Facing Change: Understanding Transitions of River Basin Policies Over Time

Naho Mirumachi, Dave D. White, and Richard T. Kingsford

Abstract The purpose of this chapter is to sythesise current knowledge and understanding of river basin management and governance in the context of water resilience. In particular, the chapter explores the politics and socio-ecological conditions that enabled or challenged policy responses to deal with major changes occurring in a basin using the case studies of the Mekong, Colorado and Murray-Darling rivers. The chapter focuses on the way institutions evolve to address uncertainties and the role of stakeholders and their use of knowledge and learning. It is shown that river basin development occurs over time with varying opportunities for institutionalising water resources management and governance across these three basins. It is found that water resilience is contested by multiple stakeholders, highlighting the power laden ways in which institutions evolve. Insights from the cases inform policy lessons on water resilience that emphasise scrutiny on an institution's suitability to support continual processes of deliberation and stakeholder engagement.

1 Introduction

Over a decade ago, a list of the world's top ten endangered rivers was published (Wong, Williams, Pittock, Collier, & Schelle, 2007). These rivers were threatened by a range of water quality, quantity and ecosystem problems, triggered by infrastructure development, water over-extraction, pollution, climate change, invasive species and over-fishing. A quick review of the state of these rivers now would seem

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J. Baird, R. Plummer (eds.), *Water Resilience*,
https://doi.org/10.1007/978-3-030-48110-0_10

to indicate that these problems are persisting and still challenging to resolve. In the years since, it has become clear that river basin management needs to deal with many factors of uncertainty particularly from anthropogenic change of climate: “stationarity is dead” (Milly et al., 2008). As chapter “The Emergence of Water Resilience: An Introduction” indicated, these rivers face a plurality of water crises. With a critical need to meet socio-ecological changes, it would seem that water resilience is being tested in these basins. The stakes are high for river basin management all the more.

In conditions of non-stationarity and instability, the traditional responses to river basin development may no longer be effective. The different paradigms of water management, ranging from diffuse low water use across a basin, intensive centralised water use, to water use seeking efficiency have hitherto prompted various policy approaches (Allan, 2003). However, the drivers and contexts of these paradigms are now much more complex with non-stationarity. Recalling the discussions highlighted in the introductory chapter, a shift in water paradigm has been advocated and increasingly applied in various water contexts. This reality reflects the need for policy approaches to address a range of compounding hydrological, climatic, socioeconomic, and political factors that influence water use and the ecosystem of the river basin.

The purpose of this chapter is to synthesise current knowledge and understanding of river basin management and governance in the context of water resilience. The chapter explores the politics and socio-ecological conditions that have enabled or challenged policy responses. We focus on the Mekong and Murray-Darling Rivers (which were named in the top ten endangered river list mentioned above) as well as the Colorado River, a river long touted as being a ‘closed basin’ where no further water can be reallocated for alternative use (Falkenmark & Molden, 2008). The chapter is particularly interested in the way institutions have evolved to address uncertainties and whose knowledge and learning underpin them. As the analysis will show, while the three basins have had varying progress in transitioning from one water management paradigm to another, all basins face the problems of adapting institutions to a diverse set of water use and interests of stakeholders. Moreover, the case studies demonstrate common challenges of strengthening institutions to support deliberation on the priorities of water use and to cope with uncertainty. Water resilience in these cases are highly contested and not a given.

The rest of the chapter is organised as follows. First, the chapter reviews the different characteristics of water management paradigms. As paradigms evolve, stakeholders change, as with their roles, resources and means of input to decision-making. In particular, knowledge as a resource and social learning as a means to influence decision-making are highlighted to examine water resilience. Second, case studies are used to examine three unique river basins and their trajectory of river basin development. As large river systems significant to their respective regions, the Mekong, Colorado and the Murray-Darling have gone through major changes of water use over time. Key events such as droughts and introduction of specific policy tools such as legislation and agreements have shaped these changes, as well as the cumulative effects of water use over time and space. The analysis draws on the authors' in-depth experiences in the basin, both as scientists and participant observers: collectively we have over four decades of working in these three river basins. The analysis is a synthesis of insights gleaned through our own research and experience of policy and management in the basins which combine documentary analysis, interviews, stakeholder meetings, conference attendance as well as surveys and data analyses of monitoring data of biodiversity and ecosystems. Therefore, quantitative and qualitative data have informed our understanding. Furthermore, the analysis in this chapter presents an interdisciplinary approach to understanding the complex challenges in each basin. This approach enables our examination of various dimensions of water resilience through multiple disciplinary lenses so as to cut across the changes apparent in the physical environment as well as the socio-economic and political environment. The synoptic view of the paradigm shifts gives insight to the way uncertainty has been dealt with, and in many cases continues to challenge governance responses. Third, the chapter discusses the contested nature of water resilience and how responding to uncertainty is a power-imbued engagement of multiple stakeholders. Fourth, the chapter concludes with insights on why water resilience is not necessarily a fixed or objective notion.

2 Managing Change

It has been argued that river basins tend to follow a trajectory of intensified water use, which then tapers off in varying degrees due to management responses, physical limits of water availability or a combination of both (Allan, 2003) (see Fig. 1). The most intense period of water use is often referred as the hydraulic mission where there are centralised efforts to withdraw, store and divert water. This paradigm of water use relies on infrastructure to aid water access and allocation. Society ordering nature through engineering and investments becomes evident. However, the limitations of this approach gradually become evident with over-abstraction and negative impacts to ecosystems. The subsequent paradigm of reflexive modernity involves exploring efficiency measures (such as recycling water or water saving technology) or utilising integrated water resources management (IWRM) to seek balance between principles of efficiency, equity and protecting ecosystems (Allan, 2003). Over time, river basin organisations are not only charged to organise water abstraction but also allocation to a range of uses, including water for the environment. In addition, it is argued that the subsequent paradigm includes alternative governance mechanisms to the hitherto top-down, centralised approach (Allan, 2003). Epistemic communities, multi-stakeholder groups, water user associations and other forms of networks are established to facilitate mediating competing water uses. A feature of these later paradigms is how and when public participation is used in decision-making. As the case studies will show, moving on from the hydraulic mission also means asking questions about how to meet water use for maintaining small-scale subsistence farming as well as large-scale water abstraction for economic development from a national perspective.

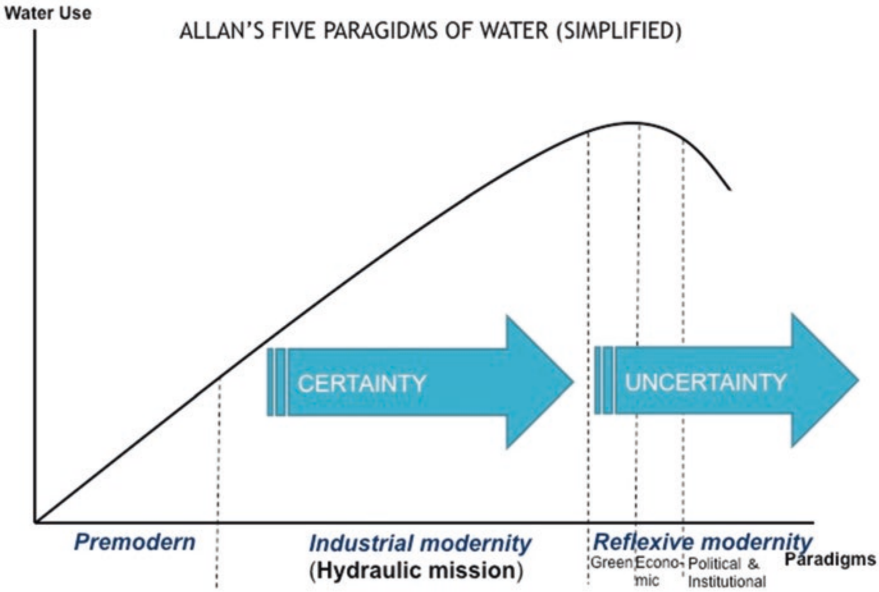

Fig. 1 Water management paradigms. (Adapted from Allan, 2003: 10)

In conditions of non-stationarity characterised by uncertainty, water use may be constrained, making it difficult to maintain existing practices. Moreover, resilience is brought into sharp focus when extensive water abstraction and low river flows compounds dealing with drought or other climatic changes. Consequently, it may become difficult to fulfil the potential of the hydraulic mission or may require pre-emptive use of efficiency measures to satisfy water demands. This means that paradigms of water management may not unfold in a sequential manner as depicted by the conceptual model above. In fact, empirical insight demonstrates that basins can continue its hydraulic mission while at the same time implementing water efficiency measures, as in the example of Thailand (Mirumachi, 2012). The transition of paradigms is not clear-cut and measures to achieve water resilience may be taken up, either as a strategic decision or a reaction to events such as droughts and flooding. Importantly, although conditions of uncertainty may challenge existing decision-making procedures, new water management mechanisms are not necessarily easier to introduce or be integrated into the existing institutional structure. Path dependency has been one explanation for this resistance to changing existing water allocation policies and mechanisms. In other words, long established practices of water management and vested interests of key stakeholders may hinder changes, despite the pressing need advocated by others (Mirumachi, 2015).

It is therefore important to analyse the kinds stakeholders involved and their vested interested in maintaining existing policy decisions or altering them. Particularly with the global uptake of IWRM, it has been widely recognised that water governance involves not only central government agencies traditionally tasked with water resources management, but also related line agencies, civil societies, local communities and businesses. These stakeholders have varying capacities and resources to influence decision-making. In particular, it has been argued that the use of knowledge is influenced by the institutional set-up, politics and cultural context in which these stakeholders operate (Kirchhoff, Lemos, & Engle, 2013). Put differently, what kind of knowledge is used and how is not a given but mediated through various factors. Here, science is (merely) one input into decision-making in this multi-stakeholder process (Armitage et al., 2015). Different kinds of expert and non-expert knowledge are mobilised by different stakeholders to advance claims and influence decision-making. Knowledge is also used by boundary organisations that translate and transfer information between policy and scientific research.

Along with knowledge, learning demonstrates how stakeholders react in the face of uncertainty. In the scholarship of resilience, learning can be defined as "a change in knowledge, skills or attitudes, that may result in changes in behavior, or even institutions" (de Kraker, 2017, p. 100). In the context of managing water, the literature on adaptive management indicates that the interaction of different stakeholders and their knowledges allow for opportunities of learning (Baird, Plummer, Haug, & Armitage, 2014; Gerlak, Heikkila, Smolinski, Huitema, & Armitage, 2018; Huitema et al., 2009). Learning may be established through experiments, such as those on environmental flows (Kingsford, Biggs, & Pollard, 2011). The effects might be better coping with change and uncertainty or increased trust between stakeholders and improved chances at cooperation (de Kraker, 2017). However, it has been pointed out that while learning has been lauded as important, the goals, means and implications of such learning are left undefined when put into practice (Armitage & Plummer, 2008). The scholarship of resilience as a whole has proven to be limited in its understanding of purposeful, functional use of social learning as a means of enhancing resilience. It has been found that despite the attention towards learning, there are only 10 empirically grounded studies that provide insight to the conditions to actual resilience. These studies found that learning contributes to building resilience at the local level where there is a semblance of power differentials between actors and that these actors have a stake in problem solving. This condition is not necessarily easily translated to larger scales. Intentionally creating opportunities for social learning, especially at national levels are challenging, requiring bridging organisations and policy entrepreneurs to help take advantage of networks and limited chances to bring about change (de Kraker, 2017). As such, particularly in the context of seeking water resilience, questioning who is included and excluded in the process of learning reveals the power relations between stakeholders (ibid). Learning, and more broadly, the governance of water resources entail contestation over values (Ingram, 2011). Such contestation is often intractable but tradeoffs are made when decisions prioritise certain water use over others. Through an analysis of learning, it is possible to better understand the deliberation and justification of these tradeoffs and how uncertainty is addressed.

3 Mekong River Basin Case Study

The Mekong river drains a catchment area of 795,000 km^2 with the upstream basin shared between China and Myanmar, and the lower basin stretching across Laos, Thailand, Cambodia and Vietnam (Mekong River Commission [MRC], 2011). The lower basin contributes the majority of annual flow (80%) and is a significant source of livelihoods for the 64.8 million people living in this region (Koponen, Paiboonvorachat, & Munoz, 2017). The river flowing over 4300 km has been the site for transportation, water abstraction and diversion for irrigation, fisheries development and, more recently, dam construction for hydropower (see Fig. 2). The river is also rich in biodiversity, including 850 fish species and those relying on a unique wet season flood pulse for their habitat (Orr, Pittock, Chapagain, & Dumaresq, 2012). Urbanisation of the basin countries also contributes to changes in domestic and industrial water use.

A set of comprehensive reports and surveys in the 1950s mark the start of transboundary river basin planning for the lower Mekong region comprised of Laos, Thailand, Cambodia and Vietnam. Commissioned by these governments, the studies focused on projects for flood control, irrigation and hydropower development. Prior to this period, while there had been some attention to transboundary water development in the region, they concerned navigation (Chi, 1997). Consequently, these studies indicate plans for active development of the hydraulic mission where opportunities to expand water use were sought. The premise of water use was to accelerate socio-economic development of the region (Mirumachi, 2015). A multilateral river basin organisation, the Committee for the Coordination of Investigations in the Lower Mekong Basin, or the Mekong Committee (MC), was established in 1957. Their Indicative Basin Plan Report published in 1970 set out ambitious engineering projects including dams on the mainstream as well as water management of the flood pulse lake, Tonle Sap (MC, 1970).

However, despite the accumulation of scientific studies and institutional development of the river basin organisation, it was only in the 1990s that hydropower development started in earnest. Until then, piecemeal hydropower and irrigation development occurred in the form of national projects, the majority in Thailand. The only multilateral infrastructure project was the Nam Ngum dam in Laos, delivering hydropower to Thailand. Consequently, hydropower development was negligible during the 1950s to 1980s. There was a general lack of engagement when basin countries' relationships broke down in the 1970 due to Cold War tensions and regional instability. Furthermore, by the late 1970s, with the Khmer Rouge regime in power, Cambodia had withdrawn from multilateral dialogue over the Mekong and from international politics. Thus, the river basin organisation could only be revived in the form of the Interim Mekong Committee, limiting opportunities for basin-wide projects.

The institutionalisation of river development projects brought to light intractable issues of water use rules and principles necessary for the expansion of the hydraulic mission at the basin level. While there was overall an appetite for dam

Fig. 2 Map of the Mekong River basin (http://www.mrcmekong.org/highlights/the-study-on-sustainable-management-and-development-of-the-mekong-river-including-impacts-of-mainstream-hydropower-projects/)

construction by the lower basin states, downstream impacts were a major concern. The use of mainstream waters directly affected water flow, which is a key aspect of river management for a region with monsoon rainfall and high seasonal variation of water availability. Whether binding rules would apply to mainstream use was debated and Thailand, with the largest prospect of utilising water resources, was opposed to restrictive decision-making processes put into place within the MC (Mirumachi, 2015).

It can be said that a second phase of the hydraulic mission began in the 1990s with large-scale hydropower development, though not led by the lower basin states and instead unilaterally by upstream China. The first mainstream dam, the Manwan dam, was commissioned in 1992 in Yunnan province. Subsequently, five further dams were built over the next two decades. This hydraulic mission is different from this first phase in that there were IWRM practices also implemented by the Mekong River Commission (MRC) and within basin countries. The MRC programmes use IWRM as a way to organise multiple sectors relating to the river and its resources. In addition, national governments have also taken up IWRM in their water policies and planning efforts. This creates a situation where while coordinated development is advocated, accelerated dam building is occurring, with seven dams currently being planned further upstream of these completed dams (see International Rivers, 2013). In addition, construction of the first mainstream dam in the lower basin, Xayaburi dam in Laos, began in 2012. Laos has since actively put forward projects with the Don Sahong dam commencing construction in 2016 and a further two projects, Pak Beng and Pak Lay proposed. It is reported that as of 2018, 150 hydropower dams are under construction, commissioned or planned with a capacity of 15 MW and above (Geheb & Suhardiman, 2019). This network of dams creates an energy market where hydropower is exported as a commodity within the region (Middleton & Allouche, 2016).

This major phase of damming the river reflects resource abstraction in the Mekong region. This abstraction is buttressed by geopolitical drivers of China extending its reach on economic opportunities abroad, with investment in large-scale infrastructure (Geheb & Suhardiman, 2019). However, there are several challenging uncertainties associated with this hydraulic mission. First, coping to ecological and socio-economic impacts from these dams is uncertain. Scenario analysis and strategic impact assessments of mainstream dam projects consistently point to significant impacts on hydrology, sediment transfers, and biodiversity loss (Mekong River Commission [MRC], 2017; International Centre for Environmental Management [ICEM], 2010). To address these challenges, developers have suggested engineering solutions that would mitigate impacts to fish migration and diversity and resolve issues of sediment. However, these means of mitigation are not congruent with experiences and views of local communities that will be most affected. These technical approaches do not take into consideration the practices of fishermen or those relying on river bank farming, who adapt to seasonal change of the physical environment. Nevertheless, these solutions are dominant in state-led development plans that aim to increase the hydropower capacity of the basin (Fox & Sneddon, 2019).

Second, the hydraulic mission may not provide as much opportunities for hydropower as anticipated. In the future, actual demand may be less than planned due to overestimation or as a result of changing energy sources (Geheb & Suhardiman, 2019). Third, there is uncertainty over whether the institutional set up of the basin can address transboundary water governance challenges. While this river basin organisation has deliberated over the lower mainstream dams through their Procedures for Notification, Prior Consultation and Agreement (PNPCA), it has been critiqued that this process has been ineffective in qualitatively changing the decision-making, particularly in taking up downstream concerns (Yasuda, 2015). Moreover, as with previous arrangements of the river basin organisation, tributary projects continue to be left off the table for multilateral discussion, thereby evading scrutiny. China, previously an ‘observer’ to the MRC, established the Lancang Mekong Cooperation framework in 2015. While much larger in scope with water issues being only one part of this economic cooperation initiative, questions arise on how and to what extent decision-making through this new platform may shape river basin development.

As the above depicts, the management of the river has been largely led by lower basin governments, as well as external agencies such as the UN and donor organisations supporting the river basin organisation. The interests of these stakeholders are generally uniform: development of the river resources. The phase of dam development opens up this stakeholder landscape to Chinese state-owned enterprises (SOEs), thereby shifting the modes of financing away from reliance on these donor agencies and onto established international financial institutions. However, the top-down nature of decision-making over these dams has nevertheless held out and the policies of transboundary water allocation are rather resilient. Non-state actors and civil society groups are increasingly rallying their concerns but the means for public participation at the MRC fora are critiqued as being inadequate (Yasuda, 2015). Legally binding rules over mainstream water use have remained un-established, thus requiring negotiations and consultations per project. This situation risks appropriate identification of cumulative ecological and socio-economic impacts across the basin, rendering efforts to mitigate piecemeal.

Infrastructure has become a fixed feature of the basin, as in many basins with intensive efforts at water abstraction. Moreover, it is underpinned by a modernistic meta-narrative shared by the Mekong countries that positions energy development as the cornerstone to transition into a more prosperous future (Geheb & Suhardiman, 2019). Tightly intertwined with this notion of modernity is the privileging of technological approaches and technical knowledge. Modernistic futures see technology as unlocking opportunities to break away from past under-development. In the context of dams, engineering and technical knowledge is prioritised over socioecological knowledge or observed, experiential knowledge of local communities. This means that not only the knowledge around the impacts of dams may be limited but also skewed, leaving out crucial aspects of livelihood changes that matter most to those relying on the river basin.

Here, Lebel, Grothmann, and Siebenhünter (2010) pointed out that the MRC in fact “learnt how to *do* public participation [emphasis in original]” by recognising the role of civil society networks which challenged technical insights (p. 347). This represents an engagement in a social learning process designed to adapt to issues of water allocation and river development challenges. Network building and knowledge sharing within civil society and with the governmental sector, campaigning and publication of reports utilising socioecological knowledge have raised awareness to some degree such that the MRC cannot make themselves immune to a social learning process. Multiple social learning processes also enabled fisheries and livelihoods to be valued and included as part of the debate on infrastructure development and to be incorporated joint assessments. However, the social learning process has fallen short of fully fleshing out alternative ideas, knowledges and inputs. Within the MRC, there was a tendency to de-politicise decision-making and controversies were not discussed widely enough. This meant a missed opportunity in seeking wider public acceptance for infrastructure development as well as giving due consideration to fairness of these interventions (Lebel et al., 2010).

This outcome can be explained in part by the role of knowledge. Fox and Sneddon (2019) argued that engineering knowledge maintains superiority over ecological or social science; furthermore, it works to de-legitimise and render local knowledge less useful. This elitist decision-making securely puts into place path dependency on the hydraulic mission, focusing on water abstraction. The phase of dam development installs infrastructure at high capital cost. The transformation of the basin through these engineering efforts further limits alternative options because of these costs (Mirumachi, 2015). While strategic plans developed by the MRC highlight the importance of public participation, it has been reported that the engagement of civil society is further required, not to mention challenges of fatigue, if not disenchantment of public participation. This inadvertently enables the top-down decision-making features of the governments implementing water management (Budryte, Heldt, & Denecke, 2018). Un-doing dams thus become highly difficult, entrenching the priority given to modernistic ideals and engineering knowledge.

4 Colorado River Basin Case Study

The Colorado River is essential to the social, economic, and environmental vitality of the western United States. From pre-history to today, the success of human settlements in this region has depended on a society's ability to capture, store, transport, and use water to support life in this semi-arid environment. The Colorado River runs 2330 km from its headwaters in the Rocky Mountains to the delta in Mexico, draining an expansive watershed of 637,137 km^2. The basin includes portions of the states of Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming. The river provides domestic water supply for more than 30 million people, including residents in major metropolitan areas of Denver (2.88 million), Las Vegas (2.20 million), Los Angeles (13.1 million), and Phoenix (4.73 million) (U.S. Bureau of Reclamation [USBOR], 2012). The Colorado River water irrigates 5.5 million acres of land, contributing to national food security, regional agricultural economies, and rural community identity. Hydropower plants on the river provide more than 4200 megawatts of renewable, low-carbon electricity. The river supports diverse natural ecosystems, wildlife refuges, and national parks, including Grand Canyon National Park. The Colorado is also integral to the history, culture, religion, and economies of nearly two dozen Native American tribal communities. A set of interacting social, economic, technological, and environmental factors, however, is increasingly stressing water availability for humans and nature in the basin, creating complex risks to current and future river basin resilience (National Research Council, 2007).

The development trajectory of Colorado River basin management and governance is characterised by episodes of significant conflict as well as periods of innovative collaboration, catalysed by interactions among dynamic networks of interested stakeholders (Fleck, 2016; Sullivan, White, Larson, & Wutich, 2017). The origins of contemporary governance can be traced to the early 1900s, when the active development of the of the hydraulic mission of the basin began in earnest. Key events in the industrial modernization of the Colorado include the National Reclamation Act of 1902, which created the United States Reclamation Service (later known as the U.S. Bureau of Reclamation), the 1922 Colorado River Compact, and The Boulder Canyon Act of 1928. In this era, mounting social and political pressure to "reclaim" the western United States strengthened the position of interested stakeholders, especially agriculturalists, who supported and benefited from rapid and widespread expansion of centralised water infrastructure to abstract, store, and divert water for irrigation. In a speech to a joint session of Congress in 1902, U.S. President Theodore Roosevelt committed to "the sound and steady development of the West" (Roosevelt, 1902, para. 56). This vision manifested on the landscape through federally-supported dams for water storage, flood control, hydropower, and irrigation. Notable milestones include the completion of Roosevelt Dam on the Salt River in Arizona in 1911, Hoover Dam on the Arizona-Nevada border in 1936, and Glen Canyon Dam in Arizona 1966. These hydropower dams represent major societal investments in water infrastructure that set the basin on a path of increasing development, population growth, and subsequent environmental degradation, especially impacting the delta.

The extensive damming of the Colorado, along with the associated water allocation and water use rules, were institutionalised over several decades through a patchwork of laws, court decisions, and regulations that are collectively known as "The Law of the River" (see USBOR, 2019b). These rules guide the allocation and distribution of water between seven U.S. states and Mexico, who regulate the end-uses. The keystone agreement is The Colorado River Compact of 1922, which established upper and lower basin boundaries (see Fig. 3) and allocated 7.5 million acre-feet (MAF) per year to each basin.

The original agreement did not include a transboundary compact with Mexico, but this oversight was addressed in 1944 by the Mexican Water Treaty, which allocated another 1.5 MAF of Colorado River water annually to Mexico. These allocations illustrate a political decision-making process negotiated among powerful stakeholders with certain groups, most notably Native American tribes, who had been marginalised and also largely excluded from consideration (see Fig. 4). Although the U.S. Supreme Court established in *Winters v. United States* in 1908 that water rights on Native American reservations belong to the tribe at the time of reservation establishment, the adjudication and allocation of these Native American rights remains a contentious and unsettled issue (see Colorado Research Group, 2016).

Fig. 3 Map of the Colorado River basin showing the upper and lower basin (https://www.usbr.gov/dcp/)

The modernist vision of the industrial Colorado reflects an understanding of a stationary climate and certainty of scientific knowledge about the reliability of natural river flows. Notably, institutional rules required that the upper basin would deliver an average minimum of 7.5 MAF per year to the lower basin, regardless of natural inflow. Thus, the allocation rules include a promise of a specific volume of

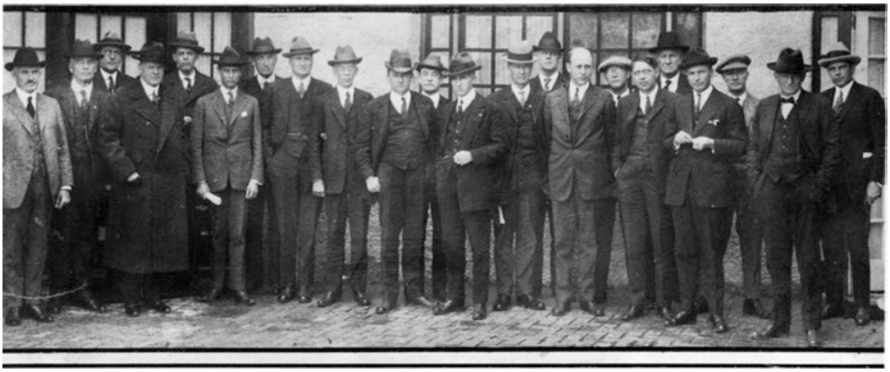

Fig. 4 Federal and state representatives to the Colorado River Compact Commission in Santa Fe, New Mexico including Arthur P. Davis, Director of Reclamation Service and Herbert Hoover, then Secretary of Commerce, November 24, 1922 (US Bureau of Reclamation 2017 https://www.flickr.com/photos/usbr/33491081615/in/photolist-cc4jmC-T2uxKD/)

water to the lower basin states, rather than a proportion of the natural flow. Unfortunately, the original allocation decisions were unintentionally formulated using overestimates of natural flow, based on an historically high-flow period (Castle et al., 2014). Indeed, quantitative reconstruction of natural flows from tree ring studies suggests that the allocations were determined based on observations in the early 1920s of what were the highest sustained flows in four hundred years (Stockton & Jacoby, 1976). While the rules obligate about 16.5 MAF annually, the basin-wide long-term historical natural flow on the river averaged just 14.8 MAF over the twentieth century (1906–2018). Even more troubling, the recent running average (1988–2015) was just 13.2 MAF, showing the effects of a two-decade long drought and the impacts of climate change (USBOR, 2018). However, because of the massive storage capacity of the major reservoirs of Lake Powell and Lake Mead (>50 MAF), water withdrawals in the Colorado river basin (excluding inter-basin transfers) averaged about 17 MAF per year from 1985–2010. Irrigation accounted for most total withdrawals in the basin, excluding instream use for hydroelectric power and inter-basin transfers, averaging 85% from 1985–2010 (Maupin, Ivahnenko, & Bruce, 2018).

In recent decades, water resilience and security of the Colorado River system has been in question. High agricultural demand, rapid population growth and urbanisation, land use changes, legacy effects of historical policies, and aging infrastructure are major pressing issues (Gober, 2018; Sullivan et al., 2017). On top of these social stressors, environmental factors have also increased risks. Since 2000, the region has experienced the most extreme drought in 100 years and among the worst in the last 1200 years, causing water levels in the major reservoirs to fall to historic lows and depleting groundwater reserves (Udall & Overpeck, 2017; USBOR, 2018). According to the Fourth U.S. National Climate Assessment the Southwest will by mid-century see higher annual mean temperatures, more frequent and severe droughts, more extreme heat, more variable precipitation, and greater wildfire risks, among other impacts (Gonzalez et al., 2018). It is unclear whether the Colorado River basin management and governance regimes can adapt rapidly enough to deal with the risks to water resilience in this era of deep uncertainty and climate change (Gober, 2013, 2018). Critics say that the traditional regimes suffer from path dependence, sunk costs, technological lock-in, and a lack of incentives to consider transformational changes necessary to address the myriad risks (Lienert, Monstadt, & Truffer, 2006).

Indeed, recent history indicates that the social and environmental risks have influenced the dominant socio-technical water governance regime. This disruption may have created windows of opportunity for networks of stakeholders to introduce innovations and transformational changes, which could precipitate a sustainability transition (Loorbach, Frantzeskaki, & Avelino, 2017; Sullivan et al., 2017; Sullivan, White, & Hanemann, 2019). Since about 2000, many stakeholders in the basin states have recognised the urgent need to adapt current policies, but progress has been halting. Growing concern over rapidly declining reservoir levels in Lake Mead and Lake Powell prompted leaders in the affected states and the U.S. Bureau of Reclamation to negotiate a policy to spell out actions to be taken in the event of a water shortage. Those negotiations culminated in a 2007 agreement establishing rules for coordinated operations of Lake Powell and Lake Mead and setting rules for water curtailments in the event of an official declaration of shortage on the river (USBOR, 2007). Along with these new institutional rules, networks of stakeholders developed a series of conservation policies and innovative programs. For example, the Bureau of Reclamation partnered with the Central Arizona Water Conservation District, The Metropolitan Water District of Southern California, the Southern Nevada Water Authority, and Denver Water to fund the Conservation Pilot System Program. This program funded a variety of locally-developed, voluntary conservation concepts created by stakeholders, including environmental, municipal and industrial, and agricultural groups, to reduce water demand and mitigate effects of drought. Despite these efforts, the reservoirs continued to decline, and risks increase, until stakeholders recognised that the 2007 agreement, which was designed to guide basin management until 2026, would not be effective in managing risks to water security.

In the face of social and environmental uncertainties, as well as shifting paradigms in basin governance and management and evolving public attitudes, Colorado River basin stakeholders entered a complex and sometimes contentious process, which ultimately culminated in the Colorado River Drought Contingency Plans (USBOR, 2019a). Collaborative governance efforts in the initial phases of the policy process leading to the Drought Contingency Plans (DCP) (2016–2018) suffered from barriers such as retreat from urgency, distrust between stakeholders, short-term thinking, lack of transparency, and lack of inclusive process (Sullivan et al., 2019). As environmental conditions continued to worsen, and the U.S. Bureau of Reclamation applied immense political pressure on stakeholders in lower basin states to reach a deal or risk federal government intervention, stakeholders relaunched negotiations and ultimately came to agreement. In the final negotiations, key players included state government agencies, cities, agriculturalists, and, notably, Arizona Native American tribes, who emerged as the powerful dealmakers. Critically, the DCPs did not address several key issues directly, most notably climate change adaptation and the overallocation that was written into the rules in the early 1900s. However, the process represents a turning point in the basin governance and management toward a more collaborative and inclusive water governance process and gives stakeholders a new framework moving forward.

5 Murray-Darling Basin Case Study

The Murray-Darling Basin in southeastern Australia extends across four of Australia's states (Queensland, New South Wales, Victoria, and South Australia) and includes the Australian Capital Territory (see Fig. 5). There are two major rivers, the River Murray and the Darling River, each with their own tributaries (Leblanc,

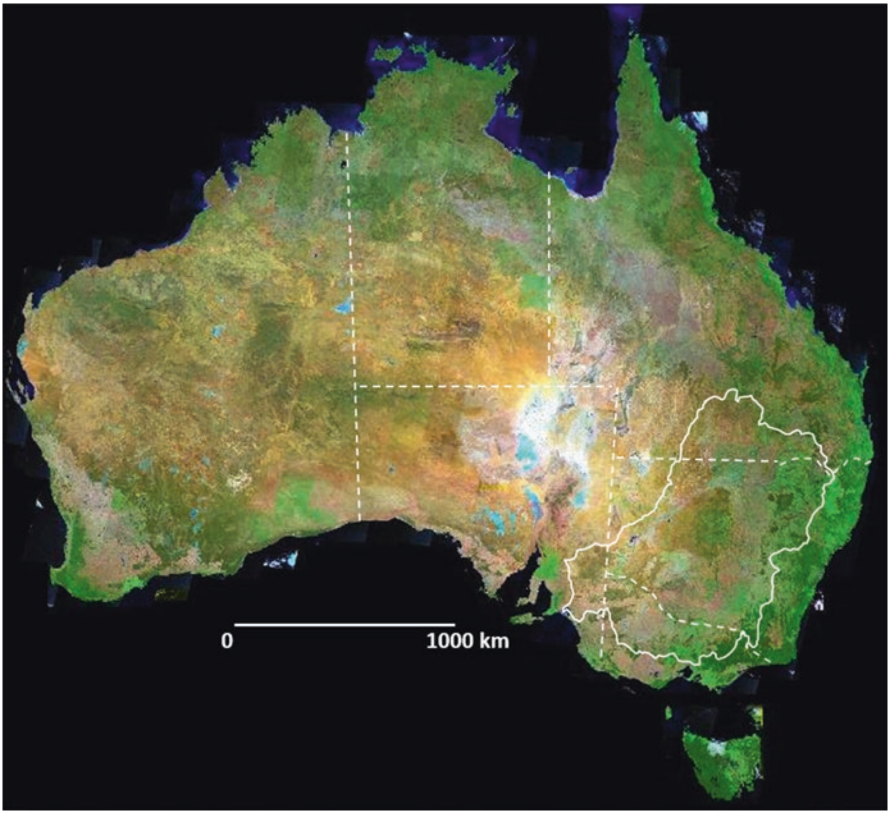

Fig. 5 Map of the Murray Darling Basin (solid line) in the southeast of the continent, with state borders (dashed lines) (author's own)

Tweed, Van Dijk, & Timbal, 2012). At 1.06×10^6 km^2, the Murray-Darling Basin occupies about one seventh of the continent, with river flows primarily driven by precipitation from the Great Dividing Range in the east of the continent. Tributary rivers typically flow into large floodplain wetlands (e.g. Macquarie Marshes, Great Cumbung Swamp) with about 4.5 million ha of wetlands in their catchments (Kingsford et al., 2004), including lakes, swamps and floodplains of which 16 are Ramsar-listed wetlands (Pittock & Finlayson, 2011). Eventually, the River Murray and Darling River join to flow southwest, reaching the sea through a system of lakes, lagoons and an estuary (Kingsford et al., 2011).

The rivers and wetlands of the Murray-Darling Basin (see Fig. 6) are rich in resources, providing for Aboriginal groups for millennia in the form of fish, caught in sophisticated traps (Humphries, 2007), with those on the Darling River at Brewarrina considered possibly the oldest human construction still functioning (Taylor, Moggridge, & Poelina, 2016). In the 1800s, the early European explorers (e.g. Charles Sturt) used the rivers to navigate to the inland of the continent. Soon afterwards, the Murray-Darling became the trade route for goods (e.g. wool) from the inland to the mouth of River Murray, south of Adelaide. The twentieth century was a period of considerable water resource development in the form of building large dams. This hydraulic mission focused on utilising the water in the upper reaches of the catchments, starting with Burrinjuck Dam on the Murrumbidgee River, the major tributary to the River Murray. There was then a significant investment by governments in large dams, particularly in the River Murray tributary but then extending into the Darling River tributaries, throughout the 1950–1970s (Kingsford, Walker, et al., 2011; Leblanc et al., 2012). Particularly iconic of this hydraulic mission phase is the Snowy Mountains Hydroelectricity Scheme, built in the late 1960s, establishing a series of large storages which regulated the southern tributary rivers (Tumut and Murrumbidgee Rivers) and once diverted 99% of the

Fig. 6 Tributaries of the Murray Darling Basin (author's own)

east flowing Snowy River as an interbasin transfer into the Murray-Darling Basin, before some river restoration (Erskine, Terrazzolo, & Warner, 1999).

As a result of this period of intensive infrastructure development, the Murray-Darling Basin now has largest storage capacity of any of Australia's river basins. This allows the diversion of most water of any river basin in Australia (Kingsford, 2000); total capacity of major storages now exceeds annual flow by about 40% (Goss, 2003). In addition, there has been considerable development of large private dams, particularly along the Darling River and its tributaries primarily to divert water for annual crops such as cotton (Australian Academy of Science, 2019; Kingsford, 2004). The role of water for agriculture is paramount because diverted water from the Murray-Darling Basin primarily supplies irrigation farming (>80%), producing much of country's agricultural commodities (rice (100%), cotton (93%), grapes (76%), oranges (100%)), worth AUD 7 billion (Murray-Darling Basin Authority [MDBA], 2016). River flows also supply major cities (Canberra, 356,600 people; Adelaide, 1.25 million people) and mining (35 mines, 1% of water use in 2004–2005) and many small rural towns.

The governance of the Murray-Darling Basin rivers has also evolved over time reflecting the demands and priorities of water use. Governance, legislation and policy for the Murray-Darling Basin rivers, as with all Australian rivers, was primarily determined by the four State Governments, originally established at Federation, under Australia's Constitution in 1901 (Connell, 2007). A cooperative management framework was first struck by the River Murray Waters Agreement in 1915 (Connell, 2007), when the States of Victoria, New South Wales and South Australia divided the flows of the River Murray, allowing development of the river. The River Murray Commission was established in 1917 followed by the Murray Darling Basin Commission (MDBC) (1986–2008). Major issues from river development including salinity and water quality degradation prompted the commission to manage water and other related natural resources under the principles of equity, efficiency and sustainability (Alexandra, 2019). However, each of the states separately established their water legislation which was primarily in effect until early in the 2000s. It was only then that a significant legislative review and renewal with modernisation of water legislation was introduced. The effects of this change emphasised the importance of the environment and sharing of waters, including with Traditional Owners. Much of this momentum came with the increasing environmental problems experienced by the river system, including the world's longest blue green algal bloom (Donnelly, Grace, & Hart, 1997) and the decline of wetland ecosystems (Kingsford & Thomas, 1995).

The sharing of river flows among users has been contested over time. First, the Murray-Darling Basin Cap was established in 1995 as a result of concerns and designed to halt further diversions at 1993/1994 levels of development in New South Wales, South Australia and Victoria and 1999/2000 levels of development in Queensland. A second major milestone was the *Water Act 2007* which allowed the Australian Government to take control and provide oversight on water use. This was precipitated by the Millennium Drought 2002–2009 which put further pressure on governments and their management of the Murray-Darling Basin Rivers. Along with the Act, an independent Murray-Darling Basin Authority, which replaced the MDBC, was charged with developing a Murray-Darling Basin Plan which included a restoration initiative for the river of more than AUD 13 billion. River plans remained the responsibility of the States but they were to be guided by the objectives of the Murray-Darling Basin Plan and approved by the Murray-Darling Basin Authority.

Many uncertainties still remain for managing the rivers of the Murray-Darling Basin equitably. There are long-term and serious environmental impacts still occurring including increased blue-green algal blooms, recent massive fish kills (Australian Academy of Science, 2019) and declining ecosystem health of wetlands, including many of the Ramsar sites for which Australia has international responsibilities. The challenges of managing ecologically complex floodplains and the interface with diversions of water for irrigated agriculture are increasingly difficult. Current legislation and compliance aspects poorly track water diverted from floodplains, reflected in a recent successful prosecution of a cotton grower for stealing water. Further, the Murray-Darling Basin plan has failed to incorporate the long-term effects of climate change in decisions on the necessary amount of water required for sustaining this river basin. For example, while environmental flows would enable restoring waterbird abundances, climate change restricts their improvement significantly (Kingsford, Bino, & Porter, 2017).

To tackle the ecological challenges, a notable feature of the changes in water management is the increasing focus on management of environmental flows, with the Australian Government buying back water from the irrigation industry to return to the river (up to AUD 3.1 billion). The Australian Government held 2,815,100 million litres of environmental flow (Department of Environment and Energy, 2019) in the form of entitlements. State governments have also purchased water for the rivers. Much of this water for the environment is stored in large dams, requiring release and management for environmental purposes, such as flooding wetlands.

These environmental flows have sustained important areas of the river, such as the Macquarie Marshes, a Ramsar-listed wetland relying on upstream water release of the tributary Macquarie River. Since the late 1980s, upstream water allocation has been regarded as a major challenge to the protection and health of the wetland. Irrigation in the upstream catchment changed the flow regime with knock on effects to the habitat of waterbirds and changes in vegetation. Over the years, environmental flows were managed by the conservation agency, though without clear ecological objectives. In 2010, strategic adaptive management was introduced "To restore the Macquarie Marshes so that it has its full functional complexity and ecology (native species, communities and processes), built around productive partnerships" (Kingsford, Biggs, & Pollard, 2011, p. 1196). This process has enabled clarity on what the wetland should look like in the future, along with specification of vital attributes which shapes planning and a nested set of objectives. Furthermore, as management of the wetland is implemented, there are opportunities for learning across a range of stakeholders for enhanced resilience (Kingsford, Biggs, & Pollard, 2011). But this adaptive management planning still lacks institutionalisation.

While such innovation has taken place in some parts of the river, river planning remains incoherent as they are developed under each of the State's respective water legislation (e.g. *Water Management Act 2000* in New South Wales). For some rivers which flow between and even form the border of the different states (e.g. Macintyre River, border of New South Wales and Queensland), this can mean two plans for different sides of the river. The centralisation of water resources development to governmental actors, as opposed to individual riparian right owners, has enabled large-scale hydraulic mission for irrigation and subsequent effects on the ecosystem (Bino, Kingsford, & Brandis, 2016). The irrigation industry remains a powerful stakeholder in influencing government decisions today. The government and irrigation sector have come under intense scrutiny recently after questions arose on the benefits of spending over AUD 5 billion to subsidise irrigation infrastructure for water recovery purposes. Net streams flows have not increased despite these engineering solutions and fall short in achieving objectives of the Water Act 2007 (Grafton et al., 2018).

Social learning processes can only be useful if the engagement becomes diversified with various stakeholders as well as at various scales of management across the basin. The stakeholder base for decision-making is expanding with government involvement in river management committees, with representation from government environment agencies, including fisheries and also conservationists (e.g. Macquarie Cudgegong Environmental Water Advisory Group).[1]

Increasingly, Traditional Owners, whose lives revolve around the rivers and their environments, are taking part in dialogues in addition to floodplain graziers, recreational users, fishers, birdwatchers and other users of the environment. Traditional owners have been largely ignored in the development of rivers, only recently receiving access to cultural flows as a legal right, albeit a small one. There is also increased realisation that landholders who use the many floodplain areas to graze their cattle are also affected by the diversions upstream for irrigation, affecting the landholders' resilience and livelihoods (Hall, 2017; Petersen, 2017).

Among these stakeholders, there is a clear realisation that too much water has been taken from this river basin. The initial steps have been taken where governments have bought water back from the irrigation industry to return to the river and maintain its environmental health. Future challenges evolve around whether enough water was recovered or if regulation is inefficient to stop further water resource development, eroding difficult to achieve gains.

[1] For further details of group, see for example NSW Department of Planning, Industry and Environment (2019).

6 Discussion

The analysis of the Mekong, Colorado and Murray-Darling river basins demonstrates that water use has changed and increased over time, throwing up issues of competing demands. While at different speeds, it is clear to see how the development of these three river basins has stored, diverted and dammed water through the use of various infrastructure. Along this physical development of the river basin, we also see different levels of institutionalisation of rules and practices first to enable further use of the river resources and second to manage incongruous interests of stakeholders. In all three basins, institutions have had to adapt over time to drivers of water use and these interests of stakeholders (see Table 1). Even seemingly static treaties, which are rarely open for wholesale renegotiation, have been part of a deliberative process in which their implementation had been contested, resulting in additional institutional arrangements or further studies, as in the case of Colorado and Mekong river basins. However, the initial phases of river basin development have been driven by a distinct modernist vision, which sees the flows of river as an object of control. Maximising the utility of these flows is particularly evident through the network of infrastructure. This has meant that dealing with ecological impacts has been relatively reactive and at later stages of the development trajectory, though there are some innovative ways in which water for the environment has been considered, as seen in the case of environmental flows in the Murray-Darling.

As the Colorado case study best illustrated, institutionalisation has occurred over time, but in a patchwork fashion with various legal instruments, policies and arrangements. This way of institutionalisation reflects a complex reality where resources are limited to deal with any and all issue relating to river development: issues are inevitably prioritised. Power relations of stakeholders have much to do with the ways issues are prioritised. The hydraulic mission sets into motion a set of institutions that facilitate allocation of water in a centralised fashion with a narrow

Table 1 Evolution of institutions to deal with uncertainties in the Mekong, Colorado and Murray-Darling river basins

	Mekong	Colorado	Murray-Darling
Progress through water management paradigms	Mixture of hydraulic mission and reflexive modernity	Gradual transition from hydraulic mission to reflexive modernity	Gradual transition from hydraulic mission to reflexive modernity
Example of key concern relating to uncertainty	Accelerated dam development	Drought	Declining ecological health
Notable features of institutionalisation	River basin organisation under a formal multilateral agreement	Contemporary additions of agreements that coordinate reservoir levels in times of water shortage to historical agreements and treaties	Basin planning and strategic adaptive management led by the river basin authority and implemented by individual states

set of stakeholders. Consequently, those with water allocation or access to water abstraction tend to have more influence over subsequent decision-making, creating winners and losers including the environment as a notable loser. However, competing water use also means it is impossible to contain deliberation to a narrow set of stakeholders. As the Mekong case study highlighted, the MRC inevitably had to face civil society and their claims regarding the role of the river for livelihoods. The quality of the river basin organisation's engagement requires further scrutiny but the example shows that path dependency of the hydraulic mission can be called into question. In all three river basins, challenging, if not reconfiguring existing power relations becomes the cornerstone in altering existing practices of the hydraulic mission and to exercise reflexive modernity.

A wider set of stakeholders engaging in deliberation over the river basin has meant that mobilising new information and inputs to decision-making have been attempted. The case studies highlighted that while knowledge about livelihoods, local conservation options or environmental flows are sought, it does not necessarily mean that new knowledge replaces those used to inform the hydraulic mission. In other words, technocratic or engineering knowledge is not entirely replaced with other forms of knowledge. In fact, different kinds of knowledge exist and are used in different ways by stakeholders to best advance their interests. Here we see plural forms of knowledge which has the potential to challenge and destabilise existing practices, but not a panacea as the Mekong example showed.

This point is insightful when thinking about how uncertainty is dealt with in basins facing multiple stressors and risks. In the Colorado river basin, it was shown that the variability of water flows has been a highly significant issue in recent years, which has in fact created opportunities for local conservation efforts. These local efforts will enable stakeholders to acquire experiential knowledge, which are separate from scientific knowledge on hydrological factors. In the Mekong, when dam development accelerated, concerns of uncertainty were not considered in detail initially. This meant that there was a narrow parameter of what was considered uncertain. While it cannot be said that alternative views regarding trade-offs of dams have been accepted, the continual contestation indicates that understanding of uncertainty can be shaped and reshaped by engagement of stakeholders. In contrast, the case of the Murray-Darling emphasises the temporal aspect of uncertainty: existing arrangements to ameliorate over-abstraction has been critiqued as falling short of being effective and raises questions about the extent of future proofing.

In all three basins, it is clear that business as usual will not suffice to deal with the pace of changes in the basin with both physical and socio-economic dimensions. The cases show that adaptive management, IWRM and adaptive governance approaches have been attempted in varying degrees in an attempt to seek water resilience. However, the trajectory of the basins showed that the start of water resilience paradigms is not clear-cut and there is a significant period of transition. It is in this period of transition where we see an overlap of hydraulic mission practices and reflexive exercises. It has been critiqued that top-down centralised practices are rigid and hard to change, however, the empirical experience showed that learning by doing is equally slow to reap rewards. Adaptive governance approaches help bring to the fore contested values over the river and its resources. Nevertheless, its novelty does not guarantee a 'fix-all'. IWRM falls short in many of the river basin realities and a simple integration of sectors does not provide answers to the various uncertainties posed.

Water resilience in these cases means more than simply to accommodate drivers of change and pace of such change. Here, the cases demonstrate what has been termed as 'negotiated resilience' (Harris, Chu, & Ziervogel, 2017). Negotiated resilience is understood as a process, rather than a goal, in which key questions around resilience are considered by diverse stakeholders. Resilience can be seen through the perspective of stakeholder interests, scales at which institutionalisation has occurred or through temporal dimensions. Put differently, iteratively defining and determining resilience is in fact the focus, rather than taking for granted what water resilience might stand for. That is why the case studies demonstrate a transition-like state of the hydraulic mission to water resilience paradigm. It can be said from the case studies that an objective state of resilience has not been identified in any of the basins. The trajectory of each river basin and their patchwork of institutionalisation contribute to a unique set of circumstances for discussing how resilience can be understood. Importantly, this deliberation is buttressed by power relations. The case studies provide an appreciation of the way power is exercised through different knowledge and social learning. In this way, enhancing resilience may expose power asymmetries and uncomfortable processes in which such asymmetries need to be addressed. Interventions to enhance resilience are not always harmonious (Hahn & Nykvist, 2017).

Negotiated resilience assumes multiplicity in understanding by a range of stakeholders (Harris et al., 2017). The multiplicity derived from these stakeholders thus makes "any discussion or planning for 'resilience' necessarily political and contested" (ibid, p. 203). The case studies show that multiple stakeholders emerge with divergent and varying interests and priorities as the paradigms of water development gradually advance through and beyond the hydraulic mission. There are multiple views as to what interventions or actions are best suited to adapt to changing water demands and pressures on the basin. Some views are more easily taken up in mainstream decision-making, while others need to seek legitimacy. The contestation over river management options reflects that a fixed understanding of resilience is hard to come by. Rather, water resilience is one of continual negotiation and deliberation that are shaped by stakeholders and what they claim as necessary, important or effective for river basin management. This version of water resilience may be more effective at tackling the problems observed in the broader resilience literature where uncoordinated changes or those done with a narrow view without consideration to the overall system yield 'undesirable resilience', 'unhelpful resilience' or 'wicked resilience' (Oliver et al., 2018). Moreover, the insights from the case studies highlight that resilience is normative (see Brown, 2011) and that the application of such normative concept needs to be worked out in a grounded, unique context.

Based on the above discussion, there are some policy lessons that can be derived from the individual cases as well as the combined insights from the three river basins. First, it could be suggested that policy needs to support a continual process where stakeholders can extend their networks and work out new relations between them so as to ensure there are opportunities for social learning and deliberations. This is not to say that there will be successful social learning or that social learning will be able to intentionally put in place mechanisms to enhance resilience. In fact, these are not a given and the second policy lesson is the need for a realistic expectation that getting water resilience 'right' is not easy and requires scope for multiple approaches to dealing with change. The third lesson is that where institutions are in place, they need to be continually invested to avoid becoming a defunct organisation: investment will likely be in the form of updating norms, protocols, agreements, revising the scope of committees so as to take into consideration drivers of water use from other sectors or factors such as climate change.

7 Conclusion

This chapter showed how river basin development occurs over time with varying opportunities for institutionalising water resources management and governance. The Mekong, Colorado and Murray-Darling river basins have experienced the hydraulic mission at varying paces as well as the effects of intense infrastructure development. These basins have been the stage for serious trade-offs that relate to economic benefits, ecological health and livelihood options. These trade-offs are notably raised by and concern a diverse set of stakeholders. These stakeholders attempt to deal with complexity and uncertainty, with use of knowledge or social learning for example. Water resilience in these cases is not an evident, fixed or neutral state to strive towards under the consensus by all stakeholders. Rather water resilience is contested and negotiated by multiple stakeholders, and continually evolves with the trajectory of the basin. The policy lessons therefore are about understanding what water resilience means in a specific basin as a start, based on a wide range of inputs from stakeholders. The lessons also point to strengthening institutions so that they are continually relevant and instrumental to enabling the process of deliberation, not restricting it.

The analysis presented in this chapter provided snap shots of how water resilience is articulated and debated. In particular, the study highlighted how power relations throw up contestations in the process of 'learning by doing', or in seeking flexibility for adaptive governance approaches. The findings from the three case studies indicated that resilience is indeed contested and power laden. In addressing water resilience, power is expressed through the way is knowledge is mobilised and networks of actors shaped. Further research can provide a more comprehensive insight to the power relations of stakeholders and their claims and influence for 'negotiated resilience'. The degree to which deliberations are politically charged differs across basins. However, the overview across the three differently endowed river basins has merit in underscoring the intractable nature of water development issues.

Acknowledgements The authors wish to acknowledge the PLuS Alliance Accelerator Grant on 'Social-ecological indicators of sustainability to inform management of transboundary rivers'.

References

Alexandra, J. (2019). Losing the authority—What institutional architecture for cooperative governance in the Murray Darling Basin? *Australasian Journal of Water Resources, 23*(2), 1–17. https://doi.org/10.1080/13241583.2019.1586066

Allan, J. A. (2003*). IWRM/IWRAM: A new sanctioned discourse?* (Occasional Paper 50) [PDF file]. Retrieved from https://lwrg.files.wordpress.com/2014/12/iwram-a-new-sanctioned-discourse.pdf

Armitage, D., de Loë, R., Edwards, T., Gerlak, A., Hall, R., Huitema, D., … Wolfe, B. (2015). Science-policy processes for transboundary water governance. *Ambio, 44*(5), 353–366. https://doi.org/10.1007/s13280-015-0644-x

Armitage, D., & Plummer, R. (2008). Adaptive co-management and the paradox of learning. *Global Environmental Change, 18*(1), 86–98. https://doi.org/10.1016/j.gloenvcha.2007.07.002

Australian Academy of Science. (2019). *Investigation of the causes of mass fish kills in the Menindee region NSW over the summer of 2018–2019* [PDF file]. Retrieved from https://www.science.org.au/files/userfiles/support/reports-and-plans/2019/academy-science-report-mass-fish-kills-digital.pdf

Baird, J., Plummer, R., Haug, C., & Armitage, D. (2014). Learning effects of interactive decision-making processes for climate change adaptation. *Global Environmental Change, 27*, 51–63. https://doi.org/10.1016/j.gloenvcha.2014.04.019

Bino, G., Kingsford, R. T., & Brandis, K. (2016). Australia's wetlands—Learning from the past to manage the future. *Pacific Conservation Biology, 22*(2), 116–129. https://doi.org/10.1071/PC15047

Brown, K. (2011). Sustainable adaptation: An oxymoron? *Climate and Development, 3*(1), 21–31. https://doi.org/10.3763/cdev.2010.0062

Budryte, P., Heldt, S., & Denecke, M. (2018). Foundations of the participatory approach in the Mekong River basin management. *Science of the Total Environment, 622–623*, 349–361. https://doi.org/10.1016/j.scitotenv.2017.11.345

Castle, S. L., Thomas, B. F., Reager, J. T., Rodell, M., Swenson, S. C., & Famiglietti, J. S. (2014). Groundwater depletion during drought threatens future water security of the Colorado River Basin. *Geophysical Research Letters, 41*(16), 5904–5911. https://doi.org/10.1002/2014GL061055

Chi, B. K. (1997). *From committee to commission? The evolution of the Mekong River Agreements*. Doctoral dissertation. University of Melbourne, Australia.

Colorado River Research Group. (2016). *Tribes and water in the Colorado River Basin* [PDF file]. Retrieved from https://scholar.law.colorado.edu/cgi/viewcontent.cgi?article=1177&context=books_reports_studies

Connell, D. (2007). *Water politics in the Murray-Darling Basin*. Leichhardt, NSW: The Federation Press.

de Kraker, J. (2017). Social learning for resilience in social-ecological systems. *Current Opinion in Environmental Sustainability, 28*, 100–107. https://doi.org/10.1016/j.cosust.2017.09.002

Department of Environment and Energy, Government of Australia. (2019). *Environmental water holdings*. Retrieved from https://www.environment.gov.au/water/cewo/about/water-holdings

Donnelly, T. H., Grace, M. R., & Hart, B. T. (1997). Algal blooms in the Darling-Barwon River, Australia. *Water Air and Soil Pollution, 99*(1), 487–496. https://doi.org/10.1007/BF02406888

Erskine, W. D., Terrazzolo, N., & Warner, R. F. (1999). River rehabilitation from the hydrogeomorphic impacts of a large hydro-electric power project: Snowy River, Australia. *Regulated Rivers:*

Research & Management, 15(1–3), 3–24. https://doi.org/10.1002/(SICI)1099-1646(199901/06)15:1/3<3::AID-RRR532>3.0.CO2-R

Falkenmark, M., & Molden, D. (2008). Wake up to the realities of river basin closure. *International Journal of Water Resources Development, 24*(2), 201–215. https://doi.org/10.1080/07900620701723570

Fleck, J. (2016). *Water is for fighting over: And other myths about water in the west*. Washington, DC: Island Press.

Fox, C., & Sneddon, C. S. (2019). Political borders, epistemological boundaries, and contested knowledges: Constructing dams and narratives in the Mekong River Basin. *Water, 11*(3), 413. https://doi.org/10.3390/w11030413

Geheb, K., & Suhardiman, D. (2019). The political ecology of hydropower in the Mekong River Basin. *Current Opinion in Environmental Sustainability, 37*, 8–13. https://doi.org/10.1016/j.cosust.2019.02.001

Gerlak, A., Heikkila, T., Smolinski, S. L., Huitema, D., & Armitage, D. (2018). Learning our way out of environmental policy problems: A review of the scholarship. *Policy Sciences, 51*(3), 335–371. https://doi.org/10.1007/s11077-017-9278-0

Gober, P. (2013). Getting outside the water box: The need for new approaches to water planning and policy. *Water Resources Management, 27*(4), 955–957. https://doi.org/10.1007/s11269-012-0222-y

Gober, P. (2018). *Building resilience for uncertain water futures*. Cham, Switzerland: Palgrave Macmillan.

Gonzalez, P., Garfin, G. M., Breshears, D. D., Brooks, K. M., Brown, H. E., Elias, E. H., … Udall, B. H. (2018). Southwest. In D. R. Reidmiller, C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. Lewis, T. K. Maycock, & B. C. Stewart (Eds.), *Impacts, risks, and adaptation in the United States: Fourth national climate assessment, volume II* (pp. 1101–1184). Washington, DC: Global Change Research Program.

Goss, K. F. (2003). Environmental flows, river salinity and biodiversity conservation: managing trade-offs in the Murray–Darling basin. *Australian Journal of Botany, 51*(6), 619–625. https://doi.org/10.1071/BT03003

Grafton, Q., Williams, J., Wheeler, S., Bjornlund, H., Connor, J., Crase, L. … Kingsford, R. (2018, February 5). Fixing the Murray-Darling Basin: Declaration calls for action on water policy. *Asia & the Pacific Policy Society*. Retrieved from https://www.policyforum.net/fixing-the-murray-darling-basin/

Hahn, T., & Nykvist, B. (2017). Are adaptations self-organized, autonomous, and harmonious? Assessing the social-ecological resilience literature. *Ecology and Society, 22*(1), 12. https://doi.org/10.5751/ES-09026-220112

Hall, G. (2017). Making a living from the Macquarie Marshes—Implications of decisions made up the river. In R. T. Kingsford (Ed.), *Lake Eyre Basin Rivers—The search for sustainability* (pp. 145–150). Melbourne, Australia: CSIRO.

Harris, L., Chu, E. K., & Ziervogel, G. (2017). Negotiated resilience. *Resilience: International Policies, Practices and Discourses, 6*(3), 196–214. https://doi.org/10.1080/21693293.2017.1353196

Huitema, D., Mostert, E., Egas, W., Moellenkamp, S., Pahl-Wostl, C., & Yalcin, R. (2009). Adaptive water governance: Assessing the institutional prescriptions of adaptive management from a governance perspective and defining a research agenda. *Ecology and Society, 14*(1), 26. https://doi.org/10.5751/ES-02827-140126

Humphries, P. (2007). Historical Indigenous use of aquatic resources in Australia's Murray-Darling Basin, and its implications for river management. *Ecological Management and Restoration, 8*(2), 106–113. https://doi.org/10.1111/j.1442-8903.2007.00347.x

Ingram, H. (2011). Beyond universal remedies for good water governance: A Political and contextual approach. In A. Garrido & H. Ingram (Eds.), *Water for food in a changing world* (pp. 241–261). Abingdon, UK: Routledge.

International Centre for Environmental Management (ICEM). (2010). *Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream* [PDF file]. Retrieved from http://www.mrcmekong.org/assets/Publications/Consultations/SEA-Hydropower/SEA-FR-summary-13oct.pdf

International Rivers. (2013). *Lancang River Dams: Threatening the flow of the Lower Mekong*. Berkeley, CA: International Rivers.

Kingsford, R. T. (2000). Review: Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology, 25*(2), 109–127. https://doi.org/10.1046/j.1442-9993.2000.01036.x

Kingsford, R. T. (2004). Wetlands and waterbirds of the Darling River. In R. Breckwoldt, R. Boden, & J. Andrew (Eds.), *The darling* (pp. 234–259). Canberra, Australia: Murray-Darling Basin Commission.

Kingsford, R. T., Biggs, H. C., & Pollard, S. R. (2011). Strategic adaptive management in freshwater protected areas and their rivers. *Biological Conservation, 144*(4), 1194–1203. https://doi.org/10.1016/j.biocon.2010.09.022

Kingsford, R. T., Bino, G., & Porter, J. L. (2017). Continental impacts of water development on waterbirds, contrasting two Australian river basins: Global implications for sustainable water use. *Global Change Biology, 23*(11), 4958–4969. https://doi.org/10.1111/gcb.13743

Kingsford, R. T., Brandis, K., Thomas, R. F., Knowles, E., Crighton, P., & Gale, E. (2004). Classifying landform at broad landscape scales: The distribution and conservation of wetlands in New South Wales, Australia. *Marine and Freshwater Research, 55*, 17–31. https://doi.org/10.1071/MF03075

Kingsford, R. T., & Thomas, R. F. (1995). The Macquarie Marshes and its waterbirds in arid Australia: A 50-year history of decline. *Environmental Management, 19*(6), 867–878. https://doi.org/10.1007/BF02471938

Kingsford, R. T., Walker, K. F., Lester, R. E., Young, W. J., Fairweather, P. G., Sammut, J., & Geddes, M. C. (2011). A Ramsar wetland in crisis—The Coorong, Lower Lakes and Murray Mouth, Australia. *Marine and Freshwater Research, 62*(3), 255–265. https://doi.org/10.1071/MF09315

Kirchhoff, C. J., Lemos, M. C., & Engle, N. L. (2013). What influences climate information use in water management? The role of boundary organizations and governance regimes in Brazil and the U.S. *Environmental Science & Policy, 26*, 6–18. https://doi.org/10.1016/j.envsci.2012.07.001

Koponen, J., Paiboonvorachat, C., & Munoz, A. (2017). *The council study: Study on the sustainable management and development of the Mekong River, including impacts of mainstream hydropower projects* [PDF file]. Retrieved from http://www.mrcmekong.org/assets/Publications/Council-Study/Council-study-Reports-Thematic/ALU-Thematic-Report-22-Jan-2018.pdf

Lebel, L., Grothmann, T., & Siebenhünter, B. (2010). The role of social learning in adaptiveness: Insights form water management. *International Environmental Agreements, 10*(4), 333–353. https://doi.org/10.1007/s10784-010-9142-6

Leblanc, M., Tweed, S., Van Dijk, A., & Timbal, B. (2012). A review of historic and future hydrological changes in the Murray-Darling Basin. *Global and Planetary Change, 80*, 226–246. https://doi.org/10.1016/j.gloplacha.2011.10.012

Lienert, J., Monstadt, J., & Truffer, B. (2006). Future scenarios for a sustainable water sector: A case study from Switzerland. *Environmental Science & Technology, 40*(2), 436–442. Retrieved from https://pubs.acs.org/doi/full/10.1021/es0514139

Loorbach, D., Frantzeskaki, N., & Avelino, F. (2017). Sustainability transitions research: Transforming science and practice for societal change. *Annual Review of Environment and Resources, 42*, 599–626. https://doi.org/10.1146/annurev-environ-102014-021340

Maupin, M. A., Ivahnenko, T. I., & Bruce, B. (2018). *Estimates of water use and trends in the Colorado River Basin, Southwestern United States, 1985–2010: U.S. Geological Survey Scientific Investigations Report 2018–5049* [PDF file]. Retrieved from https://pubs.usgs.gov/sir/2018/5049/sir20185049.pdf

Mekong Committee (MC). (1970). *Report of the indicative basin plan for the Lower Mekong Basin* [PDF file]. Retrieved from https://search.archives.un.org/downloads/united-nations-office-for-special-political-affairs-1955-1991.pdf

Mekong River Commission (MRC). (2011). *Planning atlas of the Lower Mekong River Basin* [PDF file]. Retrieved from http://www.mrcmekong.org/assets/Publications/basin-reports/BDP-Atlas-Final-2011.pdf

Mekong River Commission (MRC). (2017). *Report on the positive and negative impacts of hydropower development on the social, environmental, and economic conditions of the Lower Mekong River Basin*. Vientiane: MRC. Retrieved from http://www.mrcmekong.org/highlights/the-council-study-reports/

Middleton, C., & Allouche, J. (2016). Watershed or powershed? Critical hydropolitics, China and the 'Lancang-Mekong Cooperation Framework'. *The International Spectator, 51*(3), 100–117. https://doi.org/10.1080/03932729.2016.1209385

Milly, P. C., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008). Stationarity is dead: Whither water management? *Science, 319*(5863), 573–574. https://doi.org/10.1126/science.1151915

Mirumachi, N. (2012). How domestic water policies influence international transboundary water development: A case study of Thailand. In J. Öjendal, S. Hansson, & S. Hellberg (Eds.), *Politics and development in a transboundary watershed—The case of the lower Mekong Basin* (pp. 83–100). Berlin, Germany: Springer.

Mirumachi, N. (2015). *Transboundary water politics in the developing world*. Abingdon, UK: Routledge.

Murray-Darling Basin Authority (MDBA). (2016). *Basin Plan annual report 2015–16*. Retrieved from https://www.mdba.gov.au/report/basin-plan-annual-report-2015-16

National Research Council. (2007). *Colorado River Basin Water Management: Evaluating and adjusting to hydroclimatic variability*. Washington, DC: The National Academies Press.

NSW Department of Planning, Industry and Environment. (2019). *Macquarie Cudgegong Environmental Water Advisory Group*. Retrieved from http://www.environment.nsw.gov.au/topics/water/water-for-the-environment/macquarie/environmental-water-advisory-group

Oliver, T. H., Boyd, E., Balcombe, K., Benton, T. G., Bullock, J. M., Donovan, D. … Dominik, Z. (2018). Overcoming undesirable resilience in the global food system. *Global Sustainability, 1*, e9–4798. https://doi.org/10.1017/sus.2018.9

Orr, S., Pittock, J., Chapagain, A., & Dumaresq, D. (2012). Dams on the Mekong River: Lost fish protein and the implications for land and water resources. *Global Environmental Change, 22*(4), 925–932. https://doi.org/10.1016/j.gloenvcha.2012.06.002

Petersen, P. (2017). A river and a livelihood—All but lost in a decade. In R. T. Kingsford (Ed.), *Lake Eyre Basin Rivers—Environmental, social and economic importance* (pp. 137–143). Melbourne, Australia: CSIRO.

Pittock, J., & Finlayson, C. M. (2011). Australia's Murray–Darling Basin: Freshwater ecosystem conservation options in an era of climate change. *Marine and Freshwater Research, 62*, 232–243. https://doi.org/10.1071/MF09319

Roosevelt, T. (1902). *Message of the president of the United States communicated to the two houses of congress 1902* [PDF file]. Retrieved from https://www.presidency.ucsb.edu/documents/second-annual-message-16

Stockton, C. W., & Jacoby, G. C. (1976). *Lake Powell research project (bulletin 18): Long-term surface-water supply and streamflow trends in the Upper Colorado River Basin*. Arlington, VA: National Science Foundation.

Sullivan, A., White, D. D., & Hanemann, M. (2019). Designing collaborative governance: Insights from the drought contingency planning process for the lower Colorado River basin. *Environmental Science and Policy, 91*, 39–49. https://doi.org/10.1016/j.envsci.2018.10.011

Sullivan, A., White, D. D., Larson, K. L., & Wutich, A. (2017). Towards water sensitive cities in the Colorado River Basin: A comparative historical analysis to inform future urban water sustainability transitions. *Sustainability, 9*(5), 761. https://doi.org/10.3390/su9050761

Taylor, K. S., Moggridge, B. J., & Poelina, A. (2016). Australian Indigenous Water Policy and the impacts of the ever-changing political cycle. *Australasian Journal of Water Resources, 20*(2), 132–147. https://doi.org/10.1080/13241583.2017.1348887

U.S. Bureau of Reclamation (USBOR). (2007). *Colorado River interim guidelines for lower basin shortages and coordinated operations for Lake Powell and Lake Mead: Final Environmental Impact Statement* [PDF file]. Retrieved from https://www.usbr.gov/lc/region/programs/strategies/factsheets/Nov2007.pdf

U.S. Bureau of Reclamation (USBOR). (2012). *Colorado River Basin water supply and demand study* [PDF file]. Retrieved from https://www.usbr.gov/lc/region/programs/crbstudy/finalreport/Study%20Report/CRBS_Study_Report_FINAL.pdf.

U.S. Bureau of Reclamation (USBOR). (2017). Today for #ThrowbackThursday, we have a selection of notable people at a meeting of the Colorado River Compact Commission. 1922. #TBT. Retrieved from https://www.flickr.com/photos/usbr/33491081615/in/photolist-cc4jmC-T2uxKD/

U.S. Bureau of Reclamation (USBOR). (2018, May 9). Another dry year in the Colorado River Basin increases the need for additional state and federal actions. *USBR*. Retrieved from https://www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=62170

U.S. Bureau of Reclamation (USBOR). (2019a). *Colorado River Basin drought contingency plans*. Retrieved from https://www.usbr.gov/dcp/

U.S. Bureau of Reclamation (USBOR). (2019b). *The law of the river*. Retrieved from https://www.usbr.gov/lc/region/g1000/lawofrvr.html

Udall, B., & Overpeck, J. (2017). The twenty-first century Colorado River hot drought and implications for the future. *Water Resources Research, 53*(3), 2404–2418. https://doi.org/10.1002/2016WR019638

Wong, C. M., Williams, C. E., Pittock, J., Collier, U. & Schelle, P. (2007). *World's top 10 rivers at risk* [PDF file]. Retrieved from https://assets.panda.org/downloads/worldstop10riversatrisk-finalmarch13_1.pdf

Yasuda, Y. (2015). *Rules, norms and NGO advocacy strategies: Hydropower development on the Mekong River*. Abingdon, UK: Routledge.