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An Ecological-Economic Research Program for Desalination[1]

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1. Introduction: Desalination and Sustainability

The reliability of desalination technology, and the water world's familiarity with it, continues to grow (Mezher et al., 2011; Greenlee et al, 2009; WateReuse Association, 2011). Thermal desalination has decades of proven use from small to large scale. Membrane technology has become the standard in North America and many other locations (e.g., Australia, Europe), and is in regular use in both large- and small-scale facilities. Additional technological breakthroughs in such areas as low-pressure membranes are expected as the public and private sector continue to invest in research. Membrane and supporting pre-treatment technologies are already mature enough that desalination has taken its place as an accepted water-supply technology. In the North American context, it is likely to be a supplemental supply to areas that already have some surface and groundwater. It is also distinguishable from surface waters in that it is non-cyclical seasonally since it draws either from the ocean or brackish aquifers. Desalination therefore falls into a category of supplemental non-cyclical water supply (SNCWS). Urban water reuse also falls into this category, although its source water is different.

Our technical competence with desalination has outpaced our appreciation of its potential transformative role in society. The regular and reliable generation of drinkable water from seawater or brackish inland water marks a profound transition in humanity's ability to overcome the physical barriers of survival. Desalination technology creates new opportunities for human society in locations that previously were limited or off limits due to lack of water. Beyond mere survivability, water is a crucial ingredient in urban, agricultural, and open space transformation. The more high-quality water available, the more physical and ecological change can take place in any region.

When desalination plants have been proposed in California, unexpectedly strong public questioning has arisen (Food & Water Watch, 2009; Cooley et al., 2006). Sometimes the opposition has taken unusual forms, such as anti-desal songs, poems, and sit-ins at meetings. Opponents in Santa Cruz, California have, for example, called for a return to the pioneer era, including the per capita water use experienced in those days, as an alternative to desalination. Other challenges are more deeply rooted in the 21st century. Gratz et al. (2011) in a Santa Cruz newpaper editorial call for more thorough investigations of energy use and climate change, total cost to ratepayers, marine impacts,

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product water safety, and public decision-making processes. In Carlsbad and Marin, opponents raised legal challenges to environmental impact reports.

Regardless of the method of delivery, a theme emerges in the public challenges – that desalination should be understood in its broadest social context as a potential game-changer in societal/ecological relations. Opponents are asking: ***What is desalination's role in an ecologically and socially-sustainable future?***

Sustainability is a common theme in water research and analysis. AWWA's 2009 Sustainability Ad Hoc Committee produced a milestone report orienting the Association to the theme of Sustainability, defined as a long-term commitment to "economic growth, environmental protection, and social development" (AWWA, 2009). It proposed the development of a "G" (for Green) Standard similar to existing standards for O&M Security and Source Water Protection. Sustainability is a common term in AWWA and other industry publications and articles. The AWWA focuses on actions that fall within the control of water agencies. Raftelis (2011), for example, lists the many groups that constitute's a water agency's "community" and notes that all have an interest in how water is managed, priced, and used. He notes the importance of "community sustainability" as complementary to a utility's financial sufficiency, focusing on the role the community plays in influencing agency policy and direction.

In the public's mind, the already-broad question of sustainability is framed well beyond the purview of the typical water agency. It includes questions such as whether we have the right to develop more water than the planet can sustain, whether we are already living too far beyond our environmental means, and how one balances social justice, economic development, and sustainable living. It sometimes frames water as a renewable resource that depends on physical and ecological factors to renew itself each year. But water, which often eludes easy classification, is also an extractive resource, as is evident when groundwater is drawn down.

One might choose to dismiss it by arguing that desalination is simply one of numerous water treatment technologies and doesn't deserve the big-picture analysis missing from other established supply options. Further, as membrane technology becomes better understood and proven in performance, desalination loses any remaining sense of being an exotic technology. It becomes more amenable to being integrated into an existing water system from technical, financial, and managerial perspectives. It becomes just one more tool in the water manager's toolkit.

But arriving at answers to the technical, financial, and managerial challenges of integrating desalination into existing water systems only qualifies desalination for the larger conversation now demanded of it. Imagine if California's water systems operated without reservoirs or groundwater wells, perhaps because these technologies had never been invented. When such systems were finally developed and introduced they would generate massive public scrutiny and a range of reactions, some stridently opposed. Indeed they still do when new projects are proposed. This is the current situation facing desalination technology.

Another reason for careful scrutiny of desalination is that it may be viewed as a road that, once taken, is difficult to double back on. Initial capital costs, like many new infrastructure projects, represent a substantial regional financial commitment (WateReuse Association, 2011). Once the investment has been made, due to the vastness of its source of supply, desalination has immense potential to supplement, augment, and substitute for existing water sources. An existing facility is relatively easy to scale up, especially if scaling was anticipated during the initial design stage. Regions that adopt desalination are making more than a few-decades commitment; they are making a "foreseeable future" commitment, or what von Medeazza (2005) describes as desalination "lock-in."

So we should not be surprised that the public wants a broad discussion of desalination technology, its role in society, its cost, and its risks over the short, medium, and long term. This paper offers a research roadmap for the ecological-economic impacts of desalination, including how this agenda links to existing research on desalination. Ecological economics is a field of research that investigates economic performance under natural resource constraints. While resource constraints are commonly applied in economic optimization problems, ecological economics assumes that resources not directly involved in production are also constraining and that polluting byproducts of production can also generate constraints. Ecological economics studies common-property and "tragedy of the commons" questions, both of which arise when dealing with the ocean as a water source and effluent depository. Lant (2004) describes how ecological economics extends the concept of "capital" to include natural and human capital in ways that help us capture better what is gained and lost when society pursues new water infrastructure projects.

An irony of using ecological economics to address desalination is that the field of study stresses holism - interconnections between physical processes and human society, while membrane technologies are the ultimate example of separation – dividing a water flow into product water and effluent streams. Ecological economics will not let us lose site of the side-stream impacts of desalination.

2. Desalination Research Today

The national agenda for desalination research has been guided by a number of documents. One is the 2001 NWRI/USBR "Desalination Research and Development Workshop Report." Soon after came the Sandia/Bureau of Reclamation Desalination and Water Purification Technology Roadmap, published in 2003 by the National Academies Press, and a review of the following year affirming the main research proposals National Academies' Water Science and Technology Board. The roadmap focused on improving technologies used to purify impaired waters, including cost reduction, efficiency improvements, and contaminant removal improvements. The roadmap identified membrane technology as the leading approach but endorsed research on thermal technologies and what it called "evolutionary and revolutionary" technologies (p. 61). By 2003, the federal government had spent more than $1.4 billion on desalination research (Water Science and Technology Board, 2004). These reports informed the research program proposed in the 2008 national review of desalination called *Desalination: A National Perspective.* This report divided its research recommendations into efforts to reduce environmental impacts of desalination and efforts to reduce its cost. It also included a recommendation to study how to link desalination to renewable energy sources.

Another detailed guide to desalination and water purification research emerged in 2008/09 entitled “Implementation of the National Desalination and Water Purification Technology Roadmap.” This report was a joint product of Sandia National Laboratories, the Water Research Foundation, and the WateReuse Foundation. In addition to its technological focus, the roadmap included a section proposing research on institutional issues ranging from finished water cost to energy use, marketing, regulations, water rights, customer outreach, and communications.

In California, Proposition 50, a voter-approved initiative, funded research on desalination in the mid-2000s, including social-science research on costs and benefits of desalination that informs this paper. Water agencies are studying the use, impacts, and integration of desalination in their own systems. Private sector firms are working to improve all technical aspects of desalination, including improving membrane characteristics and reducing power needs. University researchers are investigating engineering performance of desalination. Governments are also sponsoring desalination research, including research leading up to this paper. Research is published in a variety of venues, including municipal utility reports required by law, professional and academic journals such as *Desalination*, private research institute white papers, publications of industry-sponsored research groups, such as the WateReuse Research Foundation, web sites, and conference proceedings.

More broadly, desalination research remains a global endeavor as scientists from the Middle East and Asia regularly contribute to leading peer-reviewed journals.

3. Supplementing Current Research with Ecological-Economic Perspectives

Understanding the costs and benefits of desalination has always been an important research undertaking. Identifying the total cost of any activity helps us decide if it is worth doing. If the cost exceeds the value one obtains, one shouldn’t do it. If one decides to do it anyway, an overriding reason is called for, such as a moral duty or public responsibility. Otherwise society is better off devoting its resources elsewhere. The key to these decision rules is being able to calculate the costs and benefits of one’s options and then comparing them. Calculations need to be accurate, though not necessarily exact. If risks are involved, the Precautionary Principle allows us to make choices even if the numbers aren’t exact. Some costs are quickly estimated, especially those that are initially monetized, including equipment/capital, land purchase, consulting costs. Other costs, including environmental, human-health risk, and fire protection risks, are less easily identified. Yet they contribute to a thorough cost-benefit analysis and are therefore necessary to a decision process.

It is more likely that we will accurately understand the full cost of desalinated water than the full cost of existing surface- and ground- water supplies. Desalination is a newer technology (in North America) using previously untapped water sources. It does not have the history of cumulative impacts of our existing water system. In California, the collapse and near-extinction of salmon populations is a good example of a cost of surface fresh-water supply, but who sees a Salmon Extinction Surcharge on their water bill?[2] Even if such a surcharge were authorized, how could it be calculated accurately and assessed fairly among millions of water users? Similar costs that rarely find their way into water bills include groundwater and surface water degradation, increased flood risk, loss of species abundance, including commercially-valuable species, introduction of non-native damaging species, and loss of scenic and recreational uses of water supply. As a new water supply, desalinated water does not bear these historical costs of infrastructure and transmission of water.

Costs that are routinely identified and estimated are intake and discharge, finished water quality and distribution, feedwater quality and variation, permitting and regulatory, and other costs including power, labor, and proximity to other land uses. The project delivery mechanism (e.g., DBOOT) may itself have additional costs or inefficiencies (WateReuse Association, 2011). These are construction and operations costs incurred by water agencies and appear as financial obligations on agency books. Understanding them in detail is crucial to the successful management of water agencies. Slow degradation of natural systems is accounted for elsewhere or not at all. Once property rights are established to water flows (which occurred in most cases several decades ago or even earlier), the slow, perhaps multi-decadal degradation of those flows typically does not find its way into water bills. Without a full price signal, consumers cannot make good choices about how much water to use, and likely will overconsume water. Nor can system managers raise the funds necessary to reverse the degradation.

With desalination, research could bring us closer to an estimation of its true cost. Although exceptions exist internationally (e.g., Riyadh, Saudi Arabia), desalination is likely to remain a regional water technology, consumed near its point of production. This will simplify an accounting of costs and benefits and create an opportunity to design cost allocation systems that assign accurate water costs to water users.

3.1 Environmental Impact Costs

Numerous articles describe potential impacts of desalination facilities (e.g., Einav et al. 2002; Lattemann and Höpner, 2008) and estimate the cost of desalinating both brackish and ocean water (see review by Karagiannis and Soldatos, 2008). Recent studies, including the Regional Seawater Desalination Project in Santa Cruz, have generated extensive data on impacts of ocean intakes and outfalls on sea life and ocean processes.

One important finding of this research is that direct ocean impacts of desalination are comparatively small. Coastal Power Plants, polluted coastal runoff in streams, the

[2] This insight was provided by Prof. Haddad's former student Alex Webster.

historic dewatering and delinking of coastal wetlands, estuaries, and near-shore zones, and direct impacts of over-fishing all result in more substantial ocean impacts compared to coastal desalination.

But this answer, while accurate, does not end the discussion. Oceans are still in decline and the coastal desalination process, by withdrawing coastal waters and returning salt-concentrated waters, will likely contribute to the decline of oceans. Decline is decline, even if in minor and local ways. The discussion can move in two directions, both requiring new research. The first has to do with which of the other, larger impacts on oceans will be consciously curtailed so that desalination can substitute for it/them without causing more ocean harm. The no-net-impact scenario for desalination follows the logic of "in exchange for less of this other ocean-harming activity, we will allow increased harm from desalination." This research agenda takes one well beyond the purview of water agencies to the realm of coordinated ocean policy involving state and federal legislative and regulatory bodies and the myriad public and private parties engaged in ocean policy. Among the questions to be asked in this agenda are:

- What other uses of the coastal ocean have similar impacts to desalination?
- What is the scale and location of those impacts?
- What are the costs and benefits of those uses and how do the costs and benefits compare to increased desalination?
- Who controls whether and how much other impacts occur?
- How would one scale back on those impacts?
- How does one institutionally generate a trade-off that decreases the impacts of other activities so that desalination can increase without ocean impacts?

The second has to do with whether the use of desalination can introduce changes to coastal management that will improve the health of the ocean more than the desalination process degrades it. This opportunity has arisen in Santa Cruz as federal regulators attempt to restore southern Salmon runs on rivers from which the City of Santa Cruz draws water supply. Regulators would like greater instream flows in coastal rivers at crucial times of the year to enhance salmon migration and spawning. This could be made possible by supplementing the city's water supply with desalinated water, thus reducing withdrawals from the rivers. The relatively minor ocean impacts of desalination, occurring at points of seawater withdrawal and concentrated return flow, is seen as a positive trade-off to efforts to increase salmon migration and spawning.

Thanks to the Cities of Long Beach and Santa Cruz, we now have datasets that help us understand ocean impacts of desalination. Datasets help us understand the big-picture impacts of proposed facilities. With the datasets we arrive at the next research challenge – what do the datasets mean? Society is unsettled as to the extent of new impacts it will tolerate to coastal systems. There is growing awareness of global damage to oceans and ocean fisheries, and of our dependence on oceans. As desalination impact studies improve, they need to be integrated into larger models of ocean processes. From these models will come policy agendas for ocean recovery.

3.2 Energy Choice

The "reverse" in reverse osmosis commits desalination technology to energy consumption and costs. More broadly, what is being reversed are entropic forces that will push water quality toward the average of surrounding water, so energy must be applied to separate out contaminants and other pollutants. Hanafi (1994) provides energy transfer equations for wind-powered desalination. The theoretical minimum energy requirement for reverse-osmosis desalination is 0.706 kWh/m^3 water produced, but in practice, electrical requirements range in the 3-4 kWh/m^3 and as high as 9 kWh/m^3 (Gude et al., 2010), lowering to 2-2.3 kWh/m^3 if energy recovery devices are used (Lattemann and Höpner, 2008). Mezher et al. (2011) puts brackish desalination energy demand at 2-3 kWh/m^3.

Kerri et. al. (2011) provide a comprehensive method for determining greenhouse gas generation from water facilities in the Sacramento region. Their study extends beyond the gates of the water facility to include chemical production and transportation, and staff transportation. This kind of approach can be carried out for proposed and existing desalination facilities. Desalination technology readily reveals an important connection between energy and water. The energy input to water treatment is easily measured, and energy requirements for introducing desalinated water into existing systems can also be determined. There is growing awareness in the public of the adverse impacts and risks associated with our fossil-fuel-based energy systems. The primary adverse impact is climate change. Major risks include interruption of fossil fuel supplies or grid failures that lead to power shortages. Grid failure in the U.S. Northeast in 2003 resulted in boil orders for four million customers in the Detroit region, and other cities and regions experienced sewage spills into waterways when sewage pumps lost electrical power. A reverse osmosis water system is even more dependent upon electrical power than the Detroit system since (1) the saline source water almost always originates at a lower elevation (either underground or in the ocean) than where it will be treated and used, and (2) energy is needed to pump the source water through membranes and pretreatment. So systems relying on saline source waters can be highly dependent on a reliable electrical system.

In terms of operations, historically, California water agencies have utilized grid-provided power (in some cases generated from their own hydropower plants), with gas-fueled generators providing back-up. One path forward with desalination is to maintain this approach, perhaps accounting for the increased importance of the electrical grid by expanding storage of finished water and increasing fuel-storage capacity and the capacity of back-up generators. The issue of energy sustainability can also be folded into this approach through a combination of:

- minimizing energy consumption through investment in energy-efficient pumps and other equipment;
- purchasing renewable energy credits that offset the greenhouse gas loading of the electricity consumed by the facility; and

- investing in greenhouse gas-reducing projects, from new renewable energy projects to carbon storage projects.

Another approach is possible, but requires further research and testing. It is to operate one's desalination facility using exclusively off-grid renewable power. Eltawil et al. (2009) provide an overview of cost and technology options for combined desalination-renewable energy systems. Karagiannis and Soldatos (2008) point out that systems powered by renewable energy sources are generally more expensive than systems powered by fossil fuels. Ma and Lu (2011) provide a review of wind-powered systems, including twelve systems in use around the world. Only one of these, a small facility, is located in the US, on the Island of Oahu. Miranda and Infield (2002) report on a small-scale no-battery wind-powered reverse osmosis experiment. Typically the performance of desalination technologies, especially membrane systems, is optimized based on an assumption of steady, reliable electricity input. Wind power and solar power both are intermittent, although solar is more predictable. Today's large-scale desalination systems are not designed for intermittent power. Among the many potential problems with intermittent power are the more rapid deterioration of membranes, interruption of back flushing and other cleaning cycles, and interruption of application of UV processes. Continuous water monitoring can also be interrupted. All of these problems can result in unreliable water quality, earlier replacement of parts, and increased costs. Ma and Lu (2011) identify wind power intermittency and the coupling of wind turbines to desalination systems as the two leading challenges for technological research. In terms of coupling, they point out that not all wind-generated power needs to be converted to electricity. Some can be used as mechanical power to drive pistons that pressurize water vessels, or friction-induced thermal desalination can be pursued, with both approaches bypassing the relatively inefficient wind-to-electricity conversion.

Yet another source of power is energy recovery during the RO process. Water pressure can be recaptured through pressure exchangers, reducing the overall energy utilized by an RO facility. The private sector is developing and refining pressure exchange systems.

The journal *Solar Energy* has maintained a regular stream of articles on desalination, focused primarily on solar thermal technologies. García-Rodríquez (2003) also reviews RO-connected renewable systems, identifying combinations of wind and solar as most promising, as well as efforts to adapt pre-treatment methods to solar inputs. Rybar et al. (2005) describe an experimental wind-energy with grid backup desalination system for vegetable irrigation on Gran Canaria. Eltawil et al. (2009) present comparative cost data on numerous projects. While individual-project energy costs are readily measured, Eltawil et al. point out that project-to-project energy comparisons are nearly impossible due to the idiosyncrasies of each project – source water quality, throughput, system design, and other factors.

If one begins with an assumption of intermittent power, the optimization challenge (cost minimization; reliable water supply) changes. An obvious but high-capital-cost early adaptation is the addition of battery or fuel cell storage of power to be used when renewable power isn't available. Increased storage capacity for finished water is again a likely adaptation as it would allow water treatment process to be intermittent without impacting supply. Another alternative is to provide back-up grid power to smooth the valleys in renewable-resource power production.

The more profound adjustments involve the evolution of the treatment technologies themselves so they can successfully operate under intermittent power conditions. One example would be a backflushing system that consults energy storage levels before automatic activation. If insufficient power is available, the procedure is delayed. At the end of a delay period, operators are notified that an alternative power source is needed to carry out the procedure. Membranes that operate efficiently under intermittent power are another important research area in merging renewable power with desalination technology.

This approach would be clearest in terms of understanding a project's relationship to energy supply. A system in which no fossil fuel or other polluting energy source is used leave no doubt that it is responding to the challenge of climate change.

3.3 What Desalination Enables

von Medeazza (2005) points out that even if one maximizes the energy efficiency of a process such as desalination, if it is used for frivolous or unnecessary purposes, it should be seen as wasteful. This puts a focus on the intended uses of desalinated water once generated. The concept that expanding water supply changes other aspects of a region's economy, population, building patterns, energy consumption, traffic congestion, or other urban systems derives from extensive studies of farms and ecosystems. Many natural systems are limited by a single element, such as nitrogen or phosphorus. When more of that one element is introduced, plant productivity takes off and other nutrients are consumed in greater quantity, causing changes throughout the system. For many anti-growth activists, there is a strong belief that water plays this same role in human society – as the limiting input to economic expansion and population growth. This framework motivates them to challenge any project that would increase a region's water supply. This remains a largely theoretical construct and could use further analysis.

In California, multiple water planning requirements have created a wealth of information that can be applied to the question of what desalination could provide a region that utilizes it. The 1995 urban water planning requirements and more recent SB 610 and SB 221 rules, now found in Sections 10610-10656 of the California Water Code, and called the California Urban Water Management Planning Act, both require extensive water planning and analysis by water agencies. Similarly, the Water Conservation Act of 2009 calls upon urban water agencies to generate plans for cutting water consumption over the next decade. Finally, project Environmental Impact Reports are a source of data and analysis on the interaction between water supply and economic growth. These laws as a whole have placed large data-gathering and analysis burdens on municipal water agencies. Thousands of reports are being generated throughout the state describing supply and demand for urban water in California. These reports could help immensely as a starting point for ecological-economic research related to desalination.

Some infrastructure investments may seem expensive but will provide immense benefits to vulnerable segments of society. Other investments, although lower in overall cost, may provide minimal benefits. We can't fully evaluate the value of an SNCWS proposal such as desalination until we have a better understanding of its value to society. In urban areas augmented water supply may provide the amenity of lush irrigated landscapes, fountains and other water features, hardier drought resistance, expanded fire protection, and the ability to expand economically into high-water-demanding businesses. It may also provide a basis for building more homes and businesses of all kinds. If desalination is used for drought protection, it may protect water-demanding urban landscape during a drought while also maintaining water supply to at-risk businesses. These potential impacts are poorly understood and their documentation where desalination exists would be of great value.

Starting with existing Urban Water Management Plans, Water Conservation Plans, and project EIRs where available, the following questions could be researched and addressed:

- What economic functions are protected by a SNCWS compared to a drought-impacted supply?

- How do poor and marginalized segments of society interact with municipal water supply?
    - Is their dependence the same as other segments?
    - Is there a greater dependence on non-cyclical supply?
    - Are marginal-employment jobs at greater risk in a drought?

- What is the relationship between drought and employment?
    - What jobs are at risk in a drought?

- What is the relationship between water bills and household economic security?

- What kinds of regional economic expansion are made possible by introduction of an SNCWS?

- What kinds of existing regional economic activity are put at risk by not introducing an SNCWS.

- Which segments of society most/least benefit from introduction of a supplemental non-cyclical water supply?

Answering these questions will help regions understand the impact of water supply on all segments of their service territories and help inform decision makers how to invest in their water sectors and how to bill customers for the cost of investment.

3.4 Desalination and Ecosystems

The research questions above are connected to the issue of human need for economic security and the benefits of a reliable water supply. A second area of research has to do with the preservation of regional cultural history as it is found in the existing landscape. Human society remembers its local history in part through the wild plants and animals found locally. The presence of these species and their combinations and arrangements on land in and near cities directly connects us to a region's heritage and contributes to our understanding of the origins of our current-day values regarding family, friends, neighbors, and where we live. The preservation of local minimally-disturbed ecosystems also provides society with a guide and genetic stock for reestablishing diminished open space, and for understanding how plants and animals have adapted to the climatic conditions of the region. An additional benefit of preservation is that a resilient, well-adapted ecosystem not dominated by recent arrivals is less likely to allow an outbreak of pests that harm crops, bring disease, or increase the chance of fire.

Many important ecosystems found in open spaces are dependent on their historical water regime, including the presence of standing or flowing surface water for all or certain parts of the year. The historic flow regime predates the establishment of today's water rights systems; in fact property rights in water were established over the past couple of centuries for the purpose of rerouting the historical flow regime in an orderly way. In California, the resulting system moves millions of acre-feet of water annually from east to west and north to south. As less and less public open space can be found near cities, its value has grown. Ecological science research has clarified the crucial role water plays in maintaining the functioning and diversity of these systems (Poff et al., 1997).

Desalination as an SNCWS creates an opportunity to increase the ability of open space to play the roles described above. With rare exception (one being the Yuma Project connected to the Colorado River system), desalination projects are intended to provide urban water. RO-treated water is extremely pure, nearly devoid of the constituents one finds in open-space waters. It is in that sense chemically and biologically unfit to be a sole source of water for ecosystems. It is also financially unfit given the cost of producing desalinated water. So desalination is not expected to take place in open spaces for open space irrigation or rewatering wetlands.

The direct ecological impacts of desalination use will occur either in cities through its application to planted areas or through pulling and pushing other water in the system - water that arrives from or passes into open space. Desalinated water is new water to a system, entering either from the ocean or from brackish underground sources. It will displace existing water supplies. More water of higher quality will be available, significantly during drought. The following research questions arise.

- Are there examples of different ecological impacts of water supply in regions following introduction of desalinated water?

- Have plans for desalination plants included the possibility of differential impacts on ecosystems?

- Given the beneficial nature of restoring water to natural systems near cities, how are these benefits accounted for in the cost and pricing of water systems that invest in desalination?

Desalination also has indirect ecological impacts. The introduction of desalinated water provides additional water for consumption by existing users and possibly new users. Water supply is meant to enable General Plans that have already been debated and approved. But it is also possible that actual growth can exceed what was envisioned if the region attracts additional investment and people. If produced in sufficient quantity, water could enable additional construction, population inflow, and economic activity, that itself could encroach on remaining or nearby open spaces. Additional water supply could also result in urban renewal, including reclamation of urban brownfields.

It is also possible that no indirect ecological impacts will occur that wouldn't occur anyway. This would be the case if urban planners, investors, builders, speculators, and regulators see other factors besides water as crucial to their decision-making. General Plans often contain these analyses. Other factors could include project cost and financing, potential market for finished product, and cost and availability of labor. If water supply is a minor factor on the developer's checklist then other factors will determine (albeit indirectly) the fate of nearby open space. One could also have a no- or nearly-no impacts if desalinated water is intended to be a substitute for cyclical water supply or for water supply lost to a region for other reasons. Research questions include:

- What indirect ecological impacts can be attributed to desalination at existing facilities? What are the operating parameters of the facilities? How much water is being produced and when? What percentage of overall water supply is represented? Was any water lost to the system prior to or concurrent with development of the desalination option?

- For regions with existing desalination facilities, did statistically-measured economic activity change following the launch of production? Did population or other measures of urban density change?

- For a region considering desalination, what nearby or co-located areas of ecological significance are threatened by urban expansion? How are the areas currently protected? What are the threats? What role, if any, does an SNCWS play in protection or loss of the areas?

3.5 Scale of Desalination

Individual homes and many ocean vessels have desalination units. Small-scale desalination units range in size from 1 to 10 m^3 per day. There can also be extremely large systems, in the case of Ashkelon, Israel, producing 300,000 m^3 per day on average in 2008. The size of the unit or system influences the institutional form of governance ranging from primarily the private sector for small, privately-owned units to primarily the public sector for large-scale systems.

The choice of governance system (generally framed as public vs. private) influences the level of transparency to the public, incentives for technology innovation, types of public oversight, management of energy impacts, and other factors. If desalination were a mature technology, like hydropower, there would be less need to include the private sector with its power of innovation and R&D strengths. But desalination research is still dominated by improving the actual technology so that its performance improves and costs go down, so it will be valuable to maintain a strong private-sector presence for several more years. The following research questions arise:

- What is different about the governance and impacts of small-scale desalination vs. large-scale desalination and public vs. private?

- How is desalination governed today and how should it be governed in the coming years and decades?

- Should government policy encourage development and implementation of desalination at multiple scales from home/building to city/region? What policies would accomplish this?

- What unique issues arise if a small-scale privately-owned desalination facility is located within a larger municipal system?

4. Conclusions

The importance of answering the questions posed above can be found in the differential in permitting costs reported by the WateReuse Association (2011, p. 12) between the Tampa, Florida 25 MGD facility ($2.5 - $5 million) and California facilities ($10 - $20 million). Another cost is the years of delay completing projects as opponents renew objections, as has been experienced in the Carlsbad case (e.g., Lee, 2011).

It should not be the sole responsibility of the water agency to answer these questions, although the agency will have essential data and analytical capacity. Water agencies are primarily technical agencies that focus on providing a safe, reliable, and affordable water supply to their service territory and other customers. The research agenda described here is broader since it takes on the question of where and how urban regions will grow, what kind of coastal development should occur, ecosystem impacts, and how to provide the support services to desalination, especially electrical power. Research on these topics should occur at the municipal and county level, or regionally if a regional authority like the Monterey Bay Association of Governments exists and is organized to take on the project. Another source of research leadership for these questions would be a local college or university that has a water research program. Researchers employed by government agencies, universities, and private-sector companies under contract should all participate.

A great deal of research on desalination has occurred over the past few decades, with much more underway. Without this research the current discussion couldn't occur. As examples of functioning plants grow and more municipalities consider desalination, the importance of carefully studying its broader impacts also grows. The research topics proposed here are intended to address how desalination technology can be better integrated into existing urban water systems. Progress has already been made on every question posed here so it is a question of building on existing research foundations. Building a better understanding of the ecological-economic impacts of will help regions understand better the impacts they can expect by pursuing desalination technology, providing a clearer and stronger framework for public review, and hopefully speeding up the process of project review so that regions can undertake approved projects or move on from rejected projects without the wasteful multi-year interlude of rancorous review that is too often the fate of such proposals.

Citations

AWWA, 2009. Sustainability and the American Water Works Association: Recommended Activities and Implementation Strategy. AWWA Sustainability Ad Hoc Committee. Available at: www.awwa.org/files/Resources/SustainableWater/AdHocCommitteeSustainabilityReport2009.pdf

Cooley, H, Gleick, P., and Wolff, G. 2006. Desalination…With a Grain of Salt. Oakland, CA: Pacific Institute.

Einav, R., Harussi, K., and Perry, D. 2002. The footprint of the desalination processes on the environment. *Desalination* 152: 141-154.

Eltawil, M., Zhengming, Z., and Yuan, L., 2009. A review of renewable energy technologies integrated with desalination systems. *Renewable and Sustainable Energy Reviews* 13: 2245-2262.

Food & Water Watch, 2009. Desalination: An Ocean of Problems. Washington, D.C.

García-Rodríquez, L. 2003. Renewable energy applications in desalination: state of the art. *Solar Energy* 75: 381-393.

Gratz, P., Longinotti, R., and Stearns, D. 2011. Why the city should shelve desal plan. *Santa Cruz Sentinel*. Posted 1-23-11. Available at: http://www.santacruzsentinel.com/ci_17172433?IADID

Greenlee, L., Lawler, D., Freeman, B, Marrot, B., Moulin, P. 2009. Reverse Osmosis desalination: Water sources, technology, and today's challenges. *Water Research* 43: 2317-2348.

Gude, V., Nirmalakhandan, N., and Deng, S. 2010. *Renewable and Sustainable Energy Reviews* 14: 2641-2654.

Hanafi, A. 1994. Desalination using renewable energy sources. *Desalination* 97: 339-352.

Karagiannis, I, and Soldatos, P. 2008. Water desalination cost literature: review and assessment. *Desalination* 223: 448-456.

Kerri, K., Campeon, C., Espinasse, F., and Ohlinger, K. 2011. Comparison of treatment process sustainability at water plants in the Sacramento region. *Journal AWWA* 103(9): 60-73.

Lant, C. 2004 Water Resources Sustainability: An Ecological Economics Perspective. *Water Resources Update* 127: 20-30.

Lattemann, S., and Höpner, T. 2008. Environmental impact and impact assessment of seawater desalination. *Desalination* 220: 1-15.

Lee, M. 2011. Surfrider challenges desal plant in appeals court. Sign On San Diego website. Posted August 19, 2011. Available at: http://www.signonsandiego.com/news/2011/aug/19/surfrider-challenges-desal-plant-appeals-court/

Ma, Q., and Lu, H. 2011. Wind energy technologies integrated with desalination systems: Review and state-of-the-art. *Desalination* 277: 274-280.

von Medeazza, GLM. 2005. "Direct" and socially-induced environmental impacts of desalination. *Desalination* 185: 57-70.

Mezher, T., Fath, H., Abbas, Z., and Khaled, A., 211. Techno-economic assessment and environmental impacts of desalination technologies. *Desalination* 266: 263-273.

Miranda, M., and Infield, D. 2002. A wind-powered seawater reverse-osmosis system without batteries. *Desalination* 153: 9-16.

National Research Council 2008. *Desalination: A National Perspective*. Washington, D.C.: National Academies Press.

National Water Research Institute and U.S. Bureau of Reclamation, 2001. Desalination Research and Development Workshop Report. Fountain Valley, CA: NWRI.

Poff, N. LeRoy, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg, 1997. “The Natural Flow Regime,” *Bioscience* Vol. 47, No. 11, pp. 769-84.

Raftelis, G. 2011. Balancing financial sufficiency and community sustainability. *Journal AWWA* 103(9): 56-59.

Rybar, S., Vodnar, M., Vartolomei, FL., Méndez, RL., Ruano, JBL., 2005. Experience with Renewable Energy Source and SWRO Desalination in Gran Canaria. SP05-100. International Desalination Association World Congress. Available from: http://www.membranes.com/docs/papers/New%20Folder/Soslaires%20Canarias%20Desalination%20Plant.pdf (accessed 8-15-11).

Water Science and Technology Board, 2004. Review of the Desalination and Water Purification Technology Roadmap. Washington, D.C.: National Academies Press.

WateReuse Association Desalination Committee. 2011. Seawater Desalination Cost: White Paper. Arlington, VA: WateReuse Association.