

Adaptive capacity in federal rivers: coordination challenges and institutional responses

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Water crises have been described as crises of fragmented governance, particularly in transboundary settings where freshwater resources cross political borders. Federal rivers are transboundary river basins within or shared by a country with a federal political system. In federal political systems, the territorial division of authority creates incentives for local innovation, learning and adaptation; it also creates barriers to cooperation and conflict resolution needed for adaptive capacity across scales. This review examines the relationship between institutional design and adaptive capacity in federal rivers in three steps. First, we review coordination challenges in federal rivers, highlighting such challenges as fundamental for adaptive capacity in multi-jurisdictional settings. Second, we examine institutional responses to these challenges. Finally, we review lessons about institutional design and performance from large-N studies of international and interstate rivers. Systematic efforts are needed to measure and compare institutional design in federal rivers. Such efforts must balance global inventories to measure institutional design variables with in-depth case studies to generate context-sensitive insights about the effectiveness of different approaches as well as the causal mechanisms linking institutional design with social, environmental and economic outcomes.

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The world's major rivers are facing unprecedented threats from population growth, urbanization, and climate change and the associated shortage, pollution and flooding challenges [1,2]. A large and diverse body of scholarship has examined the potential and limits for adaptive water governance to enhance social and ecological resilience

to these threats [3–6]. This research spans a range of scales from the household and community levels to international rivers [7,8^{••}]. Rivers cross multiple jurisdictions, posing governance challenges to coordinate within and across sectors and scales of decision-making [9]. The prevalence of sub-national conflict and cooperation over water has prompted interest in the special challenges posed by institutional fragmentation in federal political systems, where authority is divided between national and sub-national governments [10].

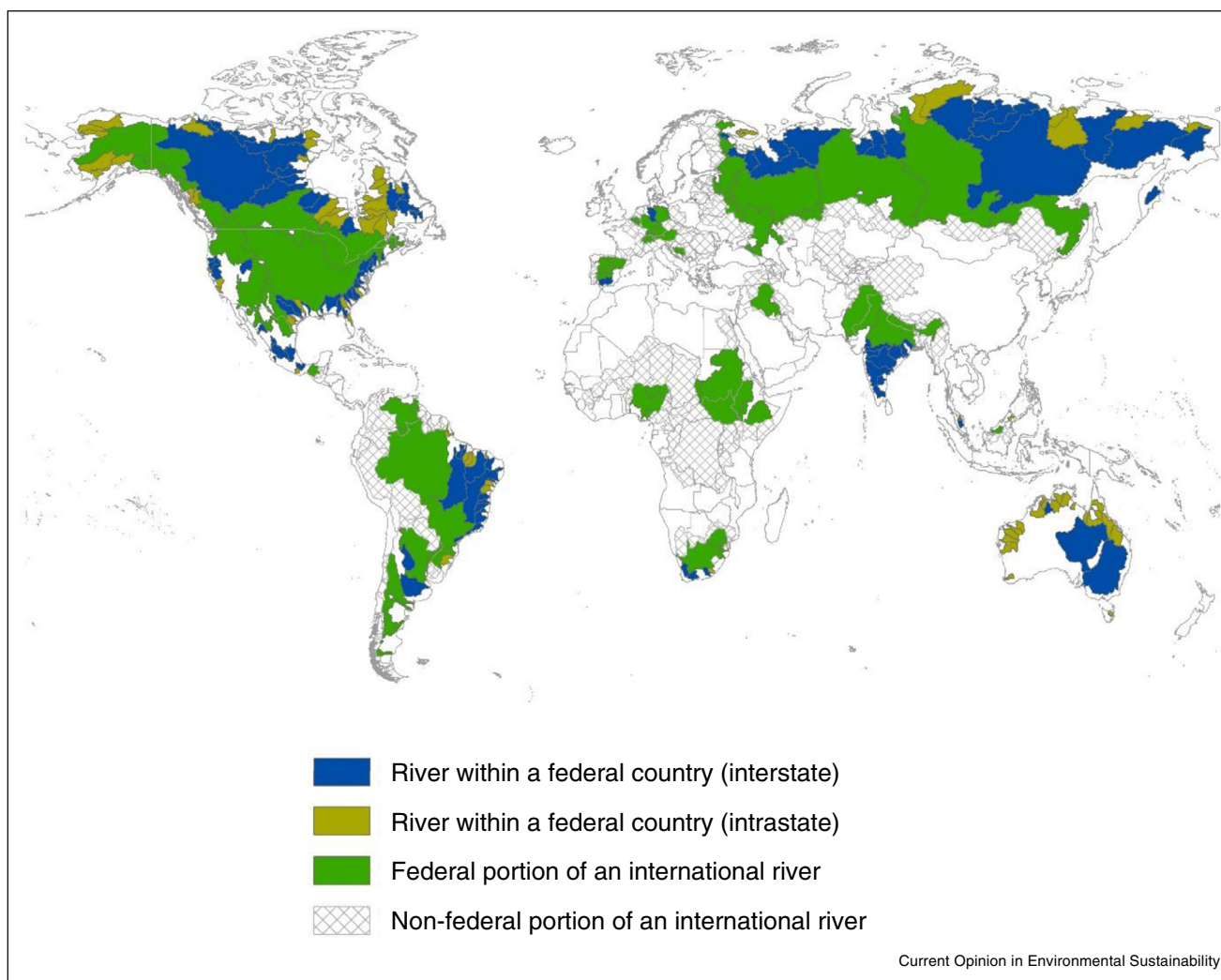
In this review, we consider adaptive capacity in transboundary rivers from a *federal perspective*, which emphasizes intergovernmental and multi-level water governance challenges, highlighting the politics and disputes that may impede coordinated approaches and require institutional mechanisms for conflict resolution, joint decision-making and adaptive governance. The federal perspective is perceived to be increasingly relevant even in non-federal countries, like China or the UK, where devolution, decentralisation or related processes create coordination challenges in shared rivers [11].

Federal rivers matter

A federal river is defined as a major river *within* or *shared* by a federal political system [12^{••}]. Federal rivers can be (Figure 1): first, rivers *within* a single state of a federal political system (e.g. Los Angeles River of California); second, rivers crossing more than one state *within* a federal country (interstate federal rivers, e.g. Murray-Darling of Australia) and finally, international rivers *shared* by one or more federal countries (such as the Nile, which has 11 countries, 3 of which are federal). More than 300 major rivers are classified as 'federal rivers' according to this definition, including iconic rivers like the Colorado, Sao Francisco, Murray-Darling, and Indus [12^{••}]. Federalism matters in each category of federal river, albeit in different ways, and poses inter-governmental and multi-level governance challenges.

The global extent, and diversity, of federal rivers makes them an important class of river, and highlights the need for systematic studies and comparisons to identify, measure and evaluate the institutional attributes of adaptive capacity within and across different contexts and over time [12^{••},13^{••},14–16,17^{••}]. Policy approaches and institutional structures vary within and across federations, yet share defining elements: a geopolitical division of territory, independent spheres of authority in territorial and national governments, and direct accountability of each

Figure 1



World's federal rivers. Major rivers within or shared by a country with a federal political system. Updated from [12**].

government to its citizens through elections [18]. Each level of government exercises primary authority over at least one policy area; in the case of water, authority over planning and allocation decisions is reserved primarily *either* for sub-national or national control depending on the federation and its constitutional provisions. Climate variability, extremes and change strain the resilience and adaptive capacity of governance arrangements in federal political systems, posing stress tests for intergovernmental relations by blurring roles and responsibilities during shortages, pollution events or floods [19].

The recent push to understand the role of institutional design to enhance adaptive capacity, reinforced by the inclusion of integrated water resources management and transboundary cooperation as part of Sustainable Development Goal 6 in 2015, requires evidence about how institutions influence patterns of interaction between

actors and across scales, as well as the associated social, economic and environmental outcomes [20]. This review assesses the institutional responses to coordination challenges in federal rivers in three steps. First, we review coordination challenges in federal rivers, highlighting such challenges as fundamental for adaptive capacity in multi-jurisdictional settings. Second, we examine institutional responses to these challenges. Finally, we review lessons about institutional design from moderate-N to large-N studies of international and interstate rivers to motivate future research.

Adaptive capacity and coordination challenges in federal rivers

Adaptive capacity has been widely debated and defined [21,22] and refers broadly to 'the ability of actors (collectively and individually) to respond to, create and shape variability, change and shocks in the state of a linked

social–ecological system (SES) [23**]. Adaptive capacity requires adaptive institutions and governance [24**], although institutions are only one of many influences on adaptive capacity, alongside infrastructure, information and technology, equity and social capital [23**]. Adaptive institutions are defined as ‘those that actors are able to adjust to encourage individuals to act in ways that maintain or improve to a desirable state’ [24**], p. 141. Koontz and colleagues [24**] identify the attributes associated with adaptive institutions,¹ which can be separated into *proximate* and *distal* factors. Social learning and leadership are examples of proximate factors, while polycentricity² and federalism comprise distal factors that set the conditions for proximate factors to emerge. The authors illustrate adaptive institutions by referring to the example of irrigation institutions in Rajasthan, India, where water scarcity triggered changes in property rights and decision-making related to tube wells [25]. Adaptive institutions may be considered a feature of adaptive governance, which explicitly focuses on coordination challenges by bringing together the ‘learning dimension’ of adaptive management with the ‘linkage dimension’ of co-management [6,26].

Adaptive capacity, adaptive institutions and adaptive governance all require effective coordination between actors at a given level (horizontal coordination) and across tiers of governance (vertical coordination). Federalism and polycentricity are two closely related concepts that describe the distribution and coordination of authority across multiple centres of decision-making to address these challenges. Both concepts identify the challenges to balance local decision-making with broader interests [24**]. Federalism and polycentricity can promote adaptive institutions, governance and capacity by fostering experimentation, learning and interactions across scales, and by providing redundancy and overlap to contain and offset failure [27]. They also pose constraints [28**]. The coordination challenges include issues of fit, mismatch and fragmentation [29,30]. The potential for tensions and trade-offs across spatial and temporal scales, whereby adaptations at a given place or time can compromise adaptive capacity at another, require coordination, collaboration and conflict resolution to limit externalities across jurisdictions [23**].

Institutional responses to coordination challenges

There is an extensive body of literature on institutional responses to coordination challenges within communities

¹ Institutional attributes have been described as ‘institutional dimensions’, ‘design principles’ and ‘enabling conditions’ — often, but not always, describing essential or necessary conditions for a given set of performance outcomes.

² Polycentricity is a ‘structural feature of social systems of many decision centers having limited and autonomous prerogatives and operating under an overarching set of rules’ see [39].

and across international borders [31–33]. At the community level, the capacity of resource users to self-organize has required institutions (rules and norms) to establish boundaries around the resource and to define eligible resource users, facilitate participation by users in rule-making, share costs and benefits proportionally, ensure adequate monitoring and enforcement, provide low-cost conflict resolution mechanisms and, when resources span multiple jurisdictions, create ‘nested enterprises’ that situate self-governance within multiple layers of governance [31].

At the international level, research has identified the role of treaties and river basin organizations to foster cooperation and resolve conflicts, requiring institutional capacity to keep pace with social, political and environmental stressors [33,34]. Several scholars have unpacked the key attributes of river basin organizations, noting the importance of inclusive membership (of nation-states), financing and capacity, and dispute resolution [35]. Climate variability and change test the resilience of institutions within communities and across international borders, requiring institutional mechanisms to manage variability, clarify the roles and responsibilities during extremes and resolve associated disputes [8**,28**,36,37].

While international rivers and community-level water governance have been well studied, a systematic understanding of these factors in federal political systems is lacking. In federations, institutional mechanisms are needed to coordinate across states (inter-governmental) and across tiers of governance (multi-level) [38,39]. Scholars have examined institutional responses to coordination challenges in the oldest federations, particularly in Australia, Canada and the US [40–42]. In the Western US context, Heikkila and Schlager emphasize the importance of cross-scale linkages³ to coordinate joint decision-making, facilitate cooperation and resolve conflicts [38,42,43]. Inter-governmental allocation agreements and associated river basin institutions coordinate joint studies, decisions, financing, dispute resolution, monitoring and enforcement. Inter-governmental water agreements are expected to be most effective when the rules are designed to share water resources, costs and benefits proportionally across jurisdictions and therefore be perceived as fair [19,43]. According to the literature on ‘institutional collective action,’ which addresses the dilemmas caused when governance functions are split across governance units, the costs and formality of coordination mechanisms are expected to increase when asymmetries — both resources and political — increase the risks of defection (exiting an

³ Cross-scale institutional linkages ‘connect actors or collective bodies that function at different scales or levels of social organization or political jurisdiction.’ [38], p. 122.

agreement), unfair division of resources, and ineffective coordination [44].

In federal rivers, roles and responsibilities for different levels of government must be clear when droughts, floods and pollution events occur to avoid shirking by state governments or encroachment by the federal government [45]. A clear division of authority should be supplemented by information sharing, accountability mechanisms and range of dispute resolution and decision-making venues, including both formal and informal venues [46]. The dependency on courts or tribunals for water dispute resolution in the US and India is a prime example of the high costs of conflict resolution in federations when roles and responsibilities are unclear, agreements are perceived as unfair or states try to promote their position at the expense of the broader regional and national interests [47].

Finally, institutional responses to coordination challenges in federal rivers often involve cost sharing and transfers of funding (or other resources) to build local capacity, incentivise cooperation or resolve conflicts [48]. Fiscal federalism refers to the ‘vertical structure of the public sector’ and how the ‘different levels of government ... relate to one another through such instruments as intergovernmental grants’ [49]. Fiscal arrangements in federal rivers refer to the sources, sharing and transfer of resources by sub-national and central governments. They affect the incentives for cooperation in at least two ways. First, federal governments can encourage cooperation by transferring funding from the federal level to states to build capacity for meeting national or interstate policy objectives or withholding such funding for lack of compliance [50]. For example, the transfer of funding from federal to state levels has provided an important means of strengthening local capacity to meet federal or interstate directives, as illustrated by the Brazilian National Water Pact, an almost USD \$50 million program launched in 2013 to address regional inequality in water management [51]. Second, state governments can withhold contributions to support the ‘joint business’ of inter-governmental agreements (e.g. funding for river basin organizations, monitoring networks, etc.) to undermine cooperative agreements or protest perceived encroachment by the central government.

Institutional responses are interdependent and do not operate on their own. For example, the combination of several institutional mechanisms is found to be critical for building resilience in five states in the USA [52]. Moreover, institutional characteristics — which are the focus of this review — need to be considered alongside infrastructure and information, and their effectiveness should be assessed through the analysis of the interactions (cooperation and conflict) across and between levels of governance

as well as in terms of social, economic and ecological outcomes (Figure 2).

Institutional design and performance: learning from large-N studies

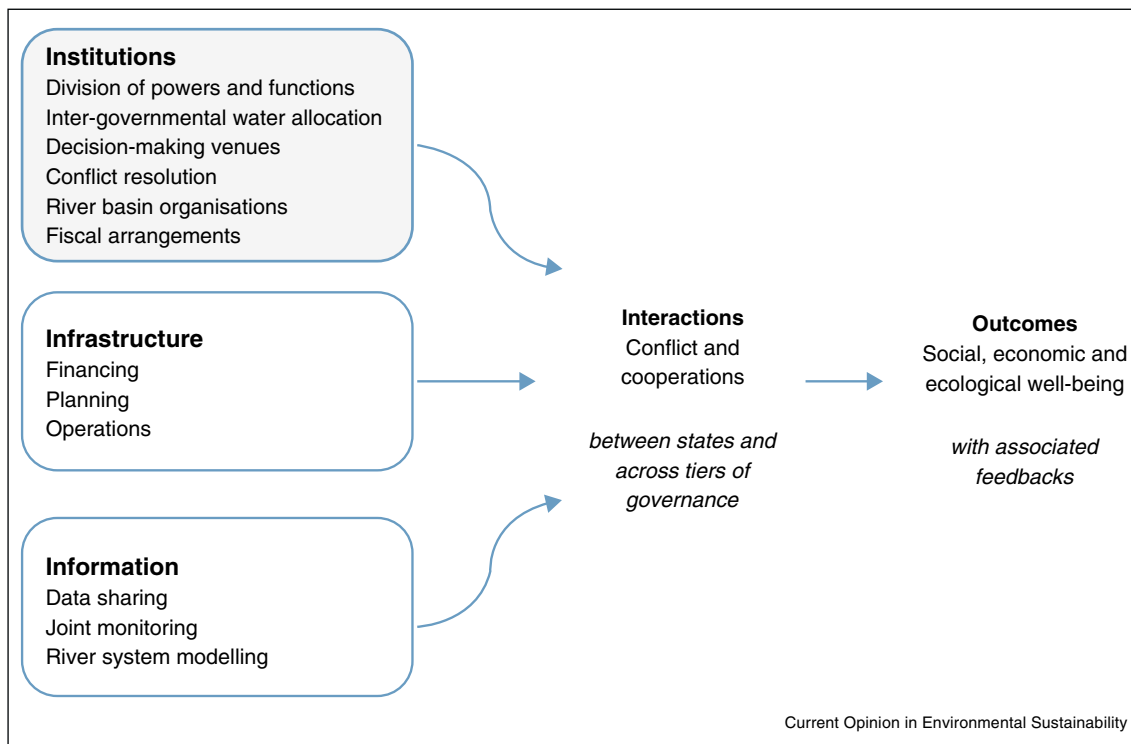
Global datasets (moderate-N to large-N) have been created for international rivers to track geographic, institutional and socio-economic factors associated with patterns of cooperation and conflict between nation-states [32,53,54]. Comparable datasets are more limited for federal rivers, hampered in part by the lack of conceptual clarity and empirical evidence of the design variables relevant for interstate and multi-level coordination in federations. We focus here on the institutional design characteristics associated with adaptive capacity in international rivers (and for interstate rivers within federations), including the institutional attributes or dimensions used to promote cooperation, resolve conflicts and enhance adaptive capacity (Table 1).

Prior studies on international rivers and domestic rivers are relevant to the different types of federal rivers considered in this review with the caveat that power dynamics and risks are substantially different at international and subnational levels [55–58]. At the international level (following Table 1), treaties [37] and shared ‘authority structures’ [8**] facilitate transboundary planning and action through formal agreements and river basin organizations. National-level capacity is also needed to give force to these agreements, share information and form common perspectives with neighbouring countries [8**,55]. At the national and sub-national levels, power must be distributed and coordinated to balance local and regional interests [28**,59]. Clear boundaries between sub-national and national roles are needed, as are mechanisms for sharing costs and benefits in a way that facilitates cooperation and low-cost conflict resolution [38].

The experience gained through the studies in Table 1 can inform the analysis of institutional design characteristics in federal rivers in several ways. First, these studies illustrate how the presence or absence of institutional attributes affects adaptive capacity or is expected to do, which can create opportunities for policy transfer to regions facing similar problems in similar contexts [12**]. Second, they highlight the unresolved challenge of effectively measuring outcomes of policy processes, as revealed by the tendency of focusing on the presence or absence of a given attribute rather than on its level of performance or its interactions and interdependence with other attributes. Third, these studies stress the importance of explicitly

⁴ In a prior 2012 study, Pahl-Wostl and colleagues [59] identify three focal ‘regime characteristics’ for adaptive governance: formal institutional setting, regime architecture and degree of integration and coordination, and knowledge and information management, each of which is further decomposed into a set of ‘underlying indicators.’

Figure 2



Type of factors influencing adaptive capacity in federal rivers.

Table 1

Moderate-N to large-N studies measuring institutional design characteristics associated with adaptive capacity.

Study	Dimensions or attributes
<i>International rivers</i>	
Institutional Resilience to Climate Variability in International Basins [37,54]	Presence of a water treaty Water allocation mechanism Variability management provisions Conflict resolution mechanism River basin organization
Institutional Capacity to Adapt to Climate Change in International Basins [8**]	Authority National-level governance Common perspective Risk planning and provision Basin information exchange Linkage (interdependence)
International River Basin Organizations and Adaptive Capacity [55]	Membership structure (integration) Functional scope (integration) Decision-making mechanisms (timely and binding) Data and information sharing Dispute-resolution mechanisms Finances and donor support
<i>Domestic</i>	
Capacity for Climate Adaptation in International Basins [28**] ⁴	Distribution of power Vertical integration Horizontal integration
Cross-Scale Institutional Linkages: Interstate Rivers [38]	Well defined boundaries Well matched provision and appropriation rules Accountable monitoring Enforcement Low cost conflict resolution

justifying the conceptual and methodological choices associated with the analysis of institutional design and performance measures [20,60**] based on a combination of theory and evidence. Finally, the analysis of institutional design and performance is subject to the numerous conceptual and methodological caveats about indicators discussed in existing studies [61] which should serve as powerful reminder of the intrinsically imperfect nature of indicators and of the challenges associated with their intended and unintended uses in science and policymaking [62**].

Moving forward, the study of institutional design and adaptive capacity in federal rivers should advance on five parallel and complementary tracks: first, the systematic inventory of key features of institutional design in federal rivers across the globe, to generate a first overview of how federal political systems tend to organize water governance; second, in-depth case studies, to generate evidence-based knowledge on the specific challenges and solutions posed by water governance in federal rivers; three, comparative studies focusing on selected institutional mechanisms, to advance the understanding of their functioning and level of performance in different contexts; four, identify methods and metrics to measure the quality of interactions and outcomes associated with water governance in federal contexts; and five, design and test indicators of institutional performance based on the body of knowledge built in the previous activities, to inform the debate about how to build more resilient and adaptive water institutions in federal rivers. Efforts to build a systematic understanding of federal rivers must be sensitive to context and the need to transfer policy lessons based on the nature of the problem and the suitability of the institutional responses given the social, economic and environmental conditions [63**,64].

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