



Discourse and desalination: Potential impacts of proposed climate change adaptation interventions in the Arizona–Sonora border region

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ABSTRACT

The specter of climate change threatens fresh water resources along the U.S.–Mexico border. Water managers and planners on both sides of the border are promoting desalination—the conversion of seawater or brackish groundwater to fresh water—as an adaptation response that can help meet growing water demands and buffer against the negative impacts of climate change on regional water supplies. However, the uneven distribution of costs and benefits of this expensive, energy-intensive technology is likely to exacerbate existing social inequalities in the border zone. In this paper, we examine the discourses employed in the construction of the climate problem and proposed solutions. We focus our analysis on a proposed Arizona–Sonora binational desalination project and use insights from risk and hazards literature to analyze how, why, and to what effect desalination is emerging as a preferred climate change adaptation response. Our risk analysis shows that while desalination technology can reduce some vulnerabilities (e.g., future water supply), it can also introduce new vulnerabilities by compounding the water-energy nexus, increasing greenhouse gas emissions, inducing urban growth, producing brine discharge and chemical pollutants, shifting geopolitical relations of water security, and increasing water prices. Additionally, a high-tech and path-dependent response will likely result in increased reliance on technical expertise, less opportunity for participatory decision-making and reduced flexibility. The paper concludes by proposing alternative adaptation responses that can offer greater flexibility, are less path dependent, incorporate social learning, and target the poorest and most vulnerable members of the community. These alternatives can build greater adaptive capacity and ensure equity.

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1. Introduction: tarnishing a silver lining—the advent of maladaptive climate responses

The silver lining of the climate crisis is that it could provide the necessary impetus to fundamentally transform our unsustainable, energy-intensive, carbon-based, and consumption-driven economy. Academics and development practitioners recognize that, “Radical changes are needed in development trajectories to reduce fossil-fuel consumption and this challenges ‘business-as-usual’ development” (Boyd et al., 2009, p. 666). Brooks et al. (2009) call for a “. . . radical shift in how we relate to our environment and to each other, and a rethinking of patterns of production and consumption, and of who and where we are” (p. 753). Recent

literature on climate change adaptation focuses on the concept of integrating, or “mainstreaming” adaptation planning into sustainable development planning (Boyd et al., 2009; Brooks et al., 2009; Huq and Reid, 2009; Persson and Klein, 2009; Sanchez-Rodriguez, 2009; Golkany, 2007; Lemos et al., 2007; McGray et al., 2007; Klein et al., 2005; Klein and Smith, 2003).

In practice, however, this silver lining is tarnishing fast. Rather than focusing on broader changes in our economy or philosophical changes in our human–environment relations, the discourse surrounding the response to climate change is increasingly focused on technological fixes that allow ‘business as usual’ development in a highly unequal world. This paper briefly examines the discourses employed in the construction of the climate problem and proposed solutions. We focus our analysis on the discourse of desalination as a “solution” to water supply uncertainties by looking at the case study of a proposed Arizona–Sonora binational desalination project. We then draw on insights from risk and hazards literature to analyze how and why desalination is emerging as a preferred climate change adaptation response and consider the potential impacts of this proposed intervention.

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Discourses, in the Foucauldian sense, “compromise groups of related statements which govern the variety of ways in which it is possible to talk about something and which thus make it difficult, if not impossible, to think and act outside of them” (Allen, 2004, p. 18). Given the important roles that language and discourse play in shaping worldviews (Hajer, 2006) and policy interventions (Ribot and Marino, this issue), we believe it is important to understand the discursive context in which desalination is being proposed as a “solution” to projected climate change impacts. As evidenced by recent proposals to deal with the climate crisis, many scientists and policymakers believe that the same technical logic that precipitated the crisis can be used to fix it. With the increasingly “alarming” and “urgent” character of the scientific climate discourse, in which climate change is described as “abrupt”, “irreversible” and “catastrophic” (Travis, 2010; Hulme, 2008; Risbey, 2008), more intensive forms of geo-engineering and technological fixes are being proposed (Kousky et al., 2009; Hulme, 2008; Niemeyer et al., 2005). For example, some atmospheric and climate scientists support the development of solar radiation management – a suite of “solutions” which includes dumping iron dust into the ocean in an attempt to trigger algae blooms that will absorb carbon dioxide; injecting the stratosphere with aerosols and filling the skies with giant satellites that will reflect solar rays back into the atmosphere; genetically engineering crops to increase their carbon uptake capacity; and further developing carbon capture and storage techniques (Robock, 2008; Schnieder, 2001). But as Robock (2008) asks, “Is the cure worse than the disease?” (p. 1).

In a similar vein, desalination – the conversion of seawater or brackish ground water to fresh water – is being touted as an “almost inexhaustible” source of water that can meet growing water demands and buffer arid regions against climate change (NRC, 2008, p. 1; see also Smith, 2009). To be sure, technical infrastructure development has dominated water resources

planning throughout most of the twentieth century, with water development based on the construction of dams, reservoirs, aqueducts, and hydropower plants (Gleick, 2000; Tortajada et al., 2003; Conca, 2006). Despite the emergence of a new water paradigm in the last 30 years that is focused on demand management, social participation, decentralized governance and environmental sustainability, the technological agenda remains surprisingly strong. Desalination as a “drought-proof” solution to water scarcity and future climate change (Cooley et al., 2006, p. 2) has appeal worldwide, with plants recently constructed or in the planning stages in Spain, Israel, Mexico, Australia, and the United States, among multiple examples. In total, as of 2005, 130 countries have developed over 10,000 desalination plants (Cooley et al., 2006). Proposals for many of these projects invoke the discourse of climate change and point to desalination as an adaptation response. For example, in Australia, the cost of building desalination plants has been described as “the cost of adapting to climate change” (Onishi, 2010, p. A6). Although the impetus for Spain’s dramatic policy shift toward to the use of desalination technology in 2004 was to quell regional fights over interbasin water transfers, it is also lauded as a source of water that “can be predicted independently of climate changes and drought” (Downward and Taylor, 2007, p. 280). While noting its high energy costs, the Intergovernmental Panel on Climate Change lists desalination as an “adaptation option” (Bates et al., 2008, p. 49). This IPCC technical report states, “In the future, wastewater reuse and desalination will possibly become important sources of water supply in semiarid and arid regions” (p. 10).

We focus our analysis on one of several recent proposals to build a binationally funded desalination plant along the Gulf of California in Sonora, Mexico (Fig. 1). This project would augment water supplies in both Sonora and Arizona. Arizona’s allotment would either be pumped northward to Imperial Dam near Yuma, Arizona, or exchanged for additional Colorado River water (HDR,

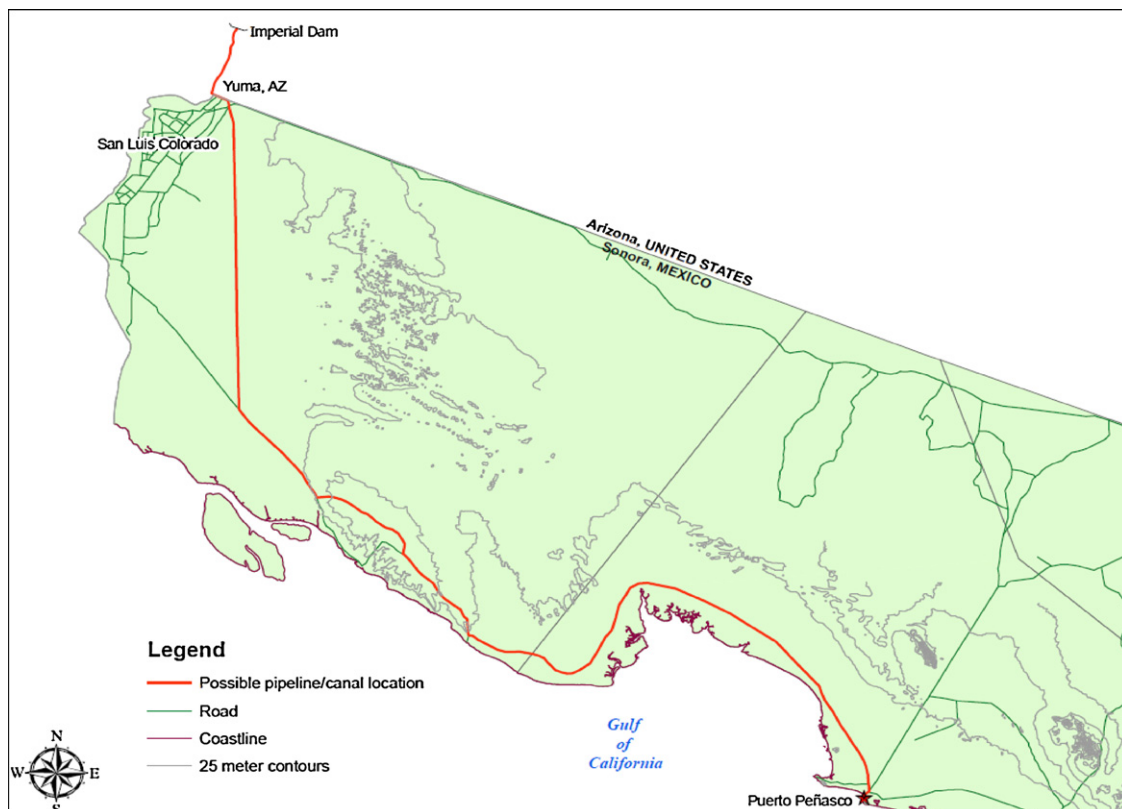


Fig. 1. Proposed binational desalination plant in Puerto Peñasco, with canal to transport water northward to Imperial Dam near Yuma, Arizona (Carpenter, 2008).

2009; López-Pérez, 2009; USTDA, 2008; McCann, 2008). In this region, climate change is expected to result in increased temperatures, intensified droughts, and greater variability in rainfall patterns (Wilder et al., 2010; IPCC, 2007). In light of these changes, desalination is being promoted by various local, state, and regional decision-makers as an adaptation response that can allow the arid west to meet increased water demands driven by increasing population and economic growth, as well as buffer the region's water supply against climate change. For example, water managers from nine U.S.–Mexico border states attended a border governors' conference on binational desalination in San Diego in May of 2010. The conference's website states:

The U.S.–Mexico border region needs upgraded and enhanced water infrastructure for projected population and economic growth as well as environmental protection. *Expected climate change impacts will exacerbate competition for the region's finite water resources. Communities throughout the border region from California to Texas are increasingly examining desalination – of seawater or brackish groundwater – as a potential water supply option.* Possible U.S.–Mexico desalination opportunities are under evaluation in the cooperative Colorado River binational process (Water Education Foundation, 2010, italics added).

In this paper, we ask: how and why has desalination emerged as a preferred climate change adaptation response and what are its potential impacts? Using Douglas' (1992) cultural theory of risk, Beck's (2009) theory of the "risk society," Perrow's (1999) "complexity/coupling" framework, and critical risk literature (Hewitt, 1983), we evaluate desalination as an adaptation response. In the following sections, we define our use of the terms vulnerability, (mal)adaptation, and adaptive capacity. We then review the key theories on technological risk and hazards that frame our analysis and are relevant for the evaluation of other adaptation proposals. Next, we present the Arizona–Sonora case study, analyze how and why desalination has become a preferred adaptation response, and conduct a critical risk analysis of the Arizona–Sonora binational desalination proposal. We conclude with a summary of the vulnerabilities and inequalities posed by desalination technology and recommendations for more flexible adaptation responses.

2. Key terms: vulnerability, (mal)adaptation, adaptive capacity

In order to evaluate climate change adaptation responses, it is critical to understand what is meant by key terms such as vulnerability, (mal)adaptation, and adaptive capacity. One insight from critical hazards research is that *vulnerability*, or "the capacity to be wounded," is caused by more than simply the physical exposure to a hazard (Füssel, 2007, p. 1). Researchers taking a political economy approach to risk and hazards have found that social, political, and economic conditions also shape people's vulnerability in the face of hazards (Ribot, 2010; Füssel, 2007; Adger, 2006; Liverman et al., 2004; Bohle et al., 1994; Hewitt, 1983). As summed up by Ribot (2010), vulnerability does not "fall from the sky" (p. 47). Instead, it is socially produced by on-the-ground conditions and results in differentiated outcomes for different social groups.

Adaptation is defined as "actions taken to adjust to the consequences of climate change, either before or after impacts are experienced" (Lemos et al., 2007, p. 1; see also Smit and Wandel, 2006). In other words, adaptation measures can be either planned and proactive or autonomous and reactive (Smit and Pilifosova, 2003), but the ultimate goal of an adaptation measure is to reduce vulnerability. Adaptation measures are ideally dynamic, flexible, and able to change in response to new stimuli and conditions (Wilder et al., 2010).

The potential for adaptation measures to (inadvertently) increase vulnerability is referred to as *maladaptation* (IPCC, 2001). Barnett and O'Neill (2010) use the case of desalination in Melbourne, Australia as a prime example of maladaptation. They propose that maladaptive responses have some combination of the following characteristics: (1) increase emissions of greenhouse gases, (2) disproportionately burden the most vulnerable, (3) have high opportunity costs, (4) reduce incentives to adapt and (5) are path dependent. Desalination, being an energy intensive, expensive technology with unintended side effects fits these first three characteristics. In addition, the perception of "limitless" water undermines conservation efforts. And once built, fixed capital invested in a large infrastructure project creates a path dependency and reduces the flexibility of future generations to respond differently (Barnett and O'Neill, 2010).

Whereas "specific adaptations" typically refer to particular actions (e.g., building new infrastructure), the concept of "generic adaptation" or "*adaptive capacity*" refers to creating an enabling environment that "allows a society to prepare for and cope with climate change" (Klein and Smith, 2003, p. 320). Enabling environments are necessary to ensure that specific adaptations are successfully implemented. Hence, much of the recent literature focuses on the concept of building adaptive capacity to enhance the ability of individuals, communities, institutions, and states to respond effectively to climate change impacts (Wilder et al., 2010; Moench, 2009; CCSP, 2008; Füssel, 2007; Lemos et al., 2007; Smit and Wandel, 2006; Smith et al., 2003).

As outlined by Smit and Wandel (2006), adaptive capacity is influenced by "managerial ability, access to financial, technological and information resources, infrastructure, [and] the institutional environment within which adaptations occur..." (p. 287). Social learning and knowledge sharing among communities of practice are critical elements of building adaptive capacity at the institutional level (Pelling et al., 2008; CCSP, 2008; Pahl-Wostl, 2007; Cash et al., 2003). Such learning can take place during iterative interactions that facilitate peer-to-peer learning and build trust among institutional actors (Wilder et al., 2010).

Many of the attributes associated with building adaptive capacity resonate with attributes emphasized in the literature on "adaptive management" of natural systems (Gunderson and Holling, 2002; Feldman, 2008). For example, both processes involve the concept of social learning, encourage participatory decision-making, and emphasize the importance of maintaining flexibility and favoring reversible, non-path dependent management options. As summarized by Feldman (2008), appropriate adaptive management decisions, "should be modest in scope, scientifically sound, and reversible in impact. To implement adaptive management, decision makers must learn from previous mistakes, monitor impacts, adopt mid-course changes, and reach consensus" (pp. 512–513). Therefore, the literature on adaptive management offers a resource for planners, managers and policy-makers who are tasked with creating and implementing climate change adaptation measures.

Mearns and Norton (2010) call for climate research that examines "not only how climate change contributes to vulnerability, but also how climate policy and response measures may magnify the effects of many existing drivers of vulnerability" (p. 3). As Kates (2009) and Dow et al. (2006) have observed, one group's adaptation may be another group's hazard. This potential to increase vulnerability among certain groups means that assessments of climate adaptation measures must be "pro-poor", taking into account the impacts of these policies on the poorest members of a community across multiple scales (Ribot, 2010, p. 47; Kates, 2009; Adger et al., 2006). In sum, based on our understanding of adaptation, responses to climate change that are inflexible, non-responsive to changing stimuli and conditions and expert-driven

(i.e., non-participatory) rank relatively low as adaptation strategies, and may be considered maladaptive if they, on balance, actually worsen vulnerability, reduce the vulnerability of some social groups at the expense of others, and/or produce new vulnerabilities.

3. Theory and literature review: risk and hazards research—framing an analysis of adaptation

In this section we review the contributions of scholars from four areas of risk and hazards research in order to frame our analysis of desalination as a climate change adaptation response. These four areas include: cultural perspectives of risk (theorized by Mary Douglas), modern technological risks (Ulrich Beck), complex systems analysis (Charles Perrow) and critical hazards research (Kenneth Hewitt and colleagues).

Anthropologist and cultural theorist Mary Douglas developed a typology of cultural attitudes toward risk (1992). Her work can be used to argue that the discourse of the technological fix as a solution to serious environmental problems is based on a culturally inscribed faith in science and engineering and a belief that humans have the ability and right to control nature. This culturally constructed world-view of a “robust” nature is associated with a growth paradigm that sees no reason to limit economic expansion or question our society’s ability to engineer our way out of any problem. As Douglas (1992) explains, this view of nature encourages “bold, individualistic experimentation, expansion, and technological development” (p. 263). We use Douglas’ typology of the instrumental, growth-based paradigm to understand the cultural drivers that give rise to proposals for desalination as solution to water supply management in the face of climate change.

While Douglas is useful for understanding how and why technological solutions arise, Beck’s theory of the “risk society” and reflexive modernization” gives us cause to question what the unintended consequences of these technological fixes might be (Beck, 2009, 1994; see also Winner, 1977). Additionally, Beck’s theory highlights a tension between an increased reliance on expert knowledge to manage complex systems and a growing distrust of experts by the public. Beck argues that western industrialized countries transitioned from a traditional society to a modern society based on scientific knowledge and trust in experts. In turn, modernity, and its associated unintended consequences, brought about new risks and hazards, hurtling us into a new phase of reflexive modernity, or a “risk society.” Beck summarizes his theory, stating, “...the further the modernization of modern societies proceeds, the more the foundations of the industrial society are dissolved, consumed, changed and threatened” (1994, p. 176). Beck emphasizes that it is the very “triumphs” of modernity that bring about new risks (Beck, 2009, p. 8). With respect to technology, Beck observes, “we are living in the *age of side effects*” (Beck, 1994, p. 175, italics in original) in which unknown and unintended consequences have become a dominant force in society leading to a disillusionment with the idea of linear progress and a waning trust in experts (Beck, 1992, p. 22). We use Beck’s notions of “side effects” and “unintended consequences” to consider the full-range of desalination-related risks.

Beck makes an important distinction between simple (early) modernity and reflexive (late) modernity in terms of trust in science and experts. He argues that simple modernity, brought about by the industrial revolution, is characterized by an increasing knowledge of the world through science, trust in experts and faith in linear progress. Simple moderns were optimistic about the ability to use increasing knowledge to improve society, confident in the ability to calculate risks using rational cost-benefit analyses, and trusting of experts to make

decisions that were in the best interest of the collective. In contrast, reflexive modernity (also called the “risk society”) is characterized by “non-knowledge” (Beck, 1994, p. 175). Dietz et al. (2002) call this “meta-uncertainty” or “uncertainty about the degree of uncertainty” (p. 332). The notion of uncertainty in risk literature resonates with the concept of uncertainty in climate change science. Climate change has a characteristic of non-stationarity, meaning that past climate trends and historical climate patterns are not a reliable predictor of the future (Milly et al., 2008). Uncertainty is one of the most challenging problems for water managers planning for future water supply. In sum, the unintended side effects of technology, a waning trust in experts, and the increasing scientific uncertainty about technologies and future climate conditions calls into question the modern reliance on technological fixes.

Complementary to Beck’s theory of the risk society is Perrow’s (1999) analysis of complex systems. However, in contrast to Beck’s grand theory, Perrow provides a grounded analysis of complex systems based on empirical case studies of technologies such as nuclear power plants, petrochemical plants and airplanes. In order to determine the riskiness of a system, Perrow looks at the interactive complexity of the system and how tightly coupled it is (pp. 88, 96–97). A complex system has multiple parts in close proximity that may share common connections between components. In contrast, a linear system has temporal and spatial separation between processes and units (Perrow, 1999, p. 88). Complex systems are more efficient, but linear systems are less risky. The second factor in Perrow’s analysis is system coupling, which refers to the degree to which two units or processes are interdependent. In a tightly coupled system, there is no buffer between units or processes so that what happens in one system has a direct effect on what happens in another. Conversely, in a loosely coupled system the connections and interactions between various units and processes are more ambiguous and flexible. This allows certain parts of the system to respond and act according to their own characteristics. He concludes that tightly coupled systems are more risky and less able to cope with system shocks. Perrow argues that technological fixes tend to increase complexity and tighten coupling, making accidents even more likely. Together, Beck and Perrow’s insights contribute to our framework for analyzing how the complexity of desalination (and energy dependency) and potential side effects may create new vulnerabilities.

Closely related to Beck and Perrow’s work on technological risk, but stemming from a different academic tradition, Hewitt (1983) provides a critique of early risk and hazards research. The main critique is that traditional risk and hazard analyses (e.g., White’s (1945) work on human settlements in floodplains and Burton et al.’s (1978) work on environmental hazards) take a reductionist view of human action and pay too much attention to individual perceptions and individual choice, rather than focusing on the causal structures or systemic nature of risks. The dominant focus on rational choice ignores the fact that the choice sets are constrained by macro-level structures. A critical risk analysis, as outlined in Hewitt (1983) must take into account not only the biophysical factors that make a social group vulnerable to risks, but also the political economic pressures that differentially affect a social group’s vulnerability and shape people’s ability to cope with and respond to risks. This type of analysis often finds that the underlying drivers of risk are related to the economic requirement for constant growth and expansion (Smith, 2008; Harvey, 2006; Hewitt, 1983).

The counter-critique of Hewitt’s (1983) approach is that such a critical analysis makes it difficult, if not impossible, to offer policies that are easy for managers and policy-makers to implement. Short of calling for radical changes in our political economic institutions, it may seem that there are few solutions that a critical analysis can

offer. However, if researchers and decision-makers wish to break the iterative risk cycle in which technological fixes simply mask the underlying problems and spawn additional risks, then a critical analysis must be conducted. It is important to seriously consider potential side effects because they may threaten to dissolve, consume, and change the foundations of industrial society (to paraphrase Beck, 1994, p. 176). Such an analysis would not only show how the economic requirement for growth and expansion breeds new risks, it would also show who wins and who loses from policies that support a status quo focus on development. With this framework in mind, we describe the case of desalination at the Arizona–Sonora border and provide a critical analysis of desalination as a technological risk.

4. Case study: binational desalination as a climate change adaptation response in the Arizona–Sonora region

As part of a larger study on climate change and water vulnerability in the Arizona–Sonora border region, we have worked with water managers in four urbanizing “hotspots” (Fig. 2) to identify water-related vulnerabilities and assess current and future adaptation responses. Over a two-year period, our research team conducted 75 semi-structured interviews, attended 10 binational water planning meetings and hosted 4 binational workshops with water managers, emergency preparedness planners, decision-makers, and local water users. In addition, we consulted archival documents such as municipal development plans, water agency reports, aquifer assessments, feasibility studies and newspaper reports to understand the context in which water management strategies arose. The case study presented here draws on fieldwork

in the municipality of Puerto Peñasco—the principle site for a proposed Arizona–Sonora binational desalination plant (Fig. 1).

Puerto Peñasco is a burgeoning coastal resort community located on the Gulf of California. Just a four and half hour drive from Tucson, Arizona, Peñasco is a favorite beach and retirement destination for landlocked Arizonans. The depleted groundwater aquifers can no longer support the growth that has recently been the economic engine of Peñasco, so water managers are searching for new ways to augment local water supplies. Peñasco’s municipal planners and officials have pinned their hopes on the construction of a major desalination plant to serve municipal needs. The desalination proposal has significant binational implications, since both Arizona and Nevada water authorities have plans to potentially utilize desalinated water from the Peñasco plant to provide water for urban dwellers in Phoenix, Tucson and Las Vegas, or farmers in Yuma.

In 2008, the municipality of Puerto Peñasco contracted with the U.S. Trade and Development Agency (USTDA) to determine the feasibility of building a desalination plant. The municipality is interested in desalination to meet its own needs, as well as to support the growing tourist sector in the region. The former president of the municipality, Heriberto Rentería Sánchez, considered seawater desalination to be the “only option for this desert community at this point in time” (USTDA, 2008, p. 20). The current president, Alejandro Zepeda Munro, is also interested in pursuing desalination as a water augmentation strategy for his town (personal communication, 2009).

During the same time period, water managers from the Salt River Project and the Central Arizona Project (CAP), along with representatives of the Arizona Department of Water Resources, the



Fig. 2. Map of urban “hotspots” in the Arizona–Sonora border region, including Puerto Peñasco. (Figure credit: Rolando Diaz-Caravantes).

U.S. Bureau of Reclamation and Sonora's State Water Commission authorized a feasibility study to determine the costs of producing and transporting desalinated water from Puerto Peñasco, Sonora to Imperial Dam near Yuma, Arizona. The study compared the estimated costs of a smaller-scale Arizona–Sonora Scenario and a larger-scale Regional Scenario (HDR, 2009). The findings show that, in the Arizona–Sonora Scenario, 120,000 acre-feet per year (AFY) of desalinated water could be produced and conveyed via pipeline from Puerto Peñasco to Imperial Dam at a cost of \$2727/AF. In the Regional Scenario, 1.2 million AFY could be produced and conveyed to Imperial Dam via canal for \$1183/AF (HDR, 2009, p. 9).

Arizona is not the only state in the region considering binational desalination. In a recent report commissioned by the seven Colorado River basin states, the construction of an ocean water desalination plant in California, Baja California, or the Gulf of California was highlighted as an option that could increase the water supply of the region (Colorado River Water Consultants, 2008). The Southern Nevada Water Authority has expressed interest in binational desalination (Holme, 2010). Additionally, the International Boundary and Water Commission (IBWC), the institution responsible for settling issues related to boundary and water treaties between U.S. and Mexico, has established a core working group dedicated to finding new water resources, of which desalination is a high priority for both countries (Ruth, 2009). The IBWC is considering potential binational desalination projects in Ensenada, Baja California; Rosarito, Baja California; and Puerto Peñasco, Sonora (López-Pérez, 2009; Salmón, 2009; McCann, 2008). At a border governors' conference on binational desalination, a representative of the North American Development Bank (NADB) stated that the Bank is interested in funding binational desalination projects. He expects to see such proposals approved through the Bank in the near future, because, as he emphasized, "Desalination will be an important part of meeting future water needs" (Garcés, 2010).

Despite the complex international arrangements that a binational project would entail, some water managers and policy experts view it as a less politically divisive solution to the region's water scarcity than the reallocation of water from rural agricultural users to urban users (Smith, 2009; Kohlhoff and Roberts, 2007). Desalination is also a more politically salient solution than imposing dramatic conservation measures or calling into question the growth paradigm that drives regional water policy (Hirt et al., 2008). The push to locate a desalination plant in Mexico, rather than California, is a result of differential power relations and uneven development. As noted by a senior CAP official, among the primary benefits of a binational desalination plant are reduced regulatory hurdles and fewer environmental protection measures in Mexico (personal communication, 2010).

5. A critical risk analysis of Arizona–Sonora binational desalination

In this section, we conduct a critical risk analysis of proposals to build binationally funded desalination plants along the Arizona–Sonora border. Using the analytical framework described in section three, this four-step analysis considers the production of risks, anticipates future risks, identifies winners and losers and proposes options to reduce risks (Table 1). Data for the analysis comes from our fieldwork including archival documents (i.e., government reports, planning documents and newspaper articles) and information from meetings, workshops and interviews, as well as relevant information available in grey literature and academic publications.

5.1. The production of risks

Our critical risk analysis begins by understanding how risks are produced. In the case of desalination along the U.S.–Mexico border,

processes of urbanization and border industrialization, uneven economic development and persistent poverty, along with water-consumptive lifestyles, have created a rising demand for water in this arid region, leading to high regional vulnerability (Wilder et al., 2010; Ray et al., 2007; Liverman and Merideth, 2002). The city of Tucson, in southern Arizona, relies on the Central Arizona Project (CAP) to transport Colorado River water 336 miles eastward and nearly 3000 vertical feet uphill to meet growing urban water demands at a cost of more than \$4 billion (Akhter et al., 2010). Water shortage sharing agreements mandate that, in the event of a water shortage, Arizona would be the first state to lose its Colorado River water allocation (Akhter et al., 2010). As Douglas' (1992) typology of culture and risk suggests, this approach to water management assumes that the environment is robust and trusts human ingenuity to engineer a solution to alleviate current and future water vulnerabilities. Similarly, desalination offers a technological fix to overcome the region's water deficit without requiring policy-makers to address long-term trade-offs between different values and uses of water (Downward and Taylor (2007). As Smith (2009) observes, desalination allows the region to "have limitless development 'cake' and eat it too" (p. 77).

In contrast to these optimistic attitudes toward technological solutions, Beck's theory of the "risk society" describes how the very triumphs of modernity and industrialization create a new category of risk. In other words, "modernization *undercuts* modernization" (Beck, 1994, p. 176). His theory also suggests that trust in experts is declining (Beck, 2009, 1994). When the option of desalination is juxtaposed to the option of wastewater re-use (i.e., "toilet-to-tap"), Beck's observations about trust in expert opinion may help to explain why desalination is the preferred policy alternative. Although desalinated water requires four times as much energy and is more costly than treated wastewater re-use, there may be a greater preference for desalinated water over treated wastewater. As shown by Ormerod (2010), the public's aversion to treated wastewater in southwestern Arizona has less to do with the "yuck" factor and more to do with a concern about the technology and a lack of trust in public officials to safely manage this resource. This is particularly worrisome in the developing country context where, as noted by Dietz et al. (2002), "Developing nations... have a limited ability to assess and manage technological risks... The legislative basis for risk protection is often weak or nonexistent. In turn, existing legislation and regulations are not adequately enforced. The problem is exacerbated by the fact that developing nations do not have enough trained operators and managers with skills necessary for managing risky technologies effectively" (p. 339).

Although the public may trust experts to manage a desalination plant, it is still a highly technical process that leads to the creation of expert networks. This is precisely the type of expert rule that Wittfogel (1957) and Worster (1985) claimed could lead to undemocratic and bureaucratic rule. Although Worster's thesis has been heavily critiqued by political ecologists who argue that water politics is a highly fragmented, contested sphere, not one controlled by an oligarchic elite (Wilder, 2002; Pisani, 1989), Worster did contribute an essential insight that in arid lands elites tend to desire control over water resources and establish a system of power relations based upon that control. This highly technological management of water resources runs contrary to the Dublin Principles and an emerging water management paradigm that calls for more participatory, transparent and decentralized water management strategies (Wilder et al., 2010; Conca, 2006). It also runs contrary to calls for more "flexible" management strategies to deal with climate change impacts (Blatter and Ingram, 2001) and calls to take a "soft-path" planning approach focused on demand management, as opposed to a "hard-path" strategy reliant on fixed infrastructure to address supply management (Gleick, 2003).

Table 1
Summary of critical risk analysis findings.

Step	Theoretical frame	Data sources	Findings
1. Production of risks	Cultural perspectives of risk (Douglas) Modern technological risks (Beck)	Archives, grey literature, academic publications	Processes of urbanization, border industrialization, uneven economic development and persistent poverty, along with water-consumptive lifestyles, have created a rising demand for water, leading to high regional vulnerability Large-scale infrastructure projects (i.e., CAP), assume that the environment is robust and trust that human ingenuity will engineer a solution to alleviate current and future water vulnerabilities Desalination may be perceived to be less risky than wastewater re-use, leading to its preference as a water augmentation strategy Large-scale infrastructure projects often lead to expert rule, create power relations over water, and are path dependent (rather than flexible)
2. Anticipated risks	Modern technological risks (Beck) Complex systems analysis (Perrow)	Archives, meetings, workshops, interviews	Discharge of brine water and chemicals is the most widely recognized risk Indirect, or unintended, risks include increased energy demands, increased greenhouse gas emissions, and increased urban growth (which is associated with a host of environmental impacts) High energy demands increase the coupling of the water-energy nexus and may encourage the co-location of desalination and nuclear energy, which entails additional risks Creation of large cities, highly dependent upon a single source of water, may make environmental security more tenuous Binational arrangements may reduce national autonomy and shift geopolitical power relations over water The tourist industry benefits from water augmentation through desalination
3. Identification of winners and losers	Critical hazards research (Hewitt)	Workshops, interviews, grey literature, academic publications	Increase in the price of water has uneven social impacts, disproportionately affecting poorer households Discharge of brine and chemicals, along with increased urban growth and higher energy demands could result in negative environmental impacts If coupled with conservation measures, desalination could reduce pressure on aquifers and make more water available for in-stream environmental flows, making the environment a winner
4. Risk reduction	–	–	Changes in political economic institutions are needed to ultimately reduce risks that are driven by our current economic system's requirement for constant growth and expansion Regulation could minimize some risks in the near-term Conservation measures, in conjunction with growth and/or water consumption limits should be implemented before desalination is adopted in order to avoid Jevons Paradox or business-as-usual A fair pricing scheme must be developed so that all residents are able to benefit from desalination

5.2. Anticipated risks

A second step in our critical risk analysis is anticipating what types of risks are likely to arise. Beck (2009, 1994, 1992) and Perrow (1999) provide a useful framework for thinking about the phenomenon of “unintended risks” or “side effects” that could be associated with the construction of a binational desalination plant to solve issues of water scarcity on the U.S.–Mexico border. Although desalination technology has been used quite extensively since the 1960s in oil-rich Middle Eastern countries and arid islands (e.g., Canary Islands), little research has been conducted on the social and environmental impacts of this technology (NRC, 2008). Of the environmental research that has been conducted, most has focused on the direct impact of the brine, or saltwater concentrate, discharge on marine ecosystems (Cooley et al., 2006). Little research has been conducted on the indirect environmental impacts—or unintended side effects—of this technology (NRC, 2008), though important exceptions exist

(see Cooley et al., 2006, pp. 59–66). These indirect, unintended impacts include increased energy demands, greenhouse gas emissions, and urban growth—which is associated with a host of environmental impacts.

As currently practiced, 41 percent of desalination plants in the U.S. discharge the brine concentrate by-product back into the ocean (NRC, 2008). Findings from existing studies on the impact of brine discharge on marine ecosystems are contradictory; some studies indicate minor to major impacts on marine ecosystems; others found no significant impacts (NRC, 2008, p. 130). The technology for producing a Zero Liquid Discharge (ZLD) process, particularly for the inland desalination of brackish groundwater, is available, but is much more expensive than dispersing the brine concentrate back into the sea. And even with ZLD, there is still a solid waste pollutant to contend with. In addition to concern about the direct impact of the brine discharge on marine ecosystems, there is also concern about the direct impact of the variety of chemicals used in the reverse osmosis process.

Perrow's (1999) complexity/coupling analysis is useful for understanding the types of potential side effects wrought by the biophysical characteristics of the desalination process. One of the main indirect environmental concerns is the energy intensity of the process (see also Cooley et al., 2006, pp. 59–66). On average, desalination requires four times as much energy as water produced in water re-use plants, ten times as much energy as traditional treatment for surface water, and nearly twenty times more energy than pumping groundwater 200 vertical feet (NRC, 2008; Prats Rico and Melgarejo Moreno, 2006). Most cost-benefit analyses of desalination fail to account for increases in energy prices over time. As Cooley et al. (2006, p. 58) found, fresh water produced by seawater desalination rises in cost more rapidly than other sources, and demonstrates higher year-to-year variability, because less of its cost is due to fixed capital expenses. Future increases in energy costs add a critical element of uncertainty to the desalination calculus. The high energy requirements of this technology cause the energy and water systems to become more tightly coupled. This is referred to as the "water-energy nexus" and it suggests that any disruption in power supply would directly impact water provision, and vice versa.

Given these energy demands, it is often proposed that desalination plants be located next to an energy production facility in order to benefit from the excess heat produced in energy production, and to provide water for the cooling process required in the electric plant. Additionally, the wastewater for the energy plant can be used to dilute the brine water concentrate that is a polluting by-product of the desalination process. Using Perrow's complexity analysis, we conclude that co-location of two processes increases the complexity of a system with non-linear production sequences, common components, and interacting controls.

Currently, most desalination plants are powered by carbon-based fuels, making them contributors to greenhouse gas emissions. This creates an ironic "hydro-illogical" cycle in which the "solution" to water scarcity caused by climate change directly contributes to a positive feedback loop that exacerbates the conditions that lead to increased climate change (Tannehill, 1947; see also Feldman, 2011). An alternative fuel source is nuclear energy, which is associated with a host of known and unknown side effects. The complexity and riskiness of the system increases dramatically if the desalination plant is located next to a nuclear power plant (as was previously proposed by the U.S.–Mexico International Atomic Energy Agency in an initial Arizona–Sonora binational desalination project in 1968).

Another major concern regarding the indirect environmental impacts of this technology is its growth inducement potential. In arid regions, scarce water resources have limited urban growth. The introduction of "limitless" desalinated water is likely to encourage urban growth, which is associated with a range of environmental impacts including increased air and water pollution, habitat fragmentation, coastal development, saline intrusion into agriculture, and loss of biodiversity (Smith, 2009; Sax et al., 2006; Cooley et al., 2006; Johnson, 2001). It is possible to imagine a scenario in which "limitless" desalinated water encourages urban growth that is highly dependent upon this sole water source, making the system more vulnerable.

Furthermore, once these urban areas come to rely upon this expensive, energy-intensive technologically produced source of water, their environmental security and autonomy may become more tenuous. Wolf (2009) suggests that desalination could have important implications for geopolitical and spatial shifts in power over water resources, with control moving from headwaters to coasts. In the case of a binational desalination plant, where the ownership and management of the plant is not within the jurisdiction of one's own country, cities and water users within the region would be increasingly dependent upon maintaining good binational relations (Wilder et al., 2010).

In sum, while the desalination plant itself poses little threat of "catastrophic potential" (in Perrow's terms), we expand Perrow's (1999) theory to consider the system as a whole. This reveals a greater level of risk due to the tightly coupled water-energy nexus, the interconnected complexity of potentially being co-located with a nuclear power plant, a range of direct and indirect environmental impacts, and the tight coupling of growth and water dependency on a single source of water.

5.3. Identification of winners and losers

A third step in our critical risk analysis is to anticipate who wins and who loses from the adoption of a proposed technology or policy. Initial investigation in Spain and Mexico suggests that it is the burgeoning tourist industry that benefits the most from this new supply of water. Water augmentation through desalination opens up new development opportunities and allows the tourist industry to grow at a profitable rate. Equity issues become increasingly important if there is a public or taxpayer subsidy for the operation of a desalination plant (Feldman, 2011). Research suggests that poorer residents are negatively impacted by the introduction of desalinated water into the public supply network. In Alicante Spain, after desalinated water was introduced in 2003, residents' water bills nearly doubled, rising from \$0.30 Euro cents per cubic meter in 2003 to \$0.55 Euro cents per cubic meter by 2009 (Prats Rico and Melgarejo Moreno, 2006). This dramatic increase in the price of water has uneven social impacts. While some water managers and policymakers argue that increasing the price of water leads to conservation of the resource, studies have shown that responses to price increases differ between wealthy and poor households (Renwick and Archibald, 1998; March and Sauri Pujo, 2009). A study of California water users found that a price increase of 10 percent resulted in a 5.3 percent reduction in water use among low income households, while wealthier households reduced their water usage by only 1.1 percent (Renwick and Archibald, 1998). This introduces an additional burden to poor households, which may only be using enough water to meet basic needs.

Lastly, it is important to consider whether the environment becomes a winner or loser when desalination is adopted. As discussed above, potential negative environmental impacts include the direct impact of the brine discharge and chemicals, as well as the indirect impacts of increased urban growth and energy demands. However, if coupled with strict conservation measures, desalination could reduce the pressure on aquifers and make more water available for in-stream environmental flows, making the environment a winner.

5.4. Risk reduction

A final step in our critical risk analysis is to consider how some of these risks may be reduced. While a narrow interpretation of a critical risk analysis might leave managers and policy-makers with the impression that, short of radical structural changes to the political economic institutions that maintain an incessant drive for the expansion of capital, there is little that can be done to reduce risks. A broader interpretation, however, recognizes that the value of a critical risk analysis is the attention given to the full-range of underlying drivers of risk. Additionally, a critical risk analysis may spur debate and politicize an issue and potentially enrich the options for policy interventions.

For decision-makers looking for less radical ways to reduce the risks associated with adopting desalination as water supply strategy, the following options can be considered. If desalination were regulated in all phases of the process (planning, construction, management and use), some of the risks could be reduced.

Regulation must include a well-developed permitting and monitoring system to ensure that all operators are in compliance. The downside of regulation, as evidenced by the 2010 British Petroleum Deepwater Horizon disaster in the Gulf of Mexico, is that regulators (in both developed and developing countries) are often unable to competently monitor and enforce regulations. This may be due to either a lack of resources, conflict of interests, or both.

To avoid unrestrained urban growth and to reduce indirect environmental impacts, two key measures should be taken. First, before desalination is considered as a water augmentation option, all conservation measures should be implemented. Once the decision to adopt desalinated is made, an urban growth limit and/or water consumption limit should be set. If this step is not taken, it is probable that increased conservation efforts and new supplies will foster further growth, rather than actual conservation (according to Jevons Paradox, see *Alcott, 2005*).

Finally, to ensure social equity and access to the new resource, a fair pricing scheme must be developed so that all residents are able to benefit from the project. Fairness must be determined through transparent processes that involve public debate, political engagement, and address issues of representation. As desalination is currently practiced, it is largely the tourist industry that derives the most benefit from the implementation of this technology. More research is needed to determine if, and how, desalination could be made more socially equitable and environmentally sustainable.

6. Discussion and conclusions

By examining the proposed intervention of binational desalination as a technological solution to increasing water scarcity under conditions of growth and climate change in the Arizona–Sonora border region, we have shown how such interventions are likely to have differentiated impacts, with costs and benefits being unevenly distributed among already stratified social groups. Our critical risk analysis shows that the associated (and unintended and under-examined) consequences of desalination are likely to exacerbate existing inequalities and introduce new vulnerabilities by compounding the water–energy nexus, increasing greenhouse gas emissions, inducing urban growth, producing brine discharge and chemical pollutants, shifting geopolitical relations of water security, and increasing water prices.

Desalination, as a highly technological form of water management, runs contrary to the Dublin Principles and an emerging water management paradigm that calls for more participatory, transparent, and decentralized water management strategies. It also runs contrary to calls for more “flexible” management strategies to adapt to climate change impacts. We understand adaptation and the development of adaptive capacity to be dynamic processes based on social learning between and within institutions. Therefore, a process-oriented analysis focused on social learning, representation, and political engagement, rather than expert-driven technological fixes, allows a better understanding of the dynamism and uncertainty associated with climate change.¹

Furthermore, recognizing the inherent contradictions in capitalism’s drive for growth and expansion and the goals of water resource conservation and environmental protection, we highlight the concerns posed by critical risk analysts who suggest that any intervention that does not address this contradiction will eventually fail. The challenges posed by climate change provide an opportunity to re-think and re-orient our fundamental institutions in more sustainable and equitable directions. However, radical political and economic changes in social and economic institutions are not easily implemented by managers. An intermediate solution

for managing desalination and reducing risk in the near-term is to ensure that, before the technology is adopted, all conservation measures are implemented and urban growth and/or water consumption limits are established. Once the technology is introduced, the industry must be well regulated and monitored. A fair pricing scheme, along with alternative energy sources need to be developed to reduce the social and environmental risks. Without mandatory conservation measures and greater focus on alternatives sources of water supply, desalination could enable a status-quo water culture that views desalinated water as a limitless substitute for freshwater, adding little to the region’s adaptive capacity.

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¹ For further discussion of process-oriented adaptation responses in the water sector, see *Wilder et al. (2010)*.

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