

1 **A Systematic Scoping Review of the Collaborative Governance of Environmental and**
2 **Cultural Flows**

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15 **A Systematic Scoping Review of the Collaborative Governance of Environmental and**
16 **Cultural Flows**

17 **Abstract**

18 This study systematically reviews English-language papers about the collaborative
19 governance of environmental and cultural flows. With mixed-methods analyses, we illustrate that
20 the determination of environmental flow needs is common, with authors in 42 countries across
21 112 watersheds describing their management. In contrast, cultural flows (characterized by
22 attention to both ecological and non-ecological needs, decision-making authority of Indigenous
23 Nations, and Indigenous rights) were reported only in papers by authors in commonwealth,
24 colonial countries: Australia, Canada, and New Zealand. Evaluated against the Organisation for
25 Economic Co-operation and Development's (OECD) Water Governance Principles, we found
26 that the literature reported efforts that considered appropriate local and regional scales,
27 information and data, regulatory frameworks, and capacity building of communities and
28 authorities engaged in environmental and cultural flow initiatives. However, there was limited
29 consideration of the roles of communities in policymaking, which was more common in
30 jurisdictions with decentralized governance. In jurisdictions with democratic community-based
31 initiatives, environmental and cultural flows have not been approached in merely technical
32 processes to communicate hydro-social-ecological information to decision-makers. Instead, the
33 initiatives have created the context for evaluating new developments at the watershed level in
34 light of communities' social and ecological water goals, collaborating during unique drought and
35 flooding conditions, working to rebalance power in decision-making through water justice,
36 creating ecological and Indigenous reserved water rights, granting legal personhood for rivers,
37 and protecting water for the environment and dependent people in water markets. Going forward,
38 we identify a need for greater attention to community roles in environmental and cultural flows
39 protection in water governance including policy creation and evaluation, regulatory initiatives,
40 strategic planning, and impact assessments.

41

42 Introduction

43 In this paper, we discuss the collaborative governance of environmental, environmental-
44 social, and cultural flows (Table 1). Environmental flows have been defined in the Brisbane
45 Declaration (2007, p. 1) as “The quantity, timing, and quality of water flows required to sustain
46 freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on
47 these ecosystems.” The concept of environmental water is similar to environmental flows in that
48 environmental water is the amount of water protected for the environment, whereas
49 environmental flows refers to the delivery of that environmental water spatially and over time
50 (Horne et al. 2017e). Recent changes to the definition of environmental flows have included
51 more attention to social values and human systems (environmental-social flows). In the 2018
52 update to the Brisbane Declaration, environmental flows were defined as “The quantity, timing,
53 and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn,
54 support human cultures, economies, sustainable livelihoods, and well-being” (Arthington et al.
55 2018, p. 4). This update has been reflected in recent work by scholars who identify a need to
56 incorporate hydro-social-ecological information and diverse ways of knowing into basin
57 management for surface and groundwater (Anderson et al. 2019; Douglas et al. 2019). In
58 contrast, the concept of cultural flows has emerged as a response to the exclusion of Indigenous
59 Peoples and rights in environmental flow assessments and has been described by Australian
60 Indigenous Nations through the Echuca Declaration (2007, p. 2) as “...water entitlements that
61 are legally and beneficially owned by the Indigenous Nations of a sufficient and adequate
62 quantity and quality to improve the spiritual, cultural, environmental, social and economic
63 conditions of those Indigenous Nations.” This definition includes both ecological and non-
64 ecological needs, decision-making authority of Indigenous Nations, and Indigenous rights
65 (Leonard et al. 2023; O’Donnell and Macpherson 2023). Together, these concepts reflect a
66 movement towards the protection of water for the environment, people, and rights in water
67 management.

68 The Brisbane Declaration and Global Action Agenda, established in 2007 and updated in
69 2018, made a recommendation to “integrate environmental flow management into every aspect
70 of land and water management” (International River Foundation, 2007, p. 3). However, six years
71 after the Brisbane Declaration, Pahl-Wostl et al. (2013) found limited evidence of the integration
72 of environmental flows principles in water management and governance and no evidence that
73 this recommendation had been taken up in most countries. More recently, scholars have called
74 for greater attention to how environmental flows are characterized in basin planning and
75 governance and how we value water for sustainable development (Garrick et al. 2017; Horne et
76 al. 2017c; King and Brown 2018). Historically, environmental flows studies have focused on
77 new methodologies and approaches (Tharme 2003; Linnansaari et al. 2013; Poff and Matthews
78 2013), rather than governance change or policy implementation (Opperman et al. 2018;
79 Wineland et al. 2022). Attention to cultural flows has generally occurred as a response to the
80 shortcomings in environmental flows approaches that omit tangible and intangible social and
81 cultural values, Indigenous rights, and linkages to wider Indigenous decision-making (Finn and
82 Jackson 2011; Moggridge and Thompson 2021; Woods et al. 2022; Arthington et al. 2023).
83 There is a need then to understand whether and how environmental and cultural flows have been
84 considered in different types of water governance contexts to help with the implementation and
85 application of sustainable watershed governance, especially in countries or regions with
86 inequitable distribution of water resources and water decision-making authority.

87 In this review, governance refers to “the set of regulatory processes, mechanisms and
88 organizations through which political actors influence environmental actions and outcomes”
89 (Lemos and Agrawal 2006, p. 298). Governance is about how decisions are made, who is
90 accountable for those decisions, and how the decisions are operationalized (Gupta et al. 2013).
91 Decision-making occurs through both formal (legislation, policies, and guidelines) and informal
92 (behaviours, norms, and relationships) mechanisms to structure how people relate and interact
93 across scales (Cortner et al. 1998). Generally, types of governance include state-based (control
94 by country), community-based (control by community), market-based (market or private
95 mechanisms) or hybrid forms, such as public-private (facilitation between state and private
96 sector), co-governance (shared authority and collaborative decision-making between two
97 sovereign political systems), and polycentric governance (multiple semi-autonomous decision-
98 making centres) (Bourceret et al. 2021). Note that inclusive decision-making with non-
99 Indigenous communities in the same political system is different from power sharing with
100 Indigenous Nations that have their own sovereign political system (Table 1). Good
101 environmental and water governance is “characterized by polycentric institutions, legitimacy and
102 transparency, empowerment and social justice, diversity of participating actors, and where
103 multilevel institutions are matched with social-ecological dynamics” (Plummer, Armitage and
104 De Loë 2013, p. 20). There has been a shift in environmental institutional arrangements from an
105 emphasis on government to governance, reflecting the need to decentralize decision-making and
106 provide equitable opportunities for collaborations linking local-level grassroots communities,
107 private authorities, markets, and regional government-level managers (Armitage et al. 2012).
108 Structuring governance in this way, with nested scales of decision-making, can be a way to
109 match and manage according to the social-ecological complexity of systems (Epstein et al.
110 2015). However, finding leverage points and transformative pathways to democratize water
111 governance, while effectively supporting communities in understanding complex connections
112 between scales, is difficult (Meadows 1999; Gupta et al. 2013; Sultana 2018). Water governance
113 that recognizes environmental and cultural flows is a way to address these challenges.

114 Achieving sustainability and equity in water governance requires greater attention to
115 involvement of communities in management across spatial, temporal, and institutional scales
116 (Vörösmarty et al. 2015; Sultana 2018). The updated Brisbane Declaration (2018, p.12) states,
117 “The full and equal participation of all cultures, and respect for their rights, responsibilities, and
118 systems of governance in environmental flow decisions can strengthen sustainable outcomes for
119 cultures, economies, livelihoods, and well-being.” Partnering with communities, Indigenous and
120 non-Indigenous, or building local autonomy and shared governance in water decision-making
121 has proven to be difficult because of limited attention by governments to Indigenous water rights
122 and the rights of Indigenous entities to self-govern water management, and to give or withhold
123 free, prior, and informed consent (UN General Assembly 2007; Harmsworth et al. 2016; Robison
124 et al. 2018). Greater uptake of approaches centred on environmental and cultural flows may
125 create more opportunities to democratize water governance. This could occur through a greater
126 understanding of institutional and actor roles and responsibilities in protecting environmental and
127 cultural water (Nowlan 2012; Jackson et al. 2015; Phare et al. 2017; Woods et al. 2022).

128
129 Community participation and leadership in environmental and cultural flow initiatives
130 has occurred on a wide spectrum, and in the last decade, there has been a recognition that these
131 processes engender a shared understanding of water systems, which can drive opportunity for
132 innovative and collaborative water management at local and regional scales if there is fairness,

133 legitimacy, and trust in environmental water allocation (Conallin et al. 2017; Godden and Ison
134 2019; Mussehl et al. 2022; Kosovac et al. 2023). To evaluate this opportunity and identify gaps
135 and opportunities in the governance of environmental and cultural flows internationally, we
136 present a systematic literature review of recent peer-reviewed journal articles and book chapters.
137 This review seeks to uncover how environmental and cultural flows concepts have been
138 investigated and adopted in different watershed governance contexts to support community
139 involvement in decision-making. Our research questions include investigating where the
140 collaborative governance of environmental and cultural water is occurring, how this governance
141 is characterised (centralized and decentralized), what methods are employed, how OECD
142 Principles are taken up, and through which governance strategies are environmental and cultural
143 water protected. We also identify gaps and directions for further scholarly research and improved
144 governance.

145 **Approach**

146 The authors conducting this review wished to investigate the global environmental flows
147 and cultural flows context to inform water governance in Canada. We are scholars from a
148 number of Canadian universities working in the areas of environmental and cultural flows,
149 Indigenous water justice, water governance, and sustainability assessment. In Canada, there has
150 been an identified need to democratize water governance, including regulatory frameworks,
151 policies, and management, through greater community involvement in environmental flow
152 decision-making and the recognition of cultural flows (Nowlan 2012; Curran 2019). This review
153 acts on an opportunity to describe countries' strategies to democratize water governance through
154 flow management processes and inform the Canadian context.

155
156 We employed a systematic scoping review method to investigate international peer-
157 reviewed literature related to the adoption of environmental and cultural flows in different
158 governance contexts. While systematic literature reviews are used to assess the effect of
159 interventions and outcomes within well-defined bodies of literature (Petticrew and Roberts
160 2006), systematic scoping reviews are used to understand and characterize emergent bodies of
161 literature and different approaches and methodologies taken to achieve those actions and goals
162 (Peters et al. 2015; Mueller et al. 2018). Pahl-Wostl et al. (2013) identified a decade ago that
163 environmental flows are rarely related to water governance but should be. Therefore, the
164 intention was to determine how environmental and cultural flows have been addressed in
165 collaborative water governance contexts and characterized from 2010 to 2024. Pahl-Wostl et al.
166 (2013) published a similar review in 2013, so we hoped to examine the literature a decade later
167 and included papers from 2010-2013 in case the previous review omitted these papers due to a
168 lag in time from paper composition to publication. Our approach applied methods similar to
169 those used for systematic reviews in the field of social-ecological systems change (Alexander et
170 al. 2019, 2021; Andrews et al. 2021; Eger et al. 2021) and in recent environmental flows reviews
171 (Owusu et al. 2021).

172 Our systematic review process followed the Preferred Reporting Items for Systematic
173 Reviews and Meta-Analyses (PRISMA) guidelines and consisted of four steps (Moher et al.
174 2015): 1) research questions development, 2) search protocol, 3) inclusion and exclusion through

175 a screening process, 4) mixed-method data collection and analysis of the sample of literature to
176 investigate research questions.

177 ***Research Question Development***

178 Our research question was developed following the PCC (Population, Concept, Context)
179 and PICO (Population, Intervention, Comparison, Outcomes) frameworks (Methley et al. 2014;
180 Peters et al. 2020). Our population was human communities and the ecosystems they depend on
181 within watersheds. Our concept was to discuss the implementation of environmental flows and
182 cultural flows policies, plans, and projects. Our context and outcomes were related to water
183 governance arrangements and potential shifts in governance, and we compared cases from six
184 continents (Asia, Africa, North America, South America, Europe, Oceania) focusing only on
185 those papers written in English, reflecting our own limited capacity.

186 ***Search and Screening Strategy***

187 Our search strategy included terms for environmental and cultural flows, governance, and
188 communities (Table 2). We used the terms environmental and cultural flows to highlight
189 ecological and social initiatives and collaborative approaches. Literature searches were trialed,
190 completed, and iterated between August and October 2022 and updated in 2024, following
191 strategies from an evidence synthesis workshop. Our search strategy included abstracts, titles,
192 and keywords in SCOPUS and Web of Science, ProQuest (all parts of the document [titles,
193 abstract, key words] except full text), and Informit. We chose these search engines because of
194 their breadth and scope (social and natural sciences), as well as the ability to access journal
195 articles, book chapters, and theses. While SCOPUS and Web of Science are more natural science
196 focused, ProQuest includes many social science (PAIS International, ABI/INFORM,
197 International Bibliography of the Social Sciences) and governance (Worldwide Political Science
198 Abstracts) repositories and Informit is an Australian-based and global search engine that covers
199 social science, legal, Indigenous, and governance scholarship. We investigated other search
200 engines, but these were ultimately excluded because of either few or zero results (JSTOR,
201 Indigenous Knowledge Portal, Oxford Handbooks Online) or no ability to search exclusively for
202 abstracts, titles, and keywords (Google Scholar, Heinonline). Citation tracing was completed to
203 include papers that were missed in the main search, but these papers were included as supportive
204 material rather than part of the main data set, figures, and analysis.

205 Two levels of screening were completed in an online review tool (covidence.org) based
206 on predetermined exclusion criteria (Veritas Health Innovation, 2023; see Supplementary Figure
207 1 for PRISMA details). The first level included sifting through titles and abstracts and
208 eliminating documents that were duplicated, published before 2010, not peer-reviewed, in a
209 language other than English and, most importantly, did not explicitly link flows concepts to
210 watershed decision making based on criteria in Table 3. A second level of screening was
211 completed with a second screener (Mark Saunders) on full texts, but with a more meticulous
212 focus on whether decision-making and flows concepts were linked and part of the research
213 question and design. Studies were eliminated if they focused on hydrological, hydraulic, hydro-
214 ecological, and habitat endpoints, or sometimes social, economic, and cultural ones, but did not

215 relate this information to watershed decision making or if watershed decision making was only
216 briefly mentioned in the implications (Table 3). Similarly, we excluded papers that did not
217 actively include community level interests in environmental and cultural flow determinations and
218 management.

219 The search returned 4571 studies from SCOPUS ($n = 1935$), Web of Science ($n = 1248$),
220 ProQuest ($n = 1346$), and Informit ($n = 42$) combined; 1403 duplicates were removed, and 2750
221 papers were deemed irrelevant after the title and abstract screening phase. We then assessed 418
222 full-text studies for eligibility based on exclusion criteria (Table 3) and included 158 after careful
223 reading and application of exclusion criteria, and consultation between two screeners (See
224 PRISMA diagram in Appendices). Our inter-rater reliability scores for a subset of full text
225 screening were 0.82 for proportionate agreement and 0.61 Cohen's Kappa. Agreement scores are
226 somewhat subjective "since there is no consensus as to which scores indicate 'adequate'
227 agreement, and the concept of 'adequate' agreement is itself subjective" (Pullin et al. 2018,
228 section 6.3.4). However, these metrics can be useful tools to measure agreement between
229 screeners (Altman 1991), and other studies have reported that an agreement level of 80% and
230 greater suggests that the results from the review are replicable (Filoso et al. 2017; Owusu et al.
231 2021).

232 *Mixed Methods Data Collection and Analysis*

233 We employed a mixed-methods approach (both qualitative and quantitative coding) to
234 determine how flows concepts have been related to decision-making structures. A codebook (see
235 supplementary information) was created in advance partially through an Evidence Synthesis
236 Workshop and data from papers were collected in spreadsheets through ordered sections,
237 including categorical information (e.g., date, author, location, watershed, social and ecological
238 components, types of flows approaches, development type, community composition and
239 involvement, and governance setting) and open codes with text (application of environmental
240 and cultural flows, community involvement, governance context, relationship between flow
241 concepts and governance). Inclusion of these concepts was inspired by gaps identified by Pahl-
242 Wostl et al. (2013).

243
244 All analyses were then completed on spreadsheets, which included quotes through
245 thematic analysis and categorical variables through comparisons by country and governance
246 type. Qualitative analysis was both inductive and deductive in that new ideas and theories
247 emerged from coding, but previous governance and community-based typologies were also
248 reflected upon and served as points of inspiration (Agrawal and Gibson 1999; Lynam et al. 2007;
249 Margerum 2008; Medema et al. 2008; Gruber 2010). Papers were grouped under environmental
250 flows if there was generally a focus on ecological considerations, environmental-social flows if
251 both ecological and social needs were included, and cultural flows if the focus was on cultural
252 and ecological concerns, Indigenous rights-based needs, and the decision-making authority of
253 Indigenous communities (Table 1).

254
255 As a basis for evaluating the identified papers, we adopted the Organisation for Economic
256 Co-operation and Development's (OECD) Principles on Water Governance in environmental and
257 cultural flows governance literature (OECD 2015, 2022). These Principles are 12 internationally

258 peer-reviewed, agreed upon, and endorsed (170+ stakeholder groups or governments) criteria for
259 governments to follow for inclusive, effective, and efficient water policy design and governance
260 processes (OECD 2015, 2022). However, we note that there are ongoing conversations about
261 reforming the OECD Principles to include greater attention to the United Nations Declaration on
262 the Rights of Indigenous Peoples and water justice frameworks (Taylor et al. 2019). O'Donnell
263 and Garrick (2017a) identified criteria for environmental water governance, inspired, in part, by
264 the OECD Water Governance Principles. We chose the OECD Principles because they are
265 reasonably comprehensive of water governance matters, are internationally agreed upon, and
266 have clear indicators and criteria. However, future research and synthesis could build on similar
267 criteria identified by O'Donnell and Garrick (2017a): effectiveness, efficiency, legitimacy, legal
268 and administrative framework, organizational capacity, and partnership. From our understanding,
269 the OECD Principles as a package are rarely considered in environmental and cultural water
270 governance. We expect this is due to their recent creation and we identify a need for greater
271 consideration of these Principles. For this analysis, we manually coded text from previously
272 coded governance quotes. Note that we did not code text for the engagement OECD Principles
273 and instead identified that this was part of every paper because of our search criteria. Few papers
274 explicitly included reference to the OECD Principles on Water Governance; rather, these
275 Principles were employed as a guiding framework to code governance-related text and the papers
276 may understate actual adoption and application. We visualized the frequency and relationship of
277 OECD Principles with co-occurrence network diagrams with the R package *quanteda* (version
278 3.3.1) (Benoit et al. 2018; Schweinberger 2021).

279
280 Inductive codes were created for actions or strategies related to environmental and
281 cultural flows by going line by line through previously created text in codes related to
282 governance and the relationships between flows concepts and governance. Qualitative analysis
283 was completed in NVivo software (QSR International Pty Ltd. 2020), whereas quantitative
284 analysis was completed in R (R Core Team 2022). Quantitative analysis generally involved
285 frequency calculations but also binary logistic principal components analysis through the logistic
286 PCA package (Landgraf and Lee 2020) to correlate the presence or absence of OECD Principles
287 and strategies to govern environmental and cultural flows.

288 ***Limitations***

289 Our literature review imposed boundaries that entailed study limitations. Our search
290 strategy was based on communities' involvement in environmental and cultural flows to achieve
291 water governance outcomes; therefore, our searches may have excluded papers that included
292 more legal or market mechanisms because there was no overt involvement of a community or
293 communities. The main reason we focused on communities was that we anticipated the
294 community involvement criterion would help to identify papers that had attention to
295 environmental and cultural flows in decentralized governance. We also excluded search engines
296 like Google Scholar and Heinonline because those platforms are searched through full texts
297 rather than only by keywords, abstracts, and titles. This was inconsistent with our approach. Our
298 focus was also on the academic literature rather than grey literature or initiatives by
299 governmental (Indigenous and non-Indigenous) and non-governmental organizations that are not
300 reported in published works. We have omitted certain key cases across the world because of
301 these restrictions. However, we believe other papers, such as the World Wildlife Federation's

302 global review (2017), have filled this gap. We have also done citation tracing to include papers
 303 as supporting material that may have been missed in our search. Lastly, our search was in
 304 English because that is the primary language of the authors. We acknowledge that this likely
 305 excluded environmental and cultural flows processes in non-English speaking parts of the world
 306 including parts of the Global South.

307 **Findings**

308 ***Countries that Emphasized the Collaborative Governance of Environmental and Cultural*** 309 ***Flows***

310 We found 42 countries and 112 watersheds featured in published English-language
 311 academic literature between 2010 and 2024 about the collaborative governance and/or
 312 management of environmental and cultural flows (Figure 1). Environmental flow initiatives have
 313 been adopted by governance structures and investigated in relation to governance regimes in
 314 many countries in the Global North and South, especially Australia (e.g., Murray-Darling,
 315 Ringarooma catchments), the United States (e.g., Colorado, Columbia basins), and China
 316 (Mekong, Yangtze rivers) (Figure 1A). Consideration of cultural flow initiatives in governance
 317 with authoritative participation by Indigenous communities was only identified in
 318 commonwealth, colonial countries: Australia (e.g., Murray-Darling, Coorong), New Zealand
 319 (e.g., Kakaunui, Waikouaiti), and Canada (e.g., Okanagan, Cowichan) (Figure 1B). However,
 320 authors used the expression cultural flows or similar concepts (Aboriginal extreme flows,
 321 Indigenous reserved water rights, Indigenous water trusts, Indigenous rights, Indigenous water
 322 allocation frameworks) in watersheds where authors argued there is not yet clear decision-
 323 making authority by communities, such as, for example, communities along the Ganges in India
 324 (Lokgariwar et al. 2014), Australia's Northern Territory (Mclean 2014; O'Neill et al. 2016;
 325 O'Donnell et al. 2022), Canada's Athabasca River (Anderson et al. 2019; Marcotte et al. 2020),
 326 Chile (MacPherson and Salazar 2020), New Zealand (Taylor et al. 2020), the United States'
 327 Colorado River (Butler et al. 2021) and Waihe'e, Waiehu, Waikapū, and Wailuku in Hawaii
 328 (Cantor et al. 2020). Academic papers also described attention to environmental flows with
 329 social values (environmental-social flows) in Angola, Australia, Botswana, Benin, Canada,
 330 Chile, India, Kenya, Mexico, Namibia, New Zealand, South Africa, and the United States
 331 (Figure 1C). Heavily featured watersheds included the Murray-Darling, Edward-Wakool,
 332 Fitzroy, Macquarie, and Ringarooma (Australia); Peace-Athabasca (Canada); Lancang/Mekong
 333 and Yangtze (China); Ganga (India); Aosta (Italy); Patuca (Honduras); Rio Grande (Mexico,
 334 United States); Ebro (Spain); Pangani (Tanzania); and Colorado (United States); among others.

335 ***Countries' Watershed Governance***

336 Watershed governance structures that consider environmental flows were generally
 337 centralized and top-down, but there were multi-national agreements and implemented
 338 decentralized governance (polycentric, co-governance) in some watersheds. Cultural flows
 339 initiatives only occurred in decentralized governance contexts. There were also identified
 340 opportunities for decentralization and governance reform in countries with mainly centralized

341 water governance, such as Canada, Chile, Greece, Mexico, South Africa, and the United States
342 (Figure 2).

343 Centralized watershed governance was present to some degree in all countries, except
344 Kenya's water user association system in the Mara basin (Richards and Syallow 2018). Countries
345 that were more centralized with some involvement of communities in environmental flow
346 assessments included Benin, Cambodia, China, Ethiopia, France, Iran, Mali, Nepal, Norway,
347 Papua New Guinea, and Uzbekistan, among others (Figure 2). Here, more active involvement of
348 stakeholders generally occurred through watershed boards or associations.

349 Multi-national governance through transboundary agreements that included
350 environmental flows was a focus for five published cases. This included the Amur basin in
351 Russia, China, and Mongolia (Simonov et al. 2019); the Colorado River, Rio Grande, and Rio
352 Bravo in the United States and Mexico (Nava et al. 2016; Kendy et al. 2017); the Okavango
353 basin in Angola, Namibia, and Botswana (King et al. 2014; King and Chonguica 2016); and the
354 Mekong, Songkhram, and Huong basins in Cambodia, China, Laos, Myanmar, Thailand, and
355 Vietnam (Lazarus et al. 2012). However, Hairan et al. (2021) report that Southeast Asian
356 countries lack attention to environmental flows policies and research. Acreman (2010) also
357 described the European Water Framework Directive's uptake of terms similar to environmental
358 flows and requiring member states to have good ecological status in their basins. More recently,
359 the European Union included a definition of ecological flows in their framework guidance
360 document (Ramos et al. 2018; European Union 2024). Other international agreements were not
361 included. For example, while the Columbia River (O'Donnell 2017; O'Donnell and Garrick
362 2017a) was included in our review, the focus was on the United States rather than the 1964
363 Canada-United States Columbia River Treaty (The Governments of the United States and
364 Canada 1964) likely because the Treaty includes no explicit attention to the terms environmental
365 or cultural flows. However, there have been recent efforts to explicitly consider environmental
366 flows and Indigenous Treaty Rights in the renegotiation of the Columbia River Treaty (Bode
367 2017; Baltutis et al. 2018; Cohen and Norman 2018).

368 Watershed co-governance that considers environmental or cultural flows, while rare, is
369 occurring in Australia, Canada, India, and New Zealand (Figure 2). This is watershed
370 governance that we identified as being shared by communities and one or more senior levels of
371 government. In Australia, scholars described co-governance through cultural flows, for example,
372 with First Nations of Wamba Wamba and Ngemba (Jackson et al. 2015), Nari Nari (Woods et al.
373 2022; O'Donnell et al. 2023), Ngarrindjeri (Hemming et al. 2019), and Ringarooma Water Users
374 (Ellison et al. 2019) in the Murray Darling Basin, Coorong, Lower Lakes and Murray Mouth,
375 and Ringarooma. In Canada, Curran (2019) describes co-governance in British Columbia with
376 the Syilx Nation, Okanagan Nation Alliance, Yinka Dene 'Uza'hné; Stelat'en First Nations,
377 Tsleil-Waututh Nation; Stk'emlúpsemc te Secwépemc Nations in Okanagan and Cowichan
378 basins. In India, Kaushal et al. (2019) describe co-governance with the Ganga River Water User
379 Association, which may indicate movement towards the establishment of a protected cultural
380 flow. Lastly, co-governance agreements were described in New Zealand's Selwyn River, Irwell
381 River, Buchannan's Creek, Merrys Stream, Waikouaiti River, and Kakaunui and Orari

382 catchments with different Māori communities or Iwis (such as Ngāi Tahu) (Tipa and Nelson
383 2012; Crow et al. 2018; Anderson et al. 2019). What is noteworthy, however, is there is some
384 disagreement between authors or discourse within papers about whether co-governance is truly
385 occurring, such as in Canada (Curran 2019) and New Zealand (Crow et al. 2018; Taylor et al.
386 2020). In these instances, there could be effort to include water justice in the water governance
387 discourse to elucidate who has power in decision-making (Robison et al. 2018; Taylor et al.
388 2019).

389 Polycentric watershed governance that includes community-level participants is
390 implemented, for example, in Australia (Garrick et al. 2012; Jackson 2017), Kenya (Richards
391 and Syallow 2018), Tanzania (Franks et al. 2013), and the United States (Hurst 2015; O'Donnell
392 2017) (Figure 2). This is generally through the combined decision-making efforts of water user
393 associations, Indigenous governments, civil society organizations, water managers and
394 regulators, municipal and state-based governments, and federal or national agencies.
395 Implementation may also include private water licences, market allocation mechanisms, and
396 environmental water managers in countries such as Australia and the United States (O'Donnell
397 and Garrick 2017b). More private-public market-based mechanisms, that may be a part of
398 polycentric governance were described in Australia (Colloff and Pittock 2022) and the United
399 States (Wurbs 2015; Richter et al. 2020; Colloff and Pittock 2022), among others (Owens 2016).
400 The following sections examine the difference between centralized/multi-national (with
401 community level interests) and decentralized governance rather than making a distinction
402 between co-governance and polycentric governance.

403 ***Environmental and Cultural Flow Methods Adopted in Watershed Governance Structures***

404 There were differences and similarities between how centralized and decentralized watershed
405 governance structures were applying environmental and cultural flow methods. The Brisbane
406 Declaration (2007, p. 3) recommended that “Environmental flow assessment and management
407 should be a basic requirement of Integrated Water Resource Management; environmental impact
408 assessment; strategic environmental assessment; infrastructure and industrial development and
409 certification; and land-use, water-use, and energy-production strategies.” Most papers referenced
410 how governing bodies managed environmental and cultural flows through water use strategies,
411 whereas fewer described legislation and policy mechanisms (more common to decentralized
412 governance, representation across flow initiatives), environmental impact assessment and
413 strategic environmental assessment requirements (centralized and multi-national, environmental
414 and environmental-social flows), dam and energy production strategies (centralized,
415 environmental flows), and integrated water resources management (centralized and
416 decentralized, environmental-social flows). To our knowledge, there was no clear mention of the
417 incorporation of environmental and cultural flows processes in land use strategies.

418 The literature reported that governance structures used a variety of processes and methods to
419 assess environmental and cultural flows. Centralized governance regimes employed many
420 approaches with the majority involving holistic frameworks (e.g., ELOHA in Poff et al. (2010),
421 SUMHA in Pahl-Wostl et al. (2013), BBM in King (2018a), DRIFT in King (2018b)), social-
422 cultural preferences (e.g., surveys and interviews in Rogers et al. (2013)), participatory models

423 (e.g., Bayesian belief networks in Xue et al. (2017), OASIS in Sauchyn et al. (2016)), as well as
424 those within adaptive management planning (e.g., Allan and Watts (2018)). Decentralized
425 governance structures used more Aboriginal or Indigenous water assessment and mapping (e.g.,
426 Aboriginal Waterways Assessment tool in Mooney et al. (2019) and Aboriginal extreme flow
427 thresholds reviewed in Anderson et al. (2019)), social-cultural preference (e.g., cultural flow
428 preference study in Tipa and Nelson (2012)), rights and entitlement, and holistic approaches
429 (Adapted ELOHA in Jackson and Finn (2011), Ngā Puna Aroha water allocation framework in
430 Taylor et al. (2020), among others (see Moggridge et al. 2022)). Scholars in both centralized and
431 decentralized governance contexts investigated how power dynamics are reproduced in how
432 water is allocated (e.g., Andrews et al. (2018)).

433 *Evaluation of Environmental and Cultural Flows Governance Strategies*

434 Environmental and cultural flows decision-making processes reported in this review are
435 meeting some OECD Water Governance Principles, but there are differences between centralized
436 and decentralized governance. More than half of the OECD Principles were considered in the
437 best examples of environmental and cultural flows governance internationally (Table 4, Figure
438 3). Appropriate scales, building capacity of communities, regulatory frameworks, roles and
439 responsibilities, finance, data and information, and engagement were common themes that co-
440 occurred in papers (Figure 3). Less common was policy coherence, the monitoring and
441 evaluation of policies, transparency across water policies and institutions, and the creation of
442 governance frameworks that assess trade-offs in sectors (Figure 3). Centralized governance of
443 environmental water generally considered engagement related to the collection of data and
444 information, appropriate scales, regulatory frameworks, capacity, and roles and responsibilities
445 (Figure 3A). There was only a small co-occurrence between regulatory frameworks and roles and
446 responsibilities. In contrast, regulatory frameworks in decentralized governance of
447 environmental and/or cultural water generally co-occurred with roles and responsibilities of
448 communities, capacity building, water finance, and engagement (Figure 3B). This potentially
449 suggests communities are only involved in engagement processes or operational management of
450 environmental flows in centralized governance, whereas communities are beginning to have a
451 role in regulatory frameworks and policymaking in decentralized governance. This is consistent
452 with Taylor et al.'s (2019) water justice critique of OECD Principles, which argues that
453 Indigenous Nations need to have roles and responsibilities in policymaking to assert held
454 relationships to water, water entitlements, and rights. Overall, the academic literature reported
455 greater emphasis on including communities in managing environmental and cultural flows
456 collaboratively than on including communities in related policy development and
457 implementation. This may reflect a gap in governance processes, reporting by scholars, or both.

458 Strategies related to governance democratization have emerged when environmental and
459 cultural flows are managed collaboratively and vice-versa (Figure 4, explored in greater detail
460 below). Eight major strategies are identified:

- 461 1) Participatory decision-making tools to support the communication of community goals to
462 decision-makers;

- 463 2) Delineating water development spaces to balance environmental, social, and economic
 464 demands at the basin-scale;
 465 3) Event space management to form collaborations opportunistically during hydrologic
 466 extremes;
 467 4) Water justice through the resurgence of customary Indigenous water laws and
 468 governance;
 469 5) Restrictions on water entitlement holders (caps on water abstraction, licence conditions
 470 and water releases by dam operators);
 471 6) Ecological reserves or Indigenous reserved water rights to protect water for the
 472 environment, culture, and rights ahead of consumptive uses;
 473 7) Market schemes in which governments, communities, or non-profits act on behalf of
 474 environmental or cultural water trusts; and,
 475 8) Legal personhood for rivers.

476 We examined the relationship between OECD Water Governance Principles and the emergence
 477 of these strategies (Figure 5). While there is considerable uncertainty in the model (34%
 478 deviance), the creation of ecological reserves and establishment of water markets appear to be
 479 more common when countries create water allocation regulatory frameworks with communities
 480 and support community involvement through water financing. These Principles were also
 481 somewhat related to water justice through the resurgence of Indigenous water laws and the legal
 482 personhood of rivers. Furthermore, opportunity for higher-level water development spaces and
 483 support tools for decision-makers are related to countries' institutional capability to assess trade-
 484 offs and collect data and information. Water use caps and releases were related to innovative
 485 water governance practices, policy evaluation, capacity, and appropriate scales. Hence, effective
 486 governance of environmental and cultural flows potentially occurs when communities benefit
 487 from and are involved in regulatory frameworks, there is adequate funding, and there is
 488 consideration of trade-offs, sufficient data and information, appropriate scales, innovative
 489 practices, and policy evaluation.

490 *Strategy One – Decision Support Tools*

491 The norm for environmental flows deliberations in centralized governance is to use these
 492 processes as participatory modelling approaches to support more inclusive decision-making
 493 (Figure 4). Decision support tools were more common to environmental and environmental-
 494 social flow initiatives. These approaches were employed to visualize water objectives, anticipate
 495 how uses may affect downstream communities and ecosystems, and ultimately communicate the
 496 impact of water extraction to decision-makers. Decision support tools, for example, included
 497 Bayesian networks (Xue et al. 2017), optimization models (Bryan et al. 2013), game theoretical
 498 bargaining (Xu et al. 2019), fuzzy models (Sedighkia et al. 2021), multi-criteria analyses (Girardi
 499 et al. 2011; Barton et al. 2020), water evaluation and planning software (Jorda-Capdevila et al.
 500 2016), interactive displays (Ellison et al. 2019), and other techniques. These approaches are a
 501 part of a group of multidisciplinary techniques designed to use expert knowledge and available
 502 data to weigh ecological, social, and economic factors and scenarios at the nexus of food, water,
 503 and energy conflict (Xue et al. 2017). They offer the opportunity to easily communicate

504 ecosystem services and trade-offs of water use with stakeholders and Rights holders to help them
505 inform and be at the negotiation table to determine water use strategies (Lazarus et al. 2012;
506 Barton et al. 2020; O’Sullivan et al. 2020).

507 Decision support tools for environmental flows consideration in water resource
508 negotiation is underway in European countries, Canada, China, Australia, Cambodia, Ethiopia,
509 Italy, Georgia, Papua New Guinea, New Zealand, Uganda and the United States, among others.
510 In the Ringarooma catchment in Australia, for example, Ellison et al. (2019) worked with the
511 Ringarooma Water Users Group using an interactive dashboard and tables to visualize and
512 predict stream flows and precipitation. This platform offered the Water Users Group the
513 opportunity to comment on and negotiate changes to water allocation in real-time and is
514 described as the technical foundation for co-governance (Ellison et al. 2019). In a second
515 example in the Aosta Valley in Italy, Vassoney et al. (2019) describe a multi-criteria analysis
516 with stakeholders to evaluate water withdrawals in the context of energy, economy, fishing,
517 landscape, and environmental criteria. The synergies, trade-offs, and stakeholder preferences
518 related to these criteria then informed the Valley’s strategic plan (Vassoney et al. 2019). As a
519 final example, Sheer et al. (2013) use Collaborative Modelling for Decision Support tools to
520 work with stakeholders in the Bow River watershed, Canada to create a new operating strategy
521 for hydropower and irrigation that sets out greater water storage, release rules, in-stream flow
522 guidelines, and water allocation to licence holders. These cases describe a movement in
523 centralized governance towards the use of participatory models that facilitate greater community
524 representation in water use strategies.

525 *Strategy Two – Water Development Space*

526 Environmental flow initiatives have been a platform to delineate a water development space
527 ahead of developments, especially in centralized watershed governance (Figure 4). The idea of
528 water development space appeared to be more common through environmental flow processes
529 than those considering cultural or environmental-social flow. King and Brown (2010, p. 135-
530 136) suggest that development space is “ the difference between current conditions in the basin
531 and the furthest level of water-resource development found acceptable to stakeholders through
532 consideration of the scenarios.” Environmental flows processes can be one key consideration to
533 understand water trade-offs and preferences to inform collaborative efforts to set the maximum
534 level of degradation to which a basin can withstand (Lazarus et al. 2012; King et al. 2014). Here,
535 there has been effort by governments who create forums to understand the priorities of different
536 sectors and visions of stakeholders. King and Brown (2018), for example, state:

537 An EFlows Assessment can identify: the incremental and cumulative effects of all proposed
538 projects; thresholds in the degree of environmental and social impacts; the least- and most-
539 sensitive river reaches in a basin; barriers to flow, sediment and biota that would be least or
540 most destructive; which tributaries could best be developed and which conserved with
541 natural flows and fish migrations (sacrificial v. sacrosanct); the configuration, design and
542 operation of dams that would best promote biodiversity and support fish populations; which
543 rivers are most important to rural communities and why; and how much water in what

544 pattern of flows would be required to maintain different parts of the river system at various
545 levels of health. (p.3)

546 Ahead of developments, environmental flow initiatives have been a means to form a consensus
547 development space for watersheds by setting goals for the improvement of water quality and
548 flows to ensure at least the minimum levels for lasting public and ecological wellbeing.

549 Delineating a water development space is a strategy in Australia, Canada, India, Italy,
550 Iran, Georgia, Greece, Lesotho, Mexico, New Zealand, Pakistan, South Africa, the United States,
551 and multi-national governance in Angola, Namibia, and Botswana for the Okavango basin and
552 Mekong, Songkhram, and Huong basins in Cambodia, China, Laos, Myanmar, Thailand, and
553 Vietnam (Figure 4). This theme generally appears in strategic planning, impact assessment, and
554 integrated water resource management. In many of these countries, there is effort to create shared
555 visions for watersheds based on scenarios (Conallin et al. 2017) and several cases identified the
556 maximum level of degradation a watershed can withstand or what benefits must be guaranteed.
557 In the Okavango basin, which is one of these cases, Angola, Namibia, Botswana, and a Global
558 Environmental Facility funded a transboundary strategic action plan, applying the DRIFT
559 (Downstream Response to Imposed Flow Transformations) process, to understand the “costs and
560 benefits of water allocation to river ecosystems, social structures, and local and national
561 economies” (King et al. 2014, p. 786). For the Poonch River in Pakistan, the state completed an
562 environmental flow assessment as part of an impact assessment for the Gulpur Hydropower
563 project, providing strategic guidance for habitat thresholds for Kashmir Catfish, dam location
564 and operation, and a regulated biodiversity action plan (Brown et al. 2019). In these cases,
565 environmental flows were considered in administrative processes at a higher strategic level to
566 facilitate broader co-designed guidance for a water development space.

567 *Strategy Three – Event Space Management*

568 Collaboration between governmental authorities, stakeholders, and Rights holders has
569 occurred more spontaneously or opportunistically during extreme hydrologic events to allow for
570 experimentation in the governance and management of environmental flows. This phenomenon
571 is called event space management reflecting that there is a unique event that alters how people
572 interact, thereby potentially altering the rules and norms of traditional management (Bark et al.
573 2016). This strategy was more common in papers that discussed environmental or
574 environmental-social flows (Figure 4). Applied to environmental flows, in extreme wet and dry
575 years there is a brief event window or space within which non-state decision-makers can have
576 greater influence over water use priorities in a dry year and over decision making on the
577 movement of water to different social and ecological endpoints to maximize benefits of a wet
578 year (Bark et al. 2016; Gilvear et al. 2017). Gilvear (2017) uses the expression hot moments or
579 hotspots to describe unique moments when ecosystem and cultural services can be delivered
580 through water allocation. These events or hot moments can act as a form of river restoration to
581 confer ecosystem and cultural benefits (Bark et al. 2017; Kaiser et al. 2020). To enable
582 cooperation during hydrologic extremes for the delivery of ecosystem services, authors recognize
583 a need to build trust and legitimacy in environmental flows processes and create strong

584 coordinated multi-level institutional relationships or multi- and bi-national agreements
585 (O'Donnell et al. 2019).

586 Most papers presented instances in which useful relationships were created because of water
587 scarcity and overallocation, but only a few papers from Australia, India, Italy, Kenya, Mexico,
588 and the United States described how a re-organization of decision-makers can occur
589 spontaneously during environmental water delivery, often because of flooding in wet years or the
590 need to deliver ecosystem or cultural services (Figure 4). In Australia's Barwon-Darling (part of
591 the Murray-Darling) catchment, for example, Jackson (2021) describes how shared responsibility
592 for dealing with an excess amount of water in a wet year (environmental flow event) in 2018
593 created a shared sense of time and space because there was greater transparency in how water
594 use was regulated by water managers. Indigenous leaders could emphasize a wider set of social-
595 cultural relational values of water as it was moving through the waterscape and landscape. This
596 led to a transient experiment in decentralized governance in some parts of the watershed while
597 emphasizing governance deficiencies in others. Jackson describes the deficiencies in flow
598 management when water movement is "objectified, compartmentalized, and represented as
599 apolitical" (p. 468). In Mexico and the United States' Colorado River, flooding in 2014 led to
600 water allocation through bi-national collaboration by many people (non-profits, government,
601 international agencies) who were personally part of an ecosystem servicing process to provide
602 water to areas of cultural and environmental importance (Bark et al. 2016; Kerna et al. 2017;
603 Butler et al. 2021). In India's Ganges River, key moments for greater ecosystem and cultural
604 service delivery have occurred during the Kumbh religious festival because of coordination
605 between the government and supportive irrigators to reduce water for agricultural uses in
606 upstream canals and send more water downstream (Lokgariwar et al. 2014; Gilvear et al. 2017).
607 Authors note that successful planning of such events requires co-development of socio-
608 hydrological monitoring and modelling. While ongoing environmental flows processes provide a
609 long-term opportunity to build relationships and scale up those collaborations to broader
610 watershed management, spontaneous events can be harnessed as an opportunity to quickly test
611 new forms of decentralized governance.

612 *Strategy Four – Indigenous Laws and Water Justice*

613 Cultural flow processes have been platforms for the exchange of diverse water values and
614 asserting of Indigenous water laws and decision-making authority (Figure 4). Through political
615 ecology and water justice lenses, flow processes can be an avenue to work towards power
616 redistribution in basin planning. Political ecology is about "an integrated understanding of how
617 environmental and political forces interact to mediate social and environmental change" (Bryant
618 1992, p. 12). Re-politicizing water means overtly recognizing that water (distribution, quality,
619 and more) choices reflect and reproduce existing power dynamics (Bourblanc and Blanchon
620 2019; Alexandra et al. 2023). Water scarcity generally results in prioritizing municipal and
621 industrial water use over the environment and for Indigenous Nations (Colloff and Pittock 2022;
622 Wineland et al. 2022; Dourado et al. 2023). Indigenous water justice, explained in Robison et al.
623 (2018, p. 841), is "water and its multi-faceted connections to Indigenous Peoples' self-
624 determination – more precisely, to the socioeconomic, cultural, and political dimensions

625 associated with Indigenous Peoples' exercise of the right to self-determination.” Cultural flow
626 processes in particular are an opportunity for water governance that includes Indigenous water
627 laws, legal pluralism, the water back agenda, and treaty agreements (Hartwig et al. 2022;
628 Leonard et al. 2023; O’Donnell 2023a). Environmental and cultural flows deliberations can be
629 venues for explicitly working towards power redistribution and acceptance of diverse knowledge
630 forms in water allocation and quality choices (Hartwig et al. 2022; Moggridge et al. 2022).

631 Commitment to water justice to improve the governance of environmental and cultural flows
632 is largely emerging in Commonwealth countries – Canada, Australia, and New Zealand – and to
633 some degree in the United States and Chile through the resurgence of Indigenous water laws and
634 governance (Figure 4). In these jurisdictions, attention to a cultural flow through Indigenous
635 water rights is an opportunity to “direct the formation of water policy from a starting point of
636 Indigenous sovereignty, with Indigenous governments adequately resourced to participate
637 equitably in environmental co-governance” (Hemming et al. 2019, p. 223). In Australia, the
638 Murray Lower Darling Rivers Indigenous Nations and Northern Basin Aboriginal Nations
639 created the Echuca Declaration (2007) to define cultural flows and recognize and reaffirm
640 sovereignty of their waters and lands. Since this Declaration, Australia has begun to move from
641 simply recognizing cultural values in plans, policies, and legislation to creating co-management
642 agreements (Robinson et al. 2015; Bischoff-Mattson and Lynch 2017; Bischoff-Mattson et al.
643 2018; O’Donnell et al. 2023). Curran (2019, p. 2) remarks that in Canada the “state depoliticizes
644 decisions about water by directing them into administrative processes like environmental
645 assessment while Indigenous communities are repoliticizing water governance by creating
646 evaluation processes that reflect their own legal traditions and standards.” In British Columbia,
647 First Nations (Syilx Nation, Okanagan Nation Alliance, Yinka Dene ‘Uza’hné, Stellat’en First
648 Nations, Tsleil-Waututh Nation; Stk’emlúpsenc te Secwépenc) in the Cowichan and Okanagan
649 basins, for example, are creating their own decision-making structures based on their water laws
650 to create community-assessments, cumulative effects management plans, and environmental and
651 cultural flows rules to assert and institutionalize their co-governance of water impacted by
652 development projects in British Columbia (Curran 2019). New Zealand is also moving towards
653 co-governance with environmental legislation that recognises Māori values, principles, and Te
654 Mana o te Wai (authority over water) (Taylor et al. 2020). However, scholars suggest co-
655 designed policy and regulations with Māori need to be created based in Nga Taonga Tuku Iho (a
656 natural resource management framework) and Nga Puna Aroha (a water allocation framework)
657 to protect water for the environment and people (Taylor et al. 2020; Challies et al. 2022). In these
658 cases, there is greater appreciation of relationships to water and the intangible, subjective values
659 therein, such as custodial responsibilities, spirituality, knowledge transmission, and creation
660 stories (Moggridge and Thompson 2021; Woods et al. 2022). Indigenous self-determination and
661 co-governance arrangements are emerging partially through the recognition of cultural flows
662 embedded in water rights and decision-making authority.

663 *Strategy Five – Water Use Caps and Releases*

664 Water use caps and releases appear to be considered in environmental flow initiatives and
665 to a slightly lesser extent in cultural flows and environmental-social flow initiatives across

666 centralized and decentralized governance (Figure 4). Horne et al. (2017, p. 363) describe three
667 sub-categories that fall into this strategy: 1) “cap on consumptive water use”, 2) “license
668 conditions for water abstractors”, and 3) “conditions on storage operators or water resource
669 managers”. Caps on consumptive water use are a “limit on the total volume of licenses issued
670 and/or the extraction/abstraction of water against these licenses” (Horne et al. 2017, p 363).
671 License conditions for water abstractors are “conditions listed on the license of individual water
672 users that restrict the volume and/or timing of extractions” (Horne et al. 2017, p 363). Lastly,
673 conditions on storage operators or water resource managers are “conditions on a storage operator
674 prescribing releases from storage for downstream ecological needs” (Horne et al. 2017, p 363).
675 These categories are generally considered as a package, alongside other legal rights, management
676 plans, and ecological reserves (Nowlan 2012; Horne et al. 2017d).

677 From our synthesis, we identified water use caps and release rules in Australia, Canada,
678 Chile, China, the European Union, New Zealand, Pakistan, South Africa, Uganda, the United
679 Kingdom, and the United States (Figure 4). In Australia, the Water of Act of 2007 details a
680 sustainable diversion limit and strategic water releases by the Commonwealth Environmental
681 Water Holder in the Murray-Darling Basin (Acreman et al. 2017). In contrast, the European
682 Union Water Framework Directive leaves each country to define flow releases and abstraction
683 rates, though the European Union does have the legal power to suggest an amendment to an
684 abstraction licence (Acreman and Ferguson 2010). In the United Kingdom (formerly part of the
685 European Union before 2020), the Thames Catchment Abstraction Management strategy
686 calculate the maximum abstraction based on environmental flow indicators, but these indicators
687 did not meet Water Framework Directive guidelines based on high abstractions (Overton et al.
688 2014). Another example is Uganda where, in 2011, the Environmental Impact Assessment
689 Guidelines for Water Resources Related Projects recognized environmental flows and
690 subsequently the government has guaranteed environmental flows in water abstraction
691 permitting, water release projects from hydropower, and dam weir design (O’Brien et al. 2021).
692 As a final example, in 2005, China’s Environmental Protection Administration required the
693 release of environmental flows from hydropower dams and this condition has been included in
694 the operation strategy for the Three Gorges Dam and other ministries’ policies (Cheng et al.
695 2018). These cases highlight consideration of water use caps and releases in countries’ regulatory
696 frameworks but also suggest a need for greater community involvement in water use caps,
697 licence conditions, and water releases.

698 *Strategy Six – Ecological Reserves and Indigenous Reserved Water Rights*

699 From our synthesis, ecological reserves appear to be equally considered across
700 environmental, cultural, and environmental-social flow initiatives in more decentralized
701 governance contexts (Figure 4). Horne et al. (2017d) describe ecological reserves as “legally
702 establish[ing] environmental water as a prior right to consumptive water use.” Reserve
703 determinations have been considered both in setting aside the required volume of water for an
704 ecosystem or for release to an ecosystem and categorizing the waterbody based on the desired
705 water quality class ahead of consumptive use and development (Pienaar et al. 2011; Brown et al.
706 2020). Either as part of an ecological reserve or independently, Aboriginal, Indigenous, or

707 cultural reserved water rights have also emerged for Indigenous people to protect and restore
708 waterbodies for rights-based, cultural, and environmental uses (Jackson 2015; O'Donnell et al.
709 2022). The creation and legitimacy of ecological reserves has been supported through Indigenous
710 title, protected areas and co-management agreements (Costanza-van Den Belt et al. 2022).
711 Recently, scholars have also described how ecological reserves require active management by
712 environmental water managers and holders to release water to achieve environmental and
713 cultural benefits (Horne et al. 2018). However, there are challenges with the implementation of
714 ecological and Indigenous reserved water rights, including frustration by water users and
715 governments because of delayed permitting and development decision-making (Pienaar et al.
716 2011).

717 We found that ecological reserves have been considered, for example, in Australia,
718 Canada, Chile, Kenya, Mexico, New Zealand, South Africa, and the United States (Figure 4). In
719 South Africa, between 1999 to 2008 the government received 1,600 requests for reserves and
720 approved 900 (Pienaar et al. 2011) and recent strategic adaptive management processes, in the
721 Crocodile River in South Africa, for example, emphasize transparent and cooperative
722 management between the state, catchment management authorities, and stakeholders
723 (McLoughlin et al. 2021). In Australia, the Murray-Darling Basin ecological reserve offers
724 opportunity for Indigenous Nations to restore aquatic ecosystems, such as the floodplain of the
725 Moorna State forest, which is managed by the Barkindji as an Indigenous Protected Area
726 (Jackson and Nias 2019). Similarly, Indigenous reserved water rights are in place for commercial
727 use by Nations in some Northern Territory (Australia) water allocation plans and there is
728 opportunity for more ecological reserve designations and strategic planning (Jackson and
729 Langton 2011; O'Donnell et al. 2022). In Mexico, the government released an ecological reserve
730 program in 2012 for 189 river basins (Salinas-Rodríguez et al. 2018). In the United States, the
731 Colorado River has wildlife refuges with entitlements and federal Indigenous reserved water
732 rights, both of which act similar to a reserve in that a water apportionment is given each year
733 ahead of consumptive uses and Indigenous water rights cannot be lost from non-use and are held
734 in perpetuity (Butler et al. 2021). In Hawaii's Waihe'e River, Waiehu Stream, Wailuku River,
735 and Waikapu Stream, there is also recent use of the public trust doctrine to reserve water for the
736 environment (Cantor et al. 2020). This doctrine has enabled Maui communities and lawyers to
737 work together to restore rivers and have them run without diversion (Cantor et al. 2020). For
738 both Chile (MacPherson and Salazar 2020) and Kenya (Richards and Syallow 2018),
739 environmental flows or reserves for surface waters are prioritized ahead of commercial
740 consumptive uses. In Canada, Nowlan (2012) mentions that environmental flows are considered
741 through reserves, limits on licences, and water management plans. Lastly, in New Zealand, there
742 are water allocations reserved for Māori, but these reservations can be relinquished if an
743 allocation limit is met; therefore, Taylor et al. (2020, p. 36) recommend "'Mana Whenua Mana
744 Wai' allocations" to support a clearer allocation hierarchy. While ecological reserves are
745 becoming more common worldwide, our synthesis points to a need for more attention to the
746 implementation of Indigenous and cultural reserved water rights.

747 *Strategy Seven – Water Markets and Trade*

748 In centralized and decentralized governance arrangements, there are opportunities for the
749 purchase of water rights for the environment and culture in water markets (Figure 4). These
750 rights can then be traded by public governments, community cooperatives, and Indigenous
751 communities where privatization of water rights is an established tradition. Water markets offer
752 opportunity to adapt to demand and supply through water trade in both formal and informal and
753 urban and agricultural settings (O'Donnell and Garrick 2019; Garrick et al. 2023). A water bank
754 refers to a “network of inter-basin water connections” and transactions (Sheer et al. 2013).
755 Rosegrant and Binswanger (1994, p. 1615) describe how “a system of marketable rights to water
756 would induce water users to consider the full opportunity cost of water, including its value in
757 alternative uses, thus providing incentives to efficiently use water and to gain additional income
758 through the sale of saved water.” In the papers we reviewed, most water market schemes were
759 created because of water scarcity and overallocation of water to licence holders. Purchasing
760 water or issuing water licences based on cultural and environmental factors is in large part a
761 response to the need to restore flows either immediately or through long-term storage. Water
762 market schemes may be a way to experiment in decentralized forms of governance.

763 In our synthesis, we found that schemes to purchase water for the environment are present or
764 proposed in Australia, Canada, Chile, the European Union, Mexico, New Zealand, Spain, the
765 United Kingdom, and the United States (Figure 4B). However, this is not an exhaustive list of
766 formal and informal water markets; instead, these countries serve as some useful cases of water
767 markets where Rights holders and stakeholders may have an active role. Australia has a long-
768 established tradition of informal and formal water markets (Seidl et al. 2020). Effective water
769 allocation and governance in Australia is suggested to be a product of water markets, regulation
770 (2007 Water Act enables setting a sustainable diversion limit and establishes a Commonwealth
771 Environmental Water Holder in the water market), and collaborative approaches (Cruse et al.
772 2013; Pahl-Wostl et al. 2013). Environmental water managers in the Murray-Darling have had an
773 active role in securing environmental water entitlements because of water buybacks from licence
774 holders and efficient irrigation technologies (Garrick et al. 2012; Costanza-van Den Belt et al.
775 2022). Additionally, through increased recognition of co-governance in the Murray-Darling
776 basin, there is now emphasis on tradeable Indigenous water entitlements, water buy-back by
777 Nations, and an Indigenous water trust or partnerships with private water trusts (Jackson 2015,
778 2017; Jackson et al. 2020; Hartwig et al. 2023). However, other scholars report limited uptake of
779 water entitlements and trade by Indigenous communities throughout Australia and in the
780 Northern Territory in particular (O'Neill et al. 2016) and a lack of clarity about how cultural
781 flows will be included in market schemes to support restoration, livelihoods, and rights-based
782 activities (Moggridge and Thompson 2021). In the United States, Richter et al. (2020) reported
783 that the most successful water purchases for flow restoration have been through funded non-
784 governmental actors and a state water trust, which participated in two-thirds of transactions in
785 the American West. Two examples of water trusts that work to recover water for the
786 environment through market mechanisms include the Colorado Water Trust (O'Donnell and
787 Garrick 2017a) and Washington State's water trust (Hurst 2015). The Colorado River Delta
788 Water Trust “secured over 6,000 acre-feet of water rights from farmers in the Colorado River
789 Irrigation District in Mexico” (Kerna et al. 2017, p. 5). In Australia, the United States, and other

790 countries, water trusts and environmental water managers have been successful in the short-term
 791 at recovery of water for the environment and managing water through markets (O'Donnell
 792 2017).

793 *Strategy Eight – Legal Personhood for Rivers*

794 The papers in this review that mentioned legal personhood for rivers were generally
 795 related to environmental or environmental-social flows and ranged from centralized to
 796 decentralized governance settings, but this was a small subset of our review (n = 7; Figure 4).
 797 Note that few papers explicitly related cultural flows and legal personhood, but this was likely a
 798 result of our small sample size. O'Donnell (2019a) describes legal personhood for rivers:

799 Giving rivers legal rights means the law can see the river itself as a legal person, and the
 800 river can take legal action to enforce those rights. Legal personhood confers legal standing
 801 (often described as the ability to sue and be sued), which enables rivers to go to court to
 802 protect their rights. (p. 1)

803 However, legal personhood does not grant a river a right to water for protection against
 804 extractive activities and extinction (O'Donnell 2020). An indirect form of legal personhood
 805 includes environmental water managers – "...organisations with legal personhood, which have
 806 been created to acquire and manage water for the aquatic environment" (O'Donnell 2017, p.
 807 503). While environmental water managers hold decision-making power and have responsibility
 808 over the environment (Horne et al. 2017; O'Donnell 2017), river rights conferred through legal
 809 personhood are represented by a "guardian or loco parentis who is the human face of the river
 810 and who interacts with the regulators..." (Davies et al. 2023, p. 405). Legal personhood for
 811 rivers is an opportunity to assert the inherent value of waterbodies; however, effective alignment
 812 with cultural flows and Indigenous water law is dependent on the guardianship process being
 813 localized and context specific (Davies et al. 2023).

814 Legal personhood of rivers has been enacted in Colombia (Río Atrato), India (Ganges
 815 and Yamuna; recently struck down), and New Zealand (Whanganui) (included in Figure 4).
 816 Indirect legal personhood through environmental water managers is occurring in many countries
 817 (principally Australia and the United States but also, for example, Brazil, Canada, Chile, Ghana,
 818 and Mexico) (O'Donnell and Garrick 2017b; O'Donnell 2019a). Direct legal personhood for
 819 rivers has also been considered or recommended for the Colorado River and Lake Erie (United
 820 States), Ethiopie River (Nigeria), Saint Lawrence River and Peace-Athabasca-Mackenzie River
 821 (Canada), Magdalena River (Mexico), the Margaret and Yarra rivers (Australia), Bangladeshi
 822 rivers, Chilean rivers, and rights for nature have also been recognized in Bolivia and Ecuador
 823 (Eckstein et al. 2019; O'Donnell 2019a, 2023b; Macpherson 2021; Cárdenas and Turp 2023).
 824 We note, as well, that the Magpie River in eastern Canada and the Marañón River in Peru were
 825 recently recognized with legal personhood, but this was not included in papers in this review. For
 826 those rivers that have direct legal personhood, New Zealand and Columbia follow collaborative
 827 approaches with co-management agreements to employ legal personhood to assert Indigenous
 828 rights and values and create alternative institutions within existing legal frameworks to govern
 829 the river, such as Te Pou Tupua (New Zealand) and 15 guardians appointed by the government

830 and community organizations (Columbia) (O'Donnell and Talbot-Jones 2018; O'Donnell
831 2019b). In contrast, India's legal personhood put forward a competitive model, where most
832 guardians are members of the Indian government, there is conflict between human industry and
833 environmental advocates, and there is an expectation of a dramatic change in river governance
834 outside of the existing legal framework (O'Donnell and Talbot-jones 2018; O'Donnell 2019b).
835 Similarly, environmental water managers in the United States are more collaborative, working to
836 change attitudes of water licence holders ahead of securing environmental water (e.g., Colorado
837 and Columbia rivers), whereas Australia environmental water managers are more competitive,
838 operating as a large participant in the water market (e.g., Murray-Darling) (O'Donnell 2017).
839 Taken together, legal personhood is an opportunity for water governance democratization to
840 collaboratively protect environmental water, but there are challenges with assigning
841 guardianship, participating as water users in water markets, and rivers having human rights but
842 not the right to water and to flow.

843 *Gaps and Directions for the Future*

844 A decade ago, Pahl-Wostl et al. (2013) identified gaps in how environmental flows are
845 addressed in governance and others, like Horne et al. (2017a), have set research priorities for
846 environmental water management. We add to the understanding of gaps and their implications to
847 identify needs for governance of watersheds to support environmental, cultural, and
848 environmental-social flow initiatives.

849 Regarding OECD Water Governance Principles, most papers described collaboration through
850 a water use strategy and the operational management of environmental flows rather than a
851 concerted effort to collaboratively design policy or regulatory frameworks to protect
852 environmental and cultural flows. Of the OECD Principles analyzed, few papers mentioned
853 policy evaluation, coherence, and transparency across levels of governance. Countries should
854 work with Rights holders and stakeholders to create laws and policies that protect flows needed
855 to meet environmental and cultural demands through water allocation, quantity, and quality
856 strategies (Magdaleno 2018; Wineland et al. 2022; Arthington et al. 2023; Dourado et al. 2023).
857 Implementation of these new law and policy regimes should include ongoing review, including
858 monitoring and evaluation of the coherence and effectiveness of the law and policies in
859 maintaining environmental and cultural flows. We also encourage scholars and governments
860 working on environmental and cultural water to investigate OECD Principles and governance
861 criteria, such as those identified by O'Donnell and Garrick (2017a) (effectiveness, efficiency,
862 legitimacy, legal and administrative frameworks, organizational capacity, and partnerships) that
863 build on the OECD Principles. This should be done at countries' local, basin, regional, and
864 national scales for legislation, polices, programs, and management strategies.

865 Environmental and cultural flows could be more proactively considered in development
866 decision-making through holistic regional approaches initiated prior to impact assessments, as
867 part of impact assessments (higher-level and project-level), and through links between watershed
868 planning and impact assessment. We found evidence of environmental flow concepts in impact
869 assessment guidance and processes for hydropower projects (McCartney et al. 2010; Brown et al.
870 2019; Simonov et al. 2019; O'Brien et al. 2021), but gaps in considering Indigenous rights and

871 cultural flows (Jackson et al. 2014). King and Brown (2018) suggest that considering
872 environmental flows at the level of a project-level impact assessment is insufficient to protect
873 ecological and cultural values and include downstream communities. Instead, they suggest basin-
874 wide attention to environmental flows to inform strategic assessments, cumulative effects
875 assessments, and project-level assessments through the creation of a development space to set the
876 maximum degradation a basin can withstand (King and Brown 2010, 2018). While higher-level
877 oversight is needed, the framing of development space may be an old goal of determining and
878 exploiting maximal sustainable yield, which is an offence against the precautionary principle
879 (Gibson et al. 2005). Instead, collaborative approaches to environmental and cultural flows
880 processes in development design and evaluation could be an opportunity to ponder how to
881 maximize prospects for lasting benefits and not foreclose opportunities for the future within a
882 watershed (Gibson et al. 2005). This could be a way to harmonize different levels of basin
883 planning and scope in hydro-social-ecological relationships and collaborations with Indigenous
884 authorities, water user associations, and local and state governments (Anderson et al. 2019;
885 Curran 2019). Other research should consider how regional as well as project-level impact
886 assessment and environmental and cultural flows are or should be integrated.

887 Few papers included attention to the concept of cumulative effects, particularly the effects of
888 cumulative water withdrawals, on environmental and cultural flows. Horne et al. (2017b)
889 identify the cumulative effects of diffuse hydrologic alterations in the context of environmental
890 water management as a field in need of further inquiry. Cumulative effects are natural and
891 human stressors in the past, present, and future that interact to affect the environment and
892 human-well-being (Blakley and Russell 2021). The overlap and relationship between cumulative
893 effects management frameworks (Dubé and Munkittrick 2001) and environmental and cultural
894 flows processes should offer opportunities for further inquiry to understand how incremental
895 water impacts are affecting the provision of water for the environment and people nearby.

896 Many papers identified the need for cultural flows to be approached more explicitly in all
897 water allocation initiatives related to water justice, decision-making authority, rights, and
898 tangible and intangible values of riparian Indigenous communities (Morgan 2012). To move
899 towards cultural flows, many countries need to share and return decision-making authority to
900 Indigenous Nations, honour free, prior, and informed consent in development deliberations, and
901 work to braid knowledge (Phare et al. 2017; O'Donnell et al. 2023). Here, there is a need for
902 emerging approaches that embrace pluralistic water governance regimes, such as the Mi'kmaw
903 concept of Etuaptmumk or Two-Eyed Seeing, where the strengths of Indigenous and other
904 knowledge systems co-exist and are respected (Reid et al. 2021; Arthington et al. 2023). To
905 move towards attention to cultural flows, countries need to create co-management agreements
906 with Indigenous Nations. Lastly, an area for further inquiry and clarification is if the cultural
907 flow concept, or a social flow equivalent, should extend to non-Indigenous communities if there
908 is consideration of non-ecological needs and decision-making authority of stakeholders.

909 Social-ecological systems were generally considered in relation to environmental and cultural
910 flows only in adaptive management or strategic adaptive management processes (Allan and
911 Watts 2018; Webb et al. 2018). Social-ecological systems refer to how nature and human society

912 interact across multiple levels through resource systems, resource units, and governance systems
913 (Ostrom 2009). To link environmental and cultural flows more explicitly and provide
914 opportunities for environmental and cultural flows processes to have wider sustainability
915 implications, application of social-ecological systems understandings should be central to any
916 water allocation scholarship or initiative.

917 Most environmental and cultural flows deliberations have considered the availability,
918 quantity, and timing of water movement to ensure different ecological and social services and
919 functions are met (Tharme 2003). However, the definition of environmental flows has expanded
920 to include water quality and the constituents of water flows (International River Foundation
921 2007; Arthington et al. 2018). Few papers mention water quality outright, except those referring
922 to classifying water quality through an ecological reserve (Pienaar et al. 2011), so we believe
923 there is a need to recognize that environmental and cultural flows decision-making is also about
924 the flux of particulate and dissolved materials and contaminants (such as nutrients, potentially
925 toxic trace metals, hydrocarbons, pharmaceuticals, sediment, gases) along with other
926 contributions of aquatic systems and components of the hydrologic cycle (Gorham 1991).
927 Determining who has decision-making power over the flux of materials between water
928 compartments involves a form of biogeochemical justice and is a possible complementary field
929 of inquiry (Meadows 1999).

930 While not a central focus of this paper, climate change will certainly affect hydrographs and
931 river, lake, and wetland quality in the 21st century (Grantham et al. 2019; UN Water 2020;
932 Baggio et al. 2021; Capon et al. 2021), yet few papers in this review report collaborative
933 governance initiatives to address the impact of climate change on cultural and environmental
934 water. However, there are many recent papers about environmental water management and
935 climate change that were outside the scope of our review (e.g., Poff 2018; John et al. 2021; Judd
936 et al. 2023). The gap we identify, that there is a need for more collaborative governance of
937 environmental and cultural water in the face of climate change, is reflected in a review by Capon
938 et al. (2018). They argue that to address climate change, environmental water management will
939 need greater attention to objectives and targets of environmental water delivery across scales,
940 planning and prioritization of environmental and cultural water goals, monitoring and evaluation
941 of outcomes, and knowledge generation about flow-ecology relationships and human values and
942 benefits (Capon et al. 2018). The review cycle for policies and regulations related to the
943 protection of environmental and cultural flows may need to be shortened as the pace of change of
944 floods and droughts increases (Berthot et al. 2021) and this should be reflected in the academic
945 literature and new research initiatives.

946 Lastly, we have drawn from the literature eight categories of many complementary and
947 overlapping strategies to assist the governance of environmental and cultural water (decision
948 support tools, development space, event space management, Indigenous laws and water justice,
949 use caps and releases, ecological reserves, water markets, legal personhood), but how these
950 actions effectively come together in a package of mutually supporting approaches needs to be
951 investigated further. For example, we found that the creation of a development space and
952 Indigenous laws and water justice are rarely considered together, suggesting a need for

953 Indigenous decision-making in strategic planning and water visions for the future (O'Neill et al.
954 2016).

955 **Conclusion**

956 In our systematic literature review, we found that between 2010 and 2024, countries have
957 included greater attention to the collaborative governance of environmental flows in watersheds,
958 but cultural and environmental-social flows/water warrant similarly greater consideration. More
959 than a decade ago, the academic literature paid minimal attention to environmental flows and
960 governance, despite recommendations to include environmental flows in all levels of water and
961 land management (International River Foundation 2007; Pahl-Wostl et al. 2013). In this paper,
962 we showed that environmental flows, and to some degree environmental-social and cultural
963 flows, are increasingly protected through water use strategies but less often served through
964 legislation and policies, environmental impact assessments, and energy production and land use
965 strategies. Evaluated against the OECD Water Governance Framework Principles, most
966 countries represented in the reviewed literature supported some examples of initiatives that
967 considered appropriate scales, capacity building, data and information, engagement, and
968 regulatory frameworks. However, we identified a need to include communities in policy and
969 regulatory framework development. Most watersheds employed decision support tools to
970 communicate recommendations to decision-makers. Moreover, there were instances of other
971 forms of governance in which environmental and cultural flow processes were treated more
972 experimentally (e.g., through the creation of a development space, event space management,
973 water justice, water markets, ecological reserves and Indigenous reserved water rights, and legal
974 personhood) to broaden and democratize governance. Finally, to improve the link between
975 governance and environmental and cultural flows management, the evidence points to more
976 authoritative involvement of Indigenous Peoples, local authorities, and knowledge holders in
977 environmental and cultural water policy development, coordination, and iterative evaluation.

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984 **Competing Interests**

985 The authors declare that there are no competing interests.

986 **Data Availability**

987 Data generated or analyzed during this study are available from the corresponding author upon
988 reasonable request.

989

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Figures

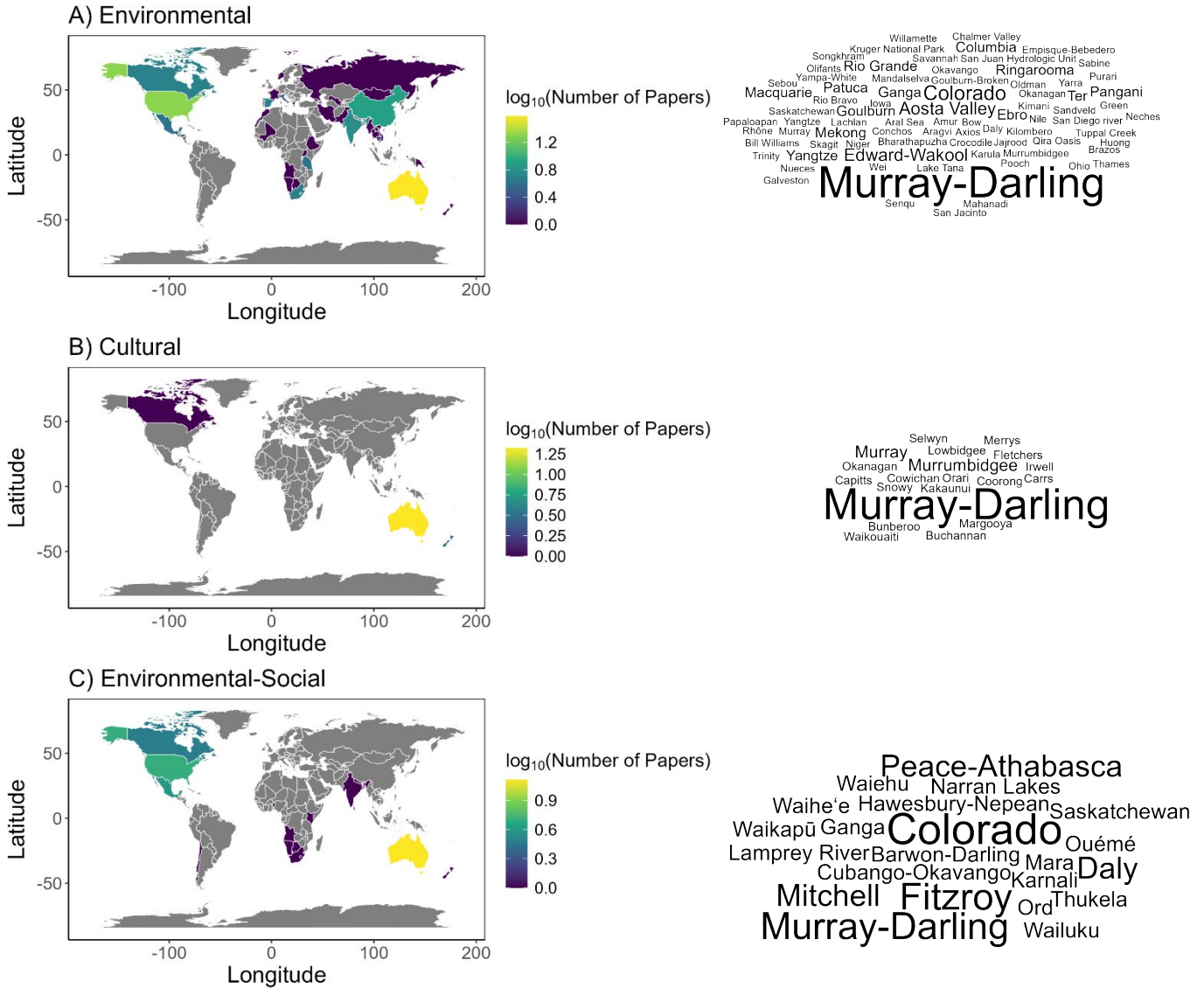


Figure 1. Countries (left) and their watersheds (right) in our review that have adopted or investigated environmental (A), cultural (B), and environmental-social flow (C) initiatives in collaborative watershed governance. Colours closer to yellow represent a greater number of published papers between 2010 and 2024.

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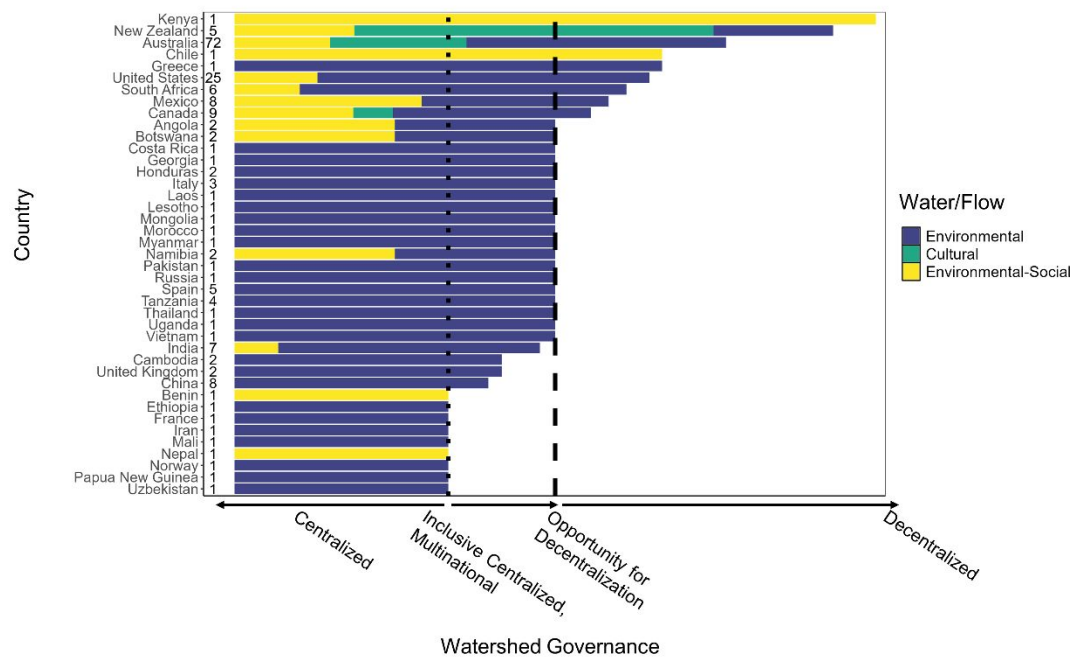


Figure 2. The watershed governance of countries in our review that have adopted environment (blue), cultural (green), and environmental-social flow (yellow) initiatives. The dotted line indicates a shift from centralized to more inclusive centralized governance and the dashed line represents the opportunity for a shift to more decentralized governance. Numbers beside bars represent the number of papers that contributed to the calculation. The watershed governance gradient was created by scoring countries within each paper based on whether they mentioned: an opportunity for inclusive centralized governance (score = 1), implementation of inclusive centralized governance (1.5), multi-national governance (1.5), an opportunity for decentralized governance (2), or implementation of decentralized governance (3). The average score was calculated for each country and the percentage of papers describing environmental, cultural, and environmental-social flows is also displayed.

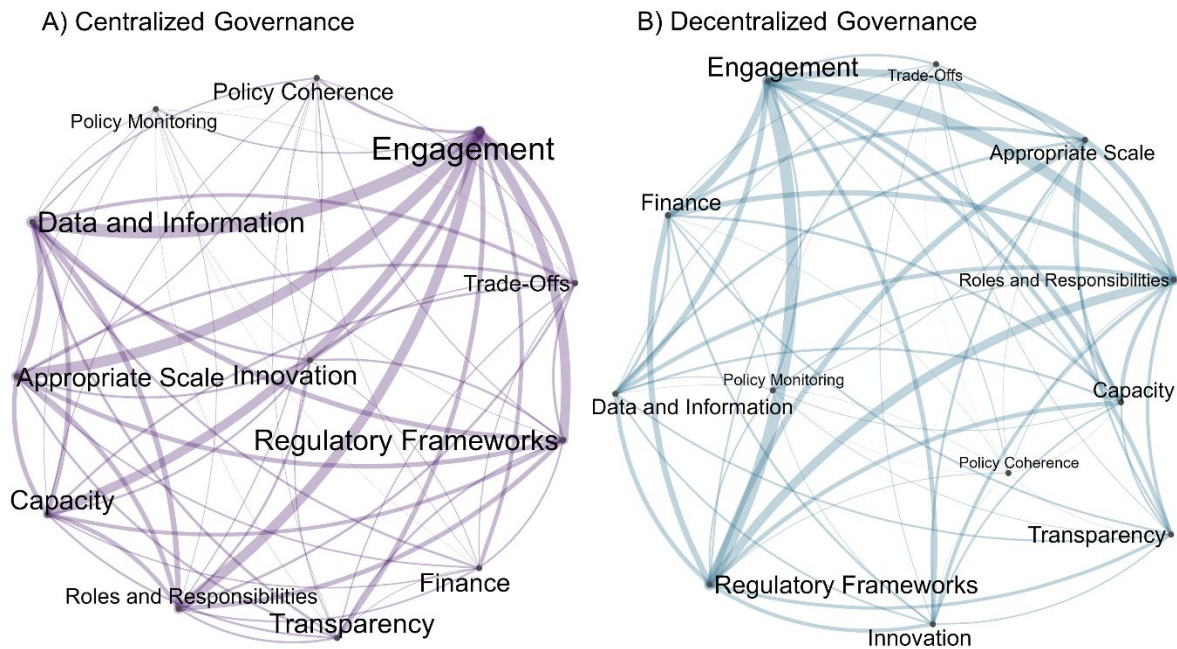


Figure 3. A co-occurrence network diagram of OECD Principles for centralized (A) and decentralized (B) governance papers. Size of the link represents the co-occurrence of the Principle in papers. Note that engagement (in the implementation of environmental or cultural flows, not policymaking) was present in all papers because of the search criteria. Principle co-occurrence was calculated based on presence and absence within papers. Multi-national governance was included in centralized governance if there was no clear bottom-up collaboration.

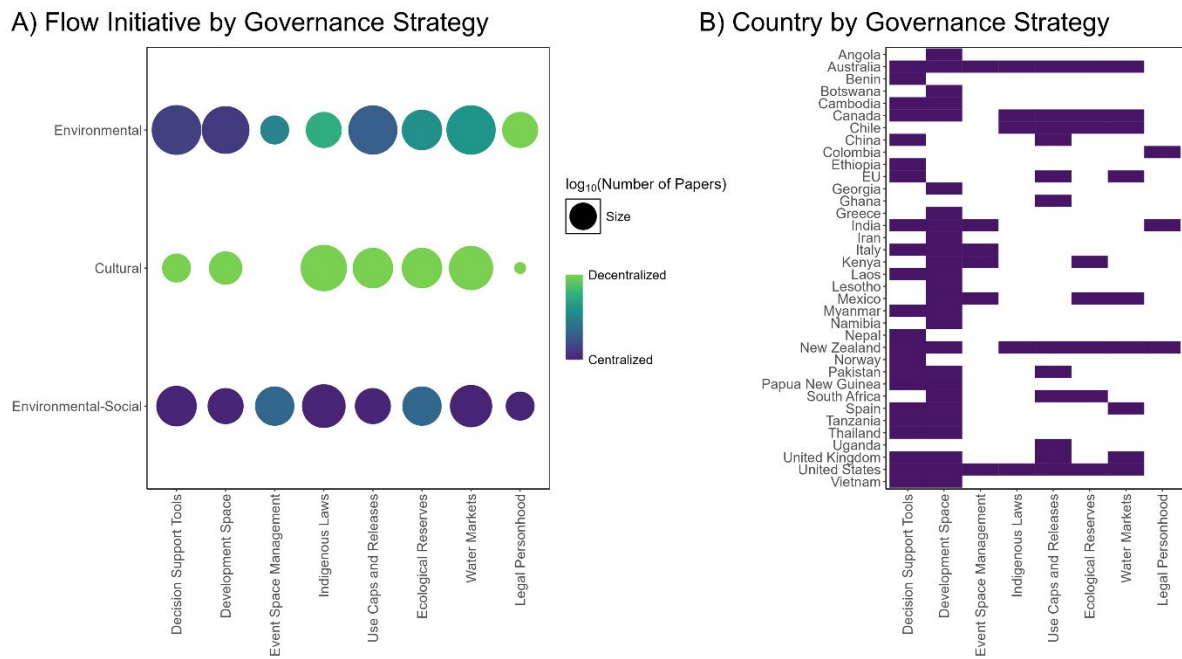


Figure 4. Flow initiatives (environmental, cultural, and environmental-social; A) and countries (B) by governance strategies. For A, the size of points and governance gradient was calculated based on the number of papers. Multi-national governance was included in centralized governance if there was no clear bottom-up collaboration. Note that B is not exhaustive of all countries and likely omits both countries and strategies because of how the review was bounded.

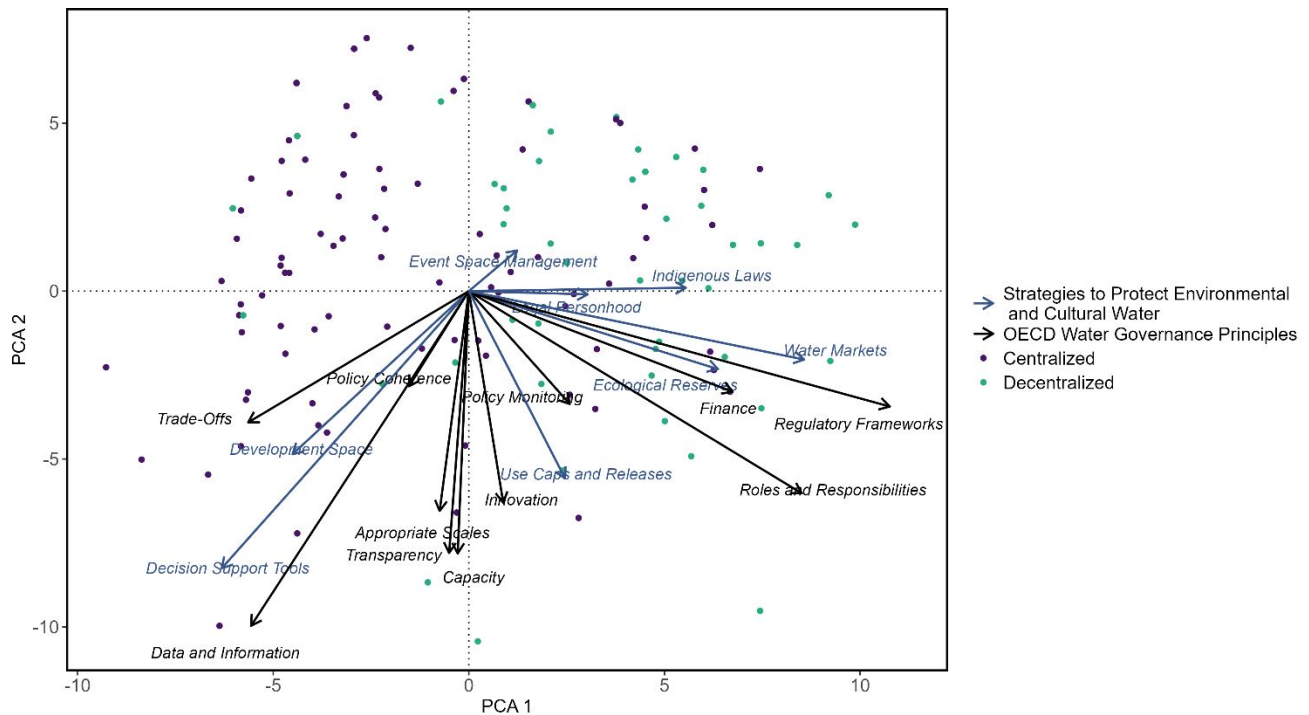


Figure 5. A binary logistic principal components analysis correlating OECD Water Governance Principles (see Table 3) and strategies to protect environmental, cultural, and environmental-social flows. The model had a deviance of 33.8%. Note that the logistic binary approach employed only has two principal components and does not display the individual variance explained of each axis. Each data point represents an individual paper. Multi-national governance was included in centralized governance if there was no clear bottom-up collaboration.

Tables

Table 1. Definitions of environmental flows/water, environmental-social flows/water, and cultural flows/water. Words following quoted text are criteria to identify these concepts in collaborative governance settings.

Term	Definition
Environmental Flows/Water	<p>“The quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems” - Brisbane Declaration (2007), Global Action Agenda (2018, p. 2)</p> <p>Ecological needs and inclusive decision-making in the same political system.</p>
Environmental-Social Flows/Water	<p>“The quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being.” – Updated Brisbane Declaration and Global Action Agenda (2018, p. 4)</p> <p>Ecological and non-ecological needs and inclusive decision-making in the same political system.</p>
Cultural Flows/Water	<p>“...water entitlements that are legally and beneficially owned by the Indigenous Nations of a sufficient and adequate quantity and quality to improve the spiritual, cultural, environmental, social and economic conditions of those Indigenous Nations.” – Echuca Declaration (2007, p. 2)</p> <p>Ecological and non-ecological needs with decision-making authority of Indigenous Nations (a separate sovereign political system), and Indigenous Rights.</p>

Table 2. The final search string implemented in Scopus, Web of Science, ProQuest, and Informit for a systematic scoping review of environmental and cultural flow concepts in decision-making.

Environment and Cultural Flows	Eflows OR "Environmental flows" OR "Cultural flows" OR "Indigenous flows" OR "Ecological flows" OR "Instream flows" OR "In-stream flows" OR "Environmental water" OR "Cultural water"
System	Watershed OR Catchment OR Basin OR "River Basin" OR Floodplain OR "Drainage Area" OR Lake OR Estuary OR River OR Wetland OR Water
Governance	Manag* OR Co-manag* OR Plan* OR Govern* OR Co-govern* OR Sustain* OR "Decision making" OR Polic* OR "Environmental assessment" OR "Environmental impact assessment" OR "Impact assessment" OR Regulat*
Population	Stakeholder OR "Rights holder" OR Indigenous OR Aboriginal OR People OR Communit* OR Human OR Collaborat* OR Partner*

Table 3. Criteria for exclusion during full text screening. Note that exclusion criteria not displayed here include papers that were not accessible through public institutions (n = 5) and were not in English (n = 1).

Exclusion Criteria	Rationale Behind Exclusion Criteria	Number of Full-Text Papers Excluded (total excluded = 260; total included = 158)	Exclusion examples
Exclude if water governance is not a central focus	Water decision-making must be central to the study research question, not implied.	17 (6.5%)	Borsato et al. 2020. Weak and Strong Sustainability of Irrigation: A Framework for Irrigation Practices Under Limited Water Availability. DOI: 10.3389/fsufs.2020.00017.
Exclude if flow concepts are not a central focus	Flow concepts (ecological, environmental, cultural, or Indigenous) must be central and not peripheral to the study questions.	29 (11%)	Pittock and Hartmann 2011. Taking a Second Look: Climate Change, Periodic Relicensing and Improved Management of Dams. DOI: 10.1071/MF09302.
Exclude if the paper focuses solely on hydrologic, social, or ecological end point	The paper should move beyond hydro-ecological or hydro-social endpoints to broader decision-making.	18 (7%)	Gwimbi and Rakuoane 2019. Impacts of Dams on Downstream Riparian Ecosystems' Health and Community Livelihoods: A Case of the Lesotho Highlands Water Project. DOI: 10.1007/978-3-030-12974-3_12.
Exclude if there is no active involvement of human communities	Human communities must be actively included in the study through the flows implementation process or water decision-making.	122 (47%)	Lane et al. 2015. Environmental Flows in a Human-Dominated System: Integrated Water Management Strategies for the Rio Grande/Bravo Basin: Research & Management. DOI: 10.1002/rra.2804.
Exclude if the paper is a review	There must be individual empirical examination even if the paper is largely a review.	38 (14.5%)	Vorosmarty et al. 2018. Ecosystem-based water security and the Sustainable Development Goals (SDGs). DOI: 10.1016/j.ecohyd.2018.07.004.
Exclude if the paper is not peer-reviewed	Conference proceeding or government, non-government organization report, or thesis	30 (11.5%)	David 2015. Socio-environmental Tradeoff Analysis using Decision Science Tools to Guide River Management. Thesis.

Table 4. OECD Water Governance Framework Principles and their consideration in environmental and cultural flows governance and scholarship.

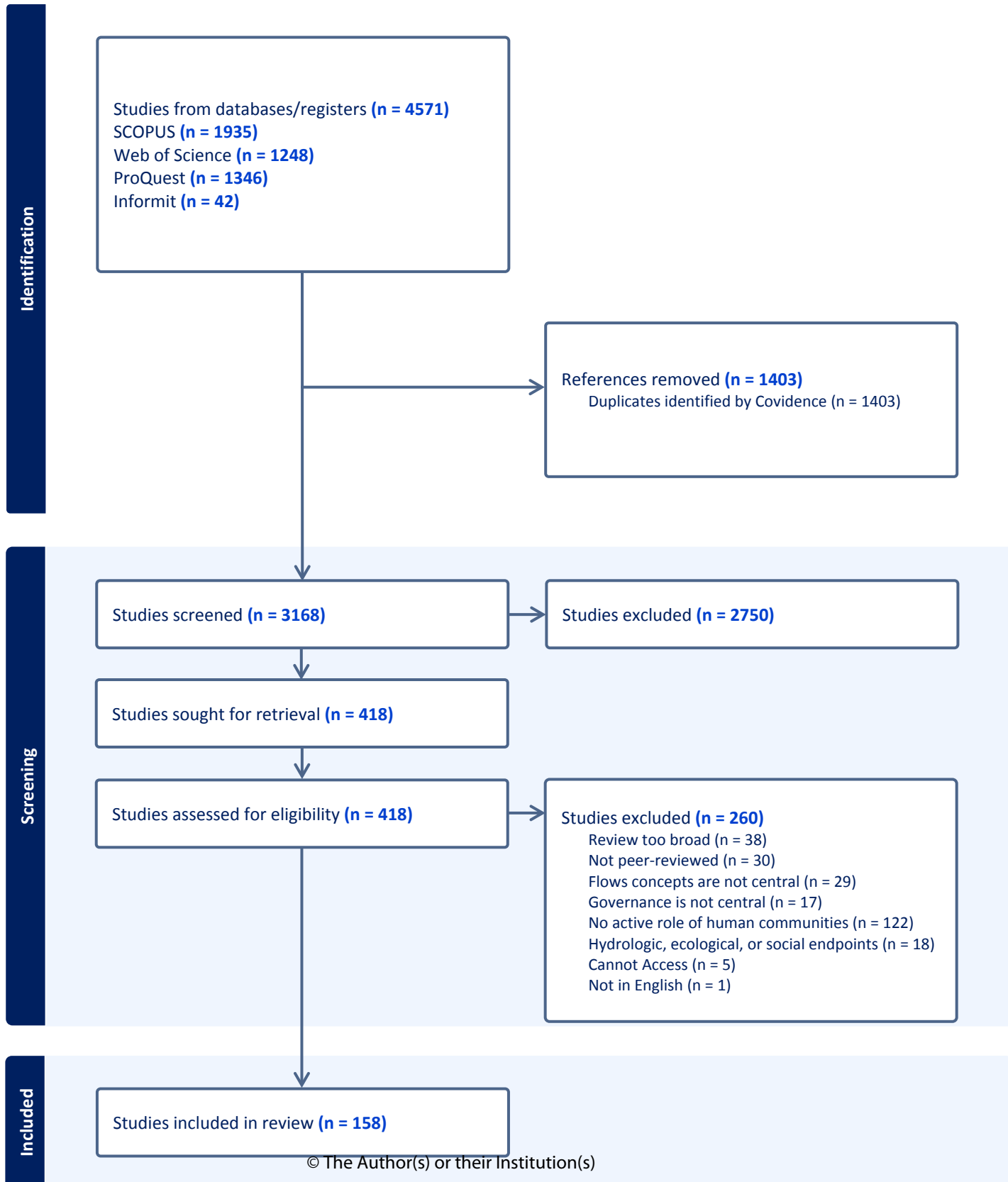
OECD Water Governance Principle	Emphasis in Environmental and Cultural Flows Governance and Scholarship
1. Roles and Responsibilities: Clearly allocate and distinguish roles and responsibilities for water policymaking, policy implementation, operational management and regulation, and foster co-ordination across these responsible authorities.	Papers in this review generally investigated or represented roles and responsibilities within the operational management of environmental water delivery or flow in water use strategies, but roles and responsibilities of stakeholders and Rights holders in policymaking and policy implementation that led to operationalization were less frequently examined. This gap was especially evident in environmental flow and centralized governance studies. In decentralized governance (co-governance in particular), there was more attention to roles and responsibilities to reform environment and cultural flow policies.
2. Appropriate Scale: Manage water at the appropriate scale(s) within integrated basin governance systems to reflect local conditions, and foster co-ordination between the different scales.	Management of environmental flows at appropriate scales was a major focus of centralized governance papers, especially those that considered strategic planning, strategic adaptive management, integrated water management, and strategic environmental assessment to inform development at a catchment scale.
3. Policy Coherence: Encourage policy coherence through effective cross-sectoral co-ordination, especially between policies for water and the environment, health, energy, agriculture, industry, spatial planning and land use.	Overall, there was minimal attention to policy coherence through the coordination environmental, social, and economic policies, but there was some attention to trade-offs in the management of environmental and cultural flows (Principle 11).
4. Capacity: Adapt the level of capacity of responsible authorities to the complexity of water challenges to be met, and to the set of competencies required to carry out their duties.	Building capacity through learning and knowledge-sharing was a major theme across papers with many reporting the need for skill-building and competencies in environmental and cultural flows by all actors to manage water equitably. Many papers also discussed building the capacity of Rights holders and stakeholders to engage in monitoring and research to support their water goals, the need to support networks for future outcomes, and supporting communities as decision-makers.
5. Data and Information: Produce, update and share timely, consistent, comparable, and policy-relevant water and water-related data and information, and use it to guide, assess and improve water policy.	Data mobilization was a focus of many papers with monitoring and modelling of environmental and cultural flows being a key opportunity to communicate community needs to decision-makers if data are accessible. This is especially true for papers describing centralized governance of environmental water. To support decentralized governance and the investigation of social and cultural values, there could be greater effort to monitor and share information in respectful ways.
6. Finance: Ensure that governance arrangements help mobilise water finance and allocate financial resources in an efficient, transparent and timely manner.	Papers that described governance arrangements that mobilised finance to support environmental and cultural flows initiatives were principally those that described cost sharing between national governments, non-profits, and international funds in multi-national watershed governance and those that supported funding for water transactions or water trusts in water markets.
7. Regulatory Frameworks: Ensure that sound water management regulatory frameworks are effectively implemented and enforced in pursuit of the public interest.	Many papers discussed existing regulatory frameworks (e.g., Australia's 2007 Water Act, the European Union's Water Framework Directive, Kenya's 2002 Water Act to define water user associations). In many cases, authors specified that current environmental and cultural flows legislation, policy, and related impact assessment initiatives are not adequate to support involvement of stakeholders and Rightsholders in setting water allocation mechanisms.
8. Innovation: Promote the adoption and implementation of innovative water governance practices across responsible authorities, levels of government and relevant stakeholders.	Innovative approaches to governing environmental flow processes occurred most in inclusive centralized governance arrangements through integrated holistic approaches, participatory modelling, and interdisciplinarity, among others.
9. Transparency: Mainstream integrity and transparency practices across water policies, water institutions and water governance frameworks for greater accountability and trust in decision making.	Few papers spoke of audits to determine the integrity and transparency of bodies governing environmental and cultural flows and whether law enforcement and program implementation is upheld. However, numerous papers advocated for integrity, inclusiveness, and transparency by building understanding, ownership, and trust in environmental and cultural decision-making.

10. Engagement: Promote stakeholder engagement for informed and outcome-oriented contributions to water policy design and implementation.	Stakeholder and Rights holder engagement were key considerations in all papers because the inclusion criteria for the review included the need for community involvement. However, stakeholders and Rights holders were mainly involved in management and implementation, not water policy design. This is represented by text coded to Principle one about roles and responsibilities in policymaking.
11. Trade-Offs: Encourage water governance frameworks that help manage trade-offs across water users, rural and urban areas, and generations.	Few papers described and assessed water governance frameworks, but many showcased trade-off models that show multiple scenarios and outcomes, often with community input. Trade-offs were those between water use for industry, cities, and then environment but also trade-offs between different environmental and social endpoints (frogs, algae, birds, vegetation, recreation, rights).
12. Policy Monitoring: Promote regular monitoring and evaluation of water policy and governance where appropriate, share the results with the public and make adjustments when needed.	While papers evaluated water policy and governance in place, few papers discussed the ongoing monitoring and evaluation of water policy and governance.

Source: OECD (2022). How to assess water governance: A methodology based on the OECD Principles on Water Governance.

Appendices

Supplementary Figure 1. The Covidence PRISMA diagram from our search process.



Codebooks

Environmental and Cultural Water

Term	Definition
Environmental Flows/Water	<p>“The quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems” - Brisbane Declaration (2007), Global Action Agenda (2018, p. 2)</p> <p>Ecological needs and inclusive decision-making in the same political system.</p>
Environmental-Social Flows/Water	<p>“The quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being.” – Updated Brisbane Declaration and Global Action Agenda (2018, p. 4)</p> <p>Hydro-social-ecological relationships (Anderson et al. 2019; Douglas et al. 2019), excluding Indigenous right and decision-making authority (Murray Lower Darling Rivers Indigenous Nations and Northern Basin Aboriginal Nations 2007).</p> <p>Ecological and non-ecological needs and inclusive decision-making in the same political system.</p>
Cultural Flows/Water	<p>“...water entitlements that are legally and beneficially owned by the Indigenous Nations of a sufficient and adequate quantity and quality to improve the spiritual, cultural, environmental, social and economic conditions of those Indigenous Nations.” – Echuca Declaration (2007, p. 2)</p> <p>Ecological and non-ecological needs with decision-making authority of Indigenous Nations (a separate sovereign political system), and Indigenous Rights.</p>

Governance

Term	Definition
Water/Environmental Governance	“The set of regulatory processes, mechanisms and organizations through which political actors influence environmental actions and outcomes” (Lemos and Agrawal 2006, p. 298).
Centralized/Top-Down Governance	Control by country (Bourceret et al. 2021)
Multi-National Governance	Control by multiple countries (Bourceret et al. 2021)

Polycentric Governance	Multiple semi-autonomous decision-making centres (Bourceret et al. 2021)
Co-Governance	Shared authority and collaborative decision-making (Bourceret et al. 2021)
Public-Private Governance	Facilitation between state and private sector (Bourceret et al. 2021)
Decentralized Governance	Co-governance, polycentric, public-private, or community-based governance (Bourceret et al. 2021)

Institutional Forms of Governance and Management

Form	Definition
Water Use Strategy	General protection of water resources for future use.
Dam and Energy production strategy	Production of energy from hydropower and operation or re-operation of dams.
Integrated Water Resource Management	“...a process that promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.” - UNEP
Environmental Impact Assessment	“...a planning and decision-making tool used to assess the potential positive and negative effects of proposed projects. Impact assessments consider a wide range of factors and propose measures to mitigate projects' adverse effects.” – Impact Assessment Agency of Canada

OECD Water Governance Principles

Principle	Definition
Principle 1 – Roles and Responsibilities in policy	Clearly allocate and distinguish roles and responsibilities for water policymaking, policy implementation, operational management and regulation, and foster co-ordination across these responsible authorities.
Principle 2 - Scale	Manage water at the appropriate scale(s) within integrated basin governance systems to reflect local conditions, and foster co-ordination between the different scales.
Principle 3 – Policy coordination	Encourage policy coherence through effective cross-sectoral co-ordination, especially between policies for water and the environment, health, energy, agriculture, industry, spatial planning and land use
Principle 4 – Capacity	Adapt the level of capacity of responsible authorities to the complexity of water challenges to be met, and to the set of competencies required to carry out their duties
Principle 5 – Data and information	Produce, update, and share timely, consistent, comparable and policy-relevant water and water-related data and

	information, and use it to guide, assess and improve water policy
Principle 6 – Finance	Ensure that governance arrangements help mobilise water finance and allocate financial resources in an efficient, transparent and timely manner
Principle 7 – Regulation (legal, administrative, and regulatory frameworks)	Ensure that sound water management regulatory frameworks are effectively implemented and enforced in pursuit of the public interest
Principle 8 - Innovation	Promote the adoption and implementation of innovative water governance practices across responsible authorities, levels of government and relevant stakeholders
Principle 9 - Transparency	Mainstream integrity and transparency practices across water policies, water institutions and water governance frameworks for greater accountability and trust in decision-making
Principle 10 – Engagement/Partnership	Promote stakeholder engagement for informed and outcome-oriented contributions to water policy design and implementation
Principle 11 – Trade-offs	Encourage water governance frameworks that help manage trade-offs across water users, rural and urban areas, and generations
Principle 12 – Monitoring or evaluation of policy	Promote regular monitoring and evaluation of water policy and governance where appropriate; share the results with the public and make adjustments when needed

Environmental and Cultural Water Governance Strategies

Strategies	Definitions
Decision Support Tools	Multidisciplinary participatory models and tools to support decision-making and policy options. - (Xue et al. 2016)
Water Use Caps	<p>1) Cap on Consumptive Water Use</p> <p>“Limit on the total volume of licenses issued and/or the extraction/abstraction of water against these licenses.”</p> <p>2) License Conditions for Water Abstractors</p> <p>“Conditions listed on the license of individual water users that restrict the volume and/or timing of extractions.”</p> <p>3) Conditions on Storage Operators or Water Resource Managers</p> <p>“Conditions on a storage operator prescribing releases from storage for downstream ecological needs.”</p>

	- (Horne et al., 2017, p. 363)
Event Space Management	A unique event that alters how people interact, thereby potentially altering the rules and norms of traditional management. - (Bark et al. 2016)
Development Space	<p>“the difference between current conditions in the basin and the furthest level of water-resource development found acceptable to stakeholders through consideration of the scenarios” - King and Brown (2010, p. 135-136)</p> <p>This category also includes incorporating regional water visions into strategic planning.</p>
Water Markets and Trade	<p>“a decentralized approach for allocating water and water rights that have been touted as part of the future of water policy for decades.” - (Garrick et al., 2023, p. 1)</p> <p>“a system of marketable rights to water would induce water users to consider the full opportunity cost of water, including its value in alternative uses, thus providing incentives to efficiently use water and to gain additional income through the sale of saved water.” - (Rosegrant and Binswanger, 1994, p. 1615)</p>
Indigenous Rights and Laws through Water Justice	“Water and its multi-faceted connections to Indigenous Peoples' self-determination – more precisely, to the socioeconomic, cultural, and political dimensions associated with Indigenous Peoples' exercise of the right to self-determination.” - (Robison et al., 2018, p. 841)
Water (Ecological and Aboriginal) Reserves and Trusts	“Legally establishes environmental water as a prior right to consumptive water use.”- (Horne et al., 2017, p. 363)
Legal Rights and Personhood	<p>Direct</p> <p>“Giving rivers legal rights means the law can see the river itself as a legal person, and the river can take legal action to enforce those rights. Legal personhood confers legal standing (often described as the ability to sue and be sued), which enables rivers to go to court to protect their rights.” - (O'Donnell 2019, p. 1)</p> <p>Indirect</p> <p>“Environmental water managers (EWMs) are organisations with legal personhood, which have been created to acquire and manage water for the aquatic environment.” - (O'Donnell, 2017, p. 503)</p>