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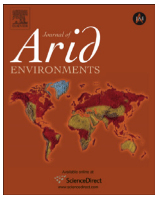

A tale of two rivers: Pathways for improving water management in the Jordan and Colorado River basins

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ABSTRACT

This paper considers two river systems that have been subject to significant development during the last 60 years: the Jordan River in the Middle East and the Colorado River in the western United States. Both play major roles in serving the demands of growing populations, and climate change models predict both semi-arid to arid regions to become hotter and/or drier in the future. The Jordan River basin, shared by five nations, is already experiencing a critical level of environmental damage. Its lower stretch is practically a sewage canal with less than 10% of its natural base-flow. Due to its unique historical, religious and environmental role, restoration efforts have gained momentum and wide public support. In the Colorado River Basin, water law is characterized by the "Law of the River" and water use is managed through regional allocation constraints. The Colorado River, shared by seven U.S. states and Mexico, is highly managed and over-allocated. Shortage declarations have serious implications for low priority users, with the Central Arizona Project being among the lowest. This makes large population centers and agricultural users vulnerable to curtailment of deliveries. We argue that there are common factors with respect to the policy and management options of these two basins that may provide insights into the similarities and divergences of their respective future pathways. These factors are: regional water supply and demand pressures, water governance, transboundary issues and demand for environmental flows. With a particular focus on the Israel and Arizona portions of these respective river basins, we address synergies and tradeoffs between groundwater and surface water usage, sectoral allocation strategies, public vs. private water ownership and legality, transboundary sharing, technical options for addressing growing regional water scarcity, and economic considerations. Difficult and bold decisions are required in both regions.

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1. Introduction

Historically, human civilization has been largely riparian. People have relied on rivers for drinking water, food, cleaning, waste removal and decomposition, transportation, commerce, power generation and recreation. Humans have been altering and regulating natural rivers' flows to meet these needs. As population and climate-related pressures continue to rise in watersheds across the globe, there is increasing recognition that the traditional exploitative management approaches must be revised (Medema et al., 2008). Climate change increases water scarcity in some parts of the world, decreasing the amount of precipitation, while increasing its temporal and spatial variability and intensity, thus directly affecting the timing and magnitude of river flows and groundwater recharge (Giorgi and Lionello, 2008; Vörösmarty et al., 2000). The combination of long periods of drought, interspersed with massive abrupt rainfall, has a negative impact on ecosystems. These climate-related shocks to water budgets are especially serious in arid regions (Arnell, 2004; Goyal, 2004; Iglesias et al., 2007; Palmer et al., 2008).

This is true for two of the most stressed river systems in the world – the Jordan River (JR) in the Middle East and the Colorado River (CR) in the western United States (U.S.). The commonalities of

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the water challenges of these two waterways are well recognized (Farber et al., 2004; Megdal et al., 2013). Both over-allocated and stressed river systems play major roles in serving the demands of growing populations through diversions, dams and other constructed projects. Climate change models predict both semi-arid to arid regions to become hotter and/or drier in the future (Abdulla et al., 2009; Garfin, 2013; Givati and Rosenfeld, 2004, 2007). In addition, both river systems have been subject to significant development during the last 60 years, and as a result, are associated with increased demand factors pushing for more water uses (Givati and Rosenfeld, 2004, 2007; USBR, 2012a). Both rivers exhibit sharp rises in water salt content due to a combination of upstream diversions and over-allocations for intensive irrigation, producing saline agricultural return flows (Farber et al., 2004; Gates et al., 2002).

A recent comprehensive three-year study by the U.S. Bureau of Reclamation projects wide gaps between water supply and demand in the U.S. portion of the vast CR Basin (USBR, 2012a). This report is cited by *American Rivers* in its annual report card on U.S. Rivers, wherein the CR was declared to be America's most endangered river (AmericanRivers, 2013). Recently called “one of the most endangered rivers on the *planet* [emphasis added]” (Abdelrahman and Jägerskog, 2013), the JR has gone through massive exploitation of its limited water resources in the last half century, affecting not only the riparian corridor of the river itself but also the health of the Dead Sea (Abu Ghazleh et al., 2009; Farber et al., 2005; Holtzman et al., 2005; Shaham, 2007; Venot et al., 2008). The cooperation of multiple governments will be needed in order to mitigate the results associated with a history of diversion and pollution of the lower portion of this river (Abdelrahman and Jägerskog, 2013; Orthofer et al., 2001).

This paper compares the management and future pathways of these two river systems, with the focus on the Israeli and Arizona-based sub-basins. Both exogenous and endogenous factors make the comparison between these two basins an interesting one. Specifically, cross border cooperation (or conflict) with other entities, growing demand including both conventional and emerging demands such as water for nature, and regulatory issues impacting water allocation are high on the policy agenda of both basins (Eden et al., 2011; Farber et al., 2004; Megdal et al., 2013). Though facing similar challenges drawn from comparable climates, human use trends, and legacies of transboundary conflict, the management and institutional contexts within these two sub-basins differ markedly. Thus, a comparison of the two provides the opportunity to explore the political, social and environmental factors that form water policy approaches in general, and, in particular, trace the horizon of possible long-term outcomes in each sub-basin.

We argue that the policy in both river basins can be conceptualized as being driven by similar forces, which are also present in many other river basins across the globe (Wolf et al., 2003). We then consider the possible options or pathways for improving water management in these two river systems, with the focus being on the lower portion of the JR shared by Israel, the Palestinian Authority (PA) and Jordan and the semi-arid portion of the Lower CR Basin located within Arizona. These forces are delineated in each basin within the local political, environmental, and management contexts in order to draw out lessons from each unique basin.

The paper continues as follows: Section 2 provides background information regarding the two study areas' natural water resources, water demands and allocations to neighboring users. Section 3 discusses the key driving forces that influence these basins' water policy. Section 4 compares the different driving forces and their impacts on Israel and Arizona. Section 5 offers suggestions for feasible pathways that would improve water management. Finally, section 6 summarizes and concludes the paper.

2. The study areas

2.1. The Lower Jordan River

The Middle East is an arid area. Along with North Africa, it is the most water challenged region in the world (Roudi-Fahimi et al., 2002). While being home to 6.4% of the world's population, it holds only 1.4% of the world's renewable fresh water reserves. With a population growth of around 2% per year, demand for water is increasing in all sectors of the economy: agricultural, industrial and domestic. In Jordan, where regional scarcity is most acute, the average amount of renewable fresh water supply per capita per year is less than 250 cubic meters (Roudi-Fahimi et al., 2002).

The JR is shared among the nations of Israel, Jordan, Syria, Lebanon and the PA (Fig. 1). Its lower portion, the Lower Jordan River (LJR), constitutes the border between the Hashemite Kingdom of Jordan (to the east) and Israel and the PA (to the west). Access to the river is limited due to imposed military restrictions on both sides. Annual precipitation in the Jordan River Basin (JRB) varies from 1200 mm in the north (Mount Hermon, including snow) to 250 mm south of the Sea of Galilee (SOG), further diminishing to around 100 mm near the Dead Sea, and averaging less than 200 mm along the JR's (Klein, 2005; Lowi, 1993). Therefore, the basin is characterized as semi-arid to arid.

The LJR extends for a distance of 105 km from the SOG in the north to the Dead Sea in the south. Its total length, due to meandering, is almost double (Farber et al., 2007). The LJR flowed freely for thousands of years and, until fifty years ago, carried 1300 million cubic meters (MCM) of fresh water annually to the Dead Sea (Farber et al., 2005). The Jordan Valley is a lush wetland ecosystem that is the biological heart of the region at large. In addition to the flora and fauna along the ground, the valley is one of the world's most important crossroads for migratory birds: 500 million birds migrate each spring and autumn, an attraction to birdwatchers from across the globe (Becker et al., 2012). The LJR is unique not only in its natural assets but also in its cultural wealth. This river is significant to billions of people from diverse religions and countries worldwide.

Though still unique in its natural and cultural wealth, the “mighty Jordan” has been reduced to a trickle south of the SOG and devastated by over-exploitation, pollution, and a lack of regional management (Farber et al., 2005; Shaham, 2007). Large-scale water diversions by Israel, Jordan, and Syria have resulted in a severe decline in water inputs (Hassan and Klein, 2002; Holtzman et al., 2005; Klein, 1985; Venot et al., 2008). Much of the water flows are effluents, agricultural runoff and drainage of poor water quality (Farber et al., 2004). Furthermore, Israeli diversion of saline springs to the LJR, while improving water quality in the SOG, has led to a large increase in the LJR's salinity: average chloride levels are between 1300 and 2500 mg L^{-1} (Chen, 2011; Farber et al., 2004, 2005), compared to an average limit of 230 mg L^{-1} set for stream ambient water quality by the U.S. Environmental Protection Agency (EPA, 1988). The frequency and magnitude of flood and high flow events have been reduced by an order of magnitude from an average of two floods per season (December–April) to merely one flood in five years. High flow pulse frequency has been reduced from an average of 6.5 pulses per season to less than one pulse per season. Currently, the only source of water at the beginning of the LJR is effluent, which flows at a relatively constant rate of 23 MCM/y, from the Saline Water Carrier and Bitania wastewater treatment plants. This is less than 4% of the SOG's historical mean annual runoff to the LJR. Without these effluent flows, the LJR would be completely dry (Chen, 2011).

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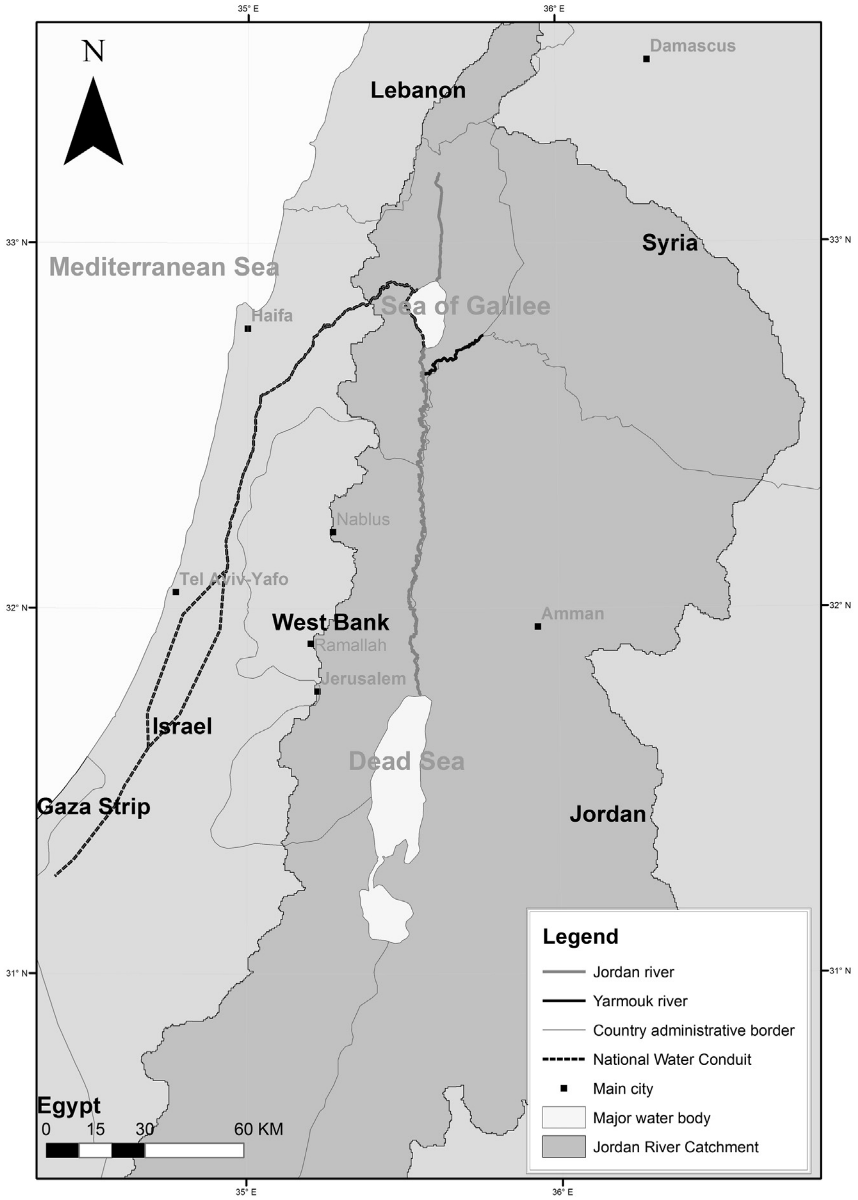

Fig. 1. The Jordan River basin.

The decline in the quantity and quality of the river's waters has imposed a huge toll on the ecology of the LJR and the Dead Sea, which suffers as a direct consequence of the low water flow in the LJR. The low flows have reduced the potential for visitors to enjoy the river and its surroundings, a situation exacerbated by the status of much of the area as a closed military territory with limited access.

2.2. The Colorado River Basin

The vast CR watershed extends across seven U.S. States and into northwestern Mexico (Fig. 2). Via conveyance systems, water from the CR serves heavily populated and growing areas outside the basin boundaries, such as Southern California and Denver, Colorado. Historical estimates of the river's base flow are close to 18,500 MCM yr^{-1} (MacDonald, 2010). However, this average, which served as the basis for the river's contested regional allocations, was found to be optimistic, since it relied on historical flows based on records during what is now recognized as a wet period in the early 20th period. This overestimation has resulted in an over-allocated river system facing additional climate-related pressures.

In the arid American Southwest as a whole, 76% of all stream flow is used for agricultural, domestic or other purposes (Sabo et al., 2010). The Lower Colorado River (LCR) basin was first officially defined in The Colorado River Compact of 1922, which divided water among the seven basin states (Pearce, 2007). The Upper Basin states (Wyoming, Colorado, Utah and New Mexico) were allocated the same amount as the Lower Basin (Arizona, Nevada and California): 9250 MCM annually. Mexico was given a share of the river as well, though its volume was less clearly articulated. It was not until 1944, when a treaty ratified under the International Boundary and Water Commission, that Mexico was officially granted 1850 MCM annually. Roughly 90 percent of agricultural land in the CR basin is irrigated, and 70 percent of the river's entire water supply is used for irrigation. The irrigation sector in the LCR consumes about three times more water than in the upper basin, and on-field

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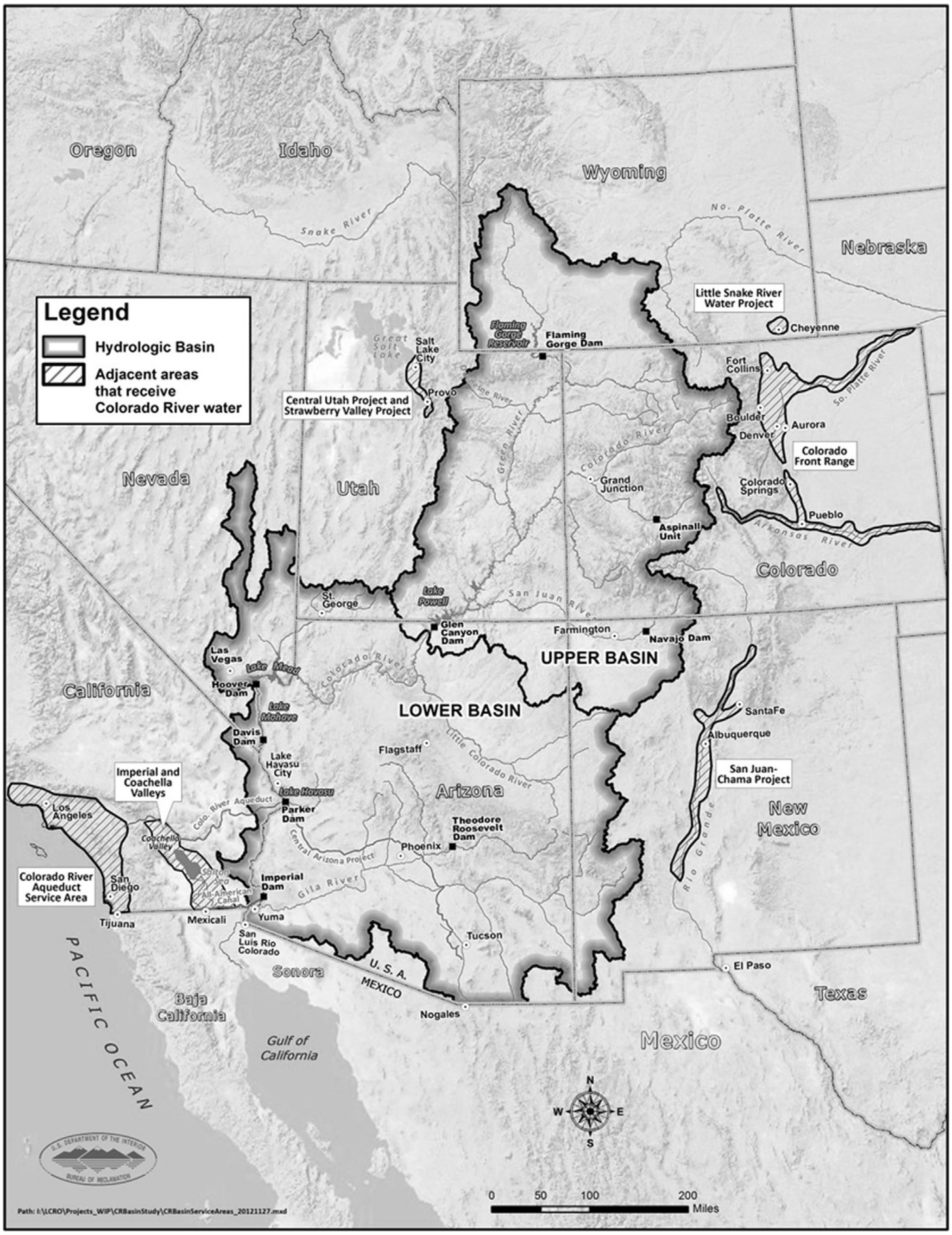

Fig. 2. The US portion of the Colorado River Basin (Source: (USBR, 2012a)).

applications are roughly four times higher due to differences in climate, crop choices and water availability. Domestic water demand, driven by the growing urban populations of three of the largest ten American cities (Los Angeles, San Diego and Phoenix), is increasing (Cohen et al., 2013).

As can be seen in Fig. 2, most of Arizona lies within the CRB, with the demarcation between the Upper and Lower Basins running through the upper right hand corner of the state. Although technically in both basins, Arizona identifies itself as a Lower Basin state. Fig. 2 also shows the Central Arizona Project (CAP), a 540 km long open lined canal, winding its way from the CR through Phoenix and then south to Tucson, built to deliver 1850 MCM of CR water annually into the heavily populated portions of Arizona, home to about 80 percent of the state's approximately 6.5 million residents. In Arizona, the agricultural sector's share of total water demand (70 percent) mirrors that of the basin (Megdal et al., 2009). Its municipal sector is growing rapidly. Much of that growth is located in the part of the state served by the CAP.

The CR flows through the Grand Canyon and onward toward the northwestern edge of Arizona, where the Hoover Dam then forms Lake Mead. Downstream of the Hoover Dam, the CR forms the western boundary of Arizona. Arizona, like the other Lower Basin States, has been fully utilizing its allocation of CR water, although some of it has been banked as groundwater for future use. Finally, the CR reaches Morelos Dam, the last dam along the river's 2330 km stretch, which serves as the delivery and diversion point for CR

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flows to Mexico. Most of Mexico's CR water allocation is used in the Mexicali Valley. River flows downstream of Mexicali's agricultural use are typically agricultural return flows. Increased water use over time, coupled with drought and low-flow conditions, has reduced water flows to the CR Delta in the Gulf of California.

3. Driving forces as explanatory variables to policy outcomes

We base the following section on the concept of "Integrated Water Resources Management" (Medema et al., 2008). This, in turn, is based on the theory of Economic Policy (Tinbergen, 1952). The theory posits that policy outcomes depend on external factors, constraints, policy instruments and targets, with each defined below:

- External factors: a set of externally defined elements faced by policymakers that lie outside their control.
- Constraints: a set of restrictions on policy choices that must be respected for any policy to be acceptable.
- Policy instruments: a set of quantities/prices/regulations that can be controlled by a policy maker for which the path over time represents alternative courses of action taken over that period.
- Targets: aims that can be represented by an explicit objective. Evaluation of outcomes using that objective permits a ranking of alternative combinations of policy instruments implemented over a time period.

We interpret policy instruments as tools to produce outcomes which can be characterized as responses to several driving forces as shown in Fig. 3. The driving forces are the external factors and constraints. The instruments are chosen in order to maximize some target function. In this paper, we focus on what we consider a key set of driving forces of water management decision-making, that result in respective policy instruments and targets (GWP, 2004). We elaborate on each of the elements below.

3.1. Driving forces

The following driving forces can be conceptualized as shaping policy outcomes:

1) *Water demand/supply gap*: This gap may be temporally and/or spatially dynamic, growing or lessening over time or at various locations within a watershed. Population increase, climate change, water use by different sectors, and water efficiency have impacts on supply and/or demand and, therefore, on the gap between them. Furthermore, the marginal cost of water tends to increase with water supplied, as growing demand necessitates greater reliance on marginal supplies that require higher treatment and/or delivery costs. This trend is especially acute in semi-arid or arid watersheds, where water scarcity drives up marginal water costs.
2) *Water governance*: Who owns, distributes, and pays for the water? What is the overarching regulatory framework and water law? The criteria by which water is allocated and the operation of water resources systems, as well as other factors, define the governance framework (Varady et al., 2013).
3) *Transboundary issues*: Is the entity (state or nation) an upstream or downstream user? Is the resource defined by unidirectional or common property? Are there other agreements between the multiple entities sharing the resource and, finally, in the case of international watersheds, is there a peace agreement or treaty between countries in the basin? These factors are further dependent on each basin entity's unique location within the management and physical landscapes of the basin.

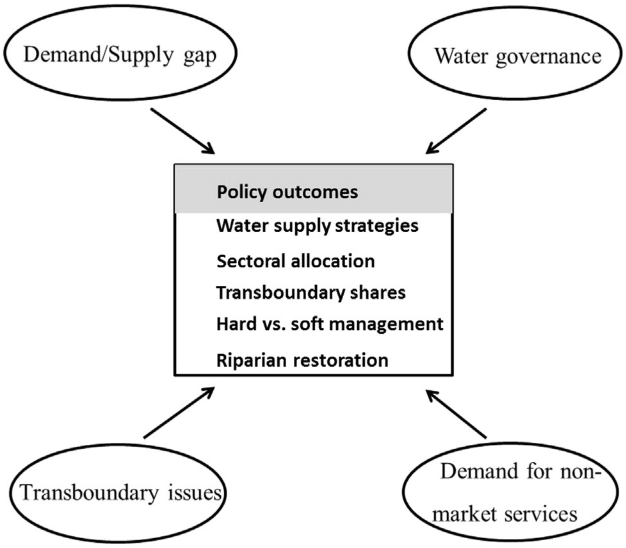

Fig. 3. Driving forces and their qualitative impact on policy outcomes.

4) *Demand for environmental and other non-market services*[1]: Here the focus is on the value of intangible, non-market goods. Unlike the demand for water from traditional sectors, which deals with values established through market-like forces, environmental services are given no clear market price. Usually, the value associated with in-stream flow varies by the quality and quantity of flow, and the presence or absence of unique species, habitat or recreation sites. The market price equivalents of these benefits are commonly elicited by various non-market valuation techniques (Abramson et al., 2010).

These four key driving forces shape the policy toward water in the basin; change in any of these forces results in new policy outcomes.[2] We identify the five general policy outcomes as follows.

3.2. Policy outcomes

1) *Water supply strategies*: Surface water is often more accessible, but less resilient to short and long-term climate change or drought. Groundwater resources also operate as a buffer and, as such, can act as a form of insurance in dry years. Both surface water and groundwater support and are impacted by economic activities, such as agriculture. Changes in any one of the driving forces, but especially the demand-supply gap and demand for environmental services, can drive changes in the relative allocation and/or utilization of these sources.
2) *Sectoral allocation*: Changes in preferences, both public and private, have a potential to alter the allocations among the different sectors. We consider here only market sectors: domestic, industrial and agricultural, and leave aside in-stream river flows as a separate category. Political agreements may act as constraints by allocating a portion of the water to another entity. Similarly, governance plays an important parallel role to

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[1] We define demand for environmental services as a social construct, rather than a physical value. Although quantifiable water parameters align with various levels of riparian restoration, demand for these riparian states are socially, rather than physically, derived. We have separated this non-market demand from other traditional sectors because of its uniqueness.

[2] The magnitude of influence on policy outcomes is largely determined by the flexibility of current policy. Flexible policy can respond to changes endogenously, whereas inflexible management may create inefficient allocations.

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market forces in determining allocations: subsidies for agricultural water and volume-based allocations for environmental uses are common examples. Finally, changes in the rights to use water resources may impact the way water is used among the different sectors.

3) *Transboundary water sharing arrangements*: Water sharing between any two entities is a function of the location of each water user relative to the other (upstream or downstream), demand for water in the different sectors and the overall legal and political atmosphere between them. Thus, any change in these driving forces has the potential to affect water sharing arrangements.
4) *Hard- vs. soft-path management*: Since Gleick coined the term "soft-path" solutions for water management, the role of less engineered or technological options for bridging water supply-demand gaps has been emerging as not only viable, but economically and socially attractive. These include low-tech interventions, such as promoting household water savings, demand management through institutional mechanisms, including water pricing, water rationing, and trade in water rights. The hard-path approach is characterized by more conventional investments in massive engineering efforts, such as constructing dams, desalination, wastewater treatment, and water storage (Gleick, 2002, 2003). Undoubtedly, successful management of water resources requires a mixture of both approaches, with the exact composition depending on economic and political considerations. Thus, any changes in the four driving forces may impact the way policy makers choose to tackle the problem.
5) *Riparian restoration*: The level of riparian restoration foreseen for a particular basin will depend on the above driving forces as well as their associated policy outcomes. We point out the importance of water governance to achieving in-stream flows; where high demand/supply gaps drive sectoral allocation decisions within a weak or decentralized water governance structure, in-stream flows may be difficult to ensure even in the face of high public demand for restored waterways. Certainly, greater public awareness and valuation of environmental services may encourage management authorities to protect or, as in Israel, allocate a fixed volume of water for in-stream flow, but the responsiveness of governance to this demand is not always direct and proportional. We also argue that environmental water uses should be considered in the context of all competing uses, and that the cost of in-stream flows approximates the marginal cost of water given current use patterns. We explore these concepts more in the following discussion (Sections 4.4 and 5).

The following section discusses the driving forces and policy options for the Israeli portion of the LJR and the Arizona component of the LCR Basin.

4. Driving forces and their implications

4.1. Regional supply and demand pressures

4.1.1. Lower Jordan River and Israel

The acute level of water stress in the JRB and especially its lower part, the LJR, is a direct consequence of the upstream water uses in Israel, the PA, Jordan and Syria. The LJR is fed almost entirely by its upper section that flows through the SOG and from the Yarmouk River (YR). However, since the water outlet is blocked at the Degania dam in the southern part of the lake, and the YR is blocked by Jordan's King Abdullah Canal (KAC) intake point, the LJR is a totally controlled river. In-stream flows from other streams to the west of the LJR consist of mainly sewage and brackish water.

The upper section of the JR contains only part of Israel's fresh water supply. Israel also draws upon a significant source of groundwater from the Mountain and Coastal Aquifers, which stretch in a north-south direction across the country's center as well as along the PA's West Bank territories. Currently, the total water supply in Israel is estimated at 1392 MCM from all renewable sources (Becker, 2013).

The demand for water in Israel is determined primarily by the agricultural, industrial and domestic sectors. In addition, Israel is responsible for supplying water to both Jordanian and Palestinian populations. Environmental flows, only recently allocated under official water law (including plans to provide additional flows into the LJR), further stress the regional water budget.

The ratio between water consumption to water availability has increased from 1.08 in 1980 to 1.5 in 2010 (Becker, 2013). In order to reduce the gap, Israel's major policy goal has been to pursue the hard-path approach of increasing available supply. This has been done primarily by increasing use of marginal water sources: desalination, wastewater treatment and reclamation, and rainwater harvesting. Fig. 4 presents the current and projected volume of marginal water supply.

As can be seen from Fig. 4, the increase in marginal water supply corresponds to the increase in the supply-demand gap of renewable fresh water. While supply augmentation has relieved part of the water tension in Israel, it has also created a unique possibility to add more water for natural systems and the possibility to solve the water shortage problem in the PA. The increased potential for desalination plants as a backstop technology for water production (currently at less than 60 cents per CM) eliminates the term "physical scarcity" from the water issue.

From the demand side, Israel's water policy has been moving more and more toward cost-based pricing, where all sectors are expected to pay at least the average cost of water consumed. Farmers receive treated wastewater in exchange for freshwater they can no longer afford, while domestic users are paying more for water consumption both because of relying more on marginal water uses (e.g., desalination) and also because the responsibility for delivery and management of urban water systems has been shifting to independent private water companies awarded governmental tenders.

4.1.2. Colorado River and Arizona

Close to 40 million people in the U.S. rely on the CR system to meet at least some portion of their water needs. The CR supplies water to lands producing approximately 15 percent of U.S. crops and supporting 13 percent of U.S. livestock. The CR serves numerous Native American Nations and flows through numerous national parks and other wildlife areas, with perhaps the most famous being the Grand Canyon, in the state of Arizona (USBR, 2012a).

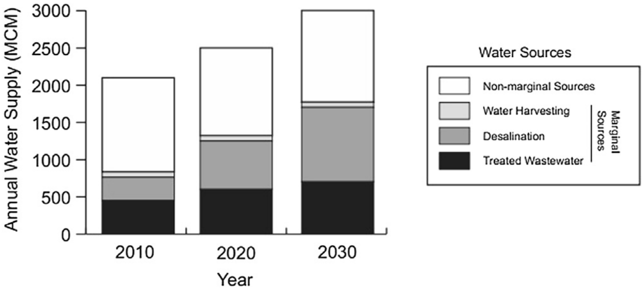

Fig. 4. Current and future marginal water use in Israel.

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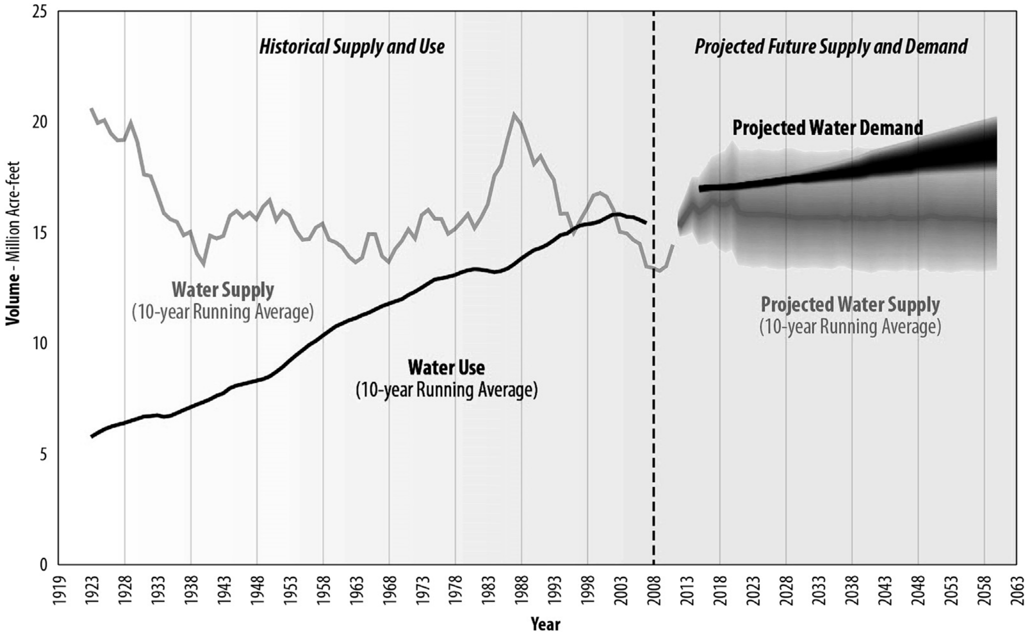

Fig. 5. Historical Colorado River supply and demand and projected future imbalances (source: USBR, 2012a).

As Fig. 2 shows, almost all of Arizona falls within the watershed of the CR and a small part of Arizona is in the Upper Basin. Within the state, important farming regions, municipalities and industries depend in whole or in part on CR water. Data available for 2001 through 2005 show that approximately 70 percent of statewide water diversions or extractions are for agricultural uses, while 24 percent for municipal and 6 percent for industrial. Environmental water needs are not quantified in this data source – an indication of the prevailing perception of in-stream flows as a management afterthought. Approximately 40 percent of these demands were met by groundwater, another 40 percent by CR water, and the remainder by other surface water supplies and recycled treated wastewater (AZWater, 2010).

In order to obtain federal congressional approval of the approximately US$4 billion in funding for the CAP, Arizona had to agree that, in times of declared shortage on the CR, water delivered through the CAP would be cut off prior to the state of California experiencing any reduction in its deliveries, including those to agriculture. While there are water use delivery priorities by type of water use, CAP water is an important water source for most cities in Arizona. These cities are therefore vulnerable to shortage conditions on the Colorado River, although the water delivery curtailments included in the shortage sharing guidelines developed by the U.S. Secretary of the Interior affect lower priority agricultural users first (USSI, 2007). This outcome is reflective of the strong political influence of California in the U.S. Congress. To date, despite drought conditions that have persisted for more than a decade and the fact that the allocations of the CR were based on an unusually wet period of record in the early part of the 20th century, an official shortage has not been declared. This is a direct result of the large storage created by damming the CR to form Lake Powell by Glen Canyon Dam and Lake Mead by Hoover Dam (Fig. 2). However, the latest predictions of the Colorado River Simulation System (CRSS), a surface water model used by the United States Bureau of Reclamation (USBR), indicate a significant chance of shortage conditions in 2016 (44%), 2017 (54%) and 2018 (53%)—in other words, there is an 88% chance of shortage conditions in at least one of the next 5 years (McCann, 2014). The CR waterway is reaching historically low levels.

The 99-page Colorado River Basin Water Supply and Demand Study Summary Report (USBR, 2012a), referred to here as the CRB Study Report, provides a comprehensive overview of the state of the CR system in terms of supply and demand and provides projections for the future gap between water demand and supply for U.S. users of the CR water over the next 60 years. The estimated gap is based on multiple scenarios for river flows and water demands for all sources of water available to the region (USBR, 2012a). Fig. 5 shows the running 10-year average of historical water supply and demand and the projected gap, all in acre feet.[3] While the CR is just one source of water for the region, the imbalance between demand and supply is expected to grow under most of the scenarios analyzed as part of the study. Although a full discussion of the study's methodology is beyond the scope of this paper, the summary of the gap analysis has caught the attention of all. After analyzing multiple demand and supply scenarios the study states: "Although a range of future imbalances is plausible, when comparing the median of water supply projections to the median of the water demand projections, the long-term imbalance in future supply and demand is projected to be about 3.2 Million Acre Feet (MAF) by 2060 (USBR, 2012a)." This 3950 MCM figure compares to the approximate demand on the CR system in 2009 of 18,500 MCM. This quantification of the gap has been termed a "call to action" for the water users in the CRB (Megdal, 2013a). Arizona water users, regulators and suppliers will continue to identify options for closing projected gaps in supply and demand (ADWR, 2011). In addition, Arizona will work collectively with the other basin states on multi-state collaborative opportunities, including those involving Mexico.

4.2. Water governance

4.2.1. Israel

According to Israel's Water Law of 1959, the government has a responsibility to manage the country's water resources for the

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[3] An acre foot of water is 1233.4 cubic meters.

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public good, and to maintain the quality of the sources. As a consequence, water in Israel is not a private property. A potential user may apply for permission (on an annual basis) to use the water. This is done by allotments. Only the domestic sector does not face fixed quantity allotments. Instead, municipal users' demand is “managed” by the pricing established by the government.

With respect to environmental flow, the Streams and Springs Authorities Law of 1965 empowers the state to create an independent Authority to coordinate the oversight of activities to protect a stream or river. This, however, has rarely been done, and no authority has been established for the LJR. An amendment to the Water Law in 2004 officially added nature as a legitimate beneficial use of water, allowing for increased allocations of water for in-stream environmental flow purposes. A maximum allocation of 50 MCM annually is set aside for this purpose.

4.2.2. Colorado River and Arizona

Water management in the U.S. is highly decentralized. Water quantity regulation is largely left to the U.S. states (Megdal, 2012). The federal government sets minimum drinking water standards and establishes water quality regulations for discharges into navigable waters of the U.S., with the compliance monitoring and enforcement largely delegated to the individual states. Water quantity regulation within states is left to state discretion, except when waters cross interstate or international boundaries. Then, the federal government is involved, although the nature of the U.S. government's approach to the management of interstate and international rivers varies. Within U.S. states, authorities can be vested in local jurisdictions, privately owned water companies, or regional water districts.

Regarding the sharing of the CR by the U.S. and Mexico, what is called the 1944 Water Treaty – the “Treaty between the United States of America and Mexico”, along with subsequent modifications to it known as Minutes – governs the international issues related to CR water allocation and quality (US-MEXICO, 1944). What is known as the “Law of the River” determines the nature of interstate allocations, storage and utilization of CR Water. While official and binding, the Law of the River is not a single law but rather a complex body of laws, regulations and court decisions that govern the management of the CR (USBR, 2012a). Although the Secretary of the U.S. Department of the Interior is the official in charge of U.S.-side river matters, the seven U.S. states are consulted with regularly and have substantive input into decisions made about river operations and management. These consultations extend across the border to Mexico on international matters. The management of the CR system is truly seen as a shared responsibility.

The State of Arizona adopted its Groundwater Management Act (GMA) in 1980. The GMA provides the regulatory framework for groundwater use in the most populated areas of the state and areas experiencing significant aquifer overdraft or mining. As in Israel, municipal water use rights and regulations differ from those for the agricultural and municipal sectors. Rules adopted pursuant to the GMA limit the extent to which new municipal developments can rely on mined groundwater. Surface water use is governed largely by the Prior Appropriation doctrine, which prioritizes users on a ‘first come, first serve’ basis (Pearce, 2007). The CAP is governed by a 15-person board of directors, who are elected by the residents of the CAP's three-county service area. Officially a subdivision of the State, the official name of the regional district is the Central Arizona Water Conservation District. Its board is responsible for setting the policies, water rates, and tax levies associated with funding and operating the CAP system, with many decisions tied into the larger water-energy nexus due to high energy costs of pumping CAP water (CAP; Eden et al., 2011).

4.3. Transboundary issues

4.3.1. Lower Jordan River

Shared water resources are increasingly a source of dispute all over the world (Ward, 2003). This is especially true in the water-scarce portions of the Middle East. The struggle over the allocation of the JRB's limited water resources has certainly added to existing political tensions in this region. Some argue that common resources are being used to satisfy Israel's needs at the expense of others, adversely affecting the water quantity and quality available for its neighboring populations. Others point to the augmentative aspect of Israel's water management strategy, including the globe's highest rate of wastewater reuse coupled with an ambitious desalination program, as signs for optimism that creative solutions exist to ameliorate conflict in light of water scarcity (Tal, 2008). Despite the animosity between Israel and its surrounding neighbors, all riparian states of the JR have participated in formal and informal negotiations in an attempt to manage the Jordan's water resources. Although the first attempt to reach an agreement was multilateral (the Johnston plan 1953–1955), all subsequent agreements were bilateral (Zawahri, 2009). Water and especially food security are also an important part of policy formation. This is true especially in the short run until a permanent peace atmosphere will be the norm (Larson, 2013).

Several governmental agencies in each of the three riparian governments (Israel, Jordan and the PA) have a range of plans to develop the areas around the LJR. Projects such as a planned “Peace Park” to be situated on the border between Israel and Jordan are being promoted by NGOs. However, there is little coordination across the three governments, and there are often overlapping mandates across agencies within the individual governments at both the national and local levels (Becker et al., in press).

The main reason for the Israeli out-of-basin diversion of the JR is due to limited and uneven distribution of surface water. While the most significant source of surface water in Israel is located in the north part of the country, the central and coastal areas, encompassing the vast majority of the population, industry and agricultural land, possess only a small fraction of Israel's continuous surface water supply (Lowi, 1993). This unfavorable resource distribution, along with the aridity of the southern part of Israel, sparked the idea for constructing the Israeli National Water Carrier (NWC) project in 1953, which was inaugurated in 1964. The NWC is an out-of-basin diversion of the upper JR waters, aiming to serve the domestic, agricultural and industrial needs of the increasing Israeli population of the coastal and central areas, and to alleviate water scarcity in the southern areas for irrigation. In response, the Arab League implemented the Headwater Diversion Plan (HDP) to divert the headwaters of the JR (the Hasbani river in Lebanon and the Banias springs in Syria) in order to prevent the JR water from flowing into Israeli territory. This conflict was partly the reason behind the outbreak of the six day war in 1967, when Israel waged war against Syria, Jordan and Egypt, and managed to capture the source of the Banias River and destroyed the foundations of the Syrian diversion canal, thus putting an end to the HDP (Cooley, 1984; Inbar and Maos, 1984).

The NWC diversion created a situation where no freshwater flows on the LJR below the Degania dam, thus preventing the riparian rights of the Palestinian people inhabiting the West Bank territories (named for its location west of the JR, occupied by Israel since the 1967 War). Water management and sharing is one of the major issues that need to be resolved in order to defuse the Israeli-Palestinian conflict. Currently, water in the Palestinian territories is almost fully managed by the Israeli water management system, including the groundwater source of the mountain aquifer (Israel's main source of groundwater), which flows westwards and

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originates at the northeastern and central mountainous area of the West Bank (Lonergan and Brooks, 1994; Sheffer et al., 2010).

Jordan's plans for diverting the YR water in order to irrigate traditional farming areas and potential arable lands along the eastern slope of the Jordan valley resulted in the construction of the King Abdullah Canal (KAC), a major national project constructing a 69 km long concrete canal (in 1969), later extended to 110 km (Shatanawi et al., 2004), the largest single irrigation project ever undertaken in Jordan. The canal, running south parallel to the JR, taps the waters of the Yarmouk and Zarka Rivers and seven other seasonal streams, all within the JRB. Construction began in 1959 and the canal was inaugurated in 1964. Since then, additional dams have been built to impound the winter flows of the YR.

During the 1980s, Syria had constructed a series of dams along the tributaries of the YR in its territory, diverting approximately half of the YR waters (Hassan and Klein, 2002). The joint Syrian-Jordanian Unity Dam (El Wahdeh dam), inaugurated in 2011, with a capacity of 110 MCM, will further impound the natural flow of the YR.

In the second annex of the peace treaty signed between Israel and Jordan, Jordan has the option to divert 20 MCM/y of the YR waters to be stored at the SOG during the winter and released directly into the KAC during the summer months (JOR-ISR, 1994).

4.3.2. *The Colorado River*

Within the CRB, there are numerous levels of transboundary issues, including those (1) between and among U.S. states, (2) between the Upper and Lower Basins, (3) involving sovereign Native American Nations, and (4) between the U.S. and Mexico. Here we will focus on the last of these, because, all treaty and transboundary matters involving the U.S. and Mexico are a responsibility of the U.S. and Mexican federal governments, not of any individual state. The U.S. federal government is responsible for delivering the required 1850 MCM of CR water not exceeding an established salinity level to Mexico annually. The U.S. government must also become involved should individual states wish to develop cooperative arrangements with Mexico related to water augmentation or storage. The International Boundary and Water Commission (IBWC) is the formal entity through which U.S.–Mexico water issues are discussed and resolved. The IBWC has a U.S. section and a Mexican section, with a federally appointed commissioner presiding over the staff and operations of each section (see http://ibwc.gov/). The commissioners, who meet regularly, have the authority to approve Minutes, which are cooperative measures pursuant to the 1944 Water Treaty.

The southwestern U.S. and northern Mexico region has been and is expected to be impacted by warmer and likely drier conditions (Garfin, 2013). Therefore, the currently over-allocated river system will be further stressed by changing climate conditions. Although the CR has been experiencing severe drought conditions, until 2007 there were no formal regulations related to shortage conditions on the river either within the U.S. or between the U.S. and Mexico. During the middle part of the last decade, water managers of the seven U.S. CRB states worked with the U.S. Secretary of Interior to develop interim guidelines for sharing of shortage within the U.S. and balancing the water levels of the two storage reservoirs. As noted above, CAP water deliveries receive low priority under shortage conditions.

In late 2012, the IBWC Commissioners approved a five-year agreement, Minute 319, to establish interim shortage – and surplus – sharing with Mexico (IBWC, 2012). The work of the U.S. states established some important foundation for the subsequent international shortage sharing agreement. Minute 319 also followed upon other recent international agreements that resulted were due in part to damage resulting to Mexico's water conveyance infrastructure due to an April 2010 earthquake. It is important to note that the cooperative efforts resulting in Minute 319 resulted from the 2010 natural disaster.

4.4. *Demands for environmental flows*

Valuation of environmental flows is a key component of cost-benefit analyses for water resource management, which in turn are useful for formulating efficient allocation strategies. However, such information is rarely adequate, especially given the low priority of environmental flows within traditional water management approaches. Both the JR and CR are cases in point: while recent efforts have been conducted to quantify and demonstrate demand for environmental restoration (Abramson et al., 2010; Becker et al., Forthcoming; Medellín-Azuara et al., 2007), prevailing policies and priorities have been slow to incorporate these values. We present recent valuation findings for the LJR's restoration, and discuss on a more conceptual level, economic and future policy pathways for the LCR.

4.4.1. *The Lower Jordan River*

In order to estimate the economic value of rehabilitation of the LJR, three scenarios were analyzed both in terms of Israel's benefit as well as that of the three entities (Israel, Jordan and the PA) together. The cost of each scenario was estimated based on known costs for wastewater purification and the alternative cost of water diverted through the Degania dam.

The benefits were estimated based on a Contingent Valuation (CV) survey. The surveys explained the current status of the LJR. Each then gathered information regarding respondents' relative preferences for each one of three possible rehabilitation scenarios covering three different flows with their associated water quality. The three scenarios were constructed based on the findings of a WEAP model (Chen, 2011; FOEME, 2011) for the LJR. The river's targeted water quality was calculated assuming that the Saline Water Carrier and Bitania wastewater effluents, estimated at a rate of 23 MCM/y, are rerouted away from the river and replaced with fresh water, accompanied with additional increased flow from the SOG as presented below:

- Scenario 1 – increased flow by 25 MCM/y, associated with a water quality level of 1250 mg/l chloride concentration.
- Scenario 2 – increased flow by 50 MCM/y associated with a water quality level of 1000 mg/l chloride concentration.
- Scenario 3 – increased flow by 100 MCM/y, associated with a water quality level of 750 mg/l chloride concentration.

The results of the surveys are presented in Table 1.

As can be seen from the table, if Israel acts unilaterally, Scenario 2 provides the highest net benefit. Scenario 3 entails higher benefits but also higher costs which makes the net benefit negative. If we take into consideration the three entities, Scenario 2 is again the optimal choice. As a result, there is ground for an agreement among

Table 1
Annual benefits from CVM (million USD).

	Scenario 1	Scenario 2	Scenario 3
Israel	8.9	19.0	23.1
Jordan	12.2	23.9	28.75
Palestine	2.8	5.5	7.5
Total benefits	23.9	48.4	59.35
Annual COSTS	5.2	11.4	37.75
Net benefit (only Israel)	3.7	7.6	−14.65
Net benefit (three entities)	18.7	37.0	21.6

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the three entities in that Israel's optimal strategy is the same (Scenario 2) with or without such an agreement, reducing potential conflicts in formulating transboundary restoration strategies. We assume here that Jordan and the PA do not contribute to cost-sharing.

4.4.2. Colorado River Basin

The discussion here focuses on the LCR Basin and the CR Delta, which is in Mexico. Because the CR is managed by the U.S. Secretary of the Interior, environmental considerations related to the river are largely a federal responsibility. Like the LJR, the CR Delta is the breeding ground for thousands of migratory birds as part of the Pacific Flyway and home of endangered species, including the Yuma clapper rail and the desert pup fish (Anderson et al., 2003). Environmental considerations figure more into CR management than in the past. In 2005, the Secretary of the Interior implemented a Lower Colorado River Multispecies Conservation Program to address issues related to LCR operations and the U.S. Endangered Species Act (http://www.lcrmscp.gov/). Water users in the Lower Basin share the costs of this long-term, extensive program. Also, environmental considerations in Mexico were explicitly considered in Minute 319, as discussed above, to share water shortages and surpluses. In addition, environmental concerns, as well as cost considerations, affect the ability of the U.S. government to operate the inland Yuma Desalting Plant, which was built to assist in meeting salinity standards required for water deliveries to Mexico. Operating the Yuma Desalting Plant has implications for water in storage in Lake Mead as well as water flowing to the Cienega de Santa Clara, an important environmental asset in Mexico. After a long period of dormancy, the plant was operated on a pilot basis at 30 percent capacity for almost a year. However, whether this plant will operate again is highly uncertain (USBR, 2012b).

The lack of natural flow to the Delta region is a significant environmental concern and a focus of many interested in restoring/improving the Delta's ecosystem conditions. Efforts to increase flows to the Delta largely focus on purchasing water rights from existing water rights holders in Mexico. Several studies indicate that the riparian corridor of the CR Delta requires annual flows of about 40 MCM, with pulse flows of 320 MCM every 4 years (Luecke et al., 1999). Medellín-Azuara et al. (2007) use an economic-engineering optimization tool to investigate the economic value of in-stream flows to the CR Delta. They estimate that the marginal costs of flows are between \$0.05 - \$0.08/CM, and the marginal value associated with flows from the U.S. is even smaller (between \$0.0135–\$0.035/CM). They conclude that transboundary CR water purchases could not be supported at these prices.

As with other water regulations within the U.S., water quality regulations pertaining to discharges into navigable waterways are established by the federal government. Some environmental water requirements are established by the federal Endangered Species Act, but, unless a federal action is involved, state governments have the authority to set their own water quantity regulations governing environmental flows. The state of Arizona has very limited environmental flow regulations (Megdal et al., 2011). Thus, both governance and transboundary issues may be key bottlenecks to translating even relatively small demand for a restored CR into action.

5. Feasible pathways for improved water management

5.1. Economically quantifiable pathways

The four drivers discussed in the prior section are major determinants of the multiple pathways or options for balancing and addressing the management goals of ensuring a sufficient water supply of acceptable quality across all sectors over time. In addition, these pathways to achieving a region's desired policy outcomes are defined substantially by the limitations of technological feasibility, which also vary significantly both within and across geographic regions and sub-regions. These pathways can be broadly divided into six categories (Orthofer et al., 2001; Roudi-Fahimi et al., 2002; USBR, 2012a; Venot et al., 2008):

1. *Water conservation* encompasses conserving water by increasing water use efficiency or decreasing demand. In the agricultural sector, this could be achieved by agro-technical methods such as drip irrigation and introducing new varieties of less water intensive crops. In the municipal sector, water conservation can be achieved at either the municipal or household scale. For example, applying plastic covers to wastewater reservoirs would save almost 70 MCM/y in the LJR valley (Becker et al., 2010). At the household level, it can be achieved by encouraging voluntary conservation through economic tools, education and awareness (Gleick, 2002). Conserving potable quality water also includes rainwater harvesting and the reuse of household wastewater such as grey-water for small-scale applications including gardening, and other point-of-use technologies (*i.e.* water conserving toilets).
2. *Watershed management* actions that have important impacts on the water budget include basin- or regional-scale interventions such as weather modification (e.g. cloud seeding), dust control, and tamarisk tree control.
3. *Desalination* involves extracting salt from sea water, brackish aquifers, such as the Nubian aquifer, which underlies the central and northern Sinai, extending to the Negev in Israel. It also can be used to remove salts from agricultural return flows, such as in the Yuma area, to supply fresh water for domestic use.
4. *Water reuse and/or sequential use* involve the recycling of either municipal or industrial wastewater, after treatment, for eventual reuse. For example, most of the municipal sewage water from the urban areas of Israel is treated and delivered to irrigate farmland in the southern part of the country. In Arizona, tertiary treated effluent is used for irrigation of golf courses, school grounds and ball fields. Some secondary treated effluent is used by agriculture in Arizona.
5. *Local supply*, such as rainwater harvesting or use of marginal water, may supplement networked water supplies at a lower marginal cost.
6. *Importation* of water from areas of high supply into areas of high demand is becoming more economical as increasing demand causes a higher reliance on marginal and costly supplies.

Fig. 6 presents a comparison of the profiles of feasible management and technological interventions for meeting projected water needs in each basin, sorted by cost-effectiveness.

Fig. 6 demonstrates that unique management pathways exist for each basin, and that significant variation in cost-effectiveness exists between alternatives, especially in the CRB. This may be explained partly by its large geographical area, accompanied by high costs of water distribution. The cost of augmenting supply with desalination, for example, ranges from \$0.49 m^{-3} for groundwater near Yuma, Arizona to \$1.70 m^{-3} from seawater from the Gulf of California. This is roughly triple the cost of desalinated water (\$0.59 m^{-3}) for augmenting supply in the JRB from the Mediterranean Sea in Israel.

This is also partly attributable to the different water policy frameworks in each basin. Israel's centralized water system optimizes water distribution efficiency, and new desalination plants will further benefit from the nation's recent discovery of off-shore natural gas reserves, contributing to a 30% reduction in

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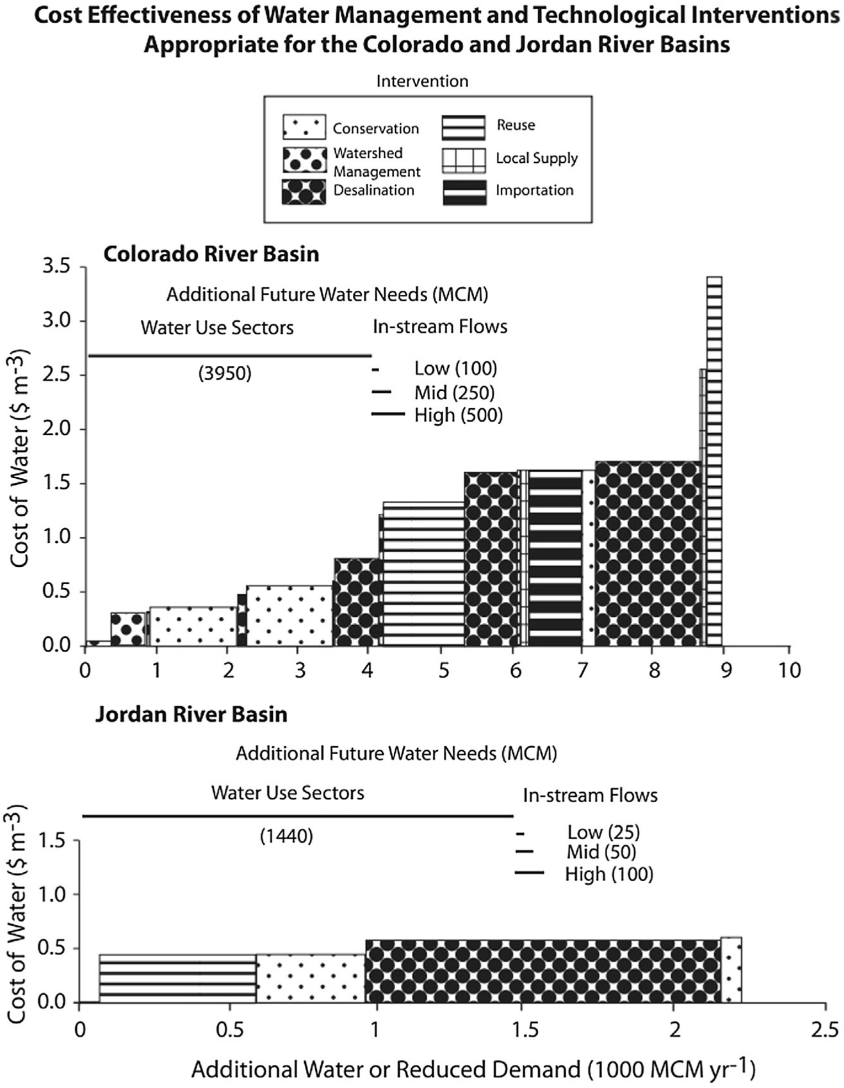

Fig. 6. Feasible water management and technological interventions for meeting the future demand and supply gaps expected in the Colorado and Jordan River basins.

desalinated water costs against conventional energy sources (Dreizin et al., 2008).

In addition, as noted by previous studies (Gleick, 2002, 2003), there is a significant potential for 'soft-path' water solutions (that is, less technical approaches such as watershed management and household conservation behaviors) to contribute to a balanced future water budget. In both basins, these are among the most cost-effective alternatives available. Lastly, the marginal increase in unit water costs is much more pronounced in the CRB than in the JRB. This may be due to the geographical constraints mentioned above. This has important implications on riparian restoration, as discussed below.

5.2. *Implications for riparian restoration*

The most notable feature of in-stream flows for riparian restoration efforts is how little of the overall water budget they represent in both basins. It is estimated that 10 MCM per month (120 MCM/y) represents the minimum base-flow necessary for restoring the LCR's delta (Medellín-Azuara et al., 2007). We assume low to high restoration levels could occur by ensuring 100 to 500 MCM per year in the CR Delta, respectively—roughly 2.5–11% of the region's forecasted total water use. In the JRB, stream restoration would require roughly 2–6% under the proposed scenarios.

While it is impossible to determine the exact cost of reaching these in-stream flow levels, some discussion may shed light on the factors involved. For one, these costs depend on the priority of environmental flows within the larger water budget. As Fig. 6 demonstrates, this prioritization is critical to determining the cost of in-stream flows due to the increasing marginal costs of water. This is much more pronounced in the CRB, and indeed more complex, as each alternative varies widely in distance to the lower portion of the basin, where restoration would occur. In the JRB, not only is desalinated water less costly, but it is more widely feasible. Thus, water supply may be expanded easily with little to no increase in marginal water costs.

For this discussion, let us assume that in-stream flows are the lowest priority of all water uses in both basins. Furthermore, let us assume that the most cost-effective interventions are indeed feasible, and are implemented in order of costs according to Fig. 6, until the future water budget is balanced. In the CRB, the cost of in-stream flows would begin at \$0.81 m^{-3} and may exceed \$1.34 m^{-3}. In the JRB, these costs would be equivalent to those of desalinated water—\$0.59 m^{-3}. It is highly unlikely that the most cost-effective

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Table 2
Policy outcomes across the two basins.

Driving forces	Demand/Supply gap	Governance	Transboundary issues	Demand for Non-market services

↓

Policy Outcomes	Similarities across Lower Jordan and Colorado basins	Differences	
		Israel	Arizona
Water Supply Strategies (Groundwater vs. surface water)	Foreseen reduction in dependence on traditional sources alongside augmentation with marginal sources. Aquifer recharge, treatment and storage, and water reuse are key coping strategies.	Long-term groundwater storage is less viable due to high rates of use and groundwater contamination.	Interstate water banking developed to offset uncertain future of imported surface water.
Water Sector Allocations	Central governing bodies regulate water use; water use shifting from agricultural to domestic sectors.	More fresh water to domestic uses due to population growth and higher standards of living. Fresh water to agriculture decreases while reclaimed (marginal) water quantities increase over time.	Sectoral allocations determined by rights to use water established by legislation and case law. Groundwater Management Act provides regulatory framework for Active Management Areas only.
Transboundary Sharing	International and national agreements establish water allocations.	Water agreement with Jordan, sharing the water of the Jordan and Yarmouk rivers and a provisional agreement in place with the PA. No agreements with other riparian states.	Transboundary flow agreements more easily brokered, stakeholders are involved and meet regularly.
Hard- vs. Soft-Path Management	A mix of both hard- and soft-approaches will optimize water management.	Hard-approaches, especially the national water network, in turn make soft-approaches more feasible, such as water conservation and aquifer recharge. Household-level approaches, such as grey-water reuse or rainwater harvesting, remain illegal.	Many hard-approaches, such as water importation and desalination, are less cost-effective yet being investigated at different geographic scales. Soft-management measures, such as conservation, household rainwater harvesting, and crop choices are foreseen.
Riparian Restoration	In-stream flows are protected by law.	In-stream flows economically attractive, perhaps due to lack of other existing environmental goods. May be blocked due to insufficient transboundary cooperation.	Less economic justification and limited legal basis for allocating water to the natural environment upstream of the CR Delta.

profile of interventions will be chosen due to the complex issues addressed above. Thus, the in-stream flows in the CRB may be expected to face an even higher marginal water cost. Interestingly, such costs in the JRB may not be impacted as heavily, or at all, due to the expandability of desalinated water within a small, centralized water supply network.

5.3. Other relevant management pathways

In addition to these pathways, there are several that are important to consider but more difficult to quantify in terms of costs and water volumes:

7. *Water reallocation and transfer*: Reallocating/transferring water away from agriculture into higher capital yields and employment providing sectors, such as businesses, services, manufacturing and tourism (Orthofer et al., 2001; Roudi-Fahimi et al., 2002; Venot et al., 2008), as well as the residential sector. This includes the concept of “Virtual water”-—Importing irrigated crops or livestock products rather than using water resources for their production (Hanasaki et al., 2010).
8. *Increasing water distribution efficiency*: Improving water distribution (fixing/replacing leaky pipes, reducing evaporation in reservoirs) (Roudi-Fahimi et al., 2002; Venot et al., 2008).
9. *Groundwater recharge and water banking*: Aquifer storage and recovery is an important mechanism to achieve policy objectives related to preparation for surface water shortage conditions, spatial or temporal water availability issues, water treatment, and aquifer management. It is a particularly important tool in Arizona (Megdal, 2007; Ronstadt, 2012) .
10. *Regional cooperation*: Increasing regional cooperation through adopting peace building initiatives and building on existing agreements and cooperation, such as interstate agreements within the U.S. and the seven CRB shortage sharing agreement, or international agreements, such as Minute 319 and the Israeli–Jordanian peace treaty.

While it is difficult to quantify the economic impact of these pathways, it is impossible to neglect their importance. The first

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three in this list relate to the water demand/supply gap and its influence on sectoral allocation strategies. Water governance is crucial to the efficacy of these pathways toward achieving optimal outcomes. The last pathway, regional cooperation, is of utmost importance, since it influences riparian restoration outcomes, water supply and allocation strategies, and transboundary sharing decisions.

Furthermore, there are significant interactions among these pathways. For example, centralized water reuse increases the cost-effectiveness of desalination where high-quality freshwater is used to improve recycled effluent for agriculture (Becker et al., 2010). Fundamental to following these pathways is meaningful stakeholder engagement and water education efforts. Implementation of identified pathways requires public understanding of issues such as the justification for higher rates, the use of marginal water supplies, and/or the importance of conservation efforts (Megdal, 2013b).

Thus, in terms of the model presented in Fig. 3, we can summarize the policy outcomes both in Arizona and Israel (Table 2). We focus on both the similarities and differences between the two basins.

The most notable divergences in outcomes involve water supply strategies (Arizona's reliance on groundwater banking and high volume of imported surface water is unparalleled in Israel), Hard-Soft path choices (Israeli focus on desalination and intensification of water reuse differs from Arizona's more diverse and smaller scale approaches), and the prospective for riparian restoration (the JR's unique standing boosts economic demand for restoration against Arizona's portion of the CR).

A key factor behind these divergences is the level of centralization seen in both the institutional and technological aspects of each basin's water management—in some sense, a factor driven by both the nature of physical water resources and of the prevailing policy of previous governments. Israel's centralized National Water Carrier may enable more efficient allocations across various sectors, including the non-market sector of environmental flows. Coupled together with the JRB's smaller geographic scale, water distribution costs are thus reduced. In some ways, this allows greater leveraging of soft measures including wastewater reuse. In other ways, it impedes the uptake of soft measures; the government has upheld a longstanding restriction on decentralized measures such as greywater reuse and rainwater harvesting – much more common in Arizona. Arizona's less centralized approach results in a greater suite of management outcomes, including both hard and soft measures and more variation in pricing (Megdal, 2012).

For policymakers, a key lesson from this analysis should be that policy tools are not the only factor in determining actual water management outcomes. Governance and transboundary cooperation, the two driving forces that can be most easily changed over time by public decision-making, are in themselves slippery objects. Governance includes the level of centralization of both regulation as well as of physical infrastructure, but it may be argued that this type of governance is often slow or reluctant to change. Similarly, transboundary cooperation requires a high level of input for often very little immediate returns, and is often dependent on factors outside of the control of national policymakers. These factors indicate that water management pathways in general and riparian restoration in particular, are not just a sum of their parts. If they were, the demand and supply for market and non-market services, determined by public preferences (demand) and natural water resources (supply), subject to governance and transboundary dimensions, would translate directly into predictable outcomes.

With that said, our analysis indicates that it is possible to conceptualize complex water management decisions through an input–output framework. As we proposed, the policy outcomes of each basin can be effectively traced to their various components or driving factors. We further suggest that future pathways for water management, and in particular, riparian restoration, can also be conceptualized in this framework. That the marginal costs of expanded water supplies differ considerably both within and between these two basins is to be expected given their technological and management differences. But while these numbers are important, we have shown that actualizing environmental priorities requires more than economic optimization. Wise environmental governance and transboundary cooperation are essential to fruitful and lasting riparian restoration efforts, especially in the presence of high demands from more established water sectors.

6. Conclusions

In this paper we have applied a driver-outcome framework to two stressed river systems of importance to the growth of their respective semi-arid to arid regions. We demonstrate that the pathways to addressing their management challenges have similar elements. Increasing demand coupled with decreasing supply and the complex relationships between upstream and downstream parties have caused water managers in both basins to pursue various strategies. While the actual policy outcomes of course will depend on the four major drivers, governance is perhaps the most significant driver and should be the focus of efforts to improve river system management, whether within or across national boundaries.

Israel has, for the most part, centralized its national water infrastructure and management framework, allowing the relatively small country to be served by a wide range of technical options and water management approaches. Of particular importance are desalination and wastewater reuse. The arid region's water budget will continue to expand as the population continues to grow and as the value of riparian restoration is more fully recognized. Eventual peace agreements with the PA may entail a higher water-sharing commitment. Arizona's water management approach has emerged out of a policy backdrop of individualism so salient in the region. Water is governed by centralized bodies, but the Law of the River and the ‘prior use’ approach may stand in the way of allocating water across the full range of users. The Central Arizona Project is a case in point - it is the first major waterway to suffer cuts during a declared water shortage. The state's water banking and groundwater savings programs are innovative coping strategies to the CAP's uncertain future.

These differences play out perhaps most acutely in the economic realm. The costs of providing more water through hard- or soft-paths differ tremendously both within and between these two basins. Israel's emerging dependence on desalination, projected to increase through 2030, is a result of primarily economic forces. Desalinated water is, at least theoretically, unlimited in quantity, and very stable in cost. In the absence of such an expandable water source, Arizona's water management, in contrast, has assumed the hydrological equivalent of a central bank, rendering climate-sensitive surface water into long-term groundwater storage. These differing approaches are seen in other basins around the world, and lessons learned here may be applied elsewhere.

We demonstrate that these driving forces and consequent policy outcomes in each basin have important implications for allocations to the natural environment in general and riparian restoration in particular. Since the LJR is highly valued as a unique environmental asset, restoration efforts may be more feasible than in the CR Delta. This value creates a positive incentive for transboundary cooperation, while at the same time, is hindered from expression by the backdrop of political conflicts. Arizona's dependence on imported surface water and lack of cost-effective augmentation alternatives makes river restoration less viable from an economic viewpoint. In the CR Delta, where the environmental stakes are higher, riparian

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restoration may only be realized if in-stream flows are legally enforced. In short, political conflict (poor transboundary cooperation) hinders restoration of the LJR, while economic considerations are the main obstacles to the restoration of the LCR. Each basin will need to identify the correct set of tools to develop effective management and restoration pathways. A resolute commitment to end the Israeli–Palestinian conflict is of paramount necessity for the solutions suggested for the LJR to be successfully implemented.

We find that understanding the driving factors—demand/supply gap, governance, transboundary issues, and demand for non-market services—which vary between these two river basins, is an important step in understanding their respective policy outcomes. Economic considerations are also important for understanding water management outcomes. While these factors are often difficult to quantify and predict, this study demonstrates that it is possible to gain a simplified causal understanding of prevailing water management choices, as well as to make informed predictions about future pathways in two very comparable, yet different, arid basins. Since many basins are shaped by similar factors, our findings may be applicable in many transboundary basins worldwide facing similar challenges. Riparian restoration in particular, so often set in either an economic or ecological context, must be considered in a larger framework for effective restoration policies and recommendations to be formulated.

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