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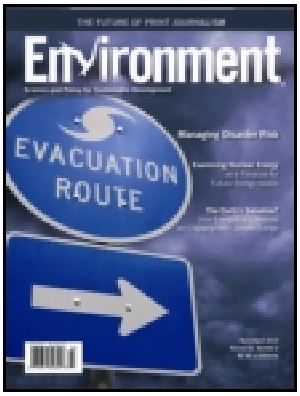

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The Desalination Debate—Lessons Learned Thus Far

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The Desalination Debate—

Technological Optimists and Pessimists: The Great Ideological Divide

For some time the world's environmental movement has tried to mediate the competing claims of two rival schools regarding planetary limitations. On the one hand, there are neo-Malthusians, acutely aware of the constraints that a finite planet places on human development. This view sees Earth's resources as limited; in the face of geometric growth in population and consumption, famine and misery are ineluctable. "Sustainable growth" by definition is an oxymoron.[1] At the heart of any environmentally sound strategy for the future is self-restraint and sacrifice.

This view is challenged by a diverse group of advocates on the other extreme who are variously referred to as "cornucopians" or Prometheans. (Presumably, by bestowing fire on humanity, Promotheus provided humans with the means and inventiveness to become like gods.[2]) These technological optimists are confident that human ingenuity will be able to overcome any pollution problems[3] or projected shortages and produce the necessary supply of resources or substitutes to expand global prosperity.[4] The two views have clashed for more than 40 years, since the pessimistic projections of the Club of Rome[5] and the highly publicized bet between economist Julian Simon and ecologist Paul Ehrlich over the anticipated rise in the prices of five metals due to scarcity.

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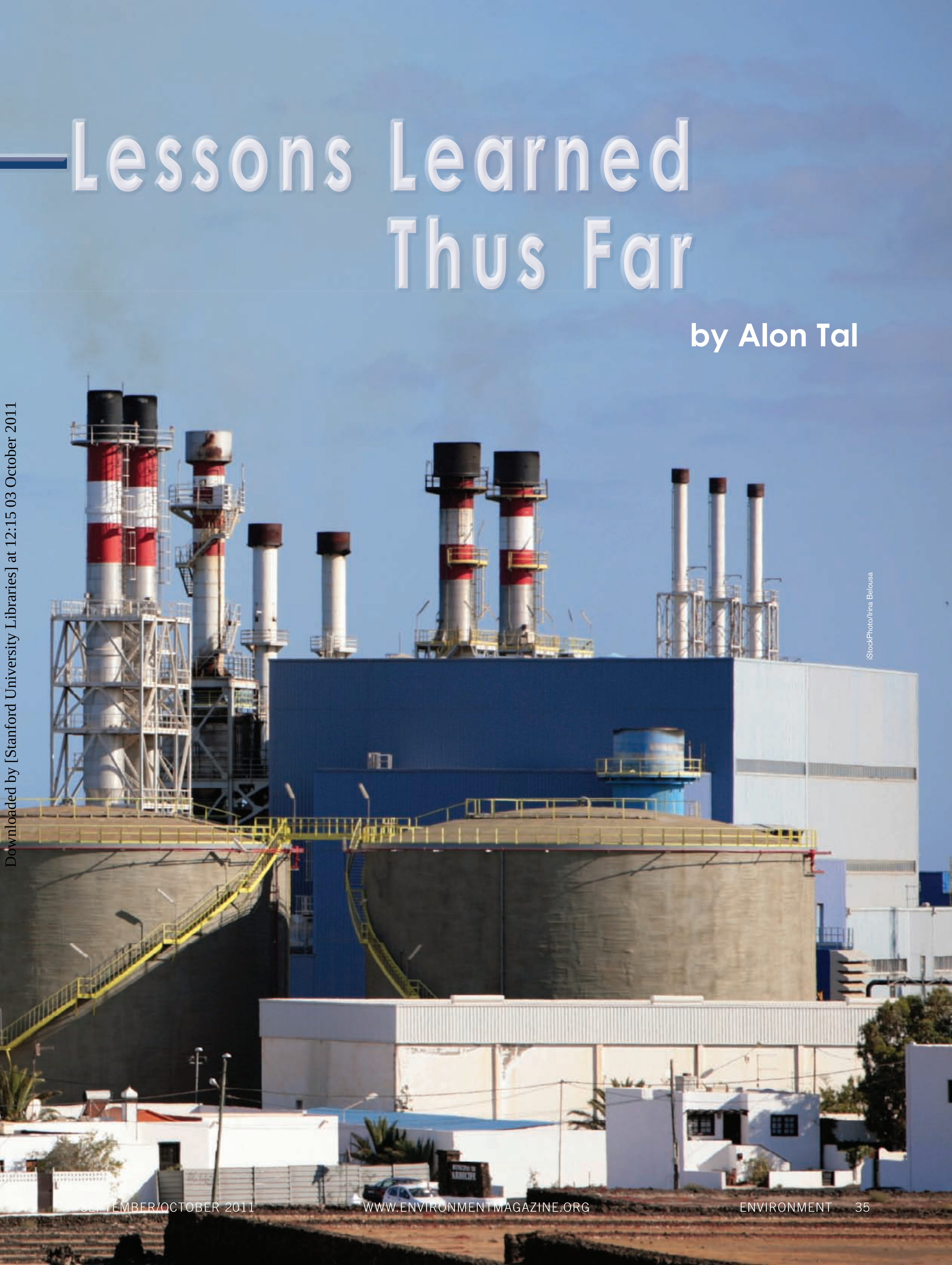
Lessons Learned Thus Far

by Alon Tal



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Salt stacks in a desalination plant in Trapani, Sicily, Italy.

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Water scarcity constitutes a defining issue in this ongoing debate. On the one hand, the neo-Malthusean pessimists foresee increased shortages leading to massive deprivation, starvation, and the proliferation of water conflicts due to competition over hydrological assets.[6] Promethian, hydrological optimists, on the other, are sanguine about future water supply[7,8]: Water is more renewable than ever before, and modern societies today can produce as much of it as they need or want. The opposing positions on the merits of seawater desalination offer a characteristic manifestation of this ideological divide. With 15,000 desalination plants presently in operation, providing some 300 million people with water today, the issue is particularly germane. Whether the world's mounting interest in "desal" constitutes a panacea for perennial scarcity or merely a greenhouse-gas-intensive bandage for wealthy nations is a debate that hitherto has largely been conducted on a hypothetical, theoretical plane. However, recent experience in several countries offers an empirical basis for assessing the sustainability of desalination, which along with wastewater reuse promises to eliminate the projected water shortages of the future. In particular, Israel, Australia, and Spain offer different policy approaches to this aspect of water management.

Our review follows the rise in desalination technology in these countries and considers the trade-offs in terms of compromised motivation for water conservation, environmental externalities in a carbon-constrained age, and of course the costs of water production. The assessment of the environmental, economic, and political aspects of desalination reveals meaningful differences in national experiences. In arid regions, desalinated water production has resolved scarcity crises and conferred considerable environmental benefits. Energy still emerges as a substantial obstacle in drylands with access to the sea or with large reservoirs of brackish groundwater. In other cases, politicians enthusiastically embraced a technological "magic bullet" that in retrospect was far more expensive (in terms of both direct price and carbon footprint) than demand management, responsible pricing, and conventional water conservation alternatives. The public has been quick to identify those situations where desalination does not make sense and expresses its opposition in the political sphere far more vociferously regarding economic profligacy than regarding the environmental harm caused by desalination initiatives.

Water is more renewable than ever before, and modern societies today can produce as much of it as they need or want.

Massive reverse-osmosis desalination constitutes an experiment that is still fairly young. Yet for countries that face acute shortages, the jury is already in on a few of the questions facing the planet's newest water-supply technology. It appears that in these contexts, the cornucopians are going to win this round.

Desalination—The New Horizon

Over the past decade, desalination has emerged as a cost-effective solution for dryland nations that suffer from

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a shortage of natural hydro-resources. Previously, several island countries, like Bermuda, Malta, and the Virgin Islands, utilized desalination to produce relatively costly drinking water as there were no other available sources. In the Middle East, a diverse array of Gulf states like Kuwait, Saudi Arabia, and Oman joined them. More recently, Mediterranean countries like Israel, Spain, and Egypt built massive desalination plants.

There is of course nothing new about removing salt from seawater to make it potable. Some 3,400 years ago, sailors utilized evaporation and condensation to produce fresh water at sea. While serving as Secretary of State, American statesman and inventor Thomas Jefferson included distillation facilities on board ships as standard equipment.[9] By 1907, the first industrial desalination facilities were built, with facilities later established by the military during World War II to provide drinking water to Allied Forces soldiers. Economics, however, constituted a serious barrier to diffusion for wide spread civilian uses.

The past 20 years have seen “reverse osmosis” (RO) gradually seize the status of most cost-effective technology available for desalinating seawater, leaving behind competing technologies such as multiple-stage flash distillation and multiple-effect distillation. (Today, roughly 60 percent of desalination plants utilize RO technology.[10]) The process is relatively simple, involving a high-pressure diffusion of fluids, which “reverses” the natural osmotic process. A thin, semipermeable membrane separates the seawater into two streams: pure H_2O and a concentrate stream. In other words, rather than moving salts from higher to lower concentration areas, the process mobilizes tremendous pressure to move them in the opposite direction.[11] Figure 1 offers a simplified description of the basic reverse-osmosis seawater desalination process.

The precipitous drop in the price associated with reverse osmosis production occurring during the past few decades as seen in Figure 2 can be attributed to improvement in membrane efficiency, increase in competition between equipment suppliers, improved management, and the reduced associated energies as well as the economies of scale associated with large facilities.

Filters in a reverse osmosis water treatment plant.

Figure 1: The desalination process.

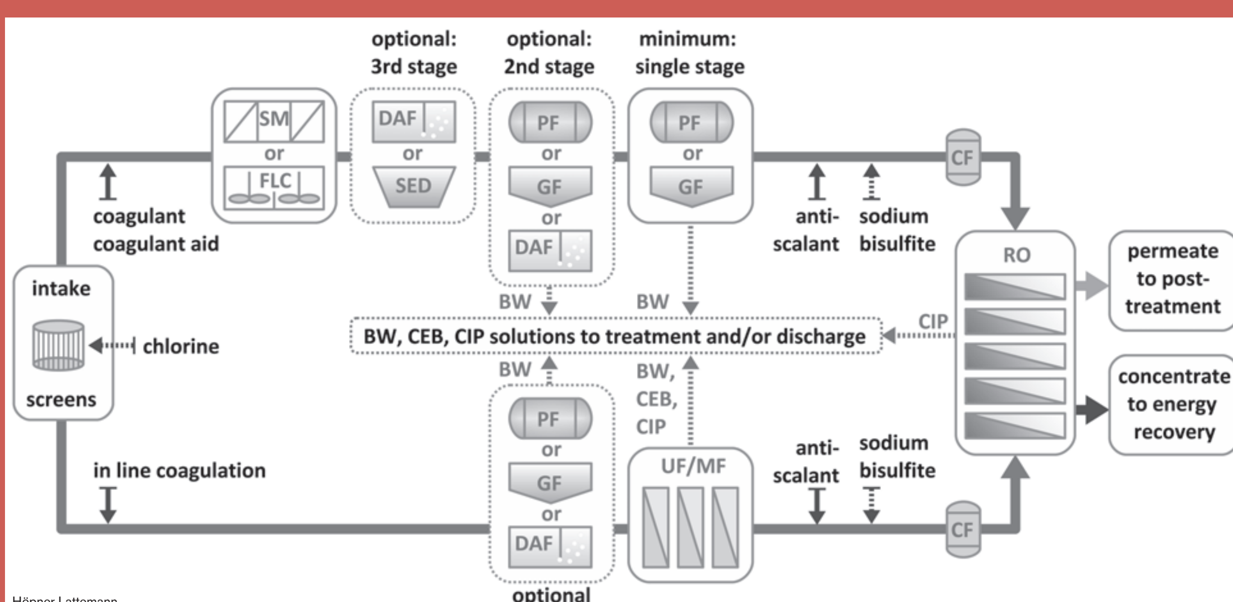
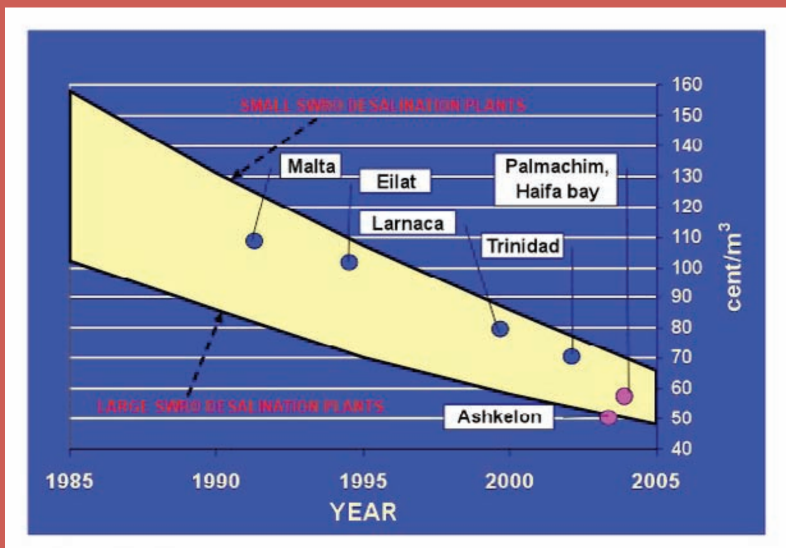


Figure 2: The price of desalinated water, 1985–2005.

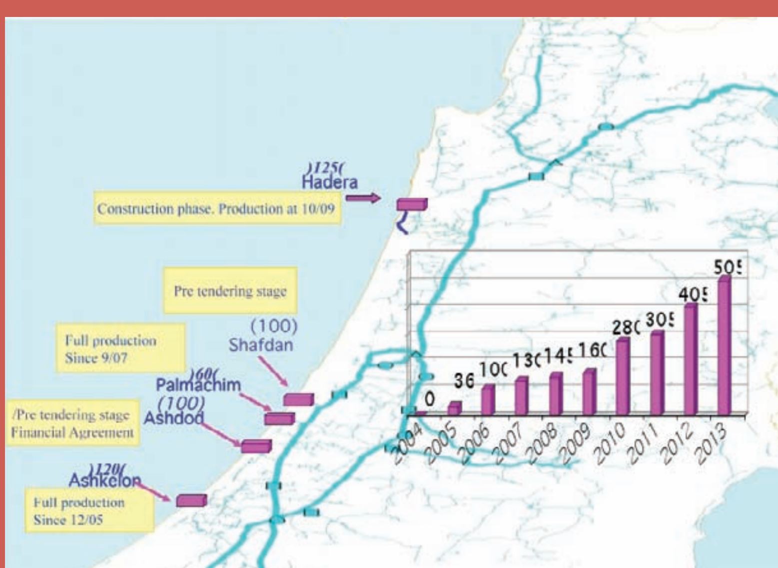


Israel Water Authority

For instance, Israeli desalination facilities are probably the most efficient in the world, producing a cubic meter of water with 3.5 kilowatt-hours (kWh) of electricity. For many countries, this has led to a fundamental change in the economic calculus of drinking water policy.

While seawater desalination is still less than 2 percent of total planetary water consumption, its phenomenal growth rate of 15 percent per year[12] suggests that it may eventually make perennial water shortages a thing of the past. The Mediterranean Sea (Figure 3) offers a dramatic example of the present expansion of desalination for drinking water, and in some cases even for agricultural water supply.[13]

Figure 4: Israel's desalination infrastructure.



Israel Water Authority

Desalination is not without environmental ramifications.[14] Antiscalants (chemicals such as polyphosphates and polymers) utilized to prevent clogging in membranes, coagulants (ferric sulfate and ferric chloride), and membrane preservatives (sodium bisulfite) are eventually released into the marine environment.[15] The higher density brine from RO plants has roughly twice the salinity of seawater and can increase surrounding saltiness, affecting benthic communities and even potentially increasing mortality among marine organisms. Furthermore, prodigious energy is required to push the water through desalination membranes or to precipitate the distillation process. If electricity sources are not clean or if they are carbon intensive, a desal plant's environmental footprint can be particularly heavy. But for the cornucopian "Promethean" perspective, these are surmountable obstacles—production costs that are more than justified by the hydrological benefits.

As countries undergo this transition in their water supply portfolio, it is well to consider their desalination experience and make an early assessment about environmental implications and the internal discourse that accompanies the move into a brave new desalinated world. Accordingly, we now turn to lessons learned in Israel, Australia, and Spain.

Israel's Experience With Desalination

Israel first turned to desalination to solve potable water delivery problems at the start of the 1950s to provide water to the nascent port city of Eilat, located on its secluded southern tip at the Gulf of Aqaba. A variety of technologies were attempted as part of a trial-and-error process.[16,17] This eventually led to establishment of the country's first "RO" facility in 1973, inaugurated on a site adjacent to a salty marsh—or

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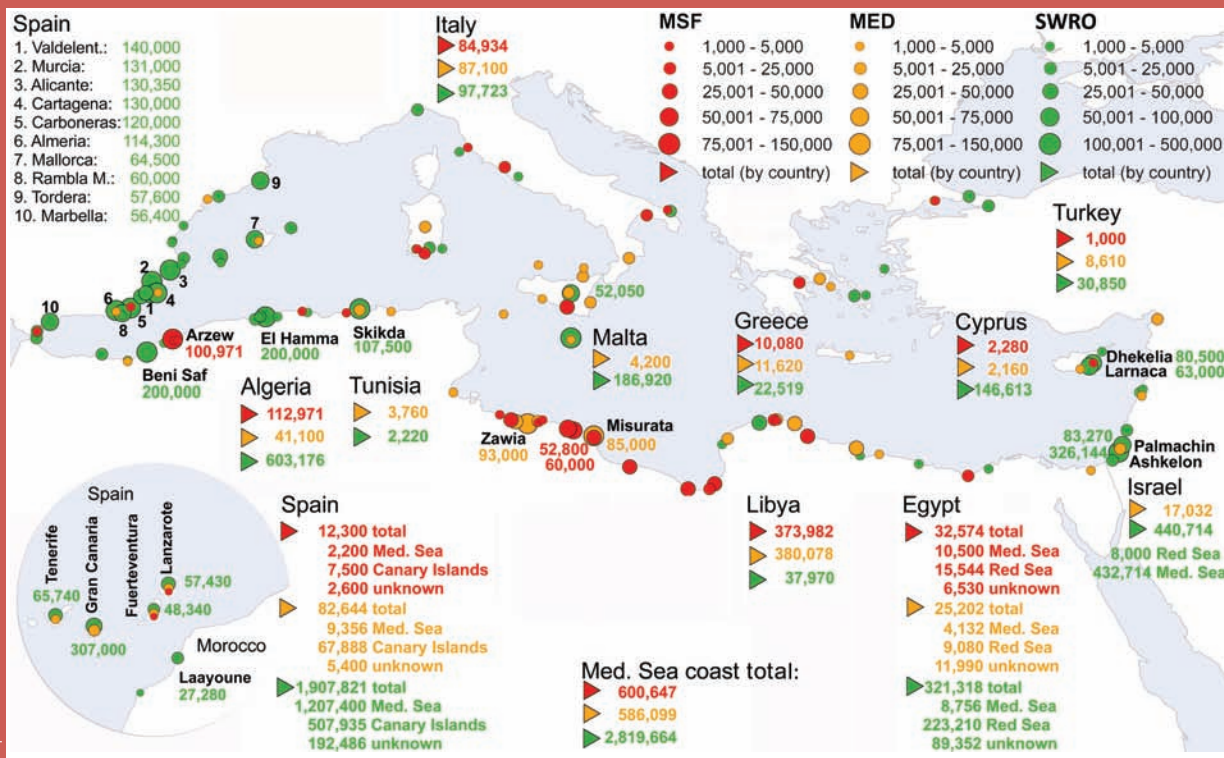
Figure 3: Present and projected sea desalination capacity in the Mediterranean Basin.



"Sabha," after which the plant is named. About half of present production relies on brackish groundwater, which costs roughly half of the 90 cents per cubic meter expense of desalinating Red Sea water.[18] But elsewhere in Israel, for 30 years, desalination remained a last resort—an exigency driven by lack of any alternative water sources for isolated desert communities. Two factors combined to change these dynamics and make desalination a centerpiece in Israel's new water management strategy:

- Three consecutive drought years beginning in 1998, highlighted the vulnerability of Israel's agricultural sector to the ineluctable fluctuations in annual precipitation.
- The availability of desalinated seawater at the bargain price of 52 cents per cubic meter (or 0.05 cents per liter).[19]

After years of stalling by treasury officials who sought to reduce agricultural water allocations, Israel's cabinet approved a proposal put forward by the country's Water Commission. In 2002 it decided to construct four sea desalination plants and produce at least 250 million cubic meters (mcm) of desalinized water.[20] In fact, by 2011, the amount actually reached 300 mcm in three plants, with additional facilities now under construction to double this capacity.

Not just the scope of the plant and the membrane technology were novel for Israel, but also the financing scheme. The new Israeli desalination ventures were privately financed "build-operate-transfer" (BOT) ventures. For instance, the Israeli–French consortium VID Desalination Company opened the first of these Mediterranean plants in the southern city of Ashkelon, investing $250 million in a facility in return for the contractual rights to run it for 25 years.[21] When it went on-line in 2005, the Ashkelon plant was not only the largest RO production facility in the world, but also the cheapest, beating a target price of $0.52 per cubic meter. Since that time, fluctuations in energy markets have led to only modest price increases.

The reliable, inexpensive, high water quality largely put to an end any serious discussions about previous proposals for Israeli acquisition of Turkish water via tankers, "medusa-bags," or "peace pipes."[22] Not only did desalina-

Not only did desalination strengthen national hydrological independence: It was half the price of the alternative schemes.

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tion strengthen national hydrological independence: It was half the price of the alternative schemes!

The three major facilities established thus far, Ashkelon, Palmachim, and Hadera, are all based on similar variations of a common engineering approach. Open submerged intake systems, based on three plastic pipelines, stretch as much as a kilometer into the sea, tapping the seawater at a depth of seven meters. The parallel intakes reduce turbulence to a minimum, while the high-density plastic allows for relatively easy maintenance and inhibits bio-growth.[23] The seawater goes through a two-stage filtration process, and a pretreatment unit adds chemicals to prevent water from fouling membrane stacks. Because Israel recycles more than 75 percent of its sewage, boron is a major water concern as it damages plant growth in high concentrations. Seawater typically has high natural boron concentrations. The desalination process was designed to include a boron removal phase that brings concentrations down to negligible levels of 0.4 milligrams per liter.

One of the surprises in the Israeli desalination story is its impact on agriculture.

One of the surprises in the Israeli desalination story is its impact on agriculture. The original Ashkelon plant went "on-line" before the delivery network of piping into the national grid was available. Thus, for the initial period of production, after water was provided to the nearby southern cities and communities, a surfeit of hundreds of millions of liters remained. The surplus was delivered to the extensive agricultural operations in Israel's Negev southlands at no extra charge. This was seen as a magnanimous gesture, with the expectation that after decades of utilizing the relatively saline waters from Israel's national water carrier, the almost pure H_2O, containing only a fifth of the salt content, would be seen by the local fruit and vegetable farmers as veritable "champagne." The lower Na^+/Cl^- levels should not only translate into better yields, but also save water when leaching salts from the soil.[24]

In fact, the farmers were not happy at all with the results. The previous supply of irrigation contained sufficient nutrients (i.e., magnesium, sulfate, and calcium) so that crops thrived without supplementary fertilizers providing these elements. The desalinized water left crops such as tomatoes, basil, and flowers with nutrient deficiencies, requiring the hasty addition of chemical fertilizers and other minerals.[25]

After seven years of experience, the initial environmental report card appears to be largely that which was projected. By siting desalination facilities contiguous to existing coastal infrastructures (e.g., power stations), practically none of Israel's limited beaches have been sacrificed thus far. In Ashkelon, for example, the seven-hectare facility is sited on lands reclaimed from the sea with low scenic value. In the planning phase there were concerns about the impact of the brine that the desalination process produces. Accordingly, it is discharged into the sea at a distance of one kilometer. Moreover, the desalination residuals are released along with the water emitted from the adjacent electricity production, diluting the salinity at a ratio of 1:10.[26] The temperature of the waste stream remains somewhat higher than the seawater, as are the concentrations of salt and the other chemicals and metals. From the outset, Israel's Ministry of Environment required installation of a diffuser situated at least two meters above the seabed to ensure dispersion and dilution at the outfall.

Monitoring of the flow of the fairly inert polyphosphate antiscalants in the sea suggests that marine water quality has not suffered appreciably. For instance, at the discharge site, a 3 percent rise in salinity above ambient seawater concentrations was measured, but this quickly dissipates to 1 percent before disappearing altogether after a couple of kilometers.[27] The high iron content in the discharged residuals (from the ferric sulfate coagulant additives) created an intermittent reddish plume with ferric concentrations reaching 42 milligrams per liter. It is not clear, however, whether such impacts are negative. Indeed, there is anecdotal evidence that the conditions actually create a positive "mini-fishery" microenvironment.

But energy remains the major environmental concern. While the Ashkelon plant is powered by a self-generating energy supply system, the other facilities rely on electricity from the Israeli power-grid, a coal-dominated system. According to one estimate, the facility's 60 megawatts per hour electricity demands can generate greenhouse gases at a level commensurate with a city of 45,000 people.[28] With 62 percent of Israeli electricity produced by burning coal, the carbon footprint of local desalination remains highly problematic. Ben Gurion University's Yaakov Garb postulates the implications for energy independence:

> *Ironically, in creating a stable source of pure water, not subject to the climatic variations of our region, Israel has buffered itself to one source of vulnerability, but exposed itself to several others. With desalination, Israel is increasingly dependent on water quality in the Mediterranean, the terms of decade-long contracts, and, above all, to energy price variability. To the extent that a larger portion of the cost of desalinated water is a variable cost dependent on rising energy costs, the relative advantage of desalination with respect to other forms of water source augmentation with lower variable costs, for the short run, can be expected to decline. Desalination allows Israel to avoid hydrological constraints now, through a technological solution for meeting the inelastic demands for potable water; but*

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> *it may introduce future energy constraints, as the world enters an era where limitations in energy supply and carbon emissions reach the forefront of the policy agenda. (245)*[29]

From a political perspective, Israel's transition into desalination was relatively painless. There have been vague concerns expressed about the implications of privatizing water resources, but no meaningful protestations from Israel's typically aggressive environmental nongovernmental organization (NGO) sector about the shift to higher energy water supplies or the associated financing modalities. As in the energy sector, there have been occasional voices wondering whether concentrating such high percentages of water supply in a single facility is wise, given the pervasive military instability. For instance, the Ashkelon plant is well within the range of the mortars and the missiles that the Hamas-led government in Gaza intermittently directs towards Israel. One could argue that diversification through a sprawling network of smaller desalination plants could be a smarter risk strategy. But the economic implications would be dramatic. These issues are not widely discussed in public forums, either professional or in the press. On the whole, opposition to Israel's bold desalination strategy has been marginal.

There are several explanations for the conciliatory political climate:

1. The historic predilection of Israeli environmentalists towards technological optimism.[30]
2. The recognition that desalination will be necessary in order to meet Palestinian water claims, and to diffuse much of the hydro-hysteria that characterized peace negotiations in the region.
3. The recognition that all local river rehabilitation strategies require a dramatic increase in the volume of Israel's depleted streams, whose flow is typically limited to municipal effluents and intermittent storm runoff. Desalination offers the possibility of restored aquatic ecosystems and transforming polluted trickles into recreational refuges.
4. In fact, regulation by Israel's Environmental Ministry and Water Authority has been highly effective, resulting in high quality water at low prices—with none of the loss of services often seen internationally in water privatization.

Israel is still categorized as a non-Annex 1 country under the U.N. Framework Convention for Climate Change. While there is considerable lip service about global responsibilities, for the present, there is no immediate pressure to reduce greenhouse emissions.

The upshot of the above is a powerful consensus that desalination has already revolutionized Israel's water management strategy, producing myriad geo-political, economic and environmental benefits. Until energy issues are addressed, and either efficiency enhanced or renewable sources tapped, it is impossible to accord desalination the status of a "magic bullet". But it is clearly a mighty step in the direction of hydrological sustainability.

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A dam on a farm in South Australia shows the impact of an extended drought.

The Australian Desalination Experience

As the driest of the world's continents, Australia has always faced water supply challenges. The worst drought in the country's recorded history between 2003 and 2007 catapulted desalination onto the agendas of every major Australian population center. Until then, desalination was restricted to small remote urban communities like the Kangaroo and Rottnest Islands.[31] The sense that climate change had exacerbated an already obnoxious hydrological balance sheet expedited one of the most dramatic and swiftest water infrastructure transitions in recorded history. A five-year process ending in 2012 will find 30 percent of the five major cities' drinking water coming from desalination plants. The total cost of the enterprise is expected to reach $13.2 billion.[32]

Australia is the first country to link desalination to renewable energy supply. This makes the costs of Australian desalination the highest in the world. One estimate from the Water Services Association projects that the price of desalinated water will reach $2 per cubic meter when full cost accounting is made. Defenders of the project claim that it is simply of "the cost of adapting

Figure 5: The price of new Australian desalination infrastructure.

The Australian, January, 23, 2010

to climate change." Others, however, are critical of the transition, calling it economically wasteful and environmentally destructive.[33]

Australian desalination enjoys far less public support, to date, than does Israel's. Environmental and consumer advocates argue that a more prudent strategy would involve stringent water conservation programs. Drip irrigation, for instance, is surprisingly rare in many parts of rural Australia, notwithstanding its dramatic water-saving properties. The desalination debate also raised questions about the sustainability of the so-called "Big Australia" initiative that would increase the nation's population from 22 to 36 million people. The dynamics of the Australian experience are perhaps best reflected in the story of Sydney's new desalination plant in Kurnell.

Precipitation in catchment surrounding Australia's largest city is highly erratic, with unpredictable cycles of drought years that suddenly give way to floods. As for other cities such as Brisbane and Melbourne, creating massive water storage was deemed the best response to the inherent uncertainty. Some 80 percent of the city's water needs are met by the reservoir system created by the Warragamba and eleven additional dams in the Blue Mountains. During the 1990s the city also sought to address this dynamic and reduce its vulnerability by an emergency drought response program that was designed to ensure demand reduction. A comprehensive policy to reduce water demand was enacted that included mandatory water restrictions, investment in infrastructure to reduce the city's leaking pipes and water recycling and education campaigns. The campaigns were remarkably successful: By 2004, per capita water use in Sydney had fallen from 506 liters per person to 342—with aggregate water consumption levels remaining at 1974 levels, despite the additional one million people now receiving water.[34]

But the intensity of the most recent drought made local politicians nervous. In 2004, a Metropolitan Water Plan (MWP) replaced the Drought Response Management Plan. It allocated $4 million to plan a desalination facility that would "ensure that if the drought continues beyond another two years, a desalination plant for Sydney could be constructed relatively quickly and efficiently."[35] With the drought showing no signs of relenting, state decision makers felt pressure to formulate a bold, preemptive response to the anticipated shortages. In the summer of 2005 the state declared its intention to build a $2 billion (Australia) desalination plant in Botany Bay on Sydney's southern coast in the event that the drought did not break within two years.[36]

Yet a transition in in the New South Wales state government led to a change in the political equation, and new Premier Morris Iemma announced his readiness to ensure water supply for the Sydney region. The local public was less enthusiastic. A public opinion survey at the time suggested that some 60 percent of the local citizenry opposed the construction of a desalination plant, given the fact that the reservoir still was 41 percent full, and still holding a full two years of water supply.[37]

In what was to have been a text book example of "adaptive management," the government established a "trigger point" of 30 percent in reservoir storage capacity: Once this level was reached, the building of the desalination plant would commence immediately, with an anticipated construction time of 26 months. Yet the political benefits of demonstrating "purposeful leadership" (or perhaps genuine fear of a water crisis) apparently proved too much for the Premier, who wanted to appear decisive prior to imminent elections. Tenders were prepared for construction in February 2007 with the reservoir was still filled at a 33.9 percent capacity level. With an irony that could easily have been prepared by a Hollywood script writer, weather changed and storms filled the reservoir to 57 percent within four months. (Such intense "drought breaking" deluges are not unusual in the Sydney catchment.) But the desalination plant was already in motion and it was built at the Kurnell site all the same.[38]

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The upshot of the Sydney story is that local citizens faced an increase in their water rates averaging $110 per year for five years. Again, greenhouse gas mitigation was a considerable part of the expense. Australia was among the last Organization for Economic Cooperation and Development (OECD) countries to join the United Nations (UN) Kyoto Climate Change Protocol, but once on board, it has taken its responsibilities seriously and is contentiously promoting clean energy sources. But even before the federal government signed on, the state governments had decided to offset the anticipated electricity increase by building wind farms. There are heavy economic implications for this level of "carbon accountability".

Australian experience confirms the positive Israeli interim conclusions regarding the impacts of brine discharge on the marine environment. The Perth desalination plant in Australia, for example, has been monitored underwater since the facility's inception. The plant mitigates potential impacts by including special filters to reduce the concentrations of chlorine and other contaminants. It seems to work. Extensive documentation exists of fish and seahorses thriving around the inlet pipes, and abundance of flora at the brine discharge site.[39]

The primary environmental concern expressed about desalination involves the energy requirements and associated greenhouse gas emissions. The Australian case is therefore a particularly interesting one for environmentalists to assess. On the one hand, the country has shown that desalination need not exacerbate carbon emissions. But critics in Australia argue that the renewable energy capacity that was created to offset the desalination plant could just as easily have been used to replace coal-generated electricity plants and move the country closer to climate change mitigation targets.[40]

In her recent review of the Sydney experience, Phoenix Lawhon-Isler considers the claim that desalination constitutes a climate adaptation solution and offers a compelling argument that the overall Australian environmental balance sheet is negative:

> *Desalination distracts from the need to build adaptive capacity and resilience into urban water systems through an integrated, whole-of cycle approach. It also reflects a misguided pursuit of elimination of climate risk as a goal attainable through technical means rather than an ongoing process of adaptation of both technical and social systems to build resilience. Desalination reinforces the institutional tendency to rely on supply-side solutions, which in turn encourages wasteful consumption habits, and reduces incentives to adapt water use behaviours. The study concludes that desalination plants may be doing more harm than good for Australian cities by locking in unsustainable patterns of water management and narrow climate adaptation trajectories.*

The plant in Kurnell is now up and running with a potential to provide Sydney with 15 percent of its total water needs. For a brief period it holds the title of Australia's largest desalination facility. But it will soon be surpassed, when in 2012 the Wonthaggi desalination plant goes on-line to provide drinking for Melbourne.

Spain and Desalination

Spain today claims the role as the most veteran and largest user of desalination in the Western world, today, producing 8 percent of worldwide capacity, even as it is home to only 0.6 percent of the world's population.[41] The verdict on Spanish desalination, however, is still out, and recent events suggest that it has hardly been a technological "knight on a white horse"—especially from the perspective of economic efficiency.

For decades, regulation of Spain's many rivers through a system of dams constituted the centerpiece of the national water management strategy. Some 1,300 dams compound 53,500 mcm of water in reservoirs for utilization by agriculture—making Spain the fifth most dam-intensive country in the world.[42] This constitutes a 38 percent capture of the aggregate runoff potential. Without the dams only 9 percent of runoff would be utilized. The country is also blessed with almost 200,000 km^2 of detritic, karstic, and volcanic aquifers. Most of the karstic aquifers are of high quality, although there are signs of steady salinization and nitrification of wells.

Spanish desalination efforts began some 40 years ago in the water-scarce Canary Islands. Eventually, in 2000 a major 10,000 cubic meters per day facility was installed there.[43] Recently, Spanish weather trends provided tail winds for the desalination lobby. During the past five years, on the mainland, hydrological conditions worsened dramatically, and by 2008, chronic drought conditions left water storage at a mere 46 percent of normal capacity. Precipitation was 40 percent below annual averages – technically just short of drought conditions according to official Spanish criteria.. Emergency measures were imposed, including 3000-euro fines for filling large swimming pools and 30 euros for watering gardens.

In retrospect, the water crisis that emerged should not have come as a surprise. Spain has the highest per capita national water consumption rates in Europe. When this is combined with a Mediterranean climate in the large population centers and intensive irrigation in semi-arid zones, shortages were inevitable.[44] But whether mismanagement or unpredictable global warming was to blame, the crisis would not wait. Spanish water managers argued that natural water resources were insufficient and lobbied for a major commitment to desalination.[45] They soon had a political partner.

Among the policy changes that José Luis Rodríguez Zapatero's Socialist government brought with it in 2004 was a 2 billion euro investment commitment to water production. Desalination—rather than conservation and efficiency—became the national man-

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agement priority.[46] Existing plans to transport water in a pharaonic system of canals and pumping stations that would carry the Ebro river water from the north to the desiccated south (where Catelonian reservoirs had dropped to 20 percent of capacity levels) were canceled unceremoniously.

Already the desalination industry was humming in Spain. Some 950 desalination plants were making more than 2 million cubic meters of water a day. This is enough to supply 10 million people. But the new wave was far greater. Barcelona opened a 200,000 cubic meters per day facility that promised to provide 20 percent of the region's needs. And recently, with the help of substantial European Union (EU) grants, an even larger $438 million desalination plant at Torrevieja on the southern coastline of Spain was completed, making it Europe's largest, and probably the second largest RO desalination facility in the world. Half of the water is earmarked for agriculture and half for the urban sector.

Yet the rationale for the new wave of Spanish desalination experience remains unconfirmed. Many of the facilities, like Barcelona's, are hardly utilized at all, serving as "backup," or are completely dormant. For example, the Torrevieja plant has yet to become operational and may wait years until the proper permits are received and water produced. Even then, it is not clear that there will be buyers, as unsubsidized water will cost two to four times more than the going rate of 30 cents per cubic meter.[47]

From the outset, many were unhappy with the decision to abandon water transport as a national strategy in favor of desalination. While not quite a "water war," the issue became a source of considerable tension between many of the 17 regions and 8,000 municipalities and the new central Spanish government, especially those affiliated with the opposition Popular Party.

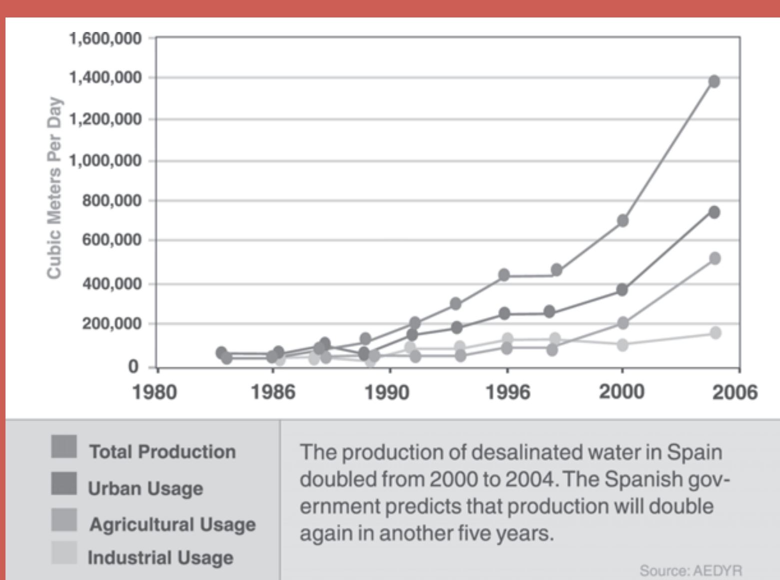
The opposition of the local governments enjoyed support from environmental quarters. Among the green critics was the World Wildlife Fund (WWF), which went on the record castigating the new policy as "frenetic," expensive, and energy-intensive. At the heart of concern for WWF was the damage expected to occur to the Spanish coastline as a result of the planned facilities. The associated greenhouse gas emissions were also part of the reproach. The Spanish Association for the Technological Treatment of Water reported that a full million tons of carbon dioxide would be emitted annually by each major desalination plant.[48]

The Spanish environmental balance sheet is probably a mixed bag, and there are those who claim that ecological benefits actually trump the downsides of desalination. Alternative sources of water involve diversion of rivers, which might lead to decimation of aquatic habitats. Introduction of invasive species, such as zebra mussels, is one of the ecological risks associated with long-distance river water delivery. The environmental debate quickly became partisan when Mariano Rajoy, the leader of the opposition, attacked desalination, stating: "I would transfer water anywhere. The desalination plants emit CO_2 and contribute to climate change."

But it is economics, not the environment, that leaves many Spanish wondering whether their desalination investment is prudent. As oil prices climbed, desalination costs grew far higher than projected, and suddenly created incentives to improve efficiency. In most Spanish cities and farms, there is considerable room for additional water conservation, which should be pursued before supply-side solutions are funded. The price of water in Spain is among the lowest in Europe. Perverse incentives frequently send an unfortunate message and it is not one that encourages efficiency. The low cost of water makes investment in local delivery infrastructure cost-ineffective. For example, during the peak of the drought, even as it was shipping in pricey drinking water from Tarragona and Marseilles in France, Barcelona suffered from leaky pipes that led to losses of millions of cubic meters per year. Frequently, groundwater resources are not fully utilized. At present, Spain utilizes some 34.7 percent of available surface and groundwater resources.

Although there are many signs of steady improvement in the efficiency of water utilization, before leveling off,

Figure 6: Desalination production in Spain.



The production of desalinated water in Spain doubled from 2000 to 2004. The Spanish government predicts that production will double again in another five years.

Source: AEDYR

Technology Review

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Area of Concern	Critics	Supporters
Economics, cost-effectiveness	Wasteful; prices higher than conventional alternatives. Many desalination plants remain closed or underutilized.	Price steadily dropping; cheaper than bottled water or tanker alternative. Commodity whose production should be driven by supply/demand.
Policy implications	Locks in supply-side orientation. Undermines motivation for conservation.	In some cases, demand management has attained maximum efficiency; more water is needed. Desalination should supplement conservation.
Environmental degradation	Greenhouse gas emissions; Anti-scalant/ coagulant/ preservative discharges affect marine environment Risk of increased marine salinity. Supplants public beaches	Alternative energy sources can be required (e.g., Australia). No meaningful evidence of marine degradation. Dilution appears successful. Planning can ensure juxtaposition to existing infrastructure. Environmental benefits (e.g., leaves water in streams for nature and natural flow).
Natural resources security	Exchanges “water vulnerability” with “energy vulnerability” Centralization leaves water supply vulnerable to terrorism/ natural damages.	Water shortages are more acute. Conventional water sources can also be sabotaged.

annual demand for water increased for many years at a rate of 1.6 percent,[49] largely due to economic development and improved standards of living. Some two-thirds of Spain’s water is consumed by agricultural operations, which enjoy extremely favorable pricing—in some cases as low as 1/200th of actual operation costs.[50] The present dynamics have led NGOs, like the Worldwide Fund for Nature, who typically are usually suspicious of water privatization and markets, to call for “water banks.” In such a system, water could be bought and sold, allowing municipal users to acquire water from farmers at a far cheaper rate than the desalinated alternative. But it is a mistake to generalize about such a diverse country. For some cities, like Barcelona, such markets are not an option as there are no major agricultural operations nearby. Indeed, for the many areas of Spain where desalinated seawater accounts for 30 to 50 percent of the water consumed, desalination appears to be a sound investment.

Conclusions

The desalination experiences of these three countries share certain elements: After decades of very modest application, seawater desalination recently came of age due to a combination of extended droughts and anticipated shortages, along with the reduced costs of producing fresh water. During the past few years, production has jumped an order of magnitude, creating a surfeit of what was frequently considered the scarcest of resources. This move has not been universally popular, and in Spain and Australia desalination has emerged as a politically divisive issue due to economic and environmental concerns. In the annals of water infrastructure controversies, it is conceivable that desalination facilities will soon become the “dams “of the 21stcentury.

Public controversy should only grow more intense as desalination becomes an integral input in farming operations. Indeed, although desalination was originally envisioned as limited to urban drinking-water supply, for some time there have been signs that agriculture will increasingly become a major consumer. According to a Food and Agriculture Organization (FAO) study, some 22 percent of the water produced by Spanish desalination plants is delivered to farmers.[51] One-third of farmers surveyed in Israel five years ago envisioned new crops allowing them to profit from additional desalination allocation.[52] Some 53 percent of Australians envisioned desalinated water as supplying future irrigation of vegetables—a rate almost twice that anticipating integration in household drinking and bathing waters.[53] For farm lobbies worldwide, water supply and pricing have always been at the heart of their agenda. Only now, desalination is beginning to emerge as a salient interest.

For the foreseeable future, however, agricultural utilization of desalinated water, even at the reasonable rates, will only be economically feasible for the

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highest value cash crops (e.g., flowers, specialty fruits, etc.). These are typically grown in developed countries. Developing countries with access to coastal or brackish waters in which agriculture is largely subsistence will probably find that desalination facilities are only cost-effective for providing drinking water.

But this does not mean that desalination should remain a "first world" technology. The World Health Organization (WHO) recommends 100 liters per person per day as a minimal level of access for human well-being. Accordingly, a back-of-the-envelope calculation would suggest that at 55 cents per cubic meter of water, the full individual supply of absolutely clean water can be provided for 5.5 cents per day—a rate that many poor communities may be able to afford. Surely, people who are already buying bottled water or receiving water from tankers would enjoy exceptional savings from a desalinated water supply. The WWF representatives, typically critical of default adoption of desalination by water-inefficient Western countries, actually argue that desalination plants are "almost never built where they are needed the most—such as in sub-Saharan African to deal with chronic shortages or in Asia, where the technology can be used to help remove arsenic and fluoride from drinking sources."[54] In short, in water-scarce regions, international development agencies should include desalination plants in their menu of aid alternatives.

Beyond the human health and agricultural dividends, typically there are meaningful environmental advantages that desalination brings to dryland communities as well as to inland aquatic ecosystems. Rivers can be restored, ecosystems sustained, salinity in aquifers reduced. But the environmental scorecard is surely not uniform. Desalinated water does not provide a "free lunch."

At present, it is not clear whether the ecological "downsides" of desalination are always fully considered, especially assuming that reduction of greenhouse gas emissions remains a global environmental priority. Based on the Australian experience, the economic feasibility of desalination is not as compelling when the full environmental accounting of production is internalized. Public support will tend to have an inverse relationship to the price of water.

The national experiences among these three desalination leaders suggest that when there is compelling evidence that the high costs of desalination is not justified, the topic quickly emerges on domestic political agendas, turning desalination into a partisan and contentious issue. While many of these disputes may be manifestations of broader ideological or cultural differences, the accompanying table demarcates substantive areas of controversy and disagreement.

The magnitude of seawater desalination's proliferation has not yet been fully internalized by international environmental agencies. It may be that beyond the greenhouse gas issue, the environmental impacts of a desalination plant are largely local and international intervention is superfluous. But this is not yet certain. Surely some systematic thought about the cumulative impact of thousands of desalination facilities and their myriad discharges on the marine environment should be considered by the United Nations Environment Programme (UNEP) and be the focus of calls for research proposals that would monitor and model such transboundary effects. One could argue that until such "macro" thinking takes place, demands for an international regulatory response are premature. But the precautionary principle posits otherwise.

For many years, green orthodoxy has preached the Malthusian gospel of sacrifice, self-discipline, and limitations. It is no surprise, therefore, that environmentalists often exhibit a discomfort with a technology that calls many of their basic assumptions into question. Environmental advocates are paid to worry and be suspicious of "good news." For countries like Israel where water allocation constitutes a volatile, diplomatic issue, advancement in desalination technology is very good news. Indeed, one can argue that the national commitment to desalination is actually an expensive gamble on a peaceful future. With each of the recent wars with its neighbors, the range of missiles has expanded, and it is likely that the new centralized and highly exposed desalination facilities would be targeted in future conflicts.

In all three countries, desalination's energy intensity offers the most convenient basis to object to the ebullient, hydrological optimism of the cornucopians. The energy issue has many dimensions. For countries that opt for desalination, the water and energy sectors will increasingly become inseparable. This is in fact constitutes a paradox. Decision makers in water-scarce regions see desalination as a hedge against the stochastic nature of precipitation and the gloomy projections about long-term precipitation trends. But improved climatic insecurity may not automatically translate into economic security. In recent years, the energy market has become particularly unstable and gasoline prices continue to fluctuate dramatically,[55]as they steadily rise toward what will likely constitute a quantum leap in price levels.[56] (In this context, the "Malthusian" pessimists can enjoy a sense of validation.)

Ever since the oil boycott of 1973, definitions of national security increasingly include natural resource factors.[57]Any decision to embrace desalination will increase a nation's vulnerability—at least economically—to a particularly volatile market. "Energy security" remains a relatively new concept, but one that the defense establishment is taking more seriously.[58] Water managers, committed to providing a reliable, clean supply of water, will need to become better versed in these national security dynamics and consider concerns about "Peak Oil" and the anticipated turbulence the associated price rises could cause.

Greenhouse gas mitigation, for the foreseeable future, should constitute an operational constraint and be addressed during the planning phase of desalination plans—as it is in Australia. This will allow decisions to be based on desalination's full costs, with externalities calculated from the outset. Undoubtedly, a breakthrough in wind or solar energy or another innovative water-based, renewable technology would serve to trump many concerns about energy vulnerability and the environmental impact of desalination proliferation.

Even without it, the price of desalination may continue to drop. In Israel, the tender agreement allows producers to link water price with energy costs. And yet after seven volatile years in the oil market, price shifts have been trivial, hardly felt by local consumers. Moreover, membrane technology is constantly improving and the desalination processes will undoubtedly grow more efficient over time, with an attendant reduction in carbon footprints and energy costs.

To the extent that electricity becomes clean and renewable, the ambivalence of environmentalists towards this technology can be ameliorated, and present water scarcity may one day be remembered as an ephemeral stage in the history of the world's water management. In the interim, water managers should continue to advance water conservation strategies. Even if farmers do not receive desalinated water directly, high levels of fresh-water consumption by the agricultural sector contribute to a substantial desalination investment for the municipal sector, with the associated increased carbon footprint and loss of coastal lands. In dryland regions, selecting non-water-intensive crops, mandating drip irrigation, and expediting effluent recycling should complement the present desalination bonanza.

As countries consider what an optimal desalination policy might be, there are several questions that could be the basis for drafting water management decision rules:

1. What are the levels of present and projected water shortages in the country?
2. What are the alternative measures that exist for reducing water demand? Is local agriculture operating at maximal efficiency?
3. What is the "shadow price" of desalinated water? Are there alternative water sources (e.g., high-quality tertiary-treated wastewater) that can be produced for a cheaper price?
4. As seawater desalination is far more expensive than brackish water, might there be saline groundwater resources that make more sense to tap as a first step?
5. What measures can reduce the carbon impact and other environmental insults of the process? Can they be integrated into the desalination facility's operating license?
6. Is the public funding available for a meaningful desalination program necessary and would a privatized investment ensure that water is supplied to all sectors of the local population?

Desalinated water is here to stay and will comprise an increasingly large percentage of the world's drinking water supply. It is already clear that seawater desalination brings water-scarce countries many blessings. Yet it surely is not a panacea. The availability of a desalination option does not make water public conservation programs any less relevant than in the past; nor does it change the imperative of monitoring and mending leaky piping infrastructures. Our common challenge is to ensure that all the environmental disadvantages associated with desalination are identified and addressed so that all human beings who suffer from water shortages can benefit from this new hydrological reality.

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