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This paper examines existing and planned binational desalination technology in the Arizona-Sonora section of the U.S.-Mexico border within a broad systemic framework. Rather than a purely technical assessment, we analyze the social, economic, institutional, political, and environmental aspects of these desalination systems or proposals. The paper first examines the advance of desalination technology internationally with an overview of its associated benefits and challenges. The paper then discusses desalination systems in the context of the Arizona-Sonora border. We consider two particular cases, the Yuma (Arizona) Desalting Plant, an inland, brackish water desalination plant, and two plans for seawater desalination plants (one for municipal use, one to serve binational needs for Arizona and Sonora) that have been proposed for Puerto Peñasco, Sonora. We examine the benefits and challenges associated with each plant or proposal in terms of its socioeconomic, institutional, and environmental impacts, including water-energy trade-offs. The final section discusses the binational prospects and implications and provides specific policy recommendations. We argue that desalination technology is likely to play a role in future water supply for the Arizona-Sonora section of the border; but that desalination technology should be developed in a way
that is socially, economically, politically, and environmentally sustainable.
Desalination Technology in a Binational Context:  
Systemic Implications for Water, Society, Energy, and Environment  
in the Arizona-Sonora portion of the U.S.-Mexico Border

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Abstract
This paper examines existing and planned binational desalination technology in the Arizona-Sonora section of the U.S.-Mexico border within a broad systemic framework. Rather than a purely technical assessment, we analyze the social, economic, institutional, political, and environmental aspects of these desalination systems or proposals. The paper first examines the advance of desalination technology internationally with an overview of its associated benefits and challenges. The paper then discusses the context of desalination systems in the context of the Arizona-Sonora border. We consider two particular cases, the Yuma (Arizona) Desalting Plant, an inland, brackish water desalination plant, and two plans for seawater desalination plants (one for municipal use, one to serve binational needs for Arizona and Sonora) that have been proposed for Puerto Peñasco, Sonora. We examine the benefits and challenges associated with each plant or proposal in terms of its socioeconomic, institutional, and environmental impacts, including water-energy tradeoffs. The final section discusses the binational prospects and implications and provides specific policy recommendations. We argue that desalination technology is likely to play a role in future water supply for the Arizona-Sonora section of the border; but that desalination technology should be developed in a way that is socially, economically, politically, and environmentally sustainable.

Este trabajo examina, dentro de un marco analítico sistémico, la tecnología binacional de desalinización existente o planeada en la sección Arizona-Sonora de la frontera entre los EEUU y México. En lugar de un análisis puramente técnico, analizamos los aspectos sociales, económicos, institucionales, políticos, y medioambientalistas de estos sistemas o propuestas. Primeramente se examina el avance de la tecnología de la desalinización en el contexto internacional, con un panorama de sus beneficios y desafíos asociados. En seguida se discuten los sistemas desalinización en el contexto de la frontera Arizona-Sonora. Se consideran dos casos particulares: la Planta Desaladora de Yuma (Arizona), una planta interior para tratar agua salobre, y dos planes para desaladoras de agua de mar (una para el uso municipal y otra para el uso binacional de Arizona y Sonora) los cuales han sido propuestas para Puerto Peñasco, Sonora. Examinamos los beneficios y los desafíos asociados con cada planta o propuesta, en términos de sus impactos sociales, económicos, institucionales, y ambientales, incluyendo las disyuntivas entre agua y energía. La sección final se centra sobre la prospectiva e implicaciones binacionales,
I. Introduction

This paper examines the prospects and implications of desalination technology for the U.S.-Mexico border, within a systemic perspective and with a particular emphasis on the Arizona-Sonora region. Increasingly, urban water utilities and water resource planners on both sides of the border view desalted seawater or brackish water as a potentially important mid- to long-term future source of supply of water for urban areas in the border region. The plans to extend desalination technology within the region have significant binational economic, social, environmental, and political dimensions. Nevertheless, existing studies primarily address the technical and economic feasibility of desalination in the region and few studies have examined desalination technology as embedded within a broader socio-ecological system.

This paper examines desalination within a broader systemic framework, including an assessment of trade-offs with water and energy use (required to operate the plant), existing policies relating to desalination, and social, environmental and economic implications.

We address the following questions with respect to two distinct desalination projects in the Arizona-Sonora region: one involving inland desalination, the Yuma

1 The authors would like to thank Dr. David Vassar and Dr. Francisco Marmolejo of the Puentes Consortium for their interest in and support of this paper. In addition, we gratefully acknowledge the helpful recommendations of two anonymous reviewers. Finally, Ms. Erica Alderete played a key role in supporting the completion of this paper. Any errors or omissions are the responsibility of the authors.
Desalting Plant (completed in 1992); and a second that would produce desalted seawater in Puerto Peñasco, Sonora (in planning).

- What are the existing and proposed plans to extend desalination technology to serve the water supply needs of the Arizona-Sonora region? What role is desalted water expected to play in augmenting (or substituting) supply under conditions of growth and climate change?
- What are the potential benefits and consequences of extending desalination technology to aid in meeting future water demand in the region?
- What are the implications of desalination technology in terms of water-and-energy use, environmental impacts, and changes for local economies and local communities on both sides of the border?

This first section is an introduction to the problem and questions that constitute the focus of the paper. In the second section, we discuss the background and context necessary to understand the potential benefits and challenges of desalination systems, and the advance of the technology worldwide. The third section provides an analysis of the binational socio-ecological context and the institutions and governance framework that guide desalination planning in the region. The fourth section discusses the two desalination projects included in the scope of this paper, and the fifth section examines the binational and regional implications of these projects and concludes with key policy recommendations.
II. Understanding Desalination in an Arid Transboundary Region: Challenges and Opportunities.

Across the globe, countries are initiating new desalination plans and expanding existing capacity. Multiple benefits are frequently ascribed to desalination systems, including the promise of a “drought proof” water supply; increased water system reliability; and the potential to reduce demands on aquifers and surface water. At the same time, concerns abound including both energy requirements (and related emissions implications) and environmental quality and impacts on local habitats and biodiversity.

In order to evaluate the potential role of desalination in the Arizona-Sonora region, it is helpful to understand the broader context shaping the adoption of desalination internationally. In this section we provide a brief background on key desalination concepts, a view of the international expansion of the technology, and an overview of the major benefits and challenges associated with desalination generally and in arid regions, specifically.

Desalination is the process of removing salts and other minerals from seawater and brackish water to create potable water for domestic and municipal purposes, treated water for industrial uses, and an emergency source for the military or refugees (Cooley et al., 2006; Global Water Intelligence www.desaldata.com). The energy needed to clean the “feedwater” of salts and minerals increases with the amount of solids (total dissolved solids, TDS) found in the water [measured in milligrams per liter (mg/l) or in parts-per-million] (see Table 1 below). Worldwide, about 60 percent of the feedwater used in desalination processes is seawater and 20 percent is brackish water (www.desaldata.com).

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2 There is no consistent agreement on the correct term to refer to this technology. Following Cooley et al. (2006), we use the terms “desalination” and “desalting” interchangeably; however, other common uses and spellings include “desalinization” or “desalinisation” (in the British Commonwealth countries).
Desalination is not a new technology. Early desalination plants used thermal processes to heat seawater and condense the evaporated water into freshwater. But given the high-energy intensity of this process, it was mainly practiced in energy-rich countries like Saudi Arabia. The key elements of the water desalination system are: (1) intakes of seawater or brackish water (2) pre-treatment to remove suspended solids and prepare the source water for further processing (3) removal of dissolved solids, primarily salts, from the water (4) post-treatment to prevent corrosion of downstream water pipes, and (5) concentrate management--the handling and disposal or reuse of the salt wastes from the process. Several desalination technologies exist today, but since the 1970s, reverse osmosis has become the preferred method of desalination (Tal 2011, Cooley et al., 2006) (Figure 1). Reverse osmosis uses the driving force of hydraulic pressure to force seawater or brackish water through a semi-permeable membrane, removing a majority of dissolved salts and other contaminants (NRC 2008). While 40 percent of desalination globally is based on distillation technology, virtually all U.S. systems utilize reverse osmosis technology (Cooley et al., 2006; NRC 2008).
Figure 1. Above: Reverse Osmosis Process Diagram, Cooley et al., 2006. Below: Reverse Osmosis Desalination Plant, Israel. (March 2010). Photo credit: Robert G. Varady. PERMISSION NEEDED FOR ABOVE IMAGE
With continued improvements in membrane technology, implementation of energy recovery devices, increased efficiencies of pumps, increased competition among suppliers, and benefits of economies of scale associated with larger projects, the cost of producing desalinated water has dropped by 50 percent from 1985 to 2005 (Elimelech and Philip 2011, Tal 2011). Despite the decline, further cost reductions may be limited by a cost-barrier imposed by the energy requirements of current technologies for both desalination and energy supply.

The efficiency gains in recent desalination technology innovations, coupled with the increasing recognition of the environmental, social and economic costs associated with alternative water augmentation options [i.e., dams or groundwater (which in many arid regions is in overdraft)], has led to an exponential growth in installed desalination capacity worldwide in the last forty years (NRC 2008) (Figure 2). According to the International Desalination Association’s 24th Worldwide Desalting Plant Inventory, worldwide there are nearly 16,000 desalination plants with the capacity to produce over 71 million cubic meters (MCM), equivalent to 57,500 acre-feet (AF)\(^3\) of water per day (IDA, 2011).

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\(^3\) A note on units – the metric system is used throughout Mexico and by U.S. scientists. Because water managers in the U.S. use acre-feet and million gallons, we present data in both systems of units. 1 AF = 1,233.48185533 m\(^3\).
Figure 2. In 2006, worldwide online desalination capacity was roughly 10 billion gallons (38 million cubic meters) a day (data from GWI, 2006). From 2000 to 2005, U.S. desalination capacity grew by around 40 percent, but the total accounts for less than 0.4 percent of municipal and industrial water used in the United States. © International Mapping Associates. Source: National Research Council 2008. Desalination: A National Perspective.

Among the leaders in developing this capacity, Ashkelon in Israel is the largest reverse osmosis plant in the world. Producing desalted seawater for municipal use, it has a capacity of 100 million gallons per day (395,000 m$^3$/day) (Cooley et al., 2006). China is “rapidly becoming one of the world’s biggest growth markets for desalted water” (Wines 2011). China plans to quadruple its desalination capacity by 2020 and has made development of desalination a policy priority, positioning itself not only to provision its own people with desalted water but also to become a purveyor of desalination technology on the global market.

Arid countries were among the earliest turning to desalination to augment their water supply. In the last 7 years, countries such as Algeria, Australia and Spain have
Wilder et al., 2012 Puentes Consortium Paper

significantly increased their adoption of desalination technology (IDA 2011). For example, in Spain, beginning in 2004, under President Zapatero’s Spanish Socialist Worker’s Party administration, Spain introduced a new water policy, known as Programa AGUA. This policy makes a distinct move away from a policy of interbasin water transfers towards a policy of constructing desalination and water re-use plants to meet the growing water demands of agriculture, tourism, and urban development in the southeast. Programa AGUA proposes to build 21 new desalination plants along the southeast coast (Downward and Taylor 2007). Overall, Saudi Arabia has the greatest installed desalination capacity in the world to treat mainly seawater (IDA. 2011). "Leading Desalination Countries" in Desalination Yearbook 2011-2012. Available online http://www.desalyearbook.com/market-profile/18-leading-desalination-countries (last accessed 2/12/2012).

The United States has the second greatest installed capacity worldwide, mainly to treat inland brackish groundwater (IDA 2011). Within the U.S., Arizona, with the Yuma Desalting Plant (discussed in section IV), has the fourth greatest installed desalination capacity (after the coastal states of Florida, California and Texas) (NRC 2008:22). El Paso, Texas, also on the U.S.-Mexico border, hosts the Kay Bailey Hutchinson plant, North America’s largest inland desalination facility. Built in 2007 at a cost of $87 million, and producing 27.5 million gallons per day (mgd) (1,200 liters, per second, lps), the plant is fed from brackish groundwater from the Hueco Bolson aquifer underlying the city and the U.S. Army’s Fort Bliss. Disposal of the salty brine discharge posed difficulties for the plant located far inland; thus the plant uses a buried pipeline to convey the discharge concentrate 22 miles into the desert surrounding Fort Bliss where it is
pumped via a deep well injection system 4,000 feet below the ground (American City and County 2011).

While Mexico does not figure as one of the world’s top users of desalination technology, interest is growing, particularly in the states of Quintana Roo and Baja California Sur, where the technology is increasingly used to support the tourist industry and related population growth (López-Pérez 2009). Mexico’s largest desalination plant in Cabo San Lucas (in the state of Baja California Sur) produces 5 million gallons a day (Spagat 2011). As of 2006, there were 435 registered desalination plants in Mexico with an installed capacity of 3,600 lps (82.2 mgd) five times more than in 2002 (López-Pérez 2009).

As we discuss in this paper, there is also growing interest in binational desalination projects located in the upper Gulf of California that could potentially benefit both U.S. and Mexico. One of these projects has significant binational dimensions. Two huge desalination plants are being planned for Playas de Rosarito (Rosarito Beach), 15 miles south of San Diego, in Baja California, with some of the desalted water planned for cross-border transport and sale. Four major water agencies that serve thirsty cities in southern California, Tijuana, Phoenix, and Las Vegas commissioned a feasibility study in 2010 and are now involved in a second study that will include cost estimates (Spagat 2011). The two plants combined will have the capacity to produce 150 mgd (567.8 mld) sufficient to supply 300,000 homes on both sides of the border; the first plant will produce 50 mgd.\(^4\) The first of a four-phase study, completed in March 2010, found no “fatal flaws” that would prohibit construction of the project (San Diego County Water

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\(^4\) The second plant is part of a proposal by Consolidated Water Co., a Cayman Islands company, with Mexican investors. The second plant would send much of its 100 million gallons a day from Rosarito to the United States via a new pipeline, with operations beginning in 2014 (Spagat 2011).
Some U.S. based environmental groups have vociferously objected to the project given anticipated impacts on marine life (Spagat 2011; Burgin 2011). The U.S. water districts want to propose helping to pay for the plants’ construction and allow Mexico to keep the desalted water, in exchange for a portion of Mexico’s annual 1.5 million AF (1,850 MCM) share of Colorado River water guaranteed by a 1944 water treaty (Spagat 2011). Such an arrangement would avoid the additional expense of a conveyance system to transport the water across the border. However, perceptions of fairness by the media and public and political considerations in Mexico would be important considerations in influencing Mexico’s stance on such an exchange. Additionally, it is possible that farmers in Mexico – the current recipients of a large share of the 1.5 million acre-feet of Colorado River water delivered from the U.S. – may express disapproval and resistance to such an exchange if expensive, desalted water were used to meet urban demands in Mexican coastal cities.

**Benefits associated with Desalination**

Arid countries around the globe are expanding their investment in desalination technology and systems due to increased water scarcity, increased demand, and the perception of its intrinsic benefits. The National Research Council (2008) deems desalination “a realistic option” though noting its financial, social, and environmental costs. In its study of California, the Pacific Institute (Cooley et al., 2006) found that desalination is not a “magic bullet” but is likely to be an important “piece of the puzzle”
in the state’s future water supply. Tal (2011:36), an environmental researcher at Ben Gurion University, states that “water is more renewable than ever before and modern societies can produce as much as they need or want of it.” Based on a detailed evaluation of the desalination experiences of three countries that have led expansions of the technology—Israel, Australia, and Spain—Tal finds, on balance, that desalination experiences have reduced water shortages without causing debilitating negative impacts on the environment due to a range of strategies and technologies capable of addressing negative externalities. Among the benefits identified in these studies are the following: reduction of water shortages (especially for drinking water but also, potentially, for agriculture), increasing cost-effectiveness, improved affordability (including at prices for developing countries), and potentially, enhanced national environmental security.

Countries with assertive desalination strategies have a range of heterogeneous experiences, suggesting that desalination experiences are context-specific. For example, Australia’s desalination experiences have met with substantial public opposition, due to system inefficiencies and a perception of insufficient conservation of existing resources. Nevertheless, Australia has expanded its desalination plans and is working to supply its new plants with renewable energy. Israel, with one of the world’s most efficient water management systems, has enjoyed public support of its expanding desalination systems. Its Ashkelon desalination plant, among others, has yielded “inexpensive, high quality water” (op. cit., p. 41). Israel’s experience, in short, is deemed “a mighty step in the direction of hydrological sustainability” (Tal 2011:41).
Economic Considerations

While the costs of producing desalinated water have dropped dramatically in the last decades, it remains a costly process. The cost varies depending on the concentration of total dissolved solids (TDS) of the source water, the amount of water produced, energy costs, and the type of technology used. Energy and fixed costs are considerable (Figure 3). Estimating costs is problematic, as there are many variables that can be considered and there is no standard method for calculating costs.

Figure 3. Cost breakdown for a reverse osmosis desalination plant. Source: Pacific Institute (Cooley et al., 2006).

Cost estimates may or may not include the cost of conveyance, distribution, membrane replacement and concentrate management, among other variables. Costs of amortization and subsidies, along with costs of planning, permitting, and environmental impact mitigation measures will also affect the final cost of a desalination project (NRC 2008, Cooley et al., 2006).
Table 1. Salt Concentration by Water Source Type. Source: Pacific Institute, Cooley et al., 2006:11.

The National Research Council (2008) reports the lowest unit cost of producing freshwater from seawater as $0.64/m³ ($800/acre-foot or $2.46/thousand gallons) (NRC 2008:153). Less concentrated brackish water can be desalinated at significantly lower costs, but depends on the TDS levels of the source water (see Table 1 for salt concentration by water source type). As shown in Figure 3, energy is the major cost associated with reverse osmosis processes. When comparing the cost of desalinated water to other water supply alternatives, NRC emphasizes the need to evaluate relative (rather than absolute) costs. Conservation and water transfers are usually the least costly water supply augmentation options (NRC 2008:180).

Much attention has been paid to the direct costs and benefits associated with desalination, but the potential expansion of growth enabled by expanding the water supply of a locale and its associated costs and benefits have been relatively neglected. Although the California Coastal Commission concluded in 2004 that “a desalination facility’s most significant effect could be its potential for inducing growth,” less attention has been paid to this potential impact (qtd in Cooley et al., 2006:67). To provide an environmental benefit, as Cooley et al. (2006) note, it is necessary to have an “explicit mechanism” to ensure that desalted water will be used in wetter-than-normal years for
environmental purposes (i.e., releasing water from dams). Otherwise it is likely that surplus water will aid further growth, rather than conservation (McEvoy and Wilder 2011; Wilder et al., 2010; Cooley et al., 2006).

**Energy Use and Costs**

Energy requirements are the “largest single variable cost for a desalination plant” (Cooley et al., 2006, p. 41) and vary widely (Figure 4). Reliance on desalted water “creates or increases the water supplier’s exposure to energy price variability and energy price increases over time” (Cooley et al., 2006:55). However, for inland desalination facilities, the cost of concentrate management may be as significant as the energy costs (NRC 2008:179).

![Figure 4. Energy requirements for desalination vary considerably worldwide. Source: Pacific Institute (Cooley et al., 2006). PERMISSION NEEDED.](image-url)
Energy requirements account for 44% of water costs in reverse osmosis plants, and nearly 60% of water costs in thermal plants (Cooley et al., 2006:41). Reverse osmosis uses approximately ten times more energy than traditional treatment of surface water, and if they are fueled by carbon-based sources will further contribute to greenhouse gas emission (NRC 2008:142). In such cases, desalination plants can have a “particularly heavy” environmental footprint (Tal 2011:38).

Environmental Impacts

Given a lack of long-term research, the U.S. National Research Council concluded there is “considerable uncertainty” about the environmental impacts of desalination (NRC 2008:144). The reverse osmosis process utilizes chemicals that are “eventually released into marine environments” (Tal 2011:38). Antiscalants (chemicals such as polymers and phosphates) that prevent clogging in membranes, coagulants (e.g., ferric sulfate and ferric chloride), and membrane preservatives (sodium bisulfite) are all used in the RO process. For seawater desalination, there is concern that marine organisms could become trapped in the intake systems. Screens and exclusion systems can help reduce the entrapment of some organisms and subsurface beach well intakes eliminate the potential of organism entrapment (NRC 2008). Discharge of the concentrated brine—containing twice the salinity level of seawater (Tal 2011)—is perhaps the thorniest of environmental issues faced in developing desalination plants. In the reverse osmosis (RO) process, when water moves through the semi-permeable membrane, two streams of water are produced. One

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5 Using case-study examples from the Natural Resources Defense Council, NRC (2008) shows that pumping groundwater 120 vertical feet requires 0.14 kWh/m³, treating surface water requires 0.36 kWh/m³, treating brackish water requires ~0.3 to 1.4 kWh/m³ and seawater desalination (excluding energy requirements for conveyance) requires ~3.4 to 4.5 kWh/m³ (p. 142).
is a freshwater stream, the other is a highly concentrated stream of brine wastewater. For both seawater and inland desalination there is concern about the impact of the highly concentrated brine discharge on marine or terrestrial ecosystems. Seawater RO systems typically recover 35 to 60 percent of feedwater, whereas brackish RO systems can recover 50 to 90 percent of feedwater. The remainder of the feedwater becomes highly concentrated salt solution that must be disposed of (NRC 2008:74-76). The most common disposal method for seawater RO plants is dispersal back into the ocean. Best practices include blending and diluting concentrate water with seawater before dispersal and using multiport diffusers to spread out the discharge stream. Cost-effective and environmentally sensitive disposal options for inland desalination are limited (NRC 2008:107). Deep-well injection of large volumes of discharge is one option, but depends on the availability of a structurally isolated aquifer to contain the discharge and avoid contamination of fresh groundwater sources. Evaporation ponds which result in zero liquid discharge (ZLD) are possible in dry, warm climates, but occupy large expanses of land (NRC 2008), ultimately destroying their environmental and cultural values.

Geopolitical Considerations

In addition to economic, social, and environmental dimensions of desalination, there are also domestic and transnational political considerations in a binational context. Thus, desalination technology as a source of water supply that links these dimensions requires a multidisciplinary approach which in turn demands a cross-sectorally-based, more comprehensive policy design. It is a mistake to think that the broad and complex water agenda can be addressed within the water sector only. Several problems have an origin in, or relate to, non-water institutions. The development of desalination projects with
benefits or impacts that cross the national boundary between two (or more) countries suggests the potential for shifts in the geopolitical power relationship between (or among) them (Wolf 2009).

Transboundary desalination raises the prospect of greater cooperation—or suggests the specter of heightened conflict—in those border regions. Two contrasting concepts capture some of the possibilities: “hydrohegemony”—in which the more powerful riparian interest can set the terms of the relationship—and “hydrosolidarity” – referring to an ethical and practical position of solidarity and cooperation that can emerge among upstream and downstream users on a transboundary watershed (Gerlak et al., 2011; Zietoun and Warner 2006; and Stockholm International Water Institute 2010).

Wolf (2009) suggests that desalination could have important implications for geopolitical and spatial shifts in power over water resources, with, for example, control moving from headwaters to coasts. In the case of a binational desalination plant, where the ownership and management of the plant and use of the water produced is not within the jurisdiction of a single country, cities and farms within the region would be increasingly dependent upon maintaining good binational relations, with implications for the water and food security of the involved countries (Varady, et al. 2010; Wilder et al., 2010).

III. Assessment of the Existing Binational Water Policy and Governance Framework for Desalination Systems in a Binational Context

Arizona-Sonoran Binational Context

Interdependence and asymmetry are two key words that capture the reality of the Arizona-Sonoran region (Wilder et al., 2012; Megdal and Scott 2011). The
interdependence of the region’s communities has helped them maintain strong trans-border economic and cultural ties and lends it resilience and capacity for meeting challenges.\textsuperscript{6} Governance distinctions and institutional complexity in water management result in unevenness in the structures available for responding in a cooperative manner. Economic distinctions on both sides of the border reflect disparities in household income levels and municipal budget capacity. This economic and institutional asymmetry can create bigger challenges in tackling environmental and other issues collaboratively but they can be overcome, in cases, through effective collaboration (Megdal and Scott 2011; McEvoy and Wilder 2011).

Institutions and Governance

The prospective advent of desalination as a mode of water-supply augmentation in the border region relies of course on suitable technology and feasible economics. But for such a significant—even if partial—transformation of the regional water network to occur, political considerations will certainly become paramount. Chief among these considerations will be the nature of institutions and governance structures that facilitate these changes in a cooperative, binational way. To determine whether such a course is possible or likely, we must ask whether the present institutional infrastructure and

\textsuperscript{6} Interdependence is evident in trans-border maquiladora assembly and warehousing processes and in agricultural trade. The shipment of Mexican produce into the United States is a significant driver of the Nogales, Ariz., economy, as Mexican produce-filled trucks are obliged to transfer their shipments to warehouses on the U.S. side of the border. Nogales, Ariz., depends heavily on the retail tax derived from this commercial and produce-shipping industry. The Mariposa Land Port of Entry (LPOE) at Nogales is the third most traversed LPOE in the United States. In 2008, it registered approximately 2 million crossings, including 303,000 commercial trucks (Gibson 2009), of which one-third transported produce of 40 different varieties, worth $2 billion, representing between 50 and 60 percent of all winter produce entering the United States annually (www.nogalesport.com). Ten percent of the total produce entering the United States in 2008 crossed through the Mariposa LPOE (Kraushaar 2009). Another $5.5 billion in non-produce goods, such as canned or processed fruits, crossed the border into the United States (Wilder et al., 2012).
arrangements are sufficiently robust to permit a new and relatively expensive technology to take hold.

As noted above, the border region is characterized by certain asymmetries and imbalances. The physical environment, landscape, and resource base is continuous across the international boundary. For the most part, so are the traditional economic mainstays—mining, farming, and ranching. But much of the human environment exhibits widely different profiles on the two sides of the border. Culture, language, political systems; demographic trends; legal traditions (English vs. Napoleonic); level of infrastructure; educational systems and research establishments; governmental organization, scale, hierarchy, and decentralization; the relative vigor of civil society, including such qualities as transparency and public notification; the degree of indigenous autonomy; and most significant for our purposes, vulnerability and ability to cope with environmental stress—all of these features continue to vary widely in the two countries.

In confronting the challenges of adopting desalination as a new water source, it’s worth asking which governance factors matter most. Two attributes serve as bookends: good relations between the neighboring countries and especially, trust among actors at all levels. In between, we can identify the following key elements of successful cross-border cooperation: access to appropriate government agencies; comparable and compatible agency priorities; a robust research environment that offers easy access to sites, information, and informants; availability of data in comparable units, scales, and accuracy; strong partnerships among officials, researchers, and stakeholders (“communities of practice”); and availability of funds and other resources; and ability of the actors to communicate effectively.
In the case of decisionmaking in the world of water, the above-noted challenges are numerous and frequently daunting. They include: insufficient appreciation of context; difficulty in obtaining timely, essential, and compatible information; incompatibility between hydrological and political world views, especially in regard to issues of sovereignty; the poor match between political and practical priorities; difficulty in overcoming bureaucratic inertia; concern about procedural fairness, distribution of costs and benefits, and management of negative externalities; weak partnerships; barriers to sharing resources and credit; poor binational relations leading to suspicions of motives; and inability to forge close working relations with agencies, communities, colleagues (Varady 2009a).

Since Mexico’s independence, that country and the United States have experienced a checkered history of political relations marked by periods of mistrust interspersed with times of relative harmony. Over the past century, and particularly since the 1940s, the two nations have built a suite of binational institutions to deal with shared waters. They have long maintained a binational commission to resolve boundary issues—originally the International Boundary Commission (IBC), created in 1889 and changed to the International Boundary and Water Commission (IBWC) in 1944 to emphasize its role in applying the water treaty and overseeing transboundary water issues. IBWC, the U.S. branch, partners with the Mexican branch, CILA, the Comisión Internacional de Límites y Agua. Also in 1944, Mexico and the United States negotiated a treaty governing allocations of the Colorado and Rio Grande/Río Bravo Rivers. Four decades later, in 1984, the two nations signed their first environmental accord, the La Paz Treaty.
The most recent additions have resulted from the 1994 North American Free Trade Agreement (NAFTA), which spawned the Border Environment Cooperation Commission and its financing sibling, the North American Development Bank (the two institutions merged in the late 2000s but have maintained their identities). Together, BECC and NADBank—both binational in composition and operation—have financed environmental infrastructure in the border zone, with an emphasis on water and wastewater treatment (Varady 2009b).

Wastewater treatment in the region features two binational plants—one in Arizona, just north of the border; the other serving the San Diego-Tijuana urban area. These plants have been managed and operated by IBWC-CILA, which also is responsible for overseeing binational desalination efforts. In these matters, IBWC-CILA proceeds with input and financing from major public and private water management agencies, including, in Arizona, the U.S. Bureau of Reclamation, Central Arizona Project, Salt River Project, and Arizona Department of Water Resources; and in Sonora, CONAGUA and the state water commission (CEA).

The degree of local involvement in desalination is not well understood, largely because of the very limited experiences to date. In Mexico, only Los Cabos, which is not in the region under study, has had a large-scale, municipal operating plant; while in the U.S., the Yuma plant has lain idle for much of its lifetime. The fact that most decisions have been taken at the federal and state levels raises the issue of scalar imbalance—that is, is equity properly considered when those who negotiate and make decisions do not

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7 Mexico has hundreds of desalination plants. Most are small-scale private plants. Some are federally funded (via CONAGUA) plants, but there are also small-scale plants for fishing villages. For example, La Paz, BCS, has two private hotel desalination plants. Los Cabos has more than 22 private hotel desalination plants, plus the larger (publicly funded) plant to serve municipal needs.
include those who are affected and may potentially benefit? In this instance and in related situations, formal legal frameworks are likely to prevail over consultative, flexible, negotiations that might leave more room for adaptation and improvement down the road as conditions change (Mumme et al., 2009; Wilder et al., 2010).

Regional social vulnerability

Multiple studies have identified the Arizona-Sonora portion of the U.S.-Mexico border as a region of high social vulnerability due to intersecting processes of rapid growth, domestic and international migration, economic intensification and globalization, and climate change (Liverman and Merideth 2002; Ray et al., 2007; Wilder et al., 2010; Scott et al., 2010; Wilder et al., 2012). The Arizona side of the border has higher poverty and water insecurity relative to the rest of the U.S., and Arizona overall ranks fourth in the poverty level among U.S. states (tied with another border state, New Mexico) (U.S. Census 2010). On the other hand, the Sonora side of the border is wealthier relative to average indicators for Mexico (Ganster and Lorey 2008).

Despite progress made over the last two decades to extend municipal water and sewerage networks, the rapid growth of Sonora has outpaced urban planning and infrastructure construction. Unplanned (informal) colonias with thousands of residents in major cities like Nogales, Sonora, and the state capital, Hermosillo, often are off-the-grid for water, sanitation, and electricity and rely on purchased water from trucks at relatively higher cost than municipal tap water (Wilder et al., 2012). Water-scarce states like Sonora use a water rationing system, or tandeo, in major cities including Hermosillo and its largest border city, Nogales. Basic infrastructure, such as paving, is limited in the informal colonias. Housing built on unsafe hillsides or in floodplains leads to severe
erosion and flooding of unpaved streets when it rains, often disrupting water supply for neighborhoods reliant on water truck deliveries. Multiple socioeconomic asymmetries exist between the U.S. and Mexico sides of the border, with average incomes and municipal budgets on the Arizona side of the border higher than in Sonora (Wilder et al., 2012).

Desalination has gained traction as a potentially important source—one among several—in part due to a prolonged drought and a recent experience of a hotter and drier climate. Future water supply is likely to be diminished by climate change in the Arizona-Sonora region. Climate changes that are projected to affect cities and agriculture include: 1) increasing annual and seasonal temperatures, (in both summer and winter; 2) decreasing precipitation; 3) decreasing Colorado River streamflows; 4) increasing droughts; and 5) longer and more frequent heat waves (Wilder et al. forthcoming, 2012).

Higher temperatures coupled with increased population growth raise demand on an already severely-stressed water system and simultaneously create potentially unsustainable peak demands on associated energy infrastructure. Major cities and irrigated agriculture in the region are heavily reliant upon the Colorado River and groundwater; the river’s supply is over-allocated while regional groundwater aquifers are severely depleted (Scott 2011).

Water efficiency improvements, water conservation and re-use practices, as well as technological changes including desalination of seawater may hold potential as adaptive strategies for the region, but uncertainties surround all policy alternatives. Supply-side solutions, including re-use and desalination, would ideally be coupled with specific mechanisms that ensure that the extra water supply is used to buffer demand
during dry periods. Otherwise, the additional water produced through desalination is likely to induce growth, adding little to the region’s adaptive capacity (McEvoy and Wilder 2011, Cooley et al., 2006). Agriculture and cities will increasingly compete for water, with potential threats to agricultural livelihoods and traditional way of life, and with implications for food security (Wilder et al., forthcoming 2012).

The water governance and institutional framework of the U.S.-Mexico border region is wide and complex. It includes a long list of institutions, programs, laws, and regulatory bodies. In the case of Mexico, broadly speaking, the following are among the major players: the three levels of government (federal, state, local); federal and state congresses; judges and magistrates; river basin councils; farmers; industrialists; development banks; academia; the media; non-governmental organizations; and of course families. In the particular case of financing water infrastructure, there are several institutions and actors from the public and private sector. Having the Santa Cruz aquifer as a case study, Milman and Scott (2010) provide a good account of the institutional arrangements in the two countries, as well as their interdependencies.

Water governability along the U.S.-Mexico border region faces several difficulties (Salmón Castillo, 2011). Even though Mexico and the United States have been able to build a legal and institutional framework to solve problems and address emerging affairs, the negotiating process encounters some difficulties. The latter – which are not exclusive for these nations - would involve cooperation which is inhibited

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8 This list comes from CONAGUAS’s Water Agenda 2030.
9 According to Gutierrez Fernández (2011) the following institutions relate to water finance. In the USA: Federal grants; local governments; public utilities; Drinking/clean water state revolving funds; water development boards; EPA; state environmental agencies; North American Development Bank; private investors; private utilities; commercial banks; institutional investors; and bond buyers. In Mexico: The three levels of government; National Water Commission; local water authorities; North American Development Bank; National Infrastructure Fund; state water commissions; private investors; private utilities; and commercial banks.
by factors such as the following: Definition of terms, concepts, and expressions in the transborder context; the wide variety of instances and stakeholders that participate, or want to participate; the bilateral agendas of the countries involved; the faraway distances of national capitals; the lack of trust in the institutions of each country; different legal systems; existing asymmetries between countries; and competition among different uses for the same resource.

Mexico’s policy on seawater desalination is a work in progress and criteria for its adoption and implementation are still under the scrutiny of experts and authorities. The issue is most relevant to the Northwest region (Sonora and the Baja Peninsula) where there have been different desalination initiatives in Hermosillo, Los Cabos and Ensenada. The word “desalination” was mentioned in Mexican law for the first time in 2004 when the Law of National Waters (LAN) was modified. What is clear is that in order to achieve a decision to establish a binational desalination plant (such as has been proposed for Puerto Peñasco, discussed in section V), all three levels of government authority—federal, state, and local-- have to line up and agree upon this project.

This list of stakeholders includes only the most critical actors; there are many other government agencies and actors that would be involved in other more ordinary issues (taxes, labor, communications, security, etc.). As required by the 2004 LAN reforms, public participation is intended to be an integral part of decisionmaking around water in Mexico (Wilder 2010; 2011). Civil society, including non-governmental organizations and local residents, ought to be maintained informed and provided a

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10 It is also relevant in southeastern Mexico's Yucatan Peninsula, where most of the small-scale desalination plants are located in hotels to serve the tourist industry.
meaningful voice in the decision-making process to ensure transparency and accountability, and to lend sustainability to the project.

**Stakeholders in the United States**

Institutions in the United States function in a highly decentralized setting, with a great deal of authority devolved to the states. At the federal level, decisionmaking on water-related issues is complicated by the existence of numerous departments, agencies, and other institutions that frequently have overlapping and sometime conflicting missions. To illustrate the complexity of this institutional framework, the U.S. Environmental Protection Agency (EPA) is entrusted with assuring adherence to federal water-quality standards. But EPA has no authority or jurisdiction in the related realm of assigning, adjudicating, or enforcing access to water supply; that function is largely left to the states, which have disparate and often incompatible rules and traditions.

Similarly, although EPA is considered the nation’s water-quality agency, “quality” for EPA refers to chemical content and the agency’s chief mandate is to control the quality of drinking water. But water quality, if it affects the viability of wildlife, comes under the purview of the U.S. Fish and Wildlife Service, which is charged with enforcing the Endangered Species Act. Similarly, salinity of major sources of water supply is the responsibility of the Bureau of Reclamation, or if excessive salinity results from agricultural practices, this issue is left to the U.S. Department of Agriculture. The National Environmental Protection Act (NEPA) governs discharges into navigable waters of the U.S., which include Arizona’s dry rivers.

At the state level, things are even more convoluted, with a replication of the above problems among state agencies responsible for environment, health, agriculture, wildlife,
and other water-related concerns. Similar—and similarly overlapping—agencies also exist at county and municipal levels. And, in the United States the past century has witnessed the addition of further layers of decisionmaking and administration: some top-down, like regional water authorities, agricultural districts, soil and conservation districts, groundwater active management areas (as in Arizona); and some bottom-up, like watershed councils, user associations, environmental NGOs, and community-based groups (Colby and Jacobs 2010). Individual (e.g. farmers and irrigators) and community (e.g., tribes) water rights are established in a complex set of regimes that varies by state and by region; thus, individual water users are also stakeholders in the process. Water rights adjudication and legal precedence have determined much of the current rights regime and will continue to do so in the future.

Stakeholders in Mexico

If institutions in the United States operate in a decentralized environment, by contrast their Mexican counterparts exist in a highly centralized context where the federal government retains dominant influence over water decisionmaking and management.

The principal Mexican stakeholders are the following: Mexico’s National Water Commission (known as CONAGUA), its Environment Ministry (Secretaría del Medioambiente, y Recursos Naturales, SEMARNAT). These ministries and agencies and the municipality in question, would all be involved in making decisions regarding a binational desalination plant.

CONAGUA, an agency of SEMARNAT, manages water concessions. This agency would grant the concession for seawater and would be a key actor throughout the policy-making and implementation process. The National Water Program 2007-2012 sets
forth objective number 3 “To promote integrated, sustainable water management in river basins and aquifers.” As part of this objective, the program states “so as to increase water availability, it is necessary to develop projects for artificial aquifer recharge, evapotranspiration management, collection and desalination of brackish or salt water in coastal zones or closed river basins, and the combined use of surface waters and groundwaters, among others” (Gobierno Federal, 2007, p. 51).

SEMARNAT carries out the Environmental Impact Assessment (EIA) (Manifiesto de Impacto Ambiental-MIA), grants (if required) the permission for the discharge of wastewater, and oversees and monitors environmental impact throughout Mexican territory (both land and sea). In accordance with the Ministry of International Relations, it is in charge of international affairs or contracts dealing with water and natural resources. In addition to these two federal agencies, the Federal Electricity Commission (Comisión Federal de Electricidad, CFE) would supply the power necessary for the plant. This is a national monopoly and is, by law, the only power supplier. Arrangements have to be made in advance in order to have the adequate amount of power available.

Preparation of an EIA would be a critical node in the decision path required by and of SEMARNAT before any further planning could take place. Such an assessment would evaluate effects on the Sea of Cortes both by the seawater extraction and, if required, by the disposal of salts and wastewaters as byproducts of the desalination process. This assessment requires a good deal of expertise where the scientific community of both countries has to be involved and agree upon the assessment conclusions. (In the past, discussions regarding establishing a transboundary
environmental impact assessment (TEIA) among the NAFTA countries—Canada, the U.S., and Mexico-- faltered on the shoals of different institutional structures; however, recently there has been a renewed interest (by the White House, at least) in moving the initiative forward.) In addition, the power supplied by CFE is a primarily a technical decision that would have to be made based upon the availability of the oil required to produce the power, the required thermoelectrical plant capacity, and the payment of the required regulatory fees to the CFE. An attractive alternative is to produce electricity by other means such as solar radiation or wind, especially appropriate in Sonora.

The Municipality (local government) that, according to city plans and regulations, grants the land use permit (permisos de uso de suelo) for the location where seawater would be tapped, the site of the plant itself and the path of the aqueduct. In case the aqueduct would cross the territory of more than one municipality, permission has to be obtained from each one of them. This would be the case, for instance, of Municipio Plutarco Elías Calles (Sonoyta) or San Luis Río Colorado whose territories could be affected if a binational desalination plant were to be sited in Puerto Peñasco (as discussed in section IV).

The municipality’s decision should be made in accordance with the criteria established by Sonora’s Law of Territorial Order and Urban Development of the State of Sonora, as well as with the Tourism and Urban Development Programs of the

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The U.S. Good Neighbor Environmental Board (GNEB) has advocated for a transboundary environmental impact assessment (TEIA) process. In January 2012, the chair of GNEB (Diane Austin) received a letter from the director of the White House Council on Environmental Quality, Nancy Sutley, stating: “In the past, differences among the federal structures of the three parties of the NAAEC presented significant challenges to achieving a TEIA agreement. The United States believes it is appropriate to take a fresh look at this issue and has initiated discussions on the subject with our Canadian and Mexican partners, with the goal of identifying a new and effective approach. Consistent with this view, the White House Council on Environmental Quality also will continue to work with the appropriate federal departments and agencies to facilitate increased collaboration on border environmental issues.”
municipality and the availability of suitable locations for this purpose. In addition, other developments planned for the Gulf of California, such as the federal “Escalera Náutica” project has to be taken into account. In the process of obtaining the land use permit, despite the fact that it is a municipal responsibility, it is very likely that the Sonora State Government and even the Federal Government (by means of the Ministry of Tourism, for instance) would intervene and adopt a leading and decisive role. Last but not least, prior to the granting of the municipal land permit, the local community (represented by key stakeholder groups such as the Chamber of Commerce or Tourism) would have to be consulted and agree the desalination decision-making path.

There are three key critical procedures that are policy-relevant: 1) the extraction of seawater; 2) the discharge of wastewater and brackish water; and 3) the exportation of desalted water across the border. We will address enabling and limiting conditions for each of these procedures in turn.

The concession for seawater extraction

It is well known that, in Mexico, water is not private property, but rather is considered the “original” property of the Nation (Article 27 of National Constitution) and its use and exploitation is governed by the Mexican President and more directly by CONAGUA. This also applies to “territorial” seawater, meaning seawater within a zone of 12 nautical miles from the Mexican coast. For this reason, seawater extraction is regulated by the LAN. This law establishes that the extraction of seawater does not require a concession, “except when it is for the purpose of desalination” (LAN, Art. 17, reformed in 2004). Therefore, in Mexico, seawater desalination requires a concession granted by the
Mexican President, via CONAGUA. Concessions may be granted for a minimum of five years and a maximum of thirty years (Art. 24).  

**The discharge of wastewater and brackish water**  
This activity is regulated by the Law of Ecological Equilibrium and Protection of the Environment under the charge of SEMARNAT which, prior to the concession, has to prepare an environmental impact assessment and is responsible for monitoring the operation of the desalination process as well as the wastewater disposal. SEMARNAT is currently working on a new regulation (norma) that would regulate the concentration levels of discharge. But at the moment there is no norm governing discharge, except as outlined in the EIA, which could vary on a case-by-case basis.

The choices for the discharge of wastewater are the following: 1) discharge salts and wastewaters into the sea. The permission for this depends on the AEI and would have a fee; 2) discharge or disposal of salts and wastewaters inland (for instance in injection

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12 The LAN does not clarify whether a concession of this kind might be granted to a foreign enterprise or individual. However, the most viable way towards obtaining a concession would be to legally set up a Mexican affiliate of a foreign enterprise that would abide by the Mexican rules and procedures and pay Mexican taxes and fees. This enterprise would be the Mexican recipient of the concession to tap seawater. It is not completely clear whether a fee has to be paid for seawater extraction. Apparently it depends on the place the seawater is extracted from and the amount of solids it contains. The Federal Law of Fees (Ley Federal de Derechos- LFD, Art. 24, VI) establishes the following criteria: a) If seawater is tapped directly from the ocean, there is not fee.  

b) If brackish water is tapped inland and it contains more than 2,500 milligrams per liter of TDS (total dissolved solids), there is no fee.  
c) If brackish water is tapped inland and it contains less than 2,500 milligrams per liter of TDS (total dissolved solids), there is a fee.  
It the situation falls in case C, in the region of Puerto Peñasco and Sonoyta, for example, (which is considered to have no water available), in 2011 the fee would be 10.0589 Mex. Pesos (approx. $0.80 U.S.D.) per cubic meter.
Exportation of desalted water across the border
There exists no previous experience of exportation of fresh water as an industrial product in Mexico.\textsuperscript{14} For this reason, apparently there are no legal provisions for this economic activity. However, since water is a natural resource in the same way as metals and minerals extracted from Mexican mines by foreign mining companies, the regulations applied for the exportation of minerals might be considered as a likely basis to determine the requirements and conditions for exporting desalted seawater. A likely difference is that border agencies, such as the IBWC, might be involved in this case.

In sum, the approval of a desalination project relies heavily on the lining up (or agreement) of these major government actors as well as on a general perception in Mexico that the deal is fair and that local communities will be benefited from this project, not only with fresh water for local use but also with other investments, employment and the protection of the desert environment and the Gulf of California.

\textsuperscript{13} The LFD defines the fee for the disposal of wastewaters. The amount of the fee depends on a) the place that receives the discharge, b) the amount of discharge and c) the amount of contaminants discharged (Art. 278). The maximum amount of contaminants that is liable for obtaining permission are 150 mg/liter of TSS (total solids in suspension) and 320 COD (Chemical Oxygen Demand) (LFD, Art. 278-B-VII). The fee charged for the kilogram of CDO (Chemical Oxygen Demand) per liter per trimester is 0.3137 Mex. pesos. The fee for the kilogram of SST (Total solids in suspension) per liter per trimester in 2010 is 0.3137 Mex. Pesos.

\textsuperscript{14} An exception to this is the “virtual water” embedded in crops exported from Mexico, although this is a “use” not explicitly recognized in Mexican water law. For a good discussion of the issues surrounding virtual water, see: Allan, J. A. 2005. Water in the environment/socio-economic development discourse: Sustainability, changing management paradigms and policy responses in a global system. Government and Opposition 40, no. 2: 181-199.
Water-energy tradeoffs in binational desalination

Desalination in the Arizona-Sonora border region reflects broader interrelations among water and energy resources and their use, on the one hand, and social and environmental context and expected outcomes, on the other. Given the region’s aridity, the relative scarcity of water in relation to human demands coupled with the region’s poor conventional-energy endowment seriously challenge (Scott and Pasqualetti, 2010) the common understanding of opportunities offered by the water-energy nexus, in which lack of one resource may be overcome through development and use of the other (Sovacool and Sovacool, 2009).

Future demand for electricity (including for desalination) in the region is expected to be met largely by using conventional, fossil-fuel sources, even though: 1) the border region possesses the best solar energy resources in North America; and 2) there have been recent developments in commissioning solar energy technology, including with binational (NAD Bank) funding. In 2008, Arizona adopted the Renewable Energy Standard and Tariff (REST), setting a target of 15% of electricity sales by 2025 to be met using renewable energy. In Sonora, electrical power supplies rely heavily on conventional sources with only 8% of the state’s generation met through a single non-fossil-fuel source, hydropower (CFE, 2011) – that presents its own water-energy nexus challenges. As a result, the generation of electricity, including that to be used for desalination, is largely from thermal power plants. Additionally, an important, but undisclosed, fraction of Sonora’s fuel for electricity generation is being imported, mostly from the U.S. – raising the likelihood of a double-reverse energy-for-water swap, i.e., U.S. energy for Mexican power generation for desalination to partially meet U.S. water
demand. And even once fuel for Sonora’s conventional thermoelectric power generation is supplied from Mexican domestic or U.S. sources, local water-energy tradeoffs are at play at the power-plant scale. In other words, cooling water is needed to generate the power needed to desalinate seawater.

At the desalination plant level, let us assume at least 85% of water used results in desalinated water, with 15% or less rejected in the brine stream.\textsuperscript{15} As noted above, the current electricity generation portfolio in Sonora is heavily thermal-based, with the result that proposed additions of 20 MW for the Puerto Peñasco municipal plant, or 50 MW for the Arizona-Sonora binational plan would increase Sonora’s current greenhouse gas (GHG) emissions by an estimated 1.9% and 4.8%, respectively. Clearly, proposed solar power generation for Puerto Peñasco desalination would reduce these increases. On the other hand, the 500 MW regional binational plan would require very substantial increases in generation, unlikely to be met by solar, and thus, that option has the most significant emissions implications in percentage-increase and total GHG terms.

Thus, the long-term implications of desalination as a carbon-intensive climate and water adaptation strategy and growth-augmentation measure require urgent policy, resource-planning, and investment attention.

IV. \textbf{Existing and Proposed Plants and Plans}

In this section, we provide a detailed analysis of two desalination projects in the Arizona-Sonora region, assessing them from a systemic perspective based on their actual or projected social, economic, and ecological benefits and impacts. In particular, we focus on the binational implications of these initiatives.

\textsuperscript{15} This recovery rate for desalinated water and for production of briny concentrate is more optimistic than typical figures cited by the National Research Council (NRC 2008).
Yuma Desalting Plant

The Colorado River system supports nearly 30 million people along its 1,400 mile (2,250 kilometer) length, 120 miles (193 km) of which are in Mexico. The Colorado River is one of the two major transboundary rivers in the United States and Mexico (with the Rio Grande/Río Bravo as the other). It has its headwaters in the Rocky Mountains (Wyoming and Colorado) (Pitt et al., 2000). Seven U.S. states, many Native American Nations and two states in the Republic of Mexico share the Colorado River flows. By treaty, the U.S. must deliver to Mexico 1.5 million acre-feet annually. It irrigates 3.7 million acres [1.5 million hectares (ha)] of farmland, including 500,000 (200,000 ha) in Mexico. Major cities in the border region drawing on the Colorado for urban uses include San Diego, San Luis Río Colorado (SLRC), and Mexicali. Major agricultural areas reliant on surface water from the Colorado include Imperial and Coachella Valleys, and SLRC and Mexicali irrigation districts.

The $280 million Yuma Desalting Plant (YDP) operated by the U.S. Bureau of Reclamation (USBR) and located near the international border in Yuma, Arizona was completed in 1992. The plant was initially constructed to gain compliance with the water quality standards required by Minute 242 of the 1944 U.S.-Mexico treaty, with its goal of reducing the salinity and improving the quality of Colorado River water being released to Mexico. The YDP was intended to desalt return flows from agricultural operations of the Wellton-Mohawk Irrigation and Drainage District. The desalted water would be discharged into the Colorado River for delivery to Mexico; the brine byproduct of the
desalination process was to be delivered to the wetlands region that is now known as the Cienega de Santa Clara, located in the Colorado River Delta region in Mexico (Figure 5).

Figure 5. Yuma Desalination Plant and Cienega de Santa Clara. Source: Central Arizona Project.

Although completed in 1992, the YDP was in operation for only a short period in the early 1990s, but then shuttered due to higher Colorado River flows and operational considerations. In that intervening period, the agricultural tail water was delivered to the Cienega instead of being treated at the YDP and then discharged into the Colorado River and delivered to Mexico. The water delivered from the Wellton-Mohawk to the Cienega is not counted as part of the 1.5 million acre-feet (1,850 MCM) the U.S. delivers to Mexico annually as part of its treaty obligations. In times of low flows of the Colorado River, water that would have been stored in Lake Mead has been used.
to meet the U.S. Treaty obligation. Lake Mead elevation levels are used by the U.S. Bureau of Reclamation and the Department of Interior as important Colorado River management triggers governing releases from Lake Powell to Lake Mead and declaration of Colorado River shortage (2007 Shortage Sharing Regulations). In addition, Lake Mead is an important recreational facility that creates significant tourism revenue and is the site for water intake by Southern Nevada Water Authority.

Reduced water storage is a concern to those who would be affected by reduced lake levels and declaration of Colorado River shortage. The continuation of drought conditions and concerns about the implications of climate change on long-term Colorado River flows have therefore led to increased interest in establishing the technical viability of operating the YDP to treat the Wellton-Mohawk agricultural return flows according to the original YDP purpose. The deliveries to the Cienega over the past 20 or so years could be considered accidental. Those relying on Colorado River flows are looking to reverse the accident, while at the same time recognizing that things have changed and the distinct environmental value of the Cienega must be considered.

In order to answer questions related to the technological and environmental viability of operating the YDP, the U.S. Bureau of Reclamation, the agency responsible for its maintenance and operation, has overseen two different test runs. After 14 years of YDP idleness, in 2007 Reclamation undertook a three-month “Demonstration Run,” during which time the plant was operated at about 10 percent capacity. The demonstration run established that the plant could operate and
yielded operational cost information, but it did not provide sufficient information regarding long-term, higher-capacity operations (USBR 2008).

In order to obtain additional information, Reclamation developed plans for a YDP “Pilot Run” in partnership with three agencies responsible for delivering Colorado River water to users throughout the Lower Colorado River Basin states -- Arizona, California and Nevada. The Central Arizona Project, Metropolitan Water District of Southern California, and Southern Nevada Water Authority shared in this effort to (1) develop additional operating cost information, (2) examine technical issues related to plant performance, and (3) study the environmental consequences of YDP operations (USBR 2009).

The pilot run, during which time the plant operated at approximately 30 percent and treated about 30,000 acre-feet of water, ran from May 2010 through March 26, 2011 (Cullom 2011). Operating costs were approximately $300 per acre-foot ($0.24 per m$^3$), with total costs of the pilot run coming in at about $500 per acre-foot ($0.41 per m$^3$). The pilot run has been deemed successful by the project partners in that it processed the water ahead of schedule and below the estimated costs. Research was conducted to identify options for renewable energy use. In addition, the environmental considerations associated with designing the pilot run were considerable.

The International Boundary and Water Commission (IBWC) facilitated the required binational communication and coordination by approving Minute 316, which authorized binational monitoring of the impacts of the pilot run on the health of the Cienega, including on bird and other endangered species, and their habitats.
Wilder et al., 2012 Puentes Consortium Paper

The $250,000 cost of monitoring would be funded by the U.S. pilot run partners. It also established that 30,000 acre-feet of water would be delivered to the Cienega to replace the redirected Wellton-Mohawk return flows. A draft report on monitoring has been delivered to the CAP and is expected to be released to the public in the next few months.

The entire Colorado delta is within Mexico (Pitt et al., 2000). It has been called “one of the most important estuaries in the world” (Zamora-Arroyo and Flessa 2009) and is the largest remaining wetland system in the southwestern North America. It includes the Cienega de Santa Clara (fed by Wellton-Mohawk (AZ) irrigation district return flows) and Andrade Mesa wetlands (fed by seepage from the All-American Canal until it was concrete-lined in 2009). Although originally comprised of 2 million acres (800,000 ha) of wetlands habitat, the delta has shrunk to only 10 percent of its original size since 99 percent of the water has been diverted (Zamora-Arroyo and Flessa 2009). These wetlands areas are critical stopovers on the Pacific migratory flyway (Pitt et al., 2000; Varady, et al. 2001) and significant breeding and wintering habitat for 371 bird species (400,000 migratory waterbirds), including endangered species such as the Yuma clapper rail (listed in both U.S. and Mexico) (photos in Appendix A).

Lacking a dedicated source of water to maintain ecological flows, the Cienega de Santa Clara is threatened (Zamora-Arroyo and Flessa 2009; Pitt et al., 2000; Liverman et

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16 A 24-mile stretch of the river known as the limitrophe forms the international border. Ninety percent of Mexico’s Colorado River allotment is delivered at the Northerly International Boundary (NIB) at Morelos Dam, with a destination of Mexicali and Tijuana for municipal use and the Mexicali and San Luís Rio Colorado irrigation districts. The point at which the border cuts to the southeast away from the river is the Southeast International Boundary (SIB), where the remaining ten percent of Mexico’s allotment is delivered for use in the San Luís Rio Colorado irrigation district. Below the SIB is the alluvial plain of the Colorado delta, where the river should empty into the sea (in the Upper Gulf of California), but in only a fraction of years in recent decades has it actually done so (Pitt et al., 2000).
Wilder et al., 2012 Puentes Consortium Paper

al., 1999). Even apart from the efficiencies associated with YDP operation, the Colorado delta is at risk from increasing regional water stress, increased agricultural efficiency (involving a potential reduction of 15 percent Mexicali Valley agricultural return flows) and increased demand. If water shifts increasingly to use by cities in the future, agricultural return flows will be reduced. Zamora-Arroyo and Flessa (2009:32) state that “In the short term, MODE (Main Outlet Drain Extension) water may be used in the Yuma Desalting Plant, resulting in reduced flows and higher-salinity water reaching the wetlands.” Overall, the best options to ensure the survival of the delta are agricultural return flows, municipal effluent, and acquisition of new water rights (Zamora-Arroyo and Flessa 2009).

Associated with YDP operation, then, are questions regarding the environmental implications of reduced inflows of water and the increased salinity of these inflows. Other questions address the practice of discharging desalinated water—which is expensive to produce—into the Colorado River rather than having that water used for other purposes, such as meeting growing municipal demands.

The water flows and ecosystem of the Colorado delta sustain both human and wildlife communities. The “efficiency paradox” (Zamora-Arroyo and Flessa 2009) of the delta is as water management becomes more efficient—to reduce water losses in the system—the accidental flows that keep the wetlands healthy are likely to be reduced for multiple reasons we have outlined. The Yuma Desalting Plant can play an important role in providing treated water for use by human

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17 A Colorado River Joint Cooperative Research Process (CRJCP) involving key binational government agencies, non-governmental organizations, and water users has a goal of finding dedicated sources to meet minimum flows required to sustain these critical wetlands (Zamora-Arroyo and Flessa 2009; López-Hoffman, et al. 2010).
communities and agriculture, but these needs must be delicately balanced with those of the natural ecosystem. YDP planners and managers have come together with a variety of environmental stakeholders to find innovative ways to meet the needs of cities, agriculture, and the ecosystem in the Colorado delta. Scientific evidence from the Cienega monitoring report will help evaluate how well the efforts to maintain a healthy Cienega in the face of YDP operation have worked.

**Puerto Peñasco Desalination Plans: Challenges and Opportunities**

In a second project, Arizona and Sonora have partnered to conduct an exploratory study for a binational desalination plant in Puerto Peñasco. Desalted water generated by the plant would increase regional water supplies, including Puerto Peñasco’s municipal supply, and two scenarios of cross-border water conveyance. However, there is a lack of knowledge about the costs of producing desalted water, the use of water and energy required to operate it, the pricing of desalted water, and its potential environmental impacts. In addition to these issues, there is also uncertainty about real current and long term prospects for the project.

The construction of a binational seawater desalination facility located in Puerto Peñasco is under consideration by water managers and planners in Arizona and Sonora. Located just 100 km (62 mi) south of the Arizona border, Puerto Peñasco has recently been transformed from a once-quiet fishing village into one of the most important tourist destinations in Sonora (Figure 6). Given its location about a half day’s drive (4.5 hours) from Tucson and Phoenix, it has become a destination for Arizona and other vacationers, retirees and second-home buyers. With a population of 45,000 residents and over 1
million tourists annually, the city’s rapid growth has put pressure on already overexploited aquifers (Wilder et al., 2012).

Puerto Peñasco is located just outside the southeastern boundary of the Upper Gulf of California and Colorado River Delta Biosphere Reserve and the southwestern boundary of the Pinacate and Gran Desierto de Altar Biosphere Reserve. There are two important estuaries – the Morua and La Pinta estuaries -- near the city. These environments provide habitat to hundreds of marine and terrestrial species. The biodiversity of the Gulf of California and its pristine beauty led oceanographer Jacques Cousteau to call it the “aquarium of the world” (Kamp 2005). The Gulf ecosystem is considered “exceptional” for its 181 bird species (90 endemic) and 695 plant species (28 endemic); the region is home to 39 percent of the world’s marine mammal species and one-third of the world’s cetacean species (Kamp 2005). With over 70 species fished, the rich marine ecosystem also provides a livelihood, albeit a declining one, for fishermen in the community. The municipal government of Puerto Peñasco has been assessing the feasibility of using desalination to meet the city’s growing water demands. At the same time, water managers from Arizona have expressed interest in partnering with the municipality to help finance a larger-scale desalination plant that could produce enough water to augment Arizona’s water supplies. Proponents suggest that the project would benefit both countries by facilitating investment, providing engineering expertise, creating trade opportunities and augmenting water supplies for both countries. If Arizona invested in a desalination plant in Puerto Peñasco, it could then exchange with Mexico for an equivalent amount of its 1.5 million acre-feet Colorado River allocation, or invest in a series of aqueducts and pump the freshwater from the Puerto Peñasco desalination
Wilder et al., 2012 Puentes Consortium Paper

plant to the Imperial Dam near Yuma, Arizona. This additional water would then be conveyed via the CAP system to the municipal areas it serves.

![Map of Arizona and Sonora](image)

**Figure 6. Proposed Arizona-Sonora Binational Desalination Plant and Conveyance Route (HDR 2009) **

However, as pointed out in section II, any proposal for such an exchange will be carefully considered, based on an assessment of its benefits and costs, and also based on public perceptions of fairness and political considerations. Moreover, it is essential to consider the cost and availability implications of the desalted water.

While Mexico’s interest in the binational plant in Puerto Peñasco was strong in 2009, the proposal has received less attention recently and seems to be on hold. This may be due to concerns about the projected negative effects on marine life in the fragile estuaries of the Upper Gulf of California (due to insufficient inshore currents to disperse the briny
concentrate) or due to changes (in 2009) in the municipal administration. In any case, the attention of CONAGUA appears now to be drawn towards the binational plant in Rosarito and away from the Sea of Cortez. However, the plans have been developed, as we outline below, and could be given new life under a new administration or changing water availability.

The aspiration for such a binational project has a long history, and was initially tied to augmenting energy supplies as well. In 1965, U.S. President Lyndon B. Johnson and Mexican President Gustavo Díaz Ordaz signed an agreement to explore the feasibility of a joint U.S.-Mexico nuclear-powered desalination and energy production facility. A 1968 U.S.-Mexico-International Atomic Energy Agency study (UMIAEA) concluded that, “large dual purpose plants using nuclear energy are technically feasible means of providing power and fresh water to the [northeastern Mexico and southwestern U.S.] area studied. Additionally, the economic forecasts for these plants appear to be sufficiently attractive to merit further consideration” (p. v).

However, due to agricultural and industrial development in the U.S., along with a prolonged drought, the salinity levels of the Colorado River water that Mexico received increased significantly. This resulted in a dispute between the U.S. and Mexico in the 1960s, which strained the relationship and impeded collaboration on water resources projects between the two countries, and the desalination project was abandoned.

Forty years later, proposals were again being discussed by water managers and planners in Arizona and Sonora. Two separate, but parallel studies were conducted in 2008-2009 to assess the feasibility of constructing a desalination plant in Puerto Peñasco (USTDA 2008; USTDA 2009; HDR 2009). In the first of the two studies, the municipal
government of Puerto Peñasco petitioned the U.S. Trade and Development Agency (USTDA) to award a grant to a U.S. engineering and consulting agency to conduct an exploratory study for a seawater desalination facility in the region.  

The USTDA, an agency dedicated to enhancing the U.S.’s trade and development goals, agreed to provide $369,325 in grant monies to fund the feasibility study because the agency had determined that a desalination project in Puerto Peñasco represents “a potentially significant commercial transaction in terms of capital investment and the long-term export potential needed for its expansion” (USTDA 2008:30). The USTDA estimated that the U.S. could export US$15-$20 million in engineering services for the desalination system design and technology. Furthermore, the facility would require frequent replacement of the membranes used in the reverse osmosis process, creating another potential trading opportunity.

The final USTDA report (2009) estimates that the municipality could build a plant with the capacity to produce 500 lps (11.4 MGD) in the first phase, with expected expansion of up to 2,000 lps (45.6 MGD) by 2020 at a cost of US$2.29/m³ ($2.29/1000 liters) (not including conveyance and storage). This is significantly more expensive than the current cost of water production and delivery of US$0.339 m³ ($0.339/1000 liters) (USTDA 2009:5-6). The Mexican Federal Electricity Commission (Comisión Federal de Electricidad, CFE) confirmed that it could provide the 20 megawatts (MW) that project coordinators estimate are needed to power the project. The estimated cost of electricity from CFE would be US$.0.25/kWh, though a better rate may be negotiable (USTDA 2009:3). Project coordinators have also contacted the Arizona Research Institute for Solar

18 W.L. Bouchard & Associates, an Arizona-based environmental consulting firm with offices in Scottsdale, Arizona, U.S. and Hermosillo, Sonora, Mexico, won the grant award and conducted the feasibility study for the municipio of Puerto Peñasco.
Energy at the University of Arizona to explore the possibility of building a 50 MW concentrated solar energy facility (personal communication, 2008).\textsuperscript{19}

However, since 2009, the project has been on hold due to local government turnover, environmental concerns, and tight financing. Officials from the local water authority have indicated that the municipality may conduct a new study which estimates the cost of desalinating brackish groundwater, instead of seawater. This new study could take up to three years to complete (personal communication, 2010).

The USTDA feasibility study for the proposed municipal level desalination plant in Puerto Peñasco estimates that the plant would have a minimum daily overall water recover rate of 40 percent. This means that for every 2.5 gallons of seawater intake, 1.0 gallon of permeate, or freshwater should be produced, along with 1.5 gallons of brine (USTDA 2009:70). During phase I, which could produce 500 lps of freshwater, it is estimated that 16.6 MGD of brine concentrate will be produced (USTDA 2009:66). The report’s preferred option for brine discharge is direct discharge into the ocean. Project engineers recommend discharging near the surface of the water to take advantage of the prevailing winds and stronger currents to aid in the dispersal of the brine concentrate (USTDA 2009:67).

Although the primary aim of the Puerto Peñasco municipal government’s desalination plan is to meet the city’s own water needs, the municipality is aware of Arizona’s interest in a binational desalination plant. Bouchard (with Bouchard & Associates, the environmental consulting firm that was awarded the USTDA exploratory grant) was quoted in \textit{The Arizona Republic} (McKinnon 2008) as saying, “the city [of

\textsuperscript{19} In addition, project coordinators stated that the long-term goal would be to completely capture all of the saltwater concentrate, but for the first phase of the project, it’s more likely that a saltwater dispersal system would be implemented (personal communication, 2008).
Puerto Peñasco] is aware of Arizona’s interest and could consider a joint project once Puerto Peñasco's needs are met” (p. 2). Bouchard believes that it is “very likely” that the project could supply water to Arizona, but notes that the main question regarding the feasibility of such a project would be the “cost of conveyance” (p. 2).

In a parallel effort, water managers from the Salt River Project (SRP) and the Central Arizona Project (CAP), along with representatives of the Arizona Department of Water Resources (ADWR), the U.S. Bureau of Reclamation and Sonora’s state water commission (Comisión Estatal del Agua, or CEA) authorized a second study to conceptualize a binational Arizona-Sonora desalination project and estimate the costs of producing and transporting desalinated water from Puerto Peñasco, Sonora to Imperial Dam near Yuma, Arizona (HDR 2009). The study considered two different project scales and associated energy needs. Results conclude that a smaller-scale Arizona-Sonora project that transports desalted water 270 km (168 mi) via pipeline from Peñasco to the Imperial Dam near Yuma, AZ could provide 120,000 acre-feet per year (AFY) (4,694 lps) at an estimated cost of US$2,727/AF and would require 50 MW of energy capacity.

The larger-scale regional project could produce 1.2 million AFY (46,936 lps), to be pumped to Imperial Dam via a canal, for an estimated cost of US$1,183/AF (HDR 2009). This scenario would require 500 MW of energy capacity (Table 2). The study assumed that energy could be provided by CAP or SRP at a rate of $0.10kWh. However, CAP officials recognize that there are strict federal rules that regulate the importation of energy into Mexico (personal communication, 2010). Because desalination is such an energy-intensive process, water suppliers are increasingly vulnerable to energy price
variability and price increases over time (Cooley et al., 2006:55; Scott and Pasqualetti, 2010).

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<th>Scale and Intended Use</th>
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<td>Arizona-Sonora Project</td>
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<th>Water Production Capacity</th>
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<td>Arizona-Sonora Project</td>
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<td>500 lps in phase I</td>
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<th>Binational Desalination Plan</th>
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<td>Arizona-Sonora Project</td>
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<th>Binational Desalination Plan</th>
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<td>$0.25/kWh</td>
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<th>Binational Desalination Plan</th>
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<td>$2.29 per m³*</td>
<td>$2,727 per AF**</td>
<td>$1,183 per AF</td>
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*Does not include cost of conveyance or storage, 1 m³ is equivalent to 1,000 liters
**Includes cost of conveyance to Imperial Dam,
Table 2. Adapted from Wilder et al., 2012 with information from USTDA 2008, USTDA 2009, HDR 2009, and interviews with project coordinators.

Puerto Peñasco’s future development is contingent upon expansion of its desalination capacity. Its groundwater aquifers severely depleted, a new water source is needed to allow the beach community’s tourism and resort potential to blossom. Since no municipal or binational plant has yet been built, there is little reliable information on which to evaluate the benefits and consequences of the proposed desalination plant(s). Economic issues including the cost of producing desalted water for domestic and municipal use and the pricing issues (affordability, equity of access to low income consumers) are significant unknowns. Environmental concerns are also paramount, but the environmental impact assessment has not been released. Probably the major issue
facing the buildout of the municipal and/or binational plant would be how to deal with
the briny concentrate discharge it would produce, without causing harm to the fragile and
ecologically significant estuaries and important marine species in the Upper Gulf.

Energy use, energy costs, and water-energy tradeoffs are another key
environmental concern. Economic and environmental consequences may inter-relate in
other ways, for example, damage to marine life in the Upper Gulf could reduce fisheries
and cause harm to local livelihoods; and economic development could improve or reduce
quality of life in the local community. Plans for major desalination initiatives in Puerto
Peñasco appear to be on hold at the present time. If and when interest revives, it will be
important to consider the social, economic, and environmental consequences associated
directly or indirectly with desalination.

V. Implications of Desalination Technology for Arizona-Sonora Portion of U.S.-
Mexico Border and Policy Recommendations

In the first four sections of the paper, we have answered to the extent possible the first
two questions we posed at the outset, regarding a detailed articulation of the two
binational desalination projects, and the potential benefits and consequences of those
projects. The two projects vary considerably from one another: the Yuma Desalting Plant
is an inland plant fed by brackish water, and it is operated and sited entirely on the U.S.
side of the border. It was completed almost two decades ago, and has been under limited
operation in the last few years. Although it is not a “binational” plant, it is integrally
related with the regional binational water supply system and its operation has potential
impacts on a critical wetlands area just across the border, in Mexico. We have available
considerable data and information about its operations and environmental impacts due to
a binational, collaborative monitoring project. On the other hand, the binational plant proposed for Puerto Peñasco is a coastal plant fed by seawater and sited wholly in Mexico. If built, it would be “binational” in terms of its service area and financing. This project is only a plan at present, and therefore information about benefits and consequences is necessarily limited.

In this final section, we respond to the third question posed at the outset-- what are the implications of binational desalination technology in terms of water and energy, environmental impacts, and local economies and communities—and offer some key policy recommendations.

In terms of water and energy in the Arizona-Sonora region, desalination is already (with the YDP) a part of the future strategy to meet the projected growth in water demand and could potentially (in Peñasco) assume a larger role in regional water supply strategy. Projected climate change is likely to have impacts on regional water supply. Given the declining costs and improved feasibility of desalination technology, regional decisionmakers not surprisingly view desalination as an attractive adaptation that will ensure future water demand can be met. At the same time, there are challenges remaining, including the use and cost of energy to operate these plants, and significant water and energy tradeoffs.

With regard to environmental impacts, due to the pilot run of the YDP and the associated collaboration to support scientific monitoring of the impacts on the Cienega de Santa Clara, planners will have access to reliable data to make future decisions about YDP operation. Doing so will require finding a balance that achieves the needs of both the human communities and natural systems there. On the other hand, the direct
environmental impacts of the proposed plant in Puerto Peñasco are uncertain. Potential impacts (that, in cases, could be subject to mitigation) include harm to marine life in fragile estuaries and in the reaches of the Upper Gulf of California due to briny concentrate dispersion, the spread of chemicals, and fish intake.

With respect to changing local economies and communities, the effects of desalination systems are not well researched at the present time. Most studies have concerned technical, logistic, or economic aspects of introducing desalination technology; few have evaluated it within a systemic framework. Binational desalination is likely to enable economic growth but could also have some negative impacts if adverse environmental consequences ensue that affect recreational tourism or livelihoods. Fishing livelihoods may be negatively affected in the event of fish dieoff or other harmful effects on marine species. However, such losses may be offset by increasing jobs in the service or tourism sector.

Finally, we offer some perspectives to consider as desalination technology and planning moves forward in the Arizona-Sonora region.

**Desalination and enhancing water supplies in Context**

It is of the utmost importance to see desalination in context. There is an emerging consensus that desalination should be tried as alternative to augment water supply only when other options have been carefully considered, and society is comfortable with how it uses its existing supplies.\(^{20}\) In fact, it could well be argued that increasing efficiency in water use is a prerequisite to enhance supply. Wastewater reuse is another strategy in the

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\(^{20}\) Eden *et al* (2011) think this statement applies to Arizona.
menu.21 This recognition links directly supply with demand strategies. As pointed out by Hutchinson et al. (2010, 327):

“…it has been a growing intellectual elaboration of an integrated water management paradigm, which recognizes that each element in both the supply side and the demand side of the equation makes a contribution to the total amount of water available, and requires consideration of linkages between urban and rural water use as well as between the domestic, industrial, and agricultural sectors”.

However, only after analyzing very carefully supply and demand side strategies, Elimelech and Phillip (2011) consider that there may be a case for desalination. Increasing demands from population and economic activities will create pressure for more water. If the conservation and “soft path” options already mentioned prove to be insufficient to meet future water demand, then desalination should be considered as a valid and crucial component to enhance water supply. The authors go on to suggest that in water-scarce countries and regions that have already tried the aforementioned options, desalination may be the only viable one to support regional economic development. In other circumstances, the particular conditions existing in some places, makes desalination an alternative worth-considering.22 Of course, this has profound implications for the binational region this paper focuses upon.

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21 Elimelech and Phillip (2011) provide a list of options: treatment of low-quality local water sources, water recycling and reuse, water conservation, environmentally-friendly regional water transfers, smart land-use planning. Eden et al. (2011) argued that in the case of Arizona there is space for more efficient use of water through use behaviors, utility infrastructure and built environment.

22 Of course, there are cases in which desalination is not only a viable option but it could be the only one. For instance, Bermudez-Contreras et al. (2008) discuss the case of Baja California Sur, a coastal state in Northwestern Mexico. Tourism-driven, accelerated population and economic growth, together with unsustainable agricultural practices, explains severe overexploitation of underground water and the existence of saline intrusion, especially in La Paz and Los Cabos. This situation pressures limited natural resources, particularly water and energy. Given the fact that the state enjoys high levels of solar radiation, the authors study the possibilities for small-scale renewable energy power desalination plants. The experience in the locality, as found by Pombo et al. (2008), signals the importance of this kind of initiatives to move away from the unsustainable use of very limited water sources. So far the municipality and hotel
In fact, outside of a realistic and comprehensive framework, supply-side approaches in general and desalination options in particular could, paradoxically, aggravate what in principle they are supposed to tackle. Within Arizona and Sonora, as we have highlighted, there is a heterogeneous range of institutions of varying capacities and with distinct responsibilities. Conservation measures and efficiency are similarly uneven across the region. Higher average municipal and state budgets, and the consumer-pays culture there, generally have given Arizona water management more resources to achieve efficiencies, whereas more restricted financial resources on average in Sonoran water management can inhibit achievement of desired system efficiencies. Unless effective measures are first taken to increase water use efficiency, having more water, from internal or external sources, may potentially fuel unsustainable growth and development. For example, unplanned urbanization – in an aging distribution system that loses a great deal of water - has a great many economic, financial, environmental, social, and, in the end, political costs. The same could be said if water management institutions are inefficient of if they do not have strong institutional capacity for necessary activities such as registering, metering, billing and collecting water fees.\textsuperscript{23}

Without tackling these structural problems, more water could amplify these inefficiencies and promote growth that leads to negative social or environmental impacts.

\textbf{Desalination is not simply a technological issue or challenge.} Of course, there are technical complexities involved. In some cases, technology is the driving force. As the industry have managed to supply water through small plants but with high environmental impacts and a fragile financial structure.\textsuperscript{23} In several cases water rates tend to be below recovering costs, which aggravates the financial situation of the local water authorities. This implies the need for carefully-crafted increase of water rates.
Wilder et al., 2012 Puentes Consortium Paper

literature and the paper show, there is uncertainty concerning environmental impacts of desalination. In other cases, economics and finance do have the central stage, and so does the need for transparency and accountability regarding the true costs and benefits of these projects. Thus, even if these technological, financial and environmental matters were properly addressed, there may still be social, institutional, legal and political obstacles to overcome in the successful drafting and execution of long-term initiatives.

In other words, the best scientific expertise on desalination may be available, but the social, institutional and political setting may not. In fact, ignoring this framework may make more difficult the financial arrangements to carry out projects, some of which could not even start or be abandoned altogether. This is true for both Mexico and the United States, as well as for the Sonora-Arizona Region.

On the other hand, desalination is not immune to changing conditions. Contexts change. This is a major lesson of the two case studies presented in this paper. Both cases contain a complex set of issues, as well as the scope for both potential collaboration and conflict in a local, regional, national and international scale. In the particular case of the Yuma Desalting Plant, Judkins and Larson (2010) underline how the changing conditions of the hydro-ecological subsystem was modified –from wet to drought periods, and hence water supply to the U.S. conflicts with environmental protection in Mexico. In other words, climate variability can affect economic, social, and environmental stability (Wilder et al., 2012). On the other hand, the Puerto Peñasco case shows the economic vulnerability of depending on externally-driven tourism. As pointed out by Eden et al. (2011), even though the Puerto Peñasco project had an initial backing from the Mexican authorities, it seems that the political uncertainty in the region makes difficult to maintain the support for the project. This is also what Pineda (2007) found in the two projects to supply water to Hermosillo, Sonora, and what Pombo et al. (2008) point out for Los Cabos, in Baja California Sur, Mexico.

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24 This is the conclusion of the well-cited 2008 Report of the National Academies on Desalination. In discussing the prospects for desalination, the report explicitly underlines (Summary, p. 9): “The potential for desalination to meet anticipated water demands in the United States is constrained not by the source water resources or the capabilities of current technology, but by a variety of financial, social, and environmental factors”. Desalination: A National Perspective. Committee on Advancing Desalination Technology. National Research Council. The National Academies, Washington, D.C.

25 This is what Judkins and Larson (2010) found in the Yuma desalting plant and Cienega de Santa Clara dispute. In this case, the hydro-ecological subsystem was modified –from wet to drought periods, and hence water supply to the U.S. conflicts with environmental protection in Mexico. In other words, climate variability can affect economic, social, and environmental stability (Wilder et al., 2012). On the other hand, the Puerto Peñasco case shows the economic vulnerability of depending on externally-driven tourism. As pointed out by Eden et al. (2011), even though the Puerto Peñasco project had an initial backing from the Mexican authorities, it seems that the political uncertainty in the region makes difficult to maintain the support for the project. This is also what Pineda (2007) found in the two projects to supply water to Hermosillo, Sonora, and what Pombo et al. (2008) point out for Los Cabos, in Baja California Sur, Mexico.
environmental and social conditions were behind the contemplation of unilateral actions by the U.S, whose implementation could potentially adversely affect Mexico’s environmental interests in the Cienega de Santa Clara ecosystem. As the work of Pineda (1997) on Hermosillo clearly shows, changes in the economic and political setting could adversely affect water projects, even before they are actually started.\textsuperscript{26}

The Sonora-Arizona region has a long tradition of border and transborder cooperation in different fields. Water is a case in point. As shown elsewhere, and reinforced in this paper, the management of water resources demonstrates the existence of both challenges and cooperation. Given the multiplicity of stakeholders and, more particularly, the large number of government agencies - from the federal to the local level - and the fragmentation of responsibilities, it is extremely difficult to arrive at both consensus and coordinated actions on desalination projects like the ones that have been discussed in this paper.\textsuperscript{27} From this particular perspective, the outlook for cooperative binational desalination may be difficult to achieve– unless significant progress is made in the management (or soft side) of water resources, including, of course, the desalination options. To offset this vision, however, the previous experience of the region in building and fostering collaboration is a step forward in addressing the complex and challenging shared water agenda. And this is an optimistic departure for facing the future.

\textsuperscript{26} Pineda argues that (though in different degrees) the lack of social participation and public consultations affected the project of transferring water to Hermosillo from El Novillo Dam, as well as the desalination plant of Hermosillo. The first project comes from 1995 and the second from 1999. At the end of the day, those projects were abandoned mainly due to changing economic and political conditions, including the political parties that take state or municipal administrations.

\textsuperscript{27} This point is also presented in the 2008 Report of the National Academies for the U.S. experience, and is extended neatly by Sanchez and Mumme (2010) in discussing environmental protection and natural resources in the U.S.-Mexico border.
Policy Recommendations for Future Binational Desalination Systems Development

General Recommendations

1) Desalination is likely to be a part of meeting our future regional water needs in the Arizona-Sonora region. However, rather than viewing desalination as a single means of solving regional water supply problems, it should be understood as a part of a broad water supply strategy that is both efficient and adaptive;

2) Plans to develop binational desalination systems should be recognized as complex endeavors subject to economic, environmental, social, and political challenges; and such an undertaking will create new interdependencies over both the short- and long-term between the two countries. In view of the complexity of the task, new desalination systems should only be pursued if there are clearly-defined benefits and fairly-shared costs for both countries.

Economic and Development Recommendations

3) Efficiency gains in our current water systems and appropriate water treatment and re-use should be implemented and/or enhanced;

4) Given the growth-inducement potential of water augmentation through desalination, desalination initiatives should be pursued as part of a sustainable growth strategy and should be integrated with land use policies;

Socioeconomic Recommendations

5) Given the complexity of binational desalination and potential benefits and impacts for human communities, the understanding of social issues and concerns associated with current and future desalination projects should be strengthened and incorporated into planning analyses;
6) As with any life-dependent resource, attention should be paid to ensuring that future desalinated water supplies are equitably available to a broad socioeconomic range of consumers and households; and/or that policy structures anticipate equity issues (such as “safety net” programs for very low income consumers).

**Environment and Energy Recommendations**

7) Since human communities rely on natural ecosystems for sustenance, desalination in the region should be pursued only if it is environmentally sustainable and in areas where natural resources will be protected from harm. Environmental goals, therefore, such as reducing pressure on aquifers or providing more (and appropriate quality) water for instream environmental flows, should be incorporated into binational desalination plans. Desalination system plans should include specific mechanisms that will ensure that extra water produced through desalination will be used as a buffer during drier-than-normal years, rather than facilitating increased growth;

8) Consider the complex interplay between water, energy, and climate change and pursue the use alternative energies (i.e., solar, wind or geothermal) to help power the desalination process.

**Institutional and Governance Recommendations**

9) Policy frameworks used to develop desalination in the region should be explicitly adaptive by being flexible and responsive to changing needs and conditions;

10) The process of developing desalination in the Arizona-Sonora region should be transparent and accountable, and should involve meaningful public participation or consultation throughout the process;
11) The two countries should evaluate current national and binational institutional arrangements that apply to regulating the operation of desalination plants. Under present conditions, only domestic agencies have authority over plants in either country. In view of the binational nature of potential arrangements, consideration should be given whether domestic agencies at federal and state levels in each country are properly mandated and sufficiently qualified to oversee desalination and the role of IBWC/CILA in overseeing desalination plants’ development should be clarified.

12) An interactive public education campaign to inform citizens of the benefits, responsibilities, and potential harms of desalination, and to facilitate the expression by members of the public of concerns or problems, is recommended. This might include public programs on lessons learned by other countries that have adopted the procedure. In turn, this initiative would facilitate more consultative, flexible negotiations to enable policy makers to be responsive to the public.
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