Chapter 7
Megatrends in Shared Waters in 2030 and Beyond

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Abstract Looking to 2030 and beyond, the future of shared waters is likely to have parallels with the present, but there is also likely to be expected and unexpected changes within shared water systems and their management. This paper identifies several trends—climate change, new technologies, and information availability and control—that will present both threats and opportunities to shared waters. Climate change may place unique stresses on shared waters by precipitating sudden, unpredictable changes in the hydrologic system that may exceed the institutional capacity to mitigate negative impacts of these changes. New technologies will provide ever-improving tools to view water as a flexible resource and aid in management, decision-making, and negotiation surrounding shared waters. Information availability and control raises questions about transparency and inclusion, and digital-physical security open shared water systems and associated infrastructure to vulnerabilities that may shift rapidly. The institutions governing shared waters will need to adapt to the threats and opportunities offered by these and other future trends. To aid in this effort, several shifts may be necessary in the understanding of shared waters—how shared waters are conceptualised, how inequities are embedded in management, and how shared water actors are broadening in scope. These shifts may support the development of adaptive and flexible institutions and enable them to anticipate and respond to uncertainties facing shared water systems in the future.

Keywords Shared waters · Climate change · Technology · Digital security Water security · Adaptive management · Institutional capacity

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7.1 Context of Shared Waters

The dynamic nature of water resources inspires a future-oriented perspective towards increased water security and enhanced cooperation over shared waters. While water security definitions have evolved since the term first emerged, the most cited definition is 'the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems, and production, coupled with an acceptable level of water-related risks to people, environments, and economies' (Grey and Sadoff 2007; Cook and Bakker 2012). Water security becomes more complex within shared waters—waters that are traversed by political and social boundaries.

Most of the literature on water resources and management focuses on the basin scale as the natural unit for planning; the basin is defined by its hydrology, giving the perception of physically determined neutrality (Giordano et al. 2015). However, these physical boundaries do not always correspond with political boundaries. There are 310 international river basins and nearly 600 international aquifers that cross boundaries between two or more nations (IGRAC 2015; Wolf et al. forthcoming). Accounting for approximately 80% of the global river flow, international basins cover 50% of the global land surface (excluding Antarctica), and they are home to about 40% of the world's population. Given the added sociopolitical and administrative complexity of rivers crossing international borders, there is great interest surrounding international river basins.

While much of the water conflict and cooperation literature focuses on international, transboundary waters, shared waters exist within state borders as well; basins within a state may cross subnational administrative boundaries, cultural boundaries, or social cleavages that do not coincide with international borders. Both international and subnational shared waters are under similar stressors to meet social, environmental and economic demands, but these stressors manifest differently depending on the spatial scale. It is critical that discussions of shared waters—including management, security, conflict and cooperation—address these differences of scale.

'Water wars' literature, especially public media and non-peer reviewed sources, has made assumptions that water scarcity can and will result in violent conflict over transboundary waters, including warfare between basin states. More recently, discussions have shifted towards climate change inducing potential war and violent conflict (Barnaby 2009); however, climate change's primary impacts will be to water. Scholarly literature shows that states do not go to war over water even when facing changes in quantity or quality; interactions between basin states fall overwhelmingly within the spectrum of cooperation (De Stefano et al. 2010a; Yoffe et al. 2003). Similarly, within subnational basins, water users are more likely to cooperate than to engage in conflict (Eidem et al. 2012).

Despite the broad absence of violent conflict, water stress and competition among water users can induce and escalate existing political or social tensions. Conflicts over water resources—mainly nonviolent conflict such as heightened tensions or threats—are likely to gain in frequency, particularly at the subnational level, as resources become scarcer in quantity and degraded in quality (Delli Priscoli and Wolf 2009). Shared water disputes at a subnational level have greater potential for and intensity of conflict (Giordano et al. 2002). This is not surprising, given the much higher prevalence of civil conflicts than interstate wars over non-water related issues (e.g. Collier and Hoeffler 2004; Fearon and Laitin 2003). As water resources become less accessible or available, the impacts from one area's use will begin to have a greater effect on neighbouring users, increasing the potential for tension. For example, during drought conditions, an upstream user might increase their proportion of withdrawal to meet internal demand for irrigation, which would further reduce the water available to downstream users and could lead to political conflict.

Humans have been using, developing, and managing shared waters in a similar, yet evolving, manner for the last 5000 years (Biswas 1970). Despite the seemingly constant nature of shared water management, it is perhaps more accurate to say that water resources and the sociopolitical contexts and relationships surrounding these resources are always changing, and institutions must constantly adapt in order to effectively manage shared waters. Therefore, 'the likelihood and intensity of conflict within a basin increases as the magnitude or amount of change in physical or institutional systems exceeds the capacity to absorb that change' (Yoffe et al. 2003, p. 1117). This relationship between water and conflict, together with the institutional capacity to address the conflict, is particularly relevant for shared waters looking towards 2030 and beyond.

7.2 What Might the Future for Shared Waters Look like?

Shared water management in the future is likely to be similar to the present. For example, governments or water users within high-income countries have, and will continue to have, greater ability to adapt to change, while low-income countries—the Majority World—will not. Despite facing similar risks as low-income countries, such as hydrologic conditions, population growth, quality concerns, and other factors, high-income country investment in water services and infrastructure may reduce their threat of water insecurity. Communities, households, and individuals living in less wealthy regions with minimal investments in water technology, infrastructure, or comprehensive management strategies are more vulnerability to water insecurity. Currently, 3.4 billion people reside in regions that are exposed to high levels of threats to water security (Vörösmarty et al. 2010); of those, many are exposed to economic water scarcity or water insecurity not produced by physical scarcity but lack of financial resources (WBGU 2008). Additionally, subnational disparities between high-income communities, households, and individuals and those from lower income or marginalised groups can also lead to a wide gap in water security within shared waters that might be overlooked when considering a basin-wide scale. This disparity in risk between the wealthy and impoverished at the international and subnational levels is likely to continue or widen in the future.

Looking at trends in shared waters, such as climate change, new technologies, and information production and control, can provide a view into a possible future for shared water in 2030 and beyond. These megatrends present new challenges and opportunities, in addition to uncertainty, for shared water management, particularly when they are viewed in combination. Given that institutions must effectively adapt to reduce the potential for conflict, they must anticipate the challenges and opportunities presented by these trends in support of their short- and long-term planning.

7.3 Climate Change

Anthropogenic climate change is widely recognised as one of the greatest challenges to our generation, and it is projected to continue or escalate in future generations. While climate changes are far reaching, most of the impacts are experienced through the hydrologic cycle. Changes in weather patterns and environmental conditions add variability and increase the likelihood for extremes, affecting the quantity and quality of water resources (IPCC 2014). The main climate change impacts on shared waters will disrupt precipitation, temperature, and evaporation patterns (Ludwig et al. 2016). The spatiotemporal variability of these changes is expected to alter flow volumes and timing, groundwater recharge rates, glacial melt, and snow pack, as well as the propensity for drought or flood. In many shared water systems, climate change is experienced in combination with other stressors, such as population growth, economic development, environmental degradation, urbanisation, and inefficient agricultural and industrial practices. Climate change trends, coupled with added spatiotemporal uncertainty and other global changes, bring new risks and challenges to the management of shared waters. In 2030 and beyond, it is likely that climate change will present unprecedented stressors and uncertainty to institutions operating within shared water management.

Water resources management has historically attempted to overcome the natural variability of river systems by designing management and infrastructure according to historically observed hydrological records. This approach assumes climate stationarity, where future variability remains within historically observed bounds (Milly et al. 2008; Ludwig et al. 2016). However, the persistent and potentially severe climate change-induced disruptions to historical patterns reduce the ability of historical records to serve as a stable foundation for management planning and infrastructure design. This in turn undermines the ability of shared water managers to rely on past experience to make future-oriented decisions (Zeitoun et al. 2013).

Two factors are potentially more destabilising than the direct impacts of climate change itself: the rate of change and our inability to predict changes with spatiotemporal precision and at scales relevant for water managers. While some changes occur over greater spans of time, such as sea level rise, other changes may occur over shorter time scales, such as episodes of extreme flood. Climate studies indicate that changes in the hydrologic cycle and the rate at which they happen will likely be exacerbated by an altered climate (Michael and Pandya 2009; Svendsen and Künkel 2009). Climate science also projects long-term trends and predicts the magnitude and distribution of global variability providing shared water managers with a range of possible changes in their basin. These models, however, are less precise at subregional and short-term time scales (Allen and Ingram 2002; Moran 2011). Policy lenses operate within local scales and immediate to short-term focus, meaning that these models are not accurate to the degree needed—neither spatially nor temporally—for water managers or infrastructure designers to make decisions (Matthews et al. 2011; Ludwig et al. 2016). Short-term uncertainty about potential changes makes it more challenging to garner the political will to adopt costly climate adaptation measures. For example, much existing infrastructure will likely be rendered obsolete or inadequate to a changing environment, provided that the current predictions for climate change rate and scope are correct. Nevertheless, there is a great political and financial cost to constructing new infrastructure that address the eco-hydrological conditions in 100–200 years, especially when climate change scenarios cannot indicate certain changes to occur in specific timeframes or locations (Ludwig et al. 2016).

Biophysical impacts of shared water systems create secondary impacts on management, infrastructure and institutional conditions (Zeitoun et al. 2013). For example, regions expected to receive less precipitation will likely experience greater water shortages and competition between water user groups, which, in turn, creates management challenges or even potential political tension or conflict. California, for example, relies on natural storage in the Sierra Nevada snow pack to supply freshwater during the drier parts of the year, which coincides with times of peak demand. California's water management, particularly its water allocation system and infrastructure, was developed based on this timing and the reliability of this snow pack, but biophysical impacts from climate change are predicted to reduce the snow pack and alter the timing of peak flow. The secondary impacts will be to the state's water rights management and allocation system, which will be threatened and potentially rendered ineffective. The complex system of dams and canals to store and transport snow melt in the summer months could also become limited in functional capacity, given that it was not designed to accommodate the altered flow timing and greater volumes in wetter months. The state's urban population and agricultural sector is dependent on this system; therefore, a reduction in water resources combined with an inefficient management and infrastructure system will likely create competition between agricultural and urban users, with tertiary impacts on food price and availability where California produce is exported throughout the country and world.

Since political tension and violence become likely when change exceeds the rate of institutional capacity to absorb the change, the potential increased variability and uncertainty due to climate change will put greater stresses on the hydro-political system and complicate existing shared water management (Dinar et al. 2015). When compared to flexible and adaptive management regimes, sudden, unpredictable changes within a more inflexible supply-side management system based on historical patterns and not future models will likely trigger greater negative effects, including political tension (Zeitoun et al. 2013; Nardulli et al. 2015).

The global distribution of climate-driven risks is not uniform at multiple levels. Politically unstable regions that lack the capacity to absorb these changes and those that are more economically reliant on climate-sensitive resources, such as primary resource commodities, will likely feel the greatest impacts of climate change (Barnett and Adger 2007). At a subnational level and regardless of state-level development, marginalised communities and individuals are disproportionately exposed to and impacted by climate change (IPCC 2014). Due to the existential nature of water, there will be increasing pressure on shared water managers to make equitable decisions in a climate of uncertainty. Further, this pressure will likely be politically charged, as '… climate politics is like all other politics; it is partly about what is real and partly, sometimes predominantly, about what is believed, expected, and feared' (Moran 2011, p. 5). As climate change drives more acute and protracted water resource disasters, the impacts will differ depending on how these crises are perceived by the public. If impacts are perceived to be focused on marginalised groups, management and institutions may not respond as adaptively or effectively to mitigate impacts as compared to potential impacts on non-marginalised groups. Furthermore, institutions serving marginalised groups may lack or have reduced capacity to mitigate impacts regardless of perception.

7.4 New Technologies

Changes in shared water management historically have occurred through improved hydrologic understanding. Within the twentieth and early twenty-first centuries, advancements in technology have substantially enhanced understanding of hydrologic, social and environmental systems, which, in turn, has increased institutional capacity to manage these intersecting systems. This trend is likely to continue in 2030 and beyond as new technologies are created and refined.

Major technological advancements have been made to increase water supply and quality. In many high-income countries, wastewater reclamation for non-potable use has become commonplace. However, recent and future improvements in purification technologies have, and will continue to make, indirect and direct potable reuse more financially viable, particularly when compared to alterative supply sources or more energy- and/or cost-intensive treatment processes (Abrams 2015). Singapore's NEWater campaign, California's Orange County Water District's indirect potable reuse Groundwater Replenishment System, and Texas's direct potable reuse program in Wichita Falls are examples of new supply-side water management technology implementation. Challenges to widespread implementation include mobilising financial resources to cover the cost, overcoming the psychological aversion to toilet-to-tap water, and devising comprehensive, transparent regulation to ensure water quality. Potential future technologies and regulatory systems will take a step forward to assuage public concerns and make the technology more acceptable.

Of the many supply-oriented technologies, desalination stands to have a significant impact on managing shared waters. While desalination is an energy-intensive, costly process, it has been used for several decades as a solution to generate potable water in water-scarce, high-income countries with access to low-cost energy. Desalination is used primarily to supply drinking water to coastal populations situated at low elevations or in areas with no other perceived alternatives. Advancements in desalination technologies, such as improvements to reverse osmosis, have significantly reduced costs, making desalination more attainable to countries without access to cheap energy (Reddy and Ghaffour 2007). Future improvements will reduce financial constraints that limit wider use. For example, a reduction in desalination costs could expand brackish groundwater use as an alternative source in areas where it might be otherwise cost prohibitive to treat to a potable quality.

Combined with innovations in green energy technology or decreases in energy cost, the economics of desalination could profoundly change in the future. Solar powered desalination is currently more expensive than traditional energy, but the cost has been dropping dramatically—a trend likely to continue. The United Arab Emirates and Saudi Arabia are taking advantage of new solar technologies by opening several new solar-powered desalination plants for domestic consumption within the next few years (Martin 2016). While current desalinated water prices are generally affordable only for high-income urban water users, if the future cost of desalinated water lowers to agricultural water prices, a large proportion of agricultural water demand would shift to the sea. This shift is probably far beyond the near future, but desalinated water costs could lower sufficiently to supplement a larger proportion of the domestic supply to coastal cities, reducing competition between shared water users of freshwater resources. With respect to international shared water management, lower desalination costs could alter existing power dynamics between upstream and downstream riparians. Upstream riparians tend to possess inherently more power in negotiations than downstream countries, given their control of the headwaters. However, desalination capabilities may disrupt this power structure by offering some water independence to downstream countries (Aviram et al. 2014).

In addition to more traditional supply-side management, there is a trend towards managing demand. Shifting trends in management are paired with demand-reduction technologies, such as irrigation efficiency tools, low-flow utilities, and plant genetic modifications. Together, these new technologies will continue to provide major advances in reducing water consumption, thereby reducing the total amount of stress on shared water systems as they seek to satisfy competing demands between nations, communities, and/or other shared water users.

The demand and supply of high-resolution temporal and spatial data are expanding. With new advancements in technology, the cost of collecting hydrologic and meteorological data is decreasing, creating shifts in shared water management and negotiation. The ubiquity of wireless internet connections and satellite uplinks will improve monitoring systems and provide water managers with extensive watershed and climate data, potentially in real-time. New innovations have reduced the size and cost of weather stations, allowing for a higher density of stations that provide complete coverage and public access. Examples include the sensors designed as part of the Trans-African Hydro-Meteorological Observatory (TAHMO) project, which will collect hydrological and meteorological data across the African continent (TAHMO 2016). These high-resolution hydrological and meteorological data, particularly regionally detailed data, will help policy makers or shared water managers understand risk and uncertainty when estimating seasonal supply and demand for domestic, irrigation, environmental and other water needs (Hamilton 2012). In addition to centrally generated data sources, data collected through the assistance of the public, or crowdhydrology, may increase low-cost methods to collect data, such as stream gauge measurements. Crowdsourcing hydrologic data collection through cell phones is in its infancy, but it could provide supplemental data and public engagement (Lowry and Fienen 2013).

Remotely sensed data provide additional information on well-studied basins and on those that might be physically or politically inaccessible. High-resolution remotely sensed data are becoming ever more important in management and technical understanding of shared waters. For example, the high-resolution topography datasets collected through the Shuttle Radar Topography Mission (SRTM) or Light Detection and Ranging (LiDAR) allow for more precise delineation of watershed boundaries—which helps to identify shared waters—and create more accurate hydrological models of these basins (Farr et al. 2007). Future sensors similar to the current Gravity Recovery and Climate Experiment (GRACE) will expand the ability to measure changes in the Earth's gravity and will be used to estimate groundwater storage change more accurately (Joodaki et al. 2014; Powell 2012). The GRACE-Follow On mission and the Surface Water and Ocean Topography mission are two examples of upcoming remote sensors that will provide more detailed data on groundwater and surface water changes, respectively (Nelson 2016a, b). Water managers can use real-time and remotely sensed data to make decisions, such as water allocations for irrigation or reservoir levels for flood control, based on existing hydrologic conditions rather than fixed quantities or limited models based on historical data. Access to these data would further allow for non-stationary decision-making in the face of uncertainty and risk from climate change within shared waters.

Looking towards 2030 and beyond, advancements in modelling and data visualisation of future water resources will make information more comprehendible to decision-makers and allow them to consider multiple possibilities within dynamic systems. High spatiotemporal resolution of remotely sensed data will enhance geographic information (GIS) and modelling systems. Currently, hydrologic models are beginning to address groundwater in conjunction with surface water (Zeitoun 2011). Future watershed models will increasingly include groundwater, particularly as demand and stress on groundwater resources intensify. Within negotiation processes, future models and GIS serve as facilitation tools to improve cooperation and joint knowledge of a shared water system, where user groups, managers, or negotiators work together to cooperatively construct models and see the potential outcomes of various water policies or water infrastructure projects. Further, decision-makers will be able to examine the viability of proposed solutions with finer detail and accuracy, while considering expanded options in negotiations over shared waters, which is often key to successful negotiations (USACE 2006; Cole and Crawford 2007). Advancements will also allow participation of a wider range of actors and public access in support of transparent management.

Detailed and future-oriented information can be used to address problems within shared waters, such as limited water availability amidst competing demands from water users, that are made even more challenging when combined with population growth, climate variability, and regulatory requirements within an expanded spatial and temporal scale of management (e.g. water management adopting a long-term perspective on basin-wide issues) (Simonovic 2000). Technological advancements may help to encourage a greater level of data transparency between co-riparians, with a future goal of achieving hydro-harmonisation—or seamless hydrologic data on shared waters. Hydro-harmonisation will improve understanding and management through consistent data available to all shared water parties and the public, increasing transparency and awareness. The USA and Canada, for example, are working to create hydro-harmonisation across the shared basins along the US-Canadian border (IJC 2014; Laitta 2010). This trend towards technological advancements and adaptation of these technologies within management and negotiation may allow for future robustness and flexibility in shared waters management, while presenting an equalising effect with respect to power differentials due to data access.

7.5 Information Availability and Control

In addition to trends in water technologies, advancements in information and communication technologies (ICT) exponentially expand our ability to generate, store and share data and information with tools that will continue to be cheaper, faster and easier to use. Data become information when they are processed and organised in a way that allows individuals or groups to draw conclusions (Ehrlich et al. 1999; Timmerman et al. 2000). While improvements in data and information production advance the technical capacity of various stakeholders to make optimal decisions about complex water resource problems, issues surrounding data and information production, control of information, and digital security threats will present increasing challenges to shared water management.

Despite our improved technical understanding about water resources, our ability to manage shared water has not improved proportionately (Sumer 2014). This discrepancy relates to meeting often-competing water use demands associated with sustaining basic human life, food production, and environmental and industrial needs across sociopolitical divides. Further, different water user groups may not hold the same values guiding decision-making, such as prioritising water uses or temporal scale of management. As such, shared water resources management will continue to be confronted by complex problems, which can be described as 'ill-defined, ambiguous, and often associated with strong moral, political, and professional values and issues' (Islam and Repella 2015, p. 4). Complex water problems cannot be managed solely through scientific and engineering approaches, which offer solutions in isolation of the sociopolitical environments through which water resources flow.

To address complex water problems, critical questions rather than technology must drive the inherently subjective information production process, including deciding how to frame problems, what data to collect, how and when to collect it, how to analyse and interpret it, and how to present it. If the guiding questions do not encompass the complexity of the intersecting social-environmental systems, the information produced will not inform integrated and sustainable water management practices. The questions that are asked or left unasked may have far-reaching consequences on decision-making. For example, if only certain marginalised communities are situated on flood-prone land and questions refer only to wealthier, higher elevation communities, it is unlikely that water managers will reach equitable decisions. Additionally, perceptions of biased decision-making may undermine trust across sociopolitical divides, further weakening cooperative processes and peace.

An inclusive and transparent information production process driven by critical questions can lead to superior information, improved decision-making, and enhanced trust and cooperation. Including all water user groups at all stages of the process may provide a foundation for high-quality information that is trusted and relevant (Sumer 2014). This approach may also facilitate the generation of win-win solutions and promote trust-building across divides. Moving towards this ideal, there is a rising trend towards data and information sharing in all geographic regions of the world, including communication and notification systems; more than 40–50% of all current international transboundary water agreements have a mechanism for data exchange or information sharing (Giordano et al. 2013; Gerlack et al. 2011). Additionally, an increasing amount of both raw data and processed information on water quantity and quality are open to the public (Bruch 2005), which promotes the inclusion of non-state actors in shared waters decision-making processes. Shared water managers may build upon these trust-building mechanisms by innovating increasingly participative, real-time means for engagement and dialogue.

Despite research indicating that data and information are being shared with increasing frequency, water managers often conceal salient facts and findings from the cooperative process. Data control may be both a signal and a source of low trust and cooperation in a shared water system. Co-riparians with a history of mistrust or lack of cooperation may not embrace total data or information sharing (Sumer 2014). Often, the regional hydro-hegemon has greater access to data than is shared, as seen in the Ganges River basin where India uses data sharing as proof of cooperation, but Bangladesh's perceived lack of access to data has forced the state to push for further water data sharing (Zeitoun and Mirumachi 2008). States or water user groups that have control over data and information have greater control over decision-making processes, which appeals to hydro-hegemons or water user groups that benefit from an asymmetrical balance of power. In cases where data control or manipulation is detected by co-riparians or competing water user groups, it may further erode trust and willingness to cooperate over shared waters and potentially lead to heightened political tension or conflict.

Paradoxically, trends in ICT create tools for state and non-state actors to both engage with diverse water user groups and also maintain total or partial control of data and information. For example, encryption technologies enable individuals or groups to store and transmit data and information securely with algorithms that block unauthorised third-party access. For shared waters management, encryption tools provide pathways to engage selectively—or not at all—with co-riparians and water user groups. At times, this data and information control leads to degraded cooperation, but simultaneously, digital securities are becoming critical to the functioning and security of shared water management.

Management and operation of water infrastructure, such as dams or water treatment facilities, are moving towards automation and remote control through online systems that aim to increase management efficiency and precision. To combat the digital risks associated with online systems, network control systems increasingly use at least some form of digital security, such as two-step verification and firewalls. However, digital security is never absolute, because it depends on all authorised parties invariably adhering to strong security practices. Additionally, off-the-shelf or standardised management and security systems are cheap and easy to use, especially when paired with simple and unchanging passwords, but they are less effective at protecting systems from digital threats. If a single employee of a water management system uses an insecure password or falls victim to a phishing scam, an entire system may be exposed to risk from a malicious third party. Running in parallel with developments in encryption technologies are advancements in decryption and hacking, which enables third parties to covertly access, view, steal, and even alter or corrupt digital data and information.

Insecure or compromised digital systems expose water infrastructure to emerging digital-physical threats conducted by state actors, organised criminal groups, and even individuals. These threats include digital dismantling or unauthorised control of infrastructure, which could have profound impacts on water quantity and quality. For example, in a recently publicised case, Iranian nationals working for Iran’s Revolutionary Guard Corps hacked into the Supervisory Control and Data Acquisition (SCADA) system of the Bowman Avenue Dam in Rye Brook, New York, in August and September of 2013. During the breach, they obtained information about water levels and temperature, and had the system not been offline at the time of access, the hackers could have gained access to the dam control system (Berger 2016). In another case, a former employee hacked into the SCADA system of Maroochy Water Services in Queensland, Australia, for three months in 2000 and released millions of gallons of raw sewage into the local rivers, parks and property, causing vast environmental damage (Gleick 2006; Smith 2001). Other means of disrupting or damaging water infrastructure include distributed denial of service (DDoS) attacks, ransomware, malicious software or viruses, or data erasure or manipulation. As the full range of adversaries expose more shared water system insecurities in the future and these events become publicised, interest and financial investment in mitigating digital vulnerabilities will grow even further. In 2030 and beyond, it is likely that shared water management will invest in more advanced digital security tools and practices, as well as full-time digital security professionals. While these measures can be costly and cumbersome, they provide a foundation for water managers to protect the water resources they oversee, the populations they serve, and the sovereignty of their management.

It is clear that co-riparians tending towards transparency and inclusion in the information production process will be much better poised to avoid political tensions. At the same time, shared water systems that employ robust digital security systems and practices will be less at risk for digital-physical threats. The tension between openness and security does not lead to simple solutions, and debates surrounding these issues will likely intensify in shared water systems with an asymmetric power balance or characterised by political instability.

7.6 Trends in Understanding Shared Water

Megatrends such as climate change, new technologies, and information availability and control will require us to reshape our vision of shared waters in 2030 and beyond. These megatrends present opportunities, challenges and uncertainties for shared water management. Further complicating our view, these megatrends are experienced in concert, which can produce unpredictable consequences. Additionally, the future will bring unforeseen global challenges and opportunities. While it is impossible to know precisely how shared water will look in the future, it is clear that shared waters management must acknowledge and grow alongside these megatrends. As a potential way to grow and bolster institutional capacity to adapt to changes, future management should acknowledge several shifts in understanding shared waters: (1) expanding how we conceptualise shared waters; (2) addressing inequities embedded within shared waters management; and (3) broadening the view of shared water actors. These shifts will strengthen shared water management's ability to generate creative and sustainable management strategies that respond to both short- and long-term challenges.

(1) **Expanding View of Shared Waters**: An expanded view of water as a flexible resource can increase water security (Islam and Susskind 2013), such as through new technologies creating alternative sources of supply. Furthermore, the economic capacity of states and shared water users can buffer the impact of water scarcity and prevent conflict over scarce water resources. For example, states that import water-intensive products such as grains are able to save water locally and use it to meet other water demands (Allan 2003, 2011), which can reduce pressure on shared water systems. There is direct evidence that virtual water trade of water intensive commodities, like grains, reduces water scarcity (Bhaduri 2016) and presents an alternative to competition and conflict over

shared waters. However, trade in most commodities is not determined by a comparative advantage in virtual water. The connection between virtual water trade and a reduction in water scarcity is also dependent on many other factors (Ansink 2010), meaning that trade in many commodities is not influenced solely by the amount of water available and therefore trade in some commodities may have limited ability to reduce water scarcity.

Given the capacity to trade virtual water globally, definitions of shared water as a watershed or groundwater aquifer that is intersected by an international or subnational boundary present a limited view of shared water potential. Basins may trade products with other basins and engage in a form of economic inter-basin water transfer. Therefore, trade and trade policy can influence water security in physically and economically shared waters, and water negotiations could discuss trade policy as part of a shared water agreement. Through trade, the import of commodities can obscure a water deficit that would otherwise be apparent if a national or local economy's water supply was required to produce all demanded foods and products. In addition to including economically shared waters, shared water understanding should include integrated groundwater and surface water systems to improve policy and decision-making that influence shared ground- and surface-water systems. An expanded view of the definition of shared waters potentially creates new solutions and creative opportunities within negotiations to reduce conflict and increase water security.

(2) **Addressing Inequities Embedded within Management**: Inequities may be embedded within potential solutions to shared water issues, and these inequities may exist at the international level between countries with differing financial or political power and also at the subnational level between communities, households, and individuals. If not addressed, an inequitable distribution of benefits and risks may lead to even greater inequity and degraded water security for marginalised states, groups, or individuals.

While the world is increasing its economic capacity as a whole, the lower economic capacity of certain states and water users can result in economic water scarcity. For example, Nepal experiences water scarcity because of its limited economy despite possessing ample physical water resources to meet its needs. While trade policies may offer potential solutions to water scarcity, they can also create a water deficit. Policies that create an economic comparative advantage in primary commodities in low-income countries will dictate the export of products that could be water intensive. For example, asparagus exported from Peru's Ica Valley to satiate demand in Western markets is rapidly depleting the region's groundwater resources and impacting the local people (Lawrence 2010; James 2015). These policies could create a cycle of exportation of high-value crops at the expense of local populations who may no longer be able to afford purchasing locally produced commodities with high nutritional content; further, these policies could work in favour of large agribusiness, reducing water resource access or availability to locally owned small businesses or local populations. Trade policies must consider their externalities on water security and inequitable social impacts.

Prioritising one state or water user at the expense of another will ultimately undermine the long-term security of an entire shared water system. Therefore, shared water management must address the structural violence underpinning the inequitable distribution of water in a shared system. While current and future advancements in new technologies provide a means to advance water security, the effect will be limited without a decrease in structural violence and inequity. Inequity with respect to water resources may be experienced at a state level (e.g. downstream or lower income countries), communal level (e.g. an indigenous or marginalised community), household level (e.g. socioeconomic or caste differences within a community), or even a sub-household level (e.g. societies where women, youth, or those with handicaps occupy a lower social status). Structural change is a difficult, long-term, and contextual process that must be driven by the involved parties. While social, political, and economic structures can be ingrained, they are recreated generationally and have latent capacity for positive change. The Majority World is generally well acquainted with calls to improve levels of equity and human development; however, high-income, developed countries are not exempt from this imperative to promote positive change towards more equitable management of shared waters at various scales.

(3) **Broadening Array of Actors**: The inherent connection between shared waters and other sectors will increase the number of actors that influence shared water management. These actors will include an increasing array of non-state actors at the subnational and international levels (e.g. local and international civil society organisations), international or multinational organisations (e.g. the World Bank or the United Nations), donor states and multinational corporations. Further, current trends in water research acknowledge that actors are not isolated within their sectors but are interrelated; for example, the water-food-energy nexus includes actors within the agricultural and energy sectors. In addition, non-traditionally water-related businesses and the financial industry are becoming actors due to the potential water-related risks to their business or investment. This broadening range of actors and sectors will potentially steer water management away from traditional approaches overseen by water resource experts towards more inclusive management within the greater sociopolitical environment (Zeitoun et al. 2013).

Engaging with a diffuse group of actors will result in opportunities and challenges. Participation of relevant actors in shared water management creates a sense of shared ownership and investment with the goal of generating creative options and alternatives in the face of conflict within the basin (Delli Priscoli and Wolf 2009). For example, water security and political stability may increase in basins that engage meaningfully and transparently with local citizens, consider best practices and technical assistance from international organisations, receive financial support from multinational organisations and/or donor countries, and initiate public-private partnerships. Further, cross-sectoral actors may be able to provide novel perspectives and alternatives not previously available within the basin. However, the inclusion of multiple third-party actors may invite a diffusion of new interests, including military, security, and economic objectives of non-riparian states or non-shared water users; these interests have the potential to be prominently represented or even prioritised in shared water negotiations. While shared waters management should aim to reflect this widening array of actors, they must also engage critically with local and global knowledge and perceptions to develop equitable management strategies.

Broadening these 'baskets of benefits' also allows for parties to pursue a path of enlightened self-interest where conversations on water alone may not have led. As we are seeing in South and Southeast Asia, for example, hydro-power generated electricity can cross borders readily, tying together countries that generate with growing markets of electricity users abroad. As issues on the table expand to include data-sharing, ecosystem protection, transportation, and flood management, networks of interests can broaden and strengthen across boundaries, as has been the case, for example, recently in the Ganges-Brahmaputra River Basin (Price and Mittra 2016). Similarly, governance in the Mekong River Basin expanded over the years, as the Mekong River Committee became the Mekong River Commission (MRC), to include the previously excluded Cambodia, but still only incorporating the four lower riparians. As dialogue became possible on more issues, the MRC was augmented first by the Greater Mekong Subregion, a development project of the Asian Development Bank that included all six riparians, and more recently by the Lancang-Mekong Cooperation Mechanism, a China-led approach working in parallel with its Bangladesh-China-India-Myanmar (BCIM) initiative, further cementing ties across South and Southeast Asia (Cronin and Weatherby 2014; Singh 2016).

7.7 Conclusions

Overall, shared water systems are experiencing both steady and punctuated change, and they will continue to do so looking towards 2030 and beyond. While change in shared waters has occurred throughout history, the magnitude and distribution of change—which is not limited to climate change—coupled with population growth, economic development, and other stressors, is increasingly placing pressure on surface and groundwater quantity and quality. Conflict over shared waters will likely change in 2030 and beyond; for example, quality will likely be a bigger issue than the available quantity of water. Subnational conflict driven by such issues as poverty, inequality and political instability is increasing, which may have direct and/or indirect influence on shared waters. Future research will need to more extensively consider subnational, transnational, and diffuse forms of conflict, despite the current emphasis on international conflict between state actors.

Cooperation over shared waters will also likely change in 2030 and beyond; for example, cooperation may extend towards the subnational direction, with citizen and non-state actor engagement, and also in the global direction, with the inclusion of multilateral and non-riparian state actors. Cooperation is not restricted by our definition of physically or economically shared waters. This opens the lens of what constitutes shared waters, as well as potential solutions to promote cooperation and mitigate conflict.

The root of water conflict and cooperation within shared water systems is dependent on the rate of change in institutions or within the physical river or groundwater system and the region's institutional capacity to adapt to these changes. Institutions provide formal and informal rules as well as structure to the interactions between shared water users, organisations, economic sectors, and other actors (Ostrom 2010). Past approaches to shared water management have focused on technocratic, supply-side solutions that limit institutional, particularly infrastructural, capacity to be flexible. Future shared water institutions will need to develop mechanisms to adapt to change and mitigate the impacts of these changes on their complex hydrological sociopolitical environments.

Adaptive institutions need to have the flexibility to adapt to rapid change and allow for non-stationary decision-making, while also provide stability in the long term. One key component of flexibility is the presence and quality of a water management body, such as a river basin organisation or groundwater management organisation. With respect to international waters, the number of river basin organisations has been increasing. There has been growing international support for their development, such as the World Bank's support for the creation of an international shared waters institution within Afghanistan (Malyar 2016). Further, the management body or agreement could contain mechanisms for clear water allocation, variability management, and conflict resolution (De Stefano et al. 2010b). Shared waters management must create long-term management plans that allow for uncertainty, for example, by building flexible infrastructure to endure a range of potential conditions.

The development of future technologies provides another potential means for adaptive management. For example, higher spatial and temporal resolution data generated in real time could allow for decision-making based on current conditions rather than historical averages. Technical information is often perceived as neutral and could play a role in supporting legitimacy and acceptability of solutions within shared water management (Nandalal and Simonovic 2003); however, technology is not a panacea, as it can promote a technocratic or Western perspective that overlooks or delegitimises local concerns and viewpoints that do not align.

Management that can adapt to current and future challenges will be better equipped to reduce vulnerability and address uncertainty in shared water systems within their sociopolitical environments. There will be many similarities between the shared waters of today and the future; there will also be different and potentially more complex challenges. Moving towards more flexible and adaptive management is a technically, financially, and politically challenging process, but it far outweighs the alternative. Future-oriented management that seeks to anticipate or respond rather than react to changes will likely result in more politically and physically stable shared water systems. Megatrends—climate change, new technologies and information availability and control—combined with shifts in understanding of shared waters may present opportunities to develop adaptive institutional capacity in pursuit of water security and enhanced cooperation between shared water users.

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