Desalination Feasibility Study
for the
Monterey Bay Region
FINAL REPORT

Prepared For

Association of Monterey Bay Area Governments

November 8, 2006

Desalination Feasibility Study in the Monterey Bay Region

FINAL REPORT

Accepted by the AMBAG Board of Directors on November 8, 2006

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1. INTRODUCTION

1.a PROJECT OVERVIEW AND PURPOSE

The purpose of the Association of Monterey Bay Area Governments Regional Desalination Feasibility Study is to investigate the environmental, economic, and social impacts, both positive and negative, of seawater desalination project implementation in the context of the Monterey Bay region. This report includes a baseline assessment of existing habitats in the Monterey Bay Region that could be potentially affected by desalination plants; an overview of existing water supply situation in the Monterey Bay region including water supply sources, demand projections, demographics, and the role of desalination and other alternatives in future water supply portfolios; an analysis of the environmental, and socio-economic costs and benefits caused by desalination plant construction and operation; an analysis of potential scenarios for the use of desalination in the Monterey Bay area, including costs and benefits, and; an overview of the existing regulatory environment associated with desalination in the AMBAG region. Specific environmental and socioeconomic impacts being addressed in the study include: impacts related to brine discharge, entrainment and impingement, construction impacts, energy use and emissions, growth inducement, and land use impacts. This report is intended to provide a comprehensive overview of desalination technologies and associated issues; however, it is not intended to be a replacement for thorough case-by-case review of desalination proposals. It was developed to provide objective, accurate, and up-to-date information to a diverse audience including but not limited to: the general public, regulatory agencies, elected officials and decision makers, desalination plant proponents and consultants.

A core group of *Technical Advisors* have conducted the majority of the research, and co-authored the report; an *Advisory Committee* was also established and met periodically to review and provide input and guidance on the study, as well as to discuss recent occurrences related to desalination in the Monterey Bay area. This advisory committee is made up of members from the California Coastal Commission, the Central Coast Regional Water Quality Control Board, Moss Landing Harbor District, NOAA Fisheries, Marina Coast Water District, Monterey County Water Resources Agency, Monterey Peninsula Water Management District, Pajaro Sunny Mesa Community Services District, Santa Cruz Water Department, California American Water Company, Moss Landing Marine Laboratories, and UC Santa Cruz.

Another key component of the project is to conduct outreach activities designed to assist the general public and regulatory agencies in better understanding the costs and benefits associated with desalination and its potential future role as a water supply alternative in the Monterey Bay region. A workshop titled "*Be Smarter About Desal*" was conducted as part of this feasibility study; this workshop was held on September 27, at the Monterey Beach Resort, to present the results of this study and to provide a regional forum to learn about and discuss desalination issues. The workshop featured panels of experts addressing issues related to seawater desalination in the MBNMS. More than 120 people attended this event.

Table 1.1 AMBAG Monterey Bay Desalination Feasibility Study Partners

Advisory Committee	
Nick Papadakis	AMBAG
Michael Stottlemeyre	AMBAG
Tom Luster	California Coastal Commission
Peter von Langen	Central Coast Regional Water Quality Control Board
Steven Leonard	California American Water Company
Mark Lucca	Marina Coast Water District
Bill Phillips	Monterey County Water Resources Agency
Robert Johnson	Monterey County Water Resources Agency
Andy Bell	Monterey Peninsula Water Management District
Peggy Shirrel	Moss Landing Harbor District
Kenneth Coale	Moss Landing Marine Laboratories
Joyce Ambrosius	NOAA Fisheries
Joe Rosa	Pajaro Sunny Mesa Community Services District
Linette Almond	Santa Cruz Water Department
Technical Advisory Team	
Brad Damitz	Monterey Bay National Marine Sanctuary
David Furukawa	Separation Consultants, Inc.
Jon Toal	Kinnetic Laboratories

1.b OBSERVATIONS AND RECOMMENDATIONS

The following observations and recommendations were developed by the authors of this report in collaboration with the Advisory Committee, based upon the research completed for the *Desalination Feasibility Study in the Monterey Bay Region*; they were reviewed, revised and accepted by the AMBAG Board of Directors on November 8, 2006. The recommendations represent the AMBAG Board of Directors' policy related to future development of desalination facilities and as an advisory guide for future research and policy development.

Observations:

1. The current water supply in the AMBAG region is not sustainable. Over-pumping of surface and ground water supplies is causing adverse environmental impacts such as salt-water intrusion and habitat damage. We are also vulnerable to drought. Because of this, it is necessary to pursue additional alternatives for public water supply and continue conservation efforts.

2. Because of limited water supplies, there have been an unprecedented number of proposals for new seawater desalination plants in the Monterey Bay area. There are currently seven proposals to build desalination plants, in addition to three existing facilities (Monterey Bay Aquarium, Moss Landing Power Plant and Marina Coast Water District).

3. Desalination is a maturing technology that has consistently provided a reliable supply of high quality freshwater throughout the world for many years; however its use has not yet been proven in the Monterey Bay area (except for a short period in Marina).

4. Desalination is highly regulated in the Monterey Bay area through federal, state and local regulations. There are many safeguards that exist to minimize environmental impacts.

5. There are a number of positive impacts or benefits associated with desalination, including:

   - Its ability to augment water supply, especially in places where there are shortages.
   - It can be used to reclaim water that is impaired and would otherwise not be available.
   - It provides a reliable source of water even during drought conditions when other sources are limited.
   - It diversifies the water supply options available, which provides a form of insurance by not having to rely too heavily on any one option.
   - It provides a very high quality source of water that meets or exceeds federal and state drinking water standards.

- There are a few cases where desalination can be used to realize environmental benefits, if the water produced is used to replace conventional sources that are overdrafted, such as rivers and aquifers (Carmel River, Pajaro and Salinas Valley's aquifers). However, in most cases regulations or legislation to ensure that these environmental benefits are realized and maintained, do not currently exist.

6. Coastal desalination plants have the potential to cause a number of socio-economic and environmental negative impacts:

    - Entrainment and impingement of marine organisms from the intake of seawater.
    - Discharge related impacts due to the introduction of highly saline brine and potentially, other constituents to sensitive marine habitat
    - High energy use and cost to produce desalted water.
    - Visual and aesthetic impacts from siting the plant on the coastline.
    - Seafloor disturbance from construction of the intake and outfall structures.
    - Impacts to biological resources and habitats.
    - Cumulative impacts from multiple desalination plants or other projects in the area.
    - Growth inducement and land use impacts from developing a new source of water.
    - Recreational and public access impacts.
    - Various other socioeconomic impacts.

7. The impacts resulting from the construction and operation of a desalination plant are highly variable from site to site. Due to the diversity of plant technologies, designs, and capacities, and the uniqueness of each site, impacts cannot be generalized and should be assessed on a site-by-site basis.

8. All desalination plant proposals must include transparent decision-making and public involvement about where they are to be located, how they are to be designed, how much water they will produce, and where the water will be used. In Monterey County, all desalination facilities are required to be publicly owned.

9. While there are operational advantages derived from co-location with a power plant, there is concern that power plant/desalination plant co-location would provide a justification for the continued use of environmentally-damaging once-through cooling systems that would otherwise be upgraded to the best available technology.

***Recommendations*:**

1. It is recommended that desalination project proposals in the Monterey Bay area be integrated and coordinated on a regional level as part of a diversified water supply portfolio. Furthermore, the timing of when such projects come on line must also be examined as part of a regional water supply portfolio.

2. It is recommended that the freshwater production capacity of all desalination projects be consistent with established local government land use policies in county and city general plans and local coastal programs.

3. Since seawater desalination is an energy intensive and expensive water source, it should only be pursued when there is a clear and established need for a new water supply, and when other economically and environmentally preferable alternatives such as increased conservation, brackish water desalination, and wastewater recycling have been thoroughly evaluated, and pursued, if feasible.

4. It is recommended to use site-specific *Best Management Practices,* designed to avoid environmental impacts, during construction and operation of any desalination plant.

5. Desalination plants should be designed to minimize visual impacts as well as impacts to coastal access, or commercial or recreational activities.

6. Due to the large number of stakeholders potentially affected by a proposed desalination project, it is essential for the project proponent, the affected stakeholders, and the regulatory agencies, to collaborate on a regular basis beginning early on in the process and continue throughout, so that issues can be identified and worked out.

7. Subsurface intakes such as beach wells have the potential to minimize or eliminate impingement and entrainment impacts and improve the performance and efficiency of a desalination project. Where found feasible and beneficial, subsurface intakes should be used. It must be ensured however, that they will not cause saltwater intrusion to aquifers, negatively impact coastal wetlands that may be connected to the same aquifer being used by the intake, or be subject to the threat of coastal erosion in the future.

8. When it is necessary to use a surface water intake, the use of appropriately sited existing pipelines of acceptable structural integrity should be investigated, to minimize impacts to the seafloor. If a new pipeline is necessary, sub-seafloor placement should be evaluated to minimize disturbances to biological resources. If such intakes are approved, they must include mitigation measures necessary to minimize their impacts to the marine ecosystem.

9. Blending of brine effluent with existing discharges, for dilution, should be considered.

10. The use of renewable energies should be further evaluated and pursued to offset the energy requirements of desalination plants.

11. Impacts should be assessed on a site-by-site basis.

12. To ensure that potential environmental benefits from a desalination project are realized, developing a regulatory or legislative mechanism at the local level to ensure optimization of environmental benefits is recommended.

13. Funding assistance, including state and federal sources, for Monterey Bay desalination projects should be investigated and pursued.

14. Desalination plants proposing to co-locate with power plant once-through cooling systems should include an assessment, during the environmental documentation phase, of the impacts that would occur when the power plant cooling system does not operate along with back up plans for alternative intake and outfall structures in case that the power plant's cooling system is no longer used in the future.

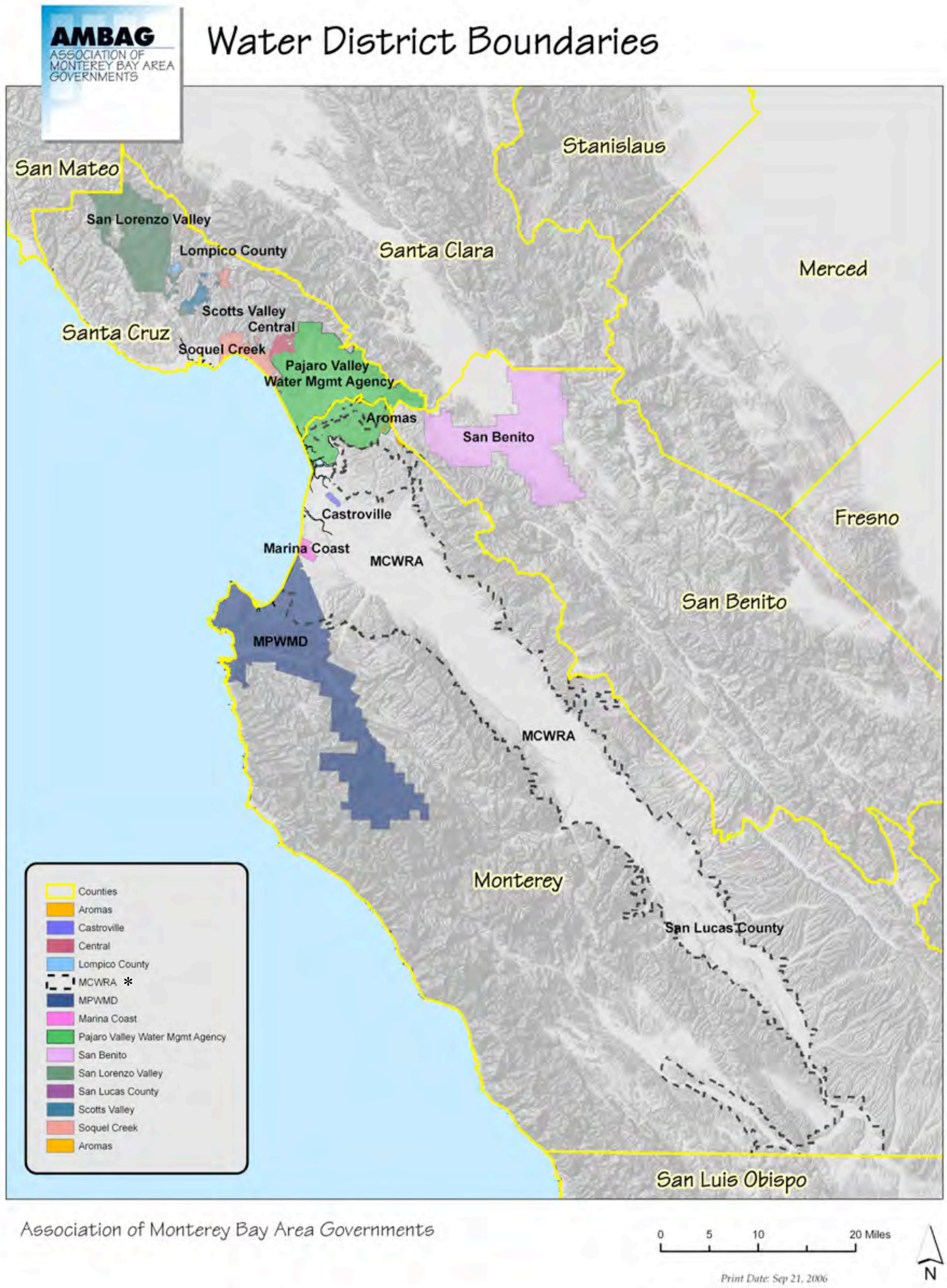
2. WATER SUPPLY BACKGROUND FOR MONTEREY BAY REGION

2.a Water Sources for the Monterey Bay Region:

A number of distinct groundwater basins and surface water systems in the region, as well as some engineered sources of supply represent the Monterey Bay area's primary fresh water sources. Presently, the majority of this supply is from groundwater pumping; according to the California Water Plan Update 2005, groundwater accounts for roughly 75 percent of the average annual water supply in the region. By distinct geological formation, the employed groundwater sources within Monterey County include the Pajaro Valley, Salinas Valley and Seaside Basins. Those within Santa Cruz County include the Santa Margarita and Pajaro Basins, the Aromas Red Sands Aquifer and the Purisima Formation; and those within San Benito County include the Gilroy-Hollister, San Juan Batista, and Tres Pinos groundwater basins. Major surface water sources within the region utilized either by direct diversion or affected by groundwater extraction include the Carmel and Salinas Rivers in Monterey County, the San Lorenzo River system in Santa Cruz County, the San Benito River system in San Benito County, and the Pajaro River system that runs along the border of Monterey and Santa Cruz Counties. Water sources by district, are described in *Table 2.1,* and *Figure 2.1* shows the locations of each water district in the AMBAG region.

Management of these resources is complicated by several factors including: sharing of water sources by multiple water management districts or agencies; inclusion of numerous stakeholders and different layers of government within water management districts; and the high number of private wells in the region. The cross-boundary nature of stream flows and water basins, combined with a relatively large number of user types, demands a substantial level of coordination by managers to ensure efficient allocation and planning. For instance, the Aromas Red Sands Aquifer in Santa Cruz County is drawn on by constituents within the Central Valley Water District (CVWD), the Pajaro Valley Water Management Authority (PVWMA), and the Soquel Creek Water District (SqCWD). Another example of a shared resource is the Purisima Formation, which is used by both City of Santa Cruz Water Department (SCWD) and SqCWD as well as by private well owners who account for nearly 40% of all extractions; although it should be noted that only four percent of Santa Cruz's annual water use is supported by Purisima Formation water in an average year. SCWD receives nearly half of its supply from the San Lorenzo River system, a source that is shared with the northern section of the San Lorenzo Water District (SLWD). Water managers in Monterey County experience a similar challenge, particularly within the Salinas Valley Groundwater Basin, which supports users in the Marina Coast Water District, Monterey County Water Resource Agency (MCWRA), California Water Service Company, California-American Water, and the Castroville Water District (CWD).

Figure 2.1. Water District Boundaries in the Monterey Bay Region



* MCWRA has purview over ALL water in Monterey County. Jurisdiction boundary should be county line.

Table 2.1. Water Source for Monterey, Santa Cruz, San Benito Counties 2005

Agency	Groundwater	Surface Capture/Diversion	Private Wells	Recycled	Info Source Title
MCWRA	Salinas Valley Groundwater Basin	Nacimiento and San Antonio Reservoirs		10865 AFY (Castroville Groundwater Replacement)	Groundwater Extraction Report 2004
MPWMD	Seaside Basin (25.4%) / Carmel River Basin (72.4%) / Peninsula, Carmel Highlands, and San Jose Creek (2.2%)	San Clemente and Los Padres Dams	4,185 AFY	674 AFY (Golf Course and Open Space Irrigation)	CalAm Water Customer Report (Fax)
MCWD	Salinas Valley Groundwater Basin		1,200 AFY		Urban Water Management Plan 2005
SBWD[i]	Hollister/Gilroy Groundwater Basin, San Juan Bautista and Tres Pinos Groundwater Basin	Central Valley Project (San Felipe water): Ag 19,294 AFY Urban 4,443 AFY Hernandez and Paicine Reservoirs			Annual Groundwater Report 2005 Draft Program Environmental Impact Report 2005
Pajaro Valley WMA	Pajaro Valley Groundwater Basin	Diversion for Agriculture and Corralitos Filter Plant -2100 AFY		4,000 AFY (Groundwater Replacement)	PVWMA Basin Management Plan 2002 Comparative Billing Summary 2005
Soquel Creek WD	Aromas Red Sands Aquifer[ii] (35%) and Purisima Formation (65%)		Estimated at ±40% of groundwater produced in the Soquel-Aptos area		Soquel Creek Water District Integrated Resources Plan 2006
City of Santa Cruz Water Department	Purisima Formation Live Oak Wells (3%)	Loch Lomond - 2003(16%), San Lorenzo River - 6086(48%) North Coast Diversion - 4033(32%)		246 AFY (Internal use in wastewater treatment plant)	Urban Water Management Plan 2005
San Lorenzo WD[iii]	Santa Margarita & Lompico Formations	San Lorenzo River Tributaries			Urban Water Management Plan 2005
Scotts Valley WD	Santa Margarita Groundwater Basin			128.8 AFY (Commercial Irrigation)	Water Production Summary (Fax)
Aromas WD	Pajaro Valley Basin				Department of Water Resources -Statistics (FAX)
Castroville WD	Salinas Valley Groundwater Basin				Department of Water Resources -Statistics (FAX)

[1] SBWD uses water sourced from local surface diversion, groundwater, and imported water. The local system is conjunctive, meaning surface water is used during wet years and stored groundwater during dry years.
[2] The Aromas Formation is shared with PVWMA and CVWD; the Purisima Formation is shared with Santa Cruz (4% of total supply).
[3] The SLWD possesses two distinct distribution systems; the north system is both groundwater and surface water, the south system is entirely groundwater.

Beyond the aforementioned local water sources, and in response to concern over water shortfalls and groundwater overdraft, a growing number of engineered solutions have been developed to help augment regional supplies. For example, the San Benito Water District imports about half their water via the San Felipe Unit of the Bureau of Reclamation's Central Valley Project, which transports water from the San Luis Reservoir in Merced County for both agricultural and urban purposes.

There are also several proposed storage and recovery projects at various stages of planning and implementation throughout the region, aimed at capturing and storing water when it is abundant, and tapping into that supply in future dry periods. In the Pajaro Valley, the Harkin Slough Project proposes to divert up to 2000 AF of water from the slough during wet times to a shallow storage aquifer. The stored water can then be released and distributed during dry months. A water recycling project outside of Watsonville is ready to supply about 4000 AF, and imported water via the Central Valley Project hopes to grant the remaining 12,500 AF believed necessary to combat saltwater intrusion along the coastline (PVWMA, 2002). The Monterey County Water Resources Agency has proposed the Salinas Valley Water Project, which would include construction and operation of a diversion facility on the Salinas River near Marina. The project would redirect 9,700 AF for storage in the Nacimiento Reservoir, which will later be delivered through existing pipelines to coastal areas near Castroville (MCWRA, 2001). Finally, in another nearby project, the Monterey Peninsula Water Management District is working toward implementing an aquifer storage and recovery project to decrease demands on the Carmel River and Seaside Basins. During wet months, up to 2,426 AF of water would be diverted from the Carmel River for storage in, and later recovery from, the Seaside Basin (MCWD, 2005).

These projects have been proposed in an effort to responsibly provide for current and future demand. The challenge facing the region and decision makers is considerable. Existing water extraction practices in the Monterey Bay area are unsustainable; and in many cases have resulted in impacts such as saltwater intrusion and damage to biological habitat. *Figures 2.2* and 2.*3* depict the advance of saltwater intrusion over time, in both the 180-foot and 400-foot aquifers in Monterey County. Examples of these current water supply shortfalls and issues, from south to north:

- Historic over-pumping of the Carmel River, which caused significant environmental impacts: California American Water Company is required to find a water supply alternative for its customers on the Monterey Peninsula. They must produce 10,730 acre-feet per year (AFY) in order to comply with State Water Resource Control Board order 95-10.

- The Salinas Valley is experiencing significant saltwater intrusion and continuous groundwater overdraft averaging 9,700 AFY.

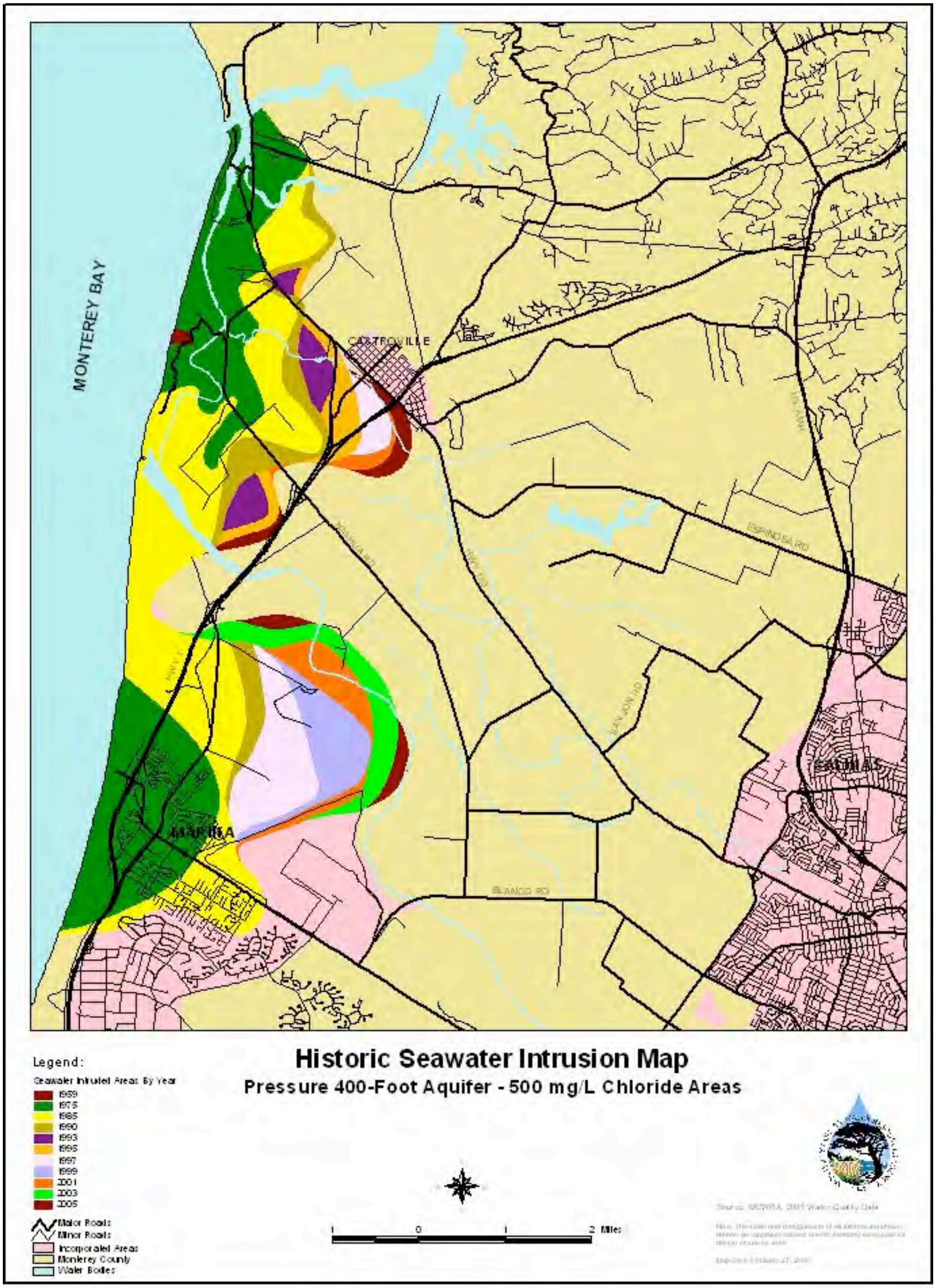
- The Pajaro Valley requires an estimated 18,500 AF of additional supply annually to halt saltwater intrusion (PVWMA, 2002).

- The Soquel Creek Water District experiences an overdraft of 500 to 600 AF each year.

- Three of the four major sources of water for the City of Santa Cruz are presently utilized at maximum capacity, leaving the City exposed to severe shortages during drought conditions.

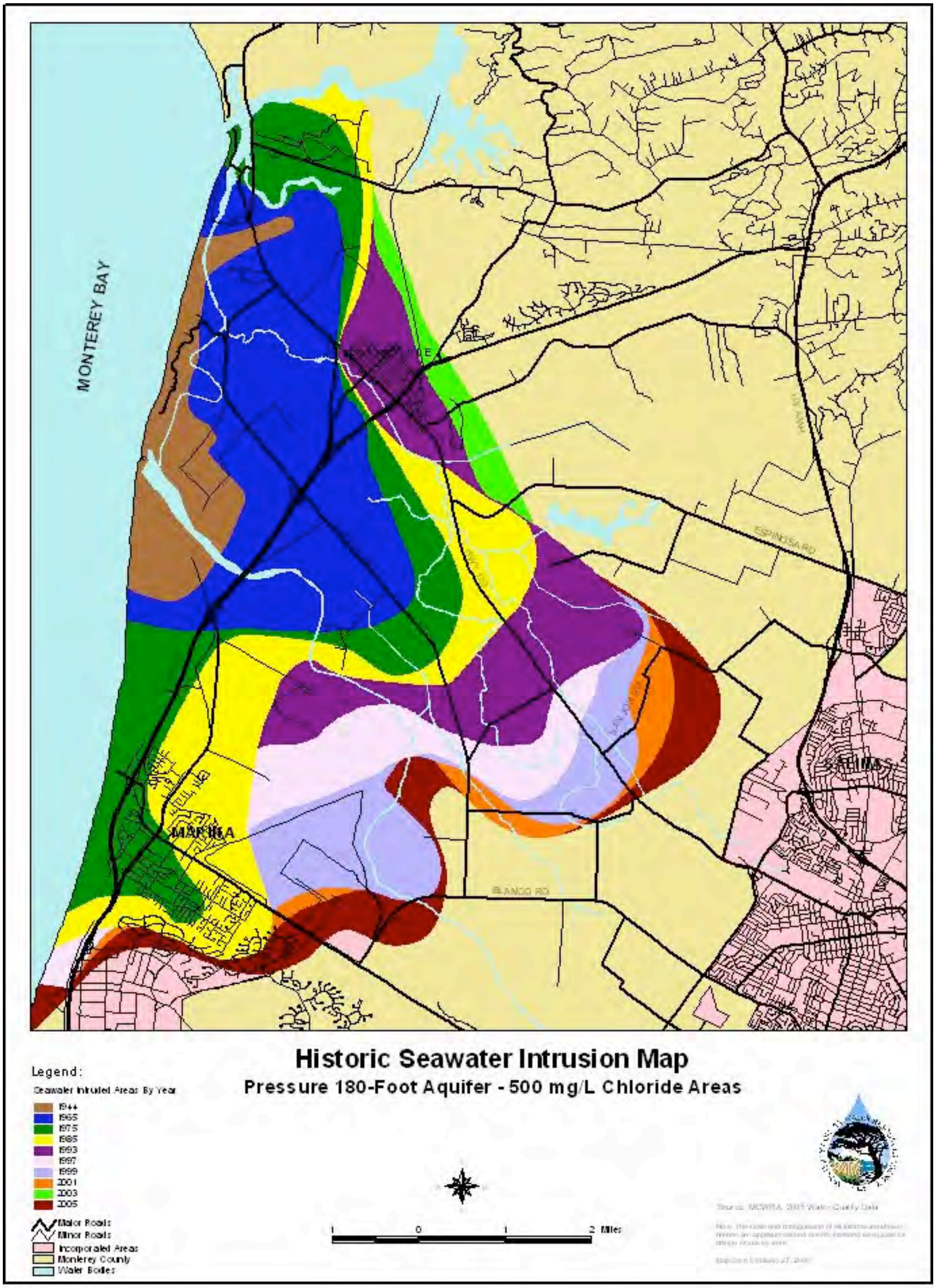
Since water demand in the region is projected to grow steadily in the future, it is expected that these water shortages will increase correspondingly. In addition to the challenges of meeting today's water needs, it is important to consider and evaluate the potential for various water supply and conservation strategies to meet future water demands.

Figure 2.2 Saltwater Intrusion in Monterey County's 400-Foot Aquifer



Source: MCWRA 2005 Water Quality Data

Figure 2.3 Saltwater Intrusion in Monterey County's 180-Foot Aquifer



Source: MCWRA 2005 Water Quality Data

2.b CURRENT WATER USE PORTFOLIO

In an attempt to characterize water use in the Monterey Bay region, the Association of Monterey Bay Area Governments (AMBAG) surveyed the eleven largest water districts and agencies, requesting data on the quantity of water consumed by agricultural, residential, commercial, industrial, and municipal users in each of the districts. These data are represented on *Table 2.2,* which shows the amount of water in acre-feet specified by use type, and the total amount of water consumed within each agency or district jurisdiction. Note that the total amount for the region is less than the sum of total water use for each of the water districts and agencies. This is because in some cases water district figures are accounted for by more than one agency. For example, MCWRA tracks water use in the Castroville Water District and the Marina Coast Water District and includes these districts' totals as part of the totals for their agency, therefore summing the water use figures from both districts and the MCWRA would result in an overestimate of water use in the region. Also, demand is expected to vary from year to year and is not constant, due to the high variability in availability of natural water resources as well as the influence of climatic conditions. This is especially true with regard to agriculture, where a dry year will result in greater water demand than a wet year. Generally speaking, water year 2005 was considered an average to wet year. Finally, another issue further complicating the accurate measurement of water use is that use is sometimes un-metered. Keeping in mind the aforementioned caveats, *Table 2.2* will nonetheless provide the reader with a general sense of how much water is used and where it is allocated in the region.

Total water use in the AMBAG region during water year 2005 (October 2004–September 2005) was 670,812 AF. The two water agencies with mandates to manage the Pajaro Valley Basin and the Salinas Valley Basin, the PVWMA and the MCWRA, had the greatest total volume, with the vast majority of use due to agriculture in the fertile Salinas Valley. The water district with the greatest volume was the Monterey Peninsula Water Management District, followed closely by Santa Cruz Water Department, not surprisingly since both of these districts have relatively high population densities for the region.

Table 2.2: Water Use in Monterey, Santa Cruz, and San Benito Counties 2005 (AFY)

Agency	Residential[1]	Commercial	Industrial	Municipal[2]	Agricultural	Other[3]	Total By Agency	Yr of Data[4]
MCWRA	27,500	IIR[5]	IIR	IIR	522,500	0	**550,000**	Yearly Average
MPWMD[6]	7,863	3,141	80	1,068	0	399[7]	**12,551**	2005
MCWD[8]	1,966	755	5	IIR	0	1,461[9]	**4,187**	2005[10]
SBWD	10,751	IIR	IIR	IIR	38,598	0	**49,349**	2005
Pajaro Valley WMA	9,600	IIR	IIR	IIR	41,940	0	**51,540**	2005
Soquel Creek WD	4,077	638	0	170	0	0	**4,864**	2005
Santa Cruz Water Department	7,147	2,086	745	193	193	352[11]	**10,716**	2005
San Lorenzo Valley WD	1,514	114	0	IIR	0	47	**1,675**	2005
Scotts Valley WD	1,793	IIR.	0	IIR	0	0	**1,793**	2005
Aromas WD[12]	854	21	0	IIR	0	0	**875**	2005
Castroville[13] WD	470	224	0	11	0	IIR	**705**	2005
Total by Sector	**63,236**	**2,859 (IIR)**	**745 (IIR)**	**363 (IIR)**	**60,3231**	**399**	**670,812**	

[1] Residential includes single-family, multi-family, and landscape irrigation
[2] Includes all public entities, e.g. police stations, firehouses, public schools
[3] Signifies discharge from hydrants and leakage unless otherwise specified
[4] Water year 2005 (October 2004 through September 2005)
[5] Included in Residential (IIR)
[6] Values for MPWMD apply only to Cal-Am water use, the majority of which lies within the MPWMD boundaries. Cal-Am is an investor owned public utility.
[7] 31afy for hydrant discharge; 368 afy for golf course use
[8] Use total for MCWD already represented in use values for MCWMA, i.e. inclusion into total would result in double accounting.
[9] Represents un-metered and unaccounted water use; unaccounted is the difference between the pumped amount and what is registered at a customer's meter. Unmetered is the estimate of water use at CSUMB.
[10] Represent calendar year 2005
[11] 12 afy for hydrant discharge; 340 afy for golf course use
[12] Amount for Aromas WD is represented in use for Pajaro Valley WMA
[13] Amount for Castroville represented in use values for MCWRA

Sector-specific use in the Monterey Bay region is noticeably skewed toward agriculture, a reflection of the agrarian nature of the regional economy and the large water demand inherent in crop production. By these figures, nearly 90 percent of total water use is allocated for agriculture, leaving approximately 10 percent for urban consumption, which is further dissected into sectors. Since many of the water agencies and districts reported commercial, industrial, or municipal use in their residential or urban figures, however, further breakdown of figures beyond the level of urban versus agricultural use has significant error associated with it. With that in mind, using available numbers of residential, commercial, and industrial uses account for around 10, 1, and 0.1 percent of total use in the region respectively.

In addition to a current use portfolio, AMBAG requested from the eleven water districts an assessment of future water demand by the year 2025. Usable information was available from seven districts, and the projected numbers were compared to the numbers for actual use in 2005; these figures are represented in *Table 2.3*. Some caveats are necessary for the San Benito Water District and the PVWMA projections. The available studies for both districts were from prior to 2000, and their estimates of water use in 2005 were much higher than actual use. Therefore it is reasonable to assume that the future projections are inflated as well. For instance, the report conducted for the Pajaro Valley concluded that 9000 AF would be needed by 2040, whereas the figures in the future demand table suggest an increase of 28,960 AF; a considerable difference. Generally speaking, future water demand depends on myriad factors that are very difficult to predict accurately.

Table 2.3: Future Water Demand in Monterey Bay Region

Agency	2005 (afy)*	2025 (afy)**
MPWMD	12,551	17,096
MCWD	4,187	15,403
SBWD	49,349	92,530
Soquel Creek WD	4,864	5,540
Santa Cruz City	10,716	16,070
Scotts Valley WD	1,793	2,343
PVWMA	51,540	80,500

*Figures are from actual use values as determined by AMBAG survey of water districts
**The projection for MPWMD is for prior to 2025; SBWDs' is for the year 2022; PVWMA projection is for 2040. Also, the SBWD and PVWMA reports projected values for 2005 were must higher than actual use, a fact that should be considered in evaluating the reports' projections for 2025. The numbers for projected demand by 2005 for San Benito and Pajaro were 67,763 and 51,540, respectively.

2.c Role of Water Recycling:

Recycled water makes up a small but growing portion of the region's water supply. There are several benefits associated with water recycling projects. In addition to producing high quality freshwater at a cost significantly lower than desalination, it also prevents environmental impacts associated with discharge of treated sewage into the Monterey Bay National Marine Sanctuary. Recycled water also has great potential for serving much of the region's irrigation needs, for farms and for urban landscapes, and can also play an important role in providing future municipal water supply via aquifer recharge.

The largest water recycling plant in the region is the Salinas Valley Reclamation Plant located two miles north of Marina, which is part of the Monterey County Water Recycling Project, which is jointly owned and operated by the Monterey County Water Resources Agency and the Monterey Regional Pollution Control Agency (MRWPCA). This plant, operated by the Monterey Regional Water Pollution Control Agency (MRWPCA) is used to supply water to the *Castroville Seawater Intrusion Project* (CSIP). This plant, which serves Pacific Grove, Monterey, Del Rey Oaks, Seaside, Sand City, Fort Ord, Marina, Castroville, Moss Landing, the Boronda area, Salinas and some unincorporated areas in northern Monterey County, treats 12,000 AFY. The MCWRP was pursued as an effort to prevent the advance of saltwater intrusion by providing an alternative source of water to 12,000 acres of farmland in the northern Salinas Valley.

This $75 million project was completed in 1997 after three years of construction. The facility is capable of producing an average of 29.6 million gallons of recycled water per day (MGD). For perspective, the largest desalination plant being proposed in the Monterey Bay area is 20 MGD, with the mean size being 5.8 MGD. The recycled water is temporarily stored in an 80 AF storage reservoir, until it is conveyed to agricultural fields via underground pipelines. During the rainy season, when farmers do not need the water, it is discharged through the wastewater outfall to the Monterey Bay, about two miles offshore. MRWPCA plans to expand the use of its recycled water to city parks, roadway landscape, and golf courses (MRWPCA, 2006).

Marina Coast Water District and MRWPCA are collaborating on a project known as the Regional Urban Recycled Water Distribution Project (RURWDP), which would increase the amount of recycled water produced at the Salinas Valley Reclamation Plant, and add a new 63-acre reservoir where the water would be stored until it is ultimately used for irrigation purposes. The project would include two phases the first would be 1,727 AFY, and the second phase would increase the capacity to 3,100 AFY (MCWD, 2004).

Another project, on the Monterey Peninsula, the *Wastewater Reclamation Project* (WRP), which was completed in 1993, is a collaborative effort involving the Carmel Area Wastewater District (CAWD), the Pebble Beach Community Services District (PBCSD), the Monterey Peninsula Water Management District (MPWMD) and the Pebble Beach Company (PBCO). The WRP consists of a tertiary treatment plant, a wastewater distribution system and storage tank, and improvements to the irrigation systems. About 650 AF of recycled water is conveyed to Pebble Beach each year, where it is used to irrigate eight golf courses, athletic fields and other landscaped areas (PBCSD, 2006).

The *Watsonville Area Water Recycling Project* (WAWRP) is another new project that will soon be constructed in a partnership between Pajaro Valley Water Management Agency and the City of Watsonville. The WAWRP is being built along with an extensive pipeline system known as the *Coastal Distribution System*, which will convey the recycled water to agricultural lands in areas being affected by saltwater intrusion. The existing Wastewater Treatment Facility, which is owned by the City of Watsonville, currently treats about 8,000 AFY of wastewater to the advanced secondary treatment level; the WAWRP will upgrade that plant to tertiary treatment level, to produce recycled water suitable for all non-potable uses. This project will occur in phases; during the first phase about 4,000 AF of recycled water will be used during the dry seasons of the year when irrigation is necessary. During the wet season the treated wastewater will be discharged through an ocean outfall. Future phases of the project may involve storage during the wet season. The first phase of the project is expected to be online by the beginning of the 2008 growing season (Pajaro Valley Water Management Agency, 2006).

Smaller facilities also exist in the area, such as a project for groundwater replacement in the Pajaro Valley, and one for commercial irrigation in Scotts Valley.

Role of Conservation:
Conservation refers to actions taken that reduce water losses through maximizing efficiency of use and minimizing waste. In some areas of the Monterey Bay region, additional water conservation efforts can increase water supply at a much lower cost, fiscally and environmentally, than the development of other supply sources such as a desalination or water recycling. In fact it is estimated that California's water use could be reduced by 33 percent by using existing off-the-shelf conservation technologies such as low flow toilets, clothes washers and dishwashers and by implementing improved irrigation and landscape management techniques outdoors. Additionally, it is possible to save a further seven percent by reducing leaks and improving metering systems (CalAm, 2006).

According to the California Department of Water Resources, it is possible to achieve an additional 1.5 to 2.5 million AFY of urban water conservation in the state (Planning and Conservation League, 2004). The Pacific Institute, in a 2004 report, estimated the number that can be conserved using existing technology to be more than 2.3 million AFY, or a third of the total amount of water used in the urban sector in the State of California; the majority of this (more than 85%) can be saved at costs below those for other new water sources (Pacific Institute, 2004). The Planning and Conservation League lists water conservation among the key reasons that urban areas use about the same amount of water they used in the 1990s, while still growing significantly in population (Planning and Conservation League, 2004). In one example of the potential effectiveness of certain conservation strategies, the Pacific Institute estimates that 130 billion gallons could be saved each year if all of the toilets in California were replaced with high-efficiency models; that is more water than could be produced by seven 50 MGD desalination plants (Gleick, 2006).

Many Monterey Bay communities have implemented some of the most successful water conservation measures in the state. The City of Santa Cruz has an extensive water conservation program. In June 2001, the City of Santa Cruz became a signatory to the *Memorandum of Understanding Regarding Urban Water Conservation*, committing to implement its 14 best management practices; MCWD and Scotts Valley are also signatories to this MOU. In 2000, the City of Santa Cruz adopted a *Water Conservation Plan* that will result in water savings of 282 million gallons per year (0.8 MGD) by 2010; the City is currently more than half way towards meeting this goal. This plan is composed of 17 demand reduction programs, which will be implemented over a period of ten years (Santa Cruz Water Department, 2005). The Monterey Peninsula also has implemented successful conservation measures resulting in a reduction in consumption from 17,913 AF in 1987 (a year with non-drought conditions) to 12,922 AF in 2003; while the number of connections grew by 18 percent during this period, overall water use decreased by more than 25%.

In addition to urban water conservation, the agricultural industry in the Monterey Bay area has also made significant contributions towards conserving water. For example, MCWRA annually collects *Agricultural Water Conservation Plans* from growers in Monterey County, and summarizes the data. These data provide information about how the agricultural industry in the Salinas Valley incorporates best management practices (BMPs) to conserve water. These practices range from significant capital investments to recurring operational considerations. The implementation of these BMPs represents a significant financial investment by the agricultural community in long-term conservation methods. Investments can include flowmeters, micro-irrigation systems and tailwater return systems. Other practices include fallowing fields, reduced sprinkler spacing and off-wind irrigation. The combined total of the incorporation of best management practices by the agricultural community from 1991 to 1997 is approximately $173,503,074 (Monterey County Water Resources Agency, 1998).

2.g EXISTING MONTEREY BAY DESALINATION PLANTS

2.g.i Marina Coast Water District

Marina Coast Water District (MCWD) owns a small desalination plant located at the end of Reservation Road adjacent to Marina State Beach. The plant is not currently operational however, due to damage to the beach wells caused by coastal erosion. MCWD built the plant in 1996, at a cost of $3 million, in response to increasing saltwater intrusion caused by over drafting of groundwater in the Salinas Valley. The Marina plant uses reverse osmosis (RO) technology, and is capable of producing 0.27 MGD of product water per day, or about 300 AF/year at peak production. It could supply up to 13% of Marina's annual municipal water consumption, at a cost of four to five times more than the cost of pumping groundwater.

The intake system draws seawater in from a well 60-80 feet below Marina State beach. It is then pre-filtered to remove suspended particles, pressurized and forced through a RO membrane, which removes the dissolved solids. The plant's recovery rate is 52%, meaning that the effluent is about twice as salty as the ambient seawater. The brine effluent is pumped into an injection well on the beach, where it is diluted through mixing with natural groundwater, and is mixed in the surf zone. This plant is one of the first to use an injection well for brine disposal. The well, pipelines and pump are all located underground on the beach and are therefore not visible. An ongoing monitoring program conducted for several years after the plant went online concluded that there was not a detectable increase in salinity of the receiving waters due to brine discharge (Kinnetic Laboratories, 1999).

Erosion caused by wind has resulted in exposure of the upper portions of the well housing that sits on top of the beach well, however the well itself is not under threat. MCWD periodically (about once per year) covers the structure with sand. Currently, the plant is not operating, however MCWD has recently entered into an agreement with several Marina Developers to use the plant if necessary, in which case they would be responsible for a necessary retrofit of the facility (Lucca, 2006).

2.g.ii Duke Energy

The Duke power plant in Moss Landing houses a seawater distillation plant that produces 0.48 MGD of fresh water. The product water is not used for consumption; rather it is used in the boiler tubes for power production purposes. The cooling water pipeline is the source for the seawater, and the brine effluent is blended with the cooling water discharge. Since such an enormous volume of water is already being discharged, the saline brine is diluted to the point at which any elevation in salinity in the cooling water would be difficult to detect.

2.g.iii Monterey Bay Aquarium

The Monterey Bay Aquarium operates a small-scale plant producing approximately 0.04 MGD of fresh water**.** The product water is not used for consumption, but is used for maintenance purposes in the Aquarium's Outer Bay Wing, such as flushing the toilets. The feed-water comes from the intake pipelines for the aquarium exhibit water, which bring in up to 2000 gallons per minute, and the brine discharge is blended with the exhibit water outfall. The effluent is effectively diluted due to the large volume of discharge water, which is at ambient salinity, and the effects of the brine effluent are considered to be negligible.

2.h PROPOSED MONTEREY BAY DESALINATION PLANTS

2.h.i City of Santa Cruz

Santa Cruz has certified a program level EIR for their integrated water plan (IWP), which provides a strategy for producing a reliable supply of water that meets long-term needs while reducing near-term drought year shortages. The IWP consists of water conservation programs, customer curtailment of up to 15% during water shortages, and a 2.5 million gallon per day desalination plant (with potential expansion to 4.5 MGD in the future). The facility is being proposed as a result of the serious water shortages that are experienced by Santa Cruz during dry periods such as drought years, and would be operated only during drought conditions (currently estimated at 1 out of every 6 years). When operated at full capacity, the plant would draw in seawater through an abandoned sewage outfall pipeline that would be retrofitted for this project. The concentrate discharge stream would be transported to the wastewater treatment plant and blended with treated sewage effluent.

The plant is expected to be online by 2012. Soquel Creek Water District, a nearby water purveyor, is considering participation in this project as well. Under this cooperative desalination strategy, the desalination plant would be operated during non-drought periods at a lower capacity and the water sold to Soquel Creek Water District as a supplementary supply (EDAW, 2005). The City of Santa Cruz has received a Proposition 50 grant to construct and operate a pilot plant at UC Santa Cruz's Long Marine Lab, for which it is currently pursuing permits.

2.h.ii California American Water Company's Coastal Water Project

In response to a July 6, 1995 ruling by the State Water Resources Control Board, which determined that that the California-American Water Company (Cal-Am) had been illegally diverting 10,730 AF of water annually from the Carmel River, CalAm has proposed a 9 MGD RO plant at Moss Landing as a replacement water supply. The Coastal Water Project also includes an aquifer storage and recovery component, for water from the desalination plant as well as from the Carmel River during high flows (California American Water Company, 2005).

Selection of the Moss Landing site was primarily due to proximity to the Moss Landing Power Plant. The facility would draw in feedwater from the power plant's cooling water discharge, use reverse osmosis technology to desalinate it, then dispose of the brine concentrate by discharging to the power plant's cooling water effluent, eliminating the need to construct a new pipeline structure. The salinity of the desalination effluent would be reduced to ambient levels when combined with the power plants 380 to 1,224 MGD outfall flow, minimizing potential impacts to the marine environment from increased salinity. The product water would be delivered to CalAm's existing distribution system, via a conveyance pipeline approximately 19 miles in length, where it would be distributed to customers in the cities of Seaside, Sand City, Monterey, Del Rey Oaks, Pacific Grove, Carmel-by-the-Sea, and parts of unincorporated Monterey County.

Other alternatives being investigated, as part of this project are horizontal directionally drilled (HDD) intake wells as a source for feedwater supply at Moss Landing and at a north Marina site, and a larger capacity regional plant. This regional scenario would involve a partnership with Monterey County on a significantly larger plant with the potential to provide up to 18 MGD (California American Water Company, 2005).

CalAm submitted environmental documentation as required by the State of California Environmental Quality Act (CEQA) at the beginning of 2006, and it is currently pursuing permits to build and operate a pilot plant. CalAm, has now received the appropriate permits from the County of Monterey, and is currently pursuing the needed permits for the pilot plant with the California Coastal Commission.

2.h.iii Pajaro Sunny Mesa Monterey Bay Regional Desalination Project

Pajaro Sunny Mesa Community Services District (PSMCSD), which supplies water to customers in unincorporated communities of north Monterey County, has proposed a 20 MGD seawater desalination plant to be located at the former National Refractories and Minerals Corporation plant, located adjacent to the power plant in Moss Landing. PSMCSD has entered into an agreement with Poseidon Resources Corporation, who will construct and operate the plant as well as manage the project design and permitting process. In addition to the existing PSMCSD service area, the proposed facility would provide water to the Monterey Peninsula, other unincorporated areas of Monterey County, and parts of the service areas of the Pajaro Valley Water Management Agency. The project is intended to serve as a replacement for existing water supplies in the area, and therefore would not result in growth inducing impacts (Pajaro Sunny Mesa, 2006).

The proposed RO plant would refurbish and use an existing, but unused, 60 MGD intake system from the former National Refractories plant as a primary source for its feedwater. In addition to the primary seawater intake station the plant would also include a new 60 MGD intake structure and pipeline connected to the Moss Landing Power Plant cooling water discharge. This would provide higher-temperature seawater, which requires less energy to desalinate. Since the Moss Landing Power Plant is typically operated only 8 to 12 hours per day, and the desalination plant would operate continuously, this new intake pump station will only operate when the power plant is being used. When the power plant is not operational, the desalination plant would obtain its feedwater from the primary intake structure at the National Refractories site. Concentrate discharge will occur through the existing National Refractories outfall (Pajaro/Sunny Mesa, 2006). The project would also include water conveyance pipelines to deliver water to customers and to an aquifer storage and recovery system operated by the Monterey Peninsula Water Management District (Kennedy/Jenks, 2004). The project's environmental review and permitting process is expected to be complete by 2008, and commercial operation is expected to commence in 2010 (Pajaro/Sunny Mesa, 2006).

Pajaro Sunny Mesa was granted a permit by Monterey County in July of 2006 to construct and operate a test facility, which would draw in 288,000 gallons of seawater per day (about 200 gallons per minute) through an existing unused intake structure. It would pre-treat the intake water, desalinate it using a reverse osmosis membrane, and then after completion of a monitoring and testing process, recombine the brine and the product water before discharging to the harbor through another existing outfall structure. While the discharge would not have elevated salinity levels, it will include traces of cleaning compounds, coagulants, and polymers. Prior to assembly and operation, the test facility will also require a permit from the California Coastal Commission. The pilot plant is expected to operate continuously for up to 3 years (California Coastal Commission, 2006).

2.h.iv Marina Coast Water District

Marina Coast Water District (MCWD), the agency responsible for providing water to the City of Marina and the former Fort Ord, proposes to build and operate a new RO plant as part of its Regional Urban Water Augmentation Project (RUWAP). This project proposes to provide an additional water supply of 2,400 acre-feet per year (AFY) for the re-development of the former Fort Ord military base, as identified in the approved Fort Ord Reuse Plan, and an additional 600 AFY for other MCWD service areas and the Monterey Peninsula (Denise Duffy and Associates, 2004). The RUWAP will consist of a recycled water component and a 1.3 MGD desalination plant component (Lucca, 2006). Options for siting of the desalination facility include the site of the existing MCWD desalination plant or the abandoned Main Garrison waste water treatment plant west of Highway 1, at the 8th Street overpass (Youngblood, 2006).

Preliminary plans for the desalination plant include beach wells for seawater intake and brine disposal. The system would also include a feedwater bypass system, which would involve bypassing approximately 40% of the seawater from the intake, for use in diluting the brine discharge (Denise Duffy and Associates, 2004). An EIR was released for this project in 2004, and the MCWD Board of Directors endorsed the plan in June 2005. Specific plans for the desalination plant are currently being pursued (Pacific Institute, 2006).

2.h.v City of Sand City Water Supply Project

Sand City has proposed a desalination plant to produce 0.45 MGD, to augment their current Cal-Am water supply, and to meet needs for their redevelopment plan. The proposal includes the construction and operation of a reverse osmosis desalination facility to supply approximately 300 AFY of potable water to residential and commercial customers in Sand City, for use in existing and future development in accordance with the planned development in the city's General Plan. The plant will extract brackish water from a shallow aquifer beneath the beach rather than drawing seawater directly from the Monterey Bay, thus eliminating impingement and entrainment impacts. The concentrate stream will be injected into a shallow horizontal well beneath the beach. The properties of the concentrate are expected to be very similar to the ambient seawater in the Monterey Bay, not exceeding a salinity of 35 parts per thousand. This project will provide a new source to replace the current water being supplied to the City by Cal-Am, thus reducing the use of the Carmel River and Seaside Groundwater Basin.

An EIR was released for this project in 2004, and the plant received a Coastal Development Permit by the California Coastal Commission in 2005. Under current agreements, CalAm Water Company will operate the plant. Sand City is currently seeking proposals for the plants design, engineering and construction. Once built, Sand City would initially sell water from the plant to CalAm, which is required to by law to reduce its diversions of the Carmel River. As Sand City's water needs increase over time however, the City would sell less of the desalinated water to CalAm, and use it for its redevelopment needs (Pacific Institute, 2006).

2.h.vi Monterey Peninsula Water Management District's Sand City Desalination Project

Monterey Peninsula Water Management District (MPWMD), the agency responsible for managing the water resources of the Monterey Peninsula, has proposed to build and operate a 7.5 MGD RO plant at one of three Sand City locations. This proposal, called the Sand City Desalination Project (SCDP), would serve the same purpose as CalAm's Coastal Water Project, providing an alternative water supply to the Carmel River and meeting the requirements of the State Water Resources Control Board's Order 95-10. The SCDP would involve construction of new seawater intake and brine discharge structures in Sand City and the former Fort Ord. Beach wells (radial and/or HDD wells) would be used for seawater intake, and discharge would occur either through beach wells in the former Fort Ord, or via the existing Monterey Regional Water Pollution Control Agency's (MRWPCA) treated wastewater effluent outfall (Bookman-Edmonston/GEI, et. al., 2006)

Preliminary geological studies and design work have been completed, and an administrative "Board Review Draft EIR" for the Water Supply Plan was delivered in a December, 2003 meeting. However, an official public draft was never released since the MPWMD Board decided to delay further action until several studies were completed. In

October of 2004, as part of the adoption of the Strategic Plan, the Board decided to put the project on hold as other options are investigated (MPWMD, 2005).

2.h.vii Ocean View Plaza

The Ocean View Plaza (OVP), previously referred to as the Cannery Row Marketplace, is a proposed mixed development on Cannery Row in Monterey, which would consist of retail shops, restaurants, and 30 condominium units. Due to water shortages in Monterey, the developers propose to supply water for the project from a 0.05 MGD onsite desalination facility. The desalination plant would be located entirely onsite and operated independently of the local water supply system and would entail a small RO membrane configuration, a pretreatment system, water storage reservoirs, onshore pumps, and offshore intake and outfall pipelines. The seawater intake for the desalination plant would be located about 700 feet offshore at a depth of 30 feet and would draw in up to 68 gallons per minute at an intake velocity of 0.2 feet per second. The concentrate discharge structure would be located 1,200 feet offshore at a depth of about 50 feet. Both the intake and discharge structures would be located along a 100-foot wide corridor free of major kelp beds and rocky seafloor habitat (City of Monterey, 2001).

The Monterey City Council originally approved a final EIR in October 2002; however a subsequent lawsuit resulted in a September 2003 Superior Court decision concluding that the EIR was incomplete. A supplemental EIR was prepared, and the development was again approved by the City Council in June of 2004. Due to a Monterey County legal requirement that all desalination plants be publicly owned, the developers recently formed a community services district (CSD) so that the facility could be legally operated onsite. According to this agreement, the Monterey City Council would be the official Board of Directors for the CSD. This agreement was consequently challenged by Save Our Waterfront, a local non-profit organization that filed a February 2006 lawsuit against the City of Monterey and Monterey County's Local Agency Formation Commission, on the grounds that the decision was based on an outdated EIR (Pacific Institute, 2006). If approved, this facility would set a precedent, in that the water produced by the desalination plant would be used entirely for a private development.

3 MARINE HABITATS OF MONTEREY BAY

3.a OVERVIEW OF MAJOR HABITATS

***Introduction*:**
Marine habitats in the Monterey Bay area are of such a diverse nature that in 1992 it was designated the Monterey Bay National Marine Sanctuary, a federally protected area. Some of the various habitats in the Monterey Bay area are 1) the submarine canyon, 2) nearshore sublittoral soft and hard bottoms (including the kelp forest), 3) intertidal sandy beach and rocky areas, and 4) estuarine/slough areas.

Upwelling of nutrient rich waters from the Monterey Bay Submarine Canyon enhance primary productivity that supports an extensive diversity of organisms including numerous oceanic species. Nearshore sublittoral habitats consist of sandy/mud soft bottoms that support infaunal and epifaunal benthic organisms and fishes, and rocky hard bottom areas where kelp forests may be found containing a variety of invertebrates and fishes. Intertidal sandy beach organisms consist primarily of invertebrate species that can bury themselves in the sand to escape the pounding and shifting action of the surf. Intertidal rocky areas support organisms with the ability to withstand variations in temperature, wetness, salinity, and wave action. In the rocky intertidal a variety of marine plants are present along with sessile and motile invertebrates, and tidepool fishes. The Elkhorn Slough National Estuarine Research Reserve is the major estuarine/slough habitat in the Monterey Bay area. Elkhorn Slough's soft bottom benthic habitat consists of sand and muddy sand bottoms of the main and harbor channels, and the intertidal mudflats. Invertebrate communities dominate this habitat and are important feeding grounds for birds and fishes. The slough is also used as a spawning or nursery ground for fishes and at times larvae of fishes and invertebrates are an important part of the midwater community.

Source water for desalination projects would likely be from beach wells and infiltration beds beneath the ocean floor in the nearshore sublittoral soft bottom or sandy beaches or from direct intakes in the nearshore sublittoral. Again, as with brine discharge, the underwater canyon and rocky intertidal are unlikely source water sites. Entrainment and impingement impacts are of major concern and would need to be taken into consideration for any direct source water intake including any new intakes in Elkhorn slough. Seawater intakes currently being considered for the various Monterey Bay area desalination proposals include the once-through cooling water discharge at the Moss Landing Power Plant, open ocean intake structures, and a variety of beach well structures. Co-location at the Moss Landing Power Plant currently would not increase entrainment and impingement impacts already occurring, as long as a desalination facility were to operate only when the power plant operates. Proposed desalination plants that are pursuing co-location must consider the likelihood that most, if not all, coastal power plants may switch from once-through cooling systems to alternative systems, and therefore the cooling water will likely not be available in the future. Beach wells and infiltration beds have no entrainment and impingement impacts.

Sandy Seafloor:
Exposed intertidal sand beaches like those found in Monterey Bay are a common feature along the California coast. Environmental factors have created conditions where virtually all of the resident inhabitants of these beaches bury themselves in the sand to escape the pounding and shifting action of the surf. Wave action, and its direct effect on the size of sand grains, is the most important physical factor governing life on sand beaches (Nybakken 1982). Seasonal changes can nearly or completely restructure the physical and biological features of a beach. Coarse beaches with steep profiles generally allow water to drain away quickly because the large interstitial spaces do not allow capillary action to occur as the tide and waves recede. By contrast, those beaches composed of fine-grain sands tend to retain water, because of capillary action, at a level that is above the tide line in the small interstitial spaces. The retention of water governs largely the presence and numbers of organisms that are able to live within the beach sands. Fine sand beaches usually have more species and a greater number of individuals inhabiting them, while coarse sand beaches typically have fewer species and usually fewer individuals. Desiccation, due to exposure, is a major problem for organisms living on beaches with steep profiles and coarse sands.

The biological community in this habitat is composed mainly of resilient primary consumers (filter feeders, detritivores, and scavengers) that depend on a supply of food imported by the tides and surf (Ricketts et al. 1985). While biological diversity is characteristically low, species abundances can be high with crustaceans being the dominant taxa (Oakden and Nybakken 1977). Species dominance is variable and dependent on the season, reproductive cycles of community members, and tidal zone (Nybakken 1982). Biomass is low within the upper tidal zone but can be variable (again, depending on season and reproductive cycles) in the mid and low zones (Foster et al. 1991). Despite the fact that sandy beach communities are intrinsically low in diversity and variable in available biomass, the fauna do provide an important food source for shorebirds and some coastal fishes.

Most of the shallow subtidal benthic habitat from the surf zone out to about 100 feet consists of a gently sloping sandy bottom that changes gradually in character with depth. Ocean currents are moderate and water quality parameters such as temperature and salinity fluctuate little. Wave and swell action maintains a bottom of relatively well-sorted fine sands with low organic carbon content throughout most of this environment (Hodgson and Nybakken 1973, Kinnetic Laboratories Inc. 1997). Diversity within the infaunal benthic community is lowest near shore where wave energy has the most influence on the bottom and sediments are highly mobile (Kinnetic Laboratories Inc. 2005). As the influence of waves on the benthos decreases with increasing depth, the sediments contain more silts, clays, and organic matter, and species diversity increases. In general, a dynamic “crustacean zone” occupies the shallower high energy environment and is gradually replaced by a more stable “polychaete zone” at 20 meters and deeper (Hodgson and Nybakken 1973, Oliver et. al. 1980).

Rocky Subtidal:

Rocky subtidal areas are much less common than soft substrata in the Monterey Bay area. In nearshore waters approximately 30 meters depth or less, hard substrata provide an area for kelp and other algae to attach (MLPA 2005). *Macrocystis pyrifera* (giant kelp) is the most common kelp in Monterey Bay and in sheltered areas of Carmel Bay and south of Point Sur. *Nereocystis luetkeana* (bull kelp) is the major kelp along the open coast to the north and south of the Monterey Bay (McLean 1962). Many sessile (permanently attached) invertebrates such as sponges, hydroids, anemones, cup corals, bryozoans, and tunicates also attach to rocky substrate. These sessile invertebrates are unable to escape any contamination that may occur once they have settled. In addition, many of these sessile invertebrate species are suspension feeders, filtering large quantities of water each day, and so are exposed very directly and continuously to water-borne contaminants. Many of the visibly dominant species in these communities appear to be slow growing and long-lived, so it may take such communities years to recover from disturbance (Kinnetic Laboratories Inc. 1999). The rocky subtidal also provides a habitat for motile invertebrates and fishes, including a variety of nearshore rockfish, abalone, and sea urchins (California Department of Fish and Game 2001).

Ecological assemblages associated with rocky subtidal habitats are also influenced by the type of rock (i.e. sedimentary versus granitic) and size (e.g., cobble, boulders, or reef) (MLPA 2005). In addition, epifaunal assemblages are often positively affected by high current speeds and negatively affected by suspended sediments (Hardin et. al. 1994), where differences in sessile invertebrate assemblages have been attributed to differences in the rates and extent of sedimentation and sand burial (Ostarello 1973, Grigg 1975, and Foster et. al. 1991).

Other Habitats:

Submarine Canyon: The Monterey Bay Submarine Canyon is approximately 470 kilometers long and 12 kilometers wide at its widest point. It is the largest submarine canyon on the west coast of North America. It has a maximum rim to floor relief of 1700 meters (SIMoN 2005). Both the canyon floor and the waters over the canyon provide unique habitat beyond the continental shelf in waters over 200 m deep. The waters of the bay support oceanic species of fishes, birds, and marine mammals. Upwelling in the area supports most of the primary productivity for the entire bay. The canyon edge serves as a feeding area for endangered blue and fin whales, Pacific white-sided dolphins, northern right whale dolphins, Risso's dolphins, Dall's porpoise, and possibly the blue shark. Meso- and bathypelagic fishes include the lanternfish (Myctophidae), sablefish, deepsea sole, and Pacific rattail. Fishes, as well as euphausiid crustaceans (krill) and other organisms, compose a "deep scattering layer" that undergoes vertical migrations to the surface waters (NOAA 1992). The canyon heads that occur in near shore waters are considered important areas of high biodiversity because of the presence of a steep elevation gradient, variation in benthic topography, and other factors that support biological richness (MLPA 2005). Steep and rocky canyon walls provide shelter for many species of benthic fishes, including rockfishes and thornyheads; sedimentary canyon heads provide habitat for species such as flatfishes (Yoklavich et al. 2000; Yoklavich et al. 2002).

Rocky Intertidal: Four zones of organisms associated with different tidal heights have traditionally been distinguished in the rocky intertidal habitat. The splash zone is almost always exposed to air, and has relatively few species. The periwinkle, *Littorina keenae,* is used in some cases as an indicator of this zone, and microscopic algae are common in winter months when large waves produce consistent spray on the upper portions of the rocky shore. The high intertidal zone is exposed to air for long periods twice a day. The barnacle, *Balanus glandula*, and red algae, *Endocladia muricata* and *Mastocarpus papillatus*, are used as indicators of the high intertidal zone, but these species are also found in other areas of the rocky shore. The mid-intertidal zone is exposed to air briefly once or twice a day, and has many common organisms. At wave-exposed sites, the mussel, *Mytilus californianus*, can dominate the available attachment substratum. The low intertidal zone is exposed only during the lowest tides, and the presence of the seagrass, *Phyllospadix*, is a good indicator of the mean lower low water tide level (0.0 m). This zone is also where sponges and tunicates are most common. Zones will form at different distances from the sea when there is no tidal height difference (Marsh and Hodgkin 1962, Lebednik et al. 1971, Kinnetic Laboratories Inc. 1985), zones will form within zones (De Vogelaere 1991), and zones will expand with increasing wave exposure (Ricketts et al. 1985) and, while dramatic and extensively referred to, zonation patterns are highly variable (Foster et al. 1988, Foster 1990) (from De Vogelaere 1996).

Elkhorn Slough: The Elkhorn Slough habitats consist of slough and harbor channels, intertidal mudflats, some hard substrate, and eelgrass beds. Polychaete worms are the dominant invertebrate species in the soft bottom benthic areas. Other common invertebrate species include amphipod, ostracod, cumacean, and decapod crustaceans, and bivalve mollusks (Nybakken, et. al. 1977; Elkhorn Slough Foundation 2002). The intertidal mudflats are important feeding grounds for birds and fishes. Numerous fishes, sharks, and rays feed on a variety of invertebrates dwelling in and on the channel bottoms (Kinnetic Laboratories Inc. 2005). The slough periodically hosts many of the same fish species found in nearshore waters, some of which use the slough as a spawning or nursery ground. The slough is also habitat to a number of partial and full-time resident species. Fish and invertebrate larvae are also an important part of the mid-water community in the slough. The rock jetties that create the permanent mouth to Elkhorn Slough and Moss Landing Harbor as well as bridge pilings provide hard substrate habitat for algae, invertebrates and fishes (PG&E 1973, Elkhorn Slough Foundation 2002, Kinnetic Laboratories Inc. 2005). The federally listed threatened southern sea otter (*Enhydra lutris nereis*) is observed in the Elkhorn Slough/Moss Landing Harbor area often feeding on benthic invertebrates. Harbor seals regularly inhabit Elkhorn Slough taking advantage of protected haul out areas.

3.b CONSIDERATIONS FOR DESALINATION PLANT SITE SELECTION

General Siting Considerations for Desalination Plants:

The process of selecting a site for a desalination plant can be very complex and can present numerous challenges. The importance of this critical step should not be overlooked however, as the site chosen can affect to a great extent several aspects of the design and operation of the plant, its socioeconomic and environmental impacts, the likelihood for the project to be accepted by the public and permitted by regulatory agencies, and the long-term success of the project. Many factors must therefore be taken into consideration when selecting sites for a desalination plant and its associated infrastructure, to ensure optimal economical, operational, and environmental performance.

Generally, there are a few basic prerequisites that must be present in order to build and operate a successful desalination plant: access to a source of feedwater (ideally with low total dissolved solids and a relatively constant salinity); a reliable source of electricity; a method or area available for disposing of the brine or concentrate discharge and; proximity to a water distribution system to deliver the product water to the end user.

An ideal site would be located near the open ocean with minimal organic discharges, low turbidity, reasonably constant salinity and temperature, and strong circulation or surf zone for mixing the brine. Since the ideal site is not always available however, it is often necessary to work within the existing parameters and adapt the plant to the site through engineering. With modern technology, engineers can properly design a desalting plant with appropriate technology, adapting to the local conditions while minimizing environmental impacts. An example of a facility that has been designed to operate in less than ideal conditions is the recently constructed Trinidad plant at Point Lisas, where the intake is in a ships turning basin and sediment is roiled each time a ship turns.

There are many issues and restrictions in California that complicate the site selection process, thus further limiting the options available. Seawater desalination plants are generally more feasible when they are close to the ocean; though one resulting impediment is the high value of coastal real estate, which can, to a large degree, limit the number of sites available for consideration. Additionally, much of the coastal land along the Monterey Bay is protected as state or local parkland; where constructing and operating a large industrial facility may not be appropriate or acceptable by regulatory agencies and the public. In California, there are stringent state, local, and federal restrictions that may further limit the number of sites available for consideration; sites that are available may be located in or near sensitive habitat where regulatory agency approval is not likely.

Environmental impacts vary significantly among projects and can affect both land-based (terrestrial) and aquatic habitats. The location of a desalination plant in part dictates the overall environmental impacts resulting from the construction and operation of the project. Siting a facility to take advantage of optimal natural conditions can minimize negative environmental impacts, while also providing operational and economic benefits ultimately lowering costs and increasing efficiency.

Any new structure built on a previously undeveloped lot will cover up existing habitat making it unusable by a variety of plant and animal species. Thus a new desalination plant and associated infrastructure installed on undeveloped land will inherently cause habitat loss and other placement impacts. In terms of environmental impacts therefore, it is preferable to make use of an existing industrial site rather than developing a pristine area. Co-locating the facility with existing sites and infrastructure can also minimize environmental and socioeconomic impacts and help to lower costs. Co-location should be considered as an option, and is discussed in more detail elsewhere in this report. Although there are several issues involved with each that need to be resolved, power plants and sewage treatment plants are two options for co-locating a desalination plant. Power plants have existing intakes and discharges. Taking water from the cooling loop may allow desalination without additional intake of seawater; however, many power plants operate only part-time, so a desalination facility could result in additional entrainment. Mixing of brine with returning cooling water can mitigate the thermal plume and dilutes the brine before discharge into the ocean; both mitigate environmental effects.

Seawater desalination facilities are dependent on the ocean as a source for the feed-water as well as for receiving the brine concentrate. This means that seawater desalination plants involve a consumptive use of a public resource subject to the Public Trust Doctrine—the ocean. This same resource that the desalination plant depends on, also is relied upon by a large number of people for a diversity of uses, both commercial and recreational. When selecting a site for a desalination plant, these other uses must be taken into consideration. A desalination facility should avoid being sited in an area where it can interfere with commercial or recreational fishing, boating and navigation, aquaculture, beach or ocean based recreational activities, or any other recreational or commercial activity. During the site selection process, it is necessary to conduct a comprehensive analysis of all activities in the vicinity of each alternative site (accounting for seasonal variability), and how the construction and operation of the plant could potentially impact these activities.

Desalination plants, like any coastal development, have the potential to affect the ability of the public to access the beach. The facility's effect on public access is something that needs to be evaluated for each site being considered. The California Coastal Act has strict safeguards that must be followed to ensure that the public has adequate access to (vertical access) and along (lateral access) the shoreline.

Socioeconomic issues must also be taken into account when considering sites for a desalination plant; one of these issues is Environmental Justice (EJ). EJ is defined by the State of California as means "the fair treatment of people of all races, cultures and income with respect to development, adoption and implementation of environmental laws, regulations and policies" (State of California, 2003). All alternative sites being considered should be analyzed for the potential of the plant to cause certain individuals or groups of people to bear a disproportionate share of the negative impacts of a project.

The actual site selected for a desalination plant proposal can influence the ease or difficulty with which the project will obtain the required permits, and it can reduce the amount of information required of the proponent for review purposes. For example the California Coastal Commission (CCC) review of a Coastal Development Permit application will likely involve fewer issues for proposals that are located away from the shoreline or use a sub-surface intake, and more difficult for projects that are on or next to the shoreline, or use an open water intake. Also the Monterey Bay National Marine Sanctuary, CCC, and other regulatory agencies may require desalination plant proponents to produce more extensive information and studies for facilities that are proposed to be located in or near sensitive areas.

A real-life example of the effect that site selection can have on the permitting process can be seen in the recently approved Sand City desalination plant. This plant was approved relatively quickly (less than ninety days) by the Coastal Commission and did not require a permit from the Monterey Bay National Marine Sanctuary since it used beach wells located far up on the shoreline and beyond the boundaries of the sanctuary. This desalination plant is an example of a small facility designed to operate with minimal environmental impacts. The plant desalinates brackish water from aquifers beneath the beach rather than drawing seawater directly from the Monterey Bay, thus eliminating impingement and entrainment impacts. Since the feedwater is brackish, it is also more economical to desalt than seawater, due to its lower salinity. The plant's discharge will be injected into a beach well and since the plant uses brackish water the salinity of the effluent is expected to be similar to that of the ambient seawater. Another important environmental aspect of this plant is that, at least in the first few years of operation, this project will provide a new source to replace the current water being supplied to the City by Cal-Am, thus reducing the use of the Carmel River and Seaside Groundwater Basin.

Another unique issue resulting from a seawater desalination plant's tendency to be located near the ocean is the potential threat of coastal erosion damaging the plant and its infrastructure. This is particularly relevant in the Monterey Bay, which experiences some extremely high erosion rates along certain sections of shoreline, especially during times when heavy storm episodes and high tides coincide. Average erosion rates are as high as 143 cm/year (4.7 feet/year) along the coast at the former Fort Ord (Thornton, 2006). If not properly sited, this coastal erosion can threaten coastal infrastructure and the continued operation of the facility and cause negative impacts to the environment and public safety. When selecting a site for a coastal seawater desalination plant, it is therefore crucial to ensure that the facility and all of its components are set back enough from the shoreline so as to not be threatened by coastal erosion throughout the expected life of a structure, as it is highly unlikely that coastal armoring structures will be approved if the plant or its infrastructure become threatened in the future. An example of how a proposed desalination plant addresses the imminent issue of coastal retreat can be illustrated in the case of Sand City's Water Supply Project desalination plant, which includes an "Adaptive Water Supply Management Program", consisting of ongoing monitoring and if necessary relocation of infrastructure.

Site Selection Considerations for Seawater Intake Systems:
Economic, operational, environmental, and public health considerations all need to be taken into account when selecting a site for the desalination plant seawater intake. The quality of the source water is one essential factor in determining the best location for a desalination plant. Ideally, a site for a reverse osmosis (RO) seawater desalination intake will have access to clear water (low turbidity) with low organic content. In many cases, this may be available from a subsurface intake. The intake must also be located to avoid a variety of potential water quality issues. This means a location separated a sufficient distance from areas affected by brine discharge at the plant's outfall and not in the proximity of sewage and other industrial discharges.

One very important water quality parameter that must be taken into account is total dissolved solids (TDS) levels. Sites with low TDS are preferred since the higher the TDS of the feedwater, the higher the energy requirement for desalting the water, and thus the higher the end cost (BCDC, 2004). Variability in salinity must also be taken into account; ideally the feedwater should experience minimal changes in salinity over time, as it is more difficult to treat water that has variable salinity levels. While lower salinity feedwater is preferable for RO plants, this is not the case with thermal plants, which are not affected by salinity changes and require the same amount of energy to desalt an equal volume of water regardless of salinity. Salinity rates in the bay average 33.4 parts per thousand (ppt) (MBARI, 2006).

The most environmentally acceptable method for intake appears to be subfloor ocean intakes, however this requires specific geological conditions not present at all sites. Beach wells also offer many benefits, and should be investigated as part of the site selection process. However, they also require specific conditions including porous, high permissivity sediments, and are often limited in capacity. Some other options are Ranney wells which have "fingers" that radiate from a central column to maximize water intake, slant drilling (under investigation at Dana Point, CA[1]), and sub floor collection laterals radiating from beach wells similar to Ranney wells (under investigation at Long Beach, CA[2]). Beach wells and other sub-surface seawater intake structures are discussed in *Section 5.d* of this report. Beach wells are being considered at proposed plants for the Marina Coast Water District, the Monterey Peninsula Water Management District, and the City of Sand City. For permit review, most proposed projects should expect to include an evaluation of whether some form of subsurface intake would be feasible (Luster, 2006).

The first choice for minimizing entrainment and impingement impacts is to use a subsurface intake, where feasible. For open-water intakes, areas of high biological productivity should be avoided. A number of measures can be taken to minimize

[1] 2005 Proposition 50 funds.
[2] Ibid.

entrainment and impingement; these are discussed in detail in *Section 5.d* of this report. It is necessary to conduct a variety of studies to aid the selection of a site, which reduces entrainment and impingement. An entrainment study and current, wave, and monitoring, and how they will interact with nearby biological communities. The entrainment and impingement impacts of a desalination plant are largely dictated by the biological productivity in the vicinity of that intake (California Coastal Commission, 2003).

One option is to use an intake that already exists (i.e. power plants). While these intakes are already permitted, their use will require additional studies to address entrainment/impingement concerns, and they will necessitate a new permit or an amendment to the existing permit. Using an existing cooling water system from a power plant may offer several advantages. Economically, using an existing intake structure means that it is not necessary to construct a new intake, which can be a significant portion of the overall cost of a plant; however, many power plant intakes were sited decades ago before their impacts were understood. Many are located in areas of high biological productivity, and many bring in water that will require extensive pre-treatment before it goes through the RO membranes. One other benefit that may be available is that by taking water as it leaves the power plant, the warmer temperature of the feedwater translates to less energy being required for the RO process, and thus a lower cost. Again, though, the cost savings may be offset by the increased pre-treatment requirements noted above (Luster, 2006). Environmentally, it may make sense to tap into the cooling water system from a power plant, if it will not cause any additional entrainment and impingement impacts other than those already being caused by the power plant. Many power plants, however, operate only part-time and so a desalination facility at those plants would cause entrainment on its own. Another major issue involving co-location with a power plant however, that is becoming a growing concern in California, is the potential for this situation to perpetuate the use of once through cooling systems which cause significant impacts already. This is covered in detail in another *Chapter 6* of this report.

If an existing intake is not available, use of existing infrastructure should always be considered; this can include existing but unused pipelines previously used for sewage discharge or intake for an industrial facility. The key advantage to utilizing an existing structure is that it obviates the need to construct a new structure, which can cause alteration of the seafloor and other environmental impacts, and can be expensive and technically challenging to construct. Again, though, this benefit may be outweighed in some cases by the environmental impacts that would result from use of an outfall that was sited before its effects on marine biology were understood. Use of existing but unused pipelines will likely require retrofit prior to use. It is crucial to ensure the structural integrity of the pipeline being considered. An example of this scenario would be the proposed City of Santa Cruz desalination plant, which would retrofit the City's former sewage outfall pipeline. The Moss Landing desalination plant being proposed by Pajaro Sunny Mesa will also use an existing unused intake structure from the former National Refractories plant.

Open intakes are another option however, due to the potential for entrainment and impingement impacts it is necessary to ensure that appropriate mitigation measures are taken. When using open intakes areas with high biological productivity should be avoided. There are a number of methods for minimizing the effects of entrainment and impingement impacts, by reducing the intake velocity or using a variety of different technologies. These are discussed in detail in *Section 5.d* of this report. Open intakes are being pursued in the Monterey Bay region at the proposed Santa Cruz and Ocean View Plaza desalination plants.

Site Selection Considerations for Concentrate Discharge Systems:
Disposal of the brine is one of the foremost issues that must be addressed when choosing a site for a seawater desalination plant, as the operation of any desalination facility is contingent upon there being an area to safely dispose of the brine.

The actual mixing and dispersion of the brine plume is dictated by the technique being used for discharge, the oceanographic conditions that exist in the vicinity of the discharge, and the properties of the discharge itself. As a general rule, the stronger the hydrodynamic force, the better dilution is achieved due to faster dispersal from the natural mixing action of the ocean. Oceanographic variables affecting the mixing of the brine include tides, currents, and bathymetry (the topography of the seafloor). Operational factors include outfall design and the velocity and volume of the discharge stream. Differences in density, due to salinity and temperature, between the brine and the ambient seawater also influence mixing rates. The brine from an RO plant is negatively buoyant, due to its high salinity, and thus sinks to the seafloor. Without mixing the brine effluent can accumulate, forming a mass of water with elevated salinity. Areas with limited water circulation such as enclosed bays or estuaries, which can “trap” the brine discharge, should be avoided (UNEP, without date). Areas of high biological productivity should be avoided as well, if there is the potential for the plant’s discharge to impact these areas. Depth also should be taken into account. To encourage mixing, Mauguin and Corsin (2005) recommend locating the outfall in a depth of at least 8-10 meters underwater during low tide.

Hopner and Windelberg (1996) identified 15 “sub-ecosystems” in the Arabian Gulf and ranked them according to their sensitivity to the impacts of desalination plant discharges. While conditions in the Gulf differ vastly from those in the Monterey Bay, certain elements of this analysis can still be applied locally. For example, high-energy oceanic coast, rocky or sandy with coast-parallel currents, and exposed rocky coasts, all of which are abundant within the Monterey Bay area were included as the most resilient of the “sub-ecosystems”. Other areas that were deemed as more sensitive, such as shallow low-energy bays and semi-enclosed lagoons, coral reefs, salt marsh, and mangroves, are non-existent or would not likely be considered for siting of a desalination plant in the Monterey Bay.

Mixing of brine effluent with existing discharges should always be considered. This can be an effective way to minimize or eliminate the impacts from the discharge through dilution, and use of an existing discharge structure has the economic advantage of not requiring the construction of a new structure. Power plant cooling water or sewage treatment plant discharges are two types of existing discharges that can be used. When combining brine with another existing outfall, it is important to address temporal variations in operation and maintenance of facilities are addressed in order to ensure sufficient dilution of brine effluent. The effects of the interactions between the brine and the constituents of the other discharge must also be investigated. This is covered in more detail in *Section 5.e.* of this report.

4 OVERVIEW OF DESALINATION TECHNOLOGY

4.a INTRODUCTION

A large percentage of the global population perceives desalination to be a process for removing salt from seawater. Although this is one of the purposes, desalination can be used for a number of applications, embracing much more than seawater. Brackish water, groundwater, impaired water, domestic wastewater, industrial process and wastewater, and food and beverage processing are some of the other applications for desalination equipment.

There are several desalination technologies employed today, including thermal evaporation, membrane separation, electrodialysis and ion exchange. Many new processes are currently under development. This section of the report will provide an overview of desalination technology today including: the different applications for which desalination is used; trends in its use worldwide and in California; the current state of the art; the available seawater reverse osmosis process engineering and equipment options as well as a description of the various stages in the process; emerging processes and new technology under development; the potential for the use of alternative energy sources; and current issues to be addressed. It will touch upon brackish water desalting and water recycling, as well as various technologies available for seawater desalination; however the main emphasis will be on seawater reverse osmosis processes, since this is the technology primarily being pursued in the Monterey Bay Region.

4.b OVERVIEW OF CURRENT USE OF DESALINATION WORLDWIDE

The ten countries with the largest desalination capacity constitute more than 70% of the global capacity.

Table 4.1[3]: Countries with Largest Desalination Capacity 2005

	m^3/d	MGD
1. Saudi Arabia	8.18	2159
2. USA	6.85	1808
3. UAE	6.66	1759
4. Spain	3.00	792
5. Kuwait	2.55	672
6. Japan	1.39	367
7. Algeria	1.04	275
8. Qatar	0.92	244
9. Libya	0.92	242
10. Korea	0.88	232
Totals	32.39	8,550

[3] 2006 IDA Worldwide Desalting Plants Inventory, Report No. 18, June 2006, Global Water Intelligence.

Saudi Arabia is the top producer of desalinated water, with most of their production coming from desalting seawater. The United States ranks second, but nearly all of this capacity is comprised of brackish groundwater and surface water, wastewater, industrial, and food and beverage applications. The only large seawater desalination plant of note in the U.S. is in Tampa Bay, Florida, designed to produce 25 MGD (95,000 m^3/d); however, there are currently several proposals to build large plants in California with single unit capacity of up to 50 MGD.

Seawater desalination has been widely utilized for water supply throughout the world for more than 40 years. The most active region in this regard is the Middle East, where revenues from petroleum sales in the 1960s were put to work in building seawater desalters of large size. In this region, the process of choice was Multi-Stage Flash evaporation (MSF), an efficient thermal process, which utilizes oil for its fuel. The largest MSF plant in Al Jubail has been expanded several times and now produces nearly ½ billion gallons per day (1.9 Mm^3/d). In oil rich kingdoms, energy intensive thermal processes were a logical choice. In other parts of the world, where oil must be purchased at market prices, the process is expensive; therefore, membrane processes have emerged as the primary technologies being implemented. For many years, thermal processes were most widely used, principally due to the large growth of thermal desalination in the Middle East starting in the early 1960's. Today, membrane processes surpass the installed capacity for thermal processes globally, and they appear to be growing yearly at a faster rate (*Figure 4.1*). Even the oil rich middle eastern countries have recognized the inherent efficiencies with reverse osmosis and recent plants have utilized this technology; sometimes in combination with thermal processes.

Global desalination capacity: At the end of the 2005 contract year, there was a global installed capacity of more than 12 billion gallons per day (45 Mm^3/d) contracted[4]. The operating capacity is slightly less than this figure since some of the early plants have been retired.[5] Identified by process:

Process	Installed Capacity (billion gal/day)	Installed Capacity (million m^3/day)
RO (Reverse osmosis)	6.1	23.8
MSF (Multi Stage Flash)	4.3	17.9
ED (Electrodialysis)	1.7	1.7
NF (Nanofiltration)	0.4	1.5
ME (Multi Effect Distillation)	0.8	4.5

These capacities are for all types of desalination and sources.

[4] Does not include blended total output.
[5] Ibid.

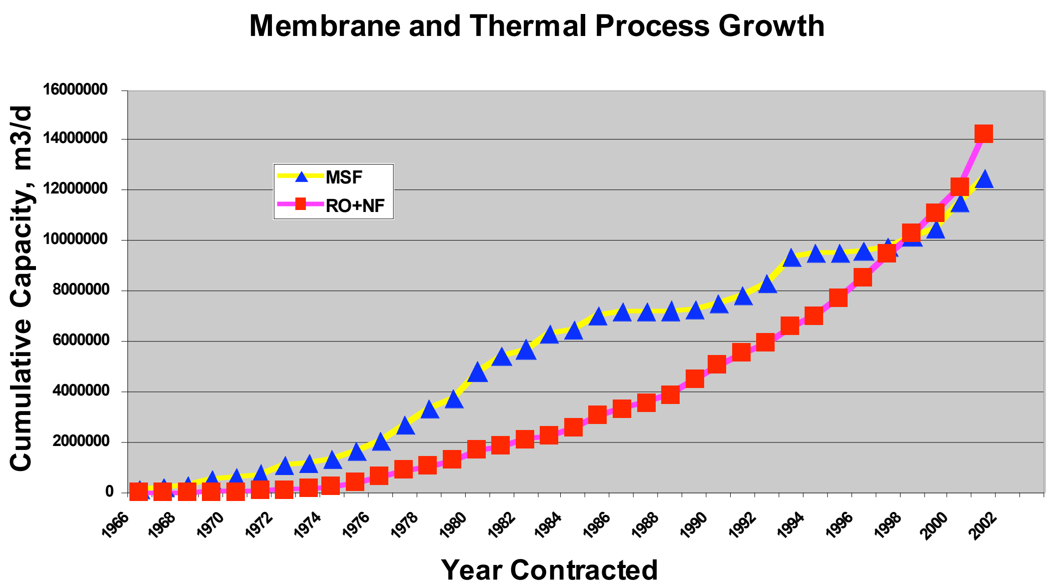


Figure 4.1 Membrane and Thermal Process Growth

4.c OVERVIEW OF THE MAJOR DESALINATION PROCESSES

Thermal processes:

The oldest desalination process is distillation, which has been used for over 2000 years. The basic concept behind distillation is that by heating an aqueous solution one can generate water vapor. The water vapor contains almost none of the salts or other materials and contaminants originally in the source water. If this vapor is directed toward a cool surface, it can be condensed to liquid water containing very little foreign material. The vaporizing and condensing temperatures and the operating pressure are process variables. The only requirement is that, at constant pressure, the heated mass must be hotter than the condensing surface.

The amount of energy required to evaporate water is very high, about 1000 BTUs per pound of water. It takes 1 BTU to raise the temperature of a pound of water one degree Fahrenheit. This energy is recovered when we condense the water, but it is at a lower temperature.

The most widely used distillation process is ***Multi-Stage Flash evaporation (MSF)***. A diagram of a single stage is shown in *Figure 4.2*. Water enters at a temperature that is above the equilibrium temperature for the stage pressure. A fraction of the water, sufficient to bring the temperature to the boiling point, flashes (vaporizes rapidly) to steam, or vapor. Vapor is condensed on tubes running through the flash chamber, heating the water inside the tubes. The brine then passes to subsequent stages, where the process is repeated. These plants are characteristically built along with power plants and use the low temperature steam from the power plants.

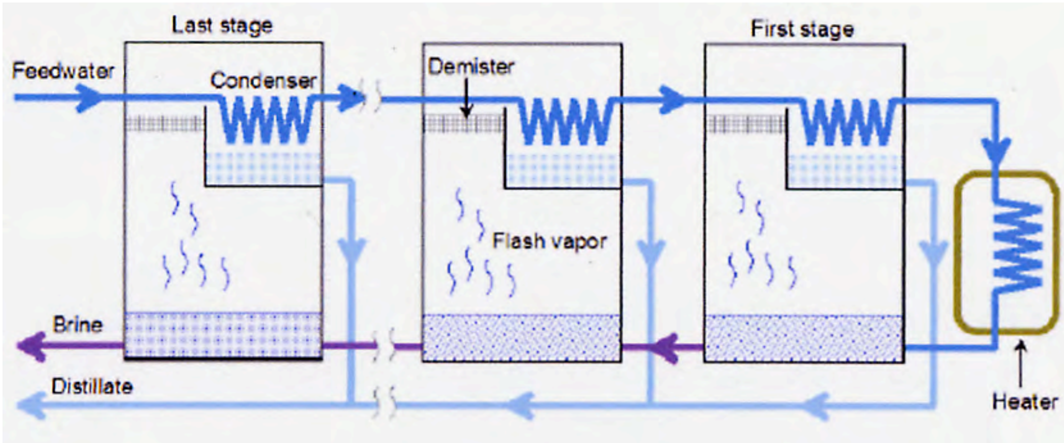


Figure 4.2: Multi Stage Flash Evaporation

Among the advantages of MSF and other distillation processes is that the composition of feedwater has an almost negligible affect on the energy required to produce a given volume of product water. The processes deliver exceptionally high purity water (less than 25 mg/l TDS) and have been successfully operated in very large sizes. Among the disadvantages are high capital cost ($4-12 per gallon day [$1.1- 3.2 per m^3day]) of installed capacity) and the requirement for large inputs of heat energy. The electrical energy requirement for recirculation pumps alone exceeds the process energy cost for seawater reverse osmosis.

Older than MSF, but currently not as widely used is ***Multiple-Effect Distillation (MED)***. This is similar to MSF except that the water evaporates from the outside of the tubes and condenses on the inside. Over the years, a great deal of effort has gone into improving the efficiency and economics of distillation. Much of this has centered on the tubes, which are the critical part of the process. Tubes have been oriented both horizontally and vertically, various metals (copper, nickel, aluminum, steel and titanium) have been tried and a wide variety of extended surface tubes have been tested. The operating temperature may be as low as 160˚F (71°C) (*Figure 4.3*).

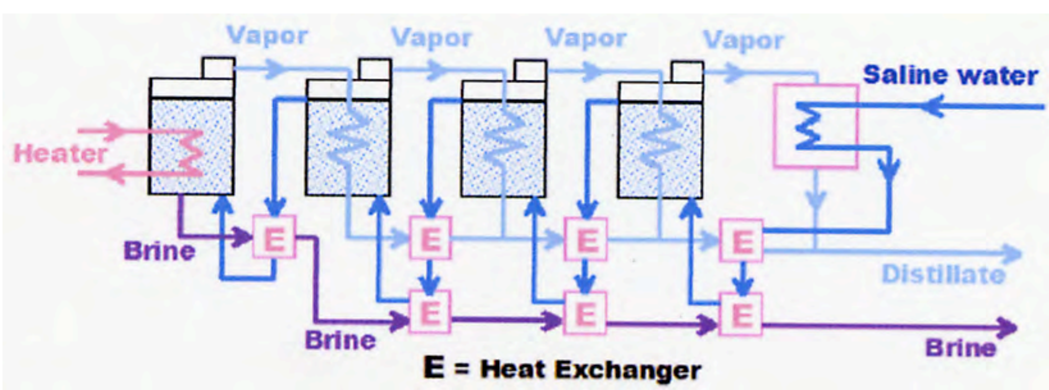


Figure 4.3. Multiple Effect Distillation

The water vapor generated by brine evaporation in each effect of the horizontal tube evaporator flows to the next effect, where it supplies heat for additional evaporation at lower temperature. Each effect serves as a condenser for the vapor from the preceding effect. The vapor generated in the last effect is condensed in a final condenser and heat is rejected to a stream of cooling water.

The major advantage of MED is the ability to operate at significantly higher performance ratio (PR); in excess of 15 pounds of product per pound of steam, where MSF has a practical PR limit of 10. MED was generally limited in size to about 10 MGD (38,000 m^3/d), but Taweelah A-1 was a breakthrough plant, with 66 MGD capacity, comprised of 14 x 4.7 MGD units (14x17,800=249,000 m^3/d). Generally, MED capital cost varies from about $3.50 - $8.00 per GPD ($0.9- 2.12 per m^3/d) installed capacity.

A somewhat different approach is taken in ***Vapor Compression (VC)*** distillation. In this process water is evaporated by flowing it over tubes in a distillation chamber. Vapor from the distillation chamber is compressed, which increases both its temperature and pressure, and returned to the inside of the tubes where it condenses. There are two general vapor compression processes, thermal (TVC) and mechanical (MVC), which differ in the manner in which the vapor is compressed. A diagram of this process is shown in *Figure 4.4*. Vapor compression makes a product of similar quality to the other distillation processes. Its source of driving force is rotating mechanical energy generally from a motor. VC units tend to be small plants in isolated locations. For some time this was the process of choice for water plants aboard ships of various types.

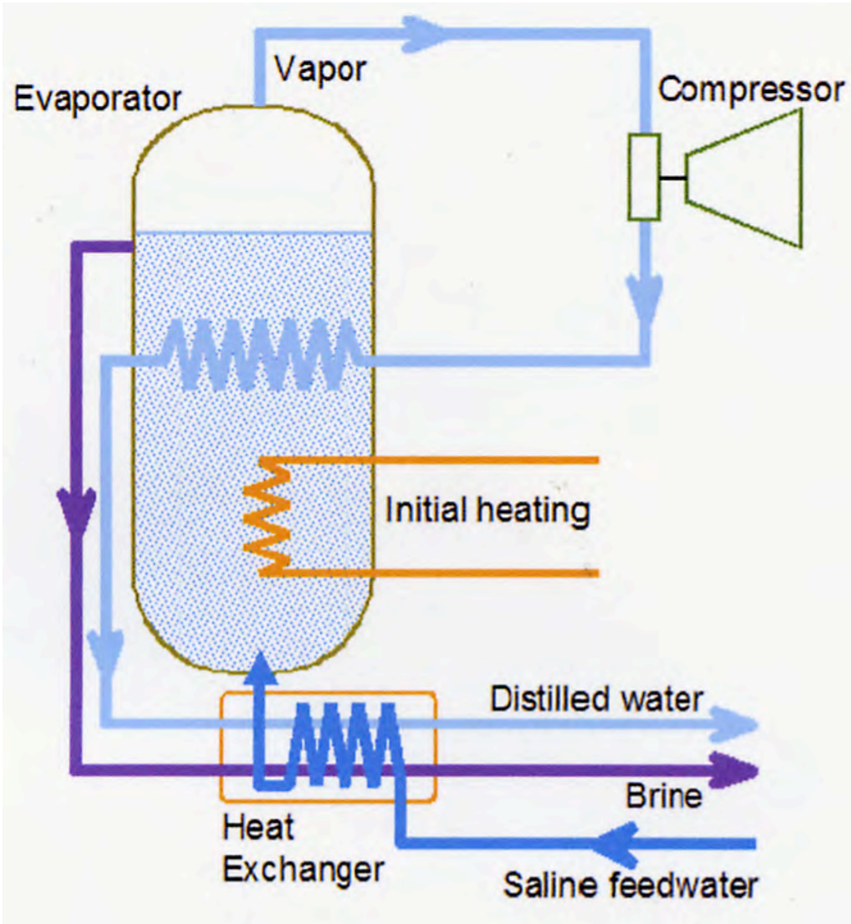


Figure 4.4: Vapor Compression Distiller

Original MVC units were of single effect design; today three effect units are built of slightly less than 1 MGD capacity. The multiple effect units require about 28 kWh/1000 gallons (7.4 kWh/m^3) of specific electrical energy. The capital cost varies from \$6.00 - \$12.00 per GPD (\$1.60-3.17 per m^3/d) installed capacity.

Generally one attempts to avoid formation of solid salts in distillation equipment. However, in the RCC[6] process, salt crystals are deliberately added to provide a basis for additional crystallization to occur. The distillation process is MVC. Since evaporation occurs at the interface between air and water, scale formation on the tubes is minimal. While this process does produce product water, its principal objective is to reduce a disposal stream to high solids sludge.

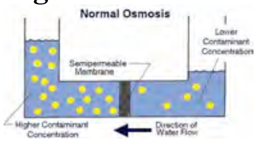
4.d MEMBRANE PROCESSES

Introduction to Reverse Osmosis:
The ***reverse osmosis (RO)*** process is based upon the use of semi-permeable membranes, which allow water molecules to pass through them, but block other, larger molecules

[6] Ionics, Inc., Watertown, MA.

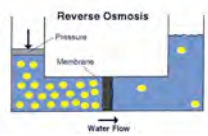
from passing through under pressurization. Membranes in our human bodies allow fluids to pass from areas of low concentration of solutes to areas of high concentration. This process, called *osmotic flow*, is nature's way of balancing concentrations (*Figure 4.5a*).

Figure 4.5a



If pressure is applied to the higher concentration liquid in excess of normal osmotic pressure, the flow of water molecules can be reversed, hence the term "reverse osmosis" (*Figure 4.5b*).

Figure 4.5b



Over the past 20 years, RO has matured rapidly and has become the process of choice where energy economics are most important. In the U.S., it has become the most economic process and is now widely utilized in the Southeast, Southwest, and West to provide an alternative source of water supply derived from surface water, groundwater, and seawater. All of the more than 20 seawater desalination plants currently proposed in California would use RO technology.

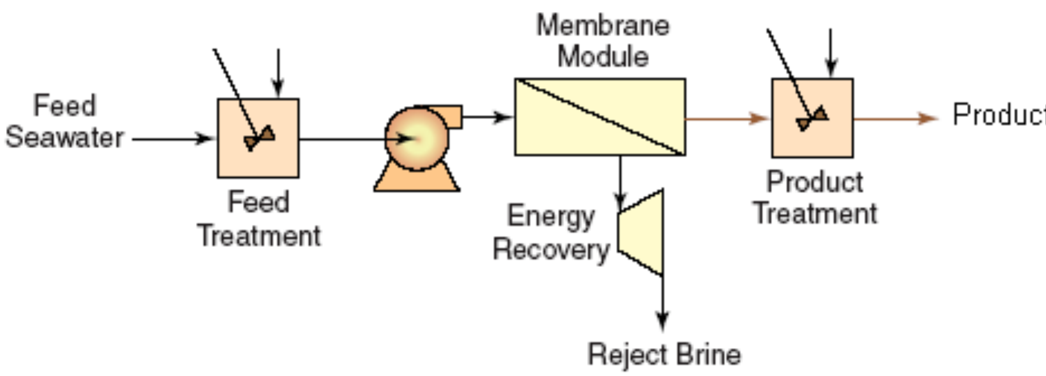


Figure 4.6 Reverse Osmosis Process

Brackish water Desalination:

Brackish water desalination is an important facet of total water resources management. The installed capacity of reverse osmosis and ***nanofiltration*** (NF, a form of reverse osmosis) in the U.S. exceeds 4 million m^3/d (>1.1 billion gallons per day). Of this total the predominant use is for brackish water desalination.

More recently, membranes have improved significantly and low-pressure reverse osmosis membranes are capable of operating at much lower pressure (e.g. 100 psi) while removing monovalent ions more completely. RO or NF plants are now utilized in more than 42 states in the USA.

Where brackish water is available, membrane processes provide an economic alternative to conventional surface supplies. Since the energy required for RO is proportional to the feedwater salinity, brackish water desalination is less costly than seawater desalination.

Recent capital cost for brackish water RO plants are $0.50 - $2.00 per GPD ($0.14-0.53 per m^3/d) installed capacity. The large cost range encompasses differences in plant size, pretreatment, feedwater salinity and specific site conditions.

The existing Marina Coast desalination plant, and the proposed City of Sand City desalination plant both use brackish water obtained from beach wells as the feedwater source. In the case of Sand City, the salinity of the feedwater is expected to range between 15.5 and 24 parts per thousand. This is expected to result in a reject stream that is very similar to that of the ambient seawater in Monterey Bay (City of Sand City, 2004).

Wastewater Recycling:
Membrane processes have advanced quickly for water reclamation facilities in the past 10 years. At the end of 2001, there were more than 20 membrane-based water reclamation facilities in the United States,[7] with many more in the planning or contracted stages. The largest project to date is the Water Factory 21 Ground Water Replenishment System of 86 MGD (326,000 m^3/d), which should be at full production in 2006. It combines microfiltration and RO technologies to produce high-quality water to be injected in barrier wells to prevent seawater intrusion and pumped to the Santa Ana River spreading basins to recharge the aquifer. Of 26 facilities reviewed, 15 were found to utilize both MF and RO, 1 used only RO, 6 used only MF and 4 utilized MF membranes as membrane bioreactors. The choice of processes is dependent on the quality of water to be achieved and its end use. Information on existing and proposed water recycling projects in the Monterey Bay area was discussed in *Section 2.c.*

One of the reasons for the surge in membrane systems is the low cost of operation. Recent results (not including capital recovery) indicate that MF can treat wastewater for about $0.25/1000 gallons ($0.07per m^3) and RO about $0.48/1000 gallons ($0.13 per m^3). Capital costs for MF plus RO have ranged from $1.65 to $3.74 per GPD ($0.44-$1.00 per m^3) installed capacity. The energy cost in these figures are based on the local cost. For California locations, an average or predicted energy cost of $0.12/kwh should be used in calculating energy cost.

Ion Exchange:
Certain natural materials called "zeolites" have fixed charges in their molecular structure. These are neutralized by closely bound, but mobile, ions in the solution surrounding the materials. In ion-exchange terminology, a cation exchanger in which the closely bound

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[7] Freeman, S., G.F. Leitner, J. Crook and W. Vernon, "A Clear Advantage," WE&T, January 2002.

ions are sodium ions, is said to be "in the sodium form." Since the mobile ions can be exchanged for other ions in a solution by equilibrating the ion-exchanger with the solution, these materials have been used for many years for water treatment. Synthetic polymeric ion exchangers were developed in the early 1950s. These have the appearance of small amber to brown colored beads.

A solution of saltwater is made up of positively and negatively charged ions called cations and anions. Water can be desalted by first passing it through a column of cation exchanger beads in the hydrogen (H+) form. Hydrogen ions replace the cations in the solution, which become bound to the exchanger. The water is then passed through a column of anion exchange beads in the hydroxyl (OH-) form where the anions in solution are replaced by the hydroxyl ions, which in turn react with the hydrogen cations in the water. This process can produce almost completely deionized water. When exhausted, the exchangers can be regenerated, the cation exchanger with acid and the anion exchanger with base. The problem is that removal of 1 pound of salt takes about 1.5 pounds of acid and 1.5 pounds of base to regenerate the exchangers.

This process makes economic sense compared to other processes only where there is just a small amount of salt to be removed from the water. Because of this, the major application of ion exchange has been in the field of production of ultrapure water. Ion exchange is often used as a "polishing" step following another desalting process.

One common use of ion exchange that has wide application is in home water softeners. These consist of a tank (or bed) of cation exchanger in the sodium form. The bed removes calcium and magnesium ions, which constitute hardness. It is periodically regenerated with sodium chloride. Thus the softener replaces the calcium in the water with sodium. Regeneration occurs either on a time cycle or on demand.

Electrodialysis:

Membranes for electrodialysis have been called ion exchange resin in sheet form. In one recipe, a mixture of a polymer, a cross-linking agent and a monomer is polymerized onto a fabric backing. The resulting sheet, treated with strong sulfuric acid, becomes a membrane with a high conductivity of positively charged ions and negligible conductivity of negatively charged ions, called a cation-transfer membrane. A similar sheet treated with different reagents produces an anion-transfer membrane. Another widely used method of making ion-exchange membranes is to grind up ion exchange beads, add a binder and roll the resultant mixture out into a sheet.

Both ion exchange membranes and saline solutions are good ionic conductors. That is, electric current is carried by motion of ions rather than by motion of electrons. If a stack of ion exchange membranes of alternating types is placed into a tank of salty water and a direct current is placed across the stack, the volume of water in the cation membrane near the cathode becomes rich in salt while the volume of water in the adjacent compartments becomes desalted.

A conceptual advantage of electrodialysis (ED) is that it removes the minor component, the salt, from salty water. It also only removes ionically charged material. Since its energy consumption is directly related to the quantity of salt removed, its primary utility is for brackish water desalination.

4.e. SEAWATER DESALINATION WITH REVERSE OSMOSIS

Introduction:
While reverse osmosis seawater desalination is a type of membrane process, it is being addressed separately in the ensuing section of the report, since RO is the main focus of this feasibility study and report due to it being a major focus of the most recent discussions of new water supply options along California's coastline.

Table 4.1 presents a list of the largest RO seawater desalination plants constructed in the last 10 years. *Sections 2.e and 2.f* of this document contain descriptions of each of the existing and proposed facilities in the Monterey Bay Area.

Proper pre-treatment of feedwater, both seawater and brackish water, is the most important factor in the successful operation of a reverse osmosis plant. For seawater, marine organisms must be safely removed to prevent membrane fouling. Additional treatment is necessary for areas where high ship traffic is present. For brackish surface water, suspended solids must be removed. Subsurface intakes may reduce treatment requirements (and costs) due to natural filtration provided by overlying sand layers.

The critical element of the system, the membrane section, has reached a mature design level and excellent performance can be expected with good pretreatment. Several membrane suppliers provide state-of-the-art membranes of nearly equal quality, providing the user with a competitive atmosphere, which results in low membrane prices and good membrane selection. Manufacturers continue to improve their products to stay competitive with features such as improved salt removal, fouling resistance, better hydraulic conditions achieved through new concentrate-side spacers, mechanical improvements, and greater active surface area.

Most recently, the major membrane manufacturers have developed membranes with greater boron rejection. This improvement was sparked by requirements in the Middle East for lower boron levels in the product water.

TABLE 4.1: LARGE RO SEAWATER DESALINATION PLANTS CONSTRUCTED IN THE LAST 10 YEARS[8]

Plant Name/Location	Capacity (MGD)	In Operation Since	Project Delivery Method	*Notes*
Tampa Bay Desalination Plant, USA[9]	25	2003	BOOT/DBO	Salinity – 26 ppt Cost of Water = $690/AF[10]
Point Lisas, Trinidad	28.8	2002	BOOT 30-yr term	Salinity – 34 ppt Cost of Water = $900/AF
Almeria, Spain	13.2	2002	Design-Bid-Build Private O&M Contractor	Salinity = 38 ppt
Las Palmas - Telde	9.2	2002	Design-Bid-Build Private O&M Contractor	Salinity = 38 ppt
Larnaca, Cyprus	14.2	2001	BOOT 10-yr term	Salinity = 40.5 ppt Cost of Water = $987/AF
Murcia, Spain Design-Bid-Build	17.2	1999	Design-Bid-Build Private O&M Contractor	Salinity = 38 ppt .
The Bay of Palma Palma de Mallorca	16.6	1999	Design-Bid-Build Private O&M Contractor	Salinity = 34 ppt
Dhekelia, Cyprus	10.6	1997	BOOT 10-yr term	Salinity-40.5 ppt Cost of Water = $1,506/AF
Marbella - Malaga, Spain	14.5	1997	BOOT 25-yr term	Salinity = 38 ppt

[8] Data provided by Poseidon Resources Corporation, San Diego, CA.
[9] As of August, 2006, the Tampa Bay Water plant had not operated at full capacity, so actual cost of water is not verified. Difficulties with the pretreatment system and the influx of green mussel larvae caused membrane fouling. Remediation steps are underway and startup is anticipated by the end of the year.
[10] First year cost. 30 year average cost including escalation, interest rate, etc., is estimated to be $811/AF.

Plant Name/Location	**Capacity Installed/Avg. (m^3/d)**	**In Operation Since**	**Project Delivery Method**	*Notes*
Fujairah, UAE	44.9	2004	BOOT 25-yr term	Salinity = 40 ppt. Cost of Water = $1,300/AF
Carboneras - Almeria, Spain	31.9	2003	BOOT 15-yr term	Salinity = 38 ppt; Cost of Water = $717/AF
Ashkelon, Israel	35.4 expanded to 75	2005	BOOT 25-yr term	Salinity = 38 ppt Cost of Water = $650/AF
Singapore	26	2005	BOOT	Salinity = 36 ppt Cost of Water = $623/AF
Cartagena – Muricia, Spain	17.2	2003	BOOT 15-yr term	Salinity = 40 ppt
Campo de Cartagena – Muricia, Spain	37	2006	BOOT 15-yr term	Salinity = 40 ppt
Almeria, Spain	13.2	2003	BOOT 15-yr term	Salinity = 38 ppt
Alicante, Spain	13.2	2003	Design-Bid-Build Private O&M Contractor	Salinity = 40 ppt

With the decrease in membrane pricing, energy and cost recovery are now the biggest equipment related cost factors. Great strides have been made in energy recovery equipment to capture the energy that remains in the concentrate. Process energy consumption has decreased from over 30 kWh/m^3 (114 kWh/1000 gallons) in 1979 to less than 3.5 kWh/m^3 (13 kwh/1000 gallons) today. Even with this improvement, energy cost at the Trinidad plant (at 2 cents/kWh) is 11% of total unit water cost. Gleick[11] reports, "On energy costs alone, if current best practice uses around 12 kWh/kgal, the minimum energy cost alone will be $1.20/kgal if electricity is $0.10/kWh. Prices already significantly exceed this in California, unless special energy contracts are signed."

Typically, 35 to 50% of the seawater taken into reverse osmosis facilities is removed as product water (recovery) of quality equal to or better than US Public Health Standards (or World Health Organization standards). The remaining 65 to 50% becomes more concentrated and must be disposed, typically to the ocean. Through careful planning including sound engineering practice and hydraulic design, the concentrate can be safely disposed in an environmentally acceptable manner; this subject is covered in depth in *section 5d* of this document.

For brackish water desalters, water recovery can range from 50–90% depending on initial salinity and presence of sparingly soluble salts. The remaining 50-10% becomes more concentrated (although not as concentrated as seawater concentrate or brine) and must be disposed. The disposal of the concentrate was identified as early as 1978[12] one of the major problems for inland brackish water desalters.

Intake Options for Seawater Reverse Osmosis:

A reliable supply of feedwater that is of a consistently acceptable quality is one of the prerequisites necessary for building and operating a desalination facility. This aspect of the plant varies enormously depending upon the specifics of the site selected, and often will dictate whether or not a plant is feasible at a given location. Seawater desalination intakes generally fall into one of two major categories: surface intakes, which are located above the seafloor, and subsurface intakes located beneath the seafloor or sandy beach. Major water quality considerations for seawater intakes include total dissolved solids (TDS) total organic carbon (TOC) and total suspended solids (TSS).

There are several factors affecting the final cost for constructing and operating an intake system, among these are the type of intake being used and the distance of the intake to the plant itself. The intake system can represent a significant proportion of the overall cost of a desalination facility; when taking into account the costs of design, construction, modeling and monitoring, and permitting, the intake can correspond to as much as 20% of the overall facility cost (Pankratz, 2004).

Specific impacts related to intake and discharge are discussed in detail in section 5, along with mitigation measures and recommendations for avoiding impacts. Site selection

[11] Gleick, Peter, "With a Grain of Salt: A Review of Seawater Desalination," Pacific Institute, March, 2006.

[12] "Evaluation of Technical Material and Information for Potential Desalting Demonstration Plants," by Boyle Engineering Corporation, San Diego, CA, for Office of Water Research and Technology, US Department of the Interior, Washington, DC, December 1978.

considerations for desalination plant intakes were discussed in *Section 3.b*. This section will focus on design and engineering options.

Surface Water Intakes:

Open water intakes are the most common type of intakes globally for large (>10 MGD; 38,000 m^3/d) desalination plants. Mainly concrete, they include trash racks and screens to remove debris and large particles. A major problem for both thermal and membrane processes facilities is the ingress of mussel larvae and other organisms in planktonic life stages, which cannot be removed by traveling band screens. They settle on the walls of the cooling water pipes, grow up into colonies, are detached by the cooling water flow and clog objects installed downstream. Specialty filters are now available to solve much of this problem.[13] State-of-the-art intake systems now use backwashable intake screens (purged with compressed air).

Submerged intakes are most commonly used for reverse osmosis systems. Pipes are submerged on the ocean floor, kept in place with concrete (usually) stanchions. A screen (either cylindrical or hexagonal) is placed on the end, which is backwashed (purged) with compressed air periodically. High-density polyethylene or fiber reinforced plastic pipe is commonly used. Where an abandoned outfall or intake pipe is in place, the pipe can be slip lined with polyethylene pipe to avoid significant environmental concerns (e.g. disturbance of benthic communities due to installation of a new structure). There are a number of mitigation measures available for reducing entrainment and impingement impacts, which are discussed in *Section 5.d* of this report.

Subsurface Intakes:

This category includes beach wells, radial wells, HDD and slant drilled wells, and infiltration galleries that all take advantage of the natural filtration of seawater provided by the sediments. These technologies are also discussed in more detail *Section 5.d.* of this report.

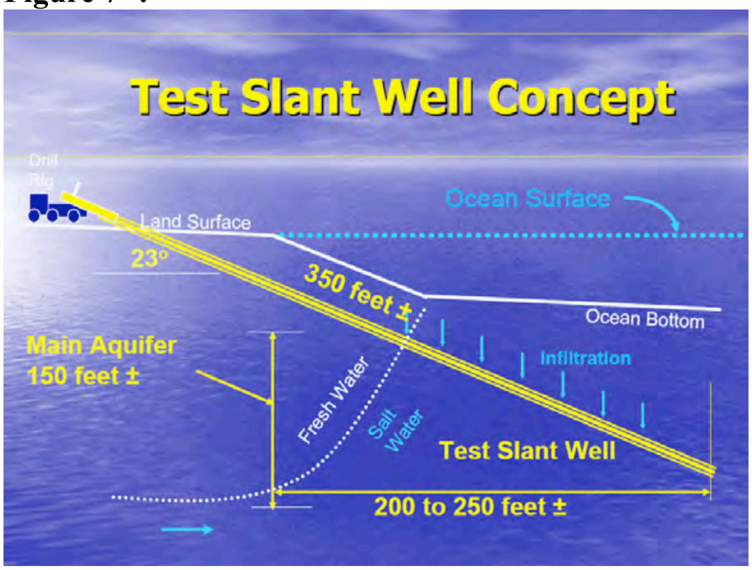
Beach wells are typically used for small (<5 MGD; 19,000 m^3/d) systems where the local hydrogeology will permit it. Recently, a plant in the Balearic Islands (Spain) increased the productivity of their seawater RO plant to 16 MGD (60,000 m^3/d); it uses an extensive well field. Seawater wells were effectively used in the Mediterranean (Spain and Malta) and have been considered for one desalination project planned in Hawaii. They cause minimal environmental concerns and the water quality is excellent. In most cases, no further pre-treatment is required and only cartridge filters are maintained as a security measure. Non-ferrous materials or plastics are preferred as well liners to prevent corrosion and development of iron reducing bacteria. One of the potential downsides of beach wells is that deep wells, such as those planned for use in Hawaii, may result in lower water temperature and hence higher pressure will be required to desalinate the water. This will increase the energy cost. Another potentially serious issue that can be related to beach wells is their potential to cause seawater to intrude into freshwater

[13] Taprogge Gmbh, Wetter, Germany.

aquifers. It is necessary to conduct a number of detailed studies, including hydrogeological analyses, to ensure that pumping seawater from a well will not interfere with groundwater quality.

Slant, and horizontal directionally drilled (HDD) wells are increasingly being considered for use in seawater desalination facilities. HDD wells are under study in Dana Point, CA, with funding from the state's Proposition 50 funds. This project is being closely watched as it may represent a viable intake method for large plants. HDD wells are being investigated as an alternative to using the Moss Landing Power Plant's cooling water as feedwater for CalAm's Coastal Water Project.

Figure 7[14].



Brine Discharge Options for Seawater Reverse Osmosis:
There are a variety of options available for desalination brine disposal, each having its own set of costs and benefits. Disposal to the ocean, which is the most feasible option in the Monterey Bay area, can be achieved though direct discharge, discharge through a beach well or other subsurface discharge, or blending with power plant cooling water or treated sewage effluent. Additionally, the cleaning compounds used during the desalination process may need to be routed to a wastewater treatment facility rather than discharged directly to ocean waters.

One of the major issues surrounding desalination is the potential for the elevated salinity of the brine to cause negative impacts to marine organisms. While the salinity of the brine is typically of higher concentration than that of the ambient seawater, good engineering practice, diffuser design and/or dilution with additional seawater (or wastewater) prior to discharge will mitigate environmental effects. These and other mitigation measures for

[14] From Proposition 50 Grants Program Proposal, California Department of Water Resources, Sacramento, CA, 2006.

reducing the environmental impacts of the brine discharge are discussed in detail in *section 5.e* of this report. Site selection considerations for a desalination plant outfall are discussed in *Section 3.b* of this report. The following section provides an overview of the options available for concentrate disposal.

Brine disposal via a direct ocean outfall is the most basic method, involving conveying the concentrate through a pipe where it is discharged to the ocean through one or many outlets. Since the brine plume is denser than seawater and tends to concentrate on the bottom, it is necessary to enhance mixing by using multi-port diffusers and other technological and operational mitigation measures.

Discharge to the shore is another option whereby discharge occurs at the beach/ocean interface or directly into the surf zone. This method is not likely to be used in plants proposed for Monterey Bay due to regulatory considerations.

Brine disposal via blending with power plant cooling water discharge is being pursued in several of the large seawater desalination proposals in California. This is the brine disposal method proposed for use in CalAm's Coastal Water Project. Co-location can provide a number of economic and environmental benefits. Because an existing structure is being used, it is not necessary to construct a new outfall structure, which can be expensive and can cause negative impacts to the seafloor. Another key benefit is the dilution of the brine that occurs by combining the concentrate with large volumes of cooling water. The thermal footprint of the power plant can also be reduced (by 20-40% in the case of the proposed plant at Huntington Beach). There are however a number of unresolved issues associated with this practice; these are discussed in detail in *Section 6.c.* of this report.

Brine disposal via blending with treated sewage effluent is another option available if an outfall is nearby. This practice provides many similar advantages to co-location with a power plant's cooling water outfall, including dilution of the brine and the economic and environmental advantages of not needing to construct a new outfall structure. There are several issues associated with this practice as well (discussed in *Section 6.b*), that must be addressed. The City of Santa Cruz' proposed desalination plant would convey its brine discharge to the wastewater treatment plant for blending with the treated wastewater outfall.

Brine disposal via a subsurface discharge structure involves discharge into a beach well or percolation gallery beneath the beach or underneath the seafloor. Since mixing occurs in the water table beneath the beach and the discharge plume is slowly dissipated into the surf zone, this can be an effective way to minimize environmental impacts. Although this can be an attractive option in many cases, it requires specific hydrogeological conditions that are not always available. This practice is discussed in much more detail, in the context of a mitigation measure, in *Section 5.d* of this report. This practice is used at the existing Marina Coast Water District desalination plant and will also be used at the proposed Sand City facility.

Other methods of brine disposal not likely to be pursued in the Monterey Bay Area include discharge to an evaporation pond, a confined aquifer, or a river. Each of these options present a number of environmental and economic issues that render them infeasible for use locally.

4.d.iv *Major Steps in the Reverse Osmosis Process*

Pilot Plants and Studies: Pilot studies are a necessary part of the planning and implementation for a desalination project. In this iterative process, data collected during the pilot study are continuously integrated into the planning and design process, in order to refine the specific design and operational aspects. It is expected that this will result in more accurate cost estimates and a more thorough design that allows the desalination plant to perform optimally given the specific conditions at the chosen site. Typical pilot studies consist of operating small-scale pilot plants that use the same feedwater that is being considered for the desalination plant and serve to fine-tune the pretreatment scheme, the specific RO process, and post treatment for the planned project. In areas where subsurface intakes are or may be feasible, the pilot plant should be designed to test water taken from a subsurface well, since that water will likely have different characteristics than surface waters. In certain cases, this period is used to test new membranes with specific characteristics such as greater boron or bromide removal to meet local requirements.

For optimizing the RO process design, parameters such as critical flux and the presence and consequences of viable but not culturable (VBNC) organisms are determined during the pilot testing period.

Typically pilot plants take in minimal volumes of feedwater compared to the proposed plant and recombine the product water and reject stream, so that the discharge is not elevated in salinity, and therefore does not typically represent a threat to the environment. It is preferable to conduct the pilot study for a full year, to account for any seasonal variability in feedwater quality and discharge characteristics. Source water conditions in the Monterey Bay can vary significantly during different seasons, depending upon weather, and upwelling and other oceanographic phenomena. In addition to helping identify specific operational considerations such as pretreatment scenarios and desalination process design, the pilot study should also be used to assess environmental characteristics of the plant such as the constituents and potential environmental impacts of the brine discharge, as well as to identify mitigation measures.

Pre-treatment: The quality of seawater available from a particular site will depend on local site factors such as: ocean depth, turbidity, ship traffic, wind conditions, littoral drift, tides, and potential contamination from nearby outfalls. Since reverse osmosis membranes require low turbidity (typically<1.0 NTU) and minimum silt density index (typically <4), the seawater source must be pre-treated to remove turbidity, normal organic matter, marine organisms and potential contaminants.

Conventional filtration methods such as media filtration and coagulation/sedimentation are still the preferred pre-treatment process for seawater reverse osmosis because they have traditionally been the most robust. Until to construction of the Tampa Bay plant, traditional gravity downward flow filtration was the norm. At Tampa Bay, an up-flow dual sand process was installed. Used for industrial applications in the past, this is the first large installation of the two-stage up-flow process for seawater. Unfortunately there were some initial problems and corrective measures are now in process.

Microfiltration (MF) and ***ultrafiltration*** (UF) membrane processes have been researched, developed, and now appear poised for commercial applications of seawater pre-treatment. Both processes are widely used for industrial and water reuse applications throughout the world (e.g. Orange County Groundwater Recharge System). Extensive pilot plant tests have been conducted at Ashkelon, Tampa Bay and Trinidad. These tests were successful, but the plant operators continued to use media filtration due to slightly higher cost for membrane pre-treatment. The continued downward trend of MF and UF pricing should soon make these the preferred choice for pretreatment. The use of MF/UF will provide a more robust process to handle fluctuations in feedwater quality with comparable unit water cost.

MF and UF are both membrane separation processes, but they have pore sizes much larger than RO. Both water molecules and solutes are free to pass through and since osmotic pressure is not a factor, water is pushed (or pulled) through the membrane at very low pressure (as low as 10-15 psi). Particles larger than the membrane pore size (~0.1 micron for MF and ~0.01 micron for UF) are easily removed. Membranes are commercially available in flat sheet, tubular, hollow fiber and spirally wound configurations.

A 3 MGD (11,400 m^3/d) ultrafiltration system feeding a 1 MGD (3,800 m^3/d) seawater RO system has operated successfully since the summer of 2002 in the United Arab Emirates[15]. Microfiltration was specified pretreatment for the seawater desalination plant in Singapore and for the Ashdod (Israel) facility. Marin Municipal Water District[16] has just completed pilot plant testing to compare MF and UF with conventional pre-treatment prior to building a 15 MGD plant (56,800 m^3/d).

The use of beach wells or undersea delivery methods greatly reduces or eliminates the need for pre-treatment. In these cases, the only filtration normally required are cartridge filters, which are generally recommended by the membrane manufacturers to provide "insurance" against upsets for their membranes. Although the initial capital cost is higher for these methods of delivery, it reduces operating and maintenance costs as well as providing environmental advantages (minimizing or eliminating entrainment and impingement, and eliminating sludge from media filters). Use of well sources in the

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15 Galloway, M. et al, "UF for Seawater RO Pretreatment," Ionics, Incorporated, Watertown, MA.

16 Marin Municipal Water District, Corte Madera, California.

Mediterranean minimize the need for extensive pretreatment and, in some cases, require only cartridge filters upstream of the RO system

Ultraviolet and ozone treatment are also being considered to replace chemical disinfection of feedwater. Both have merit, and both have been successfully used in drinking water and water reuse applications globally. Since today's membranes are sensitive to oxidants, use of UV is preferred over ozone, but ozone is more effective. Membranes resistant to oxidants are under development.

Residuals disposal: In the pretreatment step, solids are removed. In some cases, these solids (residuals) can be recombined with the brine or concentrate discharge and disposed to the source water. Typically (and including all of the Monterey Bay desalination proposals), the solids are separated further with clarifiers, then sent to a belt press for further dewatering. The resulting sludge must then be hauled to a landfill. The use of a microfilter will reduce the volume of sludge to be settled in the clarifier.

The membranes and filter cartridges also constitute a residual when they reach the end of their effective life. These residuals are commonly disposed in landfills. A few companies recover used membranes and clean them for further use in a different application.

RO Membrane Separation: Following pretreatment, the feedwater is highly pressurized using a mechanical pump and forced through a semi-permeable membrane. Specifics of this process are discussed elsewhere in this section of this report.

Post treatment: Product water from either thermal or membrane desalting processes is very low in salinity and hardness and is corrosive to metals and concrete. Desalted product water is always passivated (made non-corrosive), adding chemicals such as slaked lime or another similar chemicals. If this is not properly done, the water will attack the piping infrastructure. As experience has demonstrated, it is also important to condition the water so that it does not destroy the existing scale within the infrastructure. This is a delicate task and must be carefully considered on a site-by-site basis.

4.e.v *Advances in Reverse Osmosis Technology*:

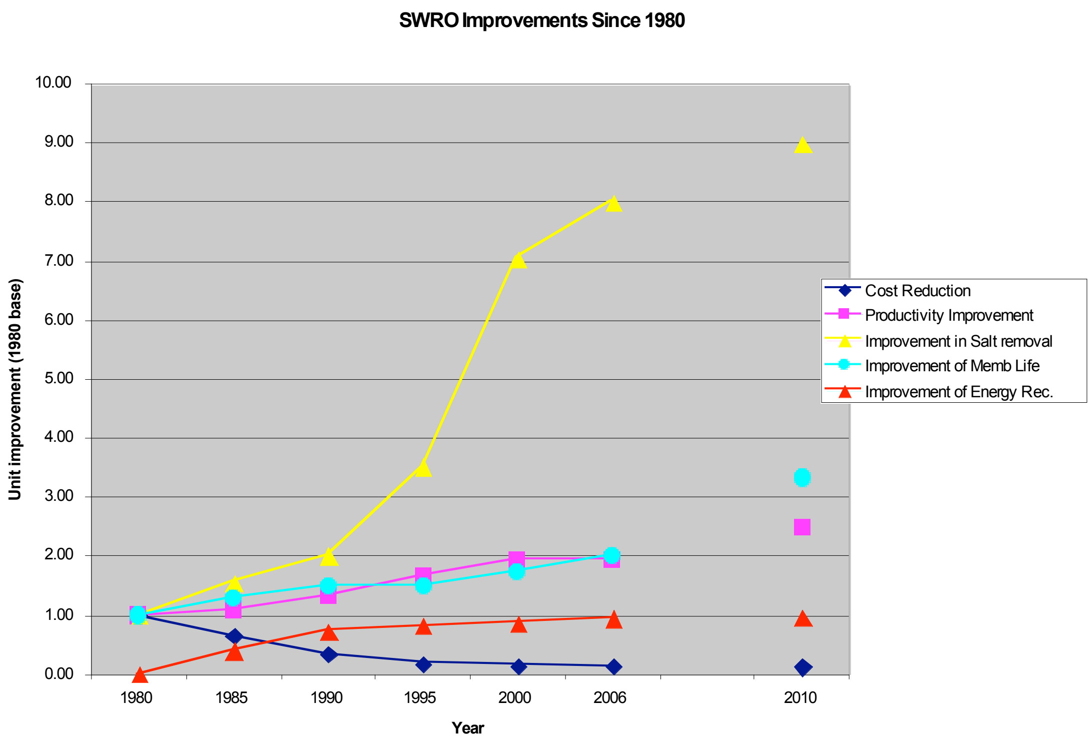
Advances in Membrane Technology: Reverse osmosis membranes have attained maturity and are currently capable of removing salts with high efficiency. Several companies around the world produce membranes capable of producing drinking water quality product from seawater in a single pass (99.7% salt removal).

One of the authors[17] of this report has tracked the improvement in membrane technology over the past twenty years. As shown in *Figure 4.8*, there have been exceptional improvements in membrane life, salt removal capability (salt rejection, or conversely reduction in salt passage), and energy efficiency with use of energy recovery devices. Membrane life has now been extended to 7 to 10 years depending on the source water

[17] David H. Furukawa, Separation Consultants, Inc., Poway, California

quality. Salt rejection has only a small window of growth; it already is at 99.8% removal efficiency (commercially offered in special cases) and any additional improvement will be very difficult to achieve without some reduction in productivity. Additionally, it is unlikely that companies will expend the substantial resources to make this improvement when product water quality is now satisfactory in most cases. Similarly, energy recovery devices are now ~95% efficient, which makes additional improvement difficult, and companies are now reaching for other system improvements to reduce operating cost. Considering all of this, the most likely area of improvement is in productivity, where membrane fouling, not membrane flux, is the inhibiting problem. Millions of dollars are already being expended to solve this problem

Figure 4.9.



The current state-of-the-art membrane material is a thin film composite polymer combining a microporous polysulfone support layer with a thin polyamide layer. This kind of membrane, commercialized in 1980, has been hugely successful and changed the course of membrane technology.

Each of the membrane manufacturers has developed its own software to guide the most efficient design of systems utilizing its membranes. Since performance of modern day membranes is similar to each other, a single design can accommodate any one of several membrane candidates.

In the past few years, several variations to the thin film composite have been commercialized, including low fouling membranes. Many of these developments have resulted from polymer addition to smooth the surface, or from surface modifications such as addition of different functional groups to change the surface charge. The 'holy grail' for membrane development is still an oxidation resistant membrane. A prototype is currently being tested at the Yuma research center.[18]

It is possible that the membrane industry is reaching a point of diminishing returns with its current technology. There seems to be little doubt, however, that membranes will continue to develop. At least three different organizations are currently investigating the potential of combining nanotechnology with membranes. In two cases, nanoparticles are being combined with polymers. It is believed that this approach will greatly reduce the resistance to molecular flow for water molecules while improving the removal of larger molecules. Chlorine resistance will improve the ability to control or remove fouling conditions. Combined research in these areas may produce a truly promising future membrane.

Trends in Energy Use and Energy Recovery Devices:
Energy consumption is largest fraction of unit water cost (capital recovery represents the second largest fraction)[19]. For many years seawater desalination was considered a prohibitively expensive process, with its greatest utility in very dry areas or places with low-cost energy. That notion is changing rapidly, as new energy recovery devices have been commercialized that greatly reduce energy consumption. In 1979, seawater RO systems consumed more than 30 kWh/m^3 water produced (114 kWh/1000 g). This high-energy consumption was partly due to the relatively small size of systems during that period. Today, seawater RO systems consume only 3.5 kWh/m^3 (13 kWh/1000 g).

Table 4.5

Energy Recovery System	**Efficiency, %**
Reverse running pump	**75-82**
Pelton turbine (ERT)	**80-86**
Turbocharger	**70**
Flow-work exchanger	**90-95**
Pressure exchanger	**~95**

Most recent installations using the pressure exchanger system show that seawater RO desalination at 2 – 2.5 kWh/m^3 (7.6-9.5 kWh/kgal) is possible. The reduction in energy consumption for RO in the past twenty years has been remarkable (*Figure 4.7*). The major plants at Ashkelon, Israel and Singapore utilize the DWEER (flow-work exchanger) energy recovery units. Most recent testing[20] at Port Hueneme, CA indicate that 1.6 kWh/m^3 (6.1 kWh/kgal) is achievable; however, when other aspects of equipment and operating and maintenance cost were considered, a somewhat less

[18] US Bureau of Reclamation, Water Quality Improvement Center, Yuma, AZ.
[19] "Desalination and Water Purification Technology Roadmap," Sandia National Laboratories and US Bureau of Reclamation, January 2003.
[20] Affordable Desalination Coalition, San Leandro, CA.

aggressive 2 kWh/m^3 (7.6 kWh/kgal) was optimum for lowest total water cost. The issue of energy use of desalination plants is also discussed in *Section 5.f.*

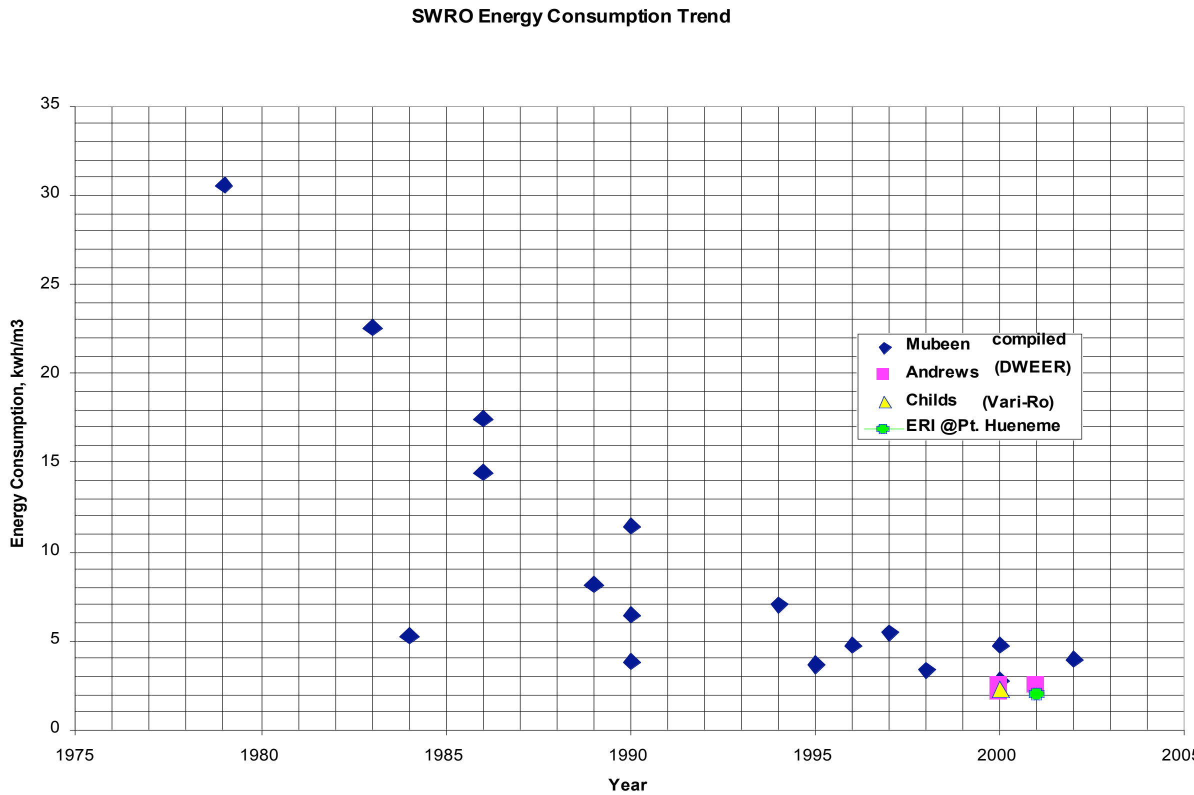


Figure 4.9 Seawater Reverse Osmosis Energy Consumption Trend

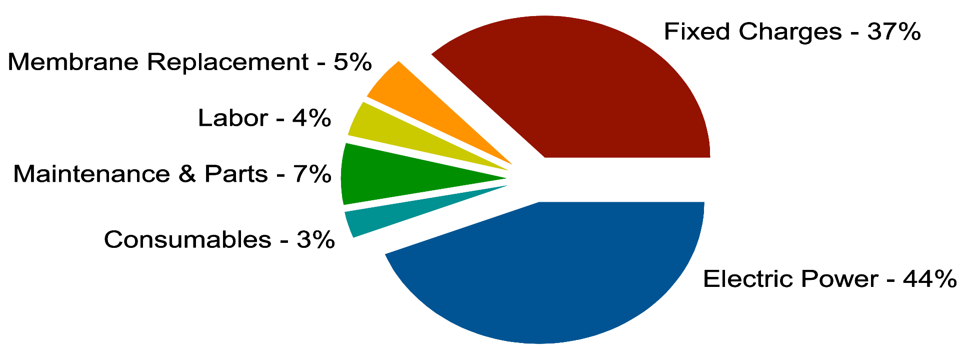


Figure 4.8 Cost components of Reverse Osmosis Seawater Desalination

Future improvements in the Reverse Osmosis Process: Improvements in the seawater reverse osmosis process can best be estimated by examining *Figure 4.9*.

From this graph, it can be clearly seen how 1) membrane cost, 2) membrane salt rejection (removal), and 3) energy recovery have improved remarkably. With salt removal already at 99.8%, it is unlikely that significant research and development cost will be devoted to achieve the next increment. Membrane cost is at an all-time low and with the large quantity required by today's large-scale plants, the competition can be expected to be fierce, but there will be a limit to the cost reduction possible due to the cost of manufacturing. The most efficient of today's energy recovery devices achieves 95% efficiency. Because of the high cost of energy in California, additional improvement may be expected, but the cost of developing systems to achieve greater than 95% will be high.

Thus, membrane life and membrane productivity are the key criteria that will be most improved in the next several years. Until different polymers are developed and membrane-manufacturing techniques are improved, the improvement in membrane life can be expected to improve from an estimated 7 years to perhaps 10 years. Membrane productivity, as measured in the factory under very clean water conditions, is already higher than common productivity design limits, but seawater RO has been limited to about 8-10 gallons per square foot per day (GFD) (12.8-16.0 l/m^2hr) due to membrane fouling. The development of better membrane pretreatment (e.g. MF and UF) is expected to improve this design figure to about 12 GFD (19.2 l/m^2hr, reducing both the number of elements required (and supporting hardware) and the energy cost per unit volume.

Membrane fouling limits the achievable membrane flux. Recent research[21] indicates that fouling may be attributable to viable but not culturable (VBNC) organisms of less than 0.2 microns. Up to this point, VBNC organisms were considered a problem since they were not detected by the usual methods of plate counts. They must be determined by epifluorescence methods. Research continues to determine how to deal with these organisms.

4.f ALTERNATIVE ENERGY SOURCES FOR DESALINATION

Solar Energy

In the solar evaporation process sunlight provides the energy for evaporation. A tray of water sits in the sun and is heated by the incident sunlight. A tight fitting, transparent cover sits over the tray. Water vapor in the space over the tray condenses on the cover and is directed into a product collection tray. Production is about a tenth of a gallon per day per square foot of tray area. It is surprising that despite efforts of some very competent investigators over a long period of time, relatively little progress has been made and little success achieved, judged by commercial usage. Limiting factors are high capital costs and the need for very large surface area.

[21] Winters. H., "Microfouling of Cartridge Filters and RO Membranes: Mechanisms and Effects, IDA World Congress, Singapore, September 2005.

Additional developmental testing is currently ongoing in the Middle East, sponsored by the Middle East Desalination Research Centre. One project investigates the principle of humidification and dehumidification of air by natural convection and using solar energy or waste heat as a source of energy. The study demonstrates that thermo solar evacuated flat plate collectors are suitable to deliver sufficient heat for this desalination process. It identified several specific areas of improvement that must be further developed.

A second project studies the use of solar tracking collectors to heat seawater, delivering steam to the first desalination effect. The steam is bubbled through feedwater for softening, to prevent scaling. The 1000-liter per day (264 GPD) plant demonstrated no need for external electricity, no additional water for cooling and no impact on the environment. The plant will be subjected to long-term testing in the Sultanate of Oman.

A third project examines the use of photovoltaic cells for pumping and desalination. Two PV grids are utilized; one for powering a submersible pump, the second for the reverse osmosis system. Storage batteries are utilized to store energy. The purpose of the test is to demonstrate the efficacy of PV powered systems for remote areas.

Wind energy

The use of wind energy for desalination is well documented. Several trials have combined wind energy with electrodialysis. Storage cells were required for energy storage to provide power during no wind cycles. One test combined wind energy with photovoltaic cells.

Wind farms are prevalent in the coastal mountain ranges of California and provide power to the grid. Desalination projects cannot directly use wind power due to the distance to the wind farms, but proponents may buy "green energy credits" which helps to support their continued development and use. At the present time, the cost of using wind energy is about 1.5 times conventional energy prices.

One innovative concept utilized wind energy to pump water to an elevated reservoir. The stored water (energy/hydrostatic head) was to be used to power a reverse osmosis system. The limited number of places this could be utilized and the poor economics caused this concept to not be further pursued.

Hydrostatic head

The previous example illustrates the use of hydrostatic head to provide the energy for desalination. A much larger concept that has been discussed for the past 10 years or more is the Red-Dead project. The project is fueled by two circumstances of the region: a) drinking water scarcity, and b) continued depletion of the Dead Sea, a major tourist attraction. The concept is to remove water from the Red Sea and capture its energy as it flows downward 1500 feet (455 m) to the Dead Sea. The water can be used to produce energy with turbines and also provide feedwater for a desalting system. The drinking water would be distributed within the immediate region, and the resulting brine would be sent to the Dead Sea. The approximate salinity and composition would be nearly the same as the Dead Sea. As attractive as this option may seem, its cost will be several $100 billions. It is a unique project and would require unique cooperation between Israel and Arab countries. It has been promoted as part of the multi-lateral peace process.

Ocean Thermal Energy Conversion (OTEC)

For years the National Energy Laboratory has investigated OTEC in Hawaii. The concept utilizes the difference in temperature between deep ocean water and surface water. In the Hawaii example, water is taken from 2000 feet depth and pumped to the surface. A Stirling engine is utilized which circulates an organic fluid. The organic fluid vaporizes at relatively low temperature (surface supply) and in turn drives a turbine, which creates electricity. As it leaves the turbine, the vapor is cooled by deep ocean water at which temperature it condenses. It is recycled and can be used for extensive periods without replacement. The deep ocean water can subsequently be used for cooling, thus replacing traditional electrified air conditioning.

Brine ponds

Brine ponds also work on the principle of differing heat sources. It is well known that with stratification, brine at the bottom of a lined pond will differ in temperature from the surface layer. A Stirling engine (as above) is introduced to produce electricity. The concept has been successfully used in Israel for decades and was demonstrated in Northern California at the State of California Los Banos Test Facility.

4.G MATERIALS OF CONSTRUCTION FOR DESALINATION PLANTS

The subject of proper materials for desalination plants would be a large report in itself. This will be a brief description. For more detailed information, please refer to specific references.

Thermal processes

The efficient transfer of heat is the major consideration in thermal plants. In an MSF plant, there are three main areas for heat transfer: heat recovery section, heat rejection section and brine heater. The most common types of corrosion found in thermal systems, particularly around the condenser tubes are: crevice corrosion, pitting corrosion, stress cracking corrosion, selective leaching, fretting corrosion, vapor side corrosion and impingement attack.[22] The preferred materials continue to be cupronickel alloys, aluminum brass, admiralty cupro nickel, titanium and cupronickel.[23] Even though these materials are also subject to some of the previously mentioned corrosion problems, the difficulties can be minimized with proper process controls, including ideal flow rates, baffle plates to deter impingement, and addition of chemicals.

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[22] El-Dahshan, and B. Bin Ashoor, "Case Studies of Corrosion of Distiller Tubing Materials," IDA World Congress on Desalination and Water Reuse, September 28-October 3, 2003, Paradise Island, Bahamas.

[23] Al-Dukheyil and Al-Fozan, "Material Selection of MSF Condenser Tubes," IDA World Congress on Desalination and Water Reuse, September 28-October 3, 2003, Paradise Island, Bahamas.

A thermal plant is much like a chemical plant with many different sub-systems in addition to the condenser tubing and shell. Each of these sub-systems have unique materials problems and must be considered separately.

Reverse osmosis
From the earliest days of reverse osmosis with seawater feed, it was well known that corrosion problems were severe, even with the early versions of stainless steels such as 304 and 316. The most common problem of pit corrosion in stagnant solutions was resolved with proper design eliminating dead spots and elimination of as many threaded connections as possible. Victaulic couplings were devised and are still used today.

Most recent successes point to the use of more sophisticated stainless steels such as 254SMO[24] (super austenitic) and super duplex Zeron 100, Sumitomo DP3W. Many plants are now electro polishing their stainless steel headers and piping to provide a slick surface that is easily washed and maintains good appearance. It has been proven that plants constructed aesthetically are more likely to receive better maintenance.

4.h DEVELOPMENTS IN DESALINATION TECHNOLOGY

4.h.i *Introduction*
It is difficult to address an issue such as emerging technologies, since the construction of large-scale seawater RO systems must be based on proven technology. The use of *microfiltration and ultrafiltration* are examples of emerging technologies and it is likely that these membrane processes will be incorporated into large-scale desalination plants as they have been at Ashdod, Israel.

The innovative low-pressure alternative using ***nanofiltration membranes in two stages*** in series is now in the proof testing stage. Its suitability for large-scale systems is now being addressed in pilot plant testing at Long Beach Water Department.

The other new ideas are considered developmental at this stage. The following paragraphs will address some of these ideas.

4.h.ii *Developmental processes*

Forward osmosis is an intriguing approach that utilizes the conventional osmosis principle. It was considered years ago, but has recently been targeted for development because of improved membrane materials and new techniques including advanced energy recovery equipment. Separation Systems Technologies and Aquagenesis are two companies developing forward osmosis designs.

Capacitive deionization was widely touted several years ago as the next “breakthrough” process. Two companies have taken licenses on the Lawrence Livermore National

[24] Composition, %: C= 0.02 (max), Cr= 19.5-20.5, Cu= 0.5-1.0, Mn= 1.0 (max), Mo= 6.0-6.5, N=0.18-0.22, Ni=17.5-18.5, P= 0.03 (max), Si= 0.8 (max), S= 1.01 (max).

Laboratories *Aerogel* process. The original aerogel concept utilized a carbon matrix for electrode material. The electrodes were alternately charged plus or minus and as feedwater passed between them, ions were absorbed into the matrix. Once the matrix was filled, the energy was cut off and the ions dispersed into the collecting solution. As many new technologies go, improvements proved more difficult than expected and the process is still developmental for large-scale desalination. Far West Corporation is testing prototypes for brackish water desalination and Sabrex of Texas is commercially offering small units for industrial applications; they also recently (11/07/04) unveiled a small (25 gpd; 6.6 m^3/d) point of use system that they plan to market on the internet via Ebay.

Membrane distillation, like many others, is to be driven by "waste heat." A warm stream on one side of a porous membrane made of hydrophobic, water rejecting, material opposite a stream of cooled product water. The membrane is required to maintain a gap of vapor about equal to the thickness of the membrane. The water distills across this gap. If there is an advantage to this process, it is that equipment cost should be low, corrosion is not a problem and the vapor flow path is very short. It has been the subject of several development projects, but hurdles remain.

Electromagnetic fields to enhance membrane transport have been discussed in the past. GrahamTek, a company whose beginnings were in South Africa, has developed a reverse osmosis system wherein electrical coils are wound into the pressure vessels holding spiral wound membrane elements. A patented flow distributor is also placed in front of each membrane. The process is said to improve membrane performance by disrupting the hydraulic boundary layer and forestall fouling and scaling. Sizable systems are now in operation in Australia (nickel processing tailwater) and Singapore (semi-conductor process water). Successful tests have been completed in Singapore (wastewater effluent) and Abu Dhabi (open intake seawater with no chemical addition). The proprietary membrane elements and pressure vessels are slated for installation in the NEWater wastewater expansion at Bedok, Singapore (9.5 MGD) and for a seawater desalination system at Power Soraya (2.6 MGD).

SAIC developed a solar process utilizing concentrating collectors (dish technology) to heat an organic fluid, which vaporized at low temperature, driving a Stirling engine. The energy could then be used for RO or VC. The process has not progressed past the development stage.

Wavemill, a Nova Scotia company, has developed a reverse osmosis system powered by wave energy. A novel energy multiplication concept (large piston driving a small piston) drives a small reverse osmosis system. It is being commercialized in small systems. An interesting concept using pistons that follow wave height, powering reverse osmosis, was introduced recently at a California Water Desalination Task Force public forum.

Ocean Motion has proposed a system, which utilizes floating "donuts" which rise and fall with waves. Connected to cylindrical pistons, the wave energy is transferred to reverse osmosis.

Aquasonics has developed a system, which sprays droplets of feedwater into the top of a tower. As air rises in the tower, water is evaporated, causing precipitation of salts. Ideally, the evaporated water would be condensed. This may have some application in the treatment of concentrate for disposal.

Hydrostatic RO is a technique developed over the past 20 years but has yet to be implemented. The largest project envisioned is the Red-Dead project, where water from the Red Sea, would be allowed to fall through conduits to the Dead Sea, some 1500 feet below it. Turbines would be used to develop the energy to power reverse osmosis. Other concepts have the difference in hydrostatic head powering the RO membranes directly.

Sea Solar Power International utilizes the ocean thermal energy conversion concept (OTEC) to drive a turbine, which generates electricity. The unique approach by Sea Solar is that they place the entire operation on a ship. OTEC has been proven at the National Energy Laboratory in Hawaii. Although it is not currently used for desalination, it supports several industries, which take advantage of the nutrient rich cold water.

Desalination Ships. Various concepts of placing desalination systems onboard ships to provide water to areas of extreme need have been proposed over the years. Several barges have been constructed, but a desalination ship of this magnitude has not been built to this date. The construction cost of these vessels historically has been very high, making the produced water too expensive for uses other than off shore drilling platforms or similar high value operations. A floating barge was built (3 MGD) and is currently in use off the coast of Abu Dhabi.

Water Standard Company's Seawater Conversion Vessel: One concept that emerged very recently and is being promoted for the Monterey Bay area during the writing of this report, is a ship-based desalination plant called a *Seawater Conversion Vessel* (SCV). Water Standard Company, in collaboration with PBS&J and a team of other companies and consultants, is promoting this project as an environmentally preferable alternative to land-based desalination plants. These large ships, which are built for the primary purpose of housing a desalination plant and producing freshwater, would be up to 800 feet in length, containing a seawater reverse osmosis desalination plant sized in capacity somewhere between 20-200 MGD. The vessel itself would be located offshore and product water would likely be shipped to shore using a food grade tanker, or a tug barge (capacity up to 14 million gallons). One potential obstacle that this project will need to address before moving beyond being conceptual is how the transfer to land-based facilities would occur. It would be necessary to store the water in facilities that may require construction and transport the water to existing delivery infrastructure. At this time this aspect of the project is unknown.

While there are a number of unknowns associated with the project, by being sited offshore on a ship there are a number of potential advantages that may be realized. From an environmental standpoint, being sited away from sensitive near shore ecosystems in a more resilient and less biologically active environment may minimize or prevent a number of impacts that are commonly associated with land-based plants. The SCV would discharge the brine through a multi-port dispersion system that dilutes the brine. By being located in much deeper water than is possible for a land-based desalination plant, the denser brine will be discharged near the ocean's surface and will become diluted to ambient salinity as it sinks, and therefore will not become concentrated on the seafloor, which can be a major issue associated with some desalination plant discharge systems. The desalination feedwater intake would occur using a telescoping screened intake device that is extended into the ocean beneath the ship. The intake can be extended to draw at a low velocity from deeper waters that are less biologically active, and is screened to minimize entrainment and impingement. From a technical standpoint this may offer the advantage of providing a high quality feedwater (minimal particulates) that may require less or no pretreatment. A deeper intake infers colder feedwater and energy consumption will increase. Another potential benefit of the SCV is that since it is located offshore it does not require the intake and outfall pipelines that are required of many other facilities, which can be costly and can cause negative impacts to the seafloor. It is still to be determined how the facility would identify its entrainment impacts, particularly if it moves to different locations, and how it would address Department of Health requirements to identify source water characteristics. The SCV would generate electricity for the desalination process using biodiesel-fired generators, which would reduce the harmful air emissions typically associated directly or indirectly with most desalination plants; this aspect of this plant will require further evaluation from agencies associated with regulating air emissions.

Because this project concept is in much earlier stages than the other desalination plant proposals for the Monterey Bay area, many of the details and issues must be further developed before the project can move ahead or be further analyzed. Some of the potential issues that need to be worked out are who would own the plant, and how the water would be delivered to shore and distributed, and the reliability of delivery during winter storms, etc. Since there is no precedent for a project of this type, it is still unclear what regulatory considerations may exist. Nonetheless, a project spokesperson stated that a ship could be built and delivered to the Monterey Bay area in just 2 years. There do not appear to be major technology based hurdles, as other proposed desalination ships and barges have been designed over the past 20 years. The delivered cost of water is not defined at this time. There is not sufficient information made available to adequately evaluate the Salinity Plume Deterrent System they propose for brine discharge and questions surrounding the mixing zone must still be answered.

Dewvaporation uses the principle of humidification to load air with water vapor, and then using films to transfer heat from cooler air supplies, condenses the vapor to liquid. One major difficulty with this concept is that copious surface area of film is required. A small prototype has been built, but further development has stalled.

Agua Via is a California based company who claim to have developed the first biomimetic membranes. Their technology is closely guarded so it is too early to establish their viability. One of their consultants is Dr. Paul Berg, a Nobel laureate.

Poderco S.A. is offering a MVC system with wind power the primary motive force. It was developed in Germany and a pilot plant is apparently available for test in Europe.

Rocent has developed a hyperfiltration process wherein spiral wound membrane elements are placed in a centrifuge. The resulting centrifugal force is said to improve the flux significantly. This concept was first tested at EPRI several years ago. At that time, it was not considered economically attractive.

Aquadyne is an Australian company that has developed an MVC desalter with apparently attractive economics. They have tested a pilot plant.

Kamen's device is a MVC desalter compressed to small size that can be used in a household. Like most MVC desalters, the long-term success will depend on the dependability of its compressor and efficient heat exchange surfaces.

Orbis was a wiped film evaporator licensed by Aqua Chem some years ago. It may have made sense for some specialty food applications, but was not proven to be a satisfactory desalination process.

Passarell's invention is a vertical tube evaporator, patented in 1993. The uniqueness of the process is its concrete shell. Its titanium double fluted tube design appears to be the same as developed by Hugo Sephton and others in the seventies. It has been revived recently with some changes.

There are many other desalination processes that can be considered developmental. One of the key issues to keep in mind is that most of these processes are seeking funding to complete their development.

4.h.iii *Research and development innovations*

Nanotechnology enhanced membrane systems. This topic was recently embraced by the Pacific Rim Membrane Collaboration Partnership[25]. This area of research may well be the next frontier in membrane development. Unusual characteristics have already been discovered when introducing nanoparticles into membrane polymers. A project sponsored by NWRI[26] resulting from the collaboration has yielded promising results in its first half year.

Ion removal with dendrimers. This unique piece of research was recently funded by NWRI. Specific dendrimers are utilized to bind heavy metals, which are then removed by ultrafiltration. It is believed that specific dendrimers exist for other ions. In its broadest sense, this may open the door for by-product recovery from membrane concentrates that will produce value or render the concentrate more easily disposed.

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[25] Organized by the National Water Research Institute, Fountain Valley, CA. 2004. Partners include delegations from China, Japan, Singapore, Australia, USA.

[26] National Water Research Institute, Fountain Valley, CA.

Membrane surface modifications (addition of functional groups). Several institutions are presently investigating the chemistries involved in adding functional groups to micro or ultra filtration membranes. The added properties will enhance the separation capabilities of current commercial membranes.

Membrane stretching to enhance membrane performance. A recently completed NWRI project[27] demonstrated that stretching of membranes changes the aspect ratio of the pores, thereby enhancing its performance. It was found that flux improves and rejection of particles increases. This research will be continued with funds from other agencies.

4.i *Summary*:

Desalination technology has matured to the point that potential users have many different processes available to meet their needs. For plants less than 10,000 m^3/d (2.6 MGD), the most appropriate processes are MED, MVC and RO. If heat is available, MED and MVC may be good candidates; the capital cost will be high, but running costs may be equal to or less than reverse osmosis, depending on specific factors (availability of waste heat, quality and dependability of heat source, maintenance, etc.). The cost of product water from either of these sources is nearly the same regardless of feed source salinity. Product TDS is typically less than 25 mg/l, so conditioning will be required depending on its intended final use.

For low TDS waters, typically less than 2500 mg/l, electrodialysis is a possibility and for very low TDS water, ion exchange comes into the picture.

For most applications, reverse osmosis or nanofiltration are considered the most feasible process. It demonstrates the lowest energy consumption. The energy required for a typical 35,000-mg/l seawater salinity is now about 2.0 kWh/m^3 or 7.6 kWh/1000 gallons (process energy only). The pre-treatment for RO is the most critical factor. For well intakes, pre-treatment is minimal and may consist of only micron cartridge filtration (mainly to protect the membrane from upsets). For highly turbid water, dual or multimedia filtration (single or two stage) may be required. In some cases where marine organisms are problematic, microfiltration or ultrafiltration may be utilized.

Post-treatment with any of the above processes is required to condition product water so that it is non-corrosive and compatible with existing infrastructure conditions.

With good engineering practice that is available today, engineers can properly design and construct reliable and economic desalination systems for just about any water quality. As always, the solution to the problem is site specific and dependent on the quality of water desired.

[27] Lloyd, D.R., University of Texas-Austin.

5. ENVIRONMENTAL AND SOCIOECONOMIC IMPACTS AND MITIGATION MEASURES

5.a INTRODUCTION:

The environmental and socioeconomic impacts of desalination plants can be both positive and negative, and are highly variable from site to site. Due to the diversity of desalination plant technologies, designs, and capacities and the uniqueness of each site selected, impacts cannot be generalized and should be assessed on a site-by-site basis. The manner and magnitude of the impacts sustained is dependent upon the influences of several emergent factors including: overall plant design and operation, methods used for seawater intake and effluent disposal and specific physical and biological conditions of the site. While there are a number of potential negative impacts that can occur, desalination also is associated with a number of noteworthy positive impacts; these will be covered in the *Section 5.b* of this report.

Generally, impacts of desalination plants fall into several major categories, which will be discussed in the subsequent sections of this chapter. These include: construction impacts, intake and discharge-related effects, impacts related to energy use and emissions, adverse effects on land use, and various socio-economic impacts. Some of the impacts of desalination plants are direct, resulting explicitly from the construction or operation of the desalination plant such as impacts associated with the discharge and intake of the plant. Others are indirect, such as the impacts resulting from population growth due to the increased availability of water that desalination plants make available.

Since desalination plants vary in size enormously, the capacity of the desalination facility clearly has a considerable influence over the degree of environmental impacts incurred. This variability in size is apparent in the Monterey Bay region where capacities for desalination plants being proposed range from less than 50,000 gallons per day to as much as 20 million gallons per day (MGD) or larger. With a capacity of 25 MGD, the largest seawater desalination plant in the U.S. is located on Tampa Bay in Florida, however this plant is not currently operating. However, there are several proposals currently moving forward in southern California with up to 50 MGD capacity. The largest existing seawater reverse osmosis desalination plant in the world is located in Ashkelon, Israel, with a capacity of 75 MGD.

Plant design and operational practices also play a large part in determining what types of impacts occur as well as the magnitude of these impacts. For example, there are a number of design options available that can reduce or eliminate impingement and entrainment, or discharge-related impacts. The specifics of these technologies and practices are discussed in detail for each of the major categories of impacts, in ensuing sections of this chapter. Another aspect that can determine the degree of environmental impacts of a desalination plant is the existing regulatory environment where the desalination plant is being proposed. In some parts of the world it is possible to build a desalination plant with minimal consideration of the environmental and socioeconomic impacts, which can lead to serious degradation of the environment. This is not the case in California, which has some of the most stringent legislation and regulations for environmental protection. The following section about the various desalination plant impacts will primarily be discussed in the context of existing California regulations and environmental standards.

While growing, the body of literature available about the environmental impacts of desalination plants is small. Much of what is available is speculative in nature in the form of environmental impact assessments, such as Environmental Impact Reports (the standard document most often required for desalination projects in the Monterey Bay area), and not based on actual monitoring of seawater desalination operations. In other cases the studies have limited relevance for the specific conditions of the Monterey Bay area. As more and more plants come online in California there will be an opportunity to closely monitor the impacts and compare the actual operating conditions to those forecasted using models. This will be crucial to ascertain the actual impacts of a particular plant, to assess the accuracy of these predictive studies and ensure continued improvements in modeling techniques, and to help develop better mitigation measures and technologies to avoid future impacts.

In order to evaluate the impacts of a desalination facility objectively, it is important to consider that most other methods of obtaining municipal fresh water also involve environmental impacts, which can at times be substantial. This is apparent in the Monterey Bay area, where there are significant issues with salt-water intrusion and damage to anadramous fish or endangered species habitat caused by over-drafting of water from aquifers, rivers, and streams. In most cases, desalination plants are proposed in the Monterey Bay area in reaction to these issues as a replacement water source, rather than to produce a supplementary supply of municipal water. When considering the options for a new water supply, which may include dams and other major projects, desalination often emerges as an environmentally preferable option for meeting water needs.

Although desalination can cause adverse environmental effects, there are numerous mitigation measures that can be commonly employed, which are effective in minimizing or eliminating these impacts. Moreover, there are a growing number of emerging technologies that show promise for the future. This report provides a comprehensive overview of the various impacts, both environmental and socioeconomic, that can result from the construction and operation of a desalination plant; it also provides information on a wide range of available Mitigation and Avoidance Measures and makes some general recommendations relating to desalination in the Monterey Bay region.

5.b POSITIVE IMPACTS OF SEAWATER DESALINATION:

Desalination plants are associated with a variety of positive impacts, particularly in locations where water is in short supply and is not otherwise available, or where normal surface water use has harmed the ecology of a system. This section will identify and briefly discuss the major benefits of desalination, although it is not meant to be an exhaustive survey.

The benefits of desalination plants as identified in the State of California Water Plan Update (Department of Water Resources, 2005) are:

- *Increase in water supply*
- *Reclamation and beneficial use of waters of impaired quality*
- *Increased water supply reliability during drought periods*
- *Diversification of water supply sources*
- *Improved water quality*
- *Protection of public health*

The most obvious benefit of seawater desalination is that it generates a new source of water. In many California locations including the Monterey Bay area the development of new water sources is necessary due to current water shortages and growing population. Existing water sources are becoming increasingly limited due to historic over-drafting and issues with water quality. Desalination, along with a limited number of other options such as increased conservation and recycling are among the few feasible alternatives available in many California coastal communities.

An aspect of seawater desalination plants that is particularly attractive to proponents in dry areas such as California is their ability to operate completely independent of the climate and weather patterns and therefore are not susceptible to inevitable shortages in natural water supply. This “drought resistant” characteristic of desalination plants enables them to produce a reliable supply of water during drought conditions, when many other conventional water supply resources can fail. In addition to being a reliable source of water, desalination plants also produce very high quality product water, free of pollutants, carcinogens, organic substances, viruses or tastes and smells, when compared to other sources (Einav, 2003). It should be noted however that the process would likely be more expensive during droughts, because of the higher electricity costs during those same periods (Pacific Institute, 2006).

An often-overlooked benefit of desalination is protection of public health. This is particularly true in other locations that experience unsanitary conditions in the water supply, leading to adverse human health effects. By either using desalination membranes to clean impaired drinking water sources, or by replacing them with high quality water from seawater desalination the health risks from drinking water can be reduced considerably.

Desalination, if properly planned and mitigated, may be able to provide future environmental benefits. Water produced can be used to replace depleted conventional sources, such as rivers and aquifers, and therefore restore in-stream flows. Several of the desalination proposals for the Monterey Bay area would provide environmental benefits. For example, CalAm’s Coastal Water Project, Monterey Peninsula Water Management District’s Sand City proposal, and Pajaro Sunny Mesa’s Monterey Bay Desalination Project are all being pursued because historic levels of extraction have resulted in damage to the Carmel River ecosystem and/or because of increasing levels of saltwater intrusion to local freshwater aquifers. CalAm’s Coastal Water Project has been proposed to offset pumping of water from the Carmel River, after being ordered by the State Water Resources Control Board to decrease by 70% the amount of pumping from the river; this reduction would result in obvious environmental benefits. Although the Moss Landing power plant is causing significant impacts, the desalination plant as proposed would not likely result in additional impacts as long as the power plant's once-through cooling system continues to operate. Another desalination plant proposed by the City of Santa Cruz would prevent significant impacts from pumping of surface waters during droughts, and would only be operated during specific drought conditions. In a project located north of the Monterey Bay area in San Rafael, a desalination plant proposed by the Marin Municipal Water District would mean that the County would no longer withdraw water from the two rivers (the Eel and Russian Rivers) from which they currently acquire a portion of the municipal water supply. It should be noted however, that with the exception of one case there is not an existing binding regulatory or legislative mechanism that will insure that commitments to the environment are met. For example, in Marin County there is no insurance that the water purveyor (The Sonoma Water District) will not transfer the water rights by selling them to another supplier. The one current exception is the proposed CalAm plant in Moss Landing, where *State Order 95-10* will ensure that the water that is being returned to the Carmel River will remain in the River.

5.c CONSTRUCTION RELATED IMPACTS OF DESALINATION PLANTS

5.c.i *Overview of Construction Impacts*

Desalination plants, like any other major coastal construction projects, have the potential to bring about significant impacts to marine and terrestrial environments. Construction of a desalination facility, especially if new offshore pipeline construction is involved, can result directly in impacts to seafloor, surf zone, and beach and dune ecology (though these can be avoided/mitigated through drilling, tunneling, and other techniques), and can result in disturbances to wildlife. Facility construction can also inconvenience and disturb local residents and interfere with recreational and commercial activities in the vicinity of the project. Major issues associated with the construction phase include water quality degradation from runoff, seafloor impacts, noise pollution, and the potential for chemical or fuel spills on the site. Construction impacts are generally mitigated using Best Management Practices (BMPs); some of these strategies are discussed in the next section on mitigating construction impacts (California Stormwater Quality Association, 2003).

Construction of desalination facilities can directly or indirectly lead to impairment of surface water quality in the nearby ocean, estuaries, streams or rivers. Grading, removal of vegetation, excavation, de-watering, and other construction-related activities can affect surface water quality through the introduction of sediment, nutrients, bacteria and viruses, oil and grease, metals, organic pollutants, pesticides, and gross pollutants such as trash and debris (California Stormwater Quality Association, 2003). Due to the proximity to the ocean of seawater desalination sites, runoff from the construction site will ultimately be deposited into the ocean unless preventative measures are taken. Most coastal construction projects present the potential for chemical spills resulting from activities such as the operation of heavy machinery or transport of hazardous materials. This can lead to contamination of the runoff water with hazardous chemicals including fuels, oils, solvents and other substances commonly used on the job site. Another issue is that in some cases excavation activities can expose previously contaminated soils. This is an important consideration since desalination plants are often located at previously disturbed industrial sites. Exposure of these disturbed soils to wind and rain can cause them to erode and be released into the environment. Finally, construction projects can affect water quality indirectly through an increase in impermeable surfaces, which increase levels of stormwater runoff.

Construction of intake and discharge pipelines and other structures located in the marine environment can result in negative environmental effects. Sediment is often excavated, which can cause disturbances to soft bottom habitats and the water column as this sediment becomes suspended and increases turbidity in the water. Studies of biological communities in nearshore soft-bottom habitat have demonstrated that such communities typically take one to three years to recover from disturbances such as those from boat anchors. High topographic relief habitat can be particularly vulnerable to environmental disturbance from construction activities (EDAW, 2005). Rocky substrate also can sustain adverse environmental effects, such as the potentially significant impacts caused by the laying of pipelines and other construction activities (Einav, 2001). Another potential impact at some plants is related to drilling beneath the seafloor to install intake and outfall structures; use of lubricants such as bentonite clay or petroleum can potentially cause negative impacts to adjacent water bodies (EDAW, 2005).

Wildlife disturbance due to construction-related noise and activity can be a significant issue as well in the Monterey Bay area. Construction projects have the potential to cause disturbances to marine and terrestrial organisms, including some particularly sensitive marine mammal and seabird and shorebird species and other protected animals. The temporary noise and disturbance of the construction project can cause marine mammals and seabirds to avoid the area, and potentially abandon their young, often resulting in juvenile mortality. In the Monterey Bay area, species with potential for disturbance include snowy plovers and harbor seals, which often haul out on coastal rocks. In addition to direct disturbances, habitat degradation or destruction due to construction can also impact local species.

5.c.ii *Mitigation and Avoidance Measures for Construction Impacts*

There are a large number of options available for mitigating the impacts of construction; these mitigation measures are referred to as Best Management Practices (BMP). Best Management Practices in the context of construction activities are defined as "any program, technology, process, siting criteria, operating method, measure, or device, which controls, prevents, removes, or reduces pollution" (California Stormwater Quality Association, 2003).

BMPs developed and implemented at construction sites may include specific measures to reduce runoff and sedimentation such as sediment retention or erosion control structures such as hay bales, sand bags, etc., or planting vegetation to restore of disturbed areas. They also should include measures aimed at avoiding water quality impacts including: placing water filters over storm drains, proper handling and refueling procedures, and seasonal restriction of certain activities (i.e. avoid certain activities during rainy season, or restrict construction activities during snowy plover nesting season).

Coastal construction projects in California are highly regulated. All major construction projects, including desalination plants, are required to have a construction plan that minimizes impacts to the marine and terrestrial environment. The Regional Water Quality Control Board (RWQCB) requires all construction projects with the potential to disturb one or more acres of land to obtain a General Permit for Storm Water Discharges from Construction Activity. As part of the permit process the RWQCB requires the development and implementation of a *Stormwater Pollution Prevention Plan*. This plan identifies BMPs for mitigating runoff and direct discharge into waterways and storm drains. Usually local jurisdictions will also require BMPs that are consistent with those of the State. The City of Santa Cruz, for example requires BMPs in conjunction with its Construction Site Storm Water Runoff Control Program (EDAW, 2005).

Using existing structures or building on a previously disturbed site can reduce impacts significantly, since it can preclude the need to build new structures and will not damage pristine habitat. For example, existing pipeline structures may be retrofitted and used obviating the need to construct a new intake or outfall and thus resulting in reduced impacts to the seafloor.

The impacts of constructing new structures can be avoided or minimized by using drilling or tunneling rather than placing structures on the seafloor, avoiding areas of hard bottom habitat or other sensitive areas, etc.

Another way to reduce potential impacts is by avoiding or minimizing the use of chemicals and substances on the jobsite that may adversely affect the environment. Alternatives may be available for a number of products; therefore, research should be done to identify those that are effective and least damaging to the environment. For example, while bentonite and other substances used for lubrication in the drilling process may cause negative environmental effects, there are biodegradable drilling muds that exist which have less impact on the environment.

Prior to construction, during the site selection process, the site should be assessed and monitored for preexisting contamination and environmental degradation. This site assessment should involve testing of the soils. For example, the proposed desalination plant in Santa Cruz includes provisions for a Phase 1 Hazardous Materials Site Assessment in conformance with American Society for Testing and Materials standards; if contamination in water or soil is detected, responsible agencies must be notified, and appropriate cleanup performed before construction of the facility commences (EDAW, 2005).

In order to devise strategies to avoid disturbances to marine or terrestrial organisms, it is necessary to conduct biological surveys prior to construction to gain a thorough understanding of organisms that reside or may be present in the project area, and to identify sensitive habitat. This will make it easier to avoid such habitat areas. For example high relief habitat, which is particularly sensitive to disturbances, should be avoided and moorings and anchors should be placed in areas free of sensitive organisms or habitats.

5.d INTAKE RELATED IMPACTS

5.d.i *Overview of Intake Related Impacts*

While environmental impacts related to the discharge of desalination brine were long considered to be of most concern, in California intake related impacts now are considered the aspect of desalination plant operation with the potentially most severe environmental impacts. A 2003 California Coastal Commission report on seawater desalination states: “the most significant direct adverse impacts of a desalination facility are likely to be caused by its intake” (California Coastal Commission, 2004). There is very little information available about the intake related impacts of seawater desalination plants, and especially when compared to the body of literature regarding discharge-related impacts. Much of what is known about these impacts is from studies based on coastal power plants, which tend to draw in significantly higher volumes of water. Desalination plant intake volumes and velocities are much less than power plant intakes; therefore the impacts are expected to be significantly less. Even so, because these are impacts that in many cases can be avoided entirely or mitigated, this issue will likely receive significant scrutiny during permit review. While potentially acute, there are a number of ways to mitigate entrainment and impingement impacts and even to completely eliminate impacts through the use of alternative designs and practices. These are discussed in the next section on mitigation measures for intake-related impacts. While it is relatively simple to assess levels of entrainment and impingement, it is very difficult and complex to estimate the actual impacts to the ecosystem that results.

All seawater desalination plants require a feedwater source, which is then treated to produce fresh water as a final product. In plants with larger production capacities, substantial volumes of seawater are required; the pumping of the feedwater into the plant can result in significant environmental impacts from ***entrainment*** and ***impingement***. Impingement occurs when organisms become trapped on intake screens due to suction from the seawater intake velocity, whereas entrainment occurs when organisms too small to be excluded by intake screens get drawn into the plant with the feedwater. Impingement and entrainment are regulated under Section 316(b) of the Federal Clean Water Act, and are often referred to as 316(b) impacts.

The coastal waters of the Monterey Bay are highly productive, due to extensive upwelling of nutrient rich waters from the Monterey Canyon. The seawater from the Bay contains a wide array of tiny photosynthetic plants and animals that drift freely in the water column, collectively referred to as plankton. This phytoplankton represents the foundation of the food web, providing sustenance for filter feeding species, which in turn are then preyed upon by larger animals. The animals (zooplankton) that make up the other “living” portion of the feedwater include both animals such as fishes and crabs that spend early life stages as plankton in the form of eggs or larvae (meroplankton), as well as other animals such as copepods that spend their entire lives as plankton (holoplankton). In the Monterey Bay this can include fish eggs and larvae, larval crabs, mollusks such as abalone, clams, and mussels, and echinoderms including sea urchins and sea cucumbers. In addition to the phytoplankton found in the seawater, spores and seeds from various species of algae, seagrass, and potentially marsh plants are also present; while often overlooked, abundances can be significant: in the waters around a kelp forest levels as high as 10^{10} giant kelp spores/1,000 m^3 can occur (California Energy Commission, 2005).

Similar to negative environmental impacts from other aspects of desalination plant operation, the magnitude of impacts due to entrainment and impingement vary enormously among desalination plants. Therefore, when assessing the impacts caused by the intake of a desalination facility, it is essential to consider the technology and operational practices used, the actual volumes and velocity of water being drawn into to desalination plants, and the species composition and abundance of the surrounding water.

While the intake related impacts of a large desalination plant might be considerable, the impacts from coastal power plants using once-through cooling are typically several orders of magnitude more severe. Since much of the academic research regarding the impacts of seawater intakes is based on coastal power plants rather than desalination plants, misconceptions about the impact of desalination plant intakes can exist. Power plants in California typically take in volumes of cooling water that are exponentially larger then the volume of feedwater required for desalination plants. CalAm's proposed desalination plant at Moss Landing would require up to 24 MGD of feedwater to produce volumes as high as 10 MGD of product water. On the other hand, the Moss Landing Power Plant is permitted to draw in as much as 1.226 billion gallons per day (CalAm, 2005). Still, for desalination intakes that would entrain sensitive or listed marine species or would result in further reductions of already depleted fish stocks, the impacts, while smaller, may still be considered significant. Not surprisingly, intake volumes (and intake technologies) vary to a large extent among the proposed plants in the Monterey Bay area.

Another indirect consequence resulting from the intake of large volumes of seawater is the dead impinged and entrained organisms that are ultimately discharged along with the brine effluent, potentially resulting in impacts such as a decreased oxygen levels and addition of nutrients. Since this issue is associated with the desalination plant outfalls, it is examined in a subsequent section on discharge-related impacts.

Entrainment and impingement of special status species may also be an issue with some desalination plants. In the Monterey Bay area some of the species of special concern potentially impacted by a desalination plant intake include abalone and certain species of rockfish. Entrainment or impingement of threatened and endangered fish species is not expected to occur in the Monterey Bay area, since chinook and coho salmon eggs and larvae are not present in the marine environment and adults are strong enough swimmers to be able to avoid being impinged against the intake screen (EDAW, 2005).

Due to technical and cost issues current entrainment studies do not account for plankton smaller than approximately 0.3mm. The result of this is that only impacts to fish and crab species (since larvae and eggs are relatively larger than other forms of plankton species) are assessed, and current studies do not account for the potentially significant ecosystem impacts caused by the entrainment of other organisms (California Energy Commission, 2005). Recent studies suggest that abundances of animals smaller than 0.3mm may be high; a study whereby molecular markers were employed to detect mussel and clam larvae entrained in the Morro Bay Power Plant suggested abundances as high as one million organisms per $1000m^3$ seawater.

The most common type of intake for a desalination plant is from surface water located 1-6 meters deep. This area tends to have high concentrations of organic and inorganic matter including sediments, fish, algae, and invertebrates. Depths of greater than 35 meters are optimal for intakes, since the amount of material contained in the water is at least 20 times less than that of the near shore shallow waters. One researcher notes "the best location for desalination plants are the so-called deep water locations where seawater depths of 35 m can be reached within 50 m from the shore line. The requirements for additional pre-treatment are low" (Gille, 2003). However, most existing desalination plants are located on shorelines where 35 m depth occurs at least 500 m offshore. Due to the high expenses associated with construction of pipelines, it may not be economically feasible to construct a pipeline greater than 500 m in length (Gille, 2003), however in some cases, for example, when the deeper water requires less pre-treatment, some or all of the additional construction costs could be recouped during the desalination facility's operational life.

In addition to impacts associated with drawing water into the plant, the presence of the structure itself can result in negative impacts to the marine ecosystem. These types of impacts are known as *placement impacts*, and they occur when the existence of a structure covers up or otherwise alters pre-existing habitats or conditions. The structure can also cause negative impacts to recreational or commercial activities; these types of impacts are discussed in *Section 5.j.* of this report. There are also potentially significant impacts related to the construction of an intake structure, and this is discussed in the previous section on construction impacts (5.c). Finally, visual or aesthetic impacts can also occur, these are discussed in *Section 5.j.* of this chapter.

Impingement*:*
Impingement rates from a desalination plant depend on the intake design and location and the velocity of the feedwater. While impingement impacts from a power plant once-through cooling system can be severe, desalination-related impingement is relatively easy to mitigate and is not a major issue of concern if the intake system is properly designed and operated. There are no associated impingement impacts with sub-surface intakes; it is an issue solely associated with surface water intakes. Impingement mortality is typically due to asphyxiation, starvation, or exhaustion due to being pinned up against the intake screens or from the physical force of jets of water used to clear screens of debris (California Desalination Task Force, 2003). The impacts of impingent are typically assessed solely on impacts to commercially and recreationally fished species, while impacts to other species are considered "negligible" (California Energy Commission, 2005).

Impingement impacts from a coastal power plant can be significant, in some cases causing fish mortality equivalent to the take of a fishery. An assessment for the Huntington Beach power plant examined the impingement impacts of eleven power plants located on the southern California coast. The estimated combined total impingement mortality was approximately 3,600,000 fish (58,000 lbs.). Surprisingly, one power plant, the San Onofre Nuclear Generating Station, accounted for a full 97% of the individual fish deaths, and 83% of the overall biomass. When compared to the overall production of the Southern California recreational fishing industry, overall impingement levels from these once-through cooling systems were estimated to amount to 8-30% of the recreational fishing totals for Southern California (California Energy Commission, 2005).

Entrainment*:*
While entrainment is an issue typically associated with coastal power plants, it occurs in all coastal facilities that draw in water from the ocean, including desalination plants. Entrainment occurs when marine organisms, including fish eggs, larvae, and plankton, that are small enough to avoid being trapped against intake screens, are sucked into the desalination facility. Since entrainment typically results in death a 100% mortality rate is assumed. Mortality usually occurs as a result of pressure changes within the facility components. Entrainment has the potential to affect biological population levels by repressing recruitment, which could affect commercially valuable fish populations (Pacific Institute, 2006)

While sub-surface intakes may be able to reduce or eliminate entrainment impacts, all desalination open water intake systems will cause a certain degree of entrainment; however, measures can be taken to mitigate against this. Entrainment impacts vary widely, based on the amount of seawater required by the facility; intake velocity; location, depth, and existing biological conditions of the affected area of the intake structure; and the technology being used (California Coastal Commission, 2003). To predict and assess impacts from a desalination plant intake, a site-specific study is necessary to identify habitats and species in the area that might be vulnerable to impingement or entrainment.

It was determined in a study based on the Moss Landing Power Plant (MLPP) in the Monterey Bay, the following fish species experienced the highest levels of entrainment: various goby species, Pacific staghorn sculpin, blennies, white croaker, and Pacific herring. (California Energy Commission, 2005).

5.d.ii ***Mitigation and Avoidance Measures for Intake-Related Impacts*:**
While desalination intake volumes can be sizeable and environmental impacts have the potential to be substantial, in many cases there are ways to mitigate so that there are little or no impacts. The intake technology chosen for the desalination plant will in part determine the subsequent impacts. For example, certain types of sub-surface intakes are expected to minimize or eliminate entrainment impacts, whereas other types of surface water intakes have a much higher likelihood for concern. Intake options, however, are

limited by the hydro-geological conditions at the site, as well as economic considerations and permitting (Campbell, 2005). There are several proven methods of reducing impacts. The first choice is to use a sub-surface intake; however, conditions are not always well suited for that type of technology. In many situations, surface water intakes are the only available option; with these intakes, impingement and entrainment cannot be avoided altogether, but there are several ways to mitigate such impacts, including a reduction in the velocity flow of feedwater into the plant, and use of a fine-mesh screen to exclude organisms from being entrained. When an open water intake is the only feasible option, then several alternative locations should be studied for their sensitivity, to determine the most compatible location for an intake structure. Placement of the intake should be based upon oceanographic conditions, habitat type, and sensitivity of organisms and communities living in the vicinity of the intake (California Coastal Commission, 2003).

Whereas impingement can be avoided relatively easily for desalination plants, entrainment impacts from open water intakes are much more of a challenge to address since entrained organisms are too small to be screened out and are unable to swim against the current created by the intake. One option is to minimize impacts by choosing a site that that does not have high biological productivity. A variety of studies are available to assist with the selection of a site that will result in fewer entrainment and impingement impacts, and these include monitoring and assessment of currents, wave patterns, and tides and their interaction with marine biological communities (California Coastal Commission, 2003). Most desalination plants using open seawater intakes pump water from depths between one and six meters, where there tends to be high biological productivity due to a number of factors, including the penetration of light for photosynthetic activity and high nutrient levels due to runoff from land. Seawater from deeper locations (below 35 meters) contains much lower abundances of organisms and suspended solids. It is therefore possible to minimize entrainment impacts by locating the intake in deeper waters. There are, however, a few disadvantages associated with this. First, due to the longer distance of the pipeline, additional costs are incurred from construction and operation, which can render it cost prohibitive. A longer pipeline also means more potential construction-related impacts. Also, deeper water is colder, and therefore not as efficiently desalinated (California Desalination Task Force, 2003). Another potential method of avoiding impacts is to use seasonal or temporal restrictions; this involves limiting the use of the desalination plant during certain seasons or times of the day where there are high abundances of plankton or special status species in the seawater.

Due to the potential to significantly damage the marine environment, intake-related impacts will require an extensive level of analysis and review by regulatory agencies. In California, for example, coastal desalination plant proponents are required to evaluate a number of issues prior to submitting a permit application for review by the California Coastal Commission. These issues include: the feasibility of using velocity caps and screening devices; proposed velocity rates; and proposed mitigation measures. The California Coastal Commission, prior to consideration for approval, will also require a review of the feasibility of using a sub-surface intake. Information required as part of the subsurface intake feasibility study may include: a bathymetric (seafloor) survey; sediment core samples; analysis of historic and current beach profiles and regional sediment transport patterns; cost estimates for construction and operation of a subsurface intake; and mitigation and monitoring plans to address the issue of erosion at the intake structure (California Coastal Commission, 2003).

To determine the scope and degree of the mitigation for intake-related impacts, extensive studies are necessary to identify the degree of entrainment impacts. The U.S. Environmental Protection Agency requires that all power plants with open water intakes conduct what is referred to as a 316(b) study to evaluate the effects of the plant's intake system on the marine environment. Desalination plants using surface water intakes will require a study equivalent to a 316(b) study, to evaluate entrainment and impingement over time. This study will look over an extended period of time to evaluate seasonal and inter-annual changes. For example, upwelling in the spring and summer brings nutrient-rich water and changes conditions completely from the fall and winter.

Subsurface Intakes:

It is widely assumed that the most effective way to minimize or eliminate entrainment and impingement impacts is through the use of subsurface intakes, since these do not acquire feedwater directly from the ocean (California Coastal Commission, 2003); it should be noted however, that this reduction in entrainment and impingement has not as of yet been scientifically validated or measured.

These intakes, often generically referred to as beach wells, are located onshore, below the surface, or offshore, beneath the seafloor. Subsurface intakes encompass a wide range of designs and technologies and include vertical and radial beach wells, infiltration galleries, and HDD wells. They offer a number of potential advantages over surface water intakes, including reduced construction, permitting, and operation costs; more consistent and better quality feedwater; mitigation against impingement and entrainment impacts; and decreased need for pretreatment and use of chemicals (California Desalination Task Force, 2003b). These benefits are discussed in more detail below. Other potentially significant indirect benefits of subsurface intakes include possible resultant shoreline stabilization effects through dewatering of the beach, and provision of a barrier against salt-water intrusion (California Coastal Commission, 2003).

Subsurface intakes work by drawing in feedwater through a substrate such as sand, which eliminates impingement and entrainment and acts as a natural filter. This filtering action provides the additional advantage of reducing the need for prefiltration and the use of chemicals. In addition to mitigating environmental impacts, subsurface intakes also result in reduced costs related to plant operation such as those associated with the transportation of solid wastes from the prefiltration process to a landfill.

Beach wells are the proposed intake technology in one-third of the proposed plants in California (Pacific Institute, 2006). The three most prevalent subsurface intakes for desalination plants include beach wells, infiltration galleries, and seabed filtration systems (Poseidon Resources, 2005). Radial beach wells are the most commonly used subsurface intakes for larger-capacity plants. Subsurface intakes are often limited in capacity, although there are plants operating elsewhere in the world that can take in as much as 45 MGD through subsurface intakes.

It is necessary to carry out a comprehensive hydrogeologic study to determine whether or not conditions at a site are favorable for a beach well intake. Several aspects of the site will largely determine the feasibility of a beach well; these include the transmissivity of the geologic formations, the thickness of the sediments, and the presence of fresh water aquifers, which can become contaminated with seawater due to the intake (Pulido-Bosch et al., 2004). To build a successful beach well specific geologic conditions are required: transmissivity should be more than 1000 and sediments of at least 45 feet in depth are preferable (transmissivity can be determined by multiplying the hydraulic conductivity by aquifer thickness). Unfavorable conditions for beach wells include beaches with high volumes of mud or alluvial deposits and a low degree of “flushing”, such as a beach in a shallow bay environment. It is necessary to have a sufficient amount of circulation or wave action to carry away fine-grained sediments that can potentially accumulate and cause the beach well to become blocked (Voutchkov, 2002).

When subsurface intakes are not feasible, it may also be possible to retrofit an open water intake by constructing a large box filled with sediment, around the intake. By doing this entrainment and impingement impacts may be reduced or eliminated (California Coastal Commission, 2003). Other subsurface alternatives to beach wells include infiltration galleries and seabed filtration systems.

Beach wells can result in economic benefits since in comparison to surface water intakes they are relatively easy to build and maintain. Since surface water intakes are often complex to construct, extending hundreds or thousands of meters from the shore to the feedwater source, they can potentially account for 10-20% of the overall cost of a desalination plant (Voutchkov, 2002). In a study comparing costs of various subsurface intake technologies with surface water intakes, the authors identified significant cost savings of beach wells over surface water intakes for plants ranging in size between 1.6 and 24 acre-feet per day. For plants of a capacity of 2000 cubic meters per day beach wells were approximately one-half of the cost of surface water intakes for capital, operation and maintenance costs (Wright, et. al., 1997). There are many other costs such as transporting solid wastes from the prefiltration process to a landfill that would be minimized through the use of subsurface intakes (California Coastal Commission, 2003).

By mid 2004 there were only four seawater reverse osmosis facilities with capacities larger than 5.3 MGD throughout the world using beach wells for intake. The largest of these plants, located in Malta, has a capacity of 14.3 MGD, and has been in operation since 1991. Another plant located in Palma, in Spain’s Canary Islands, uses 16 vertical beach wells (each with a capacity of 1.5 MGD), to draw in a total intake volume of 11 MGD (Voutchkov, 2002). Construction materials for beach well casings must be highly corrosion-resistant due to the aggressive nature of the subsurface intake water. Plastic is often the best material for this purpose, as even stainless steel may not offer adequate protection (Pulido-Bosch et al., 2004).

The quality of the feedwater from a beach well is typically of a higher quality than that from surface water intakes, with lower levels of suspended solids, silt, grease and oil, and macro- and microorganisms. In certain cases beach well-sourced feedwater is of a lower salinity than the seawater, resulting in increased efficiency for the desalination process (Voutchkov, 2002). The proposed City of Sand City desalination plant will use a beach well to draw brackish water from an aquifer beneath the beach; the existing Marina Coast Water District desalination plant, when operating, also uses brackish water from a beach well.

The existing Marina Coast Water District desalination plant uses a vertical beach well as an intake, and proposed plants in Sand City and Marina would also use beach wells. While subsurface intakes can be ideal in some scenarios, conditions often are not favorable, rendering this option infeasible in other cases. To determine whether or not sub-surface intakes can be effectively used at a particular site without the risk of causing saltwater intrusion, it is necessary to conduct geotechnical and hydrogeologic testing. For example, Santa Cruz considered using subsurface intakes during its site assessments and preliminary design work for its proposed desalination plant and determined that the geological conditions were not favorable for beach wells and ruled out their use as an alternative (EDAW, 2005). Similarly, the San Francisco Bay Conservation and Development Commission have determined that beach wells are not feasible for use in the San Francisco Bay (BCDC, 2004).

While there are a large number of clear benefits of using subsurface intakes there are also several potential issues and disadvantages to contend with; many of these potential concerns are associated with the use of subsurface intakes larger than 5 MGD. Large numbers of individual wells are often necessary to provide feedwater for larger plants, which can result in disturbance to significant areas of the shoreline. Even in an optimal situation, a 21 MGD reverse osmosis plant would require four operational wells and one “standby” well (5.3 MGD each). For radial beach wells, spacing between wells of 400 feet is necessary, resulting in a large footprint. Thus for a 21 MGD plant, this would necessitate at least 4.5 acres overall. In contrast, a submerged surface water intake for the same size plant would only require less than 2 acres as an overall footprint (Voutchkov, 2002). Beach wells for small desalination plants can be located completely below the surface, completely non-visible from the beach. However, for large capacity wells it may be necessary to locate the pump mechanism above the beach surface, due to the size of the pumps and associated components as well as for convenient servicing. This can result in visual impacts and significant alterations of the landscape, and can potentially interfere with recreational and commercial activities (Voutchkov, 2002).

Aquifers that are polluted with petroleum products, endocrine disruptors, heavy metals, and other contaminants can also present a problem for desalination plants, resulting in the need for additional pretreatment (Voutchkov, 2002).

The functional life of a beach well in certain conditions can be shorter than that of a surface water intake, with a typical lifetime of 15-20 years, whereas a surface water intake has an expected life of at least 30-50 years. The beach well, over its life, may experience diminishing returns in terms of feedwater yield. This most often is a result of "scaling" of the well collectors caused by chemical precipitates or bacterial growth, or by plugging of the well with fine sediments. Since the expected lifetime of a reverse osmosis desalination plant is 25-30 years, beach wells may either shorten that life, or necessitate a potentially costly construction of a second series of beach wells (Voutchkov, 2002). One major concern with the use of these intakes is that they can become plugged with sediment, which can cause irreversible failure or decreased performance. This commonly occurs during construction, where materials with minimal permeability, such as drilling muds, can cause problems (Missimer, without date). Beach well intake systems for seawater desalination plants are normally designed to provide 25% or more of standby excess capacity to compensate for these diminishing yields over time; this can increase the cost and overall footprint of the impacted area (Voutchkov, 2002).

An issue associated with beach wells that does not affect surface water intakes is the presence of elevated levels of Manganese and iron. This situation requires extensive pretreatment to avoid damage to the pretreatment system and RO membranes, which could ultimately shut down the plant. This issue was apparent in a California central coast desalination plant south of the Monterey Bay area at Morro Bay. This plant uses five beach wells to supply the 1.2 MGD plant, each providing 0.3-0.5 MGD of feedwater. Iron concentrations from the beach well feedwater are 5 to 17 mg/L, which is exponentially higher than concentrations in the seawater in the area. The Morro Bay desalination plant was constructed without a prefiltration system; however, within minutes of its initial operation the heavy iron concentrations had caused major problems with fouling of the plant components and required the installation of a prefiltration system that was more extensive than what would have been required by a surface water intake for the same plant. Another plant in Salina Cruz, Mexico had similar issues with iron and manganese, and necessitated the construction of a prefiltration system similar to what would be required for an open water intake.

Other contaminants not typically found in surface water intakes, that can be difficult to treat, may be present in feedwater from subsurface intakes. These may include endocrine disruptors or potentially carcinogenic compounds such as MTBE, NDMA, and 1.4-dioxane. Beach well intake water from the Morro Bay desalination plant was polluted with the gas additive MTBE due to a previously leaking gasoline tank located beneath the surface. Comparable issues were experienced at a small plant located on Santa Catalina Island that uses a beach well. Treatment of these compounds requires additional processes such as ultraviolet light, activated carbon filters, ozone, or hydrogen peroxide, which can significantly increase the cost of desalination (Voutchkov, 2002). While most beach wells offer the advantage, over surface water intakes, of buffering the fluctuations in water quality parameters such as total dissolved solids and temperature, this is not always the case; in some situations variations as much as 30% can occur. Feedwater from a particular beach well intake in Salina Cruz, Mexico varied between 16.8 and 21.8 ppt; this variation was due to the variable influx of fresh water into the aquifer being used as a source. In another more extreme example at the Morro Bay desalination facility, a feedwater salinity of 26,000 mg/L was observed in 1992 when the plant first went online. Subsequent measurements of the same beach well in December of 2001 and 2002 resulted in TDS levels of 6,300 mg/L and 22,000 mg/L, respectively. To mitigate these variations in salinity, it is necessary to employ variable frequency drives, which represent an increased cost for the plant. Since salinity of beach well feedwater can experience changes over time that are impossible to predict, this illustrates the importance of conducting testing over an extended period of time to account for a variety of circumstances and conditions (Voutchkov, 2002).

Usually surface water intake systems do not have highly variable salinity levels. An investigation for the proposed Huntington Beach desalination plant determined that salinity levels of the surface intake feedwater varied only 10% from the average feedwater salinity of 33ppt (Voutchkov, 2002). Salinity of the power plant cooling water, from which CalAm's proposed Coastal Water Project desalination plant proposes to acquire its feedwater, can vary significantly with tidal cycles (RBF Consulting, 2005). Estuarine intakes, Tampa Bay for example, can experience highly variable salinity due to storm runoff and tides.

Another issue associated with beach wells and not with surface water intakes is the typically low dissolved oxygen (DO) content of subsurface intake water, which normally is less than 2 mg/L, although it can vary between 0.2 and 1.5 mg/L. Since the dissolved oxygen concentrations are relatively unaffected by the RO process, this results in both a product water and brine concentrate with correspondingly low DO levels. The desalinated product water will require treatment to increase DO, which will include either re-aeration or treatment with considerable quantities of chlorine. The concentrate stream also may not meet USEPA dissolved oxygen standards for discharge to the ocean, of 4mg/L, and will also require re-aeration to avoid negative impacts to marine organisms; which may result in cost increases. Surface water intakes on the other hand have typical DO levels of 5-8 mg/L, reflecting DO of the surrounding seawater (Voutchkov, 2002).

Coastal erosion is another factor that can affect the long-term viability of a beach well. Sediment loss on the seaward side of a beach well can cause it to tilt, and can ultimately represent a major threat to the structure. The impacts of coastal erosion on desalination plants are discussed in more detail in *section 5.j* of this report. Subsidence can also be an issue with subsurface intakes wells due to dewatering, which can lead to compaction of the sediments, and this can slightly lower the elevation of the beach (Pulido-Bosch et al., 2004).

Finally, an issue of major concern with subsurface intakes is the potential for them to cause or exacerbate saltwater intrusion, if not properly designed and operated. One recognized method of minimizing the threat of saltwater intrusion is to concurrently pump salt water and freshwater into the same well in a ratio of 5:1. Another method is to create barriers against the saline wedge by pushing the wedge seaward via pumping seawater from below. In this sense, using beach wells to draw in desalination feedwater can actually provide protection against saltwater intrusion. Monitoring of the interaction of freshwater and saltwater is crucial to the use of any subsurface intake system. This is most effectively accomplished using sensors that detect conductivity; monitoring should include the both the freshwater and seawater heads as well as the interface between them.

Conversely, use of coastal aquifers as a seawater source can result in "freshwater intrusion", whereby the freshwater moves from the land towards the ocean (Pulido-Bosch et al., 2004).

Vertical beach wells are relatively simple structures composed of a single caisson submerged in the sand to a depth of 250 feet or less, usually constructed of a non-metallic material (concrete, fiberglass, etc.), and a stainless steel pump. The diameter of the caisson usually varies between 6 and 18 inches depending upon the capacity of the well (Poseidon, 2005). While vertical beach wells are simpler in design and less expensive to build than radial wells, they typically yield much less feedwater (normally limited to 0.1 to 1.0 MGD), and thus have limited applicability for larger plants (Voutchkov, 2002). A vertical beach well is used as the feedwater intake at the existing Marina Coast Water District desalination plant.

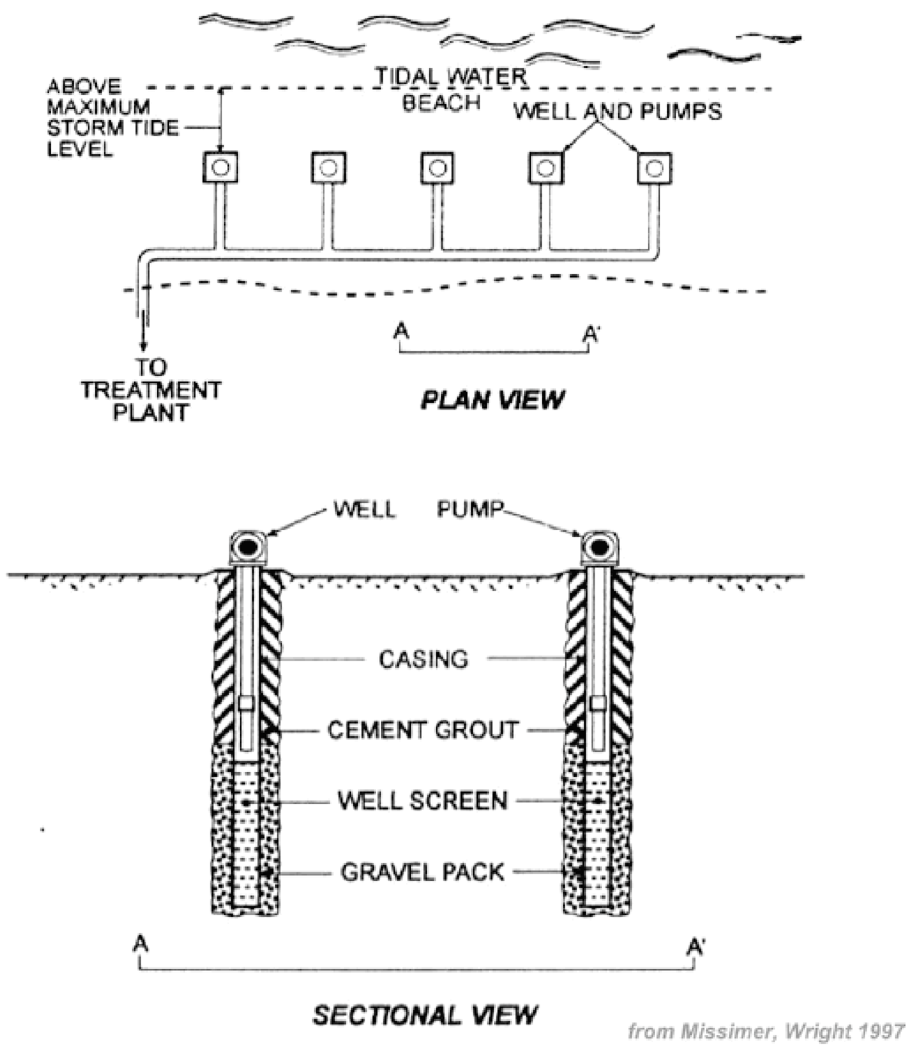

Figure 5.1. Vertical beach wells

Radial beach wells, also referred to as horizontal beach wells or Ranney collectors, are a type of subsurface intake that uses a similar design to a vertical beach well, but it employs several horizontal "arms" to collect the water. These radial collectors are attached to a caisson in the center, which is 13 feet or more in diameter (Missimer, without date), at a depth of 30 feet to more than 150 feet. Radial beach wells typically yield between 0.5 and 5.0 MGD (Poseidon, 2005). While these wells have been used in a variety of situations and locations, they have been met with mixed success. Some of the primary issues with the wells with poor performance records include improper design and construction, incompatible geologic conditions, and plugging of the sediments surrounding the horizontal intake collectors or plugging of the collectors themselves. The most advantageous conditions for the use of Ranney collectors include "fractured igneous, metamorphic, or low-permeability sedimentary rocks", and performance is best with vertical fractures in the rock, rather than horizontal (Missimer, without date). Like other types of beach wells, the overlying sediment provides filtration of the feedwater. Ranney wells have been built with capacities of up to 25 MGD.

There are several prerequisites for a successful Ranney collector, including proximity to surface water or an aquifer. In many cases improper site selection resulted in unsuccessful wells; if the conditions are not optimal then another feedwater source should be pursued. Ideally, a Ranney well will have at least 40 feet of overlying sediment between the lateral collectors and the feedwater source, to prevent the intrusion of fine sediments that can arrest the flow of water into the laterals. In cases where the overlying sediment is not of sufficient thickness, it may necessitate periodic removal and replacement of the sediment. Other issues with Ranney wells include potential vulnerability to coastal erosion or wave action during storms (Missimer, without date).

The positioning of the radial collectors does not need to be symmetrical and sometimes it is better to place most of the collectors towards the seawater source. Also length of the lateral arms can vary according to the conditions and the required volume of feedwater, and the radial arms do not need to be perpendicular to the central caisson; they can be positioned at different angles to optimize intake volumes and velocity. Since it is impossible to predict the yield volume of feedwater from a Ranney collector prior to construction, it is often necessary to customize the design during construction by varying the number of radial arms as well as their length and orientation. High concentrations of fine-grained sediments can interfere with the efficiency of Ranney collectors by reducing their permeability to water. In addition, chemical precipitates, primarily calcium carbonate, can interfere although this problem is likely restricted to tropical regions and is not an issue in the Monterey Bay area.

Radial wells are probably not a feasible option on shorelines where the sediments have minimal permeability, or are less than 15m thick. If the well is installed in sediments with high permeability, it will likely not provide significant pretreatment benefits. Radial wells are also not normally feasible in "sheltered marine environments", due to the existence of mud and fine sediments that can clog the system (Missimer, without date). A large area of beach may be impacted when using radial beach wells for large desalination plants. An assessment of the feasibility of using radial wells as an intake for the proposed Huntington Beach desalination plant determined that in order to supply sufficient feedwater for the proposed capacity, a total beach area of 23 acres would be needed on which to place the wells (Poseidon Resources, 2005).

Due to optimal conditions along the southern Monterey Bay shoreline, radial wells are being proposed as intakes for the proposed desalination plants at the Marina Coast Water District, City of Sand City, and Monterey Peninsula Water Management District.

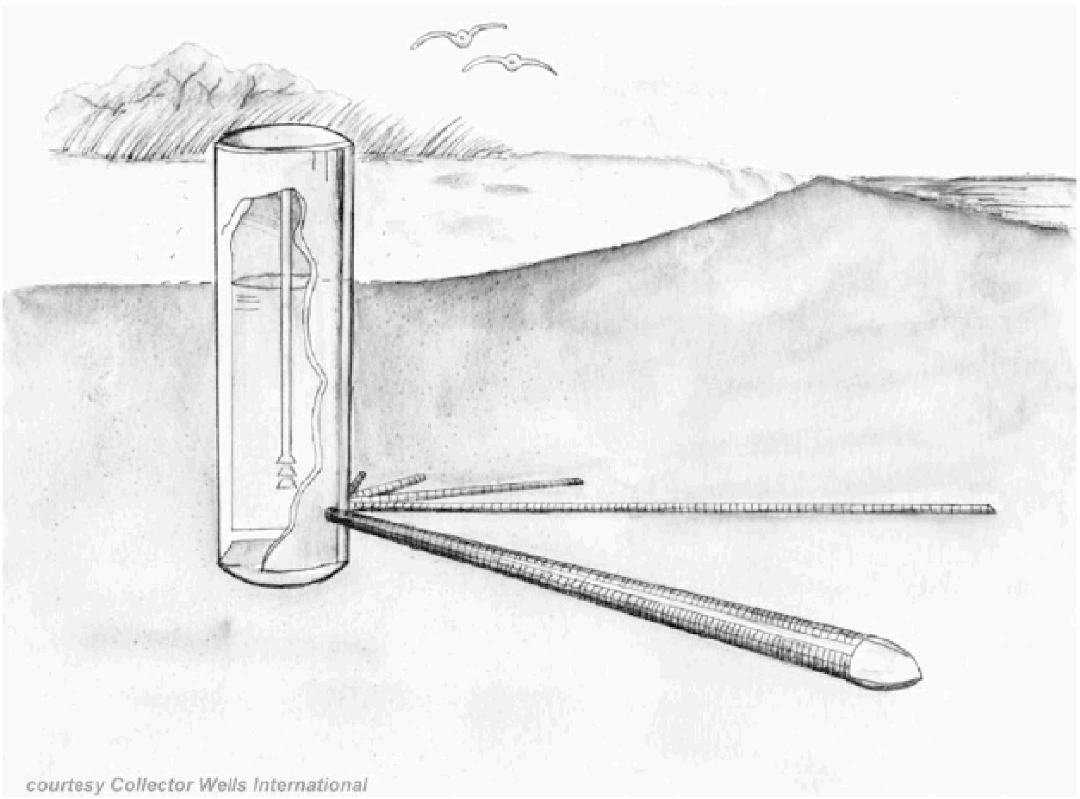

Figure 5.2 Radial beach well

Infiltration galleries are constructed by digging a trench, placing vertical or horizontal collectors in it, and packing it with a material similar to natural sediments used in beach wells, which provides filtration. These intakes are used when natural conditions are not compatible for a beach well, such as in cases where the sediments are not sufficiently permeable. The collectors are normally spaced out 100-200 feet apart and each is capable of collecting 0.2-2.0 MGD. Infiltration galleries are composed of three individual layers. On the bottom is 3-6 feet of sand, the center layer is packed gravel which surrounds the collector screens, and the top layer is 20-30 feet of sand. Infiltration galleries are typically only used when conventional beach wells are not feasible, since they are typically 15-20% more expensive (Poseidon Resources, 2004).

Horizontal directionally drilled (HDD) wells consist of a central caisson, which is supplied by a group of individual HDD wells; these wells are drilled along a horizontal axis, whereas most other subsurface wells are drilled vertically. HDD wells are being considered as an alternative for CalAm's proposed Coastal Water Project desalination plant. These were chosen for consideration instead of vertical beach wells, since they have less potential to cause saltwater intrusion to freshwater aquifers. The feedwater may require minor pretreatment to remove manganese and iron, using a greensand filtration system. This HDD system would include 2 HDD well clusters located at 2 separate parking lots for the Salinas River State Beach (one at the end of Portrero Road and one at the end of Monterey Dunes Way). It is expected that this HDD intake system would result in a more consistent and higher quality feedwater with lower turbidity and potentially lower salinity. The project would use two separate wells drilled at a 15-30 degree incline (below the horizontal axis), to a depth of about 125 feet beneath the seafloor, at which point horizontal "laterals" would extend out approximately 2,400 feet in a seaward direction at an approximate depth of 180 feet below sea level. The wells would convey the feedwater to two main caissons where it would be delivered to the desalination plant using a booster pump. While this option would be more costly than the proposed alternative of using the cooling water from the Moss Landing Power Plant, it would also reduce some costs of the desalination process due to: reduction or elimination of the need for a raw water equalization basin at the desalination plant site; reduced pretreatment and operation and maintenance costs; elimination of concerns about contaminants in the cooling water source; and reduced production of residual solids (sludge). Other expected advantages of using HDD wells rather than surface water intakes as a source of feedwater include more consistent and potentially lower salinity and turbidity of the feedwater, elimination of entrainment and impingement concerns, and the creation of a barrier against saltwater intrusion near the wells. Some of the expected disadvantages include: a higher capital cost, cooler feedwater, and increased power consumption from pumping of the feedwater (RBF Consulting, 2005). Moreover, the useful life of these wells may be significantly shorter than that of the desalination plant, which means that multiple sets of wells may be required during the operational life of the desalination plant; a surface water intake on the other hand, is expected to operate for during the entire operational life of the desalination plant (Voutchkov, 2006a).

The total capital costs for the HDD wells for the proposed CalAm Coastal Water Project desalination plant are projected to be $37,000,000 with annual operation and maintenance costs of $1,300,000; for the larger capacity regional option these costs are $58,000,000 and $2,200,000, respectively. Due to the use of existing infrastructure, the projected capital costs for the preferred alternative of using Moss Landing Power Plant cooling water as a feedwater source is $9,800,000 for the proposed option and $11,500,000 for the regional alternative. Annual operation and maintenance costs for the cooling water option are $96,000 for the proposed plant and $180,000 for the regional alternative (CalAm, 2005). These costs however, do not include potential mitigation requirements and costs if the power plant OTC system ceases to exist.

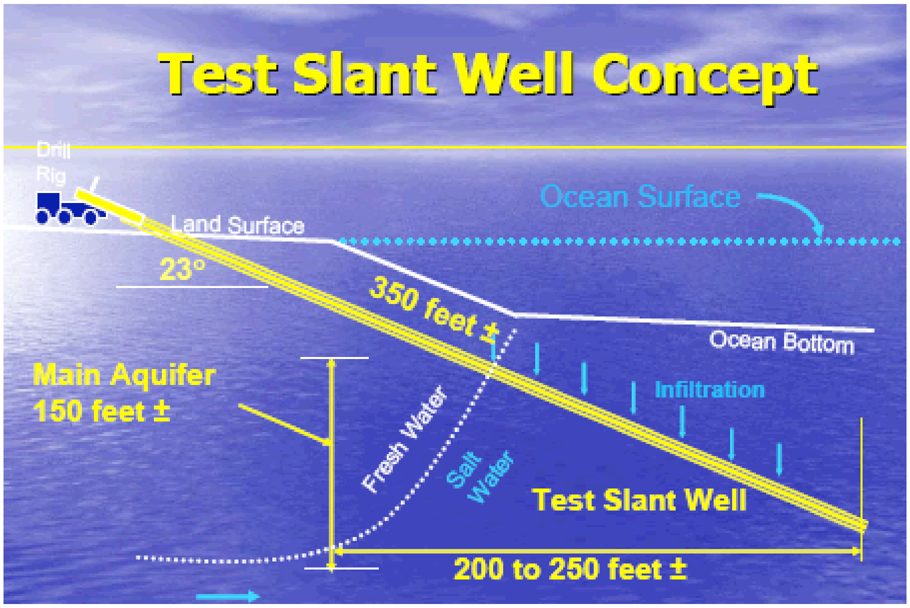

Figure 5.3. Dana Point slant well (MWDOC Prop 50 proposal, 2006)

Seabed filtration systems are another option available when conventional beach wells are not feasible due to hydrogeologic conditions. These intakes are usually located below the seafloor not far offshore in the surf zone. Similar to an infiltration gallery, they use sand and gravel as a filtration media surrounding one or more intake wells. This type of subsurface intake is the most expensive option, 20-130% more expensive than conventional beach wells. The largest seabed filtration system used as a desalination plant intake is located at the 13.2 MGD Fukuoka RO plant in Japan; the total area of the ocean floor covered by the structure is 312,000 square feet (Huntington Beach EIR, 2004). Similarly, a ***Subfloor Water Intake Structure System (SWISS)*** is an intake design consisting of a horizontally oriented well located 10-15 feet below the seafloor in conditions where the overlying geologic material is porous rock. The performance of this type of system was evaluated by the U.S. Bureau of Reclamation and was found to be very effective in removing colloidal solids, suspended solids, and organisms from the feedwater. They reported a reduced need for pretreatment and a reduction or elimination of maintenance to remove fouling organisms from the plant's components. While the testing showed promising results, this type of system has not been used in a seawater desalination plant (California Desalination Task Force, 2003b).

In a recently published study evaluating the following desalination plants in Spain using sub-sea floor intakes:

- A 45.6 MGD (172,800 m^3/d) RO plant at San Pedro del Pinatar, (2003).
- A 10.9 MGD (41,472 m^3/d) RO plant at Aguilas (2004)
- A 6.8 MGD (25,920 m^3/d) RO plant at Aguilas, Com. de Regantes, (2006)

The authors concluded that these systems have been successful in all three locations. They noted several benefits from the use of these intakes including: no effects on the physical and biological marine environments; no effects on the freshwater aquifers nor any saltwater intrusion issues; and, no need for excavation of the seabed (Peters, 2006).

Co-Location with power plant cooling water system:

Another mitigation option is the use of an intake that already exists (e.g. power plants). While these intakes are already permitted, their use for desalination plants will require additional studies to address entrainment/impingement concerns, and will necessitate a new permit or an amendment to the existing permit. Using an existing cooling water system from a power plant may offer several advantages. Environmentally, it may make sense to tap into the cooling water system from a power plant, if it will not cause any additional entrainment and impingement impacts other than those already being caused by the power plant. Many power plants, however, operate only part-time and so a desalination facility at those plants would cause additional entrainment. There are a number of other considerations regarding the costs and benefits of co-location; these are discussed in detail in *section 6.c* of this report.

Surface Water Intake Mitigation Measures

When subsurface intakes are not an option, open water intakes can be designed to minimize impingement and entrainment impacts. For example, an intake velocity of less than 0.5 feet per second allows many fish and marine organisms to swim against the current to escape being sucked into the plant or impinged against the screens. Likewise, restricting the use of the plant during certain seasons or times when there are high abundances of plankton or special status species in the seawater can reduce impingement and entrainment impacts. Another method is the use of variable speed pumps, which allow the plant operators to take in smaller volumes of water when the plant is not operating at peak capacity (California Energy Commission, 2005). Surface water intakes are being pursued for the proposed City of Santa Cruz and Ocean View Plaza desalination plants. The Santa Cruz plant would retrofit and use an existing but unused wastewater discharge pipeline as an intake. The structure extends 2,300 feet into the bay to a depth of 40 feet. The intake would use a screen with a mesh size of 0.1 inch; this size would exclude many fish larvae. The system would also use an air scour system to remove accumulated debris. The intake velocity of the plant would be limited to 0.5 feet per second, which would protect about 96% of fish species tested. An estimated intake volume of 2.4 times the plant capacity would be required (EDAW, 2005).

Another way to mitigate entrainment and impingement impacts is through the use of design options, which include physical barriers to prevent organisms from entering the intake; fish handling systems; diversion systems, which utilize bypasses to redirect fish to where they can escape; and behavioral barriers (California Energy Commission, 2005).

The location of the intake is an important determinant of the magnitude of impacts from a surface water intake system. It is possible to avoid impingement and entrainment impacts by locating intake structures away from the biologically active littoral zone, where light penetrates to the seafloor. This area, to a depth of about 100 meters, is known as the euphotic zone. Several factors come together to determine the abundance, diversity, and distribution of organisms; these include: water quality parameters such as salinity, temperature, and dissolved oxygen content; substrate type; geographic location; and oceanographic conditions such as currents and circulation (California Desalination Task Force, 2003b). Another option for avoiding these impacts would be to restrict the use of the plant seasonally, for example during times of high biological productivity.

Reducing the volume and velocity of the flow at the intake is an effective way to lessen entrainment and impingement from power plants and this is true for desalination plants as well. Flow reduction will result in a corresponding decrease in the rate of entrainment and impingement (California Energy Commission, 2005). Flow reduction can be achieved through the use of specific intake technologies such as wedge-wire screens. In addition to flow reduction, intake velocity can also be reduced to mitigate against entrainment. For example by enlarging the size of the intake pipe, it is possible to have the same flow coming through the intake while reducing the velocities. The U.S. Environmental Protection Agency recognizes reduction of through-screen velocity to below 0.5 feet per second, as *best technology available* (BTA) for impingement reduction.

Different types of screening technologies can be used to prevent impingement and in some cases entrainment as well. They must be designed to allow a sufficient amount of water into the plant, while preventing fish from being drawn in. There are a number of different screening technologies available, with varying degrees of costs and effectiveness.

Traveling screens use a rotating belt containing “screen faces”, as debris and organisms get stuck on the screen it rotates and a pressurized spray mechanism is used to displace accumulated debris from the screen. Traveling screens are standard equipment on California coastal power plants. These vary in effectiveness depending upon the velocity of water through the screen, the mesh size of the screen, and the pressure of the spray. Results from an assessment of various operating conditions of traveling screens determined that the higher the intake velocity the higher the resulting levels of impingement (California Energy Commission, 2005). Traveling screens typically include a fine-mesh screen with a mesh size of 5mm or less, designed to exclude eggs, larvae, and juvenile fish. A fine mesh can reduce levels of impingement, making it easier to escape, and entrainment, by restricting organisms from being pulled in. A specific kind of traveling screen technology known as a ***Ristroph Screen***, uses bucket-like containers to carry water containing fish away from the intake flows where they can escape. These systems minimize impingement but do not have any effect on entrainment levels, unless a fine mesh screen is also used. These fish handling systems can be expensive, ranging in price from an estimated $20-130 million for power plant intakes (California Energy Commission, 2005).

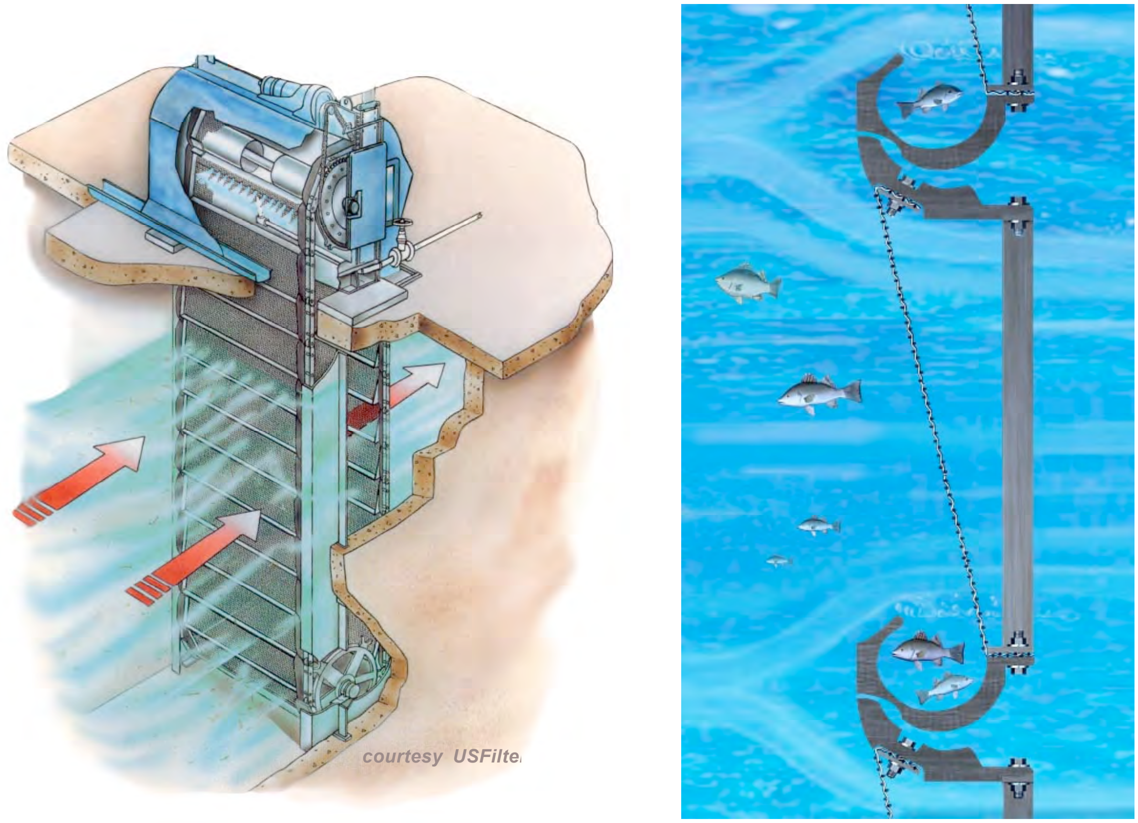

Figure 5.4. Ristroph Traveling Screen

Wedge-wire screens (also called cylindrical wedge-wire screens, profile screens, or Johnson screens) are another technological option for reducing both entrainment and impingement. The effectiveness of this type of screen is dependent up the screen mesh size being small enough to restrict eggs and larvae from passing through. Mesh sizes for these devices typically vary between 0.5-10 mm (California Desalination Task Force, 2003b). Low velocity flows through the screens will further reduce entrainment and impingement. In laboratory assessments of the effectiveness of wedge-wire screens in preventing entrainment and impingement of nine fish species' eggs and larvae, it was determined that mesh size of the device has a large influence over the resultant entrainment and impingement impacts, with lower rates for both processes associated with a reduction in mesh size. Both entrainment and impingement were at higher levels with higher velocity flows through the slots (California Energy Commission, 2005).

Figure 5.5 Wedgewire screen

Aquatic Filter Barriers**,** also known as ***fish net barriers***, are another technology that has recently been developed to minimize both entrainment and impingement. These devices are made up of semi-permeable polyester fiber mats, which allow the passage of water but restrict the passage of marine organisms. They consist of a netting of fine mesh screen that surrounds the intake area. These mats are used in conjunction with a system that sends out bursts of air to force accumulated debris off of the screen. These structures require an area of a sufficient size to ensure adequate water flow through the perforations in the screens; flow of water through the material is limited to approximately ten gallons per minute per square-foot of material, and therefore larger volume intakes will require a larger area. There has been limited experience with the use of aquatic filter barriers and they have never been used in conditions similar to those in California. The most studied intake using this device is located at a power plant on the Hudson River, where an investigation demonstrated an 80 percent entrainment reduction. Another study conducted in 2004 assessed survival rates of eggs and larvae of several fish species at different mesh sizes and flow velocities. Material with perforation sizes of 0.5 and 1.0 mm offered a high level of protection against entrainment, while material with 1.5 mm perforations was not as effective. One of the potential issues related to Aquatic Filter Barriers include their tendency toward bio-fouling, which can significantly reduce permeability of the barrier (California Energy Commission, 2005).

The larger size of these structures could also potentially raise issues related to navigational safety and other environmental concerns (California Coastal Commission, 2003).

Several intake technologies exist that essentially act as a behavioral deterrent by changing the direction of the flow of the feedwater going into the intake, since fish will notice the change in flow and avoid it. ***Velocity caps*** are devices, which can be used to mitigate impingement. These are typically concrete structures that are positioned over the intake and convert the flow of the intake from vertical to horizontal, which the fish can better detect and avoid (California Coastal Commission, 2003). ***Louvers*** consist of vertical plates oriented perpendicularly to the intake flow, and they convert the direction of the flow of water at the intake. ***Angled traveling screens*** are similar in concept, but instead of solid panels they use a mesh that allows through flow of the water. While these three options are effective in reducing impingement, they are not effective against entrainment (California Desalination Task Force, 2003b).

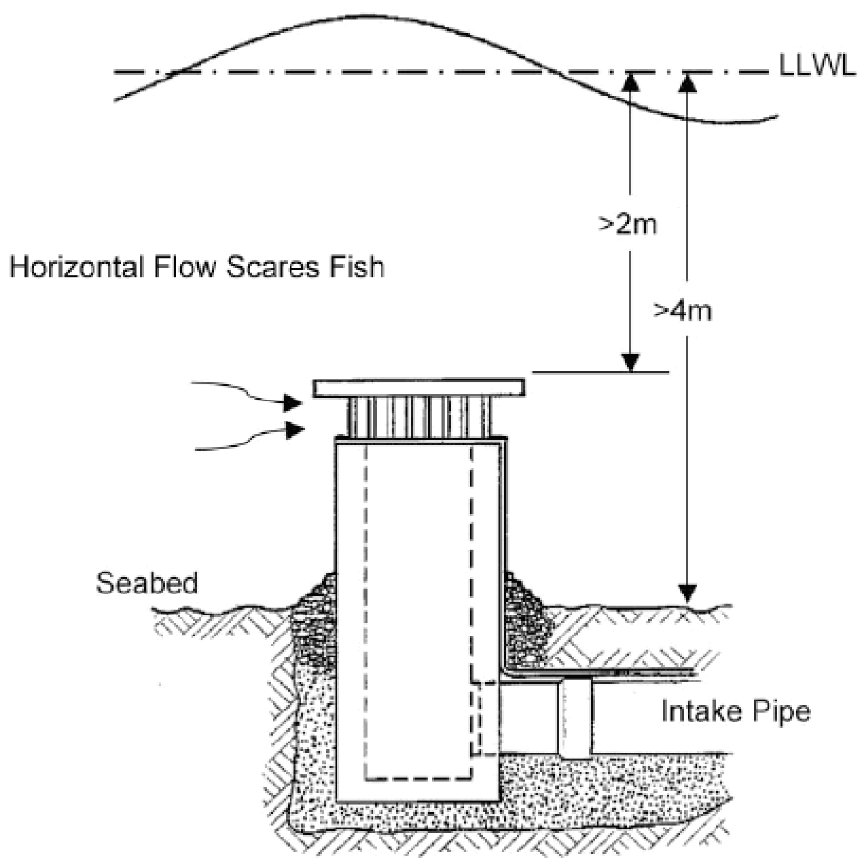

Figure 5.6 Velocity cap

Behavioral techniques for reducing impingement have been met with limited success. These techniques employ "sensory stimuli", like sound or light, to deter fish from entering the intake area and becoming impinged. Responses to various stimuli by fish are not well understood and vary considerably between fish species and conditions at the intake. Low frequency sound has not been shown to be an effective deterrent but high frequency sound (greater than 100 Hz) may be effective. Sounds are generated using compressed air or other devices, and include both "popping" and "hammering" sounds (California Desalination Task Force, 2003b). Use of light as a deterrent is another behavioral barrier method used, but its effectiveness can be limited severely due to turbidity in the water (California Energy Commission, 2005). Another disadvantage of the use of light as a deterrent is that while certain lights deter some fish species, other species may actually be attracted to that same light source. Lastly, air bubble curtains can be used as a behavioral deterrent by creating a constant screen of air bubbles, which fish may avoid (California Desalination Task Force, 2003b). A California Coastal Commission study in 2000 examining the effectiveness of behavioral barrier devices on fish at the San Onofre Nuclear Generating Station concluded that none of the various alternatives, which included several different types of light and sound deterrents, air bubble curtains, and electric screens, significantly reduced entrainment or impingement (California Coastal Commission, 2000).

Compensatory mitigation Measures

Compensatory mitigation is another way to address seawater intake impacts and the mortality of marine organisms, albeit a less desirable option. A hierarchy of preferred mitigation responses identified by the California Coastal Commission states that first impacts should be avoided, and then minimized; if this is not possible then the impacted area should be restored. Finally, if none of these is possible, then compensation should occur by "providing a replacement or substitute resource or habitat". Examples of this type of mitigation include fish hatching facilities, and habitat enhancement or restoration projects. These measures are based both upon the degree of impact to the marine environment as well as the "feasibility and effectiveness" of compensating for the marine organisms killed by the plant's intake. Often part of the mitigation is in the form of creating new habitat to compensate for losses. One potential consideration for the future of the use of compensatory mitigation is due to a recent Federal Circuit Court decision on power plant cooling water intakes, which determined that the Clean Water Act should constrain the use of compensatory measures for mitigating the environmental impacts (California Coastal Commission, 2004).

Often compensatory mitigation is used for coastal power plants, in the form of habitat restoration. Plant operators are typically required to restore an amount of habitat commensurate with the impacts of the plant or replace the same amount of organisms killed by the plant. An analysis recently completed for the Diablo Canyon power plant indicates that it would take 296-593 acres of rocky subtidal habitat to compensate for entrained larvae (California Energy Commission, 2005).

5.d DISCHARGE RELATED IMPACTS

5.d.i *Overview of discharge related impacts*

Seawater desalination plants produce two primary streams: the desalinated product water, and a highly saline waste stream, referred to as ***brine discharge***. One of the major concerns surrounding desalination facilities is the discharge of this brine into the marine environment, which can adversely affect marine organisms and ocean water quality. There are several distinct discharge streams that may be present in the effluent of a desalination plant, which have the potential to cause negative impacts. These include residuals from the prefiltration process, the actual brine concentrate from the desalination process, and chemical solutions that are used to clean the membranes (Mauguin and Corsin, 2005). In addition to high salinity and other constituents from pre-treatment or cleaning, desalination effluent may also contain entrained marine organisms that are killed during intake and enter the discharge stream (California Coastal Commission, 2003). Moreover, the discharge can cause impacts by increasing the turbidity of the receiving water, and due to the potential concentration (via the desalination process) of contaminants found in the feedwater source. Since it is denser than seawater, if unmitigated, the brine can sink to the bottom of the ocean and accumulate and spread along the seafloor, resulting in impacts to benthic organisms near the outfall.

Brine is technically defined as a waste stream containing a total dissolved solids concentration of more than 36 parts per thousand (ppt) (Younos, 2005). Although brine salinity varies with recovery rates, which typically range from 35-50% (the recovery rate of a plant is the ratio of product water to feedwater, a higher recovery rate means a higher salinity effluent), brine concentration is usually about twice as salty as ambient seawater. Typical salinity of California's coastal waters is 33 ppt, but this figure tends to fluctuate and can range from approximately 29 to 36 ppt, depending upon the season and oceanographic and atmospheric conditions (California Coastal Commission, 2003).

The actual make-up of the desalination plant's discharge stream can vary substantially based on facility design and operational practices used, as well as the quality of the feedwater (Einav, 2002). Seawater desalination plants require the use of a number of chemicals for pre and post-treatment of the seawater, and for cleaning and maintenance of the membranes and other plant components. Depending upon the specifics of each plant, many of the chemicals are removed from the discharge stream or neutralized, prior to being discharged (California Coastal Commission, 2003), but others may be discharged to the ocean with the brine.

The behavior of the brine plume and the magnitude of impacts are determined by the confluence of several variables: the production capacity of the plant, the properties of the brine concentrate, and the specific oceanographic and hydro-geological factors at the outfall (i.e. waves and currents, bathymetry, and depth of the water column). These factors will determine both the mixing of the brine with ambient seawater and the spatial extent of the plume (Sadhwani, 2005). As part of a study assessing brine discharge impacts, the plume at an RO plant in Antigua was monitored and the authors of the study concluded that the plume's size at any particular time was most influenced by the rate of flow at the outfall and by the tides. During ebbing tides or when the volume of concentrate being discharged is larger the plume was largest (Southwest Florida Water Management District, 2000).

Chemicals used for pretreatment and their residuals and by-products are present in the discharges to some degree. Unless subsurface intakes are used, in most cases RO plant performance can be seriously impaired without proper pretreatment of the intake water, and can even result in shutdown of the plant for cleaning or replacement of pipes and membranes. Growth of microorganisms like fungi and protozoa can cause severe damage in RO plants and can result in plant shutdown for cleaning or membrane replacement.

Biocide dosing is therefore, usually necessary in both RO and distillation plants that receive their intake from coastal surface waters, where productivity and thus the potential for fouling is high. Most desalination plants use chlorine because it is a strong oxidant, which makes it a very effective biocide. In RO plants, the chlorinated intake water is usually de-chlorinated prior to contact with the membrane, as most membrane materials are very sensitive to oxidation. Consequently, most RO discharges are characterized by very low to non-detectable levels of residual oxidants. Different chemicals can be used for neutralization; however, sodium bisulfite is most commonly used in RO plants. Although the reaction products are non-hazardous, overdosing should be avoided as sodium bisulfite may cause oxygen depletion, which is harmful to marine life. Plant size and design will influence the types and amounts of chemicals used. For example subsurface intakes can significantly lower or eliminate the need for the use of pretreatment chemicals.

RO membranes require cleaning on a periodic basis. This typically occurs 3 or 4 times per year and is done using primarily weak acids and detergents as well as caustic alkali (Sadhwani, 2005). After the cleaning process is complete and the cleaning agents have been circulated through the membrane, the membranes are rinsed with product water several times. In most cases the residual from the first rinse, which contains most of the constituents from cleaning, is then neutralized and diverted to a sanitary sewer for processing. The ensuing rinses are typically disposed with the brine. Tampa Bay's desalination plant, which experienced fouling problems and required higher than expected levels of membrane cleaning and maintenance, violated their discharge permit due to the presence of membrane cleaning chemicals (Pacific Institute, 2006).

During a monitoring study at a desalination plant in Antigua by the Southwest Florida Water Management District, scientists examined water quality parameters in the brine and assessed levels of chloride, copper, and aluminum in comparison with Florida water quality standards. The concentrate salinity of 57 ppt exceeded standards as expected. Copper concentrations for all samples were less than 1ug/l, which falls below Florida's water quality standard. Aluminum was well below state standards in all but one of the samples, and this was 2,520 ug/l above the state standard of 1.5 mg/l. The authors were unsure why aluminum levels were elevated in just one of the samples; one potential reason is that it may be associated with volcanic eruptions on the nearby island of Montserrat (Southwest Florida Water Management District, 2000).

The size of the brine plume and the extent of mixing at the outfall as well as the concentration and make-up of the effluent, will largely determine the overall discharge-related impacts from the operation of a desalination plant. The authors of a Southwest Florida Water Management District study (2000) visited six seawater RO plants and conducted observations and field surveys. They concluded that the brine plumes at all six facilities quickly became diluted to ambient salinities "within a relatively small area" and did not exhibit any evidence of accumulation of elevated salinity seawater, and that at one plant in Antigua, the salinity reverted to ambient levels within two to six meters of the outfall.

Since most desalination processes are either based on heating feedwater to high temperatures, or forcing it through a membrane at extremely high pressure, it is assumed that is will result in 100% mortality of entrained organisms. This can result in high levels of organic biomass present in the discharge stream, which can degrade water quality due to excess nutrients in the water, and can also cause human health concerns (California Coastal Commission, 2003). Additionally, concentrate disposal can result in increased turbidity of the receiving water, which can restrict the amount of light that penetrates through the water and interfere with phytoplankton photosynthesis (Miri, 2005).

In some cases contaminants contained in feedwater can be concentrated due to the desalination process, resulting in higher levels than found in ambient seawater. This can include contaminants that originated from non-point source pollution such as urban and agricultural runoff (Pacific Institute, 2006). The desalination plant proposed by Sand City will use a brackish water aquifer near the beach as source water. Due to past activities the source water has higher levels of nitrates than seawater, which could become further concentrated via the RO process. This would not result in a new impact however, since this groundwater is currently mixing with seawater as the freshwater from the shallow aquifer moves towards the Monterey Bay, and therefore it would result in the same net amount being introduced, albeit via different mechanisms (City of Sand City, 2004).

Thermal plants have a number of associated impacts not present in reverse osmosis plants. Among these is the elevated temperature of the brine stream from the distillation plant. This normally ranges between 8 and 15 Celsius degrees above the receiving water. The main negative effects of this elevated-temperature plume are: decreased dissolved oxygen levels, possibly leading to anoxia or hypoxia; a tendency for the water column to stratify into distinct layers based upon differences in density due to temperature differences; decreased rates of phytoplankton photosynthesis; and the replacement of native algae species with undesirable invasive species. Another issue unique to thermal plants is corrosion from the condenser system piping; this can lead to the leaching and subsequent release to the marine environment of copper, nickel, molybdenum, iron, chromium, and zinc. Many of these metals (copper in particular) can cause substantial negative effects to marine organisms, and can become concentrated in the seafloor sediments (Miri, 2005).

Effects of elevated salinity on marine organisms:

Marine organisms are able to adapt to the natural fluctuations in salinity of the Pacific Ocean, which tend to be gradual, but changes brought about by desalination discharge may be beyond the ability of local organisms to tolerate. In many cases chronic exposure to elevated salinity causes marine organisms to be stressed which can increase their vulnerability to other factors such as pollutants and diseases (California Coastal Commission, 2003).

A relatively small number of studies have been conducted that investigate the effects of hypersaline conditions on marine organisms. Gross (1957), conducted studies on the response of several species of decapod crustaceans to osmotic stress gradients, in order to assess their ability to osmoregulate. Osmoregulation is the ability of an organism to maintain its internal fluid ion balance despite being placed in fluids that are higher or lower in ionic concentration. One of the test organisms Gross used was the sand crab *Emerita analoga* (one of the major inhabitants of sandy beaches of the Monterey Bay).. Gross concluded that the sand crab cannot osmoregulate its body fluids and therefore is a stenohaline species (a species with a narrow range of salinity tolerance). Tests were run using seawater concentrations of 50, 75 90, 110, 125, and 150 percent; this corresponds to standard seawater (34.994 ppt) salinity concentrations in parts per thousand (ppt) of 17, 26, 31, 38, 44, and 52, respectively. They found that within two hours the crabs reached an isotonic equilibrium state (where an equal solute concentration exists within the crabs' cells and the seawater) with the test solution. The solute concentration in the blood did not change for the duration of the test after equilibrium was established. They concluded that a change in body solute content (salts) rather than water exchange was primarily responsible for changes in the body fluid concentrations and isotonic equilibrium. They found that within about two hours of immersion animals placed in 50 (17 ppt) and 150 (52 ppt) percent seawater concentrations died as they became isotonic to the solution. Those placed in 75 (26 ppt) to 125 (44 ppt) percent seawater concentrations were able to survive as long as 24 hours, thus demonstrating some ability to tolerate changes for a period of time longer than a tide cycle. It may be that the actual lethal salinity concentration for the sand crab lies between 50 and 75 percent and 125 and 150 percent of ambient seawater. Besides the sand crab, Gross (1957) also conducted similar studies on several other species of crabs. His studies in general demonstrated a correlation between osmoregulatory ability and relative impermeability of the organisms' carapace or exoskeleton. Those species with osmoregulatory ability tended to be either terrestrial or semi-terrestrial in nature. The species that could not osmoregulate were, for the most part, strictly marine and usually lived submerged. His work suggests that permeability of the exoskeleton directly influences the amount of time organisms can cope with exposure to air or low salinity brackish conditions, thereby conserving body fluids and internal solute levels. In the case of elevated salinity conditions it would appear that the same process would hold true but in reverse - that impermeability would slow the inward exchange of solutes long enough for osmotic regulation to occur in organisms that were capable of regulating. Where an organism's carapace was permeable, one would expect to see a net increase in salts within the body fluids.

ABA Consultants (1992) conducted bioassay studies for the Sand City Desalination Plant Project on the effects of hyper-saline water on the survival of two shallow subtidal beach species, the olive snail *Olivella pycna* and the sand dollar *Dendraster excentricus*. These two species are important community members of the shallow subtidal sands of the Monterey Bay from just outside of the surf zone to a water depth of 30 feet or greater. They concluded that salinity concentrations at some level between 43 and 48 ppt would become lethal to young sand dollars (10-15 mm diameter) but not to olive snails (3-4 mm length). The elevated salinity treatments were 33, 38, 43, and 48 ppt. They discuss other pertinent studies and concluded that measuring "chronic effects to growth and reproduction as well as survival may be a better indication of (salinity) toxicity and (therefore) require a longer test". In light of the findings of Gross (1957), ABA Consultants (1992), and others it seems likely that for many marine species the larvae and juvenile stages (and perhaps broods being carried by adults) are the stages most at risk from exposure to brine and hypersaline conditions.

Bioassay studies were conducted by the Southern California Coastal Water Research Project to determine the effects of desalination brine on a small number of marine organisms (SCCWRP, 1993). These tests consisted of a 48-hour kelp (*Macrocystis pyrifera*) spore germination and growth test, a 10-day amphipod (*Rhepoxynius abronius*) survival test, and a sea urchin (*Strongylocentrotus purpuratus*) fertilization test. In the case of the kelp spore and amphipod tests salt brine was produced by freezing and partially thawing laboratory seawater. Salinity concentrations as high as 43 ppt did not affect kelp spore germination, although the germ tube growth was smallest at the highest concentration. Amphipod survival was not affected by concentrations as high as 38.5 ppt. Brine dilutions used for the sea urchin fertilization test and another kelp spore test was made from a mixture of brine from the Diablo Canyon desalination plant and laboratory seawater. A mixture of seawater and 10% brine did not adversely affect kelp spore germination, germ tube growth, and sea urchin fertilization.

Bioassay studies conducted for the Marin Municipal Water District's pilot desalination plant involved the 7-day chronic inland silverside (*Menidia beryllina*) test, the 96-hour diatom (*Skeletonema costatum*) growth test, the 48-hour bivalve larvae test, and the 96-hour acute speckled sanddab (*Citharichthys stigmaeus*) test. Tests were performed on the brine concentrate itself and on the brine mixed with effluent from the Central Marin Sanitation Agency (CMSA) sewage outfall. The studies found that a dilution of bay water to brine of 23:1 and of CMSA effluent to brine of 20:1 were necessary to achieve a No Observable Effect Concentration (NOEC) for these organisms (Pantell, 1993).

Another series of bioassay tests conducted by researchers in Japan involved Japanese littleneck clams (*Venerupis* [*Ruditapes*] *philippinarum*), juvenile sea bream (*Pagrus major*), and marbled flounder (*Pseudopleuronectes yokohamae*) (Iso et. al. 1994). Hypertonic solutions were prepared using a commercial salt mixture called "marine essence" and aerated tap water. The littleneck clams survived and their behavior was unimpaired in solutions of 50 ppt or less but in salinities of 60 ppt and 70 ppt their reactions to tickling were sluggish. Lethal effects were observed after 48 hours in 60 ppt and after 24 hours in 70 ppt. Juvenile sea bream survived well in salinities of 45 ppt or less. In 50 ppt salinity the color of these fish darkened after 30 minutes and 25 percent died within 24 hours. In a 70 ppt concentration all fish died after 1 hour. In an avoidance experiment researchers slowly pumped colored solutions of different salinity concentrations into the bottoms of tanks holding juvenile sea bream in normal 33 ppt water (thereby creating two layers of water in the tanks). The sea bream behaved normally in water up to and including that with a concentration of 40 ppt. Between 45 ppt and 70 ppt the fish spent less and less time in the higher salinity water. The fish did not enter water with a salinity of 100 ppt. Hatchability of eggs of the marbled flounder was successful at salinities up to 60 ppt but dropped to zero percent at a concentration of 70 ppt. Hatchability was delayed with increasing salinity between 31 ppt and 60 ppt. Marbled flounder larvae survived with no ill effects in salinities up to 50 ppt. At 55 ppt mortality began to occur after 140 hours. In salinity concentrations of 60 pt and up to 100 ppt the number of dead larvae increased in shorter periods of time.

Studies have also been conducted on the salinity tolerances of the blow lug polychaete worm (*Arenicola marina*), a burrowing deposit feeder of the mid-tide zone along open and sheltered beaches of Northern Europe (MarLIN, 2005). It was found that this animal can survive salinities as low as approximately 18 ppt primarily by ceasing irrigation and compressing itself at the bottom of its burrow. Behavior returned to normal when typical salinities were restored (Shumway and Davenport 1977; Rankin and Davenport 1981; Zebe and Schiedek 1996). This avoidance behavior and burrow habitat enabled the lugworm to maintain its coelomic fluid and tissue constituents at a constant level, whereas individuals exposed to fluctuating salinities outside their burrow did not. Also in response to hypo-osmotic shock (low salinity) it was found that *A. marina* was able to osmoregulate intracellular and extracellular volume within 72-114 hrs by increased urine production and increased amino acid concentration. Worms exposed to hyper-osmotic shock (~47 ppt) lost weight, but were able to regulate and gain weight within 7-10 days (Zebe and Schiedek, 1996). Perhaps what is most relevant from these studies to desalination discharges is that environmental fluctuations in salinity are only likely to affect the immediate surface of the sediment (and the waters above) since the interstitial or burrow water is not affected for a considerable length of time. Certain infaunal organisms therefore can retreat into the sediment for varying lengths of time and protect themselves from intermittent periods of degraded water quality.

Other investigations have shown that "individual organisms are not significantly impacted by salinity variations of several parts per thousand (ppt) from the ambient" (Kinne, 1971), leading another researcher to conclude that a "conservative estimate of +/- 1 ppt or 3% deviation from normal ambient salinity would not adversely affect benthic environment" (Del Bene et. al., 1994).

A significant amount of research has been done examining the effects of salinity changes on seagrasses. McMillan and Mosely (1967) grew four different seagrass species at salinity levels as high as 74 ppt. Another study conducted on a Caribbean turtle grass species demonstrated that cellular damage occurred when exposed to salinities twice as high as ambient seawater, but the grass could withstand increases in salinity of as much as 20%. Another study in Texas in 1986 showed that three species of seagrass are physiologically equipped to endure salinity levels as high as 47 ppt. In another research and monitoring project, researchers concluded that following three months of direct ocean brine discharge there was "no detectable impacts to the seagrass *Thalassia testudinum* due to the brine discharge (Southwest Florida Water Management District, 2000).

A recent study conducted by Poseidon Resources at the Carlsbad desalination demonstration plant located at the Encina power plant in Carlsbad investigated salinity tolerances of three species endemic to a the proposed discharge location. These species, the purple sea urchin (*Stronglyocentroutus purpuratus*), sand dollar (*Dendraster excentricus*), and red abalone (*Haliotis rufescens*), were contained onsite in a marine aquarium. These organisms were exposed to elevated salinity conditions between 37 and

40 ppt (which are expected to occur after the concentrate discharge from the desalination plant is initiated), for 5.5 months. All of the organisms survived the elevated salinity, and results indicated that there were no negative effects to species growth rates or fertility (Voutchkov, 2006b).

Chemical Additives and Byproducts of Desalination:
A number of pretreatment and cleaning chemicals are routinely introduced in desalination plants to maintain the efficient operation of RO membranes. Other byproducts include corrosion products - primarily metals from the interior of piping and fittings from the plant itself – although this issue is only associated with thermal plants, since RO plant components are currently not made out of materials that can corrode.

Pretreatment additives include those used for coagulation and flocculation, antiscaling, anti-biofouling, antifoaming, and oxygen scavenging. It is important to note that the types of additives that will be necessary in the operation of a desalination plant cannot necessarily be predicted. The following discussion, therefore, is meant to give some background on these treatment compounds and the potential environmental threats they pose; it is not intended to imply what types of treatments any particular desalination facility will use or what environmental impacts they will actually have.

Coagulation and Flocculation Additives
Ferric chloride, ferric sulfate, and aluminum polychloride are examples of coagulation and flocculation agents used to remove solids from raw source water. A portion of these compounds are not entirely used up in the pretreatment process. These additives do not enter the pretreatment washwater cycle where sedimentation occurs and solids are removed (and ultimately disposed at a landfill). As a result these compounds can become part of the brine discharge.

Iron is now recognized – though not well understood - as a “keystone regulator of biogeochemical functioning in the ocean” (Johnson et al., 2002a). As a limiting micronutrient for the growth of phytoplankton, the addition of iron to the marine environment can cause blooms of these organisms (Coale, 2001). Such blooms could adversely affect the natural balance of phytoplankton and zooplankton as well as decrease light penetration. The significance of decreased light penetration in nearshore waters, as one researcher (Palacios, 2001) noted, is that “chlorophyll from nuisance algal blooms is often the cause of light limitation and eelgrass (*Zostera marina*) habitat loss”. Also, certain phytoplankton, such as the diatom *Pseudo-nitzchia australis*, are known to produce domoic acid, a neurotoxin that is responsible for causing amnesic shellfish poisoning in humans. Domoic acid is bioaccumulative and can cause neurological dysfunction and even mortality in California sea lions (*Zalophus californianus*) when it is present in high concentrations in their food (Scholin et al. 2000). A recent study has demonstrated that during seasonal blooms of *Pseudo-nitzchia* in the Monterey Bay a variety of shallow water benthic invertebrates accumulated levels of domoic acid in their tissues that were considered unsafe for human consumers (Goldberg, 2003). Domoic acid in the benthic food web could also directly affect the safety of the food source available to the southern sea otter (*Enhydra lutris*).

Iron discharged from desalination plants is almost entirely in the insoluble solid form of ferric hydroxide (Strategen, 2004), which is largely believed to be biologically unavailable for phytoplankton uptake (Lewandowska and Kosakowska, 2004). However, in a review of numerous studies of iron dynamics and the carbon cycle in marine environments many researchers have reached consensus that, although the processes and time scales are not understood, all iron is probably bioavailable (Johnson et al., 2002b). Yet, for all practical purposes, the discharge of even large quantities of ferric hydroxide to the marine environment would not create unnatural phytoplankton blooms.

Anti-biofouling Additives

Biofouling of membranes and other equipment within desalination plants is a phenomenon that occurs, particularly in tropical and subtropical regions, despite the use of pre-treatment systems and the addition of disinfectants such as chlorine (Baker and Dudley, 2003). Biofouling has typically been controlled by the addition of sodium hypochlorite, sodium bisulphite, oxidizing biocides such as chlorine, bromine chloramines, chlorine dioxide, hydrogen peroxide, peroxyacetic acid, or a combination of these. Proprietary synthetic biocides have also been developed in recent years. While traditional biocides are "neutralized" into apparently benign compounds prior to being discharged (e.g., free chlorine is quenched with sodium bisulfite), little information exists on the fate and environmental toxicity of the newer biocides. It is well known, however, that free chlorine facilitates the formation of halogenated organic compounds and even trihalomethanes and halogenated hydrocarbons under certain conditions (Hoepner, 1999). Whether these and other byproducts produced by pretreatment are also neutralized prior to being discharged is not directly addressed in any of the literature that was researched for this report. Interestingly, current theory and practical experience suggest that, for reasons that are not clear, chlorine treatment for biofouling is not always effective and in some cases has worsened the problem (Baker and Dudley, 2003). An alternative to the use of chlorine or other antifouling chemicals is mechanical filtration followed by ultraviolet light or ozone treatment.

Antiscaling Additives

Antiscaling chemicals are used to prevent metal hydroxides/oxides and compounds such as calcium carbonate, calcium sulfate, and silicates from precipitating out of aqueous solution onto membranes and other equipment. Antiscaling agents include acids, polyphosphates, organophosphonates, and synthetic organic carboxylic-rich polymers (polyacrylic acid, polymaleic acid, polymethacrylic acid), as well as proprietary formulated blends of these and other copolymers. Acids and polyphosphates are among the earliest and cheapest antiscalants but in certain conditions are not as effective as the newer polymers and proprietary blends (Amjad, 1996). Polyphosphates hydrolyze into orthophosphate which is a macronutrient essential for photosynthesis in the marine environment. Discharge of large volumes of orthophosphate could possibly cause eutrophication of the receiving waters around the outfall and lead to abnormal blooms of phytoplankton. Because polyphosphates are hydrolyzed to orthophosphate no chronic aquatic ecotoxicity studies have been conducted (HERA, 2005). Furthermore, acute aquatic ecotoxicity studies have shown that the commonly used sodium tripolyphosphate (STPP) is not toxic to aquatic organisms. Polymaleic acid, a relatively more stable compound, is largely expected to discharge to the environment intact (Hoepner and Lattemann, 2002). Once discharged its residence time and ecotoxicity are not well known. One study (Finan et al. 1989) concluded that there was no accumulation of these substances in fish and algae, and industry research indicates that polymer antiscalants have low toxicities. Bioaccumulation and acute toxicity are not the only measures of ecotoxicity, however. Polymer antiscalants have the capacity to bind metal ions and could theoretically limit the availability of essential trace metal ions to marine organisms(Hoepner and Lattemann, 2002).

Antiscalants are used continuously for the prevention of scaling as well as for the periodic cleaning of membranes which usually requires a combination of both an alkaline surfactant and an acidic cleaning solution such as sulfuric acid. The particular combination of chemicals used for cleaning depends on the nature of the fouling that occurs.

Antifoaming Additives
Antifoaming additives typically are detergents such as alcylated polyglycols, fatty acids and fatty acid esters. They are used to control foaming, which is caused by organic seawater constituents such as excretion and phytoplankton degradation products. Thus, the degree to which foaming occurs depends on the quality of the source water and can vary seasonally. Although fatty acids and their esters are non-toxic, detergents can adversely affect organisms by disturbing their intracellular membrane system (Hoepner, 1999). The marine ecotoxicity of these compounds and their possible reaction products are not well known.

Corrosion Products
Physical corrosion of the materials, especially metals, within a desalination plant can significantly shorten the lifespan of certain parts. Desalination by Multi-Stage Flash evaporation (MSF), which is most common in the energy rich Middle East, is well known to contribute deleterious heavy metals to the brine discharge due to physical corrosion. The slow corrosion of copper/nickel condenser tubing causes a constant release of a small quantity of these metals into the brine discharge. Sodium sulfite is sometimes used as an oxygen scavenger to minimize such corrosion. Sodium sulfite is ultimately oxidized to sulfate which is a normal constituent of seawater and is therefore not expected to have an adverse effect on the marine environment (Hoepner, 1999). Fortunately, the principal working parts used in current reverse osmosis desalination plants are made of plastic materials and high quality, corrosion resistant alloys that do not contribute metals to the brine discharge. Furthermore, the removal (and ultimate disposal to sanitary landfills) of suspended solids during the pre-treatment process can actually reduce the quantity of metals returned to the ocean to less than that removed (CWDTF, 2003).

<u>Brine plume monitoring studies</u>
Although information regarding the environmental effects of desalination discharges in California is largely speculative, and based on brine plume modeling and other

assessments carried out during the environmental impact assessment process, there are a number of studies monitoring the impacts of actual desalination plant discharges located in other states and countries, from which information can be inferred.

Due to a lack of research available on the environmental impacts of brine discharge, the Southwest Florida Water Management District conducted a joint study with the Florida Department of Environmental Protection, to investigate the impacts of brine discharge on Florida's coastal ecosystems. A team of researchers from the University of South Florida, the Mote Marine Laboratory, and the Southwest Florida Water Management District was assembled to conduct research on the impacts of desalination plant discharges on marine organisms, including evaluation of the impacts of desalination discharges at existing and operating plants. After a detailed and lengthy process to select a location for the study, the team settled on a seawater reverse osmosis plant in Antigua, in the Caribbean; this location was chosen due to its healthy ecosystem and the similarity of the organisms and conditions to those found in Florida. The 1.2 MGD plant, which has been in operation since 1993, produces 1.8 MGD of brine concentrate with a salinity of 57 ppt; it uses a surface water intake and an open ocean discharge (does not use diffusers). The scientists visited this facility on three occasions in 1997 and detailed biological and water quality analyses were conducted. During the first site visit for this research project, prior to a modification of the outfall, extensive biological and water quality data were collected. Following this initial collection of data, the existing discharge structure, which consisted of an elevated concrete structure used to convey the brine to the discharge site, was sealed off and a new pipeline constructed to divert the effluent to the study area where the preliminary measurements were taken. The new discharge location was in an area beyond the influence of the original discharge. Results of water quality sampling show that temperature (the concentrate is of a higher temperature than ambient seawater) and pH return to ambient levels within 2 to 6 meters of the outfall. Elevated salinity was detected as far as and beyond ten meters from the outfall. Following three months of operating the outfall at the new location, no detectable effects were noted on the density, production and biomass of the seagrass *Thalassia testudinum.* A weak positive correlation was identified between plume intensity and abundance of another alga, *Dictyota dichotoma.* This increase was likely due to increased nitrogen levels found in the brine, which may have been due to any one or a combination of a variety of factors, including the direct result of concentrating the nutrients in the seawater due to the RO process, periodic backwashing of the pre-treatment filters, periodic discharge of detergents associated with membrane cleaning, and periodic stormwater runoff that drains through the outfall channel with the brine. It is likely that the episodic events rather than the chronic exposure to the everyday brine plume were the primary cause for the elevation in *Dictyota dichotoma* abundances. On a final site visit, six months after the discharge modification, abundances of *Dictyota* were significantly lower than during the previous measurements. During this final trip to the site measurements in the seagrass meadows were again taken demonstrating that: "there is no discernable toxicity to the seagrass *Thalassia testudinum* associated with the discharge from the seawater desalination reverse osmosis plant in Antigua, since changes in density, biomass and productivity exhibited no relationship with the intensity of the plume's influence". Rates of grazing by the bucktooth parrotfish (*Sparisoma radians),* the primary consumer of seagrass in the area, were also unaffected by the introduction of the brine plume. The brine plume's effect on benthic microalgae was also assessed, due to the potential threat of the elevated salinity plume to sink directly to the bottom and spread over their habitat. The authors concluded that the brine discharge had "no detectable effect" on the abundance and biomass on benthic microalgal communities. In addition to various alga, a number of macrofauna were also monitored to ascertain the potential effects of the brine plume. Overall, eight invertebrates were analyzed, including a number of soft and hard coral species, a sea star species (*Oreaster reticulates)* and the queen conch. During three infaunal surveys over 36,000 organisms were collected, representing 339 taxa in 10 phyla: Porifera, Cnidaria, Annelida, Mollusca, Arthropoda, Sipuncula, Echinodermata, and Chordata. The authors noted "no obvious or statistically significant effects of the saline discharge were observed on the macro-epifauna or pelagic fish". Corals are known for their sensitivity to environmental alterations but they showed no apparent stress in response to the maximum salinity increase of 4.5 ppt. Some species such as the queen conch and the cushion starfish actually entered the area of maximum salinity increase. Additionally the study concluded that the plume had no effect on foraminiferal populations, which are often used as indicators for ecosystem health due to their relative sensitivity to environmental change (Southwest Florida Water Management District, 2000).

A 2005 study was conducted to establish the extent of the brine plume during different seasons from a seawater RO plant located in Alicante, in southeast Spain. The 13 MGD Alicante plant went online in September 2003; the plant uses beach wells for intake and discharges into an environmentally degraded harbor. The study was based on three surveys done in February, April, and August of 2004, at more than 100 sampling stations spaced out on a grid in the area of the brine discharge. Salinity of the water at the surface and at the seafloor was monitored. In addition to salinity, a sample of biological organisms was also monitored, and included the seagrass *Posidonia oceanica,* as well as several echinoderm species, which can be sensitive to salinity increases. Posidonia seagrass meadows are an important but sensitive ecosystem in the Mediterranean Sea that are experiencing decline in many locations due to human activity. Seagrass and echinoderm densities were monitored at three sampling stations, one in front of the desalination plant and two control sites. While salinity levels at the outfall were similar to those shown to significantly impact growth and survival rates of these species, preliminary results based upon the first year of monitoring indicated that while the discharge had affected the seagrass' vitality, it did not reduce the overall size of the meadow (Fernandez-Torquemada et al., 2005).

5.d.ii *Mitigation and Avoidance Measures for Discharge Related Impacts:*

Impacts related to desalination discharges can be avoided or mitigated through the use of specific technologies and operational practices, or through careful selection of a discharge site. Mitigation measures available for discharge-related impacts include: avoidance of sensitive habitats and biological resources; use of subsurface outfall structures; use of multiport diffusers and other technologies; minimizing the use of potentially harmful chemicals and using less harmful alternatives; processing of certain wastes at a wastewater treatment plant and disposing of others at a landfill instead of into the ocean; and combining discharges with other existing outfalls, such as treated wastewater or power plant cooling water (California Coastal Commission, 2003).

One way to mitigate impacts from discharge of desalination brine concentrate is to enhance mixing to ensure that it is diluted as rapidly as possible. This can be achieved by locating the discharge in favorable oceanographic conditions, use of specific technologies and operational practices such as multi-port diffusers or injection wells, or by blending the brine with another discharge.

By using multi-port diffusers, spaced out 50-100 meters, mixing can be significantly enhanced via increased turbulent dilution. Optimally, the diffusers should be pointed up at approximately 45-degree angle and a jet velocity of greater than 3.5 meters per second should be used (Einav, 2002). Use of subsurface discharge structures such as pressurized beach wells or percolation galleries can also reduce many environmental impacts through enhanced mixing (Campbell, 2005). Diffuser effectiveness depends on how many there are and the distance that they are spaced apart (Einav, 2002). Other technological options available for increasing the mixing/dilution of brine include increasing the discharge velocity at the outfall or the use of multiple pipes to spread the plume over a wider area.

Another way to avoid brine discharge impacts is to decrease the salinity of the discharge. This can be accomplished by using a lower recovery rate for the desalination plant. It can also be done by drawing in excess feedwater for blending with the brine prior to discharge. There is an economical compromise here, however, since either a lower recovery rate or excess feedwater requires increased water intake, which can be costly and causes entrainment and impingement (Mauguin and Corsin, 2005). Another potential way to achieve dilution is to blend the brine with another discharge, such as treated sewage effluent or power plant cooling water; this is discussed in detail in *Section 6* of this report.

In addition to waste stream blending, the effluent can be discharged in a way that improves mixing with surrounding seawater. Mixing can be optimized by taking advantage of favorable oceanographic features conditions and attributes. For example discharge to high-energy coasts will enhance mixing. These site selection considerations for desalination plant discharges are discussed in more detail in *Section 3.b* of this report. Site-specific aspects that are favorable to the rapid mixing of brine include a water column depth of at least 8-10 meters at low tide, and sufficient circulation of the water. Discharge to enclosed or semi-enclosed bays or estuaries with limited circulation should be avoided. The discharge plume will be more distinct in shallow and sheltered sites, whereas exposed and turbulent areas help to reduce salinity to ambient values within a short distance from the outfall pipe. To avoid the plume from being transported along the sensitive nearshore habitats of the coast, discharge structures can be located further offshore (UNEP, without date).

Discharge-related impacts can also be avoided by minimizing the use of chemicals for pre-treatment as well as by using options that are effective but less environmentally damaging. Alternative pretreatment practices that reduce or eliminate the use of chemicals should be evaluated. It is essential to conduct pilot studies to identify the most effective and efficient pretreatment practices, since this will reduce the need to clean the membranes and other plant components, which also results in the use of chemicals that need to be disposed. Due to environmental and health problems caused by residual chlorine and disinfection by-products, several alternative pre-treatment methods have been considered to replace chlorine in industrial and municipal applications, including desalination plants. Use of ozone for pre-treatment can be effective and should be evaluated as an alternative. Also, *ultraviolet light* (UV) at 254 nm is another potential alternative to biocides. This method is more expensive than biocide dosing but is an effective pre-treatment that may be used in small, fully automated systems (Saad, 1992). Potential benefits of the use of UV include elimination of the need for storage and handling of chemicals, unaltered physical and chemical parameters of the water and no formation of toxic by-products (Perrot and Baron, 1995). However, high turbidity decreases UV-transmission and may interfere with disinfecting properties, so this method is limited to relatively clear waters (Redondo and Lomax, 1997). This may limit its feasibility for use in some Monterey Bay desalination plants. If prefiltration membranes, beach-wells or infiltration galleries are used, the remaining pre-treatment scheme (if necessary) will likely be relatively simple and may consist of acid addition only to suppress scale formation. One pre-treatment alternative that reduces chemical use is the use of integrated membrane systems that combine microfiltration (MF) or ultrafiltration (UF) membranes with reverse osmosis units. MF removes suspended material including bacteria and algae, whereas UF also filters smaller viruses from the RO feedwater (Ebrahim et al., 2001).

There are a number of mathematical models available for predicting the behavior of the brine plume and which can be used to predict environmental impacts and develop measures to avoid these impacts. These ***plume dispersion models*** are used to predict the dispersion of the brine plume in the receiving water body in the near and far field. Variables such as water depth, density of ambient water and brine, currents (both wind and density driven), tides, depth of outfall, volume of effluent, and velocity at the outfall are evaluated (UNEP, without date).

5.e ENERGY USE AND EMISSIONS IMPACTS

5.e.i Overview of Energy Use and Emissions Impacts:

Reverse osmosis is the most energy- and cost-efficient desalination technology, but even with major increases in efficiency that have occurred over the past decade, it is a very energy intensive process requiring significantly higher inputs of energy than any of the existing water supply strategies in the Monterey Bay area. The energy requirements brought on by the operation of a newly constructed desalination plant result in the need for the generation of additional energy to meet these needs. This in turn results in the burning of more fossil fuels and release of more air pollution and greenhouse gas emissions than would have ocurred without the existence of that plant.

Anywhere from 20-35% of the cost of reverse osmosis desalination can be attributed to energy use depending upon energy costs (Voutchkov, 2006). Thermal desalination plants are substantially more energy intensive than RO plants, with energy potentially accounting for 60% of the cost of the product water from distillation. In 2005, energy prices in California ranged from \$0.093 to \$0.1472 per kWh (Pacific Institute, 2006). Since energy costs make up such a high proportion of the overall water production costs of desalination plants, the price of product water is particularly sensitive to energy prices. According to one estimate, for each one-cent increase in energy cost per kilowatt-hour there is a corresponding \$53 increase per acre-foot of desalinated water (CPUC, 2005).

While desalination plants do require a significant amount of energy to operate, they are not expected to affect the overall generation of electricity in California. Assuming state projections for a future seawater desalination production capacity of about 325,000 acre-feet per year (290 MGD), the potential electric demand for proposed seawater desalination plants in California is estimated to be 90 – 225 MW, or 0.17% to 0.42% of the state's current installed electric generation capacity of 54,000 MW (CPUC, 2005).

While the theoretical minimum energy use for RO is somewhere around 0.7 kWh/m^3 of product water, the energy use of currently operating plants is normally in the range of 3-15 kWh/m^3 (with older thermal plants representing higher figures in that range) (Schiffler, 2004). New RO plants typically would use 2.9-3.7 kWh/m^3, depending upon salinity and temperature of the feedwater (ADC, 2006), and brackish water desalting is much more energy efficient than seawater desalting, ranging from 0.5 - 1.0 kWh/m^3, requiring 1.5-5 times less energy (Voutchkov, 2006). It is estimated that a 50 MGD seawater RO plant would use approximately 33 MW of power each year if it operated 90% of the time. The state's projected future desalination capacity of 187,000 acre-feet/year (about 167 MGD) would require 123 MW of additional power in the state (California Department of Water Resources, 2005).

The Affordable Desalination Collaboration (ADC) is a non-profit organization comprised of various companies and state and other government agencies that was specifically organized to demonstrate the lowest energy consumption that can be achieved with current state-of-the-art technology. Using existing "off the shelf" RO and energy recovery technologies at its demonstration plant at the U.S. Navy Seawater Desalination

Test Facility in Port Hueneme, California the ADC has achieved as low as 1.58 kWh/m^3 energy use; at this level however, the system resulted in product water with boron levels slightly above the current California notification level of 1.0 mg/l (test results for boron were 1.11mg/l). However, it is possible to achieve the necessary boron level with a partial second pass though RO membranes or a small (but specific) ion exchanger. With improvements in membrane technology, it is likely that it will be possible to meet the standard for boron in a single pass through the RO membrane. From an economics standpoint, they found that about 1.83 kWh/m^3 was the best combination of flux, recovery, and capital cost for practical desalination. A third set of tests, using different membrane configurations, is currently being conducted. The preliminary results from the first two sets of tests demonstrate that it is feasible to desalinate seawater with much lower energy than previously thought possible, using existing technologies and practices. At the lowest energy consumption level demonstrated during the second phase of ADC testing (1.58 kWh/m^3), it would be possible to produce 400 gallons of product water using 120 watts of electricity. For comparison, in 2004 energy use for delivery of water to southern California were 2.5 kWh/m^3 for the State Water Project and 1.6 kWh/m^3 for the Colorado River Aqueduct; water recycling using reverse osmosis is in the range of 1 kWh/m^3 and brackish water desalting 0.5 - 1.0 kWh/m^3 (ADC, 2006). While the above figures account only for the desalination of seawater (including pre-treatment), energy use related to desalination projects also includes the conveyance of the product water to the end user. This can be notable, since desalination plants tend to be located at or near sea level and must pump the water up to higher elevations (California Coastal Commission, 2004).

The use of energy results in the release of polluting emissions, either directly at the desalination plant, or indirectly at the power plant that supplies the energy. The increased emissions due to desalination plant operation cause two major impacts: they can cause negative effects to human health and the environment, and they contribute to global climate change. Air emissions from power plants that can negatively affect human health include carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) (Younos, 2005). To illustrate the potential increase in greenhouse gas emissions due to desalination plants, a 50 MGD seawater RO facility would result in the production of 122,250 to 183,750 tons of greenhouse gases each year (Minton, 2006). In another example, Spain has an aggressive program to augment its water supply with desalination by more than double the current capacity in the next 5 years, which if implemented would result in an estimated 9% increase in national CO_2 emissions by the year 2010, solely to meet the energy demands of the new plants (Meerganz, 2005).

5.e.ii. Mitigation Measures for Energy Use and Emissions Impacts:

Measures for mitigating the use of energy by desalination plants include increasing the energy efficiency of the process, using renewable energies as all or part of the power source, or compensating for the use of energy by reducing energy use in other facets of day-to-day operation (e.g. replacing service vehicles with hybrid or biofuel vehicles, or purchasing "green credits"). Energy efficiency can be achieved through the use of energy recovery technologies and designing and operating the plant for maximum energy efficiency. Another way to increase efficiency is by reducing water losses in the water distribution system. Use of renewable energy for desalination was discussed in more detail in *Section 4.f* of this report. *Carbon emissions trading,* which involves the trade and purchase of carbon credits is another trend that will likely play an increasingly important role, in mitigating impacts from greenhouse gas emissions, in the future.

One important consideration is that other less energy intensive water supply or demand reduction approaches should be pursued and exhausted before considering seawater desalination. For example, water conservation programs should be maximized and recycling should be pursued when feasible. Also, due to its substantially lower energy requirements, brackish water desalination should be evaluated (and pursued if feasible) before moving ahead with seawater desalination.

5.f GROWTH INDUCING IMPACTS

5.f.i *Overview of Growth Inducing Impacts:*

Perhaps the most contentious environmental issue surrounding desalination is the potential for it to induce additional coastal development. In some cases this may lead to substantial unplanned growth, which could result in significant indirect environmental and socioeconomic impacts such as degradation of water quality from increased urban runoff, and other damages to sensitive coastal ecosystems resulting from increased population. Desalination in the Monterey Bay area has the potential to induce growth by removing an obstacle (water supply limitations) to growth, or by adding a new water supply to where it is currently not available.

Direct growth inducement occurs primarily with residential or commercial development projects that would either result in an increase in population or employees. With indirect growth inducement, obstacles to growth are removed, or a condition is created that stimulates increases in population or economic activity. Both indirect and direct growth inducement can increase population, which can strain the community's existing infrastructure (e.g. water conveyance or treatment facilities), in turn leading to the construction of new facilities that can have additional impacts. Many impacts are related to growth including water quality degradation, increased traffic, noise, and air emissions, and development of open space or agricultural land (EDAW, 2005).

Several factors influence whether or not a desalination project has growth inducing impacts, as well as the magnitude of these impacts. First, a new water supply will have a much greater potential to induce growth than projects such as CalAm's Coastal Water Project, which will replace an existing water supply source. Also, plants that provide a "baseline supply" of water will have greater growth inducing potential than those designed to be operated only during dry periods such as droughts (Pacific Institute, 2006).

The *California Environmental Quality Act* (CEQA) requires all proposed desalination project proponents to conduct an evaluation of whether that project will directly or indirectly induce growth of population, economic development, or housing construction. Pursuant to *CEQA Guidelines Section 15126.2(d)* it is necessary to analyze a proposed program's ability to "foster economic or population growth, or the construction of additional housing, either directly or indirectly, in the surrounding environment". In order to be considered significant, a program or project must encourage growth beyond what is assumed in local planning documents such as master plans, land use plans, or projections made by local planning agencies. Growth inducement from a project is also considered significant if it indirectly or directly interferes with the ability of jurisdictions to provide basic services, or alters the physical environment in another way such as increased traffic or degraded water quality (EDAW, 2005). The California Coastal Act also requires an assessment of growth inducing impacts of desalination projects located within the coastal zone. The Commission can deny a project from obtaining a Coastal Development Permit if that project has the potential to induce growth at a level beyond what is stipulated in local land use plans.

The City of Monterey provides an example of a location where development is clearly limited by water supply. There are 31 residential and commercial projects currently on the waiting list for water due to the limited supply, so in this case water is directly limiting growth (Pacific Institute, 2006). In fact, in order to avoid this restriction to development, the proposed Ocean View Plaza project in Cannery Row intends to build its own desalination plant to supply water to the project. In Santa Cruz County, the limitation of developable land is the main obstacle to growth. In the City of Santa Cruz, only around 4% of land zoned for residential purposes is currently undeveloped, with the vast majority of the undeveloped land located within the jurisdiction of Santa Cruz County. Due to low growth rates in the City of Santa Cruz, current population of 55,000 is 8% below projections in the 1990-2005 General Plan, and during recent years according to recent U.S. Census data, Santa Cruz County has experienced a stabilization or even decline in population. Growth along the north coast of Santa Cruz County is also limited by water supply; in this case it is due to a City of Santa Cruz moratorium on new connections on the north coast water system and a policy originating in the 1980s that prohibits the expansion of the water service area (EDAW, 2005).

5.f.ii. ***Mitigation and Avoidance Measures for Growth Inducing Impacts***

Growth inducing impacts can be avoided through various measures that ensure that the desalination plant does not lead to unsustainable growth levels. Since growth is regulated at the local level, it is essential to place a limit on the desalination plant's water supply growth subject to policies in local general plans, land use plans, and local coastal programs. Measures should be taken to ensure that growth is not stimulated beyond that which has a negative effect on marine or terrestrial resources.

Exhaustive review of whether the project will result in unsustainable levels of growth is necessary, and growth inducement should be considered very early during the planning phases of a desalination plant. Approval for any future expansion of a desalination plant or change in its operation should be subject to subsequent review of growth inducing and other environmental and socioeconomic impacts.

5.g CUMULATIVE IMPACTS

5.g.i *Overview of Cumulative Impacts:*

CEQA defines a cumulative impact as: "an impact which is created as a result of the combination of the project evaluated in the EIR together with other projects causing related impacts" (CEQA Guidelines, section 15130 [a][1]). Under these guidelines, cumulative impacts must be addressed for projects that are "cumulatively considerable". Therefore, an analysis of cumulative impacts is required as part of the environmental impact assessment process for desalination plants. Regarding cumulative impacts, the California Coastal Act stipulates "the incremental effects of an individual project shall be reviewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects." (California Coastal Act, section 30105.5).

The cumulative impacts of a particular desalination plant are determined by its location, the service area where the product water will be delivered, and site specific aspects of the design and operation of the plant. Cumulative impacts are not only environmental in nature, but can also include other socioeconomic impacts such as impacts to public access and aesthetics. The cumulative environmental impacts of desalination plants related to water quality and biological resources will require significant analysis for any proposed project (California Coastal Commission, 2003). Although the Monterey Bay area is fortunate to enjoy relatively good ocean water quality, there are a number of existing water quality concerns largely resulting from non-point source pollution such as urban and agricultural runoff, that must be taken into consideration when addressing cumulative impacts. Cumulative effects of a desalination plant in combination with other existing and future point sources of pollution (i.e. sewage discharges, power plant cooling water, and other existing desalination plants) as well as other seawater intakes must also be evaluated.

There is currently a lack of information evaluating the potential cumulative impacts of desalination plants. It is recommended that this issue be more thoroughly evaluated in future studies of desalination plants in the Monterey Bay area.

5.g.ii *Mitigation and Avoidance Measures for Cumulative Impacts:*

Plants should be designed to minimize individual site-specific impacts, so that cumulative impacts can also be minimized. Siting near existing industrial facilities should be avoided in cases where the combined environmental effects could lead to cumulative impacts. All proposed facilities should conduct a detailed evaluation of the potential cumulative effects that could result from the interaction of the desalination plant and other nearby projects.

5.i SOCIOECONOMIC IMPACTS

5.i.i *Overview of Socioeconomic Impacts:*

There are several ways in which a desalination project may change the lives or affect the well being of the residents (both present and future) in the area affected by the proposal, or have an affect on the local economy; these are referred to collectively as socioeconomic impacts. Mitigation and avoidance measures for socioeconomic impacts should be based on striving to establish fair and equal access to water for all, and ensuring that costs are equally spread across populations.

In order to assess the socioeconomic impacts of a project, it is first necessary to understand the concerns and values of the populations that are potentially impacted. This requires not only quantitative measures, such as population increases or housing figures, but also qualitative ones such as perceptions within the community. Also essential in the assessment of socioeconomic impacts is identifying and involving affected stakeholders, and determining who will be affected by the project both negatively and positively; identifying the issues that would have a significant impact on affected communities; evaluating if the proposed facility or any of the alternatives have disproportionate or elevated unfavorable environmental or health impacts on a particular subset of the population, including low income or minority populations; and consulting with experts such as anthropologists or sociologists (Interorganizational Committee on Guidelines and Principles for Social Impact Assessment, 1994).

One obvious socioeconomic cost is the relatively high economic cost of desalting seawater. Although current reverse osmosis technology has experienced notable increases in cost effectiveness and energy efficiency and is no longer considered prohibitively expensive, it remains an expensive water source that if pursued will result in increased water prices for Monterey Bay area customers. The cost of product water is dependent on a number of factors, including quality and salinity of feedwater, distance from the distribution system, cost of power, and the actual site of the facility.

Land Use Impacts:

The existence and operation of a desalination plant and its infrastructure can cause potential land use conflicts if inconsistent with local land use plans, as well as interfere with conservation efforts. One indirect land use impact is the potential for the plant to induce population growth in a region; these growth-inducing impacts have been discussed separately in *Section 5.f* of this report. Land use decisions are primarily made at the county and city level, depending upon where the project is located.

Nature conservation conflicts occur when effects caused by the construction and operation of the plant impact the habitat and biological resources of conservation projects, thus altering the ecological value of a site. In some cases this can change a protected area's status or minimize the probability of future protection of a site. Desalination can also lead to conservation conflicts by directly or indirectly causing the development of land.

Seawater reverse osmosis plants necessitate an area of around 10,000 square meters for a 5,000 to 10,000 cubic meter per day plant (1.3-2.6 MGD) (Sadhwani et al., 2005). This large space requirement coupled with the fact that in the Monterey Bay area, and throughout California, coastal land has a very high economic value, limits the options for sites on which to locate desalination plants; it also increases the chances for causing conflicts with existing uses of that land. Desalination, especially in the Monterey Bay area, can impact agricultural resources either via the use of agricultural land to site a desalination plant or its infrastructure, by pipelines that will need to pass through agricultural land, or indirectly through growth inducing impacts that could lead to the development or abandonment of agricultural land.

Desalination plants should be designed to minimize the use of land, and avoid disturbances to sensitive areas. Also, by siting desalination plants near other similar industrial facilities, it is not only possible to use existing infrastructure, but additional disturbances such as visual impacts and noise are minimized.

Population, Housing, and Community Structure:
Desalination plants have the potential to affect population, housing and community structure of not only the communities to which the desalinated water will be distributed (and which will probably benefit from this development), but also communities that may be indirectly or negatively affected by the project (e.g. impacts caused by the redistribution of water resources or environmental degradation). As previously discussed, desalination plants can result in the enhancement of population growth, via immigration, in the community that receives the desalinated water. This can result in changes to the organization and structure within the affected community, or to changes in availability of housing.

Impacts to Public Services and Utilities:
Desalination plants, through their potential to induce growth, can indirectly lead to impacts on public services such as fire and police protection and schools. They can also directly and indirectly affect utilities such as water conveyance infrastructure, storm water systems, electricity, natural gas, and sewer. For example, in California desalination plants typically dispose of membrane cleaning and storage chemicals to the sanitary sewer system, which can increase the load on treatment facilities. Also, desalination plants can produce significant amounts of solid wastes that can impact local landfills. Other potential impacts include changes in traffic patterns or parking impacts.

Recreational and Commercial Impacts:
In some cases a desalination plant can reduce the recreational or commercial value of the site and surrounding area, through the emission of pollutants and visual impacts. Additionally, the plant and its infrastructure may pose a hazard to or affect certain recreational or commercial activities, or may restrict access to beaches or other public areas. Recreational uses potentially affected by desalination include: beach use, surfing, scuba diving, fishing, hiking, boating, and wildlife viewing, whereas commercial activities may include fishing, tourism, navigation, and aquaculture.

By considering early on, the various activities that may be affected, it is possible to mitigate these impacts through planning via plant siting and design. For example, it is possible to minimize the invasiveness of the plant and its infrastructure in many ways, such as by locating pipelines beneath the seafloor, or ensuring that public access is not impaired. When access is temporarily or permanently cut off by a desalination plant, alternative access should be provided. The desalination plant should be designed to blend into its surroundings and minimize aesthetic impacts and noise generation in order to avoid recreational or commercial disturbances.

Aesthetic and Visual Impacts:
Comparable to other industrial facilities located on or near the coast, desalination plants and their infrastructure will likely cause some degree of visual and aesthetic impacts. This is due to the large amount of space required to build the plant as well as the number of associated facilities such intake, discharge, and water conveyance pipelines, and storage tanks and other equipment. Review of visual impacts is required by CEQA of all desalination plant proposals as part of the environmental impact assessment process. Siting the plant to avoid alteration of the landscape or blocking of views, and by designing the facility to be consistent with the existing visual character of the area can avoid these impacts. For example, issues can be avoided by siting a desalination plant inland, away from the beach. Some techniques such as dune restoration or re-vegetation can be used to hide the facility from sight.

Environmental Justice:
Environmental Justice (EJ) is defined by California state law as: "the fair treatment of people of all races, cultures and income with respect to the development, adoption, implementation, and enforcement of environmental laws, regulations, and policies" (California Government Code Section 65040.12 and Public Resources Code Section 72000). EJ communities are typically made up largely of low-income or minority populations.

Desalination projects can bring about EJ concerns in a number of ways. First, desalination plants tend to be located in industrial areas where low-income and minority populations are more likely to live. The pollution resulting from the plant can affect the local residents, as can visual impacts and noise pollution. Another way desalination may affect EJ communities is through its high economic cost for the product water that will likely be passed on to the consumer. In some cases low-income water customers may not be able to afford the increasing prices for the water.

In order to address and prevent EJ issues from occurring, it is necessary to first identify which populations may potentially be affected. Once the stakeholders are identified it is important to reach out to these groups to educate them about potential impacts and encourage their input in the planning process. Since in many EJ communities English is not the primary language, it may be necessary to provide information and conduct outreach efforts in other languages such as Spanish.

5.j OTHER IMPACTS AND ISSUES

Noise:
Desalination plants are industrial facilities that generate a substantial amount of noise mainly from the operation of high-pressure pumps, turbines, and other equipment (Einav, 2002). Noise levels of more than 90 decibels are common for desalination plants (Sadhwani et al., 2005). This can disturb local residents, wildlife, and other sensitive receptors. Mitigation measures for noise impacts include limiting construction activities to hours when local residents are less likely to be disturbed, locating loud equipment as far away as possible from sensitive receptors, or using noise reducing technologies and designs such as acoustic barriers.

***Private vs. public ownership**:*
Another presently unresolved issue of concern among many individuals, regulatory agencies, and organizations is desalination plant ownership. Whether the plant is privately owned and operated for profit, or is publicly owned, may result in different impacts. The planning and decision making processes for desalination plant proposals will likely also vary significantly depending upon whether the plant is proposed by a public or private entity. Public agencies are subject to a number of different requirements including public involvement and transparency to which private entities are not subject. Moreover, there are a number of socio-economic considerations since private corporations are operated for profit, and will likely charge a higher rate for the product water delivered. In Monterey County, pursuant to County Code *Chapter 10.7.2*, all desalination plants are required to be publicly owned.

There is also concern that foreign-owned corporations operating desalination plants in the U.S. may be exempt from some environmental regulations, due to international trade and investment rules. Rules that may potentially cause conflicts include those for trade agreements such as the *General Agreement on Trade in Services* (GATS), and the *North American Free Trade Agreement* (NAFTA). This issue is considered unresolved, as it is unclear how international tribunals would interpret the rules in these agreements, which tend to be vague and open to interpretation (Harrison Institute for Public Law, 2004). This may have potentially significant consequences since a few multinational corporations increasingly dominate the water supply industry. CalAm for example is owned by Thames Water of the UK, which is in turn owned by Germany's RWE.

Effects on regional ocean monitoring efforts:
There are a number sensitive ocean monitoring projects being initiated in the Monterey Bay area and throughout the world that will contribute valuable data in understanding even very slight changes in the ocean's conditions. There is concern that desalination plant discharges located in the vicinity of these projects may alter results due to unnaturally high salinity, and make it difficult to accurately and reliably assess current water quality parameters. It is recommended that this issue be further evaluated.

Groundwater impacts:
There are several ways that desalination plants can have negative impacts on groundwater in the Monterey Bay area. Seawater or brine can leak from pipelines, ultimately penetrating groundwater aquifers (Sadhwani et al., 2005). It is also possible for pollution from the construction process (e.g. during drilling or installation of pumps and other infrastructure) to impair groundwater. Finally, it is possible for a poorly designed sub-surface intake to cause intrusion of saltwater into freshwater aquifers; this is discussed in more detail in *Section 5.d.* This can be mitigated through proper sealing techniques, sensors and other monitoring equipment, and by the use of BMPs during construction (Younos, 2005).

Impacts on Cultural resources:
Mainly during construction, cultural resources may be uncovered and damaged through ground-disturbing activities such as excavation or grading; these resources may include archeological, paleontological, or human remains. This is a potential issue with all large-scale construction projects, and is not unique to desalination plants. Mitigation and avoidance measures for cultural resources impacts include developing of a plan that lays out procedures for avoiding cultural resources and for responding if they are encountered. At sites where the probability of uncovering cultural resources is high, a qualified expert, such as an archeologist should be at the site to monitor all excavation activities. In such a case, all workers involved in activities with the potential to impact cultural resources should be educated about their potential existence and instructed to immediately stop all construction activities upon discovery until an expert is notified.

Coastal erosion:
The Monterey Bay shoreline is one of the most highly erosive in the state. Desalination plants and infrastructure constructed on the beach without sufficient setback could ultimately be threatened during their useful life by coastal erosion, most notably during episodes where storm and high tide conditions coincide. With current projections for increased sea level rise due to global climate change, this issue can present a serious concern. Since coastal armoring structures such as seawalls would not likely be allowed by regulatory agencies to protect desalination plants and their infrastructure, it is necessary to design and locate the plant so that it is set back beyond the projected future shoreline location. The proposed City of Sand City desalination project includes an *Adaptive Water Supply Management Program*, which establishes techniques to monitor beach profiles over time. This plan also would require that any infrastructure threatened by coastal erosion be relocated (City of Sand City, 2004).

6. DESALINATION PLANT CO-LOCATION ISSUES

Co-locating a desalination plant with another facility and thus taking advantages of existing infrastructure can result in many benefits, which may ultimately lead to a decreased cost for desalinated water compared to a stand-alone RO facility; for this reason it is an approach that is growing in popularity throughout the world. There are however, a number of unresolved issues that must be taken into consideration in each case. Power plants and sewage treatment plants are the two types of facilities most often co-located with a desalination plant intake and/or discharge. Since existing infrastructure is used new construction is minimized, which can result in significant economic benefits and avoidance of construction-related environmental impacts. Co-location can involve blending desalination brine with another discharge (treated sewage or cooling water) or using an existing feedwater source (cooling water).

Mixing brine effluent with existing discharges can be an effective way to minimize or eliminate the impacts from the discharges through dilution. Power plant cooling water or sewage treatment plant discharges are two types of existing discharges that can be used. When combining brine with another existing outfall, it is important to address temporal variations in operation and maintenance of the co-located facilities in order to allow sufficient dilution of brine effluent; often an equalization basin is needed to ensure consistency of the flow volumes of the two discharge streams. The effects of the interactions between the brine and the constituents of the other discharge must also be investigated; for example there may be synergistic effects that occur due to the mixing of the two streams that do not occur with the individual effluents.

In cases where desalination plants are co-located with power plants the spent cooling for the power plant is used feedwater for the desalination plant. This too is associated with a unique set of costs and benefits that require thorough evaluation. The following section examines the practices of co-location with both treated sewage effluent and power plant once through cooling systems.

BRINE DISPOSAL VIA BLENDING WITH TREATED SEWAGE EFFLUENT:

This is one option available if there is a sewage outfall in proximity to the desalination plant. The City of Santa Cruz' proposed desalination plant would convey its brine discharge to the City's wastewater treatment plant where it will be combined with the advanced secondary treated wastewater outfall. This practice provides many similar advantages to blending discharges with a power plant's cooling water outfall, including dilution of the brine and the economic and environmental advantages of not requiring construction of a new outfall structure. For this option to be practical, the sewage outfall must be located close enough to the desalination plant's discharge to allow the brine to be delivered economically. Conveyance cost is based upon the volume of brine and the distance between the desalination plant and the wastewater treatment plant outfall; if that distance is too far then this option may be prohibitively expensive.

An advantage of this practice is that the combined properties of the high salinity brine and the low salinity sewage can counteract each other and enhance mixing. This results in the dilution of high salinity brine, and has the added benefits of mitigating the impacts caused by discharge of a freshwater plume to a marine environment by increasing the salinity of the discharge (California Desalination Task Force, 2003c). Previous examination of this option by the Electric Power Research Institute concluded that co-discharge diminishes the negative buoyancy effect and yields acceptable wastewater dilution values for the proposed plant (1995).

There are several issues associated with this practice however, that must be addressed. Most importantly, the treated sewage outfall must be of sufficient volume to provide the benefit of diluting the brine. There also may be interactions between the two discharges, that have synergistic or cumulative effects not found in the individual discharges; therefore laboratory toxicity testing of the actual combined sewage and brine effluent are required to identify any potential issues. Another issue that may restrict the ability of desalination plants to co-locate with treated sewage outfalls in the future is a likely reduction in the volume of sewage discharges as wastewater recycling becomes more prevalent. Monterey Regional Water Pollution Control Agency (MRWPCA) currently operates a facility that can treat nearly 30 MGD of wastewater. Currently the plant supplies water to the agricultural fields in Castroville during the summer. MRWPCA currently is developing plans for expanding this recycling program. Another issue of concern is that mixing of the brine and wastewater effluent must be carefully modeled and planned so that it doesn't separate in the (often long distance) discharge pipe prior to discharge (Almond, 2006).

Although there are several current proposals to do so, to date this brine disposal option has not been used by any seawater desalination plants in the U.S, except at Santa Barbara for a very brief period of time. Accordingly, there is a lack of information on the potential costs and benefits, and much of what exists is speculative in nature. There are several plants internationally that use this method of brine disposal, including a 30 MGD plant in Fukuoka, Japan which as been in operation since about July 2005. While an initial investigation suggests that this plant's discharge system has not caused any negative issues, it is currently being further evaluated.

BRINE DISPOSAL TO SANITARY SEWER:
Another co-location strategy involving wastewater treatment plants is discharge of brine to a nearby wastewater collection system prior to treatment. This is one of the most widely used methods for disposal of concentrate from brackish water desalination plants in the US today. This indirect wastewater plant outfall discharge method however, is only suitable for disposal of concentrate from very small seawater desalination plants into large-capacity wastewater treatment facilities mainly because of the potential negative effects of the concentrate's high TDS content on the wastewater treatment plant operations.

POWER PLANT CO-LOCATION

Since there are a number of economic and operational advantages to co-locating a desalination plant intake and outfall with the once-through cooling system of a coastal power plant, this option is often considered attractive desalination plant proponents, and it is being pursued extensively throughout California. In fact, the majority of the large desalination plants being proposed in the United States are considering co-location (Pankratz, 2004). Two of the desalination plant proposals in the Monterey Bay area—Pajaro Sunny Mesa Community Services District and California American Water (CalAm)—intend to co-locate some of their facilities with the Moss Landing Power Plant's cooling water system. Co-location of a desalination plant and a coastal power plant normally involves the desalination plant directly connecting to the cooling water outfall of a power plant as both the source water for the desalting plant, and as the outfall for the brine concentrate, which is used to blend and dilute the brine. While there are advantages associated with power plant co-location, there are also a number of unresolved concerns.

Among the fundamental operational considerations that must be addressed for co-location are that the power plant cooling water flow needs to be significantly larger than the volume of the desalination plant being proposed for co-location to ensure adequate dilution of the brine, and the outfall and intake structures need to be spaced sufficiently apart to avoid entrainment of the brine. Another important consideration is the potential for the power plant cooling process to contaminate the feedwater. If levels of metals such as copper, nickel, and iron are present in high concentrations they may cause damage to the RO membranes and require additional pretreatment of the intake water (Voutchkov, 2004).

The specific benefits and impacts resulting from power plant co-location vary depending upon the volume of once-through cooling water, the capacity of the desalination plant, the oceanographic and biological conditions near the site, and specific operational aspects of the power plant and the desalination plant. Several scenarios are possible when co-locating a desalination plant with a coastal power plant, each resulting in a unique set of costs and benefits. In some cases it may be possible for the operation of the desalination plant to occur only during times when the power plant is operating, thus not resulting in an increase in the amount of cooling water used. In other more likely scenarios, the desalination plant may operate at times when the power plant is offline or not operating at full capacity, requiring more intake of cooling water compared to what would have been required by the power plant alone during that time. Another potential scenario could occur in the future if a power plant co-located with a desalination plant upgrades its cooling system from the existing once-through system to a new system that requires less water or does not entail intake of seawater at all, thus necessitating the desalination plant to acquire a source of feedwater of its own. In this case, the majority of the co-location advantages, such as use of an existing source of feedwater and enhanced dilution of the brine plume, would no longer exist, however the desalination plant would still benefit from the use of existing intake and outfall structures, and the volume of intake water required would be significantly less (California Desalination Task Force, 2003c).

Potential issues with power plant co-location:
While there are a number of potential benefits from co-location, there are also several unresolved issues. As previously mentioned, the major issue involving this approach is the growing concern that co-location will result in the perpetuation of the use of outdated

power plant once-through cooling systems, which already cause significant impacts. This has resulted in co-location being perceived as a controversial practice among many in the environmental communities of California and the Monterey Bay area. Additionally there may be considerations regarding the permitting and regulatory process that can impede the ability of desalination plant proponents to pursue co-location. For example, in a study of the feasibility of co-locating a desalination plant with a power plant located in Chula Vista on San Diego Bay, SDGE concluded that mixing of the brine with the power plant cooling water would be unacceptable because it might interfere with the EPA's National Pollutant Discharge Elimination System permitting process and limit the operational flexibility of the power plant. Another potential technical issue is that many power plant intakes are located in areas of high biological productivity, resulting in the intake of feedwater that will require extensive, costly, and sensitive pre-treatment before it goes through the RO membranes (Yamada, et al., 1995).

One important consideration for co-location is the uncertain future of the use of once-through cooling systems for power plants in California. Several recent occurrences have contributed to this uncertainty. The first is a 2004 rule by the U.S. EPA under Section 316(b) of the Clean Water Act, which requires existing power plants using once-through cooling systems to reduce impingement levels by 80-95% and entrainment by 60-90%. Unless it can be demonstrated by the power plant operators that the costs of complying with the revised EPA regulations are greater than the benefits provided, the power plant operators must either meet the new standards through flow reduction at the intake, or through the use of technology, operational measures, or compensatory mitigation (Pacific Institute, 2006). Additionally, the California State Lands Commission recently unanimously approved a resolution that discourages once-through cooling for new and existing power plants. The resolution "… urges the California Energy Commission and the State Water Resources Control Board to expeditiously develop and implement policies that eliminate the impacts of once-through cooling on the environment, from all new and existing power plants in California;" and states that "… as of the date of this Resolution, the Commission shall not approve leases for new power facilities that include once-through cooling technologies." (State Lands Commission, 2006b). The California Ocean Protection Council also recently passed a similar resolution. Another notable trend that may undermine the possibility of power plant co-location in the future, is the recent decisions by 2 of the 22 coastal power plants (South Bay, and Humbolt Bay) currently using once-through cooling to voluntarily upgrade to dry cooling systems that do not require the intake of cooling water.

Some of the challenges that were identified in the aforementioned San Diego study included the temperature of the power plant cooling water which was too high to be practicably desalinated in an RO plant during the summer months (exceeding 100 degrees Fahrenheit), and the potential for a future reduction in capacity of the power plant, which left the desalination plant's feedwater supply in doubt. These and other considerations led to the ruling out of the power plant cooling water as a supply for SWRO. The preferred option identified by the authors was to construct a new intake in the existing power plant intake channel (Yamada, et al., 1995).

Another potential complication resulting from power plant co-location was observed in Tampa Bay. The debris that collects at the intake screens of a power plant is typically separated from the cooling water and disposed of at a land-based disposal facility. In the case of the Tampa Bay power plant, this practice changed from land-based disposal to ocean-based disposal of the intake screenings, resulting in the subsequent entrainment of the debris by the desalination plant and leading to major technical issues for the desalination plant by clogging filters and causing other problems. This issue can be avoided by installing individual fine-mesh screens at the intake to the desalination plant (Voutchkov, 2004).

Once-through cooling impacts:
The major issue surrounding co-location with power plant once-through cooling systems in California is the concern that such co-location can perpetuate the effects caused by the use of that once-through cooling system. The widespread use of once-through cooling can be attributed to its effectiveness and its relatively low economic costs at the time most of these plants were built several decades ago, but there are significant environmental issues associated with this process. Many power plant intakes were sited decades ago before their impacts were understood (California Coastal Commission, 2003).

The seawater that is drawn in to coastal power plants and desalination plants is in reality a habitat for a wide variety of organisms, which are consequently entrained and killed. A number of monitoring studies have been carried out to determine the effects of coastal power plants that employ once-through cooling systems on marine organisms. Power plants along California's coast typically draw in hundreds of millions of gallons of seawater each day, which can each result in the deaths of trillions of organisms every year, and potentially significantly impact marine biological communities (California Coastal Commission, 2003). It is unclear however, the actual effects and magnitude of impacts resulting from the entrainment and impingement-related mortality rates.

A 2005 staff report for the California Energy Commission states: "California marine and estuarine environments are in decline and the once-through cooling systems of coastal power plants are contributing to the decline of our coastal waters." The report also states that impacts due to impingement and entrainment from these systems are comparable to the "loss of biological productivity of thousands of acres of habitats" (California Energy Commission, 2005).

While only a third of these power plants have recently conducted entrainment studies, all of the current studies cite negative environmental impacts due to entrainment of marine or estuarine organisms. The California Energy Commission (CEC) and other agencies require periodic studies to assess the impacts associated with once-through cooling. These reports indicate that power plant once-through cooling systems contribute to the declining health of coastal ecosystems and fisheries. These facilities impact the environment in several ways. One major impact is that they draw in seawater, killing all of the organisms contained in that water. This can include fish eggs, larvae, and other organisms that spend part or all of their life cycles as plankton, drifting with the ocean currents and unable to avoid being drawn into the intake. The biggest impacts from entrainment occur to fish and shellfish species in early planktonic stages of their life cycles (California Energy Commission, 2005).

In 2005 there were 21 coastal power plants in the state of California using once-through cooling; the majority of these are located in the southern part of the state. These 21 power plants, which have a combined capacity of 29,910 megawatts, have permits from the Regional Water Quality Control Boards to draw in a total of almost 17 billion gallons per day from the ocean, estuaries and bays. To put this volume of water into perspective, if the entire San Francisco Bay were drained completely, it would take only 100 days to return to normal levels, if filled at the rate of 17 billion gallons per day. Two of these plants are nuclear (San Onofre and Diablo Canyon) and use significantly more water per unit of electricity generated, when compared to the fossil fuel-based plants (California Energy Commission, 2005). Only one of these plants, the Moss Landing power plant, is located in the Monterey Bay area; this facility is permitted to use 1.226 billion gallons of seawater per day for its once-through cooling system (CalAm, 2005).

As part of the permitting process for the modification of several of the intake units at the Moss Landing Power Plant near Elkhorn Slough, Duke energy was required by the California Energy Commission to conduct a study of the biological impacts to marine organisms caused by the intake system. This study concluded that 13% of larvae found within the source water, primarily within the Elkhorn Slough, and Moss Landing Harbor, but also within a small area of the Monterey Bay beyond the mouth of the Harbor, would be killed, primarily impacting eight species of fish. The California Energy Commission determined that the intake-related impacts of the power plant were significant, and required Duke to make improvements to the intake and provide $7 million for habitat restoration in the Elkhorn Slough, as a mitigation measure.

Potential benefits of power plant co-location:
Co-location with a power plant offers several operational benefits that may ultimately result in decreased cost of the desalinated water compared to that produced by a stand-alone facility. To begin with, using an existing intake structure means that it is not necessary to construct a new intake, which can represent a significant portion of the overall cost of a plant. For example, a surface water intake structure can account for 10-20% of the overall cost to construct a desalination plant (Voutchkov, 2004), potentially costing several million dollars (Pankratz, 2004). Moreover, since the two facilities are located in proximity to one another there may be advantages gained from sharing the costs of various services such as waste treatment and disposal, storm drains, security, and fire medical and other public safety services. There are a number of other potential opportunities as well for the desalination plant to use various facilities onsite including components of the power plants that are no longer used such as abandoned oil storage tanks to hold the desalinated water (Yamada et al., 1995). These savings must be weighed against other costs associated with co-location that may not be present in desalination projects not proposing to co-locate with power plants (i.e. those that use sub-surface intakes). These costs may include increased pretreatment requirements, higher permitting

costs, mitigation costs, shorter membrane life, or greater chance of upset due to water quality changes.

Another benefit of co-location is that the spent cooling water used for desalination feedwater is of elevated temperature. This will result in more efficient desalting with RO membranes, and thus a lower cost. The cooling water discharge from a power plant using once-through cooling is typically 10-20 Fahrenheit degrees warmer than the ambient seawater (Voutchov, 2004). In the case of the Moss Landing Power Plant, the power plant cooling water discharge is approximately 13-Celsius degrees higher than that of the seawater that is drawn into the plant (SIMoN, 2006). According to one estimate, for each 15 degree Fahrenheit increase in feedwater temperature there is a corresponding decrease of 6-8% in the pressure needed to force the water through the RO membranes. These power costs typically represent 30-40% of the final cost of the desalinated product water (Voutchov, 2004).

Another possible operational benefit for desalination plant operators, which is not currently available in the State of California, is that the cost of energy for the desalination plant could be reduced. This is because by being located "inside the fence" of the power plant, costs of transmission of electricity through the grid and some other transmission fees and tariffs do not apply. This situation occurred at the Tampa Bay desalination plant, where a negotiated a rate of 5.5 cents/kWh for inside the fence pricing. Currently however, laws in the State of California do not permit desalination plant operators to take advantage of below-market rate energy prices; although there are still potential energy savings that can be realized through power plant co-location. According to the California Public Utilities Commission (2005):

> *"Co-location of desalination facilities with existing coastal power plants may help reduce the electricity costs of a desalination project, because co-location utilizes both the power plant's seawater cooling system and the direct power supplied at the plant. Special contracts called Self-Generation Deferral Agreements authorized by the Commission in which firms could receive reduced electricity rates to deter departure from the State and to avoid bypass to non-utility energy suppliers are no longer allowed. New Economic Development Rates probably cannot be applied to desalination customers due to the restrictive qualifying conditions for this tariff. The development of desalination in California is currently not contingent upon any special rate relief or subsidy by the CPUC....A desalination facility may be able to lower its electricity bill by building its own power generation, suitable for its size and needs (self-generation), or by purchasing electricity from a non-utility generator located at or adjacent to the facility site (known as an "over-the-fence" transaction). These arrangements are not considered direct access, because electricity is transported from producer to purchaser through power lines located on-site, and does not involve a utility's transmission or distribution systems".*

A study that was conducted by the San Diego County Water Authority and San Diego Gas and Electric (SDGE) to examine the feasibility of co-locating desalination plants and coastal power plants, recognized that one of the primary benefits of power plant co-location was the discharge of brine through the power plant since it meant that a new pipeline did not need to be built. The other brine disposal alternative under consideration was an ocean-based treated sewer outfall, which would have necessitated the construction of a $14 million pipeline to convey the brine from the desalination plant to the outfall (Yamada et al., 1995).

Co-location may also present some environmentally benefits. While a power plant once-through cooling system can clearly cause significant environmental degradation, as previously discussed in this section of this report, the desalination plant will likely not have the additional impacts that would have occurred if that plant were operated independently of the power plant. There is however, considerable concern among many Monterey Bay area residents that co-locating a desalination plant with a power plant will perpetuate the use of that plant's once-through cooling system, which may have otherwise been forced to be upgraded by regulatory agencies, to a less environmentally damaging technology.

In addition to avoiding the relatively minor environmental impacts related to construction of new intake and outfall structures, there may be other environmental advantages associated with co-locating desalination intakes and outfalls with existing power plant structures. One such benefit is that by combining desalination effluent with the once-through cooling discharge of a power plant the brine concentrate is diluted, thus reducing or eliminating the environmental impacts of concentrate disposal. In order for this to work effectively the volume of cooling water must be sufficiently large to dilute the desalination effluent, and the cooling water outfall must be located far enough away from the intake that the concentrate does not get re-entrained into the power plant (Voutchkov, 2004). Since the volume of seawater required by a power plant once-through cooling system is significantly larger than that required by most seawater desalination plants, dilution is usually highly successful.

The first plant to be built in the U.S. using this co-location scenario is the 25 MGD Tampa Bay plant. It is co-located with the Tampa Electric Big Bend Power Station, which uses an average of 1.4 billion gallons of cooling water per day. Currently, there are a number of desalination proposals throughout California, the U.S. and the world that intend to co-locate facilities with power plants. One such project in Carlsbad, California, proposes to use the cooling water at a local power plant that intakes a volume of around 600 MGD; about 100 of the 600 MGD will be diverted prior to discharge, and used as feedwater for the desalination plant. The resulting brine effluent with a volume of 50 MGD would be approximately twice as salty as ambient seawater; however after diluting it with the cooling water, the salinity would be 36.2 ppt. For comparison, ambient seawater salinity in the area is about 33.5 ppt (Voutchkov, 2004). In the Monterey Bay area CalAm's proposed Coastal Water Project desalination plant intends to use the cooling water system of the Moss Landing Power Plant both as a source of feedwater and as a receiving body for the brine. The salinity of the desalination effluent would be reduced to ambient levels when combined with the power plants 380 to 1,224-MGD outfall flow, thus minimizing potential impacts to the marine environment from increased salinity (CalAm, 2005).

Another indirect benefit of blending the two discharges is the reduction of the power plant's thermal plume footprint on the marine environment (Einav, 2002). Since the warmer cooling water discharged by the power plants is of lower density than the ocean water, the power plant thermal plume typically remains on the ocean surface for a relatively long time until it eventually mixes with the ambient ocean water and becomes dissipated. As a result, power plant discharges typically have thermal footprints that can cover a significant area of the ocean surface near the outfall. Blending the warmer, and therefore less dense power plant thermal plume with higher salinity/higher density desalination plant discharge forces the thermal plume to leave the surface and quickly engage in mixing with the entire ocean water column in the vicinity of the point of the discharge, thereby reducing the thermal footprint of the power plant and at the same time accelerating the dilution of the RO plant concentrate. Hydrodynamic modeling completed as part of the environmental impact assessment process for the Poseidon Seawater Desalination Project in Huntington Beach indicates that the power plant thermal footprint can be reduced by 20 to 40% as a result of the combined discharge of power plant cooling water and RO plant concentrate (Poseidon, 2005). In addition, the desalination plant removes a portion of the power plant thermal load for conversion to potable water.

While the power plant is likely causing substantial environmental impacts due to entrainment and impingement from the once-through cooling system, its intake allows for the use of the same seawater for two purposes, once for power plant cooling water and once for desalination; therefore, additional impacts are avoided. Since the desalination plant will tap into the power plant's discharge stream as a source of feedwater, co-location means that it is not necessary to draw in additional seawater for the desalination plant, which can not only be costly and energy intensive but can also cause entrainment and impingement impacts. Another major benefit is that it eliminates the need to develop another coastal area to build a desalination plant, including the construction of new intake and discharge structures that can significantly impact benthic organisms living on the seafloor (Voutchkov, 2004).

Mitigating once-through cooling impacts
There are methods available for reducing these impacts, although they have been met with mixed results. Methods for reducing impingement may vary significantly in types of approaches as well as success rates, from those used to mitigate entrainment. Most of these methods are the same as those that can be used to mitigate impacts from a surface water intake of a stand-alone desalination plant and are discussed in detail in *section 5.d* of this report. These include the use of design options, such as physical barriers to prevent organisms from entering the intake; fish handling systems; diversion systems, which utilize bypasses to redirect fish to where they can escape, and behavioral barriers (California Energy Commission, 2005).

Restricting the use of the plant during certain seasons or times when there are high abundances of plankton or special status species in the seawater can also reduce impingement and entrainment impacts. Another method is the use of variable speed pumps, which allow the plant operators to intake lower volumes of water when the plant is not operating at peak capacity (California Energy Commission, 2005). Flow reduction can also be effective, this can be accomplished through operational or technological practices including upgrading the plant technology to combined-cycle combustion. Converting the plant to combined-cycle combustion can result in major decreases in impacts; for example two of the units at the Moss Landing power plant were upgraded to this technology. These units, with a capacity of 1,060 megawatts, only necessitate 250,000 gallons per minute of seawater for cooling, whereas two of the conventional units at the same plant with a capacity of 1,478 megawatts, require 600,000 gallons per minute (California Energy Commission, 2005).

7. REGULATORY CONSIDERATIONS

7.a INTRODUCTION

Issues related to seawater desalination facilities are varied and diverse, and include aspects related to marine and terrestrial resources, land use, public health, energy use, and urban growth and development. Accordingly, there is a large number of varying types of regulations and permitting agencies involved. Which regulations will apply and what agencies will be involved varies from project to project, based upon the siting of the desalination plant and associated infrastructure, the practices used, and many other project-specific considerations. The following section provides an overview of the roles of local, state, and federal agencies potentially involved in the permitting process for a desalination plant as well as specific legislation for proposed desalination plants in the Monterey Bay area.

7.b FEDERAL REGULATORY AGENCIES

NOAA/Monterey Bay National Marine Sanctuary (MBNMS):

The National Marine Sanctuary Program consists of a network of thirteen diverse marine protected areas, encompassing marine and freshwater resources from Washington State to the Florida Keys and from Lake Huron to the Gulf of Mexico, American Samoa, and places in between. The National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service has managed these sanctuaries since the passage of the Marine Protection, Research, and Sanctuaries Act of 1972, now called the National Marine Sanctuaries Act.

The Monterey Bay National Marine Sanctuary (MBNMS) is the largest of the thirteen sanctuaries administered by NOAA, spanning over 5,300 square miles of coastal waters off central California. The Sanctuary stretches from Marin County to Cambria, encompassing nearly 300 miles of shoreline and extending an average distance of twenty miles from shore; its deepest point is 10,663 feet under the ocean's surface (more than two miles). The Sanctuary was designated in 1992, in response to overwhelming public support to halt potential offshore oil and gas development, for the purpose of resource protection, research, education and public use. The mission is to understand and protect the ecosystem and cultural resources of central California.

In order to achieve the goal of resource protection, the MBNMS prohibits or otherwise regulates a number of activities within its boundaries. Three of the Sanctuary's regulations relate directly to desalination. The first involves a prohibition on discharging or depositing any material within Sanctuary boundaries. Since the brine concentrate, and in some cases other materials, are usually disposed of in ocean waters, this activity requires Sanctuary authorization of Regional Water Quality Control Board (RWQCB) permits. The second Sanctuary regulation pertains to discharging materials outside of the boundaries, which subsequently enter Sanctuary waters and negatively impact MBNMS resources. As with the previous regulation, Sanctuary approval via authorization of the RWQCB permit is required. The third relevant regulation involves a prohibition on activities that cause alteration of the seabed. Installation of certain desalination facility structures such as intake/outfall pipelines on or beneath the ocean floor will also require Sanctuary authorization of California Coastal Commission Coastal Development Permits.

NOAA Fisheries Service:
NOAA's National Marine Fisheries Service (NMFS) is the federal agency responsible for managing, protecting, and conserving living marine resources and their habitat throughout the Exclusive Economic Zone (waters between 3 and 200 miles offshore).

NMFS becomes involved with desalination by providing consultation pursuant to *Sections 7 and 10* of the *Endangered Species Act* (ESA), which governs potential impacts of desalination plants to species and habitats that are either federally listed or proposed to be listed. NMFS also reviews desalination proposals for their potential impacts to *Essential Fish Habitat* (EFH) under the Magnuson-Stevens Fishery and Management Conservation Act. Pursuant to the *Marine Mammal Protection Act* (MMPA), NMFS is also responsible for protection of most marine mammal species found in the Monterey Bay, with the exception of the southern sea otter (*Enhydra lutris)*, which is under the jurisdiction of the U.S. Fish and Wildlife Service. The main issues related to desalination plants reviewed by NMFS are construction impacts on subsurface hard substrate, entrainment and impingement and impacts related to the discharge of brine effluent.

U.S. Environmental Protection Agency:
The primary responsibilities of the U.S. EPA are ensuring human health and protecting the natural environment. The two primary pieces of legislation enforced by the EPA relating to desalination projects are the *Clean Water Act* (CWA) and the *Safe Drinking Water Act* (SDWA). CWA regulations require that any facility on the coastline that discharges wastewater into U.S. waters obtains a *National Pollutant Discharge Elimination System* (NPDES) Permit, and this pertains to a desalination plant's brine discharge. In accordance with the NPDES permit, dischargers are required to use the best available technology to ensure that the discharge does not cause impacts to the environment. In California, NPDES permits are administered by the State Regional Water Quality Control Boards, however review by the EPA is necessary in all cases. The SDWA stipulates that the EPA and/or individual states are responsible for ensuring the quality of drinking water supplies, including those resulting from desalination (California Desalination Task Force, 2003d), and is applicable to any desalination plant that provides a public water supply, or that discharges brine into a water body that may be used for drinking supply (Younos, 2005).

U.S. Coast Guard:
The U.S. Coast Guard (USCG) is charged with ensuring safety and security throughout the U.S. coastline, with respect to navigation, management of waterways, and protection of natural resources. USCG involvement with desalination projects involves consultation with the Army Corps. of Engineers (ACOE) under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act. The USCG typically is involved with reviewing proposals for structures to be located underwater, to ensure that they do not interfere with navigation or present other hazards (California Desalination Task Force, 2003d).

U.S. Fish and Wildlife Service:

Similar to NOAA Fisheries, the U.S. Fish and Wildlife Service (USFWS) plays a consultative role under Sections 7 and 10 of the Endangered Species Act, as well as the Marine Mammal Protection Act. USFWS reviews activities that may impact certain federally listed species or their habitats. The USFWS and NOAA Fisheries both are guided by the same set of regulations under the ESA; however each agency is exclusively responsible for different listed species. USFWS has jurisdiction over terrestrial animals and sea otters, while NOAA Fisheries is responsible for the remaining listed marine animals and all other marine mammals (Kathey, 2006). If the lead agency responsible for the desalination project is a federal agency, then a Section 7 consultation would occur; otherwise the project proponent would need to complete a Habitat Conservation Plan (HCP) and submit it to the USFWS for review and approval (MPWMD**,** 2005).

U.S. Army Corps. of Engineers:

The U.S. Army Corps of Engineers (ACOE) has regulatory authority over activities involving waters of the U.S. pursuant to Section 404 of the *Clean Water Act* and section 10 of the *Rivers and Harbor Act*. This includes the regulation of any development or structure that may cause obstructions to U.S. navigable waters, or placement of fill or dredged material (which is defined generally to include any structure that is built). Under Section 404 there are two types of applicable permits that are required. For larger-scale projects with the potential to cause significant impacts, an individual permit is typically required. For activities with minimal potential environmental impacts a general permit is usually required (California Desalination Task Force, 2003d). The ACOE may be involved in permitting the construction of desalination plant intake or outfall structures, as well as pipelines crossing waterways such as rivers, streams, or creeks (Pacific Institute, 2006). For example, in the Monterey Bay region, a Rivers and Harbor Act Section 10 Permit is required for any proposed crossings of desalination plant infrastructure across Moro Cojo Slough, the Salinas or Carmel Rivers (less than 7 miles upstream from the river mouth) or any other U.S. navigable waters in the area (MPWMD, 2005**).**

U.S. Army:

Any proposed desalination project with infrastructure (i.e. water conveyance pipelines) that passes through U.S. Army land at Fort Ord would require right-of-way approval. This would be the case for the MPWMD proposal and the regional alternative for CalAm's Coastal Water Project. For infrastructure that passes through former Fort Ord land transferred to other entities, an approval letter would be required by that entity (MPWMD, 2005).

U.S. Bureau of Land Management:

For projects located on former Fort Ord lands that have been transferred to BLM, a right-of-way permit is required. BLM would also require that archeological and biological studies be carried out and project plans would also need to be submitted. None of the currently proposed projects would likely cross BLM lands (MPWMD, 2005).

7.c. STATE REGULATORY AGENCIES

California Coastal Commission:

The California Coastal Commission (CCC), in collaboration with local counties and cities, is the primary state agency responsible for planning and regulating the use of land and water within California's *Coastal Zone*, in accordance with the specific policies of the *California Coastal Act* (CCA). All desalination plant proposals located within the coastal zone will be reviewed for consistency with the CCA and will require a *Coastal Development Permit*, which involves stringent review of the project by CCC staff.

The CCA was enacted by the state Legislature in 1976 to protect coastal resources, enhance public access, provide education to the public about the coast and issues affecting it, and establish local controls for coastal development (California Coastal Commission, 2004). The CCA includes specific policies that address a variety of issues including but not limited to: public access and recreation, protection of marine and terrestrial biological habitat, water quality, visual impacts, agricultural lands, commercial fisheries, industrial uses, power plants, ports, and public works (California Coastal Commission Website, 2006).

In addition to development within the state's coastal zone, the CCC also has jurisdiction over projects requiring federal permits or approval in federal waters.

Central Coast Regional Water Quality Control Board:

It is the responsibility of the Regional Water Quality Control Boards (RWQCB) to preserve and enhance the quality of the State's waters through the development of water quality control plans (Basin Plans) and the issuance of waste discharge requirements (WDRs), which are required by the California Water Code. NPDES permits (required under the Clean Water Act and Code of Federal Regulations) serve as WDRs for point source discharges to surface waters. Examples of point source discharges include offshore oil and gas platforms, municipal wastewater treatment plants, industrial outfalls, desalination brine, and storm water outfalls. WDRs for land and surface water discharges are issued and enforced by one of the nine Regional Water Quality Control Boards. In the Monterey Bay area it is the Central Coast RWQCB (also called RB 3). The State Water Resources Control Board also issues general WDRs, including general NPDES permits that cover similar activities in more than one region. WDRs, including NPDES permits issued by the Regional Water Boards, are subject to review by the State Water Board, but do not need the State Water Board's approval before becoming effective. However, all NPDES permits are subject to approval by USEPA before they take affect. All desalination plants with open water outfalls will require an NPDES permit; however, desalination plants using subsurface discharge structures, and not directly discharging to a surface water body will require a WDR but not an NPDES permit (von Langen, 2006).

The RWQCB also can regulate desalination intake facilities under the state's Porter Cologne water quality regulations if there is the potential for it to affect beneficial uses of water. Additionally, the RWQCB requires all construction projects with the potential to disturb one or more acres of land to obtain a General Permit for Storm Water Discharges from Construction Activity. The Storm Water Permit requires the development and implementation of a *Storm Water Pollution Prevention Plan* (SWPPP). The SWPPP identifies Best Management Practices (BMPs) for reducing or eliminating pollutants in runoff that discharges into waterways and storm drains.

As mentioned previously, projects involving discharges of dredged or fill material to waters of the United States including wetlands and other water bodies require an ACOE Section 404 permit. All ACOE Section 404 permits require Section 401 Water Quality Certification by the Regional Water Boards.

State Water Resources Control Board:

The State Water Resources Control Board (SWRCB) is the state agency responsible for water rights allocations in California, and also for establishing water quality protection measures for the state. *Water rights* are required for any desalination plant that draws water from enclosed or semi-enclosed water bodies including brackish or saline groundwater, or bays or estuaries, water rights may not be required for desalination plants using surface water intakes to draw in seawater. Statewide water quality standards are established by the SWRCB, via the *State Ocean Plan* and other means. SWRCB also is involved in appealed RWQCB decisions (California Coastal Commission, 2004).

California Department of Health Services:

California Department of Health Services (DHS) is responsible for ensuring the safety of the desalinated product water. Desalination plants require a *Domestic Water Supply Permit* as well as a *Source Water Assessment and Protection Plan* (Pacific Institute, 2006). DHS is involved in reviewing and approving both equipment and processes used in desalination plants, assessing the integrity of the equipment used, and establishing plans to respond to a variety of potentially problematic issues. A *Public Water System Permit* will be required by DHS for any proposed desalination plant that will produce a public water supply.

California Department of Fish and Game:

The California Department of Fish and Game (CDFG) requires *Streambed Alteration Agreements* for any desalination plant components that may impact streams. CDFG also evaluates the proposed desalination plant's potential to negatively affect species listed as either endangered or threatened in the state (California Coastal Commission, 2003). In certain cases, such as CalAm's proposed desalination plant, a *Section 1600 Streambed Alteration Agreement* and an *Incidental Take Permit* will also be required (CalAm, 2005).

California Department of Boating and Waterways:

California Department of Boating and Waterways (DBW) reviews certain projects that have the potential to present a hazard to boaters. This could potentially include desalination plant infrastructure such as intake or outfall structures.

California Department of Parks and Recreation:

The Department of Parks and Recreation (CDPR) is responsible for the management and protection of natural and cultural resources, and facilitating outdoor recreational opportunities within the 270 State Park units (CDPR Website). This includes nearly a third of the California coastline (California Desalination Task Force, 2003d). Any desalination plant infrastructure located on state parkland would require approval by CDPR. Land under the jurisdiction of CDPR in the Monterey Bay Area includes Monterey, Marina, Salinas River, Zmudowski, Sunset, and Seacliff State Beaches. Several of the proposed desalination plants would be at least partially located on State Park land, including MPWMD, Sand City, and potentially Marina Coast Water District. Any of these projects would require an *Encroachment Permit*.

The existing Marina Coast Water District desalination plant was issued a permit about 10 years ago, to allow a beach well intake at Marina State Beach. MCWD compensated State Parks for use of the property by making some infrastructure improvements at the State Beach such as placing utility lines underground (Gray, 2006).

California Department of Transportation:
For situations potentially affecting state highways California Department of Transportation (CalTrans) requires an *Encroachment Permit*. This permit would be required for any pipelines that would need to cross Highway 1 for example.

California Department of Water Resources:
The mission of California Department of Water Resources (DWR) is “to manage the water resources of California in cooperation with other agencies, to benefit the State's people, and to protect, restore, and enhance the natural and human environments” (DWR website). All desalination plants proposing to use any state water conveyance infrastructure require DWR approval (California Coastal Commission, 2004).

California Public Utilities Commission:
For privately owned desalination plants, the California Public Utilities Commission (PUC) is responsible for regulating the rates charged by the desalination plant operator for the product water, under the authority of the California *Public Utilities Act* (Pacific Institute, 2006). The PUC also is responsible for the designation of water service areas for individual water districts, in some cases limiting the area to which product water can be delivered (California Coastal Commission, 2003).

California State Lands Commission:
Pursuant to the *California Public Resource Code,* the California State Lands Commission (SLC) issues a *Land Use Lease* for all desalination projects that would be located or partially located in state tidelands or navigable waterways (Pacific Institute, 2006). SLC manages nearly 4 million acres of *Sovereign Lands* underlying California’s navigable and tidal waterways, which include over 120 rivers, streams, and sloughs, tidal navigable bays and lagoons, and submerged lands along the entire coastline of the state between the mean high tide line and three nautical miles offshore (State Lands Commission Website, 2006). The proposed Marina Coast Water District and CalAm desalination plants as well as any other proposals with infrastructure that would encroach onto SLC lands, would require an SLC *Encroachment Permit* (Denise Duffy and Associates, 2004).

California Energy Commission:
The California Energy Commission (CEC) reviews any desalination plants proposing co-location with a coastal power plant. The CEC evaluates the proposed desalination project's potential effects on the operation of the power plant, as well as any modifications that are necessary for the power plant to make to accommodate the desalination plant.

7.d LOCAL AND REGIONAL REGULATORY AGENCIES

Counties:
Both Monterey and Santa Cruz Counties have *Local Coastal Programs (*LCPs) that have been certified by the California Coastal Commission. Desalination projects located within the jurisdiction of either county would require a *Coastal Development Permit* issued by that county's planning department. Any facility located within 300 feet of the mean high tide line, or between the ocean and first public road is within appeal jurisdiction of the Coastal Commission, and therefore, the Commission will likely appeal most decisions regarding proposed desalination plants (Luster, 2006b).

Additionally, county zoning requirements, land use ordinances, and population growth policies also may apply to desalination plants. In many cases Monterey and Santa Cruz County Public Works Departments would require an *Encroachment Permit* for any structures such as product water conveyance pipelines, that enter County rights-of-way (Brezack, 2006). *California Government Code 53091d* stipulates that projects involving "production, generation, storage, treatment, or transmission of water" are exempt from building ordinances of a county or city, and therefore local building permits are not required of publicly owned desalination facilities (Santa Cruz, 2003).

In Monterey County, pursuant to County Code *Chapter 10.7.2*, all desalination plants are required to acquire two separate Monterey County Health Department (MCHD) permits, one to *Construct a Desalination Facility,* and one to *Operate a Desalination Facility*. This code also requires that any desalination plant that is proposed within the County be a publicly owned facility. If a water supply well is necessary, the MCHD must issue a *well construction permit*, and a *Hazardous Materials Business Plan and Inventory* may be required. Any facility with new electrical meters requires an *Electrical Permit* from the relevant city or county department. Monterey County Planning and Building Inspection Department also is involved in permitting of desalination plants located within county jurisdiction; these include a *Use Permit* (MCC Chapter 21.72 Title 21), a *Coastal Development Permit*, a *Grading Permit*, and an *Erosion Control Permit* (CalAm, 2005).

Cities:
Desalination plants located within cities with certified LCPs would require a *Coastal Development Permit* issued by that city. The following cities in the Monterey Bay area have certified LCPs: Santa Cruz, Capitola, Watsonville, Marina, Sand City north of Bay Avenue, and Carmel. Similar to the counties, any facility located within 300 feet of the mean high tide line, or between the ocean and first public road in a city is within appeal jurisdiction of the Coastal Commission and therefore, most decisions regarding proposed

desalination plants will likely be appealed by the Commission (Luster, 2006b). Additionally, city zoning requirements, land use ordinances, and population growth policies also may apply to desalination plant proposals. As in the County, a project within the City would still need a Hazardous Materials plan from the County Pursuant to local code, cities typically require a *Grading Permit* for excavation and fill activities and an *Encroachment Permit* for activities within city rights-of-way. Other permits required from local cities can include use permits, easement permits, and erosion control permits.

Monterey Bay Unified Air Pollution Control District:
The Monterey Bay Unified Air Pollution Control District (MBUAPCD) is the agency with primary enforcement responsibility for air quality within Monterey, Santa Cruz, and San Benito counties. The MBUAPCD is responsible for air quality monitoring, permitting, enforcement, air quality planning, regulatory development, and education and public information activities related to air pollution, pursuant to the *California Clean Air Act,* the *Federal Clean Air Act,* and the *California Health and Safety Code*. Each district is required to develop rules and regulations that allow that district to comply with federal and state ambient air standards (MBUAPCD Website, 2006). Any proposed desalination plant would require *Authority to Construct* by MBUAPCD pursuant to local rules required by Health and Safety Code *Chapter 32, article 3;* it would also require a MBUAPCD *Permit to Operate* (CalAm, 2005).

Monterey Peninsula Water Management District:
The Monterey Peninsula Water Management District (MPWMD) boundaries include the cities of Carmel-by-the-Sea, Del Rey Oaks, Monterey, Pacific Grove, Sand City and unincorporated areas including Carmel Valley, Del Monte Forest (Pebble Beach), and a portion of the Highway 68 corridor. Although the boundaries also include portions of former Fort Ord, that area's water supply systems are managed and operated by Marina Coast Water District. Pursuant to California Water Code (Appendix chapters 118-1 to 118-901), the mission of the MPWMD is "to manage, augment and protect water resources for the benefit of the Community and the environment" (MPWMD Website, 2006). MPWMD issues only one type of permit, a *Water Distribution System* (WDS) Permit, which is required for any new water supply system within the District's jurisdiction. There are exceptions in some cases where the system serves only one connection, but those would not apply for seawater desalination systems. In the case of CalAm, they have an existing WDS Permit; adding a desalination plant (expansion, extension, or modification of a system) requires an amendment to that Permit.

MPWMD has considered seawater desalination as a potential water supply source since the late 1980s. The only existing system in MPWMD's service area is a project owned and operated by the Monterey Bay Aquarium, constructed in the early 1990s. A number of other public and private projects have been evaluated and proposed. In the early 1990s, MPWMD developed a 3 MGD project to be constructed in Sand City. A Final Environmental Impact Report was certified, and the project was bid, with final design and construction pending the outcome of an authorizing vote. However, the project failed to be approved by voters in the November 1993 election. Subsequent water supply project proposals, including dams on the Carmel River, have considered seawater desalination as an alternative supply (Bell, 2006).

In 2006, MPWMD retained a team of consultants (Bookman-Edmonston/GEI Consultants, Separation Processes Inc., and Malcom-Pirnie Inc.) to review and evaluate all but the 300 AFY City of Sand City project. The results of this evaluation are presented in a June 26, 2006 report titled *"Seawater Desalination Projects Evaluation."* This report provides a review of the technical, environmental, and cost aspects of each of the three projects.

MPWMD also plays an advisory role as one of a group comprised of water agencies, cities, and Monterey County whose managers have been meeting for over a year to develop strategies for supplying the urban water supply needs of the Monterey Peninsula and North Monterey County. Seawater desalination will likely provide a major part of the solution to the water supply problems of these areas (Bell, 2006).

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Appendix 1. Glossary and Acronyms for Desalination

Acre-foot (AF): A unit for measuring the volume of water. One acre-foot equals 325,851 gallons (the volume of water that will cover one acre to a depth of one foot). One million gallons is equal to 3.07 acre-feet.

AFY: Acre-feet per year, used commonly as a measure of product water capacity of desalination plants.

AMBAG: Association of Monterey Bay Area Governments

Annual Cost: The total yearly cost of owning and operating a desalination plant. This cost includes carrying charges on the investment, taxes, insurance, interest on working capital, operating and maintenance labor, energy costs, consumable supplies, repair and replacement costs, and the cost of concentrate disposal.

Backwash: Reversed flow in a filter, ion-exchange column, or membrane filter to remove or wash away accumulated suspended materials.

Beach Well: See *subsurface intakes*

Biocide: A chemical used to kill biological organisms (e.g., chlorine).

Blending: Mixing waters of different purity and constituents to form a diluted solution.

Brackish water: Water with salt concentrations of between 5 and 20 parts per thousand (ppt). Seawater generally has salt concentrations of greater than 20 ppt.

Brine: Water that contains a high concentration of salt. Brine discharges from desalination plants may include constituents used in pretreatment processes, in addition to the high salt concentration seawater.

CEQA: California Environmental Quality Act

Coagulation: A pretreatment process used in some desalination plants. A substance (e.g., ferric chloride) is added to a solution to cause certain elements to thicken into a coherent mass, so that they may be removed.

Cogeneration: A power plant that is designed to conserve energy by using "waste heat" from generating electricity for another purpose.

Concentrate: The concentrated wastewater flow from reverse osmosis, electrodialysis, and nanofiltration plants.

Concentrate Reject (Stream): The concentrated wastewater flow from a desalting plant, containing most of the salts from the original feedwater. Also referred to as *blowdown.*

Contaminant: Any undesirable substance in a water resource.

Desalination: Process of removing salts from water sources. Also referred to as desalinization, and desalting

DFG: California Department of Fish and Game

DHS: California Department of Health Services

Distillation: A process of desalination where the intake water is heated to produce steam. The steam is then condensed to produce product water with low salt concentration.

DWR: California Department of Water Resources

Distribution System: The pipes, conduits, and canals bringing water to the end users.

Effluent: Water leaving a desalting process. May be applied to both concentrate, and product water.

EIR: Environmental Impact Report (CEQA)

EIS: Environmental Impact Statement (NEPA)

Energy Recovery: Possible energy savings in reverse osmosis in which the concentrate stream, under pressure, is used to drive a turbine that provides part of the feed pressure requirement.

Entrainment: Entrainment occurs when small organisms, such as plankton, larvae, and fish eggs, are drawn into a water intake past any screening equipment and are subjected to pressure or temperature changes. Entrainment is generally considered to result in the death of all the entrained organisms, if not immediately, then shortly after they are discharged back into the environment where they become prey for other animals.

FeedWater (or Source Water): Saline water supplied to the desalting plant for processing.

Fouling: The reduction in performance of process equipment (heat transfer tubing, membranes, etc.) that occurs as a result of scale buildup, biological growth, or the deposition of colloidal material.

Ground Water: Water normally found underground and obtained from wells.

Impingement: Impingement occurs when fish and other aquatic organisms are trapped against screens used in intake systems. Impingement usually results in either injury or death to the organisms, although some systems include features that allow some individuals to be moved away from the screens unharmed.

Infiltration Gallery: A structure used to draw in water using perforated pipes buried below land or below the bottom surface of a water body. Water in the saturated zone of the substrate is pulled into the perforated pipes.

Kilowatt (kW): A thousand watts. The watt is a measure of power used by electricity generating plants. One watt is equivalent to 1 Joule/second or 3.4127 Btu/hour.

LCP: Acronym for Local Coastal Program, a basic planning tool used by local governments to guide development in the coastal zone, in partnership with the Coastal Commission. LCPs specify the location, type, and scale of new or changed uses of land and water through implementation measures such as a land use plan and zoning ordinances. After an LCP is prepared by local government and certified by the Coastal Commission, the local jurisdiction is responsible for much of the planning, regulatory, and permitting requirements within its coastal zone, which is the area near the coast where Coastal Act provisions apply.

Megawatt (MW): One million watts.

Minimize: To reduce to the smallest possible level.

Membrane: In desalting, used to describe a semipermeable film. Membranes used in electrodialysis are permeable to ions of either positive or negative charge. Reverse osmosis and nanofiltration membranes ideally allow the passage of pure water and block the passage of salts.

MGD: Million gallons per day, used commonly as a measure of product water capacity of desalination plants.

Microfiltration: A membrane used to treat water, with a 1.05-5 micron pore size. The membrane filters out turbidity, algae, *Giardia* and *Cryptosporidium* spores, and bacteria. The membrane operates by sieving.

Mitigate: The California Environmental Quality Act (at Section 15370) defines "mitigation" and the sequence of mitigation as:

(a) Avoiding the impact altogether by not taking a certain action or parts of an action.
(b) Minimizing impacts by limiting the degree or magnitude of the action and its implementation.
(c) Rectifying the impact by repairing, rehabilitating, or restoring the impacted environment.
(d) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action.

(e) Compensating for the impact by replacing or providing substitute resources or environments.

NEPA: National Environmental Policy Act

Nanofiltration: A membrane used to desalinate water. The membrane has a molecular weight cutoff of about 100, and rejects ions with greater than 100 molecular weight at about 90 percent. The membrane operates by overcoming osmotic pressure.

MBNMS: Monterey Bay National Marine Sanctuary

NMFS: National Marine Fisheries Service

NOAA: National Oceanic and Atmospheric Administration

Post-treatment: The processes, such as pH adjustment and chlorination that may be employed on the product water from a desalting unit.

Pretreatment: The processes such as chlorination, clarification, coagulation, scale inhibition, acidification, and de-aeration that may be employed on the feedwater to a desalting unit to minimize algae growth, scaling and corrosion.

Reverse Osmosis (RO): A process of desalination where pressure is applied continuously to the feedwater, forcing water molecules through a semipermeable membrane. Water that passes through the membrane leaves the unit as product water; most of the dissolved impurities remain behind and are discharged in a waste stream.

Semipermeable Membrane: A membrane that is permeable for certain molecules or ions only. RO membranes, for example, ideally will pass water but not salt.

Subsurface intakes: These include various types of systems that pull in water through an overlying substrate, such as sand or fractured rock. Names for such systems include "beach well", "infiltration gallery", and "Ranney well." The feasibility of these types of systems depends on the geologic and hydrologic characteristics of a site. These types of structures are often environmentally beneficial since they avoid or reduce effects on marine organisms, including entrainment impacts.

Total Dissolved Solids (tds): Total amount of matter, typically salts and calcium carbonate, in solution in a sample of water, usually expressed in milligrams per liter (mg/L) or parts per million (ppm). The state-recommended Maximum Contaminant Level (MCL) drinking water standard for total dissolved solids is 500 mg/L, the upper MCL is 1,000 mg/L, and the short-term permitted level is 1,500 mg/L. Seawater contains roughly 30,000 mg/L.

Turbidity: Opaqueness or cloudiness caused by the presence of suspended particles in water, usually stirred-up sediments. The turbidity of water is measured by its capacity for absorbing or scattering light.

USBR: U.S. Bureau of Reclamation

Ultrafiltration: A membrane used to treat water with about a 10,000-300,000 molecular weight cutoff. The membrane rejects organic macromolecules, viruses, and asbestos. The membrane operates by sieving.

Most definitions compiled from:
Seawater Desalination and the California Coastal Act, California Coastal Commission, 2004

Desalting Handbook, United States Bureau of Reclamation, 2003

Common Conversions:
1 acre foot = 325,851 gallons
1 million gallons = 3.07 acre-feet
1 MGD = 1,120 AFY