UNIVERSITY OF CALIFORNIA
Santa Barbara

ASSESSMENT OF SEAWATER DESALINATION AS A WATER SUPPLY STRATEGY FOR SAN DIEGO COUNTY

A Group Project submitted in partial satisfaction of the requirements
for the degree of Master's in Environmental Science and Management for the
Donald Bren School of Environmental Science & Management

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Winter Quarter, 2003

ABSTRACT

Increasing water scarcity in coastal Southern California has recently evoked interest in seawater desalination as a strategy for meeting a portion of the region's water needs. While in the past the prohibitive costs of operating desalination plants have restricted their use to extreme situations, recent technological advances in desalination technology have lowered operating costs to the point that desalination is now a viable supply option in water-stressed regions of the world. In this project we assess the implications of developing a large-scale desalination facility in northern San Diego County. We assess potential impacts of the plant in terms of resource consumption and environmental impacts. We also investigate whether a portion of the excess costs of water generated at the facility are in part recovered by benefits associated with reduced drinking water salinity and water supply reliability. In light of the desirability of water supply diversification, we conclude that desalination can be an appropriate strategy for supplementing a portion of existing supplies, however despite the benefits of salinity reduction and reliability it is still unclear whether creating a regional dependence on desalinated water supplies in San Diego County is cost-effective or environmentally preferable.

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GLOSSARY OF FREQUENTLY USED TERMS

AF	Acre-Feet
AFY	Acre-Feet per Year (1 AFY = 0.00089 MGD)
CRA	Colorado River Aqueduct
CV	Contingent Valuation
MAF	Million Acre-Feet
MCL	Maximum Contaminant Load
MGD	Million Gallons per Day
MWD	Metropolitan Water District of Southern California
RO	Reverse Osmosis
SANDAG	San Diego Association of Governments
SDCWA	San Diego County Water Authority
SWA	State Water Project
SWRCB	State Water Resources Control Board
TDS	Total Dissolved Solids (mg/L)
WTP	Willingness to Pay

1 EXECUTIVE SUMMARY

San Diego County is located in a dry, coastal region with limited local water resources. Rapid population growth in past decades and limited local water supplies have forced the county to become heavily reliant on imported water resources from the State Water Project and the Colorado River. Threats to these resources, such as drought, claims by other rights-holders, and environmental restrictions on water flows, have driven San Diego County to pursue seawater desalination as a water provision strategy.

A 56,000 acre-feet per year (AFY) desalination plant capable of serving 8% of the county's water demand has been proposed for construction in Carlsbad, in northern San Diego County. The $270 million dollar plant, which would be located adjacent to the Encina Power Plant, would produce water by using reverse osmosis technology at a cost of approximately $900 per acre-foot, including distribution costs. This water would be more costly than imported water, which is purchased by local water agencies at $526 per acre-foot. A $250 per acre-foot subsidy provided by the Metropolitan Water District will help defray some of the cost difference. However, the desalinated water is still a more expensive water supply, when viewed from a pure cost perspective. It also presents some environmental challenges, such as the discharge of waste brine and heavy energy demands.

Project Approach

Although desalinated water is expensive, it possesses characteristics that differentiate it from imported water. Desalinated water produced at the Carlsbad Plant would be quite low in total dissolved solids (TDS), and thus relatively pure compared to the imported water blend that is currently supplied to San Diego County. It would be drought-proof and locally managed, unlike imported surface water resources, which are prone to quantity fluctuations and allocation disputes. Finally, whereas imported water requires a distributed network of pumping stations that draw power from the electricity grid, the Carlsbad desalination plant would draw power from a single natural gas fired power plant.

Our project approach involves performing a thorough investigation of each of these differences in order to determine whether seawater desalination is an appropriate water provision strategy for the San Diego region. Making this assessment involves dividing the impacts of the desalination plant operation into four broad categories: salinity, reliability, energy and environment.

Salinity

Excessive salinity in water supplies can have a variety of detrimental impacts, including reduced home-appliance life, the need to clean mineral deposits from surfaces, and reduced agricultural yields. Salinity affects domestic water users by increasing expenditures on bottled water, water softening, soaps and detergents.

The Carlsbad Desalination Plant is expected to produce drinking water with a quality of 250-350 mg/L of Total Dissolved Solids (TDS). This will represent a substantial decrease in salinity as compared to existing supplies, which are approximately 500 mg/L. As a result, water customers may evade certain expenditures associated with damages from salinity, and experience benefits associated with the quality improvement. The distribution and magnitude of these benefits will depend on how the desalinated water is delivered to the residents of the county.

An existing econometric model was used to value the potential benefit of introducing desalinated seawater into the San Diego County water supply. This model, developed by the Metropolitan Water District, generates regional approximations of the costs or benefits of changes in water supply salinity. The model divides these impacts into a set of customer classes: residential, commercial, industrial, agriculture, utilities and recycled water users.

In our project, Metropolitan's model was used to simulate inclusion of desalinated water in the San Diego County water supply under multiple distribution scenarios. Our results indicate that substitution of desalinated water for a portion of San Diego County's imported water supply will produce an annual benefit on the order of $3 million. The maximum benefit is observed when desalinated water is preferentially delivered to the cities of Carlsbad and Oceanside, as opposed to the entire county. The total magnitude of this benefit is highest for residential customers, however the highest per-acre benefit accrues to agriculture. Significant benefits from salinity reduction are associated with avoided water softening, increased life of dishwashers, improved water efficiency in cooling towers, and increased avocado yields. Benefits to nursery crops may also be significant, however we were not able to provide an accurate estimate of this value.

In addition to the primary benefits experienced by end-use water customers, there will also be secondary, system-wide benefits that are more difficult to quantify. These include a minor decrease in overall water consumption from irrigated soil leaching and cooling tower operation. An additional benefit of salinity improvement would be improved quality of reclaimed water. Salinity reductions in reclaimed water would generally increase the value of this water for other uses, such as agricultural irrigation for crops with limited salt tolerance.

Reliability

Water supply reliability entails the provision of supplies, expertise, and facilities to ensure the availability of sufficient and affordable water, both now and in the future. When supplies become threatened by service interruptions or drought, there can be severe economic and social consequences to agricultural, business and residential users. Therefore the issue of water reliability becomes an important element of any water agency's management plan.

An existing contingent valuation model was used to estimate the willingness to pay (WTP) among San Diego County residential users to avoid water shortages of varying magnitude and frequency. Frequency ranged from once every 3 years to once every 30 years, with intervals at 5, 10 and 20 years. Reduction in water availability ranged from 10% to 50%, with intervals at 10, 20, 30 and 40 percent. The model then created several scenarios in which respondents were asked their willingness-to-pay to avoid a percentage reduction in water availability at different time periods.

Results for San Diego County ranged from approximately $16.00 per month to avoid either a 10% shortage every 10 years or a 20% shortage once every 30 years, to a high of approximately $20.00 per month to avoid a 50% shortage every 20 years. Given the size and number of users that desalinated water could serve, the WTP for the county amounted to over $1.7 million dollars per month, or nearly $35 an acre-foot for desalinated water, and therefore could be considered when factoring in the additional costs that desalination will place on the county.

The use and reliability of desalination as a water supply option merits consideration when viewed in terms of people's willingness to pay for water reliability. Despite the fact that current costs are still more prohibitive than imported supplies, respondents in San Diego are willing to see their water bills increase in order to ensure water reliability.

Energy

As designed, the desalination plant would consume approximately 3% of the adjacent Encina Power Plant's output (965 MW), with a load of 35 MW. Between 60 and 75 gallons of water would be generated per kilowatt-hour, suggesting an embedded energy of 4,700-5,400 kWh per acre-foot. Imported water supplies, which consume energy for conveyance, are also energy intensive. The bulk of San Diego's water originates from the Colorado River, requiring 2,000 kWh per acre-foot of delivered water. The State Water Project, which provides approximately 24% of San Diego's water supplies, consumes approximately 3,000 kWh/AF to deliver water to Southern California. Thus, the energy requirements of desalinated water still exceed those of existing supplies.

An implication of devoting some of the County's local generating capacity to desalination is an increased need for energy imports. However, the Carlsbad desalination plant would not cause serious energy deficiencies in San Diego County as long as it was operated during off-peak-load hours. In addition, if planned wisely, the desalination plant could contribute to more economical power generation of the Encina power. Power plants produce electricity from fuel most efficiently at full load, however due to daily and seasonal demand fluctuations they are forced to operate at reduced loads. During these periods, fuel consumption efficiency is reduced. Therefore, if the desalination plant is operated using off-peak power, the overall efficiency of power plant operation could be improved.

Environmental considerations

Air pollution due to electric power consumption is estimated for imported water sources using U.S. nationwide average of emissions from electric power plants by fuel and the proportion of the California energy sources. Emissions for the desalination plant are estimated using the facility's load on the power plant and average natural gas emissions. The results indicate that the Carlsbad Desalination Plant emits ten times less SO_X but more NO_X and CO_2 than water delivery projects on a per acre-foot basis. This stems from the fact that the Encina power plant relies solely on natural gas as its energy source, whereas the energy used to convey water from the State Water Project and the Colorado River come from a mix of energy sources which includes natural gas, but also relatively pollution free hydroelectric power. Concerns that the desalination plant could become a significant additional contributor of air pollution in northern San Diego County are of little importance due to the low amount of energy the desalination plant will eventually consume. Thus, given the fact that the Encina Power Plant currently does not affect regional air quality in San Diego, the additional electric power use by the desalination plant will also not constitute a problem.

The separation of seawater results in a waste brine stream that requires disposal. Brine discharge to the marine environment constitutes the main environmental impact of coastal seawater desalination plants. In addition to the high concentration of salts, discharge water may also contain various chemicals used during defouling of plant equipment and pretreatment-stage of the desalination.

Diluting brine with power plant cooling water mitigates environmental impacts from brine discharge. The addition of brine to power plant thermal effluent decreases the difference in density between the combined discharge and seawater, aiding in mixing. The estimated salinity of the combined effluent would be 38,000 mg/l, as compared with 35,000 mg/L in seawater.

Conclusion

We have observed that a portion of the excess cost associated with desalinated water is recovered as reduced salinity in delivered water, which produces benefits in the form of avoided water softening, increased life of water-using appliances, improved water efficiency in cooling towers and increased crop yields. Consumers are willing to pay higher monthly water bills to avoid shortages, so presumably there is an excess value to desalinated water due to its reliability. However it is difficult to estimate this value due to the difficulty of converting a theoretical willingness to pay to a received benefit. In addition, desalination still requires more energy than the alternative of transporting water to the county using existing conveyance infrastructure, despite the energy savings associated with co-locating desalination plants and energy facilities. While the Carlsbad Desalination Facility would decrease San Diego County's reliance on imported water, it would in turn increase the County's reliance on imported power. Operation of desalination facilities during off-peak periods of power generation may be a preferable alternative. Progress in the membrane industry may eventually reduce the energy required to operate reverse osmosis facilities.

The merits of desalination are more evident when it is viewed as a form of supply diversification, and an emergency source of water. Operation of the Carlsbad Facility would provide San Diego County with a hedge against drought, as well as a source of dilution for the county's high salinity water imports. The addition of coastal seawater desalination plants to California's mix of water supplies aids in decentralizing the state's water infrastructure. As a result, a disruption at an individual location such as a pipeline or reservoir is mitigated by the presence of alternative sources of supply. The need for diversification is further heightened by today's threats of domestic terrorist attacks, plus the susceptibility of the existing system to natural disasters such as earthquakes. It is recommended that agencies involved in considering development of these facilities should attempt to simulate worst-case supply interruptions, and then evaluate the optimum level of desalination capacity for providing municipal water during emergencies.

2 PROJECT MOTIVATION

Increasing water scarcity in coastal Southern California has recently evoked interest in seawater desalination as a strategy for meeting a portion of the region's water needs. While in the past the prohibitive costs of operating desalination plants have restricted their use to extreme situations, recent technological advances in desalination technology have lowered operating costs to the point that desalination is now a viable supply option in water-stressed regions of the world.

San Diego County is located in a dry, coastal region with limited local water resources. Rapid population growth in past decades has forced the county to become reliant on imported water resources for the majority of its water supplies. Threats to these resources, including drought, claims by other rights-holders, and requirements for environmental flows, have driven the county to pursue seawater desalination as a water provision strategy.

A 56,000 acre-feet per year (AFY)[1] desalination plant has been proposed for construction in the City of Carlsbad, located in northern San Diego County. This $270 million dollar facility, to be constructed adjacent to an existing power plant, would serve 8% of the County's water demand at a cost of approximately $900 per acre-foot. This water would be more expensive than existing imported water supplies, which are purchased by local water agencies at $526 per acre-foot. While a $250 per acre-foot subsidy provided by the Metropolitan Water District will help to defray some of the cost difference, desalinated water is still a more expensive water supply when viewed from a pure cost perspective. Operation of a desalination plant also presents some environmental challenges, such as the discharge of waste brine and heavy energy demands.

Although desalinated water is expensive, it possesses characteristics that differentiate it from imported water, making it a somewhat different product. Desalinated water produced at the Carlsbad plant would be relatively pure compared to the imported water blend that is currently supplied to San Diego County. It would be drought-proof and locally managed, unlike imported surface water resources, which are prone to quantity fluctuations and allocation disputes. Finally, whereas imported water requires a distributed network of pumping stations that draw power from the electricity grid, the Carlsbad desalination plant would draw power from a single gas-fired power plant.

In this project, we estimate the potential economic and environmental impacts that would be incurred by San Diego County residents due to operation of the Carlsbad desalination plant. The intent of our analysis is to obtain an estimate of the costs and benefits incurred by the users of desalinated water, as a result of its purity, reliability, energy source and proximity of generation (as compared to imported water). We will also attempt to identify any secondary benefits associated with desalinated water, such as reduced demand for water in irrigation and cooling applications. Finally, we investigate whether operation of the desalination plant will have any adverse impacts on the San Diego environment, such as excess air emissions or

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[1] Equivalent to 50 million gallon per day (MGD)

habitat loss. Our methodology can then be expanded to assist water agencies in making decisions about desalination.

While the goal of this project is to provide additional tools for evaluating desalination as a water supply strategy, one should not discount the importance of water-use efficiency and other forms of supply management. It is drastic to invest in desalination when existing water resources are not used as effectively as possible. Despite San Diego County's longstanding attempts to increase the water efficiency of uses within the county, there still is room for improvement. In addition, alternative provision strategies, such as agriculture to urban water transfers, may also serve as effective means to provide water to residents. Nonetheless, the precarious nature of San Diego's imported supplies combined with demand growth makes locating additional supplies and diversifying the supply mix critical to the future of the County.

3 ABOUT SAN DIEGO COUNTY

With a population of 2.6 million people, San Diego County is the southwestern-most county in California, bordering on Orange, Imperial, and Riverside Counties, as well as Baja, Mexico. The county includes the City of San Diego, 17 other incorporated cities and a large unincorporated area. It is the second most populous of California's 58 counties ranking 16th in population of all metropolitan areas in the U.S. The San Diego County Gross Regional Product for 1993 was estimated to be $65.7 billion.

San Diego County covers 2.74 million acres, of which an estimated 345,000 are in agriculture, 297,300 are in urban and built-up land, and 1.5 million are in other uses. Agriculture is practiced by approximately 6,000 farmers on 6,565 small family farms

4 WATER SCARCITY IN SAN DIEGO

San Diego's pursuit of large-scale seawater desalination facilities is a response to growing water scarcity in this region of California. This scarcity is driven by several factors, including climate and geology, population pressure and institutional control of water resources.

4.1 Climate and Geology

The San Diego region relied exclusively on local water supplies until the 1950s, when population and economic growth forced the county to seek imported water supplies. The County's local water resources are constrained by its semi-arid hydrological conditions and lack of aquifer storage. Located in the southwest corner of the state, San Diego enjoys an exceptionally mild, Mediterranean climate, with an average temperature of 65˚F and annual rainfall of 10-14 inches per year along the coast. The pleasant weather, which draws new residents, supports a tourist economy, and permits unique and profitable forms of agriculture, also works to limit the county's local water resources.

San Diego's groundwater supplies are less plentiful than elsewhere in Southern California. Groundwater recharge in the County can range from 0.05 to 0.4 AFY in low and high rainfall periods, respectively (County of San Diego, 2002). The county's productive aquifers are situated in narrow river valleys, which contain shallow alluvial deposits. Outside of these areas, the geology is primarily crystalline bedrock and fine-grained sedimentary deposits, which produce limited water yields. The use of groundwater in the county is further constrained by years of overdraft and irrigation with high-salinity imported water, which has increased the salinity of certain aquifers to unusable levels. Currently, groundwater meets 2% of the water needs of the county area serviced by municipal water supplies (SDCWA, 2002a). In addition, there is some un-metered water recovery from private wells.

The mountain ranges located in the interior of the county experience rainfall in excess of 40 inches per year. A portion of this runoff is captured and stored in reservoirs capable of supplying between 20,600 and 146,000 AFY of the county supplies (SDCWA, 2003b). On average, reservoir releases provide 8% of county supply (SDCWA, 2002a). Although the county is expanding some reservoirs for emergency storage purposes, the development of reservoirs as a water supply source is not expected to continue, due to controversy over the environmental impacts associated with dam and reservoir construction.

4.2 Population Growth

Between 1980 and 2000, the San Diego region added 952,000 people to its population, and is expected by 2020 to further increase its population from 2.8 million to 3.8 million through natural growth and migration (SANDAG, 2001). Thus, the issues of population increases and land use have become a concern not only to land use planners, but also the public utilities that must provide services for these new residents.

In San Diego this growth has been accommodated through the low-density pattern of development known as sprawl. This form of development is characterized by decentralized cities surrounded by layers of suburbs, each composed of tract homes and strip-malls laid out along congested streets and freeways. It is projected that by 2020 if land consumption patterns do not change, San Diego will consume over 600,000 acres for residential and business use (SDCWA, 2002). Moreover, the movement of San Diego's population away from more urban settings into more rural and less developed areas will affect water use by impacting infrastructure and capital expenditures in negative ways. Allocation of scarce funding will have to be funneled into distribution rather than resource provision projects, therefore limiting the ability of water agencies to provide adequate supplies, and thus increased reliability, into the future.

Approximately 97% of San Diego County's population lives within the San Diego County Water Authority service area. SDCWA has projected that as a result of the additional one million people that will be added to the county over the next two decades water demands will grow by 118,000 AFY to reach 813,000 AFY. This demand growth projection, which includes additional savings due to water conservation, indicates that the future will bring increased pressure on existing supplies, further driving the county to develop new water resources.

4.3 Institutional Control of Water Resources

San Diego County imports between 75 and 90% of its water supply (SDCWA, 2003). This water, which originates from the State Water Project and Colorado River Basin, passes through several institutions and infrastructures prior to being delivered to residents of the

County. The legal and political relationships between these entities have important implications regarding the quantity and reliability of future county water supplies.

The following diagram depicts San Diego's geographical relationship with the existing imported water infrastructure:

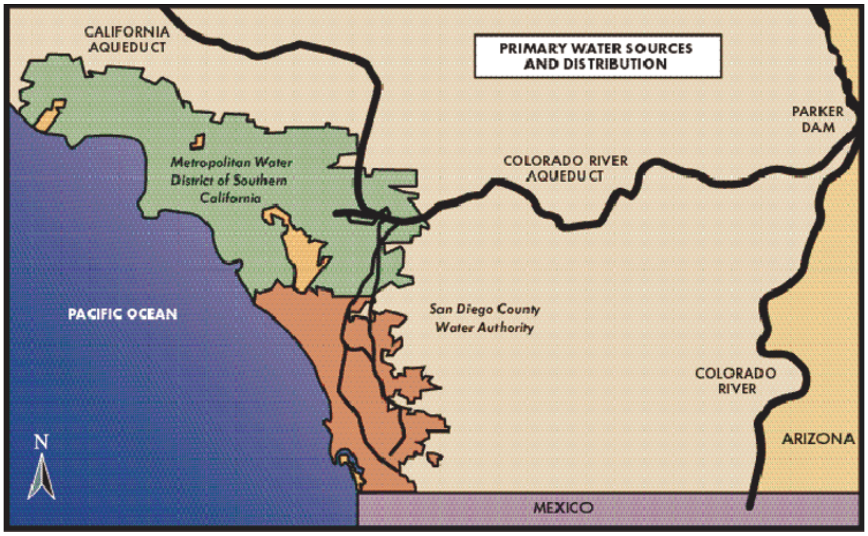

Figure 4-1 Imported Water Infrastructure (SDCWA, 2002)

4.3.1 Metropolitan Water District (MWD) of Southern California

MWD is San Diego County's wholesale water provider. In addition to San Diego County, the MWD service area includes portions of Ventura, Los Angeles, Orange, Riverside, and San Bernardino counties, an area of 17 million people. MWD was originally formed to import water from the Colorado River to urban areas of southern California, via an aqueduct built in the 1930s. MWD is the primary water wholesaler of supplemental water from the State Water Project and the Colorado River in Southern California, and currently delivers an average of 1.7 billion gallons of water per day to a 5,200-square-mile service area covering twenty-six cities and water districts. Because Colorado River water salinity levels are much higher than supplies from the State Water Project, MWD is also responsible for blending Colorado River and State water before it is delivered to member agencies to ensure acceptable water quality.

The extent to which MWD's member agencies rely upon MWD supplies varies according to local precipitation levels, and the degree to which member agencies exercise their respective preferential rights to purchase water. These rights are historic in nature, and in the case of San Diego, are a limiting factor in how much water is guaranteed to the county in times of shortages or drought. Currently San Diego imports nearly 600,000 AF per year from MWD, but is only legally entitled to 300,000 AF per year, and thus is highly vulnerable to water shortages and supply disruptions.

State Water Project

The SWP is owned by the state of California and operated by the California Department of Water Resources (DWR). Water is pumped from the San Francisco Bay / Sacramento-San Joaquin River Delta (Bay-Delta) into the California Aqueduct for transport to Southern California. The reliability of supplies is limited by a lack of planned but uncompleted infrastructure projects and by pumping restrictions due to the CALFED Bay-Delta environmental program.

The SWP was originally designed to provide 4,230,000 acre-feet of water to 32 water agencies throughout California. However, the continual deferment of planned facilities and environmental concerns led to new contract amendments that reduced total deliveries to 4,172,786 acre-feet and decreased the number of water agencies to 29. Restrictions were furthered by the creation of the CALFED Bay Delta program and new State Water Resources Control Board (SWRCB) water quality standards, both of which limited or restricted potential water supplies from development or reduced the amount of water available for diversion. Moreover, all SWP supplies were allocated to contractors in proportion to their contractual entitlements. MWD's 48 percent share of available SWP supplies entitles it to a proportionate share of available supplies. Although Metropolitan Water District's contracted entitlement is guaranteed at 2,011,500 acre-feet, or about 18 percent of the total, MWD estimates that existing SWP facilities, operated in accordance with SWRCB quality guidelines, will produce 1.2 million acre-feet in dry years and 2.7 million acre-feet in normal years. MWD's proportion of these shares is 0.6 and 1.35 million acre-feet respectively.

Issues of reliability increased dramatically in the late 1980s when the SWP was unable to meet contractor demands during drought periods. During the initial years of the 1987-1992 drought, DWR was able to maintain SWP deliveries using stored water at Lake Oroville and the San Luis Reservoir. However, by 1991 these reserves had been exhausted, and SWP was only able to deliver 549,110 acre-feet of water to member agencies. Of this amount MWD received 381,070 acre-feet, or about 20 percent of its entitlement.

SWP shortages are expected to become more frequent as demands on the system increase. DWR, under the SWRCB's 1995 Water Quality Control Plan estimated that existing facilities have a 65 percent chance of making full deliveries under 1995 level demands and an 85 percent chance of delivering 2,000,000 acre-feet to contractors in any given year (SDCWA, 2003b). However, when population growth and potential future demands are accounted for, the ability to deliver that same amount of water in 2020 drops to an astounding 25 percent. Others argue that these fears are unfounded because the CALFED Bay-Delta program will improve both the quality and reliability of Bay-delta water supplies by increasing the efficient use of water throughout California (SDCWA, 2003b). In particular the program will improve the reliability and quality of supplies by improving conveyance, pumping, and storage systems while also attempting to promote the efficient use of water to provide adequate protection for endangered species. However, many of the improvements are only planned at this time, and there are no guarantees that they will be constructed as part of the State Water Project, leaving a tremendous amount of uncertainty on where and how Southern California will meet its future water needs.

Colorado River

The 1,450-mile long Colorado River basin is approximately 250,000 square miles, encompassing portions of seven U.S. States and Mexico. The 1922 Colorado River Compact divides the Colorado River watershed into an Upper Basin (New Mexico, Utah, Wyoming, and Colorado) and Lower Basin (California, Nevada, and Arizona). The Upper Basin is required to deliver 7.5 MAF/yr to the Lower Basin, plus a portion to Mexico. The remainder constitutes the Upper Basin's apportionment. The water allocated to the Lower Basin is almost fully allocated to existing demand. The Upper Basin is facing restriction for environmental protection.

The availability of water from the Colorado River to California is governed by a system of priorities and water rights that have been developed over the last 70 years. The Colorado River Lower Basin states (California, Arizona, and Nevada) have an annual apportionment of 7.5 million acre-feet of water (MAF), with California's apportionment guaranteed at 4.4 MAF. This allotment is further divided among three Southern California agricultural agencies and the Metropolitan Water District. Before 1961, MWD had a firm allocation of 1,221,000 acre-feet of the Colorado River through contracts with the US Department of the Interior. However, as a result of the US Supreme Court decision in Arizona vs. California, MWD's firm supply fell to 550,000 acre-feet (SDCWA, 2003b). In recent years, MWD has exercised unused apportionments from other states or Department of Interior declared surplus water to keep its aqueduct at capacity. However, recent court actions, which are further discussed in Section 4.4.3, have eliminated California's ability to draw surplus Colorado River supplies. Unless California is granted a grace period for reducing its consumption, MWD, which has been supplying half of its deliveries with surplus water, will be significantly affected.

4.3.2 San Diego County Water Authority (SDCWA)

The San Diego Country Water Authority is a water wholesaler of Colorado River water to 23 member agencies in San Diego County, and is responsible for developing local water resources and maintaining the reliability of imported water supplies to the region. Imported water accounts for up to 95 percent of the total water used in the county each year, and all imported water is currently obtained from MWD. Increasing demands and dependence on water from MWD has caused SDCWA to shift its focus toward the use of water transfer agreements and the development of local water resources. This includes the newly signed water transfer agreement with Imperial Irrigation District (IID) and the creation of recycled water programs, ground water storage projects, water conservation programs, and more recently the creation of the desalination plant in Carlsbad.

SDCWA Water Supplies: Demand and Reliability

Ultimately reliance on imported supplies and the regional susceptibility to environmental and climatic factors has forced SDCWA to find new sources of water. Current projections for water supply demand through 2020 are:

Table 4-1 San Diego County – Projected Water Demand

Year	Total Projected Demand (AF)
2005	706,100
2010	733,300
2015	772,000
2020	813,000

Source: SDCWA, 2003b

SDCWA's projections for water supply availability through 2020 are:

Table 4-2 San Diego County – Projected Water Supplies, Detailed

Local Supplies	2005	2010	2015	2020
Surface Water	85,600	85,600	85,600	85,600
Water Recycling	33,400	45,100	51,800	53,400
Ground Water	31,100	45,100	51,800	53,400
Seawater Desalination	0	0	0	25,500
Imported Supplies				
Firm Supply from MWD*	303,630	303,630	303,630	303,630
IID transfer	80,000	180,000	200,000	200,000
Other sources	172,370	65,470	73,470	85,870
Total Est. Supplies	**706,100**	**733,300**	**772,000**	**813,000**

** Firm supply from MWD is based on SDCWA existing preferential right at MWD*
Source: SDCWA, 2003b

According to SDCWA estimates, supplies will match population growth demand up until 2020. However, these estimates make several assumptions that must be addressed. Currently SDCWA imports over 590,000 acre-feet per year from MWD, and the availability of these supplies are directly linked to the reliability of the State Water Project and the Colorado River. Because of existing preferential right contracts with Metropolitan Water District, SDCWA is only guaranteed 303,630 acre-feet per year, or 15 percent of MWD's total water supply, but often buys in excess of 10 percent above this allocation every year (SDCWA, 2003b). In times of drought, MWD has been able to cut back the supply allotted to San Diego County. This is possible even though SDCWA is the largest and most dependent customer of Metropolitan water. SDCWA, in the early 1990s attempted to use the courts to align its size (in terms of water purchased) and contributions to capital improvements to secure greater water rights, but failed, and thus is only guaranteed an allotment of 303,630 acre feet despite its current use of over 450,000 acre feet.

The problems of imported water from MWD are further exacerbated by the assumption that supplies from recycling and ground water will continue to increase into the future. Although

San Diego is in the process of building new reservoirs to store water and has effective best management practices (BMPs) in place to promote conservation, the contributions from these two sources only account for an additional 44,000 acre feet over the next 20 years--despite the fact that demand is forecasted to grow twice as fast. Moreover, if the region were to experience a serious drought, local supplies could be threatened and thus any reduction from MWD would be worsened by similar decreases in local supplies.

SDCWA's response to the threat of drought and reliance on imported supplies resulted in a comprehensive plan in 1993, and later in 1997, to diversify the region's water supply. This included the items discussed above, but also included water transfer programs and desalination. In 1998, SDCWA began negotiating a Water Conservation and Transfer Agreement with the Imperial Irrigation District (IID), an agricultural district in neighboring Imperial County. The agreement calls for up to 200,000 AF of Colorado River water to be conserved yearly by Imperial Valley farmers, and transferred to San Diego County via MWD's Colorado River Aqueduct, thus alleviating the County's dependence on MWD while increasing water reliability for the region (SDCWA, 2003b). However, like SDCWA's ground water and conservation plans, the IID transfer assumes that Imperial County farmers will be able to conserve that amount of water every year for the next 25 years. Moreover, it further assumes that factors such as drought or population growth in other lower basin states will not affect the amount of water flowing through the Colorado River. Although the IID transfer guarantees 200,000 acre feet of water per year after 2015, and has been touted as a means to alleviate San Diego's future water needs and increase reliability, the assumptions are fraught with risk and uncertainty. As of March 2003, SDCWA and IID had reached agreement on water transfer terms. However, the transfer will not go into effect until a series of approvals from the State and external agencies are achieved (SDCWA, 2003d).

4.3.3 Member Agencies

SDCWA delivers water to 23 member agencies, which in turn meter retail water deliveries to end-use customers. Representatives from each agency serve on the SDCWA board. The percentage of imported water used by each agency varies between 40-100%. Some districts primarily serve M&I (municipal and industrial) customer bases, whereas others have a stronger base in agricultural customers. The following map illustrates the location of member agencies within the SDCWA coverage area:

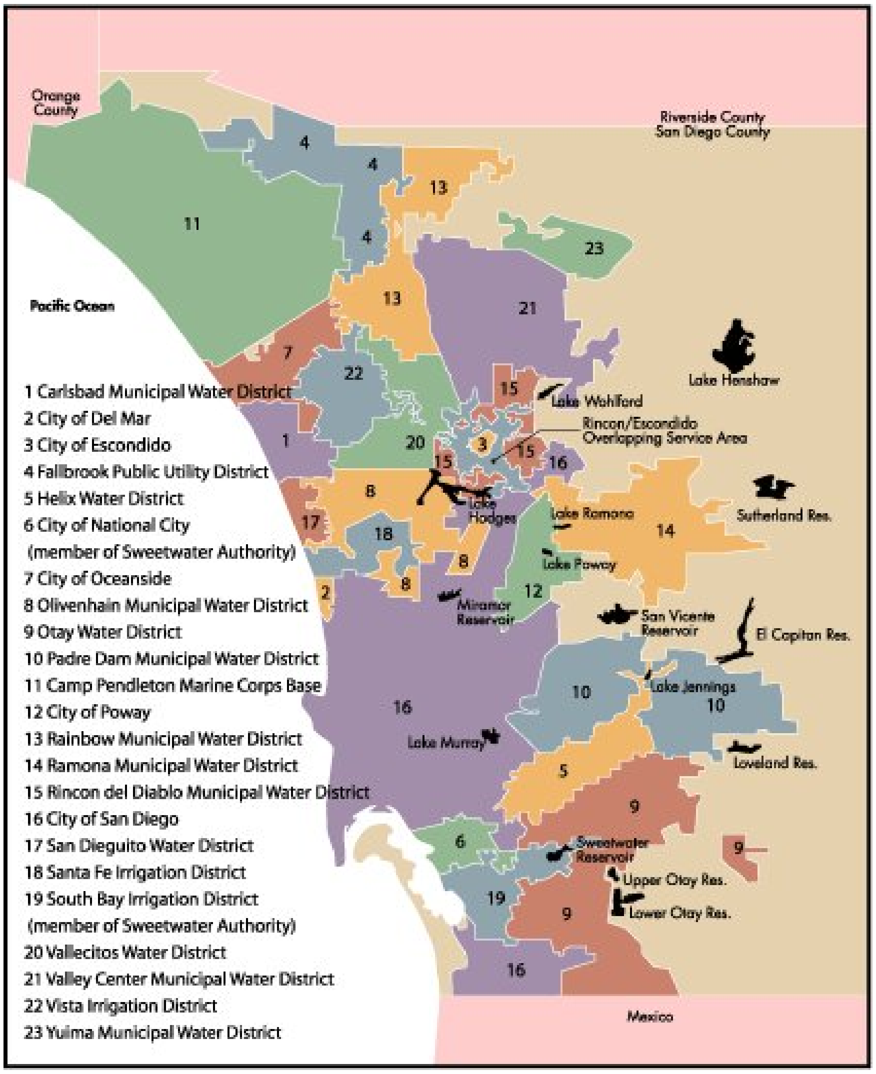

Figure 4-2 SDCWA Member Agencies (SDCWA, 2002)

4.4 Existing Water Supply Management Strategies

In addition to the proposed desalination project, the San Diego County Water Authority and its member agencies have undertaken a variety of actions to improve water supply reliability, diversify supplies, and reduce dependence on imported water.

4.4.1 Urban Demand Reduction

SDCWA and its member agencies have agreed to implement the best management practices (BMPs) set forth in the California Urban Water Conservation Council's 1991 Memorandum of Understanding Regarding Urban Water Conservation in California. These BMPs, which are expected of all urban water districts in the state that have signed the Memorandum, include: residential surveys, plumbing retrofits, water audits, metering with commodity rates, conservation pricing, landscaping programs, high-efficiency clothes washer rebates, and public education and conservation programs.

Since 1990, SDCWA has spent approximately $9 million in order to successfully implement these and other conservation measures. Water conservation funding has also been provided by the United States Bureau of Reclamation, San Diego Gas and Electric, and the Metropolitan Water District. In year 2000, the combined investment of $6.3 million was expected to produce long-term water savings of 38,000 AFY. Most savings appear to be as a result of the ultra-low flow toilet incentive and distribution system audit programs (SDCWA, 2000b).

SDCWA has projected that water conservation savings will continue its upward trend, reaching 93,200 AFY in 2020, through continued implementation of existing and proposed BMP's. Proposed BMPs include appliance efficiency standards and car wash retrofits. SDCWA estimates that by 2020 water conservation investments will reduce municipal and industrial demands by 12%, saving 93,000 AFY.

4.4.2 Agricultural Demand Reduction

Agricultural water conservation is a non-controversial practice in the San Diego area, due to the arid climate and history of high water prices. Farmers in the county pay water rates ranging from $461 to $963 per acre-foot depending on the elevation and level of treatment, compared to farmers in Imperial County, who pay $15 per acre-foot. Agricultural water conservation is also driven by the 1990 Memorandum of Understanding Regarding Efficient Water Management Practices by Agricultural Water Suppliers in California, which requires agricultural water suppliers and other interested parties to develop and implement water efficiency programs. Efficient water management practices (EWMP's) which are required by signatories of the Memorandum and practiced by County agencies include: adoption of a water management plan, providing farmers with water management services, improved pump efficiency, facilitating recycled water use, providing financial assistance for irrigation improvements, and lining ditches and canals.

As a result of these efficiency improvements, combined with the gradual conversion of agricultural to other land uses, SDCWA has estimated that agricultural water use in the county will decrease by about 17% between 2000 and 2020. (SDCWA, 2000b)

4.4.3 Imperial Transfer

SDCWA is pursuing water transfers as another strategy for providing adequate water supply to customers. In a water transfer, an agency agrees to purchase water conserved by another agency. This type of arrangement is appropriate when the negotiated water price falls below the purchasing agency's current wholesale price, and above the conserving agency's wholesale price. Water transfers typically involve shifting water from agricultural water rights holders to urban water districts.

In 1998 SDCWA and the IID began planning for a long-term water exchange, in which up to 200,000 AFY of water conserved by Imperial County farmers would be purchased by SDCWA at a price of approximately $250/AF. Imperial is primarily an agricultural water provider, with rights to 3.85 MAF/year of Colorado River Supplies.[2] The Imperial Transfer was to be a

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[2] Combined with Palo Verde Irrigation District and the Yuma Project Reservation Division (SDCWA, 2000).

critical portion of the Quantification Settlement Agreement (QSA), a plan to reduce California's draw from the Colorado River to its legal entitlement, involving the three agencies with rights to the river: MWD, IID and Coachella Valley Water District.

The Imperial Transfer fell through on December 9th, 2002, when it was rejected by the Imperial Irrigation District's Board of Directors. The Board expressed concern regarding the potential costs associated with mitigating environmental impacts to the Salton Sea as a result of the water conservation measures, plus the uncertainty associated with the transfer's impacts on the county's economy.

After negotiating a series of amendments to the original contract, SDCWA and IID signed a 75-year transfer agreement on January 15th, 2003. However, since the deal was not in place prior to the December 31st QSA deadline imposed by the Secretary of the Interior, California is now restricted to its legal Colorado River entitlement of 4.4 MAF/year. California agencies are hopeful that despite the missed deadline, negotiations of the Quantification Settlement Agreement will continue, allowing California more time to reduce its reliance on the Colorado.

4.4.4 Reservoir Construction

As of 2000, SDCWA's member agencies operated 21 reservoirs with a combined capacity of 571,000 AF. Although reservoir yields vary with climate conditions, it is estimated that a yield of 85,600 acre-feet may be sustainably used from these reservoirs during normal years (SDCWA, 2000). These reservoirs are generally managed to reduce purchases of imported water during normal and wet years, and not to store surplus water for use during dry years. Although adopting the latter strategy would result in increased evaporative losses and higher imported water needs during normal years, the county sees this strategy as a means to maintain adequate supply in dry years, when water imports may be restricted.

The County is currently adding additional reservoir storage capacity as part of its Emergency Storage Project (ESP). This project, which began in 1989 with $827 million in funding, consists of a system of reservoirs, pipelines and pumping stations designed to ensure the delivery of water in the event of a natural disaster, such as an earthquake. (SDCWA, 2003a) Although these new local water resources will increase supply reliability during potential emergencies, they are not expected to significantly contribute to the county's total supplies.

4.4.5 Wastewater Reclamation

Wastewater reclamation, or water recycling, has become a major component of regional water supplies around the world. In the United States sewage outflows are subject to primary treatment (sedimentation) and generally secondary treatment (biological oxidation and disinfection) prior to discharge to water bodies. When this wastewater is intercepted and subjected to additional "tertiary" treatment (including chemical coagulation, filtration and additional disinfection), it can be recycled for uses such as landscape irrigation, toilet flushing, food-crop irrigation, and recreational impoundments.

As of year 2000, approximately 13,700 AF or 2% of San Diego County's water needs were met by reclaimed water. This water, which is only used for non-potable applications, such as toilet flushing and landscape irrigation, is sold at a reduced cost. Customers of this water must have a dual plumbing system designed to prevent cross-connection with the potable system.

Recycled water supplies are expected to grow to 53,400 AFY by 2020, composing approximately 6.5% of projected water demands. The ability of the recycled water market to expand is constrained by the costs associated with expansion of the reclaimed water piping network and construction of new wastewater treatment facilities, and the need for interagency coordination. Expansion of the recycled water system to agricultural customers is hampered by high salinity levels, which can be toxic to sensitive crops, and seasonal variations in water demand. Efforts SDCWA has taken to expand the recycled water market have included providing funding and technical assistance to member agencies, and participating in planning for the provision of recycled water at the regional level.

4.4.6 Indirect Potable Reuse

Planned indirect potable reuse involves treating reclaimed wastewater to potable standards and then storing the water for a period of time (either in aquifers or reservoirs) to allow for mixing and natural attenuation of any residual contaminants. Potable reuse is slowly becoming an accepted method of augmenting drinking supplies, in the United States and elsewhere around the world. This practice is likened to the use of river water containing the wastewater discharges of upstream cities such as is done in Philadelphia, Cincinnati, and New Orleans. It is estimated that in the United States "more than two dozen major water utilities... draw from rivers where total wastewater discharge is greater than 50% of streamflow" (Dobbs, 1998).

Indirect potable reuse is already being practiced by other municipalities in Southern California, including the East Valley Water Recycling Project in the San Fernando Valley, and the Orange County Groundwater Replenishment System. These potable reuse systems involve either percolation or injection of treated wastewater into the ground. Elsewhere in the US, aquifer recharge with reclaimed water is currently being practiced in El Paso. The Occoquan Reservoir, which serves a portion of northern Virginia, is supplemented with reclaimed water.

In the late 1990's, the City of San Diego attempted to implement an indirect potable reuse program, termed the "water repurification project", involving the discharge of advanced treated wastewater to the San Vicente Reservoir. After a successful pilot study, a 20 million gallon per day (MGD) plant was approved by the Department of Health Services to perform advanced treatment on reclaimed water produced by the North City Water Reclamation Plant. Although health studies demonstrated that the treated effluent was in fact cleaner than the raw water supply that SDCWA was receiving from MWD, opposition to this supposed "toilet to tap" program, due to public health and environmental justice concerns, led to cancellation of the project in 1999.

4.4.7 Groundwater Resources

Groundwater supplies in San Diego County are less available as compared to elsewhere in southern California, as a result of the local geology and semi-arid climate. Currently 24,000 AF/YR of groundwater are used by member agencies for drinking water purposes. Numerous private wells exist, however their usage is not metered. Additional groundwater resources have been located in the county and are currently being studied to determine their development potential. There is also the possibility of expanding the county's use of brackish groundwater recovery, as well as developing groundwater banking (injecting potable or recycled water into groundwater basins).

5 SEAWATER DESALINATION

It is in the context of the limitations of the aforementioned water management strategies that San Diego County now turns to seawater desalination to provide a significant portion of the County's drinking water supply. Desalination is defined as the process of separating dissolved minerals from water. Desalination processes are used to treat groundwater, seawater, agricultural drainage and treated municipal wastewater.

5.1 Desalination Technology

The two primary technologies for desalinating water are membrane (reverse osmosis) and thermal (distillation). Both of these processes have significant energy requirements; the energy needs for distillation exceed those of reverse osmosis (Pantell, 1993). Worldwide, approximately 31% of desalted water is produced using reverse osmosis, and 64% by distillation (Buros, 2000).

Thermal processes, which include distillation, generally involve heating seawater to produce water vapor, which is then condensed. Distillation plants are designed to generate vapor by exposing boiling water to successively lower air pressures, resulting in "flashes" of vaporization. The water produced ranges in total dissolved solids (TDS) from 1.0 to 50 mg/L.

Membrane processes, which include reverse osmosis, involve forcing influent through a semi-permeable membrane. The membrane excludes dissolved minerals but allows water to pass, resulting in the production of potable water with TDS ranging from 10 to 500 mg/L (Pantell, 1993). Membranes are composed of thin layers of polymer films. A variety of materials are used, including cellulose acetate, polyamides, polyimides and polysulfones (Semiat, 2000).

The energy costs to run reverse osmosis plants are primarily associated with generating the pressure required to pump feed water through the membrane. The feed water must also be pre-treated to prevent particulates or microbes from fouling the membrane. Maintenance of these systems involves periodically ceasing operation to backwash pretreatment filters, scale removal, quarterly membrane cleaning, and periodic membrane replacement. Figure 5-1 depicts the generalized process flow of a reverse osmosis system.

Depending upon the technology used, desalinated water may require additional treatment to make it more appropriate for municipal use. Often, desalted water is mixed with lower quality water supplies to improve their overall quality. Desalted water is acidic, and therefore it may be mixed with other water sources or chemically adjusted to maintain the appropriate levels of pH, hardness and alkalinity to prevent corrosion to water distribution infrastructure. Corrosion-resistant materials may be required in desalination facilities, adding to overall costs.

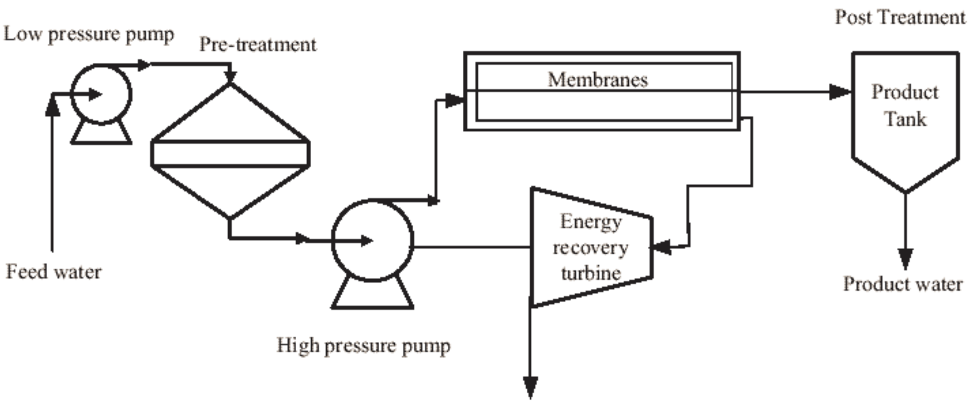

Figure 5-1 Reverse Osmosis (Semiat, 2000)

Figure 5-2 depicts a breakdown of operating costs experienced by reverse osmosis desalination plants. Electric power constitutes the majority of this cost, at 44%. The fixed charges, comprising 37%, include equipment costs associated with membranes, pumps, turbines, piping, etc (Semiat, 2000).

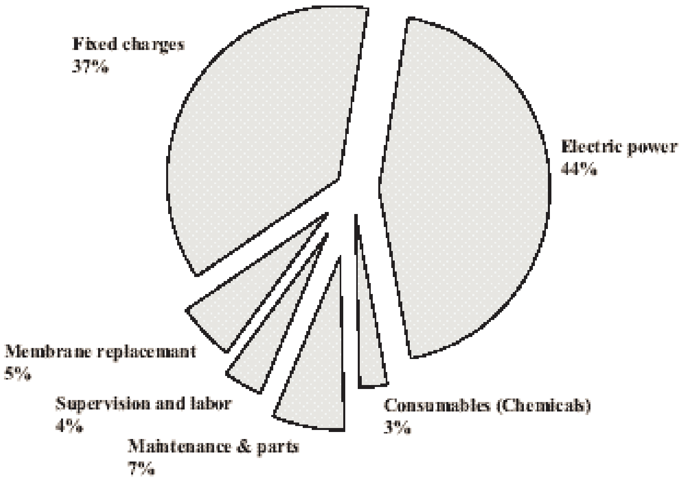

Figure 5-2 Typical breakdown of RO operating costs (Semiat, 2000)

It is typically advantageous to site desalination facilities near power plants, or even design them as one dual-purpose plant, as is commonly done in the Middle-East. Coastal desalination plants also can take advantage of the power plant's outtake for the disposal of brine (Buros, 2000). Siting desalination plants at existing power plant facilities may also result in overall cost savings due to shared security, maintenance and office operations. The major savings from integrating desalination with energy generation is the potential to take advantage of cogeneration. The term cogeneration refers to the process of recovering waste heat or steam from an industrial process in order to use it in another process, as opposed to releasing it to the environment. Dual-purpose reverse-osmosis/power facilities can be designed to extract the steam used to cool or operate turbines and use it to heat brine prior to filtration. Exhaust steam can also be recovered to operate turbines to power the desalination facility's pressure pumps (Pantell, 1993). Energy can be recovered from the reverse osmosis processes by using the hydraulic pressure of the brine stream to generate electricity. Heat can also be recovered from the turbine exhaust, heat pumps or other processes in the plant. This heating step lowers the amount of additional energy needed to vaporize the water, resulting in an overall reduction in fuel requirements for the combined operations.

5.2 History and Current Trends

Until recently, the development of desalination facilities has been generally limited to regions with extremely limited freshwater resources and/or low energy costs, such as the Middle East, North Africa and the Caribbean. Seawater is commonly desalinated on cruise ships, military vessels, shipping vessels and offshore platforms.

The first major land-based seawater desalination plant was constructed in Kuwait in 1949. Between 1960 and 1990, worldwide desalination capacity rose from 50 MGD to 3500 MGD. The International Desalination Association estimates that as of 2001, the world's 15,223 large desalination plants, of which 85% were in operation, had a combined capacity of 6.8 billion gallons per day. Nearly half of this capacity is in the Middle East and North Africa (Buros, 2000). As of 2001, the United States had the second largest desalting capacity in the world, predominately brackish water desalination with reverse osmosis. Currently, usage of distillation is waning, and that of membranes is growing. The following table lists some of California's seawater desalination facilities, several of which are not in operation:

Table 5-1 Existing Seawater Desalination Plants in California as of 1993

Plant	County, Operation Date	Technology[1]	Max Capacity (AF/Y)	Water Cost ($1993/AF)	Energy Consumption (kWh/AF)
Chevron Gaviota Oil and Gas Processing Plant	Santa Barbara, 1987	RO	460	$4000	15,000
City of Morro Bay (Emergency Plant)	San Luis Obispo, 1993	RO	1345	$1750	8,900
City of Santa Barbara (Emergency Plant)	Santa Barbara, 1992	RO	7500	$1918	6,600
Santa Catalina Island	Los Angeles County, 1991	RO	148	$2000	N/A
PG&E Diablo Canyon Power Plant	San Luis Obispo, 1992	RO	600	$2000	9,100

** Source: Pantell (1993). This is only a partial list.*
[1] RO = Reverse Osmosis

5.2.1 Desalination Case Studies

Santa Barbara

Prior to being connected to the State Water Project in 1997, the City of Santa Barbara was solely dependent upon the Cachuma Reservoir and local groundwater for its water supply. The severe drought of the early 1990's forced the City to impose severe demand restrictions on City residents. As a result of this scare, the City approved the construction of a temporary desalination plant.

The reverse osmosis plant was completed in 1992 and operated for three months for testing purposes. The water produced by the plant was expensive, with a unit cost of approximately $1500/AF at full production (amortized over 20 years). These high costs resulted in the plant being shut down once rainfall replenished local supplies. The need to operate the plant was also reduced as a result of demand management practices that were put in place during the drought, and the decision to finance a connection to the State Water Project. Even in a non-operational state, the plant still presented considerable maintenance costs that eventually led to the plant being mothballed in 1995. (City of Santa Barbara, 2001)

Tampa Bay

The Tampa Bay Seawater Desalination Project is scheduled to begin full operation in March 2003. Upon completion, this $118 million, 25 MGD reverse osmosis plant will be the largest seawater desalination facility in North America, providing 10% of the region's demand (Poseidon, 2001). The water will be produced at a cost of $680/AF. The plant's influent will consist of used cooling water from an adjacent power plant (Tampa Bay Water, 2003). The plant's waste brine will be diluted with the remaining portion of the cooling water to mitigate the impact of rising salinity on Tampa Bay. The cost to produce water at this plant is reduced due to the low salinity levels of the Bay. This plant is being developed by Poseidon Resources, the same firm that plans to develop the Carlsbad plant.

5.2.2 Industry trends

Over the past decade, a variety of factors have combined to increase the economic viability of both reverse osmosis and distillation systems. In the case of reverse osmosis, one source of cost reduction has been the steady expansion of the membrane industry. The resulting economies of scale have produced a significant drop in membrane prices. Increased demand for membranes is also a result of improvements in membrane quality and performance (product life, flow rate, ion rejection rates). The following graph, from Semiat (2000), demonstrates how the cost of a particular membrane configuration (spiral wound membranes) has declined over the last two decades.

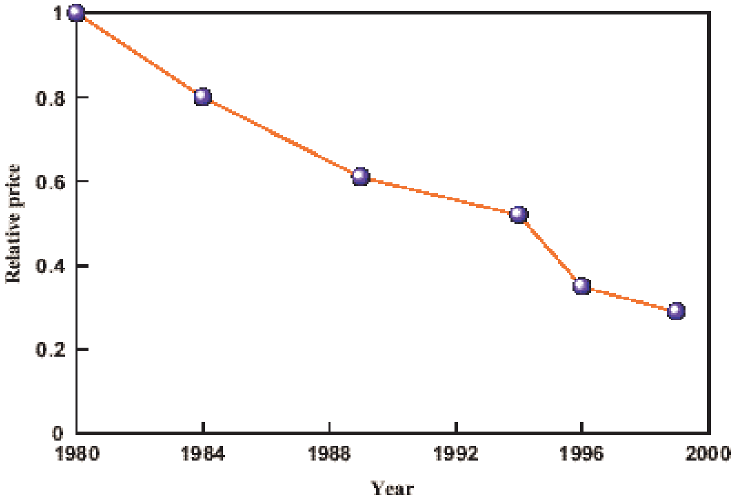

Figure 5-3 Typical RO Membrane Prices (Semiat, 2000)

5.2.3 Policy Trends

Interest in desalination has been growing at the federal, state and local levels. The federal government has within the past decade taken an interest in seawater desalination as a potential source of freshwater supplies in water-stressed areas of the United States. The U.S. Bureau of Reclamation (USBR) administers the Desalination and Water Purification Research & Development (DWPR). This program, authorized by Congress under the Water Desalination Act of 1996, aims to find additional sources of potable water. The DWPR is supposed to help desalination become more viable through cost-effective and efficient technologies with research and demonstration-based activities. For this purpose, the program is funded by the Act for six years starting in 1997. Under this program, USBR funds research projects in the area of desalination, including demonstrations and pilot programs. Areas of research have included membrane technologies, economics of desalination, plant design, and management of concentrates.

Several water-stressed states are independently pursuing the development of seawater desalination as a means of supply diversification and producing drought-proof water. The Texas Water Development Board has a Seawater Desalination Initiative to investigate the feasibility and encourage research in desalination technologies. As previously mentioned, Florida has become the first US state to develop a permanent, large-scale desalination facility.

At the local level, MWD's water provision strategy has recently come to include the encouragement of "cost-effective" seawater desalination projects. MWD sees desalination as a way to reduce demands on current local and imported supplies, plus a means to handle demand growth. Desalination would also serve as a way to diversify the regions water supplies, reducing drought susceptibility and improving water supply security.

MWD's approach to seawater desalination is to subsidize the operation of projects designed and built by its member agencies. A 2001 Request for Proposals seeking plant designs resulted in applications for five potential projects, with the combined potential to produce 126,000 acre-feet per year. Each member agency's partnership with MWD would include subsidies of $250 per acre-foot of desalinated water, bringing the costs to customers into the range of current supplies. Approval of this funding is currently contingent on the MWD board approving extending the subsidy to cover all of the proposed production, since initially only 50,000 AFY were covered (MWD, 2003).

5.3 Regulatory Considerations

Proposed desalination plants are subject to various regulatory processes required for project approval. In California, plants located in the Coastal Zone (generally, 1000 yards from the mean high tide line) are subject to the California Coastal Act. Projects in the Coastal Zone require approval by the California Coastal Commission in order to protect marine resources. Brine and other wastewater discharges require NPDES (National Pollutant Discharge Elimination System) permits as per the Clean Water Act. These permits are administered by California's Regional Water Quality Control Boards. Desalination plants are subject to environmental review under CEQA, which requires the public disclosure of environmental impacts. Other regulatory agencies which have a role in the approval and oversight of desalination plants include the California Energy Commission, the Conservation and Development Commission, the California Departments of Fish and Game, the Department of Water Resources, and the Department of Health Services (California Resources Agency, 1997).

5.4 The Carlsbad Project

The largest submittal to MWD's Request for Proposals is the Carlsbad Seawater Desalination Project, a 56,000 acre-feet per year (AFY) seawater desalination facility planned for construction adjacent to the Encina Power Station in northwest San Diego County. Upon completion in 2008, the desalination facility would provide 8-10 percent of San Diego County's water supply (SDCWA, 2003). The $270 million facility would share the gas-fired power plant's seawater intake and outfall, resulting in significant cost savings as well as compatible siting. The facility, which would be the largest desalination plant in the western hemisphere, would be designed for future expansion to over 100,000 AFY.

The Carlsbad facility would not have a dedicated power plant, but would consume 3% of the output of the adjacent Encina Power Station. Heated seawater effluent from the power station would be piped to the desalination facility[3]. The waste heat in this water would allow some energy savings in plant operation, since less energy would be required to pressurize the water prior to reverse osmosis. In addition, some of this heat would be transferred to the reverse osmosis membranes, causing pore spaces to expand, reducing the energy required to force seawater through the membrane, at the expense of some removal efficiency. Additional energy savings will occur by recovering pressurization energy from the brine flow using turbines. The location of this facility is depicted in Figure 5-4.

If final approval is obtained, the Carlsbad project will be developed by Poseidon Resources, an investment firm that specializes in public infrastructure projects. In recent years, Poseidon has participated in other large-scale desalination projects in the United States, including the previously discussed Tampa Bay facility, as well as planned facility in Huntington Beach, California. Poseidon has been developing the Carlsbad project since 1998 and has an existing contract with Encina Power Plant owner/operator Cabrillo Power I LLC giving it exclusive rights to develop a desalination facility on the site. SDCWA has executed a term sheet with Poseidon regarding the Carlsbad facility, and entered into negotiation on a development agreement. Under these agreements, SDCWA would be responsible for constructing and operating the facilities required to convey the desalinated water to the county water system. (SDCWA, 2002b)

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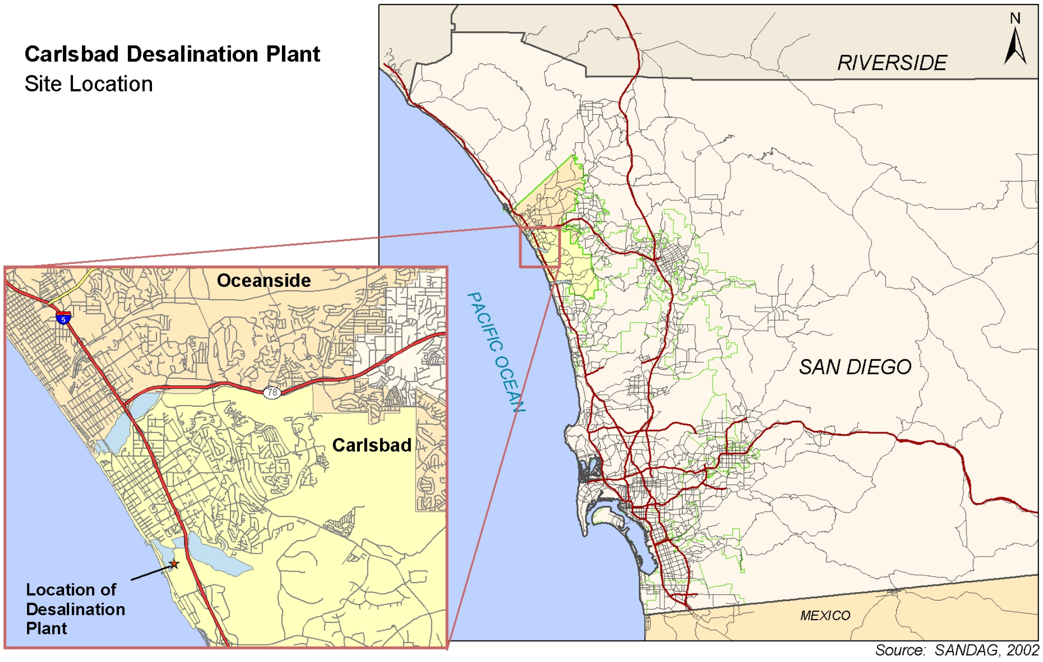
[3] The Encina Plant has 5 gas/oil boilers and a gas turbine. The effluent is heated by cooling the gas turbine, or through the boiling process.



Source: SANDAG, 2002

Figure 5-4 Carlsbad Desalination Facility Site Location

Current designs for the Carlsbad Plant indicate the use of reverse osmosis technology to desalt water. The TDS of the produced water is expected to be less than 350 mg/L, well below the EPA's secondary standards for drinking water (500 mg/L). The cost of this water is estimated to be approximately $794/AF, plus an additional $100/AF for distribution. This is significantly higher than SDCWA's wholesale treated water rate of $526/AF. However, a $250/AF subsidy provided by the MWD seawater desalination program would reduce the costs of the desalinated water to $644/AF.

To prevent volatility in the variable costs associated with energy prices, Poseidon, (and later SDCWA), will purchase long-term natural gas contracts. The desalination plant would consume 3% of the Encina Power Plant's output (965 MW), with a load of 35 MW. Between 60 and 75 gallons of water would be generated per kilowatt-hour, suggesting an embedded energy of 4700 - 5400 kWh/AF.[4] The following diagram depicts the breakdown of the anticipated water price for the Carlsbad plant.

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[4] Personal communication, Peter MacLaggan, Poseidon Resources, Feb 20, 2003

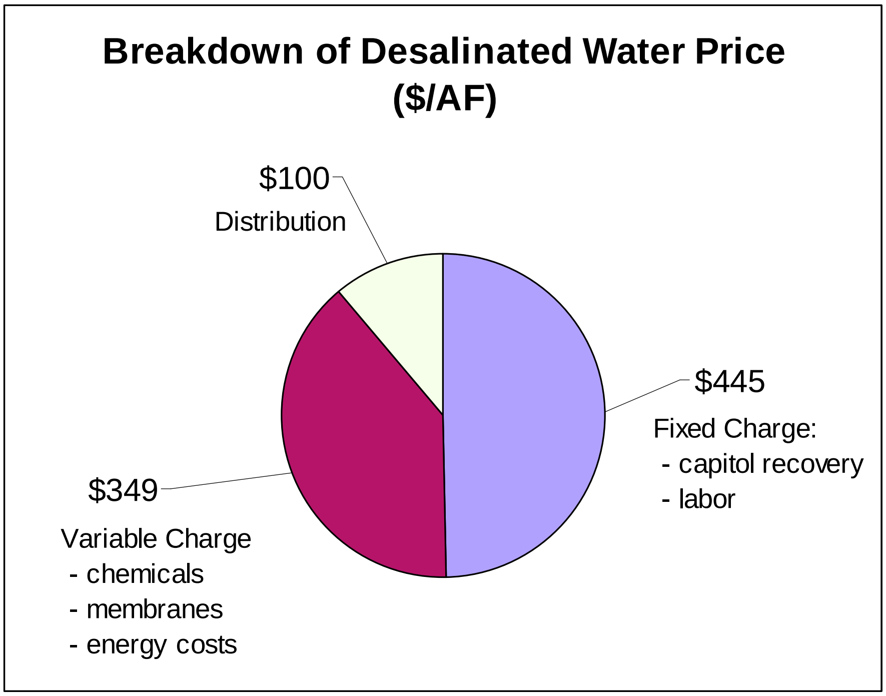

Figure 5-5: Breakdown of Desalinated Water Price for Carlsbad Facility (Poseidon, 2003)

6 RESEARCH APPROACH

In this project we will investigate the impacts that the Carlsbad desalination plant will have on San Diego County residents, businesses and the natural environment. The intent of this analysis is to estimate the additional benefits incurred by the users of desalinated water, as a result of its purity, reliability, energy source and proximity of generation. These results are then viewed in the context of the costs that construction and operation of the plant will have on the natural environment and economy.

The areas of focus, and the corresponding questions to be answered are as follows:

Salinity

Question: *Are a portion of the excess costs of desalinated seawater recovered in the form of benefits due to reduced drinking water salinity?*

Approach: Adapt existing economic model to predict the value of benefits due to salinity reduction. Determine which sectors benefit the most.

Reliability

Question: *Are the residents of San Diego county willing to pay more for the increased water supply reliability that would be achieved by operating a desalination plant? Does the presence of this willingness to pay recover some of the excess costs of desalinated water?*

Approach: Adapt existing economic model to predict residential willingness to pay for water supply reliability.

Energy and Environment

Question: *How do the energy demands of desalinated water compare with the energy required to convey water to San Diego via existing import infrastructures? Can the energy demands of the desalination plant be mitigated? What impact will operation of a desalination facility have on the natural environment in northern San Diego County? What is the air emission profile for desalinated water, compared to imports?*

Approach: Determine energy input per unit of delivered water for imported and desalinated water. Evaluate in terms of the San Diego energy market. Use what is known about the proposed facility and literature values to predict changes in discharge quality at the combined power station/desalination site. Based on the energy generators which provide this water, estimate emissions per acre-foot. Investigate the potential for other environmental impacts.

6.1 Use of study zones

To account for uncertainty in the distribution of desalinated water, the reliability and salinity sections assess distribution under three scenarios. The SDCWA service area is split into three zones: Carlsbad, Oceanside and the remainder of SDCWA. In each scenario, it is presumed that imports will only replace imported supplies, and that blended waters are evenly mixed. The study zones are depicted in Figure 6-1.

6.1.1 SCENARIO 1: EVEN MIX INTO COUNTY SUPPLY

Under this scenario, desalinated water (56,000 acre-feet) would be evenly mixed into the entire county supply, resulting in a minor but widespread decline in salinity. The blended water would be approximately 1 part desalinated water to 12 parts imported water. This is the current plan for the first five years of plant operation.[5] We assume that desalinated water will only replace imports and not local water supplies. This scenario ignores that a portion of water customers exists upstream from the desalination plant, and therefore would not be likely to experience a water quality change.[6]

6.1.2 SCENARIO 2: 20/20/60

This scenario involves supplementing a portion of supplies of the Cities of Carlsbad and Oceanside, with the majority of desalinated water being distributed into the county system. These two cities partnered with SDCWA to perform a feasibility study for the desalination plant, and thus would be likely to receive a dedicated portion of the plant's output. As of today, the only arranged purchase of water from the desalination plant is the City of Carlsbad, which plans to reserve 20% of the plant's output. Oceanside has also expressed an interest in this water, and it can be reasonably assumed that another 20% of the plant's output will go to Oceanside. The remaining 60% of the plant's output would be mixed into the county supplies. We will be assuming even mixing with imported and local supplies within the study areas.

6.1.3 SCENARIO 3: LOCAL SUPPLY REPLACEMENT

This scenario would evaluate the economic benefits if Oceanside and Carlsbad were to completely replace their imported water supplies with desalinated water, with the remainder going to the county. The results of this analysis can be used to determine if the added benefits justify the required investment in the distribution system.

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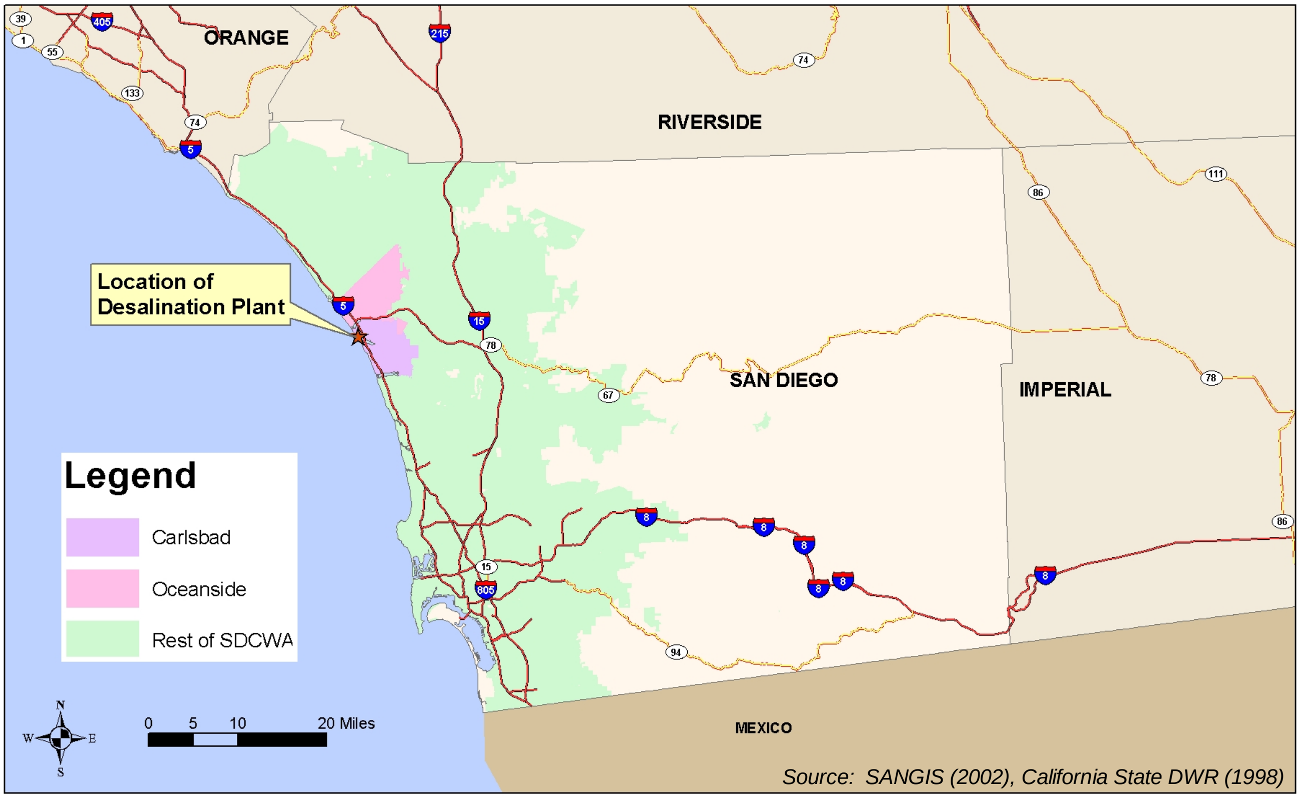
[5] Personal communication with Bob Yamada, SDCWA, 1/8/2003

[6] The Project Fact Sheet (www.poseidon1.com) provides a map of the potential service area, indicating that the following member agencies would potentially receive water from the desalination plant: Oceanside, Carlsbad, Ramona, City of San Diego, Padre Dam. However, mixing in the SDCWA aqueduct would be expected to distribute a portion of the desalinated water to all agencies downstream from the plant. Due to uncertainty as to which agencies would receive desalinated water, it is assumed that the desalinated water would mix evenly into the entire county supply among all agencies.



Source: SANGIS (2002), California State DWR (1998)

Figure 6-1 Depiction of Study Zones

7 BENEFITS OF REDUCED SALINITY

The introduction of desalinated water into San Diego County supplies would reduce the salinity of municipal water supplies. As a result, water customers would evade certain expenditures associated with damages from salinity, and experience benefits associated with the quality improvement. The distribution and magnitude of these benefits will depend on how the desalinated water is delivered to the residents of the county. The following is a discussion of how the magnitude of these benefits, under a variety of distribution scenarios, could be estimated for the residents of San Diego County.

7.1 Background

Salinity is defined as the total content of solutes in water. The salinity of water supplies has long been a concern in the southwestern United States. Freshwater salinity arises from a variety of sources, including weathering of rock minerals, the dissolution of salts in riverbeds, municipal wastewater discharges and surface water evaporation. Excessive salinity in water supplies can have a variety of detrimental impacts, including reduced life of appliances, the need to clean mineral deposits from surfaces, and reduce agricultural yields. Salinity affects domestic water users by increasing expenditures on bottled water, water softening, soaps and detergents (Ragan et al., 2000).

Salinity is a concern in both of San Diego County's imported water sources. Following a series of conferences in the 1960s and early 1970s, the Colorado River Basin states adopted a set of salinity criteria to be met by managing salt loads from anthropogenic sources, including irrigated agriculture, reservoir evaporation, water exports and municipal use. Although its salinity levels are well below that of the Colorado River, the State Water Project experiences variations in salinity due to seawater intrusion in the Bay Delta and agricultural drainage (MWD, 1999).

7.1.1 Water quality measurements and standards

Salinity is often represented as Total Dissolved Solids (TDS), the concentration of dissolved constituents in water that can pass through a standard filter. Depending on the water source, TDS may include a small portion of dissolved organic matter. Salinity can also be measured as the electrical conductivity of water.

Other common water quality standards relating to salinity are alkalinity and hardness. Alkalinity is the ability of water to buffer changes in pH, due to the presence of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-) and hydroxide (OH^-) ions. Alkalinity is measured by a titration procedure. Hardness is a related parameter, reflecting the concentration of divalent cations (Mg^{2+}, Ca^{2+}). Hardness is typically expressed as equivalent $CaCO_3$. The symptoms of hard water include the lowered performance of soaps, deposition of scale, skin irritation and taste issues.

The EPA's maximum contaminant load (MCL) for TDS in drinking water is 500 mg/L. San Diego's imported water sources, the State Water Project and Colorado River, have TDS values in the range of 250 mg/L[7] and 700 mg/L, respectively (SDCWA, 2000b). The MWD has a contractual agreement with SDCWA to provide a 50/50 blend of these waters "to the extent reasonable and practicable", delivering a blended water that is below the MCL. Periodically, the imported water in San Diego has exceeded the MCL, due to natural salinity variations in the water sources, as well as intentional shifts in the mixing ratio (SDCWA, 2000b). In 2001, 64% of San Diego's imported water originated from the Colorado River (SDCWA, 2002a). Since 1998, measured TDS levels in imported, treated water have ranged between 384-612 mg/L with average values between 480 and 512 mg/L.[8]

7.1.2 *Desalinated seawater*

During operation, the Carlsbad Desalination plant is expected to produce drinking water with a quality of 250-350 mg/L TDS, well below the MCL.[9] This will represent a substantial decrease in salinity as compared to the imported water blend currently delivered to the county. The ionic composition of the salinity will be dependent upon the composition of feed water in the lagoon from which power plant cooling water is drawn, the reverse osmosis membrane's rejection rate for each constituent, and the post-treatment processes used to stabilize the desalinated product water.

Reverse osmosis membranes tend to preferentially reject divalent cations (calcium and magnesium) as compared to monovalent cations. The reverse osmosis process produces a product water that is very low in hardness and alkalinity, and tends to be "aggressive". To prevent the corrosion of water conveyance infrastructure, desalinated water is post-treated to restore buffer capacity and raise the pH.

7.2 The MWD Salinity Impact Model

The Metropolitan Water District in collaboration with the US Bureau of Reclamation, California Department of Water Resources, and its member agencies, has developed an economic model for estimating the economic effects of changes of imported water supply quality. The model, assembled by Bookman-Edmonston Engineering, which is intended to produce a regional approximation of economic impacts, is the result a two-year process of literature review, surveys, interviews, and testing. Most of the economic relationships in the model are updates to a 1988 USBR study performed by Lohman et al. (1988). The model calculates impacts for a set of customer classes: residential, commercial, industrial, agriculture, utilities and recycled water users. It also includes methods for estimating the impacts of surface water salinity changes on groundwater resources. All model results are expressed in 1998 dollars (which we inflate to 2003 using the Consumer Price Index).

The primary purpose of the salinity impact model is to predict the economic consequences of policy changes that affect the salinity of imported water sources. Using this approach, MWD has projected that a 100 mg/L drop in salinity in both Colorado River and State Water Project supplies would produce a $95 million benefit to users in its service area. This benefit would primarily accrue to the residential sector, followed by groundwater (improved quality of

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[7] Value for the East Branch of State Water Project, which serves San Diego County

[8] Values obtained from City of Oceanside, Consumer Confidence Report of Detected Compounds, 1998-2001.

[9] Personal communication, Bob Yamada, San Diego County Water Authority, 2/03/2003

recharge) and agriculture. The model also demonstrated that the marginal benefits of salinity reduction were greater for Colorado River water, as compared to State Water Project, which is has lower salinity.

7.2.1 Application of the MWD Model

In this project, we use the MWD model to estimate the benefits of substituting desalinated water for imported water in San Diego County. The MWD economic impact model, which is designed to make generalized cost/benefit estimates over large population groups, makes use of several simplifying assumptions. The following is a discussion of how these assumptions may influence the model results, and aid in interpretation of the data.

Use of aggregate input data

The model uses average socioeconomic conditions as input values. For instance the percentage of homes owning dishwashers is obtained from census data. Applying the economic impact function for dishwashers to a relatively affluent community may therefore produce an under-estimate of the economic consequences of a salinity change on this group of uses. The generation of input values for our San Diego specific case study is discussed in section 7.4.1.

Assumption of correlation between hardness and salinity

A number of the economic impacts of high salinity water are actually attributable to the water's hardness, which is a component of the salinity. Observing that the hardness to salinity ratio is relatively stable for Metropolitan's imported water supplies allows salinity (as TDS) to be used as a proxy for hardness. A flaw in our use of the MWD economic model to estimate the benefits of salinity reduction is the assumption that the hardness/salinity ratio will stay constant after the addition of desalinated water to the San Diego County supply. Since the desalination plant is still in the design stage, the final product water composition is not conclusively decided. Although we do not know whether this ratio will be similar to that found in existing water supplies, we can estimate this ratio based on available evidence, and in turn use the results to predict whether the MWD model will tend to produce under or over-estimates of the impacts associated with hardness.

As part of the MWD study, it was determined that the ratio of hardness to salinity ranges between 45 and 51 percent for Colorado River Supplies, and between 35 and 47 percent for the State Water Project East Branch. In fiscal year 2000, the hardness/TDS ratio in Lake Skinner, the reservoir from which SDCWA receives its imported supply from MWD, had a hardness to TDS ratio of 49%[10] for both treated and untreated (filtered) water (SDCWA, 2000).

The hardness of the desalinated water will depend upon the addition of lime in the post-treatment stage. SDCWA has indicated that the Carlsbad Plant's recarbonization process will involve the addition of 40 mg/L of lime to the product water. Using this information, an estimate of the product water hardness after post-treatment is made as follows:

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[10] TDS = 475 mg/L, hardness (as $CaCO_3$) = 233 mg/L

- Ocean water typically has salinity of 34.7 parts per thousand(ppt), primarily composed of sodium and chlorine. Calcium and magnesium, the most prevalent divalent ions in seawater, are found at concentrations of 0.4 ppt and 1.3 ppt, respectively.

- The desalination facility will share the Encina Power Plant's intake from Agua Hedionda Lagoon. The salinity of the lagoon, which is open to the sea and fed by streams, is approximately 32 ppt. (California Coastal Conservancy, 2001)

- Assuming the ions in lagoon are distributed in the same proportions in seawater, the concentrations of Ca^{2+} and Mg^{2+} are scaled to 0.37 and 1.20 ppt.

- Based on the final plant salinity of 350 mg/L, the final concentrations of Ca^{2+} and Mg^{2+} are calculated as 4.0 and 13.1 mg/L. These concentrations are likely to be overestimates of the concentrations of these ions in the permeate, since reverse osmosis membranes have higher rejection rates for divalent ions. Also, it is common for desalination plant influent to be softened to prevent membrane fouling, therefore the effluent may actually contain an even lower content of these constituents. The hardness (as $CaCO_3$) of the influent after treatment with reverse osmosis is calculated using the stoichiometric formula:

  $$H = 2.5 * [Ca^{2+}] + 4.1 * [Mg^{2+}] = 64 \text{ mg/L}$$

- SDCWA has indicated that 40 mg/L lime ($Ca(OH)_2$) will be added to the desalination plant effluent to stabilize the water and improve its flavor. In this process, the hardness will be increased. Assuming all the lime goes into solution, this will involve an addition of 21 mg/L of ionic calcium (based on ratio of atomic mass of atomic calcium to calcium hydroxide). The resulting additional hardness due to post-treatment is calculated as 2.5* 21 mg/L = 52.5 mg/L.

- The final hardness/salinity ratio of the product water is estimated as

  $$(63.8 \text{ mg/L} + 52.5 \text{ mg/L}) / (350 \text{ mg/L} + 52.5 \text{ mg/L}) = 29\%$$

This ratio of hardness to salinity is lower that that of the Colorado River and State Water Project, suggesting that the MWD model will produce conservative estimates of benefits due to avoided exposure to water hardness. The estimated product water hardness (~116 mg/L) is similar to the 100 mg/L minimum hardness value used in certain water regulations (Semiat, 2000), and found in other seawater desalination facilities (Marangou, 2001).[11] This concentration is typical of a moderately soft water.

As a second estimate of the hardness of the desalinated product water, a comparison was made to the water quality produced at the Mission Bay Desalting Facility, located in the City of Oceanside. This facility, which desalts brackish seawater via reverse osmosis, experienced a

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[11] The Dhekelia Desalination Plant in Cyprus has been producing water with hardness near 100 mg/L (contracted range is 100-150 mg/L) (Marangou, 2001)

hardness to TDS ratio ranging between 45 and 64% between 1998 and 2001 (City of Oceanside, 1998-2001). This ratio is similar to that of imported sources.

Simplification of corrosion impacts

Some water-quality related residential damage is produced by corrosion. Metallic corrosion is a complicated phenomenon, influenced by a variety of parameters including pH, hardness, temperature, chloride concentration and dissolved oxygen. Low ionic concentrations can induce the dissolution of metal atoms from the interior of pipes. Corrosion is further complicated by its relationship to hardness. The scale deposited by high hardness water acts as a barrier to corrosion. Water softening may therefore increase the likelihood of corrosion damage in downstream appliances and piping.

The MWD model uses empirical relationships between TDS and damages but does not attribute corrosion damage to a particular water constituent. In order to use this model to evaluate desalinated product water, we must assume that the post-treatment is sufficient to enable the protective scale to form, and that the general reduction in ion concentrations will reduce corrosion due to conductivity and/or specific water constituents such as chlorine. In addition, two of the scenarios we evaluated involve mixing desalinated water into existing high-salinity supplies, therefore we can assume that corrosion induced by low ionic content will not occur once supplies are merged.

Variability in quality and quantity

The information provided by this model is further constrained by error in the model inputs. For instance, the distribution of water demand among customer classes in a water district will change over time. Reasons for this variability include land use changes, climate, and various economic factors (crop prices, industries going out of business, etc). Another source of error which was not accounted for is the potential for differences between delivered (into member agency system by SDCWA) and metered water quantities, as a result of system leaks. Water agencies are actively involved in leak detection and repair as a Best Management Practice, and therefore this difference is assumed to be minor.

Additional uncertainty is due to spatial variation in water quality within the distribution system. The MWD model assumes evenly mixed salinity within studied regions. In reality, individual member agencies have different mixtures of imported and local water, resulting in heterogeneous water quality levels. The introduction of desalinated water to the service area would also produce spatially heterogeneous changes in water quality, due to some agencies being upstream from the distribution point.

7.3 Methodology for Calculating Economic Impacts

The model subdivides economic impacts into a set of impact classes: Residential, Commercial/Institutional, Industrial, Agricultural, Water and Wastewater Utilities, and Groundwater Recharge. The following discusses the origin of the impact relationships used in the model, and which we have chosen to apply to evaluate the potential benefits of the desalination facility.[12]

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[12] The MWD model also includes methods for estimating costs and benefits associated with infiltration water quality, and the impacts on groundwater. Due to the limited use and availability of groundwater in San Diego County, these issues were not considered.

7.3.1 Residential Impacts

The first set of impacts addressed by the MWD model are those associated with the reduced life of water using appliances and plumbing. As discussed in Tihansky (1974), the economic damages to household items as a result of municipal water supply can be attributed to a variety of constituents in the water. These constituent produce residential damages in the form of clogging, staining, reduced effectiveness of soaps and detergents, corrosion and water flavor.

The MWD model divides residential economic impacts into two categories: extension of product life and avoided purchases.

Extension of Product Life

The process for calculating the benefits of increased product life involves first estimating each appliance's useful life at two salinity levels, using relationships derived from customer surveys. The useful life data is then inverted and multiplied by the average market price for that appliance to generate an annualized replacement cost. The difference in costs for the two salinity levels can then be used to estimate the regional economic impact, by multiplying the benefit by the number of households and the proportion of households owning that appliance. The calculated impacts do not address shifts in expenditures due to ongoing (i.e. non-catastrophic) maintenance and repair.

The functional relationships used to estimate product life spans as a function of salinity are as follows:

Table 7-1 Useful Product Life as a Function of TDS

Appliance/Plumbing Item	Life Span in Years*
Galvanized Steel Water Supply Pipes	$12 + \exp(3.4 - 0.0018 \cdot TDS)$
Water Heater	$14.63 - 0.013 \cdot TDS + 0.689E\text{-}5 \cdot TDS^2 - 0.11E\text{-}8 \cdot TDS^3$
Faucet	$11.55 - 3.05E\text{-}3 \cdot TDS$
Garbage Disposal	$9.23 - 3.87E\text{-}3 \cdot TDS + 1.13E\text{-}6 \cdot TDS^2$
Washing Machine	$14.42 - 0.011 \cdot TDS + 4.6E\text{-}6 \cdot TDS^2$
Dishwasher	$14.42 - 0.011 \cdot TDS + 4.6E\text{-}6 \cdot TDS^2$

** Equations from MWD 1998. Original data from Tihansky, 1974, Milliken-Chapman 1988*

The life span functions are a result of several decades of studies which attempted to empirically link product lifetime to water salinity levels using customer surveys, manufacturer data and interviews with appliance repair personnel. The choice of functions was based on the interpretation of these studies by the consulting firm which developed this model for MWD. In most cases, the firm did not find evidence supporting the need to modify impact functions derived by Lohman et al (1988).

The following is a discussion of the observed failure modes described by the lifetime functions which were determined to be statistically significant in the MWD study:

Galvanized Steel Water Pipe: Galvanized steel pipe is subject to corrosion, which is enhanced in high salinity water. High hardness waters will also produce mineral buildup inside of pipes. Galvanized steel pipe was used to plumb a portion of Southern California homes built prior to the 1970s. Based on the age of the housing stock, the MWD survey estimates that 13 percent of homes in the service area may still have galvanized pipe. A more detailed benefit estimate would involve surveying San Diego residents to determine how many housing units with galvanized pipe still exist. The impact function from galvanized pipe was derived by Tihansky (1974).

Water Heaters: Deterioration of water heaters occurs due to the deposition of scale from hard water. There may also be impacts associated with accelerated depletion of a water heater's sacrificial anode, due to high concentrations of dissolved ions.

Faucets: The impact of salinity on faucets is variable, due to high variation of faucet materials. The impact function used in the MWD model, which was derived in the Lohman study, indicates that a drop in salinity from 500 to 350 mg/L will increase the average faucet life from approximately 10 to 10.5 years. Although the background information used to generate the life span estimates appears to be inconclusive, this value seems reasonable and will therefore be included in the benefit estimate.

Garbage Disposals: Empirical evidence exists that the lifetime of garbage disposals is reduced by operation in high salinity waters, presumably due to scale buildup. The MWD model assumes that 75% of homes have garbage disposals.

Dishwashers and Washing Machines: Exact failure modes of these appliances are not specified, however they are assumed to be similar to the other appliances.

Benefits due to Avoided Purchases

Residences experiencing high drinking water salinity tend to engage in excess consumption of water softeners and bottled water as compared to those experiencing lower salinity levels. The salinity impact model attempts to capture the benefits associated with the avoided purchase of these goods as a result of water quality improvements.

As part of the MWD salinity impact study, the consulting firms M.Cubed and Freeman-Sullivan were commissioned to develop an econometric model linking drinking water TDS to consumer expenditures. Data for the study came from a telephone survey performed in the service area, plus vendor data. An analysis of the survey results revealed a significant statistical relationship between drinking water TDS and expenses due to water softening, purchase of bottled water, and home water filtration.

Home Water Softeners: Water softeners are devices installed at individual residences to reduce the quantities of calcium and magnesium ions in household drinking water. As a result of water softening, household devices are less prone to scale, and soaps and detergents have better performance. The water softening process involves passing water through a bed containing an ion exchange resin. As the water contacts the resin, dissolved calcium and magnesium ions are captured and replaced by sodium ions in the resin. The softened water subsequently has reduced calcium and magnesium concentrations. The substitution of cations leaves salinity unaffected.

The use of water softeners is of particular concern due to the impacts of water softening on wastewater quality. In order to purge captured calcium and magnesium from the softener, the resin must be periodically flushed with a brine solution. The effluent from this process is discharged to the sewer. This load to the wastewater stream can have significant impacts in areas where wastewater is recycled for non-potable uses, since typical treatment processes do not remove salinity.

The expected annual expense associated with water softeners is calculated as the probability of a consumer using water softeners at a given TDS level, multiplied by the expected annual cost associated with operating a water softener at that TDS level (estimated as $340/yr). The probability function is as follows:

$$P = 6.758 + 0.007 \cdot TDS + 3.01E\text{-}6 \cdot TDS^2 + 2.2E\text{-}10 \cdot TDS^3$$

<u>Bottled Water and Home Water Filtration</u>: Prior studies have demonstrated that salinity imparts an unpleasant taste to drinking water, leading to substitution of bottled water for tap water. As part of the MWD study, M.Cubed and Freeman-Sullivan performed telephone surveys of residents in the service area, the results of which confirmed that a statistical relationship exists. From the survey, the researchers determined that the average annual costs associated with these purchases is $62. The probability of a resident choosing to purchase bottled water or a filtration system is estimated as:

$$P = 61.1 + 0.00323 \cdot TDS$$

7.3.2 Commercial/Institutional Impacts

Commercial and institutional water customers consist of uses such as schools, restaurants, retail stores, hotels and laundries. Also included are landscaped municipal areas (parks, golf courses) that are not currently irrigated with recycled water. Water quality changes will impact different uses within this sector differently. As a result, the process of estimating the benefits of water quality improvements involves some knowledge of the expected uses of water, and the impacts to these uses.

The particular pattern of water consumption within the commercial/institutional group influences how changes in water quality will impact this sector as a whole. To determine the characteristic breakdown of water uses, the MWD economic model draws from an earlier survey which profiled the water uses (irrigation, kitchen, etc) by customer group in the MWD service area. The results were aggregated to produce a typical mix of water uses for the region. The overall breakdown of water using activities is as follows:

Table 7-2 Components of Commercial and Institutional Water Use

Category	Percent
Sanitation	29
Cooling	12

Irrigation	32
Kitchen	7
Laundry	8
Unaccounted	3
Other	9

Source: MWD 1998

This consumption breakdown is characteristic of the MWD service area, and may be slightly different in San Diego County. The MWD study provides impact functions for all water uses with the exception of landscape irrigation, for which no relationship was found.

Sanitation: Sanitation, mainly toilet flushing, is a major use of water within this sector. Sanitation also includes the operation of sinks and showers, which can be high in certain establishments, such as hotels and hospitals. The impacts to sanitation uses are considered to occur due to premature failure of faucets and toilet flushing mechanisms. The model estimates annual impacts to these fixtures as \$0.06 per acre-ft per mg/L of salinity.[13] Additional costs are associated with use of water softeners, especially in hospitals and hotels. Based on the results of the aforementioned study, it was estimated that the marginal cost of water softening is \$0.12 per AF-mg/L. Thus, the total economic impact inflated to 1998 dollars is \$0.18 * 1.05 = \$0.19 per AF-mg/L.

Cooling Towers: Salinity has a significant impact on the operation of cooling towers, which constitute 12% of commercial/industrial water use. Cooling towers are used to reduce the temperature of water, and are commonly used in air conditioning systems. They operate by forcing air through hot water, encouraging the transfer of heat to the atmosphere by evaporation. Make-up water is added to the system as needed to replace the evaporated water. The cooling water is continually monitored to keep it below a maximum salinity level. Since evaporation will tend to increase the salinity, some water is occasionally released from the system (blow-down) and replaced by additional make-up water. Blow-down, which constitutes approximately half of cooling tower use, is typically sent to the sewer (West,2002).

The water use efficiency of cooling towers is directly affected by the salinity of municipal water supplies. High salinity water requires additional consumption of biocides, anti-corrosion and anti-scaling additives. A rise in salinity will also decrease a tower's cycle of concentration, which represents the ratio of make-up to blow-down water.

The MWD model estimates the change in operational costs for cooling towers as the change in water consumption times the price of water. The water price is comprised of the retail water price (\$700/AF), the chemical treatment costs (\$150/AF) and the blow-down disposal cost (\$600/AF). The change in water consumption is estimated using the following table:

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[13] The use of this value is not well justified by the MWD model. We confirmed it to be in range by observing the results of the benefit estimate for improved residential faucets. For a 3 mg/L salinity improvement in the SDCWA region, the model predicts a benefit of $\$40209/(295695\text{AF}*3\text{mg/L}) \approx \$0.05(\text{AF})^{-1}(\text{mg/L})^{-1}$.

Table 7-3 Cooling Tower Make-Up Water vs. Salinity

Salinity mg/L	Make Up Water as % of Evaporative Loss
100	104
350	116
500	125
600	132
699	139

Source: MWD 1999

The MWD Model estimates the marginal increase in make-up water per mg/L of salinity using the data points at 500 and 600 mg/L (0.0007 % increase per mg/L). Since the San Diego model will involve decreases from a baseline of 500 mg/L, this percentage was re-evaluated for the 350-500 mg/L range (0.0006 % increase per mg/L). After inflating to 1998 dollars, the cost per mg/L increase in salinity is given by:

$$\$1450\ (AF)^{-1} * 0.0006\ \%(mg/L)^{-1} * 1.05\ = \$0.91\ (AF)^{-1}(mg/L)^{-1}.$$

Kitchens and Laundries:
Approximately two-thirds of the commercial/industrial facilities in the MWD area use water softening for a portion of their kitchen needs. Based on typical softening costs (\$0.60 $(AF)^{-1}(mg/L)^{-1}$ in 1996 dollars) scaled to a reasonable proportion of kitchen use, the marginal impact is estimated a \$0.30 $(AF)^{-1}(mg/L)^{-1}$.

The MWD model indicates a marginal impact of \$0.63 $(AF)^{-1}(mg/L)^{-1}$ for laundry water use. To arrive at this value, the model assumes that those laundry facilities that do not engage in water softening will still incur economic impacts of a similar magnitude as softening expenditures (presumably due to increased maintenance costs, increased soap consumption of customers, decreased lifetime of clothing). To gain a rough estimate of the magnitude of this number, the benefit of a 100 mg/L salinity decrease was estimated for the city of Carlsbad (population 78,000). The result, approximately \$30,000, seems reasonable for a city this size.

7.3.3 Industrial Impacts

The MWD model calculates industrial impacts in a similar manner as commercial/institutional impacts. Typical water-intensive industries located in the MWD service area include electronics, aerospace, petrochemicals, and processed foods. The water quality required by these industries varies greatly. Many industrial customers have begun to reduce their water and wastewater costs by recycling water onsite and/or purchasing reclaimed wastewater.

Each industry uses water differently. However there are several uses that are common to most industries. Estimates of each major industry's characteristic water-using applications and total water demands were obtained from prior studies. Employment data and water audits were used to subdivide industrial water use by application for all sub-areas within the MWD service area. The results for San Diego County are as follows:

Table 7-4 Industrial Water Use in San Diego County

Water Use	Percent of Total	Impact $ (AF)$^{-1}$(mg/L)$^{-1}$
Process Water Demineralization	30	1.48
Process Water Softening	13	0.63
Process Water Minor	9	0.00
Boiler	18	1.05
Cooling	3	0.61
Sanitation and Irrigation	27	0.00

Source: MWD, 1999

The marginal increase in operation costs associated with a loss in water quality will depend on the degree of water quality degradation that has occurred since the plant's onsite water treatment facilities were designed. Initially, rising salinity may result in additional costs associated with modifying existing processes to mitigate the salinity. Additional water quality declines may produce a sharp increase in marginal cost, if new equipment, such as an additional water softener, is required to maintain operations. The MWD model simplifies this relationship to a linear function by aggregating a broad spectrum of industries (MWD, 1999).

The following is a discussion of the impacts of water salinity on each class of industrial water uses:

Process Water: The term process water is used to define water that is consumed directly in an industrial process, such as for rinsing or quenching. The minimum acceptable water quality will vary by industry – therefore treatment costs are a function of industry and municipal water quality. The characteristic breakdown of process water treatment requirements was presented in the previous table. Economic impact coefficients are estimated for demineralization and softening. The marginal cost associated with demineralizing water is estimated as $1.48 per mg/L. This value is based on small-scale reverse osmosis costs (treatment plus brine losses). The marginal cost associated with softening is the value presented earlier for commercial/institutional use, $0.63/AF. The remainder of process water uses are assumed to not require treatment, or rises in cost at the salinity levels evaluated by the model.

Boiler Feed Water: Industrial boilers require large quantities of make-up water, to replace water lost to evaporation or used in processes. Boiler feed water is typically softened to reduce scale. It is also typical for a portion of boiler feed to be demineralized. An economic impact of $1.05/AF-mg/L is used to represent the impact of salinity to boilers.

Cooling Water: The use of cooling water is primarily in cooling towers. Impacts to industrial cooling towers are handled identically to the commercial/institutional sector.

Sanitation and Irrigation: These water uses are considered to be minor and are not evaluated by the model.[14]

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[14] The authors justify this omission based on the typical household reaction to increased salinity (purchase of water softeners and bottled water), which is presumed not to apply to industrial water use.

7.3.4 Agricultural Impacts

Excess salinity in irrigation water results in decreased crop yields, as plants must expend more energy to overcome the increase in osmotic pressure when drawing water up through their roots. Agricultural irrigation water is not typically treated prior to application. As a result, the economic impact of salinity change on agriculture is primarily linked to yields, market values, and quantities of applied water. Another important factor is the variety of crop, since each crop has a characteristic sensitivity to salinity. Long-term trends in water salinity will also impact the choice of crops in the affected area.

The MWD model predicts yield loss as a function of salinity based on the results of studies performed at the United States Salinity Laboratory in Riverside. The USBR has used these studies to derive functional relationships between irrigation water salinity and yield for a variety of southern California crops.

The MWD model determines crop acreage using the results of DWR land surveys. For our application of the model, acreage values were updated using GIS data provided by SANGIS (2002), and the California Department of Water Resources (1998), as discussed in Section 7.4.1. The particular crops evaluated by the model are: strawberry, miscellaneous vegetables, nursery crops, cut flowers, citrus, avocado, vineyard, pasture and grain, deciduous, and field crops. In some cases, USBR yield formulas for a particular crop were also used for related crops (for instance, oranges were used to represent all citrus), due to lack of data.

The USBR functions for ornamental crops were modified to take into account the practice of leaching. The researchers observed that growers of ornamental crops (nursery crops and flowers) tended to add excess irrigation water to flush the root zone in order to achieve full yields, and thereby avoided yield reductions. In this case, the economic impact is related to this excess quantity of water. The MWD study authors chose not to modify the impact functions for the other crops to take leaching into account, believing that the high cost of water and limited drainage in the MWD region would make this impact minimal. Our conversations with SDCWA indicated that farmers growing a variety of crops in San Diego County apply on the order of 10% excess irrigation water for leaching. This impact is significant, however in the absence of more specific behavioral data we were unable to factor this excess consumption into the model.

The USBR yield formulas produce ideal yields up to a threshold salinity value, beyond which yield declines occur. These functions are as follows:

Table 7-5 Salinity Impact Functions for Crops

CROP	THRESHOLD TDS (mg/L)	PERCENT OF FULL YIELD
Strawberry	427	$132.879 - 0.077 \cdot \text{TDS}$
Misc. Vegetables	640	IF(TDS< 640,100), ELSE $121.12 - 0.033 \cdot \text{TDS}$
Cut Flowers + Nursery Stock *	400	MAX($100.87 - 0.0024 \cdot \text{TDS}$, $99.937 + 0.0004 \cdot \text{TDS} - 0.000004 \cdot (\text{TDS})^2$)

Citrus	544	127.2 - 0.05 · TDS
Avocado	378	120.79 - 0.055 · TDS
Vineyards	480	114.4 - 0.03 · TDS
Pasture and Grains	853	114.501 - 0.017 · TDS
Deciduous	480	127.12 - 0.0565 · TDS
Field	725	119.33 - 0.0267 · TDS

source: MWD, 1998

** The MWD model calculates impacts to cut flower and nursery crop yields separately. We were unable to disaggregate these two crop types in our dataset. A conservative estimate of benefits was made by estimating the yield improvement with both the nursery and flower functions, and taking the maximum yield percentage (i.e. the minimum yield loss). Value per acre for cut flowers, which is lower than the value for nursery crops, is used for both crop families.*

Crop values per acre were obtained from the MWD salinity study. The study indicates that these values were originally obtained from San Diego County crop reports.

7.3.5 Impacts to Water Utility Infrastructure

The MWD model considers the costs associated with scale and corrosion damage to water and wastewater treatment facilities and distribution infrastructure. The presumption is that a decrease in the useful life of these systems will result in increased replacement costs. These costs will then be passed on to consumers as higher water and wastewater charges. The relationships between useful life and salinity are obtained from Tihansky (1974). They are as follows:

Life of Local Production Facility[15] $= 30.83 - 0.0033 \cdot \text{TDS}$
Life of Local Distribution Facility $= 60 + 50 \cdot \exp(-0.0009 \cdot \text{TDS})$

The first relationship, regarding production facilities, was omitted from our version of the model. The desalination plant will not impact water salinity at pumping and treatment facilities, which are mainly upstream from the plant. Model runs suggested that the benefits to production facilities would be fairly low.

Although the earlier Lohman model contained functional expressions for wastewater facilities, these were omitted from the 1998 model, after consultations with plant engineers suggested that most facilities are already constructed to handle high-salinity loads.

The local water distribution facility replacement cost is estimated as $1,800 per capita (not annualized), based on studies performed by the American Water Works Association. Annual per capita cost is determined by dividing this value by the expected facility life. The results of our model runs indicate that these impacts are relatively minor compared to other benefits.

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[15] Production facilities are defined as those used for water source generation, raw storage, pumping and treatment. Distribution facililites are defined as those used for delivery and treated water storage.

7.4 Application of the MWD model

Our aim is to use the MWD salinity model to predict the consequences of anticipated drinking water salinity changes on the residents of San Diego County. As discussed, the model incorporates the results of a variety of studies, makes use of aggregated data, and relies on numerous assumptions. Therefore our use of this model is intended to provide an estimate of potential benefits, and help determine which sectors of the water market will benefit most from these supplies.

We have chosen to model three different scenarios, based on potential distributions of 56,000 AFY of desalinated water throughout the SDCWA area. The service area is divided into three zones: Carlsbad, Oceanside, and the remainder of the SDCWA service area (henceforth referred to as SDCWA for simplicity)[16]. Carlsbad and Oceanside are singled out for analysis since they have both expressed interest in reserving a portion of the desalination plant's water. Also, as the closest cities to the plant, they would be the primary recipients of environmental impacts associated with the plant (and presumably would demand a higher share of the benefits).

A description of the three distribution scenarios and a map depicting the three study zones is provided in Section 6: Research Approach.

7.4.1 Generation of model input data

Additional data resources were required to customize the MWD model to San Diego County. For each study area, data was gathered to enable estimates of the following inputs: baseline TDS, simulated TDS, water consumption by customer class, agricultural acreage by crop, population and number of households. These are discussed as follows:

Baseline TDS

The baseline TDS is an estimate of typical salinity values experienced in the study zones. This value is heterogenous in time (both seasonally and with climate) and space (between districts and within districts), and therefore must be represented as an average or most probable estimate. In our analysis, data from year 2001 was used to compute the baseline. Therefore the benefit estimates should be interpreted as characteristic of year 2001 consumption patterns and water quality levels.

For Oceanside and Carlsbad, baseline TDS values were obtained from each city's year 2001 Water Quality Report. The City of Carlsbad specifies the average TDS value as that taken at the Skinner Filtration plant, which in 2001 ranged between 480 and 521 mg/L with an average value of 500 mg/L. Oceanside's water supply is composed of 53% locally-treated imported water, 40% pre-treated imported water, and 7% desalinated groundwater. The average weighted TDS using 2001 values is estimated using the average TDS for each source as: $0.53 \cdot 512 + 0.40 \cdot 500 + 0.07 \cdot 351 = 496$ mg/L.

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[16] The eastern portion of the county which is not covered by SDCWA contains approximately 3% of the population, exists exclusively on groundwater resources, and would not be impacted by the presence of the desalination plant.

The expected TDS for the remainder of SDCWA is estimated based on average values the City of San Diego, which represents approximately 40% of water used in this zone.[17] In year 2001, San Diego's three treatment plants experienced mean TDS levels of 487, 515 and 425 mg/L. The average of these three is 476 mg/L.

Simulated TDS

Each distribution scenario requires an estimate of the resulting salinity after the desalination plant becomes operational. It is assumed that desalinated water will only replace imported supply. In the case of Oceanside, it is assumed the desalinated water will replace imported treated supply before replacing imported untreated supply. It is also assumed that both treated and untreated MWD water will be supplemented with desalinated water.

The Oceanside Water Quality Report (2001) indicates that the water leaving its filtration plant has a TDS value 12 mg/L higher than that of water treated at the Skinner Filtration plant. Since filtration does not remove salinity, we can assume that both treated and untreated water leaving the Skinner plant have salinity of 500 mg/L. This excess 12 mg/L is therefore attributed to some other treatment process occurring at the plant or intermittent plant operation times, and would be expected to add this quantity of TDS to blended supply.

The first calculation is to estimate the effective TDS of imported water, after it has been mixed with the portion of desalinated water left after Carlsbad and Oceanside receive their allotment. This value, TDSi, was determined for each scenario to be 485 (100% of desal water), 492 (60% of desal water), and 498 (16% of desal water).

The following functions were then used to estimate the overall simulated TDS values for each zone:

Carlsbad:
TDS = [Qd(350) + Qi(TDSi)]/Qtot

Oceanside:
TDS = [Ql(351) + Qi,t (TDSi) + Qi,u(TDSi+12) + Qd(350)]/Qtot

Rest of SDCWA:
TDS = [Ql(359) + Qi(TDSi)]/Qtot[18]

Where,

TDSi = Effective TDS of imported water
Qd = Quantity of desalinated water
Qi = Quantity of imported water
Qi,t = Quantity of treated imported water
Qi,u = Quantity of untreated,imported water
Ql = Quantity of locally provided water (groundwater)
Qtot = Total water consumed

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[17] Furthermore, the city's water supply composition, 83% imported, is characteristic of SDCWA as a whole (590,000AF/695,000AF = 85%)

[18] The local supply quality of 359 mg/L was backed out of the baseline SDCWA quality estimate by assuming that 83% of the water was imported with TDS=500 mg/L

The following table summarizes the model inputs for the baseline conditions and three scenarios:

Table 7-6 Model Input TDS Values

	Baseline	Scenario #1	Scenario #2	Scenario #3
Carlsbad	500	486	408	350
Oceanside	496	483	435	350
SDCWA	476	467	472	476

Estimation of water consumption by customer category

We chose to use data from year 2001 to generate our benefit estimates. Annual consumption data were obtained from water agencies as either fiscal year or calendar year totals. Rainfall for October-December of 2000 and 2001 were determined to have only varied by 0.5 inches.[19] Therefore, for the purposes of this research both fiscal and calendar year data were used interchangeably. Year 2000 appears to represent an average rainfall year, with 11 inches of rain recorded in the city of Oceanside.

The MWD model requires estimates of water consumption for commercial, institutional, landscape irrigation and industrial customers for each zone. The first three are aggregated into a single category. Year 2001 water consumption data was obtained from each city. An estimate of imported water deliveries to member agencies during fiscal year 2001 was obtained from SDCWA. The deliveries were categorized for all agencies using data from the calendar year 2000 Member Agency Rate Survey (SDCWA, 2000). The resulting customer class breakdown is as follows:

Table 7-7 Year 2001 Customer Water Demands (AFY)

	Residential	*Commercial, Institutional, Landscape Irrigation*	*Industrial*	*Agriculture*	*Reclaimed Water*
Carlsbad[20]	9825	7046	260	943	1681
Oceanside	19029	8292	739	2571	154
SDCWA[21]	295695	123275	17561	98493	5107

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[19] Using data from CIMIS taken at the Oceanside Station. 2000 and 2001 Oct-Dec rainfall were 2.13 and 2.65 inches, respectively.

[20] Carlsbad's customer data for 2001 aggregates commercial and industrial water use into the same category. The two uses were separated based on the proportion of each use in prior years, when the values were reported separately.

[21] SDCWA's commercial/institutional water use was estimated as 25% of residential use, based on 1994 data presented in the MWD study (1998). This number was then used to back out the industrial water use value.

Estimation of agricultural acreage and economic value
GIS was used to estimate crop acreage in each study zone. Data sets used to generate the acreage values included a San Diego County Land Use Survey (California Department of Water Resources, 1998), and San Diego County Water District Boundaries (SANGIS, 2002).

The following procedure was used to generate acreage figures:

1) Outlines of the three zones were generated from the water district layer
2) The land use layer was clipped by each zone
3) The acreage of each land use polygon was determined by a field calculation
4) Acreages were aggregated by the dominant crop type and crop family

This procedure resulted in the following acreage values:

Table 7-8 Agricultural Acreage in Study Zones

	Carlsbad acreage	Oceanside acreage	SDCWA acreage
Strawberry	112	138	237
Misc. Vegetables	548	1008	4494
Cut Flowers + Nursery Stock *	591	995	5960
Citrus		131	8958
Avocado		797	39047
Vineyards			133
Pasture and Grains		15	9656
Deciduous			149
Field	292		193
TOTAL	**1543**	**3083**	**68828**

Estimates of crop values per acre were obtained from the MWD model. For San Diego County, these values are:

Table 7-9 Crop Value Per Acre

Crop	1998 Value ($ / Acre)
Strawberry	$23,800
Misc. Vegetables	$9,600
Cut Flowers + Nursery Stock*	$22,000
Citrus	$6,100
Avocado	$4,200

Vineyards	$700
Pasture and Grains	$400
Deciduous	$2,600
Field	$3,700

** Initially, cut flowers acreage value was also used for nursery stock. The implication of this assumption is discussed in the model results section.*

Population and number of households

Population and household estimates for Carlsbad, Oceanside and San Diego County were obtained from 2000 United States Census Data. This data is provided by the San Diego Association of Governments Data Warehouse (SANDAG, 2000). Estimates of population and households within the SDCWA study zone, which excludes Carlsbad and Oceanside, were made by reducing the total county values by 3%, and then deducting the values for Carlsbad and Oceanside.[22]

Inflation to 2003 dollars

The consumer price index was used to inflate the model results (which are calculated in 1998$) to 2003$. The index for this transformation is 1.11, or 11%.

7.5 Summary of Results

Our model results indicate that substitution of desalinated water for a portion of San Diego County's imported water supply will produce an annual benefit on the order of $3 million, in all three scenarios, under year 2001 conditions. The results for the three scenarios are as follows:

Table 7-10 Total Annual Benefit to San Diego County from Salinity Reduction

	Benefit ($)
Scenario 1: Distribution to Entire County	$3,161,000
Scenario 2: 20 % Carlsbad; 20% Oceanside; 60% SDCWA	$3,199,000
Scenario 3: Full replacement of Carlsbad and Oceanside Imported Supply	$3,560,000

The total benefits are approximately 10% higher for Scenario 3. This suggests that this would be the preferable distribution strategy, assuming that it would involve similar investments in distribution infrastructure as compared to the other scenarios.

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[22] Personal communication, Cindy Hansen, SDCWA (January 27, 2003)

Is desalinated water worth the extra cost?

In year 2002, imported water was purchased from MWD at $431/AF[23]. SDCWA adds a surcharge of $95/AF to the M&I rate, resulting in wholesale treated water price of $526/AF. The desalinated water produced by the Carlsbad Plant is expected to cost $794/AF, plus an additional $100/AF for pumping. Reducing this value by the MWD subsidy ($250/AF) results in an effective water price of $644/AF. Thus, the overall wholesale price difference between the desalinated seawater and imported supplies is approximately $100/AF.

The model results indicate that after the subsidy, nearly half of this price differential is recovered in the form of water quality benefits. Under Scenarios #1 and #2, water quality improvements result in a $57 benefit per acre-foot of desalinated water. Under Scenario #3, where desalinated water is preferentially distributed to the cities of Carlsbad and Oceanside, this benefit grows to $64/AF. Thus, in combination with the MWD subsidy, desalinated water is effectively $36-$43/AF more costly than imported water.

Who receives the benefits?

The model results suggest that in all scenarios, approximately half the benefits of water quality improvement will be received by the residential sector. In nearly all scenarios, agriculture receives the second highest portion of benefits, followed by the commercial and institutional sector. The size of the residential benefit is primarily due to the overall size of this sector within the County.

Estimates of the annual benefits associated with reduced salinity that would accrue to each customer class under each scenario are displayed in Table 7-11. The values are calculated by dividing the sector benefit within each zone by the water consumed in that zone. The results indicate that potential changes in salinity produce higher marginal benefits to agricultural customers than any other customer class. Combined with the MWD subsidy, agricultural users in Carlsbad and Oceanside will experience benefits in excess of the extra cost for the desalinated water. As discussed in Section 7.5.1, the total agricultural benefit may be understated due to assumptions made regarding flower and nursery crops. Therefore, the marginal benefit of salinity reduction to agriculture may actually be higher than suggested by the table.

The overall model results are summarized in Table 7-12 to Table 7-14, and presented graphically in Figure 7-1 to Figure 7-3.

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[23] Treated Municipal and Industrial (M&I) rate for SWP and Colorado River blend. Untreated water is $341/AF.

Table 7-11 Annual Benefit per Sector ($/AF)

	SCENARIO 1		
	Carlsbad	**Oceanside**	**SDCWA**
Residential	$7.41	$6.35	$4.54
Commercial	$3.68	$3.42	$2.37
Industrial	$10.37	$9.62	$6.67
Agriculture	$38.97	$27.50	$9.91

	SCENARIO 2		
	Carlsbad	**Oceanside**	**SDCWA**
Residential	$47.19	$29.21	$2.02
Commercial	$24.21	$16.05	$1.05
Industrial	$68.13	$45.15	$2.96
Agriculture	$210.20	$129.02	$4.40

	SCENARIO 3		
	Carlsbad	**Oceanside**	**SDCWA**
Residential	$75.25	$67.66	$0.00
Commercial	$39.48	$38.42	$0.00
Industrial	$111.09	$108.05	$0.00
Agriculture	$226.91	$199.52	$0.00

Figure 7-1 Salinity Model Results for Scenario 1

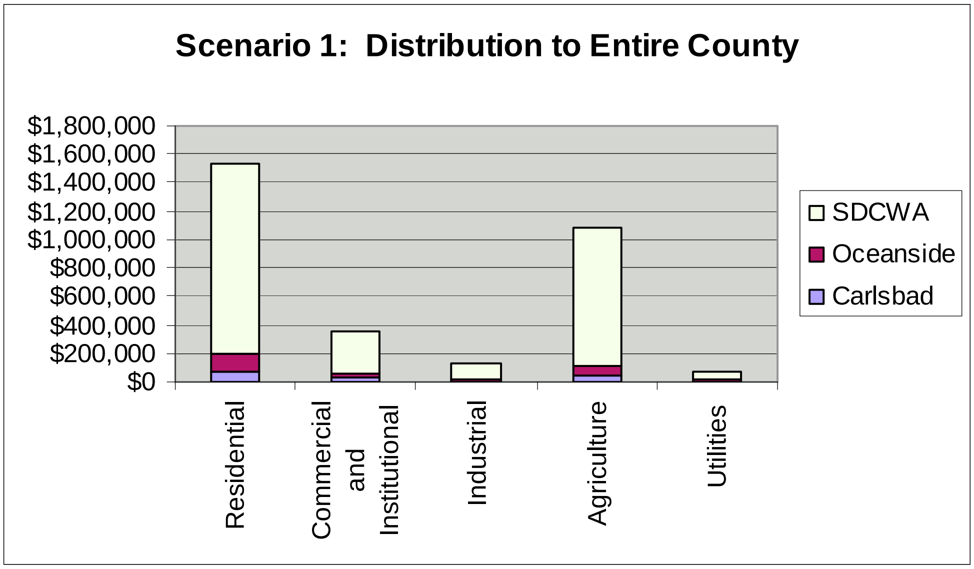

Table 7-12 Salinity Model Results for Scenario 1

	City of Carlsbad	City of Oceanside	Remainder of SDCWA territory
Baseline TDS (mg/L)	496	500	476
Final TDS (mg/L) [1]	483	486	467
Drop in TDS (mg/l)	13	14	9
Percent reduction	2.6%	2.8%	1.9%
Benefit Breakdown:			
Residential	$72,781	$120,766	$1,343,299
Commercial[2]	$25,961	$28,370	$291,992
Industrial	$2,696	$7,110	$117,051
Agriculture	$36,753	$70,690	$975,910
Utilities	$3,153	$5,251	$59,556
Total Annual Benefit:	$141,344	$232,187	$2,787,808
per acre foot[3]	$7	$8	$5
per capita	$1.81	$1.44	$1.12

[1] *after addition of desalinated water to drinking water supplies*
[2] *includes institutional benefits*
[3] *benefit divided over all water consumed (local, imports and desalinated seawater)*

Figure 7-2 Salinity Model Results for Scenario 2

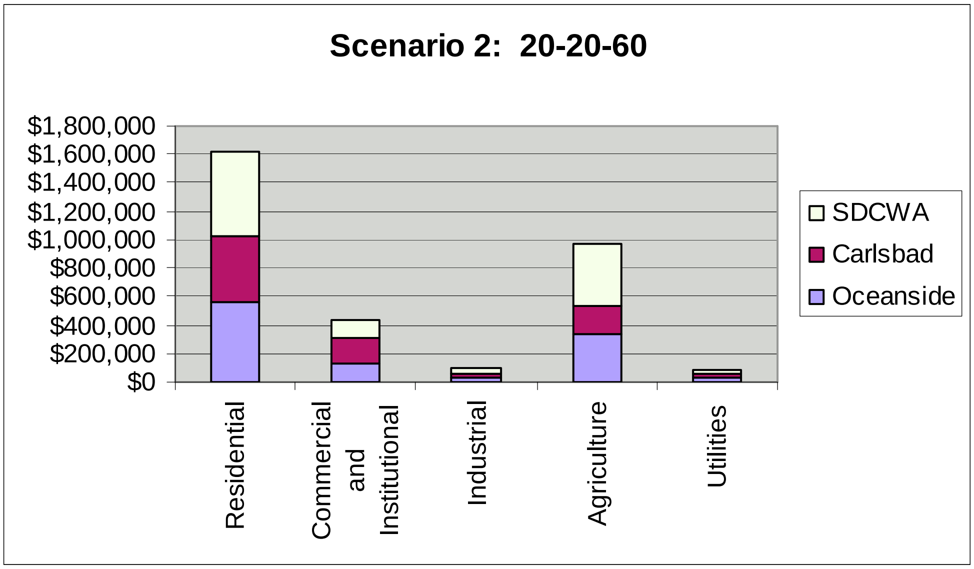

Table 7-13 Salinity Model Results for Scenario 2

	City of Carlsbad	City of Oceanside	Remainder of SDCWA territory
Baseline TDS (mg/L)	496	500	476
Final TDS (mg/L) [1]	435	408	472
Drop in TDS (mg/l)	61	92	4
Percent reduction	10.7%	11.4%	9.9%
Benefit Breakdown:			
Residential	$463,661	$555,880	$598,223
Commercial[2]	$170,602	$133,119	$129,774
Industrial	$17,715	$33,363	$52,023
Agriculture	$198,221	$331,701	$433,738
Utilities	$24,823	$24,797	$31,418
Total Annual Benefit:	$875,022	$1,078,859	$1,245,176
per acre foot[3]	$46	$36	$2
per capita	$11.18	$6.70	$0.50

[1] *after addition of desalinated water to drinking water supplies*
[2] *includes institutional benefits*
[3] *benefit divided over all water consumed (local, imports and desalinated seawater)*

Figure 7-3 Salinity Model Results for Scenario 3

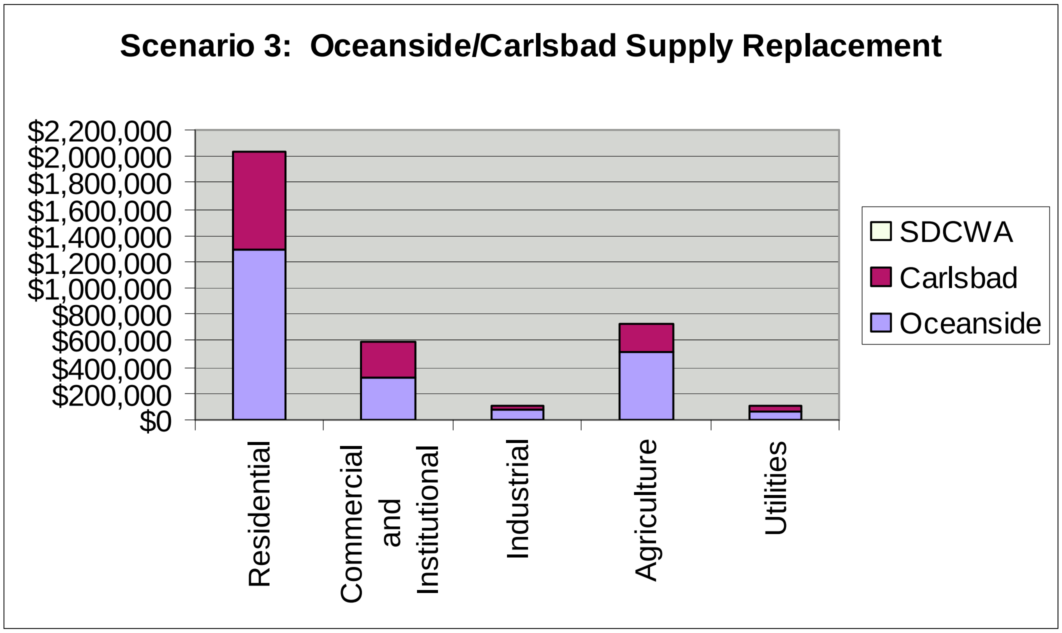

Table 7-14 Salinity Model Results for Scenario 3

	City of Carlsbad	City of Oceanside	Remainder of SDCWA territory
Baseline TDS (mg/L)	496	500	476
Final TDS (mg/L) [1]	350	350	476
Drop in TDS (mg/l)	146	150	0
Percent reduction	29.4%	30.0%	0.0%
Benefit Breakdown:			
Residential	$739,331	$1,287,518	$0
Commercial[2]	$278,156	$318,611	$0
Industrial	$28,883	$79,851	$0
Agriculture	$213,980	$512,959	$0
Utilities	$40,676	$59,984	$0
Total Annual Benefit:	$1,301,026	$2,258,924	$0
per acre foot[3]	$68	$75	$0
per capita	$16.63	$14.03	$0

[1] *after addition of desalinated water to drinking water supplies*
[2] *includes institutional benefits*
[3] *benefit divided over all water consumed (local, imports and desalinated seawater)*

7.5.1 Discussion of Benefits by Customer Class

Residential:
The total annual benefits to residential customers are as follows:

Scenario 1: $1,537,000
Scenario 2: $1,618,000
Scenario 3: $2,027,000

This benefit is mainly a result of decreased household expenditures on water softening, and improved lifetime of dishwashers. Bottled water purchases appear to be independent of drinking water salinity. The residential benefits scale proportionately in each scenario and within and between zones.

Commercial/Institutional:
The total annual benefits to commercial and institutional customers are as follows:

Scenario 1: $346,000
Scenario 2: $433,000
Scenario 3: $597,000

Nearly half of the savings to this sector are associated with improved water use efficiency in cooling towers.

Industrial:
The total annual benefits to industrial customers are as follows:

Scenario 1: $126,000
Scenario 2: $103,000
Scenario 3: $108,000

The primary source of savings to the industrial sector comes as reduced costs for process water demineralization. Interestingly, Scenario 1 produces a higher overall benefit to industry than the other scenarios.

Agriculture
The total annual benefits to agriculture are as follows:

Scenario 1: $1,083,000
Scenario 2: $964,000
Scenario 3: $727,000

As with the Industrial Sector we results, we again see Scenario 1 showing the highest benefit. This indicates that a small salinity benefit spread out over the entire county will have a stronger impact than a larger but more geographically focused benefit. Strawberries, avocados, and flower and nursery crops were the only crops showing benefits from the modeled salinity reductions.

The largest benefit was associated with increased avocado yields. Avocados are sensitive to salinity, which can reduce tree size, produce leaf "scorching", and depress avocado yields (Crowley, 2002). The search for salt-tolerant rootstock is an active area of research in the County.[24] Although a switch to new root stock may minimize the economic benefits of improved water quality, water salinity reduction may be viewed as an alternative investment for increasing avocado production.

The model results indicate that benefits to flower and nursery crops are dwarfed by the avocado benefits. Initially, estimates of impacts to ornamental crops were made using the empirical yield reduction relationship for flowers, which is more conservative than that of nursery crops. The sensitivity of the economic impact functions to salinity are depicted graphically as follows[25]:

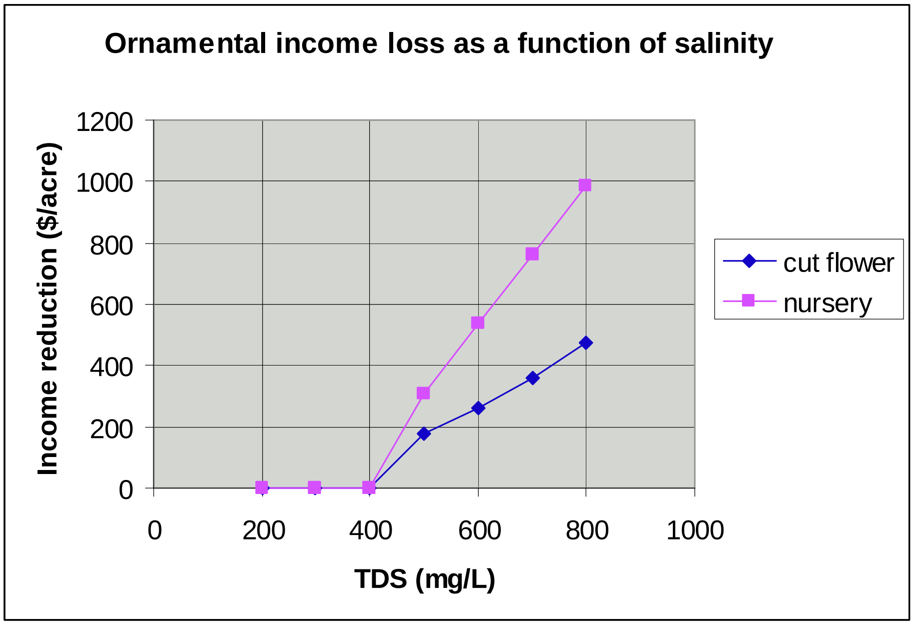

Figure 7-4 Loss of Ornamental Crop Income from Irrigation Water Salinity

It is evident that salinity reductions produce higher benefits to nursery crops than cut flowers on a per acre basis. Cut flowers appear to be more sensitive to salinity, however their value per acre is much lower. Thus, our benefit estimates for these combined crop categories are likely to be significantly understated.

An effort was made to better estimate the upper bound of the benefit to ornamental crops under Scenario 1. The MWD model includes estimates of nursery and cut flower acreage for

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[24] Personal communication, Vickie Driver, SDCWA, 12/18/2002

[25] Benefit calculated as difference in yield reduction * value per acre. The values per acre are $93,838 and $20,518, for nursery crops and cut flowers, respectively (in $1995)

Northern San Diego county. These values, which are based on data from 1986 and 1996, are 6,487 and 1,676 acres, respectively. Using the ratio of acreages, the total ornamental acreage of the county estimated with GIS is divided into 6,000 acres of nursery crops, and 1,500 acres of cut flowers.

For a salinity reduction from 476 to 467 mg/L (typical of SDCWA under Scenario 1), the total benefits to the ornamental crop sector are calculated as $131,000. Using the same input values for salinity and acreage, the benefits to ornamentals calculated as flower crops is: $47,000. These results indicate that for this small salinity drop, benefits to ornamental crops may actually be 2-3 times higher than the value we have estimated. In the three scenarios, benefits were originally estimated as:

Scenario 1: $125,000
Scenario 2: $81,000
Scenario 3: $44,000

If these values are tripled, to encompass the benefits to nursery crops, the results are:

Scenario 1: $376,000
Scenario 2: $244,000
Scenario 3: $132,000

The estimates of county-wide benefit to all sectors increase to:

Scenario 1: $3,412,000
Scenario 2: $3,362,000
Scenario 3: $3,648,000

Scenario 3 remains the preferable scenario. However the relative gap in benefits between the three scenarios has narrowed, indicating that it is less clear that Scenarios 1 and 2 are inferior.

Utilities

Benefits to water distribution facilities are relatively minor. The results are as follows:

Scenario 1: $68,000
Scenario 2: $81,000
Scenario 3: $101,000

Figure 7-5 Salinity Model Results – Detail of Residential Benefits

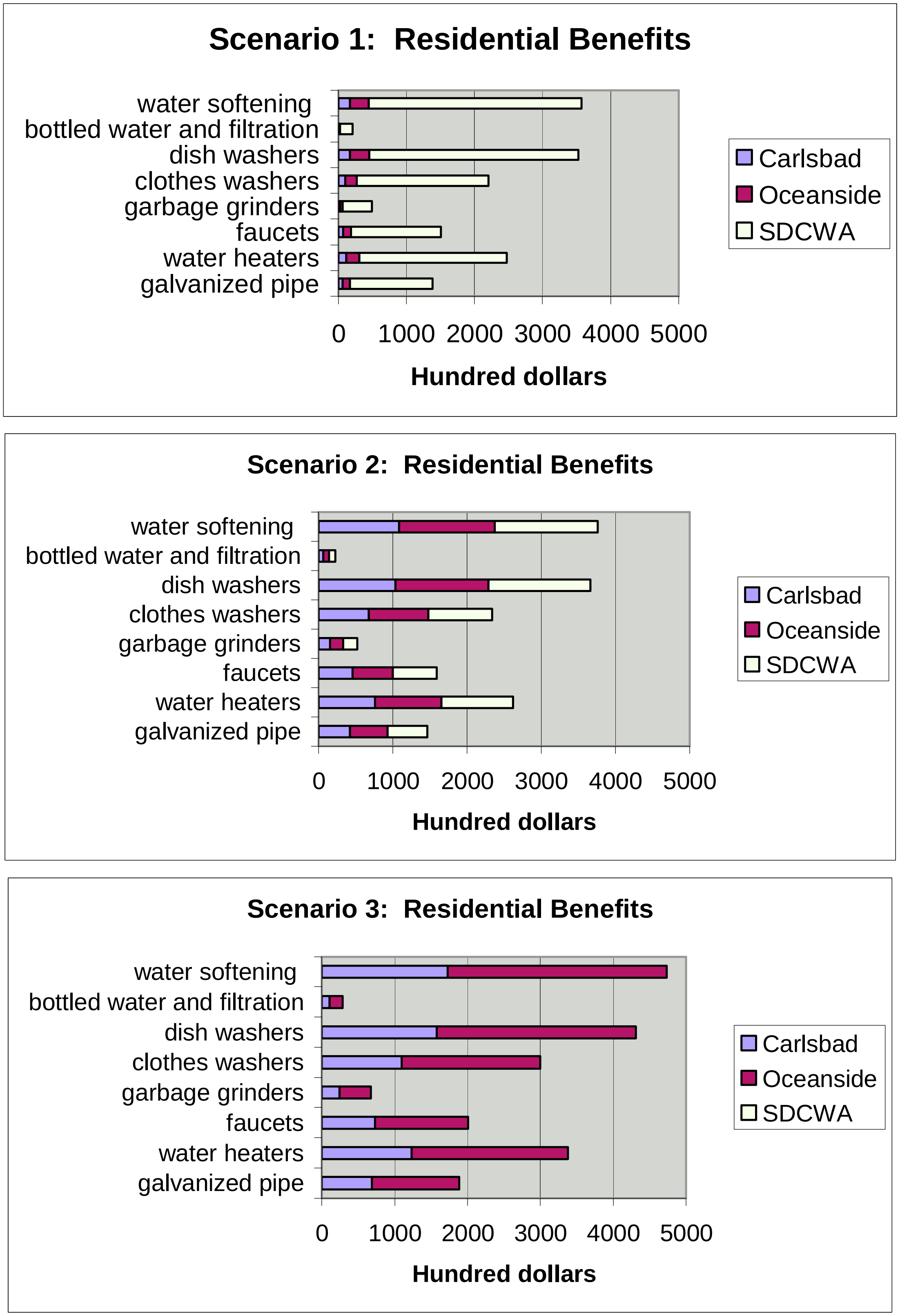


Figure 7-6 Salinity Model Results – Detail of Commercial/Institutional Benefits

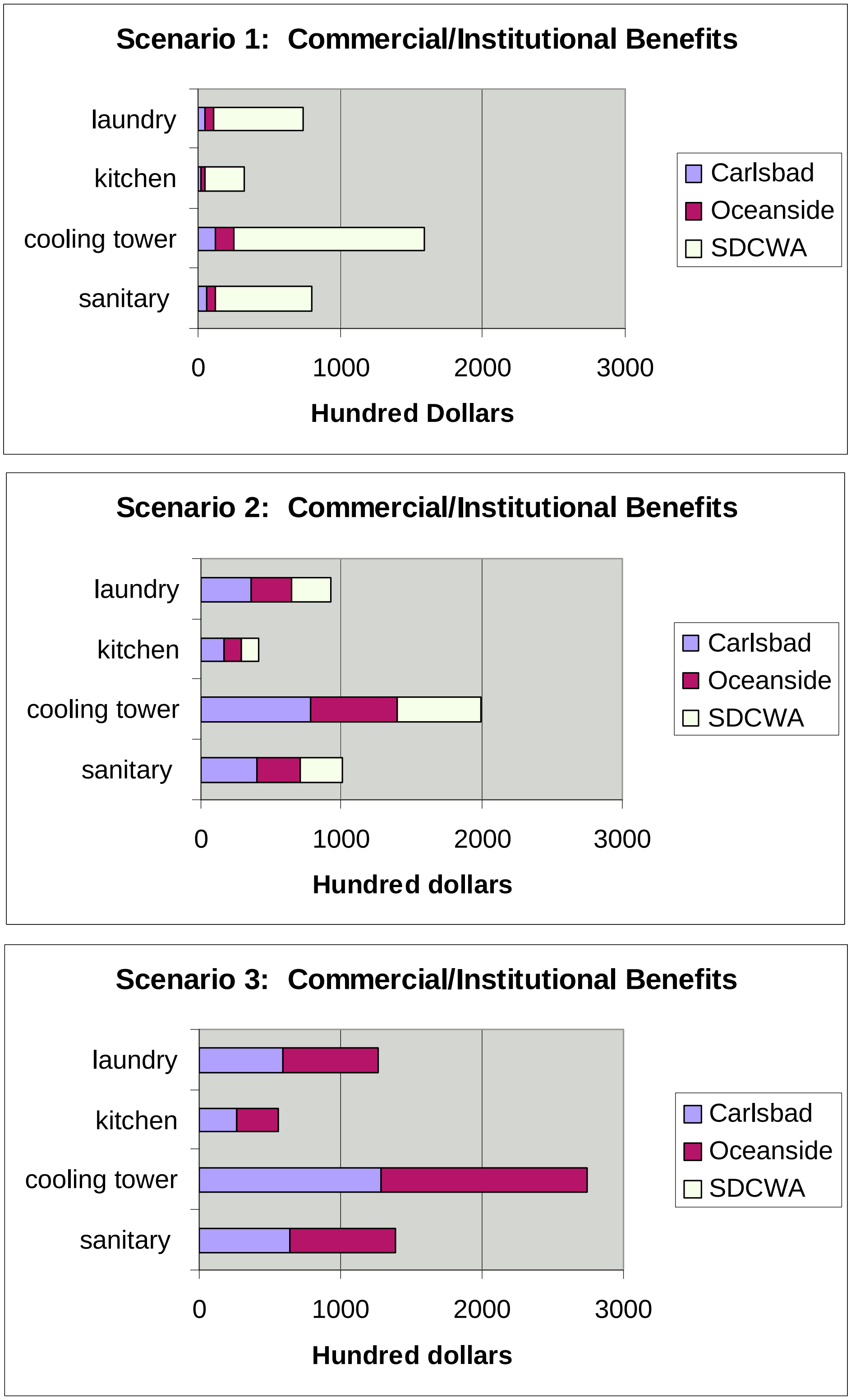


Figure 7-7 Salinity Model Results – Detail of Industrial Benefits

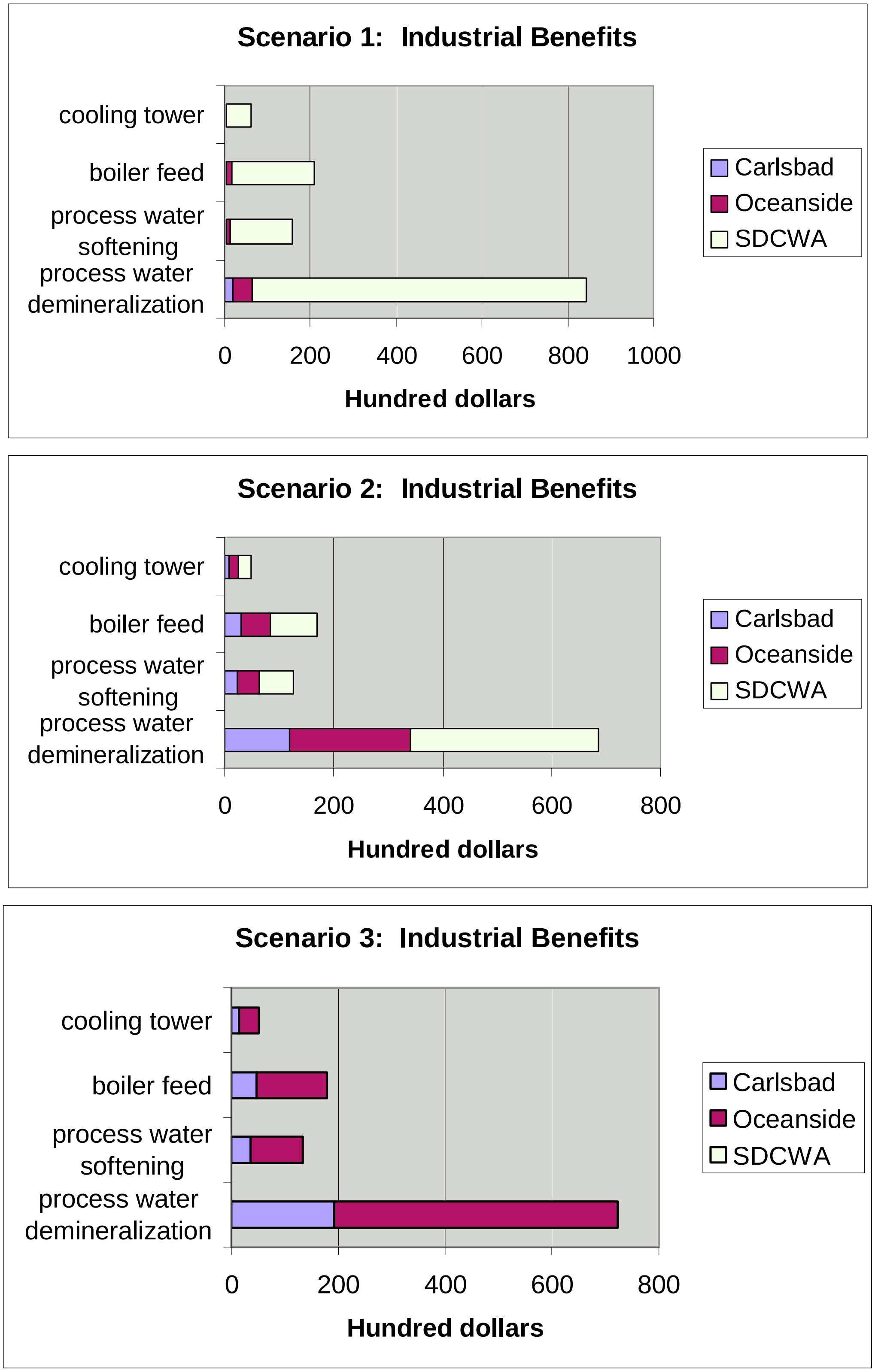
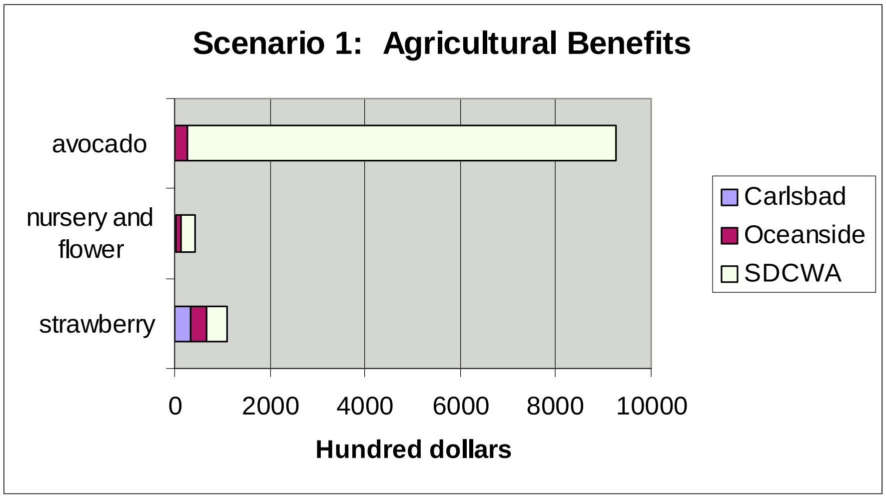
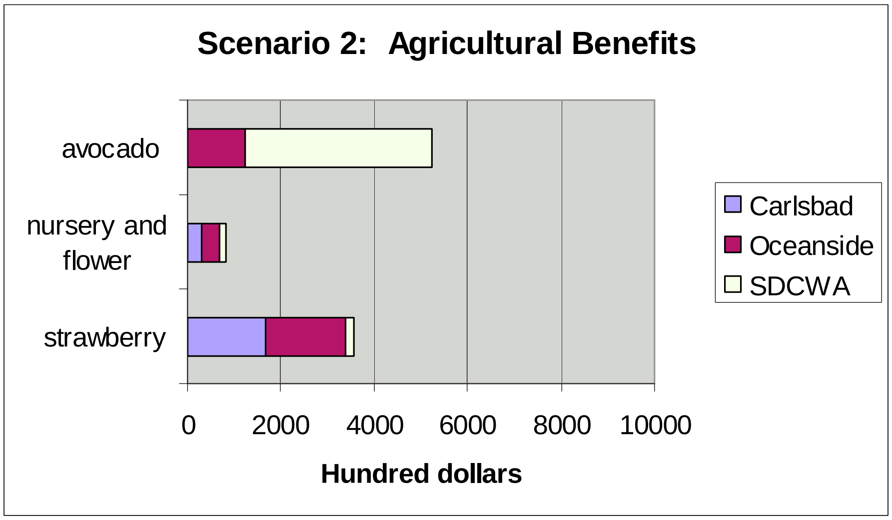
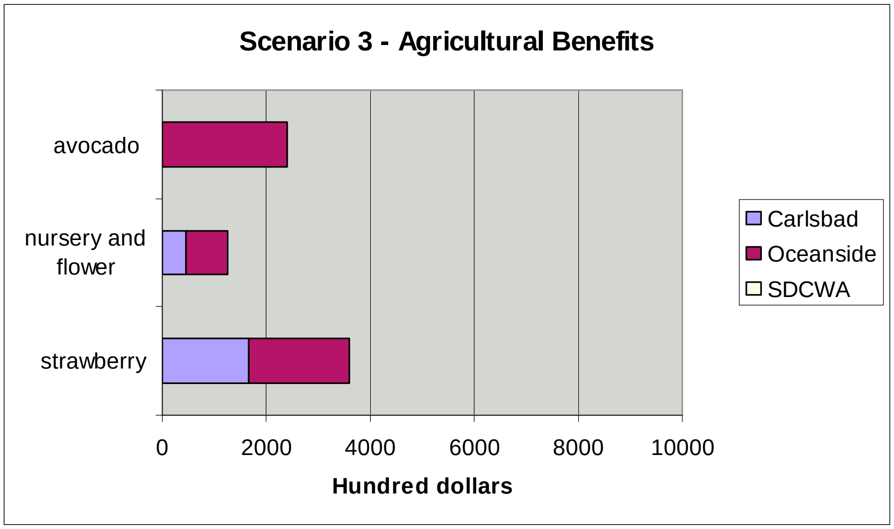


Figure 7-8 Salinity Model Results – Detail of Agricultural Benefits







7.5.2 Other Implications of Salinity Reduction

Reduction in overall water demand

Certain benefits associated with salinity reduction can be attributed to reduced water consumption. Both commercial/institutional and industrial customers experience improved efficiency of water used in cooling towers. The economic model incorporates the value of avoided water purchases, however we can also estimate the quantity of water conserved. Based on the general water allocations used in the MWD model and the distribution of water between uses in the county, cooling tower use constitutes 3-6% of total water consumption. Using data provided in the MWD model, a drop in salinity from 500 to 350 mg/L would increase the number of cycles of concentration (the recycling rate) from 5.0 to 7.0 for a tower operating at 2,500 mg/L. This roughly represents a 30% decrease in water consumption by cooling towers. Thus, under Scenario 3, Carlsbad and Oceanside would expect to see a 1-2% decrease in overall water consumption. Knowledge of the exact number and water demand cooling towers in these cities would enable a more accurate estimation of water conserved.

Another significant conservation benefit may be associated with agricultural customers. Although the MWD model only accounts for reductions in leaching for ornamental crops, anecdotal evidence suggests that San Diego County farmers apply an excess of 10% of irrigation water for soil leaching. If under Scenario 3, farmers in Carlsbad and Oceanside were able to reduce non-reclaimed water use by 10%, the overall water consumption in these cities may be reduced by another 1.3% and 0.4%, respectively.

In total, water quality improvements under Scenario 3 have the potential to reduce water consumption in the cities of Carlsbad and Oceanside by roughly 1-3%, a modest reduction in water demand.

Increased market for reclaimed water

While salinity reduction has direct impacts on drinking water quality, a secondary benefit is reduced salinity in sewage effluent, which would improve the quality of reclaimed water. As a local resource, expansion of the recycled water market would be a welcome addition to the water supply portfolio of regional water districts.

On average, residential use contributes 200-300 mg/L of excess salinity to wastewater. Home water softeners, which discharge brine to the sewer system, add an additional 60-100 mg/L. (SDCWA, 2000) Tertiary treatment does not typically remove salinity. As a result, reclaimed water can have salinities in excess of 1000 mg/L, limiting its use in industrial and irrigation applications.

Recycled water with TDS levels below 900 mg/L are suitable for irrigation. Above this level, excess irrigation water must be applied to leach salts from the root zone. The MWD salinity model provides methods for estimating the economic impact of increased water purchases for leaching. However, since Oceanside supplies less than 1% of water uses with recycled water, and since the majority of Carlsbad's recycled water is purchased from adjacent water districts, the benefits of reduced wastewater salinity were assumed to not have a measurable effect on the reclaimed water market in these cities, and thus were not assessed in our implementation of the salinity model.

As of 2000, the Carlsbad Municipal Water District provided 1,740 AFY of reclaimed wastewater. Additional reclaimed water was obtained from adjacent water districts. (City of Carlsbad, 2003) An interesting area for future study would be to determine whether this water would be more marketable under Scenarios 2 and 3. For instance, salinity reduction may make recycled water suitable for irrigation of citrus and avocado, which are not very salt tolerant. Reduced salinity may also make reclaimed water more attractive for commercial and industrial cooling applications. If salinity reductions allow for expanded use of recycled water, the overall water use efficiency of the region would be greatly improved, and future growth in water demand could be more easily assimilated. This would be a future benefit, since the region currently experiences excess demand for existing high-salinity reclaimed water.

An estimate can be made of the salinity of recycled water produced by this plant under Scenario 3. Assuming that all of the wastewater reaching the treatment facility originates in Carlsbad and Oceanside, and that both residential and non-residential uses add 200-300 mg/L of TDS to wastewater, the expected quality of tertiary treated wastewater will be approximately 550-650 mg/L. In California, all crops may be irrigated with tertiary treated wastewater. The crops currently grown within these cities include: lemon, avocado, orange, cherry, peppers, flower and nursery, bush berries, strawberries, tomatoes, melons and beans. (SWP, 1998) These crops are considered to be moderately sensitive to salinity (Pescod, 1992). The Lohman model, on which the MWD model is based, lists the following TDS thresholds for these crops (in mg/L): oranges: 725, strawberries: 427, lemons: 768, beans: 427, peppers: 640, berries: 640, avocado: 427. Thus it if reclaimed water underwent a salinity decline from 900-1000 mg/L to 550-650 mg/L, the water would be of suitable quality for irrigation of oranges, lemons, peppers, and berry crops. Further research is required to identify the potential of this market.

7.6 Conclusions

- The reduced salinity in county water supplies due to substitution of desalinated water for imported water would produce total annual benefits on the order of $3 million/year, under year 2001 conditions.
- The highest portion of this benefit accrues to residential customers, however the highest per-acre benefit accrues to agriculture.
- The benefits are maximized under Scenario 3, where the majority of the desalinated water is dedicated for use by the Cities of Carlsbad and Oceanside
- Significant benefits from salinity reduction are associated with avoided water softening, increased life of dishwashers, improved water efficiency in cooling towers, and increased avocado yields. Benefits to nursery crops may also be significant, however we were not able to provide an accurate estimate of this value.
- There will be a minor decrease in overall water consumption due to quality improvements
- The salinity improvement may increase the suitability of reclaimed water for agricultural irrigation, as well as generally increase the value of this water for other uses.

8 RELIABILITY OF WATER SUPPLY

Water supply reliability entails the planning, management, and provision of supplies, expertise, and facilities to ensure the availability of sufficient and affordable water, both now and in the future. When supplies become threatened by service interruptions or drought, there can be severe economic and social consequences: agriculture products become more expensive, manufacturing of goods is interrupted or curtailed, and in extreme cases, whole regions can experience net losses that create unemployment and geographical dislocation. Residential users, even in times of limited cutbacks, are burdened with having to conserve water out of fear that shortages could be prolonged. In the past this has resulted in the installation of water saving devices, repair of poor plumbing, changes in water use, and reduction in water intensive activities. Therefore, for water agencies in California that are constantly threatened by population pressures, economic growth, inter-institutional squabbling, inadequate precipitation and drought, the issue of water reliability becomes an important element of any water agency's management plan.

Despite attempts by SDCWA to diversify, increase, or recycle current water supplies, the amount required to meet future demand may be inadequate. Population pressures, environmental concerns and institutional barriers have all but forced the County to look to desalination for new water supplies. Taking uncertainty and the need for supplies to meet future demand as a given, it is the purpose of this section to demonstrate the willingness to pay for reliability among residential water users. By determining and quantifying this willingness to pay of water reliability, SDCWA can better understand the real cost of providing desalinated water to its users.

The section is divided into three parts: 1.) An explanation of the methodology used in the California Urban Water Authority (CUWA) contingent valuation survey, 2.) an explanation and results of CUWA's model when applied to the state of California, 3.) an explanation and results of CUWAs model when applied to San Diego, and finally, 4.) the use of the CUWA model using current census data to better understand the willingness to pay for desalinated water in the San Diego region. This step-by-step format has been chosen to first verify the effectiveness of the CUWA model and then to demonstrate its usefulness as a tool in this study. Moreover, by linking desalinated water to reliability, a more robust and accurate assessment of the true costs and benefits of the desalination project in Carlsbad can be ascertained.

8.1 Willingness to pay for water reliability

In 1994, the California Urban Water Authority (CUWA) published a report to measure the willingness to pay for water reliability among residential water users in northern and southern California, entitled, "The Value of Water Supply Reliability: Results of a Contingent Valuation Survey of Residential Customers", to better understand water reliability issues. In that study the CUWA and its consultant, Barakat and Chamberlin, Inc. used a contingent valuation (CV) model to show that on average, California residents are willing to pay \$12 to \$17 more per month per household on their water bills to avoid water shortages similar to those experienced in recent California droughts. The implications to California of such additional consumer payments would be well over $1 billion per year, and thus in the opinion of the CUWA, reliability should be an important consideration and deciding factor in the use of sourcing supplies, conservation measures, or the use of new technologies such as desalination to ensure water reliability (CUWA 1994).

8.1.1 The CUWA Contingent Valuation (CV) Survey

The purpose of the CUWA survey was to estimate the willingness to pay (WTP) among residential users to avoid water shortages of varying magnitude and frequency. The survey was designed to elicit a "yes" for increased prices of a designated amount for no future water supply interruptions, and a "no" for water bills that would remain the same, yet with water shortages of a specified magnitude and frequency. In both cases it was assumed that customers WTP would differ depending on their aversion to water shortages. While the survey did specify the amount of price increases, magnitude and frequency of water supply interruptions, it explicitly did not tell customers where the additional supplies would come from. This was done to focus respondents on "supply reliability" and away from "supply sourcing" in order to prevent biasing during the survey.

Due to the complexity associated with this type of survey, it was decided that a mail survey would be used in order to reach a broad range of customers followed by telephone interviews to assess how the respondent had reached his or her stated preferences. The documents that were sent to customers contained questions that set the context for the analysis as well as the CV questions themselves. The CV questions included a carefully worded description of a hypothetical scenario that formed the foundation of the "yes" or "no" vote, followed by questions that provided insight into the customer's preferences. The survey then concluded with demographic questions to create a more robust picture of a respondent's viewpoint.

The hypothetical scenarios that respondents were asked to examine were distributed across a range of different shortage scenarios. Water shortage magnitudes ranged from 10% to 50%, frequency of interruptions ranged from every 3 years to 30 years, and the amounts that customers would be expected to pay in order to avoid any interruptions ranged from $1 to $50 monthly increments. Magnitudes and frequencies were combined to accomplish three objectives (CUWA, 1994):

- To cover a wide range of shortage severities
- To present shortage scenarios that would be perceived by respondents as realistic possibilities
- To avoid shortage scenarios that were too mild to elicit reliable WTP responses

It was soon recognized in pretests and focus groups conducted during the survey design process that there were concerns that should not be intentionally addressed by the survey due to their biasing effects on respondent preferences . This included such things as environmental and social impacts that might be associated with providing new water supplies. However, a CUWA Advisory Committee and the consultants determined that these issues would be treated as costs associated with the particular resource additions in the resource planning process, and therefore felt that it was permissible and pertinent to omit them from the survey in order to maintain balance (CUWA, 1994).

The survey was conducted from August 1993 through February 1994 and consisted of 3,769 completed surveys from participating CUWA member agencies.

8.2 Contingent valuation

Estimating the costs and benefits of water supply reliability are difficult because environmental service and goods are complex, if not impossible to directly measure. To properly appreciate and understand how intricate such measurements are, it is important to first understand the traditional framework that economists use to value common goods and services. The standard economic framework is grounded in human self-interest and rational choice, with costs and benefits being measured by the utility provided by those goods and services. In such a framework, competitive market prices represent both the additional cost to society *and* the subjective incremental value of goods to each individual, so that prices and values are equal at the margin (Farrow et al, 2000). However, when there are no markets to generate prices for qualitative items such as risk reduction, biological diversity, or in our case water reliability, the ability to directly observe people's behavior becomes difficult. The lack of such markets are often missing because benefits and costs cannot be measured directly, different people have different preferences and values, and most often, such goods and services often produce uncompensated or indirect impacts (externalities) on third parties that are hard to estimate. Thus, market transactions never fully capture the true values for such goods and services, and therefore require a different approach to estimate their value.

One tool that can be employed to measure and value non-market amenities which is consistent with the valuation of marketed goods is the contingent valuation (CV) survey method. In fact some consider the use of the CV to be the only means to effectively measure the monetary values of such environmental goods and services (Carson, 2000). First proposed by Ciriacy-Wantrup in 1947, the CV approach first asks individuals (through surveys) what their willingness to pay (WTP) for environmental goods and services are, and then aggregates individual values in order to create a market-demand schedule that shows the monetary value of that good or service. Contingent valuation is now used around the world, both by government agencies and the World Bank for assessing a variety of investments, and has been used in over 1600 cases in 40 countries to measure the environment, transportation, sanitation, health and education (Hanemann, 1994). What is important to realize about the CV method is that it acts as an indicator of preference; the exact monetary values should not be taken literally, but looked upon as a guide for what people prefer and value. Higher willingness to pay simply allows the researcher to understand how non-market goods are valued (perhaps in relation to other amenities), and then create policies or recommendations that help protect or satisfy that willingness to pay.

8.3 1993-1994 CUWA Contingent Valuation Survey Model

8.3.1 *Analytical Approach*

The approach used in the CUWA survey bounds the maximum willingness to pay by asking the customer whether they would be willing to pay a specified monthly amount for water supply reliability. A "yes" response indicates a lower bound to the maximum WTP whereas a "no" response gives an upper bound. The mean WTP to avoid a shortage scenario can then be estimated statistically from responses of different respondents to different shortage descriptions (CUWA, 1994). In order to improve the accuracy of their report, the CUWA contingent valuation used a more statistically reliable "double-bounded" technique to estimate customer WTP. This differs from the referendum approach in that it asks a set of questions to more narrowly focus the respondents WTP. For example, the survey would ask the customer whether they would be willing to pay to avoid a particular percentage shortage occurring within a specified time frame, and if the respondent answered "yes", a second choice question was asked to determine the amount that the customer was willing to pay. In this scenario, "yes" answers to the first question raised the willingness to pay of the second question, and "no" answers decreased the bid amount of the second question. Through such an approach, the lower and upper WTP amounts could be more accurately determined.

8.3.2 *Specifications of the Statistical Model*

Two statistical models were used to estimate a customer's monthly WTP for water reliability. The first, was a detailed model consisting of the survey questions discussed above and a set of explanatory variables pertaining to demographics, attitudes and perceptual variables. This was accompanied by a simplified model that paired the set of explanatory variables into a set that could be obtained from census or agency data records in order for local water agencies to re-estimate WTP in the future without having to resurvey residential customers.

8.3.3 *Explanatory Variables:*

Table 8-1 Explanatory Variables for CUWA Model

Variable	Detailed Model	Simple Model
Number of years living in area	Yes	No
Household size	Yes	Yes
Age	Yes	Yes
Income	Yes	Yes
Education	Yes	Yes
Household type	Yes	Yes
Concern for other public issues	Yes	No
Perception of drought severity	Yes	No
Perception of water shortages as a long-term problem	Yes	No

Awareness of agency mandates to cut back on water use	Yes	No
Home ownership / rental status and water bill responsibility	Yes	No
Amount and type (private or shared) of external landscaping	Yes	No
Population growth preferences	Yes	No
Average residential water rate for respondent’s water agency	Yes	No
Northern California or Southern California Agency	Yes	No

8.3.4 Analytical Expression

The mean WTP for each shortage frequency (F) and magnitude (R) combination results in the following equation:

$$\text{WTP}(R, F) = \frac{\log(1+\exp(\alpha+\beta_1(R)+\beta_2(F)+\sum\gamma_n \text{Xmean}_n+\sum\delta_t \text{Zprop}_t))}{-\beta_3}$$

Where:

Xmean_n = the mean of the explanatory variables that are not binary (i.e. either zero or one.
Zprop_t = the proportion of customers for which each of the binary explanatory variables takes on a value of one.
α = Constant
β = Explanatory Variables (see above)

This expression enables us to derive the WTP to avoid a water supply interruption of a particular scenario. Moreover, WTP to avoid an event can also be interpreted as the loss (“loss function”) that a customer would have to pay if a shortage did occur, and thus can be used as a measure to determine how people value water supply reliability.

8.3.5 Results

WTP for the detailed model as well as the simplified model ranges from approximately \$12 per month to avoid either a 10% shortage every 10 years or a 20% shortage once every 30 years, to a high of approximately \$17 per month to avoid a 50% shortage every 20 years (CUWA, 1994). Moreover, while individual agencies did exhibit some differences in their WTP, the range of estimates were consistent across all participating agencies. It was also determined during the course of the study that respondents who were older, more educated, and wealthier had a higher willingness to pay to avoid water shortages.

8.3.6 Concluding Remarks of the 93-94 CUWA Survey

- Respondents are willing to pay more to avoid larger shortages and shortages that are more frequent. However, the magnitude of the reduction is more important than shortage occurrence.
- Customers are willing to pay substantial amounts to avoid even minor shortages (e.g., 10% once every 10 years) due to the perceived inconveniences associated with water supply interruptions. It appears that respondents may make a greater distinction between "shortage" and "no shortage" than between different magnitude or frequencies of shortage (CUWA 1994).
- Although results differ by agency, the differences are consistent across all agencies. Moreover, there are no significant differences in WTP between Northern and Southern California.
- The goodness-of-fit showed that the simplified model has the same explanatory power as the detailed model. Therefore, it is not necessary to re-survey participants in order to reuse the model for future analysis.

8.4 1993-1994 CUWA Model Results for San Diego County

While the CUWA survey worked well for the entire State of California, it is important for the purposes of this paper to examine the results of the survey for the San Diego County Water Authority (SDCWA). This is done both to confirm the validity of the model at the agency level, and also to establish a baseline for comparison before updating the model using 2000 census data.

8.4.1 Survey Administration

The total amount of survey completions for SDCWA was 407. Two SDCWA member agencies, Helix Water District and Vallecitos Water District were chosen by SDCWA to obtain customer-billing records from. Helix and Vallecitos provided a total sample of 1,812 customer billing records, and the sample was divided among single-family and multifamily records in proportion to the number of single-family and multi-family households in San Diego County, exclusive of the City of San Diego, which was surveyed separately (CUWA 1994).

Table 8-2 SDCWA Response Rates

	Helix	Vallecitos	Total
Initial sample	867	945	1812
Unused sample[a]	369	312	681
Out of sample[b]	28	37	65
No telephone number available	50	124	174
Corrected sample size	420	472	892
Refusals	65	75	140
Not reached during study	137	147	284
Unable to participate[c]	13	48	61

Completed interviews	205	202	407
Response rate[d]	49%	43%	47%

[a] There was no attempt to contact the sample points

[b] These include businesses, landlords, vacancies, duplicate sample points, and sample points no longer residing in study area

[c] Includes language and other communication barriers, or mailing not received, not read, or thrown away

[d] Calculated as a percent of the corrected sample size

8.4.2 Results

In order to determine the WTP for reliability in the SDCWA service area, it is first important to determine the difference between the survey sample and the underlying population. This was accomplished by comparing census results to sample characteristics with respect to the explanatory variables.

Table 8-3 Comparison of Sample with Population

Explanatory Variable	Sample	Population
Household size	2.4	2.7
Age (18-34)	10%	33%
Age (35-54)	30%	24%
Income $50,000 +	29%	31%
Education (College graduate)	31%	25%
Household type (Single-family)	59%	63%

8.4.3 Results / Conclusion

- WTP for San Diego County ranges from approximately $11 per month to avoid either a 10% shortage every 10 years or a 20% shortage once every 30 years, to a high of approximately $19 per month to avoid a 50% shortage every 20 years
- Respondents are willing to pay more to avoid larger shortages and shortages that occur with higher frequency. However, the effects of frequency variations are considerably smaller than the impact of magnitude for respondents.
- Respondents are willing to pay substantial amounts to avoid even minor shortages.
- These results are consistent with the results of the CUWA contingent valuation survey for the entire state of California
- The model is acceptable for the purpose of determining the WTP for year 2000

Table 8-4 Mean Monthly WTP, Simple Model (additional $ per month)

Shortage (% Reduction from Full Service)	Frequency (Occurrences / Years)				
	1/30	**1/20**	**1/10**	**1/5**	**1/3**
10%			$10.36	$10.60	$10.70
20%	$11.36	$11.86	$12.36		
30%	$13.43	$13.96	$14.50		
40%	$15.64	$16.19	$16.76		
50%	$17.94	$18.52			

[a] *Blank cells in the table reflect scenarios that were not part of the survey*
[b] *95% confidence interval for SDCWA is ±$1.18*

8.5 Re-evaluation of the CUWA Model Using Year 2000 Data

The purpose of explaining the 93-94 CUWA State and San Diego County contingent valuation survey was to build a case for the use of the model as a predictive tool to measure people's willingness to pay for higher monthly prices associated with the proposed desalination plant in Carlsbad. In the case of desalination the limiting factor regarding reliability is the not the availability of water, but the provision of energy to run the desalination plant. The Carlsbad plant would be situated next to the Encina Power Station, and therefore it is assumed that desalination would provide a continuous and unbroken stream of potable drinking water to the San Diego area despite the occurrence of drought or other water shortage scenarios. One could argue that an energy crisis could endanger the dedicated use of power for desalination, but for the purpose of this paper it is assumed that operation of the Encina plant will not be limited by future energy inputs. Therefore, given that the Carlsbad desalination represents a constant and reliable source of water, the CUWA contingent value model will be used to determine if the extra costs associated with providing desalinated water are mitigated by resident's willingness to pay for reliability. We have chosen to model three different scenarios, based on the potential distributions of desalinated water throughout the San Diego region. These scenarios mimic the same distributions that are outlined in Section 6.1.

- Scenario 1: The WTP for distribution of desalinated water throughout San Diego County.
- Scenario 2: The WTP for distribution of desalinated water to Carlsbad (20%), Oceanside (20%), and San Diego County (60%).
- Scenario 3: The WTP for full replacement of Carlsbad and Oceanside imported water with desalinated water.

The revised model is based on the 93-94 and uses the same equation (refer to Section 8.3.4) to derive the willingness to pay for water reliability amongst residential users.

8.5.1 *Notes on reevaluating the simple model:*

Coefficients: Coefficients were taken from the original model and applied to all scenarios. In addition to the explanatory variables, the coefficients for frequency (F), magnitude (R), and the constant (α) were also used.

Mean percentage of explanatory variables: The mean percentage for each explanatory variable was taken from data obtained in the 2000 Census. In this case the mean percentage represents the amount out of 100%. For example, in scenario one, the age category of 18 to 34 year olds represents 27% of all age categories (100%) listed in the census for San Diego.

Table 8-5 Mean Percentage of Explanatory Variables

Variable	Coefficient	Mean percentage of explanatory variables		
		San Diego	**Carlsbad**	**Oceanside**
HH size	-0.0359107	(2.89)	(2.60)	(2.97)
Age (18-34)	-0.5978690	27%	20%	25%
Age (35-54)	-0.1138274	29%	35%	27%
Income	0.2988739	30%	46%	22%
Education	0.3525352	46%	60%	41%
HH type	0.2505196	67%	66%	70%

8.5.2 *Results / Conclusions of updated model*

- WTP for all three scenarios ranges from approximately $16 per month to avoid either a 10% shortage every 10 years or a 20% shortage once every 30 years, to a high of approximately $21 per month to avoid a 50% shortage every 20 years (see tables 8-6 through 8-8 below for greater detail).
- Much like the CUWA model, respondents are willing to pay more per month to avoid larger shortages and shortages that occur with higher frequency. Furthermore, frequency variations are also considerably smaller than the impact of magnitude for respondents (see tables 8-6 through 8-8 below for greater detail).
- Respondents are willing to pay substantially more per month to avoid even minor shortages (see tables 8-6 through 8-8 below for greater detail).
- Scenario 2, followed closely by scenario 1, has the highest aggregated WTP out of the three scenarios. This amounts to $1,791,000, and therefore should be considered when factoring the additional costs that desalination will place on the County (see table 8-9 for greater detail).
- Scenario 2 has the highest value per acre-foot for willingness to pay for reliability. This equates to $31.98 an acre-foot per month, or $383.79 an acre-foot per year, for WTP. Therefore this amount could be used to better determine the real cost of desalinated water from its initial cost of $900 an acre foot

- The use and reliability of desalination as a water supply option merits consideration when viewed in terms of people's willingness to pay for water reliability. Despite the fact that current costs are still more prohibitive than imported supplies, respondents in San Diego are willing to see their water bills increase in order to ensure water reliability. However, it must be remembered that this model assumes that energy supplies will not face disruptions of their own, and in future studies, the reliability of energy production should be factored into the overall model.
- WTP for water reliability in this model appears to be a reflection of both income and education levels, and therefore questions regarding the validity and usefulness of the model must be given consideration as these values change over time. Thus if demographic changes take place in the next 20 years in the areas studied, where either income or education levels change dramatically, a reassessment of the model should be re-run in order to re-value WTP among SDC water users.

Table 8-6 Monthly Household WTP - Scenario 1

Shortage (% Reduction from Full Service)	Frequency (Occurrences / Years)				
	1/30	1/20	1/10	1/5	1/3
10%			$15.58	$15.73	$15.79
20%	$16.19	$16.48	$16.77		
30%	$17.38	$17.67	$17.96		
40%	$18.57	$18.86	$19.16		
50%	$19.76	$20.06			

Blank cells in the table reflect scenarios that were not part of the survey

Table 8-7 Monthly Household WTP - Scenario 2

Shortage (% Reduction from Full Service)	Frequency (Occurrences / Years)				
	1/30	1/20	1/10	1/5	1/3
10%			$15.67	$15.81	$15.87
20%	$16.27	$16.56	$16.86		
30%	$17.46	$17.76	$18.05		
40%	$18.66	$18.95	$19.24		
50%	$19.85	$20.15			

Blank cells in the table reflect scenarios that were not part of the survey

Table 8-8 Monthly Household WTP - Scenario 3

Shortage (% Reduction from Full Service)	Frequency (Occurrences / Years)				
	1/30	1/20	1/10	1/5	1/3
10%			$15.71	$15.86	$15.91
20%	$16.32	$16.61	$16.90		
30%	$17.51	$17.80	$18.09		
40%	$18.70	$18.99	$19.29		
50%	$19.89	$20.19			

Blank cells in the table reflect scenarios that were not part of the survey

Table 8-9 Average WTP

Area	Total Housing Units servable by the Carlsbad Desalination Plant	Average Monthly WTP	Avg Ac-ft Value per Month	Avg Ac-ft Value per Year
SDC	100,000	$1,782,000	$31.82	$381.86
C&O&SDC	100,000	$1,791,000	$31.98	$383.79
C&O	92,009	$1,651,562	$29.49	$353.91

9 ENERGY AND ENVIRONMENT

In this section, we investigate impacts on energy use and the environment associated with operation of the proposed Carlsbad Desalination Facility.

9.1 Electric power consumption

It is well known that desalination processes are energy intensive. However, California's water systems also require large inputs of energy. Moving water from the Bay Delta and the Colorado River to populated areas along the coast requires significant energy inputs for pumping and treatment processes. It has been estimated that energy required to convey water to a home in southern California is similar to quantities consumed to power large appliances such as refrigerators and air conditioners (Wilkinson, 2000). Moreover, during conveyance to southern California, much water is lost due to evaporation from the water surface and seepage from the canal structures. This inefficiency of water delivery leads to waste of energy use.

Energy intensity is defined as the total system energy input required for use of a unit of water at a specific location, and thus represents the resource investment required for water deliveries. Energy intensity is measured as electricity consumed per unit water, in this case, kWh/AF. In this section we compare the energy intensity of San Diego's imported water sources with that of the proposed Carlsbad Desalination Facility.

State Water Project

The SWP, which provides approximately one quarter of San Diego County's water supply, is the largest electric power consumer in California. SWP water originates in watersheds in northern California and where it is stored in a 3.5 MAF dam. Water is periodically released from this dam and allowed to flow through natural water courses to reach the San Francisco Bay Delta. Water is diverted from the Bay Delta for conveyance to the Bay Area and central and southern California. Diversion to southern California involves lifting SWP water about 1,000 ft (300 m) through the San Joaquin Valley at four pumping plants. It is then lifted about 2,000 ft (600 m) to cross the Tehachapi Mountains at Robert D. Edmonston Pumping Plant, the highest lifting capacity in the world. Beyond the mountains the aqueduct is split into two branches. The eastern-most branch, which terminates at Lake Perris in Riverside County, serves San Diego County (CDWR, 1997).

About two-thirds of electric power required to run the SWP is provided by seven SWP-owned hydroelectric power plants. The remainder is provided by commercial utilities and a SWP-owned thermal power plant using coal (CDWR 1997). The electric power generated by SWP is connected to the state grid system. In 1997, SWP delivered about 4.7 MAF including 1.3 MAF for the Federal Central Valley Project (Wilkinson, 2000). Considering that the SWP consumed 6,245 GWh in the same year, the system-wide electric power consumption per AF in 1997 was 1.3 MWh/AF.

In order to compare the energy intensity of SWP and desalinated water in San Diego, we must consider the energy that is consumed to deliver water exclusively to southern California, which requires more energy than the system average. To deliver to southern California, approximately 3 MWh/AF is consumed. This energy includes net power consumption through delivery systems but excludes hydroelectric power generation separate from the delivery systems (Wilkinson, 2000).

Colorado River Aqueduct

The conveyance system linking the Colorado River to the Los Angeles Basin consists of a 242-mile aqueduct with a 1,600 ft (480 m) elevation gain, terminating at a reservoir in Riverside County. Lifting is achieved with five pumping plants located near the California/Arizona border. In an average year the CRA delivers 1.2 MAF while consuming 2,400 GWh for pumping operation. This energy includes power consumption through delivery systems but excludes power generation by water systems. Three-fourths of required electric power is provided by CRA-owned power plants and the remainder by commercial utilities (Wilkinson, 2000). Thus, the electric power consumption per acre-foot of delivered water is 2,400 GWh / 1.2 MAF = 2 MWh/AF.

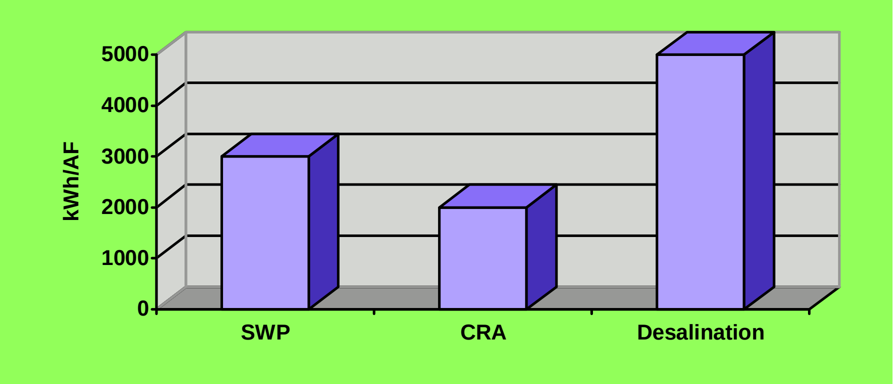
Carlsbad Desalination Facility

The desalination plant is expected to consume 3% of the Encina Power Plant's output (965 MW), with a load of 35 MW. Between 60 and 75 gallons of water would be generated per kilowatt-hour, suggesting an embedded energy of 4700 - 5400 kWh/AF[26]. This does not include the additional energy input required to convey water from the desalination plant to the distribution system.

9.1.1 Comparison of energy intensities of water supplies

The following chart summarizes the relative difference in energy intensity of San Diego's imported water supplies, as compared to desalinated water:

Figure 9-1 Comparative Energy Intensity of San Diego Water Supplies



As we see, the energy intensity of desalinated water is approximately double that of imported water, and therefore requires a greater resource investment. It also suggests that the provision of desalinated water is more likely to be influenced by occurrences in the energy market.

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[26] Personal communication, Peter MacLaggan, Poseidon Resources, Feb 20, 2003

Another implication of devoting some of San Diego's local generating capacity is an increased need for energy imports in the county. In the event of energy shortages, energy deficiencies could be avoided by operating the plant using off-peak load power. Regular operation of the desalination facility during off-peak periods may assist in improving the overall efficiency of power plant operation, which is optimized at full load.

9.2 Air pollution caused by electric power generation

As discussed, water projects consume electricity to produce, treat and deliver water. During electricity generation, thermal fuel-fired power plants produce air pollutants and carbon dioxide. These by-products affect human health and the environment.

The emissions associated with electrical power generation vary by fuel type and the use of control technology. While the Carlsbad Desalination Facility would be powered by a single gas-fired power plant[27], California's imported water systems are supplied by a mixture of power sources. In order to assess the impacts associated with a unit of delivered water, we must first characterize the mix of generators for water imports.

The SWP has its own power generating facilities in the form of hydroelectric and thermal power plants. The CRA also uses energy from hydroelectric projects on the Colorado River. However, the electric power generated by these facilities is connected to the regional grid system. Thus, we have used statewide average energy use for estimating the air pollution caused by SWP and CRA energy loads. It is more appropriate to use generated power than that actually consumed in order to estimate the air pollution caused by electric power consumption because this number is the actual amount of energy produced.

The Federal Clean Air Act (CAA) designates six common air pollutants as criteria pollutants, which are regulated through a set of national ambient air quality standards (NAAQS). The criteria air pollutants are as follows: ground-level ozone, particulate matter, carbon monoxide, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and lead. Of these, nitrogen dioxide and sulfur dioxide are produced in significant amounts by power generation.

Nitrogen dioxide is component of NOx (nitrogen oxides), a group of highly reactive gases which are formed when fuel is burned at high temperatures. The major sources of NOx in the U.S. are motor vehicles and electric utilities. NOx contributes to the formation of ground-level ozone, which can cause respiratory problems. NOx can also combine with moisture in the atmosphere to form acid rain. Nitrogen dioxide, a criteria pollutant, is the most prevalent component of NOx (EPA, 2002).

SOx is produced when sulfur-containing fuels (coal and oil) are combusted. Most SOx is in the form of sulfur dioxide, a heavy, colorless gas. SOx is of concern, due to its contribution to acid rain and its tendency to cause respiratory distress in children and the elderly (EPA, 2002).

Although not a criteria pollutant, carbon dioxide is of concern due to its link to global climate change and the subsequent risks to human health, food and water resources, and biodiversity.

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[27] The Encina plant can also operate on fuel oil, however natural gas is its primary supply.

Carbon dioxide concentrations in the atmosphere have increased 30% since the late 1800s, a historically unprecedented change. Most of this increase is attributed to fossil fuel burning. While the individual carbon dioxide load attributed to the energy needs of desalination facilities is small, an increase in the energy intensity of water supplies represents an added challenge to mitigating this global problem.

9.2.1 Electric power resources by fuel

In order to estimate the amount of air pollutants caused by power consumption of individual California water supply systems, the electric power resources by fuel are required because combustion of each fuel produces different amount of air pollutants per unit energy. As shown in Table 9-1, the electric power sources in California include coal, oil, natural gas, nuclear, hydropower, and other non-renewables. About half of California's power is generated with natural gas (DOE, 2001). California is much less dependent upon coal as compared to the national average. Half of the power in the U.S. is generated by coal-fired plants, which contribute 90% or more of the SOx, NOx, CO_2, and Hg emissions in the U.S. (DOE, 2003). Thus, compared to the nationwide balance, the electric power sources in California are cleaner.

Table 9-1 Sources of Electric Power Generation in California in 1999

Energy Source	Utility (MWh)	Non-utility (MWh)	Total (MWh)	Portion (%)
Coal	0	2,376,045	2,376,045	1.2
Petroleum	51,769	2,127,223	2,178,992	1.1
Gas	13,917,748	76,597,923	90,515,671	47.2
Nuclear	33,371,857	0	33,371,857	17.4
Hydroelectric	38,842,389	1,508,064	40,350,453	21.1
Other	1,691,046	21,100,412	22,791,458	12.0
Total	**87,874,809**	**103,709,667**	**191,584,476**	**100.0**

Source: State Electricity Profiles, DOE, 2001

In order to assess the air emissions per unit imported water delivered to southern California, an estimate was made of air emissions produced by unit of fuel consumed by generating facilities in the state. We were unable to locate accurate emissions data for California, and therefore used nation-wide data of emissions from power generating facilities. The source data provided in Table 9-2, was used to estimate emissions by fuel, shown in Table 9-3.

Table 9-2 Emissions from Electric Power Plants in the U.S. in 1993

Source	Billion KWh	Portion (%)	SOx (1,000t)	Portion (%)	NOx (1,000t)	Portion (%)	CO_2 (1,000t)	Portion (%)
Coal	1,639	83.1	13,844	95.9	5,288	90.4	1,711,673	87.9
Petroleum	96	4.9	583	4.0	136	2.3	84,129	4.3
Gas	237	12.0	1	-	424	7.2	146,584	7.5
Total	**1,973**	**100.0**	**14,428**	**100.0**	**5,848**	**100,0**	**1,942,386**	**100.0**

Source: Electricity Generation and Environmental Externalities: Case Studies, Sep 1995, DOE

Table 9-3 Emissions per MWh from Electric Power Plants in the U.S. in 1993

Source	SOx/MWh (ton)	NOx/MWh (ton)	CO_2/MWh (ton)
Coal	8.45x10^{3}	3.23x10^{-3}	1.04
Petroleum	6.07x10^{-3}	1.42x10^{-3}	8.76x10^{-1}
Gas	4.22x10^{-6}	1.79x10^{-3}	6.18x10^{-1}

Air emissions per unit of desalinated water were estimated using data specific to the Encina Power Station, as provided in Table 9-4:

Table 9-4 Air Pollutant Emission from Encina Power Plant

Name	Fuel	Capacity (MW)	Generation (MWh/day)	SOx (ton/day)	NOx (ton/day)	CO_2 (ton/day)
				(ton/MWh)	(ton/MWh)	(ton/MWh)
Encina	Gas (*1)	965 (*1)	16,200 (*2)	6.84x10^{-2}	29	1.00x10^{4}
				4.22x10^{-6}	1.79x10^{-3}	6.17x10^{-1}

*(*1) Source: California Energy Commission (2001)*

*(*2) Generation per day is calculated from the capacity assuming the plant's average load is 70%.*

9.2.2 Results

The emissions data was combined with the energy intensity data discussed in Section 9.1 to estimate air emissions per unit water as follows:

Table 9-5 Air Pollutant Emission per AF, California, 1999

	MWh/AF	Coal	Petroleum	Gas	SOx/AF (ton)	NOx/AF (ton)	CO_2/AF (ton)
					SOx/m^3 (kg)	NOx/m^3 (kg)	CO_2/m^3 (kg)
SWP	3	1%	1%	47%	$4.42x10^{-4}$	$2.66x10^{-3}$	$9.30x10^{-1}$
					$1.09x10^{-2}$	$4.76x10^{-3}$	1.58
CRA	2	1%	1%	47%	$2.94x10^{-4}$	$1.77x10^{-3}$	$6.20x10^{-1}$
					$7.28x10^{-3}$	$3.17x10^{-3}$	1.06
Desalination	5	0%	0%	100%	$2.11x10^{-5}$	$8.95x10^{-3}$	3.09
					$1.71x10^{-5}$	$7.25x10^{-3}$	2.51

These results are presented graphically as follows:

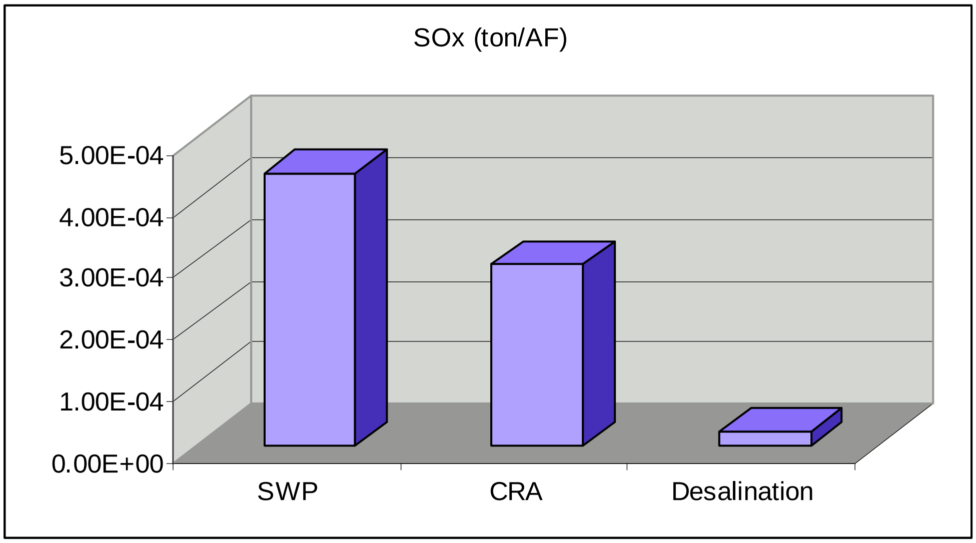


Figure 9-2 Comparative Sulfur Dioxide Emissions

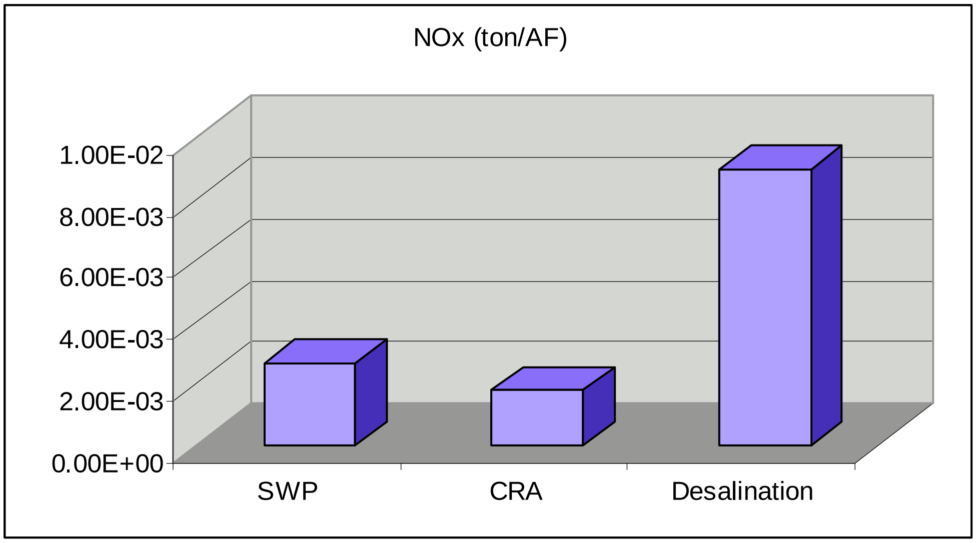


Figure 9-3 Comparative Nitrogen Oxide Emissions

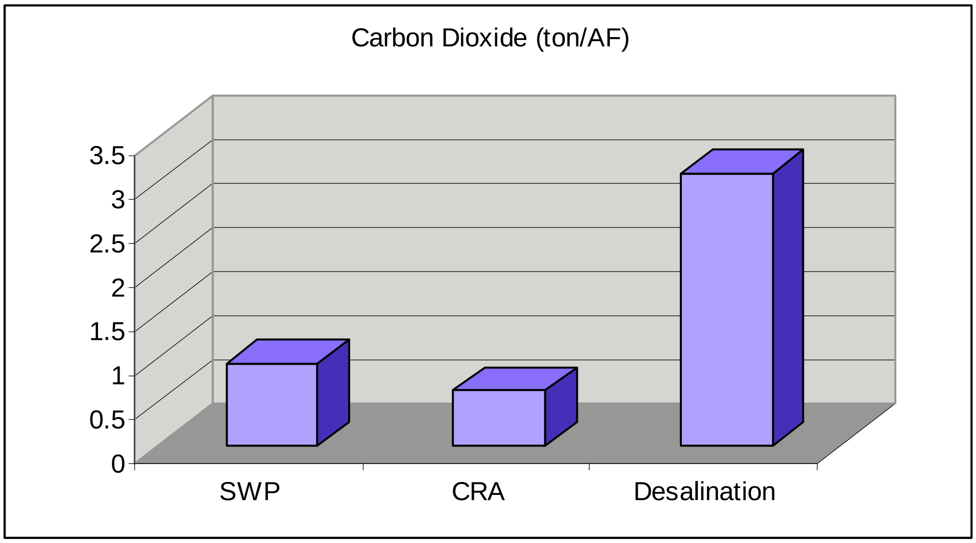


Figure 9-4 Comparative Carbon Dioxide Emissions

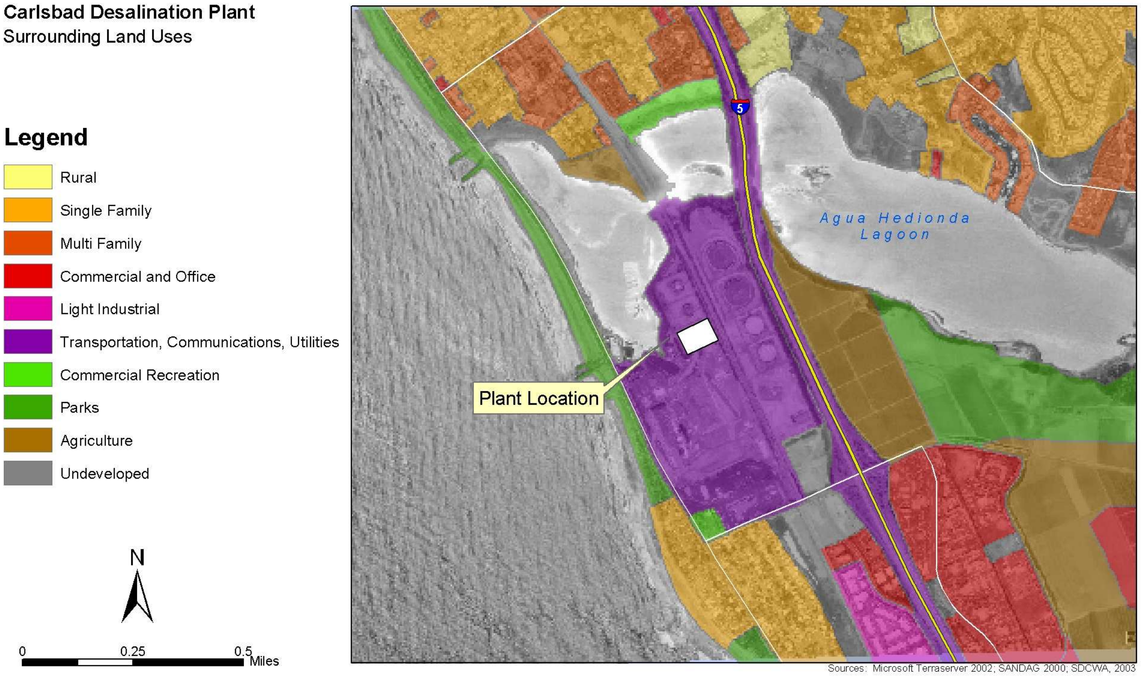
These results demonstrate that despite using a "cleaner" power source, the production of water by seawater desalination is much more intensive in NOx and CO_2 than importing water with grid-supplied power, due to its heavier overall power demands. However, it is also is significantly less intensive in SOx, by a factor of ten.

Although desalinated water appears to be more NOx and CO_2 intensive than water imports, it relies upon locally-supplied power, as opposed to water imports, which operate off the grid and therefore produce emissions that are distributed regionally. Given that fact that the Encina Power Plant does not affect regional air quality overall as measured at the Oceanside Station, the small additional use of electric power by the desalination plant will not result in degraded air quality in the County (County of San Diego, 2001).

9.3 Impacts on land use and aesthetics

An indirect impact of creating coastal desalination facilities is the potential for land use conversion, especially in areas where limited water supplies act as a constraint to growth. Siting these facilities along the coast may also present some aesthetic concerns, such as impaired views, noise and vibration from pumps, and the potential for incompatibility with neighboring land uses. Constructing desalination plants in zones already containing industrial development, such as power plants, minimizes these effects.

The Carlsbad seawater desalination plant is planned to be built adjacent to the Encina Power Station near Agua Hedionda Lagoon. The project site is developed with power station facilities; therefore the desalination plant will not result in additional land conversion. Figure 9-5 depicts land uses surrounding the site. Neighboring land uses include agriculture, parks, and residential development.



Sources: Microsoft Terraserver 2002; SANDAG 2000; SDCWA, 2003

Figure 9-5 Site of Carlsbad desalination plant and surrounding land uses

9.4 Impacts on the marine environment

Coastal desalination plants discharge waste brine to the sea. The salts returned to the sea are present in a higher concentration than those present in the feed water. In addition to the high concentration of salts, discharge water may sometimes contain various chemicals used during defouling of plant equipment and pretreatment of seawater. Although the concentrated brine contains the same ions as found in marine environments, its high density may cause it to sink to the sea floor without mixing and it may harm the marine life in the area of the discharge pipe (Einav, 2002).

9.4.1 Brine Disposal

Brine discharges are regulated under the federal Clean Water Act (CWA) and are subject to discharge permits issued by the state's Regional Water Quality Control Board (Pitzer; 2003). Generally, in plants with reverse osmosis, the discharge concentration is 1.3-1.7 times that of the natural seawater (Einav, 2002).

Brine discharges are of concern since changes in the salinity of seawater can disturb the migration patterns of fish along the coast. If the fish can sense a change in salinity, they tend to avoid that area and move further offshore (Pitzer, 2003). The high salt concentration of the discharge water and fluctuations in salinity could potentially kill organisms which are unable to tolerate either high salinity levels or fluctuations in the levels. This is especially true of larvae and young individuals which are more sensitive than the adults to changes in salinity (Boyle Eng. Corp., 1991).

The brine discharges can impede mixing because of stratification between natural seawater and brine discharge. This problem is partially overcome by blending brine with other wastewater streams that are less dense than seawater, such as treated municipal wastewater or power plant cooling water.

The Carlsbad desalination facility will dilute its brine discharge with waste cooling water from the Encina Power Station in order to mitigate brine impacts. The salinity of the combined waste stream is estimated as follows. The salinity of seawater is about 35,000 mg/L. According to information provided by SDCWA, the desalination facility's brine discharge is anticipated to have salt concentration in the range of 70,000 mg/L, and be discharged at a rate of 50 MGD (Mega gallon per day).[28] The brine is planned to be discharged into the power plant's cooling water system, which recirculates approximately 600 MGD of seawater. On the average, the 50 MGD concentrate from the Carlsbad seawater desalination facility is diluted with 600 MGD cooling water discharge from the power plant. Thus, the final discharge after dilution will be roughly equal to 38,000 mg/L in combined effluent, an 8% increase above ocean salinity levels. The waste brine stream is returned to the power plant's cooling water discharge line, which terminates at a discharge pond located at the head of an approximately 1,000 feet long discharge channel that then conveys the diluted flow out to the "surf zone" in the open ocean. By diluting the concentrate in such a manner, impacts to the ocean environment are reduced.

9.4.2 Pre-treatment Chemical Discharges

Prior to reverse osmosis seawater must be pretreated to remove constituents that can harm the reverse osmosis membrane. Pretreatment can be done with chemical processes or membrane separation. The pretreatment method for the Carlsbad Facility has not yet been decided.

A variety of chemicals used in the treatment of drinking water may be used for pretreatment. Sodium hypochlorite (NaOCl) or free chlorine is often used as disinfectants to prevent

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[28] Personal communication, Cesar Lopez, San Diego County Water Authority, March 3, 2003

biological growth (antifouling). The residual chlorine is neutralized by the addition of sodium bisulfite ($NaHSO_3$), which may also be present in effluent. Either ferric chloride ($FeCl_3$) or aluminum chloride ($AlCl_3$) can be used for the flocculation and removal of suspended matter from feed water. Ferric chloride is not a toxic chemical, but it can change the color of the receiving when discharged. Sulfuric acid and hydrochloric acid may be used for pH adjustment. Sodium hexametaphosphate (SHMP) or similar materials prevent scale formation on the pipes and on the membranes (Einav, 2002).

The chemicals used in the pretreatment stage are discharged along with the discharged brines into the sea. To determine the actual concentrations of the pretreatment chemicals entering the ocean, it requires the operational procedures and volumes of the chemicals. This information is currently unavailable and proprietary for the Carlsbad Facility.

9.4.3 *Cleaning Chemical Discharges*

Reverse osmosis membranes must be cleaned 3 or 4 times a year by weak acids and detergents such as citric acid, sodium polyphosphate, and EDTA (ethylene diamine tetra-acetate) to remove carbonate deposits. While a plant is not operating, it uses chemicals for RO membranes preservation and disinfection including sodium bisulfite, propylene glycol, or glycerin. When these chemicals are rinsed from the membrane, the rinse water is stored in a titration container and treated through titration and neutralization. Finally, the waste can be disposed off either by transporting it in closed containers to an authorized salt disposal site, or by the continuous flow of small quantities together with the discharged brine back to the sea (Boyle Eng.Corp, 1991). Thus, these processes imply that there would not be a significant impact to the environment.

9.5 Conclusion

By considering the overall environmental impacts associated with the seawater desalination plant, included adverse impacts on land use, impacts on the marine environment affected by the concentration of brine discharge, intensified use of energy, and finally noise pollution, the conclusion is summarized as following:

- The Carlsbad Desalination Plant consumes more electric power per acre-foot than other existing water projects (i.e. Carlsbad: 5 MWh, SWP: 3 MWh, and CRW: 2 MWh).
- The Desalination Plant would not cause energy deficiencies in San Diego County if it were operated using off-peak-load power.
- Since the Desalination Plant will use approximately 3% of power generation of the adjacent gas-fired power plant, its contribution to entire emission is very small.
- The existing gas-fired power plant has not affected regional air quality. Thus, the additional use of electric power by the Desalination Plant will not be a problem.
- The desalination plant requires the intensified use of energy (4,655-5,431 kWh/AF to produce 60-75 gallons of water) to power the plant; therefore, it contributes indirect environmental impacts from the burning of fuels and eventually leads into global warming.
- The plant site is already developed for industrial uses; therefore the addition of the desalination facility will not result in an adverse land use.

- The salinity of the combined desalination and power plant effluent will have a salinity of approximately 38,000 mg/L, as compared with seawater with salinity 35,000 mg/L. It is unlikely that this discharge will have an adverse effect on marine life.
- There need to be further information about the pre-treatment chemical discharges to be able to determine if effluents significantly affect the environment.

10 CONCLUSION

We have observed that a portion of the excess cost associated with desalinated water is recovered in the form of reduced salinity in delivered water, which produces benefits in the form of avoided water softening, increased life of water-using appliances, improved water efficiency in cooling towers and increased crop yields. Consumers are willing to pay higher monthly water bills to avoid shortages, so presumably there is an excess value to desalinated water due to its reliability. However it is difficult to estimate this value due to the difficulty of converting a theoretical willingness to pay to a received benefit. In addition, desalination still requires more energy than the alternative of transporting water to the county using existing conveyance infrastructure, despite the energy savings associated with co-locating desalination plants and energy facilities. While the Carlsbad Desalination Facility would decrease San Diego County's reliance on imported water, it would in turn increase the County's reliance on imported power. Operation of desalination facilities during off-peak periods of power generation may be a preferable alternative. Progress in the membrane industry may eventually reduce the energy required to operate reverse osmosis facilities, however at the present time this is not the case.

The merits of desalination are more evident when it is viewed as a form of supply diversification, and an emergency source of water. Operation of the Carlsbad facility would provide San Diego County with a hedge against drought, as well as a source of dilution for the county's high salinity water imports. The need for diversification is further heightened by today's threats of domestic terrorist attacks, plus the susceptibility of the existing system to natural disasters such as earthquakes. The addition of coastal seawater desalination plants to California's mix of water supplies aids in decentralizing the state's water infrastructure. As a result, a disruption at an individual location such as a pipeline or reservoir is mitigated by the presence of alternative sources of supply. The agencies involved in considering development of these facilities should attempt to simulate worst-case supply interruptions, and then evaluate the optimum level of desalination capacity for providing municipal water during emergencies.

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