Water Policy 20 (2018) 1–20

Conjunctive management of surface and groundwater in transboundary watercourses: a first assessment

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Abstract

Cooperative management of transboundary river basins is widely recognized as important. Emphasis on joint management of shared aquifers has also grown in recent years. Perhaps surprisingly, despite abundant focus on transboundary surface water and growing focus on shared groundwater, there is scant focus on their intersection. To address this knowledge limitation, this article reviews experiences in transboundary water treaties oriented toward different water sources, in order to: (i) understand how transboundary water institutions vary according to the water source to which they are oriented, (ii) gauge the nature and strength of conjunctive transboundary water management treaties, and (iii) identify ways to enhance conjunctive water management in transboundary contexts. The results reveal the existence of more than 50 treaties that make mention of both water sources. Nonetheless, only eight treaties devote 'substantive' focus to both surface and groundwater. Review of treaty contents reveals that their focus is on 'softer' issues related to institutional development. Moving forward, the reality that the evolution of conjunctive treaties is relatively nascent, and that scope of such treaties is still limited to institutional issues, may indicate large untapped potential – it may be time to outline pathways toward practical implementation of conjunctive water management in transboundary contexts.

Keywords: Conjunctive; Cooperation; Groundwater; Surface water; Transboundary water management; Treaties

Introduction

The imperative for cooperative management of transboundary basins to achieve equitable and sustainable development is widely accepted (UN Water, 2013; Adeel *et al.*, 2015). UN Water (2013) highlights how international cooperation is necessary to share water resources of a transboundary river basin

doi: 10.2166/wp.2018.033

between upstream and downstream users with different needs, claims and cultures. Adeel *et al.* (2015) express concern with the reality that 60% of shared basins globally are currently without cooperative frameworks. The post-2015 UN Sustainable Development Goal 6.5 addresses the need to achieve operational arrangements for water cooperation in transboundary basins (Saruchera & Lautze, 2015). In practice, transboundary water treaties now cover 68% of the world's total land area (Giordano *et al.*, 2014). Moreover, more than 25 river basin organizations (RBOs) have been created since 1990 (Lautze *et al.*, 2013; Saruchera & Lautze, 2016).

The importance of transboundary aquifers has also received growing recognition in recent years (e.g., Matsumoto, 2002; Eckstein & Eckstein, 2003; Jarvis *et al.*, 2005; Eckstein, 2011). Driven by the relative abundance of ground to surface water in global supply, the increased reliance on groundwater under climate change, growing human water demands, and the perceived conflict potential associated with uncoordinated management of shared aquifers (Jarvis *et al.*, 2005; Jarvis, 2010), transboundary groundwater management has risen on the global development agenda. In 2000, the International Shared Aquifer Resources Management Initiative was launched by UNESCO, and the International Association of Hydrogeologists as a multi-agency effort aimed at improving the understanding of scientific, socio-economic, legal, institutional and environmental issues related to the management of transboundary aquifers. In 2003, UNESCO supported the establishment of the International Groundwater Resources Assessment Centre, which has given substantial focus to transboundary aquifers.

Recognition of the importance of shared aquifers has driven recent institutional development related to transboundary groundwater (Burchi & Mechlem, 2005; Dellapena, 2011; Sugg *et al.*, 2015; Pateiro, 2016). In 2008, the UN General Assembly considered the adoption of the Law of Transboundary Aquifers containing 19 Draft Articles focused on management of shared groundwater (Eckstein, 2011; McCaffrey, 2011; Yamada, 2011). Burchi & Mechlem (2005) identified transboundary treaties and other instruments that deal with groundwater. Dellapena (2011) suggested that customary law on transboundary groundwater may be emerging, based on practices of aquifer-sharing states. Sugg *et al.* (2015) examined the increasingly complex nature of governance of the Guarani aquifer system (GAS; which includes Argentina, Brazil, Paraguay and Uruguay) following conclusion of an agreement in 2010. Pateiro (2016) reviewed ad hoc legal mechanisms governing transboundary aquifers.

Somewhat surprisingly given the recognition for the importance of transboundary surface and groundwater and the prevalent hydrologic linkages between the two water sources (Sophocleous, 2002; Liang & Xie, 2003; Hatch *et al.*, 2006), institutional frameworks for conjunctive management – i.e., the monitoring and coordination in the use of surface and groundwater – of transboundary waters have not received extensive focus. Limited recommendations in existence are mainly centred on incorporating groundwater into RBOs where they exist (Scheumann & Herrfahrdt-Pähle, 2008; BGR, 2015), although the potential for creation of hybrid institutions has also been flagged (Altchenko & Villholth, 2013)[1]. While these constitute important first efforts, the analytical basis on which such suggestions are proposed is fairly thin. Indeed, suggestions have been based largely on assumptions rather than evidence. There is therefore a need to elaborate and adapt meaningful and effective institutional frameworks for conjunctive management of surface and groundwater in transboundary contexts.

[1] Notably, certain RBOs have expanded their mandates to cover GW (Scheumann & Alker, 2009; Schmeier, 2010).

This document reviews transboundary water treaties to understand the differences in their scope and content based on the water source(s) on which they focus: (i) surface water, (ii) groundwater and (iii) conjunctive surface-groundwater. The objectives are to:

- understand how transboundary institutions have responded to different water sources, and in particular how conjunctive water management has been addressed;
- assess the status and strength of conjunctive water management in transboundary treaties;
- identify ways to enhance conjunctive water management in transboundary contexts.

Why, where and when to conjunctively manage?

Surface and groundwater systems are connected in most landscapes. It is generally groundwater discharge that keeps streams flowing between precipitation events or after snowmelt. For a stream to gain water, the elevation of the groundwater table in the vicinity of the stream must be higher than the stream water surface. For a stream to lose water to groundwater, the water table must be below the elevation of the stream–water surface in the vicinity of the stream. If the water table has large variations during the year, a stream segment could receive water from groundwater for a portion of the year and lose water to groundwater at other times (Vandas *et al*., 2002). Surface water and groundwater are, as such, two components of a single water system (Gemma & Tsur, 2007).

Interconnectedness between and among water sources calls for conjunctive management of those sources to enable their optimal use. Conjunctive management is the integrated management of ground and surface water resources, to enhance security of water supply and environmental sustainability (Blomquist *et al*., 2001; World Bank, 2005; Dudley & Fulton, 2006). Unlike conjunctive water use, which refers simply to the combined use of surface and groundwater to improve reliability of water supply, conjunctive management focuses on the monitoring and coordination in the use of the two water sources. Conjunctive management of water resources can bring a range of benefits that include reducing vulnerability (Blomquist *et al*., 2001) and improving water security (van den Born, 2011; Government of Australia, 2014).

Guidelines for conjunctive management of transboundary waters are not known to exist. However, work at national level contains lessons that may be relevant at an international level. Blomquist *et al*. (2001) suggest that well-defined, quantified water rights, encompassing understanding of surface and groundwater interactions, are essential in implementing conjunctive management. Dudley & Fulton (2006) state that the practice of conjunctive management requires scientific knowledge to inform decision-making, and technical and management capacity development. Foster & van Steenbergen (2011) support the establishment of an apex body at a national level that supervises both groundwater and surface water institutions. Evans & Evans (2014) propose that groundwater and surface water monitoring should be aligned through joint planning and assessment of surface and groundwater resources. Drawing on experience in Australia, the Government of Australia (2014) notes that water rights frameworks must be flexible to allow conjunctive surface and groundwater use, and recommends harmonizing objectives across institutions that manage surface and groundwater.

At a transboundary level, practical implementation of conjunctive approaches is scant. In the Syr Darya Basin, there is evidence that freshwater is 'banked' in Fergana Valley aquifers to manage seasonal water supply fluctuations for irrigation (Karimov *et al*., 2010; Puri & Struckmeier, 2010; Villholth, 2015).

In Africa, efforts have been made to implement conjunctive water management in at least two basins. In the Lake Chad Basin (Algeria, Cameroon, Chad, Central African Republic, Libya, Niger, Nigeria, Sudan), implementation of groundwater recharge assessments, and hydrological monitoring in order to improve water supply in the South Chad Irrigation Project, began around 2000 (Isiorho *et al*., 2000). In the Orange-Senqu Basin (Botswana, Namibia, South Africa), the management of the transboundary Stampriet Aquifer together with the basin's surface water is being attempted through the Orange-Senqu River Commission (ORASCOM) and the Southern Africa Development Community (SADC), but specific institutions to facilitate conjunctive management are still to be developed (Ross, 2015).

Failure to take conjunctive approaches has given rise to notable challenges and risks in transboundary waters. In the Limpopo Basin, nitrate pollution of the transboundary Ramotswa Aquifer (Botswana and South Africa) by pit latrines was discovered only recently, as the transboundary RBO (the Limpopo Watercourse Commission – LIMCOM) had focused only on surface water (Abiye, 2012). Another challenge from Limpopo is associated with river depletion from groundwater abstraction for irrigation along the reaches of the river in South Africa affecting Mozambique (Owen, 2011). In the Indus Basin, aquifers along the India–Pakistan border have suffered excessive groundwater abstraction and caused salinization on agriculture land, but the Indus Water Commission could not act as this falls outside its mandate[2]. The Indus Treaty, signed between the two countries in 1960, does not cover groundwater (IUCN, 2013). In South America, failure to take a conjunctive approach in the GAS has undermined effective water management. Surface water cooperation is implemented through the La Plata Treaty of 1969, which covers the five riparians of Argentina, Brazil, Bolivia, Paraguay and Uruguay and is coordinated through an RBO. The underlying GAS, spanning the same countries except Bolivia, is governed by the Guarani Aquifer Agreement of 2010 (Sugg *et al*., 2015). This agreement protects the national sovereignty of groundwater use, which has contributed to overexploitation of the aquifer to enable land use changes and agriculture development.

Methods

Data collection

The fundamental data on which analysis was conducted were extracted from formally codified examples of water sharing, reflected in transboundary water treaties. While informal practice and associated customary law is also important, challenges associated with compilation of such practice precluded its inclusion in this paper. Several databases were mined to generate the largest known compilation of transboundary legal water instruments. First, we used the set of water treaties assembled by Giordano *et al*. (2014). Second, the well-known Transboundary Freshwater Dispute Database (TFDD) was utilized. Third, the United Nation's Food and Agricultural Legislation database (FAOLEX) was used. Fourth, additional treaties assembled by the international water law project[3] (IWLP) were identified and utilized. Lastly, online searches for water treaties were undertaken.

Building on earlier work (Hamner & Wolf, 1998; Giordano *et al*., 2014), we included agreements that treat water as a 'scarce or consumable resource', a 'quantity to be managed', or 'an ecosystem to be

[2] This challenge may also be faced by aquifers contained within one country.
[3] http://www.internationalwaterlaw.org/.

improved or maintained' and excluded agreements that focus on peripheral issues like border delineation, fishing, navigation or financial aspects of water projects[4]. Consistent with Giordano *et al.* (2014), a 'lineage' concept was utilized to group related agreements as single units for analysis. Two relaxations were made to filters conventionally applied for sifting treaties in transboundary water law analysis, given the presumed dearth of transboundary conjunctive management. First, treaties with ambiguously legally enforceable intents (i.e., Memorandum of Understanding (MOU)) and multilateral treaties not signed by all involved parties were included. Second, expired treaties that have not been replaced by other agreements were utilized in this paper. Ultimately, 266 treaties were utilized in this analysis. This total includes: 214[5] treaties compiled by Giordano *et al.* (2014), 22 from TFDD[6], 15 from FAOLEX, 14 from IWLP and 1 from the Food and Agriculture Organization's Corporate Document Repository website[7].

Data classification

The expanded collection of water treaties was stratified according to a set of general and technical parameters (Table 1) adapted from previous work (TFDD; Giordano *et al.*, 2014; Holmatov & Lautze, 2016). General parameters include attributes that provide general information about treaties. For this paper, a set of five general parameters were considered: date signed, signatory countries, water source, depth of conjunctive management and geographic scale. The first two parameters are self-explanatory. The third parameter, water source, was divided into three groups: (i) surface water, (ii) groundwater (or aquifer), (iii) conjunctive. Surface water treaties apply to surface water bodies without explicit coverage of groundwater. Groundwater treaties apply exclusively to groundwater with no reference to surface water. Conjunctive treaties refer to both surface and groundwater. Importantly, reference to both water sources in a transboundary agreement implies that both water sources are shared. Nonetheless, there is a difference in the depth of textual coverage of both sources.

In an effort to identify treaties that give meaningful coverage to surface and groundwater, conjunctive treaties were also subdivided into four categories that gauge the depth of coverage of diverse water sources. The four categories are:

(i) *Treaties that give substantive coverage to groundwater and surface water (HG-HS):* With both surface and groundwater, coverage goes beyond simple mention of the term and significant specificity is provided on how each of the two water sources will be jointly managed.
(ii) *Treaties that focus overwhelmingly on surface water and provide only vague, often singular reference to groundwater (LG-HS):* Treaties provide significant specificity on how surface waters will be

[4] For clarification, some agreements focus on these issues but nevertheless treat water as 'a scarce or consumable resource' and are included in the analysis, e.g., *Framework Agreement on the Sava River Basin* (2002) focuses on navigation but treats water as a consumable resource.
[5] Although Giordano *et al.* (2014) compiled 217 treaties, close scrutiny revealed that 2 treaties were in fact associated with earlier agreements and as such were merged and an *Agreement Annex between Lebanon and Syria concerning the distribution of water of the Al-Asi River rising in Lebanon* (2002) was excluded due to translation limitations, reducing the total to 214 treaties.
[6] Eleven previously unclassified (non-English language) treaties contained in the TFDD were translated, classified and utilized in this paper.
[7] http://www.fao.org/docrep/008/y5739e/y5739e05.htm.

Table 1. Treaty classification framework.

	Parameter	Classification
General parameters	Date signed	Date of the primary document
	Countries and continent	Countries that are party to the treaty; Continent where the basin is located
	Water source(s) to which treaty applies	(i) Surface water (ii) Groundwater (iii) Surface and groundwater
	Depth of conjunctive management	(i) Heavy groundwater–heavy surface water (HG-HS) (ii) Heavy groundwater–light surface water (HG-LS) (iii) Light groundwater–heavy surface water (LG-HS) (iv) Light groundwater–light surface water (LG-LS)
	Scale	Shared waters, full basin, aquifer, border waters, tributary/sub-basin, infrastructure, other
Technical parameters	Primary issue area (focus)	Water use: environment/water quality, flood control, hydropower, irrigation, navigation Water institutions: policy framework, organizational development, allocative rules
	Water allocation	Yes/No; if Yes, quantitative or conceptual allocation
	Water quality	Yes/No; if Yes, category one (comprehensive standards), two (no standards), or three (simple commitment)
	Type of BO	Does a treaty create a BO? If Yes, type one (committee), two (commission), or three (authority)
	Data and information exchange	Yes/No
	Joint monitoring	Yes/No

jointly managed, but do not provide the same level of detail on joint groundwater management despite reference to groundwater sources[8].

(iii) *Treaties that focus overwhelmingly on groundwater and provide only vague, often singular reference to surface water (HG-LS):* Treaties provide significant specificity on how groundwater will be jointly managed, but do not provide the same level of detail on joint surface water management despite reference to surface water.

(iv) *Treaties that provide light reference to both ground and surface water (LG-LS):* Treaties contain only general reference to both ground and surface water.

The fifth general parameter was geographic scale. A scale classification system with six categories was developed by Holmatov & Lautze (2016): shared waters, full basin, border waters, tributary/sub-basin, infrastructure, and other. In this paper, the scale typology is expanded to accommodate a new category – groundwater or aquifers. 'Shared waters' scale treaty applies to all shared waters between two or more countries. 'Full basin' scale treaty applies to a river's entire basin. An 'aquifer' scale treaty applies to an aquifer or aquifer system. 'Tributary' scale treaty applies to the tributary and associated sub-basin.

[8] To be fair, inclusion of groundwater language is positive and the authors in no way mean to diminish the importance of this. That said, the sincerity of groundwater coverage we believe to be greater when treaty contents present evidence on specific aspects of groundwater.

'Border waters' scale treaty is limited to watercourses in the border or frontier areas between water-sharing states. 'Infrastructure scale' treaty applies to specific infrastructure(s) in shared watercourse(s) (e.g., dam, canals). 'Other' scale treaty applies to distinct portion(s) of a basin or aquifer or defined combined parts of a basin and an aquifer that do not fall into one of the other categories.

For the purpose of this paper, treaties were classified according to six technical parameters adapted from TFDD, Giordano *et al*. (2014), Lautze *et al*. (2013) and Holmatov & Lautze (2016): primary issue area, water allocation, water quality, type of basin organization (BO), data and information exchange, and monitoring (Table 1).

The first specific parameter was primary issue area. Consistent with Holmatov & Lautze (2016), this parameter was first divided into two groups with common themes: (i) water use and (ii) institutional development. The first group was then subdivided into five categories: environment/water quality, flood control, hydropower, irrigation and navigation. The second group was subdivided into three categories depending on the primary focus of the treaty: policy framework, organizational development or allocative rules. Each treaty was categorized exclusively into one of the eight primary issue areas.

A second parameter on water allocation was defined, classified into a quantitative or a conceptual category using an approach previously utilized (Lautze & Giordano, 2006; Drieschova *et al*., 2008; Holmatov & Lautze, 2016). Quantitative allocation refers to quantities or proportions of water, whereas conceptual refers to a qualitative process or rationale given for water allocation.

A third parameter was water quality. Consistent with the work of Giordano (2003) and Holmatov & Lautze (2016), treaties that cover water quality were classified into one of three categories: (i) category 1 – establishes a comprehensive management framework, standards or action plan; (ii) category 2 – secures some action but lacks standards or a comprehensive management framework; and (iii) category 3 – confirms a simple commitment to address the issue.

A fourth parameter was BO type. The language of BO was utilized as it is presumed to encompass organizations applying to surface and groundwater. BOs were classified into three categories using a previous approach (Lautze *et al*., 2013). (i) *Committee* (less robust in terms of mandate and implementation remit) refers to a group of official representatives of riparian governments who meet with some frequency to discuss conditions and developments in a shared watercourse, seek compromises where appropriate, and advise their governments; no regular full-time staff are kept. (ii) *Commission*, which has full-time staff and maintains a technical office, has functions focused on monitoring (e.g., data collection) and regulation (e.g., coordination, policy setting and harmonization). (iii) *Authority* (most robust in terms of mandate and implementation remit), which also has full-time staff and a technical office, has responsibilities that typically include development and operation of projects. Importantly, two assumptions were made when determining the BO type, into which a particular BO was classified: (i) in ambiguous cases, a BO was classified as the weaker of two possible options; (ii) in treaties that created more than one BO, classification was made according to the form of the more robust BO.

The fifth and sixth parameters were adapted from TFDD and Giordano *et al*. (2014). Presence or absence of information and data exchange provisions in treaties was determined. Similarly, presence or absence of joint monitoring provisions in treaties was determined.

Data analysis

With data classified, nine quantitative analyses and one qualitative analysis were undertaken. To summarize treaties' coverage of different water sources, a first analysis focused directly on the number of

treaties applying only to surface waters, only to groundwater, and to conjunctive management of both surface and groundwater. The number of conjunctive treaties that fall into each of the four sub-categories outlined above (HG-HS, HG-LS, LG-HS and LG-LS) were then determined.

A second analysis was focused on understanding the evolution of number of treaties applying to surface water, groundwater, and conjunctive management of surface and groundwater. Treaties covering different water sources were stratified by the decade of conclusion of their primary agreement and the number completed each decade was determined.

A third analysis was focused on determining the geographic scale at which treaties applying to different water sources have been formed. Treaties applying to each type of water source (surface water, groundwater, conjunctive) were stratified by scale and the proportion of treaties concluded at each of the seven scales was determined for treaties applying to the alternate types of water source.

A fourth analysis sought to determine how treaty focus varies as a function of the water source to which it is oriented. The distribution of the eight primary issue areas was therefore determined for surface water, groundwater and conjunctive treaties. These eight primary issue areas are presented in two groups: those focused on water use (environment/water quality, flood control, hydropower, irrigation, navigation); and those focused on water institutions (policy framework, organizational development, allocative rules).

A fifth analysis aimed to reveal how water allocation varies across treaties applying to different water sources. To quantify variation in inclusion of water allocation across surface water, groundwater and conjunctive treaties, a proportion of treaties containing water allocation in each group was determined. Further, among treaties containing water allocation provisions in each group, the proportion containing different types of allocation (quantitative vs conceptual) was determined.

A sixth analysis was focused on water quality. To determine variation in inclusion of water quality provisions across surface water, groundwater and conjunctive treaties, the proportion of treaties containing water quality in each group was determined. In addition, among those treaties in each group that contain water quality provision, the depth of water quality coverage was considered.

Three additional quantitative analyses of transboundary water treaties were undertaken, one focused on BOs and two focused on data and monitoring. These three analyses are:

- To determine the frequency and nature of BOs created in treaties focused on different water sources, the proportion of treaties creating BOs across the surface water, groundwater and conjunctive treaties was determined. Further, BOs in each treaty group were unpacked to determine the proportion of committees, commissions and authorities.
- To understand variation in inclusion of data and information exchange across surface water, groundwater, conjunctive treaties, the proportion of treaties containing data and information exchange in each group was determined.
- To determine variation in inclusion of a monitoring clause across surface water, groundwater, conjunctive treaties, the proportion of treaties containing monitoring in each group was determined.

In addition to the set of quantitative analyses just outlined, a final analysis was focused on qualitatively reviewing the subset of truly conjunctive treaties (HG-HS) to understand more precisely what – if anything – sets them apart. Are there any ‘staples’ or common elements found in conjunctive treaties, for example, that are not as commonly found in treaties applying to single sources? Treaties were therefore closely reviewed in order to identify distinguishing characteristics.

Results

Almost 80% (209) of water treaties globally are surface water-oriented (Table 2). Five treaties (2%) are groundwater-oriented, while 52 water treaties (19%) are conjunctively-oriented. An example of a purely surface water treaty is the *Agreement on the action plan for the environmentally sound management of the Common Zambezi River System* (1987) concluded among Botswana, Mozambique, Tanzania, Zambia and Zimbabwe to adopt an action plan for the management of the Zambezi River. An example of a purely groundwater-oriented treaty is the *Guarani Aquifer Agreement* (2010) concluded between Argentina, Brazil, Paraguay and Uruguay to manage waters in the GAS. An example of a conjunctive treaty is the *Convention concerning the protection of Italo-Swiss waters against pollution* (1972) concluded between Switzerland and Italy to protect common surface and groundwater against pollution.

Most conjunctive treaties (75%) have light groundwater reference and heavy surface water reference (Table 3). Three treaties (6%) have light ground and surface water reference. Two treaties (4%) have heavy groundwater and light surface water reference. Eight treaties (15%) have heavy reference to ground and surface water.

The first conjunctive treaty – the *Convention regarding the water supply of Aden between Great Britain and the Sultan of Abdali* – was concluded in 1910 between Great Britain, on behalf of colonial Yemen, and a neighbouring sultanate. This treaty, classified as a heavy groundwater and light surface water-oriented treaty, was focused on granting permission to the British to drill wells in a piece of land near an ephemeral stream in the border area. The next conjunctive treaty was not signed until the 1950s (Figure 1). The rate of conclusion of conjunctive treaties rose substantially from the 1990s. The first exclusively groundwater-oriented treaty was signed in 1991 between Egypt and Libya – *Bilateral Cooperation Agreement Minutes between Egypt and Libya on the establishment of the Joint Authority for the Study and Development of Groundwater of the Nubian Sandstone Aquifer System*. Three more groundwater-oriented treaties were concluded in the 2000s and one in the 2010s. In contrast, the first surface water-oriented treaty was signed in the 1820s and the rate of conclusion of treaties in this group peaked in the 1990s.

Table 2. Breakdown of water treaties by source.

	SW	GW	Conjunctive
Number	209	5	52
%	79	2	19

Table 3. Breakdown of conjunctive treaties.

	Heavy groundwater–heavy surface water coverage (HG-HS)	Heavy groundwater–light surface water coverage (HG-LS)	Light groundwater–heavy surface water coverage (LG-HS)	Light groundwater–light surface water coverage (LG-LS)
Number	8	2	39	3
%	15	4	75	6

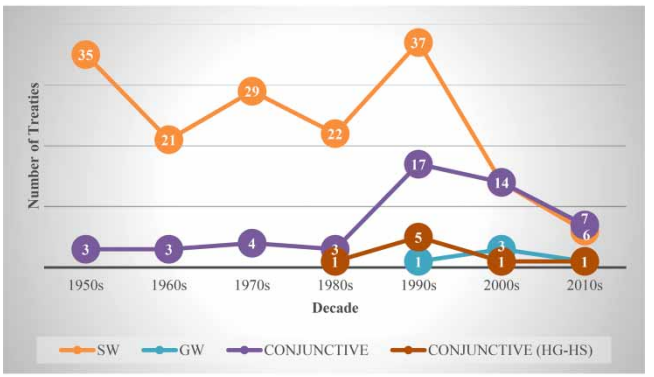

Fig. 1. Number of treaties by decade of completion. One conjunctive treaty was concluded prior to the 1950s.

Conjunctive treaties are concluded at all scales except at the aquifer scale (Figure 2). Conjunctive treaties with heavy focus on both ground and surface water, believed to reflect the most complete form of conjunctive management, are concluded at only two scales: shared waters and other. An example of heavy ground–heavy surface (HG-HS) conjunctive treaty in a specific aquifer is the *MOU between the City of Juárez, Mexico Utilities and the El Paso Water Utilities Public Services Board of the City of El Paso, Texas* (1999). This treaty concluded between sub-national entities of the United States and Mexico refers to both Rio Grande (surface water) and Hueco Bolson aquifer (groundwater). As expected, all of the purely groundwater-oriented treaties are concluded at the aquifer scale. Surface water-oriented treaties are most frequently concluded at the infrastructure scale, followed by border waters scale.

The primary thematic focus of treaties is water use (navigation, irrigation, hydropower, flood control or environment/water quality) in less than half of the cases (Figure 3). Just over 40% of surface water and conjunctive-oriented treaties focus on water use; hydropower is the most frequent focus in the former case, the environment in the latter. The primary focus of approximately 20% of groundwater and strong conjunctive (HG-HS) treaties is water use; in both instances, the use receiving focus is the environment.

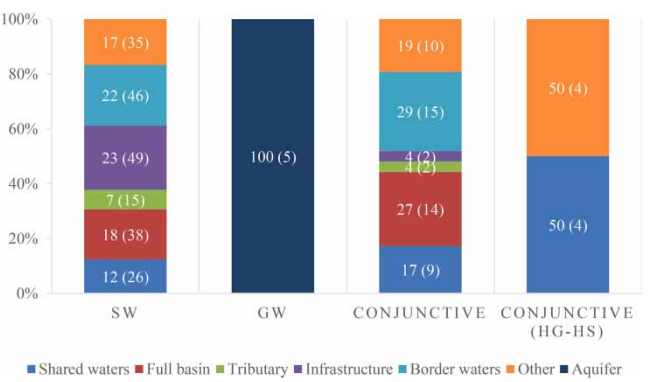

Fig. 2. Per cent breakdown of global water treaties by scale. Numbers are shown in parentheses.

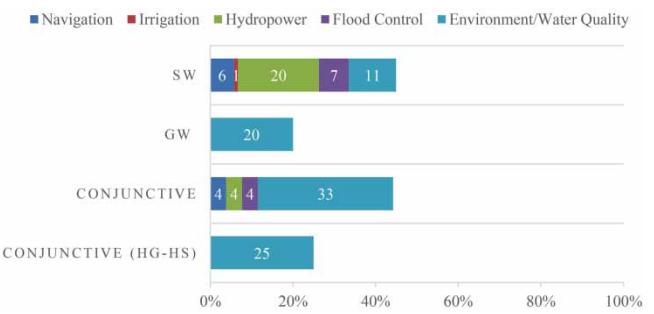

Fig. 3. Primary issue area, water uses[9].

A larger proportion of treaties in each group are focused on water institutions (Figure 4). In the conjunctive-oriented treaties group, 31% focus on organizational development, 15% on allocative rules and 8% on policy framework. Among substantive (HG-HS) conjunctive-oriented treaties, 38% focus on allocative rules and 38% on the organizational development. Four (80%) of groundwater-oriented treaties focus on organizational development. Twenty-three per cent of surface water-oriented treaties focus on allocative rules, 16% on the organizational development and 8% on policy framework.

Water allocation is more frequently contained in groundwater and conjunctive treaties than surface water treaties (Figure 5). Just over half (55%) of surface water treaties contain water allocation mechanisms, whereas this is the case for 80% and 73% of the groundwater and conjunctive treaties, respectively. Nonetheless, in groundwater- and conjunctive-oriented treaties, conceptual water allocation is more common than quantitative allocation.

At least 80% of groundwater and conjunctive treaties contain reference to water quality, far more than in surface water treaties (Figure 6). The least stringent, category 3 water quality provisions, are the most frequent in groundwater, surface water and conjunctive (HG-HS)-oriented treaties. Among all conjunctive treaties, water quality focus is divided roughly equally between category 2 and category 3 forms of

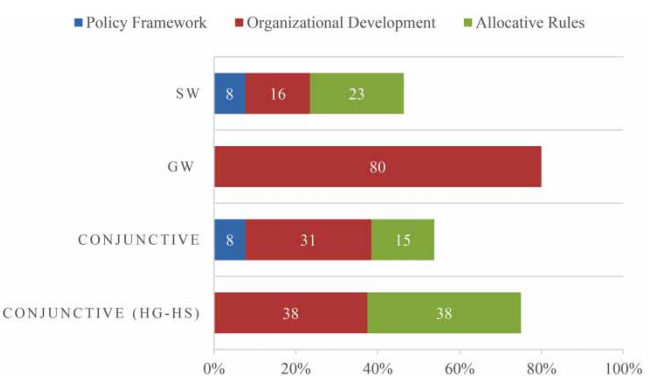

Fig. 4. Primary issue area, institutions.

[9] For 19 treaties (18 SW and 1 conjunctive), the primary issue areas could not be conclusively determined; these were therefore excluded from the analysis.

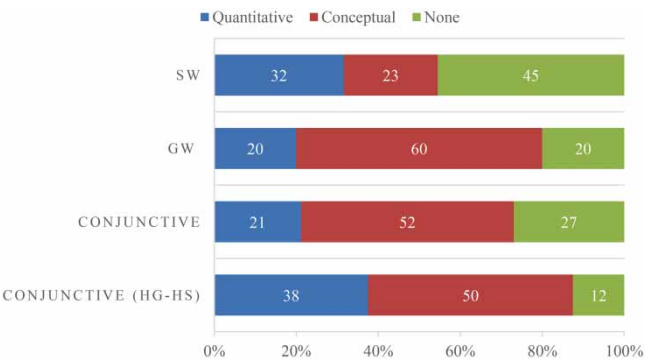

Fig. 5. Water allocation.

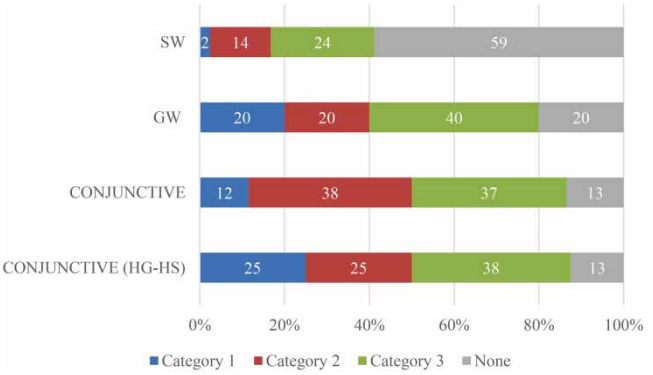

Fig. 6. Water quality.

water quality. Groundwater and conjunctive (HG-HS)-oriented treaties refer to water quality provisions meeting category 1 and category 2 with very similar frequency. Surface water-oriented treaties most often contain category 3 water quality provisions.

The weakest form of BOs, committees, are created most frequently in treaties across all four water source orientations (Figure 7). Commissions are created in surface water- and conjunctive-oriented treaties, but the proportion of commissions in conjunctive treaties is substantially greater than in surface water treaties. The relative proportion of authorities created is greatest in groundwater treaties.

Conjunctive and groundwater treaties are more likely to include provision for data and information exchange (Figure 8). Ninety-two per cent of treaties concluded in the conjunctive treaties group include a data and information exchange clause. All treaties concluded at the groundwater and conjunctive (HG-HS) treaties include a data and information exchange clause. In contrast, just 43% of surface water-oriented treaties include a data and information exchange clause. An example of a groundwater-oriented treaty that includes a data and information exchange clause is *MOU relating to the setting up of a Consultative Mechanism for the management of the Iullemeden Aquifer System (IAS)*, 2009, between Niger, Nigeria and Mali. Specifically Art. 19 states, 'The signatory States shall, separately and, where necessary, jointly, manage the IAS water resources so as to ensure the sustainability and maintain the quality of

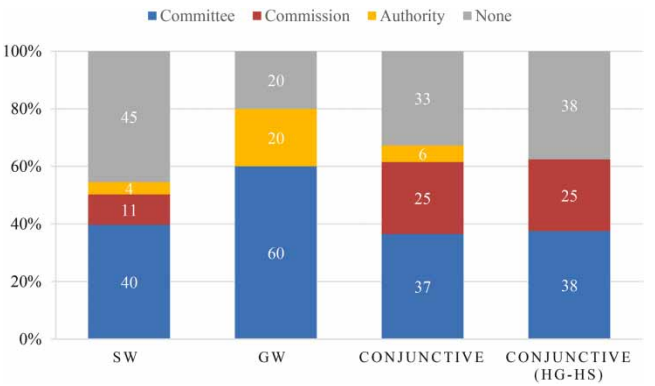

Fig. 7. Basin organizations.

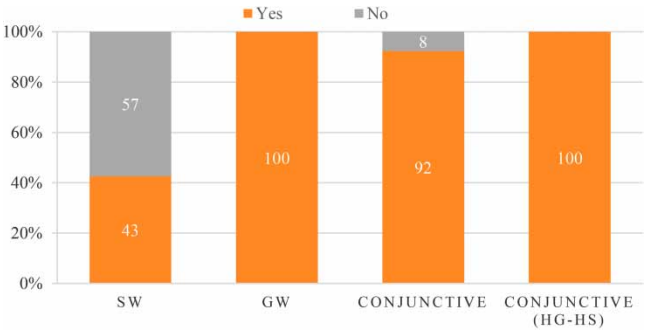

Fig. 8. Data and information exchange clause.

these resources at the highest possible levels. For this purpose, they shall undertake: a) to exchange data and information related to the IAS.'

Monitoring clauses are most frequently contained in groundwater treaties (Figure 9). In contrast, joint monitoring is least common in surface water treaties. Sixty per cent of conjunctive treaties and 75% of the conjunctive (HG-HS) treaties include a monitoring clause.

Qualitative review of truly (HG-HS) conjunctive management treaties

There were eight treaties that gave heavy or substantive focus to both surface and groundwater. These treaties are:

1. The USA–Canada *Protocol Amending the 1978 Agreement between United States of America and Canada on Great Lakes Water Quality*. This treaty, signed in Ohio in 1987, is focused on maintaining the quality of surface and groundwater in the Great Lakes.
2. The *Israel–Jordan Treaty of Peace*, signed at the Wada Araba Border in 1994, which is a cooperative treaty aimed at resolving water issues (e.g., water allocation conflicts and pollution of water resources) arising from two shared rivers – Jordan River and Yarmouk River, and the adjacent Araba aquifer.

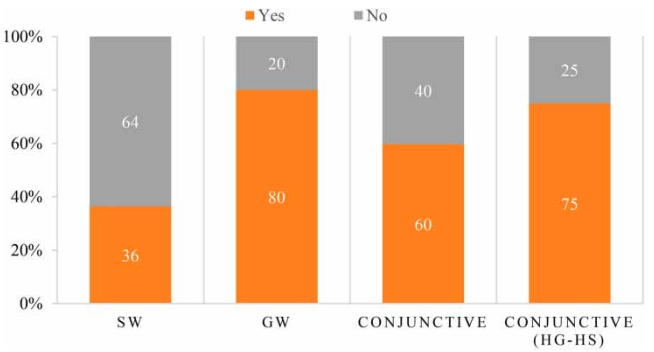

Fig. 9. Monitoring clause.

3. The Israeli–Palestinian *Interim Agreement on the West Bank and the Gaza Strip* (originally signed in 1994 as the Gaza Jericho Agreement) signed in Washington DC in 1995, which covers a wide range of issues, but has a specific section on water cooperation.
4. The British Columbia (Canada)–Washington (USA) *memorandum of understanding (MOU)* of 1996, focused on water rights in shared watercourses (e.g., Columbia River Basin) and the Abbotsford/Sumas Aquifer.
5. The *Convention on Cooperation for the Protection and Sustainable Use of the River Basin Waters* between Portugal and Spain, signed in Albufeira in 1998. It is a bilateral treaty to protect ground and surface water ecosystems between the two countries, spanning five shared river basins, and their linked groundwater systems.
6. The *Junta Municipal de Agua y Saneamiento de Juarez (JMAS) (Mexico) – and the Public Services Board (PSB) of El Paso town (USA) MOU, on technical cooperation in managing the waters of the Hueco Bolson Aquifer and the Rio Grande River*. The treaty, signed in 1999, is focused on guaranteeing water supply and attending to water quality problems that had spiralled because of rapid population growth.
7. The *Additif a L'accord Instituant Un Regime Fluvial Uniforme et Creant La CICOS*, a 2007 agreement signed in Kinshasa among Cameroon, Central Africa Republic, Congo Republic, DRC and Gabon – with Angola having observer status, to promote integrated water resources management in the watershed of the Congo Basin and its aquifers.
8. The *Agreement on the Protection and Sustainable Development of the Prespa Park Area* signed in 2010 among Albania, Greece and Macedonia, and focused on ecosystem protection of the ground and surface water in the Prespa Lakes.

Consistent with most other treaties, conjunctive treaties focus on typical features like basin management plans, water management institutions, and data and technical exchange. The Great Lakes agreement (no. 1) specifies the need for 'remedial and lake wide management plans', for example, and the Israel–Jordan treaty (no. 2) states that riparians shall write basin development plans and share them. The Albania–Greece–Macedonia treaty (no. 8) emphasizes that parties must design integrated water management plans. Examples of water management institutions are the Executive Committee (JMAS–PSB) (no. 6), the International Joint Commission (USA–Canada) (no. 1) and the Joint Water Committee (Israel–Palestine) (no. 3). The agreements also provide for governance

mechanisms like information exchange, monitoring and dispute resolution. The Israel–Jordan treaty (no. 2) emphasizes that riparians 'undertake to exchange data', for example, while the JMAS–PSB agreement (no. 6) gives the parties responsibilities to 'share technical support and information'.

Conjunctive treaties display two characteristics that are somewhat different from other treaties. First, as might be expected, they grant similar legal protection to both groundwater and surface water. For example, the British Columbia–Washington MOU (no. 4) requires that both licences for surface and groundwater abstraction be submitted and adjudicated on the same criteria, and the Portuguese–Spanish agreement (no. 5) explicitly includes both ground and surface water in their definition of transboundary waters, and further seeks the ecological protection of both groundwater and surface water. This closes the loophole evidenced in some surface water agreements that treat groundwater as a separate, national good – allowing it to be mined indiscriminately while surface water resources are regulated.

Second, the scales at which conjunctive (HG-HS) treaties are concluded are somewhat creative. It indeed appears that conjunctive treaties are oriented towards 'problemshed' (Kneese, 1968) scales rather than the watershed. The Great Lakes treaty (no. 1) applies to several catchments that supply water to the lakes and their linked aquifers like the Glaciofluvial, Saginaw, Parma-Bayport and Marshall, for example, and the JMAS–PSB treaty (no. 6) covers the water supply sources of the two towns – the immediate watercourse of the Rio Grande River and the underlying aquifer. Similarly, the Israeli–Palestine treaty (no. 3) recognizes the need to coordinate management of all shared water resources, and therefore focuses on all shared water bodies. While the scale of evidenced cooperation no doubt relates to more than the water sources to which that cooperation applies, as other contextual factors may play a role such as in the context of resources shared between Israelis and Palestinians (Brooks & Trottier, 2010), there remains a pattern of conjunctive management treaties applying to creative scales.

Discussion

The paper developed a framework for analysing transboundary water treaties according to the water source(s) to which they were oriented, and applied it to expand the state of knowledge on conjunctive management in transboundary waters. The paper treated conjunctive management of multiple water sources as distinct from separate management of surface water or groundwater, in order to reveal the depth and nature of conjunctive transboundary water treaties. By placing explicit focus on a type of transboundary water management that had previously been overlooked or conflated with either ground or surface water management, the paper has unearthed insights that may help clarify the nature of engagement in international waters.

This work produced at least three main findings. First, there is a discernible body of conjunctive treaties (eight identified with substantive focus on both sources), whose formation is relatively recent. The identity of conjunctive treaties may be overlooked due to the recent spotlight on transboundary groundwater as a new discipline and the concomitant growth of transboundary groundwater law. The number of conjunctive treaties is indeed higher than that of purely groundwater-oriented treaties (five identified). Second, the existing set of conjunctive treaties place emphasis on data and information exchange, monitoring and organizational development. Conversely, conjunctive treaties possess limited focus on specific water uses other than the environment. Third, the scale to which conjunctive treaties are

oriented can be described as somewhat creative, responding to issues and problems rather than adhering to the hydrologic boundaries of an aquifer or basin.

The paper's first finding, focused on the existence of a discernible body of conjunctive transboundary water law, should not be shocking. Giordano *et al*. (2014) and Pateiro (2016), for example, highlighted growing focus on groundwater in transboundary water law in the context of a long history of surface water cooperation; some orientation toward multiple sources would seem virtually inevitable. Nonetheless, what is surprising is that the growing focus on groundwater in transboundary water law is often treated, perhaps misleadingly, as distinct to focus on surface water. Indeed, in the rush to identify and understand treatment of groundwater in transboundary water treaties, the growing body of conjunctive transboundary water law may have been overlooked.

The paper's second finding is that conjunctive treaties place greater emphasis on softer aspects of cooperation like data exchange, monitoring and organizations – conversely, focus on 'harder' issues like irrigation, hydropower and flood control is not common. Water quality, nonetheless, does receive relatively high focus. Coupling these findings with the reality that virtually all conjunctive treaties have been concluded after 1990 suggests that either: (i) the development of conjunctively oriented transboundary water law may be in its infancy and, as such, still somewhat coordinative; (ii) content of conjunctive treaties may be consistent with global trends, which have increasingly focused on softer issues (Mostert, 2003; Giordano *et al*., 2014). Either way, transition toward more specific water uses may be a logical next step.

The paper's third finding relates to the scale of conjunctive water treaties, which are somewhat more likely to be concluded at 'other' and shared waters scales – particularly among the group of substantive conjunctive (HG-HS) treaties. This finding corresponds with the reality that the scale of conjunctive water management is not straightforward. A surface water focus lends itself to basin frameworks. A groundwater focus lends itself to aquifer frameworks. The scale of conjunctive surface–groundwater management, by comparison, calls for crafting innovative approaches that thoughtfully respond to issues most relevant to riparians and aquifer-sharing states.

Contextualization of this paper's findings in transboundary waters literature referenced at the outset of this document calls for revisiting at least one recommendation contained in current best practice. That is, one recommendation is centred on incorporating groundwater into RBOs (Scheumann & Herrfahrdt-Pähle, 2008; BGR, 2015), which presumably operate at the scale of the river basin. Clearly, it is likely good to incorporate groundwater into transboundary water organizations (Altchenko & Villholth, 2013). However, evidence presented above suggests that substantive (HG-HS) conjunctive management is rarely undertaken at the basin level. This triggers questions about whether the optimal scale of such organization is in fact the river (or other surface water body, like lake) basin, or whether more fit-for-purpose scales – similar to those evidenced in practice – may be more desirable. While an evidence-base to provide a definitive resolution does not exist, the bottom line is that it may be worthwhile to explore rationales that explain on-the-ground realities in which substantive conjunctive water cooperation has been undertaken at creative, 'problemshed' scales.

Contextualization of this paper's findings in national-level recommendations on conjunctive water management reveals a good degree of alignment. Dudley & Fulton's (2006) recommendation, for example, for scientific knowledge to inform decision-making, and technical and management capacity development is consistent with conjunctive water treaties' emphasis on data sharing. Similarly, Evans & Evans' (2014) proposal for alignment of ground and surface water monitoring through joint planning, and assessment of ground and surface water, also appears consistent with treaties' focus on monitoring.

Other suggestions for establishment of water rights (Blomquist *et al.*, 2001) – and flexibility in those rights (Government of Australia, 2014) – may, to some extent, be reflected in the allocative rules found in just over a third of substantive conjunctive treaties (Figure 5).

Ultimately, one reason for the relative paucity of robust water rights concerning both surface and groundwater in transboundary contexts – as well as the limited evidence of action-oriented cooperation related to water uses that draw on multiple sources – may be knowledge gaps on how to meaningfully conjunctively manage at a transboundary level. Another reason may relate to inter-country power games; countries may perceive it to be in their interest to avoid formalization of rights to groundwater. Indeed, there may be more scope for under-the-radar use of groundwater given the difficulties surrounding monitoring of its use (Milman & Scott, 2010).

Whatever the case, the fact remains that well-intentioned states, seeking to cooperate on their shared surface and groundwater sources, may be constrained in their efforts to achieve conjunctive cooperation due to a lack of guidance on how this should be done. There seems no clear template for this. As noted above, simply converging towards a logical scale on which to cooperate may require more careful thought than is required with a surface- or groundwater-oriented treaty.

Conclusions

This paper is the first to review and characterize the evolution of conjunctive management in transboundary water law. Transboundary water treaties have historically been heavily focused on surface water. Recognition for the formation of a body of groundwater-focused agreements has nonetheless now grown. Into discussions of ground vs surface water treaties must now be firmly inserted treaties focused on conjunctive management of multiple sources. The reality that the development of conjunctive treaties is relatively nascent, and that their scope is mainly limited to institutional issues at this point, may indicate large untapped potential – benefits and opportunities derived from implementation of conjunctive approaches have only begun to be exploited.

At least two areas for future work may be pursued. One area for future work is determining when conjunctive water management is most necessary. Indeed, while often beneficial, conjunctive management of ground and surface water is likely not universally required and may in fact lead to unnecessary transaction. Valuable future investigation may therefore be devoted to identifying the set of criteria that make conjunctive water management desirable and necessary. In particular, a topic worth exploring may be when formalizing conjunctive transboundary cooperation adds value, as compared with a status quo of no or informal cooperation.

A second area for future work is developing legal and other guidance related to conjunctive management of water sources in transboundary watercourses. Several international principles exist primarily oriented toward surface watercourses, such as the 1997 UN *Convention on the Non-navigational Uses of International Watercourses*. A somewhat distinct set of international principles, such as the 2008 UN Draft Articles on the Law of Transboundary Aquifers, relate to groundwater. What remains to be done is to determine synergies and complementarities between the two sets of principles in real-world integrated systems, as well as the potential tenets of international principles on cooperative conjunctive water management.

Before concluding, two caveats should be pointed out. While the size of the aggregate set of transboundary water law used in this paper was large, most treaties applied to surface water. The depth of

groundwater and conjunctive treaties was fairly thin. As such, conclusions drawn related to their contents may change rapidly in the future should substantial additional treaties be concluded. Second, this paper examined formalized cooperation on different water sources. A set of informal, customary water sharing no doubt also exists for different water sources. By its nature, informal water cooperation is more difficult to collect, compile and analyse, which explains why it is not reflected in this paper. Nonetheless, valuable future work may be undertaken to explore the dynamics of informal water cooperation on different water sources.

In closing, it is worth returning to the fact that the development of conjunctive water treaties may not yet be mature. As such, it may be time for conjunctively oriented water cooperation to begin to move from the collaboration and coordination on which it has been predominantly focused thus far, to joint actions for improved water management. Ultimately, there seems little doubt that optimal transboundary water management solutions may often benefit from frameworks that account for, and foster collective responses to, surface and groundwater storages and flows. Implementation of such solutions are nonetheless constrained by institutional and knowledge barriers. Moving forward, therefore, it may be time to outline pathways toward practical implementation of conjunctive management in transboundary contexts in order to unlock the potential of this approach.

Acknowledgements

This article forms part of the RAMOTSWA 2 Project, supported by the US Agency for International Development (USAID) under the terms of Award No. AID-674-IO-17-00003, and implemented by the International Water Management Institute.

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Received 14 March 2017; accepted in revised form 16 July 2017. Available online 2 January 2018