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Locking in hydro-engineered pathways: the lower river Murray, Australia, 1880–1940

Margaret Cook[1]

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Abstract
Located downstream from substantial irrigation extraction at the "end" of the Murray–Darling River system, South Australia (SA) struggles to maintain flows and the health of the rivers within its borders. Analysis of early twentieth century engineering reports reveals that this problem is not new, beginning in the 1880s with the growth of irrigation in Australia and the riparian demands of the eastern, upstream states. I use the theory of path dependency to analyse the history of the Murray–Darling Basin from a South Australian perspective to argue that the state's current water issues stem from cultural, institutional, and technological lock-ins shaped by its geo-political position that made it vulnerable to upstream demands for water. As SA's negotiations for a larger water allocation failed, it turned to construction of an enviro-technical network of weirs, locks and barrages designed to assist navigation, regulate the river's flow, keep water fresh for landholders and towns, prevent the ingress of salty sea water, and mitigate the consequences of upstream irrigation. With construction of each component the state's hydro-engineering scheme engineers warned that with increasing extraction these strategies would only buy time and bigger-scale structures would be essential in the future to alleviate accelerating problems. Within decades SA experienced the foretold problems of diminishing flows, increasing salinity, environmental degradation and declining water quality, problems that continue and with climate change are likely to grow worse. Only a fundamental shift in cultural, institutional, and technological lock-ins can change a future trajectory that could improve the health of the river.

Keywords Australia · Murray–Darling Basin · Weirs · Barrages · Path dependency · Hydro-engineering

✉ Margaret Cook
margaret.cook@griffith.edu.au

[1] Australian Rivers Institute, Griffith University, Brisbane, QLD, Australia

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At the southern-most part of the Murray–Darling Basin, in the Sea Country of the Ngarrindjeri people in South Australia (SA), stand five barrages that obstruct the River Murray's flow to its mouth. These barrages were constructed between 1935 and 1940 by the River Murray Commission to provide an artificial barrier across the Murray to impound water, impede the ingress and egress of water flows, and prevent flooding. The Murray–Darling Basin (MDB) includes six of Australia's seven longest rivers and traverses the states of Queensland, New South Wales (NSW), Victoria and South Australia (SA), all of which have competing needs for the rivers' waters (Fig. 1). At a length of 36,272 km, the Murray–Darling is Australia's longest river system, comparable in length to the Mississippi River than runs 37,656 km from Northern Minnesota to the Gulf of Mexico. At the lower reaches of the river system, the River Murray passes into two large, connected lakes—Lake Alexandrina (649 km^2) and Lake Albert (168 km^2). From there it flows through multiple paths within the coastal estuarine system of the Coorong and into a narrow mouth to the Southern Ocean. However, since the 1920s its riverine flows have been highly regulated by construction of an interconnected system of six weirs (with locks) and, after 1940, by five barrages. These interventions have fundamentally altered the river, locking the river into engineered segments and replacing natural flow regimes. Today, the 250-km stretch in SA between Blanchetown and Goolwa is the most regulated portion of the Murray–Darling River system (Fig. 2).

Australia is the world's driest inhabited continent and SA, with its arid climate, is the driest state. Australian rivers are characterised by highly variable streamflow, two times more than those in comparable climatic zones throughout the world (Finlayson & McMahon 1988, p. 27). Southern MDB rivers also have low annual flow rates, with less than 80

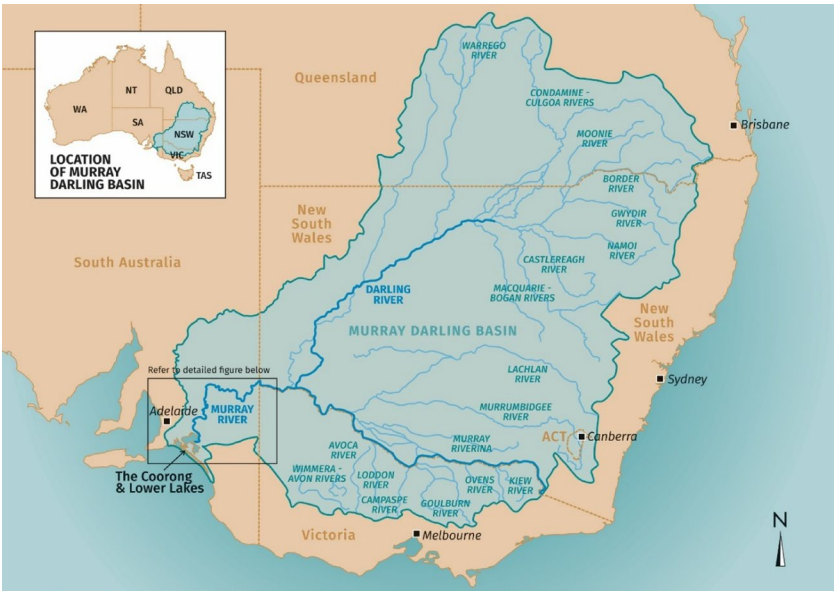

Fig. 1 The Murray–Darling Basin in Australia

Fig. 2 The lower Murray with the locations of the weirs with locks and the barrages produced by First Class Communications

m^3/s for the Murray compared to around 2500 m^3/s for the Missouri or the Yellow Rivers (Van der Leeden 1990). SA's geo-political position is similar to Mexico within the Colorado River Basin. Downstream of the most populous states of NSW and Victoria, SA is less wealthy and powerful and contributes lower rainfall and negligible run-off. Its water supplies depend greatly on deliveries from upstream states (Walker 2019, p. 14) and is the state with the least leverage in the inter-state and Federal negotiations over access to water. Rivalry and contestation over who should control and benefit from use of the waters of the rivers of the Murray and its tributaries have been a constant feature of Australian political debate since the 1880s and the rise of irrigation. This article contributes a South Australian perspective to existing histories of the MBD (for example Sinclair 2001; O'Gorman 2012, 2021; Rothenburg 2023 among them). It builds on Connell's book, *Water Politics in the Murray–Darling Basin* (Connell 2007) with a focus on how water policies, water extraction and hydro-engineering impacted on SA between 1880 and 1940 and the measures the State took to improve their situation. SA's water history has been one of contestation, negotiation, inter-state agreements, legislation and regulation as the state deployed a variety of measures to address the problem of reduced water flows that were exacerbated by upstream extraction in Victoria and NSW.

In this article, I play on the word "lock" to conceptualise the lower Murray as a redesigned river, disassembled "literally and figurately" and "locked-in" to separate spaces and parts (White 1995, p. 110). Between 1913 and 1929 the Murray–Darling Basin Commission constructed six weirs, a low dam built across the width of a river that alters the flow characteristics and maintains river heights. Each weir divided the river into cascading segments to create a storage pool upstream that water managers keep as stable as possible, with a lock that can be raised and lowered to adjust water levels to allow the passage of boats. The weirs assisted navigation by maintaining consistent river heights all year, including during the average seven months of low flow. The Murray mouth was locked from the Southern Ocean by five barrages that were operated to regulate

the river's flow regime and divert water by opening and closing the gates. The barrages would restrict the inflow of sea water thereby reducing the lakes' salinity levels to maintain a fresh water supply for towns, farmers, and irrigators. These hydro-engineering projects have locked in riverine paths by diverting water into the main channel.

I develop the idea of locking the river by using the theoretical framing of path dependency—a process whereby past events or decisions constrain later events or decisions and lock in paths that determine future outcomes. I argue that SA's current struggle to secure adequate water to sustain riverine health is the result of cultural, institutional and or technological lock-ins that were created since the introduction of irrigation in the 1880s that continue to shape SA water issues. SA is currently facing increasing environmental degradation because of decades of diminishing flows, with concerns that climate change will increase the problem. But, I argue, changing the course that was adopted in the 1880s, while essential, is proving difficult because of path dependency that has been created by these cultural, institutional, and technological forces, made worse for SA as the weaker state at the bottom of the river system.

The article begins with an explanation of my use of path dependency and lock-ins as a theoretical framing, before turning to SA's historical and cultural context in which these dependencies manifested in the construction of a regulatory network of weirs and barrages. I draw heavily on archival research of engineers' reports and correspondence between technical experts and the SA government, as well as departmental annual reports, to analyse the major hydro-engineering schemes designed for the Murray River in the twentieth century. These documents highlight the thinking of engineers behind the hydro-technologies and the decision-making framework. Commonwealth government records and those of the first inter-governmental body established with the affected states to regulate the southern MDB—the River Murray Commission (and its successors)—provided further information on the schemes and the intra and inter-state negotiations that occurred regarding the governance and technological changes that were applied to the river. Together with newspaper accounts, these records helped determine the cultural, structural, and technological context that created the lock-ins and path dependency.

I then analyse three main engineering schemes: those of Alexander Bain Moncrieff in 1890, Stuart Murray in 1909–1910 and Captain Edward Neale Johnston in 1911–1913. Although charged with the task of recommending hydro-technical solutions to meet SA's water needs, these engineers also regularly highlighted concerns about declining flow rates and river conditions in engineering and Commissions of Inquiry reports. An analysis of these reports helps counter dominant narratives within the MDB that diminished water flows and salinity were unexpected. These concerns were known from the outset but were deemed to be of lesser importance by river administrators and state interests in comparison with the wealth and nation building that could be created through irrigation. Throughout the processes of inter-state negotiations and agreements there were opportunities to respond to these environmental concerns and allow more water to reach SA, but the importance placed on irrigation and the negotiating power of NSW and Victoria at the expense of SA meant that the warnings largely went unheeded, leading to the current environmental consequences caused by an ongoing paucity of water in the lower Murray. Since the 1980s there have been legislative and regulatory measures introduced to reduce extraction and give back water to SA, but these same priorities and power differentials continue to permeate the governance, politics and grievances in the water management of the southern reaches of the River Murray and impede river restoration.

Path dependency & theoretical lock-ins

Path dependency theory provides a valuable framing for the historical analysis of hydro-structures, water management and governance and can be used to identify various forms of lock-ins. For example, Rodriguez (2023) challenges socio-environmental imaginaries in his study of environmental flows in Costa Rica to offer a vision of a less anthropocentric future. Marshall and Alexandra (2016) use the concept of institutional path dependency in their analysis of water reform and environmental water recovery since 2012 in the Murray–Darling Basin. Similarly, foregrounding path dependency in the Lower Murray illuminates how cultural and historical context is needed to be able to understand current water issues in the Basin.

The lock-ins that create path dependency can be cultural, institutional, or technological. Path dependency theory has been used by political scientists to demonstrate how, governance and political junctures create an institutional path dependency and lock-ins (Goldstein et al. 2023, p. 3). Sociologists (Mahoney 2000; Barnes et al. 2004; Urry 2013) identify behavioural lock-ins (from habits, culture, values, or organisations) that are often linked with historical events (for example, drought). Scholars of science and technology studies (STS) and political ecology draw on notions of sociotechnical and environmental imaginaries to examine the co-production and inter-connectedness of science and society. Path dependencies evolve as "they are conditioned and shaped by their respective historical" and current "socio-political and territorial context" (Mahoney 2000, p. 58; Hommes et al. 2022, p. 4). For example, Australian political and legislative frameworks shaped decisions made in the MDB. Lock-ins also reflect the economic framework and historical context (David 1993), including an increasing reliance on irrigation for agriculture. As Hommes et al. (2022, p. 4) note, weirs and barrages are "entrenched" within history and socio-technical imaginaries at the time of construction determine the type of engineering structures built. Their construction reflects "modern aspirations", a "fascination for expert and engineering skills" which reinforces a faith in hydro-technology to control nature, build nations and ensure progress. Socio-technical lock-ins determine the type of engineering structures built, changes to water flows and governance, and the relationships between "society and the environment" (Hommes et al. 2022, p. 4).

To develop the idea of lock-ins further, I draw on an idea developed by political scientists Marquardt and Nasiritousi (2021, p. 622) of a deeper path dependency where an imaginary lock-in constrains decisions. They argue that powerful discourses and "complex societal mechanisms" can "limit our ability to reimagine society and develop an alternative future" (Marquardt and Nasiritousi 2021, p. 624). The issue with path dependencies is they constrain changes. They become entrenched and underlie "structural conditions that are seemingly inescapable" and "intractable" (Goldstein et al. 2023, p. 2). As Levi explains (1997, p. 28) "the costs of reversal are very high". In the case of the lower Murray there were opportunities to change the trajectory, but cultural, institutional, and technological lock-ins made an alternative future unlikely. The construction of SA's weirs and barrages reflected many types of cultural, institutional, and technological lock-ins. Escalating engineering and increasing upstream extraction forced SA's hand in addressing the problem (cultural lock-in) by turning to engineering structures to mitigate the diminishing flows and regulate the river (technical lock-in). Institutional lock-ins, including Commonwealth and state governments' interests, MDB legislation and governance, as well as SA's location at the "end" of the system made future alternatives difficult to implement.

South Australian water uses

From the 1850s, SA's primary water interests in the River Murray were driven by the need to maintain river navigation to secure its inter-colonial trade with London. The Colony of SA dominated river trade, transporting wool from the inland to the British markets from their sea-port at the mouth of the Murray, with trade revenue in excess of £1 million in 1882 (Webster 2017, p. 15). As rail replaced river transport in the late nineteenth century, SA lost its competitive advantage and the other colonies no longer used their port. With this change, SA lost negotiating power for maintaining water flows in the lower reaches. By contrast Victoria, followed by NSW, focussed on the riverine potential for irrigation to develop their economies through agriculture.

In nineteenth century Australia the "hydro-engineer was the liberator of nature" (Cathcart 2009, p. 199) who would unlock the untapped resources of water to irrigate, develop the country and increase the population. Irrigation brought with it the promise of opening up the land for closer settlement, creating smaller agricultural blocks for yeomen farmers. The state would call on engineers to "conserve" floodwaters by "locking up the rivers" in dams to drought-proof Australia and irrigate the land to create national prosperity (Cathcart 2009, p. 200). The seductive power of this vision attracted followers and created a cultural lock-in for governments and settlers alike that favoured irrigation and made it difficult for SA to argue against extraction. To do so was tantamount to standing against national growth and prosperity. Instead, as Victoria and NSW reaped the benefits of river extraction for agriculture and shipping declined, SA also shifted its river interests to irrigation and embraced the vision.

Drought in the early 1880s diverted colonial attention to water utilisation with NSW, Victoria and SA all holding separate Royal Commissions with a focus on irrigation and water conservation, a term that refers to the utilisation, regulating and engineering of rivers. As extraction increased across the MDB, NSW and Victoria attempted to divide the waters of the Murray–Darling into equal shares between them in 1886 (Eaton 1945, p. 8). Their main justification was that although the River Murray traversed SA, much of its flow came from upstream in high rainfall areas (in Victoria and NSW) and they argued that any water that fell in their jurisdictions belonged to them. The Engineer for Water Conservation in NSW, Hugh MacKinney, argued that SA had no moral claim to Murray–Darling waters as the colony had no contributing tributaries (Webster 2017, p. 38). SA was increasingly concerned about the impacts of upstream extraction and tried to prevent or mitigate these affects through inter-colonial negotiations with very limited success. Reflecting an institutional lock-in of governance systems, the colonies (states after Federation in 1901) negotiated the management of the Murray–Darling system through extensive interaction from the 1880s with formal inquiries and intercolonial agreements. SA was unable to make purely local decisions in their own interests, tied into wider-scale relations and decisions.

The colony of SA was justified in its concerns about upstream extraction. As early as 1889 the SA Parliament noted that irrigations in Victoria were "diverting to their own use immense quantities of water". Experts estimated that Victoria took ~ 4 cubic metres of water per minute from the Murray "more than is discharged into that stream by the feeders flowing through its territory" (Express and Telegraph 1889, p. 3). Newspapers reported SA residents' concerns about upstream extraction, as they believed "extensive withdrawal was making fresh riverine waters brackish" (Express and Telegraph 1889, p. 3). Efficiencies gained by reducing waste within SA borders would have minimum

impact if the eastern states captured upstream flows. Charles Hussey, the parliamentarian for Encounter Bay in SA and a member of the Murray Waters Commission, called for an inter-colonial trust comprising the three colonies of NSW, Victoria and SA to manage the waters of the Murray to "secure a fair share to each colony" otherwise SA "will be obliged to take steps for the protection of its interests" (Express and Telegraph 1889, p. 3). Although this was largely a hollow threat proffered by a colony powerless to regulate upstream extraction, the debate that ensued reflected a growing awareness of the impact of upstream extraction on lower Murray flows.

Unable to force an inter-colonial inquiry, SA conducted its own inquiry into the volume and discharge of the river in 1889—the Commission on the Utilisation of River Murray Waters. Reflecting the prevailing dependency on technological engineering solutions, the brief included investigating hydro-engineering structures that could prevent the ingress of salt from the Southern Ocean, maintain river heights for navigation and protect the rights of settlers around the lakes to access fresh water. The inquiry was conducted amidst a growing anxiety within SA over its economic decline as railways superseded river trade. Having experienced diminished flows in the 1880s drought, SA also feared the impact of increasing water extraction from irrigation in NSW and Victoria and their determination to share equally the water upstream.

Merchant, Thomas Goode of Goolwa in SA, informed the Commission that the river was salty for three months of the year and he assumed that with greater irrigation the supply of water would reduce, thereby impeding navigation and making salinity worse. From his standpoint as a steamboat trader, he supported hydro-engineering as he had "no doubt" that a "series of locks" would preserve fresh water and navigability for the whole year (South Australia 1891, p. 10). James W. Jones, the Conservator of Water and government adviser, gave evidence that if the other colonies undertook their irrigation schemes "in their entirety, reports show that they will take all the water of the river in a dry year" (South Australia 1890, p xvii). Even if the full extent of these irrigation schemes were not constructed, Jones estimated that salt water would reach Murray Bridge in several summer months (South Australia 1891, p. xviii). Despite these protestations, the Commission did not make any firm recommendations, recognising the impacts on flow rates from irrigation in NSW and Victoria would determine decisions within SA borders (South Australian Chronicle 1890, p. 11). The cultural and structural lock-ins imposed by constraints of inter-colonial governance curtailed SA's management of its waters.

The Commission also took evidence from Engineer-in-Chief, Alexander Bain Moncrieff. Born in Ireland from Scottish descent, he emigrated in 1874 and was appointed SA Engineer-in-Chief in 1888. He testified that "it was not impossible" that tidal waters could be kept out by "locking the river" (South Australia 1891, p. xv). He outlined a scheme, based on his knowledge of Scottish engineering in Glasgow, whereby rivers could be impounded by a lock or barrages to raise the water to a higher level. On reaching that height the water would flow over the structure and into the channel below. Thus "the waters of the stream are penned back". The water would only flow into the next lock (South Australia 1891, p. 5). Following the inquiry, Alexander Moncrieff was asked to investigate a suitable scheme and report back to Parliament.

The first scheme: Alexander Moncrieff

Alexander Moncrieff's report, tabled in parliament on 29 July 1890, stated that in heavy floods fresh water could be found "at long distances from the shore". But when the river

was low the tides affected the "level and taste of the water of the river, the bed of which with the lake becomes practically an inlet of the sea for 40 miles, or nearly up to Wellington" (South Australian Register 1890, p. 5). This was caused by the fall of the lower reaches of the river and evaporation from Lake Alexandrina.

Moncrieff's intent was to "give free vent to flood waters without encroaching on useful land, but at the same time prevent the sea waters from entering the lake" and conserve waters downstream. He recommended construction of weirs or barrages across Goolwa, Mundoo and Coorong channels to prevent the ingress of salt water and "conserve the river to the level of the ordinary low water". Shutters on the weirs and barrages would control releases, thereby altering natural flows, and Moncrieff conceded that this would cause siltation (The Daily Telegraph 1890, p. 5).

The Federation Drought (1895–1903) exposed SA's vulnerability to reduced flows. By 1903 the *Adelaide* Observer (1903a, b, p. 1) noted that the river at Morgan was "lower than it had been for years", the river coated in a "green scum" reminiscent of the "stagnant waters of a billabong instead of the waters of the Murray" (Adelaide Observer 1903a, b). Stock, forced to drink the lakes' salty water, had been reduced to "an emaciated condition" (Advertiser 1916, p. 6). While the newspaper conceded that the drought was a factor, Victoria was also to blame:

> the drought may have had something to do with the low rivers, but the conservation schemes carried on by Victoria have taken a tremendous amount of water from the river that should come down, and navigation has been considerably interfered with (Adelaide Observer 1903a, b, p. 1).

The *Southern Argus* maintained that the drought showed that SA should be "alive to its interests" and "should not allow" NSW and Victoria "to deal with the contents of the river as though no one else had any proprietary rights to them" (Southern Argus 1904, p. 4).

In 1902, within the context of the Federation Drought, the new Commonwealth of Australia (formed in 1901) held a Royal Commission with NSW, Victoria, and SA to determine each state's water allocation, purpose and works required. The Royal Commission argued for a co-ordinated approach and that in considering rights to water the river system should be "looked on as one" (Interstate Royal Commission 1902, p. 49). The Commission's report stated that "water for irrigation was of paramount importance" and while the Commissioners acknowledged the water needs of the SA Lower Lake settlers, they considered an open (or unregulated) river would restrict national development and "could not be justified", even if it reduced navigation to a minimum (Eaton 1945, p. 10). SA was allocated 702 Gigalitres annually (Interstate Royal Commission 1902, Appendix 1). For context, 1 Gigalitre equals one million litres or 400 Olympic sized swimming pools.

Frederick Burchell, the SA representative on the Royal Commission, argued that the recommendations were "a flagrant breach of the Constitution" and "grossly unfair to South Australia" (Eaton 1945, Appendix 2; Guest 2016, p. 31), and wrote a dissenting report to that effect. He believed that the inter-state agreement would render the SA portion of the River Murray un-navigable for five months of the year (Eaton 1945, Appendix 2) and would have a detrimental effect on the state's economy. Australia's new constitution did not grant the Federal Government management of the Murray–Darling waters as a whole and there is legal consensus that section 100 establishes a State's right to "reasonable use" (Connell, p. 48). This provides a "strong constraint" on the Federal government to interfere with irrigation and other water matters within states, thereby creating an institutional lock-in that continues today. In 1902 this left SA in a weak legal position to contest the allocation (Connell, 2007, pp. 48–49), dependent on

negotiation and co-operation with the more powerful and wealthy upstream states that was not forthcoming.

The severity of the Federation Drought had reinforced SA's anxieties, leaving it more fearful of upstream extraction. The drought had demonstrated that "it would have required nearly all the available flow of the river to keep the lakes sweet and open for navigation" (Johnston 1913) and the State feared that NSW would in future "drain the Murray dry" (Connell, 2007, p. 62). As Federation had failed to create an equitable inter-government agreement between the State and Commonwealth governments over water allocations and after decades of unsuccessful negotiations, SA was left with little option other to fund the construction of weirs and locks between Blanchetown and the Murray mouth in order to maintain river navigation and the water levels in Lakes Alexandrina and Albert to keep their water fresh.

In 1903 SA commissioned another study to consider engineering options. Engineers Alexander Bain Moncrieff (SA), William Davidson (Inspector General of Public Works Victoria) and Thomas W. Keele (Principal Engineer of Harbors and Rivers NSW) were appointed to prepare a joint report for the SA government to consider several proposals for construction of a barrage in the lower Murray. The engineers rejected a barrage at the mouth, as it would be "impracticable" to exclude tidal effects to prevent salt, instead suggesting construction of a series of barrages throughout the SA River Murray. Their report concluded with a warning about the impact of flow rate on the potential success of the scheme:

> if the supply of water from the upper reaches of the river is not sufficient to keep the lakes reasonably full the effect of the erection of the barrages would be a serious injury to the conditions of the Lakes instead of being an improvement (The Register 1903, p. 8).

The success of the barrages in keeping the lakes fresh and the river healthy was contingent on maintaining upstream flows from the eastern states. But, perhaps reflecting reality, the Register (1902, p. 6) reported that if NSW and Victoria continued to extract water, then locks were needed, otherwise SA's "riparian interests would be destroyed".

Faced with increasing interstate irrigation and the accelerating demise of river transport by rail, SA engineers now focussed their efforts on mitigating the impact of extraction through hydro-engineering. On 9 December 1905 SA passed the *Murray Works Act to* allow construction of "a series of locks and storage areas" to prevent the egress of water from the river's mouth. The vision was that the river "may become part of a large general scheme for locking and conserving the whole or main parts of the river in the three States" (Moncrieff 1905). Furthermore, these measures would facilitate the development of irrigation in the state. The river was to become a large hydro-engineering scheme but there was still a lack of consensus about the best solutions.

Investigations turned further afield as SA called on state, inter-state and inter-national engineers for their expertise. The government first called on John B. Labatt, the engineer of water supply, to investigate the contemporary effect of extraction of the existing river, the impact of future diversions and the works required to mitigate their impact. Labatt's (1905) report found that the matter was growing in urgency, calculating that it would only be seven years before the diversions in NSW and Victoria would affect the "navigable flow of the main river" and in 20 years diversions by NSW would be "producing maximum effects upon the flow" (Labatt 1905, p. 8). He recommended gradual installation of locks as diversions in NSW and Victoria increased.

Further opinions were sought and in 1906 the government again consulted Moncrieff who agreed with Labbatt. He recommended the erection of six weirs with locks in the state, reclamation of lands (including drainage of Lakes Alexandrina and Albert), building storage areas (weirs with locks for navigation), and construction of barrages as "defences against the entrance of salt water from the sea at the mouth" (Moncrieff 1905). The weirs would mitigate or, in Labatt's words, "counteract" or "neutralise" the impact of increasing water demands and diminish upstream flows and be built when and where "necessitated by the injurious effects of diversions on the flow" (Labatt 1905, p. 19; Labatt to Premier SA, p. 2). Reflecting the dependence on engineering structures and the likelihood of increasing extraction (including SA's own irrigation), the state justified these riverine interventions with an estimation that with barrages and weirs a lower annual flow of 2265–2832 Gigalitres would be sufficient to keep the river flowing. Without weirs the engineers calculated that the state would need twice that amount per annum to keep the lower lakes and river salt free. Victoria, NSW, and SA agreed that until the locks and weirs were constructed the upstream states would limit their diversions for seven months each year between July and January. This consensus suggests that all three states were aware of the impact of water extraction but none was willing to reduce extraction. The only concession was to grant SA a larger water allocation in 1906 of 2120 Gigalitres per year (Guest 2016, p. 18).

Despite this seeming acknowledgement of the detrimental impact of upstream extraction on the lower reaches of the MDB, when an inter-state agreement was finally reached in 1907 it did not include provisions that prevented the states from constructing storage reservoirs or diverting water, despite previous agreements. SA's concerns were given scant attention. Federation and the hardships of the Federation Drought had only strengthened Australia's links with irrigation and nation-building. The detrimental effects of irrigation on SA held no sway in a vision of prosperity. In an act reflecting SA's increasing anxiety, the government sought interstate expertise, commissioning Victorian civil engineer Stuart Murray to investigate the most suitable engineering scheme to meet the state's water needs.

The second scheme: Stuart Murray

Scottish born, Stuart Murray had acquired extensive experience working on water matters in Victoria from the early 1880s, most notably as a secretary of the Royal Commission on Water Supply in 1884, the Victorian Engineer-in-Chief from 1886 and the state's delegate on the 1902 Royal Commission on the River Murray. He was appointed chairman of the State Rivers and Water Supply Commission from 1906 to 1908 (Yule 2006). Employed by the SA government as a consultant, Murray was given the task of assessing the flow rates SA needed for steamers and to keep the weirs and locks "fully and permanently efficient" (The Advertiser 1909, p. 6). SA was still concerned with river navigation but increasing looked to using land and water for irrigated agriculture as their riverine trade advantage declined. Murray was charged with investigating land reclamation for irrigation and "how far" it was "expedient and possible for the sea water to be kept from entering the Lakes" primarily for water supply and agriculture (Murray 1909).

Murray's (1910) report found that as well as increasing extraction, rivers faced another problem that affected flows. In dry years, evaporation consumed up to half the discharge measured at Morgan (near the SA and Victoria border), and to him, evaporation and any water that could not be used for irrigation, "or any other economic purpose", was a waste. He recognised all states were motivated by self-interest and believed it "hopeless to expect that the upper States would consent to send down such a volume of fresh water" to

maintain water levels that in years of low flow would be "dissipated by evaporation from the lakes". With the popular support and political advantage to be gained by supporting irrigation, NSW and Victorian governments were unlikely to limit their extraction for the benefit of another State. Nor did Murray think that any "higher authority"—for example, the Federal government—would force them to relinquish water (Murray 1910, p. 17). They were not bound by any interstate agreement that required the upper states to "sacrifice" their water allocations for downstream needs. Murray's brief and training, as well as ongoing dependency on technology, made a hydro-engineered solution likely if SA was to maximise its riverine flows.

Stuart Murray recommended that a barrage should be constructed at the head of Lake Alexandrina, with a "condition that a sufficient supply of water be sent down the river, to maintain freshness". Without these flows, he maintained, the "lower Murray will, as the result of diversions higher up, become permanently salt[y]". Murray acknowledged the impact of irrigation on SA, advocating the cost of these works should be paid for by the upper riverine States, as they "alone would benefit from the diversions" that necessitated these works (Murray 1910, p. 17). These extracts from Murray's (1910) engineering report indicate this was an opportunity to consider alternatives as he was foreshadowing future environment problems whereby upstream extraction would continue to diminish water flows and increase salinity.

Problems caused by extraction were already increasing. *The Register* reported that in "bad seasons there was a large influx of salt water into Lakes Alexandrina and Albert, and the inundation was generally accompanied by a green weed" (Register 1912, p. 7). Diminishing grasses and fresh water caused great loss to stock. At a gathering of "river men" in 1912 there was consensus that lower river levels had increased salt levels and stock were dying. They felt the government needed to act immediately in the interests of "posterity" so as not to "imperil" the economic productivity of the region (Chronicle 1912, p. 42). In May 1912 Richard Butler, the SA Commissioner of Public Works, received a deputation from 250 "influential" settlers who informed him that vegetation was drying and stock levels had halved from only a few years earlier, with concerns of a repeat of the 1901 river lows. They maintained that "year by year" the flows were "getting worse", even in wet years. They were unequivocal that the "diversion schemes up-stream" had a "disastrous effect and salt water flowed in much more readily" (The Register 1912, p. 7). The *Southern Argus* in 1912 made its opinion clear. While Victoria and NSW were "vigorously prosecuting irrigation schemes" and curtailing downstream flows, the river's lower reaches were becoming "almost tidal" and increasingly saline,

> so sluggish is the current opposing it. Lakes Alexandrina and Albert have been robbed of their value and character to a very great extent and become a menace instead of a rich asset to the people resident on their shores (Southern Argus 1912, p. 2).

The view that upstream extraction was effectively stealing from SA was widely shared and resonates with South Australian debates today (for example ABC News 2017). With water viewed as an economic resource, losing farmland justified riverine engineering interventions.

Although Moncrief and Murray had reached similar conclusions that engineering was required, SA sought an international opinion. Engineer-in-Chief, Graham Stewart who succeeded Moncrieff in 1909, was sent to England, Europe and America to engage the "services of an engineer skilled in river regulation to advise with regard to locking the River Murray" (The Register 1918, p. 4). The service of Captain Edward Neele Johnston of the

United States Army Corps, a recognised expert on the construction of locks and barrages, was secured through courtesy of the USA government (Chronicle 1916, p. 12). He drew on his knowledge of successful harbour works in the USA (Chronicle 1913, p. 46). In securing such an expert it appears as though weir, lock and barrage construction was a forgone conclusion for South Australian authorities.

The third scheme: Johnston

Johnston reached SA in April 1912 and devised a complete system of locking the river between Swan Reach and Lake Victoria (near the NSW and SA border) to ensure permanent navigation between the Murray Mouth and Wentworth (Butler 1913). Johnston was recalled to SA to complete a second report in 1913 that detailed further engineering works that would "ensure the navigability of the river" year-round, "particularly at low river time between February and May", the most productive time of year for agriculture. His scheme included three weirs and locks, regulators, embankments, and land purchase (Butler 1913). With some modifications, the SA government adopted Johnston's plans and construction proceeded.

In 1913 engineers from SA, NSW, and Victoria prepared a joint report that was ratified by the Commonwealth and three state parliaments in 1915. The engineers recognised that the period of navigability in an unlocked river had been shortened by extraction and would "be seriously shortened by further diversions, and practically prevented" without locking. But concerns about navigation in SA were over-ruled and the report reiterated that irrigation was paramount. The report addressed a concern, reassuring governments that "locking could be carried out without affecting the volume of water available for irrigation" (Irrigation Record 1913, p. 15). This report provided the basis for the 1914 Murray Waters agreement and the *River Murray Waters Act 1915* that created the River Murray Commission (RMC) and a policy and governance framework that still largely governs the Basin. Under the River Murray Waters Agreement SA's annual volumetric entitlement was set at 1547 Gigalitres per year", but this would be reduced in dry years, arguably when SA needed it the most (Walker 2019, p. 81). It was agreed that the Federal and three state governments would fund regulatory works, but this did not include barrages.

Fig. 3 The first weir and lock constructed at Blanchetown, author, 2023

In 1916 the SA government again sought the opinion of Captain Johnston, now a Major in the US Corps of Engineers. He concluded that the barrages were warranted with movable gates to control floods and recommended weirs (River Murray Waters Acts Report 1931). Ultimately, only six weirs were constructed in the State (Fig. 3), all completed by 1929. No provision was made for barrages. John Gore Stewart, who replaced his brother Graham Stewart as SA Engineer-in-Chief in 1924, acknowledged that as diversions upstream increased, the inflow of salt would increase, and barrages would be required above the lakes to prevent the increased ingress of brackish water. He noted "it would not be practicable to keep the lakes permanently fresh, but the barrages across the various channels south of the Goolwa Channel would lengthen the periods of freshness". He also sounded a word of caution, noting that as irrigation in SA increased, the barrages would "become less effective" in freshening the lakes (Stewart 1924).

Plans for barrage construction stalled when another investigation of construction works on the lower Murray was conducted—the 1930 Commonwealth River Murray Commission of Inquiry. Settlers testified that riverine salinity was increasing every year from low flows and the ingress of the sea. The resultant 1931 report found that salinity had reduced agricultural production by 25–50%, compromised farmers' riparian rights, and had diminished town and railway water supplies. The largest acknowledged contributor was upstream extraction, which meant the problem would only increase as irrigation's development continued apace. The report summarised "there is no possibility of the allocation of additional water to South Australia" (River Murray Waters Acts Report 1931, pp. 4–6). An institutional lock-in committed the state to the 1915 agreement and an ongoing cultural lock-in continued to support engineering solutions rather than reduce extraction. The report concluded that the most suitable means of protecting the lower Murray against salinity was the construction of barrages (River Murray Waters Acts Report 1931, pp. 4–6) as the institutional lock-in of NSW and Victorian dependence on irrigation remained. Instead of restricting extraction, the report recommended hydro-engineering to compensate for its impact. In January 1931 the River Murray Commission recommended the construction of barrages, the matter referred to the Parliamentary Standing Committee on Public Works in July 1933 by the South Australian Governor (Report of Standing Committee 1933).

The Standing Committee recommended barrage construction on the grounds of economy and the advantages for the settlers and gained the approval of the Commonwealth, NSW and Victorian governments. Having failed through negotiation to receive higher water allocations from upstream, SA also agreed (River Murray Acts Report 1931, p. 17). Work commenced in 1935 and by 1940 five barrages, 7.6 km total in length, were built across the tidal channels at the Murray mouth: at Goolwa, Boundary Creek, Mundoo, Ewe Island, and Tauwitchere Island (Fig. 4). The barrages were designed to maintain water quality by keeping out sea water, facilitating irrigation, mitigating floods, and ameliorating shoreline erosion.

On completion in 1940, the barrages were celebrated in the Chronicle (1940, p. 33) as "one of the greatest engineering and irrigation schemes ever undertaken in Australia" heralding potential "big economic benefits". The *Advertiser* similarly reported: "the River Murray Commission believes that it has built barrages which will indefinitely endure the strains of flood and tide, and confer notable economic benefits on this State". Settlers near Mannum, Murray Bridge, and Wellington "will now have little cause for anxiety" about salinity. "With abundant fresh water available on each side of the river", agriculture would substantially increase through irrigation. Furthermore, it would "not appreciably increase the danger of floods" as the sluice gates on the barrages could release water (Advertiser 1940, p. 18).

Fig. 4 Barrage at River Murray mouth, author, 2022

While SA may have congratulated itself on solving their water issues, water extraction continued with NSW and Victoria providing an annual allocation to SA. As salinity issues grew in the lower River Murray in the 1960s, for the "first and only time during the life" of Murray–Darling Basin Agreements, SA's annual entitlement increased from the 1547 Gigalitres agreed upon in 1914–1850 Gigalitres per year (Walker 2019, p. 83). But the benefit was offset by increasing extraction and by the 1970s combined irrigation diversions from NSW, Victoria, and SA had increased seven-fold since Federation to 3950 Gigalites per year (Walker 2019, p. 83).

The warnings of river degradation come to fruition

Decades of over-extraction across the Basin and river regulation have fundamentally changed the character of the River Murray, not least of which is the diminished flows that have been forecast since the early twentieth century. The impacts include reduced pre-development long-term average annual inflows into SA from more than 13,000 Gigalitres to 7443 Gigalitres (Chiew et al. 2020, p. 6). In 2022 scientists calculated that the lower lakes received an average annual reduction of 54% of inflow, a figure that can be less than 25% in drought (Mosley et al. 2022, p. 574). While the barrages have prevented the ingress of the sea (Chiew et al. 2020, p. 6), lower upstream flows have increased the salinity that settlers and engineers had hoped to prevent nearly a century ago (Environmental Water Delivery 2012, p. 9).

Changes in the extent and frequency of natural flows have altered the river's mouth. Pittock et al. (2013, p. 112) calculated that water consumption has reduced average annual flows at the mouth by 61%. In 2022 the Murray Basin Commission Authority found "there are now more frequent and longer periods of zero or very low river flows at the barrages" (Murray–Darling Basin Commission 2002, p. 8). Prior to regulation, the River Murray ceased to flow through its mouth 1 percent of the time, now it is 40 percent (Ferguson et al. 2018, p. 461). These reduced flows have compromised the dynamism of the estuary and tidal flows, allowing sediment to build, and constant dredging is needed to keep the mouth open (Mosley et al. 2022, p. 575). Although severe constrictions of the mouth have historically occurred during periods of drought, it closed completely in 1981 for the first time in

recorded history after almost 20,000 tonnes of sediment accumulated across 196 days of barrage closure (Murray–Darling Basin Commission 2002, p. 9). During the Millenium Drought (1997 to 2010)—a period of consistently low rainfall and flows—no flows reached the sea for four years (Mallen-Cooper and Zampatti 2018, p. 11). *South Australia's River Murray Act* of 2003 declared that the Murray mouth must be kept open to maintain navigation and the passage of fish to improve the health of the river. However, without reducing extraction upstream throughout the entire Basin, the only solution appears to be a constant regime of dredging.

While scientists document the declining health of the river, the Ngarrindjeri believe the River Murray is dying. They are adamant that:

> too much water has been diverted from the river system and not enough water now reaches the Lakes and Coorong. The quality of the water has also fallen. The water is cloudy, polluted and not fit for drinking. The Murray, the Lakes and the Coorong are no longer environmentally healthy and this is partly why the Ngarrindjeri people are not healthy. The Ngarrindjeri know that the Coorong, Lakes and River are dying (Hemming et al. 2002, p. 15).

With climate change the Murray River inflow is predicted to decline between 14 and 40% (depending on emission scenarios), lake evaporation will increase, and sea levels may rise by 52–98 cm by 2100 which means the barrages will be overtopped and the lakes will be inundated with sea water (Chiew et al. 2020, p. 10). The "societal responses" to climate change, are "likely to increase diversions of water", making matters worse (Pittock et al. 2013, p. 112). Much of the reform needed to restore the health of the river is dependent on increasing flows and with lower rainfall predicted under climate change, the best way to do this is through decreasing water extraction. But the constraints of cultural, institutional, and technological lock-ins remain.

Path dependency has shaped the development of the lower River Murray, making future systemic change problematic. Institutional processes in terms of interstate cooperation (or lack thereof) and the interplay of state legislation and interstate agreements have constrained outcomes. Decisions were made in a cultural context where water was regarded simply as a resource extracted for the benefit of humans and development. Continuation of the path's trajectory catered to Australia's perceived increasing dependence on irrigation schemes and the belief that they would deliver national prosperity provided a powerful disincentive for politicians and river regulators to seek alternatives. Cultural, technological, and institutional lock-ins have created a path dependency on ever-increasing irrigation and hydro-engineering interventions. But as this article shows, the potential for failure was ever-present, built into the initial (and subsequent) engineering schemes as a staged process with the hope of delaying the incremental problems of diminishing water flows.

Thinking about how rivers have been shaped and affected by path dependency is essential for determining how we might be able to unlock ourselves for the future. As Bret Walker concluded his 2019 SA Royal Commission Report (2019, p. 14), "SA has not succeeded in its repeated attempts to obtain a more advantaged position than it has had, in relation to sharing the waters of the Basin". I argue that this has been the result of ongoing political imperatives, economics, ideology and state rivalries that have made taking a different approach fraught and seemingly "intractable" (Goldstein et al. 2023, p. 2). While SA negotiated from a weaker position, in inter-state agreements and Federation provided opportunities to rectify past decisions, treat the MDB as a whole system (as suggested in 1915) and increase SA's water allocation and yet they did not. If underlying cultural, institutional, and technological path dependencies remain constant how can we change

the future paths that guarantee the health of the river and sustainable communities that depend on Murray waters? Perhaps unlike past droughts and other crises, climate change may be sufficiently disruptive to create an existential force that will alter long-standing path dependent trajectories as David (1993) suggests is possible. Will an increasing awareness of environmental and riverine health and climate change break path dependency by reframing the problem in a way that will allow us to reshape the cultural, institutional, and technological contexts? We can only hope that Australians begin to realise that without water, contemporary concerns about the economic, political and hydro-technological costs of changing Basin water politics, policy, regulations and allocations are immaterial. Ultimately, necessity may make alternative pathways the only viable future.

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Margaret Cook is a Research Fellow in the Australian Rivers Institute at Griffith University and La Trobe University in Australia. As an environmental historian she is interested in how historical inter-relationships with water, humans and the more-than-human world have shaped outcomes, policies and behaviours today. Her current work concentrates on floods, climate adaptation, and the Murray–Darling Basin.