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Article

Can the Adoption of Desalination Technology Lead to Aquifer Preservation? A Case Study of a Sociotechnical Water System in Baja California Sur, Mexico

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Abstract: There is growing concern about the sustainability of groundwater supplies worldwide. In many regions, desalination—the conversion of saline water to freshwater—is viewed as a way to increase water supplies and reduce pressure on overdrawn aquifers. Using data from reports, articles, interviews, a survey, and a focus group, this paper examines if, and how, the adoption of desalination technology can lead to aquifer preservation in Baja California Sur (BCS), Mexico. The paper outlines existing institutional arrangements (*i.e.*, laws, rules, norms, or organizations) surrounding desalination in BCS and concludes that there are currently no effective mechanisms to ensure aquifer preservation. Four mechanisms that could be implemented to improve groundwater management are identified, including: 1) integrated water-and land-use planning; 2) creation of an institute responsible for coordinated and consistent planning; 3) improved groundwater monitoring; and 4) implementation of water conservation measures prior to the adoption of desalination technology. This paper concludes that viewing water technologies, including desalination, as sociotechnical systems—*i.e.*, a set of technological components that are embedded in complex social, political, and economic contexts—has the potential to create a more sustainable human–environment–technology relationship. By assessing desalination technology as a sociotechnical system, this study highlights the need to focus on institutional development and capacity building, especially within local water utilities and urban planning agencies.

Keywords: desalination; aquifer preservation; sociotechnical systems; Mexico

1. Introduction

There is growing concern about the sustainability of the world's groundwater resources. Recent research using NASA's GRACE satellites found that about one-third of the world's largest aquifers are being depleted [1]. In many water-stressed regions, desalination is increasingly viewed as a technical solution for increasing water supplies and reducing the pressure on overdrawn aquifers. However, there is concern that surplus water will aid further urban and industrial growth, rather than conservation and aquifer preservation [2,3]. Aquifer overdraft occurs when the rate of extraction exceeds the rate of recharge. The term aquifer preservation is used to describe a situation in which the rate of groundwater extracted from an overdrawn aquifer is reduced to prevent further aquifer depletion, reduce the possibility of land subsidence, and/or reduce the risk of saline intrusion. If the adoption of desalination technology is to lead to aquifer preservation, I argue that desalination must be viewed as a sociotechnical system—*i.e.*, a set of technological components that are embedded in complex social, political, and economic contexts [4,5]. A sociotechnical systems perspective emphasizes the need to develop institutions and regulatory mechanisms in order to shape and manage the outcomes of technology and infrastructure. Using a case study of water planning in the arid state of Baja California Sur (BCS), Mexico, I summarize existing institutional arrangements for desalination and water management in BCS and identify four mechanisms that that could be implemented to better ensure that desalination technology achieves the purported environmental benefits. This paper proceeds with a review of relevant literature on desalination and social studies of technology, followed by a description of the methods, an overview of the case study, and presentation of research results and conclusions.

2. Literature Review

Desalination is a technical process that converts seawater or brackish groundwater into high quality freshwater that that can be used for potable purposes [6]. This technology poses a conundrum to water managers who are increasingly concerned with the environmental impacts of water development and water use. On one hand, there is concern about the negative environmental impacts of this energy-intensive technology, including the impact of brine discharge and chemical pollutants on marine ecosystems, the entrapment of marine organisms during the seawater in-take process, increased emissions of greenhouse gases, and the potential for growth inducement [7,8]. The California Coastal Commission identified growth inducement as potentially the "most significant effect" of a desalination facility [2] (p. 67). Swyngedouw's study on the recent desalination boom in Spain concluded that desalination is "increasingly seen as a socionatural fix that permits a productivist water logic to remain the bedrock of Spain's global eco-modernization projects so that 'nothing really has to change' (di Lampedusa 1960)" [9] (p. 268). Political ecologists argue that technological fixes to environmental problems, including water scarcity, is simply a deferral of the contradictions of capitalism, which requires the exploitation of labor and natural resources to sustain growth and accumulation [8–11].

On the other hand, desalination can be seen as a "green" or "environmentally friendly" technology. Lattemann, Kennedy, and Amy [12] argue that using the "best available techniques" to design desalination facilities can reduce the negative impacts associated with water in-take, discharge, and energy consumption. Desalination is promoted as a rain-independent water source that can buffer against uncertain water availability and climate change impacts on water resources [13,14]. In Spain, desalination has been viewed as a "cornucopia" that can reduce the need for interbasin transfers, which have negative social and environmental impacts [15]. In Mexico, desalination is seen as a technology that can augment water supplies to meet growing needs, as well as aid in the preservation of overdrawn aquifers [16].

While desalination has the potential to reduce pressure on groundwater resources, an appropriate and effective institutional and regulatory framework must be in place in order to realize this "green" potential. Cooley, Gleick, and Wolff [2] note that 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 and aquifer preservation (*ibid*). Thus, the degree to which desalination will help achieve sustainable groundwater management remains questionable, especially if the technology is evaluated apart from the social, political and economic context in which it is embedded.

The study of the relationship between technology and society is a broad field of inquiry that includes science, technology and society (STS), sociology of technology, history of technology, social construction of technology, political ecology, and actor network theory, among others. For simplicity, I use the term STS, but draw on concepts from various subfields. STS scholarship provides a framework for evaluating desalination as a sociotechnical system. STS studies examine the social and physical conditions that shape the development and adoption of various technologies and/or how technology shapes society [17,18]. Perhaps one of the most important contributions from this field is the recognition that modern society is more accurately viewed as a "seamless web" comprised of various social and technical factors that cannot be analyzed and understood separately [4]. From this perspective, a technology is better understood and investigated as a "sociotechnical system" [5] in which technical components are embedded in social, political, and economic contexts that influence the development, operation, and outcome of the technology—and *vice versa*.

An on-going debate within the field is the degree to which technology is shaped and controlled by society *versus* how autonomous a technology is (*i.e.*, how its technical requirements determine, or at least shape, the developmental path of society) [18]. An example of the latter is that expensive technologies and/or large-scale infrastructure projects (e.g., dams) often develop momentum and thus have a tendency to become obdurate (or stubborn) [4]. In other words, technologies may become so tightly embedded in social and economic contexts that it is difficult to switch to a different set of technologies. Another way to think about the autonomous nature of technology is to consider how, and to what degree, certain operational requirements (or "technological imperatives") make a technology more or less compatible with certain political arrangements [19]. For example, a complex technology with multiple components may be more compatible with a highly centralized bureaucratic structure, rather than a decentralized management structure. Expensive technologies may require economies of scale that encourage large projects and/or require investment from private industry. These factors may then limit who is involved in the decision-making process and shape how the benefits of the technology are distributed. While skeptical about the ability to fully control technologies, Winner [19] provides the following observation about how and when social institutions should intervene to shape technologies and their outcomes:

By far the greatest latitude of choice exists the very first time a particular instrument, system, or technique is introduced. Because choices tend to become strongly fixed in material equipment, economic investment, and social habit, the original flexibility vanishes for all practical purposes once the initial commitments are made. In that sense technological innovations are similar to legislative acts or political foundings that establish a framework for public order that will endure over many generations. For that reason, the same careful attention one would give to the rules, roles, and relationships of politics must also be given to such things as the building of highways, the creation of television networks, and the tailoring of seemingly insignificant features on new machines. The issues that divide or unite people in society are not only in the institutions and practices of politics proper, but also, and less obviously, in tangible arrangements of steel and concrete, wires and transistors, nuts and bolts [19] (pp. 127–128).

STS scholars also seek to understand the ways in which technologies themselves often spawn the creation of new social institutions (*i.e.*, new laws, rules, norms, or organizations) [20]. For example, Jasanoff's [21] comparative study of different regulatory frameworks for controlling risks associated with new biotechnologies and chemicals shows how different social and political contexts can affect the management of these technologies. These regulatory decisions can minimize (or exacerbate) the risks associated with a technology. Birkenholtz's [22] study of tubewell technology in Rajasthan, India found that the proliferation of tubewells not only "intensify and extensify production" but also "demand the further creation of new social institutions" such as cooperative tubewell partnerships (p. 128). In the 1960s in the southwestern United States, federal funding for the Central Arizona Project (CAP) —a $36 billion dollar system of pumps, pipes, canals, and aqueducts that transports 1.5 million acre-feet of Colorado River water across 336 miles of arid, mountainous terrain to augment water supplies in central and southern Arizona—was contingent upon the imposition of restrictions for groundwater use in Arizona [23]. This spurred Arizona to adopt its first groundwater code (*i.e.*, the Groundwater Management Act), establish new zones of governance (*i.e.*, Active Management Areas), and create a new administrative agency (*i.e.*, the Arizona Department of Water Resources). While the ultimate effectiveness of regulatory efforts to restrain groundwater pumping in Arizona is questionable [24], it is significant that policymakers recognized that unless new groundwater regulations were imposed, it was unlikely that the new CAP water would be used to address the existing groundwater depletion problem.

This paper contributes to the body of scholarship that seeks to understand if, and how, society can manage and regulate technology to achieve societal and environmental objectives. I argue that a critical understanding of our human-environment-technology relationship, informed by STS scholarship, could be the basis of a more sustainable approach to water management. After providing an overview of the methods and case study, I summarize the types of agencies and institutional arrangements that have been developed in BCS to manage desalination technology. Where institutional developments fall short, I identify four potential mechanisms that would need to be developed if desalination is to achieve the purported environmental goal of aquifer preservation.

3. Methods and Case Study

3.1. Methods

This research is part of a larger dissertation project that involved nine months of field research in Baja California Sur, Mexico (August 2011–May 2012). The data presented in this article are derived primarily from analysis of secondary documents (*i.e.*, government reports, reports by non-governmental organizations or NGOs, newspaper articles, and scholarly articles). This analysis is supplemented by selected data gathered through semi-structured interviews, a short survey, and a focus group. During nine months of field research, I conducted semi-structured interviews with 71 different stakeholders, including federal, state and municipal water managers, representatives from environmental and water-related NGOs, real estate developers, academics, and residents (Table 1). The semi-structured format was selected because it allows the researcher to begin with some predetermined questions, but also move and/or digress from the interview schedule through probes and new insights that emerge during the interview [25]. Furthermore, this format allows the interview schedule to vary depending on the interviewees' area of expertise. In addition, I conducted a short, non-representative, exploratory survey and a focus group with 36 individuals who were participating in a week-long seminar on water management in arid regions at the Universidad Autónoma de Baja California Sur (UABCS), in La Paz, BCS [26]. Participants included marine biologists, students, government employees, professors, and representatives of water-related NGOs, among others (Table 2). The survey consisted of a series of five-level Likert scale questions to assess perceptions of water security in La Paz, views on the potential benefits and concerns related to desalination technology, and trust in governmental regulations for water management and urban development. The survey results were presented during the focus group and discussed in more detail. Results from the larger research project are available in other publications [8, 27–29].

Table 1. List of interviewees by affiliation type.

Affiliation	# of Interviewees
Federal government representatives	9
State government representatives	4
Local government representatives	11
Environmental Non-Governmental Organization (NGO) representatives	5
Academic/Researcher	6
Private sector representatives	10
Community residents	23
Other	3
Total # of Interviewees	71

Table 2. List of participants in survey and focus group by affiliation type.

Affiliation of Participants in Survey and Focus Group	# of Participants
Marine biologists	7
Students (marine biology, sustainable development, ecology, and unspecified)	7
Government employee (federal, state and local)	5
Professors (marine geology, agronomy, economy, unspecified)	4
Water-related NGO representatives	2
Other (geologist, economist, environmental consultant, system engineer)	4
No affiliation given	7
Total # of Participants	36

3.2. Case Study

Water management in Mexico is marked by an imbalance in the distribution of people, industry, and water. Northern Mexico is where the majority of irrigated agriculture, industry, and population are located, but has only nine percent of the country's water resources [30]. Arid northwestern Mexico, including BCS, faces high levels of water stress. A report by Mexico's National Water Commission (Conagua) [31] indicates that in 2008,101 of Mexico's 653 aquifers were in overdraft. As reported by Scott [32], the criterion for listing these aquifers as overexploited appears to be when the rate of extraction exceeds the rate of recharge by greater than 9.5% (p. 3). Twenty-one of these overdrawn aquifers are located in the northwest and Baja Peninsula [31] (p. 43) (Figure 1). This geographic context has contributed to the overpumping of northern aquifers, costly river basin transfers, and conflicts among competing users [33]. Despite the overexploitation of aquifers, many households do not have a reliable source of water. For example, in the capital city of La Paz, BCS, residents in the poorest neighborhood receive piped water only once every three to fifteen days [28].

Figure 1. Overdrafted aquifers in Mexico by Hydrological-Administrative Region, 2008 [31] (p. 44).

In this context, there is growing interest in adopting desalination technology to augment water supplies and reduce pressure on overdrawn aquifers in northwestern Mexico. The International

Boundary and Water Commission (IBWC) is evaluating the feasibility of binational desalination projects in Sonora, Baja California, and Baja California Sur, which could increase water supplies in both Mexico and the U.S. [34]. Additionally, as part of the federal government's 2007–2012 National Infrastructure Program, eight priority desalination projects have been identified in northwestern Mexico [35]. In BCS, there are at least 22 hotels with private desalination plants that support the continued growth of the tourist industry [36]. In 2006, Mexico's first-ever, large-scale public desalination facility was built in Los Cabos, BCS to provide water to 40,000 residents [27]. A 2012 state-level comprehensive water planning document, identifies desalination as the principal means by which the major cities of Los Cabos and La Paz will address the gap between water demand and water supply by 2030 [37]. There is a current proposal to build a large-scale desalination facility in the capital city of La Paz. As stated in the environmental impact assessment (EIA) report for this project, aquifer preservation is a central goal of the desalination initiative in La Paz [16]. On the opening page, the report states:

There are diverse desalination schemes that have been successfully implemented in coastal zones with water supply problems, similar to the case of La Paz, BCS. But these schemes must be analyzed in conjunction with the dynamic behavior of the aquifer in order to *find a suitable alternative that allows for the correction of this problem [of overexploitation and saline intrusion] and achieve not only the necessary water supply, but also the recovery of the aquifer*, at least in the areas where saline intrusion and depletion of the water table, caused by excessive pumping, have significantly impacted the groundwater [16] (p. 1, emphasis added).

The document goes on to state:

The National Water Commission (Conagua) considers the installation of a reverse osmosis seawater desalination plant of 200 Lps (6.3 Mm^3/year), as a vanguard technological option that would satisfy the excessive short-term water demands for potable water for the population; it would also contribute to the control of the overexploitation and accelerated depletion of the aquifer and saline intrusion [16] (p. 7).

While aquifer preservation is a central water management goal, as Cooley *et al.* [2] note, an "explicit mechanism" is needed to ensure environmental benefits of desalination. In the following section I summarize the existing rules and regulations regarding the use and management of desalination in BCS and identify gaps in institutional development for managing this technology to ensure aquifer preservation.

4. Results

4.1. Existing Institutional Arrangements for Managing Desalination Technology

At present, there has been little institutional development associated with the adoption of desalination technology in Mexico. The few regulations that do exist pertain primarily to the extraction of seawater and the discharge of wastewater. As established in the 2004 amendments to the Law of National Waters (LAN), a concession for the extraction of seawater or brackish groundwater must be obtained from Conagua. All water in Mexico, including seawater within 12 nautical miles of the country's coasts, is property of the Nation and under the purview of the Mexican President and Conagua [38,39]. To dispose of the brine discharge, an environmental impact assessment (EIA) must be completed and a separate concession from the federal Environmental Ministry (SEMARNAT) must be obtained. While there are currently no federal or state laws governing brine discharge, SEMARNAT is in the process of establishing a new regulation that would set a limit on discharge concentrations and provide technical guidelines on where to locate the intake pipes [28]. In the meantime, limitations and guidelines for brine discharge are set on a case-by-case basis in the EIA [39].

While desalination projects are required to undergo an EIA, lawyers with the Mexican Center for Environmental Law (CEMDA) have observed that these studies do not always adequately address the impacts of desalination technology [28]. For example, the EIA for the proposed desalination plant in La Paz claims to consider a wide range of impacts, including abiotic, biotic, and socioeconomic elements of the land and marine components, including the impact on the aquifer [16] (p. 7). However, the analysis focuses primarily on the potential impacts of brine discharge to the exclusion of other issues. The report recognizes that urban growth threatens water supplies (p. 26), but there is no analysis of how desalination could induce urban growth. The report highlights the potential for desalination to aid in aquifer preservation, but there is no discussion of how this goal will be achieved.

In addition to the federal permits required from Conagua and SEMARNAT, the Federal Electricity Commission (CFE), the only power supplier in Mexico, must agree to supply the power necessary for the plant. Also, a land-use permit must be obtained for the siting of a desalination facility [38,39]. This approval may occur at the local, state or federal level, depending upon who owns the land.

While the regulation of desalination occurs primarily at the federal level, it is important to note that BCS is the first state to address desalination in a state water law [36]. This law allows the State Water Commission (CEA) and the local municipal government to establish regulations for the construction, operation, administration, and maintenance of desalination systems; resolve issues related to desalination; and determine the average rate of potable water supply services and desalination [40]. Within the CEA, there is a department dedicated to desalination, but at present, their role is limited to providing technical expertise on the implementation and maintenance of desalination facilities. Importantly, there are no effective state regulations that link the adoption of desalination technology to integrated water- and land-use planning, groundwater monitoring, or water efficiency measures. As I discuss below, these gaps in institutional development are likely to lead to a situation in which municipalities use *both* desalinated water and groundwater to meet the needs of growing water demands, rather than reducing their reliance on groundwater.

4.2. Institutional Gaps for Ensuring Aquifer Preservation through Desalination Technology

As noted, the existing institutional arrangements for managing desalination technology in BCS fall short of what is necessary to ensure aquifer preservation. Based on a synthesis of information obtained during nine months of field research (including analysis of secondary literature, semi-structured interviews, a survey, and focus group), I have identified four institutional mechanisms that could help achieve this goal. The first mechanism is the development and enforcement of an integrated water- and land-use plan. In BCS, urban development is guided by local zoning plans, known as a *Planes de Ordenamiento Ecológico Local* (POELs). According to the La Paz POEL, "In La Paz, freshwater is the limiting factor, therefore it is the quantity of groundwater of each unit of environmental management (*Unidad de Gestion Ambiental, UGA*) that determines the maximum population" (p. 3). As one stakeholder commented in the EIA report for the proposed desalination plant in La Paz, "The POEL insists that there should not be one more development, not one additional hotel room, until there is a new source of water" [16] (p. 109).

This report goes on to strongly critique the lack of adequate zoning laws and enforcement, stating:

The current situation (in La Paz) shows an aggravation of the availability and efficiency of water in the area, with respect to the 1970s in which the social, politic and economic development of the area began, which led to the accelerated urban and demographic growth that has occurred in the area since the 1990s, with a 380% increase in population and *anarchic expansion of the urban footprint*, principally in the southern zone of the city, an area of aquifer recharge. *The 1983 Plan de Desarrollo Urbano has not been updated, and this plan is not respected or followed because there is a lack of regulation in the land-use, which has allowed and encouraged irregular human settlements and tourist real estate development in federal coastal zones and natural protected areas* [16] (p. 22, emphasis added).

However, even if municipalities were to adopt new regulations regarding urban development, there remains a concern about enforcement. This is an issue of particular concern in a developing country context, where weak institutions may be even more susceptible to corruption, or government agencies may lack the resources necessary for enforcement. As part of the survey, I asked about the degree to which respondents agreed with the following statement: The government institutions that regulate urban growth are strong enough to deal with greater development pressure. Survey results indicate that there is little trust in the ability of the local government to effectively regulate urban growth. Of the 34 respondents who answered this question, eighty-two percent either strongly disagreed (15 respondents) or disagreed (13 respondents) with this statement. Twelve percent were neutral (4 respondents) and only two respondents (six percent) agreed with this statement. Nobody strongly agreed with this statement and two participants did not answer this question (Figure 2).

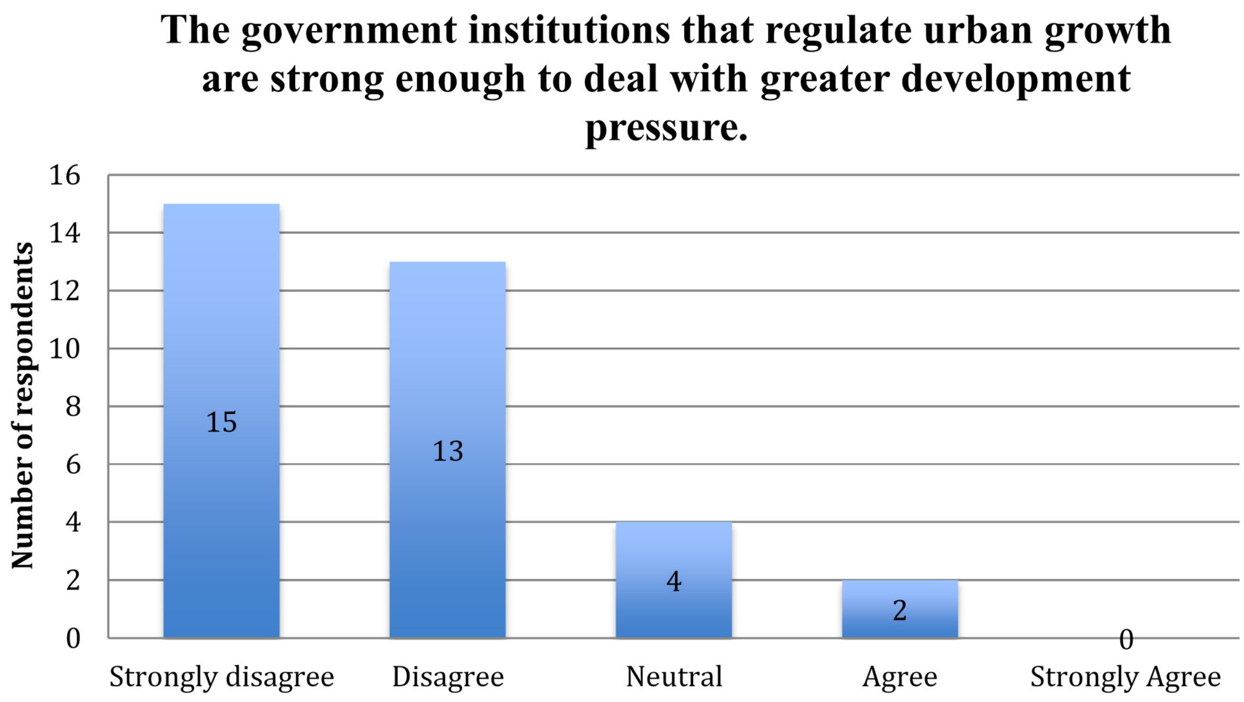

Figure 2. Graph of responses to survey question about trust in government institutions to regulate urban growth.

These findings highlight the importance of seeing desalination as a sociotechnical system, which requires an evaluation of the social and cultural context within which technologies and regulations are developed. Before planners can ensure that desalination will lead to aquifer preservation, they must first ensure that urban development and water use regulations are enforced.

The 1995 Los Cabos POEL (which also has not been updated) encouraged new tourist developments to provide their own water supply through desalination [41]. The wording in the planning document specifies that new developments must also be able to provide water for the associated population growth. As the 1995 Los Cabos POEL reads:

The planned tourist developments in [specified] units *must secure their own supply of water, as well as water for the population centers that they will generate*, without impairing the resource for other surrounding locations, preferably by the establishment of desalination plants or other technologies for water utilization [41] (p. 17, criteria A1, emphasis added).

While there are now 22 private, small-scale desalination plants in Los Cabos [36], new tourist developments have not provided adequate water for the growing resident population that provides labor for this industry. Due to lack of enforcement of the POEL, water provision for residents remains the task of the municipality. Furthermore, the 1995 POEL's recommendation for self-supply only applies to tourist developments, not to residential developments. Despite the limited water supply in both Los Cabos and La Paz, developers are still able to obtain the necessary permits to build, highlighting a lack of coordination between the urban planning office and the water utility. As one stakeholder commented in the La Paz EIA:

There are new *colonias* and settlements. They let them build—they do not require the developers to guarantee water availability for 20, 50 or 100 years. The only thing that matters is the economics of it…But if we build a desalination plant, will there be a reduction in extraction from the groundwater aquifers? No! With the new plant they will build two or three new developments. (A developer) comes with a housing project for 5000 homes in (the neighborhood of) El Centenario. (The government) only cares if they pay taxes. But what about the *colonias*, like Lázaro Cárdenas, that only receives water every four days, or once a week [16] (pp. 111–112)?

A second potential mechanism for ensuring aquifer preservation is the creation of a coordinated planning institute. For example, in response to a lack of coordinated urban plans, Los Cabos established a Municipal Institute of Planning (IMPLAN) in 2009. This public planning consultancy provides advice and coordination among various agencies, including the urban planning office and the water utility. IMPLAN is also designed to compensate for the rotation of key administrative directors, such as the water utility director and urban planning director, who are typically replaced every three years when there are new municipal elections [42]. While it may be too soon to assess the effectiveness of this nascent institution, it appears to be improving the coordination of urban planning efforts. An institution like IMPLAN could develop policies that ensure that desalination technology is adopted in conjunction with new rules for groundwater management. Again, enforcement of any new policies would be necessary.

A third institutional development that would be necessary to ensure that the adoption of desalination technology leads to aquifer preservation is to improve the monitoring and metering of groundwater extraction and water consumption. At present, the water networks in La Paz and Los Cabos lack full-metering, including both macro-meters at the extraction wells, as well as micro-meters at the level of the individual user [43,44]. Improved metering would allow the water utilities to better detect leaks and improve system efficiencies. Given the financial costs associated with establishing and maintaining an effective metering program, it is likely that a cross-subsidy or a groundwater users' fee would need to be implemented. A program that provides full and accurate accounting of aquifer withdrawal and water consumption would be an important step in ensuring aquifer preservation. However, it is important to recognize that there is often public resistance to water meters for fear that they may lead to the commodification of what would otherwise be a public good and human right [45,46].

A final potential mechanism for ensuring that the adoption of desalination technology achieves environmental benefits would be the pre-conditioning of desalination adoption upon the successful implementation of a range of water conservation and system efficiency measures. As in many regions of Mexico, the water distribution systems in BCS operate inefficiently due to deteriorating infrastructure and/or lack of reinvestment and repair. Conagua [47] estimates that most water systems in Mexico lose 30% to 50% of their water due to leaks (p. 37). In Los Cabos there is still an estimated 19% to 30% of water loss due to system inefficiencies [44,48]. Other water conservation measures are outlined in the 2030 Water Agenda planning document including the installation of water efficient showers, water faucets, toilets, and urinals [37]. More stringent codes for new buildings could require new homes, hotels, and industries to install efficient appliances. Rebate programs could be implemented to incentivize the replacement of older infrastructure. There is the potential for achieving both environmental and social equity goals by subsidizing efficient appliances for poorer households. This type of subsidy program has been shown to not only supply poorer households with the basic infrastructure they need, but also reduce their water expenditure by increasing household water-use efficiency [49].

5. Discussion and Conclusions

In exploring the contradictions of desalination as an environmentally sustainable water augmentation strategy in BCS, I have shown that, despite the central goal of achieving aquifer preservation, there is little evidence of appropriate and sufficiently effective institutions that can provide a mechanism through which the environmental benefits of desalination might be realized. While there are a limited number of federal- and state-level laws regarding desalination, the primary focus is on regulating the impact of the brine discharge on the marine ecosystem. In BCS, there is no policy or regulation that specifically links the adoption of desalination technology to aquifer preservation. As Cooley *et al.* [2] observe, an explicit mechanism is necessary to ensure that desalination technology is used to achieve environmental objectives. Without such a mechanism, it is likely that desalination will result in increased urban growth and water use, rather than resource conservation.

This conundrum, however, comes as no surprise to those who take a sociotechnical systems approach to understanding human-technology-environment relationships. An STS perspective requires water managers, decisionmakers, and citizens to think about the social, political, and economic context in which a technology is adopted. This means thinking through the types of technological imperatives, or "autonomous" requirements associated with large, expensive technologies like desalination [19]. Additionally, an STS approach highlights the ways in which a large-scale technical solution can create technological obduracy or path-dependency, making it more challenging to implement alternative water management solutions in the future [4].

STS scholarship also highlights the need to create regulatory institutions that can minimize and control the risks associated with a new technology [21]. Winner [19] suggests that it is best to adopt rules governing new technologies early on, before social habits and economic investments become "strongly fixed" in the technology (p. 127). Around the globe, as desalination technology is increasingly contemplated as a water supply strategy that can meet growing water demands and reduce the pressure on overdrawn aquifers, it is important to consider the types of institutions that will be necessary to ensure that desalination achieves environmental objectives. In this case study of desalination in BCS, I have outlined four institutional mechanisms that have the potential to ensure that desalination contributes to more sustainable groundwater management, rather than growth inducement. These include: (1) integrated water- and land-use plans; (2) new agencies to coordinate and enforce urban plans; (3) improved monitoring and regulation of groundwater extraction; and (4) the pre-conditioning of desalination upon the successful implementation of a range of water conservation and system efficiency measures. However, I have also problematized the issue of enforcement. Hirt *et al.* [24] argue that in the case of the CAP in Arizona, developers, farmers, water providers, lobbyists, and lawyers have taken advantage of loopholes in the Arizona Groundwater Management Act and undermined the effectiveness of this regulatory mechanism. In a developing country context, where resources for building institutional capacity are often limited, the ability to enforce new (and existing) regulations is a concern.

In conclusion, my analysis indicates that the current institutional arrangements surrounding desalination in BCS are insufficient to achieve the purported environmental benefits of aquifer preservation. Using an STS framework, I have highlighted the ways in which technologies can both shape and be shaped by society. I argue that using an STS framework can prompt water managers, decision-makers and citizens to think about the type of human-technology-environment relationships that are desirable and sustainable. By assessing desalination technology as part of the social, political and economic context in which it is embedded, this study highlights the need to focus on institutional development and capacity building, especially within local water utilities and urban planning agencies.

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Author Contributions

Jamie McEvoy conceived and designed the study, conducted the research, analyzed the data, and wrote the paper.

Conflicts of Interest

The author declares no conflict of interest.

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