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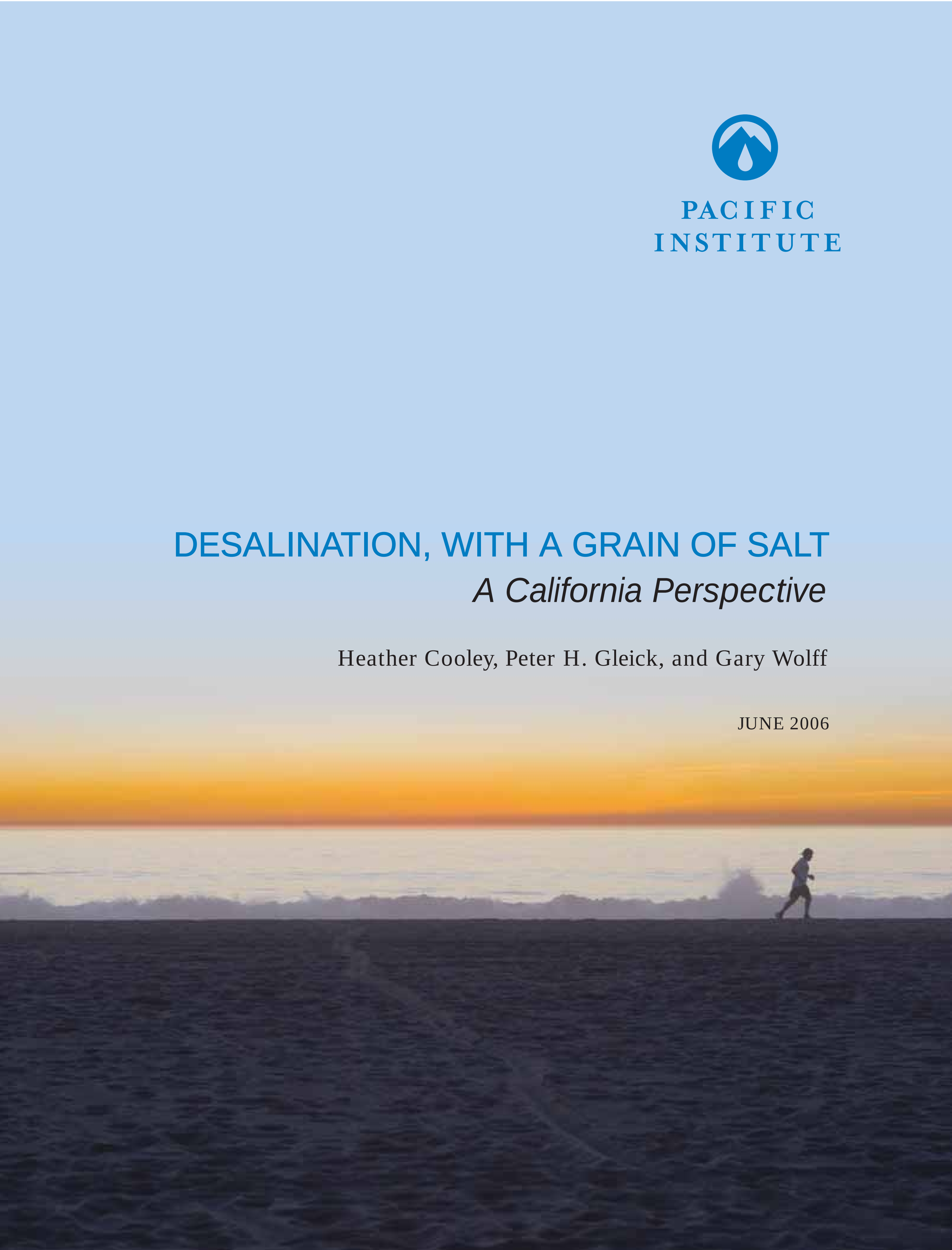
DESALINATION, WITH A GRAIN OF SALT

A California Perspective

Heather Cooley, Peter H. Gleick, and Gary Wolff

JUNE 2006



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ABOUT THE PACIFIC INSTITUTE

Founded in 1987 and based in Oakland, California, the Pacific Institute for Studies in Development, Environment, and Security is an independent, nonprofit organization that provides research and policy analysis on issues at the intersection of sustainable development, environmental protection, and international security.

The Pacific Institute strives to improve policy through solid research and consistent dialogue with policymakers and action-oriented groups, both domestic and international. By bringing knowledge to power, we hope to protect our natural world, encourage sustainable development, and improve global security. This report comes out of the Institute's Water and Sustainability Program.

More information about the Institute, staff, directors, funders, and programs can be found at www.pacinst.org and www.worldwater.org.

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ACKNOWLEDGEMENTS

In this report, the Pacific Institute provides a comprehensive overview of the history, benefits, and risks of ocean desalination, and the barriers that hinder more widespread use of this technology. We offer a set of **Conclusions and Recommendations** that will help water users and planners interested in making desalination a more significant part of international, national, and local water policy. Our intention is to provide information to help the public and policymakers understand and evaluate the arguments being put forward by both proponents and opponents of the current proposals.

Major funds for this report were provided by the California Coastal and Marine Initiative (CCMI) program of the Resources Legacy Fund Foundation and the David and Lucile Packard Foundation. Additional support was provided by the William and Flora Hewlett Foundation and the Flora Family Foundation. We thank them for their generosity and foresight.

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ABBREVIATIONS AND ACRONYMS

AF: acre-feet

AFY: acre-feet per year

BCDC: San Francisco Bay Conservation and Development Commission

BLS: U.S. Bureau of Labor Statistics

Cal Am: California American Water Company

CCC: California Coastal Commission

CCSD: Cambria Community Services District

CDWR: California Department of Water Resources

CEQA: California Environmental Quality Act

D_E: current drought-year demand

D_F: future drought-year demand

D_N: difference between future drought-year demand (D_F) and current drought-year demand (D_E)

EBMUD: East Bay Municipal Utility District

ED: electrodialysis

EDR: electrodialysis reversal

EIR: Environmental Impact Report

FY: fiscal year

IPCC: Intergovernmental Panel on Climate Change

kWh/m^3: kilowatt-hours per cubic meter

kWh/kgal: kilowatt-hours per thousand gallons

LADWP: Los Angeles Department of Water and Power

LBWD: Long Beach Water Department

LCP: Local Coastal Program

m^3: cubic meter

m^3/d: cubic meters per day

MD: membrane distillation

MED: multiple-effect distillation

MF: microfiltration

MGD: million gallons per day

mg/l: milligrams per liter

MMWD: Marin Municipal Water District

MPWMD: Monterey Peninsula Water Management District

MSF: multi-stage flash distillation

MWD: Metropolitan Water District of Southern California

NEPA: National Environmental Policy Act

NF: nanofiltration

NPDES: National Pollutant Discharge Elimination System

OTC: once-through cooling

ppm: parts per million

RO: reverse osmosis

RWQCB: Regional Water Quality Control Board

SD: standard deviation

SDCWA: San Diego County Water Authority

SWFWMD: Southwest Florida Water Management District

SWRCB: State Water Resources Control Board

TDS: total dissolved solids

UF: ultrafiltration

US$/kgal: U.S. dollars per thousand gallons

U.S. EPA: United States Environmental Protection Agency

VC: vapor compression

WBMWD: West Basin Municipal Water District

WtP: willingness to pay

$/kgal: dollars per thousand gallons

$/$m^3$: dollars per cubic meter

$/kWh: dollars per kilowatt-hour

CONVERSIONS

1 cubic meter (m^3) = 264 gallons = 0.0008 acre-feet (AF)

1,000 gallons (kgal) = 3.79 cubic meters (m^3) = 0.003 acre-feet (AF)

1 million gallons = 3,785 cubic meters (m^3) = 3.1 acre-feet (AF)

1 acre-foot (AF) = 325,853 gallons = 1,233 cubic meters (m^3)

1 cubic meter per day (m^3/d) = 264 gallons per day = 0.3 acre-feet per year (AFY) = 2.6×10^{-4} million gallons per day (MGD)

1 million gallons per day (MGD) = 3,785 cubic meters per day (m^3/d) = 1,120 acre-feet per year (AFY)

1 acre-foot per year (AFY) = 3.4 cubic meters per day (m^3/d) = 8.9×10^{-4} million gallons per day (MGD)

$1 per thousand gallons ($/kgal) = $0.26 per cubic meter ($/m^3) = $325.85 per acre-foot ($/AF)

EXECUTIVE SUMMARY

LONG CONSIDERED THE Holy Grail of water supply, desalination offers the potential of an unlimited source of fresh water purified from the vast oceans of salt water that surround us. The public, politicians, and water managers continue to hope that cost-effective and environmentally safe ocean desalination will come to the rescue of water-short regions. While seawater desalination plants are already vital for economic development in many arid and water-short areas of the world, many plants are overly expensive, inaccurately promoted, poorly designed, inappropriately sited, and ultimately useless. To avoid new, expensive errors, policymakers and the public need to take a careful look at the advantages and disadvantages of desalination and develop clear guidance on how to evaluate and judge proposals for new facilities.

In this report, the Pacific Institute provides a comprehensive overview of the history, benefits, and risks of ocean desalination, and the barriers that hinder more widespread use of this technology, especially in the context of recent proposals for a massive increase in desalination development in California.

The potential benefits of ocean desalination are great, but the economic, cultural, and environmental costs of wide commercialization remain high. In many parts of the world, alternatives can provide the same freshwater benefits of ocean desalination at far lower economic and environmental costs. These alternatives include treating low-quality local water sources, encouraging regional water transfers, improving conservation and efficiency, accelerating wastewater recycling and reuse, and implementing

> The potential benefits of ocean desalination are great, but the economic, cultural, and environmental costs of wide commercialization remain high.

smart land-use planning. At present, the only significant seawater desalination capacity is in the Persian Gulf, on islands with limited local supplies, and at selected other locations where water options are limited and the public is willing to pay high prices.

In the United States, almost all seawater desalination facilities are small systems used for high-valued industrial and commercial needs. This may be changing. Despite the major barriers to desalination, interest has recently mushroomed as technology has improved, demands for water have grown, and prices have dropped.

Interest in desalination has been especially high in California, where rapidly growing populations, inadequate regulation of the water supply/land-use nexus, and ecosystem degradation from existing water supply sources have forced a rethinking of water policies and management. In the past five years, public and private entities have put forward more than 20 proposals for large desalination facilities along the California coast (Figure ES1; Table ES1). If all of the proposed facilities were built, the state's seawater desalination capacity would increase by a factor of 70, and seawater desalination would supply 6% of California's year 2000 urban water demand. Project proponents point to statewide water-supply constraints, the reliability advantages of "drought-proof" supply, the water-quality improvements offered by desalinated water, and the benefits of local control. Along with the proposals, however, has come a growing public debate about high economic and energy costs, environmental and social impacts, and consequences for coastal development policies. We review and analyze these factors here.

Figure ES1
Map of Proposed Desalination Plants in California, Spring 2006

- ● > 20 MGD (76,000 m³/d)
- ○ 5 – 20 MGD (19,000 – 76,000 m³/d)
- ● < 5 MGD (19,000 m³/d)

Operator	Location	Max Capacity MGD	Max Capacity m³/d
Marin Municipal Water District	San Rafael	10-15	38,000-57,000
East Bay Municipal Utility District/ San Francisco Public Utilities Commission/ Contra Costa Water District/ Santa Clara Valley Water District	Pittsburg/Oakland/ Oceanside	20-80	76,000-300,000
East Bay Municipal Utility District	Crockett	1.5	5,700
Montara Water and Sanitary District	Montara	N/A	N/A
City of Santa Cruz	Santa Cruz	2.5, possible expansion to 4.5	9,500, possible expansion to 17,000
California American Water Company	Moss Landing	11-12	42,000-45,000
Pajaro-Sunny Mesa/Poseidon	Moss Landing	20-25	76,000-95,000
City of Sand City	Sand City	0.3	1,100
Monterey Peninsula Water Management District	Sand City	7.5	28,000
Marina Coast Water District	Marina	1.3	4,900
Ocean View Plaza	Cannery Row	0.05	190
Cambria Community Services District/ Department of the Army	Cambria	0.4	1,500
Arroyo Grande/Grover Beach/ Oceano Community Services District	Oceano	1.9	7,100
Los Angeles Department of Water and Power	Playa Del Rey	12-25	45,000-95,000
West Basin Municipal Water District	El Segundo	20	76,000
Long Beach Water Department	Long Beach	8.9	34,000
Poseidon Resources	Huntington Beach	50	190,000
Municipal Water District of Orange County	Dana Point	25	95,000
San Diego County Water Authority/ Municipal Water District of Orange County	Camp Pendleton	50, expanding to 100	190,000, expanding to 380,000
Poseidon Resources	Carlsbad	50, possible expansion to 80	190,000, possible expansion to 300,000
San Diego County Water Authority	Carlsbad	50, possible expansion to 80	190,000, possible expansion to 300,000

Table ES1
Proposed Plants in California as of Spring 2006

Based on this assessment, we conclude that most of the recent seawater desalination proposals in California appear to be premature. Among the exceptions may be desalination proposals where alternative water-management options have been substantially developed, explicit ecosystem benefits are guaranteed, environmental and siting problems have been identified and mitigated, the construction and development impacts are minimized, and customers are willing to pay the high costs to cover a properly designed and managed plant.

When the barriers to desalination are overcome, carefully regulated and monitored construction of desalination facilities should be permitted. We urge regulators to develop comprehensive, consistent, and clear rules for desalination proposals, so that inappropriate proposals can be swiftly rejected and appropriate ones identified and facilitated. And we urge private companies, local communities, and public water districts that push for desalination facilities to do so in an open and transparent way, encouraging and soliciting public participation and input in decision making.

Is desalination the ultimate solution to our water problems? No. Is it likely to be a piece of our water management puzzle? Yes.

Is desalination the ultimate solution to our water problems? No. Is it likely to be a piece of our water management puzzle? Yes. In the end, decisions about desalination developments will revolve around complex evaluations of local circumstances and needs, economics, financing, environmental and social impacts, and available alternatives. We urge that such decisions be transparent, open, public, and systematic. To that end, we offer a set of **Conclusions and Recommendations** that will help water users and planners interested in making desalination a more significant part of international, national, and local water policy. Our intention is to provide information to help the public and policymakers understand and evaluate the arguments being put forward by both proponents and opponents of the current proposals.

Desalination Conclusions and Recommendations

Economic Costs of Desalination

The cost of desalination has fallen in recent years, but it remains an expensive water-supply option. Desalination facilities are being proposed in locations where considerable cost-effective conservation and efficiency improvements are still possible.

The cost of desalination has fallen in recent years, but it remains an expensive water-supply option.

- Water planners, agencies, and managers must comprehensively analyze all options, including conservation and efficiency, and pursue less costly, less environmentally damaging alternatives first.

- Desalination facilities should be approved only where water agencies have implemented all cost-effective water conservation and efficiency measures.

Desalination costs are influenced by many factors, making comparisons difficult and estimates uncertain.

- All cost estimates should explicitly state the underlying assumptions.

- Cost comparisons must be made on a comparable basis.

The assumption that desalination costs will continue to fall may be false. Further cost reductions may be limited, and future costs may actually increase.

- Projected costs must be justified over the lifetime of the facility, taking into account possible changes in the cost of energy and construction materials, limits to membrane performance, and other factors.

More energy is required to produce water from desalination than from any other water-supply or demand-management option in California. The future cost of desalinated water will be more sensitive to changes in energy prices than will other sources of water.

- Project proponents should estimate and publicly disclose the full energy requirements of each proposed project and provide details of energy contracts.

- Project proponents should explicitly evaluate energy price risk, including year-to-year variation and trends over time, in the revenue requirement of water utilities that invest in or purchase water from ocean desalination.

Public subsidies for desalination plants are inappropriate unless explicit public benefits are guaranteed.

- Decisionmakers should offer public subsidies to desalination facilities only when the facilities come with a guarantee of public benefits, such as restoration of ecosystem flows.

More research is needed to fill gaps in our understanding, but the technological state of desalination is sufficiently mature and commercial to require the private sector to bear most additional research costs.

- Public research funds should be restricted to analyzing the public aspects of desalination projects, including environmental impacts, mitigation, and protection.

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Reliability and Water-Quality Considerations

Desalination plants offer both system-reliability and water-quality advantages, but other options may provide these advantages at lower cost.

- Water agencies should estimate the value of reliability or water-quality advantages in general, regardless of how that reliability or water-quality improvement is achieved.

- Water agencies should compare the cost of providing reliable or high-quality water from various sources, including ocean desalination. Water managers must still apply the standard principles of least-cost planning.

Desalination can produce high-quality water but may also introduce biological or chemical contaminants into our water supply.

- In order to ensure public health, all water from desalination plants must be monitored and regulated.

- When new or unregulated contaminants are introduced, new legislation, regulatory oversight, or standards may be needed.

Desalination can produce water that is corrosive and damaging to water-distribution systems.

- Additional research is needed to determine the impacts of desalinated product water on the distribution system.
- Water-service providers must ensure that distribution systems are not adversely affected.

Environmental Considerations

Desalination produces highly concentrated salt brines that may also contain other chemical pollutants. Safe disposal of this effluent is a challenge.

- More comprehensive studies are needed to adequately identify all contaminants in desalination brines and to mitigate the impacts of brine discharge.
- Water managers should carefully monitor, report, and minimize the concentrations of chemicals in brine discharges.
- Federal or state regulators should evaluate whether new water-quality regulations are needed to protect local environments or human health.
- Under all circumstances, water managers must minimize brine disposal in close proximity to sensitive habitats, such as wetlands.
- Disposal of brine in underground aquifers should be prohibited unless comprehensive and competent groundwater surveys are done and there is no reasonable risk of brine plumes appearing in freshwater wells.

> Impingement and entrainment of marine organisms are among the most significant environmental threats associated with seawater desalination.

Impingement and entrainment of marine organisms are among the most significant environmental threats associated with seawater desalination.

- The effects of impingement and entrainment require detailed baseline ecological assessments, impact studies, and careful monitoring.
- Intake pipes should be located outside of areas with high biological productivity and designed to minimize impingement and entrainment.

Subsurface and beach intake wells may mitigate some of the environmental impacts of open ocean intakes. The advantages and disadvantages of subsurface and beach intake wells are site-specific.

- For all desalination projects, proponents should evaluate the advantages and disadvantages of these options, including a review of impacts on freshwater aquifers and the local environment.

Desalination may reduce the need to take additional water from the environment and, in some cases, offers the opportunity to return water to the environment.

- Desalination proposals that claim environmental benefits must come with binding mechanisms to ensure that these benefits are delivered and maintained in the form, degree, and consistency promised.

Climate Change

Desalination offers both advantages and disadvantages in the face of climatic extremes and human-induced climate changes. Desalination facilities may help reduce the dependence of local water agencies on climate-sensitive sources of supply.

- Desalination proposals should evaluate the long-term climatic risks and benefits.

Extensive development of desalination can lead to greater dependence on fossil fuels, an increase in greenhouse gas emissions, and a worsening of climate change.

- Plans for desalination must explicitly describe the energy implications of the facility and how these impacts fit into regional efforts or requirements to reduce greenhouse gas emissions or meet regional, state, or federal clean air requirements.

- Regulatory agencies should consider requiring desalination plants to offset their greenhouse gas emissions.

Coastal desalination facilities will be vulnerable to the effects of climate change, including rising sea levels, storm surges, and extreme weather events.

- Planners should design and construct all desalination facilities using estimates of future, not present, climate and ocean conditions.

- Regulatory agencies should permit desalination facilities only when consideration of climate change factors and other hazards has been integrated into plant design.

Desalination offers both advantages and disadvantages in the face of climatic extremes and human-induced climate changes.

Siting and Operation of Desalination Plants

Ocean desalination facilities, and the water they produce, will affect coastal development and land use.

- Project proponents must evaluate the growth-inducing impacts of desalination facilities on a case-by-case basis and not assume these impacts to be incidental, minimal, or secondary.

- Desalination proponents must identify to the public and appropriate regulatory agencies all buyers and potential buyers of project water.

- California coastal development permits should be denied to desalination plants that will induce growth beyond levels projected in certified Local Coastal Programs.

There are unresolved controversies over private ownership and operation of desalination facilities.

- Negotiations over project contracts should be open, transparent, and include all affected stakeholders.

- Contracts that lay out the responsibilities of each partner are a prerequisite for the success of any project. These contracts must include explicit dispute resolution mechanisms and provisions addressing financial risks in the event of project failure.

- Independent technical and contract review should be standard.

Co-location of desalination facilities at existing power plants offers both economic and environmental advantages and disadvantages.

- Proponents should not use desalination to keep once-through cooling systems in operation longer than would otherwise be permitted under current or proposed regulations.

- Regulators should not issue exemptions to permit once-through cooling systems to remain in operation solely to service desalination plants.

- Project proponents must assess the effects of desalination independently of the power plant due to uncertainty associated with once-through cooling system systems.

- Additional research is needed to determine whether there are synergistic effects caused by combining desalination's high salinity discharge with the high temperatures and dead biomass in power plant discharge.

Siting, building, and operation of desalination facilities are likely to be delayed or halted if local conditions and sentiments and the public interest are not adequately acknowledged and addressed.

- The process of designing, permitting, and developing desalination facilities must be transparent and open.

- Draft contracts, engineering designs, and management agreements should be widely available for public review beginning in the early stages of project development.

- Project developers and local water agencies should commission and make publicly available independent review of the social and economic impacts of desalination facilities on local communities.

- Affected community members should be invited to participate in desalination project planning, implementation, and management during the early stages of the process.

The regulatory and oversight process for desalination is sometimes unclear and contradictory.

The regulatory and oversight process for desalination is sometimes unclear and contradictory.

- Federal, state, and local policies should standardize and clarify the regulation of desalination.

- Desalination should not be hindered by inappropriate regulation nor accelerated by regulatory exemptions.

CHAPTER I

INTRODUCTION

The oceans contain 97% of the Earth's water. This water is too salty for humans to use for irrigation, drinking, and most commercial and industrial purposes. Because of growing concerns about water scarcity and quality, and disputes over allocations of scarce water resources, a tremendous amount of effort has been devoted to developing technologies to desalinate the vast quantities of seawater available. While substantial progress has been made in recent years, desalination remains a minor source of water in all but the wealthiest, most water-scarce regions. In particular, desalination remains too expensive to be a primary source of fresh water and presents significant social, environmental, and technological obstacles that must be overcome. Nevertheless, in some regions, water planners are looking to desalination as a way to overcome natural limitations on freshwater availability, quality, and reliability.

This report provides a comprehensive overview of the benefits and risks of desalination and the barriers that hinder more widespread use of this technology. It does not address whether desalination is needed in California, nor does it comprehensively compare this supply option with other options, such as conservation, conjunctive use, or water recycling. Previous work at the Pacific Institute suggests that water continues to be used wastefully in California and that substantial amounts of water can be conserved cost-effectively compared to almost all proposed supply expansions, including desalination.[1]

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[1] See Gleick et al. 2003 and Gleick et al. 2005 for an assessment of the potential for conservation and efficiency to meet future demands in California.

We offer a set of **Conclusions and Recommendations** to help water users and planners make desalination a more significant part of international, national, and local water policy where appropriate. We emphasize recent activities in California, where a combination of factors has led to a revival of interest in desalination, a series of project proposals, and a growing public debate. This debate should be encouraged, but it should also be informed. Our intention is to provide information to help the public and policymakers understand and evaluate the arguments being put forward by both proponents and opponents of the current proposals.

Background to Desalination

The Earth's hydrologic cycle naturally desalinates water using solar energy. Water evaporates from oceans, lakes, and land surfaces, leaving salts behind. The resulting freshwater vapor forms clouds that produce precipitation, which falls to earth as rain and snow and moves through soils, dissolving minerals and becoming increasingly salty. The oceans are salty because the natural process of evaporation, precipitation, and runoff is constantly moving salt from the land to the sea, where it builds up over time.

"Desalination" refers to the wide range of processes designed to remove salts from waters of different qualities (Box 1; Table 1). Desalination technology is in use throughout the world for a wide range of purposes, including providing potable fresh water for domestic and municipal purposes, treated water for industrial processes, and emergency water for refugees or military operations.

Box 1: What's in a Name? Desalination? Desalinisation? Desalinization? Desalting?

There is no consistently accepted technical term (or spelling) for the process of removing salt from water, though most water engineers and professional organizations use the term "desalination." When one conducts a Web search on Google for the term "desalinization," the search engine asks, "Did you mean: 'desalination'?" Conversely, *The New Dictionary of Cultural Literacy, Third Edition* (2002) has an entry for desalinization, but nothing for desalination. The Commonwealth countries spell it with an "s" in place of the "z." The diversity of professional associations and organizations (organisations?) in this field reflects the diversity of terms used, including the International Desalination Association, the Australian Desalination Association, the European Desalination Association, the Southeast Desalting Association, the American Desalting Association, and the Middle East Desalinisation Research Center. In this report, we use "desalination" and "desalting" interchangeably; why use six syllables when three (or five) will do?

Table 1
Salt Concentrations of Different Water Sources

Water Source or Type	Approximate Salt Concentration (grams per liter)[a]
Brackish waters	0.5 to 3
North Sea (near estuaries)	21
Gulf of Mexico and coastal waters	23 to 33
Atlantic Ocean	35
Pacific Ocean	38
Persian Gulf	45
Dead Sea	~300

Sources: OTV 1999, Gleick 1993

Notes:

a. Slight spatial variations in salt content are found in all major bodies of water. The values in the table are considered typical. A gram per liter is equal to approximately 1000 parts per million.

Desalination facilities in many arid and water-short areas of the world are vital for economic development. In particular, desalination is an important water source in parts of the arid Middle East, Persian Gulf,[2] North Africa, Caribbean islands, and other locations where the natural availability of fresh water is insufficient to meet demand and where traditional water-supply options or transfers from elsewhere are implausible or uneconomical. Increasingly, other regions are exploring the use of desalination as a potential mainstream source of reliable, high-quality water as the prices slowly drop toward the cost of more traditional alternatives.

History of Desalination

The idea of separating salt from water is an ancient one, dating from the time when salt, not water, was a precious commodity. As populations and demands for fresh water expanded, however, entrepreneurs began to look for ways of producing fresh water in remote locations and, especially, on naval ships at sea. In 1790, United States Secretary of State Thomas Jefferson received a request to sell the government a distillation method to convert salt water to fresh water. A British patent was granted for such a device in 1852 (Simon 1998). The first place to make a major commitment to desalination was the island of Curaçao in the Netherlands Antilles. Plants have operated there since 1928 (Birkett 1999), and even the local beer is made with desalinated water.

A major seawater desalination plant was built in 1938 in what is now Saudi Arabia. Research on desalination was conducted during World War II to identify ways to meet military needs for fresh water in water-short regions. The United States and other countries continued that work after the war. The U.S. Congress passed the Saline Water Conversion Act (PL 82-448) in 1952, which created and funded the Office of Saline Water within the Department of the Interior's Bureau of Reclamation.

In the 1960s, Senator and then President John F. Kennedy strongly supported the idea of large-scale commercial desalination. Such a system "can do more to raise men and women from lives of poverty than any other scientific advance" (Kennedy 1961). An early version of modern distillation plants was built in Kuwait in the early 1960s. In the early 1970s, the federal Saline Water Conversion Act (PL 92-60) created the Office of Water Research and Technology, which focused on desalination efforts associated with designing and building the Yuma Desalting Plant,

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[2] As noted by the National Geographic Society, "Historically and most commonly known as the Persian Gulf, this body of water is referred to by some as the Arabian Gulf."

as required by the Colorado River Basin Salinity Control Act of 1974 (PL 93-320). Many of the advances in membrane technologies used in this plant and more advanced reverse osmosis (RO) plants have their roots in publicly funded research and development programs. In 1977, the U.S. spent almost $144 million for desalination research (Simon 1998), and additional funding was committed to desalination programs in other countries, including the Persian Gulf and Japan.

In 1982, the Reagan administration cut federal funding for non-military scientific research of almost every kind, including desalination work, and the Office of Water Research and Technology was closed. The next 14 years saw limited U.S. support for desalination, with the exception of some work on water-treatment technologies supported by the U.S. Bureau of Reclamation (Bach 2005).

In 1996, Senator Paul Simon revived interest in federal support for a modest desalination research program, authoring the Water Desalination Act (PL 104-298). This bill was signed into law and authorized $30 million over a six-year period for desalination research and studies, together with another $25 million over fiscal years 1999 to 2002 for demonstration projects. Authority for these activities was renewed through 2005 and partly funded in the FY 2005 Omnibus Bill. The original legislation required 50% cost sharing from the private sector and the support of multiple technologies. For the 1999 fiscal year, the U.S. government appropriated only $2.5 million; for fiscal year 2000, only $1.3 million was appropriated (ADA 1999, Price 1999).

U.S. efforts have expanded in the past few years. The U.S. Bureau of Reclamation has been working with professional research organizations and corporations to publish a collection of desalination literature (called DESALNET) containing the full reports of the federal efforts. They produced the “Desalination and Water Purification Roadmap” with funding from the FY 2004 Energy and Water Development Appropriations Bill. This roadmap was intended to establish long-term goals for research and development in desalination and water purification (Bach 2005). Additional funds have been provided to build a national desalination research facility at Alamogordo, New Mexico, scheduled for completion in 2006, and to support research and development activities at the site of the mothballed Yuma Desalting Plant in Arizona. All together, additional appropriations in recent years have brought the total to just over $28 million, with more than $12 million in Reclamation desalination research and development alone since 2004.

Despite a hot-and-cold approach to research and development, by the early 21st century, the U.S. government alone had spent nearly $2 billion on the basic research and development framework for many of the technologies now used for desalting seawater and brackish waters. Other government and private investments are also helping to stimulate the global desalination market, and many private commercial efforts are now advancing the technology and expanding operating experience.

Desalination Technologies

There is no single best method of desalination. A wide variety of desalination technologies effectively remove salts from salty water (or extract fresh water from salty water), producing a water stream with a low concentration of salt (the product stream) and another with a high concentration of remaining salts (the brine or concentrate). Most of these technologies rely on either distillation or membranes to separate salts from the product water (USAID 1980, Wangnick 1998 and 2002, Wangnick/GWI 2005). Ultimately, the selection of a desalination process depends on site-specific conditions, including the salt content of the water, economics, the quality of water needed by the end user, and local engineering experience and skills. Desalination technologies are briefly summarized below, and more detail is provided in Appendix A.[3]

There is no single best method of desalination. Ultimately, the selection of a desalination process depends on site-specific conditions, including the salt content of the water, economics, the quality of water needed by the end user, and local engineering experience and skills.

The earliest plants were based mostly on large-scale thermal evaporation or distillation of seawater, mimicking the natural hydrologic cycle. Some early distillation plants were used to desalt brackish water, but high costs prevented widespread adoption of this approach in most regions. The major exception was several countries in the Persian Gulf region where excess or inexpensive energy is available.

Beginning in the 1970s, more plants were installed using membranes that mimic the natural biological process of osmosis, because these systems have a number of advantages over thermal systems. Membrane technologies can desalinate both seawater and brackish water, although they are more commonly used to desalinate brackish water because costs increase along with the salt content of the water. Membrane technologies can also remove microorganisms and many organic contaminants. In addition, membrane technologies generally have lower capital costs and require less energy than thermal systems. Thermal desalination systems, however, can produce water with much lower salt content than membrane systems (typically less than 25 parts per million (ppm) total dissolved solids (TDS) in thermal systems compared to less than 500 ppm in membrane systems) (USBR 2003).

The technology for desalinating water continues to improve, driven by advances in technology, the need to reduce costs, and commercial competition. Recent reviews recommend that research focus on several areas, including the development of smart sensors to monitor water quality, improved filtration, better heat-transfer materials, and less environmentally damaging intake methods (NAS 2004). Specific improvements for thermal and membrane processes are described in greater detail under the appropriate headings and in Appendix A.

Membrane and Filtration Processes

Membranes and filters can selectively permit or prohibit the passage of certain ions, and desalination technologies have been designed around these capabilities. Membranes play an important role in the separation of salts in the natural processes of dialysis and osmosis. These natural principles have been adapted in two commercially important desalting processes: electrodialysis (ED) and RO. Both of these concepts have been understood for a century, but commercialization lagged until the tech-

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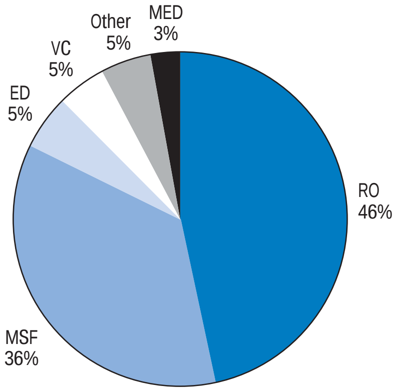
[3] Appendix A is available online at www.pacinst.org/reports/desalination.

nology for creating and maintaining membranes improved. These two approaches now account for more than half of all desalination capacity, and although they have typically been used to desalinate brackish water, versions are increasingly being applied to seawater (Figure 1). In recent years, the industry has achieved great advances in RO technology, and since the 1970s new membrane capacity has exceeded new distillation capacity. A growing number of desalination systems are also adding filtration units prior to the membranes in order to remove contaminants that affect long-term filter operation. Box 2 lists the characteristics of major filtration and membrane systems.

Figure 1
Global Desalination Capacity by Process, January 2005



ED = electrodialysis
MED = multi-effect distillation
MSF = multi-stage flash
Other = freeze, hybrid, nanofiltration, thermal, and all other processes
RO = reverse osmosis
VC = vapor compression

Source: Wangnick/GWI 2005

Among the needed improvements specific to membrane systems are improved membrane integrity and selectivity and reduced fouling. These improvements can reduce costs as well as provide higher-quality product water. See Appendix A for a more detailed discussion.[4]

Box 2: Filtration/Membrane Systems

Microfiltration (MF) membranes reduce turbidity and remove suspended solids and bacteria. MF membranes operate via a sieving mechanism under a lower pressure than either UF or NF membranes.

Nanofiltration (NF) membranes soften water, remove organics and sulfates, and eliminate some viruses. Removal is by combined sieving and solution diffusion.

Reverse osmosis (RO) membranes desalinate both brackish water and seawater and are capable of removing some organic contaminants.

Ultrafiltration (UF) membranes remove contaminants that affect color, high-weight dissolved organic compounds, bacteria, and some viruses. UF membranes also operate via a sieving mechanism.

Sources: Heberer et al. 2001, Sedlak and Pinkston 2001, NAS 2004

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[4] Appendix A is available online at www.pacinst.org/reports/desalination.

Electrodialysis and Electrodialysis Reversal

Electrodialysis is an electrochemical separation process that uses electrical currents to move salt ions selectively through a membrane, leaving fresh water behind. The process was commercially introduced in the mid 1950s, providing a cost-effective way to desalinate brackish water and spurring considerable interest in the use of membranes. The energy requirements for ED, and hence a large part of the costs, are proportional to the salts removed. ED can produce more product and less brine than distillation processes, can treat water with a higher level of suspended solids than RO, and needs fewer pretreatment chemicals. These systems produce water for industrial and power plant cooling towers, freshwater fish farms, and municipal uses; treat industrial wastes; and concentrate polluted groundwater for further treatment.

In the early 1970s, a modification of ED was introduced: electrodialysis reversal (EDR). EDR systems can operate on highly turbid feed water and are less prone to biofouling than RO systems (see below). Experience suggests that EDR can also achieve higher water recovery than RO systems. The major energy requirement is the direct current used to separate the ions in the membrane stack. ED and EDR represent about 5% of worldwide desalination capacity (Wangnick/GWI 2005).

Reverse Osmosis

Reverse osmosis uses pressure on solutions with concentrations of salt to force fresh water to move through a semi-permeable membrane, leaving the salts behind. The amount of desalinated water that can be obtained ranges between 30% and 85% of the volume of the input water, depending on the initial water quality, the quality of the product needed, and the technology and membranes involved.

The energy requirements for RO depend directly on the concentration of salts in the feed water and, to a lesser extent, on the temperature of the feed water. Because no heating or phase change is necessary for this method of separation, the major use of energy is for pressurizing the feed water. As a result, RO facilities are most economical for desalinating brackish water, and the product water increases in cost as the salt content of the source water increases.

Reverse osmosis has become a relatively mature technology and is experiencing rapid growth.

RO has become a relatively mature technology and is experiencing rapid growth. Some of the largest new desalination plants under construction and in operation now use RO membranes, including Ashkelon in Israel and the new plant at Tuas in Singapore. Ashkelon, the largest RO plant in the world, desalinates seawater for municipal purposes with a capacity of 100 million gallons per day (MGD) or 395,000 cubic meters per day (m^3/d) (Wangnick/GWI 2005).

Among the needed improvements in RO systems are better pretreatment of feedwater to reduce the use of chemicals that often end up in the brine and cause a disposal problem, improved membranes that are more durable and increase the flux of pure water, new approaches to reduce biofouling in membranes, more effective energy recovery and use, and development of less expensive materials (Awerbuch 2004).

Thermal Processes

Around 40% of the world's desalted water is produced with processes that use heat to distill fresh water from seawater or brackish water. The distillation process mimics the natural water cycle by producing water vapor that is then condensed into fresh water. In the simplest approach, water is heated to the boiling point to produce the maximum amount of water vapor. Water will boil under atmospheric pressure at 100°C. By decreasing pressure, however, the boiling point can be reduced. At one-quarter of normal pressure, for example, water will boil at 65°C, and it will boil at only 45°C if the pressure is decreased to one-tenth normal. To take advantage of this principle, systems have been designed to allow "multiple boiling" in a series of vessels that operate at successively lower temperatures and pressures. The concept of distilling water with a vessel operating at a reduced pressure has been used for well over a century.

Around 40% of the world's desalted water is produced with processes that use heat to distill fresh water from seawater or brackish water.

Distillation systems are often affected by scaling, which occurs when substances like carbonates and sulfates found in seawater precipitate out of solution and cause thermal and mechanical problems. One of the most significant concerns is gypsum, which forms from solution when water approaches about 95°C. Gypsum is the main component of concrete and can coat pipes, tubes, and other surfaces. Scale is difficult to remove and reduces the effectiveness of desalination operations by restricting flows, reducing heat transfer, and coating membrane surfaces. Ultimately scaling increases costs. Keeping the temperature and boiling point low reduces the formation of scale.

Multi-Stage Flash Distillation

The process that accounts for the greatest installed thermal distillation capacity is multi-stage flash distillation (MSF). Like all evaporative processes, MSF can produce high-quality fresh water with very low salt concentrations (10 ppm or less), from source water with salt concentrations as high as 60,000 to 70,000 ppm TDS, nearly twice the salinity of seawater. In MSF, evaporation "flashing" occurs from the bulk liquid, not on a heat-exchange surface, as is the case with other distillation processes (see multiple-effect distillation, below). This approach minimizes scale and is a major reason MSF has been popular for several decades (Birkett 1999). Up until recent advances in membrane technology, MSF was the primary technology used for desalinating seawater. As of early 2005, the largest MSF plant in operation was in Shuweihat in the United Arab Emirates. This plant desalinates seawater for municipal purposes with a total capacity of 120 MGD (455,000 m^3/d) (Wangnick/GWI 2005).

Multiple-Effect Distillation

Multiple-effect distillation (MED) is a thermal method that has been used successfully for over 100 years, substantially predating MSF (Birkett 1999). MED takes place in a series of vessels (“effects”) and reduces the ambient pressure in subsequent effects. This permits seawater to undergo multiple boilings without supplying additional heat after the first effect.

Although some of the earliest distillation plants used MED, MSF units – with lower costs and less tendency to scale – have increasingly displaced this process. In the past few years, interest in the MED process has been renewed and MED appears to be gaining market share. According to the Wangnick/GWI desalting inventory, MED has a 15% share of the thermal market, but a 21% share of proposed projects (Wangnick/GWI 2005). MED plants are typically built in units of 0.3 to 3 MGD (1,000 to 10,000 m^3/d) for smaller towns and industrial uses.

Vapor Compression Distillation

Vapor compression (VC) distillation is a thermal process that has typically been used for small- and medium-scale seawater desalting units. These units also take advantage of the principle of reducing the boiling point temperature by reducing ambient pressure, but the heat for evaporating the water comes from the compression of vapor rather than the direct exchange of heat from steam produced in a boiler. VC units are usually built in the 0.066 to 0.50 MGD (250 to 2,000 m^3/d) range and used for tourist resorts, small industries, and remote sites.

Other Desalination Processes

Water can be desalted though many other processes including small-scale ion-exchange resins, freezing, and membrane distillation. None of these processes has achieved the commercial success of RO, thermal distillation, or ED. Together they account for less than 1% of total desalination capacity (Wangnick/GWI 2005). Nevertheless, some of these approaches can be effective, and even preferable, under special circumstances.

Ion-Exchange Methods

Ion-exchange methods use resins to remove undesirable ions in water. For example, cation-exchange resins are used in homes and municipal water-treatment plants to remove calcium and magnesium ions in “hard” water. The greater the concentration of dissolved solids, the more often the expensive resins have to be replaced, making the entire process economically unattractive compared with RO and ED. At lower concentrations and for small-scale systems, however, these methods have proven effective. Thus, some form of ion exchange is sometimes used for the final polishing of waters that have had most of their salt content removed by RO or ED processes (Birkett 1999).

Freezing

Freeze separation takes advantage of the insolubility of salts in ice. When ice crystals form, dissolved salts are naturally excluded. If the resulting pure ice crystals can be separated from the brine, desalinated water can be produced. Extensive work was done in the 1950s and 1960s on separation technology using freezing of water. Freezing has some theoretical advantages over distillation, including a lower minimum energy requirement, minimal potential for corrosion, and little scaling or precipitation. Among the disadvantages, however, is the difficulty of handling and processing ice and water mixtures. A small number of demonstration plants have been built over the past 40 years but, except for the treatment of some industrial wastes, the process has never proven commercially feasible.

Membrane Distillation

Membrane distillation (MD) combines the use of both thermal distillation and membranes and was introduced commercially on a small scale in the 1980s. The process relies primarily upon thermal evaporation and the use of membranes to pass vapor, which is then condensed to produce fresh water. Thus far, MD has been used only in a few facilities, since it requires more space, more pumping energy per unit of fresh water produced, and more money than other approaches. The main advantages of MD lie in its simplicity and the need for only small temperature differentials to operate. MD is probably best suited for desalting saline water where inexpensive low-grade thermal energy is available, such as from industries or solar collectors.

CHAPTER II

CURRENT STATUS OF DESALINATION

Global Status

Some form of desalination is now used in approximately 130 countries, according to a database developed by Klaus Wangnick and now managed by Global Water Intelligence (Wangnick/GWI 2005). By January 2005, more than 10,000 desalting units larger than a nominal 0.3 MGD (100 m^3/d) had been installed or contracted worldwide. These plants have a total capacity to produce about 9,500 MGD (36 million m^3/d) of fresh water from all sources.[5] In 2000, the cumulative installed desalination capacity was around 6,900 MGD (26 million m^3/d) (Figure 2), implying a growth rate of around 7% per year. While desalination provides a substantial part of the water supply in certain oil-rich Middle Eastern nations, globally, installed desalination plants have the capacity to provide just three one-thousandths (0.3%) of total world freshwater use.

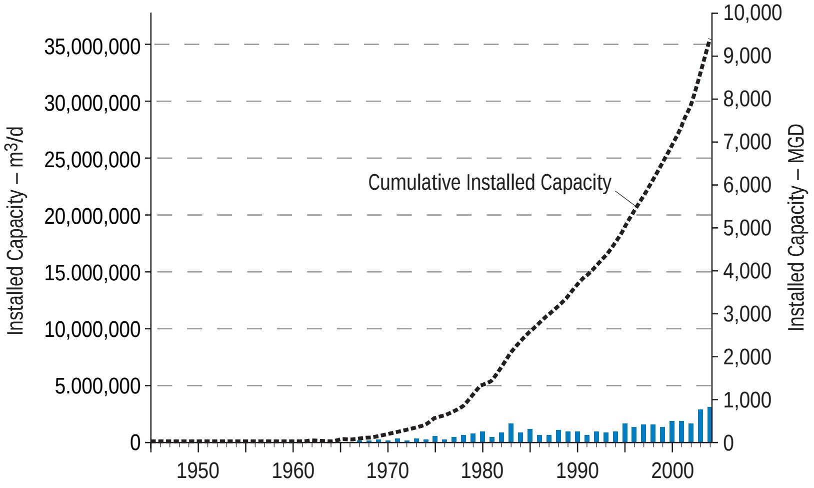

Figure 2
Time-Series of Global Desalination Capacity, January 2005

The bars show annual new installed capacity, and the line shows cumulative installed capacity. Source: Wangnick/GWI 2005

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[5] Actual production is likely to be considerably less than this, since the database adds plants when they are commissioned (or sometimes just planned) but does not have reliable information on plants that were never built or no longer operate. Figures on actual production of desalinated water are not collected.

Available technologies can desalinate water from a variety of sources. Figure 3 and Table 2 show the breakdown of water sources as of January 2005 (Wangnick/GWI 2005). Around 5,300 MGD (20 million m^3/d), or 56%, of desalination capacity was designed to process seawater. Another 2,200 MGD (8.5 million m^3/d), or 24% of total capacity, can process brackish water. The remaining capacity is used to desalinate waters of other kinds.

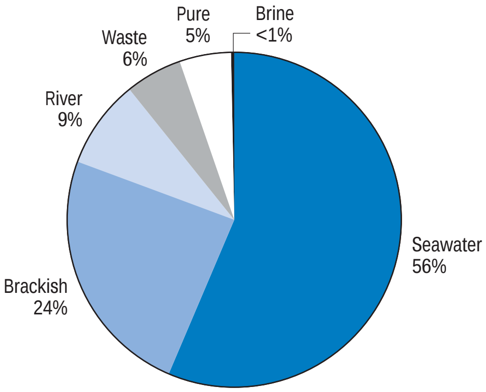
Table 2
Global Desalination Capacity by Source Water, January 2005

Source: Wangnick/GWI 2005

Water Source	Percent of Worldwide Installed Capacity
Seawater	56
Brackish	24
River	9
Waste water	6
Pure	5
Brine	< 1

Figure 3
Global Desalination Capacity by Source Water, January 2005

Source: Wangnick/GWI 2005



Half of the world's desalination capacity is in the Middle East/Persian Gulf/North Africa regions. Figure 4 shows those countries with more than 1% of global desalination capacity, as of January 2005. Eighteen percent of global capacity is in Saudi Arabia, followed by 17% in the United States, 13% in the United Arab Emirates, 6% in Spain, and 5% in Kuwait (Wangnick/GWI 2005). Most plants in Saudi Arabia, Kuwait, and the United Arab Emirates use distillation, while those in the United States rely upon RO and VC. It is important to note that many smaller island communities, not shown in this figure, rely on desalination for a large fraction of their total water need.

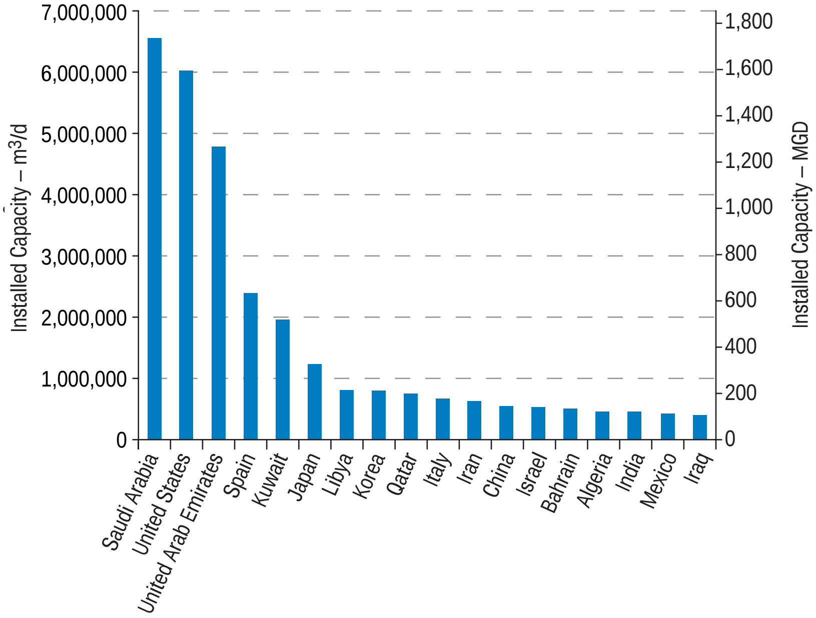


Figure 4
Countries with More Than 1% of Global Desalination Capacity, January 2005

Source: Wangnick/GWI 2005

Desalination in the United States

Desalination plants have been built in every state in the United States. By January 2005, over 2,000 desalination plants larger than 0.3 MGD (100 m^3/d) had been installed or contracted. These plants have a total installed capacity of only around 1,600 MGD (6.0 million m^3/d) – less than four one-thousandths (0.4%) of total U.S. water use.[6] Installed capacity has increased somewhat in recent years (Figure 5); between 2000 and 2005, the reported installed capacity has increased by around 30%, but again, the Wangnick/GWI (2005) database includes plants contracted but never built, built but never operated, and operated but now closed.

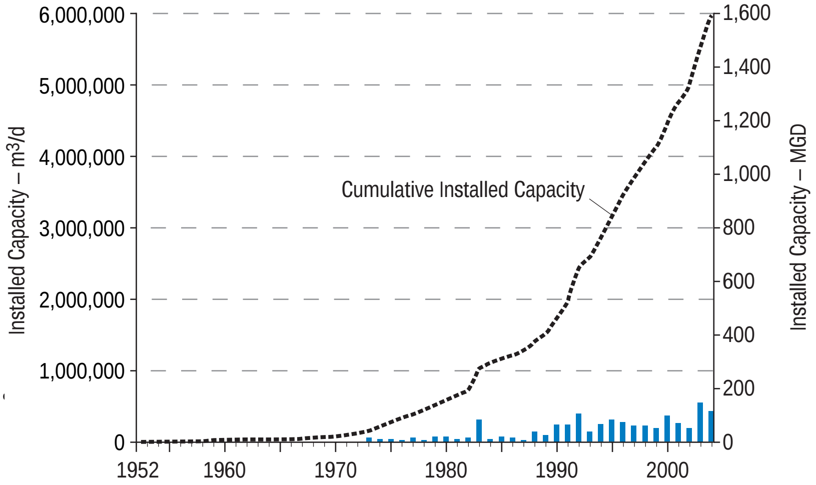


Figure 5
Time-Series of U.S. Desalination Capacity, January 2005

The bars show the installed capacity by year, and the line shows cumulative installed capacity.

Source: Wangnick/GWI 2005

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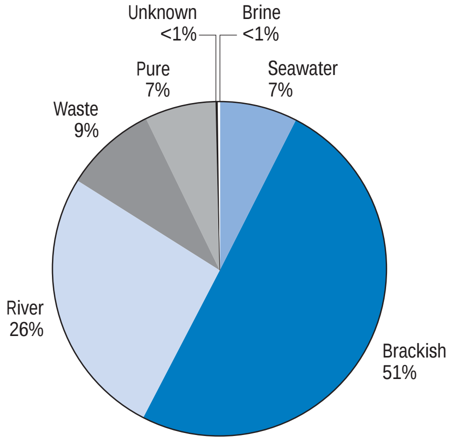
[6] The United States Geological Survey reports total U.S. water withdrawals in 2000 at around 565 cubic kilometers per year, or around 1,500 gallons per person per day for all uses.

The source of water treated in the U.S. plants differs from that of the rest of the world (Figure 6). Around half of all U.S. capacity is used to desalinate brackish water. Twenty-five percent of all U.S. capacity desalinates river water, which is relatively easy and cost-effective for industrial, power plant, or some municipal use. While seawater is the largest source globally, less than 120 MGD (0.45 million m^3/d) of seawater, or less than 10% of U.S. capacity, is desalinated in the U.S. The remaining capacity is primarily dedicated to desalinating wastewater and pure water for high-quality industrial purposes.

Figure 6
U.S. Desalination Capacity by Source Water, January 2005

Source: Wangnick/GWI 2005



Like the rest of the world, RO is the most common desalination technology used in the U.S., accounting for nearly 70% of the U.S. installed desalination capacity, or roughly 1,100 MGD (4.0 million m^3/d) (Figure 7). However, the second-most common desalination technology globally, MSF, is uncommon in the U.S.; only 1% of the total U.S. desalination capacity is based on MSF. By contrast, NF is much more common in the U.S., accounting for around 15% of total U.S. capacity. Of the 370 MGD (1.4 million m^3/d) of water that is desalinated worldwide using NF, about 65% of it (nearly 240 MGD, or 0.89 million m^3/d) occurs in the U.S.

Figure 7
U.S. Desalination Capacity by Process, January 2005

ED = electrodialysis
MED = multi-effect distillation
MSF = multi-stage flash
NF = nanofiltration
Other = freeze, hybrid, and all other processes
RO = reverse osmosis
VC = vapor compression

Source: Wangnick/GWI 2005

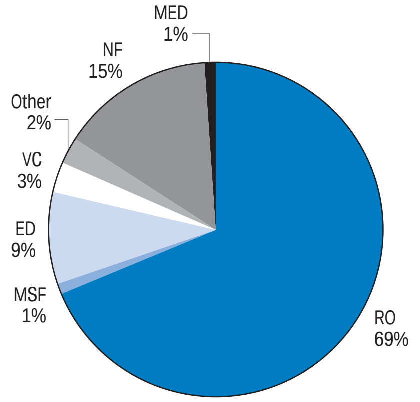


Figure 8 shows the U.S. states that have more than 1% of the U.S. total installed capacity. Three of the four states with the greatest installed capacity—Florida, California, and Texas—are coastal, while the fourth, Arizona, is an arid state with limited water-supply sources. A large plant built by the U.S. government in Yuma, Arizona to desalinate Colorado River water is included in this estimate, but this plant has never operated outside of short test periods. One of the largest desalination plants ever proposed for the United States is the Tampa Bay plant. Touted as a breakthrough in low-cost desalination, this plant has been rife with problems, as noted briefly in Box 3 and in greater detail in Appendix C. Like the Yuma desalter and the Santa Barbara desalination plant (Box 4), the Tampa Bay plant is included in the national inventory but has never operated commercially or reliably.

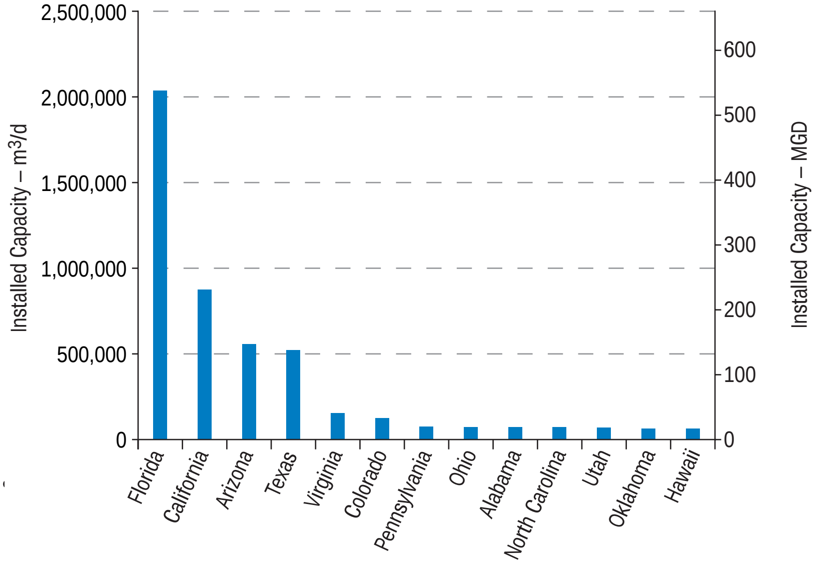


Figure 8
U.S. States with More Than 1% of the Total U.S. Installed Capacity, January 2005

Source: Wangnick/GWI 2005

Box 3: The Experience of the Tampa Bay Desalination Plant[7]

In March 1999, regional water officials in Florida approved plans to build an RO plant with a capacity of 25 MGD (95,000 m^3/d). Claims were made by project proponents that the cost of water would be very low and competitive with other local sources. The project and the apparent breakthrough in price excited desalination advocates. The desalination facility was to be privately owned and operated and upon completion would supplement drinking water supplies for 1.8 million retail water customers. The plant was considered necessary to help reduce groundwater overdraft and to meet future demands.

The planning process for the plant began in October 1996. In early 1999, Tampa Bay Water selected S&W Water, LLC, a consortium between Poseidon Water Resources and Stone & Webster. Their proposal called for construction of the plant on the site of the Big Bend Power Plant on Tampa Bay to begin in January 2001, and for operation to begin in the second half of 2002 (Heller 1999, Hoffman 1999). A total of 44 MGD (167,000 m^3/d) of feed water would be used to produce around 25 MGD (95,000 m^3/d) of potable water and 19 MGD (72,000 m^3/d) of brine. The desalinated water would then be added to the municipal supply.

Continued on next page

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[7] A more detailed review of the Tampa Bay plant is provided in Appendix C, online at www.pacinst.org/reports/desalination.

Box 3 *Continued*

The agreement called for desalinated water to be delivered at an unprecedented wholesale cost of \$1.71 per thousand gallons (\$1.71/kgal), or \$0.45 per cubic meter (\$0.45/m^3), for the first year, with a 30-year average cost of \$2.08/kgal (\$0.55/m^3) (Heller 1999). Southwest Florida Water Management District (SWFWMD) agreed to provide 90% of the projected \$110 million in capital costs for construction of the plant and the cost of the pipeline needed to transport the water to the water-distribution system (U.S. Water News 2003, Heller 1999).

The project has been fraught with difficulties, and as of May 2006, it is still not in operation due to serious management and technological failures. A number of contractors declared bankruptcy, forcing Tampa Bay Water to purchase the plant and assume full risk. Excessive membrane fouling was also problematic, decreasing the life of the membranes and increasing costs. The plant also violated its sewer discharge permit because additional chemicals were needed to clean the fouled membranes.

In November 2004, Tampa Bay Water agreed to a \$29 million, two-year contract with American Water-Pridesa (both owned by Thames Water Aqua Holdings, a wholly owned subsidiary of RWE) to get the plant running. Tests revealed that membrane fouling was still a problem and many of the water pumps had rust and corrosion problems. Both problems have been attributed to cost-cutting (Pittman 2005).

To further complicate matters, SWFWMD threatened to withhold financing for the plant because of a disagreement with Tampa Bay Water about the capacity at which the plant would operate. In January 2006, the water authorities agreed that the plant could be operated at less than full capacity as long as groundwater pumping was reduced. Environmentalists and activists strongly opposed the deal because they “felt cheated” (Skerritt 2006).

American Water-Pridesa expects the plant to open in late 2006 for another assessment period, after \$29 million in repairs are finished, and expects the plant to be fully operational in January 2008, six years late. In a press release issued in early 2004, the new cost was estimated at \$2.54/kgal (\$0.67 per m^3), up from an initial expected cost of between \$1.71 and \$2.08/kgal (\$0.45 to \$0.55/m^3) (Business Wire 2004). The recent decision to reduce the amount of water that the plant will produce and additional unforeseen problems will likely drive the price up further.

Careful examination of the project’s cost claims should caution desalination advocates against excessive optimism on price, and indeed, cost-cutting is in part responsible for the project’s difficulties. Moreover, the project had a number of unique conditions that may be difficult to reproduce elsewhere. For example, energy costs in the region are very low – around \$0.04 per kilowatt-hour – compared to other coastal urban areas. The physical design of the plant – sited at a local power plant – permitted the power plant to provide infrastructure, supporting operations, and maintenance functions. Salinity of the source water from Tampa Bay is substantially lower than typical seawater: only about 26,000 ppm instead of 33,000 to 40,000 ppm typical for most seawater. In addition, financing was to be spread out over 30 years, and the interest rate was only 5.2 percent (Wright 1999).

Desalination in California

Like the rest of the country, desalination has traditionally been a minor component of California's water-supply portfolio. The Wangnick/GWI (2005) database lists nearly 350 desalination plants larger than 0.3 MGD (100 m^3/d) installed or contracted in California since 1955, with a cumulative installed capacity of 230 MGD (870,000 m^3/d) (of which around 40 MGD (150,000 m^3/d) is listed as ocean desalination). By comparison, the estimated water use in California in 2000 was 40,000 MGD (150 million m^3/d) for urban and agricultural purposes. Most desalination facilities are small industrial plants that provide high-quality water for plant operations or cooling. Like the rest of the U.S., California's installed capacity appears on paper to be increasing at around 7% annually (Figure 9).

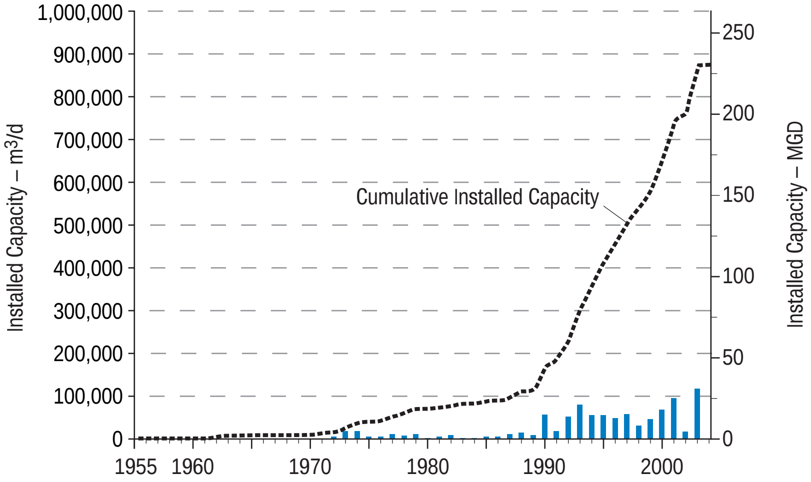

Figure 9
Time-Series of California Desalination Capacity, January 2005

The bars show annual new installed capacity, and the line shows cumulative installed capacity.

Source: Wangnick/GWI 2005

In actuality, California's desalination capacity appears to be far less than that reported in the Wangnick/GWI database. In a recent report, the California Coastal Commission (CCC) compiled a list of the desalination facilities currently in operation along the California coast (CCC 2004). The CCC lists about ten, mostly small, desalination facilities along California's coast with a total capacity of 6.1 MGD (23,000 m^3/d) (Table 3). By contrast, the Wangnick/GWI database lists about 20 seawater desalination plants with a capacity of 40 MGD (150,000 m^3/d), nearly seven times greater than the estimate produced by CCC (Wangnick/GWI 2005). Table B-1 in Appendix B attempts to reconcile the Wangnick/GWI data (2005) on seawater desalination plants with the CCC data.[8] As this table notes, the Wangnick/GWI data overestimates the total capacity by including plants that have not been built, have been built but never operated, have been built but are no longer in operation, or were small test facilities. We were unable to get definitive information about all facilities in the Wangnick/GWI database because repeated attempts to contact private companies about the status of their desalination plants were ignored. The actual installed capacity is likely closer to the CCC data, although Figures 10-12 are based on data from Wangnick/GWI (2005).

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[8] Appendix B is available online at www.pacinst.org/reports/desalination.

Operator/Location	Purpose	Ownership	Maximum Capacity		Status
			MGD	m^3/d	
Chevron/Gaviota	Industrial processing	Private	0.4	1,550	Active
City of Morro Bay	Municipal/domestic	Public	0.6	2,270	Intermittent use
City of Santa Barbara	Municipal/domestic	Public	2.8	10,600	Decommissioned
Duke Energy/Morro Bay	Industrial processing	Private	0.4	1,630	Not known
Duke Energy/Moss Landing	Industrial processing	Private	0.5	1,820	Active
Marina Coast Water District	Municipal/domestic	Public	0.3	1,140	Temporarily idle
Monterey Bay Aquarium	Aquarium visitor use	Non-profit	0.04	150	Active
PG&E/Diablo Canyon	Industrial processing	Private	0.6	2,180	Not known
Santa Catalina Island	Municipal/domestic	Public	0.1	500	Inactive
U.S. Navy/Nicholas Island	Municipal/domestic	Government	0.02	90	Not known
Oil and gas companies	Platform uses	Private	0.002-0.03	8-110	Active

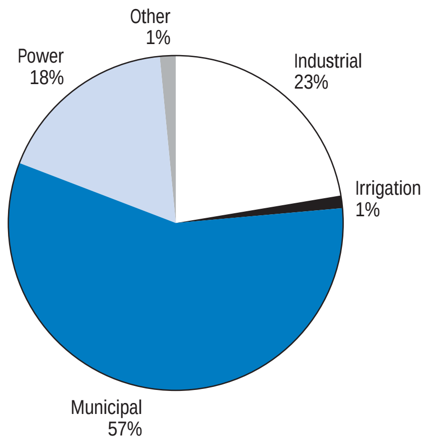
Table 3
Desalination Facilities Located Along the California Coast

Source: CCC 2004, Baucher 2006

Figure 10 shows California's cumulative installed capacity by user. Nearly 57% of the reported ocean desalination capacity was designed for municipal purposes. Industrial uses account for 23% of the cumulative installed capacity. Power plants use 18% of the cumulative installed capacity to produce fresh water for boilers and cooling systems.

Figure 10
California Installed Desalination Capacity by User, January 2005

Source: Wangnick/GWI 2005



California's cumulative installed capacity by process is shown in Figure 11. Reliance on RO (85%) may be due, in part, to the fact that desalination didn't take hold in California until 1990, coinciding with when RO technology was experiencing rapid growth worldwide due to improvements in the technology for creating and maintaining membranes.

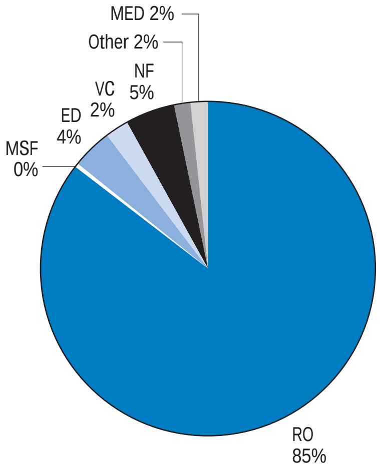


Figure 11
California Desalination Capacity by Process, January 2005

ED = electrodialysis
MED = multi-effect distillation
MSF = multi-stage flash
NF = nanofiltration
Other = freeze, hybrid, thermal, and all other processes
RO = reverse osmosis
VC = vapor compression

Source: Wangnick/GWI 2005

The source water for desalination in California differs from the rest of the U.S. Figure 12 shows the cumulative desalination capacity by source water. Like the rest of the U.S., brackish water is the largest supply source, accounting for 43% of the cumulative installed capacity. Seawater and wastewater, however, are more important supply sources in California than in other states due to California's proximity to the ocean and greater emphasis on recycling and reuse to meet its water demands than in other states. Approximately 40 MGD (150,000 m^3/d), or 17% of the reported capacity, is designed to desalinate seawater, compared to 7% on average in the rest of the U.S. About 14% of the desalination capacity in California is used with wastewater, compared to only 9% on average in the rest of the U.S.

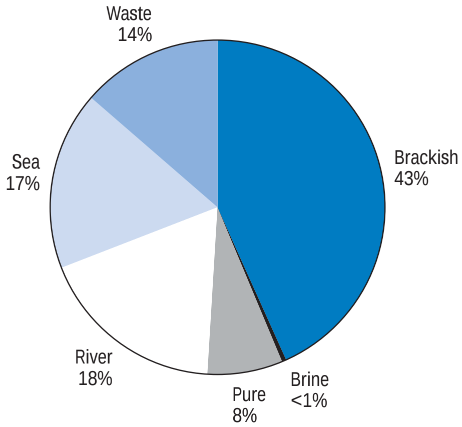


Figure 12
California Desalination Capacity by Source Water, January 2005

Source: Wangnick/GWI 2005.

One of the largest ocean desalination plants in California was built in the 1990s in Santa Barbara in response to serious water-supply constraints and a persistent drought. This plant also never operated commercially and proved to be an expensive burden (Box 4), though it still appears in the Wangnick/GWI database.

Box 4: The Experience of the Santa Barbara Desalination Plant

The City of Santa Barbara's experience with desalination should caution local communities planning desalination facilities. Between 1987 and 1992, California experienced an extended drought. This drought was felt particularly strongly in the coastal Santa Barbara region, where water resource options are limited: Santa Barbara relies extensively on rainfall and local groundwater to meet its water needs. By 1991, Santa Barbara residents were faced with a severe shortage. The city's few reservoirs were rapidly drying up despite successful conservation efforts that reduced water use by nearly 40 percent. City officials requested proposals to identify a new water source. As fears mounted, Santa Barbara residents overwhelmingly approved construction of an emergency desalination plant as well as a piped connection to the proposed Central Coast Branch of the State Water Project.

In 1991, the City of Santa Barbara partnered with the Montecito and Goleta Water Districts to construct a 7,500 acre-feet per year (AFY) RO desalination facility at a cost of $34 million.[9] Over the five-year repayment period, the City of Santa Barbara and the Montecito and Goleta Water Districts paid the capital cost of the facility as well as the cost to produce the water or maintain the facility in standby mode. The cost of the water was estimated to be roughly $4.60/kgal ($1.22/m^3), which was substantially more expensive than local supplies.

Construction of the desalination plant began in May 1991. The plant was completed in March 1992 and successfully produced water during start-up and testing. Shortly after construction was completed, however, the drought ended. The desalination facility was placed in an active standby mode, as the cost to produce the water was too high to warrant use during non-drought periods. In addition, the high cost of building the plant and connecting to the State Water Project raised water prices high enough to encourage substantial additional conservation, further decreasing need for the plant.

Water demand never fully rebounded after the drought. Conservation measures implemented during the drought, such as low-flow toilets and low-water-use gardens, continued to provide water savings. In addition, connection to the State Water Project through construction of the Coastal Branch Pipeline, which was completed in 1997, provided an additional 2.7 MGD (10,000 m^3/d) at a cost of around $4.60/kgal ($1.22/m^3) (CalPoly 2005, City of Santa Barbara 2005). The cost of water from the State Water Project will decline as 35-year bonds are repaid.

At the end of the five-year repayment contract, the Montecito and Goleta Water Districts opted out of the agreement, and the City of Santa Barbara became the sole owner of the facility. In January 2000, the City of Santa Barbara sold over half of the plant's capacity to a company in Saudi Arabia. The new capacity of the desalination plant is 2.8 MGD (11,000 m^3/d). Not foreseeing use for the facility in the short term, the facility has been decommissioned and components that are expensive to maintain in standby mode were removed. The facility now "serves as a sort of insurance policy, allowing the City to use its other supplies more fully" (City of Santa Barbara 2005). Restart costs and the amount of time needed to get the plant running remain uncertain.

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[9] This plant was designed with a capacity in acre-feet. This is equivalent to 6.7 MGD (25,000 m^3/d).

CHAPTER III

CALIFORNIA'S PROPOSED EXPANSION

California is currently in the midst of a surge in interest in desalination, far exceeding any time during the past few decades. This new interest is the result of a number of factors, including technological improvements and cost reductions in desalination, ongoing water management and scarcity concerns, and increased commercialization and promotion efforts on the parts of private desalination companies and promoters. There are currently more than 20 proposed desalination plants along California's coast (Figure 13), 12 of which are considerably larger than any previously built in the state. Table 4 lists the major proposed projects as of early 2006. With one exception, all of the proposed plants employ RO to treat ocean, estuarine, or brackish water. The total capacity of the proposed plants is around 450 MGD (1.7 million m^3/d), which would represent a massive 70-fold increase over current seawater desalination capacity. If all of these plants were built, seawater desalination would supply 6% of California's 2000 urban water use. Below we summarize the major proposed projects and their status as of mid 2006. Note that details on each plant can change very rapidly, and readers interested in the status of specific plants should seek more up-to-date information.

Figure 13
Map of Proposed Desalination Plants in California as of Spring 2006

- ● > 20 MGD (76,000 m^3/d)
- ○ 5 – 20 MGD (19,000 – 76,000 m^3/d)
- ● < 5 MGD (19,000 m^3/d)

Table 4 (Opposite Page)
Proposed Desalination Plants in California, Spring 2006

WW: waste water

Northern California

As of spring 2006, four desalination plants are proposed in Northern California, far fewer than in Central or Southern California (Figure 13). This is in part because water shortage concerns in this region are much less severe than in other parts of the state. The purposes of the proposed plants vary, ranging from improved reliability during droughts and emergencies to meeting anticipated growth needs and providing environmental benefits. With the exception of the Marin Municipal Water District, which is operating a pilot plant, agencies in Northern California are still in the early planning stages, and no project is likely to be built before 2010. Water from three of the plants would provide municipal supply, and one would provide water solely for industrial purposes. All are proposed by public agencies. The plants are described in greater detail below.

Marin Municipal Water District

The Marin Municipal Water District (MMWD) is proposing to build a 10-15 MGD (38,000-57,000 m^3/d) desalination plant in San Rafael. The plant would take water from the San Francisco Bay and mix the brine with wastewater effluent before discharging it back into the Bay. A pilot plant began operating in June 2005 and is expected to run into Spring 2006. Results from the pilot plant will help MMWD with project design

Operator	Location	Co-located?	Max Capacity		Intake	Discharge
			MGD	m^3/d		
Marin Municipal Water District	San Rafael	No	10-15	38,000-57,000	Surface	Mixed with WW
East Bay Municipal Utility District/San Francisco Public Utilities Commission/Contra Costa Water District/Santa Clara Valley Water District	Pittsburg/Oakland/ Oceanside	Likely	20-80	76,000-300,000	Surface	Not known
East Bay Municipal Utility District	Crockett	No	1.5	5,700	Surface	N/A
Montara Water and Sanitary District	Montara	No	N/A	N/A	N/A	N/A
City of Santa Cruz	Santa Cruz	No	2.5, possible expansion to 4.5	9,500, possible expansion to 17,000	Surface	Mixed with WW
California American Water Company	Moss Landing	Yes	11-12	42,000-45,000	Surface	Surface
Pajaro-Sunny Mesa/Poseidon	Moss Landing	Yes	20-25	76,000-95,000	Surface	Surface
City of Sand City	Sand City	No	0.3	1,100	Subsurface	Subsurface
Monterey Peninsula Water Management District	Sand City	No	7.5	28,000	Subsurface	Subsurface
Marina Coast Water District	Marina	No	1.3	4,900	Subsurface	Subsurface
Ocean View Plaza	Cannery Row	No	0.05	190	Surface	Surface
Cambria Community Services District/Department of the Army	Cambria	No	0.4	1,500	Subsurface	Subsurface
Arroyo Grande/Grover Beach/ Oceano Community Services District	Oceano	No	1.9	7,100	Subsurface	Mixed with WW
Los Angeles Department of Water and Power	Playa Del Rey	Yes	12-25	45,000 to 95,000	Surface	Mixed w/ cooling water or WW
West Basin Municipal Water District	El Segundo	Yes	20	76,000	Surface	Surface
Long Beach Water Department	Long Beach	No	8.9	34,000	Subsurface	Subsurface
Poseidon Resources	Huntington Beach	Yes	50	190,000	Surface	Surface
Municipal Water District of Orange County	Dana Point	No	25	95,000	Subsurface	Mixed with WW
San Diego County Water Authority/Municipal Water District of Orange County	Camp Pendleton	Yes	50, expanding to 100	190,000, expanding to 380,000	Surface	Surface
Poseidon Resources	Carlsbad	Yes	50, possible expansion to 80	190,000, possible expansion to 300,000	Surface	Surface
San Diego County Water Authority	Carlsbad	Yes	50, possible expansion to 80	190,000, possible expansion to 300,000	Surface	Surface

and be used to prepare required environmental assessments. The new water is supposed to help meet growth needs as projected in city and county planning documents and provides an alternative to building a new pipeline to the Russian River (MMWD 2006).

> The purposes of the proposed Northern California plants vary, ranging from improved reliability during droughts and emergencies to meeting anticipated growth needs and providing environmental benefits.

East Bay Municipal Utility District/San Francisco Public Utility Commission/Contra Costa Water District/Santa Clara Valley Water District

Four San Francisco Bay Area utilities are exploring the option of building a regional desalination plant with a total capacity of between 20-80 MGD (76,000-300,000 m^3/d). The facility would provide supplemental long-term supply, drought and emergency supply, and alternative backup when current facilities "are taken out of service for inspection, maintenance, or repairs" (EBMUD 2005). Sites being considered include Pittsburg, Oakland, and Oceanside. The utilities completed an initial study in October 2003 and are preparing detailed feasibility and environmental studies. Even with an aggressive construction and development schedule, the facility would be completed no earlier than 2010 (EBMUD 2005).

East Bay Municipal Utility District

In addition to the Bay Area regional desalination plant, the East Bay Municipal Utility District (EBMUD) is evaluating a separate option to build a small 1.5 MGD (5,700 m^3/d) desalination plant at the C&H Sugar refinery in Crockett. The water would replace potable water that is currently used at the sugar factory, making it available for other EBMUD customers (EBMUD 2005).

Montara Water and Sanitary District

Montara Water and Sanitary District (MWSD), located between Half Moon Bay and San Francisco, received a state grant in 2005 to conduct a desalination feasibility study that will examine the possibility of using beach wells for providing source water for this small community. The project would be very small, although few details are available at this time.

Central California

Nine desalination plants are proposed for Central California, the most of the three California regions (Figure 13). Concerns about drought, water-supply constraints, and growth moratoriums are prevalent in this part of the state, thus accounting for high levels of interest. The total capacity of these plants would be about 48 MGD (180,000 m^3/d), but the size of individual plants ranges from less than 0.30 MGD to 25 MGD. Three of the nine proposed plants are fully or partly supported by private companies. Proposed plants are described in greater detail below.

City of Santa Cruz

The City of Santa Cruz is considering building a desalination plant with an initial capacity of 2.5 MGD (9,500 m^3/d). The plant would take water from the ocean through an abandoned wastewater effluent pipe and mix the brine with wastewater prior to releasing it to the ocean. The City has suggested it would use the plant only during droughts but may opt to sell surplus water during non-drought periods to the Soquel Creek Water District. As demand grows, increments of 1.0 MGD (3,800 m^3/d) would be added to the plant for drought protection up to a final capacity of 4.5 MGD (17,000 m^3/d). In the future, the plant may also be used to provide a baseline water supply. In May 2005, the City received Proposition 50 grant funds to construct a pilot plant.[10] The City expects the plant to be on line in 2010 (City of Santa Cruz 2005).

Nine desalination plants are proposed for Central California, the most of the three California regions.

California American Water Company

California American Water Company (Cal Am) is proposing to co-locate an 11-12 MGD (42,000-45,000 m^3/d) desalination plant at the Duke Energy site in Moss Landing. The water provided by the desalination plant would offset water diversions from the Carmel River, as required by State Water Resources Control Board (SWRCB) Order 95-10 (see the "Environmental Benefits" section for more detail), and overpumping of the Seaside groundwater basin (Townsley 2006). As of early 2006, Cal Am has provided its California Environmental Quality Act (CEQA) environmental documentation to the California Public Utilities Commission, which is acting as lead agency on the project, and is seeking to secure county permits to build a pilot plant. Thus far, Cal Am has been unable to secure these permits because Duke Energy has not met wetland mitigation obligations associated with removing oil tanks from the property. Cal Am is in competition with the Pajaro facility (below), which hopes to use some of the same infrastructure.

Pajaro-Sunny Mesa Community Services District/ Poseidon Resources

Pajaro-Sunny Mesa Community Services District and Poseidon Resources are proposing to build a 20-25 MGD (76,000-95,000 m^3/d) desalination plant, also at the Duke Energy facility in Moss Landing. The plant would use Duke Energy's intake and outfall infrastructure but would be located at the former National Refractories site, adjacent to Duke Energy. Pajaro-Sunny Mesa and Poseidon are seeking to secure county permits to build a pilot plant. The county has indicated that they intend to provide the appropriate permits (Hennessey 2006a). Local groups appealed the permits to the CCC, which expects to issue a staff recommendation in mid June (Howe 2006). This plant is in direct competition with the Cal Am plant described above.

City of Sand City

The City of Sand City plans to build a 0.3 MGD (1,100 m^3/d) desalination plant. The plant would take brackish water via beach wells and discharge the brine, which the proponents state would not exceed salinity

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[10] Proposition 50, approved by California voters in 2002, provides grant money to public agencies for projects that promote development of new water supplies using desalination technologies.

levels of 35 parts per thousand, into injection wells. Cal Am would operate the plant, and the City has issued a request for proposals for the design and construction of the plant. Initially, the City would sell the water produced by the desalination plant to Cal Am, who would use the water to offset water diversions from the Carmel River, as required by SWRCB Order 95-10. Over time, the City would reduce the amount of water it sells to Cal Am in order to meet its growth needs. The CCC approved the plant in May 2005. The City expects the plant to be fully operational by June 2007 (Hennessey 2006b).

Monterey Peninsula Water Management District

The Monterey Peninsula Water Management District (MPWMD) proposed to build a 7.5 MGD (28,000 m^3/d) desalination plant in Sand City. The plant would use wells for water intake and brine discharge. The produced water would offset water diversions from the Carmel River, as required by SWRCB Order 95-10. In 2004, the MPWMD placed the project on hold, opting to pursue a regional desalination plant at Moss Landing (MPWMD 2005a).

Marina Coast Water District

The Marina Coast Water District (MCWD) is proposing to replace an idle desalination plant with a larger plant. The new plant, which would have a capacity of about 1.3 MGD (4,900 m^3/d), is part of a plan to meet water-supply needs that includes building a recycling plant of the same capacity. The water would satisfy future needs of the Fort Ord community, and a small amount (less than 0.3 MGD, or 1,000 m^3/d) would be available for the current needs of the greater Monterey Peninsula. The plant would use beach wells for water intake and brine discharge. The MCWD Board of Directors endorsed the plan in June 2005 and is scoping the project to develop specific plans (Marina Coast Water District 2005).

Ocean View Plaza, Monterey

The developers of Ocean View Plaza in the City of Monterey propose to build a small desalination plant with a capacity of 0.05 MGD (190 m^3/d) to provide water for a new development along Cannery Row. The Monterey City Council approved the project Environmental Impact Report (EIR) in October 2002. A Superior Court judge ruled that the EIR was incomplete in September 2003, and in response, the City Council vacated their previous certification and approval. A Supplement EIR was prepared to address the issues raised by the Superior Court judge (CCC 2005). In June 2004, the Monterey City Council approved the development project. Because county and state laws require a local entity to own and operate the plant, the developers organized a community service district. The Monterey City Council would serve as the new district's board of directors. A local community organization, Save Our Waterfront, filed a lawsuit against the City of Monterey, its City Council, and the county's Local Agency Formation Commission in February 2006 because it claims that the decision to form the district is based on an outdated EIR (Reynolds 2006).

Cambria Community Services District

Cambria Community Services District (CCSD) is proposing to build a 0.4 MGD (1,500 m^3/d) desalination plant in Cambria. The water would provide drought protection for the District's current residents and would meet the needs of those on the water waitlist. It would also "mitigate the potential impacts of MTBE contamination" and allow current residents to increase their water use (CCSD 2006). CCSD secured $4 million in funding from the federal government to conduct design, permitting, and environmental studies. Because it would be funded with federal money, the Army Corp of Engineers would manage the project. CCSD completed an Initial Study/Mitigated Negative Declaration in 2005 and is conducting additional studies.

City of Arroyo Grande/City of Grover Beach/Oceano Community Services District

The project partners are proposing to build a 1.9 MGD (7,100 m^3/d) desalination plant in Oceano at the South San Luis Obispo County Sanitation District wastewater treatment plant site. The plant would use seawater from wells on or near the beach and mix the brine with wastewater prior to discharge. The water would meet future water-supply needs for the three communities and is an alternative to a pipeline extension that would deliver water from Lake Nacimiento. The project partners are preparing a grant application for state funds to prepare a detailed feasibility study (City of Arroyo Grande 2006).

Southern California

Eight desalination plants are proposed for Southern California as of early 2006 (Figure 13). Although Central California has more plant proposals, the capacity of the proposed plants in Southern California is substantially larger, at around 300 MGD (1.1 million m^3/d). Over half of the proposed facilities would co-locate with existing power plants that use once-through cooling (OTC) systems. Concerns about drought reliability, population growth, and the desire to reduce dependence on water from the Sacramento-San Joaquin Delta and Colorado River have created a high degree of interest in pursuing desalination in Southern California. Two of the plants are supported by private companies and are further along than any of the other proposed plants in California. Proposed plants are described in greater detail below.

> Concerns about drought reliability, population growth, and the desire to reduce dependence on water from the Sacramento-San Joaquin Delta and Colorado River have created a high degree of interest in pursuing desalination in Southern California.

Los Angeles Department of Water and Power

Los Angeles Department of Water and Power (LADWP) is proposing to co-locate a 12-25 MGD (45,000-95,000 m^3/d) desalination plant at the Scattergood Generating Station in Playa Del Rey. According to the LADWP Urban Water Management Plan (2005), desalinated water would offset water committed from the Los Angeles Aqueduct for environmental restoration in the eastern Sierra Nevada. LADWP has conducted a fatal flaw assessment and is now conducting additional feasibility studies. LADWP expects the plant to be operational no earlier than 2015 (LADWP 2005).

West Basin Municipal Water District

West Basin Municipal Water District (WBMWD) is proposing to co-locate a 20 MGD (76,000 m^3/d) desalination plant at the El Segundo power plant in El Segundo. The power plant cooling water would provide source water for the desalination plant as well as a means to discharge the brine. The District has operated a 40 gallons-per-minute pilot plant and was awarded Proposition 50 grant funding to build a 0.5 MGD (1,900 m^3/d) demonstration facility in May 2005. The demonstration facility would be located within the West Basin service area (WBMWD 2005).

Long Beach Water Department

The Long Beach Water Department (LBWD) is considering constructing an 8.9 MGD (34,000 m^3/d) desalination plant in Long Beach. The plant would intake water from collector wells located under the ocean floor and discharge the brine through a second set of subsurface laterals. LBWD has been operating a 9,000 gallon/d (34 m^3/d) pilot plant to test the feasibility of using NF membranes in two passes in order to reduce the energy consumption over the more conventional single-pass RO seawater desalination process. The testing, which was formalized in an American Water Works Association Research Foundation-funded project, indicated that up to a 30% energy savings may potentially be achieved through the use of the NF membranes. Based on this research, LBWD, in partnership with the Los Angeles Department of Water and Power and the U.S. Bureau of Reclamation, began operating a 0.30 MGD (1,100 m^3/d) prototype plant at the Haynes Generating Station in early 2006.

The prototype project has two objectives: compare the energy required for both the NF treatment and RO in side-by-side testing under the same finished water quality conditions; and further refine and optimize the two-pass NF membrane desalination method, termed the "Long Beach Method." Additional research conducted at another site will examine the feasibility of subsurface intake and discharge wells. The research should conclude by 2010 (Cheng 2006, LBWD 2005a).

Operation of the full-scale facility is expected to commence no earlier than 2015 if the project proves to be economically, technically, and environmentally feasible. Water produced by the desalination plant would be used within the City of Long Beach and replace water imported from Metropolitan Water District of Southern California (LBWD 2005b).

Poseidon Resources/Huntington Beach

Poseidon Resources is proposing to co-locate a 50 MGD (190,000 m^3/d) desalination plant with the AES Power Plant in Huntington Beach. The desalination plant would be located adjacent to the AES site. The power plant cooling water would provide source water for the desalination plant as well as a means to discharge the brine (Poseidon 2005a). The project was rejected by the Huntington Beach City Council (4-3 vote) in December of 2003 after review of the EIR. An updated EIR was narrowly approved by the City Council (4-3 vote) in September 2005 (Overley 2005). A vote on land-use permits was postponed twice due to uncertainty about how the city would benefit from the project (Wahid 2006). The City Council approved the land-use permits in late February, and the project now moves on to the CCC and the Regional Water Quality Control Board (RWQCB). A local citizens group, however, has appealed these permits with the CCC. This is one of the first big desalination proposals in California and is being watched carefully by both supporters and opponents of desalination.

Poseidon Resources/ Huntington Beach is one of the first big desalination proposals in California and is being watched carefully by both supporters and opponents of desalination.

Municipal Water District of Orange County

Municipal Water District of Orange County (MWDOC) is considering building a 25 MGD (95,000 m^3/d) desalination plant in Dana Point. Intake water would likely be provided by a subsurface intake system, and brine would be mixed with wastewater effluent prior to discharge. Water produced by the plant would improve system reliability and provide a new source for development in south Orange County. MWDOC expects to finish feasibility studies by mid-2006. Once the feasibility studies have been completed, MWDOC will decide whether to proceed with the project (MWDOC 2005).

San Diego County Water Authority/Municipal Water District of Orange County

San Diego County Water Authority (SDCWA) and MWDOC are considering the option of building a 50-100 MGD (190,000-380,000 m^3/d) desalination plant at Camp Pendleton. The plant would use the intake and outfall structure from Unit 1 of the San Onofre Nuclear Generating Station, which is being decommissioned. A pre-feasibility/fatal flaw assessment was conducted in 2005, and a detailed feasibility study is currently underway. The product water, which would be split equally between the project partners, provides a new supply source and would improve system reliability. Camp Pendleton also has the right to receive desalinated water via SDCWA (SDCWA 2005). Because the proposed desalination plant would be co-located with a nuclear power plant, public perception remains a formidable obstacle. To complicate this matter, the site is being used to store nuclear waste until a remote federally approved nuclear waste site opens (Jimenez 2004).

San Diego County Water Authority

San Diego County Water Authority is proposing to co-locate a 50 MGD (190,000 m^3/d) desalination plant at the Encina Power Station in the City of Carlsbad. The plant may be expanded by an additional 30 MGD if it is deemed feasible. The power plant cooling water would provide source water for the desalination plant as well as a means to dilute the brine. SDCWA began an environmental impact report in 2003 and expects certification by mid 2006. SDCWA has secured nearly $1.5 million in federal funding for the project and expects the plant to be operational by 2011. The City of Carlsbad has been negotiating with SDCWA to receive up to 4.5 MGD (17,000 m^3/d) (SDCWA 2005). This project is in competition with the Poseidon/Carlsbad facility (below), which hopes to use some of the same infrastructure.

Poseidon Resources/Carlsbad

Poseidon Resources in proposing to build a 50 MGD (190,000 m^3/d) desalination plant at the Encina Power Station in the City of Carlsbad that directly competes with the SDCWA proposal. The desalination plant would be located on a site adjacent to the power plant and would use its intake and outfall infrastructure. The final EIR was released in late 2005, and a demonstration facility is in operation at the site (Poseidon 2005b). The City Council unanimously approved the project in May 2006. The City of Carlsbad and the Valley Center Municipal Water District have signed water purchase agreements with Poseidon. The Olivenhain Municipal Water District has signed a letter of intent, and the Rincon del Diablo Municipal Water District has a pending deal with Poseidon (Broderick 2006, Burge 2005).

It remains to be seen whether expansion of desalination in California will occur, whether these proposals are premature, or whether other solutions to California’s long-term water challenges will be found. In the following sections we review the arguments made for and against desalination. These arguments are being made in California and wherever else desalination is proposed to address water supply, quality, and reliability problems. Ultimately a wide range of factors will have to be considered, problems overcome, and solutions found. The issues discussed in the next few sections also highlight a number of critical conditions that will have to be met before large-scale desalination can become a reality.

A number of critical conditions will have to be met before large-scale desalination can become a reality.

CHAPTER IV

ASSESSING THE ADVANTAGES AND DISADVANTAGES OF DESALINATION

Economics

Economics is one of the most important factors determining the ultimate success and extent of desalination. Desalination's financial costs, energy demands, environmental implications, reliability, and social consequences are intertwined with economic issues.

Cost Comparisons

Experience to date suggests that desalinated water cannot be delivered to users in California for anything less than the cost of production, which our research indicates is unlikely to fall below the range of \$3.00 to \$3.50 per thousand gallons (\$/kgal) (roughly \$0.79 to \$0.92 per cubic meter (\$/m^3)) for even large, efficient plants. Because the cost of production can be as high as \$8.35/kgal (\$2.21/m^3) (MPWMD 2005b), the cost of delivered water could be in the range of \$9 to \$10/kgal (\$2.37 to \$2.64/m^3). This wide range is caused by the factors discussed below and the large variation in the cost of water distribution among service areas. Even the low end of this range remains above the price of water typically paid by urban water users, and far above the price paid by farmers. For example, growers in the western United States may pay as little as \$0.20 to \$0.40/kgal (\$0.05 to \$0.10/m^3) for water. Even urban users rarely pay more than \$1.00 to \$3.00/kgal (\$0.26 to \$0.79/m^3).

Discussion of actual costs has been muddled and muddied.

To date, the discussion of actual costs has been muddled and muddied because estimates have been provided in a variety of units, years, and ways that are not readily comparable. For example, some authors report the cost of desalinated water delivered to customers (Table 1-2 in NAS 2004), while others present the cost of produced water prior to distribution (e.g., Semiat 2000, Chaudhry 2003, Karnal and Tusel 2004, Figure 1-6 in NAS 2004, Segal 2004, Wilf and Bartels 2005). These costs are not comparable. In some cases, it is not clear what values are being reported, as in a recent story in the Sydney Morning Herald.[11] The basis for these

[11] A cost of AUD\$1.44 per kilolitre is presented for seawater desalination, and compared with a cost of AUD\$1.35 per kilolitre for recycled wastewater. The description of the latter project includes separate distribution to customers, but it is not clear if the former number includes distribution (Sydney Morning Herald 2006).

cost estimates is often obscure, failing to clearly state such underlying variables as the year and type of estimate (actual operating experience, bid, or engineer's estimate), interest rate, amortization period, energy cost, salinity of the source water, environmental conditions, and presence or absence of subsidies. The effect of these variables on the cost of desalination is discussed in greater detail below.

Table 5 is an effort to standardize the reported costs of produced water from RO seawater desalination plants around the world. These values exclude distribution costs.[12] When necessary, we have converted the estimates to U.S. dollars per thousand gallons (US$/kgal), but we have not adjusted the apparent year of each reported cost for inflation since inflation varies from country to country. Even without adjustment to current-year dollars, it is apparent from the table that costs vary far more widely than can be explained by inflation.

Table 5
Summary of Reported First-Year Cost of Produced Water for RO Plants

1 May include conveyance costs from the desalination facility to the existing distribution mains.
2 May include some or all distribution costs.

Facility or Location	US$/kgal (first year)	US$/$m^3$ (first year)	Operational?	Year	Source
Ashkelon, Israel	2.03	0.54	Yes	2002	EDS (2004), Segal (2004), Zhou & Tol (2005)
Ashkelon, Israel	2.00	0.53	Yes	2003	NAS (2004)
Ashkelon, Israel	2.10	0.55	Yes	2004	Wilf & Bartels (2005)
Ashkelon, Israel	2.34	0.62	Yes	2005	Red Herring (2005), Semiat (2006)
Bahamas	5.60	1.48	Yes ?	2003	NAS (2004)
Carlsbad, CA (Poseidon)	2.90	0.77	No	2005	San Diego Daily Transcript (2005)
Dhekelia, Cyprus	4.14	1.09	Yes	1996	Segal (2004)
Dhekelia, Cyprus	5.40	1.43	Yes	2003	NAS (2004)
Eilat, Israel	2.80	0.74	Yes	1997 ?	Wilf & Bartels (2005)
Hamma, Algiers	3.19	0.84	No	2003	EDS (2004), Segal (2004)
Larnaca, Cyprus	2.84	0.75	Yes	2000	Segal (2004)
Larnaca, Cyprus	3.20	0.85	Yes	2003	NAS (2004)
Larnaca, Cyprus	3.23	0.85	Yes	2001 ?	Wilf & Bartels (2005)
Moss Landing, CA (Cal Am)	4.75[1]	1.28[1]	No	2005	MPWMD (2005b)
Moss Landing, CA (Poseidon)	3.63	0.96	No	2005	MPWMD (2005b)
Perth, Australia	3.49	0.92	No	2005	Water Technology (2006)
Singapore	1.75	0.46	Yes	2002	Segal (2004)
Singapore	1.70	0.45	Yes	2003	NAS (2004)
Sydney, Australia	4.21[2]	1.11[2]			
Tampa Bay, FL	Four bids from 1.75 to 2.18	0.46 to 0.58	No	1999	Semiat (2000)
Tampa Bay, FL	2.10	0.55	No	2003	Segal (2004)
Tampa Bay, FL	2.18	0.58	No	2003 ?	Wilf & Bartels (2005)
Tampa Bay, FL	2.49	0.66	No	?	Arroyo (2004)
Trinidad	2.77	0.73	Yes	?	Segal (2004)
Trinidad	2.80	0.74	Yes	2003	NAS (2004)

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[12] Thermal desalination costs are not in the table. Awerbuch (2004) reports that Abu Dhabi recently completed a 50 MGD MSF plant and claims the plant produces water at $2.65/kgal ($0.70/m^3). By contrast, the cost of thermal desalination in Kuwait is reportedly between $5.03 and $6.93/kgal ($1.33 and $1.83/$m^3$) (Al Fraij et al. 2004).

Subsidies

Hidden and visible subsidies affect the reported and actual costs. For example, all four bids for the Tampa Bay project were in the range of \$1.75 to \$2.18/kgal (\$0.46 to \$0.58/m^3) in 1999 (Semiat 2000). They were among the lowest costs ever proposed for a significant desalination project, in part because a Florida regulatory entity provided low-cost capital. Similarly, five projects in Southern California have qualified for a \$0.77/kgal (\$0.20/m^3) subsidy from the Metropolitan Water District of Southern California (MWD). The proposed Poseidon project in Carlsbad is reported to cost about \$2.90/kgal (\$0.77/m^3) without this subsidy (San Diego Daily Transcript 2005) and about \$2.15/kgal (\$0.57/m^3) with the subsidy. Since water customers in Southern California ultimately pay for the subsidy, the subsidized cost is potentially misleading.

Sometimes the subsidies are more difficult to quantify. The Ashkelon, Israel desalination plant that opened in August 2005 involved initial payments of about \$2.00/kgal (\$0.53/m^3). The land on which the plant is constructed, however, was provided at no cost by the Israeli government (Semiat 2006). As a result, it is misleading to compare the cost of Ashkelon with that of a new facility on the California coast, where land is expensive.

Energy Costs

Energy is the largest single variable cost for a desalination plant, varying from one-third to more than one-half the cost of produced water (Chaudhry 2003). Semiat (2000) reports that electrical energy use accounts for 44% of the typical water costs of an RO plant, with the remainder from other operation and maintenance expenses and fixed charges (amortization of capital) (Figure 14). Thermal plants use even more energy. Wangnick (2002) reports that in a very large thermal seawater desalination plant, energy costs account for nearly 60% of the typical cost of produced water (Figure 15). At these percentages, a 25% increase in energy cost would increase the cost of produced water by 11% and 15% for RO and thermal plants, respectively. Unless there is a way to greatly reduce the actual amount of energy used in desalination processes, the share of desalination costs attributable to energy will rise as energy prices rise.

> Energy is the largest single variable cost for a desalination plant, varying from one-third to more than one-half the cost of produced water.

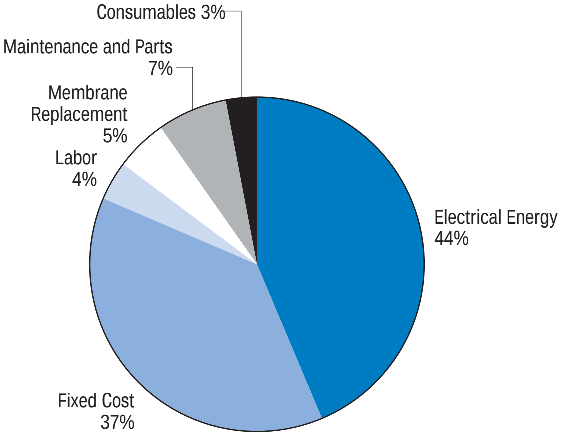
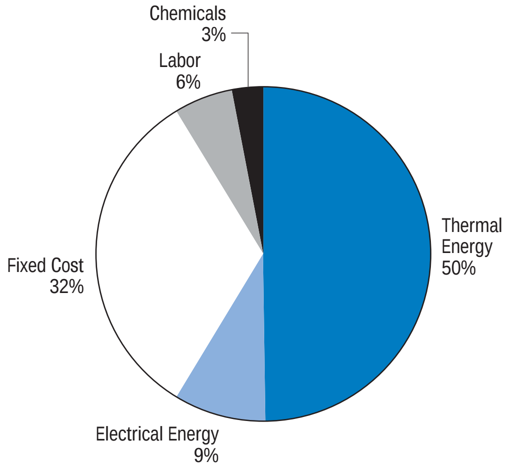


Figure 14
Typical Costs for a Reverse-Osmosis Desalination Plant

Source: USBR and SNL 2003

Figure 15
Typical Costs for a Very Large Seawater Thermal Desalination Plant

Source: Wangnick 2002



The data in Table 5 show a dependency on energy costs, although it is somewhat blurred by other costs. The facilities with the lowest reported costs – Ashkelon, Tampa Bay, and Singapore – either had or expected to have low energy costs in the first year. Velter (undated) and Segal (2004) report initial energy costs of around $0.04 per kilowatt-hour ($/kWh) for both Ashkelon and Tampa Bay. However, at least one higher-cost facility (Trinidad) also reported a low initial energy cost of $0.04/kWh, so energy does not explain all or even most of the variation in reported cost.

Efforts to reuse energy or minimize energy demands will help reduce overall costs.

Costs at the less expensive facilities are on the rise. Ashkelon, for example, was reportedly constructed on time and on budget; however, the cost of produced water has already increased by about 17%, a seeming reflection of higher-than-anticipated fuel costs at the new, on-site energy production facility (Jerusalem Post 2005). The Singapore contract contains an energy price escalator that does not take effect until the fourth year of operation. This means the cost shown in Table 5 reflects energy prices prior to the large energy price increase of recent years. The actual cost of produced water at Tampa Bay is still uncertain due to construction delays, design problems, and management changes (see Appendix C).[13] Recent energy price increases throughout the world may drive costs even higher.

Efforts to reuse energy or minimize energy demands will help reduce overall costs. While opportunities for reducing energy use certainly exist, there are ultimate limits beyond which energy-efficiency improvements cannot be made (NAS 2004). The theoretical minimum amount of energy required to remove salt from a liter of seawater using RO is around 2.8 kilojoules (or around 3 kilowatt-hours per thousand gallons (kWh/kgal) or 1 kilowatt-hour per cubic meter (kWh/m^3)).[14] Even the most efficient plants now operating use as little as 4 times the theoretical minimum; some use up to 25 times the theoretical minimum (Chaudhry 2003, Wilf and Bartels 2005, EDWR 2006, Water Technology 2006). If current best practice uses around 12 kWh/kgal (3 kWh/m^3), the minimum energy cost will be $1.20/kgal ($0.32/m^3) if electricity is $0.10/kWh. Utility-wide weighted average retail electricity prices in California in 2005 vary from $0.0931 to $0.1472/kWh.[15] Although electricity could be produced at lower cost if a dedicated power plant was developed along with the

[13] Appendix C is available online at www.pacinst.org/reports/desalination.

[14] Not accounting for the inefficiency of conversion from thermal to electrical energy, as required by some desalination systems.

[15] See www.energy.ca.gov/electricity/weighted_avg_retail_prices.html for data by utility since 1980.

desalination plant (as was done at Ashkelon, Israel), federal and state utility laws prohibit existing power plants co-located with other facilities from selling power at a preferential rate to those facilities (CDWR 2003, CPUC 2005).

Plant Size

Engineers often create "cost curves" that can be used to estimate costs for various types of facilities as a function of their size. For example, a typical curve might present the cost of produced water as a function of plant capacity in MGD. This curve would be based on other curves that address capital (e.g., intake structures) and operating (e.g., energy) expenditures per unit of capacity. All of the curves are based on a combination of actual costs, bids, and engineering estimates.

The U.S. Bureau of Reclamation (2003) compiled a comprehensive set of cost curves for desalination facilities.[16,17] The figures in Chapter 7 of that document show two important features of the current economics of seawater desalination: First, RO is considerably less costly than thermal processes throughout the range of sizes; second, there are economies of scale for all the technologies shown.[18] These economies are large as one moves from small (e.g., < 5.0 MGD) to medium-sized (e.g., 10-20 MGD) plants, but are not as important as one moves from medium to large (e.g., > 25 MGD) plants. A doubling of size from 2.5 to 5.0 MGD, for example, might reduce cost by 30%, while a doubling from 25 to 50 MGD might reduce cost by only 10 percent.

Stated in reverse, these curves imply that water produced by smaller plants is much more expensive than the costs presented in Table 5, all of which are for medium to large plants. Costs per unit of water produced in small plants can be 50% to 100% higher than in large plants. For example, a small proposed plant in southern San Luis Obispo County has an estimated cost of about $7.35/kgal ($1.94/m^3) (Hill 2006), and an even smaller proposed plant in Sand City, Monterey County has an estimated cost of $8.35/kgal ($2.21/m^3) (MPWMD 2005b).

Other Cost Factors

A number of other cost factors further complicate cost comparisons. For example, environmental damages or the costs of environmental protection are not well understood, especially in sensitive coastal settings like California and the Persian Gulf. The experience of developers, the amortization period, the interest rate, and regulatory issues also affect final costs.

For example, an often-overlooked cost factor is the period over which the facility investment is amortized. A 20-year rather than 30-year amortization period at 6% interest would increase the cost per unit of water produced by about 20% over that period. In addition, development and operating experience affects costs, although there is no clear trend and we were unable to quantify the impact of experience. In some cases, experience may lower cost or may increase the likelihood of winning a contract. A team that had previous experience in Eilat, Israel and Larnaca, Cyprus developed the Ashkelon facility in Israel (Semiat 2006), which is among

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[16] The assumptions behind the curve are described on page 156 of that document. The most critical, albeit unrealistic, assumptions for our purposes are that land cost is excluded, a groundwater well field is assumed for RO intake water, discharge pipe and environmental conditions are not specified, and energy cost is assumed to be $0.033 per kWh. These assumptions result in much lower costs than are likely to occur in any actual plant, especially in California, where land, energy, and discharge construction costs are relatively high. Nonetheless, the cost curves are useful for comparison.

[17] The U.S. Bureau of Reclamation also reports that a detailed computer program (WTCost©) for costing membrane systems has been developed by the Bureau, I. Moch & Associates, and Boulder Research Enterprises. It is available from imoch@aol.com. The American Water Works Association (1999) also provides cost curves for the capital portion of reverse osmosis and nanofiltration facilities but does not provide adequate information to estimate operations and maintenance costs.

[18] Electrodialysis, a membrane process, is not shown in the cost curves, presumably due to data limitations.

the plants with the lowest produced water cost. The Algiers facility is only somewhat more expensive than the plant in Trinidad, despite the upward trend in energy and capital costs described above. Ionics/GE is the developer of these facilities, and successful experience in Trinidad may have helped to win the contract in Algiers and temper the price increase.

By contrast, a lack of experience may also result in unrealistic, and ultimately unobtainable, cost estimates. The development team in Tampa Bay, Florida, for example, did not have much previous experience. Problems with design, construction, and management of that plant have led to delays of nearly six years, and much higher estimated costs.

Future Costs of Desalination

One should use extreme caution in evaluating different estimates and claims of future desalination costs. Predictions of a facility's costs have sometimes differed significantly from actual costs once plants were built. And as noted at the beginning of this chapter, cost estimates are based on so many factors that simplistic comparisons are often not meaningful.

> One should use extreme caution in evaluating different estimates and claims of future desalination costs.

Despite these difficulties, the long-term cost trend has been downward. Until recently, many authors claimed that the trend would continue, making desalination competitive with other options. Chaudhry (2003) shows a decline in California from $6.00/kgal ($1.59/m^3) in 1990 to about $2.40/kgal ($0.63/m^3) of produced water in 2002, and replicates a graph from the Southern Regional Water Authority in Texas that shows a decline from $6.00/kgal ($1.59/m^3) in 1980 to a projected cost of about $3.00/kgal ($0.80/m^3) in 2010. Zhou and Tol (2005) show that capital costs have been decreasing over time by performing regressions on a worldwide dataset compiled by Wangnick (2002). However, their article reads as if this trend applies to total costs (the sum of operation and maintenance costs and capital costs), when in fact the Wangnick data set is for capital costs only. Additional improvements, such as assembly of individual membrane components into large membrane modules, or packaging along with valves, pumps, etc. in so-called "package plants," may allow costs to fall somewhat further, though past trends are no indication of future ones.

The capital and operating costs for desalination have decreased historically in part because of declining real energy prices in the 1980s and 1990s, but even more so because of technological improvements, economies of scale associated with larger plants, and improved project management and experience. Improvements in RO technology have yielded the greatest progress in cost reduction. Salt rejection, a measure of the ability to remove salt from feed water, can be as high as 99.7% today, up from 98.5% a decade ago, while the output of product from a unit of membranes has risen from 16 to 22 thousand gallons per day (60 to 84 m^3/d) (Glueckstern 1999). Membrane manufacturers are now offering longer guarantees on membrane life, reflecting greater confidence in design and performance of the most sensitive technical component of the process. Other advances that could lead to costs savings are the development of inexpensive corrosion-resistant heat-transfer surfaces, using off-peak energy produced by base-load plants, co-generation of electricity and thermal energy, and co-locating desalination and energy plants.

Despite hopeful projections from desalination proponents, the long-term objectives of reducing costs 50% by 2020 (see, for example, USBR and SNL 2003) are daunting and may not be achievable via incremental improvements. Radical new technologies or breakthroughs in both materials and energy costs may be necessary to achieve this goal. While these are possible, they are certainly not easy and are unlikely to occur in the short term.

Indeed, a counter-trend in reported costs is emerging, and some experts think that membrane costs are unlikely to fall much further in the near term (AWWA 2006). All of the newer cost estimates are notably higher than similar plants bid just a few years ago. The director general of the majority owner of the consortium operating the Ashkelon plant stated last year that more recent tenders for plants in Israel and elsewhere were in the range of \$3.10 to \$3.90/kgal (\$0.82 to \$1.03/m^3) due to increases in the cost of raw materials (e.g., steel) and energy and rising interest rates (Jerusalem Post 2005). This comment is consistent with numbers reported elsewhere. Plants under construction in Hamma, Algiers and Perth, Australia, for example, were bid at \$3.19/kgal (\$0.84/m^3) and \$3.49/kgal (\$0.92/m^3), respectively (EDS 2004, Segal 2004, Water Technology 2006). Notably, the Hamma plant is similar in size and other features (e.g., water temperature and salinity) to the Ashkelon plant, but is priced about 35% higher. Cost estimates at Moss Landing, California and Sydney, Australia are even higher, exceeding \$4.00/kgal (\$1.06/m^3) in two of three reported estimates. Higher capital and energy costs appear to have created an upward trend in overall desalination cost in recent years (Water Desalination Report 2006a and 2006b).

Ultimately, no one can predict the actual cost of seawater desalination in coming years. Nonetheless, unless energy prices decline substantially, it seems unlikely that the cost of produced water in the next few years in California will fall below the range of \$3.00 to \$3.50/kgal (roughly \$0.79 to \$0.92/m^3) for even the most efficient larger plants, and costs will be considerably higher for small plants. Environmental restrictions, land costs, and other factors unique to California (e.g., cold ocean water is more expensive to desalinate than warmer ocean water, such as in the Mediterranean) may increase costs further.

> Ultimately, no one can predict the actual cost of seawater desalination in coming years.

Water Supply Diversity and Reliability

Urban water users expect a reliable supply of high-quality water and are typically willing to pay premium prices to obtain that reliability. Water users have different requirements for reliability, and they have different approaches for judging the value of that reliability depending on a number of factors, including use, availability of alternatives, implications of losing supply, and production costs.

Proponents of desalination argue that one of the important benefits of desalination is the supply reliability provided by diversifying sources, especially in arid and semi-arid climates where weather variability is high (i.e., Southern California). The production of desalinated water is largely independent of weather, and instead depends on ensuring the continued operation of the desalination infrastructure. There is also a value to new supply under local control and to increased diversity of supply as a way to increase resilience to natural disasters or other threats to water systems. The related issues of climate change and of local control are discussed elsewhere in this report.

In a region like California, the reliability value of desalination appears to be especially high. Water allocations, rights, and use are often in flux, or even dispute. Renewable natural water supplies are highly variable and increasingly overallocated or overused. Population is growing rapidly. Ecosystems are increasingly being seen as deserving of water that was once taken for human uses. Increased demands on such limited supplies affect reliability, especially during dry periods. And regional controversies threaten continued large-scale diversion of water from the north to the south, from the Colorado River basin, and from the mountains to the coastal regions.

Defining and Measuring Water-Supply Reliability

Various definitions of water-supply reliability exist, but the most general characteristic is consistent availability on demand. Water utilities invest substantial amounts of money to reduce the risk of supply interruptions because they understand that the cost to their customers of supply disruptions is often far greater than the cost of improved system reliability. For example, the East Bay Municipal Utilities District (EBMUD), which serves 1.2 million people on the east side of San Francisco Bay, recently invested over $200 million in a Seismic Improvement Program to strengthen the ability of their reservoirs, treatment plants, and distribution systems to continue to function and provide post-earthquake firefighting capability after a large earthquake on the local Hayward Fault. EBMUD estimated that an earthquake that damaged the water system would cause nearly $2 billion in water-related losses (EBMUD 2005). This investment had no effect on the quality of current supply but had the sole effect of improving reliability in the event of an earthquake. The cost of this program is explicitly, and separately, reflected in customer rates.

In addition to earthquakes, there are a number of threats to water-supply reliability. These include, but are not limited to, climate change, changes in runoff patterns and groundwater recharge as more impermeable surfaces are created by land development, changes in water quality or environmental regulations, variation in important cost factors (e.g., interest rates, labor, energy), legal issues related to water rights or contracts for water deliveries, and cultural and political factors. In addition, new threats – or simply threats that already existed but were not recognized – may also arise.

A number of options are available to improve reliability. Infrastructure is often built with local reliability concerns in mind, and water utilities often invest in multiple sources of supply with different levels and kinds of risks. Similarly, dams and reservoirs are used to reduce the risk of supply interruption due to drought.

There is no widely accepted method for measuring water-supply reliability. The simplest approach is to measure the risk of projected supply falling below projected demand, on average, for a specified duration (e.g., a year). For example, a system with a reliability level of 95% implies that supply will meet or exceed demand 19 times (e.g., years) out of 20. This approach has the advantage of being very simple. Like most simple approaches, however, it has drawbacks; most notably, it does not measure the severity of the water shortfalls. One can imagine a system with reliability of 90% that is more desirable than another system with reliability of 95% because the shortfalls in water supply in the first system are very small while the less frequent shortfalls in the second system are very large.

Nonetheless, for the discussion below we use this simple definition because it allows a clear discussion of an important issue. The reliability percentages presented in the numeric illustration can be thought of as a summary statistic for all of the uncertain issues mentioned above, although in practice many of these factors are difficult to quantify accurately.

The Value of Reliability

Proponents of seawater desalination correctly point out that more reliable water is worth more. They then argue that the higher reliability justifies its higher cost. How can one evaluate this important claim? Economists typically address this question by assessing customer willingness to pay (WtP) for a slightly reduced chance of water shortages. For example, suppose the chance of a water shortage that would require rationing is 1 in 40 in any given year, but an investment in a new reservoir can reduce that chance to 1 in 41. If additional water isn't needed (except in severe drought), then customer WtP for the reservoir is a measure of the value customers place on increased reliability. Numerous economic studies have estimated WtP for avoiding drought-related or other restrictions on water uses, ranging from \$32 to \$421 (2003 dollars) per household per year (Carson and Mitchell 1987, Griffin and Mjelde 2000). When the estimated quantity of water use forgone due to a drought restriction is multiplied by the probability (frequency) of the drought scenario investigated, these annual household WtP estimates imply a reliability value to residential customers as high as about \$12.00/kgal (\$3.20/m^3) (Raucher et al. 2005). These numbers reflect the value of a little more water when a severe shortage exists, not its value under average circumstances.

The Pacific Institute developed a method for adjusting estimated unit costs of water-supply options.

Unfortunately, this approach alone does not answer our question: How does one evaluate the claim that water reliability justifies the cost of a desalination facility? Customers do not need to know how reliability will increase in order to value it. Customers are not saying anything about the relative value of different options for increasing reliability. Customers are only saying that greater reliability – regardless of source – has a value.

Consequently, the Pacific Institute developed a method for adjusting estimated unit costs of water-supply options (including conservation and end-use efficiency). The method borrows and adapts tools from financial portfolio theory.[19] It leads to constant-reliability-benefit unit costs that provide a more fair comparison between supply options with different uncertainty characteristics.

The method involves a two-step process. In the first step, water managers define the level of reliability benefit they want to maintain or achieve. For example, they might want to ensure that enough water is available to

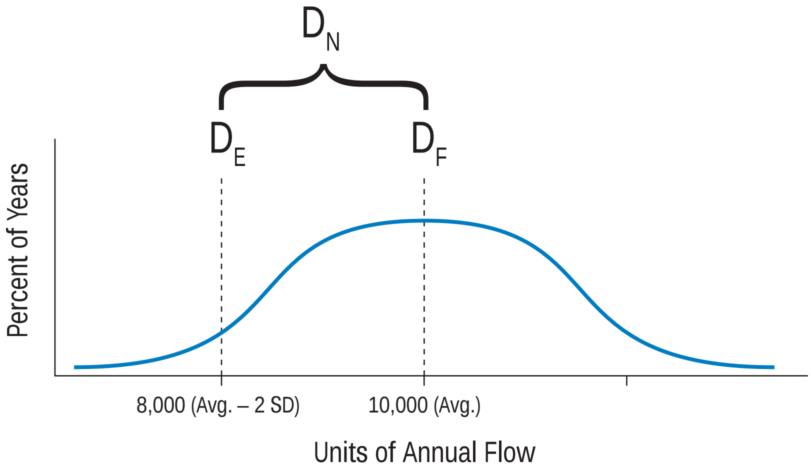
[19] This work was supported in part by the U.S. Bureau of Reclamation. See Wolff and Kasower (2006).

meet demand in 39 out of 40 years, on average. In the second step, they create an "apples to apples" comparison of options by adjusting average unit costs to get constant-reliability-benefit unit costs. The following example briefly illustrates the method. The relevant mathematics are presented in Appendix D.[20]

Illustration of Constant-Reliability-Benefit Unit Costs

Suppose a community is served by a run-of-the-river water supply. Figure 16 shows water available from the river for human extractive purposes each year as having a normal distribution.[21] The average flow is the most common level of flow.[22] Our example assumes the extractable yield in average years is 10,000 acre-feet (AF), and the standard deviation of annual flow is 1,000 AF. Low and high flows are increasingly rare as they get further from the average. The relative flatness of the bell is described by the standard deviation of the normal distribution. The larger the standard deviation as a percentage of the mean (this ratio is called the coefficient of variance), the flatter the bell, and the more variable the annual flow available for human extractive purposes.

Figure 16
Reliability in a Run-of-the-River Water-Supply System



The average flow and the flow two standard deviations below the average are marked in Figure 16. A property of the normal distribution is that in 2.5% of the years, flow will be less than the lower of these two marks. In our illustration, the flow two standard deviations below the mean is 8,000 AFY. Flow available for human use will be lower than the lower mark (8,000 AFY) in only 1 out of every 40 years over a long period of time.

Now let us consider demand. The demand numbers in our illustration are conveniently chosen to match some of the numbers in the description of supply, above. Any other numbers could be assumed, but they would make the illustration harder to follow. Assume that current drought-year demand (labeled D_E in Figure 16) is at the lower tick mark.[23] Then the community served by this water system will experience a water shortage only 1 year out of 40. As defined above, this is a reliability level of 97.5 percent.

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20 Appendix D is available online at www.pacinst.org/reports/desalination.

21 The normal distribution is used for convenience. Hydrologic phenomena are usually better described by other distributions, e.g., log-normal, Pearson Type III.

22 We use AF as the unit of water volume here, but any units are possible, of course.

23 We define drought-year demand as the demand that would exist when flow is at a point chosen by the planner on the horizontal axis of Figure 16 – in this case, demand when flow is at the lower tick mark. Note that drought-year demand will often be higher than average year demand because outdoor water use will increase when rainfall is below average or temperature is above average.

Suppose drought-year demand is projected to grow by 2,000 AF over the next decade.[24] As drought-year demand grows, reliability will decrease in the sense that the likelihood of a water shortage will increase from 1 in 40 to 1 in 2. That is, the reliability level would fall from 97.5% to 50%, because enough water would be extractable in only half the years. One of the standard jobs of water managers is to ensure that this doesn't happen. But how they satisfy new demand may affect reliability.

Suppose they want to maintain the current level of reliability at 97.5 percent. This is the first step in the planning process – choose a design reliability level and the benefit level associated with it. This is held constant in the analysis that follows.

The amount of physical water (or water-use efficiency) required to satisfy growth in drought-year demand is the difference between future drought-year demand (D_F) and existing drought-year demand (D_E). This has been labeled D_N in Figure 16, and in our example is 2,000 AF. If a supply option were to provide exactly this amount in every year, the planner should procure D_N of new supply. Water from advanced treatment processes (e.g., desalinated seawater or recycled wastewater) has this characteristic if treatment facilities are designed with enough redundancy to prevent downtime other than for regularly scheduled maintenance.[25]

But if the water-supply option is variable from year to year, the planner must procure enough of it to have D_N available 39 out of 40 years, or reliability will decline. For example, when the chosen option is a surface-water source, the amount available in an average year must be greater than D_N in order to ensure D_N is available in a dry year.

The amount of water supply greater than D_N that has to be purchased from the new water source depends on two factors: the new source's standard deviation of annual yield and the correlation of annual yield with the existing supply. The higher the new source's standard deviation of annual yield, the more water that needs to be procured from the new source to ensure adequate water in a low-flow year. The lower the correlations of annual yield between the new source and the existing source, the less of the new source will be required, on average, to ensure D_N is available in a dry year.

What this means is that comparing unit costs for options based on the average amount of water each option will deliver leaves out an important piece of the economic picture. For illustration purposes, suppose that advanced treatment of impaired water, a new surface-water supply, and outdoor conservation have an average unit cost of $600 per acre-foot ($/AF). Ignoring reliability impacts, there is no financial difference among these sources.

But suppose further that the new surface-water supply has a similar pattern of wet and dry years to the old surface-water supply but is more variable. Then ensuring the 2,000 AF of new supply that will be needed in a drought year requires that the new source be sized to deliver more than 2,000 AF of water each average year, just as the old source was capable of providing 10,000 AF on average but only 8,000 AF with the desired level of reliability. If the new surface water source has a coefficient of variance (the standard deviation over the mean) of 20%, the

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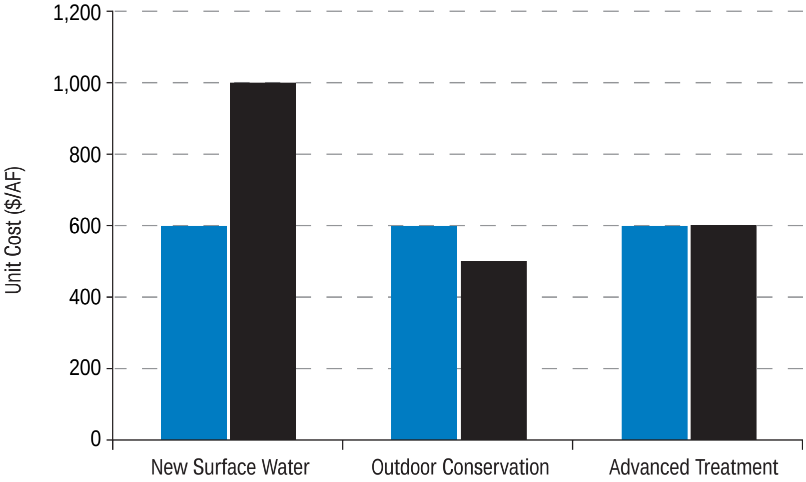
[24] A water demand projection is based on many factors, such as projected growth in population and employment in the service area.

[25] Some indoor water conservation measures may also have this characteristic of supplying exactly D_N every year if they are designed carefully.

water planner will need to procure 3,333 AF in an average year to ensure 2,000 AF in the constant-reliability-benefit design year (3,333 - (2 x 0.2 x 3,333) = 2,000). This in turn implies that each unit of water during drought will cost $1,000/AF on a constant-reliability-benefit basis ($600/(1 - 2 x 0.2) = $1,000).[26] See Figure 17 for an illustration of the average and constant-reliability benefit of surface water in this example.

Figure 17
Illustration of Average and Constant-Reliability-Benefit (Drought Year) Unit Costs

🟦 – Average Unit Cost
■ – Constant-Reliability-Benefit (Drought Year) Unit Costs



If an outdoor water-conservation measure were to save more water during dry weather,[27] its constant-reliability-benefit unit cost would be less than the assumed $600/AF. If it were perfectly counter-correlated with the current surface-water source, and had a coefficient of variation of 10%, its constant-reliability-benefit unit cost would be $500/AF = ($600/(1+2 x 0.1)). That is, ensuring 2,000 AF of water in a drought year would require outdoor conservation measures sized to deliver only 1,667 AF in an average year. The counter-correlation implies that during a drought where flows in the current supply source are two standard deviations below its mean, outdoor conservation would save two standard deviations above its mean, which equals 2.0 when the mean is 1.667 and the standard deviation is 0.1667 (10% of the mean).

Figure 17 summarizes the average unit costs and constant-reliability-benefit (drought year) unit costs under these assumptions. Accounting for variance and correlation among water sources – as is done for securities when managing a portfolio of financial assets – is clearly important. Water-supply planners who do not consider these factors might think options are similar in cost when they are in fact quite different once reliability benefits of the options are equalized. Worse yet, an apparently inexpensive source might turn out to be very expensive on a constant-reliability-benefit basis, or an apparently expensive source might turn out to have the lowest cost per acre-feet when reliability is considered.

Local Control Over Supplies

In many regions of the world, water resources are increasingly transferred from one place to another, especially from rural to urban communities,

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[26] Stated differently, the utility could pay 67% more per average unit of water from the advanced treatment facility (1,000/600 = 1.67) compared to each average unit in the new surface water alternative – and provide the same economic benefit at the same cost to customers. Note that the premium is not in total, but per unit. The smaller advanced treatment facility is just as good as the larger surface water facility at reliably providing 2,000 AF, so a per unit premium is justified.

[27] For example, laser leveling, drip or micro-spray irrigation, scheduling improvements, evapotranspiration (ET) controllers, and adjustments in sprinkler heads to improve distribution uniformity reduce the percent of applied water that percolates or evaporates. Since applied water must go up during drought, these measures will save more water during drought than during average or wet weather. Auto-rain shut-off devices, by contrast, save more water when it rains than when it is dry.

from water-rich to water-poor regions, and toward economic interests willing and able to pay for water. These transfers raise two separate issues of local control of resources.

The first concern is the worry of rural – often agricultural – areas that distant urban or economic powers will steal local resources. The classic example is the efforts of the City of Los Angeles in the early part of the 20th century to obtain water from farming communities hundreds of miles away, which has colored California water politics ever since (Reisner 1986). Las Vegas is currently contemplating major investments in water systems capable of taking groundwater from distant towns and farms in order to diversify its water-supply options and reduce dependence on limited supplies from the Colorado River – a move strongly opposed by some of those rural communities. Other examples can be found around the world, including in India and China. The second concern is that urban centers will become dependent on distant resources and increase their vulnerability to supply disruptions over which they have limited control.

Desalination may offer a solution to both of these political problems by providing a reliable, high-quality source of water under direct local control, reducing the need for imported water at the same time that it reduces the vulnerability to outside disruptions. To the extent that local control measurably reduces the probability of supply disruption, local control would improve reliability and can be considered as a factor in the method for estimating constant-reliability-benefit unit costs presented above. That is, the standard deviation of yield from a water source is not purely hydrologic but can also include evaluation of political, environmental, legal, and other risk factors. Ironically, this may set up a situation where rural agricultural interests support and even promote urban desalination that they will not have to pay for, in order to reduce political pressure to transfer cheaper water from the agricultural sector to the cities.

Water Quality

One of the advantages of desalination is the potential to produce high-quality water. Desalination facilities are designed to remove numerous impurities and produce water that may be a large improvement over existing water sources. However, the desalination process can also run the risk of introducing harmful chemicals and metals into the water it produces or leaching them out of the distribution system on the way to users.

Quality Advantages

Customers are often willing to pay more for better-quality water, especially when hardness in the source water creates water softening expenses for the customer or when taste is noticeably affected by high TDS. However, the willingness of customers to pay for higher-quality water is not directly relevant to the value of higher-quality water from desalination, just as willingness to pay for higher reliability was not directly relevant to the reliability value of desalination. Planners need to compare supply options (including conservation) on a "constant-water-quality" basis.[28] This involves choosing a quality standard based on community

[28] Water conservation may help, harm, or be neutral with respect to blended water quality. Unlike physical water supplies, conserved water does not have a water quality "of its own." Conserved water will help to improve blended water quality when conservation allows less water from a poor quality source to be used, but in contrast it will worsen blended water quality if it leads to less water from a high-quality source.

standards and willingness to pay for quality. It also involves finding the lowest-cost option or combination of options for attaining that standard. Again, a simplified example may be useful. Assume the following:

- A community needs 100 AFY of water that satisfies the secondary drinking water standard of 500 ppm of TDS 99.5% of the time. The 99.5% requirement can be thought of as an internal water-quality standard.
- The purchased quantities will be delivered exactly every year. That is, water quantity reliability is not a problem.
- There are three sources of water available. The planner can purchase any two of them in any quantities desired that add up to 100 AFY.
- Source One has the lowest cost but unfortunately has average annual TDS content of 650 ppm. Its annual TDS is normally distributed with a standard deviation of 65 ppm (10% of its average). Colorado River water delivered to Southern California has approximately these characteristics (Redlinger 2005).[29] Water from Source One costs $100/AF.
- Source Two is a higher-cost surface water and has normally distributed TDS with a mean of 350 ppm and standard deviation of 70 ppm (20% of its average). Water from Source Two costs $500/AF.
- Source Three is from seawater desalination and also has normally distributed TDS but with a mean of 50 and a standard deviation of 5 ppm (10% of its average). Water from Source Three costs $800/AF.
- The water quality of the three sources is completely uncorrelated.

Under these assumptions, there are two possible lowest-cost portfolios with TDS of 500 ppm or lower 99.5% of the time. Both involve using as much of the low cost Source One as possible. Source Two is less expensive than Source Three but also has higher TDS. So it is possible that paying for the higher-quality Source Three will allow more of the lowest-quality Source One to be used, reducing the average cost of suitable water. Table 6 shows the mix of sources and the unit cost of produced water with TDS 500 at least 99.5% of the time. The relevant math is presented in Appendix D.

Table 6
Portfolios Providing 500 ppm TDS 99.5% of Years

Portfolio	Source One	Source Two or Three	Average Unit Cost
Sources One and Two	5 AFY	95 AFY of Source Two	$484/AF
Sources One and Three	51 AFY	49 AFY of Source Three	$443/AF

Table 6 shows that only 5% from Source One may be used when Source Two is the only other water available for blending, under the assumptions made. In contrast, 51% of blended water can come from Source One when Source Three is available for blending. Although Source Three is 60% more expensive per unit than Source Two ($800/$500 = 1.6), its high quality and low variance in quality make it more than worth the

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[29] Water-quality data for the Colorado River is provided in Appendix E, available online at www.pacinst.org/reports/desalination.

premium. In fact, in this example, one could pay about 75% more for it (i.e., about \$2.69/kgal or \$0.71/m^3) and have an average unit cost for blended water that is equal to the average unit cost of water obtained by blending Sources One and Two.

As this example demonstrates, when there is no water-quality problem or standard that must be met, there is no need for the water-quality benefits of desalination and, hence, no appropriate economic premium. When there is such a standard or need, and only a single high-quality, high-cost water source, then the water agency must use the minimum of the higher-quality source required to meet the standard. When an agency has multiple water sources available, the appropriate mix of sources depends on the relative quality and costs, as described in the method and example above.

Health Concerns

While the quality of desalinated water is typically very high, a number of potential health concerns have been identified. End-use water quality of desalinated water is a function of source water quality, treatment processes, and distribution of the product water. Harmful contaminants can be introduced at each of these stages.

While the quality of desalinated water is typically very high, a number of potential health concerns have been identified.

The water fed into a desalination system may introduce biological and chemical contaminants that are hazardous to human health. Biological contaminants include viruses, protozoa, and bacteria. Chemical contaminants include regulated and unregulated chemicals, xenobiotics (including endocrine disruptors, pharmaceuticals, and personal care products), and algal toxins (MCHD 2003). These contaminants are of particular concern if they are not removed during subsequent treatment processes.

Boron, for example, is found in very low levels in average U.S. drinking water supplies (a survey of 100 U.S. drinking water supplies showed a median boron concentration of 0.03 milligrams per liter (mg/l)) (Mastromatteo and Sullivan 1994), but much higher levels are normally found in seawater (typical concentrations are between 4 and 7 mg/l). Boron is known to cause reproductive and developmental toxicity in animals and irritation of the digestive tract. It also accumulates in plants, raising concern about high boron levels in water used for irrigation or landscaping (ATSDR 1995). RO membranes can remove between 50% and 70% of this element but pass the rest, where it is then concentrated in the product water. Concern has been expressed that boron may be found in desalinated water at levels greater than the World Health Organization's provisional guideline of 0.5 mg/l and the California Action Level of 1 mg/l (WHO 2003, CDHS 2005). Some membranes and processes are being developed to improve boron removal (Toray 2005). For example, the Long Beach Water Department adjusts the sodium hydroxide levels between stages of the two-stage NF process, which changes the chemistry of boron (by changing the size and charge) and improves boron removal (Cheng 2006). Other methods for addressing boron include blending the desalinated product water with water containing low boron levels, but all of these methods will entail greater expense. Arsenic, small petroleum molecules, and some microorganisms unique to seawater are also capable of passing though RO membranes and reaching the product water (Cotruvo 2005).

Treatment may also introduce new contaminants or remove essential minerals. For example, combining disinfection agents, such as chlorine and chloramine, with waters containing high bromide levels can produce brominated organic byproducts (Weinberg et al. 2002), which "have greater carcinogenic or toxic potential than many chlorinated byproducts" (Cotruvo 2005). In addition, essential minerals, such as magnesium and calcium, are often stripped from the product water. When ingested, water with a low mineral content can leach essential nutrients from the human body. Similar leaching can occur within a distribution system, introducing contaminants into the product water (as noted below). Post-treatment can replace some of these minerals, and the World Health Organization suggests that remineralization with calcium and magnesium can have positive health effects, such as is the case with fluoridation (WHO 2004).

Assuring public health and environmental protection requires monitoring and appropriate regulation of all desalination facilities.

Assuring public health and environmental protection requires monitoring and appropriate regulation of all desalination facilities. Cotruvo (2005) notes, "monitoring of source water, process performance, finished water, and distributed water must be rigorous to assure consistent quality at the customer's tap. Moreover, additional water quality or process guidelines specific to desalination are needed to assure water quality, safety, and environmental protection." Regulatory oversight by public utility commissions or health departments or new legislation can provide this much-needed protection.

The California legislature recently sought to address some of the potential health implications of desalination. California Assembly Bill 1168 would have required the Department of Health Services "to identify potential contaminants and sources of contamination and ensure the safety and effectiveness of treatment processes" before issuing a water system operating permit for groundwater or ocean water desalination projects. This bill passed the Assembly and Senate but was vetoed by the governor in October 2005.

Water Distribution System

Reverse osmosis and distillation alter the chemical content of the product water. The RO process lowers both the calcium and carbonate concentrations, which produces acidic product water that can corrode the distribution system. When this happens, iron and other toxic metals, such as copper, lead, cadmium, zinc, and nickel, can be leached from the distribution system.

System corrosion has an economic impact. "The losses resulting from the reduction of the useful life of the system, from repair and maintenance, and from wasted water and chemicals are but some sides of the economic aspects of corrosion in the water distribution system. These costs are borne directly or indirectly by the municipality" (Shams El Din 1986).

To minimize adverse effects on the distribution system, desalinated water must undergo post-treatment. The risk of corrosion is reduced by reintroducing calcium carbonate in the form of lime or limestone, which neutralizes acidity and forms a non-porous film along the distribution system. Aeration increases the oxygen content of the water and raises the pH.

Chlorination may then be required to disinfect the water and control biological growth in the distribution system.

While balancing the chemical content of the product water is possible, experience in the Middle East suggests that careful monitoring and proper management are required. In a desalination plant in Abu Dhabi, for example, Shams El Din (1986) notes that "some difficulty is experienced in producing water with uniform characteristics, and daily analysis shows a range of variation in the composition of the product," leading to product water that is extremely aggressive in attacking pipes. The California Department of Water Resources (CDWR) recommends that desalination proposals "[e]valuate the effects of desalinated water on existing water supply distribution systems" (CDWR 2003). This indicates that the overall effects on California water distribution systems are not yet known. Careful monitoring and management are necessary to ensure that the distribution system is not adversely affected. Problems of monitoring and reporting may be further complicated when a private company operates the desalination plant and distributes it to a public water-supply system.

Energy Intensity

As discussed above, desalinated seawater has reliability and water-quality advantages that must be weighed against its higher cost and potential environmental impacts. However, another potential disadvantage of seawater desalination should be accounted for when considering whether or how to implement seawater desalination projects. Because desalinated seawater is an energy-intensive water source (Figure 18), relying on it creates or increases the water supplier's exposure to energy price variability and energy price increases over time.

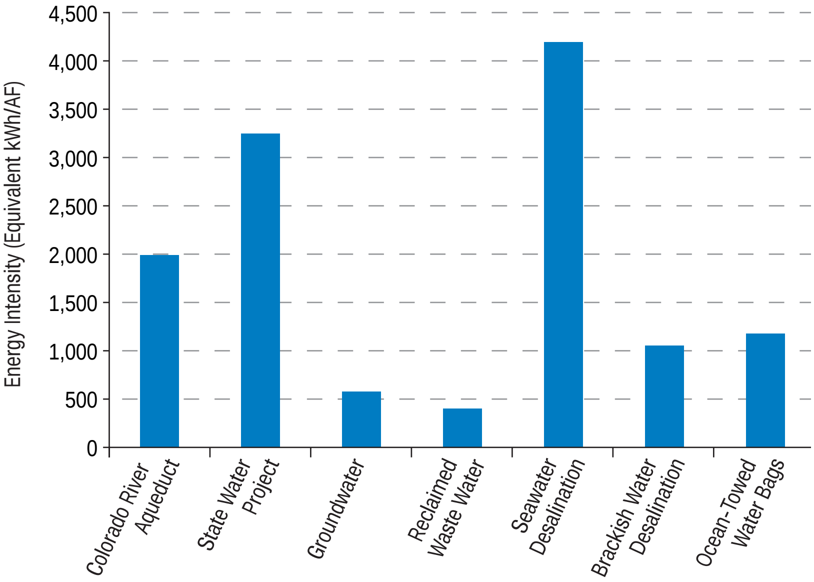

Figure 18
Energy Intensity of Water Sources in San Diego County

Source: Wolff et al. 2004

Figure 18 shows that even in San Diego – the farthest point of delivery in the State Water Project and Colorado River Aqueduct systems – seawater desalination requires more energy than any other source of supply.[30] Because energy embedded in imported water supplies is at a maximum in San Diego, seawater desalination is even more energy-intensive in relation to other options elsewhere in California.

Exposure to Energy Price Variability

Water suppliers are concerned not just about variability in water yield from various sources, but in the variability of important production costs. Variability in cost can force the utility to raise rates to cover unexpected costs. This can be especially embarrassing in response to drought, when revenues are already down due to reduced water sales. Since desalination plants will likely be operated at peak output during drought, unexpectedly high costs could amplify revenue instability already experienced by water suppliers.

We investigated this potential problem by examining historical energy prices and rainfall in California.[31] Our findings are presented in Table 7. The raw data are presented in Appendix F.[32]

Table 7
Portfolios Providing 500 ppm TDS 99.5% of Years

Data Series	Average	Standard Deviation	Coefficient of Variance	Correlation w/ Precipitation
Mean Statewide Precipitation	24.1 inches	8.5 inches	35.2%	N/A
LA Metropolitan Natural Gas Price Index	83.3	14.8	17.7%	0.08
LA Metropolitan Electricity Price Index	102.9	11.8	11.5%	-0.27
SF Metropolitan Natural Gas Price Index	79.3	18.3	23.1%	-0.04
SF Metropolitan Electricity Price Index	107	15.9	14.8%	-0.32

Notes:
1) Data are annual averages from 1971 to 2002.
2) Price Index Base Year is 2002-2004 = 100.

The coefficients of variance in the table reveal – at least on a preliminary basis – that energy price volatility in California over three decades is significant, not just a recent event. For example, a coefficient of variance of 14.8% implies that energy prices will be at least 14.8% higher or lower than the average about one year out of three.[33] Those who implement desalination projects either will need to be prepared for costs that may vary significantly from year to year (e.g., if their water purchase contract from a private desalination plant developer has an energy cost pass-through clause) or will need to pay an energy or project developer to hedge against this uncertainty for them (e.g., through a long-term energy purchase contract or through on-site energy production from sources with less variability such as solar electric). In any case, energy price uncertainty creates costs that are ultimately paid by water users but which might be neglected in an estimate of project cost.

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[30] The units in Figure 18 are in equivalent kilowatt-hours per acre-foot. This is the sum of actual kilowatt-hours of electricity used to pump water plus the amount of electricity that would be produced by a central power plant using other types of fuel to transport water (e.g., direct drive diesel pumps).

[31] Time-series data for statewide precipitation by water year were available from the California Department of Water Resources (CDWR 2006, Roos 2006). Time-series data for retail electricity and piped gas price levels in the San Francisco and Los Angeles metropolitan areas were available from the U.S. Bureau of Labor Statistics (BLS 2006). These time series overlapped from 1972 through 2002. Precipitation data were available by September through August “water years.” That is, precipitation data labeled 1971 represents four months of 1971 and eight months of 1972. We adjusted the retail energy price level data to remove the upward trend of inflation and calculated the mean, standard deviation, and coefficient of variance (standard deviation over the mean) for each series. We also calculated the coefficient of correlation between energy and precipitation data.

[32] Appendix F is available online at www.pacinst.org/reports/desalination.

[33] The range from one standard deviation below to one standard deviation above the mean of a normal distribution includes about 2/3 of the occurrences of the random variable (in this case, gas prices will fall within the average price +/-14.8% two out of three years). This further implies the variable (gas prices) will be greater than one standard deviation above or below the mean about 1/3 of the time.

What this means is that in regions like California, building a desalination plant may decrease a water utility's exposure to reliability risks, such as from droughts, at the added expense of an increase in exposure to energy price risk. As with any risk, there are hedging options available, but this may increase the overall cost. Very few of the current California desalination proposals have adequately or publicly addressed these factors.

> In California, building a desalination plant may decrease a water utility's exposure to reliability risks at the added expense of an increase in exposure to energy price risk.

The negative correlation coefficients between electricity and precipitation shown in the table suggest that electricity costs more, hence desalinated water will cost more, when less precipitation occurs.[34] This makes logical sense given that inexpensive hydropower is an important source of electricity in California. By contrast, there is next to no correlation between natural gas prices and precipitation, which suggests that at least historically, shortages of hydroelectricity were either compensated for with power sources other than natural gas (e.g., coal from the western area grid), or that natural gas prices for power plants were isolated from variation in retail natural gas prices via long-term contracts.

These negative correlations imply another concern for desalination project developers. If the desalination plant were operated more in dry years than in wet years, the average cost per unit of water produced (e.g., $/kgal) will be higher than the estimated cost based on average electric price. This is because more units of electricity will be purchased at prices higher than average (during drought) than at prices lower than average (during wet years). One must be careful to compare the expected profile of water production against the projected profile of energy cost in order to get an accurate estimate of cost. Failing to do so – unless the plant will produce the same amount of water regardless of surface water availability – could understate costs in California because, unlike many other parts of the world, California's electricity prices are more closely correlated with the availability of surface water.

Exposure to Energy Price Increases

The energy intensity of water from seawater desalination plants will likely increase the relative cost of water from the plant over time. If energy prices rise over time, in nominal dollars, then the cost of produced water from desalination will likely increase more than the cost of produced water from less energy-intensive water sources. This is because capital amortization payments do not rise steadily over time. If a fixed-rate loan is involved, they will be constant over time. If a variable-rate loan is involved, they will rise when interest rates rise and fall when interest rates fall. But over several decades or more, there will be no upward trend in payments for capital.

By contrast, energy prices are rising over time. Even if that increase is less than the rate of inflation, they are rising. For example, consider a situation where energy is the only variable cost and all other costs are amortized at a fixed interest rate. Suppose energy costs rise at 1% per year. A desalination facility with 50% variable and 50% fixed costs will have higher costs over time than a surface-water facility with 33% variable costs and 67% fixed costs. The relative cost of desalination will be rising, and the water supplier will have underestimated the cost of desalination relative to other options if they have compared costs for the options

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[34] A correlation value of 1 equals a perfectly positive correlation. A correlation value of -1 equals a perfectly negative correlation. A correlation value of 0 equals no measurable correlation. In our measurements, the correlation is weak. It might not be statistically significant if a rigorous analysis of energy prices versus precipitation, or more generally, water availability, were performed. Such analysis is beyond the scope of this report. The analysis done in this report is intended to make the questions and issues surrounding energy use and desalination projects concrete, but the particular numbers provided need to be developed more rigorously and specifically for individual projects.

without accounting for energy price increases.

Figures 19 and 20 show the cost time trends for the relative cost of potable water from a typical ocean desalination, wastewater recycling, and gravity surface water source, in Northern and Southern California, using the electricity price time series described above, from 1971 through 2005. By relative cost, we mean that the cost of each option has been normalized to "1" in the first year of the time series. This does not mean that the three options have equal costs in that year. The normalization simply makes the comparison of options over time more convenient. The figures show that the upward trend in cost, and the year-to-year volatility in cost, varies significantly by source as a function of energy intensity. Potable water produced by seawater desalination rises in cost more rapidly than other sources, and has greater year-to-year variability, because less of its cost is due to fixed capital expenses.

Figure 19
Relative Cost of Potable Water from a Typical Ocean Desalination, Wastewater Recycling, and Gravity Surface Water Source in the Los Angeles Metropolitan Area

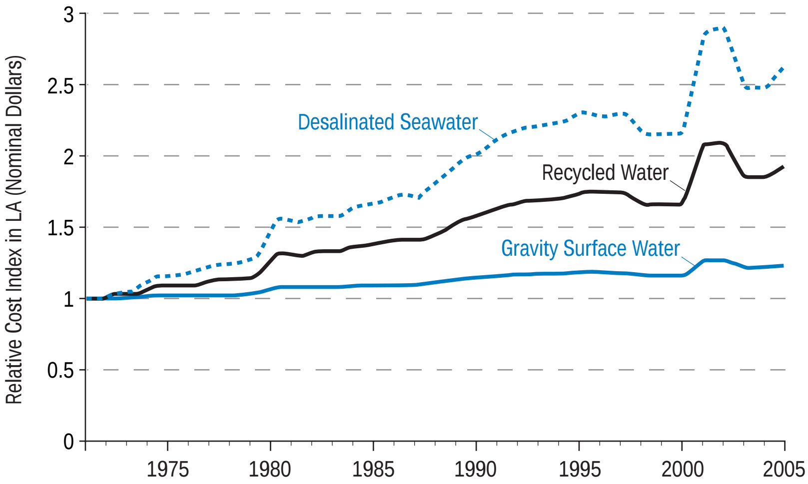
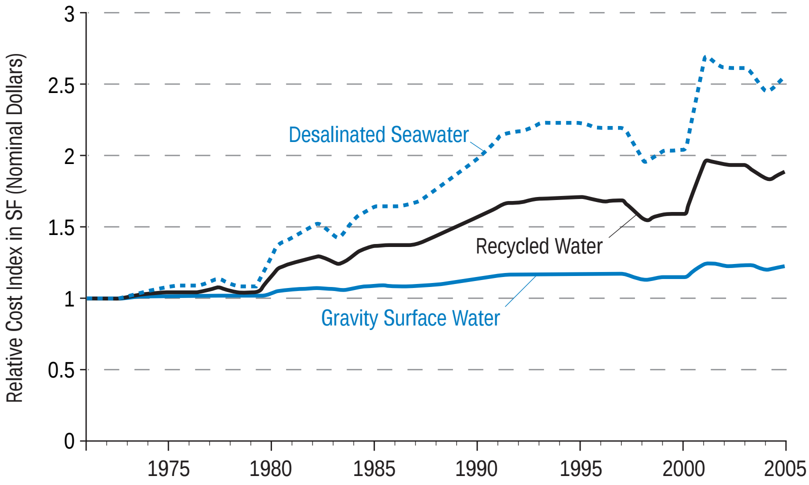


Figure 20
Relative Cost of Potable Water from a Typical Ocean Desalination, Wastewater Recycling, and Gravity Surface Water Source in the San Francisco-Oakland-San Jose Area



Environmental Impacts

Desalination, like any other major industrial process, has environmental impacts that must be understood and mitigated. These include effects associated with the construction of the plant and, especially, its long-term operation, including the effects of withdrawing large volumes of brackish water from an aquifer or seawater from the ocean and discharging large volumes of highly concentrated brine. Indirect impacts associated with the substantial use of energy must also be considered. Below we discuss a number of the most important environmental impacts of desalination, although this discussion is not meant to be exhaustive. Each desalination facility must be individually evaluated in the context of location, plant design, and local environmental conditions. In addition, we briefly describe some of the design and operational considerations that can reduce some of the environmental impacts associated with desalination.

Each desalination facility must be individually evaluated in the context of location, plant design, and local environmental conditions.

Impacts of Water Intakes: Impingement and Entrainment

Intake water design and operation have environmental and ecological implications. As described above, coastal plants typically take in large volumes of seawater during operation. In a recent report on power plant cooling-water intake structures, the California Energy Commission notes that "seawater … is not just water. It is habitat and contains an entire ecosystem of phytoplankton, fishes, and invertebrates" (York and Foster 2005). Large marine organisms, such as adult fish, invertebrates, birds, and even mammals, are killed on the intake screen (impingement); organisms small enough to pass through the intake screens, such as plankton, eggs, larvae, and some fish, are killed during processing of the salt water (entrainment). The impinged and entrained organisms are then disposed of in the marine environment. Decomposition of these organisms can reduce the oxygen content of the water near the discharge point, creating additional stress on the marine environment.

Impingement and entrainment introduce a new source of mortality to the marine environment, with potentially broad implications for local fish and invertebrate populations. More specifically, impingement and entrainment "may adversely affect recruitment of juvenile fish and invertebrates to parent or resident populations or may reduce breeding stocks of economically valuable fishes below their compensation point resulting in reduced production and yield" (Brining et al. 1981). The magnitude and intensity of these effects depend upon a number of factors, including the percent mortality of the vulnerable species, the mortality rate of the organism relative to the natural mortality rate, and the standing stock in the area of interest (Edinger and Kolluru 2000).

The effects of impingement and entrainment are species- and site-specific, and only limited research on the impacts of desalination facilities on the marine environment has been done. A recent overview of desalination seawater intakes, however, asserts that "[e]nvironmental impacts associated with concentrate discharge have historically been considered the greatest single ecological impediment when siting a seawater desalination facility. However, recent analyses have noted that marine life impingement and entrainment associated with intake designs were greater, harder-to-quantify concerns and may represent the most significant direct adverse environmental impact of seawater desalination" (Pankratz 2004).

Some relevant work has been done on the impacts of power plants that use OTC systems. An analysis of coastal and estuarine power plants in California suggests that impingement and entrainment associated with OTC systems have significant environmental impacts: "… impingement and entrainment impacts equal the loss of biological productivity of thousands of acres of habitat" (York and Foster 2005). It is important to note that power plant intake structures typically operate at a significantly higher capacity than many of the proposed desalination plants in California, and as a result, their environmental impact is substantially greater. The power plant intake studies, however, suggest that open water intakes may have significant impacts on the environment and that mitigation is required.

A number of technological and operational measures as well as design considerations can reduce impingement and entrainment associated with open water intake systems. Technological measures generally fall into four categories: physical barriers, collections systems, diversion systems, and behavioral barriers (Taft et al. 2003) and include passive screens, velocity caps, ristroph screens, and variable speed pumps. The operation of pumps can be modified to reduce impacts, by limiting pumping during critical periods. Surface intake pipes can be located outside of areas of high biological productivity.

Subsurface intake wells, which include infiltration galleries and horizontal and vertical beach wells, provide an alternative to open ocean intake systems and are being considered for 7 of the 21 proposed plants in California. Many feel that subsurface intake wells will prove to be an environmentally superior option. Subsurface intake wells use sand as a natural filter and can reduce or eliminate impingement and entrainment of marine organisms and reduce chemical use during pretreatment. These wells, however, have some limitations; they require a gravelly or sandy substrate and appear to be limited to intake volumes of 0.1 to 1.5 MGD (380 to 5,700 m^3/d) of water per well (Pankratz 2004, Filtration and Separation 2005a). They can also damage freshwater aquifers and the beach environment. The CCC recommends that "[b]each wells should only be used in areas where the impact on aquifers has been studied and saltwater intrusion of freshwater aquifers will not occur. Infiltration galleries are constructed by digging into sand on the beach, which could result in the disturbance of sand dunes" (CCC 1993).

Subsurface intake wells use sand as a natural filter and can reduce or eliminate impingement and entrainment of marine organisms and reduce chemical use during pretreatment.

Ultimately, the individual volumes, designs, locations, and local ocean conditions will determine the impacts of desalination impingement and entrainment. As a result, careful siting, design, and monitoring are required. Mitigation may also be required where impacts are expected or observed.

Brine Composition and Discharge

Adequate and safe disposal of the concentrated brine produced by the plant presents a significant environmental challenge. Brine salinity depends on the salinity of the feedwater, the desalination method, and the recovery rate of the plant. Typical brines contain twice as much salt as the feedwater and have a higher density. In addition to high salt levels, brine from seawater desalination facilities can contain concentrations of constituents typically found in seawater, such as manganese, lead, and iodine, as well as chemicals introduced via urban and agricultural runoff, such as nitrates (Talavera and Ruiz 2001), and impinged and entrained marine organisms killed during the desalination process, as noted above.

Composition

Chemicals used throughout the desalination process may also be discharged with the brine. The majority of these chemicals are applied during pretreatment to prevent membrane fouling (Amalfitano and Lam 2005). For example, chlorine and other biocides are applied continuously to prevent organisms from growing on the plant's interior, and sodium bisulfite is then often added to eliminate the chlorine, which can damage membranes. Anti-scalants, such as polyacrylic or sulfuric acid, are also added to prevent salt deposits from forming on piping. Coagulants, such as ferric chloride and polymers, are added to the feedwater to bind particles together. The feedwater, with all of the added chemicals, then passes through a filter, which collects the particulate matter. The RO membranes reject the chemicals used during the desalination process into the brine. The particulate matter on the filter is also discharged with the brine or collected and sent to a landfill.

In addition to using chemicals for pretreatment, chemicals are required to clean and store the RO membranes. Industrial soaps and dilute alkaline and acid aqueous solutions are commonly used to clean the membranes every three to six months. The membranes are then rinsed with product water. The first rinse, which contains a majority of the cleaning solution, is typically neutralized and disposed of in local treatment systems. Subsequent rinses, however, are often discharged into the brine. Frequent cleaning and replacement of the membranes due to excess membrane fouling may lead to discharges in violation of sanitary system discharge permits. This problem has occurred in Tampa Bay, as noted in Box 3 and Appendix C.

Brine also contains heavy metals introduced during the desalination process. Corrosion of the desalination equipment leaches a number of heavy metals, including copper, lead, and iron, into the waste stream. In an early study of a desalination plant in Florida, Chesher (1975) found elevated copper and nickel levels in the water column and in sediments near the brine discharge point. Copper levels were particularly high during unstable operating periods and immediately following maintenance, although engineering changes made at the plant permanently reduced copper levels.

Perhaps the best way to reduce the effects of brine disposal is to reduce the volume of brine that must be discharged and minimize the adverse chemicals found in the brines. Both man-made filters and natural filtration processes can reduce the amount of chemicals applied during the pretreatment process. Ultrafiltration, for example, can replace coagulants, effectively removing silt and organic matter from feedwater (Dudek and Associates 2005). Ultrafiltration also removes some of the guesswork involved in balancing the pretreatment chemicals, as pretreatment "must be continuously optimized to deal with influent characteristics" (Amalfintano and Lam 2005). These filters, however, are backwashed periodically to remove sludge buildup and cleaned with the same solution used on RO membranes. Backwash can be disposed of with the waste brine or dewatered and disposed of on land. Additionally, subsurface intake wells, which use sand as a natural filter, reduce chemical usage during pretreatment by reducing the biological organisms that cause biofouling.

Discharge

A number of brine disposal options are available. For desalination plants located on the coast, disposal methods include discharge to evaporation ponds, the ocean, confined aquifers, or saline rivers that flow into an estuary. Options for inland disposal of brines and concentrates include deep-well injection, pond evaporation, solar energy ponds, shallow aquifer storage for future use, and disposal to a saline sink via pipeline or injection to a saline aquifer (NAS 2004).

Each disposal method, however, has a unique set of advantages and disadvantages. Large land requirements make evaporation ponds uneconomical for many developed or urban areas. Sites along the California coast, for example, tend to have high land values, and coastal development for industrial processes is discouraged. Injection of brine into confined groundwater aquifers is technically feasible, but it is both expensive and hard to ensure that other local groundwater resources remain uncontaminated. Unless comprehensive and competent groundwater surveys are done, there is a risk of unconfined brine plumes appearing in freshwater wells. Direct discharges into estuaries and the ocean disrupt natural salinity balances and cause environmental damage of sensitive marshes or fisheries. All of these methods add to the cost of the process, and some of them are not yet technically or commercially available. As noted by the 2003 U.S. Desalination Roadmap, "finding environmentally-sensitive disposal options for this concentrate that do not jeopardize the sustainability of water sources is difficult, and, thus, next-generation desalination plants will have to be designed to minimize the production of these concentrates, or find useful applications for them" (USBR and SNL 2003).

Ocean discharge is the most common and least expensive disposal method for coastal desalination plants, although this approach can have significant impacts on the marine environment.

Ocean discharge is the most common and least expensive disposal method for coastal desalination plants (Del Bene et al. 1994), although this approach can have significant impacts on the marine environment. Brine discharged into the ocean can be pure, mixed with wastewater effluent, or combined with cooling water from a co-located power plant.[35] Ocean discharge assumes that dilution of brine with much larger volumes of ocean water will reduce toxicity and ecological impacts. The notion that diluting brine with cooling water reduces the toxicity of the brine is based on the old adage, "Dilution is the solution to pollution." While this may be true for some brine components, such as salt, it does not apply to others. The toxicity of persistent toxic elements, including some subject to bioaccumulation, such as heavy metals, is not effectively minimized by dilution. In addition, little is known about the synergistic effects of mixing brine with either wastewater effluent or cooling water from power plants.

Because brine is typically twice as saline as the feedwater, it has a higher density than the receiving water and exhibits a distinct physical behavior. As a general rule, brine follows a downward trajectory after release. If brine is released from an outfall along the seafloor, as is typical, it tends to sink and slowly spread along the ocean floor. Mixing along the ocean floor is much slower than at the surface, thus inhibiting dilution and

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[35] Mixing brine with waste water may contaminate what is increasingly being considered a new source of water. For this reason, municipal waste water should not be used for brine dilution.

increasing the risk of ecological damage (Chesher 1975). Other factors are also important, however. Brine behavior varies according to local conditions (i.e., bottom topography, current velocity, and wave action) and discharge characteristics (i.e., concentration, quantity, and temperature) (Del Bene et al. 1994, Einav and Lokiec 2003). The site specificity of brine behavior suggests that plume models optimized to handle negatively buoyant discharges should be employed to determine the potential marine impacts of all proposed desalination plants.

The chemical constituents and physical behavior of brine discharge pose a threat to marine organisms. Brine can kill organisms on short timescales and may also cause more subtle changes in the community assemblage over longer time periods: "Heat, trace metals, brine, and other toxicants may result in acute mortality to organisms in the receiving waterbody. Subtle changes in distribution and abundance patterns and sublethal changes in the physiological, behavioral, and/or reproductive condition of resident organisms may occur" (Brining et al. 1981). Bioaccumulation of toxicants and synergistic effects are also possible.

The chemical constituents and physical behavior of brine discharge pose a threat to marine organisms.

Certain habitat types, organisms, and organismal life stages are at greater risk than others. Along California's coast, rocky habitat and kelp beds are particularly rich, sensitive ecosystems, and effort should be made to avoid these areas. Benthic organisms in the immediate vicinity of the discharge pipe are at the greatest risk from the effects of brine discharge. These can include crabs, clams, shrimp, halibut, and ling cod. Some have limited mobility and are unable to move in response to altered conditions. Many benthic organisms are important ecologically because they link primary producers, such as phytoplankton, with larger consumers (Chesapeake Bay Program 2006). Additionally, juveniles and larvae may also be at greater risk (Cal Am and RBF Consulting 2005).

In 1979, Winters et al. noted the risks that the chemical constituents and physical behavior of brine may pose a threat to the marine environment and stressed the need for adequate monitoring:

> It is impossible to determine the extent of ecological changes brought about by some human activity (e.g., desalination) without totally studying the system involved. Ideally such studies should involve a thorough investigation of both the physical and biological components of the environment. These studies should be done over a long period of time. Baseline data should actually be gathered at the site prior to construction for subsequent comparative uses. This will allow for a thorough understanding of the area in its 'natural' state. Once the plant is in operation monitoring should be continued on a regular basis for a period of at least one year but preferably for two or three years.

More than 25 years later, however, only a few studies have performed a comprehensive analysis of the effects of brine discharge on the marine environment, particularly on the West Coast of the United States, as noted in Cal Am and RBF Consulting (2005); the majority of studies conducted thus far focus on a limited number of species over a short time period with no baseline data.

More comprehensive studies are needed to adequately identify and mitigate the impacts of brine discharge. A study conducted by Chesher on the biological impacts of a multi-stage flash desalination plant in Key West, Florida in 1975 serves as a good model but is in serious need of updating. Chesher's thorough analysis included a chemical and physical analysis of the discharge, a historical analysis of sediments to determine the concentration of heavy metals and the abundance of certain fauna over time, and in situ and laboratory biological assessments of a number of organisms. Chesher found that "[a]ll experiments showed the effluent had a pronounced impact on the biological system within Safe Harbor. Even the organisms which were more abundant at Safe Harbor stations than at control stations were adversely affected in the immediate vicinity of the discharge." Although impacts are site-specific, Chesher's study suggests that further research and monitoring are necessary and that mitigation may be required.

In their 1993 report on desalination, the CCC also cites a lack of information about the marine impacts of desalination – a problem that has yet to be resolved. The CCC compiled a thorough list of pre- and post-operational data that should be collected to evaluate the marine impacts associated with brine discharge (CCC 1993). Table 8 summarizes these data. We strongly recommend that this information be acquired for all plants proposing to locate along the California coast before permits are issued.

Table 8
Pre- and Post-Operational Monitoring Required to Assess the Impacts of Desalination on Marine Resources

Source: CCC 1993

Pre-Operational Monitoring and Baseline Information

- Studies of the effects of discharges from a pilot plant built where a final plant will be located
- Measurements of dispersion rates to determine how readily brine will disperse in the ocean
- Laboratory studies to determine the effect on particle size of mixing brine and sewage water
- Laboratory studies to determine the dispersion of metals
- Tracer studies using small quantities of nonradioactive isotopes of metals to determine the quantity of metals that end up in the ocean microlayer
- An inventory of marine organisms in the area of the outfall
- A long-term inventory of marine organisms in the microlayer

Post-Operational Monitoring

- Secchi Disk Depth Test to measure how much light is penetrating the water column (to determine whether there may be an impact on the benthos)
- Measurements of impacts on habitat in the microlayer
- Measurements of impacts on fish in the water columns
- Plume trajectory evaluation of depth, temperature, salinity, and density
- Nontoxic dye tests to measure dilution
- Sampling of sediments
- Measurements of salinity at various offshore sampling locations

A number of disposal practices are available to reduce the salinity and possibly the toxicity of brine. Proper outfall siting can minimize adverse effects; for example, outfalls constructed in the open ocean, rather than in protected bays and estuaries, can improve mixing. Diffusers placed at the end of the discharge pipe promote mixing. Brine can also be diluted with effluent from a treatment plant or with water from a power plant using OTC systems, though this has drawbacks that are discussed in greater detail elsewhere in the report. Caution must be exercised when combining brine with wastewater effluent. If the combined mixture is denser than seawater, it may introduce nutrients to the ocean floor, a zone that is not well mixed, with possible impacts on the benthic community. Because wastewater and power plants have variable flow, mixing must also involve careful monitoring. Additional research is needed to determine whether there are synergistic effects caused by combining desalination's high salinity discharge with the high temperatures and dead biomass in a power plant discharge.

Point-source discharges into waterways, including those from desalination plants, are subject to regulation under the Federal Clean Water Act. In California, the SWRCB and RWQCBs implement this act via the National Pollutant Discharge Elimination System (NPDES) permit program. SWRCB and RWQCBs issue NPDES permits according to identified water-quality standards set forth in the California Ocean Plan and the basin plans for discharges into the ocean and inland waterways, respectively. RWQCBs require dischargers to establish a self-monitoring program and submit periodic reports and may require monitoring of bioaccumulation of toxicants. It is critical that standards for all brine components be established and that monitoring is adequate to address all possible marine impacts.

Environmental Benefits

Increased water-system reliability – whether from desalination facilities or other measures – might yield environmental benefits. The key to this possibility is that actions implemented to cover shortfalls during droughts must be operational during wet years. Doing so is cost effective. Although one could in concept construct a desalination facility and operate it only during droughts, the cost per unit water produced would typically be prohibitively high. Even if two-thirds of the cost were variable and could be avoided by shutting the plant down in average and wet years, the remaining one-third of fixed costs, spread over the water produced in drought years (say, 1 in 10), would create a unit cost during drought four times higher than the unit cost if the plant were run every year. Since these are generous assumptions and seawater desalination is already costly, we can expect new plants to produce water in most years, not just dry ones.

> It is critical that standards for all brine components be established and that monitoring is adequate to address all possible marine impacts.

Using desalination plants to increase system reliability will in practice also create surplus water during average and wet years. If this water is used to support growth in baseline water use, customers are paying not just for increased reliability but also to expand supply. However, it may be possible to release some surplus water to the environment after a desalination plant comes on line. That is, there is an implicit opportunity to provide more water for the environment buried in most reliability improvements. The opportunity is not easy to capture, nor is it uniform for all parts of the state. But this opportunity should be analyzed for each proposed desalination project. For example, a desalination or water recycling facility may make it possible (or necessary once storage is full) to release water from storage facilities for critical environmental purposes during average or even dryer-than-average years. Or it may make it possible to pump less groundwater or deliver less surface water.

Proponents argue that a proposed desalination plant at Moss Landing has the potential to reduce withdrawals from the Carmel River. Cal Am supplies water from the river to users in the Monterey Peninsula. In 1995, the SWRCB found that Cal Am's water diversions from the Carmel River exceeded their water rights and that these excess diversions were causing damage to public trust resources. With Order 95-10, the SWRCB required Cal Am to reduce water diversions from the Carmel River by nearly 11,000 AFY (approximately 9.6 MGD or 36,000 m^3/d), a 70% reduction in withdrawals at that time, or obtain appropriative permits. Order 95-10 specifies that any new supplies must be used to offset diversions from the Carmel River on a one-to-one basis (SWRCB 1995). A number of new supply sources have been examined, including a dam, desalination, groundwater recharge, and reclamation. If Cal Am builds a desalination plant for the purpose of satisfying the SWRCB Order, the plant will have explicit environmental benefits.

A less direct example of an ecosystem benefit involves the Marin Municipal Water District, which is proposing to build a desalination plant on the San Francisco Bay that will produce 10-15 MGD (38,000 to 57,000 m^3/d) of water. According to MMWD, the desalination plant will render a proposed pipeline for increased diversions from the Russian and Eel Rivers unnecessary. In turn, this plant will reduce pressure on threatened coho and steelhead salmon populations: "For MMWD, desalination is part of an ongoing commitment to reducing harmful diversions from rivers and streams" (MMWD 2006).

Typically, however, the link between desalination (or other new sources) and more water for environmental purposes is weak. Unless a water rights order (as in Monterey) or potential order (as in Marin) makes water for the environment mandatory or more water taken from the environment problematic, there is usually no explicit mechanism to link desalination project approval with environmental water. Without a mechanism, there is no guarantee that water will be used for ecosystem restoration. Desalination project proponents who claim an environmental benefit from their project need to describe the binding mechanism by which product water will become "environmental water" rather than a new source of supply for future demand.

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Coastal Development and Land Use

In addition to affecting the coastal environment through water intake and discharge, desalination can also affect the coast through impacts on developments, land use, and local growth, which are often controversial and contentious topics. Rapid, unplanned growth can damage local environmental resources as well as the social fabric of a community anywhere. For example, building new homes and businesses without investing in infrastructure can cause overcrowded schools, traffic, and water shortages. Urban and agricultural runoff and increases in wastewater flows create water-quality problems in local rivers, streams, and/or the ocean. Coastal developments are often particularly divisive. Some developments can change the nature of views, beach access, and other environmental amenities.

In coastal areas throughout California, clean, potable water is sometimes considered a limiting resource and constrains development. Some of these coastal communities have already reached “build-out” – the level of development considered to be the maximum a region can sustain – and resource limitations should not be considered unusual. For example, in 2005 the City of Monterey, which is near build-out, had 31 residential, commercial, and institutional projects on its water wait list due to insufficient water supply. According to the City’s General Plan, “The City does not have any water available for new residential or commercial development until an additional water supply is found. The Housing Element goals are structured to provide housing opportunities if and when water is removed as a constraint to housing development” (City of Monterey 2005).

By comparison, other coastal communities that have not reached build-out are experiencing water-supply constraints. The town of Cambria, for example, is relatively undeveloped, with a 20% build-out in 1998, and has a limited local supply and no connection to the state or federal water-supply system (CCC 1998). In 2001, the Cambria Community Services District Board of Directors issued a water moratorium due to concerns about their ability to provide water for fighting wildfires and continue service to residential and commercial customers. Because a new water supply will remove this limitation, some desalination opponents worry that water provided by desalination may facilitate growth.

Some desalination opponents worry that water provided by desalination may facilitate growth.

In 2004, the CCC, which administers the Coastal Act, highlighted the importance of the growth-inducing impacts of desalination. “A desalination facility’s most significant effect could be its potential for inducing growth,” it concluded (CCC 2004). In conjunction with their assessment, the CCC produced a series of questions to determine the potential growth-inducing impacts of a desalination plant, including:

- “Where will the water go?”
- “Is the project meant to provide a baseline supply or is it to be used only for emergencies or drought relief?”
- “Does the project replace an existing supply of water or provide a new one?” (CCC 2004).

The CCC argues that desalination plants that provide a new source of water will have a greater growth-inducing effect than those that provide water to replace an existing supply source. Similarly, water that provides a baseline supply will likely have more of a growth-inducing effect than water produced only during emergencies or droughts (CCC 2004). As noted elsewhere, however, it is unlikely that desalination plants will be built purely for emergency or drought supply because of the higher costs involved.

California’s Water Desalination Task Force (CDWR 2003) also discussed the potential growth-inducing impacts of desalination but made no judgment about whether this is a desirable or undesirable outcome. Rather, the state recommended deferring to local communities and the appropriate regulatory agencies to make this determination: “Growth inducing impacts of any new water supply project, including desalination, must be evaluated on a case-by-case basis through existing environmental review and regulatory processes.” The review processes referred to include CEQA, the California Coastal Act, and local and regional planning bodies.

CEQA and the Coastal Act require evaluation of the growth-inducing impacts of a project. CEQA applies to all projects in California, whereas the Coastal Act applies to projects within an established coastal zone. Both are likely to apply to seawater desalination facilities. CEQA guidelines explicitly require an evaluation of how additional infrastructural and service needs associated with growth may affect the environment:

> Discuss the ways in which the proposed project could foster economic or population growth. … Included in this are projects which would remove obstacles to population growth (a major expansion of a wastewater treatment plant might, for example, allow for more construction in service areas). Increases in the population may tax existing community service facilities, requiring construction of new facilities that could cause significant environmental effects. ... It must not be assumed that growth in any area is necessarily beneficial, detrimental, or of little significance to the environment (CEQA Guidelines 15126.2 (d)).

CEQA does not place a value or a limit on growth per se; rather, it considers growth a significant impact if it exceeds levels established in local or regional plans. Mitigation, where feasible, is required for projects that have identified significant effects.

The Coastal Act takes a similar approach to growth, but it adopts more restrictive and specific language on growth restrictions along the California coast. The Coastal Act contains policies that seek to limit growth to developed areas with the appropriate infrastructure:

> … these policies generally require new development be located within or next to existing developed areas able to accommodate such development … and provide that public work facilities be sized based on the ability to maintain, enhance, or restore coastal resources, and that development allow all coastal resources to remain viable (CCC 2004).

The CCC seeks to ensure that growth does not exceed limits established in certified Local Coastal Programs (LCPs).[36] The CCC can deny a coastal development permit to those desalination plants that induce growth beyond levels projected in the LCPs.

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[36] LCPs are developed by local governments and establish land-use plans (and measures to implement the plan) in accordance with the goals and policies of the California Coastal Act.

CHAPTER V

OTHER RELEVANT ISSUES

Privatization

Privatization of the water sector involves transferring some or all of the assets or operation of public water systems to private companies. Desalination may be privatized in three distinct ways: the desalination plant is solely sponsored by a private company and the water produced is sold to local public agencies (such as the plants proposed by Poseidon Resources in Huntington Beach and Carlsbad); the desalination plant is sponsored by a private water company that is responsible for delivering water directly to its customers (such as the plant proposed by Cal Am in Moss Landing); or a private company partners with a public agency in a possible range of capacities to produce and deliver water (such as the plant proposed by Pajaro-Sunny Mesa and Poseidon Resources in Moss Landing). The general form of the arrangement has important implications for how it should be regulated.

In California, coastal resources, including ocean waters, are part of the public commons and are protected under the public trust doctrine. Some individuals feel that privatized desalination violates the public trust doctrine by turning a public good into a private commodity subject to market rules. Objections to desalination are particularly strong because it is a consumptive use.[37] The CCC argues that while consumption is small compared to the size of the resource, local or regional impacts may be significant:

> Given the risks to the program, to the state's coastal resources, and to most of the state's other significant environmental, health, and safety requirements meant to protect the public and the state's resources, California should proceed cautiously in reviewing proposals to further privatize water and water services, particularly those involving seawater desalination (CCC 2004).

It is important to note that other consumptive uses of coastal resources—such as commercial fishing and oil extraction—are allowed, and even protected, by state law. This raises the question of how these consumptive uses differ from desalination.

[37] Desalination is consumptive because product water is consumed, unlike most water used, for example, for cooling, which is typically returned immediately to the source.

Multinational companies may be able to circumvent regulations, including those protecting the environment, by claiming that they represent a trade barrier.

In addition, individuals and governmental agencies have expressed concern about the impact of international trade agreements on local, state, or national regulations. The CCC, for example, states, "If the U.S. were to agree to include the provision of water as a service subject to the General Agreements on Trade in Services, Coastal Act policies as applied to private desalination facilities could potentially be interpreted as barriers to free trade" (CCC 2004). Under the North American Free Trade Agreement, the World Trade Organization Agreement, and other trade agreements, multinational companies may be able to circumvent regulations, including those protecting the environment, by claiming that they represent a trade barrier. Currently water services are not included within trade agreements, but they may be included in the future.

The Tampa Bay plant, discussed previously, highlights the danger of privatization and should serve as an important lesson for water agencies considering partnering with a private entity. Tampa Bay Water negotiated a "design-build-operate-transfer" scheme with Poseidon Resources in 1999. When Poseidon and its project partner were unable to secure financing, Tampa Bay Water was left with the financial liability and engineering consequences. Tampa Bay Water was forced to purchase Tampa Bay Desal, thereby assuming full responsibility, and risk, of the desalination plant.

Gleick et al. (2002) provide principles and standards for water privatization that should be applied to desalination plants within California. These include the following:

- Governments should retain or establish public ownership or control of water resources.
- Public agencies and water-service providers should monitor water quality.
- Governments should define and enforce water-quality laws.
- Contracts that lay out the responsibilities of each partner are a prerequisite for the success of any privatization.
- Clear dispute-resolution procedures should be developed prior to privatization.
- Independent technical assistance and contract review should be standard.
- Negotiations over privatization contracts should be open and transparent and include all affected stakeholders.

Although briefly mentioned above, the issue of transparency warrants further discussion. A comparison between the desalination plant proposed by Long Beach Water Department and the plants proposed by Poseidon Resources reveals a starkly different picture. The LBWD, as described in other sections of this report, has performed extensive research on ways of reducing the energy requirements and environmental impacts of desalination. Their Web site provides operational data, and their employees have given numerous public talks about problems they have encountered. By contrast, Poseidon Resources has either not performed these types of analyses, or has not made them public, but are seemingly much further along in the planning process for three large desalination plants in California: one for which it has received city permits (Huntington Beach), another for which it received county permits to build a pilot plant (Moss Landing), and a third for which it completed a final environmental impact report (Carlsbad). Experiences in Tampa Bay, to which Poseidon Resources was a partner, and strong interest by the private sector in California highlight additional need for transparency and accountability.

Experiences in Tampa Bay and strong interest by the private sector in California highlight additional need for transparency and accountability.

Desalination and Climate Change

Climate change will result in significant changes to California’s water resources and coastal ocean conditions. These changes have important implications – both good and bad – for desalination. In a literature review of the effects of climate change on California’s water resources, Kiparsky and Gleick (2003) indicate that climate change will likely increase temperatures in California; increase climate variability, including storm intensity and drought frequency; raise sea level; and alter the effects of extreme events such as the El Niño/Southern Oscillation. Although some uncertainty remains about how precipitation patterns, timing, and intensity will change, there is general consensus that climate change will “increase the ratio of rain to snow, delay the onset of the snow season, accelerate the rate of spring snowmelt, and shorten the overall snowfall season, leading to more rapid and earlier seasonal runoff” (Kiparsky and Gleick 2003).

These climatic changes will affect the supply of, and demand for, California’s water resources. According to the Intergovernmental Panel on Climate Change (IPCC), “Increases in average atmospheric temperature accelerate the rate of evaporation and demand for cooling water in human settlements, thereby increasing overall water demand, while simultaneously either increasing or decreasing water supplies (depending on whether precipitation increases or decreases and whether additional supply, if any, can be captured or simply runs off and is lost)” (IPCC 2001). In addition, rising sea levels may exacerbate seawater intrusion problems in coastal aquifers or rivers that communities depend on for water.

Desalination Can Buffer the Hydrologic Impacts of Climate Change

Some view desalination as a means of adapting to climate change and argue that desalination facilities can reduce the dependence of local water agencies on climate-sensitive sources of supply. As climate change begins to alter local hydrology, the resilience of water-supply systems may be affected. When variability of supply goes up, the risk of some extreme events increases. A reliable supply of high-quality water from desalination systems that are independent of hydrologic conditions can provide a buffer against this variability.

The IPCC lists desalination plants as a supply-side adaptive measure available to meet potential increases in urban water demand associated with climate change (IPCC 2001). In a recently released water plan, the Australian government contends that desalination plants “provide a reliable supply and a good quality water and are immune from drought and climate change impacts" (NSW 2004). Climate change has also been used to justify a desalination plant in London, where a Thames Water representative said, "We've two challenges. One is population …. At the same time we've got climate change" (Barkham 2004). This advantage must be considered in any long-term water plan and evaluated in the context of our method for calculating constant-reliability-benefit costs, discussed above. Using the method for two different levels of variability – say "with" and "without" climate change – would allow one to quantify the additional value of desalination as an adaptive response to climate change.

Desalination Facilities Will Be Vulnerable to Some Climatic Impacts

Desalination facilities are likely to have some special vulnerability to climate impacts. Ocean desalination plants are constructed on the coast and are particularly vulnerable to changes associated with rising sea levels, storm surges, and increased frequency and intensity of extreme weather events. Intake and outfall structures are affected by sea level. Over the expected lifetime of a desalination facility, sea levels could plausibly rise by as much as a foot or more, and storm patterns are also likely to change on a comparable time scale. All of these impacts have the potential to affect desalination plant design and operation and should be evaluated before plant construction and operation is permitted.

Altering plant design to decrease vulnerability associated with climate change is rarely discussed. As the IPCC suggests, new development can be an opportunity; infrastructure can be designed to account for changes expected under an altered climate at lower cost than retrofitting existing development. Current proposals in California, however, typically make no mention of design considerations necessary to adapt to climate change and are thus missing an important opportunity.

Desalination Facilities Exacerbate Climate Change with Their Large Use of Energy

The water sector consumes a tremendous amount of energy to capture, treat, transport, and use water. The California Energy Commission (2005) estimates that the water sector in California used 19% and 32% of total electricity and natural gas use, respectively, in 2001. Substantial quantities of diesel were also consumed in California's water sector. Because desalination is the most energy-intensive source of water, desalination will increase the amount of energy consumed by the water sector. The currently proposed desalination plants would increase the water-related energy use by 5% over 2001 levels.[38]

> We recommend that regulatory agencies consider requiring all new desalination facilities be carbon-neutral.

The energy-intensive nature of desalination means that extensive development can contribute to greater dependence on fossil fuels, an increase in greenhouse gas emissions, and a worsening of climate change. We recommend that regulatory agencies consider requiring all new desalination facilities be carbon-neutral – i.e., that the greenhouse gas emissions associated with desalination facilities be offset through energy efficiency improvements, or greenhouse gas emission reductions elsewhere. While this approach has not yet been adopted for other sectors in California, we

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[38] Calculation based on average energy use for desalination of 12.9 kWh/kgal (3.4 kWh/m^3).

believe it is warranted given the likely significant impacts of climate change on California's water resources.

Desalination with Alternative Energy Systems Can Reduce Climate Impacts

One way to decouple the impacts of desalination facilities on climate emissions is to power them with non-fossil fuel sources. Desalination optimists have long pointed to the possibility of running desalination plants with alternative energy systems, from solar to nuclear, as a way of reducing costs or dependence on fossil fuels, and more recently, as a way of reducing greenhouse gas emissions and local contributions to climate change. While this discussion continues, there is, as yet, no economic advantage to dedicating alternative energy systems to desalination because of the high costs relative to more-traditional energy systems and the lack of a regulatory agreement to control greenhouse gases.

The barriers to greater use of alternative energy are rarely technical. Solar energy has been used directly for over a century to distill brackish water and seawater. The simplest example of this type of process is the greenhouse solar still, in which saline water is heated and evaporated by incoming solar radiation in a basin on the floor and the water vapor condenses on a sloping glass roof that covers the basin. When commercial plate glass began to be produced toward the end of the 19th century, solar stills were developed. One of the first successful solar systems was built in 1872 in Las Salinas, Chile, an area with very limited fresh water. This still covered 4,500 square meters, operated for 40 years, and produced over 5,000 gallons/d (about 20 m^3/d) of fresh water (Delyannis and Delyannis 1984). Variations of this type of solar still have been tested in an effort to increase efficiency, but they all share some major difficulties, including solar collection area requirements, high capital costs, and vulnerability to weather-related damage.

There are examples of desalting units that use more-advanced renewable systems to provide heat or electrical energy. Some modern desalination facilities are now run with electricity produced by wind turbines or photovoltaics. An inventory of known wind- and solar-powered desalting plants (Wangnick/GWI 2005) listed around 100 units as of the end of 2004. Most of these are demonstration facilities with capacities smaller than 0.013 MGD (50 m^3/d), though a 0.08 MGD (300 m^3/d) plant using wind energy was recently built in Cape Verde. The largest renewable energy desalination plant listed by the end of 2005 was a 0.5 MGD (2,000-m^3/d) plant in Libya, which was built to use wind energy systems for power. A 0.3 MGD (1,000-m^3/d) plant in Libya in the same location was designed to use photovoltaics for energy. Both of these plants went into operation in 1992 and desalted brackish water using RO. No plants run solely with nuclear power have been built, although a few desalination plants supply high-quality water for nuclear facilities (Wangnick/GWI 2005).

Renewable energy systems can be expensive to construct and maintain. While the principal energy input is free, the capital cost of these systems is still high. As with conventional plants, the final cost of water from these plants depends, in large part, on the cost of energy. A pilot plant combining photovoltaic electricity production with ED operated for a while in Gallup, New Mexico, producing around 800 gallons/d (3 m^3/d) of fresh water at a cost of around \$11.36/kgal (\$3.00/m^3) (Price 1999). At present, this cost is prohibitive for typical water agencies, but these systems may be more economical for remote areas where the cost of bringing in conventional energy sources is very high. If the price of fossil fuels increases or renewable energy costs drop, such systems will look more attractive. Ultimately, these energy systems must prove themselves on the market before any such coupling can become attractive.

Co-Locating Desalination and Energy Facilities

Co-location can produce substantial energy and economic advantages and, some argue, reduce environmental impacts.

Integrating desalination systems with existing power plants (or building joint facilities) offers a number of possible advantages, including making use of discarded thermal energy from the power plant (co-generation), lower-cost electricity due to off-peak use and avoided power grid transmission costs, and existing intake and outfall structures to obtain seawater and discharge brine. In addition, building on existing sites may prevent impacts at more pristine or controversial locations. Co-location can produce substantial energy and economic advantages and, some argue, reduce environmental impacts.

Co-location is common for distillation plants built in the Persian Gulf, was proposed by Poseidon Resources for the Tampa Bay desalination plant, and is being considered for nearly half of the proposed plants in California (Filtration and Separation 2005b). While many of the distillation plants installed in the Middle East and North Africa use co-generation, the proposed co-located plants along the California coast share physical infrastructure like the intake and outfall pipes and are only loosely thermally coupled to the power plant. Under this arrangement, a portion of the power plant cooling water is pumped to the adjacent desalination plant, where it undergoes treatment. Warm water from the power plant requires less energy to remove salts, thereby lowering treatment costs. The brine is then returned to the outfall and diluted with cooling water from the power plant.

Given the type of co-location proposed in California and conditions in California, it is not clear whether the economic advantages of co-location are as substantial as some claim. Since intake and outfall pipelines can be 5% to 20% of the capital cost of a new facility (Voutchkov 2005), co-location can potentially reduce costs by up to 10% (assuming capital costs are 50% of total costs). But savings from co-location may be much smaller, even trivial, depending on the setting. And as noted above, a 25% increase in energy cost would more than offset a 10% savings from co-location. In addition, current state and federal utility laws do not allow desalination plants to obtain below-market rates from an adjacent power plant that sells power to the grid, thus lessening the economic advantages of co-location (CDWR 2003, CPUC 2005).

Co-location may also have drawbacks that require careful review and consideration.

Co-location may also have drawbacks that require careful review and consideration. Opponents argue that co-location will prolong the life of power plants that use OTC systems. OTC is an inexpensive, simple technology in which seawater is pumped through the heat exchange equipment once and then discharged. These cooling systems impinge and entrain marine organisms and discharge warm water laced with antifouling chemicals into the ocean, resulting in significant environmental damage. Many of the power plants using OTC systems were constructed prior to 1980, when the marine impacts of this technology were not well understood or regulated. The California Energy Commission recently concluded that "California marine and estuarine environments are in decline and the once-through cooling systems of coastal power plants are contributing to the degradation of our coastal waters" (York and Foster 2005).

The future of OTC systems remains unclear; as a result, the proposed co-located plants face a large degree of uncertainty about future operations. Federal and state agencies, whose regulations cover coastal power plants, including the United States Environmental Protection Agency (U.S. EPA), CCC, California Energy Commission, and State Lands Commission, recognize the problems posed by OTC systems and are pushing for tighter restrictions. For example, the State Lands Commission, which administers and protects public trust lands that underlie navigable waters, adopted a resolution that calls for denying new land leases or extensions of existing land leases for facilities associated with OTC systems after 2020 (CSLC 2006). In addition, U.S. EPA, which regulates cooling water intake structures under section 316(b) of the Clean Water Act, issued new regulations for existing power plants in 2004 requiring them to reduce impingement by 80% to 95% and entrainment by 60% to 90 percent. The U.S. EPA provided a number of compliance options to meet the new 316(b) requirements, such as (1) reducing intake flow to levels similar to those of a closed-cycle cooling system; (2) implementing technology, operational measures, or restoration measures that meet the performance standard; and (3) demonstrating that costs exceed the benefits for that specific site. A pending lawsuit by Riverkeeper and a number of other organizations may disallow restoration and site-specific benefit-cost analysis as a means of complying with U.S. EPA's new requirements.

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In California, SWRCB and the nine RWQCBs administer the U.S. EPA's regulations on power plant cooling water discharge. Currently statewide policy regulates only the thermal discharge of power plants, whereas the RWQCBs regulate impingement and entrainment associated with cooling water intake structures. This arrangement has led to inconsistent regulation of impingement and entrainment effects across the state. Because of the flexibility in the U.S. EPA's new 316(b) regulations, however, SWRCB will likely adopt a statewide strategy regulating impingement and entrainment. The statewide policy may be more stringent than the U.S. EPA's regulations.

Alternative technologies and operational practices may help reduce or eliminate the marine impacts associated with OTC systems, but they also reduce power plant efficiency. York and Foster (2005) concluded that flow reduction and alternative cooling technologies, such as dry cooling and recirculating cooling, are the best options available, as "other entrainment and impingement reduction methods such as changes in intake location or physical or behavioral barriers have not proved to be feasible and/or effective for most power plants." Further, "EPA's own figures suggest that mandating recirculating cooling on all plants was highly cost-effective and would result in increased power costs to average residential customers of under a dollar per month" (Clean Air Task Force 2004). Ninety-five percent of the newly licensed power plants since 1996 use alternative cooling technologies (York and Foster 2005).

Flow reduction and alternative cooling technologies, however, may be incompatible with co-located desalination plants. Significant reductions in water flow reduce the desalination plant's feedwater supply and lead to more concentrated brine discharges. The desalination plant may also occupy the limited real estate needed to install alternative cooling technologies.

Co-location may create a regulatory loophole. It can be argued that the desalination plant will have no impacts above and beyond the OTC system and that any externalities associated with water intake, i.e., impingement and entrainment, are due to the OTC system. Once the desalination plants are built, however, they may then be used to justify continued use of OTC systems and allow the power plant operator to obtain a site-specific 316(b) exemption. Currently a power plant operator can obtain an exemption from the EPA's 316(b) regulations if he or she can demonstrate that the cost of installing the new technology exceeds the benefits. If the forgone water supply is considered an additional cost of installing an alternative technology, the cost-benefit analysis may favor co-located plants. Thus, allowing desalination plants to piggyback off of power plants using OTC may prolong the life of this technology.

A desalination plant should not be an excuse to continue using an outdated, environmentally damaging technology.

A desalination plant should not be an excuse to continue using an outdated, environmentally damaging technology. In the event that the SWRCB adopts strict OTC regulations, desalination plant operators must plan for the possibility that the co-located power plant will cease operation or reduce water flow significantly. In Huntington Beach, Poseidon has negotiated a contingency plan should the Huntington Beach Generating Station cease operation. If this occurs, Poseidon would have the option to buy the intake and discharge infrastructure but must acquire its own operating permits due to a change in project description (Poseidon Resources 2005a). This contingency, however, does not address the fact that there will no longer be cooling water available for brine dilution. The EIR for the Carlsbad plant, also submitted by Poseidon Resources, offers no such contingency plan (Poseidon Resources 2005b).

Because of the uncertainty associated with OTC systems, the effects of desalination must be assessed independently of the power plant. The California Desalination Task Force's recommendation suggests that regulatory agencies are moving in this direction: "For proposed desalination facilities co-locating with power plants, analyze the impacts of the desalination facility operations apart from the operations of the co-located facilities. This will identify the impacts of the desalination facility operations when there are reductions in cooling water quantities" (CDWR 2003). The CCC has also adopted this approach.

In addition, co-location requires close coordination between two separate entities, the desalination plant and the power plant, thereby introducing additional uncertainty and cost into building and operating the desalination plant. For example, Cal Am, which is proposing to build a desalination plant at the Duke Energy power plant in Moss Landing, has not yet obtained a county permit to build a pilot plant because Duke Energy failed to comply with county wetland mitigation requirements. Duke Energy, which is now selling the site, was required to submit a wetland management plan and pay a $25,000 bond for removing an oil storage tank from their property. Duke Energy failed to pay the bond and must now update the bond assessment, a process that could take months to complete. Cal Am officials feel that these delays are unwarranted given the limited impact of the pilot plant and warn that delays in the constructing the pilot plant will delay project completion.[39] The uncertainty about future operations associated with OTC systems and coordination among separate entities suggests that permitting agencies and the public should apply a higher level of scrutiny to co-located desalination plants.

Public Transparency

It is vital that decisions about siting, building, and operating desalination facilities take account of local conditions, opinions, and sentiment. Open and early access to draft contracts, engineering designs, and management agreements are necessary for public review. Further, contracts with private companies must include provisions about who assumes the risk associated with the project if one or more of the contractors declares bankruptcy, as occurred in Tampa Bay. Adequate comment periods and appropriate public hearing schedules are also necessary to ensure that decisions about desalination plants are fair and equitable.

Environmental Justice Considerations

Most of the proposed desalination plants in California are likely to be located in existing industrial areas to take advantage of infrastructure and local resources. Because low-income populations tend to live in these areas, desalinations plants may have a disproportionate impact on these communities. These communities have traditionally borne significant air-quality impacts from local facilities, higher exposure to noise and industrial chemicals, and truck traffic. When desalination facilities are built as co-located plants, the on-site energy plant may be forced to operate at a higher capacity or continuously, thereby increasing air-quality impacts. Local communities may also suffer as a result of the desalination plant's water-quality impacts; fish may have elevated levels of metals or other toxin, and those who rely on caught fish to supplement their protein intake may be adversely affected. Low-income and people of color may also bear disproportionate effects of increases in water rates (EJCW 2005). The Environmental Justice Coalition for Water recommends several principles on environmental justice and water use:

- State legislatures should establish independent reviews of social, economic, and environmental inequities associated with current water rights and management systems.

- There should be independent review of the social and economic impacts of water development on local communities.

- Local public review and approval should be required for any proposals to introduce private control, management, or operation of public water systems.

- All water and land-use projects should be planned, implemented, and managed with participation from impacted community members.

- Actions are required to clean up pollution of water bodies upon which low-income populations rely for subsistence fishing (EJCW 2005).

[39] Poseidon Resources and Pajaro-Sunny Mesa are planning to build a desalination plant that uses Duke's seawater intake system but is located on the National Refractories site. Although portions of this site have substantial soil contamination, the county approved the permit for a pilot plant without requiring cleanup (Hennessey 2006a). This permit has been appealed to the CCC, who will make a decision in mid June.

Project Review Process in California

Desalination plants are subject to extensive review. However, as we have alluded to above, the regulatory and oversight process for desalination is sometimes unclear and contradictory. Table 9 summarizes the major review processes that apply to desalination projects in California. As this table indicates, as many as 26 state, federal, and local agencies may be involved in the review or approval process for a desalination plant. Adequate review is essential to ensure environmental protection, public health, and appropriate use of our resources. However, it is likely that uncertainty about the project review process acts as a barrier to project development. To ensure that desalination plants are built where and when appropriate, federal, state, and local policies should standardize and clarify these regulations.

Table 9
Overview of Required Permits and Approvals for Desalination Plants in California

Data Sources: CCC 2004, EDAW 2005, Padre Associations, Inc. 2005

Agency	Permit/Approval	Regulated Activity	Project Relevance	Authority
Federal Agencies				
Monterey Bay National Marine Sanctuary	Use permit (possible); National Marine Sanctuaries Act	Disturbance of the seabed; discharge into sanctuary	Intake facility; brine discharge	National Marine Sanctuaries Act
National Marine Fisheries Service	Endangered Species Act, Section 7 Consultation	Impacts to species and habitat that are federally listed or proposed for listing	Desalination plant and associated facilities; brine discharge	Federal Endangered Species Act
National Oceanic and Atmospheric Administration	Consultation with Army Corp of Engineers	Offshore components with potential to affect marine resources	Intake facilities; brine discharge	
	Marine Sanctuary Protection	For projects in national marine sanctuaries	Desalination plant and associated facilities	National Marine Sanctuaries Act
	Marine Mammal Protection Act, Small Take Authorization for Incidental Harassment	For harassment or unintentional take of marine mammals	Intake facility	Marine Mammal Protection Act
State Historical Preservation Office	Section 106 Review and Compliance; National Historic Preservation Act	Impacts to historic and pre-historic resources	Desalination plant and associated facilities	National Historic Preservation Act
U.S. Army Corps of Engineers (ACOE)	Clean Water Act, Section 404 Nationwide Permit 6 and 33	To place fill in navigable waters; to place a structure in navigable waters	Intake facility; pipelines at creek crossings	Clean Water Act, Section 404
	Rivers and Harbors Act, Section 10 Permit			Rivers and Harbors Act, Section 10

Agency	Permit/Approval	Regulated Activity	Project Relevance	Authority
Federal Agencies (Continued)				
U.S. Bureau of Reclamation		Lead agency if federal funding involved		
U.S. Coast Guard	Consultation with Army Corp of Engineers on Section 404 Permit and Section 10 Permit	Review based on potential hazard to navigation	Intake facility	
U.S. Environmental Protection Agency	State Water Resource Control Board has regulatory authority	Power plant cooling water intake; drinking water quality; brine discharge	Co-located facilities; product water	Clean Water Act; Safe Drinking Water Act; National Environmental Policy Act
U.S. Fish and Wildlife Services	Endangered Species Act, Section 7 Consultation	Impacts to species and habitat that are federally listed or proposed for listing	Desalination plant and associated facilities; brine discharge	50 CFR Section 17; Federal Endangered Species Act
State Agencies				
California Coastal Commission	Coastal Development Permit; Consistency with Coastal Zone Management Program	Projects affecting coastal waters; projects requiring federal permits and approvals	Desalination plant and associated facilities	California Coastal Act
California Department of Boating and Waterways	Document Review	Impacts on boating safety	Intake and discharge facility	
California Department of Fish and Game	Stream Alteration Agreement, 1602 Permit	Change or modify lake, stream, or river	Pipelines at creek crossings	California Fish and Game Code, Sections 1601-1607
	California Endangered Species Act, Section 2081 Permit	Impacts to species and habitat that are listed or proposed for listing by California	Desalination plant and associated facilities; intake facilities; brine discharge	California Endangered Species Act
California Energy Commission	CEQA review	Modification of power plant over 50 MW	Co-located plants	Warren-Alquist Act
California Ocean Protection Council				California Ocean Protection Act

Agency	Permit/Approval	Regulated Activity	Project Relevance	Authority
State Agencies (Continued)				
Department of Health Services	Amended Domestic Water Permit; Source Water Assessment and Protection Plan	Domestic Water Amendment	Desalination components	
Department of Parks and Recreation	Approval for facilities within or near state parks		Desalination plant and associated facilities	State Parks Regulations
Department of Transportation	Encroachment Permit	Activities affecting state highway right-of-ways	Pipelines	
Department of Water Resources	Approval	Use of state water conveyance facilities	Product water distribution	
Public Utilities Commission		Regulates water services, rates, and service areas	Plants owned and operated by private entity	Public Utilities Act
San Francisco Bay Conservation and Development Commission (BCDC)	BCDC permit	Placing fill materials; dredging or extracting materials; substantially changing the use of any structure or area; constructing, remodeling, or repairing a structure; or subdividing property or grading land within BCDC's jurisdiction	Desalination plant and associated facilities	McAteer-Petris Act
State Lands Commission	Land Use Lease	Development in tidelands or navigable waterways	Intake facility	California Public Resources Code
State Water Resources Control Board/Regional Control Boards Water Quality	Clean Water Act, Section 401 Water Quality Certification	Activities affecting surface water quality (review of federal permits)	Intake facility; brine discharge	Porter-Cologne Water Quality Control Act; Clean Water Act
	NPDES Permit/Stormwater Runoff	Brine discharge	Brine discharge	Porter-Cologne Water Quality Control Act; Clean Water Act
Local Agencies				
City and/or County/ Local Utilities/ Water Management Districts/ Health Department/ Air Quality District	Varies by local jurisdiction and may include building permits, health department certifications, operating permits, or other types of approvals			

CHAPTER VI
CONCLUSIONS

IN ENERGY-RICH ARID and water-scarce regions of the world, desalination is already a vitally important option. Many areas of the Caribbean, North Africa, Pacific Island nations, and the Persian Gulf rely on desalinated water as a source of municipal supply. In some regions of the world, nearly 100% of all drinking water now comes from desalination – providing an essential and irreplaceable source of water. But the goal of unlimited, cheap fresh water from the oceans continues to be an elusive dream for most of us. Despite all the progress over the past several decades, and despite recent improvement in economics and technology, desalination still makes only modest contributions to overall water supply. By 2005, the total amount of desalinated water produced in a whole year was about as much as the world used in a few hours.

California is seriously considering desalination as a part of its water future, and there is no doubt that plants will be built. We are concerned, however, about desalination's current technological and economic competitiveness, and about the ultimate impacts desalination plants could have along California's coasts. Climate change and a lack of state and local regulatory mechanisms to ensure proper implementation of desalination intensify our concerns.

This report identifies the advantages and disadvantages of desalination that must be carefully evaluated before any plant should be built. In addition, we offer a set of conclusions and recommendations that should be met before desalination facilities are permitted and built.

Perhaps the greatest barrier to desalination remains its high economic cost compared to alternatives, including other sources of supply, improved wastewater reuse, and especially more efficient use and demand management. We do not believe that the economic evaluations of desalination commonly presented to regulators and the public adequately account for the complicated benefits and costs associated with issues of reliability, quality, local control, environmental effects, and impacts on development. In general, significant benefits and costs are often excluded from the costs presented publicly. California should pursue less costly, less environmentally damaging water-supply alternatives first.

Is desalination the ultimate solution to our water problems? No. Is it likely to be a piece of our water management puzzle? Yes. In the end, decisions about desalination developments will revolve around complex evaluations of local circumstances and needs, economics, financing, environmental and social impacts, and available alternatives. We urge that such decisions be transparent, honest, public, and systematic.

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