald, D. 2015. Measuring price elasticities of demand and supply of water entitlements based on stated and revealed preference data. American Journal of Agricultural Economics 98(1), pp. 314-332.

Estimates of price elasticities of water entitlements, known as permanent water or water rights in the United States, are complicated by data limitations and problems of endogeneity. To overcome these issues, we develop an approach to generate stated preference data and combine them with revealed preference data to estimate price elasticities from various types of water entitlement sales in the southern Murray-Darling Basin, Australia. Our results suggest that price elasticities of demand and supply of high security water entitlements are inelastic in the relevant market price range between AUD $1,700 to $2,100 per mega-liter, and that supply is relatively more inelastic than demand. For lower reliability water entitlements, the price elasticity of demand is estimated to be even more inelastic than high security water entitlements. The price elasticity of supply for general security water entitlements is similar to high security water entitlements, while the supply of low reliability water entitlements is extremely inelastic for our data set. The comparison between the stated and revealed preference data provides strong evidence of support for a data fusion approach, nevertheless, some differences in water sale preferences were found for irrigators choosing not to sell all of their water. The consistency of our results signals support for the use of this methodology in other water basins around the world.

Zuo, A., Wheeler, S.A., Boxall, P., Adamowicz, W.L., Hatton-MacDonald, D. 2015. Identifying water prices at which Australian farmers will exit Irrigation: results of a stated preference survey. Economic Record 91, pp. 109-123.

Among the measures taken by the Australian government to address one of the worst droughts on record in the Murray-Darling Basin, exit package issues have rarely been investigated. A stated preference survey was designed to identify the range of water prices required for irrigators to sell all their water entitlements and leave the irrigation industry. Farmer participation responses are generally price elastic. There are large regional differences in price elasticities, but within a region there are few differences based on subgroups of farmers.

2014

Acreman, M.C., Arthington, A.H., Colloff, M.J., Couch, C.A., Crossman, N., Dyer, F., Overton, I.C., Pollino, C., Stewardson, M.H. and Young, W.J. 2014. Environmental flows for natural, hybrid and novel riverine ecosystems in a changing world. Frontiers in Ecology and the Environment 21, 466–473. http://dx.doi.org/10.1890/130134

The term 'environmental flows' describes the quantities, quality, and patterns of water flows required to sustain freshwater and estuarine ecosystems and the ecosystem services they provide. Environmental flows may be achieved in a number of different ways, most of which are based on either (1) limiting alterations from the natural flow baseline to maintain biodiversity and ecological integrity or (2) designing flow regimes to achieve specific ecological and ecosystem service outcomes. We argue that the former practice is more applicable to natural and semi-natural rivers where the primary objective and opportunity is ecological conservation, such as the Paroo (Australia), Lambourn (UK), Doring (South Africa), Green (USA) and Mekong (Southeast Asia). The latter 'designer' approach is better suited to modified and managed rivers where return to natural conditions is no longer feasible and the objective is to maximize natural capital as well as support economic growth, recreation, or cultural history, such as the Goulburn (Australia), Itchen (UK), Orange (South Africa) and Connecticut (USA). This permits elements of ecosystem design and adaptation to environmental change. In a future characterized by altered climates and intensive regulation, where hybrid and novel aquatic ecosystems predominate, the designer approach may be the only feasible option. This conclusion stems from a lack of natural ecosystems from which to draw analogs and the need to support broader socioeconomic benefits and valuable configurations of natural and social capital.

Akter, S., Grafton, R.Q., Merritt, W.S. 2014. Integrated hydro-ecological and economic modelling of environmental flows: Macquarie Marshes, Australia. Agricultural Water Management 145, pp. 98-109.

This study provides a method to combine hydro-ecological response model outputs and nonmarket economic values of wetland inundation to estimate a unit price of environmental water. The approach is shown to help policy makers to assist in water reallocation across competing uses.

Bino. G., Steinfeld. C., Kingsford, R.T. (2014) Maximizing colonial waterbirds' breeding events using identified ecological thresholds and environmental flow management. *Ecological Applications* 24, 142-157.

Global wetland biodiversity loss continues unabated, driven by increased demand for freshwater. A key strategy for conservation management of freshwater systems is to maintain the quantity and quality of the natural water regimes, including the frequency and timing of flows. Formalizing an ecological model depicting the key ecological components and the underlying processes of cause and effect is required

for successful conservation management. Models linking hydrology with ecological responses can prove to be an invaluable tool for robust decision-making of environmental flows. Here, we explored alternative water management strategies and identified maximal strategies for successful longterm management of colonial waterbirds in the Macquarie Marshes, Australia. We modeled fluctuations in breeding abundances of 10 colonial waterbird species over the past quarter century (1986–2010). Clear relationships existed between flows and breeding, both in frequencies and total abundances, with a strong linear relationship for flows .200 GL. Thresholds emerged for triggering breeding events in all 10 species, but these varied among species. Three species displayed a sharp threshold response between 100 GL and 250 GL. These had a breeding probability of 0.5 when flows were .180 GL and a 0.9 probability of breeding with flows .350 GL. The remaining species had a probability greater than 0.5 of breeding with flows .400 GL. Using developed models, we examined the effects of five environmental flow management strategies on the variability of flows and subsequent likelihood of breeding. Management to different target volumes of environmental flows affected overall and specific breeding probabilities. The likelihood of breeding for all 10 colonial waterbirds increased from a regulated historical mean (6SD) of 0.36 6 0.09 to 0.53 6 0.14, an improvement of 47.5% 6 18.7%. Management of complex ecosystems depends on good understanding of the responses of organisms to the main drivers of change. Considerable opportunity exists for implementing similar frameworks for other ecosystem attributes, following understanding of their responses to the flow regime, achieving a more complete model of the entire ecosystem.

Bond, N., J. Costelloe, A. King, D. Warfe, P. Reich and S. Balcombe. 2014. Ecological risks and opportunities from engineered artificial flooding as a means of achieving environmental flow objectives. Frontiers in Ecology and the Environment 12(7), pp. 386-394. Pay per view with link: https://esajournals.onlinelibrary.wiley.com/doi/pdf/10.1890/130259

Restoration of floodplain ecosystems through the reinstatement of floods is often hampered by insufficient water as a result of competing human demands. An emerging alternative approach relies on floodplain infrastructure – such as levees, weirs, regulators, and pumps – to control water levels within floodplains without requiring landscape-scale overbank floods. This technique, albeit water efficient and capable of achieving some ecological targets, does not mimic the hydraulics, hydrodynamics, and lateral connectivity of natural floods. Engineering approaches like this may risk detrimental ecological outcomes, including reductions in biotic connectivity, river–floodplain productivity, and water quality, and thus may fail to support the range of ecological processes required to sustain healthy river–floodplain systems. Here, we review the potential benefits, risks, and mitigation options associated with engineered artificial flooding. Given the growing challenge of equitable water allocation, further research on and monitoring of engineered floods as a tool to sustain floodplain ecosystems are urgently required.

Colloff, M.J., Ward, K.A. and Roberts, J. 2014. Ecology and conservation of grassy wetlands dominated by spiny mud grass *Pseudoraphis spinescens* in the southern Murray-Darling Basin, Australia. Aquatic Conservation: Marine and Freshwater Ecosystems 24, 238–255. http://dx.doi.org/10.1002/aqc.2390

The distribution, ecosystem functions, conservation status and threatening processes of grassy wetlands are reviewed, with an emphasis on changes in flood regimes, water resource development and land use. The focus of the review is the ecology of spiny mud grass *Pseudoraphis spinescens* (R.Br.) Vickery, a C4 perennial aquatic grass. In Australia P. spinescens is a dominant species in grassy wetlands of the southern Murray–Darling Basin, the Wet–Dry Tropics and coastal New South Wales. Adapted to high irradiance and ambient temperatures, and to intermittent inundation for several months' duration, it is a rapidly growing (> 20 mm d-1), stoloniferous species, requiring prolonged, deep flooding interspersed with drying to achieve maximum growth and reproduction. *Pseudoraphis spinescens* can be considered an important species of grassy wetlands, providing food and habitat for waterfowl and other aquatic organisms through high primary productivity and nutrient cycling. Grassy wetlands in Australia are under threat from altered flood regimes, water resource development, grazing and land-use change. The provision of flood regimes that most closely match plant-specific water requirements represents the management action with the best prospect for the conservation of grassy wetlands on regulated rivers. A basic model for the water regime of *P. spinescens* grassy wetlands is presented to inform conservation and management, and stressing the need of such wetlands for large areas and rivers with high flow volumes that generate relatively deep prolonged flooding followed by drying out of the floodplain

Grafton, R.Q. and Horne, J. 2014. Water Markets in the Murray-Darling Basin. Agricultural Water Management, 145, pp. 61-71.

The paper reviews the history of water markets and recent water reforms in the Murray-Darling Basin. A detailed examination of the operation of water markets is provided in the Basin with a focus on: water trading rules, trade restrictions, gains from trade, water market information, inter-temporal market price responses, and the environmental benefits of trade.

Grafton, R.Q., Pittock, J., Williams, J., Jiang, Q., Quiggin, J. and Possingham, H. 2014. Water planning under hydro-climatic change in the Murray Darling Basin, Australia. Ambio 43(8), pp. 1082-1092.

Using actual data and previously published models that account for climate variability, the trade-off between water extractions and water essential to long-term ecological function of river systems is evaluated. Using data from the Murray-Darling Basin indicates that better water planning could: (1) increase the overall benefits of consumptive and non-consumptive water use; improve riparian environments under climate variability; and (3) be achieved with only small effects on the profits and gross

value of food and fibre production.

Horne, J. 2014. The 2012 Murray-Darling Basin Plan – issues to watch, International Journal of Water Resources Development, 30:1, 152-163, DOI: 10.1080/07900627.2013.787833

The Murray-Darling Basin Plan is now in place, marking a further significant step in water policy development and water reform in Australia's Murray-Darling Basin (MDB). While it is an important planning and regulatory framework in its own right, and one that should further enhance the efficiency and effectiveness of water markets in the MDB, implementation and enforcement of the plan and continued action by governments, communities and stakeholders on key reform commitments are required to ensure much-needed improvement in economic, social and environmental sustainability. This article outlines seven watch points that will affect whether the desired outcomes are achieved.

Loch, A., Wheeler, S., Boxall, P., Hatton-Macdonald, D., Adamowicz, W.L., Bjornlund, H. 2014. Irrigator preferences for water recovery budget expenditure in the Murray-Darling Basin, Australia. Land Use Policy 36, pp. 396-404.

This study presents results from a survey of southern Murray-Darling Basin irrigators about the percentage of funds they would allocate towards a variety of current and hypothetical trade-off choices for recovering environmental water. The findings, allowing for state-based differentials, suggest irrigators marginally prefer infrastructure expenditure above the sum of a set of market-based options (namely water entitlement purchasing, temporary water market products and exit-based packages). However, their infrastructure preference weighting is less than current budget expenditure, and use of market-based options has higher support from irrigators than current policy recognises. Further, analysis of past and current infrastructure and market-based water recovery expenditures reveals large price-per-megalitre disparities, which may be explained by diminishing marginal returns. Targeting expenditure in line with preferences of irrigators may result in increases in economic efficiency.

Ren, S. and Kingsford, R.T. 2014. Modelling impacts of regulation on flows to the Lowbidgee floodplain of the Murrumbidgee River, Australia. *Journal of Hydrology*, 519, 1660-1667.

Major wetland systems have been significantly affected by alteration of flows by dams and subsequent abstraction upstream around the world. Estimating the level of this impact is particularly difficult where there is high flow variability, such as dryland rivers in Australia. Such information remains critical for assessing ecological impacts to ecosystems (e.g. long-lived flood-dependent trees). To determine effects of flow reduction to a large floodplain wetland, we built statistical flow models, integrated flow

and flood modelling (IFFM), for the extensive and ecologically important Lowbidgee wetland, supplied by the Murrumbidgee River, based on local annual rainfall and upstream flow data (1880–2010). Large volumes of water are diverted upstream primarily for irrigation and to Australia's capital city, Canberra, achieved with 26 large dams: Burrinjuck Dam, Snowy Mountains Scheme dams and other upper catchment dams. We identified two periods using structural change analysis, low (before 1957) and high (after 1958) regulated periods; the year marked significant alteration in monthly flow at Redbank gauge, within the Lowbidgee wetland, after which most major dams were built. To determine differences in flow between these periods, we developed two models for three flow gauges on the lower Murrumbidgee River: Hay, Maude and Redbank. The latter two were within the floodplain wetland. The models were based on annual rainfall from stations in the upper catchment and flow, using LOESS and leave-one-out samples without overfitting. This flexible local polynomial regression method was a useful approach to modelling complex processes without theoretical models. The proposed low and high regulated models performed well using the goodness of fit (Nash–Sutcliffe coefficient of efficiency ⩾91.5%) and Kolmogorov–Smirnov test ($p > 0.9999$), i.e., there was no significant difference between the observed and fitted distributions of flow data at the Hay, Maude and Redbank flow gauges for both before 1957 and after 1958 periods. And these models were used to extend and predict annual low and high regulated flows from 1880 to 2010, where the Kolmogorov–Smirnov test ($p < 0.0001$) compared low and high regulated flow data, identifying significant reductions in long-term annual median flow between low and high river regulation within the lower Murrumbidgee (47.22% for the Maude and 52.58% for the Redbank flow gauges). Considerable degradation has occurred to floodplain during the period of high flow regulation.

Vivian, L., Godfree, R.C., Colloff, M.J. , Mayence, C.E. and Marshall D.J. 2014. Wetland plant growth under contrasting water regimes associated with river regulation and drought: implications for environmental water management. Plant Ecology 215, 997–1011. http://dx.doi.org/10.1007/s11258-014-0357-4

An important characteristic of many wetland plants in semi-arid regions is their capacity to withstand fluctuations between extended dry phases and floods. However, anthropogenic river regulation can reduce natural flow variability in riverine wetlands, causing a decline in the frequency and duration of deep flooding as well as extended droughts, and an increase in shallow flooding and soil saturation. Our aim in this paper was to use an experimental approach to examine whether reductions in flooding and drought disadvantage species adapted to both these extremes, and favours those with water requirements that match the new regime of frequent low-level flooding. We compared the growth characteristics and biomass allocation of three native Australian aquatic macrophytes (*Pseudoraphis spinescens*, *Juncus ingens* and *Typha domingensis*), which co-occur at Barmah Forest, south-eastern Australia, under three water treatments: drought, soil saturation and deep flooding. The responses of species to the treatments largely reflected changes in their relative abundance at Barmah Forest since river regulation. *Typha domingensis*, which has remained uncommon, performed relatively

poorly in all treatments, while *J. ingens*, which has increased its range, exhibited more vigorous growth under soil saturation. *Pseudoraphis spinescens*, which was once widespread but has declined markedly in its distribution, grew strongly under all water treatments. These findings suggest that a return to more natural, variable river flow regimes can potentially be an important conservation and restoration strategy in ecosystems characterised by species that have adaptations to extreme hydrological growing conditions.

Wheeler, S. 2014. Insights, lessons and benefits from improved regional water security and integration in Australia. Water Resources and Economics 8, pp. 57-78.

The Murray-Darling Basin (MDB) in Australia provides a leading example of a region that has established wide-ranging transboundary water agreements. The MDB extends into four states and one territory, and these states have disagreed continuously over water sharing since Federation in 1901. The first major transboundary water agreement was the 1915 River Murray Waters Agreement, which was followed a century later by the 2012 Basin Plan. One of the objectives of the Basin Plan is to reallocate 2750 GL from consumptive to environmental use in the MDB. Although the Basin Plan built on many other water reforms of the previous century, it does represent the most significant effort to date to estimate sustainable water use levels in the MDB and value the benefits and costs of various water reallocation scenarios. This study provides an overview of the major water policy reforms in the MDB, and reviews the identified benefits and costs of the 2012 Basin Plan. A number of insights and lessons are drawn throughout. Overall, the results signal that the quantified benefits of the Plan may outweigh the costs by up to three times. However, there are lessons to be learned from the extensive consultation, valuation and compensation paths that were adopted in Australia. It may not be possible for many other countries to implement such paths. Although Australia is on a path to sustainable water extraction, there is still much to be done and further policy will need to be flexible enough to allow further adaptation and innovation.

Wheeler, S., Loch, A., Zuo, A., Bjornlund, H. 2014. Reviewing the adoption and impact of water markets in the Murray–Darling Basin, Australia. Journal of Hydrology 518, pp. 28-41.

Water markets have increasingly been adopted as a reallocation tool around the world as water scarcity intensifies. Water markets were first introduced in Australia in the 1980s, and water entitlement and allocation trade have been increasingly adopted by both private individuals and governments. As well as providing an overview of water policy in Australia since the 1900s, this paper examines the adoption of water trading in the southern Murray–Darling Basin of Australia (the largest hydrologically connected water market in Australia), and investigates the associated social, economic and environmental impacts that have arisen from the implementation of water markets. This study found that up to 86% of irrigators in one state in the southern Murray–Darling Basin had undertaken at least one water market trade by 2010–2011, hence,

water market strategies are now a common tool employed by irrigators to assist their farm management. A variety of institutional, policy and informational changes are identified to increase the benefits from water markets in the future. There is no doubt that managing the impact of climate change and water scarcity are intertwined, suggesting that policy, institutional and governance responses should be similarly structured and coordinated.

Wheeler, S., Zuo, A., Bjornlund, H. 2014. Australian irrigators' recognition of the need for more environmental water flows and intentions to donate water allocations. Journal of Environmental Planning and Management 57(1), pp. 104-122.

Future water policy strategies to address low environmental flows in the River Murray in Australia may include the continued development of programmes for irrigators to donate water. We identify and control for the interdependence between irrigators' recognition of the need for increased flows and their stated intention to donate seasonal allocations over time. The increased uncertainty of seasonal water allocations played one of the largest roles in negatively influencing both recognition and intention. An increase in the opportunity cost of water donation over time was negatively associated with intention. The identification of significant willingness to donate allocations supports the movement towards a more adaptive water policy approach.

Wheeler, S.A., Zuo, A., Bjornlund, H. 2014. Investigating the delayed on-farm consequences of selling water entitlements in the Murray-Darling Basin. Agricultural Water Management 145, pp. 72-82.

Up to one-fifth of all irrigators in the Murray-Darling Basin sold water entitlements to the Australian Commonwealth in the period from the beginning of 2008 to the start of 2012. The sale of water entitlements has positive and negative consequences for irrigators and rural communities. This study focuses specifically on these potential on-farm consequences, by providing an overview of the reasons irrigators sell water, examining fluctuations in water use by irrigators over time, and modelling the delayed impact of water sales in the previous five years on net farm income. It suggests that to date, many irrigators who sold water to the Commonwealth and continued farming in the southern Murray-Darling Basin have predominately sold their surplus and buffer water (water not used in production). There is only weak to no significant evidence from the regression modelling to suggest that there is a delayed negative impact on net farm income from selling water entitlements, which supports the notion that the reduction in farm production has been offset by many irrigators using water sales proceeds to reduce debt (and hence interest payments), restructure and reinvest on farm. However, given the advent of climate change and future water scarcity, all irrigators, but particularly for some of those who have sold part of their water entitlements, will need to plan for further incremental adaptation, water management or on-farm changes, or risk facing regular water shortages.

Wheeler, S., Zuo, A., Hughes, N. 2014. The impact of water ownership and water market trade strategy on Australian irrigators' farm viability. Agricultural Systems 129, pp. 81-92.

Reforms in the Murray-Darling Basin over the past several decades have led to well developed water entitlement and allocation markets. Irrigators now use a diversity of water trade and ownership approaches, ranging from owning relatively large amounts of water entitlements relative to their annual demand and selling when they have excess water, to owning smaller amounts (or less secure) water entitlements and relying heavily on water allocation markets to meet annual demands. Some irrigators do not trade at all. Although the benefits of water markets in reallocating water have been well established, there has been very little empirical analysis of the impact that water ownership and water market trade strategy has had on irrigators' farm net incomes. This study uses irrigation industry survey data collected over a five-year period from 2006/2007 to 2010/2011 across the Murray-Darling Basin to investigate the relationship that water trade strategy and water ownership have with farm viability (namely farm net income and rate of return). Although this is an interesting period to investigate these relationships, it must be noted that it was a period of extreme water scarcity and high water prices; hence any interpretation of results must take this into account. It was found that the actual volume of water received (which is a measure of water allocations for that region and size and security of water entitlements) is a more significant and positive influence on farm net income than water ownership per se, with this result strongest in the horticulture industry. Water reliability is not as important in the broadacre industry as other industries. Selling water allocations was a significant and positive influence on farm net income and rate of return. Buying water entitlements was sometimes associated negatively with farm net income and rate of return in our time period, with no statistical significance found for the impact of selling water entitlements in the current year.

Zuo, A., Brooks, R., Wheeler, S., Harris, E., Bjornlund, H. 2014. Understanding irrigator bidding behavior in Australian water markets in response to uncertainty. Water 6(11), pp. 3457-3477.

Water markets have been used by Australian irrigators as a way to reduce risk and uncertainty in times of low water allocations and rainfall. However, little is known about how irrigators' bidding trading behavior in water markets compares to other markets, nor is it known what role uncertainty and a lack of water in a variable and changing climate plays in influencing behavior. This paper studies irrigator behavior in Victorian water markets over a decade (a time period that included a severe drought). In particular, it studies the evidence for price clustering (when water bids/offers end mostly around particular numbers), a common phenomenon present in other established markets. We found that clustering in bid/offer prices in Victorian water allocation markets was influenced by uncertainty and strategic behavior. Water traders evaluate the costs and benefits of clustering and act according to their risk aversion levels. Water

market buyer clustering behavior was mostly explained by increased market uncertainty (in particular, hotter and drier conditions), while seller-clustering behavior is mostly explained by strategic behavioral factors which evaluate the costs and benefits of clustering.

2013

Baldwin, D.S., Rees, G.N., Wilson, J.S. Colloff, M.J., Whitworth, K.L., Pitman, T.L. and Wallace, T.A. 2013. Provisioning of bioavailable carbon between wet and dry periods in a semi-arid floodplain. Oecologia 172, 539–550. http://dx.doi.org/10.1007/s00442-012-2512-8

Ecosystem functioning on arid and semi-arid floodplains may be described by two alternate traditional paradigms. The pulse-reserve model suggests that rainfall is the main driver of plant growth and subsequent carbon and energy reserve formation in the soil of arid and semi-arid regions. The flood pulse concept suggests that periodic flooding facilitates the two-way transfer of materials between a river and its adjacent floodplain, but focuses mainly on the period when the floodplain is inundated. We compared the effects of both rainfall and flooding on soil moisture and carbon in a semi-arid floodplain (Yanga National Park, Murrumbidgee Floodplain, New South Wales) to determine the relative importance of each for soil moisture recharge and the generation of a bioavailable organic carbon reserve that can potentially be utilised during the dry phase. Flooding, not rainfall, made a substantial contribution to moisture in the soil profile. Furthermore, the growth of aquatic macrophytes during the wet phase produced at least an order of magnitude more organic material than rainfall-induced pulse-reserve responses during the dry phase, and remained as recognizable soil carbon for years following flood recession. These observations have led us to extend existing paradigms to encompass the reciprocal provisioning of carbon between the wet and dry phases on the floodplain, whereby, in addition to carbon fixed during the dry phase being important for driving biogeochemical transformations upon return of the next wet phase, aquatic macrophyte carbon fixed during the wet phase is recognized as an important source of energy for the dry phase. Reciprocal provisioning presents a conceptual framework on which to formulate questions about the resistance and ecosystem resilience of arid and semi-arid floodplains in the face of threats like climate change and alterations to flood regimes.

Baldwin, D.S., Colloff, M.J., Rees, G.N. Watson, G.O., Chariton, A.A., Court, L.N., Hartley, D.M., Morgan, M.J., King, A. and Hardy, C.M. 2013. Impacts of inundation and drought on eukaryote biodiversity in semi-arid floodplain soils. Molecular Ecology 22, 1746–1758. http://dx.doi.org/10.1111/mec.12190

Floodplain ecosystems are characterized by alternating wet and dry phases and periodic inundation defines their ecological character. Climate change, river regulation and the construction of levees have substantially altered natural flooding and drying regimes worldwide with uncertain effects on key biotic groups. In southern Australia, we hypothesized that soil eukaryotic communities in climate change affected areas of a semi-arid floodplain would transition towards comprising mainly dry-soil specialist species with increasing drought severity. Here, we used 18S rRNA amplicon pyrosequencing to measure the eukaryote community composition in soils that had been depleted of water to varying degrees to confirm that reproducible transitional changes occur in eukaryotic biodiversity on this floodplain (Yanga National Park,

Murrumbidgee Floodplain, New South Wales). Interflood community structures (3 years post-flood) were dominated by persistent rather than either aquatic or dry-specialist organisms. Only 2% of taxa were unique to dry locations by 8 years post-flood, and 10% were restricted to wet locations (inundated a year to 2 weeks post-flood). Almost half (48%) of the total soil biota were detected in both these environments. The discovery of a large suite of organisms able to survive nearly a decade of drought, and up to a year submerged supports the concept of inherent resilience of Australian semi-arid floodplain soil communities under increasing pressure from climatic induced changes in water availability.

Barton, P.S., Colloff, M.J. Pullen K. and Cunningham, S.A. 2013. Grassland area determines beetle assemblage dissimilarity from surrounding floodplain forest. Journal of Insect Conservation 17, 1209–1219. http://dx.doi.org/10.1007/s10841-013-9602-8

Patch size is known to affect biodiversity in fragmented landscapes, but is usually examined in systems where the surrounding matrix habitat is unfavourable. We examined beetle diversity in a floodplain ecosystem (Barmah Forest, Southern Murray-Darling Basin) that is characterised by naturally occurring grassland patches within a dominant matrix of contrasting yet habitable forest. We asked whether differences in the beetle assemblage between grassland and forest vegetation depended on the area of the grassland patch, which is a function of its flooding frequency and duration: smaller grasslands tend to be higher on the floodplain and are flooded less often and for shorter periods than larger grasslands. We found a negative relationship between grassland area and beetle abundance and species richness, and a positive relationship between grassland area and compositional dissimilarity from the surrounding forest. As expected, we found an overall difference in composition between forest and grassland assemblages, with five beetle species more common in the grasslands. Our study indicates that floodplain grasslands not only support beetle assemblages that are distinct from the surrounding forest, but that assemblages from the larger grasslands are compositionally more distinct than those from smaller grasslands. A likely cause of this pattern is the reduced edge effects and greater environmental contrast between forest and large grasslands that may be exposed to greater variation in local climate. Ongoing changes to flood regimes and potential encroachment of forest plants may decrease grassland area in the future, which may reduce spatial heterogeneity in the insect community in this unique floodplain ecosystem.

Connor, J.D., Franklin, B., Loch, A., Kirby, M., Wheeler, S.A. 2013. Trading water to improve environmental flow outcomes. Water Resources Research 49(7), pp. 4265-4276.

As consumptive extractions and water scarcity pressures brought about by climate change increase in many world river basins, so do the risks to water-dependent ecological assets. In response, public or not for profit environmental water holders (EWHs) have been established in many areas and bestowed with endowments of water

and mandates to manage water for ecological outcomes. Water scarcity has also increasingly spawned water trade arrangements in many river basins, and in many instances, EWHs are now operating in water markets. A number of EWHs, especially in Australia, begin with an endowment of permanent water entitlements purchased from irrigators. Such water entitlements typically have relatively constant interannual supply profiles that often do not match ecological water demand involving flood pulses and periods of drying. This article develops a hydrologic-economic simulation model of the Murrumbidgee catchment within the Murray-Darling Basin to assess the scope of possibilities to improve environmental outcomes through EWH trading on an annual water lease market. We find that there are some modest opportunities for EWHs to improve environmental outcomes through water trade. The best opportunities occur in periods of drought and for ecological outcomes that benefit from moderately large floods. We also assess the extent to which EWH trading in annual water leases may create pecuniary externalities via bidding up or down the water lease prices faced by irrigators. Environmental water trading is found to have relatively small impacts on water market price outcomes. Overall our results suggest that the benefits of developing EWH trading may well justify the costs. Environmental water holdings are sometimes poorly timed for environment Water trade can match flow timing to environmental needs Irrigator profit impact is likely to be small.

Grafton, R.Q., Pittock, J., R. Davis, J. Williams, G. Fu, M. Warburton, B. Udall, R. McKenzie, X. Yu, N Che, D. Connell, Q. Jiang, T. Kompas, A. Lynch, R. Norris, H. Possingham and J. Quiggin. 2013. Global Insights into Water Resources, Climate Change and Governance. Nature Climate Change 3, pp. 315-321.

The paper evaluates the threats to four world river systems (Colorado, the Murray, the Orange and the Yellow). In all four basis outflows have been greatly reduced because of water extractions. While climate change will exacerbate the negative effects on these rivers, levels of water extractions remains (and is expected to remain) the biggest factor in reducing system flows.

Horne, J. 2013. Australian water policy in a climate change context: some reflections. International Journal of Water Resources Development, 29(2), 137-151. DOI:10.1080/07900627.2013.725537

This paper focuses on Australian water reform in a climate change context over the period between mid-2006 and end 2011, with a particular focus on the Murray Darling Basin (MDB). In Australia, during this period, the potential impacts from climate change became more central to the policy debate, and the implementation of what can be said to be a large-scale climate change adaptation programme commenced. The paper outlines the policy framework adopted by the government of the day and then draws out some of the key issues for water management against this background, and the attendant increased uncertainty.

Lane-Miller, C.C., Wheeler, S., Bjornlund, H., Connor, J. 2013. Acquiring water for the environment: lessons from natural resources management. Journal of Environmental Policy and Planning 15(4), pp. 513-532.

Over-allocation of water resources to irrigation, industry, and cities has severely impacted flow-dependent riverine ecosystems and led to growing interest in ways to restore water to the environment; one increasingly popular approach is water buybacks. This paper reviews US and Australian experiences in buying back water, focusing on the conditions which enable and inhibit environmental water acquisitions in each country. We also compare experiences with buyback efforts in fisheries, another natural resource sector. Lessons from these experiences provide important insights into how future water buyback programmes to acquire environmental water could be operated more effectively. The review suggests that the overall success of an environmental water buyback is likely to be enhanced by (1) legal and institutional settings which clearly define water rights and lower administrative and other barriers to water transfers, (2) non-governmental organizations and community groups which play a complementary role to government, (3) creation of a system that will fairly distribute future risk of water availability and provide choices for a variety of ways of obtaining water, and (4) efforts that minimize negative community impacts, thus helping to maximize irrigator participation.

Lukasiewicz, A., C. M. Finlayson and J. Pittock. 2013. Identifying low risk climate change adaptation in catchment management while avoiding unintended consequences. Gold Coast, National Climate Change Adaptation Research Facility. Open access with link: https://www.nccarf.edu.au/synthesis/identifying-low-risk-climate-change-adaptation-catchment-management-while-avoiding

The "Climate Change Adaptation Catchment Assessment Framework" Tool - an ecosystems-based approach to climate change adaptation - was developed for use by regional management bodies to assess natural resource management (NRM) actions in the context of climate change adaptation, thus focusing on interventions to improve environment health as a way of ameliorating climate change impacts. A range of experts and Catchment Management Authority (CMA) representatives from three catchments in the Murray-Darling Basin - the Goulburn-Broken (VIC), Lachlan (NSW) and NSW Murray catchments - were brought together to assist in the development and testing of the method to promote. The Framework consists of six sections: 1) catchment relevance; 2) climate change adaptation benefit (including effectiveness under different climate change scenarios and the potential for maladaptation); 3) ecosystem services benefits; 4) implementation constraints; 5)socio-economic outcomes; and 6) risk assessment. This report also identifies challenges to an approach of adaptive management, as well as explanation of how the Framework can assist in catchment decision-making.

Pittock, J. 2013. Lessons from adaptation to sustain freshwater environments in the Murray-Darling Basin, Australia. Wiley Interdisciplinary Reviews: Climate Change 4(5), pp. 429-438. Pay per view with link: https://onlinelibrary.wiley.com/doi/10.1002/wcc.230

Governance of Australia's Murray–Darling Basin (the Basin) is frequently lauded as an example to other river managers globally. Freshwater environments in the Basin are particularly vulnerable to water scarcity and change. In this paper, governmental responses are assessed to draw global lessons on climate change adaptation for rivers. A range of climate change adaptation measures for freshwater ecosystem conservation in the Basin are outlined namely: higher, long-term allocations of water to the environment; reviewing water allocation on a cyclical basis; allocating an equal or greater share of available water to the environment in dry years; and environmental works and measures to use less water to conserve wetlands. Examples of poor translation of science into policy that do not adequately consider the risks, costs, and benefits of adaptation interventions are explored. Adaptation policy in the Basin illustrates the risks of heavy reliance on infrastructure, of the high costs of trade-offs between environmental measures versus socio-economic and political concerns, and of dependence on too few measures. Lessons include the need for rigorous evaluation of risks, costs, and benefits to minimize perverse outcomes, and for adequate incentives and penalties for implementation of adaptation policies across governance scales. It is concluded that rather than a focus on only a few interventions, such as environmental flows, better adaptation practice requires deployment of a suite of different but complementary measures that spreads risk and maximizes resilience to climate variability and change.

Reid, J.R.W., Colloff, M.J., Arthur, A.D. and McGinness H.M. 2013. Influence of catchment condition and water resource development on waterbird assemblages in the Murray-Darling Basin, Australia. Biological Conservation 165, 25–34. http://dx.doi.org/10.1016/j.biocon.2013.05.009

River regulation and water resource development have resulted in significant deterioration in aquatic ecosystems worldwide, including reductions in wetland extent, changed flow regimes, and declines in biodiversity. The impacts on the composition and distribution of waterbird assemblages has not been studied previously at the scale of a major river basin. We investigated the relationship between waterbird assemblage composition and ecosystem health across the 21 catchments of the Murray-Darling Basin, which contains major wetlands that have been adversely affected by river regulation and over-allocation of water for irrigation. We allocated 51,000 surveys of 96 waterbird species, obtained from the New Atlas of Australian Birds database, to 117 one-degree grid squares for multivariate statistical analysis (MVA). Hierarchical clustering showed five main groups of squares reflecting strong biogeographic gradients. Pronounced spatial autocorrelation in the waterbird assemblage data was found. Unequal survey effort across grid squares and varying taxonomic scope also hindered conventional MVA and interpretation. To circumvent these constraints, survey data were recompiled at the half-degree square resolution after removing

surveys with few waterbird records, leaving 17,448 surveys of 80 species. A novel sequential approach of multivariate regression of distance matrices, ordination of Bray-Curtis residuals, and *post-hoc* correlation of the independent variable was used to test the hypothesis that assemblage composition varies systematically with catchment condition, after controlling for spatial autocorrelation, biogeographic trends and unequal survey effort. Ordination of the residuals of the half-degree square Bray-Curtis association matrix revealed a strong relationship between a nine-point index of catchment condition and waterbird assemblage composition. The colonial nesting waterbird guild (egrets, herons, ibis and spoonbills), was uniquely identified as being aligned with catchments in moderate to good condition. Waterbird assemblage composition shows significant spatial variation throughout the Murray-Darling Basin, influenced by the hydrological and ecological condition of catchments as well as by natural biogeographic factors. The least degraded catchments offer the best habitat for the colonially nesting waterbird guild, the group most adversely affected historically by river regulation and water diversions. These catchments require protection from water resource development if such habitat is to be maintained. Our results support the conservation objective of improving wetland health in degraded catchments through delivering environmental flows to ensure breeding and population maintenance of colonial nesting waterbirds.

Rogers, K., Saintilan, N., Colloff, M.J. and Wen, L. 2013. Application of Thresholds of Potential Concern and Limits of Acceptable Change in the condition assessment of a significant wetland. Environmental Monitoring and Assessment 185, 8583–8600. http://dx.doi.org/10.1007/s10661-013-3197-0

We propose a framework in which thresholds of potential concern (TPCs) and limits of acceptable change (LACs) are used in concert in the assessment of wetland condition and vulnerability and apply the framework in a case study. The lower Murrumbidgee River floodplain (the 'Lowbidgee') is one of the most ecologically important wetlands in Australia and the focus of intense management intervention by State and Federal government agencies. We used a targeted management stakeholder workshop to identify key values that contribute to the ecological significance of the Lowbidgee floodplain, and identified LACs that, if crossed, would signify the loss of significance. We then used conceptual models linking the condition of these values (wetland vegetation communities, waterbirds, fish species and the endangered southern bell frog) to measurable threat indicators, for which we defined a management goal and a TPC. We applied this framework to data collected across 70 wetland storages', or eco-hydrological units, at the peak of a prolonged drought (2008) and following extensive re-flooding (2010). At the suggestion of water and wetland mangers, we neither aggregated nor integrated indices but reported separately in a series of chloropleth maps. The resulting assessment clearly identified the effect of rewetting in restoring indicators within TPC in most cases, for most storages. The scale of assessment was useful in informing the targeted and timely management intervention and provided a context for retaining and utilising monitoring information in an adaptive management context.

Wheeler, S.A., Cheesman, J. 2013. Key findings from a survey of sellers to the Restoring the Balance programme. Economic Papers 32(3), pp. 340-352.

This study provides the key results from a survey of water entitlement sellers to the Commonwealth's Restoring the Balance programme. At the start of 2012, the programme was a third of the way to achieving the current environmental water target. A large-scale survey of water sellers found that 60 per cent of respondents had sold some water and kept farming; 30 per cent sold all water and left farming; and 10 per cent sold all water and continued farming. The majority were compelled to sell water because of debt and cash flow issues, but many used the sale as an opportunity to restructure and achieve other objectives. Half of the respondents who continued farming said selling water had no farm production consequences.

Wheeler, S., Garrick, D., Loch, A., Bjornlund, H. 2013. Evaluating water market products to acquire water for the environment in Australia. Land Use Policy 30(1), pp. 427-436.

Australia currently provides a leading example of a government buying back water for the environment. The Australian Government is at the midpoint of a $3.1 billion programme of buying water for the environment. The current acquisition programme relies heavily on the purchase of water entitlements (the long-term right to receive seasonal water allocations). An alternative acquisition method would be to use time-limited water products such as water allocations (temporary right to use water), entitlement leasing and options contracts. Scenario analysis, the Western US experience and irrigator surveys are used to examine whether the use of such alternative water products may be viable in the Australian context. This approach distributes the costs of transition over a longer period and has the potential to generate several benefits, namely: incremental structural adjustment; increased flexibility; enhanced environmental flows; increased irrigator willingness to participate; and, in some circumstances, increased cost-efficiency. However, the inclusion of alternative water products will involve more complex institutional arrangements and the need for more understanding of the dynamics of water markets and government budgeting processes.

Wheeler, S., Zuo, A., Bjornlund, H. 2013. Farmers' climate change beliefs and adaptation strategies for a water scarce future in Australia. Global Environmental Change 23(2), pp. 537-547.

Climate change is likely to require irrigators in Australia's Murray-Darling Basin to cope with less water, which will require ongoing farm adjustment. Possible incremental adjustment strategies include expansive and accommodating responses, such as irrigators buying land and water, increasing their irrigated area, changing crop mix and adopting efficient infrastructure. Contractive strategies include selling land and water, and decreasing their irrigated area. Using historical surveys we provide a comparison of irrigators' planned and actual strategies over the past fifteen years, thereby offering a strong foundation to support analysing future adaptation strategies. We explore

influences associated with farm adjustment strategies, and in particular the role that climate change beliefs play. Farmers convinced that climate change is occurring are more likely to plan accommodating, but not expansive, strategies. The relationship between climate change belief and adopting various adaptive strategies was found to be often endogenous, especially for accommodating strategies. Such results suggest the need for irrigation farming policies to be targeted at improving irrigators' adaptability to manage water variability, and its link with farm future viability.

2012

Grafton, R.Q., Libecap, G., Edwards, E.C., O'Brien, R. and Landry, C. 2012. A Comparative Assessment of Water Markets: Insights from the Murray-Darling Basin of Australia and the Western USA. Water Policy 14: 175-193.

The paper compares water trades in the Western USA and the Murray-Darling Basin (MDB). It is shown that the gains from trade in the MDB are worth hundreds of millions of dollars per year. The comparison shows that policy attention should be given to promoting water trades while simultaneously mitigating third party concerns about how and where water is used, especially conflicts between consumptive and in situ uses of water.

Gross, C., J. Pittock, C. M. Finlayson and M. C. Geddes (2012). Climate change adaptation in the Coorong, Murray Mouth and Lakes Alexandrina and Albert. Final report to the National Climate Change Adaptation Research Facility. NCCARF Publication 06/12. Gold Coast, National Climate Change Adaptation Research Facility. Open access with link: https://www.nccarf.edu.au/publications/limits-adaptation-coorong-murray-alexandrina-albert

The Coorong and Lakes Region offers critical lessons for adapting to climate change because it is at the end of the iconic River Murray, and comprises a large and complex wetland system of international environmental importance by the coast. It is the traditional country of the Ngarrindjeri Nation and supports vibrant communities. The Region has been subject to continual environmental change, from a range of natural drivers in prehistoric times to the more recent human drivers of change, including a succession of environmentally damaging semi-permanent technological interventions created since the time of European settlement. This research project investigates adaptation to climate change in the Coorong and Lakes Region from a number of angles and perspectives. It is one part of the National Climate Change Adaptation Research Facility (NCCARF) program of seven Australian geographically-based projects exploring the "limits to adaptation" and adaptation options in ecologically sensitive areas, such as wetlands, alpine areas and coastal areas. In this context adaptation includes social adaptation to changing climatic conditions as well as ecological adaptation. Climate change adaptation has been investigated from a holistic perspective that examines connections between the social, institutional and ecological elements of this complex system. The research explores limits to adaptation, adaptation options, vulnerability, resilience and environmental health from an historical perspective and by examining the current situation to assess future adaptation options. The project delivers findings in two main areas. First, at a localised regional level the project answers specific climate change research questions related to the Coorong and Lakes Region and offers conclusions and recommendations to enhance adaptation. Second, at a broader level, the research delivers findings for the research community in relation to notions of adaptation and limits to adaptation.

Horne, J. 2012. Economic approaches to water management in Australia. International Journal of Water Resources Development, DOI:10.1080/07900627.2012.712336

This paper focuses on the use of three economic approaches to water management in Australia that can increase the efficiency of water use and water security, thus providing a fillip to sustainability and economic growth: the establishment of water markets and water pricing; government spending; and the adoption of legislation and economic regulations promoting the development of water markets. Australia is well down the reform path, but needs to complete implementation. Australia's challenge is relevant to many countries struggling with demand and supply water imbalances, and the consequential declining environmental outcomes in rural areas and persistent water shortages in urban areas.

Jiang, Q. and Grafton, R.Q. 2012. Economic effects of climate change in the Murray-Darling Basin, Australia Agricultural Systems 110, pp. 10-16.

The study uses a hydro-economic models of the Murray-Darling Basin to examine the role of water trading and the economic impacts of climate change and reduced surface water availability in the Murray-Darling Basin. The results show that losses to irrigated agriculture under a median climate change scenario are modes. A comparison of model results with and without inter-regional water trades shows that trade in periods of much reduced water availability mitigates the on-farm impacts of climate changes.

Loch, A., Bjornlund, H., Wheeler, S., Connor, J. 2012. Allocation trade in Australia: a qualitative understanding of irrigator motives and behaviour. Australian Journal of Agricultural and Resource Economics 56(1), pp. 42-60.

Governments in Australia are purchasing water entitlements to secure water for environmental benefit, but entitlements generate an allocation profile that does not correspond fully to environmental flow requirements. Therefore, how environmental managers will operate to deliver small and medium-sized inundation environmental flows remains uncertain. To assist environmental managers with the supply of inundation flows at variable times, it has been suggested that allocation trade be incorporated into efforts aimed at securing water. This paper provides some qualitative and quantitative perspective on what influences southern Murray–Darling Basin irrigators to trade allocation water at specific times across and within seasons using a market transaction framework. The results suggest that while irrigators now have access to greater risk-management options, environmental managers should consider the possible impact of institutional change before intervening in traditional market activity. The findings may help improve the design of intervention strategies to minimise possible market intervention impacts and strategic behaviour.

Pittock, J., C. M. Finlayson and J. A. Howitt. 2012. Beguiling and risky: Environmental works and measures for wetlands conservation under a changing climate. Hydrobiologia 708(1), pp. 111-131. Pay per view with link: https://link.springer.com/article/10.1007/s10750-012-1292-9

In Australia's Murray–Darling Basin, small-scale engineering works called 'environmental works and measures' have been implemented as a basis for river and other wetland conservation. While implementing these, governments seem to have embraced the beguiling notion that scarce water supplies can be divided further, while conserving the environment and maintaining agricultural production. The difficulties in doing this are expected to increase in the face of extreme climate variability. With this scenario as a backdrop, the $280 million (Monetary values ($) in this paper are in Australian dollars (AUD). At the time of writing AUD $1.00 = ~USD $1.02.) Living Murray and related programmes are assessed to see whether microengineering works to manage the hydrology of wetlands make for effective adaptation to water scarcity and climate change or whether it amounts to an overly narrow adaptation or maladaptation. Some measures were found to be substantially beneficial, such as the construction of fishways. However, under these programmes, only 0.6% of the Basin's wetlands would be inundated and there are significant risks including desiccation of non-target wetlands and further reductions in water allocations for the environment. It is recommended that trade-offs between alternative strategies are assessed as the basis for minimising perverse impacts under changing climatic and hydrological conditions.

Sims, N.C., Chariton, A., Jin, H. and Colloff, M.J. 2012 A classification of floodplain ecosystems in the Murray-Darling Basin based on changes in flows following water resource development. Wetlands 32, 239–248. http://dx.doi.org/10.1007/s13157-011-0231-2

We present a regional classification of 40 floodplains and wetlands of the Murray-Darling Basin, Australia, based on changes in flows since river regulation and water resource development. The classification is based on a similarity percentage analysis of nine metrics relating to frequency, duration and volume of floods, and seasonality of flows. The major changes in flows were a delay in mean Julian day of occurrence of low flow and reduced variation in occurrence, lower frequency of flood events and reduced variation of flood duration. The spatial distribution of floodplain classes highlights the differential effects of river regulation across the Basin, with greatest change in rivers in the southern Basin, particularly the Murray, Murrumbidgee, and Lachlan, and the least change in unregulated or less-regulated rivers, predominantly in the north. There is generally good spatial concordance between distribution of floodplain classes and the Murray-Darling Basin Sustainable Rivers Audit index of riverine ecosystem health, and the distribution of major communities of waterbirds. Our results suggest, when compared with published reports of ecological condition, that very low-gradient, terminal floodplain wetlands characterized by low discharge volume and anastomosing distributary channels may be particularly susceptible to adverse ecological impacts arising from relatively slight alterations to flows.

Sims, N.C. and Colloff, M.J. 2012. Remote sensing of vegetation responses to flooding of a semi-arid floodplain: Implications for monitoring ecological effects of environmental flows. Ecological Indicators 18, 387–391. http://dx.doi.org/10.1016/j.ecolind.2011.12.007

Environmental flows are used to support the structure and function of floodplain, wetland and riverine ecosystems that are subject to stress from drought, climate change or water resource development. The financial costs of environmental flows are considerable and it is therefore highly desirable that the ecological benefits are monitored. Productivity of floodplain vegetation is a critical ecological response to flooding, and represents an indicator of ecosystem 'health', being linked to structural integrity, habitat provision, nutrient cycling and numerous other ecosystem functions. Productivity of floodplain plant communities is hard to measure, being highly variable over time depending on seasonal and climatic factors and the frequency, magnitude and duration of flood events. We compared an index of plant growth – the Normalised Difference Vegetation Index (NDVI) calculated from MODIS satellite imagery – in the Paroo River Wetlands ecosystem, Australia, to NDVI in a nearby terrestrial area to quantify the magnitude and duration of floodplain vegetation responses to flooding alone. This analysis shows that a flood which inundated more than 50% of the Paroo River Wetlands in 2008 increased NDVI by up to 19% above non-flood levels and for a period of 13 months following flood recession. This approach has applications in planning environmental flows and in monitoring the ecological responses.

Wheeler, S., Bjornlund, H., Zuo, A., Edwards, J. 2012. Handing down the farm? The increasing uncertainty of irrigated farm succession in Australia. Journal of Rural Studies 28(3), pp. 266-275.

Farming is still primarily a family concern in Australia. Having a farm successor in place is important as it is associated with the likelihood of the current farmer adapting to external conditions and hence may have long-term implications for the structure and profitability of agriculture. We used current and historical surveys across a number of irrigation districts in the southern Murray-Darling Basin to study the changing nature of farm succession. Irrigation farms with (and without) a named successor have decreased over time, while uncertainty about succession has increased rapidly. There was strong evidence that the identification of a successor is positively associated with the current and future management of farms. Those with no successor in place are more likely to go into a period of stagnation (such as selling land, not adopting efficient irrigation infrastructure and not increasing irrigated area). One key finding is that increasing uncertainty about succession among irrigated farmers in recent years has been influenced by issues surrounding water security in the Murray-Darling Basin.

Wheeler, S., Zuo, A., Bjornlund, H., Miller, C. 2012. Selling the farm silver? Understanding water sales to the Australian government. Environmental and Resource Economics 52(1), pp. 133-154.

In 2007–2008 the Australian federal government committed $3.1 billion over 10 years to purchase water from irrigators in the Murray-Darling Basin and to deliver this water to key environmental assets. Given that water entitlements often represent one of the most valuable assets owned by irrigators, this study investigates irrigators' willingness to sell water, and their actual water sales, to the government. It uses 1,570 surveys from 2008–2009 and 2010–2011 in the southern Murray-Darling Basin. Water sales can be classified as either last resort or strategic. Overall, the results suggest that farmers who do not hold strong traditional farming attitudes, and have higher debt, lower farm income, larger high security water entitlements, lower water allocations over the past 5 years, and those who have been net sellers of water allocations are more likely to have sold water or are thinking of selling water to the government. A dynamic comparison of how water sale preferences change, and an estimate of the total amount of water entitlements irrigators are willing to sell, indicates that it is probable that there will be enough water offered to the program in the future, at least to meet initial minimum environmental water targets. However, other concerns indicate that a potential restructure of the program may be required.

Williams, J. 2012. Catchment management – setting the scene: An overview of catchment management models in Australia. Water: Journal of the Australian Water Association, April 2012, 1–5.

There is a wide range of catchment management models in Australia that vary according to the resources and historical framework of the particular catchment and jurisdiction. This paper reviews the progress of catchment management in New South Wales over the past six years and has observed the development of significant co-operative relationships, particularly involving water planning.

2011

Connell, D. and Grafton R.Q., 2011. Water reform in the Murray-Darling Basin. Water Resources Research 47, WG00G03, doi: 10.1029/2010WR009820, 2011.

The paper reviews recent reforms in the Murray0Darling Basin and places them in an historical context and considers factors that will affect effective implementation including tensions in the Australian federal system and challenges in relation to managing social, environmental and economic limitations.

Grafton, R.Q. 2011. Economic Costs and Benefits of the Proposed Basin Plan. In *Basin Futures-water reform in the Murray Darling Basin.* Daniel Connell and Quentin Grafton (eds), ANU Press, Canberra.

This chapter examines the cost and benefits of increasing environmental flows in the Murray–Darling Basin (MDB) relative to the recent past, and the costs of business as usual of not increasing flows. The starting point for the analysis is the Guide to the proposed Basin Plan. Volume 1: Overview released on 8 October 2010 by the Murray–Darling Basin Authority (MDBA).

Grafton, R.Q., Chu, L., Stewardson, M. and Kompas, T. 2011 Optimal Dynamic Water Allocation: Irrigation Extractions and Environmental Trade-offs in the Murray River, Australia. Water Resources Research 47:12 DOI: 10.1029/2010WR009786.

The paper presents a a general stochastic dynamic programming model with four state variables (drought status, current weather, weather correlation and current storage) and two controls (environmental release and irrigation allocation) to optimally allocate water between extractions and in situ uses. The model is calibrated to the Murray River and shows: (1) from 2001 to 2009 a water reallocation to increase environmental flows would have increased total benefits from half a billion to over three billion USD and (2) water market increase optimal environmental releases by reducing the losses with water diversions.

Grafton, R.Q. and Jiang, Q. 2011. Economic Effects of Water Recovery on Irrigated Agriculture in the Murray-Darling Basin. Australian Journal of Agricultural and Resource Economics 55, pp. 487-499.

In October 2010, the Murray-Darling Basin Authority (MDBA) proposed that a range of 3000–4000 GL per year, on average, of additional water be made available for the environment in the Murray-Darling Basin (MDB) to mitigate the effects of what it considers to be inadequate environmental flows. To help quantify the costs of this water reallocation, a hydro-economic model was constructed based on the 19 regions of the MDB. The model results indicate the following: (i) substantial reductions in surface water extractions of up to 4400 GL per year impose only a moderate reduction on net

profits in irrigated agriculture, Basin wide, given competitive water markets, but the effects are much more pronounced in particular regions/catchments and (ii) the costs of the water reallocation are comparable with the amount budgeted by the Australian government to acquire water from willing sellers and increase environmental flows if inter-regional water trade is unrestricted.

Hatton-MacDonald, D., Morrison, M.D., Rose, J.M. and Boyle, K.J. 2011. The Australian Journal of Agricultural and Resource Economics, 55, pp. 374-392.

The River Murray and the Coorong in Australia have been in a state of decline. With the prospect of extended droughts and shifts in inflows due to climate change, difficult choices loom. The options include halting the decline, triage of some assets along the River or staying with the declining river system. To support decision-making, a survey was designed to elicit willingness to pay for improvements in environmental quality. Over 3000 Australians responded to this survey. The study focuses on key River Murray environmental quality indicators: the frequency of bird breeding along the River Murray, increasing native fish populations in the River Murray, increasing the area of healthy vegetation along the River Murray, and restoring water bird habitat in the Coorong. State/Territory models were jointly estimated using a panel multinomial logit error-components model. Willingness to pay estimates for improvements in environmental quality were calculated for the River Murray and the Coorong. Respondents were found to be willing to pay most for the Coorong and to improve waterbird breeding frequency. Respondents from the Australian Capital Territory were found to have significantly higher willingness to pay whereas those in Victoria had a significantly lower willingness to pay than respondents in other states.

Kingsford, R.T., Walker, K.F., Lester, R.E., William J. Young, Fairweather, P.G., Sammut, J. and Geddes, M.C. (2011). A Ramsar wetland in crisis - the Coorong, Lower Lakes and Murray Mouth, Australia. *Marine and Freshwater Research* 62, 255-265.

The state of global freshwater ecosystems is increasingly parlous with water resource development degrading high-conservation wetlands. Rehabilitation is challenging because necessary increases in environmental flows have concomitant social impacts, complicated because many rivers flow between jurisdictions or countries. Australia's Murray–Darling Basin is a large river basin with such problems encapsulated in the crisis of its Ramsar-listed terminal wetland, the Coorong, Lower Lakes and Murray Mouth. Prolonged drought and upstream diversion of water dropped water levels in the Lakes below sea level (2009–2010), exposing hazardous acid sulfate soils. Salinities increased dramatically (e.g. South Lagoon of Coorong >200 g L–1, cf. modelled natural 80 g L–1), reducing populations of waterbirds, fish, macroinvertebrates and littoral plants. Calcareous masses of estuarine tubeworms (Ficopomatus enigmaticus) killed freshwater turtles (Chelidae) and other fauna. Management primarily focussed on treating symptoms (e.g. acidification), rather than reduced flows, at considerable expense (>AU$2 billion). We modelled a scenario that increased annual flows during

low-flow periods from current levels up to one-third of what the natural flow would have been, potentially delivering substantial environmental benefits and avoiding future crises. Realisation of this outcome depends on increasing environmental flows and implementing sophisticated river management during dry periods, both highly contentious options.

Morrison, M.D., Wheeler, S.A., MacDonald, D.H. 2011. Towards a more nuanced discussion of the net-benefits of sharing water in the Murray-Darling Basin. AFBM Journal 8(2), pp. 27-38.

Despite the focus by stakeholders, the States and the Murray-Darling Basin Authority on exploring the economic costs and benefits of the proposed Murray-Darling Basin Plan, there are a number of issues relevant to an economic evaluation of the Plan that are easily overlooked. While a proposed Murray-Darling Basin plan has been released, water sharing agreements will continue to evolve and much detail remains to be worked out as part of implementation at the state level. Given this, we seek to synthesise current research on the costs and benefits of the Murray-Darling Basin plan. In doing so we discuss eight issues relevant to understanding the net-benefits of water reforms that, though recognised in the literature and policy debates, have become somewhat peripheral despite their potential importance. The first two issues are related to the potential social costs associated with reduced viability of communities and ongoing viability issues for farms. The next three issues are focused on benefits from the proposed Plan. This includes the estimation of benefits for downstream beneficiaries, the opportunity provided to farmers from selling water and the benefits associated with reductions in system risk due to non-incremental changes in ecosystems. The remaining three issues relate to approaches for maximising the benefits associated with the water reform process. This includes the evaluation of a wider range of options, consideration of how to better use water markets to assist farmers to manage risk, and evaluating not only how much water is needed but how it can be more effectively managed.

Pittock, J. and C. M. Finlayson.2011. Australia's Murray-Darling Basin: freshwater ecosystem conservation options in an era of climate change. Marine and Freshwater Research 62, pp. 232–243. Pay per view with link: http://www.publish.csiro.au/MF/MF09319

River flows in the Murray–Darling Basin, as in many regions in the world, are vulnerable to climate change, anticipated to exacerbate current, substantial losses of freshwater biodiversity. Additional declines in water quantity and quality will have an adverse impact on existing freshwater ecosystems. We critique current river-management programs, including the proposed 2011 Basin Plan for Australia's Murray–Darling Basin, focusing primarily on implementing environmental flows. River management programs generally ignore other important conservation and adaptation measures, such as strategically located freshwater-protected areas. Whereas most river-basin restoration techniques help build resilience of freshwater ecosystems to climate change impacts, different measures to enhance resilience and reoperate water

infrastructure are also required, depending on the degree of disturbance of particular rivers on a spectrum from free-flowing to highly regulated. A crucial step is the conservation of free-flowing river ecosystems where maintenance of ecological processes enhances their capacity to resist climate change impacts, and where adaptation may be maximised. Systematic alteration of the operation of existing water infrastructure may also counter major climate impacts on regulated rivers.

Qureshi, E., Grafton, R.Q. and Kirby, M. 2011. Understanding irrigation water use efficiency at different scales for better policy reform — a case study of the Murray Darling Basin, Australia. Water Policy, 12, pp. 1-17.

The paper examines water use efficiency and economic efficiency with a focus on the Murray-Darling Basin. The different measures of efficiency are defined and explained and it is shown that the current policies to subsidise investments for improvements in irrigation efficiency are not cost effective compared to the buy back of water entitlements.

Ren, S. and Kingsford, R.T. 2011. Statistically integrated flow and flood modelling (IFFM) compared to hydrologically integrated quantity and quality model (IQQM) for annual flows in the regulated Macquarie River in arid Australia. *Environmental Management* 48, 177-188.

Water resource management traditionally depends on use of highly complex hydrological models designed originally to manage water for abstraction but increasingly relied on to determine ecological impacts and test ecological rehabilitation opportunities. These models are rarely independently tested. We compared a relatively simple statistical model, integrated flow and flood modelling (IFFM), with a complex hydrological model, the integrated quality and quantity model (IQQM), on the highly regulated Macquarie River of the Murray-Darling Basin, southeastern Australia. We compared annual flows (1891–2007) at three gauges to actual data and modelled output: before dams and diversions (unregulated) and after river regulation (regulated), using the goodness of fit (Nash-Sutcliffe coefficient of efficiency) and nonparametric tests. IQQM underestimated impacts of river regulation respectively on median and average flows at the Macquarie Marshes (Oxley gauge) by about 10% and 16%, compared to IFFM. IFFM model output more closely matched actual unregulated and regulated flows than IQQM which tended to underestimate unregulated flows and overestimate regulated flows at the Ramsar-listed wetland. Output was reasonably similar for the two models at the other two flow gauges. Relatively simple statistical models could more reliably estimate ecological impact at floodplains of large river systems, as well as an independent assessment tool compared to complex hydrological models. Finally, such statistical models may be valuable for predicting ecological responses to environmental flows, given their simplicity and relative ease to run.

Steinfeld, C.M.M. and Kingsford, R.T. 2011. Disconnecting the floodplain: Earthworks and their ecological effect on a dryland floodplain in the Murray-Darling Basin, Australia. *Rivers Research and Applications* 29, 206-218.

Globally, dams and water extractions are well-recognised disruptors of flow regimes in floodplain wetlands, but little is known of the hydrological and ecological impacts of floodplain earthworks constructed for irrigation, flood mitigation and erosion control. We mapped the distribution of earthworks with high-resolution SPOT (Système Probatoire d'Observation de la Terre) imagery in an internationally recognised Ramsar wetland, the Macquarie Marshes of the Murray–Darling Basin, Australia. There were 339 km levees, 1648 km channels, 54 off-river storages and 664 tanks (0.5–5 m high), detected within the 4793 km2 floodplain study area. Earthworks reduced localised flooding compared with undeveloped sites. The most pronounced disconnection of the original floodplain (73.0%) occurred where earthworks were most concentrated compared with areas with few earthworks (53.2%). We investigated relationships between hydrological connectivity and mortality of the perennial flood-dependent river red gum Eucalyptus camaldulensis at 55 floodplain sites (225 150 m). Over half of the river red gums were dead at 21.8% of the sites. Earthworks blocked surface flows to flood-dependent vegetation and drowned vegetation in artificially inundated off-river storages. Mortality was due to impacts of earthworks and potentially exacerbated by effects of river regulation, water extraction and climate. River red gums were healthiest in narrow river corridors where earthworks confined flows and flows could recede freely. Rehabilitation of flood-dependent ecosystems should focus on reinstating lateral connectivity and protecting environmental flows.

Thomas, R.F., Kingsford, R.T., Yi, L. and Hunter, S.J. (2011). Landsat mapping of inundation (1979-2006) of the Macquarie Marshes in semi-arid Australia. *International Journal of Remote Sensing* 32, 4545-4569.

Measuring inundation over long timeframes is essential for understanding the responses of large floodplain wetlands on regulated rivers, such as the internationally Ramsar listed Macquarie Marshes (2000 km^2) in central-eastern Australia. We used near-spring Landsat images (Multispectral Scanner (MSS) and Thematic Mapper (TM) imagery) over 28 years (1979–2006) and classified for inundation, integrating water and vegetation response using Iterative Self-Organizing Data Analysis (ISODATA) clustering. A spatially explicit inundation index showed that zones inundated with high frequency were mostly in the northern region. Change detection of inundation indices over three consecutive water management periods (period 1 (1979–1987), period 2 (1988–1996) and period 3 (1997–2006)) showed that zones inundated with high frequency across the Macquarie Marshes contracted, equating to the loss of three or more spring floods from each 9-year period, despite no corresponding change in annual catchment or local rainfall. Landsat represents the only effective available long-term information for analysing long-term changes in inundation patterns of floodplain wetlands.

Williams, J. 2011. Understanding the Basin and its Dynamics. In *Basin Futures-water reform in the Murray Darling Basin.* Daniel Connell and Quentin Grafton (eds), ANU Press, Canberra.

The chapter provides a bio-physical-ecological overview of the Murray-Darling Basin. It reviews the climate change and examines its possible futures.

2010

Colloff, M.J. and Baldwin, D.S. 2010. Resilience of floodplain ecosystems in a semi-arid environment. The Rangeland Journal 32, 305–314. http://dx.doi.org/10.1071/RJ10015

Implicit to loss of ecosystem resilience is that systems can shift from one stable state to another as a result of disturbance. We present a conceptual model of ecosystem resilience of floodplains and wetlands in semi-arid environments like those of the Murray-Darling Basin. The model is based on a single state characterised by fluctuating wet and dry phases driven by episodic floods and droughts. It might appear that such a single state is inherently unstable, but stability, and the measure of resilience, is conferred by the capacity of floodplains and wetlands to undergo drought and yet return to a functioning wet phase following inundation as well as to undergo flooding and return to the dry phase following flood recession. Floodplains and wetlands are driven by strong, periodic abiotic disturbances and their ecosystem functions and biogeochemical processes are highly rate-limited, spatiotemporally variable and driven by relatively species-poor assemblages of plants and animals adapted to withstand drought and flooding. Extreme drying due to climatic change and over-allocation of water resources represents the primary mechanism via which resilience is lost.

Davies, P. E., J. H. Harris, T. J. Hillman and K. F. Walker (2010). The Sustainable Rivers Audit: assessing river ecosystem health in the Murray–Darling Basin, Australia. Marine and Freshwater Research 61(7), pp. 764-777. Pay per view with link: https://www.publish.csiro.au/MF/MF09043

The Sustainable Rivers Audit (SRA) is a systematic assessment of the health of river ecosystems in the Murray–Darling Basin (MDB), Australia. It has similarities to the United States' Environmental Monitoring and Assessment Program, the European Water Framework Directive and the South African River Health Program,but is designed expressly to represent functional and structural links between ecosystem components, biophysical condition and human interventions in the MDB. Environmental metrics derived from field samples and/or modelling are combined as indicators of condition in five themes (Hydrology, Fish, Macroinvertebrates, Vegetation and Physical Form). Condition indicator ratings are combined using expert-system rules to indicate ecosystem health, underpinned by conceptual models. Reference condition, an estimate of condition had there been no significant human intervention in the landscape, provides a benchmark for comparisons. To illustrate, a synopsis is included of health assessments in 2004–2007. This first audit completed assessments of condition and ecosystem health at the valley scale and in altitudinal zones, and future reports will include trend assessments. SRA river-health assessments are expected to play a key role in future water and catchment management through integration in a Basin Plan being developed by the Murray–Darling Basin Authority for implementation after 2011. For example, there could be links to facilitate monitoring against environmental targets.

Grafton, R.Q. 2010. How to Increase the Cost-effectiveness of Water Reform and Environmental Flows in the Murray-Darling Basin. Agenda 17(2), pp. 17-40.

The paper reviews the $12.9 billion Water for the Future package in the Murray-Darling Basin from the perspective of cost-effectiveness and assesses the possible losses to irrigators from reduced diversions to achieve desired environmental flow regimes. It argues that combining the $3.1 billion allocated to buying water entitlements with the $5.8 billion targeted by Water for the Future for water infrastructure subsidies into a purchase of water entitlements from willing sellers would maximise the water acquired for the environment per dollar of expenditure, provide greater assistance to holders of water entitlements, and reduce the expected gap between average water diversions for agriculture and sustainable diversion limits.

Leigh, C., Sheldon, F., Kingsford, R.T. and Arthington, A. 2010. Sequential flooding: the driver of 'booms' in dryland rivers. *Marine and Freshwater Research* 61, 1-13.

Flow is a key driver regulating processes and diversity in river systems across a range of temporal and spatial scales. In dryland rivers, variability in the timing and scale of floods has specific ecological significance, playing a major role in sustaining biotic diversity across the river-floodplain mosaic. However, longitudinal effects of floods are equally important, delivering water downstream through channels and wetland complexes. Interaction among spatially distributed wetlands, their connecting channel and floodplain geomorphology and the temporally variable flow events not only creates the spatial complexity in dryland rivers but also determines temporal persistence of wetlands. These act as hydrological 'sponges', absorbing water from upstream and needing to fill before releasing water downstream. Sequential high flow events are essential for the ecological persistence of riverine wetlands and the transmission of flows further downstream through the channel network. These flood sequences maintain aquatic refugia and drive booms in productivity sustaining aquatic and terrestrial biota over large spatial and temporal scales. Disrupting the sequence, with modified flow regimes and water removal for diversion (e.g. irrigation), significantly reduces the opportunity for wetland replenishment. As a result, the benefits of sequential flooding to the wetland 'sponges' and their biotic communities will be lost.

Pittock, J., C. M. Finlayson, A. Gardner and C. McKay 2010. Changing character: the Ramsar Convention on Wetlands and climate change in the Murray-Darling Basin, Australia. Environmental and Planning Law Journal 27(6), pp. 401-425. Pay per view with link: https://openresearch-repository.anu.edu.au/handle/1885/61026

The Ramsar Convention on Wetlands was established to conserve the world's diminishing wetlands on the assumption of a stationary hydrology, which is now threatened by climate change. This article examines how the Australian Commonwealth government is using the provisions within the Convention to deal with

the degradation of six Ramsar-listed wetlands in the Murray-Darling Basin in Australia. The ecological character of the wetlands is changing, primarily due to the manner in which the rivers have been managed and excessive extraction of water for human consumption. Climate change is expected to exacerbate this situation. The authors outline breaches in the government's obligations under the Convention. The Environment Protection and Biodiversity Conservation Act 1999 (Cth) and the Water Act 2007 (Cth), which are based in part on supporting the implementation of the Convention, are undermined by a lack of adherence to the Convention. Gaps and inconsistencies are also identified in the Convention for managing the impacts of climate change on wetlands.

Ren, S., Kingsford, R.T. and Thomas, R.F. 2010. Modelling flow to and inundation of the Macquarie Marshes in arid Australia. *Environmetrics* 21, 549-561.

Building of dams and subsequent abstraction upstream of rivers significantly affects major wetland systems. Knowledge of anthropogenic impacts of river regulation, relative to stochastic variation, is essential if managers are able to adequately manage flows to wetlands. We built annual flow and inundated area models for the Macquarie Marshes supplied by the Macquarie River, based on available annual rainfall data (1879–2006). We used LOESS, the flexible local polynomial regression method, ideal for modelling complex processes where no theoretical models exist. To compare effects of river regulation and abstraction, we developed two models, before river regulation ('natural' or 'unregulated') and after river regulation ('regulated'). The division was when Burrendong dam, the most significant regulatory structure affecting flows, was built in 1963 and completed in 1967. After this point, water was diverted upstream, predominantly for irrigation. We developed 'natural' and 'regulated' flow models for three flow gauges Dubbo, Warren and Oxley based on annual rainfall at rainfall stations in the upper catchment and flow, and then inundated area models based on flow and local rainfall to fit annual inundated area data (1979–2006) in the Macquarie Marshes, using LOESS and leave-one-out samples without overfitting. We evaluated the performance of the proposed models and used these models to predict annual flows and inundated areas from 1879 to 2006. Comparison was done in terms of 'natural' and 'regulated' data using Kolmogorov–Smirnov test, identifying significant reductions in flow and wetland area.

Stokes, K.E., Ward, K.A. and Colloff, M.J. 2010. Alterations in flood frequency increase exotic and native species richness of understorey vegetation in a temperate floodplain eucalypt forest. Plant Ecology 211, 219–233. http://dx.doi.org/10.1007/s11258-010-9833-7

The delivery of environmental flows for biodiversity benefits within regulated river systems can potentially contribute to exotic weed spread. This study explores whether exotic plants of a floodplain forest (Barmah Forest) in Victoria, Australia, are characterised by specific functional groups and associated plant traits linked to altering hydrological conditions over time. Permanently marked $20\times20m^2$ plots from five

wetland sites in *Eucalyptus camaldulensis* floodplain forest were sampled twice, first in the early 1990s (1993–1994) and then 15 years later (2007–2008). Species cover abundance data for understorey vegetation communities were segregated by season and analysed using ordination analysis. Exotic species richness was modelled as a function of site flooding history and native species richness using general linear models. Site ordinations by detrended correspondence analysis showed differential community compositions between survey dates, but native and exotic species were not clearly differentiated in terms of DCA1 scores. Most exotics belonged to functional groups containing annual species that germinate and reproduce under drier conditions. Exotics reproducing under wetter conditions were in the minority, predominantly perennial and capable of both sexual and asexual reproduction. Site flooding history and native species richness significantly predicted exotic species richness. Vegetation changes are partially structured by reduced flood frequency favouring increased abundance of exotic, sexually reproducing annuals at drier sites. Sites of low flood frequency are more sensitive to future exotic weed invasion and will require targeted management effort. Flow restoration is predicted to benefit propagule dispersal of species adopting dual regeneration strategies, which are predominantly natives in this system.

Wheeler, S., Bjornlund, H., Zuo, A., Shanahan, M. 2010. The changing profile of water traders in the Goulburn-Murray Irrigation District, Australia. Agricultural Water Management 97(9), pp. 1333-1343.

This paper examines the changing profile of water traders (both allocation and entitlement traders) in the Goulburn-Murray Irrigation District in Australia, and examines the efficiency of the water allocation and entitlement markets from 1998–99 to 2003–06. The results suggest that the profile of traders in the early and mature stages of the water allocation market differ greatly. In addition, the profile of allocation traders is significantly dissimilar from that of water entitlement traders at all stages of water market development. The decision to buy or sell water allocations was more likely to be associated with a farmer's socioeconomic characteristics and the type of farm, while the decision to buy or sell water entitlements was more likely to be associated with the extent of existing farm infrastructure and farm productivity. Finally, there was strong evidence to suggest that trading in the water allocation market has become more efficient over time, though there is no evidence to suggest the same for the water entitlement market.

Wheeler, S., Bjornlund, H., Zuo, A., Shanahan, M. 2010. Erratum to "The changing profile of water traders in the Goulburn-Murray Irrigation District, Australia" by Wheeler et al. [Agric. Water Manage. 97, (2010), 1333-1343]. Agricultural Water Management 98(1), pp. 222-225.

This paper examines the changing profile of water traders (both allocation and entitlement traders) in the Goulburn-Murray Irrigation District in Australia,and examines the efficiency of the water allocation and entitlement markets from 1998–99 to 2003–06. The results suggest that the profile of traders in the early and mature stages

of the water allocation market differ greatly. In addition, the profile of allocation traders is significantly dissimilar from that of water entitlement traders at all stages of water market development. The decision to buy or sell water allocations was more likely to be associated with a farmer's socioeconomic characteristics and the type of farm, while the decision to buy or sell water entitlements was more likely to be associated with the extent of existing farm infrastructure and farm productivity. Finally, there was strong evidence to suggest that trading in the water allocation market has become more efficient over time, though there is no evidence to suggest the same for the water entitlement market.

2009

Wheeler, S., Bjornlund, H., Shanahan, M., Zuo, A. 2009. Who trades water allocations? Evidence of the characteristics of early adopters in the Goulburn-Murray Irrigation District, Australia 1998-1999. Agricultural Economics 40(6), pp. 631-643.

This article applies a model of innovation to analyse the characteristics of irrigators within the Goulburn-Murray Irrigation District in Australia and examines the efficiency of the early water market in the late 1990s. Using multinominal and binary logit analyses we identify the factors associated with irrigators who sold or bought water allocations during 1998-1999 and irrigators who at that time had never participated in any kind of water trading. Contrary to expectations we find that early adopters of water trading were older farmers with low farm productivity, but that in line with theory they had higher levels of education, had spent less time farming, had larger irrigated area, farm operating surplus and farm assets, owned farms that were more intensively farmed, and were more progressive in their planning. There was only weak evidence to suggest that water moved from lower value uses to higher value uses, suggesting the water allocation market had limited efficiency in its' initial years.