www.water-alternatives.org Volume 8 | Issue 2
Sternlieb, F. and Laituri, M. 2015. Spatialising agricultural water governance data in polycentric regimes. Water Alternatives 8(2): 36-56

Spatialising Agricultural Water Governance Data in Polycentric Regimes

Faith Sternlieb

Colorado Water Institute, Colorado State University, Fort Collins, Colorado, USA; faith.sternlieb@gmail.com

Melinda Laituri

Colorado State University, Fort Collins, Colorado, USA; Melinda.laituri@colostate.edu

ABSTRACT: Water governance in the Colorado River Basin (CRB) is based on a historical and complex set of policies, legal decisions, and operational guidelines called the *Law of the River*. Behind the complex institutional structure lies an intricate web of data on water, most of which are hydrogeological in nature. However, we posit that in order to realise sustainable water governance, management efforts must also address data on water governance. Therefore, our central research question is: *what is the role of water governance data in water governance, as it pertains to agriculture*? First, we lay out the digital landscape and theoretical framework that justify the development of the Colorado River Basin Water Governance Relational Database. Then, we conduct an analysis of water-sharing policies within *Law of the River* to identify and categorise boundaries. By operationalising a boundary typology in a geographic information system, we found that data on agricultural water governance have little to no current role in water governance due to scale discrepancies, insufficient availability and collection of data, and lack of standardisation. In addition, agricultural water governance in the CRB was found to exhibit polycentric patterns. However, unlike the flexible and adaptive nature of some polycentric systems, polycentric data sets may pose challenges to water governance due to limited information regarding organisational changes, policy developments, and special interests. This study advances the science-policy dialogue in four ways: 1) by emphasising the salience of the data on water governance, 2) by incorporating water governance data in water governance and policy decisions, 3) by demonstrating the value of integrating data types, and 4) by engaging users through geo-visualisation.

KEYWORDS: Colorado River Basin, boundary, Geographic Information Science, relational database, science-policy discourse

INTRODUCTION TO WATER GOVERNANCE DATA

Water governance research, especially as it pertains to river basins or watersheds, is well established (Conca, 2006; Garrick et al., 2014; Huitema and Meijerink, 2014; Squires et al., 2014). However water governance *data* are less defined and are in need of further development and management (Gallaher and Heikkila, 2014). Building off of the definition provided by Stoker (1998), "governance refers to the development of governing styles in which boundaries between and within the public and private sectors have become blurred". These boundaries are at the heart of the spatialisation of water governance. Water governance, according to Gallaher and Heikkila (2014) focuses on "how the organizational and institutional arrangements address the challenges of supplying, storing, treating, maintaining, protecting and sharing water for growing populations and competing demands". Water data, as Laituri and Sternlieb (2014) define it are "diverse sets of information that address the physical, environmental, ecological, social, economic, cultural, and political parameters of water use, availability, and accessibility". Drawing upon these definitions, we maintain, for the purposes of this paper, a broad but simplistic definition for water governance data as information about institutions and organisations interested in water use, availability, and accessibility. Compounded by the obscurity of data on water governance, there is a limited quality and quantity of data that can be spatialised or viewed in a geospatial platform.

Geospatial governance data extend beyond thematic maps that show political boundaries (e.g. countries and states), voting blocks, election results, and socioeconomic or demographic characteristics across a defined area. Governance data are thematic in nature but also include data that have not been traditionally spatially represented such as data that can be obtained from sets of policies, rules, and laws that shape interests (e.g. agriculture) and decisions (e.g. selling a water right), which are more difficult to map. Spatial representation of formal and informal policies, rules and laws as well as the organisations that are mandated to carry out these policies in the form of geographic boundaries linked to thematic data can demonstrate different types of rulings about who can or cannot use water and how, where, when, and why water is used or not. Such policies dictate water management, particularly as it relates to 'sharing' water between people, parties, organisations, and sectors. Here, such policies are referred to as water sharing arrangements (WSAs).

WSAs are transactions that allocate and reallocate water between and among water users. New WSAs involve reallocation of water between and across sectors, which involve many overlapping jurisdictions across multiple geographic scales (e.g. international, interstate, and intrastate transactions) (Cash et al., 2006; Feitelson and Fischhendler, 2009). The term 'water sharing' is used here to describe multiple facets of water quantity (e.g. shortages and surpluses), as well as benefits and costs (Draper, 2007; Jones and Colby, 2012). In this paper, water sharing is the initial apportionment and the later reallocation of water between users across a landscape. The link between WSAs and geography can be made explicit through data transformation and geo-visualisation.

Theoretically, a geospatial perspective on governance allows us to spatially analyse policy outcomes at multiple scales (Wolf, 1999; Starr, 2002; Fischhendler and Feitelson, 2003; Feitelson and Levy, 2006; Feitelson and Fischhendler, 2009). There is a need to better understand the geospatial aspects or spatialisation of water governance, especially at regional and local scales (Fabrikant, 2000; Kraak, 2004) in order to decipher political, economic, and social trends and interests. One way to spatialise governance is through boundaries, which are key to understanding governance (Sternlieb, et al., 2013). Maps are used to visualize governance and to "stimulate visual thinking about geospatial patterns" (Kraak, 2003: 391, 2004: 85; Tufte, 2006). When manipulated in a geospatial platform, political, ecological, economic, social and cultural boundaries generate such geospatial patterns, which are continually more accessible via the Internet, software, and digital globes. Furthermore, the development of multiple types of boundaries in a geospatial platform can facilitate the spatialisation and geo-visualisation of governance. Due to increased activity on the Internet with and for stakeholders as well as the availability of spatial data and maps online, the Colorado River Basin (CRB) is ripe for investigation into the linkage between science and policy, as it relates to governance in a geospatial arena.

This paper introduces the CRB Water Governance Relational Geodatabase (WGRG), an effort that was commissioned and funded by the Environmental Defense Fund with additional support from the USDA project *Addressing Water for Agriculture in the Colorado River Basin*[1] between 2010 and 2013. The first section unfolds the geospatial nature of water governance through a framework that links policies, boundaries, and patterns as they fit within a polycentric system, with a special focus on agriculture. Agriculture is of particular relevance due to the high dependence on water both in and across sectors and the geographic fragmentation of agricultural water governance in the basin. The second section reviews the geospatial data landscape of the CRB, providing specific examples of efforts

[1] www.crbagwater.colostate.edu/AddressingAg/index.shtml

to map agricultural water governance in the CRB. The third section converts the framework into a systematic methodology that spatialises water governance through the development of a boundary typology by linking corresponding geospatial data in a relational geodatabase. We present detailed results from data analyses that demonstrate polycentric data sets, which feed challenges in agricultural water governance related to scale, the role of standardisation in data sources, and data availability. These results inform the science-policy debate regarding the generation of new knowledge, sustainability in the governance of water and data, a new frontier for interdisciplinarity in the geospatial sciences, manifest through the integration of physical and governance geospatial data sets, and the geo-visualisation. The authors also offer recommendations for future research on the spatialisation of water governance and the advanced definition of boundaries enabling the further development of governance data.

POLYCENTRIC SYSTEMS

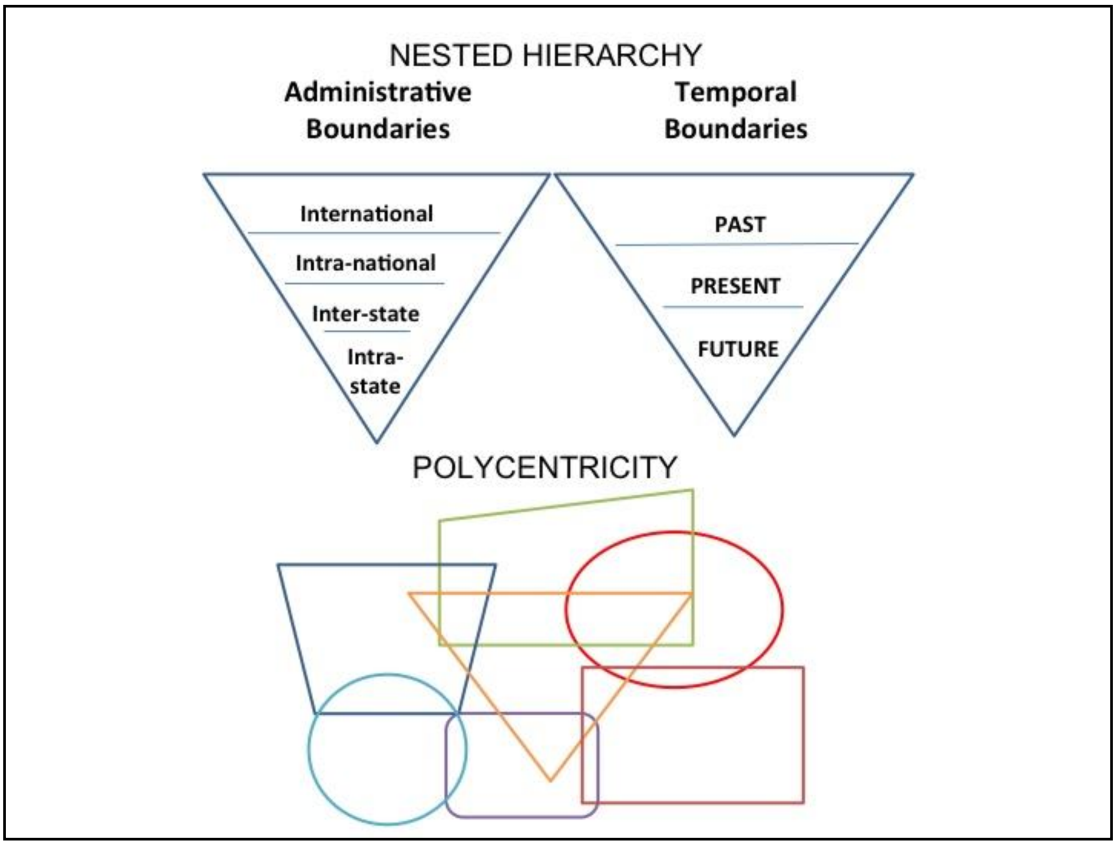
According to Fabrikant (2000), "spatialization is based on envisioning and comprehending spatial properties… rooted in physical and cultural experiences" (68). Therefore, to spatialise governance means to create a metaphor that represents "abstractions and selections of reality" (Kraak, 2004: 83). In this study, spatialise means to map geospatial attributes represented by geographic boundaries, which retain and demonstrate governance attributes through the visualisation of geospatial data.

As geospatial attributes, boundaries are key to governance studies. Governance boundaries can be explained as normative or *bonafide* (Sternlieb et al., 2013) or the agreement (cooperation) or disagreement (conflict) between two water users in river basins where sharing limited supplies of water is essential for collective survival (Wolf, 1999; Starr, 2002; Fischhendler and Feitelson, 2003; Feitelson and Levy, 2006; Feitelson and Fischhendler, 2009). Boundaries also have an important role in providing the link between qualitative geographic information science (GIScience) data analysis and textual materials (e.g. policy documents) that are otherwise absent in geographic information system (GISystem) software (Kwan and Ding, 2008). More specifically, they are a fundamental underlying component that can be used to link governance to geospatial data.

Historically, governments have been mapping their territories using cartographic lines to depict boundaries. Governance however, entails more than just lines that represent territoriality; it is the formal and informal rules, policies, regulations and boundaries defined by decision-making at multiple levels (Krahmann, 2003; Biermann et al., 2010; Gallaher and Heikkila, 2014). Governance can be easily framed within a GIScience context through definitions of scale (among other means) by coupling the analytical problems of Biermann et al. (2010) with the governance dimensions of Krahmann (2003). Sternlieb et al. (2013) describe scale as a transboundary concept, which is useful for linking governance attributes and geospatial data. Both scale and organisational dispersion are factors that dictate governance dynamics, patterns and processes.

Geopolitical patterns convey the nature of the jurisdiction and how it manifests itself geographically on the landscape. Based on Grimm et al. (2005: 987) definition, "patterns are defining characteristics of a system and often, therefore, are indicators of essential underlying processes and structures". Nested hierarchy and polycentricity are two geopolitical patterns that are pervasive in governance systems, both of which can be geospatially represented, as shown in Figure 1. Where nested hierarchy is a system of hierarchical patterns of concentric polygons that nest within each other in any one location or region, from a global to local scale, ranging in geographic and temporal extents (Sheppard and McMaster, 2004), polycentricity, is a pattern of governance made up of institutions consisting of governmental and nongovernmental actors within a system of overlapping jurisdictions at multiple scales (McGinnis, 1999; Ostrom, 2005; Andersson and Ostrom, 2008). Geospatial data for physical (hydrologic) and political boundaries represent hierarchical patterns from local (micro) to global (macro) levels. In the US, the smallest unit of measurement for political boundaries is the municipality at the local level; according to the US Geological Survey (USGS) the smallest unit for hydrologic boundaries is the 12-digit hydrologic unit code (Seaber et al., 1987). Scale is embedded in different sets of geopolitical patterns, exemplified by a hydro-agricultural landscape among other waterscapes.

Figure 1. Conceptual spatialisation of two governance patterns: Nested hierarchy and polycentricity.



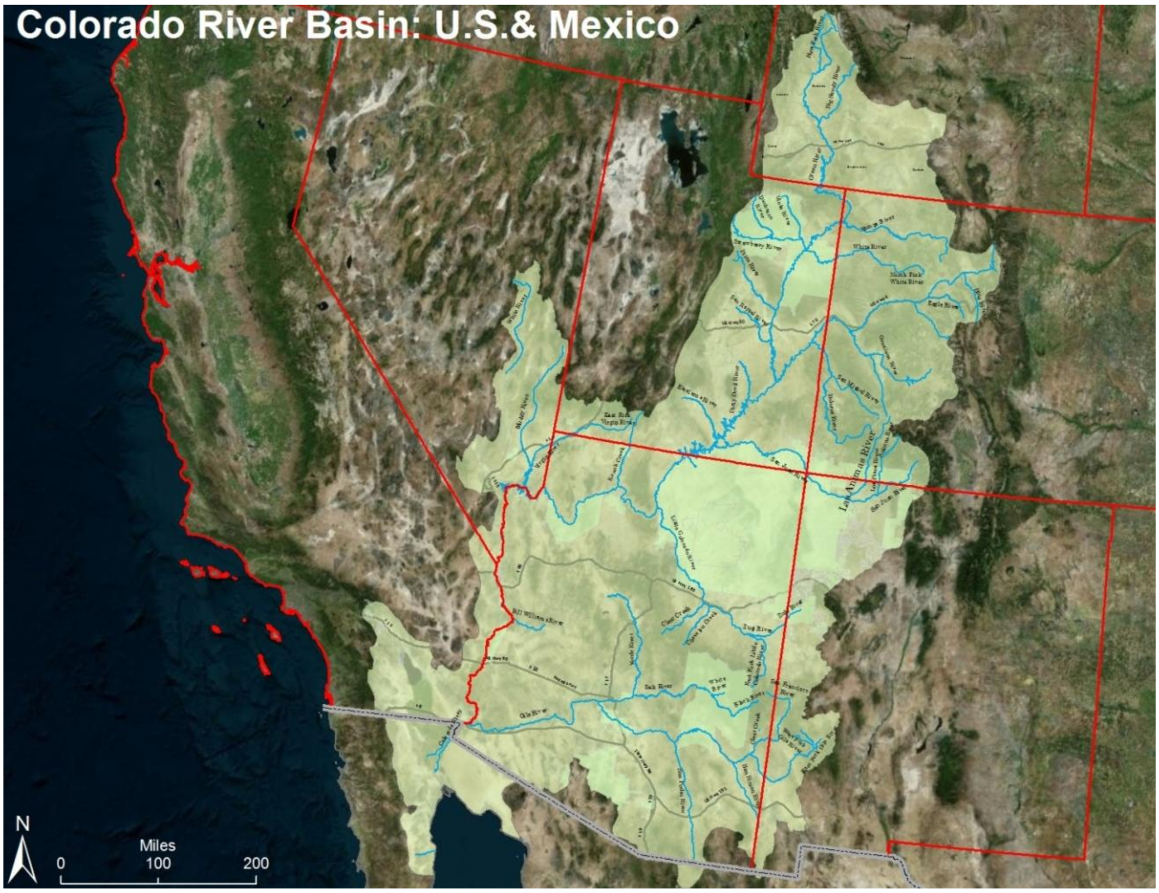
Polycentric systems are regarded as mechanisms that increase institutional capacity where decisions are made by diverse sets of actors linked across different organisational units (McGinnis, 1999; Ostrom, 2005; Andersson and Ostrom, 2008). Organisational units within agricultural water governance in the CRB are defined by statutory law of each state and are generally situated across the local scale in both hierarchical and polycentric patterns. Key components that define polycentric systems include: dispersal of political authority, separately constituted bodies, overlapping jurisdictions, increased self-governing capacity of local communities and increased cross-scale linkages between horizontal and vertical levels of organisations (Berkes, 2002; Ostrom, 2005; Cash et al., 2006; Huitema et al., 2009).

Empirical studies point to benefits of polycentric governance systems as more resilient and adaptable to change for two reasons: 1) issues from a range of geographic scopes can be managed at different levels and 2) due to a high degree of overlap and redundancy, they are less vulnerable (Ostrom, 2005; Huitema et al., 2009). However, Kim et al. (2015) argue that fragmentation makes resource management more challenging. One of those challenges is in water- and data-sharing, which are difficult to attain "because of the need to accommodate the complexity of spatial patterning, multiple function overlays, partial polity formation, and variable systems coupling" (Huitema et al., 2009: 3). The operationalisation of the boundary typology and analysis of data on agricultural water in the CRB tests and supports this hypothesis. Our results offer specific examples from these analyses.

GEOSPATIAL DATA OF THE COLORADO RIVER BASIN

The CRB, as shown in Figure 2, is an international transboundary river basin, measuring 2736 km (1700 miles) long from Green River headwaters in Wyoming to the Gulf of California in Mexico and draining an area of 63.7 million hectares (246,000 miles^2). The Colorado River is one of the world's most highly regulated river systems, where agriculture uses up to 75% of the available water (USBR, 2012). Agricultural water in the CRB is currently under pressure due to projected increases in population, water demand and water use, as well as significant uncertainty in climate and future water supply. Special districts that manage the supply of agricultural water to farmers and producers are situated at the centre of these pressures. An increase in competition for limited supplies has incited a demand for data on agricultural water governance, and with the technological reach and capability of the Internet, collection of data has been focused on geo-visualisation. Geospatial data collections include online interactive maps (Web maps) that demonstrate and visualise physical water data (including supply and quality) from multiple sources at different scales (Kraak, 2003, 2004; MacEachren and Kraak, 2013).

Figure 2. Colorado River Basin overlaid on a satellite image: US (state in red outline), US tribal lands (in opaque green) and Mexico (USBR, 2012).



Private and public entities that have a stake in water governance have a greater presence on the Internet, in part to provide data and information on water to the public due to the urgency of water scarcity in the CRB. Water scarcity is characterised by an increase in water demand, a decrease in supply, and increasingly variable precipitation patterns (USBR, 2012). Water scarcity in the CRB has captured the attention of media venues evidenced by radio, newspapers, and blogs, and in privately funded initiatives like *Save The Colorado* (Wockner, 2010), *Nuestro Rio* (Kane, 2011*)*, and *Change the Course* (National Geographic, 2013) among others. With the prevalence of Colorado River initiatives and research, maps are widely available for the Colorado River Internet community that include themes such as expeditions, conservation areas, management challenges, as well as water supply and development issues. An analysis of the boundaries from a review of interactive maps of the CRB reveals new boundaries, such as anecdotal boundaries (stories and narratives found in PBS' Powell's First Voyage) and graphical boundaries (pictures and drawings demonstrated in National Geographic's Change the Course). Stories, narratives, and pictures demonstrate places of cultural significance, highlighting cultural boundaries (Pellow, 1996).

There has also been an influx of investment of time and financial resources by federal and state agencies responsible for managing resources in the basin. Each state provides online water data related to Colorado River use, development, and conservation. Physical, political, and sectoral boundaries are represented in geospatial data sets per state, especially those representing sectoral boundaries where agriculture, municipal, environmental, and industrial water is characterised. The US Bureau of Reclamation (USBR) CRB Supply and Demand Study (Basin Study) is the most extensive federal-state data collection effort in the CRB to date (USBR, 2012). The Basin Study was a result of a partnership between the Upper and Lower Basin states, which are boundaries based on the *Law of the River,* a historical set of policies, court cases, laws, and operational guidelines that set the political course for governing water in the CRB. The geospatial data collected for the Basin Study were largely based on physical boundaries related to water measurements to identify quantity and quality scenarios (USBR, 2012). Such an overlap of jurisdictions in the CRB, the quantity and varying degrees of quality of data, as well as the organisational diversity have resulted in increasingly complex boundary intersections.

At a local scale, special districts such as irrigation districts represent special interests but the data on this level is disparate, at best. Special interests like agriculture are central to agricultural water development and management in the CRB (Leshy, 1982) and are organisational units that exemplify sectoral boundaries. There is often a fuzzy distinction between private and public districts because of how they are organised and authorised. Special districts such as service and supply organisations for agriculture can be classified into two types: (a) private and owned by shareholders, and (b) public, which are federal, state, or quasi-governmental (Getches, 2009). Water utilities, mutual water companies, carrier ditch companies, and mutual ditch and irrigation companies are private service and supply organisations. Examples of public service and supply organisations (and quasi-governmental organisations) include municipalities, irrigation districts, conservancy districts, conservation districts, USBR districts, water control districts, freshwater supply districts, and municipal water districts. These are examples of formal political entities; however water markets in the West have dominated water-sharing arrangements, and data on water from these arrangements are highly valued.

The most important data in water-sharing arrangements relate to water rights. Data on water rights provide both governance and hydrogeological information and dictate the use, the user, the timing, the quantity and the user's seniority to receive water. In addition to the organisational structure dictated by policy, water users in the U.S. West may share water through more informal apportionment and reallocation mechanisms such as compacts, appropriation systems, water markets and water banks, transfers, exchanges, sales, and other types of interactions (Grafton et al., 2010; Grafton et al., 2011). For example, the Bren School of Environmental Science & Management hosts the Water Transfer Database (WTD),[2] which is a compilation of water right transactions from 1989 to 2008 in the Western U.S. from data published in a journal called the Water Strategist. The data collected include water use (agricultural, environmental, urban, combination and recycled, among others), contractual form (water sales, leases, exchanges), water quantities, and transfers among and between sectors (of which there

[2] www.bren.ucsb.edu/news/water_transfers.htm

are at least 11 possibilities) (Libecap, 2010).

Although the WTD is one of the most comprehensive collections of water rights transactions in the world and has been used to better understand trends in water policies in water-scarce places, the database is dependent on voluntary reporting. Even though volunteer data are often reliable, it cannot always capture the more sophisticated nuances of scale or the hydrologic extent of water rights information. In addition, older water rights have historically changed hands countless times, making it hard to trace the vast number of smaller rights that were obtained informally but continue to be used. Data on water governance in this paper are focused on the use and the user, in this case agriculture and the agricultural producer. Due to the many challenges that data on water rights present, including inaccuracies in quantities of water and water rights holders as well as thousands of records, we chose to take a geographic approach, collecting geospatial data arranged in different types of patterns such as watershed and organisational information. This approach operationalises a boundary typology of formal policies at federal, state and local levels that permit water sharing.

METHODS

The CRB WGRG responds to the need to collect and examine geospatial water governance data. The goal of this geodatabase is to integrate three different types of governance data based on physical, political, and organisational boundaries[3] from which sectoral boundaries are derived. Using ESRI ArcGIS 10.1, a file geodatabase was constructed containing feature data sets and feature classes arranged by WSA and by state. Data were collected from a number of different federal, state, and local agencies across the CRB including the USBR, the Colorado River Water Conservation District, the seven basin states (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) as well as from the National Atlas, a collection of data provided by the US government. Most of the data collected were freely available on the Internet and the data that were not, were freely provided when requested. Although the data came from different sources and have different geographic references, all of the data have been transformed to North America Albers Equal Area Conic projection and the GCS North American 1983 geographic coordinate system.

In order to spatialise water governance data, we developed a systematic methodology to 1) analyse a subset of water sharing arrangements to identify geographic boundaries, 2) apply a boundary typology in a GISystem, as shown in Table 1, a method used to transform tabular, categorical data to spatial data in a geospatial integrated relational database; and 3) demonstrate patterns of water governance data through the geo-visualisation of physical, political, and sectoral boundaries. Physical boundaries are formed naturally through time and hydrogeologic processes. There are two types of naturally occurring physical boundaries: hydrologic, those based on natural drainage systems defined by the National Hydrography Dataset of the USGS (Seaber et al., 1987), and hydrographic boundaries delineated by a state or tribe. Political boundaries, sometimes referred to as organisational or institutional boundaries (Heikkila, 2004), are politically constructed and are formed by a combination of political, social and cultural forces. Political boundaries are based on four types of governance: statutory, judicial, administrative, and time. Sectoral boundaries are socially constructed and formed by social and cultural processes that delineate different types of water users as well as economic interests at local and regional scales (Fischhendler and Heikkila, 2010). Agricultural water decisions have formed and evolved from physical, political, and sectoral boundaries specified in policies, laws, and rules, all of which can be georeferenced. More importantly, some boundaries have actually initiated informal rules and norms on sharing water in the CRB (Sternlieb et al., 2013).

[3] Some organisational boundaries are political and others are not. We differentiate between the two in order to define sectoral boundaries.

Table 1. Boundary typology: Spatialising water governance through governance layers.

Boundary type	Governance layer	Governance attributes
Physical	Hydrologic	Based on natural drainage systems defined by the National Hydrology Dataset (USGS)
	Hydrographic	Based on drainage basin delineated by each state and tribe
Political	Statutory	Based on federal, state and tribal laws and policies
	Judicial	Based on US Federal/State, District and Appellate Court system
	Administrative	Rules and regulations based on governmental jurisdictions (federal, state, tribe, county, municipality, city)
	Temporal	Based on time/history largely due to sequential legal and political decisions
Sectoral	Agricultural Environmental Municipal Industrial Recreational	Based on social and political interests and supported by organisations' bylaws reinforced by state statute

Due to the hierarchical nature of some policies, a subset of WSAs was selected to demonstrate governance. We chose to demonstrate the Colorado River Compact (1922),[4] Mexico Water Treaty (1944),[5] the Upper Colorado River Basin Compact (1948),[6] *Arizona v. California* (1963),[7] Interim Guidelines (2007),[8] and Minute 319 (2012).[9] Geospatial data from these WSAs include: 1) hydrologic boundaries defined both by state and by hydrologic unit and 2) political boundaries that represent entities and their respective scale and jurisdiction (e.g. county, city, and district). Physical, political, and sectoral boundaries were linked by joining related tables in the relational database to governance layers (geospatial data) in the geodatabase, as shown in Figure 2.

Each geospatial file represents a governance layer in both the geodatabase and relational database, which are linked through related tables. Each administrative area refers to a jurisdiction governed by distinct rules, actors, and cultural, social, and behavioural codes. Governance layers depict the complexity of water governance in the CRB because they demonstrate overlapping jurisdictions and arrangements driven by norms and behaviours of actors who have different and sometimes opposing

[4] Colorado River Compact of 1922, 70 Cong. Rec. 324 (1928).

[5] Rio Grande, Colorado and Tijuana Treaty of 1944, TS 994, 59 Stat. 1219 (1944).

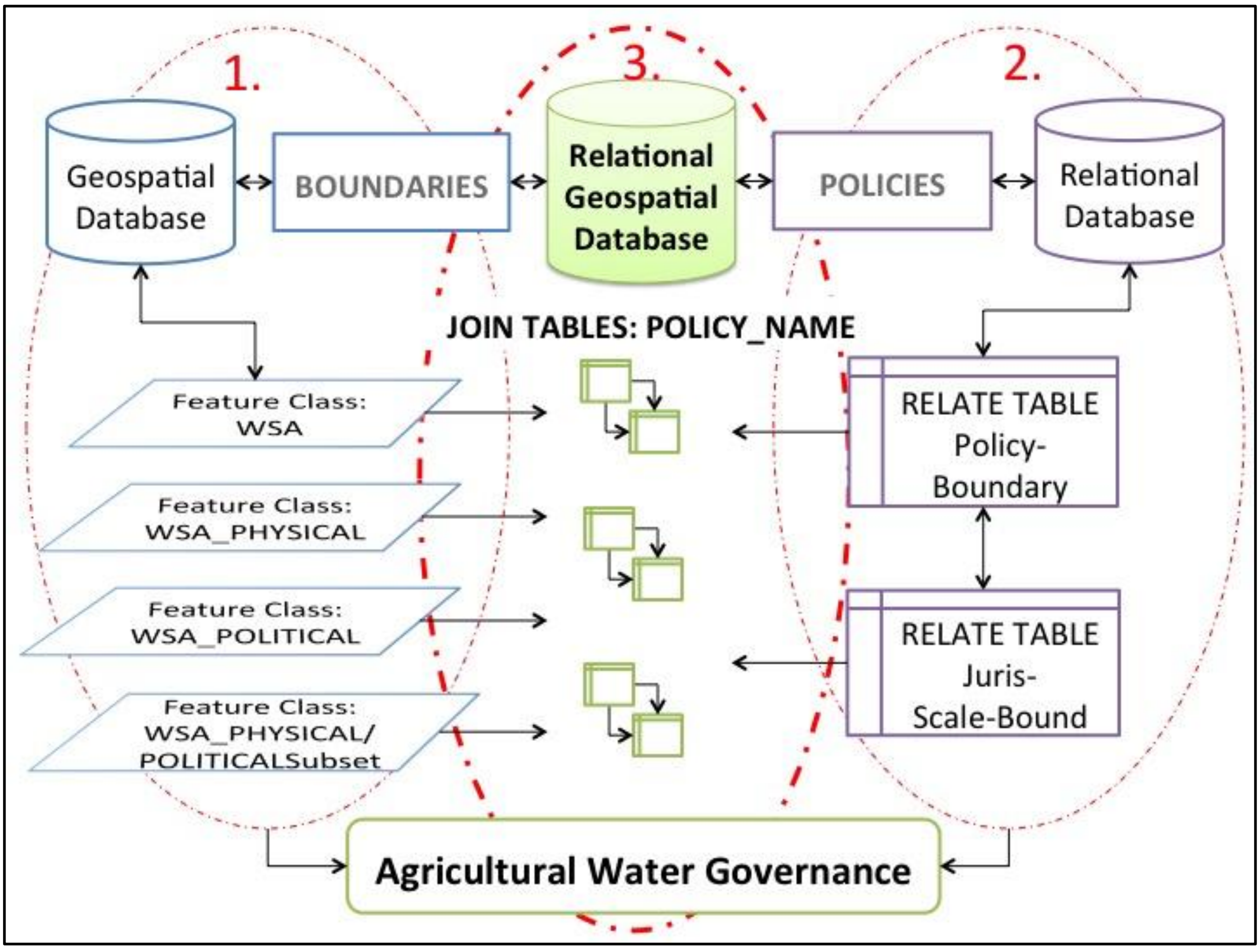
[6] Upper Colorado River Basin Compact of 1948, 63, Stat. 31 (1949).

[7] Arizona v. California, et al., 373 U.S. 546 (1963).

[8] See (USBR, 2007) in the references.

[9] Interim International Cooperative Measures in the Colorado River Basin through 2017 and Extension of Minute 318 Cooperative Measures to Address the Continued Effects of the April 2010 Earthquake in the Mexicali Valley, Baja California, Minute 319 (2012).

Figure 2. The Relational Geospatial Database architecture and process.



Notes: 1.The structure and process for the development of the geospatial database, 2. the relational database, and 3. the relational geospatial database, which is where both databases are joined through a like item in their database tables (i.e. Policy_Name).

claims in the use, conservation, and development of water resources. The process required to map physical boundaries is simple because geologic features such as mountain ranges and rivers can be georeferenced. However, sectoral boundaries are more difficult to locate because they are not necessarily tied to specific geographic coordinates and are often founded upon lifestyles and social and cultural norms. For example, temporal governance layers represent the political aspect of time (i.e. doctrine of prior appropriation). In the CRB, prior appropriation is the rule that established western state's water rights. Although water rights data are not represented in the geodatabase, they can be represented as geospatial data as long as the water right is tied to a specific location (accomplished in the California New Water Atlas[10]).

Because many of the boundaries in the *Law of the River* are configured in a temporally and spatially nested hierarchical pattern, it was necessary to identify all of the boundaries that applied to the agreements, policies, laws, and infrastructure upon which each WSA was founded. Although not explicit, projects built by the U.S. Bureau of Reclamation (here within referred to as Reclamation

[10] http://ca.statewater.org

projects) are at the centre of WSAs, as shown in Figure 3. Initially built to support expansive agricultural development in the West, Reclamation projects foster WSAs through infrastructure such as dams, reservoirs, and water delivery systems. Projects maintain the viability of agriculture but they also sustain multiple sectors, water users, and water uses. They cross physical (watersheds), political (federal and state), and sectoral boundaries (agriculture among others), while creating new boundaries and linkages between boundaries by moving water across the landscape for multiple uses. Reclamation projects are at the centre of agricultural water governance due to their authorisation by federal acts of Congress and the mandate bestowed upon them by the three scales of authorisation: the federal, the state, and the local.

For example, in the text of the Mexico Water Treaty, specific reference was given to the Colorado River Compact. Thus, the jurisdictions within the Compact also apply to the Mexico Water Treaty and all of the water sharing arrangements thereafter. In the geodatabase, the jurisdictions and the entire boundary data set previously identified for the Compact were imported to the Mexico Water Treaty feature data set. This same process was realised for all of the WSAs. In addition to the Colorado River Compact, Reclamation operational facilities were referenced in the Mexico Water Treaty, such as Davis Dam and the All American Canal System. Although the Davis Dam was a result of the Mexican Water Treaty, the All American Canal (AAC) System was the result of the Boulder Canyon Project Act (BCPA) of 1928. Even though the BCPA was not an original WSA in the analysis, the BCPA was added to the data set in the geodatabase in order to establish a political link between the Colorado River Compact and the Mexico Water Treaty feature data sets.

The spatialisation of agricultural water governance in the CRB through the operationalisation of key policies in the *Law of the River* confirmed the dominance of polycentric versus hierarchical governance systems. Superimposing governance layers revealed both the complexity of water governance and the governance of water data within polycentric systems as well as the challenges in developing such a database. Such challenges include scale, data collection and availability, and standardisation.

RESULTS

Complications that stem from polycentric systems translate into challenges of water governance and the governance of data on water. Agricultural water governance in the CRB has evolved into a polycentric system made up of overlapping public (federal, state, city, county), quasi-governmental, and private jurisdictions as well as different water management systems in the Upper and Lower Basins, impacting scale, data availability, and standardisation. The complex configuration of jurisdictions poses challenges when mapping scale, both in terms of water governance and governance of data on water, especially when the origins of data are from multiple sources, some of which are private and hold local, proprietary information. In addition, organisations collect multiple scales of relevant data for different purposes.

Different types of data such as satellite imagery, paper maps, historical records, and raw field data as well as data collection techniques and methods such as global positioning systems, surveying instruments, and photogrammetry, among others, compound upon data governance challenges. Finally, data collection at a coarse versus fine resolution as well as disparate standards for metadata and minimal coordination in data collection efforts make it difficult to standardise data sets and to visualise governance through GIS. Table 2 demonstrates the results of operationalising the boundary typology as it applies to state data, testing the absence and presence of data on agricultural water governance. Although many of the agencies collect data on governance, the quality, the themes, the scale, and the purpose of such data sets vary considerably. These inconsistencies, therefore, warrant a more detailed discussion of the results of data on agricultural water in the CRB and its relationship to scale, availability of data, and standardisation. This detailed account not only stresses the complexity of data on water governance, in general, and polycentric data sets, more specifically, but also supports our proposition that sustainable agricultural water governance must be supported by robust governance data sets.

Table 2. Operationalising the boundary typology as it applies to states' databases and data sets to test the absence or presence of data on governance (see database websites in the Annex).

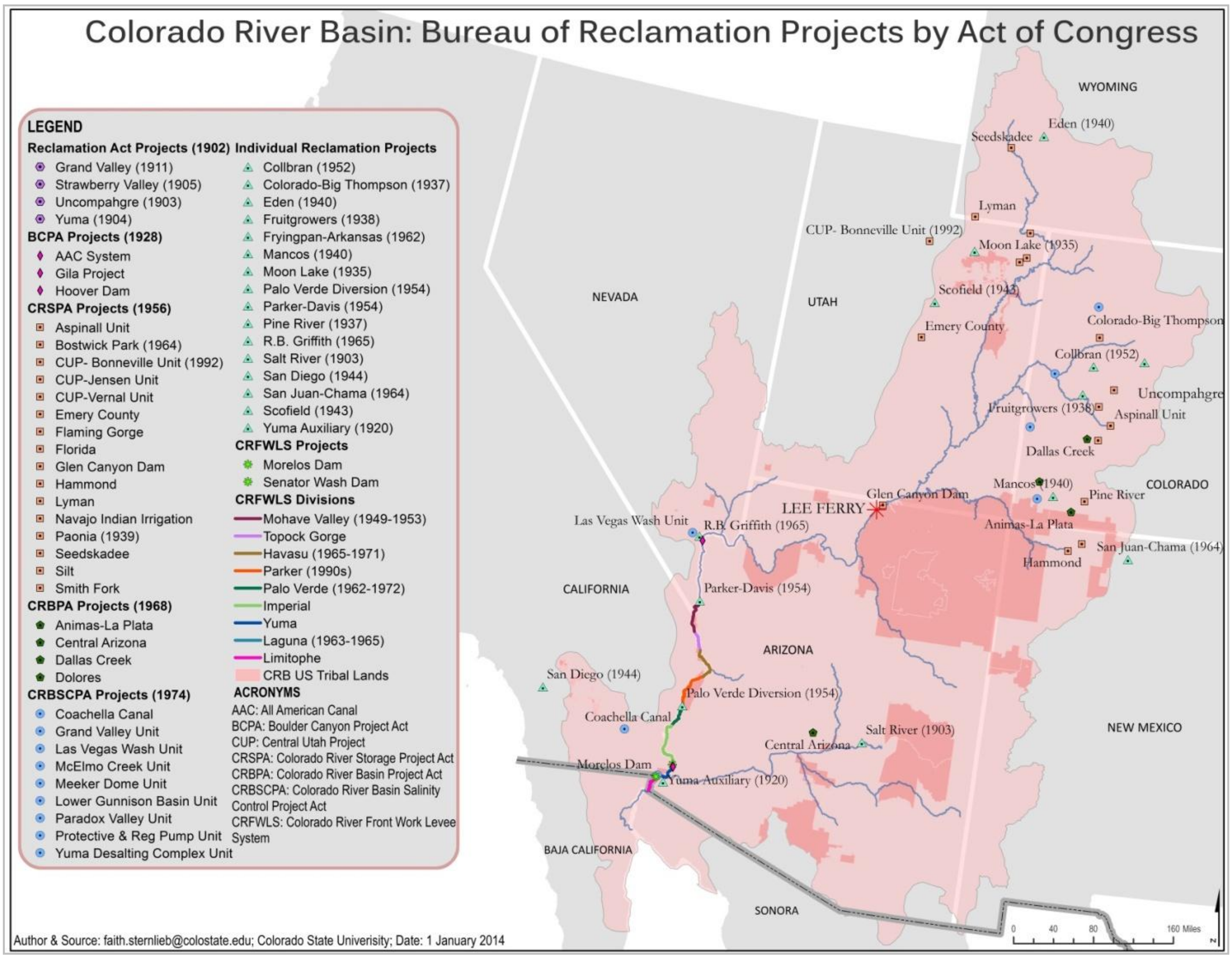
State	State databases	Governance attributes		
		Physical	Political	Sectoral
AZ	Department of Water Resources (ADWR, 2013)	X	X	
	Department of Water Resources, Geographic Information Systems	X	X	X
CA	New California Water Atlas (NCWA, 2013)		X	X
	CA Department of Water Resources Integrated Water Resources Information System (IWRIS) (CDWR, 2014a)	X		X
	CA Department of Water Resources Water Data Library (CDWR, 2014b)	X		
	California Department of Technology, Geoportal (California Geoportal, 2013a, b)	X	X	X
CO	Division of Water Resources (CDWR, 2014)	X	X	
	Colorado Water Conservation Board (CWCB, 2014)	X	X	X
NM	Geospatial Advisory Committee (NMGAC, 2012)	X	X	X
	Resource Geographic Information System Clearinghouse (EDAC, 2014)	X	X	X
UT	Maps (UDWR, 2011)	X	X	
	Utah State Geographic Information Database (AGRC, 2013)	X	X	X
WY	Wyoming Water and Climate Map Server (WWDO, 2014)	X		
	2010 Green River Basin Plan: GIS Products (WWDO, 2010)	X		

Scale

Scale is a prevailing trait in polycentric systems and the easiest for geo-visual demonstration. Scale ranges in both horizontal and vertical direction and plays an important role in characterising agricultural water governance. Agricultural water governance and the governance of data in Colorado (an Upper Basin state) can be characterised at three different scales: at a federal scale where large reclamation projects manage thousands of acre-feet as shown in Figure 3 (Lieberman, 2011); at a local and regional scale, where private and quasi-governmental undertakings manage a much smaller quantity of water and are difficult to map due to the mere quantity of such districts and limited data available about their boundaries as shown in Figure 4; and water management at the state level, which can range in the number of acres anywhere between local and federal projects (data on water at the state level are shown in Table 2). To begin with, agricultural water governance data related to Reclamation projects were collected from both districts (local) in charge of projects and the USBR itself (federal).

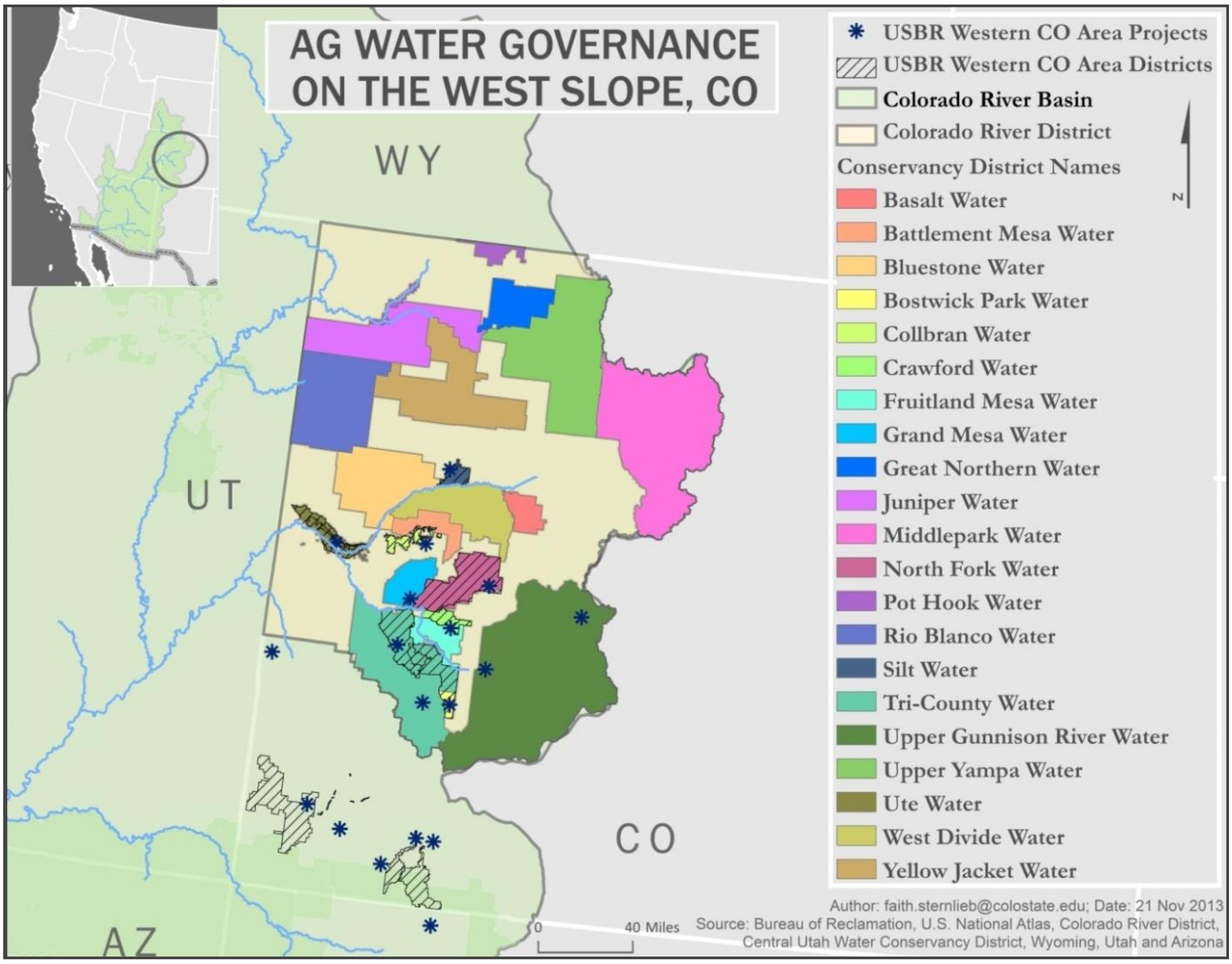
The states of Utah and California within the CRB demonstrate classic challenges that result from the complexity of data on water governance. The 'county rule' is one informal rule that emerged from an analysis of geospatial data in the CRB. The county rule states that, usually, agricultural water does not fall under the jurisdiction of a county, a mid-level jurisdiction that falls between the city (local) and the state. The major exception to this rule is the state of Utah. Utah is a state that is divided by the Upper and Lower Basin and the only state in the basin where the county has a political presence in the agriculture sector in governing agricultural water and data on agricultural water. In the other basin states, counties' responsibilities generally rest with municipal and industrial water management, not agricultural water. California is privy to a relative exception to the county rule in the California Seven Party Agreement, an intrastate WSA where counties have a role in agricultural water. The governance structure of the Seven Party Agreement is an intersection of water jurisdictions from the agricultural (irrigation districts) and municipal (counties and cities) sectors, where counties are part of the agreement but do not necessarily manage the agricultural water.

Figure 3. The distribution of U.S. Bureau of Reclamation projects according to the policies under which they were authorised in the CRB.



Intrastate districts such as the Colorado River District (CRD), responsible for managing water as well as advocating for special West Slope interests, are entrusted with representing two-thirds of the western extent of Colorado from the Continental Divide to the border of Utah. CRD manages, collects, and provides much of the data and information for their stakeholders, including those of the agricultural sector. In the Upper Basin, data for small, privately owned agricultural water organisations are difficult to obtain because they are responsible for paying the costs associated with collecting and maintaining geospatial information. However, the geospatial data CRD provided on boundaries for quasi-governmental conservancy districts within their jurisdiction was a starting point to mapping agricultural water governance in Colorado and the CRB, as shown in Figure 4.

Figure 4. Agricultural Water Governance on the West Slope, CO of the Colorado River Basin.



There are six levels of governance layers in Figure 4. Beginning with the most local level are the irrigation and water conservancy districts (represented by the State, the USBR and the local agricultural interests); the Colorado River District (represented by the State and two-thirds of the Western Slope constituency); the full extent of the West Slope defined by the Continental Divide, which includes the Colorado River District and south-western Colorado; the State of Colorado; the Upper CRB; and full extent of the CRB, which includes the Upper and Lower Basins as well as Mexico.

Availability and collection of data

The ability to collect data was dependent on the source, whether federal, state, or local, and whether parties were willing to share what they considered propriety data. The geospatial data from agricultural water companies (administered by the state legislature but managed independently), whether surface water or groundwater, were more difficult to obtain. The geospatial data on agricultural water districts in the Lower Basin (governed by the USBR) were available and provided by the Lower Colorado River Office (LCRO); however these data pertain only to the Lower Basin Division states (Arizona, California, Nevada, and New Mexico) and were outdated. In fact, the best, most comprehensive data set we found geo-visualising the extent of the agricultural water governance landscape was from the USBR. They provided the geospatial data, however they requested that we refrain from publishing them because they were in the process of updating the geospatial file; and we have yet to see it published in another venue.

Data for Reclamation projects were easier to obtain from the Yuma (Arizona), Western Colorado, and Provo (Utah) regional offices. USBR offices in the CRB range in jurisdiction, a few of which cross state lines, resulting in data for one project in one state, which resided in a regional office located in another state. This was also true for USBR offices in Arizona and California. Geospatial data for Wyoming were provided by the state; however the state was not able to verify which districts still supplied water for agriculture (personal communication).[11] Geospatial data for the individual irrigation companies were often not available online and because there are hundreds if not thousands of small irrigation companies and ditches, it was not feasible to contact each one individually. More importantly, when and if data regarding district and farm boundaries were available, that information was often considered private and confidential. In some cases, districts responded to our data requests with scepticism and suspicion about the use of data and their intended audience, raising questions about transparency and the proprietary nature of water rights data (personal communication).[12]

Standardisation

The case of California can help illustrate the challenges with standardisation of data on water. Just as in many CRB states, water governance in California is situated within a complex arena and the geospatial data available on agricultural water governance compound the problem. For example, the state of California differentiates between Private Water Districts and State Water Districts. "Private water district boundaries are areas where private contracts provide water to the district in California" (California Geoportal, 2013a) and "state water district boundaries are areas where state contracts provide water to the district in California" (California Geoportal, 2013b). Although the source of this information originated from metadata maintained in the California Geoportal, a state-driven geospatial data provider, a district’s boundaries can be easily misconstrued, complicating the governance rules for a district within a sector. Based on these definitions, the Imperial Irrigation District (IID) and the Coachella Valley County Water District (CVCWD) are Private Water Districts while the Coachella Valley Water District (CVWD) is listed as a State Water District. Yet the CVCWD and the CVWD are one of the same. In 1979, CVCWD changed its name to the CVWD dropping 'County' from the name (CVWD, 2013) but the geospatial data sets never reflected the change. As a side note, neither the IID nor the CVWD is an exception to the 'county rule'. The IID is an irrigation district in the Imperial County. The county does not govern agricultural water; the district does. And although the county was originally in its name, CVWD’s boundaries extend beyond the county.

In the case of CVWD, the number of services it provides to different sectors confounds governance complexity. In the Geoportal, there are two distinct data sets: the Private Water District data set and the State Water District data set. CVWD is a 'special district' established by state legislature in 1918, which provides a range of services including domestic water, groundwater replenishment and imported water, wastewater treatment, recycled water, storm water protection and flood control, agricultural irrigation and drainage, and water conservation (CVWD, 2013). Also confusing is that some irrigation districts are private while others are state and still others are simply considered Special Districts or quasi-public entities, which have a taxing or financing authority like a public jurisdiction, but retain some authorities that are more 'private' in nature.

[11] Steve Wolff, Colorado River Coordinator, Interstate Streams Division, Wyoming State Engineer’s Office (6 March 2012).

[12] Comments by participants in the Agricultural Water Mapping Workshop at Colorado River Water Users Association in Las Vegas (14 December 2011).

The state of California has varying types of authorising legislation for special districts for different purposes. Some districts are formed under 'general authorization' (e.g. farmers who want to create a district have to petition to meet the requirements of the state that have been set under general legislation for districts) and others are formed under specific legislation (e.g. the legislature creates a number of specific, named districts via legislation). The Palo Verde Irrigation District is not listed in either data set; however it is listed in the USBR LCRO data set (dated 31 May 2011) as a district with a USBR contract; therefore it would be considered a Reclamation project. The Private Water District IID and State (or 'Special') Water District CVWD both have contracts with the USBR and are listed in the LCRO data set as well. As these examples demonstrate, standardisation is a challenge because geospatial data often do not reflect changes in policy and management, and are therefore frequently left as relics that make it difficult to understand the governance and data landscape.

CONCLUSION

The impact of the mapping exercises has increased the complexity of the digital landscape and shed questions on the role of water governance data in water governance. In collecting and geo-visualising water governance data, CRB entities are verifying the importance of such data, yet little effort has been made to collect, standardise, and merge such data collections, undermining the impact that data on water governance have on water governance. Most of the data pertain specifically to water policy (e.g. water rights data), the management of water through multiple, layered jurisdictions, and the purpose and function of water use, conservation, and development in any one locale. Although agricultural markets are glocal by nature (Swyngedouw, 1997) and water can be virtually traded in the amount of water to produce any agricultural commodity (Pahl-Wostl, 2003), the use of agricultural water occurs at a local scale: on a field, within community, and within an agricultural jurisdiction such as irrigation districts and companies, water users associations, state and private water districts, among other types of jurisdictions, sanctioned by the state.

The polycentric landscape plays out in the variations of rules that govern agricultural water use, development, and conservation as well as the differences in jurisdiction types. Although there is a greater tendency to share resources in polycentric systems due to overlapping jurisdictions, the agricultural community in the Colorado River Basin has historically been removed from cooperative efforts to collect and share data, which has hindered attempts to bring producers and farmers together. Differences in water rights, policies, and management between Upper and Lower Basin agricultural communities, as well as between states across the Basin are so dramatic, that a unified front remains prohibitive. In addition, tensions between demand and supply for water lie within the federal, state, and local scales of water management. With these differences, a coordinated data effort is still an outside likelihood. And although farmers and producers may value the data for themselves and for their districts, we have found through interviews and meetings, that some prefer to keep the data and results internal to their organisation or district. Within states, however, there are efforts to coordinate management of water resources and their accompanying data systems, as in the case of Colorado where a partnership between non-profit organisations, the state, and the federal government have come together to study the possibility of an intrastate water bank (Kuhn, 2012). Although progress continues through new research and partnerships, results of this effort remain to be seen.

There are a number of ways in which to improve the quality, availability, and salience of data on water governance. The most important and the one on which we focus here is through coordination (Braden, Jolejole-Foreman and Schneider, 2014). Coordination of geospatial data is key regardless of the purpose of the data. Coordination ensures 1) that data sets will be compatible, even if they do not have the same spatial reference or file format; 2) minimal duplication in collection efforts; 3) complimentary data sets that add value; and 4) communication between and across managing entities of their needs, the availability of resources, as well as inconsistencies and data gaps. As many of these organisations are already cooperating through formal and informal partnerships, coalitions, and networking, coordinating efforts around water governance data sets should be a possibility.

This study fits neatly within the science-policy dialogue in four ways: 1) by emphasising the salience of water governance data (production of new knowledge) and sharing that data across scales (transboundary knowledge generation), 2) by incorporating water governance data in water governance and policy decisions (sustainability) (Lehmann et al., 2014; Braden et al., 2015; Lehmann et al., 2015), 3) by demonstrating the value of integrating data types from the natural and social sciences (interdisciplinarity) (Lehmann et al., 2014), and 4) through visualisation, which McInerny et al. (2014) argue is essential for science-policy training to increase innovation, limit miscommunication and more importantly, to limit scientific bias. Therefore, the role of water governance data in water governance, as it pertains to agriculture is a science-policy question that is based on the generation and production of new knowledge (e.g. availability and collection of data), the integration of that knowledge with existing knowledge (e.g. standardisation) across intersecting and diverging boundaries or scales, and the geo-visualisation of that knowledge. We came to this conclusion by laying out and analysing the geospatial landscape for agricultural water governance, which was grounded in a polycentric framework and further realised through boundaries. The geopolitical patterns that ensued shed light on both governance and governance data, justifying the development of the Colorado River Basin Water Governance Relational Database. The water-sharing policies within the *Law of the River* were a means to operationalise the boundary typology.

Although the operationalisation of the boundary typology is meaningful in a federalist government that enables and empowers individual stakeholders and groups of stakeholders on the decision-making stage, it might be less useful in centralised governments, where management of resources and data is streamlined within a few government agencies. The Colorado River Basin is an excellent example of this dichotomy. Due to the transboundary nature of the Colorado River, two different government systems have had to work together to develop and enforce policy. As was demonstrated in the operationalisation of the boundary typology for the Mexico Water Treaty, only governmental forces entered into the treaty language, leaving behind the institutional backbone of water governance in the U.S. – state constituents along with the numerous districts that manage agricultural water at a local scale, as well as the non-profit sector. Again, scale is at the heart of this governance question, as it pertains to water and data sharing. If policy only reflects one scale, a disconnect between science and policy will prevail.

FINAL REMARKS

According to Butenuth et al. (2007), practical integrated database applications include the verification, update, and enrichment of data sets, projections for future development based on past analyses that have been updated from cross-referencing integrated data sets, as well as more detailed classifications of specific areas and regions. Based on this assessment, the purpose of this geodatabase is twofold. First, inclusion of the water sharing governance data derived from formal political and institutional boundaries enriches the geophysical data set of the CRB. Secondly, the transformation of such boundaries classified in the boundary typology into governance layers expands upon the descriptive nature of the political and institutional setting in the region. Finally, by introducing socially constructed boundaries such as sectors' additional governance patterns and processes as well as new data sets may be considered. In this case, the agriculture sector in the CRB is viable precisely because of the infrastructure that is supported by the federal government's water policy. In short, infrastructure, whether funded by a local entity, the state or the federal government enables the fluid movement of water across boundaries, but complicates agricultural water governance by enforcing polycentric data sets.

Water governance is geospatial on both macro and micro-scales. The CRB WGRG was created from select WSAs in the *Law of the River* by developing a systematic process to identify boundaries. The boundary typology provides a geospatial method to examine the governance of water resource use by sector. Agricultural water policy has both formed and evolved from physical, political, and sectoral boundaries. A close examination of WSAs, the application of the boundary typology as well as the collection of geospatial data pertaining to agricultural water governance have shown the diversity of agricultural jurisdictions across boundaries at multiple scales. Specific places enhance our understanding of macro-governance systems (e.g. *Law of the River*) and the micro systems that depend upon them (e.g. irrigation districts). Through the geo-visualisation of water governance, adaptation strategies (e.g. WSAs) demonstrate that water managers have been able to navigate a highly regulated water system in the face of climate uncertainty (Mulroy, 2008).

Geospatial analysis of micro-governance systems such as agriculture, the environment, recreation, and municipal and industrial sectors are important to better understand levels of actors' influence and participation in decision-making. Each sector is also geographically tied to a place. Geo-visualisation can help identify those places where there is an abundance of competing interests, or are polycentric in nature. The agriculture sector was the only geospatial data collected for the CRB WGRG. However, through the transboundary analysis of WSAs, other sectors that pertain to specific locations with a stake in water resources became evident. By implementing the methodology outlined here, it is possible to overlay governance layers from each sector to locate places where high demand and competing management are challenges. Adding physical data including infrastructure and flow quantities pertaining to the Basin, salinity control areas, wild and scenic stretches of the Colorado River and tributaries, and areas where endangered species are of concern may espouse new explanations about governing competing demands and their respective data sets and how they relate to policies that pertain to locations identified.

Additional inquires for future research include: 1) an empirical test of the boundary typology, using different units of analysis such as ecoregions (Omernik, 1987) or the boundaries established by the Bureau of Land Management Landscape Conservation Cooperatives, which like watersheds, are jointly managed by political and physical influences, 2) a compilation of additional governance data, specifically on groundwater, water rights, and infrastructure to contribute to data sets from other sectors, 3) the addition of small irrigation companies to the agricultural water governance data set, 4) the creation of new data sets for other river basins, both national and international, and 5) a scaled analysis of boundaries at more localised and global levels representing different governance regimes. Finally, this study provides the grounds to identify hot spots of tension, especially between demand and supply and between federal, state, and local scales of water management.

As complexity and uncertainty in the hydro-political landscape increase, it is important to make projections on the future needs where geospatial data are concerned, especially that of governance data, data sets, and databases that extend beyond typical physical data collections. This is a field that is wide open for exploration. Results from this research espouse two new polycentric governance questions: that of data governance and data sharing for sustainable water management. In polycentric regimes, it is essential to integrate multiple data methods and types at the global, regional and local scales to maximize potential at the science-policy interface.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Environmental Defense Fund and USDA grant, *Addressing Water for Agriculture in the Colorado River Basin,*[13] for funding the research and development of the

[13] www.crbagriculturalwater.colostate.edu/AddressingAgricultural/index.shtml

Colorado River Basin Water Governance Relational Geodatabase. The Colorado Water Institute and the Geospatial Centroid at Colorado State University were central to providing administrative and technical support for this project. The U.S. Bureau of Reclamation and the Colorado River District were instrumental in sharing governance data. The authors would also like to extend special thanks to Dr. Sternlieb's PhD Committee: Dr. Reagan Waskom and Dr. Stephen Mumme of the Colorado State University and Dr. Tanya Heikkila of the University of Colorado-Denver.

References

Andersson, K.P. and Ostrom, E. 2008. Analyzing decentralized resource regimes from a polycentric perspective. *Policy Sciences* 41(1): 71-93.

Berkes, F. 2002. Cross-scale institutional linkages: Perspectives from the bottom U. In Ostrum, E. (Ed). *The Drama of the Commons,* pp. 293-321. Washington, DC: National Academy Press.

Biermann, F.; Betsill, M.M.; Vieira, S.C.; Gupta, J.; Kanie, N.; Lebel, L.; Liverman, D.; Schroeder, H.; Siebenhuner, B.; Yanda, P.Z. and Zondervan, R. 2010. Navigating the anthropocene: The Earth System Governance Project strategy paper. *Current Opinion in Environmental Sustainability* 2(3): 202-208.

Braden, J.; Brown, D.; Maidment, D. and Marquart-Pyatt, S. 2015. Populating the water world: Exploring data aspirations of water experts. *Society and Natural Resources* 28(4): 439-451.

Braden, J.; Jolejole-Foreman, M. and Schneider, D. 2014. Humans and the water environment: The need for coordinated data collection. *Water* 6: 1-16.

Butenuth, M.; Gosslein, V.; Tiedge, M.; Heipke, C.; Lipeck, U. and Sester, M. 2007. Integration of heterogeneous geospatial data in a federated database. *Journal of Photogrammetry & Remote Sensing* 62: 328-346.

California Geoportal. 2013a. Private water districts. http://portal.gis.ca.gov/geoportal/catalog/search/search.pagriculturale (accessed on November 5, 2013)

California Geoportal. 2013b. State water districts. http://portal.gis.ca.gov/geoportal/catalog/search/search.pagriculturale (accessed on November 5, 2013)

Cash, D.W.; Adger, W.N.; Berkes, F.; Garden, P.; Lebel, L.; Olsson, P.; Pritchard, L. and Young, O. 2006. Scale and cross-scale dynamics: Governance and information in a multilevel world. *Ecology and Society* 11(2): 8.

Conca, K. 2006. *Governing water: Contentious transnational politics and global institution building*. Cambridge, MA: MIT Press.

CVWD (Coachella Valley Water District). 2013. Groundwater replenishment and imported water. www.cvwd.org/about/groundwater.php (accessed on November 5, 2013)

Draper, S.E. 2007. Introduction to transboundary water sharing. *Journal of Water Resources Planning and Management-Asce* 133(5): 377-381.

Fabrikant, S. 2000. Spatialized browsing in large data archives. *Transaction in GIS* 4(1): 65-78.

Feitelson, E. and Fischhendler, I. 2009. Spaces of water governance: The case of Israel and its neighbors. *Annals of the Association of American Geographers* 99(4): 728-745.

Feitelson, E. and Levy, N. 2006. The environmental aspects of reterritorialization: Environmental facets of Israeli-Arab agreements. *Political Geography* 25(4): 459-477.

Fischhendler, I. and Feitelson, E. 2003. Spatial adjustment as a mechanism for resolving river basin conflicts: The U.S.-Mexico case. *Political Geography* 22(5): 557-583.

Fischhendler, I. and Heikkila, T. 2010. Does integrated water resources management support institutional change? The case of water policy reform in Israel. *Ecology and Society* 15(1): 4.

Gallaher, S. and Heikkila, T. 2014. Challenges and opportunities for collecting and sharing data on water governance institutions. *Journal of Contemporary Water Research & Education* 153(1): 66-78.

Garrick, D. anderson, G.; Connell, D. and Pittock, J. (Eds). 2014. *Federal rivers: Managing water in multi-layered political systems*. Northampton, MA: Edward Elgar Publshing.

Getches, D.H. 2009. *Water in a nutshell*. St. Paul, MN: Thomson Reuters.

Grafton, R.Q.; Landry, C.; Libecap, G. and O'Brien, R. 2010. *Water markets: Australia's Murray-Darling Basin and the US Southwest.* Cambridge, MA: National Bureau of Economic Research.[No. 15797].

Grafton, R.Q.; Libecap, G.; McGlennon, S.; Landry, C. and O'Brien, B. 2011. An integrated assessment of water markets: A cross-country comparison. *Review of Environmental Economics and Policy* 5(2): 219-239.

Grimm, V.; Revilla, E.; Berger, U.; Jeltsch, F.; Mooij, W.M.; Railsback, S.F.; Thulke, H.H.; Weiner, J.; Wiegand, T. and DeAngelis, D.L. 2005. Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science* 310(5750): 987-991.

Heikkila, T. 2004. Institutional boundaries and common-pool resource management: A comparative analysis of water management programs in California. *Journal of Policy Analysis and Management* 23(1): 97-117.

Huitema, D. and Meijerink, S. (Eds). 2014. *The politics of river basin organizations: Coalitions, institutional design choices and consequences*. Northhampton, MA: Edward Elgar Publishing.

Huitema, D.; Mostert, E.; Egas, W.; Moellenkamp, S.; Pahl-Wostl, C. and Yalcin, R. 2009. Adaptive water governance: Assessing the institutional prescriptions of adaptive (co-) management from a governance perspective and defining a research agenda. *Ecology and Society* 14(1): 26.

Jones, L. and Colby, B.G. 2012. Measuring, monitoring and enforcing temporary water transfers: Consideration, case examples, innovations and costs. Tuscon, AZ: University of Arizona.

Kane, L. 2011. Nuestro Rio. http://nuestrorio.com/splash.php (accessed on November 5, 2013)

Kim, J.; Keane, T. and Bernard, E. 2015. Fragmented local governance and water resource management outcomes *Journal of Environmental Management* 150: 378-386.

Kraak, M.J. 2003. Geovisualization illustrated. *ISPRS Journal of Photogrammetry and Remote Sensing* 57(5-6): 390-399.

Kraak, M.J. 2004. The role of the map in a Web-GIS environment. *Journal of Geographical Systems* 6(2): 83-93.

Krahmann, E. 2003. National, regional, and global governance: One phenomenon or many? *Global Governance* 9(3): 323-346.

Kuhn, E. 2012. Risk management strategies for the Upper Colorado River Basin. District, C.R. (Ed), 45. Colorado River District Website.

Kwan, M. and Ding, G. 2008. Geo-narrative: Extending geographic information systems for narrative analysis in qualitative and mixed method research. *The Professional Geographer* 60(4): 443-465.

Laituri, M. and Sternlieb, F. 2014. Water data systems: Science, practice, and policy. *Journal of Contemporary Water Research & Education* 153: 1-3.

Lehmann, A.; Giuliani, G.; Mancosu, E.; Abbaspour, K.; Sozen, S.; Gorgan, D.; Beel, A. and Ray, N. 2015. Filling the gap between Earth observation and polcy making in the Black Sea Catchment with enviroGRIDS. *Environmental Science & Policy* 46: 1-12.

Lehmann, A.; Giuliani, G.; Ray, N.; Rahman, K.; Abbaspour, K.; Nativi, S.; Craglia, M.; Cripe, D.; Quevauviller, P. and Beniston, M. 2014. Reviewing innovative Earth observations for filling science-policy gaps in hydrology. *Journal of Hydrology* 518: 267-277.

Leshy, J.D. 1982. Irrigation districts in a changing west: An overview. *Arizona State Law Journal* 345: 345-376.

Lieberman, S. 2011. Water organizations in Colorado: A first look into water organizations' control of agricultural water rights and their transfer potential in the Colorado River Basin. *University of Denver Water Law Review* 15: 31.

MacEachren, A. and Kraak, M.J. 2013. Researches challenges in geovisualization. *Cartography and Geographic Information Science* 28(1): 3-12.

McGinnis, M.D. (Ed). 1999. *Polycentric Governance and Development*. Ann Arbor: University of Michigan Press.

McInerny, G.; Chen, M.; Freeman, R.; Gavaaghan, D.; Meyer, M.; Rowland, F.; Spiegelhalter, D.; Stefaner, M.; Tessarolo, G. and Hortal, J. 2014. Informaiton visualisation for science and policy: Engaging users and avoiding bias. *Trends in Ecology & Evolution* 29(3): 148-157.

Mulroy, P. 2008. Climate change and the Law of the River: A southern Nevada perspective. *West Northwest Journal of Environmental Law & Policy* 14(2).

National Geographic. 2013. Change the Course.

http://environment.nationalgeographic.com/environment/freshwater/change-the-course/colorado-river-map (accessed on November 5, 2013)

Omernik, J.M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77(1): 11-125.

Ostrom, E. 2005. *Understanding Institutional Diversity*. Princeton: Princeton University Press.

Pahl-Wostl, C. 2003. Polycentric integrated assessment. In Rotmans, J. and Rothman, D.S. (Eds), *Scaling in integrated assessment,* pp. 237-261. Lisse, the Netherlands: Swets & Zeitlinger Publishers.

Pellow, D. 1996. *Setting boundaries: The anthropology of spatial and social organization*. Westport, Conn.: Bergin & Garvey.

Seaber, P.R.; Kapinos, F.P. and Knapp, G.L. 1987. Hydrologic unit maps. U.S. Department of the Interior, U.S. Geological Survey. [2294].

Sheppard, E.S. and McMaster, R.B. 2004. *Scale and geographic inquiry: Nature, society, and method*. Malden, MA: Blackwell Pub.

Squires, V.R.; Milner, H.M. and Daniell, K.A. (Eds). 2014. *River basin management in the twenty-first century: Understanding people and place*. Boca Raton, FL: CRC Press.

Starr, H. 2002. Opportunity, willingness and geographic information systems (GIS): Reconceptualizing borders in international relations. *Political Geography* 21(2): 243-261.

Sternlieb, F.; Bixler, R.P.; Huber-Stearns, H. and Huayhuaca, C. 2013. A question of fit: Reflections on boundaries, organizations and social-ecological systems. *Journal of Environmental Management* 130: 117-25.

Stoker, G. 1998. Governance as theory: Five propositions. *International Social Science Journal* 50(155): 17-28.

Swyngedouw, E. 1997. Neither global nor local: 'Glocalization' and the politics of scale. In Cox, K. (Ed). *Spaces of globalization: Reasserting the power of the local,* pp. 137-166. New York/London: Guilford/Longman.

Tufte, E. 2006. *Beautiful evidence*. Chestire, CT: Graphic Press.

USBR (United States Bureau of Reclamation). 2012. Colorado River Basin Water Supply and Demand Study: Study Report. In *Reclamation: Managing water in the West.* Boulder City, NV: Department of the Interior.

Wockner, G. 2010. Save the Colorado. www.savethecolorado.org (accessed on November 5, 2013)

Wolf, A. 1999. The Transboundary Freshwater Dispute Database Project. *International Water Resources Association* 24(2): 160-163.

ANNEX

ADWR (Arizona Department of Water Resources). 2013. Water Resources Data. https://gisweb.azwater.gov/waterresourcedata/Default.aspx (accessed February 10, 2013)

AGRC (Automated Geographic Reference Center). 2013. Utah Automated Geographic Reference Center. http://gis.utah.gov/data/ (accessed February 10, 2013)

California Geoportal. 2013. State of California Geoportal. http://portal.gis.ca.gov/geoportal/catalog/main/home.page (accessed November 5, 2013)

CDWR (California Department of Water Resources). 2014a. Integrated Water Resources information System. www.water.ca.gov/iwris/ (accessed February 10, 2014)

CDWR (California Department of Water Resources). 2014b. Water Data Library. www.water.ca.gov/waterdatalibrary/index.cfm (accessed February 10, 2014)

CDWR (Colorado Division of Water Resources). 2014a. AquaMap. water.state.co.us/DATAMAPS/GISANDMAPS/AQUAMAP/Pages/default.aspx (accessed February 10, 2014)

CWCB (Colorado Water Conservation Board). 2014. Colorado River Water Availability Study Data Viewer. www.dataviewer.info/CRWAS/info (accessed February 10, 2014)

EDAC (Earth Data Analysis Center). 2014. Earth Data Analysis Center. http://edac.unm.edu/ (accessed February 10, 2014)

NCWA (New California Water Atlas). 2013. California Water Rights. http://ca.statewater.org/ (accessed October 17, 2013)

NMGAC (New Mexico Geospatial Advisory Committee). 2012. Geospatial Advisory Committee. www.gac.state.nm.us/index.html (accessed February 10, 2013)

UDWR (Utah Division of Water Rights). 2011. Maps. www.waterrights.utah.gov/gisinfo/maps/ (accessed February 10, 2014)

WWDO (Wyoming Water Development Office). 2010. Green River Basin Water Plan: GIS Products. http://waterplan.state.wy.us/plan/green/2010/gis/gis.html (accessed February 10, 2014)

WWDO (Wyoming Water Development Office). 2014. Wyoming Water and Climate Map Server. http://ims2.wrds.uwyo.edu/Website/Statewide/ (accessed February 10, 2014)

THIS ARTICLE IS DISTRIBUTED UNDER THE TERMS OF THE CREATIVE COMMONS *ATTRIBUTION-NONCOMMERCIAL-SHAREALIKE* LICENSE WHICH PERMITS ANY NON COMMERCIAL USE, DISTRIBUTION, AND REPRODUCTION IN ANY MEDIUM, PROVIDED THE ORIGINAL AUTHOR(S) AND SOURCE ARE CREDITED. SEE HTTP://CREATIVECOMMONS.ORG/LICENSES/BY-NC-SA/3.0/LEGALCODE