Arnold Schwarzenegger
Governor

SEAWATER SOURCE COOLING FOR AIR CONDITIONING COMMERCIAL BUILDINGS

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Lawrence Berkeley National Laboratory

Month Year
CEC-500-99-013

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Commission Contract
Commission Work Authorization No. BOA# 165-P-06

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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- Renewable Energy Technologies
- Transportation

Seawater Source Cooling for Air Conditioning Commercial Buildings is the final report for the Scoping Study of Cold Seawater Source Cooling Systems for California project (work authorization number BOA# 165-P-06) conducted by Lawrence Berkeley National Laboratory. The information from this project contributes to PIER's Buildings End Use Energy Efficiency Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

Please cite this report as follows:
Radspieler, A., Xu, P and Haves, P. Seawater Source Cooling for Air Conditioning Commercial Buildings. California Energy Commission, PIER Program. CEC-500-99-013.

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Abstract

This study is a preliminary evaluation of the potential for using Seawater Source Cooling (SWSC) to air condition commercial buildings in California. It also identifies the regulatory policies and permitting requirements that influence implementation of SWSC projects in California. The technical and economic feasibility of SWSC systems for both individual buildings and district cooling systems is examined, as is the viability of application to existing buildings and to new construction and major retrofits that employ radiant cooling and other advanced cooling technologies that allow the use of higher temperature chilled water. Three case studies are included. Recommendations for further study are presented.

Keywords: seawater cooling, commercial buildings, California, air conditioning, existing buildings, district cooling, radiant cooling, regulations, permits, feasibility

Executive Summary

Introduction

Energy is becoming increasingly limited and expensive in California and there is a mandate to significantly improve the energy and water efficiency of new and existing buildings in the State.

Purpose

This study is a preliminary evaluation of the potential for using Seawater Source Cooling (SWSC) that uses cold seawater as a heat sink, to air condition commercial buildings in California. It also identifies the regulatory policies and permitting requirements for implementing SWSC projects in California.

Outcomes

The outcomes of this research included: 1) a literature review of SWSC research and projects; 2) a coastal survey of cold seawater resources, population centers, and regulation and permitting requirements; 3) an applicability analysis of SWSC by coastal regions, 4) a feasibility model to compare SWSC and conventional cooling systems, and 5) three case studies of standalone and hybrid SWSC project currently under consideration in California.

Conclusions and Recommendations

The most promising locations for SWSC are near the high population centers of San Francisco Bay and Los Angeles and San Diego coastal areas.

The findings of this study suggest that, due to the distances to reach sufficiently cold seawater, standalone SWSC systems for individual buildings and district cooling applications are not economically feasible except in selected cases where there is an existing intake pipeline infrastructure and/or where underwater canyons bring colder water closer to shore.

Hybrid SWSC systems, which meet part of the cooling load using seawater, appear economically feasible for existing commercial buildings in district cooling applications and in new construction and major retrofits of individual buildings that employ radiant cooling. Radiant cooling, and other advanced cooling technologies that allow the use of higher temperature chilled water have the potential to increase the efficiency, feasibility and overall applicability of SWSC systems using higher temperature seawater.

Barriers to the adoption of SWSC include unfamiliarity on the part of both designers and owners, together with significant regulations and permitting requirements. State, utility, and federal incentive programs combined with a streamlined regulatory and permitting approval process would assist in reducing these barriers and encourage the development of SWSC systems.

Recommendations for further study include:

- Conduct a building stock analysis for dense coastal populations, e.g., North Central region around San Francisco and in Southern California region around the Los Angeles and San Diego areas, to estimate the potential cooling demand, associated energy and fresh water savings, and the avoided carbon and/or other emissions.
- Develop a parametric model for estimating the capital costs to SWSC project implementation and compare cost of SWSC to convention cooling, as well as other alternative pollution control measures.
- Develop guidelines for a single, general permit to be administered by one of the principal regulatory agencies involved in the permitting or review of SWSC systems.
- Investigate how SWSC may be used in combination with other innovative low-energy cooling technologies in passive and hybrid applications to meet a greater fraction of the cooling loads and reduce energy consumption and costs.
- Investigate the potential of introducing SWSC to locations with existing distribution infrastructure and high energy use buildings, e.g., university campuses, data centers, laboratories.

Benefits

By using the ocean as a heat sink, SWSC offers significant energy savings, reducing the electricity required to chill water by 75 to 90 percent compared to conventional air conditioning systems and completely eliminating the use of fresh water for evaporative cooling and chemicals used by cooling towers.

Introduction

Overview

Energy is becoming increasingly limited and expensive in California and there is a mandate to significantly improve the energy and water efficiency of new and existing buildings in the State. Growing environmental concern over climate change and greenhouse gas (GHG) emissions will continue to encourage a shift away from energy supply based on fossil fuel to renewable sources of energy. This report documents the results of a pilot study to assess the potential of Seawater Source Cooling (SWSC) to reduce the energy consumption and peak electricity demand associated with air conditioning in commercial buildings. Office buildings are primary candidates because they have the largest consumption and peak demand of the different building types in the commercial sector[1] and the limited resources available for the study did not permit consideration of other building types.

Decades of research have shown that SWSC can be a cost-effective technology. SWSC systems have been applied successfully in new build and retrofit applications ranging from dedicated cooling systems for individual buildings to district cooling systems serving multiple buildings [1, 5, 8, 10, 11, 14, 15, 16]. Further information is provided in Appendix D SWC Projects and Appendix E Literature Review.

Air conditioning in large commercial buildings is typically provided by centrifugal vapor compression chillers and cooling towers that use electric power to chill fresh water that is distributed throughout the building to air handling units that remove heat from the air stream supplied to the conditioned space.

SWSC is a low-energy cooling technology that uses naturally cold bodies of water as a thermal sink. SWSC systems are usually configured with open-loop seawater and closed-loop fresh water distribution systems, a shared heat exchanger, and independent pumping, filtration, and treatment equipment. The electrical energy required by a SWSC system is primarily used to run the pumps.

In appropriate applications, SWSC can be used to replace or augment conventional cooling systems, potentially reducing the electricity required to chill water by 75 to 90 percent, together with a corresponding reduction in the use of drinking-quality water in cooling towers [5]. Assuming that 45 percent of the peak electricity demand is due to air-conditioning and 60 percent of the total air conditioning system cooling energy use is for chilled water production [12], SWSC systems could provide ~ 20 percent reduction in the peak electricity demand in those commercial buildings to which it is applicable.

As discussed in Section 1, the maximum usable seawater temperatures range from 16°C (60°F) for radiant cooling systems to 8°F (47°F) for conventional cooling systems if seawater is the only source of cooling. If the seawater temperature is too high to meet the full cooling load, seawater

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[1] http://www.fypower.org/bpg/index.html?b=offices

can be used to provide pre-cooling and hence meet part of the cooling load. As discussed in Section 3, for a given location, the available seawater temperature depends on the depth at which the water is extracted. Since the depth of the ocean increases with distance from the shore, there is a trade-off between seawater temperature and the length of the intake pipe. The pumping power required to circulate the seawater depends on both the length and the diameter of the pipe, so there is a trade-off between pumping power and pipe diameter, and hence between pumping energy consumption and first cost. Thus there is an overall trade-off between seawater temperature, capital cost and operating cost.

Objective

The objectives of this study were to determine the applicability of SWSC for air conditioning commercial buildings in California, taking into account coastal permitting and other constraints that limit the economic and market potential. The study characterizes the coastal cold seawater resources and regulatory-permitting considerations with the objective of identifying the regions where SWSC systems might realistically be implemented in California.

Scope and Methodology

The scope for this project involved conducting: 1) a literature review, 2) a coastal survey, and 3) an applicability analysis described below. This study does not evaluate SWSC for specific sites, nor does it estimate the total demand, potential energy and water savings, or the regulatory and permitting costs for SWSC in California.

Literature Review. We conducted a literature survey of the publications of the seawater source cooling technology to understand the current state-of-art of the technology. We investigated completed and ongoing projects to document the practical considerations associated with using current available technology, including construction and operating costs, and to identify the barriers to implementing this technology for commercial buildings in California. See Appendix E for an annotated reference list of research and feasibility studies.

Coastal Survey. We conducted a survey of California's coastal seawater resource, population centers and regulation and permitting.

*Seawater Resource***.** We retrieved previously measured temperature profiles and bathymetry data along the California coastline to determine the depth and distance to sufficiently cold seawater and characterized the cold seawater resource. See Appendix A, Figures A1, A5-A8 and Appendix B, Table B1 and Figures B1-B5.

Population Centers. We used population centers to identify areas of potential cooling demand. There is limited commercial building sector information available.

*Regulation and Permitting***.** We reviewed California coastal water use policies for similar cooling applications to identify the relevant California regulatory agencies and permitting requirements involved in a SWSC project. See Appendix A, Figure A4, and Appendix C, Figures C1-C3.

Applicability Analysis. We assessed the regional suitability of SWSC for commercial buildings in California using a cost model based on the literature review and the overall distance of the cold seawater to the cooling load coastal survey data.

Organization of Report

This report is organized into the following sections:

- *Systems and Equipment* describes various SWSC system configurations and requirements as compared with conventional cooling systems;
- *System Costs and Feasibility Model* provides a cost comparison between SWSC and conventional cooling and introduces the model developed for this study;
- *Coastal Survey* provides an overview of California's seawater resource, costal populations, and regulation and permitting requirements;
- *Applicability Analysis* assesses potential applicability for SWSC by region in California;
- *Findings, Conclusions and Recommendations* presents the results of the study, describes how they apply to the objectives and discusses next steps for further development; and
- *References, Web-Sites, and Appendices* lists resources for supplemental information.

1.0 Systems and Equipment

This section compares conventional cooling and SWSC system concepts, configurations and operational issues. Under favorable conditions, SWCS can be used to replace conventional cooling. Elements of both conventional air conditioning and SWSC systems may be used in combination as a hybrid system.

A standalone SWSC system does not involve mechanical vapor compression chilling or a cooling tower. A hybrid system refers to SWSC cooling in combination with a conventional chiller or heat pump to directly and/or indirectly cool the chilled water.

1.1. Design Concepts-Configurations

A chilled water air conditioning system can be divided into discrete design elements or functions.

- Heat-sink: In a conventional system, heat is rejected to the outside environment using cooling towers or water to air heat exchangers ('dry air coolers'). In a SWSC system, heat is rejected to the ocean. The temperatures of these heat sinks are the ambient wet bulb, the ambient dry bulb and the seawater extract temperature, respectively.
- Chilled Water Production: Chilled water is produced using vapor compression or absorption chillers. If the temperature of the heat sink is low enough and the design of the system is suitable, chilled water may be produced by rejecting heat from the chilled water to the heat sink directly, without the aid of a chiller ('water-side free cooling').
- Chilled Water Distribution: Chilled water is circulated from the point of production to the air handling units. In a radiant cooling system, the chilled water is circulated through ceiling panels or pipes embedded in the floor slab. This may involve primary, secondary and, occasionally, tertiary loops. In a district cooling system, the chilled water is produced at a central location (the 'central plant') and distributed to the different buildings.
- Secondary HVAC System: In a conventional system, an air handling unit (AHU) uses chilled water to cool the air supplied to the occupied spaces. If the outside air temperature is lower than the required supply air temperature, chilled water is not required and the system operates in economizer mode ('air-side free cooling', or just 'free cooling').

Conventional cooling systems and SWSC systems differ in their heat-sink and chilled water production (see Figures 1-3), while the other elements remain essentially the same for both systems.

Maximizing the use of free cooling depends on minimizing the temperature difference between the occupied space and the heat sink that is required to transfer the cooling load. Radiant cooling systems, which use chilled water temperatures ~17^{o}C (63^{o}F) are the most effective in this respect, although they are most readily implemented in new construction and major refurbishments. Displacement ventilation, which requires ~19^{o}C (67^{o}F) supply air, and hence ~14^{o}C (57^{o}F) chilled water, and under-floor air distribution (UFAD) with swirl diffusers, which requires ~18°C (64°F) supply air, and hence ~12°C (54°F) chilled water, are also more readily deployed in new construction and major refurbishments. By contrast, conventional, mixed ventilation systems require ~16°C (60°F) supply air, and hence ~10°C (50°F) chilled water at peak load. All these values assume that no dehumidification is required – if the seawater is cold enough to provide full cooling, the surface temperature of the ocean can be expected to be low enough for the ambient dew point temperature within a few miles of the shore to be low enough that latent loads are met by the ventilation air. Assuming a 1.7 °C (3 °F) degree temperature difference in the sea-water to cooling water heat exchanger, the maximum usable seawater temperatures range from 16°C (60°F) for radiant cooling to 8°C (47°F) for conventional cooling systems if seawater is the only source of cooling. These limiting seawater temperatures are based on assumptions about the temperature difference between the supply air and the chilled water based on conventional sizing of the heat exchangers ('cooling coils'). In a new or refurbished system, it is possible to reduce this temperature difference by increasing the size of the cooling coils, thereby increasing the limiting seawater temperature for air-based systems.

In the case of conventional mixing systems, seawater temperatures greater than 8°C (47°F) could be used to provide pre-cooling and hence meet part of the cooling load. Seawater at 12°C (54°F) could be used to meet ~50 per cent of the cooling load, though at the expense of additional fan energy to overcome the pressure drop of the additional cooling coil. Seawater at higher temperatures could be used to remove heat from the condenser of a chiller; a seawater to fresh water heat exchanger would still be required.

In California, commercial buildings with conventional central chiller systems represent a significant portion of the existing stock of commercial buildings greater than 100,000 sq ft. while smaller commercial buildings typically have all-air systems without chilled water or condenser water. Given that 8°C (47°F) seawater is generally not available at economically feasible distances and depths, these larger buildings might use hybrid SWSC systems that provide pre-cooling from seawater and meet the remainder of the load using chillers.

Conventional HVAC System

A conventional mechanical cooling system in a large commercial building or a campus typically consists of one or more electric motor-driven vapor compression chillers and cooling towers that supply chilled water at ~6-10°C (42-50°F) to a number of variable air volume air-handling units (VAV AHU) , shown in Figure 1. Electricity is consumed by the chiller, the cooling tower fans, the distribution pumps and the fans in the air handling units.

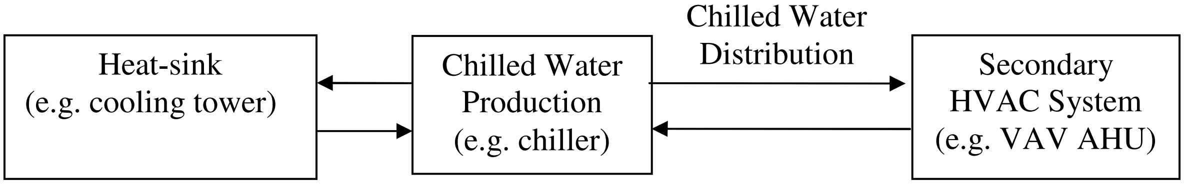

Figure 1. Conventional air conditioning system

SWSC System - Standalone

A SWSC system can similarly be divided into three subsystems, shown in Figure 2. The heat-sink subsystem consists of seawater intake and outlet pipes, a wet well, a pump and a seawater to fresh water heat exchanger. The chilled fresh water subsystem consists of the chilled water loop that links the seawater to fresh water heat exchanger to the cooling coils in the air handling units or to ceiling panels or to pipes in the slabs. The secondary HVAC subsystem can take one of two forms: (i) air handling units and air distribution systems, or (ii) ceiling panels or pipes in the slabs, accompanied by a dedicated outside air system (DOAS) for ventilation. Electricity is consumed by the seawater pump, the distribution pumps and the fans in the air handling units. The pumps and heat exchanger for chilled water production are typically sited in the building itself or at a separate centralized heat exchanger and pump facility. The intake structure, intake pipe, and outfall pipe are located outside the building. The seawater and chilled water systems are separated by the heat exchanger.

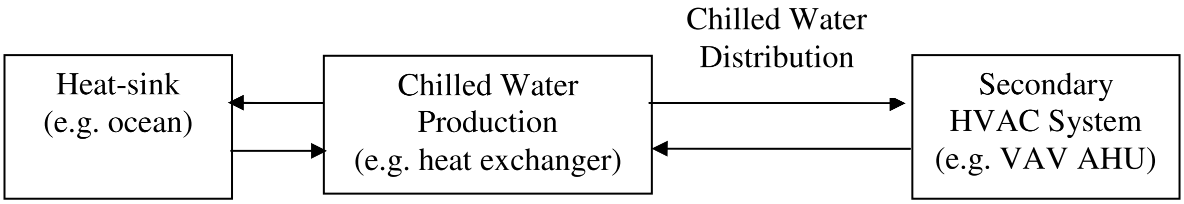

Figure 2. Standalone SWSC air conditioning system

SWSC System - Hybrid

A hybrid SWSC system combines elements of both SWSC and conventional cooling systems. One configuration is to have a SWSC system that provides chilled water to a pre-cooling coil in the air handling unit and a conventional chilled water system that supplies chilled water to a second cooling coil immediately downstream. The pre-cooling coil meets some of the sensible cooling load and the second coil meets the remainder of the sensible cooling load and any latent load, although, as noted above, latent loads are likely to be small in climates where SWSC has significant potential. Seawater may also be used to cool the condenser water from the chiller instead of using a cooling tower. This configuration is shown in Figure 3. Electricity is consumed by the seawater pump, the chiller, the cooling tower fans, the distribution pumps and the fans in the air handling units.

In California, the summer is typically very dry and the ratio of the latent load to the total cooling load is relatively small. A hybrid system that uses conventional cooling for dehumidification and SWSC to offset sensible load may be a cost-effective solution.

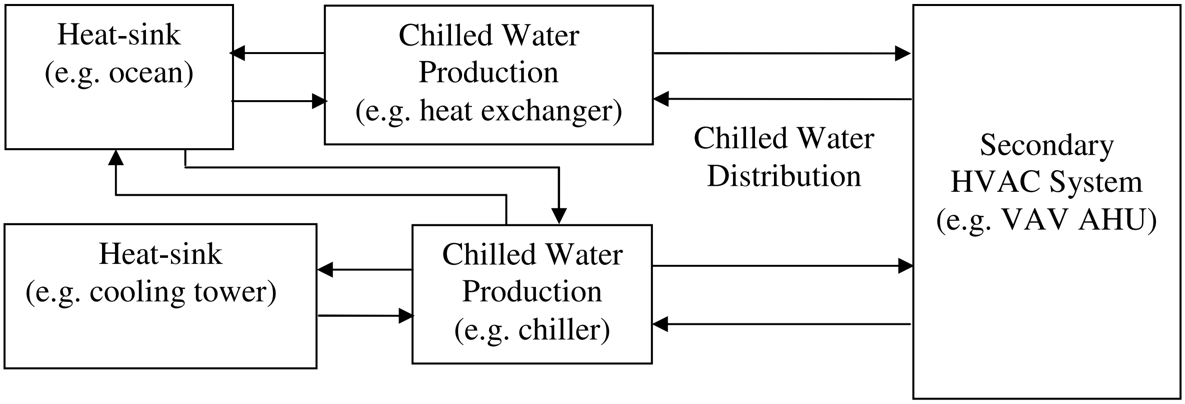

Figure 3. Hybrid SWSC air conditioning system

2.0 System Costs and Feasibility Model

This section describes the key economic parameters used to compare SWSC and conventional cooling systems and develop a SWSC feasibility model.

2.1. System Costs

In general, SWSC systems have higher initial capital costs and lower operating and maintenance (O&M) costs and longer life expectancy than conventional chiller-based systems. These costs vary between retrofit and new building applications and whether standalone or hybrid systems with conventional or low energy space cooling systems, such as radiant cooling or displacement ventilation, are employed. In the case of Cornell University's Lake Source Cooling (LSC) system "LSC is designed to last over 75 to 100 years, over twice the typical life of a chiller. [2]

Figure 4 shows the relative cost comparison between conventional and standalone SWSC chilled water district cooling facilities with peak cooling load values ranging from 5,000 to 20,000 ton, where the system provides chilled water to buildings located three to six miles from the cold seawater sources. The data are based on studies of typical systems conducted over the last several decades. [1].

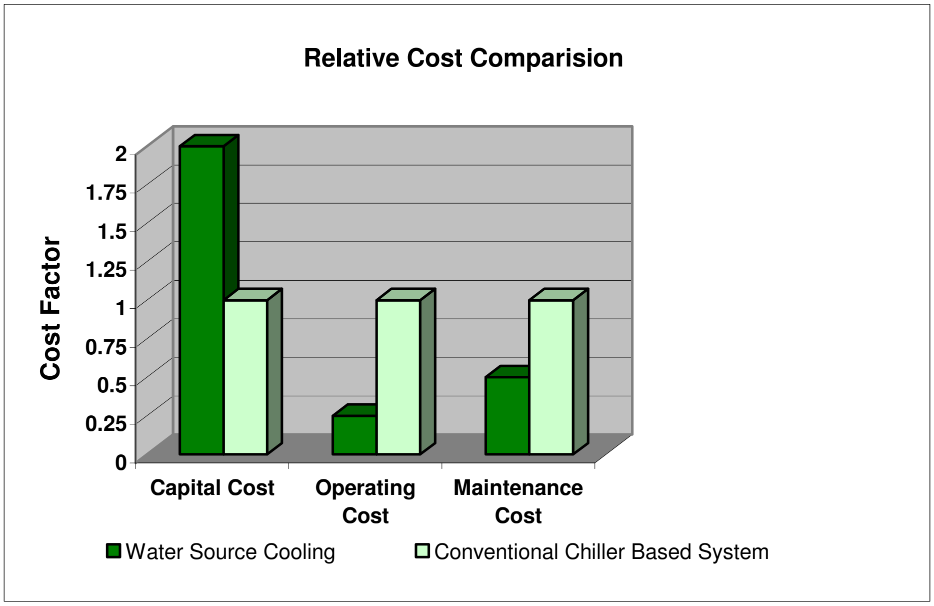

Figure 4. Relative cost comparison of deep water source cooling and conventional chiller based systems.

SWSC systems may be divided into the following three sub-systems: 1) seawater intake and outfall, 2) heat exchange facility, and 3) chilled water distribution. The relative initial capital cost structures for these sub-systems will depend on the system configuration and distance between the cold seawater supply and the air conditioning demand. For example, the seawater

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[2] http://www.utilities.cornell.edu/utl_lscabout.html

intake and outfall sub-system would represent a relatively higher percentage of the overall system cost in a deep as compared to a shallow SWSC application. Similarly, the chilled water distribution sub-system costs would be relatively higher for a district cooling system as compared to a dedicated SWSC application. The heat exchange facility sub-system costs will vary according to the overall size of the air conditioning load.

In deep SWSC applications, the design and implementation costs of small and larger diameter seawater intake and return pipelines may be similar, as the pipe material is a relatively small portion of the total piping construction cost. The relative cost of the onshore and offshore piping will depend on the application, yet "on average, approximately half the capital costs is in the seawater supply system [intake pipe, seawater pumps, outfall pipe], 15 percent is in the heat exchanger, and the last 35 percent is in the distribution system"[15].

The cost of operation depends on the amount of water to be pumped, the size and length of the pipelines, the size and complexity of the onshore distribution system and the local cost of electrical power, together with the size and utilization rate of the A/C system. To justify the higher initial capital investment, SWSC systems need to have a relatively high utilization rate in order to pay back the capital costs in a reasonable time.

The maintenance costs are primarily related to the water depth and quality. A shallow seawater system will generally require more frequent cleaning and maintenance than a deep seawater system due to higher biotic growth.

2.2. Feasibility Model

We developed an Excel-based data analysis model to estimate the economic feasibility of deep water SWSC systems for district cooling in California. The model is able to estimate the investment payback period using basic information such as piping distance and cooling plant size and takes into account the largest impacts on the return on investment such as: the overall distance from the cold seawater source to the building site, the total cooling load, and utilization rate. The default values of piping and other construction costs are based on an initial feasibility study of a hybrid, district SWSC system considered for the University of California at San Diego (UCSD) and reflect the current market costs in California [11].

Instead of using a building simulation program such as EnergyPlus or DOE-2 to conduct hourly simulations of SWSC and conventional systems, we made the following assumptions to estimate the operation and maintenance cost of SWSC systems. We assume the overall COP is eight times higher than in the conventional chiller system. We assume the personnel and general maintenance cost of both SWSC and conventional systems are equivalent. These values are based on cited studies and projects [1, 5, 10, 11].

2.2.1. Key Economic and Input Parameters

The key economic parameters related to the first investment costs of a SWSC system are:

- Offshore piping cost ($/ft)
- Onshore piping cost ($/ft)

- Seawater pumping station cost ($)
- Heat exchanger and distribution cost ($)
- Regulatory, permitting and environment study cost ($)

The key input parameters include:

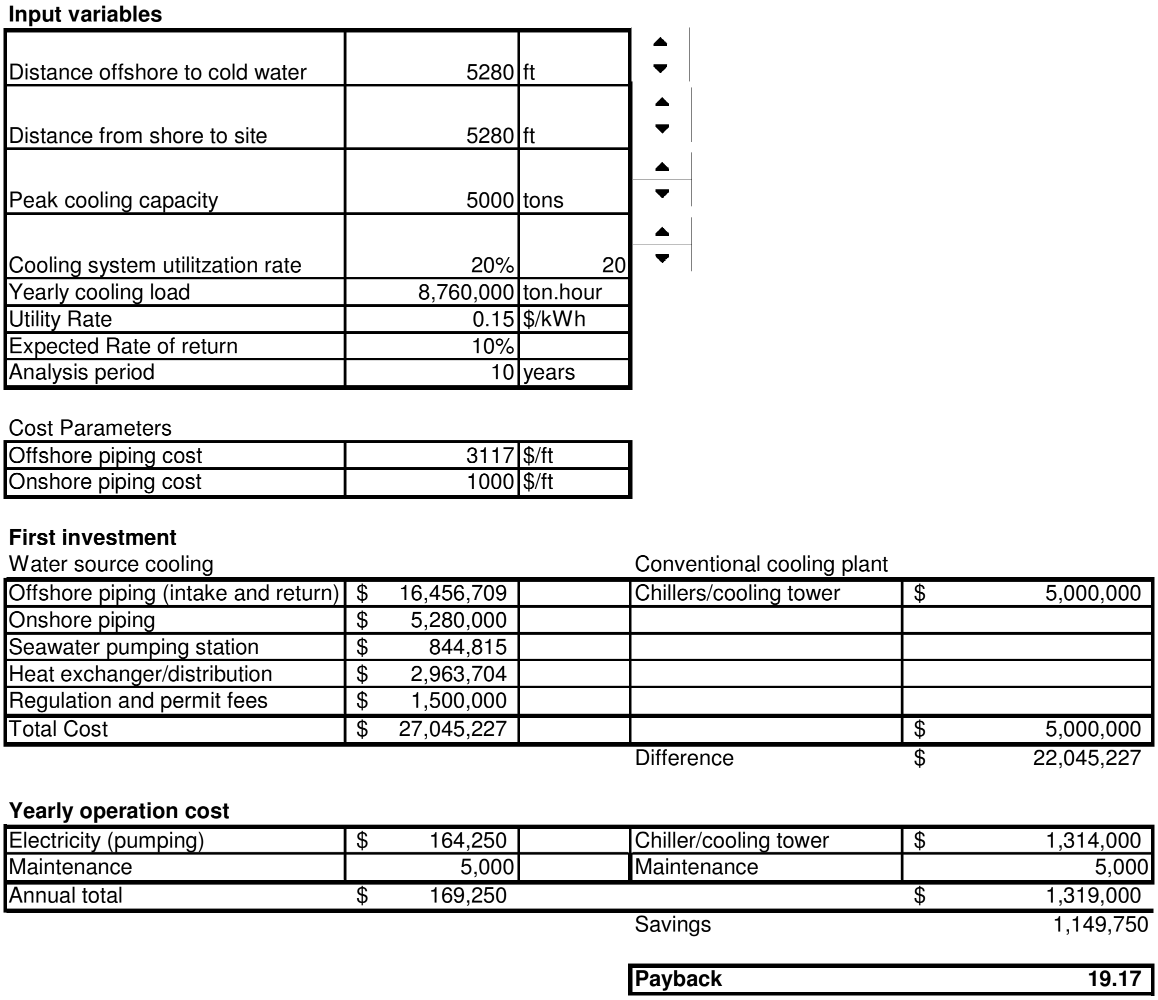
- Distance offshore to cold water
- Distance from shore to site
- Peak cooling capacity
- Cooling system utilization rate
- Yearly cooling load
- Utility rate
- Expected rate of return

Utilization rate is defined as:

$$Utilization\ rate = \frac{Annual\ cooling\ load\ (kW \cdot hours)}{Peak\ cooling\ capacity\ (kW) \times 8760\ hours}$$

2.2.2. Analysis

Figure 5 shows the SWSC feasibility model analysis.



Input variables

Distance offshore to cold water	5280	ft	▲▼
Distance from shore to site	5280	ft	▲▼
Peak cooling capacity	5000	tons	▲▼
Cooling system utilitzation rate	20%	20	▲▼
Yearly cooling load	8,760,000	ton.hour	
Utility Rate	0.15	$/kWh	
Expected Rate of return	10%		
Analysis period	10	years	

Cost Parameters

Offshore piping cost	3117	$/ft
Onshore piping cost	1000	$/ft

First investment

Water source cooling			Conventional cooling plant	
Offshore piping (intake and return)	$ 16,456,709		Chillers/cooling tower	$ 5,000,000
Onshore piping	$ 5,280,000			
Seawater pumping station	$ 844,815			
Heat exchanger/distribution	$ 2,963,704			
Regulation and permit fees	$ 1,500,000			
Total Cost	$ 27,045,227			$ 5,000,000
			Difference	$ 22,045,227

Yearly operation cost

Electricity (pumping)	$ 164,250		Chiller/cooling tower	$ 1,314,000
Maintenance	5,000		Maintenance	5,000
Annual total	$ 169,250			$ 1,319,000
			Savings	1,149,750

Payback	**19.17**

Figure 5. SWSC feasibility model analysis

Figure 6 shows the payback analysis of a typical system with 1.6 kilometers (1 mile = 5,280 ft) of on-shore and 1.6 kilometers (1 mile = 5,280 ft) of offshore piping. For such a building site needing 3.2 kilometers (2 miles) of piping, the size of the SWSC system must be larger than 5000 tons with a 20 percent utilization rate in order for the payback period to be less than 20 years. The results provide rough parameters to assess the feasibility of the various coastal regions.

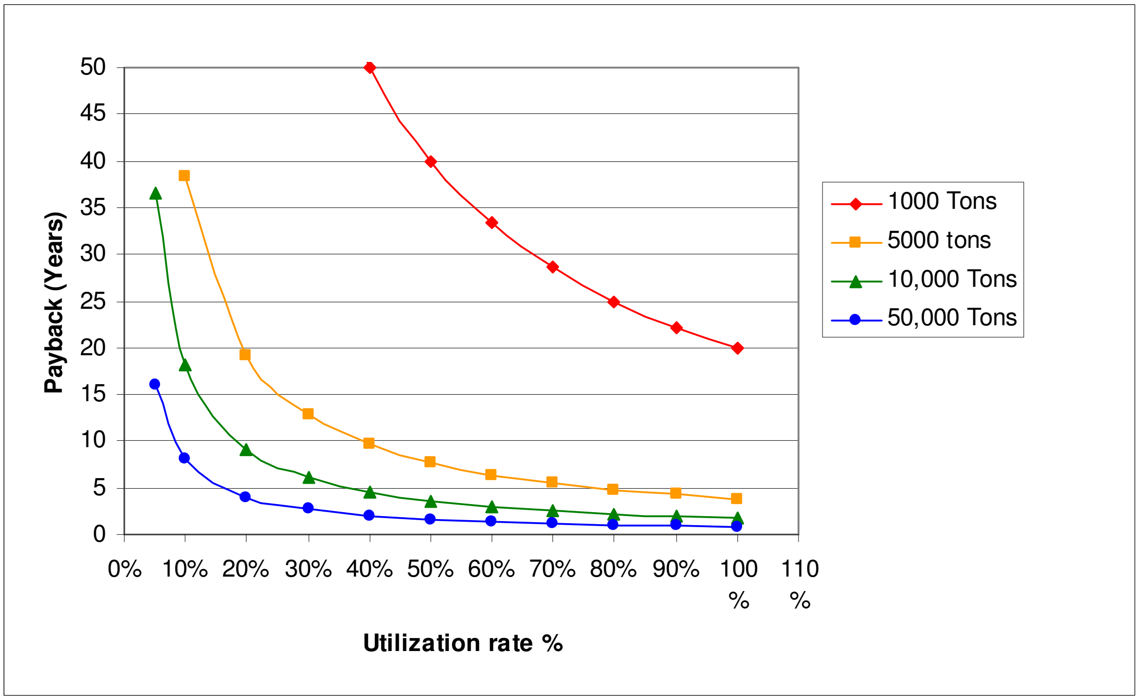


Figure 6. SWSC system size, utilization rate and payback period

3.0 Coastal Survey

This section characterizes California's cold seawater resources, coastal population centers, and coastal environmental regulations and permitting.

3.1. Cold Seawater Resources

Cold seawater resources for California were surveyed using climatological data from the National Oceanographic Data Center (NODC) World Ocean Atlas 2005 (WOA05) and World Ocean Atlas Select (WOAselect).[3] Coastal seawater temperatures tend to increase from northern to southern California. The temperature increase and variability are functions of depth, with shallow waters exhibiting greater temperature increase and variability than deeper water. See Appendix B table B1 for the depth-distance- temperature and Figures B1-B5 for the seasonal temperature-depth profiles for the California north, north central, south central, and south coastal regions.

3.2. Coastal Population Centers

The original intent was to conduct a stock analysis of commercial buildings within 5 miles of the California coast to determine the overall SWSC market size and energy saving potential. The air conditioning demand was to be assessed using commercial building sector information to determine the total floor area (sum of all buildings and floor spaces), and calculate the aggregated potential cooling load, energy savings and water savings. However, this was not possible due to limited availability of commercial building data, and instead all the California cities with populations greater than 5,000 and located within 5 miles of the coastline were identified. See Appendix A, Figures A2 and A5-A8.

3.3. Regulations and Permitting

This section identifies the principal regulatory agencies, their roles and associated legislation, plans, and policies, and how they affect implementing a SWSC project. The main regulatory issues concerning SWSC involve impingement (i.e., trapping aquatic organisms in intake screens), entrainment (i.e., passing aquatic organisms through cooling systems and pumping intake valves and turbines), and thermal and nutrient discharge. The permitting process requires extensive coordination between federal, state, and local environmental regulatory agencies that review the placement of pipes, the water withdrawal and return, and how it affects beneficial uses and water quality. A number of federal, state and local policies and regulatory agencies are involved and may have overlapping jurisdictions related to environmental protection policies and the permitting of SWSC systems. It is difficult to estimate the time required for obtaining the necessary approvals and permits for a water source cooling system until a specific proposal has been developed.

The principal agencies concerned with withdrawal or discharge of water into the ocean are the Regional Water Quality Control Board, the Department of Fish & Game and the local city or county. The regional water quality control board issues National Pollutant Discharge

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[3] World Ocean Atlas Select website: http://www.nodc.noaa.gov/OC5/SELECT/woaselect/woaselect.html

Elimination System (NPDES) permits under the Clean Water Act for discharges to surface water. The Department of Fish and Game and the Army Corp of Engineers would likely need to issue permits for a new intake and discharge because of fill and/or dredging requirements. The local jurisdiction may have California Environmental Quality Act (CEQA) permit responsibilities as well. For the San Francisco Bay region, this would involve the San Francisco Regional Water Control Board and also the Bay Conservation and Development Commission (BCDC) [13].

Similar to seawater cooled power plants, SWSC systems employ once pass cooling, yet there is a considerable difference in the scale between them. The current environmental permitting trend is moving away from one-pass cooling and if not possible to use best available technologies to minimize entrainment and impingement impacts by the seawater intake system. Concerns for health and safety are drivers for limiting the use of copper and other materials used to keep the seawater intake and discharge pipes safe for, and free from, marine life and growth accumulation.

Marine Life Protection Act (MLPA) and Marine Protected Areas

"In 1999, California passed the first law of its kind in the country – the Marine Life Protection Act, or MLPA. Sponsored by coastal legislators, the MLPA requires the state to improve the way it sets aside marine areas for further protection."[4] MLPA is intended as a model for managing oceans on an ecosystem basis. The MLPA designated the California Department of Fish and Game (CDFG) as having responsibility for managing a network of Marine Protected Areas (MPA). MPAs' have restrictions that limit activities such as fishing.

The schedule for completion of the MPA plans for the regions is shown in Appendix C, Figure C1:

- North Coast (to be completed by 2011)
- North Central Coast (completed by January 2009)
- South Central Coast (completed April 2007)
- South Coast (to be completed by 2011)
- San Francisco Bay (to be completed by 2011)

Appendix C, Figure C2 shows a map of MPAs for the central coast. "On April 13, 2007 after nearly three years of public meetings and proposal reviews, the Fish and Game Commission evaluated and voted on a final MPA proposal for the Central California Coast. The commission voted on a plan to establish 29 MPAs covering approximately 204 square miles (18%) of State waters with 85 square miles designated as no-take state marine reserves. The network ranges from Pigeon Point in San Mateo County south to Point Conception in Santa Barbara County, and contains several types of MPAs with varying degrees of protection. Central coast MPA regulations will be effective starting summer 2007. The CDFG plans to follow a similar process in developing MPA networks along the rest of the California Coast."[5]

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[4] Cal Oceans-Marine Life Protection Act

[5] Department of Fish and Game: <www.dfg.ca.gov/mrd/mlpa/science.html]

State Water Quality Protection Areas

State Water Quality Protection Areas (SWQPAs) "are non-terrestrial marine or estuarine areas designated to protect marine species or biological communities from an undesirable alteration in natural water quality. All areas of Special Biological Significance (ASBS) that were previously designated by the State Water Board Resolutions in 74-28, 74-32, and 75-61 are now also classified as a subset of State Water Quality Protection Areas and require special protection s afforded by this Plan." [6] See Appendix A, Figures A4-A8.

Areas of Special Biological Significance (ASBS)

ASBSs "are those areas designated by the State Water Board as ocean areas requiring protection of species or biological communities to the extent that alteration of natural water quality is undesirable. All Areas of Special Biological Significance are also classified as a subset of State Water Quality Protection Areas".[7]

"The California State Water Resources Control Board, under resolution No.74-28, designated certain Areas of Biological Significance (ASBS) in the adoption of water quality control plans for the control of wastes discharged to ocean waters. The ASBS are intended to afford special protection to marine life through prohibition of waste discharges within these areas… Specifically the following restrictions apply to ASBS in the implementation of this policy: 1. Discharge of elevated temperature wastes in a manner that would alter natural water quality conditions is prohibited". See Appendix C, Figure C3.[8]

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[6] Appendix I – Definition of Terms, California Ocean Plan 2005, Water Quality Control Plan Ocean Waters of California, State Water Resources Control Board, California Environmental Protection Agency

[7] Ibid

[8] California Marine Waters Areas of Special Biological Significance, Reconnaissance Survey Report, San Diego Marine Life Refuge, California State Water Resources Control Board Surveillance and Monitoring Section, September 1980, Water Quality Monitoring Report No. 80-5, Introduction, p3, http://www.swrcb.ca.gov/general/publications/docs/asbs_sd_marine.pdf

4.0 Applicability Analysis

In this section, the applicability of SWSC in California is evaluated for four coastal regions: North Coast, North Central Coast, South Central Coast, and South Coast.

One important factor in the applicability analysis is the utilization rate, which defines the extent to which a cooling system actually uses its installed capacity. As noted in Section 2.2.1, it is the ratio of the actual cooling produced to the cooling that could be produced with installed equipment if it was used to its full capacity. The utilization rates for cooling equipment in the four coastal regions were estimated indirectly from the California Commercial End-Use Survey (CEUS) (Itron, 2006) and are shown in table 1 below.

Table 1. CA utilization rates for cooling equipment by coastal regions.

Regions	CEUS region	Annual cooling electricity use (kWh/ft^2)	Peak cooling electricity demand (W/ft^2)	Utilization rate
North Coast	PG&E FCZ 01	0.91	1.51	6.9%
North Central	PG&E FCZ 05	2.91	1.52	21.9%
South Central	PG&E FCZ 04	2.55	1.27	22.9%
South Coast	SCE FCZ 08	4.76	1.72	34.6%

The applicability of SWSC is evaluated for each region as high, medium, or low potential based on: 1) the average distance to reach 10°C (50°F) seawater per Appendix B, Table B1; 2) the utilization rate using Table 1; 3) the population density per Appendix A, Figures A2 and A5-A8, environmental regulations per Appendix C, Figures C2- C3. We use 8-10°C (47-50°F) as the maximum operating temperature for a typical SWSC system based on cited studies and projects [1, 5, 10, 11]. We use for comparison the feasibility model results shown in figures 5-6 that a SWSC system with 3.2 kilometers (2 miles) of piping must be larger than 5000 tons with a 20 percent utilization rate in order for the payback period to be less than 20 years.

4.1. North Coast

Cold seawater: The summer average 8-10°C (47-50°F) can be reached at a depth of ~ 50-150 m (165-500 ft), and a distance of 5-15km (3-9 miles) offshore.

Utilization rate: The cooling season is relatively short, and the average utilization rate is ~7%.

Population density: The largest coastal populations are in one city with 25,00-50,000 inhabitants and two with 10,000-25,000 located in Humboldt County.

Environmental regulation: There are four ASBS (#8, 6, 7, 1). They do not overlap with the three cities noted above.

Applicability: Low potential. Combined distance with low utilization rate and population density.

4.2. North Central Coast

Cold seawater: The summer average 8-10°C (47-50°F) can be reached at a distance of ~11-28 km (7-17 miles) offshore and a depth of ~75-200 m (250-650 ft), yet relatively cold water is accessible near shore in SF Bay. The depth in SF Bay is generally less than 30 m (100 ft) and temperatures fluctuate in the range 50-65°F.

Utilization rate: The average utilization rate is ~22%.

Population density: The largest coastal population is in San Francisco, which has ~750,000 inhabitants.

Environmental regulation: There are five ASBS (#5, 12, 11, 13, 15), with no overlap with populated areas. San Francisco Bay has its own jurisdiction.

Applicability: Medium potential. It may be technically feasible to use hybrid SWSC systems that tap shallow waters of the Bay, yet environmental regulation may present a barrier. See description of the hybrid SWSC dedicated cooling system being considered for the Exploratorium (See Appendix D).

4.3. South Central Coast

Cold seawater: The summer average 8-10°C (47-50°F) can be reached at a distance of 8.5-13 km (5-8 miles) offshore and a depth of 100 -250 m (325-825 ft).

Utilization rate: The average utilization rate is ~23%.

Population density: This region has a relatively low density - the largest city is Santa Cruz, which has a population of ~55,000.

Environmental regulation: There are five ASBS (#19, 34, 22, 18, 20) and relatively few sanctuaries. There is no significant overlap with populated areas.

Applicability: Low potential. There is long distance to reach cold water and relatively small populations. The exception would be a location with direct access to cold seawater close to shore and/or an existing seawater intake. See description of the proposed system at Moss Landing Marine Laboratories (see Appendix D).

4.4. South Coast

Cold Seawater: The summer average 8-10°C (47-50°F) can be reached at a distance of 8-12 km (5-7.5 miles) offshore and a depth of 125 -300 m (400-825 ft).

Utilization rate: The average utilization rate is ~35%

Population density: This region has the highest coastal population concentrations in California. Along the Pacific shore, the areas with the largest populations are San Diego and the 'Beach' cities (Huntington Beach, Long Beach etc).

Environmental regulation: There are six ASBS (#24, 30, 32, 33, 29, 31) and relatively few MPAs - virtually none overlap with coastal populations.

Applicability: Medium potential. A prior feasibility study conducted in 1975 noted that "The South California sites [Los Angeles and San Diego areas] were rejected because the cooling demand in degree days was quite low, and the built-up areas requiring large amounts of air conditioning are much further inland. These sites may warrant reconsideration at a later date [7]." Given that coastal populations have grown during the last 30 years the South Coast may now offer suitable sites, particularly where submarine canyons bring this cold seawater closer to shore. A hybrid SWSC district cooling system is currently being considered for UC San Diego (see Appendix D).

4.5. Results

The initial findings suggest that hybrid SWSC systems are viable in California both in deep seawater district cooling for multiple buildings and shallow seawater dedicated systems for sensible cooling in individual building applications. This opportunity is mainly limited to the high population centers of north central California in the San Francisco Bay Area and southern California in the Los Angeles and San Diego areas. In this southern California region, access to this cold seawater is particularly economically viable in those locations where submarine canyons bring this cold seawater closer to shore, and existing and planned projects take advantage of these conditions. SWSC will be less economically feasible where these conditions do not prevail.

Potential barriers for SWSC systems are the regulatory and permitting requirements intended to protect and preserve beneficial uses of aquatic resources. These requirements can add significantly to the overall project cost. Generally, densely populated areas do not overlap with Special Biological Significance (ASBS) or other marine protected areas locations.

Aside from technical, economic, and environmental considerations, one of the greatest barriers for SWSC is perceived risk. The commercial buildings industry is risk-averse and requires an established record, extensive prior experience and product and performance warranties before adopting any new technology.

5.0 Conclusions & Recommendations

5.1. Conclusions

In California, hybrid SWSC appears most feasible for air conditioning in district cooling configurations.

SWSC is not viable for cooling individual existing buildings with conventional HVAC systems. In the North Coast region, the cooling loads are too small to be economically feasibility. In the other three regions, SWSC systems are not viable because of the distances and depths required to obtain sufficiently cold water. Hybrid SWSC systems are potentially viable in the San Francisco Bay Area and along the Pacific coast from San Francisco to San Diego. Both single building and district systems are potentially viable in the Bay Area. The greater distances and depths required to access suitable water in Southern California require the economies of scale associated with district cooling systems for economic feasibility. Case Studies for the application of SWSC at the San Francisco Exploratorium and at the University of California, San Diego are presented in Appendix D.

For new construction and major retrofits, SWSC systems are viable in San Francisco, and potentially in other parts of the Bay Area, if radiant cooling is employed. Radiant cooling allows the use of 16^{o}C (60^{o}F) sea-water. No dehumidification is required in the Bay Area, which also obviates the need for cooler water. Radiant cooling is potentially applicable in the South Central and South Coast regions; dehumidification can be provided using a desiccant system, which requires sea-water temperatures of 16^{o}C (60^{o}F) in order to temper the hot dry air leaving the desiccant. As with hybrid systems, standalone SWSC systems in the South Central and South Coast regions require the economies of scale associated with district cooling systems for economic feasibility.

Barriers to the adoption of SWSC include unfamiliarity on the part of both designers and owners, together with significant regulations and permitting requirements. State, utility, and federal incentive programs combined with a streamlined regulatory and permitting approval process would assist in reducing these barriers and encourage the development of SWSC systems.

5.2. Recommendations

Further research is recommended to:

- Conduct a building stock analysis for dense coastal populations, e.g., North Central region around San Francisco and in Southern California region around the Los Angeles and San Diego areas, to estimate the potential cooling demand, associated energy and fresh water savings, and the avoided carbon and/or other emissions.
- Develop a parametric model for estimating the capital costs to SWSC project implementation and compare cost of SWSC to convention cooling, as well as other alternative pollution control measures.

- Develop guidelines for a single, general permit to be administered by one of the principal regulatory agencies involved in the permitting or review of SWSC systems.
- Investigate how SWSC may be used in combination with other innovative low-energy cooling technologies in passive and hybrid applications to meet a greater fraction of the cooling loads and reduce energy consumption and costs.
- Investigate the potential of introducing SWSC to locations with existing distribution infrastructure and high energy use buildings, e.g., university campuses, data centers, laboratories.

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Web-sites

Cornell University Lake Source Cooling
http://www.utilities.cornell.edu/utl_ldlsc.html

City of Toronto Deep Lake Water Cooling
http://www.toronto.ca/environment/initiatives/cooling.htm

Honolulu Seawater Air Conditioning, LLC
http://honoluluswac.com/index.php

Makai Ocean Engineering Seawater Air Conditioning
http://www.makai.com/p-swac.htm

Natural Energy Laboratory of Hawaii Authority (NELHA)
http://www.nelha.org/

Purdy's Wharf seawater cooling case study
http://www.ecbcs.org/docs/annex_28_case_study_buildings.pdf

Appendix A Coastal Maps

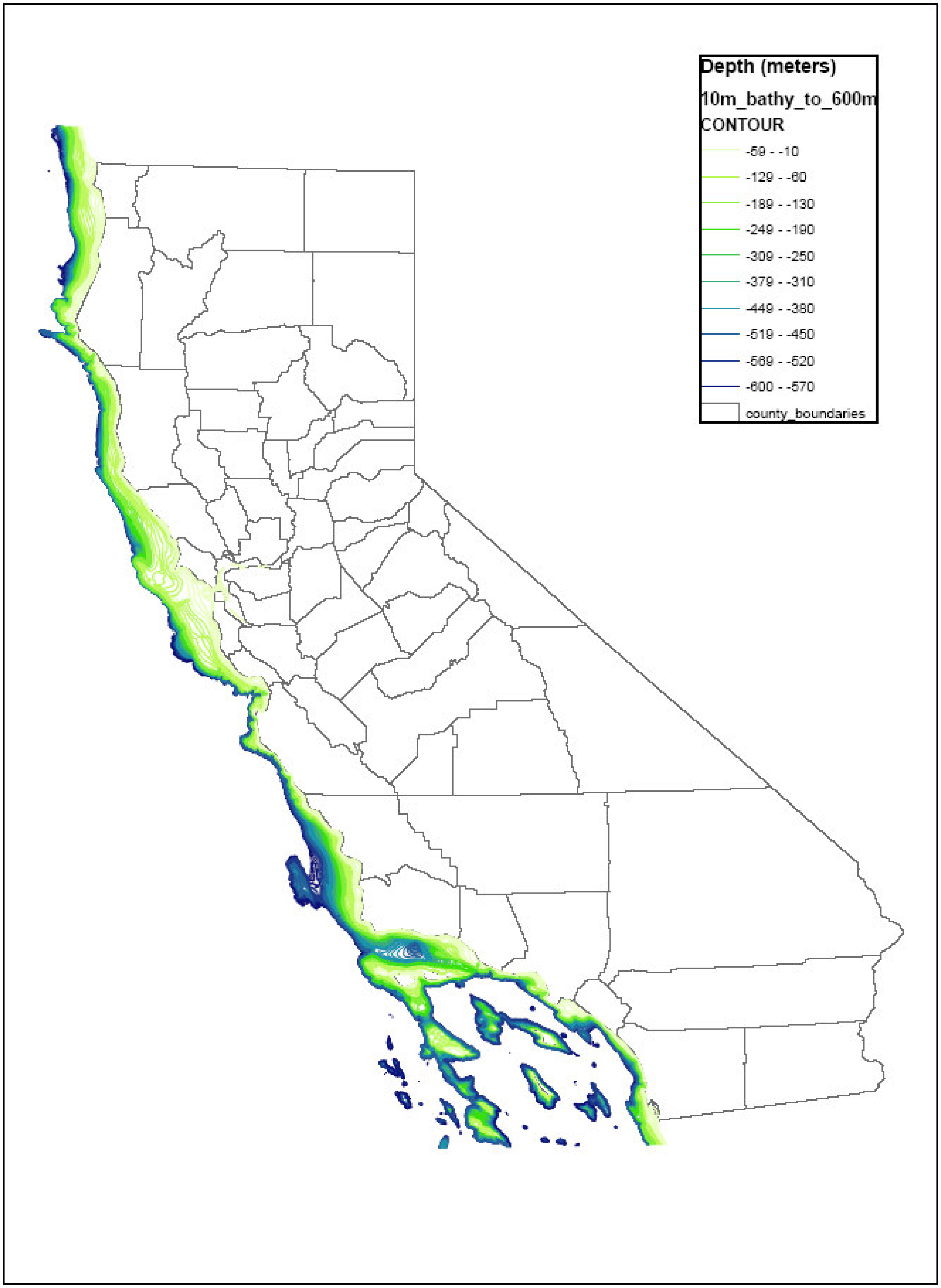

Figure A1. California coast: depth of water

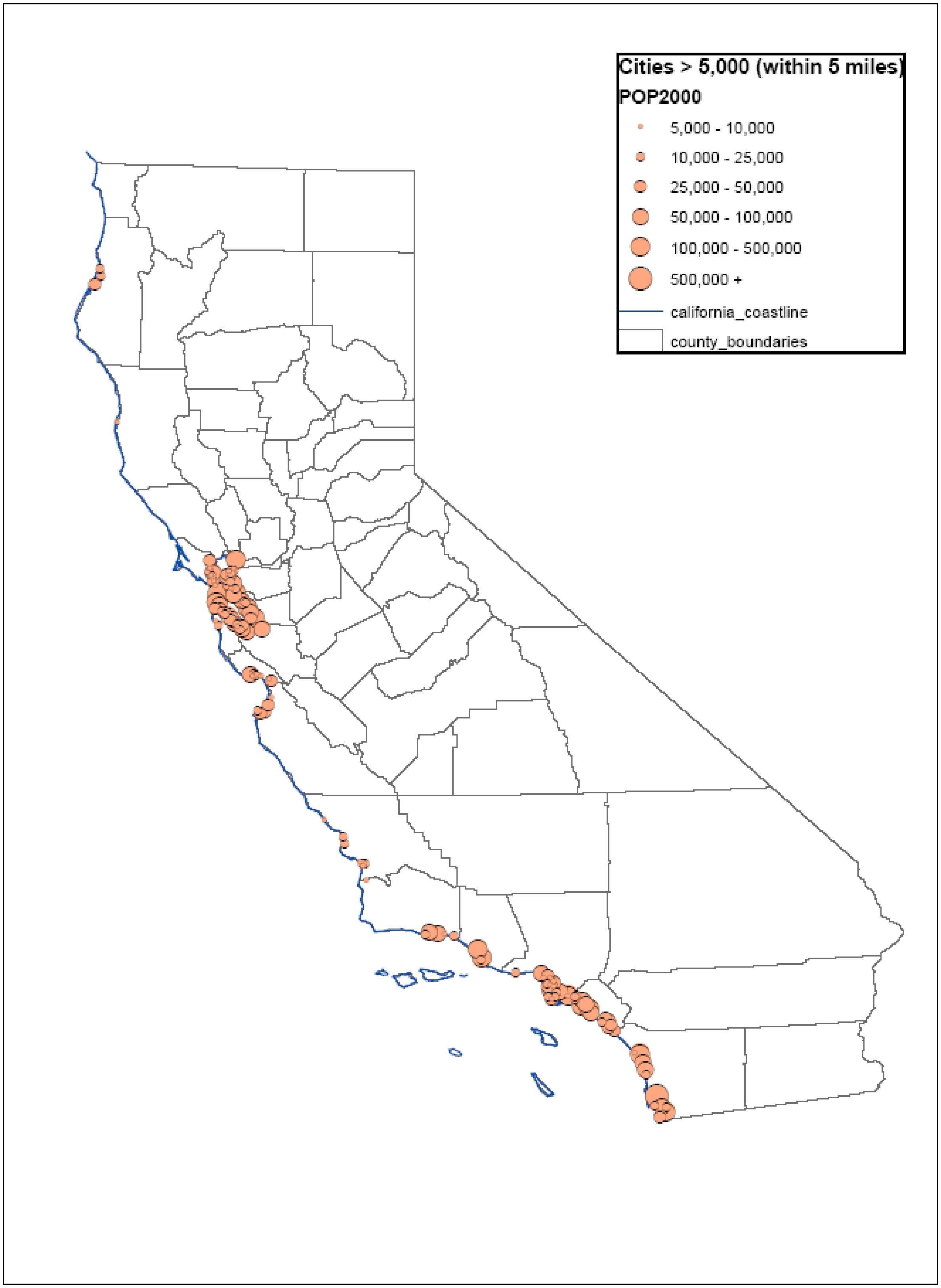

Figure A2. California coast: cities with populations > 5,000 within 5 miles of coastline

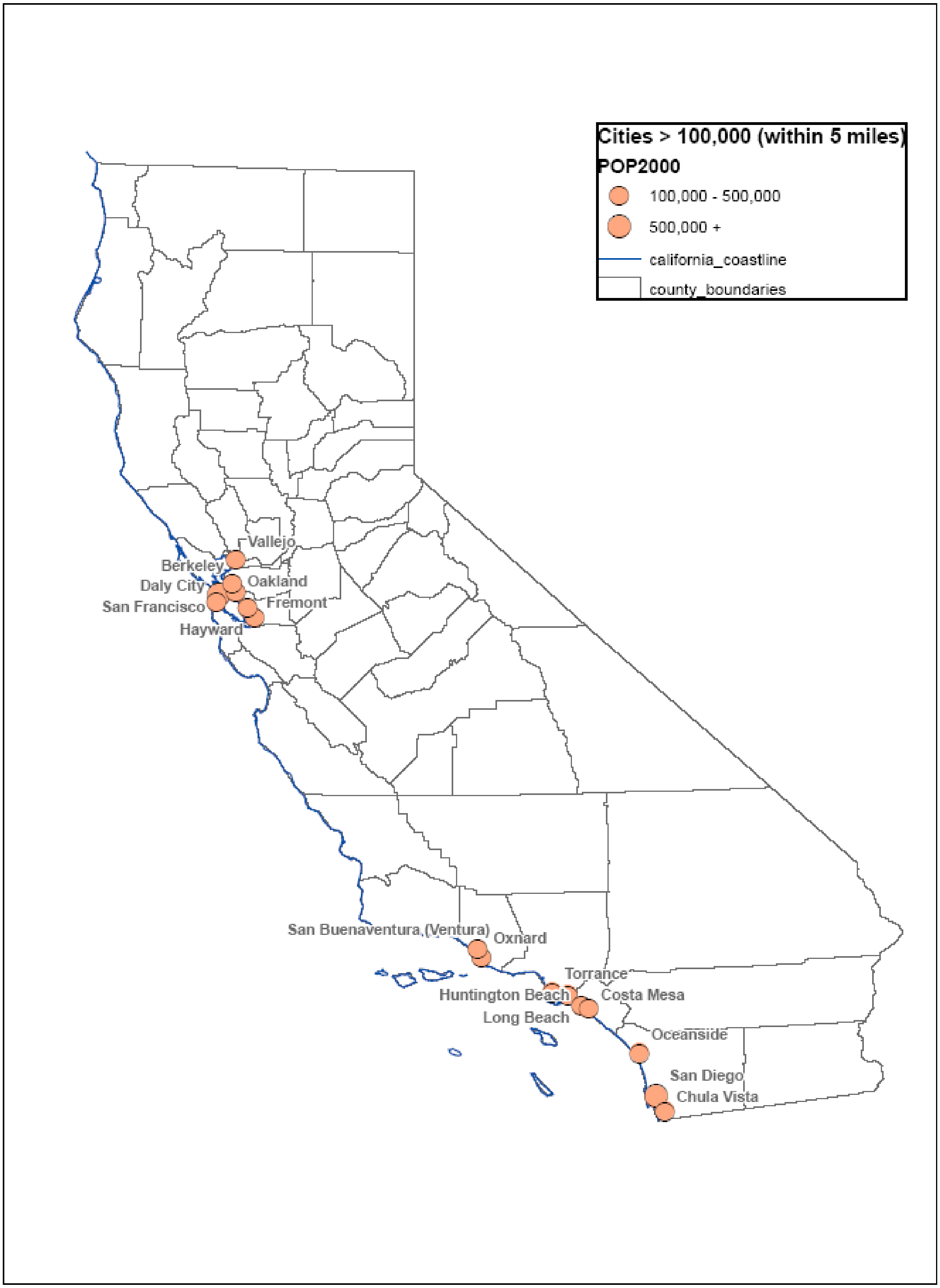

Figure A3. California coast: cities with populations > 100,000 within 5 miles of coastline

Figure A4. California coast: State Water Quality Protection Areas (SWQPAs)

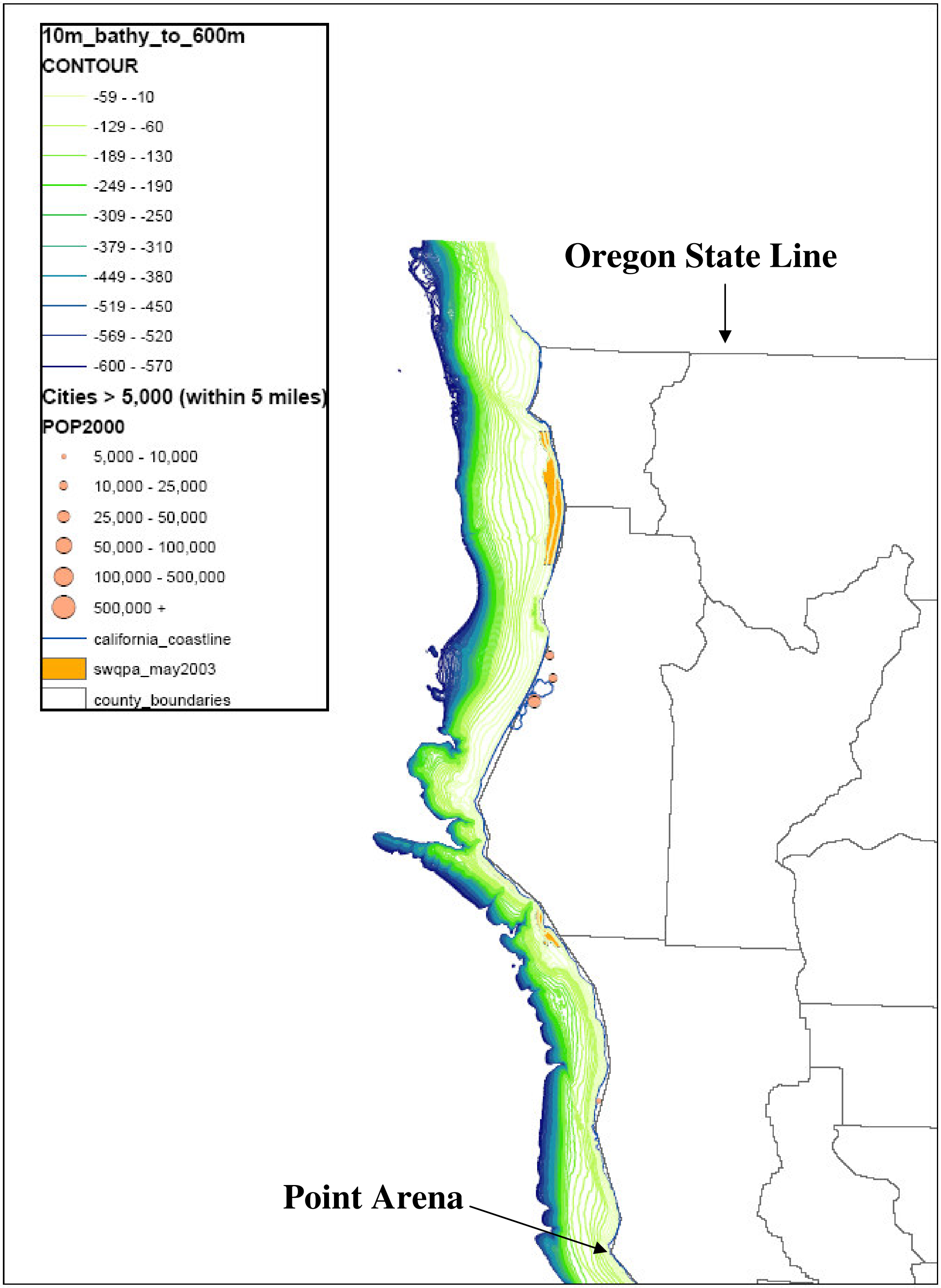

Figure A5. California North Coast (Oregon State Line to Point Arena)

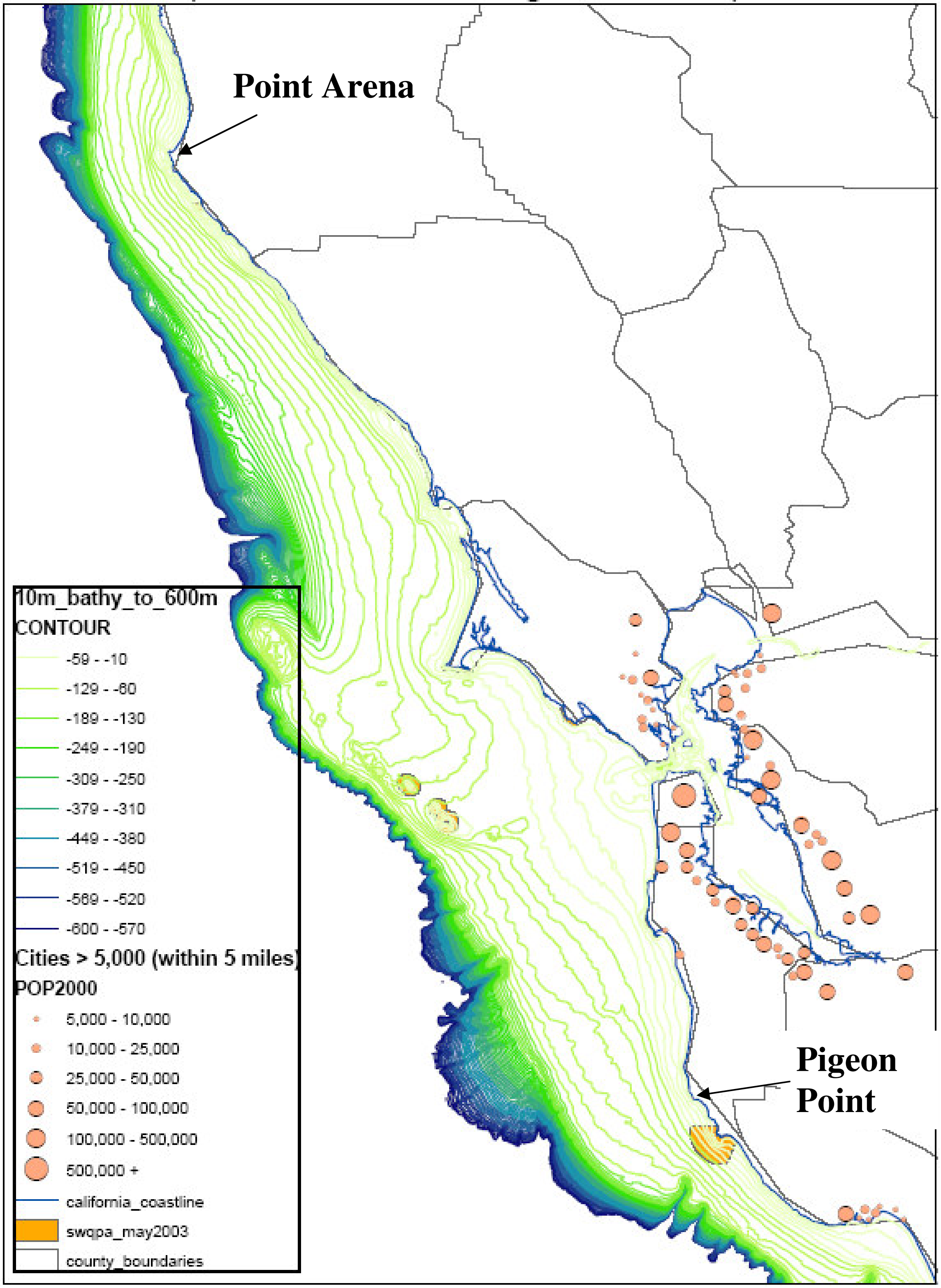

Figure A6. California North Central Coast (Point Arena to Pigeon Point)

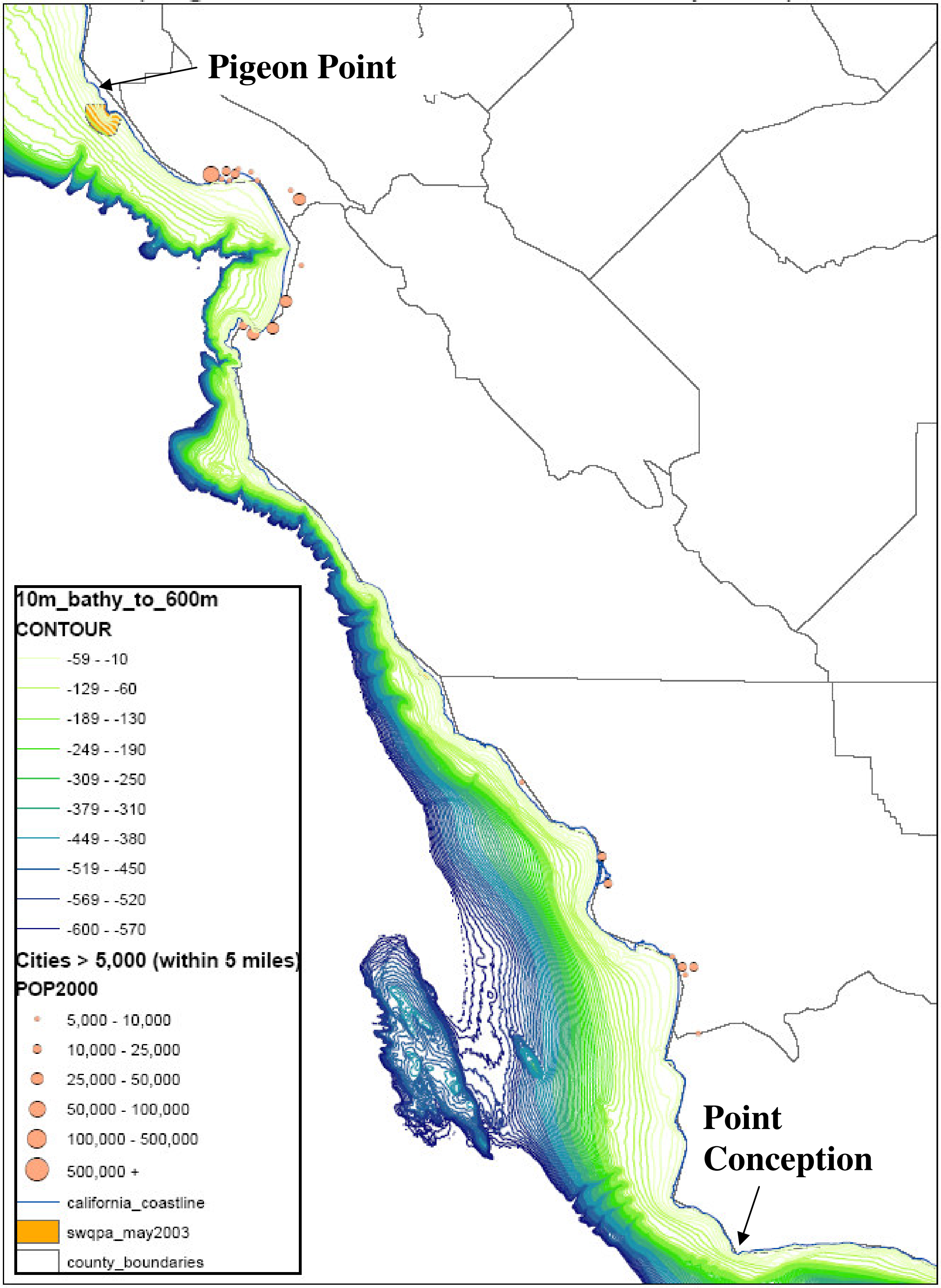

Figure A7. California South Central Coast (Pigeon Point to Point Conception)

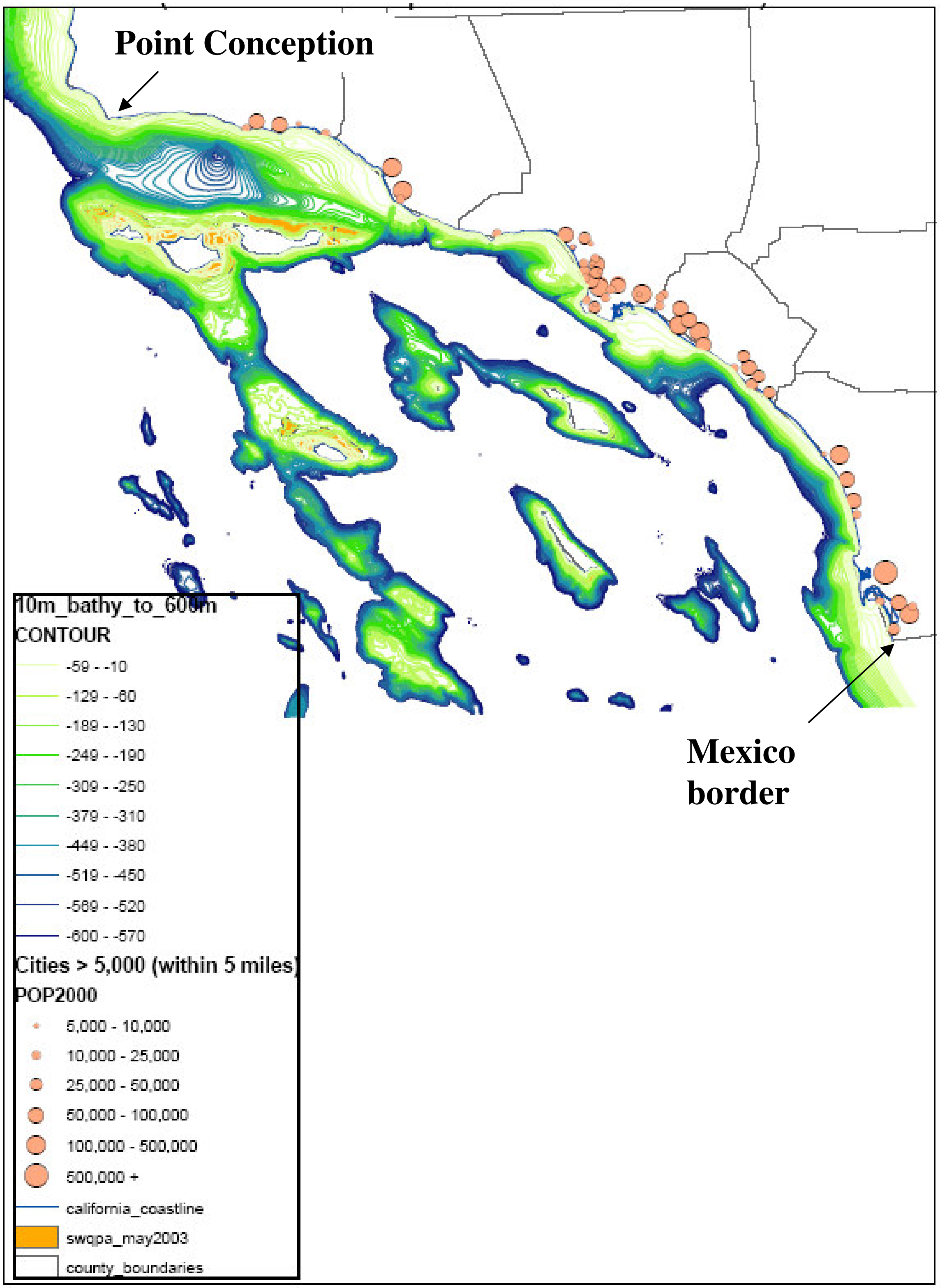

Figure A8. California South Coast (Point Conception to Mexico border)

Appendix B California Seawater Data

Table B1. CA Coast Summer (July-September) Depth-Distance-Temperature Profile

California Coastal Average Summer (July-September) Depth-Distance-Temperature Profile					
Coastal Region	North	North Central	South Central	South	
Latitude	41? 2'N-38? 2'N	38? 2'N-36? 2'N	36? 2'N-34? 7'N	34? 7'N - 32? 7'N	
Longitude	124? 2'W - 123? 3'W	123? 3'W - 122? 'W	122? 'W - 120? 1'W	120? 1'W - 117? 1'W	
Depth (m)	Distance (km)	Distance (km)	Distance (km)	Distance (km)	Temperature C
0	0.0	0.0	0.0	0.0	<20C
10	0.7	0.8	0.5	0.8	<18C
20	1.6	2.0	1.3	2.1	<16C
30	2.7	3.7	2.7	3.2	
50	5.2	6.3	4.4	4.8	<14C
75	8.2	10.6	6.8	6.4	<12C
100	10.2	14.6	8.5	7.6	
125	13.3	24.3	9.9	8.3	<10C
150	14.7	25.9	10.5	8.8	
200	16.9	27.7	11.5	9.5	
250	18.0	29.0	12.8	10.6	
300	18.6	29.8	14.0	11.9	
400	19.8	31.0	16.6	14.5	<8C
500	21.4	32.3	19.9	17.4	
600	36.8	61.8	35.9	25.6	<6C
700					
800					
900					
1000					<4C

California Coastal Average Summer (July-September) Depth-Distance-Temperature Profile					
Coastal Region	North	North Central	South Central	South	
Latitude	41? 2'N-38? 2'N	38? 2'N-36? 2'N	36? 2'N-34? 7'N	34? 7'N - 32? 7'N	
Longitude	124? 2'W - 123? 3'W	123? 3'W - 122? 'W	122? 'W - 120? 1'W	120? 1'W - 117? 1'W	
Depth (ft)	Distance (mi)	Distance (mi)	Distance (mi)	Distance (mi)	Temperature F
0	0.0	0.0	0.0	0.0	<68F
33	0.4	0.5	0.3	0.5	<64.4F
66	1.0	1.2	0.8	1.3	<60.8F
98	1.7	2.3	1.6	2.0	
164	3.2	3.9	2.7	3.0	<57.2F
246	5.1	6.6	4.2	4.0	<53.6F
328	6.3	9.1	5.3	4.7	
410	8.2	15.1	6.2	5.2	<50F
492	9.1	16.1	6.5	5.4	
656	10.5	17.2	7.2	5.9	
820	11.2	18.0	7.9	6.6	
984	11.5	18.5	8.7	7.4	
1312	12.3	19.3	10.3	9.0	<46.4F
1640	13.3	20.1	12.3	10.8	
1968	22.9	38.4	22.3	15.9	<42.8F
2296					
2624					
2952					
3280					<39.2F

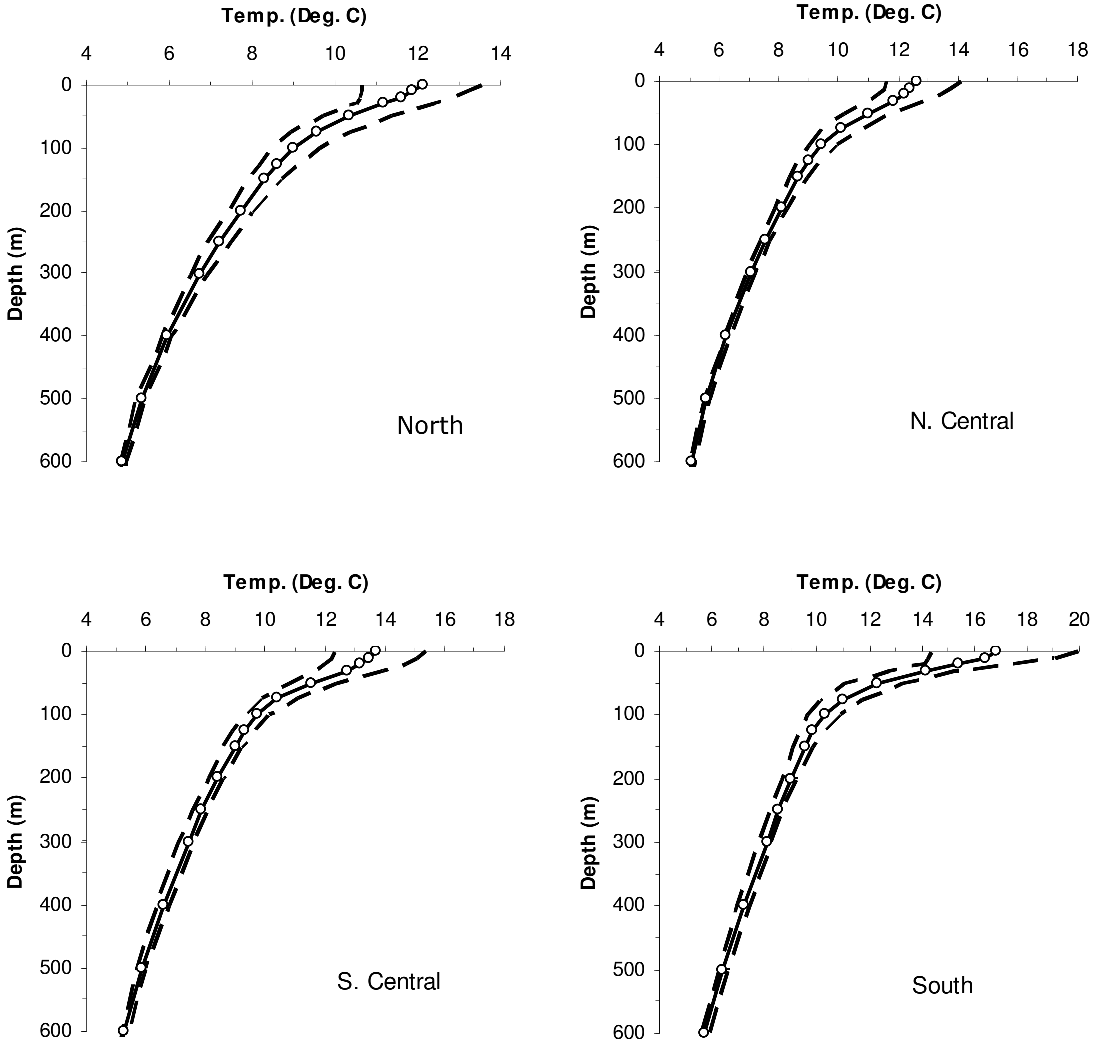

Figure B1. California coast average temperature-depth profile

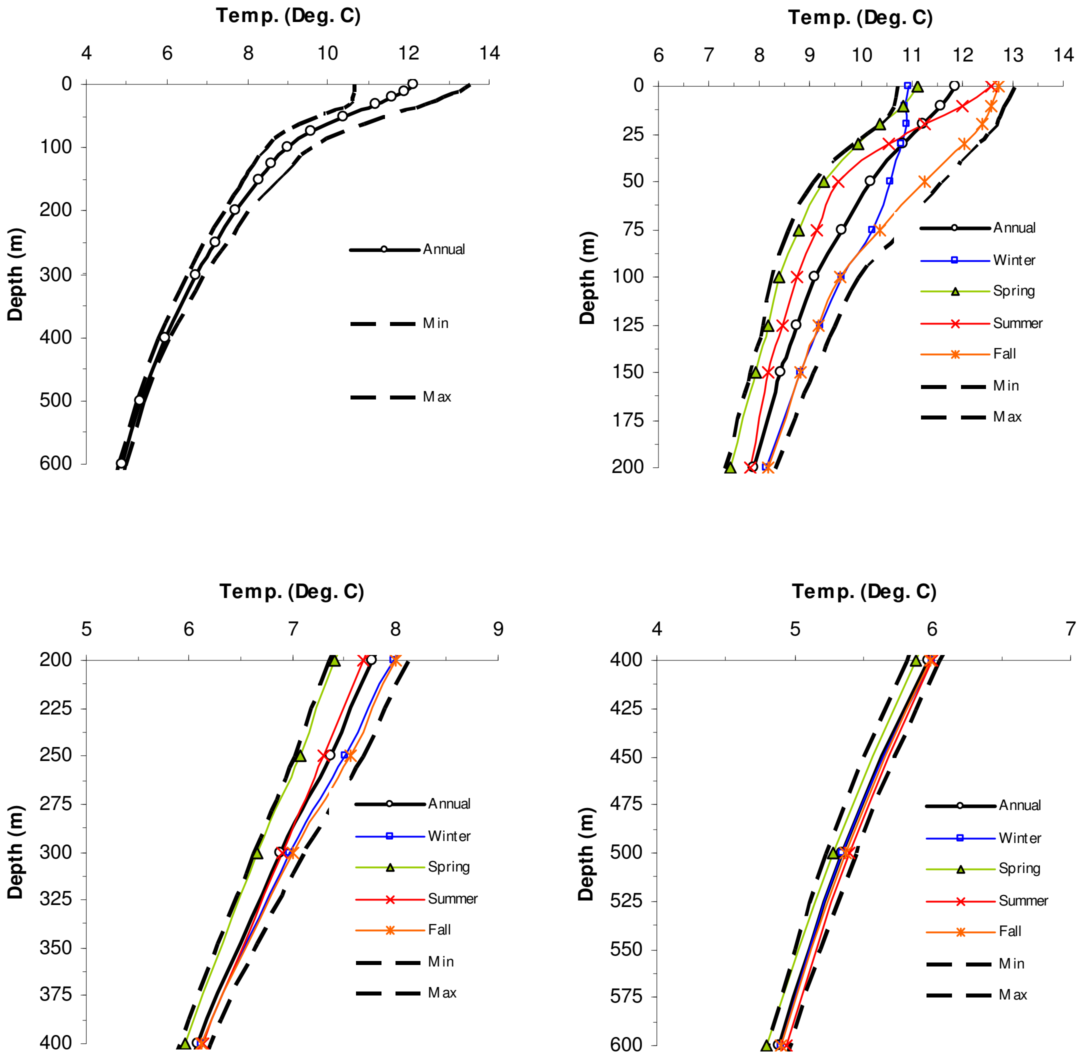

Figure B2. California North Coast average temperature-depth profile

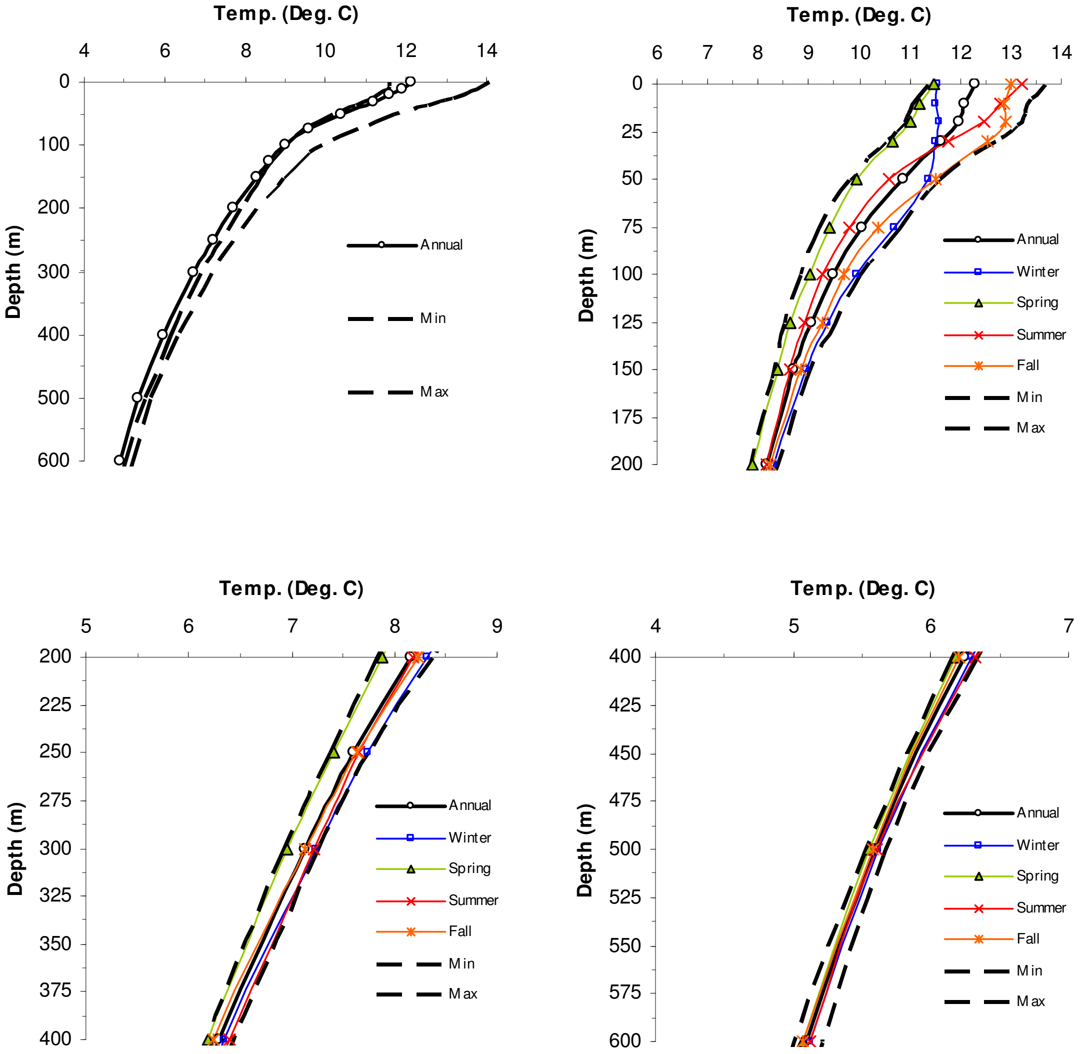

Figure B3. California North Central Coast average temperature-depth profile

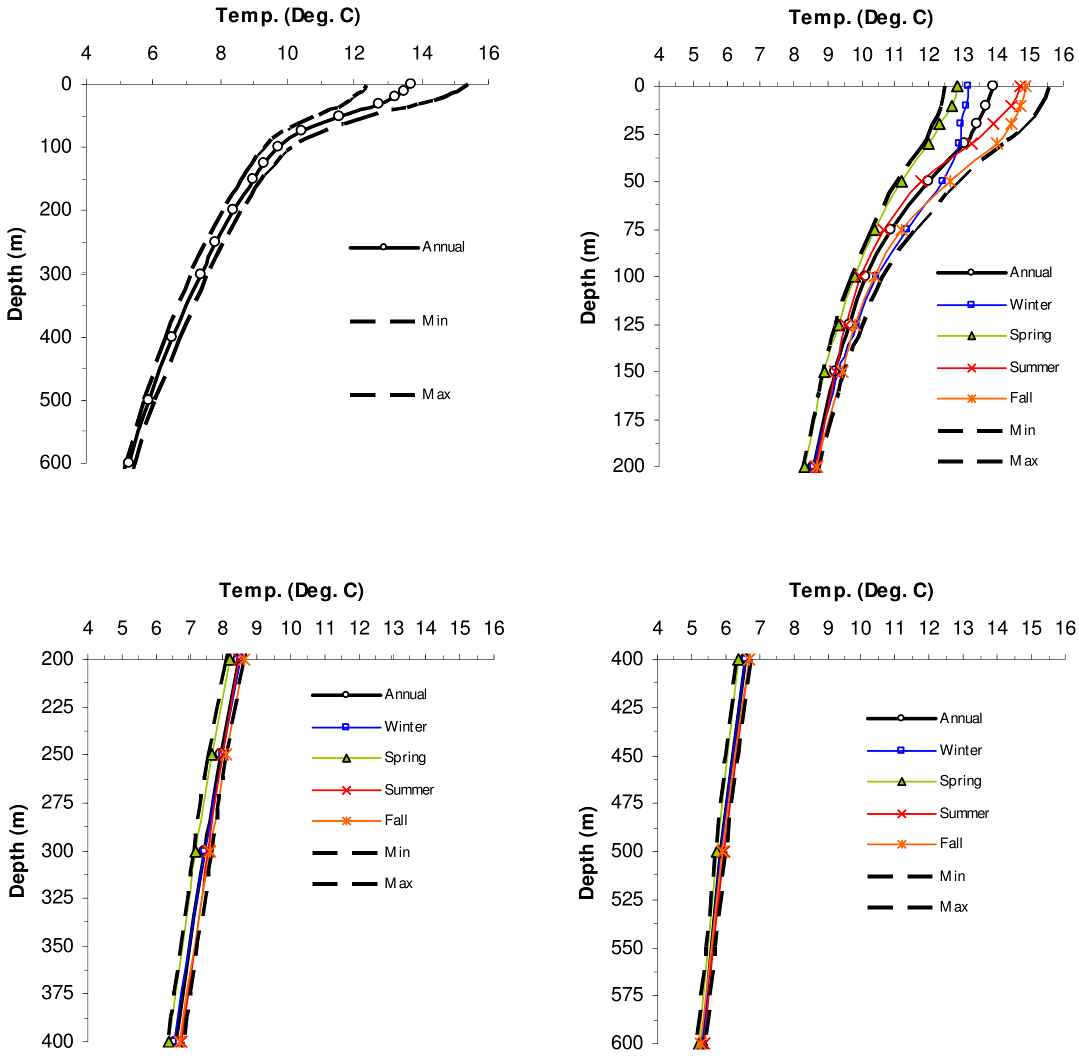

Figure B4. California South Central Coast average temperature-depth profile

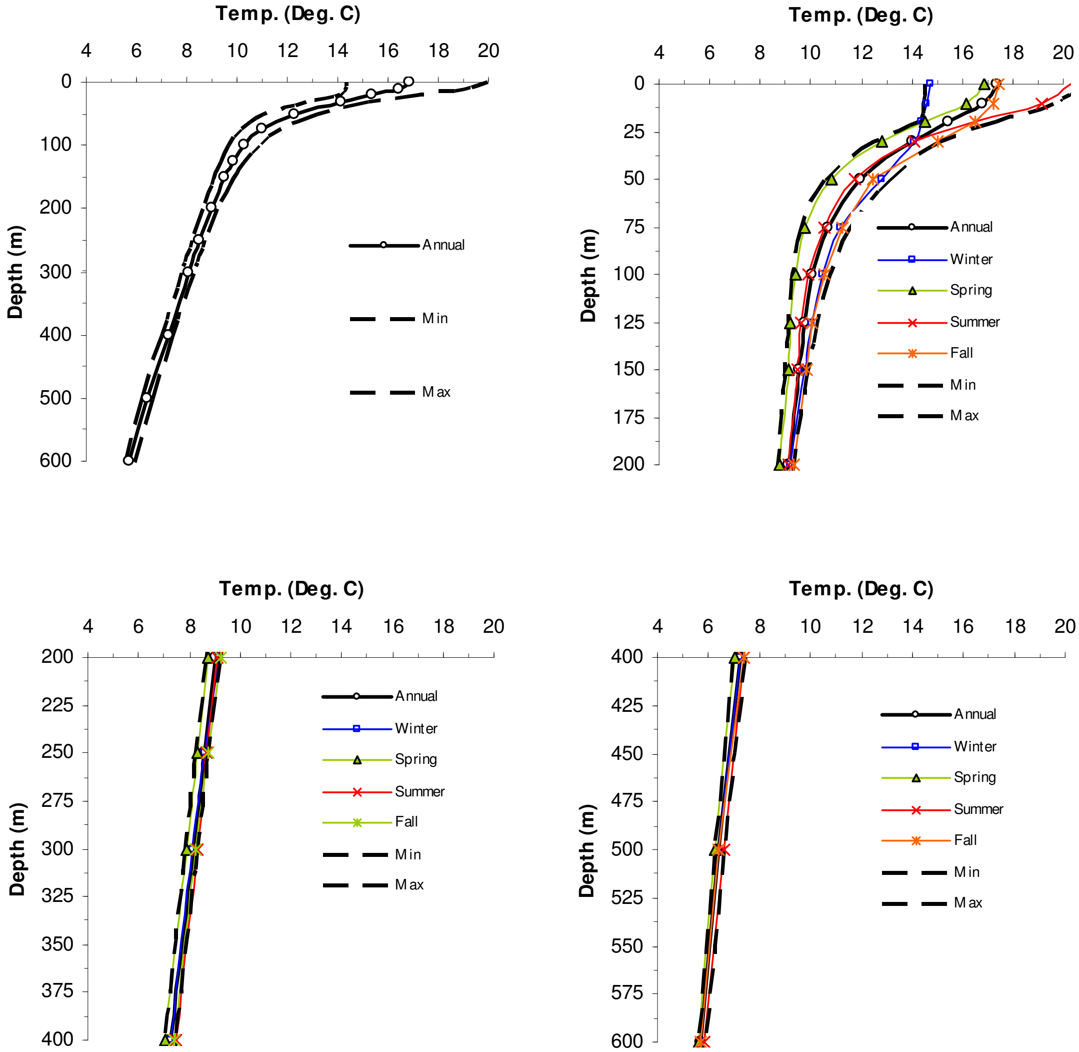

Figure B5. California South Coast average temperature-depth profile

Appendix C California Regulatory Data

Figure C1. Timeline to complete regional MPA plans for the marine life protection Act[9]

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[9] Ocean Conservancy website: http://www.oceanconservancy.org/site/DocServer/CA_Map_wMPA_region_deadlines.pdf?docID=2701

SMCA = state marine conservation area SMP = state marine park
SMR = state marine reserve SMRMA = state marine recreational management area

Figure C2. California Central Coast Marine Protected Areas[10]

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[10] Ocean Conservancy website: http://www.oceanconservancy.org/site/News2?news_iv_ctrl=1&abbr=issues_&page=NewsArticle&id=8703; http://www.oceanconservancy.org/site/DocServer/Central_Coast_mpas041907.pdf?docID=2981

Figure C3. California State Water Quality Protection Areas.[11]

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[11] California State Water Resources Control Board website: http://www.swrcb.ca.gov/plnspols/asbs_info.html

Appendix D SWSC Projects

D.1 World Wide

SWSC systems have been successfully implemented around the world. Several include:

- 1983, 1989: Halifax, Nova Scotia. Purdy's Wharf has two commercial buildings on the waterfront of Halifax harbor that utilize seawater source cooling in a hybrid configuration. Through reductions in operation and maintenance costs these SWSC systems operate 10.5 months per year and provide a simple payback of two to three years.[12]
- 1986: Keahole Point, Hawaii. The Natural Energy Laboratory of Hawaii Authority (NELHA) constructed a pilot plant that has used cold ocean water to cool a selected facility building since 1986. Based upon the success of the plant, a second building was added.[13]
- 1995: Stockholm, Sweden. Stockholm Energy completed a deep SWSC system that uses deep, cold ocean water to cool a large portion of downtown Stockholm. The system was completed in May 1995. The peak cooling capacity of the system is approximately 17,000 tons.[14]
- 2006 Bora Bora, Tahiti: In May 2006 The InterContinental Resort and Thalasso Spa Bora Bora, began operating a deep seawater air-conditioning system that provides the hotel with 5°C (41°F) seawater from 900 meters (2950 feet) deep. Predicted electricity cost savings are $400,000 per year, a 90% reduction.[15]

D.2 California

Several SWSC systems are currently being investigated in California. Brief descriptions of three of these proposed systems are presented below.

D.2.1 Exploratorium, San Francisco

The Exploratorium, the Museum of Science Art and Human Perception, is considering a SWSC system coupled with electric heat pumps, radiant slab and radiant ceiling panels for their proposed new building to be located on the San Francisco Bay waterfront at Piers 15 & 17 (See Figures D1 and D2).[16]

The average daily San Francisco Bay water temperature varies from a minimum of 50°F in winter to a maximum of 63°F in the summer. Bay water would be used as the free cooling source whenever the bay water temperature is below 59°F. The bay water would not be used directly in the building hydronic system, but indirectly though a titanium heat exchanger after passing through a filtration system specifically designed to filter salt water. For design purposes,

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[12] Hosatte, 1998; Annex 28: http://www.ecbcs.org/docs/annex_28_case_study_buildings.pdf
[13] Daniels, 1989; NELHA website: http://www.nelha.org/
[14] Makai Ocean Engineering website: http://www.makai.com/p-swac.htm
[15] Makai Ocean Engineering website: http://www.makai.com/news.htm
[16] Exploratorium website: http://www.exploratorium.edu/

an approach of 3°F through the heat exchangers is assumed so, under typical conditions, the building will operate with 62°F chilled water. On peak days and when the bay water rises above 59°F, modular water source heat pumps will be staged on to supplement the bay water cooling and supply 60°F chilled water (see Figure D3).

Using San Francisco Bay as both a heat sink for cooling and a heat source for winter heating, this hybrid system would be able to provide for both the building design cooling load of 400 tons (300 tons building load and 100 tons ventilation load) and design heating load of 3.3 million BTU/hr. In combination with a roof-mounted PV system, it is possible that the Exploratorium's building could be "zero-carbon" by meeting 100% of its energy needs and completely eliminating CO_2 emissions.[17]

	Figure D1: San Francisco
	Figure D2: Location of Pier 15&17 Embarcadero

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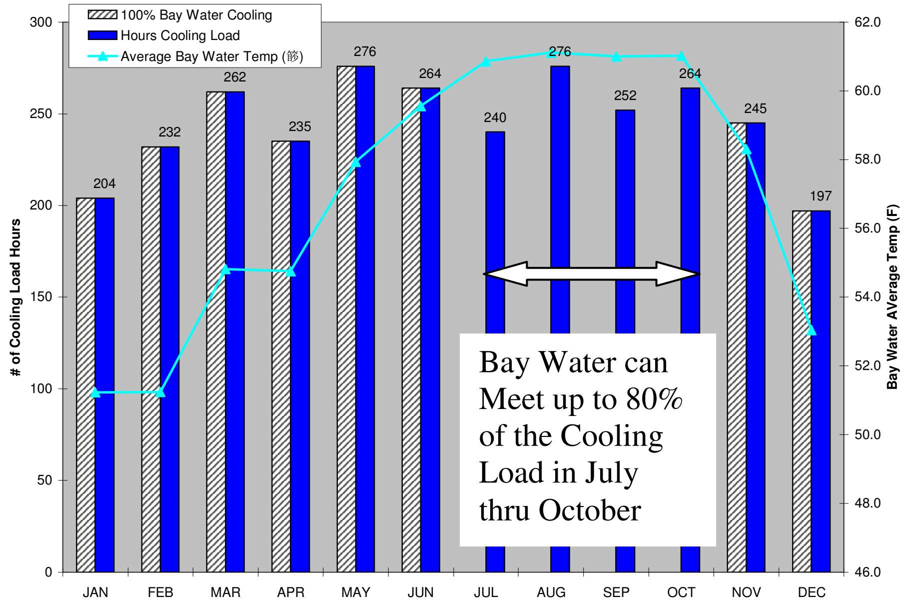
[17] Information courtesy of the Exploratorium, EHDD Architecture, and Rumsey Engineers, Inc.



Bay Water can Meet up to 80% of the Cooling Load in July thru October

Figure D3: Percent (%) Bay Water Cooling and Hours Cooling Load

D.2.2 Moss Landing Marine Laboratories, Moss Landing

Established in 1966, Moss Landing Marine Laboratories (MLML) is internationally recognized for excellence in marine science research and education, and is the second oldest marine lab on Monterey Bay. MLML is situated between two large upwelling centers and the Monterey Submarine Canyon, the largest such feature on the west coast of North America, which begins within a few hundred meters of the Moss Landing harbor.[18]

MLML is considering installing a seawater source cooling (SWSC) system to replace a failed air cooled chiller unit. A life cycle cost analysis comparing the SWSC with a conventional cooling system was performed that showed the economics of retrofitting with a heat exchanger to be advantageous over an air-cooled chiller unit.

MLML basically needs only to install a titanium plate and frame heat exchanger between the existing seawater and chilled water cooling system. MLML currently provides seawater for marine experiments at the various laboratory spaces. A central pumping facility located at the shoreline draws in and filters cold seawater (48° F to 53° F) from an approximate depth of 60 feet via two 8-inch polyethylene pipes each with a rated capacity of 288 GPM and screened inlets raised off the ocean floor. This cold filtered seawater is then pumped approximately one mile from the pumping facility to the laboratory facility.

The intake pipelines enter the central pumping facility through an underground concrete storm drain that also acts as the outtake for the returning seawater. Only one intake pipeline is in use at a time allowing marine growth in the idle pipeline to die and then back flushed out into the ocean. If further cleaning is needed the system is capable of directing water with sufficient

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[18] Moss Landing Marine Laboratories website: http://www.mlml.calstate.edu/

pressure to push a bullet shaped, plastic-foam object, or "pig," through and scour the inside of the seawater pipelines (see figures D4-D7).[19]

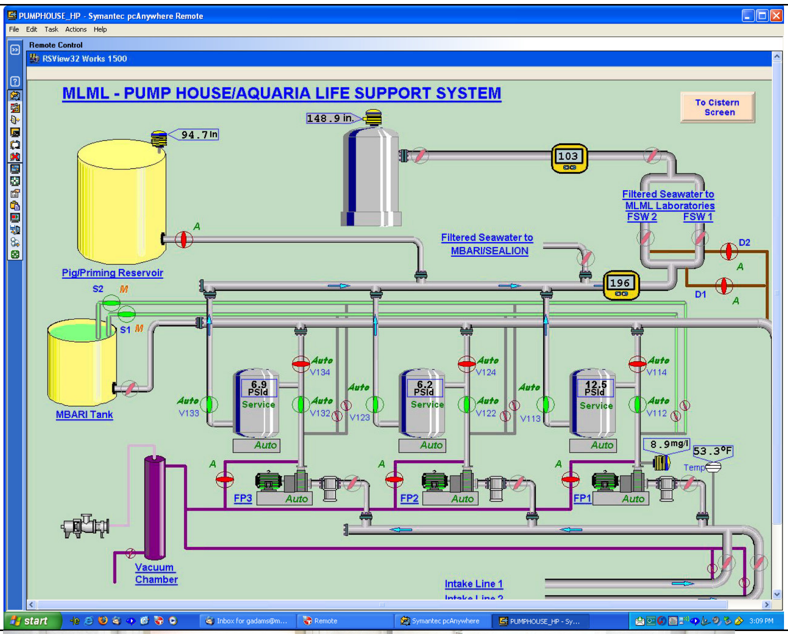

Figure D4:

Screenshot of MLML – Pump House/Aquaria Life Support System

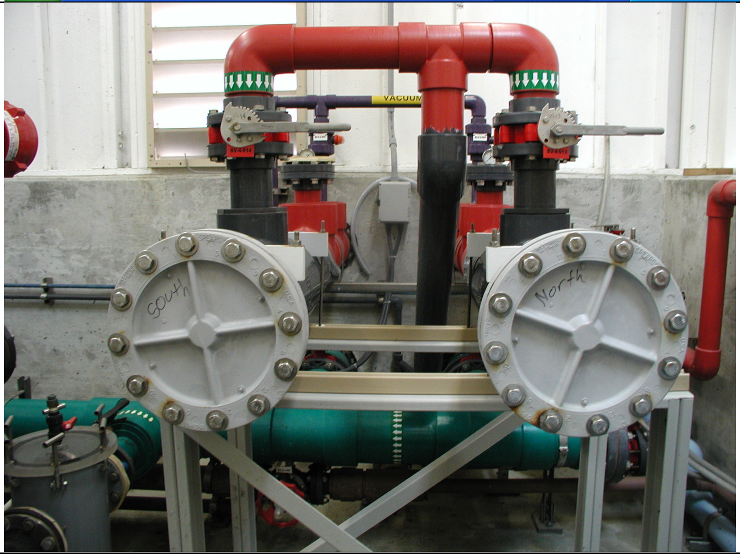

Figure D5:

Seawater Intake Pipes & Pig Launching Assembly

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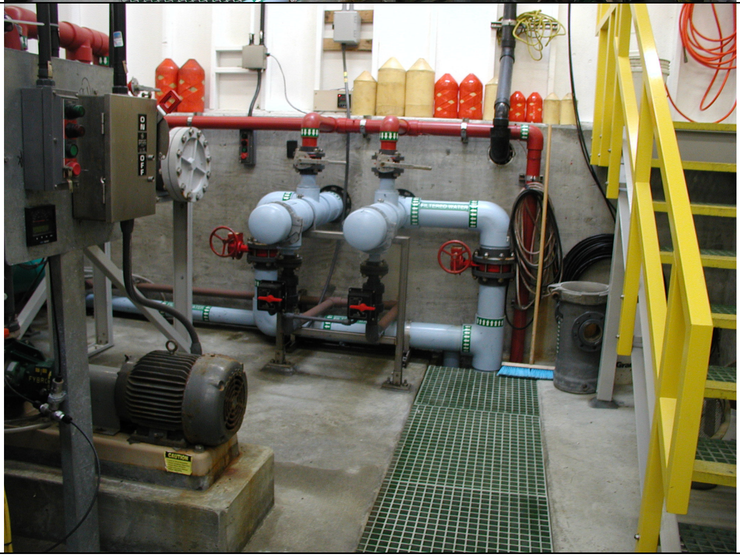
[19] Information courtesy of Moss Landing Marine Laboratories.

	Figure D6: Seawater Intake Pumping and Filtration Plant Facility
	Figure D7: Filtered Cold Seawater Transmission Piping

D.2.3 University of California San Diego, La Jolla

The University of California at San Diego (UCSD)[20] is currently investigating the potential of using deep cold seawater for air conditioning the UCSD main campus, Scripps Institution of Oceanography (SIO)[21], and Birch Aquarium[22].

An initial feasibility study proposes a hybrid system that would provide 44°F chilled water using 53 percent seawater and 47 percent chiller cooling. This system would provide for the full time capacity of 8000 tons and halve the overall power needed by the present system, and by using the chilled water as a heat sink to supplant the evaporative cooling towers would save

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[20] University of California at San Diego website: http://infopath.ucsd.edu/
[21] Scripps Institution of Oceanography website: http://sio.ucsd.edu/
[22] Birch Aquarium website: http://aquarium.ucsd.edu/

100 million gallons of potable water per year. The base case estimated cost is $60+ M and simple payback time is 14 years.

As shown in figures D8 & D9, the proposed 36” intake and 32” outtake pipelines would extend from the shoreline south of the SIO pier respectively 1 mile to the La Jolla canyon to reach a depth of 750 ft and nominal cold seawater of 49.7 ° F and 0.5 miles returning the seawater into 70 ft ambient conditions. These pipelines would pass via 0.3 mile long tunnels created by horizontal directional drilling or micro-tunneling under and beyond the San Diego Marine Life Refuge State Water Quality Protection Area (SWQPA) - Area of Special Biological Significance (ASBS) No. 31 that runs parallel and 1000’ offshore. The SWQPA-ASBS No. 31 is part of the San Diego La Jolla Underwater Park and limits the types and amounts of discharges into the waters. Biological concerns over impingement and entrainment of marine life in the withdrawn water would be addressed by a screened intake structure and elevated return water temperatures with a diffuser on the outtake structure.

A schematic of the proposed system shows three separate onshore insulated chilled water loops that make up the campus chiller plant district cooling system and warmer chilled water being used to replace the existing cooling towers. The key components include a titanium plate heat exchanger, chilled water loop running through chiller for additional cooling, seawater and chilled water pumps (see figure D10).

There are number of stakeholders that include state & federal agencies, e.g. San Diego Regional Water Quality Control Board (RWQCB), Coastal Commission, Lands Commission, Environmental Protection Agency (EPA), National Marine Fisheries (NMF), City and County of San Diego and public interest groups, e.g. Coastkeeper, Surfrider Foundation, La Jolla residents.

Further site specific data collection and analysis is needed. The next phase would be to conduct a more detailed study to determine site-specific parameters and address environmental concerns on both the water and land sides.[23]

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[23] Information courtesy of University of California at San Diego.

Figure D8:
Scripps Institution of Oceanography Pier

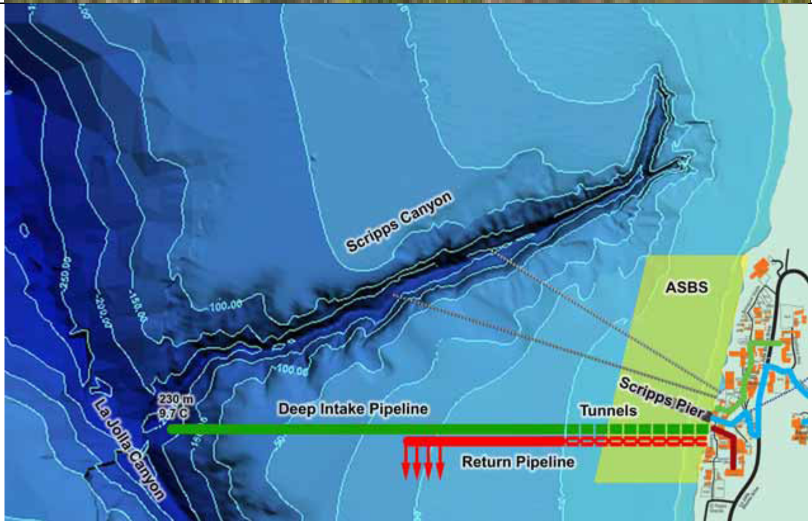

Figure D9:
Overview of UCSD Deep Seawater Intake and Return Pipelines and San Diego Marine Life Refuge Area of Special Biological Significance (ASBS) No. 31

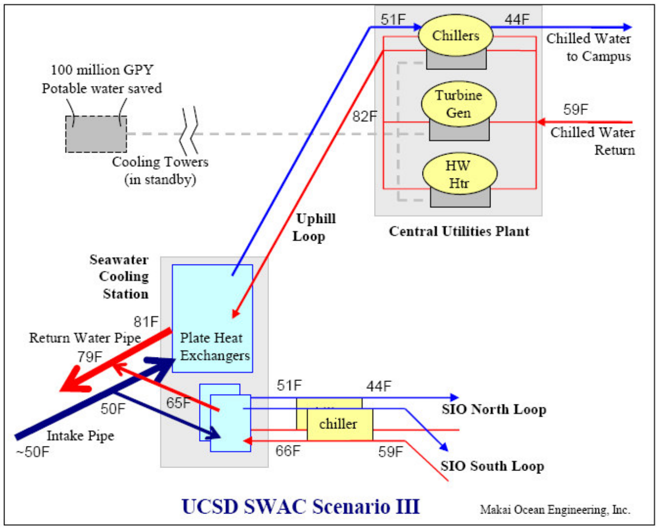

Figure D10:
Seawater Intake and Filtration Plant Facility

Appendix E Literature Review

Seawater and lake water source cooling research and feasibility studies.

- **Burford, Hazen E., Les Wiedemann, W.S. (Lanny) Joyce, Robert E. McCabe, "Deep Water Source Cooling: An Un-tapped Resource", 10th Annual District Cooling Conference of the International District Energy Association, Miami, FL, October 18-20, 1995**. This paper discusses the basic design concepts, environmental considerations and performance related to the application of deep lake and ocean WSC systems. Several studies referenced include:
    - Miami, Florida. A feasibility study considering the use of cold ocean water for the cooling of several commercial districts in Miami, Florida was performed for the U.S. Department of Energy (DOE). The study addressed approximately 20,000 tons of cooling load from shoreline hotels and apartment complexes using as much as 50,000 gpm of cold seawater. The seawater intake was at an offshore depth of 700 feet and at a point approximately 22,000 feet from shore. The study concluded that a deep SWSC facility was technically and economically feasible for this particular application.
    - Nova-Scotia Power, Nova-Scotia, Canada. The local utility serving the City of Halifax has been studying the potential of a scaled up WSC version of Purdy's Wharf as a district cooling for the Halifax waterfront.
    - West Beach, Oahu, Hawaii. A study prepared for the State of Hawaii, Department of Business, Economic Development and Tourism, Energy Division was completed in September 1994. The study evaluated the technical and economic feasibility of using cold seawater to cool a centralized deep SWSC system for a new master planned development on the island of Oahu. The study extensively evaluated several system configurations and load scenarios. The system evaluated deep SWSC configurations ranging in size from 1,300 to 12,700 peak tons. The study concluded that a deep ocean SWSC system is technically feasible and economically attractive alternative to conventional, chiller based systems for this application.
- **Ciani, John B., Seawater Cooling for Naval Facilities, Naval Material Command, Civil Engineering Laboratory, Technical Memorandum TM no. M-44-76-10, 1976**. This study was an initial scoping study of seawater cooling for naval facilities.
- **Ciani, John B., Sea/Lake Water Cooling for Naval Facilities, Naval Material Command, Civil Engineering Laboratory, Technical Note TN N-1528, 1978**. This study found seawater cooling to be economically feasible for a trial Naval facility in San Diego, California and recommended an operational test for the Naval Security Group Activity (NSGA), Winter Harbor, Maine.
- **Ciani, John B., Sea/Lake Water Air Conditioning at Naval Facilities, Naval Material Command, Civil Engineering Laboratory, Technical Note N-1577, 1980**. This study recommended that: "Sea/lake water AC should be considered as an energy and LCC

saving alternative to conventional AC at Naval Facilities which adjoin bodies of water; The computer models introduced in this report should be used to make estimates of the capital cost and energy use of sea or lake water AC systems; No further research and development on sea/lake water AC is recommended".

- **Gardner, Kent E., Impact of the Lake Water Supply Project: An Innovative Cooling and Water Supply Partnership, study prepared for the Monroe County Water Authority, May 1998**. The Xerox Corporation-Monroe County Water Authority (MCWA)-NYSERDA Lake Water Supply Project proposed using cold water from Lake Ontario for WSC at Xerox's Webster, NY facility. This in-depth feasibility study was conducted to assess the potential for using cold Lake Ontario water to provide comfort cooling for a large manufacturing and administrative complex in upstate New York. The system combined cooling with providing water to the local municipal water district's treatment facility. The impact study of this project concluded that it would "stimulate economic growth and improve environmental quality by overcoming one of New York's competitive disadvantages–high cost energy–while reducing demand for electricity generated by fossil fuels."
- **Hirshman, Jules B., Douglas A. Whithaus, and Irving H. Brooks, Feasibility of a District Cooling System Utilizing Cold Seawater. Phase I: Final Report by Tracor Marine, Port Everglades, FL, for the U.S. Department of Commerce, National Technical Information Service, June 16, 1975**. This report was conducted for the U.S. Department of Energy and completed June 16, 1975. This study examined in two phases the feasibility of using cold seawater to directly cool buildings in four potential U.S. sites (South Florida; South California; Honolulu, HI; San Juan, Puerto Rico). The first phase of the study indicated that the concept is technically and economically feasible and can save 70-80% of electrical energy used for air conditioning or 35-40% of the total electrical energy in the areas serviced. Of the four potential sites studied, Miami/Ft. Lauderdale and Honolulu were identified as the most suitable. The second phase of this study investigated the specialized pipeline and pipeline installation design for large diameter deep seawater intakes and time-series temperature measurements at potential intake sites.
- **Hirshman, Jules B., R. Kirklin, Feasibility of District Cooling Systems Utilizing Natural Cold Waters; Phase II and Phase III - Final Report. ERDA Report No. ORO 4875-B, September 1977**. Phase II: Site-Specific Study and Preliminary Design of a Miami Beach Seawater Cooling District; Phase III: Preliminary Assessment of the U.S. Fresh Water Resource for the District Cooling of Buildings.
- **Hirshman, Jules B., "Direct Seawater/Lakewater Cooling Systems", (Tracor Marine, Inc., Fort Lauderdale, FL), "Energy Use Management, Fazzolare, R., Smith, C.B (eds.), Elmford, New York: Pergamon Press, Inc., pp.795-807, 1978**. Summary report of the findings of several studies performed by Tracor Marine for Energy Research and Development Administration (ERDA) to evaluate the technical and economic feasibility and the energy savings potential for large direct seawater/lakewater cooling systems. The results of the studies indicate that: 1) 70% to 80% of the electrical energy used for air

conditioning can be saved with this method, 2) Lifecycle costs for the locations studied are lower for direct cooling systems that for conventional air conditioning; 3) Technology is available for near-term construction of intake pipelines in deep lakes and ocean sites; 4) Prospective projects of this type must be individually evaluated in terms of specific characteristics of the site.

- **Leraand, T.K., J.C. Van Ryzin, "Air Conditioning with Deep Seawater: A Cost-Effective Alternative for West Beach, Oahu, Hawaii", May 1994**. This work was funded by the Energy Division of the State of Hawaii Department of Business, Economic Development and Tourism. This paper summarizes the technical and economic feasibility of a deep cold seawater source cooling centralized air conditioning system (uses cold seawater from approximately 2000′ depth to cool via a heat exchanger a centralized fresh chilled water distribution loop) for a development of resort hotels at West Beach, Oahu, Hawaii. The paper presents an analysis and comparison of the construction and operating costs of seawater air conditioning system to the construction and operating costs of conventional air conditioning systems. This analysis and comparison concludes that centralized seawater air conditioning is technically feasible and unsophisticated alternate energy concept that has the potential of significant impact in Hawaii and other similar regions. The installation of large systems at selected locations is economically attractive today.
- **State of Hawaii, Sea Water District Cooling Feasibility Analysis for the State of Hawaii, Department of Business, Economic Development & Tourism's (DBEDT) Energy, Resources, and Technology Division, October 2002**. This study looked at applications in Hawaii and concluded that seawater district cooling would save more than 90% of the energy used for conventional cooling systems. On a weighted average basis, the West Waikiki, Honolulu Waterfront, and Kakaako case studies saved 92.5% of the energy typically used in CCSs. This is equivalent to 4,526 kWh/rated ton-yr, or 8.43 Bbl of imported crude oil/rated ton-yr. Estimates of reductions in future utility electricity generation capacity are also provided.
- **Makai Ocean Engineering, Inc., "Feasibility Analysis of Air Conditioning with Deep Seawater at the University of California, San Diego" prepared for Facilities Management, University of California at San Diego, July 2006**. This report analyzes the technical and economic feasibility of using deep cold seawater to assist in cooling the University of California San Diego and Scripps Institution of Oceanography.
- **Van Ryzin, Joseph, T.K. Leraand, "Air Conditioning with Deep Seawater: A Cost-Effective Alternative", 1979 and published in Ocean Resources 2000, Sea Technology, September 1993**. This paper concludes that seawater air conditioning is technically and economically feasible today, environmentally safe, and renewable. It identifies applications buildings, resorts, hotels, and military installations in tropical and subtropical climates, where air conditioning represents the major energy demand. Research and experimentation on ocean thermal energy conversion (OTEC) conducted at the Natural Energy Laboratory of Hawaii has provided information and eliminated

uncertainties related to deep water pipelines and the unknowns relative to heat exchanger fouling and corrosion.

- **Van Ryzin, Joseph, T.K. Leraand, "Air Conditioning with Deep Seawater: A Reliable, Cost-Effective Technology", Prepared for presentation at the IEEE OCEANS '91 Conference, Honolulu, HI, October 1991**. This paper summarizes the operation of an air conditioning system using deep, cold seawater and identifies the primary conditions under which such systems can be cost effective. The primary factors impacting the economic success of such a system is the size of the air conditioning load, the accessibility to deep cold water, the percent utilization of the air conditioning system and the local cost of electricity. This paper provides data and graphs that are suitable for an initial assessment of the economic payback period based on these site specific conditions.