An Investigation of the Marginal Cost of Seawater Desalination in California

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Abbreviations, Acronyms & Definitions

ADC: Affordable Desalination Coalition

Ann: Annual

Avg: Average or statistical mean

AF: An acre-foot of water or 325,851 gallons, which is enough water to flood one acre of land one foot deep and supply about four single-family households with enough water for one year

AFY: Acre-feet per year

kWh: Kilowatt-hour, or 1,000 watts of energy used for a duration of 1 hour

Marginal Cost: The cost of producing one more unit of a good, or in this report the cost of producing or saving and acre-foot of water. The marginal cost provides a mechanism to compare the cost of different water supply and conservation options on a realistic cost comparison basis.

MG: Million gallons

MGD: Million gallons per day, a 1 MGD facility is theoretically equivalent to 1,120 AFY at 100% capacity for 365 days a year

MMWD: Marin Municipal Water District

NPV: Net present value, a term used to account for the discounted future value of dollars

O&M: Operations and maintenance, this will exclude project design, capital costs and financing

PPM: Parts per million

Executive Summary

There is much interest, but little clarity on the cost of desalinated seawater in California and how it compares to other urban water management options. To address this issue, this investigation collected general information along with costs and production records and cost projections for many prominent seawater desalination facilities and proposed projects in North America and California. Along with many others, this included Tampa Bay, Carlsbad, Santa Barbara, and Marin. These four projects are described and evaluated as case studies in this paper.

The marginal cost of water produced by any specific seawater desalination project will depend on many variables including:

- Site characteristics
- Size of the facility
- Financing cost
- Energy cost
- Water quality conditions for intake seawater
- Environmental mitigation and monitoring costs
- Actual water production
- Connection and pumping costs to existing infrastructure
- Taxes (privately own facilities)
- Profit (privately owned facilities)

Seawater desalination for $800 to $1,000 per acre-foot?

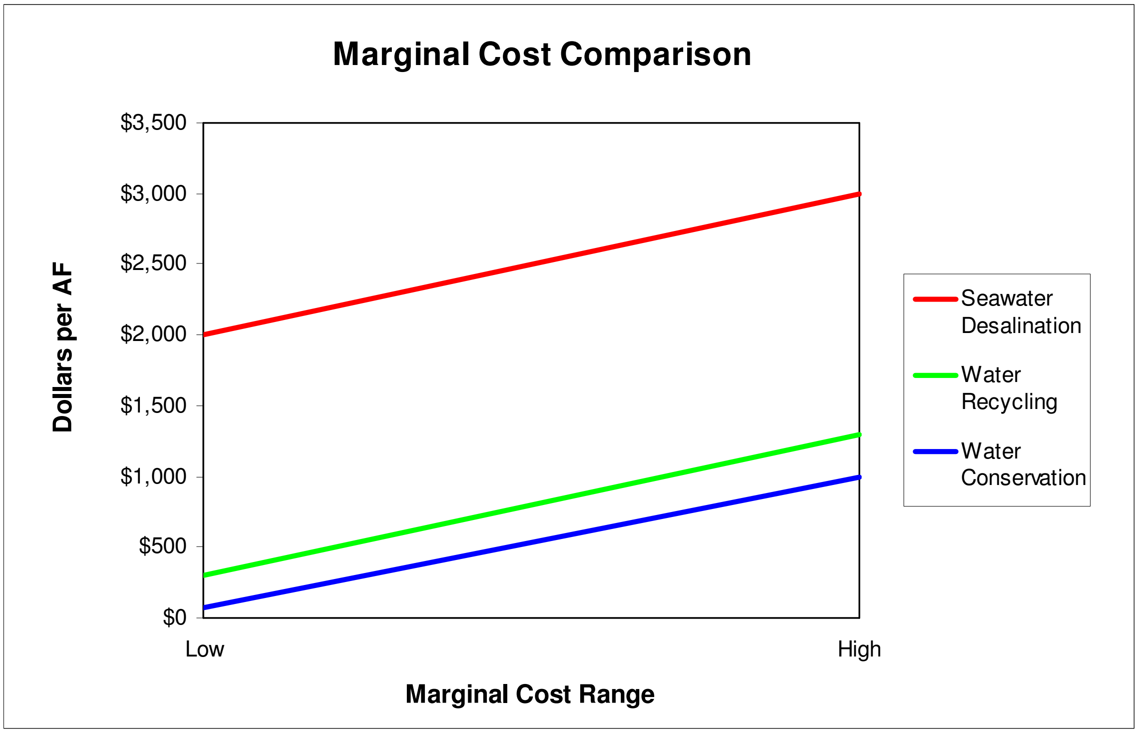
Some advocates of seawater desalination suggest marginal costs of $800 to $1,000 per acre-foot are now possible in California. However, despite a thorough investigation, **this study found no evidence of seawater desalination facilities in North America producing water in that cost range.** This study also found no credible evidence that new seawater desalination projects in California, given local conditions, could produce water in that cost range.

Given the best presently available technology, this investigation found **realistic estimates of the marginal costs for seawater desalination in California will range from a minimum of about $2,000 to $3,000 or more per acre-foot of water produced.**

This compares to typically much lower marginal costs of well under $1,000 per acre-foot for most urban water conservation measures.[1] **Water recycling for urban areas typically costs between $300 and $1,300 per acre-foot.**[2] Both water conservation and recycling appear to be far from fully utilized in California's urban areas.[3]

For comparison, the relative marginal costs in California of seawater desalination, water recycling, and water conservation are shown in Figure 1 below.

Figure 1



While many agencies pursuing seawater desalination cite it as a drought proof supply, as evidenced by the demand reductions by urban consumers in California during a recent series of dry years, it appears many water managers may underestimate demand elasticity during shortages. Behavioral-based demand reductions during shortages can occur at very low cost to ratepayers and society.

Many areas in California are now seriously evaluating and pursuing a suite of promising new water conservation measures such as graywater use and local rainwater harvesting that may be less costly and environmentally beneficial compared to seawater desalination. Low-impact development and integrated watershed and floodplain management practices are also gaining favor that can increase groundwater recharge and locally available water supplies while improving environmental conditions.

A better understanding of the real costs of the various water management options is important to rational decision making and appropriately prioritizing limited funding for the best alternatives for individual water users and society. The realistic costs of seawater desalination need to be more transparent and understood by the public. Proponents of seawater desalination projects should clearly delineate the costs of the projects in the categories identified in this paper. Also the costs of emerging water management alternatives such as graywater use, and rainwater water capturing, low-impact development and integrated watershed and floodplain management practices should be better evaluated for identifying the most cost-effective options for improved water management in California.

Background

California is faced with increasing competition for water supplies. Concern over the possible impacts of climate change further alarms many water managers. As a result, there is increasing interest in seawater desalination, its potential benefits, costs, energy use, and environmental impacts.

Some advocates of seawater desalination suggest the cost has decreased in recent years and is now similar to the cost of other urban water supply options.[4] Private water industry interests view the production and sale of desalinated seawater water as a potentially lucrative business opportunity. Some environmental advocates hope increased use of seawater desalination will reduce present or future water diversions and their impacts on California's rivers, streams, and groundwater basins. Others express concern over the cost, the potential privatization of water supplies, energy use and the environmental impacts, and potential health risks.[5] This investigation focuses exclusively on the cost issue and leaves the other important issues to other analyses.

Numerous new desalination projects are proposed in California and in various stages of development. These include proposed projects in Carlsbad, Huntington Beach, Santa Cruz, Marin County, and Cambria. In the early 1990s, a seawater desalination facility was constructed in Santa Barbara but immediately mothballed without being operated for water production.

The Carlsbad project, at 50 MGD design capacity, is the largest presently proposed project in California and the most progressed within the permitting process. It is proposed by a private corporation, Poseidon Resources, and is subject to less cost transparency than public projects. Since Poseidon Resources is seeking publicly subsidized funding and financing, and indicates a willingness to match the cost of existing water supply options, much interest is presently focused on the realistic cost of water produced by the proposed Carlsbad facility. This analysis evaluates the realistic cost of desalinated water for the proposed Carlsbad and other desalination facilities from which adequate cost records and projections could be obtained.

What Will Large-Scale Seawater Desalination Realistically Cost in California?

With limited exceptions, water agencies and private interests involved in seawater desalination appear reluctant to release verifiable marginal costs analysis for their seawater desalination projects. This has troubled many observers since marginal costs analyses form the basis of integrated water resources planning and rational decision making for water management plans and infrastructure investments.

This project was undertaken to better identify realistic marginal costs of seawater desalination in California and the actual or realistic costs of various categories of costs. These categories are listed below and include facility design, capital, operating, maintenance, energy use, permitting and environmental mitigation and monitoring costs. Ideally, the sub categories of the costs listed below should have been tallied and compared. However, despite considerable effort, it was not possible to obtain detailed and credible enough cost figures for most of the various categories in order to provide a reliable comparison. However, data useful in identifying likely overall marginal costs were obtained and will be used in this analysis.

Cost Categories for Seawater Desalination Projects:

Capital Costs
Land/site acquisition and right-of-way for pipelines
Building construction
Electrical connections
Miscellaneous piping and plumbing
Intake pipes, screens
Prefiltering components
Pumps
Membranes and cartridges
Discharge pipes, diffusers
Facility controls and monitoring equipment
Treated water connection to water distribution system including pipes, pumps, tanks
Construction contingency
Contractor costs – overhead, profit, bonding, insurance, etc
Mitigation, including capital for sensitive area acquisition for protection/environmental mitigation
Taxes (privately owned facilities)

Operations and Maintenance Costs (O&M)
Electricity
Treatment chemicals
Membrane replacement
Pump maintenance/replacement
Plant operator labor
Plant maintenance labor
Solids disposal
Environmental monitoring and mitigation costs
Carbon offsets
Profit (for privately owned facilities)
Taxes (for privately owned facilities)

Miscellaneous Design and Approval Costs
Design fees
Permitting fees
EIR and public process costs

Financing Costs
Financing term and interest rate

In addition to the above noted costs categories, other factors would impact marginal costs, including actual production from the facility compared to design production, and uphill delivery of desalinated water to existing infrastructure for the service area. Since seawater desalination draws its source water at or below sea level, the distribution and delivery of the product water to its targeted service area will require uphill pumping. Service areas with high elevations will require more pumping, and incur the associated higher energy cost for delivering the water to end users.

The Affordable Desalination Collaboration

The Affordable Desalination Collaboration (ADC) is a group of desalination industry advocates and many California water agencies interested in seawater desalination. The organization is chaired and managed by industry advocates and leaders in promoting desalination. Their mission "is to demonstrate affordable, reliable and environmentally responsible reverse osmosis desalination technologies and to provide a platform by which cutting edge technologies can be tested and measured for their ability to reduce the overall cost of the SWRO treatment process." [6]

ADC indicates the cost seawater desalination ranges from around $800 to $1,000 per acre-foot of fresh water produced

The Affordable Desalination Collaboration's website has a test results page with links to numerous spreadsheets with analyses that indicate the cost seawater desalination ranges from around $800 to $1,000 per acre-foot of fresh water produced.[7] According to ADC's CEO and Managing Director, the engineering assumptions, such as optimum membrane feed pressures for the different membranes tested, were based on a pilot project with tests conducted in Port Hueneme, California in 2005 and 2006.[8] The remainder of the **cost figures in the ADC projections were not based on an actual operating facility but instead were estimates and projections**.[9] Given the membership and participants of this group,[10] it is very likely that these figures serve as a primary source of widely circulated suggestions that the cost of seawater desalination is now similar to the cost of other water supply sources. Many interested observers find the prospect of seawater desalination in California at a marginal cost near or below $1,000 per acre-foot highly appealing.

Problems with ADC costs projections

However, a review of ADC's website costs analysis for their theoretical 50 MGD facility found many fundamental flaws with the cost projections and associated assumptions. [11] These include:

- ***Energy Costs is underestimated***

  An energy cost of $0.08/kWh was used for the ADC analysis. This compares with an energy cost of $0.116/kWh determined in two recent independent analyses for the proposed Carlsbad project[12] and $0.12 for the Marin project.[13] Energy is one of the largest components of O&M costs. This represents an underestimate of about 32% for this major cost.

- ***Energy requirement is underestimated***

  The range for the specific energy use assumption in the ADC analyses, which represent the overall energy efficiency of the desalination process, appear unrealistically low. It ranges from a low of 10 kWh/1000 gallons to a high of 14 kWh/1000 gallons of water produced. The ADC tests were a series of short-run tests with new membranes, generally less than a full day run for each test, and the membranes were tested for less than a full year of run time.[14] This does not replicate operating a facility at 100% of design capacity 95% of the time for 365 days per year, which is the assumption of ADC's marginal costs calculations. It also does not reflect performance decline from membrane scaling and clogging during an assumed 6-year membrane life.

  By comparison, the O&M records from the Tampa Bay facility, which operates with warmer temperature and lower salinity feed water than seawater facilities in California can expect, indicate that in 2007, with new membranes, the energy requirement was 9kWh/1000 gallons produced. The energy requirement increased to 15.9kWh/1000 gallons in 2009 with membranes that were less than three years old.[15] The Santa Barbara facility, located near the site of the ADC tests, projects an energy requirement of 17.1kWh/1000 gallons produced with a refurbished and modernized facility.[16] The proposed Marin facility projects an energy requirement of 15kWh/1000 gallons to 16kWh/1000 gallons per water produced during drought periods with a new state-of-the-art facility using feed water with generally lower salinity and warmer temperatures than typical California seawater.[17] Table 1 provides an energy use comparison.

Table 1
Energy Requirement Comparison

Facility	ADC	Tampa Bay	Santa Barbara	Marin
Water Temp (°F)	53.6 to 64.4	86	56 - 65	62.7 (avg)
Salinity (ppm)	31,668	29,000	34,000	21,700 (avg)
kWh/1000 gal	10 to 14	15.9	17.1	15 to 16

- ***Capital costs are underestimated***
  The capital costs in the ADC projections per MGD of capacity are much lower than other completed or proposed projects. Table 2 below provides a comparison of capital cost per MGD of design capacity for various facilities discussed in this paper. The ADC high estimate is 17% lower than the actual capital cost of the Tampa Bay facility. As noted, the Tampa Bay location has advantages for feed water quality compared to California facilities. These advantages, subsequently discussed in this paper, would increase capital costs for a comparable facility in California. The capital cost for the proposed Carlsbad facility in California is presently 41% higher than the ADC high estimate.

Table 2
Capital Cost per MGD Design Capacity (2009 Dollars)

Project	ADC (Low Estimate)[18]	ADC (High Estimate)[19]	Tampa Bay[20]	Santa Barbara[21]	Carlsbad	Marin[22]	Marin[23]
Design Capacity	50 MGD	50 MGD	25 MGD	6.7 MGD	50 MGD	10 MGD	5 MGD
Capital Cost (Millions)	$239.3	$313.8	$190.3	$59.6	$534	$131.4	$88.6
$ (Millions)/MGD	$4.8	$6.3	$7.6	$8.9	$10.7	$13.1	$17.7

- ***Intake water salinity lower than average seawater***
  Average intake water salinity of 31,688 parts per million (ppm) was reported for the ADC tests and cost projections.[24] This compares to 33,520 ppm for the proposed Carlsbad site[25] south of Port Hueneme and 34,000 ppm for the Santa Barbara site[26] just north of Port Hueneme. Given present membrane technology, the higher source water salinity for the Carlsbad and other California coastal sites will result in either higher product water salinity or the selection of

membranes with lower water permeability, which correlates with lower salt permeability.[27] Membranes with lower water permeability require higher feed water pressure, which will result in higher energy use. [28]

- ***Unrealistic water production assumptions***
  The ADC cost projections are based on unrealistic water production assumptions of operating at 100% of design capacity 95% of the time for 356 days per year. This is a production level that the best comparative example in North America, the Tampa Bay facility discussed below, has not come close to achieving on an annual basis. As noted above, the ADC tests were a series of short-run tests with new membranes, generally less than a day long run for each test, and the membranes were tested for less than a full year of run time.[29] This does not reflect operating a facility at 100% of design capacity for 95% of the time, 365 days per year. It also does not reflect performance decline from membrane scaling and clogging during an assumed 6-year membrane life. Even with the best known chemical and physical maintenance techniques, reverse osmosis membranes are known to experience a performance decline as they age and suffer increased clogging and scaling. Declining performance as membranes age will lower water production or require increased design capacity, either of which would increase marginal costs over the life of the project.

- ***O&M costs underestimated***
  The ADC analyses have unrealistic overall O&M costs ranging from a low of $496 per acre-foot to a high of $616 per acre-foot. A 2009 report by Carollo Engineers determined the O&M costs for a rehabilitated and modernized Santa Barbara facility would be $1470 per acre-foot.[30] This is more than double the ADC high cost projection. Costs based on a pilot project by Kennedy/Jenks Consultants for a proposed new, state-of-the–art 10 MGD facility in Marin projected O&M marginal costs of $1,107 per acre-foot for a facility being operated at 100% capacity.[31] The Marin facility is proposed to be sited along San Rafael Bay in the San Francisco Bay. As a result of bay water mixing with runoff from inland California, in most years the Marin facility would be operating with significantly lower feed water salinities and frequently warmer feed water temperatures than typical California seawater. This should result in lower O&M costs for the Marin facility compared to projects using typical California seawater, yet the O&M cost projections are nearly double the highest ADC projected cost.

- ***Inaccurate discount rate for net present value calculations***
  The net present value calculations in the ADC spreadsheets do not accurately account for the discount rate as the difference between the rate of inflation and the interest rate for financing. Rather than subtracting the assumed inflation rate of 3% from the financing rate of 5% for a 2% discount rate, which is standard economics practice, the ADC calculations use a 5% discount rate. Using the proper discount rate actually lowers the long-term capital costs, but this issue is more than offset by underestimated initial capital cost assumptions and other underestimated cost assumptions.

- ***Costs estimates do not include many necessary costs***
  The marginal costs do not include any land cost for citing a facility, costs for an intake water structure, brine discharge structure, or necessary improvements to deliver the desalinated water to a local distribution system for end users.[32] The marginal costs assumes that a facility will be co-located with a power generating plant and share the generating plant's cooling intake water facility, which will not always be possible.[33] In addition, the ADC assumptions do not account

for high capacity electrical power lines that will often be necessary to provide adequate power supply to desalination facilities. Cost also do not include expenses for administrative, laboratory, legal, reporting or management.[34]

- ***Costs figures do not include environmental mitigation and monitoring***
  The ADC marginal costs figures do not account for environmental permitting costs, or substantial environmental mitigation and monitoring costs that can be expected for new facilities as a condition of environmental permits.

A more thorough analysis of all the ADC assumptions and calculations may reveal additional problems with the projections, but this is sufficient to illustrate that these figures are not a reliable indication of realistic seawater desalination costs in California. ADC's CEO/Managing Director appears aware that these projections are based on many "best case" assumptions, some of which may no longer be valid.[35] However, the figures remain on ADC's website at the time of this writing as valid projections for seawater desalination cost. The figures appear to provide a reference point as valid cost estimates for desalinated seawater for many interested parties, including agencies considering or planning seawater desalination facilities. Therefore, it is important to note the limitations of the ADC cost projections.

Case Studies

To better assess the realistic costs of seawater desalination in California, this investigation collected actual and projected cost and water production data on a broad range of constructed and proposed desalination projects in California and North America. Despite considerable effort, in many cases, very limited data were available. However, sufficient data were collected to provide the following four case studies and to develop a realistic marginal cost estimate range for seawater desalination in California.

Marin Project

The Marin Municipal Water District (MMWD) in the San Francisco Bay Area recently approved an EIR and issued a Notice of Determination to build a 5 MGD desalination facility expandable to 15 MGD. MMWD is now moving forward with detailed design work and permitting for the facility.

The Marin facility is proposed to be located on land already owned by MMWD along San Rafael Bay in the northern part of San Francisco Bay. The San Francisco Bay experiences water temperatures and salinities that range from typical seawater near the Golden Gate to less saline, and often warmer estuarine conditions further upstream in the estuary. The water quality conditions in San Rafael Bay vary widely based on tide cycles, wind conditions, season and runoff conditions for the very large watershed that includes most of California's Central Valley and the Sierra Nevada mountains. As a result of bay water mixing with freshwater from inland California, in most years the facility would operate with feed water with significantly lower salinity compared to California seawater. There would also be periods when water temperatures would be warmer than California seawater.

MMWD conducted a desalination pilot project to better understand conditions for the proposed site and optimum facility design parameters. A water quality sampling program at the proposed site was conducted between March 2005 and April 2006.[36] This was during a period of very wet winters with serious flooding in California. As a result, freshwater outflow through San Francisco Bay was heavier than occurs in many years, and particularly during drought years. Salinity readings recorded during the pilot study ranged from a high of 29,000 ppm to a low of 2,500 ppm, with an average of 21,700 ppm.[37] The area is documented to have salinities of up to 32,000 ppm.[38] Water temperatures recorded during the pilot study ranged from a high of 69.8 degrees F to a low of 50 degrees F with and average of 62.7 degrees F. [39] The maximum temperature documented is 71.1 degrees F. [40]

Pilot program data were used to develop capital and operating costs projections for a 5 MGD and 10 MGD facility that could be expanded to 15 MGD. MMWD did not release an actual marginal cost analysis for the 5 MWD or 10 MGD facility. Furthermore, MMWD did not publicly release any capital or O&M cost projections for a 15 MGD facility, despite board approval of the facility in 2009.

A recent independent analysis based on MMWD's publicly released cost figures determined the marginal costs of the 5 MGD facility to be $3,600 per acre-foot of product water and the 10 MGD facility to be $2,903 per acre-foot.[41] These marginal costs figures were in nominal dollars to provide a better comparison to water conservation program costs publicly released by MMWD. These marginal costs did not include a 15% construction contingency fee identified in MMWD reports.

For this analysis, the marginal costs are updated to include the 15% construction contingency fee and the financing costs are discounted back to net present value terms in 2009 dollars. The result is a marginal cost of $3,009 per acre-foot for the 5 MGD facility and $2,430 for the 10 MGD facility. Table 3 below provides costs for various categories that are the basis of these marginal costs figures.

Table 3
Marginal Cost for Marin's Proposed Desalination Facility

Facility Capacity	Capital Cost (Millions)	Annual Cap Cost (Millions)	Ann Op Cost at 100% (Millions)	Projected Avg Annual Op Cost[42] (Millions)	Total Avg Ann Cost (Millions)	Avg Ann Production[43] (AF)	Marginal Cost per AF
5 MGD	$111.2	$5.0	$6.5	$4.1	$9.1	3,024	$3,009
10 MGD	$173.4	$7.4	$12.4	$6.8	$14.7	6,048	$2,430

The capital cost figures include the costs of connection to MMWD's water distribution system. The capital cost figures reflect shared use of an existing pier with the nearby Marin Rod and Gun Club for part of the feed water intake structure to reduce the cost of this facility. The rejected brine would be discharged with wastewater from the nearby Central Marin Sanitation Agency, reducing the cost of a discharge structure.

Unlike the ADC energy costs projection of $0.08/kWh noted above, MMWD assumes a $0.12/kWh average energy cost in their O&M projections.[44]

It should also be noted that these marginal cost figures are based on water production with the management scheme indicated in MMWD's EIR for the facility.[45] Under the proposed management scheme, the facility would be operated at 50% of capacity during wet years, and 100% of capacity during drought years to reduce costs, energy use, and environmental impacts. This analysis assumed 23 wet years of production for every 2 years of drought production. The operating costs were reduced to reflect the reduced production in most years. Operating the facility at 100% capacity in all years would result in a marginal cost several hundred dollars lower, since the capital costs would be spread over higher water production and the facility would produce more water during conditions of more favorable intake water quality on San Francisco Bay during wet years. However, it would also result in higher overall costs to ratepayers for water produced unnecessarily in wet years when adequate supply already exists for the service area.

Tampa Bay Project
The largest facility now functioning in North America is the 25 MGD Tampa Bay project, which began operation in 2003. The project has a troubled history. Shortly after beginning operations, serious problems developed which required closing the facility and undergoing a major rehabilitation to correct design and construction flaws. Rehabilitation was completed and water production resumed in 2007. Since the Tampa Bay project is an actual operating facility, it provides information useful for assessing the cost of seawater desalination. Using Tampa Bay as a base case, operating conditions can be adjusted to reflect local conditions in California to provide a more accurate projection of realistic costs for seawater desalination facilities in California.

A recent independent analysis determined the marginal costs of water actually produced at the Tampa facility since 2003 is $1,826 per acre-foot.[46] The results of the analysis are summarized in the following tables. Tampa Bay Case 1 in Table 4 below was based on a total capital cost of $158 million financed 30 years at 5.2%, and an average of 7-year O&M costs and water production from all seven operating years from 2003 through 2009.

Table 4
Tampa Bay Case 1

Total Capital Cost	Ann Cap Cost	Avg Ann O&M	Avg AF/Yr Produced	Marginal Cost/AF
$158 Million	$7,250,167	$9,620,560	9,240	**$1,826**

Tampa Bay Case 2 in Table 5 below was based on a total capital cost of $158 million financed 30 years at 5.2%, and an average of 2-year O&M costs since completion of rehabilitation and water production for 2008 and 2009.

Table 5
Tampa Bay Case 2

Total Capital Cost	Ann Cap Cost	Avg Ann O&M	Avg AF/Yr Produced	Marginal Cost/AF
$158 Million	$7,250,167	$16,953,837	20,173	**$1,200**

Table 6 below shows that if the Tampa Bay facility was constructed with 2009 dollars and experienced for the 30-year life of the project the same operating costs and production the facility actually experienced during its first sever years, the marginal costs of water produced will be $1,961.

Table 6
Tampa Bay w/2009 Cap Cost and Case 1 assumptions

Total Capital Cost	Ann Cap Cost	Avg Ann O&M	Avg AF/Yr Produced	Marginal Cost/AF
$190.3 Million	$8,495,447	$9,620,560	9,240	**$1,961**

Table 7 below shows that if the Tampa Bay facility was constructed with 2009 dollars and experienced the same operating costs and production levels for the 30-year life of the project as the facility actually experienced in the two years since completion of the major rehabilitation, the marginal costs of water produced would be $1,262.

Table 7
Tampa Bay with 2009 Cap Cost and Case 2 Assumptions

Total Capital Cost	Ann Cap Cost	Avg Ann O&M	Avg AF/Yr Produced	Marginal Cost/AF
$190.3 Million	$8,495,447	$16,953,837	20,173	**$1,262**

The marginal costs figure of $1,262 per acre-foot is based on the actual costs and performance of an actual, full-scale facility and is only about 30% higher than the high marginal cost estimate by ADC. However, **it is important to note numerous costs differences between this facility and California facilities.** The Tampa Bay energy cost thus far is lower then expected energy costs in California, feed water is much warmer than in California, the feed water salinity is lower, and the geography of the service area is much flatter so less energy will be required to pump the water produced uphill to end users. It is also important to note that the two years of operations would not reflect potentially declining membrane performance as they age and reach the end of their operating life, which is generally assumed to be six years. These important factors that add significantly to the cost of a project in California will subsequently be discussed in more detail in this paper.

Table 8 below is based on operating records provided by Tampa Bay Water and show water production and energy use since the Tampa facility was initially completed in 2003.

Energy at $0.04/kWh?
Original cost projections for the Tampa Bay project assumed a very low electrical cost of $0.04/kWh.[47] However, as indicated in Table 8, **recent records obtained from Tampa Bay Water document actual energy cost of $0.069/kWh in 2004 rising to $0.096/kWh in 2009.**[48]

Also note that the kWh's of energy consumption per 1,000 gallons of water produced rapidly increases after the installation of new membranes. This occurred after completion of the facility in 2003 and was exacerbated by inadequate pretreatment systems. However it occurs again, but to a lesser extent, after upgrading the pretreatment systems and replacement of the membranes in 2006. This appears indicative of a decline in membrane performance that can be expected as the membranes age, even with the best pretreatment, chemical, and physical flushing maintenance processes in place. It demonstrates that projections of desalination energy consumption and production levels based on short-term trials, as in the ADC projections previously discussed, are not realistic for long-term operation performance.

Table 8
Tampa Bay Desalination Energy Use Analysis[49]

Fiscal Year	Energy Use kWh/MG	Total Energy use kWh	Water Production (MG)	Energy Cost	Avg Energy Cost per MG Produced	Avg Energy Cost $/kWh	Energy Consumption kWh/1000 gal
2003		NA	2,680.53	$1,398,349.08	$521.67	NA	NA
2004	23,010	39,792,325	1,729.34	$2,772,641.73	$1,603.29	$0.069678	23.01
2005	34,680	9,156,107	264.02	$826,440.86	$3,130.22	$0.090261	34.68
2006	NA	1,234,519	0.00	$99,110.21	NA	$0.080282	NA
2007	8,995	29,279,472	3,255.04	$2,623,705.29	$806.04	$0.089609	9.00
2008	13,407	98,695,350	7,361.40	$8,282,058.69	$1,125.07	$0.083915	13.41
2009	15,923	92,122,660	5,785.61	$8,843,750.00	$1,528.58	$0.096000	15.92

Use of preheated feed water from power plant discharge
The Tampa facility is co-located with a power generation project and uses the power plant's cooling water discharge as warm feed water for the desalination facility. This reduced the capital cost of the facility and provides heated feed water that reduces operating costs. Records obtained from Tampa Bay Water indicate an average feed water temperature of 86 degrees F. Seawater water temperatures in Southern California average around 55 to 60 degrees F.[50] Cooler feed water temperatures have a substantial impact on energy use for seawater desalination. According to membrane manufacturers, the general rule is a 3% increase in energy use for each 1.8 degree F drop in feed water temperatures.[51] New regulations for once-through cooling water in California will have the effect of prohibiting the shared use of warmed water discharged from the cooling systems of power plants after 2017.[52]

Feed water salinity is lower than average seawater
The Tampa facility is located where it experiences lower feed water salinity due to mixing with land-based freshwater inflows. The Tampa Bay facility has feed water with an average salinity of 29,000 ppm.[53] This compares to typical seawater salinity of 32,000 ppm to 35,000 ppm. Intake water salinity at the proposed Carlsbad site in California averages 33,520 ppm.[54] Given present membrane technology, the higher source water salinity for most California sites will result in either higher product water salinity or the selection of membranes with lower water permeability, which correlates with lower salt permeability.[55] Membranes with lower water permeability require higher feed water pressure, which will result in higher energy use.[56] Membranes used in higher

feed water salinities may also experience a more rapid performance decline compared to membranes used in areas with lower salinities.

Since the Tampa facility operates with lower salinity and warmer seawater intake temperatures than experienced on California, the costs should be expected to be significantly higher in California.

Santa Barbara Project

In 1992, a 6.7 MGD facility was completed in Santa Barbara at a capital cost of $34 million[57] ($59.6 million in 2009 dollars). The facility was mothballed four months after completion and since that time has not been operated for water supply production. After several original partners withdrew from further participation in the project, some of the components were removed and sold. The remaining facility has been maintained by the City of Santa Barbara in a mothballed state for a cost of about $100,000 per year.[58] A recent detailed engineering analysis of the facility by Carollo Engineers determined it could be rehabilitated with more up-to-date technology and reactivated for $20.2 million. The result would be a facility with a 2.8 MGD capacity.[59]

The 2009 Carollo report for Santa Barbara determined the O&M cost of a rehabilitated facility, excluding past and rehabilitation capital cost, would be $1,470 per acre-foot of water produced.[60] Energy costs were based on September 2008 pricing for the city of $0.086/kWh.[61] This may not be realistic for future energy costs as evidenced by the actual 2009 energy cost for the Tampa Bay project of $0.096/kWh[62] and projected energy costs for the proposed project in Marin of $0.12/kWh and Carlsbad of $0.116/kWh.

It is important to note that even with the potentially low energy cost assumption, the O&M cost alone for a rehabilitated and modernized facility in Santa Barbara is projected to be $1,470 per acre-foot of water produced. As is evidenced by past capital costs for the Santa Barbara facility and the figures for the Marin facility in Table 3, the capital cost will result in a total marginal cost well above $2,000 per acre-foot of water produced if the facility is brought back into operation.

Carlsbad Proposed Project

Poseidon Resources is a private corporation working to develop a 50 MGD seawater desalination facility in Carlsbad, California. Poseidon projects a $534 million capital cost for the proposed 50 MGD facility.[63] O&M costs and a marginal cost analysis were not publicly released. There has been considerable interest in the realistic marginal cost of water for this proposed facility. But since the proposed project is privately managed, there is no requirement for cost transparency.

A recent independent study examined costs figures from the Tampa Bay facility and adjusted the costs for local conditions at the proposed Carlsbad site.[64] In order to reflect a reasonable range of uncertainty with assumptions and cost variables, four cases of marginal costs with a range of assumptions were developed for the proposed Carlsbad project. Average energy cost for the Carlsbad facility was assumed to be $0.116/kWh,[65] which is consistent with two independent analyses[66] and differs from Poseidon Resources' estimate of $0.075/kWh figure.[67] All four cases are expressed in net present value terms in 2009 dollars. The four cases along with a summary of the assumptions in each case are listed below. Interested readers are referred to the report "Marginal Cost Analysis for the Proposed Carlsbad Project" for a full description of the analytical techniques and assumptions in the four Carlsbad cases.[68]

As shown in Table 9, **if the proposed Carlsbad desalination project performed at the same level as the Tampa Bay facility has performed over its seven year operational life, the marginal cost of water produced by the Carlsbad facility would be $3,507 per acre-foot.**

Assumptions for Carlsbad Case 1 in Table 9:

- Based on Tampa Bay Case 1 with capital cost overruns, 7-year average production and O&M costs
- Financing was assumed to be 30 Years at 5.2%
- The energy cost was adjusted to $0.116 per kWh, which is the likely minimum energy cost as determined by two independent studies[69]
- A modest 5% profit on O&M, but not capital costs was assumed to begin in year eight
- Warm intake water from the nearby Encina Power Station once-through cooling water discharge was assumed to continue through 2017
- A cost of $15 per metric ton of carbon dioxide emitted for power consumption was added as a carbon mitigation cost
- Federal. state, and local taxes for a private facility not included

Table 9
Carlsbad Case 1

Ann Cap Cost	Avg Ann O&M	Energy Cost Adj	Temp Impact Adj	Carbon Offset Adj	Avg AF/Yr Produced	Profit	Marginal Cost/AF
$35,196,267	$22,941,119	$2,714,217	$3,345,999	$619,046	18,480	$1,220,627	**$3,507**

As shown in Table 10, if the proposed Carlsbad project does not encounter the same operational problems experienced by the Tampa Bay facility, and functions and produces water at the rate of the post-rehabilitated Tampa Bay facility for its 30-year life, the marginal cost would be $2,175 per acre-foot.

Assumptions for Carlsbad Case 2:

- Based on Tampa Case 2 above with capital cost overruns, 2-year average production and O&M
- Financing was assumed for 30 Years at 5.2%
- The energy cost was adjusted to $0.116 per kWh
- A modest 5% profit on O&M, but not capital cost, was assumed to begin in year eight
- Warm intake water from the nearby Encina Power Station was assumed to continue through 2017
- A cost of $15 per metric ton of carbon dioxide emitted for power consumption was added as a carbon mitigation cost
- Federal, state, and local taxes for a private facility not included

Table 10
Carlsbad Case 2

Ann Cap Cost	Avg Ann O&M	Energy Cost Adj	Temp Impact Adj	Carbon Offset Adj	Avg AF/Yr Produced	Profit	Marginal Cost/AF
$35,196,267	$37,607,673	$6,547,964	$7,086,827	$1,311,139	40,347	$1,898,956	**$2,175**

Two additional cases provide marginal cost results if the proposed Carlsbad project does not incur capital cost overruns equivalent to the capital cost overruns experienced by the Tampa Bay project.

Assumptions for Carlsbad Case 3 in Table 11:

- Based on Tampa Bay Case 1 with 7-year average production and O&M
- $534 million capital cost with no cost overruns
- Financing was assumed for 30 years at 5.2%
- The energy cost was adjusted to $0.116 per kWh
- A modest 5% profit on O&M, but not capital cost, was assumed to begin in year eight
- Warm intake water from the nearby Encina Power Station was assumed to continue through 2017
- A cost of $15 per metric ton of carbon dioxide for power consumption emitted was added as a carbon mitigation cost
- Federal, state, and local taxes for a private facility not included

Table 11
Carlsbad Case 3

Ann Cap Cost	Avg Ann O&M	Energy Cost Adj	Temp Impact Adj	Carbon Offset Adj	Avg AF/Yr Produced	Profit	Marginal Cost/AF
$24,503,730	$22,941,119	$2,714,217	$3,345,999	$619,046	18,480	$1,220,627	**$2,929**

The Carlsbad Case 4 assumptions in Table 12 represent a suite of all best-case assumptions for the proposed facility. Under this scenario, the marginal cost is $1,910 per acre-foot. However, this does not include taxes on a private facility. It also assumes financing at low interest rate generally only available to public facilities.

Assumptions for Carlsbad Case 4 in Table 12:

- Based on Tampa Bay Case 2 with 2-year average production and O&M
- $534 million capital cost with no cost overruns
- Financing was assumed for 30 Years at 5.2%
- The energy cost was adjusted to $0.116 per kWh
- A modest 5% profit on O&M, but not capital cost, was assumed to begin in year eight
- Warm intake water from the nearby Encina Power Station was assumed to continue through 2017

- A cost of $15 per metric ton of carbon dioxide emitted for power consumption was added as a carbon mitigation cost
- Federal, state, and local taxes for a private facility not included

Table 12
Carlsbad Case 4

Ann Cap Cost	Avg Ann O&M	Energy Cost Adj	Temp Impact Adj	Carbon Offset Adj	Avg AF/Yr Produced	Profit	Marginal Cost/AF
$24,503,730	$36,607,673	$6,547,964	$7,086,827	$1,311,139	40,347	$1,898,956	**$1,910**

Another method of projecting marginal costs for the Carlsbad project is to combine the Carlsbad capital costs of $534 million with the recently released operating costs projections for a rehabilitated and modernized Santa Barbara seawater desalination facility discussed in the above section. The result is provided in Table 13 below, along with a range of financing costs and their impact on the marginal costs. A February 26, 2010, Research Update by Standards & Poor's assigned Poseidon Resources a BBB- credit rating.[70] A rating any lower would be considered junk bond status. Public agencies with tax power or rate assessment revenue streams generally obtain long-term financing for capital projects in the 5% range. Since Poseidon Resources is a private corporation with a BBB- credit rating, its ability to obtain financing at low public interest rates is in question. Therefore, a range of interest rates from 5% to 10% were included in the analysis.

Table 13
Carlsbad Marginal Costs Analysis Using Santa Barbara Operating Costs

Interest Rate	Annual Cap Cost[71]	Actual Production, % of Design Capacity	Actual Production, afy	Marginal Cost per af for Cap Cost Only	Santa Barbara O&M Costs/afy	Total Marginal Cost per af
5%	$23,887,708	100%	56,007	$427	$1,470	$1,897
5%	$23,887,708	90%	50,406	$474	$1,470	$1,944
5%	$23,887,708	80%	44,806	$533	$1,470	$2,003
7.5%	$32,844,475	100%	56,007	$586	$1,470	$2,056
7.5%	$32,844,475	90%	50,406	$652	$1,470	$2,122
7.5%	$32,844,475	80%	44,806	$733	$1,470	$2,203
10%	$43,113,726	100%	56,007	$770	$1,470	$2,240
10%	$43,113,726	90%	50,406	$855	$1,470	$2,325
10%	$43,113,726	80%	44,806	$962	$1,470	$2,432

This costs evaluation method does not provide for any capital cost overruns, profit or taxes on the capital or O&M costs, or for any ongoing carbon offset costs to provide a carbon neutral project as stated by Poseidon Resources on its website. Private facilities are subject to taxes that are generally not applicable to publicly owned and operated facilities. These can include property, sales, and income taxes. As evidence of the potential tax assessment on private facilities, Poseidon Resources has been negotiating with the City of Huntington Beach on tax assessment issues.[72] Taxes are costs that will be passed along to ratepayers and will increase the marginal costs of a project. These additional costs can be expected to increase the marginal cost by 5% to 10% or more.

All of the various analytical approaches suggest a marginal cost for the Carlsbad facility of at least around $2,000 per acre-foot in the best case scenarios. The marginal cost ranges as high as around $3,507, which is based on the actual costs of the Tampa Bay facility, adjusted for conditions at the Carlsbad site, after seven years of Tampa Bay's 30-year operating life.

The Comparative Marginal Costs for Water Conservation and Recycling

Although not the primary focus of this analysis, for a comparison basis, well-accepted marginal costs are provide for a range of water conservation measures and water recycling programs. These are important as a comparison point for seawater desalination costs and a primary reason for developing marginal costs. A recent comprehensive study of the marginal costs of well-accepted conservation measures was funded by the CALFED Bay-Delta Program. It found that water conservation savings from a broad range of measures can be obtained for a cost of well under $1,000 per acre-foot.[73] The 2009 California Water Plan published by the Department of Water Resources lists the recycled water marginal costs for most California urban areas ranging between $300 and $1,300 per acre-foot.[74]

While it remains uncertain if the often optimistic and unproven marginal costs for seawater desalination in the analysis above can be obtained, the marginal costs for water conservation and recycling programs are well-proven with a large number of functioning projects in California.

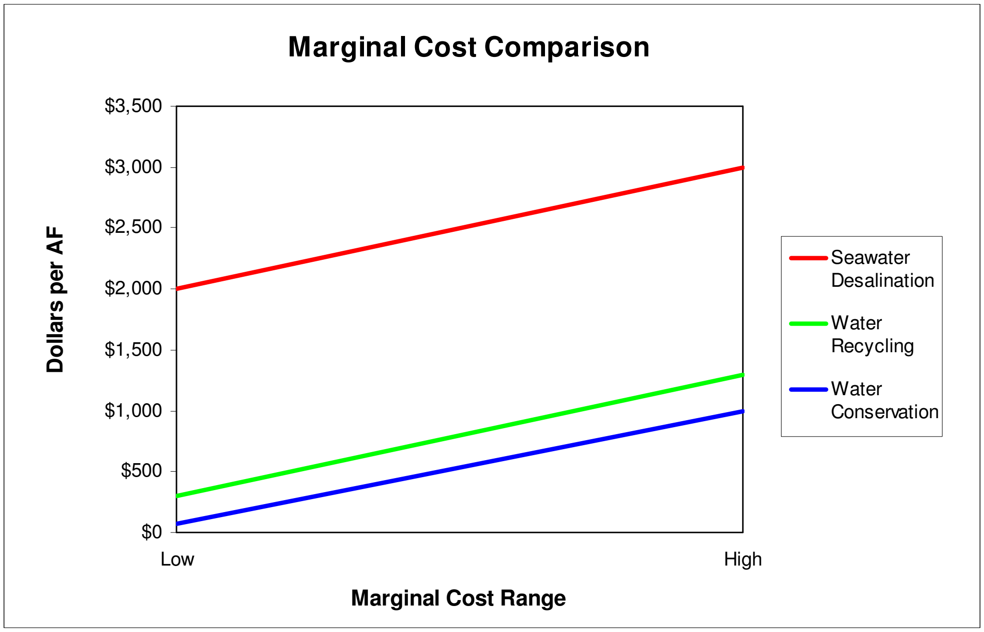
Conclusion

It appears that realistic estimates of seawater marginal costs in California given current technology will range from a low of about $2,000 to $3,000 or more per acre-foot depending on local variables such as the site characteristics and cost, size of the facility, financing cost, energy cost, local intake water quality conditions, environmental mitigation costs, actual water production, and the cost of a connection and pumping to existing infrastructure.

This compares to much lower marginal costs of generally well under $1,000 per acre-foot for water conservation measures[75] and generally $300 to $1,300 per acre-foot for water recycling.[76] Both of these options appear to be far from fully utilized in California's urban areas.[77]

The relative marginal costs in California of seawater desalination, water recycling, and water conservation are shown in Figure 1 below.

Figure 1



While many agencies pursuing seawater desalination cite it as a drought-proof supply, as evidenced by the demand reductions by urban consumers in California during a recent series of dry years, it appears many water managers may underestimate demand elasticity during shortages. Behavioral-based demand reductions during shortages can occur at very low cost to ratepayers and society.

Many areas in California are now seriously evaluating and pursuing a suite of promising new water conservation measures, such as graywater use and local rainwater harvesting, which may be less costly and environmentally beneficial compared to seawater desalination. Low-impact development and integrated watershed and floodplain management practices are also gaining favor that can increase groundwater recharge and locally available water supplies while improving environmental conditions.

A better understanding of the real costs of the various water management options is important to rational decision making and appropriately prioritizing limited funding for the best alternatives for individual water users and society. The realistic costs of seawater desalination need to be more transparent and understood by the public. Proponents of seawater desalination projects should clearly delineate the costs of the projects in the categories identified in this paper. Also the costs of emerging water management alternatives such as graywater use and rainwater water capturing, low-impact development and integrated watershed and floodplain management practices should be better evaluated for identifying the most cost-effective options for improved water management in California.

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About the Author:
James Fryer has over 20 years of experience working on freshwater, estuarine, and marine conservation policies, programs, and projects. He has produced numerous papers and reports on water management policies, practices, and economics. He was the head of Marin Municipal Water District's water conservation programs in the 1990s. In subsequent work with the NGO community in the Florida Keys, he directed coral reef and water quality monitoring programs. He helped establish the Tortugas Ecological Reserve, a 191 square nautical mile, and largest marine protected area in U.S. continental waters while serving on the Florida Keys National Marine Sanctuary Advisory Committee. He developed a conservation planning GIS analysis of the Indian River Lagoon watershed, a 156-mile stretch of coastal lagoons and surrounding watershed in Southeast Florida, considered the most biologically diverse estuary in North America, and served on the Indian River Lagoon National Estuary Program Advisory Committee. He also assisted the Florida Dept. of Environmental Protection in the development of statewide water conservation plans for Florida. In 1997, he served on the U.S./South Africa Bilateral Commission sent to South Africa to assist the Mandela government with watershed and water resources planning. In 1996 he served as an advisor to the British Columbia Water and Wastewater Association for development of a regional planning effort. He has a M.S. in Environmental Management from the University of San Francisco where his thesis project was developing an Integrated Floodplain Management model for the San Francisco Bay-Delta watershed. He is an experienced river runner, scuba diver and sailor and recently returned to California after spending the previous five years on a global sailing voyage.

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Endnotes

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[5] For more information on these issues see Residents for Responsible Desalination at: http://R4RD.org/
Also see: www.marinwatercoalition.org
www.desalresponsegroup.org
www.foodandwaterwatch.org
www.environmentnow.org
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[9] Personal communication with John MacHarg, March 3, 2010.
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[14] See: http://www.affordabledesal.com/home/test_data.html
[15] Figures provided by and derived from operational records supplied by Tampa Bay Water in response to a request for public records in the fall of 2009. Records received from Tampa Bay Water include: Annual Desalination Budget Reports for FY 2003 through 2009, Desalination Product Water Production Report for 2003 through 2009, kWh energy usage per MG product water, Desalination Construction Cost by Major category spreadsheet, intake water temperature and salinity tables and graphs. There is more information on this issue in Tampa Bay section of this report.
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[18] The 2006 capital cost figures were adjusted to 2009 dollars to provide a more level comparison basis with the capital costs of other facilities.
[19] The 2006 capital cost figures were adjusted to 2009 dollars to provide a more level comparison basis with the capital costs of other facilities.
[20] The Tampa Bay capital cost figure of $158 million ($110 million in 2002 and $48 million in 2007) was adjusted to $190.3 million in 2009 dollars to provide a more level comparison basis with the capital costs of other facilities.
[21] The 1991 capital cost figure of $34 million was adjusted to $59.6 in 2009 dollars to provide a more level comparison basis with the capital costs of other facilities. The original design capacity of 6.7 MGD was used to reflect the original capital cost per MGD design capacity.
[22] The distribution system improvement cost of $42 million was deducted from the total capital cost capital costs of $173.4 for a 10 MGD facility. These figures are from MMWD staff Excel spreadsheet "Desalination Conceptual Cost Estimate" Updated October, 23, 2008 and based on costs in "Seawater Desalination Pilot Program." Marin Municipal Water District Engineering Report, Kennedy/Jenks Consultants. January 26, 2007.

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[36] "Seawater Desalination Pilot Program." Marin Municipal Water District Engineering Report, Kennedy/Jenks Consultants. January 26, 2007. p.46.

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[43] Reflects an average operating scheme of 23 years at 50% capacity and & 2 years at 100% capacity every 25 years.

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