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Institutional levels of water management in the Colorado River basin region: A macro-historical geographic review

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Complex water-stressed basins like the Colorado River in North America have multiple institutional levels of water management. Each institutional level is characterized by rules, organizations, and spatial jurisdictions that developed over decades to centuries to shape a dynamic multi-level system. After introducing the concept of institutional levels, and its relationship to geographic scales, this paper employs systematic bibliographic search methods to review their development in the Colorado River basin region. Results begin with the community level of water management from prehistoric Indian water cultures to early Hispanic water communities, 19th century water communities, and 20th century water organizations. Conflict among water communities shaped the state level of constitutional authority over water rights administration during the 19th century. Competition among states led in the 20th century to the interstate level of apportionment that often paralleled federal and tribal level water development policies, eventually leading to the international level of treaty relations between the U.S. and Mexico. This macro-historical geographic progression from institutions that were relatively small in size and early in time to those at higher levels and more recent in time offers insights into the multi-level institutional logic of the "law of the river" in the Colorado River basin region.

KEYWORDS

levels, multi-level, institutions, scale, Colorado River basin, historical geography, law of the river

1. Introduction

Complex river basins have centuries of institutional development that are often challenging to understand (White, 1977; Wescoat et al., 2018). The Colorado River basin region of North America provides a good example (Figure 1). It encompasses parts of seven states in the western United States plus two states in Mexico that drain from the headwaters of the intermountain region into the Colorado River delta and Sea of Cortez. Water transfers extend beyond basin boundaries to the South Platte and Arkansas River basins in eastern Colorado, the Rio Grande basin of New Mexico, the Great Salt Lake basin of Utah, and the Salton Sea basin and coastal cities of southern California

(Schmidt, 2022). The Colorado River's complexity arises in part from its centuries-old mosaic of water communities, which was reframed by state water laws in the second half of the 19th century, followed by interstate compacts, river basin plans, extra-basin transfers, and international treaties through the 20th century (Hundley, 1966, 2009; Meyers, 1966; U.S. Bureau of Reclamation, 2010; Robison, 2017). Many readers may be familiar with the distinctive system of prior appropriation doctrine water rights in the western United States. It originated in mining camps and early irrigation systems where seniority of water use rather than place of water use established the basis of a right (Schorr, 2012). This paper shows how those water rights, defined at the state level, fit within longer histories and multiple institutional levels of water management (Benson et al., 2021; Zellmer and Amos, 2021).

The Colorado River basin has a long history of water problems—conflict, competition, salinity, scarcity, and others – no more so than in the current crises of drought and overappropriation that have jointly led to the lowest main stem reservoir levels and largest cutbacks in history (U.S. Bureau of Reclamation, 2012; Kuhn and Fleck, 2019; Salehabadi et al., 2020; Robison et al., 2021; Congressional Research Service, 2022; U.S. Department of Interior, 2022; Wheeler et al., 2022). Each water problem, large and small, has been shaped by the basin's elaborate water institutions, i.e., its norms, laws, policies, and organizations that enable, constrain, and regulate alternative courses of action (National Research Council, 1968; Ingram et al., 1984; Ostrom, 2008; Easter and McCann, 2010).

1.1. A brief historiography of research on water institutions

Research on water institutions belongs to the broader scope of research on the political economy of water governance. That scope is enormous and growing, as surveyed in recent volumes by Burnett et al. (2014), Conca and Weinthal (2018), Harris et al. (2019), Bogardi et al. (2021), and others. The historiographical perspective offered here thus focuses directly on institutions, and considers related lines of water politics as they arise.

The word institution has ancient origins, stemming from the Latin *institutio* ("set up"), and has early English usage in Thomas More's *Utopia,* translated in 1551, where it refers to regulative social norms and laws. Research on water institutions that influenced the United States dates to mid-19th century studies of irrigation systems in the Andalusian region of Spain. Those historic systems developed community water rights and tribunals to adjudicate disputes among water rights holders that date back to medieval times (Glick, 1970). They were studied as successful irrigation precedents by British colonial engineers in India (Garrido, 2014), and Californian engineers and lawyers who compiled surveys of irrigation laws from around the world (e.g., Hall, 1886). A century later a political scientist and economist, Maass and Anderson (1978), compared the economic efficiency and equity of three of these Spanish systems with three irrigation systems in the western U.S. While some eastern U.S. politician-scholars like George Perkins Marsh criticized the social and environmental effects of irrigation, western engineers like Mead (1903) believed irrigation institutions would enable the progressive reclamation of arid lands for small farmers. A smaller body of scholarship at that time wrote of health spas and bath facilities, i.e., organizations, as "water institutions." By the turn of the last century, the term institutions thus denoted water rights, reclamation policies, and a wide range of water organizations.

The mid-20th century witnessed a wave of critical political scientific research on water institutions, especially those of federal river engineering and basin development (Wengert, 1957). Early case studies featured the unique federal corporation known as the Tennessee Valley Authority (Selznick, 1949). Maass (1951) wrote a deeply critical account of *Muddy Waters: The Army Corps of Engineers and the Nation's Rivers.* Outside the U.S., Wittfogel (1957) directed stronger criticisms of centralized irrigation regimes that he described as *Oriental Despotism* – from antiquity to the present—though oddly omitting U.S. case studies (cf. Worster, 1992; Wescoat, 2000).

Early research on water politics in the western U.S. included Dean Mann's (1963) study of state water policy in Arizona. Political scientist Ostrom (1953) analyzed the politics of metropolitan water systems, which he characterized as polycentric rather than as centralized (Ostrom et al., 1961). Ostrom (1990, 2005, 2010) carried forward that line of research on polycentric dimensions of political economy and related concepts of institutional diversity.

Although studies of water institutions became mainstream in the decades that followed [Smith, 1960; Federal Council for Science and Technology (U.S.), 1969; Fox, 1976], there were growing concerns about both the subfield and the problems it needed to address. Ingram et al. (1984) described institutional studies as more descriptive than analytical. Institutional problems ranged from fragmentation across water sectors to rigid hierarchical structures of control, intractable stakeholder conflicts, and persistent constraints on social change (Ingram and Ullery, 1980). These criticisms helped spur an international literature on strategies for institutional reform (e.g., Gopalakrishnan et al., 2005; Saleth and Dinar, 2005; Crase and Gandhi, 2009).

On the broader plane of institutional economics, advances were made in linking research on economic history and political economic change (North, 1990, 1991), which included many applications to property rights, common property regimes, and environmental policy evaluation (Saleth and Dinar, 2004). Anthropologist Douglas (1986) critiqued rational choice models of institutions, arguing that societies construct institutions to support cooperation. In between these views,

FIGURE 1
Map of the Colorado River basin region (Courtesy of: J.C. Schmidt, Center for Colorado River Studies, Utah State University, 2022).

political scientists Elinor and Victor Ostrom developed a framework of Institutional Analysis and Design (IAD) that focuses on institutions as informal rules-in-use rather than as formal written documents. An important application of that framework involved the crafting of institutions for self-governing irrigation systems (Ostrom, 1992), which built upon earlier comparisons of bottom-up community water systems and top-down bureaucratically managed systems (e.g., Coward, 1980). Cole (2017) argues for including formal laws within the IAD framework. Recent research treats these institutional hierarchies as multi-level systems, which has special relevance for the Colorado River basin region (e.g., Moss and Newig, 2010; and for the Colorado see York, 2021).

Most recently, theorists have generated research on the dynamic social and political nature of institutions (e.g., Guala, 2016; Philosophy of the Social Sciences, 2018; Jupille and Caporaso, 2022). Recent water resources research does not appear to cite these works yet, which may reflect a shift from institutions toward the expansive theme of governance (Woodhouse and Muller, 2017). However, a focus on institutional levels of water management promises insights into their origins, logic, and interactions. The historical geographic approach taken here shows how institutional levels of water management in the Colorado River basin region—from the community to international level – co-evolved with changing ideas about the enabling and constraining, regulative and reforming, dimensions of water institutions. An important step in the context of this journal issue on scale is to consider the relationships among institutional levels and geographic scales of water inquiry.

1.2. Relationships among institutional levels and geographic scales of water management

A core argument in this paper is that water management institutions develop at different socially-defined *levels*, from communities to states and nation states. It is important to consider how these institutional levels are related to geographical *scales* of water inquiry (for related but somewhat different perspectives on levels and scales see Sheppard and McMaster, 2004; Neumann, 2009; Islam and Susskind, 2013, p. 46–51, 71–79; York, 2021). Institutional levels are socially-defined jurisdictions with distinctive rules and organizations that guide water management. They include community water norms, state water rights, interstate river compacts, tribal water laws, federal water policies, and international water treaties. Complex river basins, like the Colorado, have all of these multiple levels of water management (Wheeler et al., 2018; York et al., 2019). Although often described hierarchically, whereby international treaty agreements take precedence over federal policies, which take precedence over state and local policies, local actors retain significant authority and agency in river basin deliberations. Over time, each level shapes and is shaped by all of the others, while retaining and adapting its own distinctive rules and organizational structures.

It will be shown that community (including tribal) levels arose first, followed by state, interstate, federal, and international levels in successively larger geographical areas. This progression calls for consideration of relationships between institutional levels and geographic scales. For example, the state *level* of water laws applies to geographical configurations of water use and hydrologic processes within the jurisdiction of a state. However, those water patterns and processes can be examined at multiple geographical scales that do not correspond or fall within institutional boundaries. Hydrologists analyze variations within and across scales in quantitative ways (e.g., Sposito, 1998). Social scientists, by comparison, have focused recently on the politics of scale (Norman et al., 2012, 2015; Perramond, 2012, 2015); political dynamics across scales (Mumme and Leigh Taylor, 2014); and political ecologies that encompass multiple spatial and temporal scales (Ward, 2003; Buechler and Hanson, 2015). These political approaches challenge the "fixity" of scale (Martin, 1999) and "stationarity" of water rights and compacts (Perramond, 2020). At the same time, they tend to conflate institutional levels and geographical scales of water inquiry.

Sometimes efforts are made to align levels and scales, as for example when a state water agency uses river basins, watersheds, or economic regions to administer water rights or water policies in those areas. As water users compete with one another over transboundary streams and aquifers, states develop higher-level interstate institutions to address those larger geographical issues. In the Colorado River basin context, its multi-level system of institutions is collectively known as the "law of the river" (MacDonnell et al., 1995).

1.3. Approaches to the study of institutional levels of water management

The argument in this paper is that a systematic review of levels of water management helps understand the institutional logic at each level. Understanding the multiple levels of institutions that develop in the historical geography of a river basin region sheds light on basin challenges and opportunities. There are several ways to construct a multi-level review (e.g., see York, 2021). Many studies start with a pressing water problem, and review its institutional context starting at the international treaty level and proceeding to the federal policies, interstate compacts, state laws, and local organizations that define the problem (e.g., Wescoat, 1984, 25–58 on oil shale development; and Wescoat, 1986 on salinity). This top-down progression from relatively recent international water institutions to lower level institutions that have earlier histories cuts against the grain of history.

A second approach in river basin histories thus proceeds in the opposite direction. It may begin with a current situation or problem in the basin, but it strives to reconstruct the origins and development of relevant water management institutions over time. Historians have offered rich accounts of western water management from early records of Hispanic and 19th century colonization, followed by 20th century river basin development (e.g., Meyer, 1984; Worster, 1992). This historical approach tends to either proceed from local water communities to changing state, federal, and international policies; or, more commonly, it retraces the dynamic interactions across multiple levels of water management over time. Historians often focus in depth on institutional changes over relatively limited time periods, e.g., negotiations over the Colorado River compact in the early 20th century (Hundley, 2009). Their *longue durée* rarely extends to the archaeological record of prehistoric water management that is important in the Colorado River basin.

A third approach comes from water lawyers in the western U.S. who recount the institutional history and trajectory of the "law of the river," often beginning with basin state water laws, followed by documents that shaped the Colorado River Compact in 1922, and subsequent laws and policies up to the present (e.g., MacDonnell, 2021). Some legal histories mention prehistoric and early Hispanic communities (Meyer, 1984; Ragsdale, 1998), but most begin with late-19th century water laws. Water law casebooks are often organized by these state, interstate, federal, and international levels (e.g., Benson et al., 2021; Zellmer and Amos, 2021).

This paper builds upon these three approaches, especially the "law of the river" tradition, by presenting a systematic review of levels of water management in the Colorado River basin region. It shows how rules and organizations at each level differ from, and relate to, those above and below. It extends the law of the river approach by adopting a macro-historical geographic approach that proceeds from community water institutions that are early in time and small in size to institutional levels that are larger in size and more recent in time. Within the constraints of a journal article, it is only possible to offer a brief review of research conducted on each institutional level of water management. The paper used bibliographic search methods described in the next section to identify sources for each level that are summarized in the results section. The discussion reflects on interactions among levels and the conclusion on insights from this review.

2. Methods

This review adapted systematic bibliographic search methods [cf. Gough et al., 2012; Collaboration for Environmental Evidence (CEE), 2013; Fischer et al., 2021, ch. 7]. They were initially developed to identify potential environmental impacts of FAO Investment Center projects (Wescoat, 1997). They were subsequently used to survey ex-post evaluations of water projects globally (Halvorson and Wescoat, 2002). Legal materials search methods were added to trace the diffusion of public trust doctrine cases in the U.S. and South Asia (Wescoat, 2009). A search for rural and urban water conservation research in the U.S. and India identified gaps and linkages between those fields and regions (Wescoat, 2005, 2014), as did a review of intersections between research on political ecology and natural hazards (Wescoat, 2015). Extension of these methods to the Colorado River basin began by identifying the following levels of water management:

- Community water management
- State water laws and policies
- Interstate water apportionment
- Indian tribal water law and policies
- Federal water policies
- International treaty relations

A common set of bibliographic indexes was used to give consistent treatment to each level:

- WorldCat—for books.
- Web of Science—for journal articles in all fields.
- Compendex—for water engineering articles.
- LexisNexis Uni—for laws and law reviews.
- Water Resources Abstracts—for water publications and reports.
- Proquest Dissertations—for full text doctoral dissertations.
- America History and Life—for community levels.

Keywords varied somewhat for each level, so search results were used to identify major studies and not to conduct quantitative bibliometric analysis across levels (cf. Fischer et al., 2021). Pairs of search terms were entered as keywords or equivalent. When hits exceeded 50, one or more search terms were treated as title words. If still large, results were limited to the past 10 years. Raw hits were reviewed for their relevance and, if relevant, for their breadth and depth of coverage. Top hits are cited in the review. These methods are demonstrated below with results from an initial search for the key concepts of "levels," "scales," "institutions," and related concepts in Colorado River basin research (see Supplementary Table 1). We included "scale" as a search term as it often encompasses levels as defined here.

2.1. Levels

Many studies have dealt in colloquial terms with levels of water management in the Colorado River basin (e.g., local level, village level, state level, and so on), but few treat the concept of levels systematically. An early study by Larson et al. (1979) shows how levels of decision making in the Uintah basin and Colorado River basin dealt with 20 obstacles to conflict resolution in water resources planning. Moore (2017) examines how interactions at the subnational level of state and non-state actors affect collaboration in federal river basins like the Colorado. Several studies employ concepts of *multi-level* water management. York et al. (2019) consider the concept of a *nested hierarchy* as one of three lenses for understanding the socio-hydrology of Arizona water resources. Evans et al. (1982) developed an early multi-level model for salinity control in the Upper Colorado Basin. Aghnami and Hogue (2005) discuss computational strategies for model calibration in multi-level watershed hydrology. Wheeler et al. (2018) compare methods of multi-level modeling with applications to the Colorado and Murray-Darling River basins.

Suykens (2018) explicitly frames the "law of the river" as a multi-level system. Several studies examine decision-making processes at multiple levels in relation to sustainability criteria (Berggren J., 2018; Iribarnegaray et al., 2021; York, 2021).

2.2. Scales

As mentioned above, institutional levels are often conflated with concepts of *scale* in water resources research. This bibliographic search yielded larger numbers of keyword and title hits for scale than for levels. Many of those hits describe research of a specific size, e.g., small-scale, large-scale, landscape scale, and so on (e.g., Huenneke et al., 2015). The largest group of studies involve scale in hydrological and ecological vis-à-vis management terms. Some focus on downscaling climate models to generate hydroclimatic scenarios (Freeman, 1993; Kim et al., 2006; Mendoza, 2015; Foster, 2018). Others analyze temporal and spatial scales of streamflow, peak flow, stream networks, and watershed hydrology (Peckham, 1995; Veitzer, 1999; Mantilla, 2007; Nowak, 2011; Ficklin et al., 2013). Studies of ecological scale examine riparian and aquatic species and community dynamics (Lammers, 1998; Shafroth et al., 2017), and ecosystem threats (Paukert et al., 2011; Comte et al., 2022). An interesting law review article assesses what water lawyers can learn from large-scale ecological research (Bosselman, 2002).

Another significant group of studies deal with scales of water management in the Colorado River basin. Page and Dilling (2019) ask how "communities of practice" can help scale-up the use of climate information in water management. Several studies examine multi-scalar dynamics of water quantity and quality issues along the U.S.-Mexico border (e.g., Mumme, 2008; Mumme and Leigh Taylor, 2014). Fischhendler and Feitelson (2003) underscore how U.S.-Mexico negotiations on Colorado flows were linked to the larger border region that includes the Rio Grande and Tijuana River basins. Fraley (2012/2013) reviews challenges of "scaled legislation" that has promoted regional development in the Colorado River basin from the New Deal era to the present. A recent study re-reads 19th century natural surveys of the Colorado River "from source to sea" through the politics of scale (Kroepsch et al., 2021).

2.3. Institutions

The most common approach to levels of water management in the Colorado River basin involves various types of policy analysis that situate urban, regional and subsectoral water policies within broader sociopolitical contexts (e.g., Al-Sabbry, 1998; Gerlak, 2017; Karambelkar, 2020). Colorado River Simulation System (CRSS) models using the Riverware platform incorporate institutional rules for reservoir operations to simulate the effects of hydroclimatic and policy scenarios (Fulp et al., 1999; Zagona et al., 2001; Gilmore et al., 2004; Gastélum and Cullom, 2013; and a critique by Wheeler et al., 2019). Hadjimichael et al. (2020) model the distributional effects of institutional variables within the basin.

Institutional analysis has been employed to characterize water laws and policies in the basin (e.g., Kenney, 1995; Lord et al., 1995; Kenney et al., 2011). This is the principal approach used in research on the law of the river, which involves structured analyses of Colorado River laws, compacts, and treaties (Fahmy et al., 1983; MacDonnell et al., 1995; Anderson, 2004; Harkins and Snow, 2004; CLE International, 2013; Robison, 2017, 2022). State and federal agencies have produced compilations of the law of the river documents (e.g., Arizona Department of Water Resources, 2000; U.S. Bureau of Reclamation, 2010). In addition to descriptive and analytical studies, some law of the river research advances normative proposals for river basin management (e.g., Quesada, 2016; McKenzie, 2021, on the neighboring middle Rio Grande). MacDonnell (2021) offers an upper basin perspective on concerns about institutional uncertainties in the law of the river (also Carrico, 2014).

2.4. Governance and related concepts

Institutional research is increasingly framed within the broader socio-political context of water governance (e.g., Getches, 1997; Koebele, 2017; Berggren J. G., 2018; Singh et al., 2019; Juricich, 2020). Governance research in Arizona, for example, has focused on pressing issues of groundwater and transboundary water management (e.g., Wilder, 2020; Albrecht, 2021). Burnham (2022) employs discourse analysis in a study of the Central Arizona Project. Several studies employ a *political ecological* framework to examine power relations across boundaries in the lower Colorado (Ward, 2003; Butler, 2015; Scarrow, 2016). A significant body of governance research addresses transboundary relationships (e.g., Sternlieb, 2014; Mead, 2017; Tapia Villaseñor, 2020). Institutional levels of water management are incorporated in most of this governance research.

With this demonstration of bibliographic search methods applied to levels, scales, institutions, and governance of the Colorado River basin region—and the rationale for focusing on institutional levels—we proceed to substantive results and review. Given the breadth of review, the results are necessarily limited to major institutional structures and references.

3. Results

3.1. Community levels of water management

Communities constitute the earliest and most local level of water management from prehistoric times to the present.

The community level includes four major historical periods and culture groups in the Colorado River basin region—from prehistoric times to the present – each of which has distinctive institutions and continuities that have shaped subsequent multi-level systems of water management.

3.1.1. Prehistoric water communities

Prehistoric hunter-gatherers sought campsites with proximity to favorable water, vegetation, fish, and game conditions, and protection from winter winds and summer heat (Soule, 1981; Bozovich, 1987; Lubinski, 2000; Schneider, 2002; Yansa, 2007; Adams, 2010). This bibliographic search concentrated on later prehistoric cultures engaged in water management, using search terms such as, "Hohokam" for canal irrigating tribes in central Arizona; "Anasazi" for check-dam building tribes in the Colorado Plateau region; and "Mogollon" for tribes in the middle Rio Grande basin (Supplementary Table 2A; Figure 2). Research on prehistoric water communities involves archaeological studies of material culture with input from ethnohistorians (e.g., Toll, 1995). In these prehistoric contexts informal institutions are inferred from their material and geographical contexts. Search results are thus categorized by water management technologies, settlement patterns, and hydrologic contexts, from flood-farming to canal irrigation.

3.1.1.1. Flood farming communities

Flood farming communities lived along large perennial rivers like the Rio Grande and lower Colorado that were too large for those groups to physically control. Bryan (1929) documented flood-water farming methods that ranged from simple plant gathering to encouragement of preferred species. At a more advanced level, farmers planted seed in moist floodplain soils (Wellman and Ahlstrom, 2008). Some lower Colorado River tribes continue to harvest floodplain vegetation, though mobile flood farming has largely been replaced with irrigation systems (Smith, 2010).

3.1.1.2. Check dam, cistern, and well water communities

Small, intensively managed, water works were developed along intermittent stream channels in semi-arid upland environments by Anasazi (Ancestral Puebloan) cultures of the Colorado Plateau (Kirkpatrick, 1986; Doolittle et al., 1993), and some Hohokam settlements (Logan, 1999). Wells, check dams, and cisterns supported architecturally sophisticated defensive settlements in the Mesa Verde cliff-face settlement (Wright, 2003, 2004; Reese, 2020). Check dams impounded sediments to create favorable planting beds and control erosion (Doolittle, 1985). They sometimes directed water to small square basins, later called "waffle gardens" (White et al., 1998). Ragsdale (1998) has sought to infer a "jurisprudence," i.e., institutions, from these prehistoric Anasazi community systems.

At the larger scale of soil moisture management (Dominguez and Kolm, 2005), runoff diversion works directed water to gridded (Dominguez, 2002) and pebble-mulched fields (Lightfoot and Eddy, 1995). Some impoundments created water reservoirs (Wilshusen et al., 1997). One diversion canal has been interpreted as a flood control structure in Chaco Canyon (Wills et al., 2016), which developed numerous water sources and structures (Scarborough et al., 2018). Further south in the Sonoran borderlands, Mogollon settlements developed dynamic spatially-aggregated settlements in areas with favorable water conditions (Nisengard, 2006; Frost, 2021). Water-sensitive settlements in these arid regions adjusted their locations and subsistence strategies in relation to climate variability (Bensen et al., 2007; Smith, 2010).

3.1.1.3. Hohokam canal irrigation communities

The largest body of prehistoric water research has focused on canal builders in what is now central Arizona (Bahr, 1994; Henderson and Banerjee, 2004; Fish and Fish, 2008, 2012; Mills et al., 2017; Hill, 2019). Hohokam canals diverted water from the Salt, Gila and Santa Cruz rivers, which are among the few medium-size perennial rivers in the region subject to human control (Figure 3). Excavation at the Snaketown, Arizona site identified brush diversion weirs, changing canal alignments, and cross-sections (Haury, 2016). Recent excavations include morphological analysis of canal alignments, channel sediments (Purdue et al., 2010), and associated wells (Wright et al., 2013). Water management in adjacent areas of the Sonora desert by Tohono O'odham (Papago) (Bryan, 1925) relied on mixed strategies of cultivation, gathering, and hunting (Nabhan, 1983; Darling et al., 2004; Raab, 2009; Loendorf, 2010; Loendorf and Lewis, 2017).

Hohokam canal irrigation had remarkable longevity (c. 600-1450 CE) (Caseldine, 2020), which Fish and Fish (2008) describe as the Hohokam millennium. Its settlements shifted from relatively undifferentiated building types in the pioneer period to socially stratified patterns in the classic period that some regard as a factor contributing to socio-environmental vulnerability, though interpretations of settlement abandonment vary (Ackerly, 1982; Rice, 1998; Clark, 2001; Fish and Fish, 2012; Howard, 2014; Woodson, 2016). Murphy (2009) has conducted simulation modeling of Hohokam expansion and contraction. Simon (2002) reviews the conservation of Hohokam canal heritage in modern urban environmental design.

3.1.1.4. Summary

Prehistoric water communities adapted to varied sociohydrologic conditions with a range of institutional practices inferred from their material cultures. However, they underwent dramatic regional reorganization in the mid-14th to mid-15th centuries that involved community dispersal and resettlement associated with combinations of climatic and

FIGURE 2
Hohokam, Ancestral Pueblo, and Mogollon cultures circa 1350 CE (Source: Wikimedia Commons, 2015, https://commons.wikimedia.org/wiki/File:Hohokam,_Ancestral_Pueblo,_and_Mogollon_cultures_circa_1350_CE.png, modified by Yuchitown. Creative Commons Attribution-Share Alike 4.0 International).

socio-cultural stresses. Their significance for modern water management lies in part in: (1) assessment of hydroclimatic impacts and adjustments; (2) revival of early canal irrigation systems in Phoenix, Arizona, where Pima Indian tribes renewed some canals, followed by Anglo irrigators, and later urban developers; and (3) continuing technical refinement and government support for check dams and related soil and water conservation practices.

3.1.2. Hispanic water communities in the 16th–19th centuries

The 16th century witnessed several trajectories of Hispanic in-migration and water management in the region, notably in the middle Rio Grande and Santa Cruz River valleys (Meyer, 1984, 1989). This bibliographic search used keywords such as, "acequia," "pueblo," "mission," and "Hispanic water," (see Supplementary Table 2B). Some of the earliest Hispanic settlements developed around military forts (*presidios*) that needed strategic access to water for domestic use, cavalry animals, and defensive purposes. Once secured, areas were developed by large *rancho* land grants for grazing and related agrarian purposes. *Missions* were religious colonizing communities led by priests with conscripted Indian converts and laborers who irrigated nearby lands for local consumption and trade (Ressler, 1966; Waters, 2005). Larger town settlements (*pueblos*) developed drinking water and urban irrigation systems, e.g., at Nogales and Tucson in the Colorado River basin.

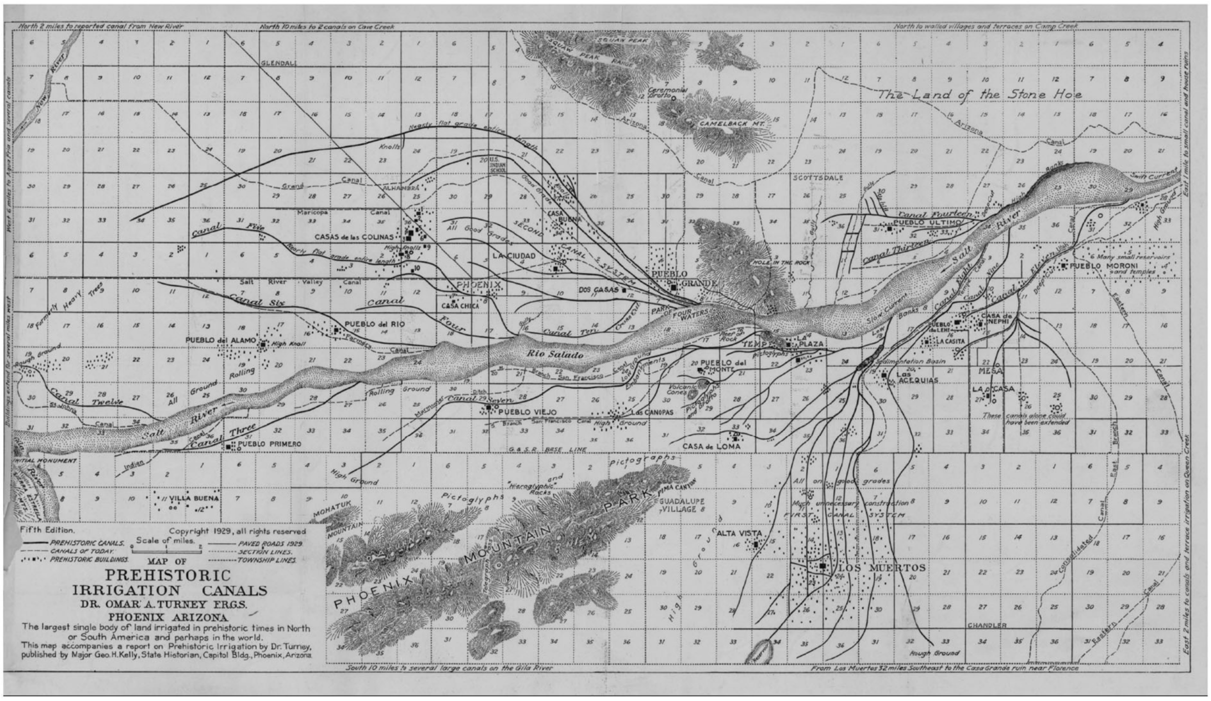


FIGURE 3
Map of Hohokam prehistoric irrigation canals [Turney, 1929; https://repository.arizona.edu/bitstream/handle/10150/623395/azu_h9791_a72_h6_02_02_art2_w.pdf?sequence=1andisAllowed=y (accessed December 16, 2022)].

It is important to distinguish *pueblo* Indian communities in the Rio Grande valley (Hughes, 2017; Ebright and Hendricks, 2019) from Hispanic town *pueblo*s. The latter were guided in part by a 17th century legal code known as the *Recopilación de las leyes de los reynos de las Indias,* which included principles for siting towns in proximity to good water and drainage (Briggs and Van Ness, 1987). Towns had customary practices of water sharing during drought (Tyler, 1995) that carried forward into later historical periods (Reich, 1994; Tyler, 1995).

Hispanic settlers developed several enduring institutions for community water management, notably *acequia* irrigation organizations (Lopez et al., 2018). Irrigators contribute labor to acequia maintenance, sharing seasonal surpluses and shortages of water, and making collective decisions about ditch operations (Hicks and Pena, 2010; Baker, 2013, 2018; Trott, 2017; Montoya, 2020; Romero, 2021; Conrad, 2022). Rivera (1998) retraces their historical development in the southwest, as well as their current status, challenges, and prospects. Rodríguez (2006) stresses intercultural affective relationships in acequia water management (cf. Romero, 2021). That is not to say that *acequia* communities have not had internal and external conflicts (Reichard, 1996; Ebright, 2001; Sanchez, 2011). Crawford (1988) offers a first-hand account of cooperative and conflict management experience as a ditchmaster (*mayordomo*) in New Mexico. However, acequias are under increasing pressure to measure and adjudicate their community held rights within the larger and more individualistic context of state water rights administration (Levine, 1990; KleinRobbenhaar, 1996; Rango et al., 2013; Fernald et al., 2015; Perramond, 2015; Raheem, 2015). Wise and Crooks (2012) conduct agent-based modeling of acequia sustainability (cf. Raheem et al., 2015). Some cities with Hispanic origins claimed pueblo water rights dating to the time of their original settlement, which they argued should expand as the city grew. While creative as legal arguments, they have been rejected both by courts and legal historians (Tyler, 1990; Mulvany, 2005; Reich, 2018). *Pueblo Indian* communities, by contrast, have different water management and settlement systems (Vlasich, 1980; DuMars et al., 1984; Quintana, 1990; Anschuetz, 1998; Wood, 2008; Hughes, 2017). Most pueblo tribes are located in the Rio Grande basin, though some like Zuni are in headwaters of the Colorado River basin. Some such as Taos practice acequia irrigation methods that exemplify community-based approaches to water management (Cox and Ross, 2011; Cox, 2014; Flint, 2021).

3.1.3. 19th century water communities

Colonization from the eastern United States brought Euro-American communities into the region that had complex interactions with Indian and Hispanic communities (see Supplementary Table 2C). Some were Gold Rush miners (Kanazawa, 2006), others Mormon irrigators (Arrington and

May, 1975), and still others tried to form utopian irrigation "colonies" (Clark and Clark, 2005). Among the latter, New York City publisher Horace Greeley supported the Union Colony in northeastern Colorado (Pabor, 1871). That communal experiment was soon engulfed by larger-scale processes of immigration and irrigation development. An African-American farming community in Dearfield, Colorado was located nearby but declined during the Depression and drought of the 1930s (Waddell, 1988).

Mormon settlers fled persecution in the eastern and midwestern states arriving in the Utah Valley in 1847. They adapted rapidly to the landscape of mountain streams and desert plains, establishing some of the most enduring irrigation communities of the 19th century (Dyal, 1980; Alexander, 2002; Wheeler, 2011). Their towns emulated Joseph Smith's visionary Zion Plan, which featured broad streets flanked by ditches for homestead garden irrigation, and larger ditches for outlying fields (Jackson, 1994). Mormon communities had successful institutional combinations of hierarchical decision-making coupled with egalitarian sharing of surplus and scarcity that enabled them to weather various stresses and establish new colonies across Utah and the wider southwest (e.g., Toelken, 1991; Lavoie and Sleipness, 2018). Several studies have focused on Mormon collaboration and conflict with Native American communities, e.g., in the Uintah Valley of Utah (Endter, 1988) and Tuba City on the Navaho Indian reservation in Arizona (Smallcanyon, 2010).

Colonization processes displaced tribal communities onto regressively sited and scaled reservations with limited access to water. Initially, Pima (Akamel O'odham) and Ak Chin O'odham tribes revived old Hohokam irrigation canals in central Arizona and thrived by supplying early miners and others (Hudanick, 1983; Heslop, 2012). Later colonization displaced these tribes onto reservation lands resulting in impoverishment of many (Ezell and Fontana, 1994; Frantz, 2012; cf. Glaser, 1996). The nearby Tohono O'odham (Papago) tribe who occupied arid lands of the Sonoran Desert that have limited surface and groundwater water resources developed mixed livelihood strategies (Bryan, 1925; Nabhan, 1983). Analogous processes of displacement and adaptation occurred along the lower Colorado main stem (Blossom, 1979; Caylor, 1996; Sudol, 2019).

3.1.4. 20th century and contemporary water communities and organizations

Continuing immigration in the late-19th and early-20th centuries involved diverse ethnicities, including various European groups, Hispanic communities, and small but significant Asian groups (e.g., Chinese, Japanese, and Punjabi Indians) (see Supplementary Table 2D). The latter faced systematic social and legal exclusion, discrimination, and conflict (e.g., Leonard, 1992; Walz, 1998; Ho, 2003; Metraux, 2019; Lau-Ozawa, 2021). While Native American Indian reservation communities had an early water rights victory in the *Winters v. United States* (207 U.S. 564, 1908) case, that rarely translated into viable reservation water supplies (i.e., "wet water") for much of the 20th century.

Relationships among 20th century water communities and their organizations developed in dynamic ways. By the late 19th century, local irrigators established mutual ditch companies (quasi-private not-for-profit organizations) to secure water rights, finance irrigation works, and maintain those systems (Taylor et al., 2019). Maass and Anderson (1978) compare the socio-economic performance of six Spanish and western US irrigation communities, stressing the importance of water rights markets and local community vis-à-vis governmental control. As ditch companies expanded in size they organized larger irrigation districts with the power to levy taxes (e.g., Crider, 2018 in California, and the Grand Valley of Colorado, Struthers, R. E., and United States Bureau of Reclamation, 1963; Raley, 2001). Water User Associations encompassed a still wider range of water uses (e.g., Yuma County Water Users' Association., 1987), as did water conservancy districts and municipal water utilities (Wescoat, 1984, 161–82; Sherow, 1989; Schorr, 2006; Lieberman, 2011). These organizations have ranged in geographical scope from individual ditches to regional water systems. Most of them combine elements of private and public control, and thus link community and commodity values in water (cf. Mumme and Ingram, 1985; Brown and Ingram, 1987). Research on modern tribal irrigation communities underscores the importance of local control (Leeper, 1989). Weber (1991) showed that water access is a necessary but insufficient condition for community economic viability in southern Colorado. Social research on modern irrigation communities includes surveys designed to inform economic development (Abruzzi, 1985; Borden et al., 2005, 2006).

Recent research has highlighted the emergence of environmental communities concerned with riparian and aquatic species protection and watershed conservation (Propst and Culp, 2000; Benson, 2007; Long, 2010; Osenga et al., 2021). Hubbard et al. (2018) describe a community test-bed for watershed science in the upper basin of western Colorado (cf. Kakalia et al., 2021). Credo (2022) discusses the cultural sensitivity and practices required when working with Colorado River tribes on environmental quality concerns. Flores and Briggs (2003) emphasize community level environmental restoration of the Colorado River delta (cf. Muehlmann, 2013). Non-governmental organizations are rapidly broadening the scope of community level institutions for water management.

3.1.4.1. Summary

This review of community level institutions found that they have had: (1) over a millennium of prehistoric and historical developments; (2) enormous diversity of community forms, organizations, contexts, and cultures; (3) dynamic processes of community interaction, exchange, conflict, and development;

and (4) emergent community movements and organizations in the late 20th and early 21st centuries (De Borhegyi-Forrest, 1998; Wood, 2008). An influential volume on *Values and Choices in the Colorado River Basin* included a chapter on community development by Mann (1978), who emphasized the contingent nature of local community control in the region (cf. also Adler, 2020, on communitarianism in the western US). While community institutions have had some measure of local autonomy, they have been subject to expanding formal institutions at higher levels of governance. Competition and conflict among communities leads us to consider state level institutions established in part to deal with such conflicts as well as broader aims of economic development, public welfare, and territorial control (Formisano, 2012; Robison et al., 2021).

3.2. State level water rights and policies

Constitutionally, water is a state subject in federal governments like the United States and Mexico, which means that states have primary jurisdiction over water matters within their boundaries. Portions of seven states lie within the Colorado River basin in the United States and two in Mexico. It is fascinating to compare these state and basin boundaries (Figure 1). Southwestern Wyoming has a relatively small sparsely populated grazing and mining area of the basin's headwaters. The western half of Colorado has the headwaters of four regional river basins that support irrigation agriculture, energy, and recreational uses. It also exports water across the Rocky Mountains to irrigated and rapidly urbanizing basins in eastern Colorado. New Mexico has the San Juan River basin in its northwest corner and arid headwaters along its western border. It exports water from the San Juan River basin into the Chama tributary of the Rio Grande valley. Utah receives headwater flows from Colorado, Wyoming, and New Mexico. It exports water from the Colorado River across the Wasatch Mountains into the intensively irrigated interior drainage of the Great Salt Lake Basin. Each of these states has promoted transbasin exports *within* state boundaries to maximize its use of Colorado River basin waters.

The three lower basin states include hydrologically small contributions from Nevada and California, though those states have politically powerful water users. The extrabasin region of southern California receives massive water transfers *via* the Colorado River Aqueduct and All-American Canal. Arizona is the one state that lies almost entirely within the basin. It receives a long-distance water transfer from the main stem of the Colorado through the Central Arizona Project canal. A small area of Sonora state in Mexico drains into the Santa Cruz watershed at Nogales, Arizona (Ingram et al., 1995). A small area of northern Baja California state drains into the New River and Salton Sea from the Mexicali area (Dicochea, 2010), and also into the shared Tijuana River that discharges into the Pacific Ocean. Sonora and Baja California share the lowest reach of the Colorado River before it discharges into the depleted and degraded Colorado River delta and Sea of Cortez (Ward, 2003).

With the exception of California's early statehood in 1850, basin states were initially established as territories that were nevertheless empowered to pass water statutes and decide legal cases. They became states between 1864 (Nevada) and 1912 (Arizona and New Mexico) (Supplementary Table 3). The bibliographic search at this level, and those that follow, gave more attention to Lexis/Nexis legal databases that include law reviews, cases, and statutes. The America History and Life and Web of Science databases were omitted as less focused on water policy at these levels. Search terms included the seven basin state names and "water law" or "water policy" (see Supplementary Table 4).

Each state has guides to its water laws for professional and public use [e.g., CLE International, 2013; Howard and Alstead, 2009 (Nevada); MacDonnell, 2014 (Wyoming); Hobbs and Colorado Foundation for Water Education, 2018 (Colorado); Liebert, 2019 (California)]. Given the importance of legal precedents in state water law, histories of those laws have been compiled in legal treatises, books, and reviews [e.g., Reich, 1995 (Arizona); Kanazawa, 1998, 2015 (California); Harrison, 2001 (Nevada); Olds, 2004 (Utah); MacKinnon, 2006 (Wyoming); Hall, 2008 (New Mexico); Walston, 2008 (California); Schorr, 2012 (Colorado); Bennion, 2014; Hundley, 2020 (California)].

The prior appropriation doctrine became an important principle in state water laws that defined water rights institutions in the latter part of the 19th century. Colloquially termed "first in time, first in right," it stipulates that in the event of scarcity water rights holders must divert water in the order of their "seniority" (i.e., the date when they put water to a "beneficial use"). Prior appropriation had its origins in mining camps where miners diverted water from stream channels to their mineral claims. Early users had priority over later ones, which was adopted as a legal precedent in *Irwin v. Phillips* (5 Cal. 140, 1855) on federal lands in California, and in mining districts of Colorado (Schorr, 2012, ch. 1). Colorado courts extended the prior appropriation rule to irrigation water rights, rejecting the riparian rule of reasonable use among streamside land owners, which governed in the eastern United States. The Colorado case of *Coffin v. Left Hand Ditch* (6 Colo. 443) ruled that the historical *time* of use established the basis of a water right, rather than the riparian *place* of use, even when senior uses lay outside the basin of origin but within state boundaries. The Colorado Doctrine (Schorr, 2012), as it was called, was adapted in all of the other basin states, except California. The California case of *Lux v. Haggin* (69 Cal. 255, 1886) ruled that prior appropriation must allow for some reasonable use by downstream riparian claimants, which led to a hybrid system of surface water laws. That hybrid arrangement was adopted by other Pacific coast and Great Plains states.

Colorado also stood out for water articles in its 1876 State Constitution that declared:

> The water of every natural stream, not heretofore appropriated, within the state of Colorado, is hereby declared to be the property of the public....the right to divert the unappropriated waters of any natural stream to beneficial uses shall ***never*** be denied. Priority of appropriation shall give the better right as between those using the water for the same purpose. (Art. 16, 5-6, 1876; emphasis added)

Not surprisingly, this constitutional right to divert all waters of natural streams in the state led to overappropriation. Wyoming adopted similar language in 1889 with the more flexible provision that, "No appropriation shall be denied except when such denial is demanded by the public interests" (Art's. I, 31 & VIII, 1, 3). Over the past century, state water laws have addressed whether a "diversion" is required to establish a water right, what constitutes a "beneficial use," and how to limit "waste." They differ as to whether and how appropriations can be made for instream flows for environmental, aesthetic, and recreational uses; and for on-site use of diffuse surface flows [Elliott, 2011; Connell, 2019 (Wyoming); Hobbs, 2019 (Colorado); Matheson, 2004 (Utah)]. The states have refined methods for estimating water use efficiency, conservation, and waste [Glennon, 2018 (Arizona); Zisch, 2014 (Wyoming)]. Transbasin "developed water", for example, can be reused and recycled within the state, provided its water right is in priority in its basin of origin [*City and County of Denver v. Fulton Irrigation Ditch Co.*, 179 Colo. 47, 506 P.2d 144 (1972) (cf. Fuller, 2014 (Wyoming)].

States vary in their procedure for establishing a water right, which generally begins with an expression of intent to appropriate, followed by diligence in developing the right, putting the water to a beneficial use, and fulfilling any recording steps that may be required. Once developed, a right must be put to continuing beneficial use, the standards of which can evolve with increased competition and standards (Clegg, 2005; Hobbs, 2013; MacDonnell, 2015). Some states permit filings of conditional water rights, especially by cities, in anticipation of increased future water demand. For those rights the priority dates back to the time of filing rather than the later time of beneficial use [e.g., *City & County of Denver v. Sheriff,* 96 P.2d 836, 839 (Colo. 1939)]. This controversial policy can contribute to water rights uncertainty and overappropriation. When a senior water right does not receive its full amount, a "call" is placed on the river that requires all users to divert only their decreed amounts, at which point the most junior users are shut off until more senior uses are fully served.

States allow changes of water rights to meet new demands subject to two rules. First, changes are limited to the "historical beneficial use" of the right – any claim beyond that amount reverts to the water rights priority queue or the stream. Second, the proposed change must cause "no-injury" to any other water right holder in the system, junior or senior, whether by changes in withdrawals, place of use, or return flows (Banks and Nichols, 2015). Wyoming initially forbade water transfers as speculative but later allowed them (MacKinnon, 2006; on anti-speculation see Cannon, 2009; Schorr, 2012; Hobbs, 2013). These rules and procedures for changing a water right can have substantial transaction costs, particularly in states like Colorado where changes are reviewed in special water courts, as compared to states where the state engineer's office evaluates proposed changes (National Research Council, 1992; Womble and Hanemann, 2020). States differ on how one can lose a water right, e.g., through cancellation, forfeiture, or abandonment, though they have been reticent to implement those provisions in areas of the Colorado River basin seeking to develop a state's share of the river (Zellmer and Amos, 2021, p. 165–70).

Where states differ most is in their groundwater laws and their approaches to conjunctive management of surface and groundwater resources (DuMars, 1985; Meyer, 1989; Avery et al., 2007; Ruple, 2011; Meldrum, 2013). California developed a concept of correlative groundwater rights whereby rights are proportionate to one's land ownership above the aquifer [*Katz v. Walkinshaw*, 74 P. 766, 772 (Cal. 1903)] and historical levels of pumping. Colorado adapted prior appropriation for groundwater deemed tributary to streamflow; and state permitting of "non-tributary groundwater" [*State Dep't of Natural Res. v. Southwestern Colorado Water Conservation Dist.*, 671 P.2d 1294 (Colo. 1983)]. Most states have developed some form of pumping permits, with historical exceptions for domestic wells (Zellmer and Amos, 2021, p. 242–6). Groundwater use for energy development (e.g., shale oil or fracking) have posed new legal as well as environmental issues that include groundwater contamination, overdraft, subsidence, and air pollution [cf. Ariz. Rev. Stat. Ann. §45–401, 596(I); and Colo. Rev. Stat. §37–91–110; Ruple and Keiter, 2010; Ritchie, 2014; Whitney-Williams and Hoffmann, 2015].

All of the basin states initially relied on a State Engineer to administer water rights, i.e., to record perfected rights and physically turn off junior rights in times of scarcity. By the mid-20th century, however, growing water competition and environmental conflict led some basin states to create broader departments or divisions of water resources management. As noted above, Colorado stands out for its heavy reliance on water courts in its seven regional water divisions, four of which are headwaters basins of the Colorado River (i.e., the Yampa, Colorado, Gunnison, and Animas-La Plata headwaters). Not surprisingly, Colorado has the largest body of water rights case law (Supplementary Table 2D), as well as high transaction costs associated with water rights changes and transfers (National Research Council, 1992; Womble and Hanemann, 2020).

Notwithstanding the variations noted above, the prior appropriation doctrine distinguishes the state level of water management from institutions at other levels in the basin. State water laws have evolved to address myriad issues within their boundaries. States engage in intense internal debates about property rights in water (Benson, 2012; MacDonnell, 2015), but passionately defend those property rights institutions against encroachment by other states or federal organizations (Schorr, 2012). When states come into conflict with one another over transboundary waters, they turn to the interstate level of water management.

3.3. Interstate level water institutions

Interstate relations constitute the next higher institutional level of water management. They have their own institutional logic and organizations distinct from those of the participating states. Three types of interstate apportionment have developed in the Colorado River basin: (1) interstate litigation; (2) interstate compacts; and (3) Congressional apportionment. In each case, the US. Constitution stipulates involvement of the federal government. Bibliographic search terms for this level were "interstate" or "compact" and "Colorado River," again with increased emphasis on law reviews and legal sources (see Supplementary Table 5).

3.3.1. Interstate litigation

When states have conflicts over water they may go to court, and the U.S. Supreme Court has original jurisdiction over such cases. The Supreme Court often appoints a special master to provide technical reports and recommendations. In some early cases the Supreme Court used the prior appropriation principle to adjudicate local claims on each side of a border. However, a progression of cases from *Kansas v. Colorado* (1907) to *Wyoming v. Colorado* (259 U.S. 419, 1922), *Nebraska v. Wyoming* (325 U.S. 589,618, 1945), and *Colorado v. New Mexico I* (459 U.S. 176, 1982) elaborated the new concept of "equitable apportionment," in which seniority is one of several considerations used to determine each state's water share. The U.S. Supreme Court recently extended that concept to interstate groundwater in another region of the country [*Mississippi v. Tennessee*, 595 U.S. ___, 142 S.Ct 31 (2021)]. The equitable apportionment precedent in the American West has been invoked in interstate disputes around the world, notably colonial Punjab and Sindh in the Indus River basin. Interestingly, *Arizona v. California* (373 U.S. 546, 1963) is one of the few interstate cases *within* the Colorado River basin, and it is also one of the most protracted decades-long cases in history (Robison and MacDonnell, 2014). It is closely connected with Congressional apportionment of lower basin waters, so it is discussed in that section below.

3.3.2. Interstate compacts

A second form of interstate dispute resolution involves voluntary agreements or compacts among states, subject to approval by the U.S. Congress (U.S. Constitution, Art. 1, Sec. 10, Clause 3 *et seq*.). Interested states must first obtain Congressional authorization to enter into negotiations, and Congress may provide incentives for them to negotiate, e.g., investment in major infrastructure that could not proceed without a reliable interstate agreement. Compacts must be ratified by Congress as well as the states.

In 1922, Colorado and New Mexico negotiated an early compact on the La Plata river, a tributary of the San Juan River that flows into the upper Colorado River. It provides for measurement at key locations and equitable apportionment of flows in winter and non-winter seasons of the year with provisions for apportionment when flows drop below 100 c.f.s. (C.R.S. 37-63-101 et seq., 1995). These two states later entered into a compact for sharing waters of the U.S. Bureau of Reclamation's Animas-La Plata project (U.S. Public Law 90-537, section 501, 1968; Ellison, 2009).

Anticipation of major infrastructure development in the lower Colorado River basin led basin states to negotiate the Colorado River Compact of 1922. That agreement: (a) divides the river basin into upper and lower basins at Lee Ferry, Arizona (art. II); (b) allocates 7.5 million acre-feet (MAF) to each basin (art. IIIa); (c) requires the upper basin to deliver an average of 75 MAF over ten-year periods (art IIId); (d) anticipates a future U.S.-Mexico treaty obligation (art.IIIc); (e) recognizes future U.S. obligations to Indian tribes (art. VII); and (f) requires ratification by the seven basin states and Congress. These provisions proved problematic for Arizona, which did not ratify the compact, and uncertain for other basin states in later decades (MacDonnell, 2021). As the compact's centennial approaches, there have been several reviews of its impact and unresolved issues (from early appraisals like Grunsky, 1922 to recent ones like Robison, 2022).

The 1922 Compact and subsequent development projects led upper basin states of Colorado, New Mexico, Utah and Wyoming to negotiate their respective shares to secure federal funding for large dams on major rivers and smaller ones in their headwaters areas. Those projects would enable them to develop their compact shares while meeting their obligation to the lower basin. The Upper Colorado Basin Compact of 1948 allocated 50,000 acre-feet per year to Arizona for its relatively small area of the upper basin (art. III, 1) and apportioned the remaining waters as follows (art. III, 2):

Colorado: 51.75%
Utah: 23%
New Mexico: 11.25%
Wyoming: 14%

These negotiated figures reflect a range of considerations that did not have a precise scientific basis, or measurement provisions. The compact is administered by an Upper Colorado River Commission (art. VIII). Although less contested than the Colorado River Compact because upper basin states have taken longer to develop their compact apportioned shares, that may change with pressures from the unfolding drought and climate change (MacDonnell and Castle, 2017; MacDonnell, 2021).

3.3.3. Congressional apportionment

Arizona contested the 1922 Compact and refused to ratify it. Anxious to proceed with large main stem dam, reservoir, and canal projects, Congress passed the Boulder Canyon Project Act of 1928 which authorized:

- Construction of the multi-purpose Boulder Canyon (Hoover) Dam.
- Construction of the All-American Canal that conveys Colorado River irrigation water to the Imperial and Coachella valleys of southern California.
- Allocation of the lower basin's supply of 7.5 MAF with 4.4 MAF for California, 2.8 MAF for Arizona, and 0.3 MAF for Nevada.
- The U.S. Secretary of the Interior to manage lower basin reservoirs to fulfill state and eventually treaty allocations.
- Ratification of the Colorado River Compact by any six *of the seven* basin states, thus bypassing Arizona.

This act stands out as the only instance in which Congress legislatively apportioned interstate waters. Not surprisingly Arizona sued, but the federal government initially did not consent to be sued, and when the case of *Arizona v. California* (373 U.S. 546, 1963) ultimately did proceed, the U.S. Supreme Court deemed the Congressional apportionment to be constitutional. While the original compact negotiations had excluded Indian tribes, *Arizona v. California* began to change that situation by quantifying lower Colorado River tribal rights, described in the tribal section below.

The interstate institutional level thus includes federal and state governments. As with other levels, it developed its own principles of equitable apportionment, interstate case law, and compact organizations that play a major role in shaping complex river basin management.

3.4. Federal level water institutions

The federal level has been mentioned on multiple occasions above, and notwithstanding state jurisdiction over many water matters, federal institutions have broad importance for the Colorado River basin region. The US Constitution stipulates federal powers of water management that include the:

- Supremacy clause [Art. 6; clause 2]—federal laws take precedence over state laws.
- Commerce clause [Art. 1; sec. 8; clause 3]—Congress has the authority to regulate commerce among states, tribes, and foreign powers.
- Property clause [Art. 4; sec. 3; clause 2]—Congress has the authority to manage property including water rights owned by the United States.
- General welfare clause [Art. 1; sec. 8; clause 1; taxing & spending] –power to undertake work and regulations for broad public benefit.
- Treaty-making power [Art. 2; sec. 2; clause 2]—the President with the advice and consent of the U.S. Senate has the sole power to make treaties with foreign governments.

The bibliographic search at this level involved the same sources as in previous sections, plus websites of major federal agencies involved in the region. The results are so broad in scope and rich in content that we can only outline some of the major elements here. Federal agency programs are complicated by non-overlapping regional boundaries. For example, those of the US Department of Interior, which is most directly involved in basin management, combine the Upper Colorado with the Upper Rio Grande rather than with the Lower Colorado basin; while other agencies have different regional boundaries (Figure 4).

By way of background, most of the Colorado River basin region became part of the United States and subject to federal laws through the Mexico Cession of 1848 and Gadsden Purchase of 1854. The Indian Appropriations Act of 1851 provided for reservations with limited sovereignty for Indian tribes. While territories, states, and reservations were being created, the federal government undertook a series of explorations of the Colorado River led by John Wesley Powell (1875) in 1869–1872 (Robison et al., 2020). Scientific surveys of this period also started to refer to the Colorado as a "basin" (e.g., Macomb and Newberry, 1876).

A movement promoting irrigation in the western states in the late-19th century led Congress to pass the Reclamation Act of 1902, which established a Reclamation Service (later the Bureau of Reclamation) under the U.S. Geological Survey (Lee, 1980; Pisani, 1992; Worster, 1992). The Act provided for federal reclamation projects for farms <160 acres in size, though that socio-economic policy would later be abandoned. *Irrigation Investigations* led by the U.S. Department of Agriculture Office of Experiment Stations identified potential project locations and beneficiaries. The Salt River Project (2017) in central Arizona was one of the first US Bureau of Reclamation projects in the Colorado River basin, authorized in 1903. It funded a large masonry dam and canal construction, some of which followed the prehistoric Hohokam canal alignments (Heslop, 2012).

When Congress passed the Boulder Canyon Project Act in 1928, it greatly increased the scale of federal dam

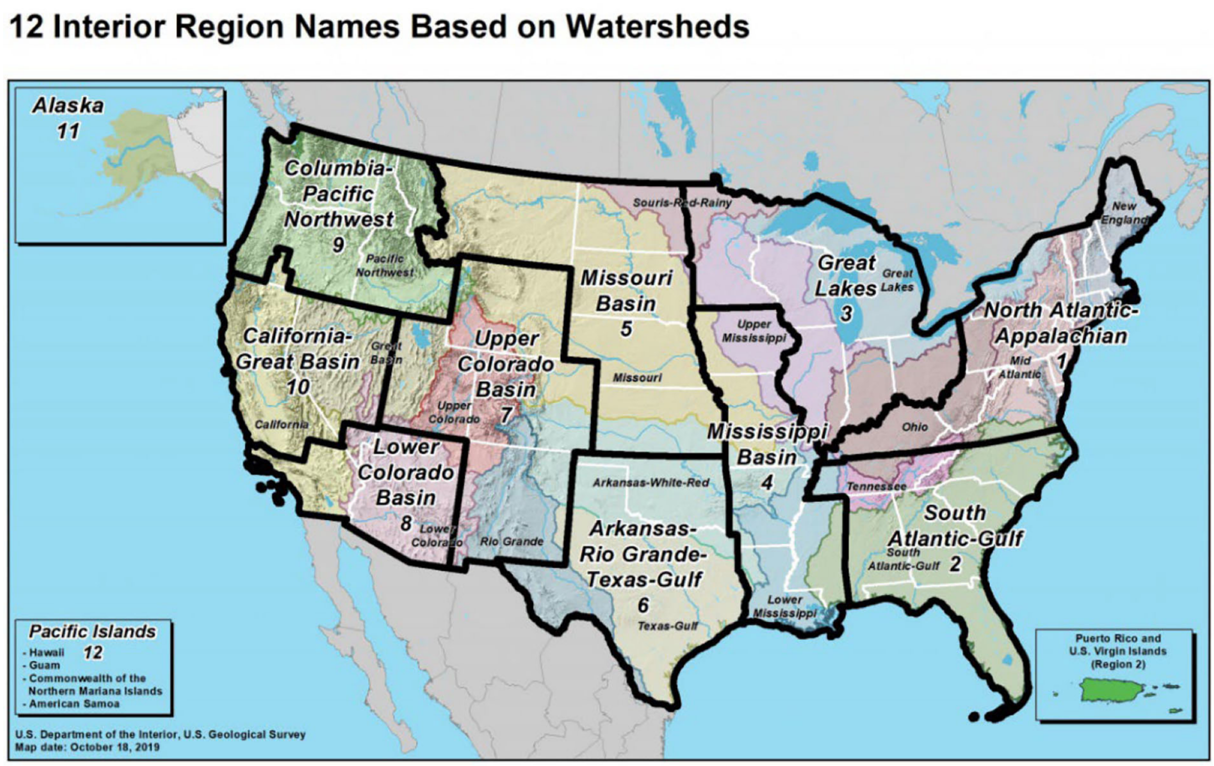


FIGURE 4
U.S. Department of the Interior (2019). Map of U.S. Department of interior regions based on watersheds.

construction including the massive multi-purpose Hoover Dam and All-American Canal across southern California. It empowered the Secretary of Interior to manage lower basin reservoir deliveries, which became the institutional basis for federal river operations and, recently, federally-mandated cutbacks in 2022. In 1937, the Bureau of Reclamation began work on the large Colorado-Big Thompson Project that transferred supplemental water from the upper Colorado River basin to the South Platte River basin in eastern Colorado. The Boulder Canyon Project Adjustment Act of 1940 financed dams in the upper and lower Colorado basins in part by using hydropower revenues from Hoover Dam. The Colorado River Project Storage Act of 1954 added five additional large upper basin dam projects—(1) Glen Canyon Dam on the Colorado River in Arizona; (2) Flaming Gorge Dam on the Green River in Wyoming; (3) Curecanti Dam on the Gunnison River in Colorado; (4) Navajo Dam in New Mexico; and (5) the Central Utah Project—i.e., one dam for each upper basin state. These large dams helped fulfill the upper basin's compact obligation while enabling them to physically develop their own compact-apportioned shares. It did so in part by providing for 16 small "participating projects" and another 19 potential participating projects, financed in part by hydropower revenues from the large hydropower projects.

The last massive federal infrastructure project came in 1968 with the Colorado River Project Act that among other things authorized the 336-mile-long Central Arizona Project from the lower Colorado River to central and southern Arizona. The 1968 Act stipulated that Central Arizona Project waters are subordinate to California's 4.4 million acre-feet entitlement (under the Boulder Canyon Project Act)—provisions that became relevant in the 2022 drought cutbacks. The Act omitted a large dam proposed for the sublime Marble Canyon of the Colorado River, which signaled the ascent of environmental values and decline of large dam construction (Reisner, 1993; Summitt, 2013; Perramond, 2018; Di Baldassarre et al., 2021).

Environmental opposition to large dams coalesced with the implementation of new federal laws and agency regulations. All proposed federal actions are subject to environmental impact assessment under the National Environmental Policy Act of 1969 (42 U.S.C. 4321-4347, January 1, 1970, as amended). Legislation protecting endangered plant, animal, and fish species led to greater roles for the US Fish and Wildlife Service under the Endangered Species Act (16 U.S.C. 1531-1544, as amended). The Clean Water Act of 1972 (33 U.S.C. §1251 et seq.) included water quality regulations implemented by the U.S. Environmental Protection Agency and wetlands protection permitting by the U.S. Army Corps of Engineers. Large federal lands are managed by the Forest Service, Bureau of Land Management, National Park Service, and others. Energy crises in the 1970s led to transfer of the Bureau of Reclamation's hydropower role to the Department of Energy's Western Area Power Alliance in 1977.

In addition to their expanding regulatory roles, Federal agencies claimed "reserved rights" for water on national lands that were legislatively set aside for forests, parks, grazing, and other uses (*Federal Power Commission v. Oregon,* 349 U.S. 435, 1955). In a series of cases the U.S. Supreme Court stipulated that reserved rights are based on the central purpose of the lands reserved with water rights priorities dating to the time of their establishment (*U.S. v. New Mexico*, 438 U.S. 696, 1978).

There was a major attempt to coordinate these diverse federal water roles through the Water Resources Planning Act of 1965 (P.L. 89-80), which established a national Water Resources Council, regional River Basin Commissions, and *Principles and Standards for Planning Water and Related Land Resources* that adopted four accounts for evaluating federal projects: (1) national economic development, (2) regional economic development, (3) environmental effects, and (4) other social effects. However, these reforms were reversed in 1983, revisited in 2009, and updated in 2015, albeit on a level far short of integrated national water policy and planning.

In the absence of nationwide water policy, the Department of Interior's Bureau of Reclamation has the lead federal role in Colorado River basin operations. It prepares monthly 24-month model runs, drought contingency planning, and basinwide policy analysis (U.S. Bureau of Reclamation, 2019, 2022; U.S. Department of Interior, 2022). In the 2022 drought emergency, for example, the Secretary of Interior invited states to prepare a voluntary drought reduction plan. The Upper Colorado River Commission (2022) presented a five-point plan, but when the lower basin states were unable to agree, the Secretary announced 2023 cutbacks of 592,000 acre-feet in Arizona; 25,000 acre-feet in Nevada; 104,000 acre-feet in Mexico; and none for California (based on the 1968 Colorado River Project Act) (U.S. Department of Interior, 2022). The California Colorado River Board (2022) offered 400,000 acre-feet of conservation measures through 2026, and negotiations continue.

What distinguishes the federal level from levels below are its constitutional role in interstate relations, river basin development, treaty-making authority with Mexico, and trust responsibility with Indian tribes. Most federal policies and projects thus entail multi-level stakeholder processes, with greater or lesser degrees of inclusion, historically greater for the basin states and lesser for Indian tribes as elaborated below.

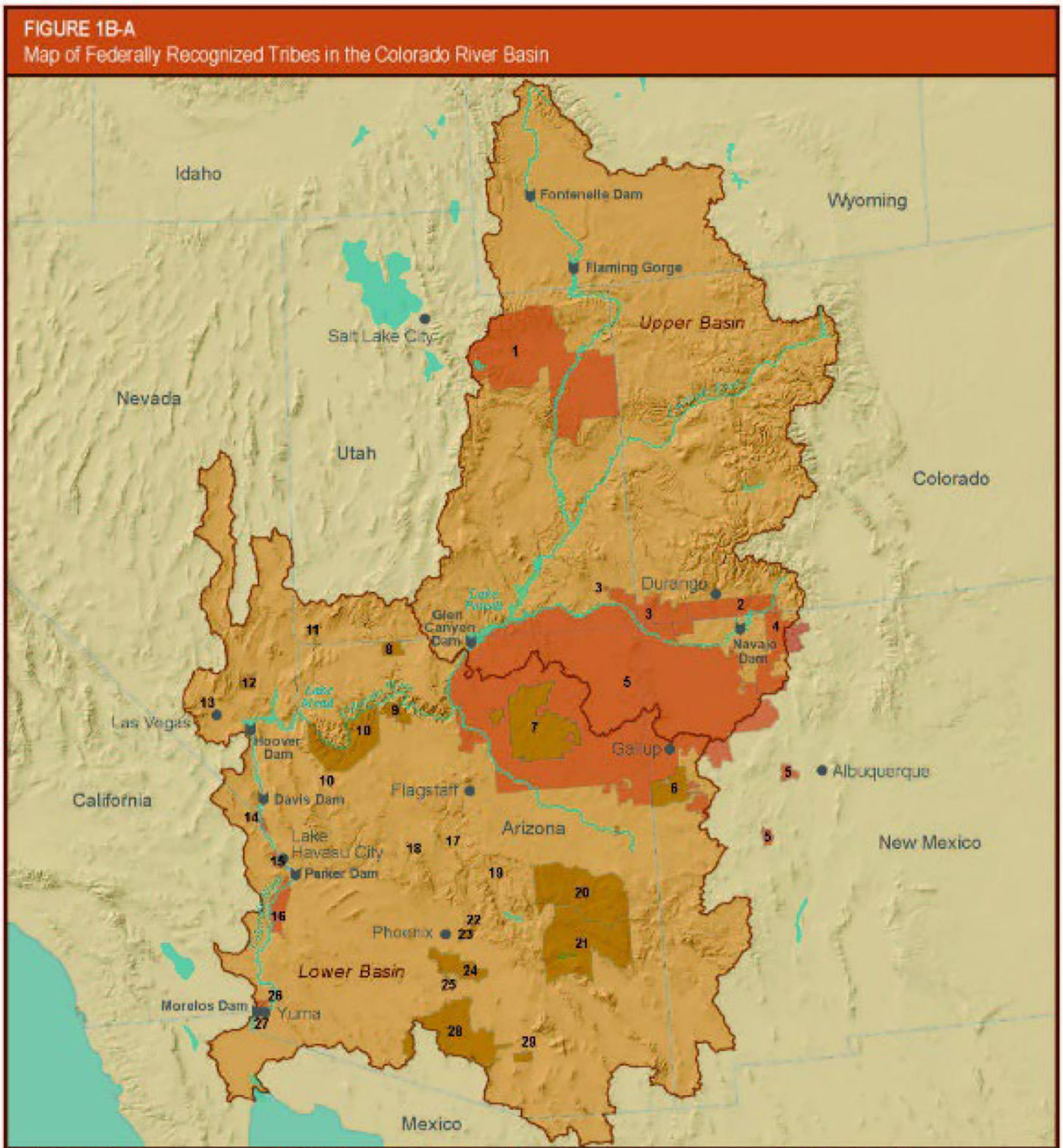
3.5. Indian tribal "levels"

American Indian tribes have operated at every institutional level of water management in the Colorado River basin from prehistoric communities to historical interactions with Hispanic and Anglo communities, basin states, and the United States—processes that involved dispossession and relocation to reservation lands slowly leading toward Indian reserved water rights. The tribal level is quasi-national as tribes have sovereignty over their lands, waters and institutions. However, the U.S. federal government has a trust responsibility for tribal interests that affects their water institutions.

There are thirty federally recognized tribes within the Colorado River basin (Figure 5). Their reservations vary in spatial scale from the large transboundary reservation of the Navajo Nation, which surrounds the Hopi reservation in northeastern Arizona, to smaller reservations within each state of the basin except Wyoming. The basin's largest number of tribes and area of reservations lie in Arizona. This bibliographic search followed previous conventions with an emphasis on law review articles and cases. The search terms "Colorado River" and "tribe" or "tribal" yielded rich results. "Colorado River" and "Indian" was fruitful, though it gave a disproportionate number of hits on Colorado River Indian Tribes who live on the banks of the lower Colorado in Arizona and California, two of which have longstanding roots on those lands (Mohave, Chemehuevi), while two tribal groups have modern resettlement histories (Hopi and Navajo) (Blossom, 1979; Caylor, 1996; Ramirez, 2019).

It has long been recognized at other levels that tribal water rights would eventually be recognized, adjudicated, and developed, but fulfillment of those obligations has lagged for decades. Several aspects of Indian water rights distinguish tribal water institutions from water rights at the state level (Zellmer and Amos, 2021, p. 372–84). The case of *United States v. Winans* (198 U.S. 371, 384, 1905) in the Pacific northwest recognized aboriginal tribal rights for fishing that were not granted away or lost by treaty with the United States. As aboriginal rights, they have priority dates that are time immemorial, and thus intrinsically senior to all in prior appropriation systems, and they often have an intrinsically sacred significance (Bryan, 2017). In contrast to state prior appropriation rights, they do not require diversion or consumptive use of water, which pose challenges for state water rights administration based on diversions and historical beneficial use (Nania and Guarino, 2014).

A second pivotal case in Montana in 1908, *Winters v. United States* (207 U.S. 564, 1908), determined that Indian reservations have reserved rights to the water necessary for their viability, which cannot be expropriated by later non-Indian users. Like federal reserved rights, Indian reserved rights date to the establishment of the reservation. Unlike other prior appropriation rights, however, their size is not based on the quantity of historical beneficial use. Tribal reserved rights affirmed in the lower Colorado River basin context of *Arizona v. California* (373 U.S. 546, 600, 1963) quantified them on the basis of "practicably irrigable acreage," i.e., the amount of water required for potential vis-à-vis actual irrigation. That amounted



ID	Tribe Name
1	Ute Indian Tribe of the Uintah and Ouray Reservation
2	Southern Ute Indian Tribe
3	Ute Mountain Ute Tribe
4	Jicarilla Apache Nation
5	Navajo Nation
6	Zuni Tribe
7	Hopi Tribe
8	Kaibab Band of Paiute Indians
9	Havasupai Tribe
10	Hualapai Indian Tribe
11	Shivwits Band of Paiute Indian Tribe
12	Moapa Band of Paiute Indians
13	Las Vegas Tribe of Paiute Indians
14	Fort Mojave Indian Tribe
15	Chemehuevi Indian Tribe
16	Colorado River Indian Tribes
17	Yavapai-Apache Nation
18	Yavapai-Prescott Indian Tribe
19	Tonto Apache Tribe
20	White Mountain Apache Tribe
21	San Carlos Apache Tribe
22	Fort McDowell Yavapai Nation
23	Salt River Pima-Maricopa Indian Community
24	Gila River Indian Community
25	Ak-Chin Indian Community
26	Quechan Indian Tribe
27	Cocopah Indian Tribe
28	Tohono O'odham Nation
29	Pascua Yaqui Tribe

FIGURE 5
Map of federally recognized tribes in the Colorado River basin [U.S. Bureau of Reclamation map. Available online at: https://www.usbr.gov/lc/region/programs/crbstudy/tws/docs/Appx%201B%20Federally%20Rec%20Tribe%2012-13-2018.pdf (accessed December 16, 2022)].

to over 900,000 acre-feet in the Court's initial award to tribes along the lower Colorado River. The Supreme Court rejected Arizona's argument that tribal rights should be quantified on the basis "equitable apportionment," as that principle applies at the interstate level, and Indian tribes are not states. These debates came up again in the Gila River context where the Arizona

Supreme Court held that practicably irrigable acreage is one of several criteria to be used when quantifying Indian water rights (*In re General Adjudication of All Rights to Use Water in the Gila River Sys. & Source*, 201 Ariz. 307, 2001; cf. Hedden-Nicely, 2020).

Tribal water rights were further enmeshed in the multi-level system by the McCarren Amendment (43 U.S.C. 666, 1952) and U.S. Supreme Court case of *Colorado River Water Conservation District v. United States,* 424 U.S. 800 (1976), which stipulated that adjudication of Indian water rights must originate at the state court level, along with all other water rights in a state. The state level argument is that Indian water rights cannot be administered effectively unless they are part of a comprehensive state water rights adjudication. The counterarguments are that states do not have a trust responsibility for tribal interests, and that state water rights holders have an interest in constraining the size of Indian water rights.

A third category of *Pueblo Indian* rights, concentrated in New Mexico, dates to the Treaty of Guadalupe Hidalgo with Mexico in 1848 (art. VIII, 9 Stat. 922), which recognized the continuing validity of land and water rights in territory ceded to the United States at that time (Richard, 2017). The U.S. Supreme Court recognizing Pueblo Indian rights as aboriginal, i.e., prior to Hispanic rule (*United States v Abouselman*, 976 F.3d 1146, 1160, 2020). In contrast to *Winters* rights, however, historical water use is the basis for quantifying Pueblo Indian rights.

Subsequent Indian water rights cases have dealt with the implications of these precedents in various contexts, e.g., non-agricultural water uses, changes in water use, leases to locations off reservation lands, and to non-Indian allotment purchasers. A U.S. Bureau of Reclamation (2012) study estimated that adjudicated Indian water rights in the Colorado River basin currently amount to 2.9 million acre-feet (Getches-Wilkinson Center, 2021). Twelve tribes have quantifications that are pending. Ten are located in the lower basin, one in the upper basin, and the Navajo Nation has land in both halves of the basin. These unquantified, and quantified but undeveloped, Indian water rights pose uncertainties for users in the Colorado River system.

A number of inter-tribal initiatives address water concerns in the Colorado River basin. Five tribes have been involved in the Glen Canyon Dam Adaptive Management Program as it relates to the Grand Canyon ecosystem (Hopi, Hualapai, Navajo, Southern Paiute Consortium, and Zuni) (Jacobs and Wescoat, 2002). Every aspect of tribal involvement in this program, from representation to ways of expressing tribal views and processes of decision-making reflect the rich diversity of tribal water institutions (Hart, 1995; Roberts et al., 1995; Stoffle et al., 1995; Ferguson, 1998; Hualapai and Stevens, 1998; Shepherd, 2002; Austin et al., 2007; Seibert et al., 2007; Dongoske et al., 2010; Tribal Resources, 2022). In 1992, a Ten Tribes Partnership (2018) was organized to represent tribal interests and concerns. The Partnership prepared a water study with the Bureau of Reclamation that examines current tribal water rights, water uses, future development plans, challenges, opportunities, and potential effects in the basin. Tribes along the lower main stem (Colorado River Indian Tribes and Quechan tribe) have recently produced a series of videos titled, "One River, One Mission, One Voice: Protecting the Colorado River" to urge a new vision for basin stewardship (Ten Tribes Partnership., 2021). A Water and Tribes Initiative (Tanana et al., 2021) has prepared a report calling for *Universal Access to Providing Clean Water for Tribes in the Colorado River Basin,* which draws attention to longstanding deficiencies in safe domestic water supplies on reservations. These inter-tribal initiatives call for a different approach, one that encompasses and transcends historical institutional levels of water management in the basin—one that regards the river in some respects as a person, as sacred, and as alive—views considered in the discussion section below (Water Tribes Initiative, 2020).

3.6. The international and emerging global levels of water management institutions

As noted earlier, the United States acquired almost all of the Colorado River basin region from Mexico through the Treaty of Guadalupe Hidalgo (9 Stat. 922, 1848) and Gadsden Purchase (10 Stat. 1031, 1853-4), which established the international boundary. The treaty created a joint US and Mexico Boundary Survey (1857-59) that produced a three-volume report on the border region. In 1889 the two countries established an International Boundary and Water Commission/Comisión Internacional de Límites y Aguas (IBWC) to address alluvial changes in the international boundary and other mutual concerns.

The Colorado River Compact of 1922 and Boulder Canyon Project Act of 1928 anticipated a water treaty with Mexico at some point, which the states regarded as a federal obligation. Hundley (1966) reviewed the treaty negotiations in detail, highlighting the importance of their changing historical context. In early negotiations in 1927 Mexico sought 3.5 MAF per year while the U.S. offered 0.75 MAF. A decade later, Mexico sought 2 MAF while the U.S. offered 0.9 MAF. It is often reported that the negotiators incorrectly assumed that a total average annual yield of 19 MAF was available, though that is critically discussed by Kuhn and Fleck (2019). Finally, in 1944 for purposes of international comity during a time of war, the two countries concluded the *Treaty on Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande* (Department of State Treaty Series No. 994; 59 Stat. (Pt. 2) 1219, 1944). The U.S. wanted a treaty on the Rio Grande while Mexico wanted its share of the Colorado. In the Colorado River provisions, the treaty stipulates that the US. will deliver an average flow of 1.5 MAF per year, from any and all sources, with an additional 0.2 MAF in surplus years. The two countries agreed to make proportionate reductions during severe droughts, share flood protection costs, and coordinate through the IBWC (for critique of the latter see Mumme, 2005; McCarthy, 2011). The treaty was ratified in 1945, and as an agreement at the international level it takes precedence over policies at lower levels.

Soon after ratification Mexico relayed complaints about the salinity of water deliveries from the U.S. that caused agricultural damages. The U.S. began biennial salinity reports in 1965, and in 1973 the IBWC issued Minute 242 calling for the U.S. to establish salinity control standards and methods to ensure that the salinity of water delivered to Mexico would be no more than 115 $\pm$ 30 ppm greater than that of the water behind Imperial Dam (IBWC, 1973). That international level policy triggered a multi-level cascade of actions with federal, tribal, state, and community level implications across the basin. At the federal level, Congress passed the Colorado River Salinity Control Act of 1974 (Public Law 93–320 amended in 1984), which funded salinity control works below and above Imperial Dam. Upstream projects included water management improvements on local U.S. Bureau of Reclamation projects like the Grand Valley Project in western Colorado. That project co-financed improvements in irrigation efficiency to reduce groundwater leaching and brackish return flows–and it expressly did not alter irrigators' water rights held under Colorado water law.

Subsequent IBWC minutes have dealt with border sanitation at various localities, and with provision of emergency water deliveries to the city of Tijuana, the most recent in 2022. Concerns about severe and sustained drought arose in the 1950s, not long after the treaty was signed, and in subsequent droughts up to the present (Powell Consortium, 1995; Gangopadhyay et al., 2022).

At the start of the 21st century, the Colorado River basin region entered a multi-decadal megadrought that affects international treaty obligations and all levels of water management in the region. When the present drought became protracted, the U.S. Department of Interior (2007) developed "Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead." As the drought continued for another decade, the IBWC (2017) issued Minute 323 on a "Binational Water Scarcity Contingency Plan," to cover the period to 2026. Finally, in late 2021, the U.S. and Mexico negotiated a reduction of U.S. treaty obligations to Mexico (50,000 AF and 30,000 AF in recoverable savings) (IBWC, 2021); along with Tier 2 lower basin water reductions within the U.S. (330,000 and 200,000 AF in recoverable savings) in 2023, the first time since the treaty came into force in 1945, and it is not clear whether they will be sufficient.

Gleick (1988) undertook early investigations of potential international effects of global climate change on U.S. and Mexican water interests in the Colorado River. He and others extended that research to analyze impacts on international streamflow (Nash and Gleick, 1991) and environmental restoration flow requirements for the Colorado River delta in Mexico (Postel et al., 1998).

As at other levels, the international level has developed its own institutional rules, procedures, and organizations. They include the treaty-making power of the two nations, administrative role of the binational commission, and policy minutes that it negotiates on matters of mutual concern. As illustrated in recent salinity and drought issues, international deliberations are influenced by actors and arguments at all local and regional levels. And the resultant international agreements have implications that cascade through all institutional levels of water management (Conca, 2015; Rivera-Torres et al., 2021).

4. Discussion: Toward an expanded multi-level law of the river

The Law of the River historically refers to the multi-level institutions that developed from the Colorado River Compact of 1922 to the present. Spatially, it ranges from international treaty agreements with Mexico to federal policies, interstate compacts, tribal water policies, and constitutive state water laws. This paper has sought to extend the law of the river in several ways.

Conceptually, it has argued for a focus on institutional levels of water management. It has shown that each level has distinctive rules and organizations that guide water management at that level and in relation to other levels. The organizations at some levels have socio-statutory foundations, while some at the community level have socio-cultural vis-à-vis jurisprudential bases. All of them evolve over time. The paper showed how community level institutions arose in contexts that were relatively small in geographical size and early in historical time. At least from 16th century Hispanic period onwards formal state institutions shaped those at the community level (e.g., through water rights legitimation and administration). From the late-19th century on, higher level institutions developed for interstate, federal, and international regions. This basic progression falters when considering tribal level water institutions that extend from aboriginal communities to modern state and national level relationships and beyond them to transcendental levels that have yet to be institutionalized. Tribal levels of water institutions exemplify the *expanded multi-level law of the river* in the Colorado River basin region.

In substantive terms, a large portion of the paper made the case for including community level institutions within the law of the river (Robison et al., 2021). The community level is defined by various forms of social solidarity that originate in prehistoric tribal cultures of water management followed by Hispanic, Euro-American, Asian-American, professional, environmental, and other communities. These communities have collectively shaped the macro-historical geography of the Colorado River basin region. One might argue for differentiation of community water management by households, firms, or individuals. However, in most cases these smaller groups belong to communities and to states that govern their water uses and water rights.

Methodologically, the bibliographic search proved more complicated than standard systematic reviews. It required a combination of common search terms and level-specific terms. The indexes searched had different filters for keyword and abstract fields. A large number of hits for some search term pairs required title searches, along with a significant amount of filtering by the author to identify relevant hits. With these limitations in mind, the bibliographic search results were able to document rich bodies of research on how each level in the macro-historical geography of water management developed over centuries, and in interaction with other levels.

One way to recount the macro-historical geography of any complex river basin is thus to review the progressive development of its levels of water management from communities that are small in geographical area and early in time to those larger and more recent in time. While only a fraction of the references and policy documents identified could be cited within the scope of this review, it is hoped that they capture the institutional breadth, depth, and logic of multi-level water management in the basin.

It is important to note that while each level has a relatively well-defined jurisdictional extent, that can change over time. In addition, it has subdivisions (e.g., districts) that enable it to operate down to local levels. Conversely, networks of local level organizations organize to influence higher level state, national, and international institutions, which contributes to dynamic interactions and outcomes across levels. These phenomena are sometimes described as "scale-jumping" whereby strategic political interactions occur across rather than within levels.

A good example of multi-level historical geography discussed at various points above is the Grand Valley area of western Colorado, which lies at the confluence of the Colorado and Gunnison Rivers (Wescoat, 1984). That region was occupied for centuries by hunter-gatherer Ute Indian tribes until their removal to the Uintah and Ouray Reservation in Utah in 1881. Soon after, Anglo settlers appropriated senior water rights on the Colorado River under state water law to irrigate Grand Valley and establish the town of Grand Junction. In 1911, several larger irrigation organizations contracted with the U.S. Bureau of Reclamation to build the federal Grand Valley irrigation project. The Upper Colorado River Compact and Colorado River Storage Project Act provided funding for smaller reclamation projects near Grand Valley, including the Silt and West Divide projects upstream. In 1974, Reclamation included Grand Valley in its salinity control plan to help fulfill the US obligation to Mexico, with the provision that it would not affect the project's senior water rights in Colorado. Continuing economic growth of Grand Junction led to tensions between irrigators and newer urban water communities. In just this one local area, as in countless others, one observes all institutional levels operating and interacting severally and with one another.

Understanding the rules and organizations that operate at each level offers insights into the historical geography of a basin and its institutional logic relevant for periods of stress (Lord et al., 1995). Understanding the multi-level logic of basin institutions can also help envision alternative institutional strategies and pathways—e.g., through new community formation, increasing standards of beneficial use, proscriptions against waste, implementation of Upper Basin drought conservation policies, exercising the Secretary's authority in the Lower Basin, and transforming emerging tribal visions of the river into action.

5. Conclusion

This paper has sought to show that reviewing levels of water management in a complex river basin is a useful complement to research on geographical scales of hydrologic and water management processes. Each level has rules and organizations shaped by their historical geographic context. Each institutional level intersects with multiple geographical scales of water management. A stream may have thousands of water rights, ranging in quantity from tenths to hundreds of cubic feet per second, but state level rules of water rights administration apply in principle to them equally. The federal Bureau of Reclamation has hundreds of local projects, as well as large river basin development programs and policies. Focusing on institutional levels of water management helps clarify the rules and organizations applicable in different situations. Retracing the historical geography of water institutions helps ensure that they are regarded as dynamic and capable of adapting to changing needs and conditions.

Institutional levels of water management in the Colorado River basin thus have a macro-historical geography. They have developed from community level systems relatively small in geographical size and early in time to levels larger in size and more recent in time. Importantly, each level has endured and influenced those that followed. The community level shaped prior appropriation doctrines in state water law beginning in the second half of the 19th century. States became engaged in interstate institution building in the early 20th century. The tribal level spans all periods and scales, and calls for a new vision and approach to the river. In the current mega-drought those calls may yet be heard. Dramatic processes of decentralization occurred in prehistoric times, and could occur again.

In general, higher levels of water management constrain those at more local levels. A treaty constrains interstate compact deliveries, which constrain state water rights and community water use. However, the macro-historical geographic perspective shows that community water management also influences higher institutional levels. The community level is extraordinarily diverse, increasingly networked, and efficacious. Tribal levels of water management are entering a new era of coordinated organization and authority. An emergent global level of water institutions is on the horizon.

Preparing a macro-historical geography of a complex river basin like the Colorado is challenging. This paper used bibliographic search and review methods that are increasingly feasible in the era of online scholarly indexes and full text publication, though some resources like doctoral dissertations depend upon university library access. A value of this institutional approach is that it seeks to comprehend and expand the historical depth and geographic breadth of the law of the river. Its limitation in article format lies in the limited detail that is possible for each level, omitting important events, rules, and studies from the macro-historical geographic map produced. Systematic search and citation methods reduce those limitations somewhat but not entirely.

The Colorado River basin region offers an especially salient case study for these concepts and methods. Its law of the river framework invites continuing exploration and interpretation. This framework of multiple institutional levels of water management that develop within a macro-historical geographic context can be constructed for comparative purposes in most complex river basins (e.g., Wescoat, 2005; Reich, 2013; Pande and Ertsen, 2014; Sattar et al., 2018). The levels may vary, and their historical geographies certainly do, but the institutional levels of water management are often comparable, and they can help situate the Colorado River basin region within the global context of comparative river basin research and management.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

Author contributions

JW was responsible for conceptualization, bibliographic searches, and writing.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2022.1024055/full#supplementary-material

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