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Snowy River environmental flows post-2002: lessons to be learnt

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ABSTRACT

In 2002, the Australian, New South Wales and Victorian governments agreed to the Snowy Water Inquiry Outcomes Implementation Deed for environmental flows to (in part) restore the health of the Snowy River in south-eastern Australia. This was the first legally binding commitment to deliver annual environmental flows in Australia. Twenty years on, we assess this Deed and its implementation to derive lessons that can inform environmental flows agreements globally. Information from governance documents, flow release data and interviews with stakeholders are used to evaluate the effectiveness of the Deed. The target of 212 GL year^{-1} from 2012 has not once been reached. In turn, we find that implementation has been hindered by release of too little water, overly complex institutions that lack ownership and accountability, and no provision for review of the Deed. The lessons for effective environmental flow institutions are: (a) set clear, science-based environmental restoration objectives with stakeholders; (b) make roles and responsibilities for implementation clear; (c) enable independent and transparent monitoring, reporting and regulation; and (d) undertake periodic review to incorporate new knowledge, and to adapt to climatic and other unanticipated changes.

Keywords: environmental flows, flow regime, hydropower, restoration agreements, Snowy River, water-dependent ecosystems, water management, water entitlements.

Introduction

Over the last 40 years, the concept of environmental flows (e-flows) has evolved from providing a minimum flow, to delivering e-flows to mimic the dynamic relation between hydrology and ecosystem structure and function (Poff and Matthews 2013). This conceptual development followed recognition that: (a) water-dependent ecosystems have a legitimate right to water, and (b) human alteration of natural flow regimes, like that from hydropower dams, has damaged riverine ecosystems (Arthington 2012). One such river is the Snowy River in eastern Australia, an iconic river extensively affected by inter-basin water transfer and hydropower generation. Here, the delivery of e-flows was set out in a legally binding, 2002 document entitled the Snowy Water Inquiry Outcomes Implementation Deed (henceforward SWIOID or 'Deed'). This is one of the first legally binding agreements in Australia to restore a riverine ecosystem and, with the Colorado River, United States of America (Patten *et al.* 2001), is one of the earliest attempts to restore a riverine ecosystem using e-flows.

E-flow development

The Deed to restore the Snowy River represented a consolidation of thinking on the utilisation of e-flows. Prior to the 1980s it was common practice globally to incorporate e-flows into water management to provide minimum volumes of water to sustain riverine ecosystems, usually with the primary ecological objective to support a particular fish species (Postel and Richter 2003; Poff and Matthews 2013). From the early 1980s, there was increasing recognition of the importance of hydrological variability in sustaining ecosystem function and structure (Postel and Richter 2003). In the late 1980s to

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mid-1990s came recognition of the ecologically harmful impacts of hydrological alteration on water-dependent ecosystems, and the need to use e-flows to mitigate further damage (Poff *et al.* 1997; Postel and Richter 2003; Arthington 2012; Poff and Matthews 2013; Chen *et al.* 2019). In the late 1990s, this dynamic between hydrologic variability and ecosystem function was described by the Natural Flow Regime Paradigm, comprising five main components of flow, magnitude, frequency, duration, timing, and rate of change (Poff *et al.* 1997). The life-cycles of riverine flora and fauna were recognised as being adapted to a certain flow regime (Arthington 2012), hence altering this flow regime in turn alters the ecosystem (Poff and Matthews 2013). In turn, it was understood that riverine ecosystems could be restored by releasing e-flows that as much as possible mimicked the natural flow regime (Loehman and Charney 2011).

From the mid-1990s this emerging science was integrated into water management with increasing legislative recognition of ecosystems as legitimate water users (Arthington and Pusey 2003; Pahl-Wostl *et al.* 2013; Harwood *et al.* 2018). Legislation is vital to entrench the right of water-dependent ecosystems to receive water (Harwood *et al.* 2018). Before the SWIOID in 2002, there were few legal agreements or legislation that committed government agencies to the annual delivery of e-flow for the restoration of a degraded river. Although the first release of e-flows to the Colorado River, USA, was in 1996 (Patten *et al.* 2001), it was not until 2012 that there was any legally binding agreement to ensure an annual delivery (Summit 2013; Tarlock 2014).

Australian history of e-flows

In the 1980s in Australia, drought-induced ecological crises in the Murray–Darling Basin were catalysts for reform of water management (Connell and Grafton 2011). Flow regulation was acknowledged as a major cause of the deteriorating condition of many Australian water-dependent ecosystems (Arthington and Pusey 2003). Several legislative steps were taken to recognise water-dependent ecosystems as legitimate water users. This started with the Murray–Darling Basin Agreement (Commonwealth of Australia *et al.* 1992; Horne 2017), which aimed to ensure a reliable supply of water for both communities and the environment (Murray–Darling Basin Authority 2021*b*). This was followed by all tiers of government (Australian, State or Territory, and local) committing to a process of national water reform in 1994 (Arthington and Pusey 2003). Finally, in 1996, 12 National Principles for the Provision of Water for Ecosystems were established. This included the goal to put the environment on a similar footing as consumptive users who already had entitlement, by providing legally recognised water entitlements for the environment for the first time (Arthington and Pusey 2003).

Water entitlements in Australia are a licence to use a volume of water, that is variable, being determined proportionally by the overall availability of water in any 1 year (Murray–Darling Basin Authority 2021*a*). In 1999, the first rivers to be granted environmental entitlements were the Murray, Wimmera and Glenelg in the state of Victoria (Stafford 2008). However, there were no legal commitments by Australian or State governments to deliver e-flows to restore a riverine ecosystem until those for the Snowy River were codified in the 2002 SWIOID.

The SWIOID sets out, among other provisions, the process for obtaining, quantifying, and delivering e-flows to the Snowy River. It was agreed to by the Australian, New South Wales and Victorian governments.

Aims

To date, there has been no formal, systematic assessment of the effectiveness of the SWIOID in ensuring the delivery of e-flows to restore the Snowy River. This research seeks to discern lessons from SWIOID implementation to enhance future river restoration agreements. Three subsidiary questions were asked:

1. What were the main measures relating to e-flows for the Snowy River agreed to in the SWIOID?
2. Did the implementation of these measures honour the agreements embodied in the SWIOID?
3. Did key stakeholders have a common understanding and expectations of these measures?

Method

Case study of the SWIOID: context and background

The headwaters of the Snowy River are in the alpine region of New South Wales (NSW), Australia. Here, the Snowy Mountains Hydro-electric Scheme (the Scheme; Fig. 1) diverts the headwaters of the Snowy, Eucumbene and Murrumbidgee rivers westward to provide water for irrigators in the Murray and Murrumbidgee catchments (Vanderzee and Turner 2002), and to generate hydroelectricity (New South Wales Office of Water 2010).

The Scheme, which opened in 1972, reduced the flow in the Snowy River downstream of Jindabyne Dam to just 1% of mean annual natural flow (MANF) (Miller 2005). This led to the decline in the health of the Snowy River (New South Wales Office of Water 2010). In the 1990s, Australian and State governments proposed corporatising the government-owned Scheme so that its electricity could be traded on the National Electricity Market (Smith 2000; Young *et al.* 2004). This sparked a debate on how much water should be returned to the Snowy River for its restoration.

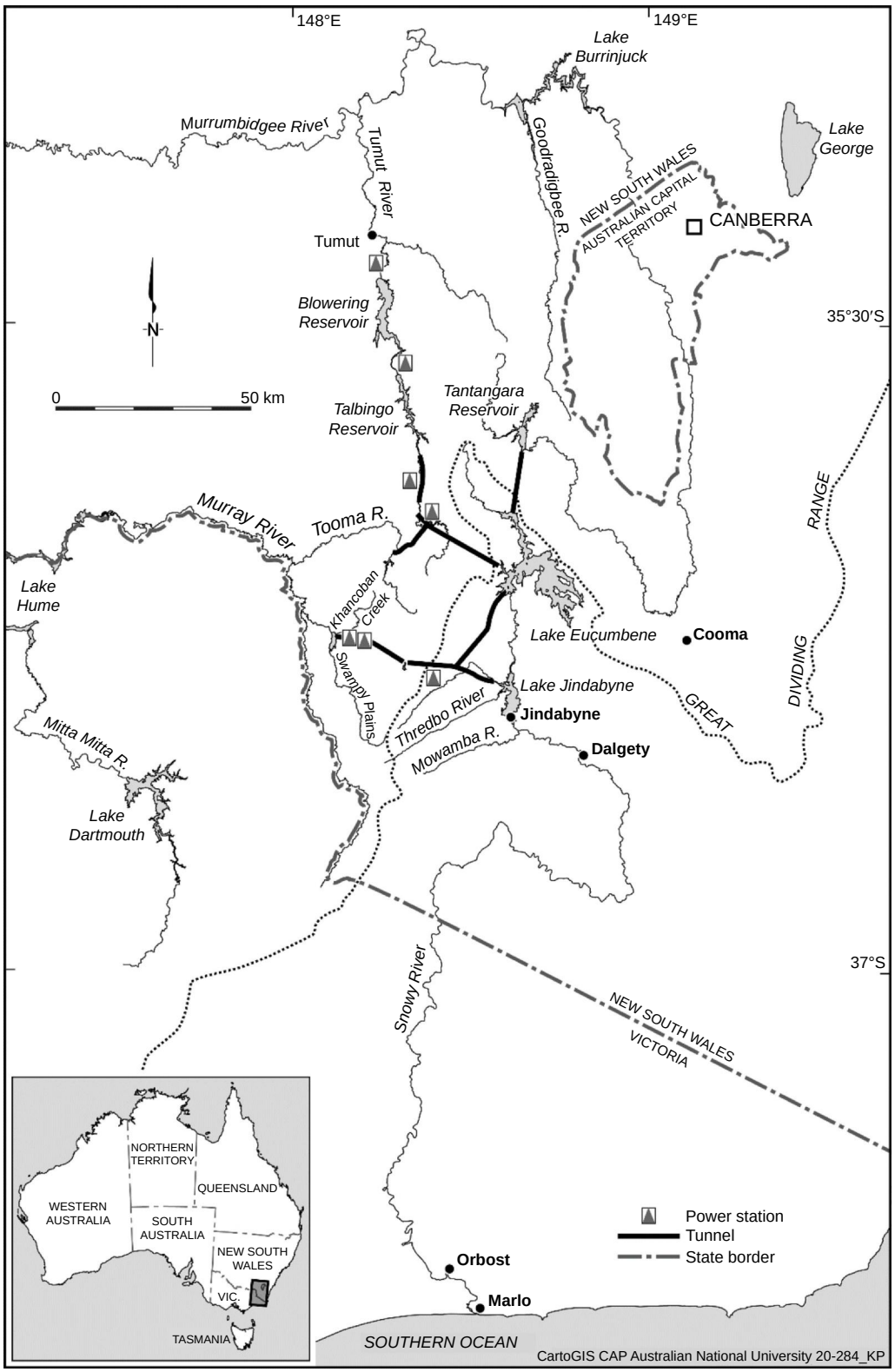

Fig. 1. Map of the Snowy Mountains Hydro-electric Scheme.

Recommendations as to the volume required varied. An expert panel (Snowy Genoa Catchment Management Committee 1996) recommended a volume equivalent to 28% MANF, whereas the Snowy Water Inquiry recommended volumes equivalent to 15% MANF (Smith 2000). The final decision, as set out in the SWIOID, lay between those, and

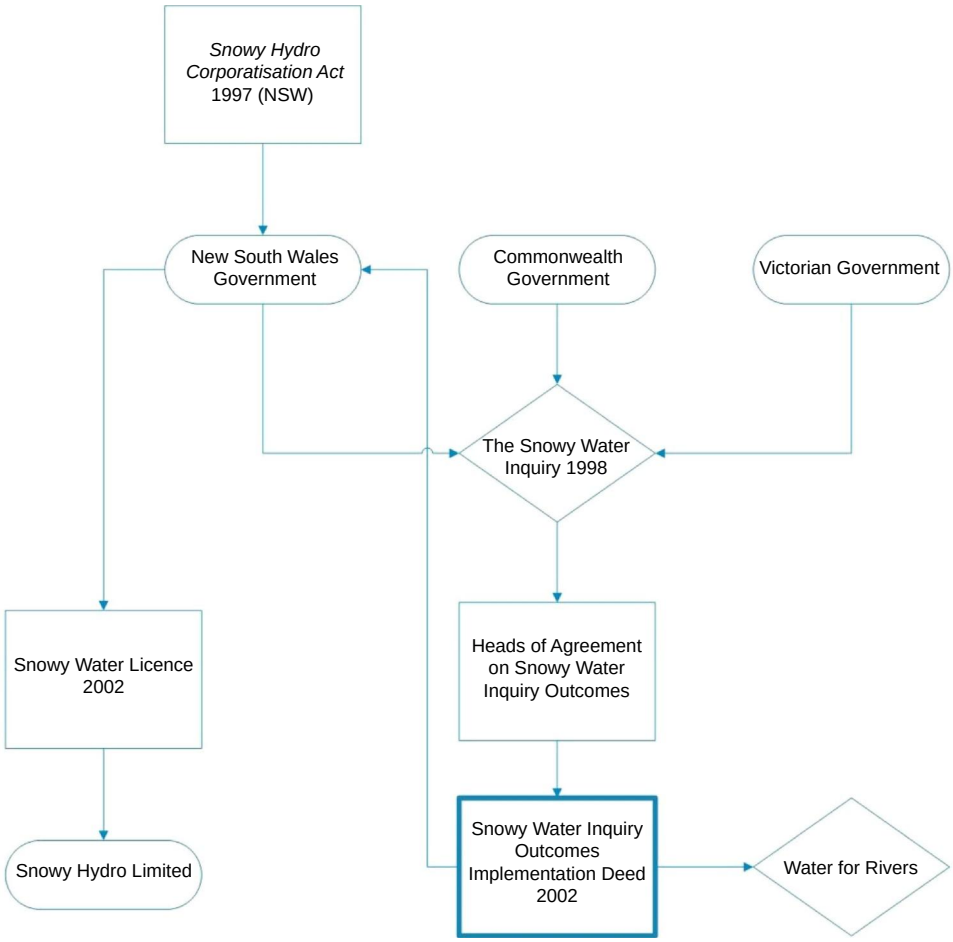

Fig. 2. Representation of legal and political framework to deliver environmental flows to the Snowy River. Modified from Vanderzee and Turner (2002).

presumably was influenced by political negotiations, primarily between the NSW and Victorian state governments (Vanderzee and Turner 2002; Miller 2005).

The SWIOID committed the Australian, NSW and Victorian state governments to deliver the equivalent of 15%, then 21%, and under limited circumstances 28% of the MANF (Young *et al.* 2004). This equated to an average annual volume of 142 gigalitres per year (GL year^{-1}), 212 GL year^{-1} and potentially 294 GL year^{-1}. In addition to the SWIOID, the State of New South Wales (2002) Snowy Water Licence is used by the NSW Government to place obligations on Snowy Hydro Limited to ensure the successful implementation of the SWIOID (Fig. 2).

Methodology

This study used triangulation of data from multiple sources to compare and look for corroboration, to provide a holistic understanding, and to improve the overall robustness of the research (Hay 2010; O'Leary 2017). Having multiple sources allows for the use of both quantitative and qualitative data (O'Leary 2017). Separate data sources were used to answer the three subsidiary questions.

For the first question on what was agreed, the SWIOID was scrutinised to determine the main environmental measures relevant to the Snowy River, and interpretation was confirmed by consulting government documents and parallel legislation like the NSW *Snowy Hydro Corporatisation Act* 1997 and the Snowy Water Licence.

For the second question on what was implemented, data on volumes of e-flows released since 2002 until 2020 were compiled – for the first time – from 15 different sources. The quantitative data was primarily sourced from Water Compliance Reports published by Snowy Hydro Limited; Water Savings Summary tables produced by NSW Government departments; reviews of the Snowy Water Licence and Snowy Scientific Committee reports. This information was collated in tables and compared to that agreed in the SWIOID. See Supplementary Tables S3–S7 for data on the calculation of e-flow volume to deliver to the Snowy River from 2002 to 2020. Additionally, e-flows to the Snowy River are contingent on allocations from acquired entitlements. To analyse if the allocations and e-flows released to the Snowy River were appropriate, the e-flows for the Snowy were compared to the average yields from entitlements in five zones of the Murray and Murrumbidgee systems. Yields from entitlements for each water year are

expressed as a percentage. To enable comparison between percentage yields and SWIOID targets, in the absence of more specific data on entitlement holdings, the average percentage yields were used to calculate a conservative potential GL allocation from each SWIOID target – 38, 142 and 212 GL.

For the third question on stakeholder expectations and understanding, semi-structured interviews were conducted with key stakeholders who had been involved in the lead up to, during or after the creation of the SWIOID. Three categories of key stakeholders were identified: members of the Snowy River Alliance, a community group promoting restoration of the Snowy River, former or current NSW Government officers, and scientists contributing to either the Snowy Water Inquiry or the Snowy Scientific Committee. The interviews were used to establish their expectations and understanding of what was agreed to, and to assess perception of implementation since 2002. Semi-structured interviews were used to prompt discussion and allow for flexibility as per Hay (2010) to elicit a range of opinions on this topic. The same set of questions was used for each participant (see Supplementary Table S1). From the transcripts, responses to each question were compiled and compared across interviewees for similarities and differences to establish themes in the responses.

The semi-structured interviews were conducted in accordance with Australian National University human research ethics approval requirements, under protocol number 2019/869. The snowball technique was used to identify potential interviewees who were then contacted by phone or by email, and the interviews were conducted by phone. Limited resources restricted the number of interviewees to eight: three from the Snowy River Alliance, three from relevant NSW Government departments, and two scientists.

Results

Measures for e-flows for the Snowy River

The SWIOID has six main measures for e-flows for the Snowy River: volume of e-flows; the process to obtain and calculate the volume per each year; delivery; environmental objectives to be achieved; monitoring and advice; and responsibility for implementation.

Volume of e-flows

E-flows for the Snowy River were to be delivered in a staged approach by progressively increasing allocated volumes of water (Commonwealth of Australia *et al.* 2002, Pt. 2 s.7 ss.1; Table 1). The flow targets were an average rather than a set annual volume to reflect water available each year (New South Wales Department of Water and Energy 2007; Snowy Hydro Limited 2007).

Process to obtain and calculate volume of e-flows

The SWIOID specified numerous steps to obtain and calculate volume of e-flows for the Snowy River (Fig. 3).

1. A program called Water for Rivers (Fig. 2) obtained water entitlements from the Murray–Darling Basin for the Snowy River (Commonwealth of Australia *et al.* 2002, Pt. 2 s.7 ss.1). These entitlements were created by investing in irrigation efficiency projects within New South Wales and Victoria along the rivers benefitting from interbasin transfers from the Scheme (New South Wales Department of Planning, Industry and Environment 2020*a*). E-flows from their 'additional water' or 'offset water' could then be released from the Scheme to the Snowy River without negative socio-economic impacts on irrigation communities (Vanderzee and Turner 2002).
2. The total volume of environmental entitlements was intended to improve the health of both the Snowy and the Murray rivers, and was allocated 2:1 between them. The Water for Rivers program only had funding to obtain 212 GL worth of entitlements for e-flows for the Snowy River (Vanderzee and Turner 2002). The volume of water required to increase e-flows from 212 to 294 GL was agreed to be funded through the public and private sector (Young *et al.* 2004), under a Capital Works Program (Commonwealth of Australia *et al.* 2002, Annexure 1

Table 1. Summary of staged delivery of Snowy River Increased Flows as per the Snowy Water Inquiry Outcomes Implementation Deed.

	Year	Snowy River Environmental Flows release location	Target average annual flow volume	Target volumes as a percentage of Mean Annual Natural Flow of the Snowy River
Stage 1	2003	Mowamba River and Cobbon Creek	Up to 38 GL year^{-1}	–
Stage 2	2003–2006	Mowamba River and Cobbon Creek	Up to 38 GL year^{-1}	–
	2006–2009	Jindabyne Dam	142 GL year^{-1}	15%
Stage 3	2009–2012	Jindabyne Dam	212 GL year^{-1}	21%
Stage 4	2012 onwards	Jindabyne Dam	212 GL up to 294 GL year^{-1}	21% up to 28%

Note: target average volumes to be delivered per water year beginning on 1 May to April the following year (Commonwealth of Australia *et al.* 2002, s.1 ss.1 (79)). MANF volumes in addition to base passing flow: 0.5 GL unregulated flows from Mowamba and Cobbon Creek over Mowamba Weir and 8.5 GL from Jindabyne Dam for a total of 9 GL (Commonwealth of Australia *et al.* 2002, s.1 ss.1 (6a)(59)). Target volumes as a percentage calculated from target annual flow volume and base passing flow.

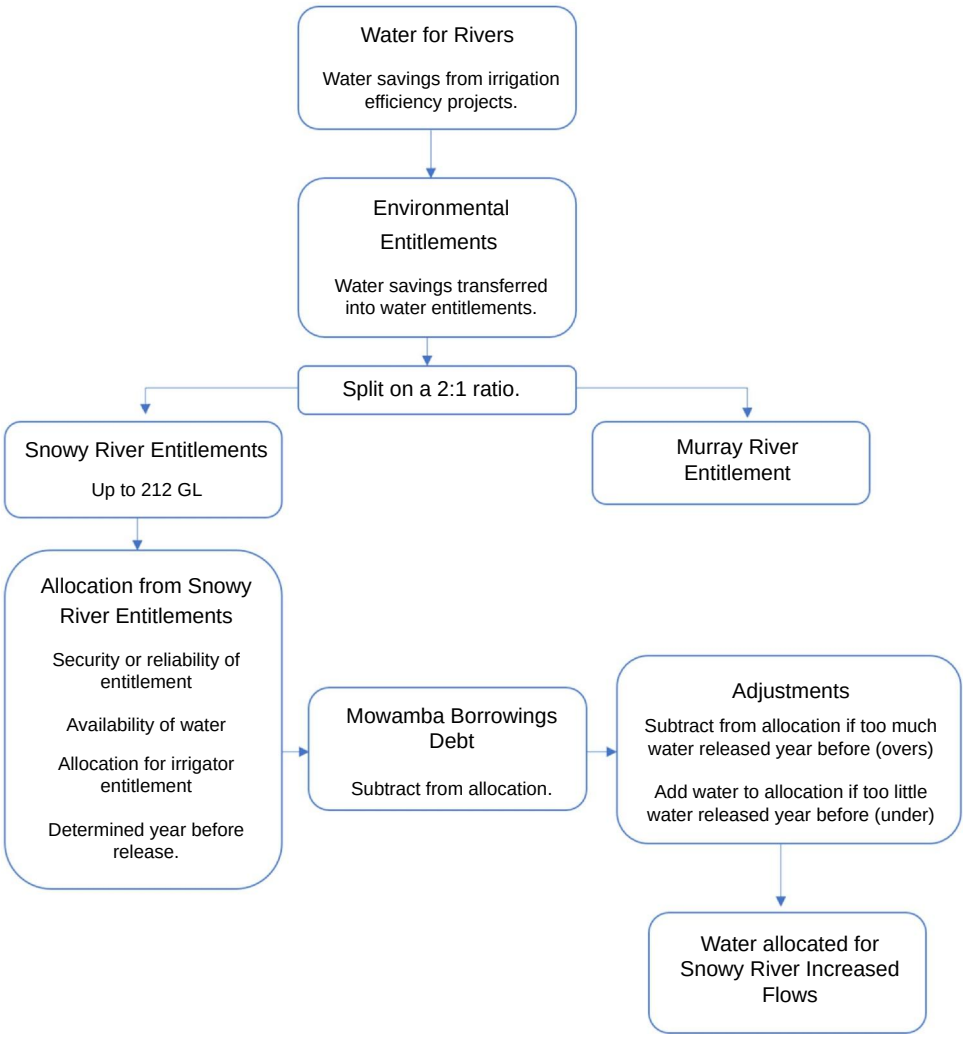

Fig. 3. Process for delivering environmental flows to the Snowy River.

Pt.1 s.5 ss.2 (2)). However, no trigger for doing this was set out in the SWIOID.

3. The Snowy River entitlements each receive an allocation determined partly by water availability in the irrigation area where the entitlement was obtained (New South Wales Department of Planning, Industry and Environment 2020*b*), and partly by the type of entitlement, known as security (NSW) or reliability (VIC). A high security or high reliability entitlement receives a higher allocation compared to general security or low reliability (Murray–Darling Basin Authority 2021*a*). The SWIOID stipulates that 142 GL worth of entitlements for the Snowy River (whether created or purchased) were to be high reliability or high security (Commonwealth of Australia *et al.* 2002, Pt.2 s.17 ss.3). Entitlements from 142 GL to 212 GL, the reliability or security was the status at the time of acquisition (Commonwealth of Australia *et al.* 2002, Pt.2 s.17 ss.2; New South Wales Office of Water 2010) and is often lower reliability.
4. Once water has been allocated for e-flows for the Snowy River, two adjustments occurred: the so-called 'Mowamba Borrow', and 'overs and unders'. First, the SWIOID established the concept of 'borrowed water' from the Mowamba Weir that diverts water from two downstream tributaries (Mowamba River and Cobbon Creek: Table 1) into Jindabyne Dam via an aqueduct. While Water for Rivers gathered entitlements, the Mowamba Weir was briefly decommissioned to allow unregulated flows directly into the Snowy River (Commonwealth of Australia *et al.* 2002, Annexure 1 Pt. 2 s.6 ss.1; Vanderzee and Turner 2002; New South Wales Department of Water and Energy 2007). The SWIOID stipulated that this was 'borrowed' water that would be 'repaid' (Commonwealth of Australia *et al.* 2002, Pt. 2 s. 24 ss.1; Snowy Hydro Limited 2007; New South Wales Department of Water and Energy 2009). Second, if more water was delivered than allocated for that year, this 'over' amount had to be subtracted from

the next year's allocation. Alternatively, if less water was delivered than allocated, this 'under' amount had to be added to next year's allocation.
5. The remaining water was to be released as e-flows to the Snowy River.

Further complicating this process, the allocation of water for e-flows to the Snowy River was determined by climate conditions in the year preceding the actual delivery of e-flows (Snowy Scientific Committee 2009). This was to ensure that the allocation of environmental water, that is primarily released in spring, was in the same proportion allocated to entitlements held by irrigators in the previous year.

Delivery of e-flows

The SWIOID stipulates that e-flows for the Snowy River were to be released from Jindabyne Dam (Commonwealth of Australia *et al.* 2002, Pt. 2 s.8 ss.2(4) and Pt.3 s.31 ss.1). In 2002, the dam did not have the infrastructure to do this (New South Wales Department of Water and Energy 2007), so a multi-level offtake was constructed on the dam (Commonwealth of Australia *et al.* 2002, Annexure 1 Pt.1 s.2 ss.1). This also allows water to be drawn from above and below the thermocline, and so ensure that releases are of adequate temperature (Commonwealth of Australia *et al.* 2002, Annexure 1 Pt1. s2 ss.2; Snowy Hydro Limited 2018). The requirement for an outlet to be built is an early, if not the first, example, of retrofitting a multi-level offtake to enable release of e-flows in Australia.

The release of e-flows was expected to mimic the natural seasonal pattern as far as possible (Commonwealth of Australia *et al.* 2002, Pt. 2 s.7 ss.2), however, this pattern was not formally defined. Additionally, sediment 'flushing flows', a daily release of 5 GL, were to be delivered if the allocation for Snowy River e-flows exceeded 100 GL (Commonwealth of Australia *et al.* 2002, Pt. 2 s.13).

Environmental objectives for e-flow delivery

The overall environmental objective was to improve the habitat for a diverse range of plant and animal species. To achieve this, there were five environmental objectives (Commonwealth of Australia *et al.* 2002, Annexure 1 Pt. 1 s.1 ss.1):

1. Improving the temperature regime of river water;
2. Achieving channel maintenance and flushing flows within rivers;
3. Restoring connectivity within rivers for migratory species and for dispersion;
4. Improving triggers for fish spawning; and
5. Improving the aesthetics of currently degraded riverine environments.

No quantified targets for these objectives or indicators of success were defined. The SWIOID had to cover a broad range of issues and because the complexity around staged increases in e-flows could only be communicated with high level objectives, specific objectives and hypotheses were to be defined post-2002 (B. Miners pers. comm. 24 April 2020).

Monitoring and advisory bodies

The SWIOID did not stipulate any monitoring bodies. It only defined an advisory body, the Water Consultation and Liaison Committee, which was responsible for advising Snowy Hydro Limited on preparing and implementing their Annual Operating Plan for releasing e-flows (Commonwealth of Australia *et al.* 2002, Introduction G. (3); New South Wales Department of Industry 2018).

However, the NSW *Snowy Hydro Corporatisation Act* 1997, number 99 (Fig. 2) required the establishment of the Snowy Scientific Committee to advise the NSW Government. The Snowy Scientific Committee's principal function was to advise on the timing and pattern for release of e-flows, and advise on the restoration of the Snowy River (NSW *Snowy Hydro Corporatisation Act* 1997, s. 57 ss. 3 (a)(b)). This committee was an independent body, not to be subject to control or direction of the Minister (NSW *Snowy Hydro Corporatisation Act* 1997, s. 57 ss. 7).

Further, the NSW Government undertook to assess and monitor the environmental changes through the Snowy Flow Response Monitoring and Modelling Program (New South Wales Office of Water 2010).

Responsibility for implementation or regulatory bodies

As the Scheme is situated in NSW, it was agreed that the NSW Government would oversee and be responsible for the implementation of the obligations in the SWIOID relating to delivery of e-flows (Vanderzee and Turner 2002). The NSW Government placed certain obligations on Snowy Hydro Limited in the Snowy Water Licence (Vanderzee and Turner 2002; New South Wales Department of Planning, Industry and Environment 2019). Although reviews are required for Snowy Hydro Limited's implementation of the Snowy Water Licence, there were no such provisions for review of the NSW Government's implementation of SWIOID (NSW *Snowy Hydro Corporatisation Act* 1997, s. 55 ss.5(2); New South Wales Department of Water and Energy 2007).

Implementation of measures

The implementation of the SWIOID was assessed by comparing the quantitative data on volumes of e-flows released between 2002 and 2020 to what was agreed in the SWIOID. Also assessed was how the e-flows were delivered, the environmental objectives achieved, the presence of monitoring, advice and regulation, and evidence of accountability.

E-flow volumes delivered

When the volumes of e-flows released are compared to the targets stipulated in the SWIOID (see Supplementary Table S3), it is evident (Fig. 4) that the target for each stage has not been reached in any 1 year.

From 2003 to 2009 (Supplementary Table S5), the greatest release was 40 GL in the water year 2005–2006, well below the SWIOID target of 142 GL year^{-1} for that period. Releases were low mainly because only 45 GL of environmental entitlements had been acquired for the Snowy River but also due to prevailing drought, and they were further reduced to repay the Mowamba Borrow. To address this, in 2010, there was an intergovernmental agreement to payout the outstanding Mowamba Borrow to increase e-flow volume delivered (New South Wales Department of Industry 2018).

From 2009 to 2012 (Supplementary Table S6) the greatest volume delivered was 150 GL in 2011–2012, below the SWIOID target of 212 GL year^{-1} for that period. E-flow releases were below the target as only ~145 GL of environmental entitlements had been acquired for the Snowy River. Additionally, allocations for irrigation entitlements were all below 100% for that period. For example, in 2009–2010 – a drought year – the allocation was 62 GL or 42.8% of the target.

From 2012 onwards (Supplementary Table S7), the greatest volume delivered was 207 GL in the 2017–2018 water year, below the SWIOID target of 212 GL year^{-1}. There were at least 238 GL of entitlements for the Snowy River by 2020–2021, indicating that the shortfall in delivery was because of low annual allocations. For example, in 2016–2017, when there was 238 GL of entitlements, only 125 GL or 52% of the target was released.

Yields

E-flows to the Snowy River are contingent on allocations from acquired entitlements. Comparison of average yield from entitlements in the Murray and Murrumbidgee system with annual e-flow volume released for the Snowy River (Fig. 5, Supplementary Table S8, S9) shows there is a shortfall in allocations to the Snowy River every year except 2017–2018 (displayed as 2016–2017 on Fig. 5) as compared to the average yields for the previous water year. As of 2015, there was at least 212 GL available in the Snowy River Apportioned Entitlement. Therefore, any shortfall before 2015–2016 can potentially be attributed to limited entitlements available for the Snowy River. Additionally, before 2010, allocations were reduced to repay the Mowamba Borrowings debt. However, from 2015, there is no publicly available explanation as to why in some years there is a significant shortfall in allocation to the Snowy River as compared to average yields.

Flow regime

In 2013, the Snowy Flow Response Monitoring and Modelling Program proposed adoption of a naturally scaled

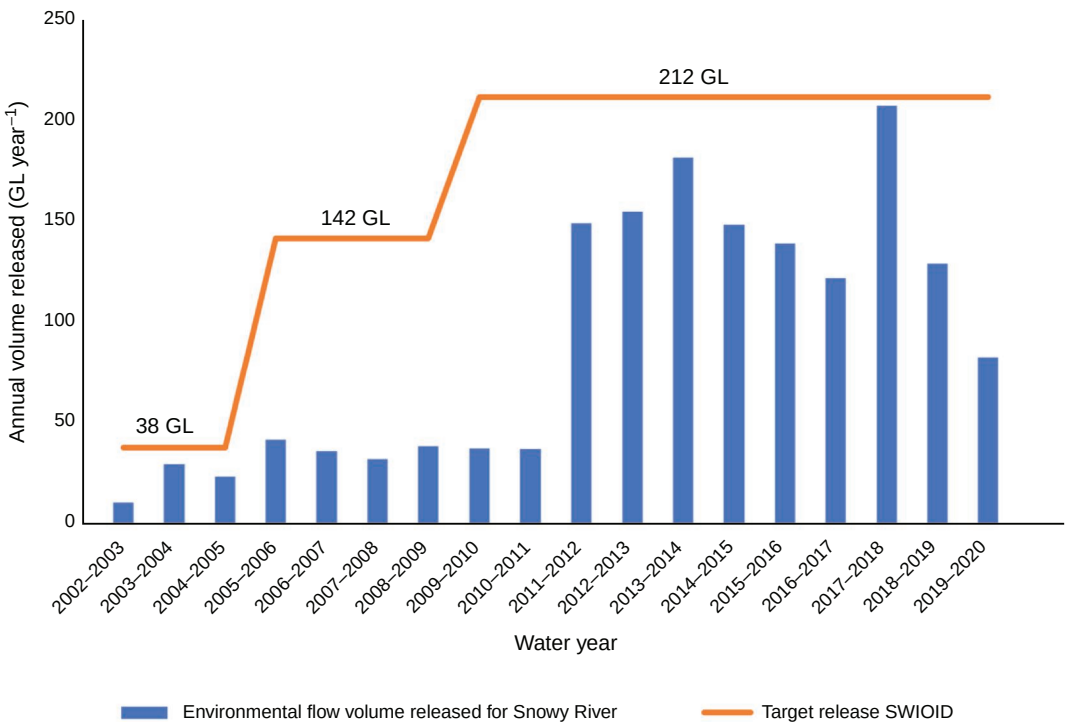

Fig. 4. Annual volume released for environmental flows to the Snowy River compared to targets in the Snowy Water Inquiry Outcomes Implementation Deed (summarised from Supplementary Tables S3–S7).

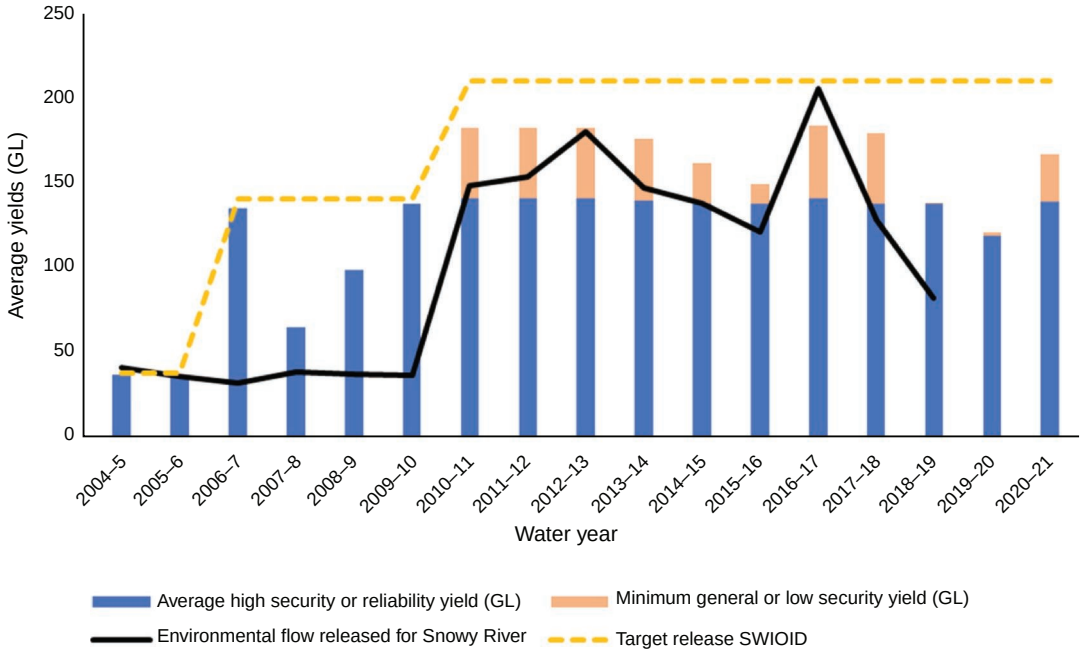

Fig. 5. Average yields from high security and general security entitlements in the Murray and Murrumbidgee systems compared to the annual volume released for environmental flows to the Snowy River and the targets in the Snowy Water Inquiry Outcomes Implementation Deed (summarised from Supplementary Table S8, S9). The Environmental flow released from the Snowy River is, or was, offset by 1 year as allocations are based on the yields from the previous water year. There are several assumptions in this figure. The Snowy Water Inquiry Outcomes Implementation Deed (SWIOID) indicates 142 GL is to be made up of high security entitlements, and the difference to 212 GL (70 GL) was to be the security at acquisition. This graph conservatively assumes the 70 GL difference are general security entitlements, in absence of data that indicates proportion of security of entitlements for the Snowy Apportioned Entitlement (New South Wales Department of Planning, Industry and Environment 2020*d*). The yield is the average of yields from five water entitlement zones on the Murray and Murrumbidgee systems, where the percentage yields may vary in each zone in each water year. This average of yields is indicative only in the absence of data on the actual entitlement holdings of each security category from each zone.

e-flow regime. This was to be achieved by delivering e-flows to the Snowy River that mimic the daily flow sequences of the unregulated Thredbo River, an alpine stream that flows into Jindabyne Dam (Reinfelds *et al.* 2013). The rationale for this decision was that similar volumes of water were available for both rivers (allocated water for the Snowy and naturally available for Thredbo), and the natural flow regime of both rivers is largely driven by snowmelt (New South Wales Department of Primary Industries 2013).

Environmental objectives

In 2010, the New South Wales Office of Water reported that four of the five environmental objectives could not be achieved with the available water (New South Wales Office of Water 2010). The fifth environmental objective, to improve aesthetics, was considered achieved with willow eradication and re-establishment of native riparian plants (New South Wales Office of Water 2010).

In 2016, the NSW Department of Primary Industries acknowledged that the environmental objectives stipulated in the SWIOID did not effectively define what was needed to recover the Snowy River to a desired state and did not reflect current scientific understanding of good practice for e-flow delivery (Williams 2016). Accordingly, the environmental objectives were revised and expanded to 12 objectives (see Supplementary Table S8, S9). However, it is not clear whether these revised objectives have been formally adopted by the NSW Government and there has been no reporting on progress towards their achievement.

Monitoring and advisory bodies

The Snowy Flow Response Monitoring and Modelling program has reported from 2011 on the long-term changes in various environmental variables such as river discharge, geomorphology, water quality, plants, macro-invertebrates and fish. This program has created hydrological, hydraulic and ecological models to inform decisions on e-flow releases and long-term objectives (New South Wales Department of Planning, Industry and Environment 2020*a*, 2020*c*). Additionally, several research papers have been published on various responses to e-flows (Morton *et al.* 2010; Brooks *et al.* 2011; Rohlfs *et al.* 2016; Rose *et al.* 2019).

Table 2. Summary of responses for each stakeholder category in the semi-structured interviews.

Sl. no.	Semi-structured questions	Alliance	Scientists	Government
1	At the time the SWIOID was made, from your point of view, were the measures for the Snowy River a satisfactory outcome?	No, for two of the three interviewees, mainly regarding flow volumes	No, regarding a lack of definition of what was wanted for the river	Yes, regarding the agreement being based on negotiations and trade-offs
2	Do you think that measures for e-flows for the Snowy River could have been improved in the SWIOID?	Yes, regarding issues associated with flow targets and Mowamba Weir	Yes, regarding issues with flow targets and environmental objectives	Yes, for two of the three interviewees, regarding environmental objectives and drought
3	Do you think the socio-economic outcomes could have been improved in the SWIOID or its implementation?	Yes, regarding perceived unequal trade-offs favouring irrigation and hydroelectricity	Yes, regarding lack of agreement between stakeholders and separation of scientific advice	No, for two of the three interviewees as negotiated agreements considered to be a good compromise
4	Do you think the implementation of the measures for the Snowy River have honoured the intent of the SWIOID?	No, flow volumes have not been delivered and due to issues associated with the Mowamba Weir and Snowy Scientific Committee	No, regarding drought affecting volume of flows delivered and issues associated with differing expectations	No, regarding drought affecting volume of flows delivered Yes, regarding environmental objectives achieved
5	If you were making a river restoration agreement again, what would you do differently?	Ensure more equal consideration of environmental concerns in negotiations	More clearly define and communicate what is expected to be achieved for the river	More adaptive mechanisms, ensuring need for review with climate change and consistent monitoring with consistent funding

SWIOID, Snowy Water Inquiry Outcomes Implementation Deed.

Crucially, from 2002 to present (2021), there has been a total of 12 years (of 19) without an independent advisory body. Although the NSW *Snowy Hydro Corporatisation Act* 1997 mandated the Snowy Scientific Committee in 1997, it was not established until 2008 (New South Wales Department of Primary Industries 2013). The Snowy Scientific Committee was abolished in 2013 (New South Wales Department of Industry 2018) as the NSW Government judged that its independence was misaligned and duplicated other government work, funding was discretionary and from a single source (NSW Government) and committee membership was inconsistent with other environmental water advisory committees in NSW (New South Wales Department of Primary Industries 2013).

Section 57 of the NSW *Snowy Hydro Corporatisation Act* 1997 was amended in 2014 to establish the Snowy Advisory Committee (SAC) (Le Feuvre 2017). Although it has a similar role as the original Snowy Scientific Committee, it has broader, mainly non-scientific representation and is subject to the control and direction of the Minister, except on the contents of its advice (NSW *Snowy Hydro Corporatisation Act* 1997, s. 57 ss. 7). The SAC was established in 2018 to provide advice from the water year 2019–2020 (New South Wales Department of Industry 2018).

Regulation and accountability

Snowy Hydro Limited has declared that their only responsibility is to release the e-flows and they are not responsible for meeting e-flow targets for the Snowy River (Snowy Hydro Limited 2007; New South Wales Department of Industry 2018). E-flow targets for the Snowy River are not detailed in the Snowy Water Licence. Consequently, the two completed reviews for the Snowy Water Licence (NSW *Snowy Hydro Corporatisation Act* 1997, s. 55 ss.5(2); New South Wales Department of Water and Energy 2007) did not assess the delivery of the e-flow targets or achievement of the environmental objectives.

Thus, implementation of the e-flows for the Snowy River relies on an annual water allocation determination by the NSW Government and there are no provisions to review the implementation of the SWIOID.

Stakeholder expectations and understanding

The results from semi-structured interviews with eight key stakeholders are summarised here (Table 2). The interviewees are numbered according to the category of stakeholder, namely Alliance interviewees, scientists and government. See Supplementary Table S10 for detailed summaries of responses to each interview question.

Question 1: were measures satisfactory?

Interviewees had conflicting responses to the question of whether measures for e-flows for the Snowy River were satisfactory, ranging from dissatisfactory to satisfactory but with common perspectives within each interviewee category.

Alliance interviewees ALL1 and ALL2 thought the agreement was unsatisfactory as they preferred e-flows of 294 GL year^{-1} over 212 GL year^{-1}. By contrast, all government interviewees indicated the SWIOID was satisfactory as the e-flow volumes were derived from negotiations and informed by good science to balance competing needs. Neither scientist specifically commented on whether the overall measures for the Snowy River were satisfactory. However, they both identified specific issues, such as the oversimplification of the environmental measures (discussed below).

Question 2: could measures be improved?

Answers centred on three themes – e-flow volume targets, objectives, and the role of science.

E-flow volume targets

There were a range of stakeholder views on the adequacy of two key environmental measures – flow targets and environmental objectives.

Responses around the volumetric targets demonstrated that there was no consensus on what e-flows are required to restore the Snowy River. All the Alliance interviewees thought 294 GL year^{-1} was the minimum for the Snowy River, rather than an aspirational target volume:

> [The 294 GL] figure came from … the best available science to identify by what was needed to restore the river … what was required to restore the river'. [ALL3]

By contrast, although GOV1 and GOV3 recognised that more environmental benefits can be achieved with 294 GL year^{-1}, there was no suggestion that the targets needed to be changed.

The scientists reiterated that more water is always better for any river restoration but indicated that how the water is delivered is almost as important as the volume.

Environmental objectives

There was limited consensus between interviewees on what the e-flows should achieve for the Snowy River, different opinions on the overall objective, and if these objectives could be achieved. For example, GOV2 indicated that channel maintenance was the primary objective and had been achieved in the first flushing flow. By contrast, ALL3 thought a minimum of 294 GL year^{-1} with natural snow melt was needed to achieve environmental objectives like channel maintenance to scour the riverbed.

This lack of congruence supports the view of scientist interviewees that the environmental objectives in the SWIOID did not clearly define what was desired:

> I guess it's about what people want from the river, and everybody wants different things from the river … we tend to, I think, skip over that step of trying to get to an agreement about what people want from the river and why; [SCI1]

> we were to do something for the river, we would actually start off by defining what we mean by the health, the healthy river. [SCI2]

Role of science in environmental measures

There was disagreement on the role science played in the determination of the environmental measures. All government interviewees indicated the flow volumes were informed by good science, whereas ALL1 suggested 212 GL year^{-1} was not a scientifically valid figure. Similarly, both scientist interviewees considered that the focus on e-flow volumes and environmental objectives in the SWIOID reflected a gap between scientifically and socially defined environmental outcomes. SCI1 elaborated by stating that the environmental considerations for the Snowy River were oversimplified to flow volume targets for use in political debates, and that these did not reflect the dynamic, complicated science of e-flows. Further, SCI2 thought the environmental objectives were more politically than scientifically defined, were too broad, and subsequently hard to implement and monitor:

> At the moment, these objectives are just high level … how do you achieve things like that?… Wishful thinking and politically you could give a big tick, environmentally very hard. [SCI2]

Question 3: socio-economic outcomes improved?

Responses related to the socio-economic outcomes did not focus on specific provisions within the SWIOID. Instead, opinions focussed on the trade-offs made in negotiations, as well as issues surrounding the Snowy Scientific Committee.

All interviewees agreed that the SWIOID agreements were based on trade-offs but they differed in their perceptions of the equity of these decisions.

The negotiations were perceived negatively by all Alliance interviewees who considered that the trade-offs favoured hydropower generation and irrigators, and were not adequately codified or enforced:

> there was nothing mandatory or binding within the SWIOID and that's what had the environmental objectives in it … pretty evident that … the New South Wales [government] had no intention at all of delivering any more water than they wanted to, and that was informed potentially by their major shareholding in Snowy Hydro. [ALL2]

By contrast, the negotiations were perceived positively by all government interviewees. They considered the volumes of water were a good compromise between environmental needs and other water users:

> All of the flow components (142 GL, 212 GL and 294 GL) reflect the complexity of balancing trade-offs, and based on good science, 212 [GL] may not be everyone's ideal result, but it is a reasonable compromise. [GOV3]

GOV3 indicated that because of the continual trade-offs being made with implementation, it was important to have an independent scientific body, like the Snowy Scientific Committee, so communities could be kept informed and aware of the trade-offs being made. GOV3 further noted that the gaps between advisory body operations did not help with transparency or communication with stakeholders. This was supported by ALL2 and ALL3, who reiterated their perception of unfair consideration of environmental interests due to the lack of publicly available information and limited Snowy Scientific Committee oversight.

Question 4: implementation honoured intent of SWIOID?

There were a range of views on the adequacy of implementation.

Generally, for the Alliance interviewees, the implementation of the environmental measures did not honour the intent of the SWIOID:

> We never got 21% (212 GL)… No, it was a complete breach of the legislation … you could drive a car through it… Well the river is still dying. That's the tragedy of it all. [ALL1]

By contrast, all government interviewees perceived an improvement in the health of the Snowy River and considered that implementation has honoured the intent of the SWIOID:

> I think everybody achieved a lot. It's a real story to be told about the benefits, the river is much, much better below Jindabyne now. [GOV1]

This incongruence in perceptions of what had been achieved was predicted by SCI1, who noted there would be issues with implementation due to differing expectations in the initial negotiations and insufficient articulation of what was to be achieved.

Finally, a common response among all the government interviewees and SCI2 is that the Millennium Drought reduced the water availability of entitlements, resulting in low allocations. Government interviewees commented:

> [When] recovery of water for the Snowy was designed the reliability of general security water was very high but the last 20 years it's probably been very low. The last 2 years it's been zero. [GOV2]

Question 5: lessons learnt?

In terms of lessons learnt from the Snowy measures (see Supplementary Table S15), responses varied by stakeholder category. Alliance interviewees recommended better codification of environmental targets, scientist interviewees recommended more rigorous scientific input into defining outcomes and expectations, and government interviewees recommended more adaptative mechanisms and review, especially in the context of climate change.

Discussion

The SWIOID can be considered a partial success considering the context in which it was created. When the SWIOID was being negotiated, there was limited science on delivery e-flows for restoration, in terms of the volume required, suitable flow regimes, or how to allocate or find suitable volumes of water (Poff and Matthews 2013). In turn, assessment of the likely impacts of climate change on future allocations and on e-flow delivery was beyond the available information for scientific input into the SWIOID (Supplementary Table S1). Additionally, negotiations for the Snowy River were a product of complex and protracted negotiations and trade-offs between governments over a wide range of issues related to Hydro Scheme, including energy markets, tax, and future water allocations for the MDB (Vanderzee and Turner 2002).

Despite these limitations, the SWIOID represents a first attempt of an intergovernmental agreement in Australia to restore e-flows to a major river system. In turn, the legal recognition that the Snowy River required e-flows for its restoration, the alteration of a hydropower dam to allow for these releases, and the legally binding agreement to commit the Australian governments to deliver e-flows, has allowed some water to return to the Snowy River (Arthington 2012; Pahl-Wostl *et al.* 2013; Harwood *et al.* 2018).

However, it is clear the target volumes of e-flow and environmental objectives have not been reached as intended, and there is minimal consensus among stakeholders as to the expectations and perceptions of the SWIOID (Table 3). Thus, the SWIOID and its implementation have several shortcomings. We acknowledge the criticism outlined here are with a degree of hindsight. However, there are lessons from the SWIOID that can enhance future river restoration agreements.

First, a major hindrance to successful implementation of the SWIOID has been the changing climate. The original provision for water recovery assumed higher yields from general security/low reliability entitlements than what eventuated (New South Wales Office of Water 2010). The acquisition of lower security entitlements beyond 142 GL (noting that we have not been able to access precise data on the security of the 142–212 GL entitlements) could reflect a

Table 3. Outcomes and perceptions of 20 years of environmental flows in the Snowy River.

	What was agreed to	What was implemented	Stakeholder expectations
Flow targets for e-flows and flow regime	Stage 1: up to 38 GL year^{-1}	Targets not delivered	Targets only partially delivered because of drought and low allocations from entitlements
	Stage 2: 142 GL year^{-1}	Stage 1: –	Targets not delivered as measures were not legally enforceable
	Stage 3: 212 GL year^{-1}	Stage 2: 40 GL year^{-1}	
	Stage 4: 212–294 GL year^{-1}	Stage 3: 150 GL year^{-1}	
	Mimic natural flow regime	Stage 4: 207 GL year^{-1}	
		Mimicking natural flow regime of Thredbo river	
Environmental objectives	1. Improving the temperature regime of river water	4/5 environmental objectives not achieved by 2010	Different expectations on what e-flows for the Snowy River were meant to achieve
	2. Achieving channel maintenance and flushing flows within rivers	Revised environmental objectives adopted from 2016	Different opinions on what e-flow volumes were required to achieve environmental objectives
	3. Restoring connectivity within rivers for migratory species and for dispersion	Limited assessment as to whether objectives have been achieved	
	4. Improving triggers for fish spawning		
	5. Improving the aesthetics of currently degraded riverine environments		
Independent advice, monitoring and reviews	Snowy Scientific Committee under Corporatisation Act to commence 2002	Commissioned in 2008–2009 water year (return e-flow)	Gaps in communication challenged the accountability and transparency of delivery
		Discontinued in 2013	Limited scientific input and communication of trade-offs being made in implementation
		Reinstated in 2017 as non-independent advisory body	

Note: summary of what was agreed to, what was implemented and stakeholder expectations of provisions within the Snowy Water Inquiry Outcomes Implementation Deed for the Snowy River. The associated hindrances and enablers of implementation are identified from the literature.

trade-off between security and cost in the context of a fixed budget for water acquisition and increasing cost of water. Low allocations of entitlements for the Snowy River were attributed to the Millennium Drought (1996–2010) (New South Wales Department of Industry 2018) and persistence of dry conditions in the Murray–Darling Basin region from 2016 to 2020 (Snowy Advisory Committee 2019). These long and intense dry periods are now perceived as part of changing climate. Climate change is diminishing inflows, and this will only intensify the impact on water allocations (Murray–Darling Basin Authority 2020). However, the SWIOID did not consider climate change. This is unsurprising as e-flow planning in and before 2002 was based on: (a) a stationary climate and (b) motivated by the desire to return a riverine ecosystem to a 'natural state' based on an historical baseline (Poff and Matthews 2013). Yet, a key factor to ensure effective implementation is monitoring and provisions for adaptive management to allow for incorporation of new scientific knowledge, and to learn from implementation (Arthington and Pusey 2003; Pahl-Wostl *et al.* 2013; Harwood *et al.* 2018). The lack of a trigger for the review of implementation of the SWIOID has significantly hindered effective implementation, especially in the context of a changing climate.

Second, for implementation to be effective, there needs to be processes to ensure agreements are being implemented transparently and implementers are accountable (Arthington 2012; Harwood *et al.* 2018). Whereas political will to implement effectively can wane over time (Harwood *et al.* 2018), well-crafted regulations can maintain accountability (Chen *et al.* 2019). Accountability requires continual and secure funding for scientific guidance (Arthington 2012; Pahl-Wostl *et al.* 2013; Harwood *et al.* 2018). The 12-year gap in independent advice diminished communication of information and transparency, and with no trigger to review the agreement, the effectiveness of SWIOID implementation is reduced. Additionally, despite the SWIOID being legally enforceable, current or future governments are able to

withdraw from the agreement (Vanderzee and Turner 2002). This limits the ability for one government to hold another legally accountable. In turn, the complexity of the institutional arrangements, absence of explicit performance indicators and lack of an overarching regulator has enabled the government signatories to the SWIOID to avoid accountability.

Finally, it is crucial to establish a shared vision among stakeholders and to convert this into realistic restoration objectives (Harwood *et al.* 2018). Conflict in water management is almost inevitable as ecological objectives enacted by government are based on value judgments of what is wanted and are contingent on how water is shared between other uses (Arthington and Pusey 2003; Pahl-Wostl *et al.* 2013; Rosenfeld and Ptolemy 2017). The Australian governments have publicly justified the e-flow volumes for the Snowy River as a reasonable trade-off between the needs of the environment, irrigation, and hydroelectricity (Young *et al.* 2004; New South Wales Department of Water and Energy 2007). However, they were not explicit as to how these trade-offs were made by drawing on science, nor the value judgements as to what environmental attributes were to be conserved. As demonstrated by the stakeholder interviews, opinions differed as to whether this trade-off was satisfactory. There was limited conflict resolution or consensus, reflected in the lack of a common vision and quantified indicators of success (Harwood *et al.* 2018). Crucially, if any stakeholder remains or becomes unsupportive of e-flow delivery, or there is limited conflict resolution, then implementation can fail (Pahl-Wostl *et al.* 2013; Harwood *et al.* 2018). Greater stakeholder engagement in these trade-off decisions may have reduced conflict and engendered greater ownership of the e-flows agreement.

Conclusions

20 years after the agreement to deliver e-flows to restore the Snowy River, there are lessons to be drawn from the limited effectiveness of its implementation that may inform conservation of other rivers. Delivery of e-flows to the Snowy River from 2002 to 2019 has not honoured the intent of the SWIOID that was agreed among the Australian, Victorian, New South Wales governments. The intended environmental flows to restore the Snowy River have only been partly delivered, and as of 2016, four of the five environmental objectives have not been achieved.

Thus, several lessons can be drawn from this situation that have global relevance and can be summarised as: (a) set clear, science-based environmental restoration objectives in a process where stakeholders are engaged in the trade-off decisions; (b) make roles and responsibilities for implementation clear; (c) establish institutions for independent and transparent monitoring, reporting of progress and regulation, and (d) provide for periodic review of the institutions to incorporate knowledge from implementation, and to adapt to climatic and other unanticipated changes.

Supplementary material

Supplementary material is available online.

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