A fifth stage of water reforms: policy lessons for future natural resource management

Loch, A.[†*] Adamson, D.[†] and Dumbrell, N.P.[†]

[†] Centre for Global Food and Resources, The University of Adelaide, South Australia 5005

[*] Corresponding author. E: adam.loch@adelaide.edu.au | P: +61 8 8313 9131

Abstract

Effective management of water resources is a critical policy issue for governments globally. Both natural and social science input will be required to develop evidence-based water policy with robust properties. However, the robustness of evidence-based policy decisions may suffer under any inability to consider and represent inherent risk and uncertainty in future water supply/demand, requiring relatively costly arrangements capable of adaptive change in response to dynamic outcomes. Australian water reform and management offers an advanced example of adaptive policy arrangements that has developed over four previous stages. This paper charts those stages of reform to examine if they are consistent with hypothesised future outcomes, and posits a fifth stage of possible reform—with adaptive properties by design. Our analysis is motivated by the need for increased policy flexibility and adaptability in response to: potential transformations toward inflexible production systems, on-going uncertainty associated with climate change impacts on future water reliability, and the need for increased possible future equity between uses/users (productive/consumptive, environmental, cultural). This approach highlights risk issues that may not feature in current policy assurance reviews or performance assessments, and enables a clearer representation of uncertainty with respect to water resources where fixed input requirements may feature more prominently. Some potential for improved future science-policy interaction is also discussed.

Keywords: uncertainty, water, markets, science-policy nexus, risk management

A fifth stage of water reforms: policy lessons for future natural resource management

1. Introduction

Government policy is designed to reflect the expectations of the society that elected them, and/or minimise the risks of adverse outcomes that would consequently harm social welfare (Laffont and Triole, 1990; Rostow, 1959). The risk of adverse outcomes can increase significantly where future uncertainty can negatively affect implementation success and/or the realisation of policy objectives. Research to better understand and reflect uncertainty factors in policy design, and how they may evolve, is therefore critical for robust policy development and implementation, including the identification of key tipping-points.

It follows then that effective risk management and robust policy decision-making requires accurate information and well-informed judgements (Department of Finance, 2017). What is considered a 'well-informed judgement' will change through time as more information comes to light and societal expectations change, where/when risks are known (or knowable), and evidence in support of policy design becomes obtainable. Assurance reviews provide an early opportunity to identify policy risks and tipping-points during design stages, while on-going review of the science/economic and policy interface will improve future policy design to reflect social expectations—or transition society along alternative pathways to accurately forecast future social issues. Thus, the accuracy of policy design/performance monitoring information will always hinge on a range of criteria: availability, consistency, completeness, reputation, and/or usefulness (Lee et al., 2002). Accurate information provides an evidence-basis for decision-making, which may involve scenario-testing to explore complex options and inform or assess policy judgements (Wiebe et al., 2018).

However, evidence associated with uncertain (unknown) outcomes is usually limited, while evidence and information for unknown-unknowns will be non-existent. Hence, while policy-makers are aware that we have incomplete information about the future, evidence gaps will encourage pre-emptive judgement of systems, often without measurement (Lankford, 2016). Alternatively, evidence gaps may force policy design or assessment back toward 'rosy' scenarios driven by (past) expectations and familiar assumptions (e.g. the political economy of promise: Leach et al., 2012), rather than recognising the governance needs of today, and including mechanisms that adjust in response to future uncertain outcomes. It is important to therefore note that the governance needs of today are (among other factors) a reflection of past policy decisions, available information, and current social expectations that may constraint inter- and intra-generational choice sets tomorrow. Incorporating uncertainty into policy design or performance assessment requires input from both the natural and the social sciences (Loch et al., 2014a). Interaction between these discipline groups involves its own challenges. Further, designing and implementing adaptive policy to address multiple (uncertain) future governance requirements may not sit well within existing assurance review processes, will be costly to transact, and at conflict with the political economy of promise—that is, delivering effective policy solutions at low transaction costs and without the inequity generated by winners or losers. These issues raise additional challenges that undermine policy-science interactions. Nevertheless, a failure to achieve science-policy interactions can drive differences between hypothesised performances and realised future outcomes, with more costly policy adjustment investments to achieve stated objectives where past decisions limit future policy or program opportunities. Finally, where scientific evidence and societal expectations of policy objectives are dynamic, the associated challenges and costs can increase significantly.

1.1. Water resource management—an example

The management of scarce water resources provides a useful framework for examining evidence-based and adaptive policy challenges, and discussing their implications with lessons for other jurisdictions. Water scarcity is a global concern (World Economic Forum, 2017) with social, cultural, economic and natural capital risk elements. Water supply is highly uncertain over short- and long-term horizons, and thus water policy typically benefits from early adaptive design principles followed by effective performance assessment after implementation. In addition, water demand is dynamic in many contexts with evolving objectives including economic growth traded off against alternative welfare from increased environmental flows, recognition of cultural rights, or effective reallocation mechanisms as examples. What is becoming increasing important is the role water has as a fixed or variable input of production for all water users, and the irreversible capital loss consequences when fixed water inputs are not available (Adamson et al., 2017).

Australian water reform, particularly that in the Murray-Darling Basin (MDB), provides a world-leading example of policy design and implementation aimed at addressing dynamic demand changes within highly uncertain and constrained water supply conditions. Price signals, polluting behaviour deterrents, shared environmental rights, welfare savings, and market-based reallocation mechanisms are all features of the Australian policy arrangements (Krutilla and Alexeev, 2014). The design and implementation of market-based reallocation required significant investments toward closing the MDB Basin via limits on further water extraction, and unbundling (separation) of land and water rights to enable market-based transfers (known as the MDB 'Cap and trade' process). More recently, policy reforms have focused on buying back water rights from willing irrigators to recover water for environmental use, and the *Water Act* (2007) that empowers a basin-wide management plan for the MDB incorporating sustainable diversion limits and agreed objectives for social, economic and environmental uses of water (Wheeler et al., 2014), known as the Basin Plan.

The development of Australia's water policy over decades places it at the forefront of world water management. However, the advanced stage of reform in Australia also prompts a question of the trajectory of future water policy. Has the legacy from prior investments situated MDB water managers on a trajectory where current performance is consistent with hypothesised future outcomes? What are possible future reform trajectories, and are they in the best interest of past or future social acceptability? Will future reform be limited by the previous policy choices or is adaptation possible following prior reform investments? Following this, should risk and uncertainty feature more prominently in discussions between scientists and policy-makers? Answers to these questions provide important insights for Australian policy-makers, and useful lessons for other jurisdictions with less advanced resource policy design and implementation.

To structure our discussion, we first review the current four stages of water policy reform with particular focus on the MDB, in south eastern Australia. Next, we posit and define a fifth stage of reforms with adaptive properties by design. This approach highlights risk issues that may not feature in current policy assurance reviews or performance assessments, and enables a clearer representation of uncertainty with respect to water resources. We conclude with a detailed discussion of the relevance of this fifth stage, and what insights it may provide for water managers following the more advanced reform states present in the Australian context.

2. Australian water reform policy stages

Water policy in Australia has occurred in four major stages:

2.1. Exploratory Stage

The period of water reforms from European settlement to approximately 1915 is referred to as the *Exploratory Stage* (Musgrave, 2008). During this period, the allocation of water resources was via riparian rights. The *Victorian Irrigation Act* (1886) first altered riparian rights so that ownership and control of water resources vested with the state (in the MDB these include Queensland, New South Wales, Victoria and South Australia), allowing state-centralised management and greater utility of larger areas. New water entitlement rights that varied with the climatic conditions were created to provide a proportion, rather than a fixed, volume of water to users which was novel in comparison to the rest of the world (Connell, 2007). At the time of Federation in 1901, the new *Constitution* upheld state rights to own and use water for conservation and irrigation (Waye and Son, 2010), requiring cooperative arrangements to design and implement water policy that persist to this day.

2.2. Expansion (Growth) Stage

The second period of reforms (1915 to the 1970s) is referred to as the *Expansion Stage* (Musgrave, 2008). During this period, water resource and irrigation development was sold as a nation-building exercise following a mantra of drought proofing the country (Davidson, 1969). After Federation, the states controlled and operated water resources. However, federal government funding helped to develop irrigation schemes and soldier-settlement farms for successive returning servicemen after World War One, World War Two, and the Korean and Malayan Operations (NWC, 2011). This period saw: a shift of water resources from navigation uses to irrigated-production; a ten-fold increase in major dam storage capacity; and protectionist agricultural policy that included tariffs on imported products, production controls and quotas, price reserve schemes, and statutory marketing to bolster irrigation water uses and promote food security (Industry Commission, 1991). Each state responded differently to these signals. For example, New South Wales agriculture was dominated by annual cropping such as rice and cotton under incentives to use all water each year (Musgrave, 2008). Victorian farmers invested in dairy and horticulture cropping with higher fixed demand characteristics that required access to reliable water supplies and conservative water management arrangements (Bjornlund and McKay, 2001). Finally, South Australian water use focused on irrigated horticulture and navigation uses that, closer to the end of the river system, required even more conservative attitudes to management (Crase, 2008).

2.3. Maturity Stage

Water policy and reform in the 1960s and 1970s reflected a growing awareness among society and policy makers of the limits to water resources. Moratoriums on new water entitlements in South Australia in 1969 were followed by a general 10% reduction in volumetric allocations by 1979 (Bjornlund and O'Callaghan, 2003). New South Wales imposed catchment-specific embargoes on new entitlements in 1977, and a full state embargo in 1981. Victorian rights to pump from unregulated streams during summer months ceased after the 1967/68 drought, effectively capping extraction at existing levels of use. However, MDB extraction had already exceeded sustainable diversion levels, causing environmental degradation in the form of widespread algal bloom events, rising soil and water salinity, and flora/fauna species losses experienced on a regular basis (Connell, 2007). Irrigators could avoid extraction restrictions by submitting and approving entitlement applications ahead of embargos, increasing groundwater extraction, building on-farm dams to capture runoff, and/or investing in other interception schemes (NWC, 2011). Beneficial informal seasonal or temporary trade arrangements provided each of the states with capacity to redistribute water under discretionary powers to grant and withdraw licenses (Clark and Moore, 1985) suggesting a continuing policy preference toward supporting consumptive water uses. However, agricultural protectionist policies began to wane, low-cost water storage infrastructure sites were largely exhausted, and the need to manage environmental externalities (e.g. salinity) were increasingly reflected in MDB water management agreements (MDBC, 2007). An Australian Agricultural Economics Society meeting in 1984 concluded that water reallocation should be exposed to market forces with inputs/outputs valued at their economic cost (AWRC, 1986). These factors meant that water policy had shifted into a *Maturity Stage* (1980s to 2007) characterised by appreciation of the limits on river systems, federal powers increasingly being applied to resource management, and arguments for market-based reallocation (Randall, 1981).

Market-based reallocation arrangements required several key reforms. First, riparian rights were gradually replaced with legislative arrangements and *de jure* property rights recognised by formal legal instruments that, if challenged jurisdictionally or administratively, would most likely be upheld (Schlager and Ostrom, 1992). Such rights are critical for encouraging investment (Bjornlund and O'Callaghan, 2003), and the successful market reallocation of natural resources (Demsetz, 1964); despite some difficulty in defining these rights due to high supply variability, climate change, and land use change impacts (van Dijk et al., 2006). Second, land and water rights were unbundled to enable transfers in response to risk attitudes, seasonal conditions, and/or strategic planning. Separation was essential for market-based reallocation to work effectively and efficiently (Wilson and Francis, 2010). Low levels of trade began to occur from the early 1980s (South Australia), with New South Wales and Victoria experiencing transfers by the early 1990s. Third, a 1995 audit of river flow regimes concluded that median annual flow-to-sea levels were 27% of natural, creating drought-like flow patterns in 60% of years as compared with 5% under natural conditions (MDBMC, 1996). Between 1984 and 1994, extractions had increased by nearly 8%, and on July 1 1997 regulators imposed a Cap on further extraction in the MDB. Fourth, the states were encouraged to introduce water management and planning arrangements to address water over-allocation and achieve sustainable levels of extraction. However, by 2004 many states had failed to deliver on their commitments, and planning proved inappropriate for the task (NWC, 2007). Finally, an assessment of water requirements to achieve sustainable outcomes concluded that a ~1,900 gigalitre (GL) reduction in current extractions would be needed to achieve a moderate probability of future environmental health (Jones et al., 2003).

2.4. Environmental (Contraction) Stage

Recognition of the need to recover water from consumptive (e.g. irrigation) uses to enable increased environmental flows triggered an *Environmental Stage* (2007 to present)—also described as a contraction phase (Watson and Cummins, 2010). A series of intergovernmental agreements made the states responsible for achieving sustainable environmental and economic outcomes (COAG, 2004b) and set requirements to recover water via market mechanisms or efficiency investments for public benefit (COAG, 2004a). In addition, a federal MDB-wide plan was enacted with periodic reviews to ensure sustainable water use outcomes (MDBA, 2012). Part of the Basin plan addresses better understanding of all conjunctive water resources, including groundwater, to recognise their non-linear relationships (Chiew et al., 1992) and attempts to effectively manage both known future risks as well as uncertainties (Carey and Zilberman, 2002).

Three significant water recovery programs have occurred to date. First, The Living Murray (TLM) initiative, which invested AU$1 billion to recover 500GL between 2005 and 2009 under a mixture of irrigation efficiency and buyback offers. Second, under a new recovery target of up to 3,200GL, the Restoring the Balance (RtB) program that invested AU$3.1 billion to purchase up to 1,500GL of water entitlements from willing irrigators between 2008 and 2015. This was coupled with the Sustainable Rural Water-Use and Infrastructure Program (SRWUIP), which will ultimately invest AU$8.4 billion to achieve up to 1,700GL of water savings for environmental use. Total MDB recovery volume objectives may reduce if water managers can achieve environmental objectives with less water (i.e. *supply measures*), greater delivery system efficiency savings (i.e. *efficiency measures*), and/or more effective environmental water delivery in future (i.e. *constraint measures*); as long as they avoid negative socio-economic impacts (MDBMC, 2014). Current progress (DAWR, 2018) suggests that 2,117GL have been recovered to 31 August 2018; comprising 1,227GL of buyback, 728GL of efficiency savings, and 163GL of state government recovery. The four stages of water policy reform in Australia and the corresponding phases of water market development are summarised in Figure 1, together with a standard product life-cycle evolution diagram following an s-shaped transition pattern which reflects the policy transitions.

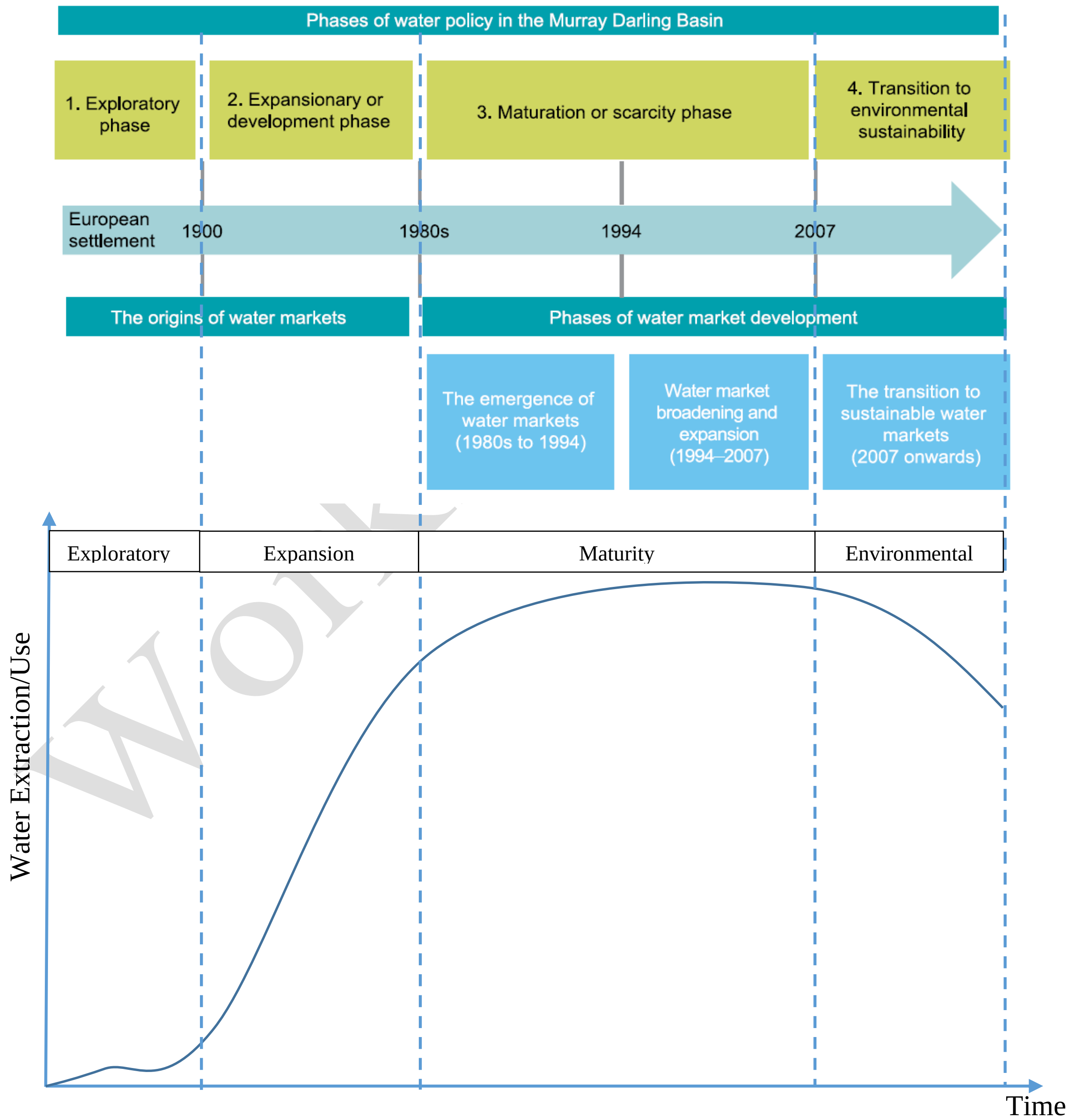


Figure 1: Stages of water policy reform (adapted from Watson and Cummins, 2010)

2.5. Reform stage criteria

The major stages of water reform policy can be characterised using a set of water development criteria (Adamson, 2015). These criteria were first proposed by Randall (1981) to discover the true price of water resources and capture externalities, and later adapted by Cummins and Watson (2012). In particular, these criteria assess how policy i) impacts on demand curve transitions in response to water scarcity, and ii) deals with the complex nature of trade-offs between all water users. Table 1 applies these criteria across the four stages of water reform in Australia to provide examples of outcomes and development over time.

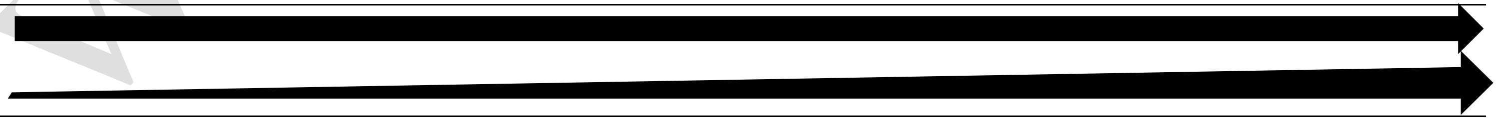
We begin with the state of long-run supply of impounded water that reflects current storage dams, and the potential for new storages to increase total supply (Criteria 1). The physical condition of storages and delivery systems will also change over time (Criteria 2). Supply-system characteristics can be set against the total demand for delivered water (Criteria 3), and increased right security/reliability for all water users (Criteria 4). Bringing supply and demand together should provide equilibrium outcomes, although periodic extreme positive/negative water supply outcomes may dramatically alter demand (non-convex solutions) as prices can no longer be depended upon to provide appropriate signals and the point at which users settle or meet social objectives must be made collectively using cost-benefit techniques (Baumol and Bradford, 1972) (Criteria 5). Non-convex demand creates irreversible losses for all water users when water is not available, especially for those that lack well-defined rights. A growing recognition of non-convex solutions may require social-costs to subsidise increased water use—at least in the short-term (Criteria 6). Finally, water managers should become more exposed to and familiar with both the positive and negative externalities from water use (Criteria 7), and be able to evaluate the sustainable nature of the system as a whole (Criteria 8).

Table 1: Assessing the four stages of water development in Australia's MDB

Stage Criteria	Exploration	Expansion	Maturity	Environmental
Long-run supply from of impounded water	Elastic.	Elastic to Inelastic.	Inelastic.	Inelastic.
Physical condition of impounds and delivery system	Little to no infrastructure. All infrastructure systems are new.	Public-funded infrastructure is in new to good condition.	Aging public infrastructure in need of expensive repair, upgrade, or replacement.	No new large-scale public infrastructure.
Demand for delivered water	Minimal, often no or minimum charges to access water.	Low but growing demand. Elastic (but not perfectly) at low prices; inelastic at high prices.	High and increasing demand. Elastic at low prices; inelastic at high prices. Market failures.	High but stable demand. Elastic at low prices; inelastic (but not perfectly) at high prices. Market reallocation.
Improved security/reliability for water users	Not applicable. Only during extreme drought or low-supply events.	Minimal but increasing. Drought exposure prompts new rounds of investment in long-run supply.	Intense apart from periods of increased supply (e.g. flooding).	Reallocation improves security/reliability for all users.
Non-convex demand solutions in market	Nil.	Nil.	Yes (increasing frequency of occurrence).	Yes (stable frequency of occurrence).
Social costs of subsidising increased water use	Zero to very low.	Low.	High and rising.	Should be nil.
Externalities	Nil.	Minimal.	Extensive externalities (mainly negative).	Reduction (increase) in negative (positive) externalities.
Equitable water-sharing arrangements.	No.	No.	No.	Yes.

Role of policy:

Role of science:



Source: Adapted from Adamson (2015)

Note the roles of policy/science in the design and development of water management over the stages (bottom of Table 1). While the complexity of the policy role has undoubtedly increased, it has remained relatively stable. However, note the increasing complexity and role of science that stems largely from added contributions by economics, sociology, hydrology, biology, ecological conservation, psychology etc. to early discipline contributions that were largely grounded in engineering. Shifts over time in the role of science highlight the need for greater interface between policy-makers and scientists. Paradoxically, the reverse appears common, and is the subject of discussion and debate among many in the scientific community in terms of timing of information provision (e.g. Wesselink et al., 2013) and language for effective communication (e.g. Hinkel, 2011). Introducing uncertainty into the policy-science discussion requires longer processes to collect/consider complex data or measures, which also tends to confound dialogue between the parties. Policy or programs aimed at managing uncertainty will undoubtedly be expensive in terms of short-run institutional transaction costs (Loch and Gregg, 2019), take longer to implement/realise, and thus be at odds with the political economy of promise. Yet, in the long-term, all capital (social, economic, cultural and natural) should be increased by effective sustainable objectives and management (e.g. the 2030 Sustainable Development Goals; United Nations, 2016). Next, we examine three key programs under the broader MDB water reform agenda to provide insight into the effectiveness of policy in achieving common objectives, and to suggest what trajectory future reforms may be on.

2.6. Ideals versus implementation

Australian water reform is most-advanced in the MDB, where three key policy programs are driving reallocation of resources toward natural capital (i.e. environmental) gains in the fourth-stage. The three key components driving (ideally) increased positive (common objective) environmental water reallocation via a contraction in total consumptive water use are: (1)

groundwater regulation to increase sustainable future management; (2) buy-back of water entitlements from willing farmers through the RtB program; and (3) water-use efficiency investments to create savings of water that contribute toward environmental stocks through the SRWUIP program. In this section we evaluate these policy ideals based on their implementation to achieve *Environmental Stage* (contraction of consumptive resource use) outcomes, and what they might suggest for necessary future reforms.

If we return to our earlier assessment of water development stages (Table 1), we see that the most recent *Environmental Stage* should provide us with resilient future outcomes if the policy component characteristics conform to ideal criteria. Contrasting ideal characteristics of water reform against current MDB policies allows us to assess how well those elements align with the characteristics of different stages of water reform. Next, we can assess whether we are on the cusp of a fifth, more advanced stage of water reform where current reforms may not be responding effectively to evolving, more demanding, and multi-facetted objectives (Table 2). Subsequently, we may be able to posit what trajectory that fifth stage (if any) may take. Groundwater regulation recognising resource limits but increasing access to users under the MDB Basin Plan (MDBA, 2012) will result in elastic supplies of water resources in the short-run, with relatively new infrastructure maintained by those users. Demand will be high and stable, inelastic at higher prices, and increased total water use should see resources reallocated to irrigators over time as surface water sources decrease. Some non-convex market solutions may still occur where uncertainty results in short-run adaptation, but overall the impact to positive/negative externalities should be low together with the social cost of subsidising groundwater investment. The sustainability of the groundwater system will depend on the final water user, where any future increased negative environmental externalities will signal failure. Therefore, the groundwater component of the Basin Plan contains elements of both the *Expansion* and *Environmental* stages as defined above.

In contrast, market buy-back of water entitlements via the RtB recovery program will not reduce the inelastic supply of water, following redistribution of those resources toward environmental flows. Infrastructure will be maintained by irrigators (on-farm and off-farm), and increasingly by public programs via environmental manager contributions to costs (off-farm and new structures at environmental sites). Demand will remain high and stable, but consumptive water availability may decrease in certain years, potentially increasing competition among irrigation users. This will drive non-convex market solutions in such years. However, there are no social costs of subsidised water uses, and reduced (increased) negative (positive) externalities. The result is equitable water-sharing arrangements that most closely resemble an *Environmental* stage of development.

Last, we examine the SRWUIP recovery component via investments in on- and off-farm water-use efficiency. Again, the long-run supply of water will remain inelastic as no new large-scale storages are built. However, a significant proportion of smaller-scale water infrastructure will be new, subsidised, and more expensive to operate (Adamson and Loch, 2018). Demand will likely increase, particularly during drought events, and total water use may increase under changes to land-use or irrigation practices (Ward and Pulido-Velazquez, 2008). If commodity transitions also occur, then competition for water resources will increase with non-convex market solutions becoming more evident (Adamson et al., 2017). Importantly, if production systems (economic, natural, cultural and social) transition towards requiring fixed water inputs in all years, then the system will become less flexible and exposed. The social costs of achieving these outcomes will be relatively high, increasing over time as investment options diminish (Loch et al., 2014b). Uncertainty surrounding the savings from efficiency investments will undermine any assessment of equitable water sharing, suggesting that the component resembles both the *Expansion* and *Maturity* stages of development (Table 2).

Table 2: Comparing key components of the MDB Basin Plan to stages of water development

Stage Criteria	**Ideal characteristics of the *Environmental* Stage**	**Basin Plan Policy Components**		
		Groundwater	**RtB**	**SRWUIP**
Long-run supply from of impounded water	Inelastic.	Elastic in the short-run.	Inelastic.	Inelastic.
Physical condition of impounds and delivery system	No new large-scale public infrastructure.	Private infrastructure new and maintained by users.	On-farm infrastructure maintained by private users; off-farm unknown.	Public infrastructure (on- and off-farm) new and subsidised.
Demand for delivered water	High but stable demand. Elastic at low prices; inelastic (but not perfectly) at high prices. Market reallocation.	High but stable demand. Elastic at low prices; inelastic at high prices. Some market failure. Water use increases.	High but stable demand. Elastic at low prices; inelastic at high prices. Market reallocation decreases water use.	High, potentially increasing demand in droughts. Elastic at low prices; inelastic at high prices. Water use may increase.
Improved security/reliability for water users	Reallocation improves security/reliability for all users.	Reallocation of groundwater to irrigators.	Reallocation increases security/reliability for all users.	Reallocation results in regional winners/losers for water security/reliability.
Non-convex demand solutions in market	Yes (stable frequency of occurrence).	Yes but with low probability.	Yes with stable frequency.	Yes with increasing frequency.
Social costs of subsidising increased water use	Should be nil.	Nil to very low.	Nil.	High and rising as low-hanging fruit expended.
Externalities	Reduction (increase) in negative (positive) externalities.	No impact.	Reduction in externalities and social costs.	Some reduction in externalities but social costs remain high.
Equitable water-sharing arrangements.	Yes.	Depends on the final user.	Yes.	No.
Stage the policy component resembles:		**Elements of *Expansion* and *Environmental* Stages.**	**Elements of *Environmental* Stage**	**Elements of *Expansion* and *Maturity* Stages.**

Source: Adapted from Adamson (2015)

This assessment suggests that the *Environmental* stage outcomes for water reform in the MDB may not be consistent with the expected contraction outcomes for fourth stage policy development, as depicted in Figure 2. We should expect to see contraction in total water use, suggesting a mixture of stability, further growth and/or contraction of water resource uses occurring simultaneously under current policy conditions (Figure 3). Critically, until revealed, we will remain uncertain as to which path the reform outcomes have taken.

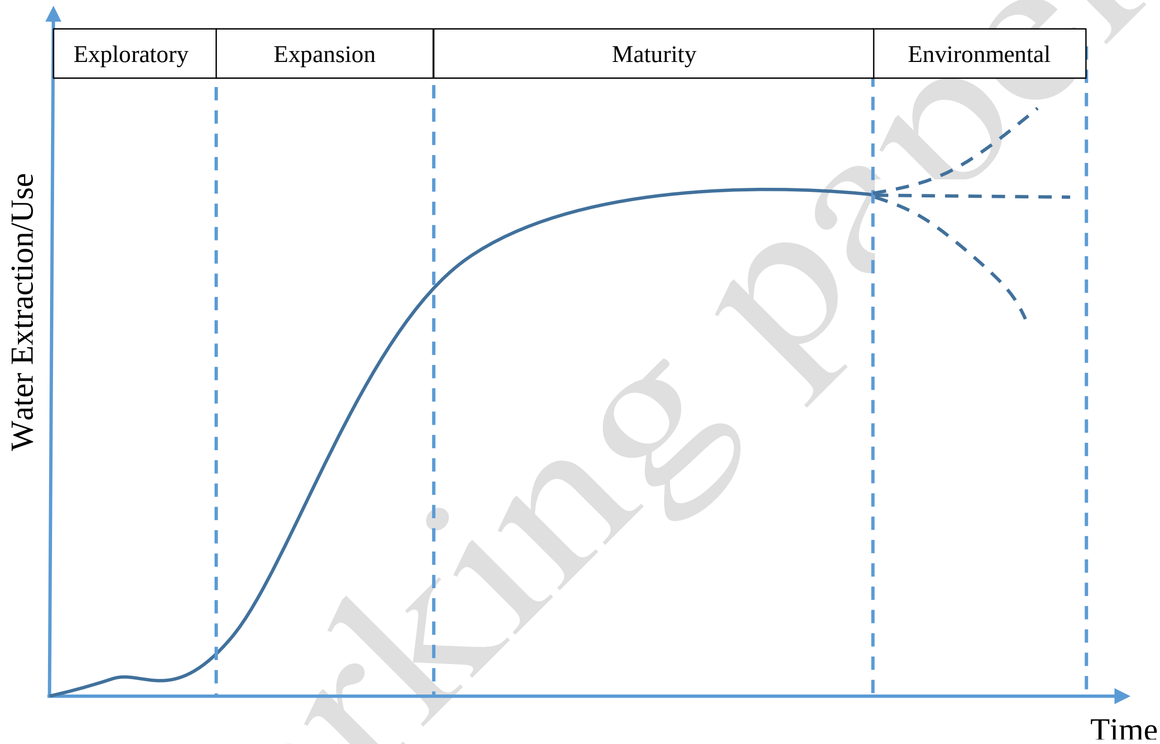


Figure 3: Uncertain reform path outcomes following MDB Basin Plan component choices

Australia must accept future performance risks associated with current policy choices, as there is no policy review guidance available from other contexts. Further, future and on-going political interference in the reform process is guaranteed wherever trade-offs need to be considered. By way of example, the recent Murray-Darling Basin Royal Commission drew on evidence provided to conclude that politics had moderated the best scientific recommendations concerning a sustainable level of water consumption to favour economic uses over environmental (Davies, 2018), providing uncertainty around the future of the Basin Plan. Other examples abound in jurisdictions across the world. In response to these cautionary examples, water managers should consider and invest in flexible policy components that provide adjustment capacity in response to future realised outcomes. Flexible policy components will require higher institutional transaction costs, take longer to design and implement, and not conform to political cycles or a need for tangible short-run success. Thus, if risk and uncertainty must feature in science-policy interactions, what might any fifth stage of reforms look like?

3. Defining a fifth stage of water reform

Table 3 suggests definitions of a fifth stage of water reform in Australia. For many contexts that are not as advanced as Australia, future shifts beyond the *Maturity* stage may resemble this newly proposed fifth stage, rather than the standard fourth stage described earlier. Only time will tell. However, common key variations include a reduced role of public investment in water storage/delivery infrastructure, with maintenance/operation/refurbishment costs increasingly met in full by water users. As the true value and/or price of water is increasingly revealed, markets (where available) will more effectively reallocate resources between all users; including new market entrants (e.g. cultural flows) in response to shifts in social objectives. New social objectives may create a need to review the security/reliability properties of existing rights, but any changes to those property rights must be carefully signalled to users, consulted upon, and reviewed ahead of implementation. Ideally, the process for adjusting security and/or reliability properties would feature in the original policy design. Care will be needed when dealing with an inequitable share of water resources though, as the reallocation process may transition production systems towards inflexible demand arrangements that always require water to preserve the capital base. If the adoption of inflexible production systems increases, when uncertain water supply events (i.e. droughts) are realised the capital base (natural, social, cultural and economic) associated with inflexible demand will be exposed to unnecessary risk.

Currently, scientific models struggle to represent risk, uncertainty and water-user adaptation well, reducing the potential for useful discussions with policy-makers and water managers (Chavas et al., 2010).

Table 3: Defining a fifth stage of water development

Stage Criteria	Ideal characteristics of the Fifth Stage
Long-run supply from of impounded water	Inelastic. The opportunity for new large-scale public impound and/or delivery infrastructure recognised as extremely limited and costly. If new storages are invested in, then the real opportunity cost of their development are understood in the policy setting and paid for by all water users.
Physical condition of impounds and delivery system	New infrastructure increasingly paid for via private investment. Costs of existing state infrastructure maintenance and operation fully paid for by water users.
Demand for delivered water	High but stable demand. Elastic at low prices; inelastic (but not perfectly) at high prices. True value/price of water increasingly revealed over time. Market-based mechanisms using price signals to reallocate across all users/uses.
Improved security/reliability for water users	Scope and planning for some increased competition between existing and new users. May require complex assessments of risk, and then some carefully signalled adjustments to security/reliability arrangements.
Non-convex demand solutions in market	Yes, with a decreasing frequency of occurrence. This will ultimately depend on the impacts of climate change and other input shocks.
Social costs of subsidising increased water use	Low where associated with new users or social objectives (e.g. cultural flows). Subsidy program limits embedded in policy.
Externalities	Measured reduction (increase) in negative (positive) externalities on the back of scientific evidence and ex-post policy analysis.
Equitable water-sharing arrangements.	Yes, with long-run resilient characteristics.
Base flows	Full transition from mixed status of protected/unprotected resource, such that base flows are separate, prioritised over all other rights/uses, monitored, and any breaches prosecuted.

Ideally, non-convex outcomes are still present but with greater awareness of how to adapt to water risk and uncertainty. This should lead to a situation where natural, social and financial capital is less exposed to risk. However, the probability of such outcomes will ultimately depend on climate change impacts and the frequency/severity/longevity of periodic system shocks, highlighting the importance of incorporating risk and uncertainty into policy design and performance assessments. As stated, reliance on business as usual approaches to policy formulation and assessment, as well as 'tried and true' sources of information, will limit capacity to incorporate risk and/or uncertainty policy factors. New approaches (e.g. assessment models incorporating state contingent analysis) will be increasingly required.

Some increase in social costs may occur where new or altered objectives trigger public institutional transaction costs to reconfigure existing arrangements or create new policy and programs. The opportunity cost of such policy change is understood and reflected in the policy design. Adaptively efficient policy design will potentially lower lock-in transaction costs and provide for alternative arrangements when necessary in response to revealed outcomes. However, ideally policy arrangements will include limits to the duration of social investments based on performance assessments and requirements for further support. The appropriate place for those assessments are part of on-going measurements of externality impacts (both positive and negative) from the policy and reform components selected, where scientific evidence and advice have a key role based on agreed prerequisites with policy-makers during initial interactions.

Finally, note a characteristic not evident in our previous water reform stages—base flows. In Australia, base flows (i.e. water required to support core ecological functions and refuge sites during extended low-inflow periods) enjoy mixed importance and protection status across and within state boundaries. Ideally, the fifth stage characteristics include uniformly specified base flows, established as a separate right prioritised ahead of all other rights, and vigorously defended through prosecutions for breach. Implemented that way, base flows offer the foundation for resilient water systems with an underlying resource buffer to protect against future shocks and uncertain outcomes. We expand our consideration of these fifth stage characteristics in our final section below.

4. Discussion

This paper highlights challenges in natural resource management and policy design and implementation. The development of water policies in Australia offers useful examples to illustrate some of these challenges: the impact of past policy decisions, the role of generating and incorporating new information, and challenges to reflecting social expectations in policy processes and decisions. Closer examination of Australia's water policy also highlights the potential for a fifth stage of reforms, motivated by the need for increased policy flexibility and adaptability in response to increasing uncertainty in production systems (social, economic, cultural and natural). Any fifth stage of reforms must be capable of adapting to on-going uncertainty associated with climate change impacts on future water reliability, and the need for increased future equity between uses/users (productive/consumptive, environmental, cultural). What then are the lessons from Australia's experience that may provide useful insight in other jurisdictions?

4.1. Missing markets and reallocation

As discussed above, Baumol and Bradford (1972) suggest cost-benefit analysis will provide insights toward the true price of countering negative externalities from consumptive resource uses. Where intergenerational benefits for all sectors of the economy accrue from the development of public (common) ownership of all natural resources (Ciriacy-Wantrup and Bishop, 1975), a cost-benefit evaluation of effective policy pathways highlights why society may be willing to pay above market rates. Differentials between society's stated willingness to pay for common (public) benefits and the revealed market prices for consumptive (private) uses of resources may provide some mandate for policy-makers to intervene and reduce any misallocation of natural resources.

However, the regulatory and institutional bases required to establish natural resource markets in jurisdictions where they do not currently exist are complex and costly (Wheeler et al., 2017). Further, while markets may be viewed as providing inherently flexible arrangements, they are not necessarily a panacea for reform requirements, and will not be able to supply resources: beyond inelastic realities, below minimum conveyance levels, and/or where transaction costs outweigh the surplus generated from transfers (Gomez et al., 2018). In Australia, future market reforms will likely include the recognition and reallocation of resources to new users (e.g. cultural/indigenous/first people flows). Questions remain over required investments to achieve that transition, whether existing institutions have the flexibility to incorporate that change, and/or whether other structural reforms (e.g. bolstered compliance, enforcement and monitoring to increase market integrity) will be required ahead of those changes. This has important implications for other jurisdictions in their own reform design and implementation choices.

4.2. Social consultation to reflect dynamic change

As the need for an expanded set of market property rights (e.g. cultural flows) is increasingly recognised by society, effective policy should include mechanisms capable of incorporating changes into new/existing arrangements, and implementing appropriate assessment metrics which assist in evaluating progress toward new collective objectives. Thus, another issue contributing to the emergence of a fifth stage of water reforms in Australia is the dynamic nature of social expectations and increasing community involvement in decisions about the management of natural resources. At a broad scale this shift to greater community involvement has been linked to a growing awareness of the complexity and interconnectedness of many environmental and social policy problems (Head, 2007). Locally this could be linked to the growing distrust of institutions in Australia (AICD and KPMG, 2018), the dynamic nature of social expectations, and the emerging issue of irrigators' social licence (e.g. Martin and Shepheard, 2011). The increasing involvement of community expectations and potency of social licence issues has implications for policy. Any policy change may result in a transfer of welfare from one group to another (Shleifer, 2005); for example, from irrigators to the community, or from upstream to downstream water-users. The task for policy-makers is to manage the trade-offs between different groups in society, their respective expectations for change, and facilitate social change toward desired long-term outcomes.

To achieve this balance, policy-makers will need to employ information from social and natural sciences at all stages of policy design and implementation. As part of this process, risk and uncertainty would feature prominently in the discussions between natural and social scientists, and policy-makers. Ongoing research will provide policy-makers with knowledge which can be used to enable a policy response or a change in policy settings (Wesselink et al., 2013). But generally, while policy has traditionally looked for simplicity, familiarity and easy solutions, science must express truthful, innovative and detailed investigations. Finding the common interaction point between science and policy will be critical in future natural resource policy design/effective implementation.

4.3. Uncertainty and adaptability

Transforming possible solutions into actual policy creation/change and implementation requires a full consideration of effective pathways (Gruère et al., 2018). However, the past is often no indication of the future. Effective policy design and assessment therefore must account for uncertainty and unawareness of how to adapt to future realised events, such as climate change impacts on water supplies. A first step toward recognising the requirement for increased future policy flexibility may be to accept that complexity is a defining characteristic of sustainability, conservation and governance of natural resources—limiting simple policy approaches based on attractive ‘quick-fixes’. This complexity is increasing through more refined understandings of nature-human interactions (Norgaard, 2010), and because scarcity, innovation and rising population disturb the balance of environmental protection and economic development (Tainter, 2011). More complex problems will require nuanced policy responses with capacity to (ideally) respond proactively in the face of dynamic adjustment requirements and shifting social objectives.

A second step may be to recognise that many familiar and low-cost policy options may already/will be exhausted. This may then require increased institutional transition costs to avoid policy lock-in outcomes and sustain adaptive efficiency (Loch and Gregg, 2019). We discuss this below in the transaction costs section. A third step involves creating improved communication between scientists and policy-makers about relevant risk and uncertainty impacts on policy outcomes. Evidence-based policy must prevail; emotion should have no place in policy design/implementation. One approach may be to combine familiar policy assessments (e.g. cost-benefit analysis) with innovative models such as state-contingent analysis that use scenarios to capture adaptation to future variability and uncertainty of systems, including low-probability extreme events at the tails of distributions (Quiggin, 2018). This is the subject of current research into the riskiness of stochastic water supply, and the viability of encouraged investments in water-use efficiency to reduce that riskiness. The findings of this research are discussed elsewhere (Adamson and Loch, 2019). However, these findings will be important for informing future policy selection and program design in developing nation contexts consistent with the advice provided by Gruère et al. (2018).

4.4. The transaction costs of adaptation

The process of transitioning existing policy/programs to more adaptive arrangements—or creating new policies with inherent adaptive characteristics—is complex and challenging. As our understanding of issues increases through scientific research in response to changes in social priorities and/or management requirements, this complexity also grows. Perhaps this is one reason why science and policy are drawing further apart in places, as the differential between useful and available information supporting quick and easy solutions in a political context and scientific goals of rigorous, informed and consistent information becomes stark. Yet the complex nature of these problems is reality, and our growing appreciation of future uncertainty for many natural resources suggests new requirements for governance capable of change and adaptive learning in response.

Adaptive policy combining social expectations and rigorous science is possible. Salinity management in the MDB provides an example, where public institution investments over 30 years have resulted in: positive (and increasing) reductions to riverine salinity levels based on ex-post performance assessments, flexible management arrangements despite a reliance on engineering interventions to achieve those reductions, and improved scientific knowledge of management options. It must be noted that the underlying program budget was sufficient and the institutional transaction costs (i.e. static transaction and institutional transition) were high; periodically increasing in response to the need for further change. However, these investments appear (thus far) to have avoided increased lock-in costs that reduce management options, and are following a downward trend over time (Loch and Gregg, 2019). This case suggests natural resource policy can transverse a tendency toward meeting objectives combining governance requirements of today, incorporating new information, and meeting social expectations of tomorrow. But it also stresses the critical importance of investing correctly over a sustained period (beyond political cycles) to achieve success. While we identify some potential requirement for limits to public subsidisation of reforms above, it is important that budgets must be sufficient over the life of implemented change (Garrick, 2015).

4.5. The importance of base flows

Finally, we return to the importance of base flows in water governance arrangements, as a specific feature of our posited fifth stage of reforms. Base flows can be thought of as a critical 'line in the sand' for many water governance contexts, where any reduction of resources below that line represent increased risk of irreversible long-term natural, social, cultural and financial capital loss. Where those same base flows provide the basis for consumptive benefits to other users (e.g. flows on which to piggyback conveyance water, recreational flows, aesthetic gains etc.) they should be fully protected and awarded priority status within the system of rights that arise from policy development or change. As discussed, where possible, this should be openly communicated to users ahead of design and implementation, and consulted upon widely before adoption.

Australia is presently struggling with illegal extraction of base flows, and how best to more adequately detect infringements, prosecute offenders, and recoup losses to ecological functions. The situation in Australia suggests future research should be focussed on better understanding the nature of resource demand and supply, and vulnerability of a range of shocks beyond climate change to enable informed policy-making and investment choices. The shift to contraction within the *Environmental stage* has improved our understanding of the true value of water, encouraging all property right owners to maximise the return on their assets. In the absence of proper enforcement, existing users may exceed their rights, and third-parties without rights may also attempt to profit. Therefore, failures to properly account for total water use may mean that current actual water use is already on an upward trend—consistent with our earlier assessment of uncertainty regarding the real stage of water reform in Australia. Therefore, an exploration of the economic incentives behind illegal resource extractions—and the relevance of effective enforcement—underpins the broader policy design and implementation discussion above (Loch et al., 2019).

4.6. Inflexible production systems

Dealing with any intra- and inter-generational inequity (reallocation) issues associated with water resources and social expectations is a complex real-world problem, and care is needed to prevent unintended consequences. The combination of reallocating water resources between all (new) water users, giving everyone (greater) market access, preserving base flows, and allowing existing (new) water owners to learn and adapt to (unrealised) climate change, ensures that a unawareness associated with the future is guaranteed.

One issue that is becoming evident in Australia has been the transition towards inflexible production systems that always require a fixed unit of water to maintain their capital integrity. As debated by Adamson (2019), all water users have the same set of rights, and all production system (social, natural, cultural and economic) water inputs can be represented by fixed and variable requirements. Fixed water production systems include perennial crops, permanent wetlands, and critical human water supplies, while variable water production systems may be represented by ephemeral wetlands, recreation uses, and annual crops. Any increased transition towards higher fixed water production system requirements may result in unintended consequences such as capital loss where the net water demand in every year exceeds the ability of supply sources and/or the market to reduce risk from climate variability. This is a topic of research that will require some considerable future work to better understand and incorporate into the science-policy discussions.

5. Conclusion

Improved science-policy interactions are required to build policy/program capacity to deal with the risk and uncertainty surrounding natural resource management. In this paper we have detailed natural resource management reforms over the course of a century in Australia's Murray-Darling Basin to highlight the increasing role of science-policy interactions with regard to water reforms. Despite the best intentions of all parties during the development of those reforms, inevitably political trade-offs and rent seeking have delivered instances of second best outcomes. Further, as the need for future adaptation to climate change risk and uncertainty has emerged, together with evolving social expectations, it has become clear that effective response to dynamic outcomes are best achieved in the design/implementation stages.

However, in reality the Australian approach to water reform has been more reactive than proactive in terms of design and implementation—resulting in actual outcomes far-removed from the original hypothesised arrangements. In this paper we have used previous reform stages to hypothesise a future fifth stage with adaptive properties, and attempted to analyse the trajectory for future Australian water reforms. This analysis is motivated by the need for increased policy flexibility and adaptability in response to rising uncertainty associated with transitions toward inflexible production systems that could result in irreversible capital (social, economic, cultural and natural) loss. The risk of irreversible losses may be compounded by future climate change and/or the adaptation strategies adopted by new entrants under any reallocation of resources.

The fifth stage path will only be revealed over time in response to decisions made today. This highlights the importance of our current choices, the role that both science and politics have in making those decisions. Ideally, any fifth stage reforms should improve national welfare via the recognition of increasing risk and uncertainty, the effective reallocation of resources in response, and a capacity to reflect dynamic social expectations. Defining the fifth stage of water reforms in this way also provides some additional assessment goalposts for periodic MDB Basin Plan reviews. Additionally, this framework has applications that extend beyond water to describe and assess any critical resource (e.g. the 2030 Sustainable Development Goals). Therefore, the lessons learned from this analysis of reforms in Australia provides valuable insights for jurisdictions at earlier stages of water management change and adaptation, where water managers may invest in adaptive policy design/implementation that minimise future lock-in costs, reflect the opportunity cost of public expenditure, and results in adaptive arrangements more capable of responding to dynamic change and political rent-seeking.

6. References

Adamson, D., 2015. Restoring the Balance: Water Reform & the Murray-Darling Basin Plan, School of Agriculture and Food Sciences. University of Queensland, Brisbane.

Adamson, D., 2019. Irrigating the environment, Centre for Global Food and Resources. University of Adelaide,, Adelaide, South Australia.

Adamson, D., Loch, A., 2018. Achieving environmental flows where buyback is constrained. Australian Journal of Agricultural and Resource Economics 6, 83-102.

Adamson, D., Loch, A., 2019. Investments and uncertainty: Cost-benefit analysis and water-use efficiency, Centre for Global Food and Resources Working Paper. University of Adelaide, Adelaide, South Australia.

Adamson, D., Loch, A., Schwabe, K., 2017. Adaptation responses to increasing drought frequency. Australian Journal of Agricultural and Resource Economics 61, 385-403.

AICD, KPMG, 2018. Maintaining the social licence to operate: 2018 KPMG-ACID Trust Survey. Australian Institute of Company Directors and KPMG, Sydney, Australia.

AWRC, 1986. Proceedings of the Joint AWRC-AAES Seminar on Transferable Water Rights, Joint AWRC-AAES seminar on transferable water rights. Australian Water Resources Council, Rural Water Commission of Victoria Auditorium, Melbourne 11 December

Baumol, W., Bradford, D., 1972. Detrimental Externalities and Non-Convexity of the Production Set. Economica 39, 160-176.

Bjornlund, H., McKay, J.M., 2001. Current issues and future directions for Australian water market policies. Water Australia 28, 74-78.

Bjornlund, H., O'Callaghan, B., 2003. Property implications of the separation of land and water rights, Ninth Annual Pacific-Rim Real Estate Society Conference, Brisbane, Queensland, 19-22 January.

Carey, J.M., Zilberman, D., 2002. A model of investment under uncertainty: modern irrigation technology and emerging markets in water. American Journal of Agricultural Economics 84, 171-183.

Chavas, J.-P., Chambers, R.G., Pope, R.D., 2010. Production Economics and Farm Management: A Century of Contributions. American Journal of Agricultural Economics 92, 356-375.

Chiew, F.H.S., McMahon, T.A., O'Neill, I.C., 1992. Estimating groundwater recharge using an integrated surface and groundwater modelling approach. Journal of Hydrology 131, 151-186.

Ciriacy-Wantrup, S.V., Bishop, R.C., 1975. Common Property as a Concept in Natural Resources Policy. Natural Resources Journal 15 713-728.

Clark, S.D., Moore, H., 1985. Economic Criteria for Water Resource Planning and Management: Some Legal Implications, in: Department of Arts Heritage and the Environment (Ed.), Conservation and the Economy: Conference Papers and Proceedings. AGPS, Canberra, pp. 469-497.

COAG, 2004a. Intergovernmental agreement on a National Water Initiative, Canberra.

COAG, 2004b. Intergovernmental agreement on addressing water over-allocation and achieving environmental objectives in the Murray-Darling Basin, June 2004.

Connell, D., 2007. Water politics in the Murray-Darling Basin. The Federation Press, Annandale, NSW.

Crase, L., 2008. An introduction to Australian water policy, in: Crase, L. (Ed.), Water Policy in Australia: The impact of change and uncertainty. Resources for the Future, Washington DC, pp. 1-16.

Cummins, T., Watson, A., 2012. A hundred year policy experiment: The Murray-Darling Basin in Australia, in: Quiggin, J., Mallawaarachchi, T., Chambers, S. (Eds.), Water Policy Reform: Lessons in Sustainability from the Murray-Darling Basin. Edward Elgar, Cheltenham, UK and Northampton, USA, pp. 9-36.

Davidson, B., 1969. Australia wet or dry?: The physical and economic limits to expansion of irrigation. Melbourne University Press, Carlton, Victoria.

Davies, A., 2018. Murray-Darling authority accused of maladministration and ignoring best science, The Guardian (Australian edition online). The Scott Trust, Melbourne Australia.

DAWR, 2018. Progress towards meeting environmental needs under the Basin Plan. Department of Agriculture and Water Resources Canberra, ACT, p. Web pages.

Demsetz, H., 1964. The exchange and enforcement of property rights. Journal of Law and Economics 7, 11-26.

Department of Finance, 2017. Australian government assurance reviews, Resource Management Guide No. 106. Australian Government, Department of Finance, Canberra, ACT.

Garrick, D., 2015. Water allocation in rivers under pressure. Edward Elgar Publishing, Cheltenham.

Gomez, C.M., Pérez-Blanco, D., Adamson, D., Loch, A., 2018. Managing Water Scarcity at a River Basin Scale with Economic Instruments. Water Economics and Policy 4, 1750004.

Gruère, G., Ashley, C., Cadilhon, J., 2018. Reforming water policies in agriculture: Lessons from past reforms, OECD Food, Agriculture and Fisheries Papers. OECD, Paris.

Head, B.W., 2007. Community engagement: Participation on whose terms? Australian Journal of Political Science 42, 441-454.

Hinkel, J., 2011. Indicators of vulnerability and adaptive capacity: Towards a clarification of the science–policy interface. Global Environmental Change 21, 198-208.

Industry Commission, 1991. Statutory marketing arrangements for primary products. Industry Commission report No. 10, Canberra.

Jones, G., Arthington, A., Gawne, B., Hillman, T., Kingsford, R., Thoms, M., Walker, K., Young, B., 2003. Ecological assessment of environmental flow reference points for the River Murray System: Interim Report. Scientific Reference Panel for the Murray-Darling Basin Commission, Living Murray Initiative, Canberra.

Krutilla, K., Alexeev, A., 2014. The Political Transaction Costs and Uncertainties of Establishing Environmental Rights. Ecological Economics 107, 299-309.

Laffont, J.-J., Triole, J., 1990. The politics of government decision making: regulatory institutions. JL Econ & Org. 6, 1.

Lankford, B., 2016. The liminal paracommons of future natural resource efficiency gains, Releasing the Commons. Routledge, pp. 66-88.

Leach, M., Fairhead, J., Fraser, J., 2012. Green grabs and biochar: revaluing African soils and farming in the new carbon economy. Journal of peasant studies 39, 285-307.

Lee, Y.W., Strong, D.M., Kahn, B.K., Wang, R.Y., 2002. AIMQ: a methodology for information quality assessment. Information & management 40, 133-146.

Loch, A., Adamson, D., Carmody, E., Seidel, C., 2019. The importance of compliance under increasing water scarcity, Centre for Global Food and Resources Working Paper. University of Adelaide, Adelaide, South Australia.

Loch, A., Adamson, D., Mallawaarachchi, T., 2014a. Role of hydrology and economics in water management policy under increasing uncertainty. Journal of Hydrology 518, 5-16.

Loch, A., Gregg, D., 2019. Salinity management in the Murray-Darling Basin: a transaction cost study. Water Resources Research online, https://doi.org/10.1029/2018WR022912.

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

Martin, P., Shepheard, M., 2011. What is meant by the social licence?, in: Williams, J., Martin, P. (Eds.), Defending the social licence of farming. CSIRO Publishing, Melbourne, Australia.

MDBA, 2012. *Water Act 2007* - Basin Plan. Murray-Darling Basin Authority, Canberra.

MDBC, 2007. A brief history of the Murray-Darling Basin Agreement. Murray-Darling Basin Commission, Canberra.

MDBMC, 1996. Setting the Cap: Report of the Independent Audit Group. Murray-Darling Basin Ministerial Council, Canberra.

MDBMC, 2014. The sustainable diversion limit adjustment mechanism. Murray-Darling Basin Ministerial Council, Canberra.

Musgrave, W., 2008. Historical development of water resources in Australia: Irrigation policy in the Murray-Darling Basin, in: Crase, L. (Ed.), Water Policy in Australia: The impact of change and uncertainty. Resources for the Future, Washington DC.

Norgaard, R.B., 2010. Ecosystem services: From eye-opening metaphor to complexity blinder. Ecological economics 69, 1219-1227.

NWC, 2007. National water Initiative: First biennial assessment of progress in implementation. National Water Commission, Canberra, Australia.

NWC, 2011. Water markets in Australia: a short history. National Water Commission, Canberra.

Quiggin, J., 2018. The importance of "extremely unlikely' events: tail risk and the costs of climate change. Australian Journal of Agricultural and Resource Economics 62, 4-20.

Randall, A., 1981. Property entitlements and pricing policies for a maturing water economy. Australian Journal of Agricultural and Resource Economics 25, 195-220.

Rostow, W.W., 1959. The stages of economic growth. The Economic History Review 12, 1-16.

Schlager, E., Ostrom, E., 1992. Property-rights regimes and natural resources: a conceptual analysis. Land Economics 68, 249-262.

Shleifer, A., 2005. Understanding regulation. European Financial Management 11, 439-451.

Tainter, J.A., 2011. Energy, complexity, and sustainability: A historical perspective. Environmental Innovation and Societal Transitions 1, 89-95.

United Nations, 2016. Sustainable Development Goals Report 2016. United Nations, New York.

van Dijk, A., Evans, R., Hairsine, P., Khan, S., Nathan, R., Paydar, Z., Viney, N., Zhang, L., 2006. Risks to the shared water resources of the Murray-Darling Basin. Murray-Darling Basin Commission, Canberra, Australia.

Ward, F.A., Pulido-Velazquez, M., 2008. Water conservation in irrigation can increase water use. Proceedings of the National Academy of Sciences 105, 18215-18220.

Watson, A., Cummins, T., 2010. Historical influences on irrigation and water policy in the Murray-Darling Basin, Network: a publication of the ACCC for the Utility Regulators' Forum. Australian Competition and Consumer Commission, Canberra, p. 7.

Waye, V., Son, C., 2010. Regulating the Australian water market. Journal of Environmental Law 22, 431-459.

Wesselink, A., Buchanan, K.S., Georgiadou, Y., Turnhout, E., 2013. Technical knowledge, discursive spaces and politics at the science–policy interface. Environmental Science & Policy 30, 1-9.

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

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, 28-41.

Wiebe, K., Zurek, M., Lord, S., Brzezina, N., Gabrielyan, G., Libertini, J., Loch, A., Thapa-Parajuli, R., Vervoort, J., Westhoek, H., 2018. Scenario development and foresight analysis: exploring options to inform choices. Annual Review of Environment and Resources 43, 545-570.

Wilson, A., Francis, R., 2010. Liquid markets. Utility Week 32, 21-22.

World Economic Forum, 2017. Global Risks 2017, 10 ed. World Economic Forum, Geneva.