Evaluation of Cooling System Alternatives
Diablo Canyon Power Plant

Prepared for the
California Regional Water Quality Control Board
Central Coast Region
81 Higuera Street
San Luis Obisbo, California 93401

Revised Draft

Prepared by
Tetra Tech Inc.
27972 Meadow Drive
Evergreen, Colorado 80439

November 2002

CONTENTS

FIGURES

TABLES

I. Introduction

Tetra Tech Inc. has been requested by the Central Coast Regional Water Quality Control Board (Board) to provide cost estimates for cooling system alternatives that will minimize environmental impacts associated with the once through cooling system of the Pacific Gas & Electric Company's (PG&E) Diablo Canyon Power Plant (DCPP), located in Avila Beach, San Luis Obisbo County, California. In response to this request, the following report provides an independent analysis and approximate cost estimates for conceptual cooling system alternatives for the DCPP, to enable the Board to consider feasibility and determine if additional analysis of alternatives is warranted. Although an independent report, it has been prepared with input from PG&E plant personnel, who have provided meaningful site-specific information and insight. Tetra Tech, Inc. has also visited the plant site on October 18, 2002 in order to provide a meaningful analysis.

In 1982, TERA Corporation prepared the *Diablo Canyon Power Plant Assessment of Alternatives to the Existing Cooling Water System* for PG&E. The primary objective of that comprehensive assessment included the reduction of heat in the facility's cooling water discharge, whereas the primary objective of this assessment is to examine alternatives that will reduce impingement of aquatic organisms on components of the plant's cooling water system and reduce entrainment of aquatic organisms within the system. With reduction of impingement and entrainment a primary objective, feasible cooling system alternatives must significantly reduce the power plant's cooling water flow requirement and/or limit the number of aquatic organisms that come into contact with or pass through the power plant's cooling water intake structure.

Although Tetra Tech, Inc. has considered a wide range of cooling system alternatives for the Diablo Canyon Power Plant, only two get considerable attention within this report – the use of fine mesh traveling screens with fish handling and return systems at the cooling water intake structure and the use of mechanical draft, wet cooling towers using seawater makeup. Other methods of cooling, such as natural draft wet cooling towers, dry cooling towers, and hybrid (wet/dry) cooling towers have been given consideration but are not discussed in great detail, due to their technical limitations or the practical difficulties that would be encountered during their construction and use at the Diablo Canyon facility. Other intake technologies, such as cylindrical wedgewire screens, fish net barriers, and louver systems have also been given consideration; however, most such technologies have never been used on a scale that would be required at the Diablo Canyon Power Plant and/or would have significant technical limitations in the unique physical setting of this facility. Many cooling system alternatives considered in the TERA Corporation's 1982 report have simply not been considered here, because they were viewed as a means to reduce thermal discharges and would not meet the objective of this assessment to evaluate technologies for reducing impingement and entrainment of aquatic organisms.

For this analysis, Tetra Tech Inc. has used, to some degree, EPA's cost projections for cooling water intake technologies and for alternative cooling systems, presented in the Agency's *Technical Development Document* (TDD) and in its *Economic and Benefits Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule* (EPA 821-R-02-003 and EPA 821-R-02-001, both April 2002). Tetra Tech Inc. has also worked with the engineering firm of Hatch &

Associates Ltd (Hatch) to develop capital cost projections for closed cycle cooling alternatives based on approximate cooling requirements and ambient meteorological conditions of the DCPP. And, Tetra Tech, Inc. has received site-specific information from PG&E that has been considered in developing costs estimates.

II. Background[1]

The DCPP is a two-unit nuclear power plant sited on 585 acres owned by PG&E, approximately 12 miles west southwest of San Luis Obisbo. Units 1 and 2, which began commercial operation in May 1985 and March 1986, respectively, are operated as base loaded units and have gross rated capacities of 1,133 and 1,165 MW and net outputs of 1,103 and 1,119 MW, respectively. Ocean water for cooling is pumped through an intake structure in Intake Cove and then through two steam condensers per unit, with the total cooling water flow rate for Unit 1 ranging from 778,000 to 854,000 gallons per minute (gpm) and for Unit 2 from 811,000 to 895,000 gpm. During 1977 – 1986, daily mean seawater temperature ranged from approximately 10.5°C in May to approximately 15°C in September. The maximum seawater temperature during 1972 – 1982 was 18°C (64°F).

With the plant at full load, the temperature of once through cooling water is raised approximately 11°C (20°F) as it passes through the power plant. Each unit has two, single speed, cooling water pumps, each driven by a 13,000 horsepower, 238 rpm motor. Auxiliary cooling systems account for approximately one percent of the facility's total cooling water volume. After exiting the condensers, approximately 2.5 billion gallons of cooling water per day flow by gravity to a discharge structure on the shoreline of Diablo Cove, which is north of Intake Cove.

The shoreline intake structure for the DCPP contains inclined bar racks and travelling screens along with auxiliary and main cooling water pumps. At the face of the intake structure, a concrete curtain extends 7.75 feet downward, below mean sea level, to keep out floating debris. After entering the structure, water flows through inclined bar racks, consisting of flat bars, 3 inches x 3/8 inches on 3 3/8 inch centers, which create 3 inch openings in the racks, designed to exclude large debris. From the bar racks, ocean water flows through a series of pump bays, which house vertical travelling screens of 3/8 inch stainless steel mesh. Six travelling screens per unit, each at 10 feet (width) x 30 feet (depth), filter seawater ahead of the two main circulating water pumps per unit; and a smaller travelling screen, with 150 square feet of filter surface, precedes the auxiliary pumps. Screens can be set to rotate at 10 or 20 feet/minute and can be washed manually or automatically, with high-pressure spray. Material is washed from the screens into sloping sluiceways that empty into a refuse sump before being discharged to the ocean.

Two single speed, main circulating pumps per unit, each capable of supplying 433,500 gpm, move water through two 11.75 feet square conduits to the top of a coastal bluff at an elevation of 85 to 105 feet, where it is vented and routed through the plant's condensers. Approximate cooling water velocities are:

---

[1] Background information has been assembled from the *Staff Report for Regular Meeting of July 13, 2000, Diablo Canyon Nuclear Power Plant, Resolution of Thermal Discharge and Entrainment/Impingement Impacts,* California Regional Water Quality Control Board, Central Coast Region (June 6, 2000); *Section 2.0, Diablo Canyon Power Plant 316(b) Study, Draft Evaluation of Alternative Intake Technologies,* Engineering Services, Pacific Gas and Electric Company (Dec. 10, 1999); *Chapter 2, Diablo Canyon Power Plant, Cooling Water Intake Structure 316(b) Demonstration,* Tenera Environmental Services (April 28, 1988); and *Diablo Canyon Power Plant, Revised 316(b) Study Plan,* Tera Corporation (June 13, 1983); Comments of September 2002 provided to Tetra Tech, Inc. by PG&E DCPP plant personnel in response to a Preliminary Draft Evaluation of Cooling System Alternatives for the Diablo Canyon Power Plant.

Through bar rack	1.1 feet per second (fps)
Approaching travelling screens	1.0 fps
Through 3/8 in. travelling screens	1.95 fps
From intake structure to condenser	7.0 fps
Through condenser	7.0 fps
Through discharge conduits	7.0 fps
Discharge structure exit channel	8.5 fps

Based on comprehensive entrainment studies performed at the DCPP between October 1996 and June 1999, there is potentially a high loss of larvae of near shore species attributable to the once through cooling system at the DCPP. Offshore species, which include more sport and commercial species, were not entrained in significant amounts during these studies. And, impingement studies, performed in 1985 and 1986, showed that very few adult fish were actually impinged on the travelling screens at the DCPP cooling water intake structure.

Several features of the DCPP's physical location are important to the consideration of cooling system alternatives.

- The DCPP is located on a coastal terrace above a rocky shoreline. Normal wave activity is in the 5 to 10 feet range, with storms generating waves between 20 and 30 feet. During the storm season between September 1997 and August 1998, peak swells exceeded 10 feet on 64 days.
- The DCPP cooling water intake is located in an area of significant production of marine algae, including surface kelp and understory algae. Kelp growth can reach two feet per day during the growing season between June and October.
- The DCPP is located in a "wet marine" weather environment where ocean winds are commonly 10 to 25 miles per hour and can reach 40 to 50 miles per hour. Rainfall averages 20 inches per year; and the normal daily weather pattern is characterized by wet/foggy conditions in the morning and mild to strong winds in the afternoon.
- Bathymetry in the vicinity of the DCPP is characterized by a sloping bedrock bottom with steep relief, rocky pinnacles, and prominent rocky ridges.
- The area of the DCPP, in general, exhibits steep topographic relief. The plant itself lies on gently sloping, narrow, coastal terrace at an elevation of 85 feet (MSL) above a rugged coastline, with the Irish Hills rising steeply behind the facility, to the east. Figure 1 shows the plant site, including topography surrounding principal structures.
- A protected archeological site, north and adjacent to Diablo Creek, exists on the plant site.

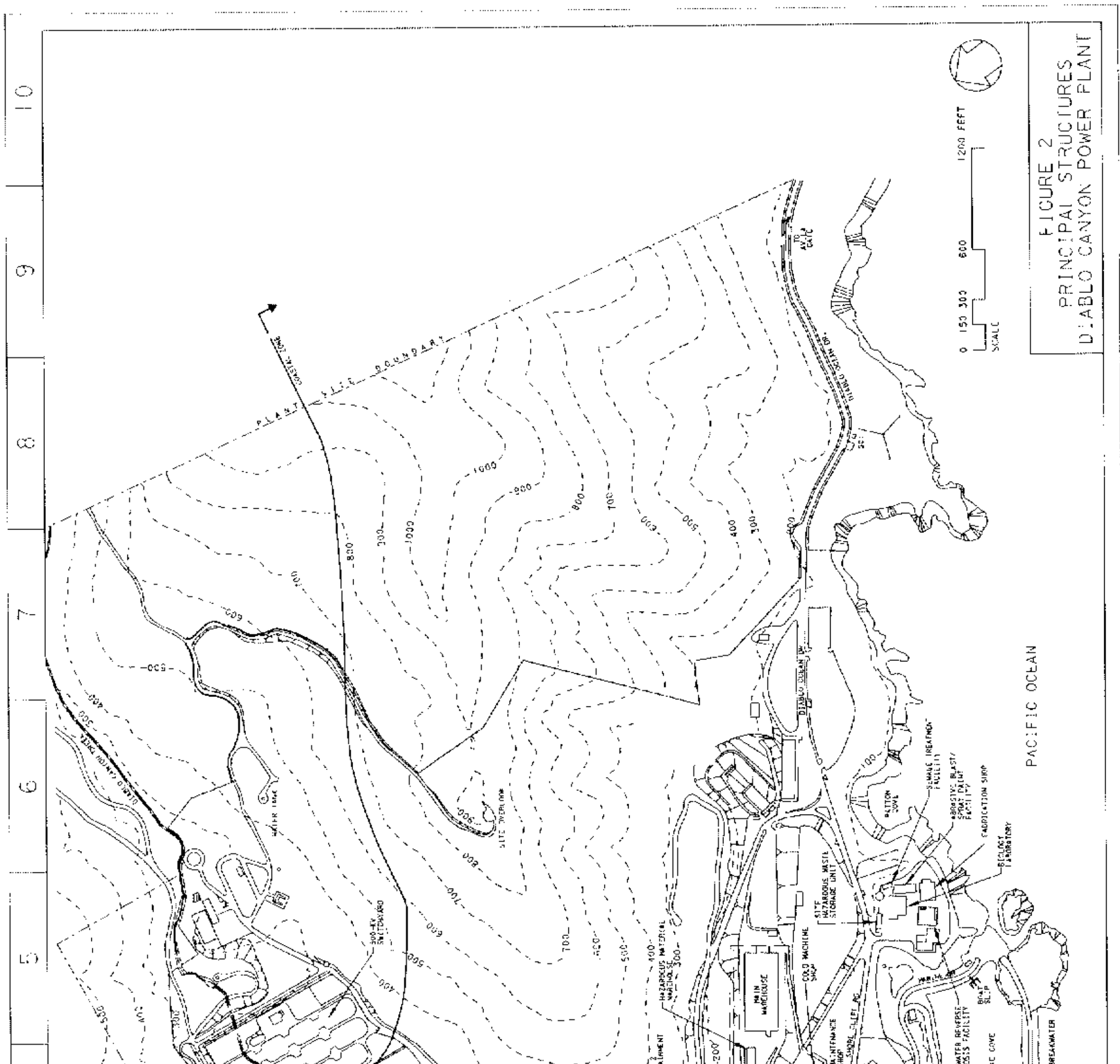

Figure 1: Diablo Canyon Power Plant, Site Drawing

III. Summary of Cost Estimates

Table 1, below, provides a summary of cost estimates for the two cooling system alternatives considered viable for further consideration at the Diablo Canyon Power Plant. Sections IV and V provide discussion of each alternative, including how costs were determined.

Table 1 - Summary of Cost Estimates for Cooling System Alternatives at the DCPP - $MM

	Fine Mesh Screens With Fish Handling and Return Systems	Mechanical Draft, Wet Cooling Tower System Using Seawater Makeup
Capital Cost	23	822
Annual O&M	1	1.7
Total Annual Energy Penalty	NA	13
Lost Revenue During Construction	660	330
Net Present Value[2]	- 650	- 1,320
Annualized Cost[3]	663 (first year) 3.2 – 3.9 (thereafter)	422.5 (first year) 92.6 – 94.2 (thereafter)

NA = not applicable

[2] Assumes a 20 year project life
[3] Assumes capital costs amortized over 20 years

IV. Evaluation of Cooling System Alternatives – Modification and/or Additions to the Once Through System

At the DCPP, studies of both impingement and entrainment activity appear to show that modifications to the cooling water intake system must focus on reducing entrainment, as impingement effects were insignificant in studies performed by PG&E in 1985 and 1986. Intake technologies, with the potential to reduce entrainment, include fine mesh screens with fish handling and return systems and aquatic microfiltration barriers (both addressed in this section), as well as cooling systems that would significantly reduce the cooling water requirement – wet, dry, and hybrid (dry/wet) closed cycle cooling designs (addressed in Section V).

A. Fine Mesh Travelling Screens with Fish Handling and Return Systems

Fine mesh screens of 5 mm or less can be mounted on conventional, continuously operated, traveling screens to exclude eggs, larvae, and juvenile fish from intake structures. A low-pressure screen wash is typically used to gently release impinged eggs, larvae, and juvenile fish to a bypass/return system; and a high-pressure spray wash then removes debris.

0.5 mm fine mesh screens have been used on Units 3 and 4 of the Big Bend Station of Florida Power and Light (FP&L) since the mid 1980s. After evaluation of intake velocities and screen rotational speeds, and recognizing that frequent manual cleaning was necessary to avoid biofouling, the FP&L system has generally demonstrated long-term success at reducing entrainment. Fish eggs are screened at greater than 95 percent efficiency, with latent survival for predominant species between 80 and 93 percent. Larvae are screened at 86 percent efficiency, with latent survival at approximately 65 percent.

Fine mesh, 0.5 mm, screens have also been successfully used in a marine environment at the Barney Davis Station in Corpus Christi, where impingement mortality has been reduced significantly, although entrainment performance data is unavailable. In periods of limited use or study, fine mesh on two of four screens at the Brunswick Power Plant in North Carolina showed 84 percent reduction in entrainment as compared to conventional screens, while similar results were seen in pilot studies at the Chalk Point Generating Station in Maryland and at the Kintigh Generating Station in New Jersey. In pilot studies in the 1970s, the Tennessee Valley Authority showed reductions in striped bass entrainment up to 99 percent using 0.5 mm mesh screen and reductions of 75 and 70 percent using 0.97 mm and 1.3 mm screen size, respectively.

Of the plants mentioned above that have actual experience or have conducted pilot studies using fine mesh screens, the Barney Davis, Big Bend, Brunswick, and Chalk Point Stations each utilize salt water or brackish water for cooling. Data for the Big Bend Station of the Tampa Electric Power Company is cited from two impingement and entrainment (I&E) studies performed between 1976 and 1980. Those studies, like the 316(b) Demonstration Study for the Diablo Canyon Power Plant, were conducted in accordance with EPA guidelines, which propose identification and focus on target or "representative important species" (RIS). Such species are targeted for study because, in general, they are commercially valuable, recreationally important, and/or locally abundant. Fifteen taxa were targeted in the Big Bend I&E studies, and sixteen taxa were listed as RIS in the Diablo Canyon Demonstration Study.

Attachment 1 of this report contains two tables, which present detailed life cycle information for the RIS targeted in the Big Bend and Diablo Canyon studies. The RIS taxa can be summarized as:

Big Bend	Diablo Canyon
1 swimming crab species	2 Cancer crab species
1 stone crab species	1 herring species
1 Penaid shrimp species	1 anchovy species
6 drum species	1 scorpionfish/rockfish species
1 herring species	1 scorpionfish/rockfish complex
1 grunt species	1 combfish species
2 porgie species	3 sculpin species
1 pufferfish	1 drum species
	1 prickleback species
	1 kelpfish
	1 goby species
	1 Paralichthyid flounder species
	1 lefteyed flounder species

Based on the near absence of overlap of Big Bend and Diablo Canyon RIS at the family and species levels, there would appear to be very little opportunity to predict success for fine mesh screens at Diablo Canyon based on results at Big Bend. The only taxa common to both locations are drums and herrings. Closer examination of life cycle histories of both sets of RIS, however, shows that most of the RIS at both facilities are nearshore spawners and/or utilize the nearshore as nursery habitat. Another possible level of comparison (not performed for this assessment) would be to look at egg sizes and/or size ranges of larvae to see whether the primary species in both locations are similar in size.

When considering the comparability of Big Bend experience with potential effectiveness of fine mesh screens at Diablo Canyon, the strongest statement, from a biological perspective, is that both facilities are dealing primarily with species that spawn in nearshore areas, have buoyant eggs, and/or planktonic (detached/floating) larvae. Diablo Canyon may have a few more species known to have demersal (sinking) eggs, but those species also have planktonic larvae, more subject to the currents and vulnerable to entrainment.

Although the limited experiences described above suggest that 80 percent reduction in entrainment could potentially be achieved at the DCPP, through the use of fine mesh screens, any further consideration of such technology would require pilot studies to take into account site specific variables, including local species of concern and the potential for screen fouling with kelp and algae.

Use of fine mesh traveling screens at any facility would need to be optimized. The potential for fouling by kelp and algae at the DCPP would be significant, and intensive maintenance should be anticipated to avoid biofouling. Applications of this technology also suggest that intermittent, rather than continuous use of fine mesh, during periods of larvae and egg abundance, may be appropriate at some facilities. The example facilities, discussed above, do not have cooling water flow requirements near that of the DCPP. Tetra Tech Inc. acknowledges that these examples demonstrate limited full-scale use of the technology and have resulted in limited performance data.

At the DCPP, there are currently 6 travelling screens per unit, each 10 feet (width) x 30 feet (depth). With an average cooling water flow of 835,000 gpm per unit, through screen velocity is calculated at 1.0 fps, or approximately 2 fps, when a 50 percent screen efficiency is assumed. For the purpose of cost estimates, below, the screen surface area at the plant is doubled to allow a through screen velocity closer to 1 fps at a 50 percent screen efficiency. Such a reduction (50 percent) in through screen velocity would also reduce, rather than raise, concerns regarding possible impingement effects caused by alternative screen technology.

In its *TDD for the Proposed Section 316(b) Phase II Existing Facilities Rule* (EPA 821-R-02-003, April 2002), EPA estimates capital and operation and maintenance (O&M) costs for travelling screens with fish handling features at various well depths and screen widths. The Agency arrives at cost estimates for retrofitting an existing facility with such technology by determining costs for a new plant and then applying a retrofit factor (1.3), a construction factor for nuclear facilities (1.65), and a regional cost factor (1.081). The retrofit factor accounts for needed changes to existing cooling water and intake structure systems; and the construction factor takes into account differences in construction costs between nuclear and non-nuclear facilities and differences in installation costs between the various cooling water intake technologies.

Although EPA is conservative in developing its cost figures, it does not address cooling water intake facilities with the very large intake flows required of the DCPP and acknowledges that flows greater than what the Agency considered could require a custom design. Nevertheless, to arrive at an approximate cost estimate, Tetra Tech Inc. has extrapolated EPA's cost figures presented in Table 2-11 of the TDD to arrive at a figure of $870,000 per screen for the DCPP. After applying the regional, retrofit, and construction cost factors, total capital costs are estimated at $1.8 MM per screen or $21.4 MM to retrofit the DCPP intake structure with fine mesh travelling screens having an effective through screen velocity of 1 fps.

O&M costs for travelling screens will vary by type, size, and mode of screen operation. In the TDD for existing facilities, EPA projects O&M costs for travelling screens to range from 5 percent of their total capital cost (before cost factors are applied) for the largest travelling screens to 8 percent for the smallest travelling screens, since O&M costs would not increase proportionately with screen size. Using EPA's costing methodology and the worst-case scenario of 8 percent, costs to operate and maintain fine mesh travelling screens on the main circulating water system at the DCPP would be approximately $835,000 per year. PG&E has indicated, however, that O&M costs for its existing screen technology are already close to $1 MM per year; and it is reasonable to assume that O&M costs at the Diablo Canyon Power Plant for fine mesh screens would be unusually high due to high algae and kelp production in the vicinity of the facility's cooling water intake structure. This would be especially true during the first years of operation (like at Big Bend) during system optimization. Based on best professional judgment, Tetra tech, Inc. has assumed that EPA's O&M estimate of S870,000 per year would be in addition to the $1 MM currently spent by PG&E.

Tetra Tech, Inc. and Hatch estimate that both units would be off line and not generating, simultaneously for approximately thirteen months during construction and retrofitting activity. Although a staged construction, where only one unit at one time would be off line, would be possible, total downtime has not been projected for such a construction scenario. Over a thirteen month period, in which both units would have been off line for scheduled outages of 1 month, PG&E would lose revenue of approximately $660 MM. This figure was determined with a revenue estimate provided by PG&E for the DCPP of $900,000 per unit per day; and it is in line with Tetra Tech, Inc.'s independent estimate based on a net plant output of 2,222 MW over 364 days and a wholesale price of electricity of $34 per MW. Before modifying the main cooling water intake structure, a smaller intake for auxiliary salt water (ASW) pumps will also be required, as the ASW system is a safety related system that cannot be shut down, when the facility is off line. Costs for implementing a new ASW intake would be approximately $1.6 MM (resulting in a total capital cost figure of $23 MM). These costs would include new ASW pumps, trash rack, traveling screens, pit, enclosed structure, and electrical components. 24 inch hyprescon piping would be installed underground to connect the ASW pumps with the existing ASW supply piping. The structure would be suitable for saltwater application and would be seismically qualified per UBC 1997 Code Zone 4.

The net present value (NPV) of this alternative, assuming a twenty year project life that takes into account capital and *additional* O&M costs is $650 MM. Net present value (NPV) is often referred to as the "value" of an asset. In this case, Tetra Tech, Inc. is using it to reflect the long-term cost of each alternative in terms of current dollars. Annual costs, assuming amortization of capital costs over twenty years and additional O&M costs inflated by three percent each year, would be $663 MM in the first year and $3.2 to 3.9 MM thereafter. A twenty year project life is used based on a twenty year duration for the facility's operating license, as reported by PG&E.

For comparison, in the *Diablo Canyon Power Plant 316(b) Demonstration Report* (March 2000), TENERA Environmental Services estimates capital costs of $51,000,000 just to reduce intake flow velocities by increasing the area of the intake structure. TENERA provided a separate cost estimate to modify travelling screens and add a fish handling system ($12 MM) and a separate estimate to employ fine mesh screens ($7 MM). TENERA also contends that both units would be out of production for about one year, while modification to the intake structure was taking place, thus adding a significant figure for lost revenue to total project costs.

B. Aquatic Microfiltration Barriers

Aquatic microfiltration barrier systems rely on a filter fabric that allows water to pass into a cooling water intake structure (CWIS) while excluding aquatic organisms. These systems are designed to be placed at a considerable distance from the CWIS and have very large filter surface areas, and as such, velocities through the filter remain very low. Gunderboom, Inc. produces a full-water depth, 20 micron mesh filter curtain that is suspended by flotation billets at the surface and anchored to the substrate below. Gunderboom's system uses periodic bursts of air to maintain the filter fabric.

Although the use of microfiltration barriers near cooling water intake structures has been limited and is considered experimental in nature, the technology does show significant promise as a method for reducing entrainment of aquatic organisms within cooling water systems. The only power plant where the Gunderboom system has been used at a full-scale level is the Lovett Generating Station along the Hudson River in New York. At this facility, entrainment reductions up to 82 percent have been maintained for extended periods between 1999 and 2001, while several operational difficulties, such as tearing, overtopping, and clogging, have been overcome through design modifications.

Gunderboom Inc. estimates that with 20 micron mesh, at intake flows of 100,000 and 200,000 gpm, its microfiltration barrier would need to be 500 and 1,000 feet long, respectively, assuming a depth of 20 feet. Based on these estimates, intake flows at the DCPP (1.6 million gpm) would require a filter area of approximately 160,000 square feet or a filter length of 8,000 feet at a depth of 20 feet. In addition, as discussed in Section II, normal wave activity in Intake Cove is 5 to 10 feet, and storms can generate 20 to 30 foot waves. The potential for overtopping at the DCPP would be much greater than at the Lovett Station, where its location on the Hudson River protects the intake area from significant wave activity. With such a large filter area, the steep and irregular bathymetry of the near shore sea bottom, significant wave activity, and potentially extreme maintenance requirements, such a system cannot be viewed, at this time, as a proven and realistic means, for further consideration, of reducing entrainment at the DCPP. In the *Diablo Canyon Power Plant 316(b) Demonstration Report* (March 2000), a microfiltration barrier was not evaluated as an alternative technology for minimizing entrainment at the DCPP.

V. Evaluation of Cooling System Alternatives – Alternative Methods of Cooling

Tetra Tech, Inc. has considered several alternative methods of cooling for the DCPP that would significantly reduce the volume of seawater needed for cooling. These alternatives include the use of dry cooling towers, which rely on air cooled condensers to dissipate heat; wet cooling towers, which rely on evaporation of cooling water to dissipate heat; and hybrid (wet/dry) cooling systems. Both fresh water and seawater makeup sources have been considered, as well as mechanical and natural draft, wet cooling towers. Most of these alternatives have received limited attention, however, due to technical limitations and/or the unique physical setting of the power plant, which would present serious obstacles to their successful construction and implementation at the DCPP.

Dry cooling systems have not been evaluated as a viable alternative for the DCPP. Preliminary analysis determined that eight air-cooled condensing systems would be required, each occupying an area of 316 feet by 197 feet with an overall height of 119 feet. Each condenser would use forty, 150 hp fans; and the resulting turbine backpressure would be in the range of 3.5 to 4 inches HgA, considerably higher than the facility's design value of 1.5 inches HgA. Based on discussions with GEA Energy Technology Division, a leading designer of dry cooling systems, "the length of duct for an air-cooled condenser should be limited to a distance less than or equal to 200 feet."[4] Because of limited available land area at the DCPP, however, cooling system configuration to keep duct lengths less than 200 feet would not be possible. A dry system located

[4] Memo of Nov. 4, 2002 from Jamie Clark of GEA Energy Technology Division to Bernard Bruman of Hatch.

in the area suggested for a wet cooling tower system, described below, would have duct lengths of approximately 500 to 1,000 feet. These duct lengths would result in significantly larger pressure drops, a need for even larger air-cooled condensers, and difficulties arising from thermal expansion. GEA has not designed or constructed dry cooling systems with comparable duct lengths. Based on these considerations, dry cooling systems did not receive further attention as an alternative for the DCPP.

At the DCPP, which has limited space available for additional facilities, hybrid (wet/dry) cooling systems were also not evaluated as a viable, alternative means of cooling. Design of a hybrid cooling system at the DCPP would encounter the same difficulties related to duct lengths, as described for dry cooling systems.

Cooling systems using freshwater makeup were also not evaluated as viable alternatives for the DCPP. Although wet cooling tower systems using fresh water makeup would use far less water than cooling tower systems using seawater makeup, there is no adequate source of fresh water within 25 miles of the facility. The costs and logistical difficulties of piping such a quantity of freshwater, or even treated wastewater, to the plant preclude serious consideration of such alternatives.

The possibility of producing freshwater from seawater at the power plant site, for use as makeup to a wet cooling tower system, was also not given serious consideration as an alternative to the existing once through cooling system. Freshwater makeup to wet cooling towers would reduce the power plant's cooling water requirement to below 50,000 gpm, which would represent a reduction of greater than 95 percent, and a proportionate reduction in impingement and entrainment. These reductions in cooling water requirement and impingement and entrainment, would come, however, at a disproportionately high cost. Not only would the power plant need to be retrofitted with a wet cooling tower system, but an appropriate desalinization facility would also need to be constructed. Such a facility would have high initial and operation and maintenance costs; there is limited land available to locate a desalinization facility; and concentrated brine wastes resulting from the production of freshwater would present disposal concerns.

The following analysis of alternative cooling systems for the DCPP focuses on the use of mechanical and natural draft cooling towers using seawater makeup. The use of wet cooling towers allows some recirculation of cooling water, thus cooling water makeup requirement is reduced, as compared to a once through system. Impingement and entrainment losses are reduced proportionately to the reduction in makeup water requirement.

Wet cooling towers rely on evaporation of water to dissipate heat; and as pure water is lost to evaporation, dissolved and suspended solids present in cooling water are left behind and increase in concentration. A wet cooling tower using seawater makeup will operate in the range of 1.1 to 1.5 cycles of concentration, meaning that solids will be allowed to build up to concentrations approximately 1.1 to 1.5 times greater than their levels in makeup water. This type of cooling tower operation, at 1.1 to 1.5 cycles of concentration, at the DCPP would result in a cooling water makeup requirement of approximately 100,000 to 340,000 gpm, total (both units). Thus, wet cooling towers using seawater makeup at the DCPP would reduce cooling water requirements by approximately 80 to 94 percent; and a corresponding reduction in impingement and entrainment losses could be expected.

This section presents cost estimates for both natural and mechanical draft, wet cooling tower systems. Much greater detail is provided for mechanical draft systems, as this type of cooling tower appears to be much more appropriate at the DCPP, given the potential seismic activity in the area, the limited land area available near the power plant, and the probable visual impacts of natural draft towers,

Costs considered for each alternative include capital, O&M, and energy penalty costs, as well as estimates of lost revenue that would occur during the downtime needed for retrofitting the power plant.

A. Wet Cooling System – Mechanical Draft Cooling Towers

Capital Costs

Estimates of capital costs for a mechanical draft cooling tower system at the DCPP are presented in Table 2. The design basis for these estimates includes the following.

- 2 unit, nuclear facility
- 7599.6 MM BTU/h thermal load condenser
- 61°F design wet bulb; exceeded less than 1 percent of the time
- 9°F approach to design wet bulb temperature for cooling tower sizing
- 1,725,380 gpm, total cooling water flow rate
- Cooling water supply temperature at 70°F; cooling water return temperature at 87.6°F
- Blowdown and makeup rates based on 1.5 cycles of concentration
- Seismic design per Zone 4 of the 1997 Uniform Building Code

Table 2 - Capital Costs, Mechanical Draft Cooling Towers

	Capital Cost ($MM)
Mechanical Draft Cooling Towers	140
Recirculating Water Pumps and Piping	32
Makeup Water Pumps and Piping	10
Startup water Holdup Tank, Pumps and Piping	3
Condenser Replacement Bundles	20
Cooling Tower Supply Piping/Risers	18
Civil Works	248
Electrical	17
Process Control and Instrumentation	39
Total Direct Costs	527
Project Indirects (30% of Direct Costs)	158
Contingency (20% of Direct and Indirect Costs)	137

Total Capital Costs	822

Mechanical draft, cooling tower costs are based on a cooling system with 132 cells, each using one 250 hp fan. The cooling system layout, considered by this analysis, is presented in Figure 2. Other potential locations at the site were considered less optimal due to topography and other physical constraints, including the location of an archeological site, north of Diablo Creek. Cooling towers would be concrete, with a counter flow design, utilizing materials suitable for saltwater application. Individual tower cells would use film fill, rather than splash fill, to take full advantage of available space (film fill provides a greater cooling surface area than splash fill) and would be 60 feet by 60 feet, with a (concrete) basin depth of 4 feet, and an overall tower height of 65 feet. Cells would be laid out in a back-to-back arrangement; and cooling water risers would be equipped with one isolating valve per riser.

Capital costs reflect a cooling water pumphouse constructed of concrete, suitable for saltwater application. There would be 4 recirculating cooling water pumps of the prefab, concrete volute design, total - 2 for each generating unit. The pumphouse would be equipped with a 75 ton overhead crane. These costs also include a 120 feet diameter by 40 feet high startup water holdup tank and two supply pumps. All cooling tower supply lines and risers, as well as pump discharge piping is included. Capital costs reflect costs of three, vertical, turbine type makeup water pumps (two running, one standby), which would be located in the existing pumphouse, after three existing, circulating pumps are removed to make room for the new pumps.

Estimates for electrical components include costs for a main substation, an additional transformer, switchgear, and cabling and services for the new pumphouse.

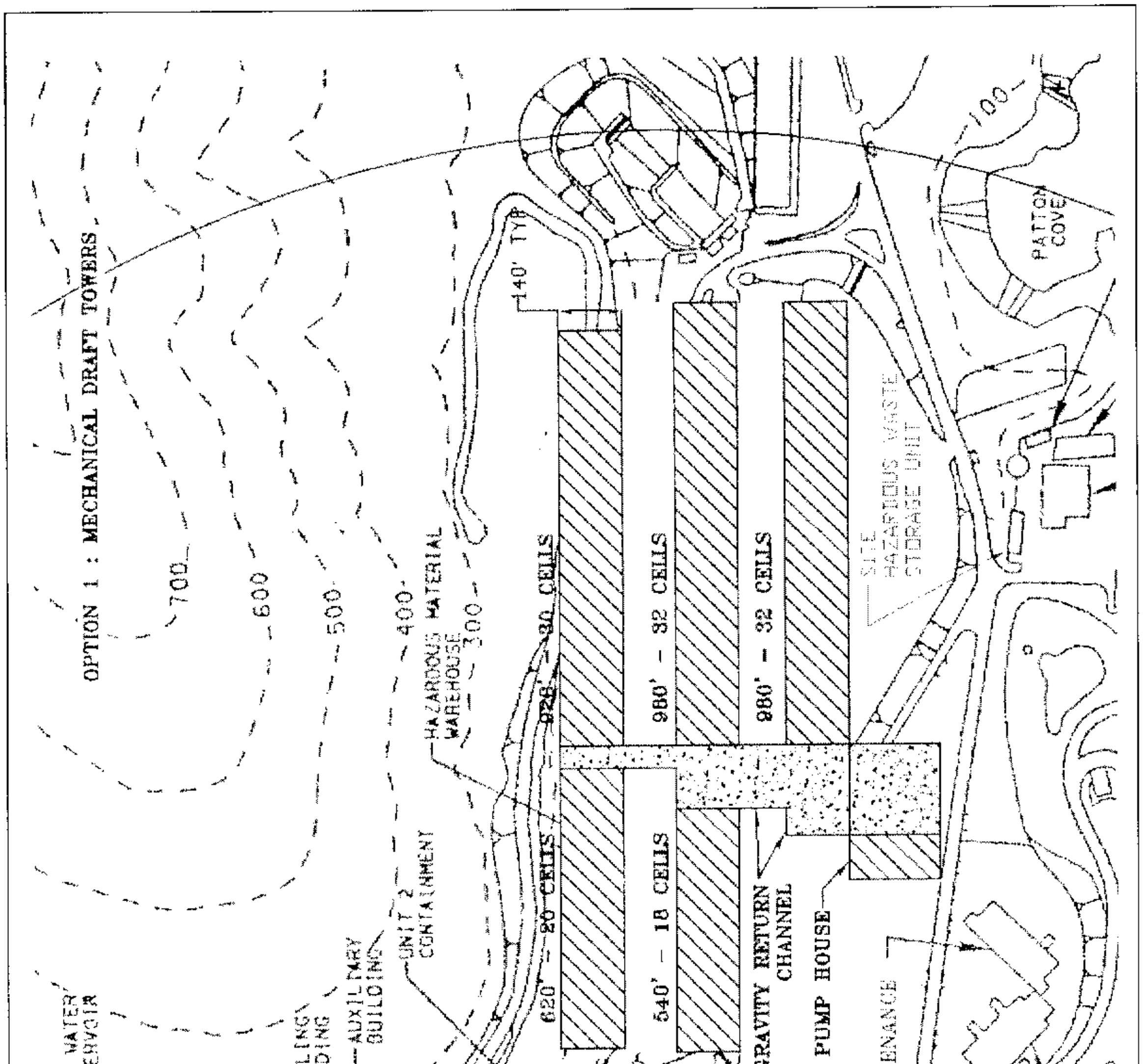

Figure 2: Mechanical Draft Cooling System Layout

Civil work contemplated in developing the capital cost estimates include:

- Clearing, grubbing, roadwork, and general landscaping and dewatering.
- Cooling tower concrete basins
- Cooling water supply and return conduits, including tie-ins to the existing condenser supply and return conduits.
- Demolition of the existing warehouse, southeast of the generating building and installation of a new warehouse, roadways and parking
- Demolition of the existing hazardous materials warehouse and construction of a new warehouse and associated roadways and parking
- Excavation, including rock work, on the hillside where the cooling tower system would be located, and installation of a retaining wall approximately 1,800 feet long by 100 feet high
- A new, cooling water pumphouse
- Concrete duct banks
- Miscellaneous structures, including a substation and a powerhouse building.

Costs for condenser replacement bundles include costs of tube sheets, tubes (3/4 inch diameter, 25 BWG B338/2 tubes with a total condensing surface of 617,536 square feet), support plates and structural stiffeners. No other material is included to support the bundles within the existing condenser shells. Costs for solid titanium, B265/2 tube sheets are included.

The condenser design for which these costs estimates were developed, were proposed by Alstom, formerly Ingersoll Rand, and were based on a 70°F cooling water supply temperature, which would yield a condensate temperature of approximately 100°F and a condenser backpressure of 1.89 inches HgA. Condenser performance could possibly be optimized to achieve a backpressure closer to the current design of 1.5 inches HgA; however, a very formal analysis of condenser and turbine performance would be required, and a backpressure of 1.5 inches HgA may still not be attainable. Based on condenser performance curves specific to the DCPP, as it currently operates, an increase in condenser backpressure to 1.89 inches HgA, would cause a loss in efficiency of 21 MW, over both generating units.

Capital cost figures in Table 2 include $158 MM for indirect costs, calculated as 30 percent of the direct costs. This very conservative indirect cost figure is meant to cover such items as design and engineering, construction management, owner's cost, vendor's assistance, startup and training. The total capital cost figure from Table 2 also includes $137 MM (20 percent of direct and indirect costs) for contingencies, or unanticipated, unexpected costs.

Some items not considered in this capital cost estimate include the impact of increased condensate temperature on the performance of hydrogen coolers and the possibility of hazardous waste removal or soil decontamination, if necessary, preceding construction activity.

As shown by Figure 1, the DCPP is located within the Coastal Zone; and any project, such as the cooling alternative considered here, would require approval by the California Coastal Commission. Tetra Tech, Inc. recognizes that such a land use approval process can be timely and expensive.

Operation and Maintenance (O&M) Costs

O&M costs for a wet cooling system at the DCPP utilizing mechanical draft cooling towers, as described above, are estimated to be approximately $1.7 MM per year. This figure is based on $750 per MW and a gross generating capacity of 2,298 MW, and is an approximation derived from information provided by Marley Cooling Technologies (a leading supplier of wet cooling towers) and from previous cost estimates developed by Tetra Tech, Inc. for the evaluation of alternative cooling systems at other power plants. These O&M costs are meant to take into account the costs of chemical treatment, routine operation and maintenance, and long-term equipment replacement, as appropriate.

Energy Penalty

Energy Penalty costs occur, because alternative methods of cooling, when compared to the existing once through system, will reduce plant efficiency. In a steam driven turbine, power is extracted from steam as it passes from high temperature and pressure conditions at the turbine inlet to low temperature and pressure conditions at the outlet. When steam exits the turbine, it is condensed to water by the steam condenser. The process of condensing steam to water assists to draw steam through the turbine and is very important to overall plant efficiency. The temperature of the steam condensing surface is dependent on the design and operation of the condensing system but is especially dependent on the temperature of the cooling water or air that removes heat from the condenser. And thus, the use of different cooling systems will affect the temperature maintained at the condensing surface and will affect plant efficiency. Any resultant loss in efficiency, when using alternative cooling systems in place of a very efficient once through cooling design, is referred to as the energy penalty associated with turbine efficiency.

As stated earlier, the mechanical draft cooling tower system for which cost estimates have been developed would result in a backpressure of 1.89 HgA, indicating some loss in efficiency, when compared to the plant's design backpressure of 1.5 HgA. Based on performance curves for the DCPP's operation, such a loss in efficiency would correspond to an energy penalty of 21 MW.

Use of alternative cooling systems will also result in a second energy penalty – that associated with increased in-plant power requirements needed to operate equipment such as fans and pumps required by the alternative cooling system. This energy penalty is also called the parasitic load.

Differences in the parasitic load seen in alternative cooling systems are due primarily to the different uses of fans and pumps. Once through and wet cooling tower systems have nearly offsetting energy requirements for cooling water pumps; however, a mechanical draft cooling tower system will have significant power requirement for the fans, which create the "mechanical draft." The mechanical draft cooling tower system presented in this report would use 132 fans at 250 horsepower each. Based on an energy requirement of 0.746 KW per horsepower, the total parasitic load at the DCPP would be approximately 25 MW, following implementation of such a cooling system. This figure is generally in line with EPA's calculations of penalties attributable to cooling system energy requirements, as presented in the *TDD for the Final Regulations Addressing Cooling Water Intake Structures for New Facilities*, November 2001 (EPA-821-R-01-036). Table 3-20 in the TDD includes a factor of 0.92 percent as the parasitic load associated with a mechanical draft, wet cooling system when compared to a once through cooling system at nuclear facilities. With EPA's factor of 0.92 and a gross generating capacity of 2,298 MW at the DCPP, the parasitic load would be 21 MW. For these cost estimates, Tetra Tech, Inc. has used the more conservative parasitic load determination of 25 MW.

The total energy penalty associated with implementation of a mechanical draft, wet cooling tower system at the DCPP is estimated as the sum of the penalties attributed to decreased turbine efficiency and the parasitic load, or 46 MW.

In this evaluation of alternatives, the total energy penalty, in MW, is converted to a figure representing annual lost revenue ($) attributable to the energy penalty. The conversion uses a wholesale electricity price of $34/MWh – a figure forecast by the U.S. DOE in 1999 using POEMS (the Policy Office Electricity Modeling System) and then adjusted to 2001 dollars using the Electric Power Producer Price Index.

Based on operation 350 days per year, the annual revenue loss attributable to the energy penalty for this alternative, using a wholesale electricity price of $34/MWh, is estimated at $13 MM per year.

Lost Revenue Due to Shutdown During Retrofit

If a cooling alternative such as the one discussed here were implemented at the DCPP, the facility would experience a temporary and one time loss in generation (and revenue), when the plant was brought off line for construction and retrofitting activity. During and after the site visit on October 18, 2002, Tetra Tech, Inc. and Hatch reviewed detailed site diagrams for the existing cooling water system, related units, and other facilities which would be impacted by retrofitting. It is important to recognize that the cooling water piping (intake and discharge) is located in areas with significant other operational equipment, utilities, etc. Moreover, extra care is required when working in a nuclear facility. Therefore Tetra Tech, Inc. and Hatch estimated that the power plant would be off line for 6 months in these circumstances. For this period, Tetra Tech, Inc. further estimates that PG&E would lose revenue of approximately $330 MM. This figure was determined with a revenue estimate provided by PG&E for the DCPP of $900,000 per unit per day. It is in line with Tetra Tech, Inc.'s independent estimate based on a net plant output of 2,222 MW over 182 days and a wholesale price of electricity of $34 per MW. It is possible that construction and retrofitting activity could be staged to allow one unit to remain operational for much of the time that the other unit was being modified.

Total Costs

The net present value (NPV) of the mechanical draft, cooling tower alternative presented here, with a twenty year project life, that takes into account capital, O&M, plus energy penalty costs, as well as lost revenue that would be incurred during construction and retrofitting is $1.32 billion. Annual costs, assuming amortization of capital costs over twenty years and O&M costs inflated by 3 percent each year, would be $422.5 MM for the first year and would range from $92.6 to $94.2 MM for the following nineteen years. First year costs are higher because of the one time loss of revenue due to shutdown for retrofitting.

In the *Diablo Canyon Power Plant 316(b) Demonstration Report* (March 2000), TENERA Environmental Services acknowledged that natural and mechanical draft cooling towers, using saltwater makeup, have been demonstrated on a scale required for a closed loop system at the DCPP, and that such a system could reduce cooling water makeup requirement by 80 percent. That report provides a capital cost estimate of $658 MM for a hyperbolic, natural draft system but did not specifically evaluate a mechanical draft cooling system.

B. Wet Cooling System – Natural Draft Cooling Towers

Capital Costs

Estimates of capital costs for a natural draft cooling tower system at the DCPP are presented in Table 3. The design basis for these estimates includes the following.

- 2 unit, nuclear facility
- 7599.6 MM BTU/h thermal load condenser
- 61°F design wet bulb; exceeded less than 1 percent of the time
- 9°F approach to design wet bulb temperature for cooling tower sizing
- 68% relative humidity; 10% of the time relative humidity will be less than or equal to 68% when the wet bulb temperature is approximately 61°F
- 1,725,380 gpm, total cooling water flow rate
- Cooling water supply temperature at 70°F; cooling water return temperature at 87.6°F
- Blowdown and makeup rates based on 1.5 cycles of concentration
- Seismic design per Zone 4 of the 1997 Uniform Building Code

Table 3 - Capital Costs, Natural Draft Cooling Towers

	Capital Cost ($MM)
Natural Draft Cooling Towers	500
Recirculating Water Pumps and Piping	32
Makeup Water Pumps and Piping	10
Startup water Holdup Tank, Pumps and Piping	3
Condenser Replacement Bundles	20
Cooling Tower Supply Piping/Risers	9
Civil Works	396
Electrical	11
Process Control and Instrumentation	30
Total Direct Costs	1,011
Project Indirects (30% of Direct Costs)	304
Contingency (20% of Direct and Indirect Costs)	263
Total Capital Costs	1,578

The cooling system for which these capital costs estimates were developed would include five cooling towers per unit, each with a shell diameter of 208 feet and a shell height of 450 feet. These capital costs estimates were developed in a manner similar to those for a mechanical draft cooling system. The condenser retrofit for this system would result in a condenser backpressure of 1.89 inches HgA. O&M costs, energy penalty costs, and lost revenue incurred during construction and retrofitting activity would be similar to those figures developed for a mechanical draft cooling tower system.

Further analysis of a natural draft, wet cooling system for the DCPP is not presented in this report, as such an alternative does not appear to be viable. As highlighted by Tables 2 and 3, capital costs for a natural draft system will be approximately two times the estimated capital costs projected for a mechanical draft cooling tower system. Further, the performance of a natural draft, cooling tower is dependent on relative humidity. In the vicinity of the DCPP, the relative humidity falls below 68 percent about 10 percent of the time (when the wet bulb temperature is 61°F). When this occurs, tower performance will be reduced and plant efficiency will be further impacted. The visual impacts of 450 foot high towers would also be significant. Finally, Marley Cooling Technologies strongly recommended not using very large, hyperbolic, natural draft cooling towers in an area of potentially significant seismic activity, like the area of the DCPP.

As stated previously, TENERA Environmental Services in the *Diablo Canyon Power Plant 316(b) Demonstration Report* (March 2000), provided a capital cost estimate of $658 MM for a hyperbolic, natural draft system but did not specifically evaluate a mechanical draft cooling system.

VI. References

Technical Development Document for the Final Regulations Addressing Cooling Water Intake Structures for New Facilities, United States Environmental Protection Agency, EPA-821-R-01-036, November 2001.

Economic Analysis of the Final Regulations Addressing Cooling Water Intake Structures for New Facilities, United States Environmental Protection Agency, EPA-821-R-01-035, November 2001.

Technical Development Document for the Proposed Section 316(b) Phase II Existing Facilities Rule, United States Environmental Protection Agency, EPA-821-R-02-003, April 2002.

Economic and Benefits Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule, United States Environmental Protection Agency, EPA-821-R-02-001, April 2002.

Diablo Canyon Power Plant 316(b) Demonstration Report, TENERA Environmental Services, March 2000.

Staff Report for Regular Meeting of July 13, 2000, Subject: Diablo Canyon Nuclear Power Plant Resolution of Thermal Discharge and Entrainment/Impingement Impacts, California Regional Water Quality Control Board.

Diablo Canyon Power Plant Cooling Water Intake Structure 316(b) Demonstration, TENERA Environmental Services, April 1988.

Diablo Canyon Power Plant 316(b) Study, Draft Evaluation of Alternative Intake Technologies, Engineering Services of the Pacific Gas and Electric Company, December 1999.

Diablo Canyon Power Plant, Revised 316(b) Study Plan, TERA Corporation, June 1983.

Diablo Canyon Power Plant Assessment of Alternatives to the Existing Cooling Water System, Tear Corporation, March 1982.

Attachment 1.

Table A-1 : Major Aquatic Species Vulnerable to I&E at Big Bend

Species	Scientific name		*ADULT*	*Juvenile*	*EGG*	*Spawning*
Atlantic blue crab	Callinectes sapidus	*Portunidae*	*Most abundant near bays and river mouths, but are found in brackish or fresh water.Found in shallower water in summer, deeper water in summer. Reach maturity at 130-139mm*	*Usually found at base of estuaries and seagrass beds.*	*Approx 0.025mm*	*Eggs carried externally by female. Hatch near high tide, larvae carried to sea by current.*
Black drum	*Pogonias cromis*	Sciaenidae	Schooling species. Adults found in offshore waters and enter estuarine habitats only to spawn. Mature at approx 650mm.	Larvae inhabit bottom waters during the day and rise to upper areas of the water column at night. 1.8 – 7.3mm	Buoyant, 0.8 - 1.0mm diameter.	Spawning in Tampa Bay takes place in the lower Bay or nearshore waters during the evening. Spawning peaks in April or March.
Florida stone crab	*Menippe mercenaria*	Xanthadae	Approx 140mm CW. Nocturnal. Found in coastal marine to estuarine environments. Require substrate suitable for refuge. May also dig burrows as deep as 1m.	Juveniles often found on oyster clumps. Larvae are free swimming and planktonic. Larvae pass through five zoeal stages.		Females carry egg masses.
Gulf menhaden	*Brevoortia patronus*	Clupeidae	Peak Gulf-ward migration occurs between October and January.	Larvae spend 3- 5 weeks in offshore waters before moving into estuaries at 9-25mm SL^2.	Eggs float near surface	Spawning occurs October through March, in Gulf of Mexico waters from 2 to 168 m deep but concentrated in waters of less than 18m deep.
Northern kingfish	*Menticirrhus saxatilis*	Sciaenidae	Prefers hard sandy bottom and forms large schools that occur in coastal waters, occasionally entering estuaries. Reach maximum length of 17 inches	Larvae are transported inshore to estuarine nursery areas by currents and winds.	Pelagic eggs	Spawning occurs in the spring and summer: April and May off North Carolina, and from June through August off the coast of Maine.
Pigfish	*Orthopristis chrysoptera*	Haemulidae	demersal; oceanodromous; brackish; marine ; depth range - 10 m. Inhabits coastal waters, over sand and mud bottoms. Forms schools. Mainly nocturnal and non-		buoyant (pelagic)	

Species	Scientific name		*ADULT*	*Juvenile*	*EGG*	*Spawning*
			burrowing.			
Pinfish	*Lagodon rhomboides*	Sparidae	Prefer deeper water (40 feet- 180 feet) in bays, passes, and on offshore reefs.	Prefers bays and estuaries around structure, vegetation, and reefs		Adults spawn offshore in schools in early spring, abandoning the eggs to the current. As young hatch, they swim into bays and estruaries where they grow and mature. Mature fish (over 8") head to deep water reefs.
Pink shrimp	*Penaeus duorarum duorarum*	Penaidae	Found in highest densitics at depths of 11 to 35m, but abundant to 65 m. Can be found as deep as 310m. prefer firm or hard sandy or mixed substrate bottoms. Primarily nocturnal. Mature approx 65mm TL.	0.34 – 0.61mm. Found in seagrass substrates. Not nocturnal.	0.23-0.33mm.	Spawn in deeper offshore waters, at depths of 3.5 to 50m.
Puffer spp.	*Sphoeroides* spp.	Tetraodontidae	Most often in clear, shallow, tropical waters, over sand, sea grass, and around small appatch reefs; most abundant inshore.	Grass flats with bare sandy patches.	Maculatus spp.-demersal	Maculatus spp.-Occurs in shoal waters near shore.
Sand seatrout	*Cynoscion arenarius*	Sciaenidae	predominantly found inshore residing in bays and inlets but may move offshore during winter months;	Occur inshore in shallow bays. Sand seatrout have been reported to use estuarine areas and nearshore gulf waters as nursery grounds		prolonged inshore spawning season extends through spring and summer
Sheepshead	*Archosargus probatocephalus*	Sparidae	Bottom-loving, frequenting oyster beds and muddy shallow waters, particularly about inlets, also frequents piers, breakwaters, and wrecks; often runs far up rivers; does not typically school, but forms feeding aggregations. Occurs inshore from spring to fall in North Carolina; probably present throughout the year in the Tampa Bay area.	Larvae are pelagic, smallest (6mm) taken at surface near sandy shore; later stage taken in shallow areas over grass beds. Juveniles inhabit grass beds; eventually leave grass beds to establish themselves in adult habitat.	Buoyant; diameter about 0.8mm, transparent; incubation period is 40 hours at 24-25 degrees C.	Reported to spawn in Florida on sandy beaches, but more recent evidence indicates spawning probably occurs offshore during the spring.

Species	Scientific name		*ADULT*	*Juvenile*	*EGG*	*Spawning*
Silver perch	*Bairdiella chrysoura*	Sciaenidae	Mature at approx. 95mm. Found in shallow coastal areas outside Tampa Bay. During colder months, move to deeper bay or offshore waters.	1.5 -1.9mm. Remain planktonic for several weeks then sink to the bottom. Prefer structural habitats such as seagrass beds, rocks, piers, jetties, and seawalls. During colder months, move to deeper bay or offshore waters.	Buoyant, 0.59-0.82mm.	Spawn in deeper areas of bay and estuary, although eggs have been found in offshore waters.
Southern kingfish	*Menticirrhus americanus*	Sciaenidae	Found in abundance in the surf area along the beach. demersal; brackish; marine ; depth range - 40 m. 50.0 cm TL.	Juveniles occur usually in water of lower salinity in shallow water habitats. Juveniles are primarily bottom-dwelling over soft mud and decaying vegetation. Spend first summer in shallow water habitat. Open surf on sandy beaches; inshore in estuaries; apparently gradually move towards ocean as they mature.		Spawning occurs largely or entirely offshore in 9-36 m May-June in Tampa Bay area. Some indication of second fall spawning season; year-round in Everglades.
Spotted seatrout	*Cynoscion nebulosus*	Sciaenidae	Mature by 200mm TL. Found in nearshore vegetated seagrass areas	1.3mm. Found in deeper central areas of Tampa Bay	0.9mm	
Drum/croaker spp.	Family Sciaenidae	Sciaenidae	Inhabit deep offshore waters during the winter months and move into bays and estuaries during the spring, summer and fall	Juvenile croaker tend to prefer low salinity to freshwater habitats and open-water rather than submerged aquatic vegetation areas.		

Table A-2. Major Aquatic Species Vulnerable to I&E at Diablo Canyon

Species	*Scientific name*		*ADULT*	*JUVENILE*	*EGG*	*SPAWNING*
Brown rock crab	**Cancer antennarius**	**Cancridae**	Habitat extends from the low intertidal zone to depths greater than 100 m, and includes substrates of rocky shores, subtidal reefs, and coarse to silty sands	Larvae hatch as prezoeae and molt to first stage zoeae in less than 1 h. They advance through six stages of successive increases in size-fivezoeal and one megalopal. Juvenile brown rock crabs are common in the intertidal zone, where they may be exposed to the air daily for several hours. Mortality is unlikely, however, provided they are shaded from direct sunlight beneath algae, or protected in rock crevices. During their planktonic existence, crab larvae become widely distributed over the continental shelf. Early stage larvae of rock crabs generally occur on the bottom, or in depths up to 80 m, during the day; late stage larvae, however, were more abundant near the surface.	Shallows with emergent vegetation [littoral zone]	***The eggs are fertilized internally as they are extruded, about 11 weeks after the mating, and are carried by the female during development.***
Slender crab	Cancer gracilis	Cancridae				
Pacific sardine	Sardinops sagax	Clupeidae	pelagic	3.5 – 3.8mm; Inshore congregations, near beach	buoyant (pelagic), non-adhesive	
Northern anchovy	*Engraulis mordax*	Engraulidae	found in coastal waters within about 30 km from shore, but as far out as 480 km, forming large,	2.5 – 3.0 mm	buoyant (pelagic), non-adhesive. The oblong eggs float vertically at first,	Spawns either in inlets or offshore , throughout the year but mainly in winter

Species	*Scientific name*		*ADULT*	*JUVENILE*	*EGG*	*SPAWNING*
			tightly packed schools. Enters bays and inlets.		then horizontally	and early spring, depending on hydrological conditions (preferably at 10 to 23.3° C in upper water layers and around 22.00 hours).
Blue rockfish	*Sebastes mystinus*	Scorpaenidae	May be found near the surface or off the bottom, generally over shallow reefs, but also around kelp and over deep reefs. 61.0 cm TL max size	3.8 mm planktonic Juveniles are pelagic, Form schools		
Kelp/Gopher /Black-and-Yellow rockfish (KGB rockfish complex)	*Sebastes spp.*	Scorpaenidae				
Painted greenling	*Oxylebius pictus*	Zaniolepididae	Found in rocky areas, from the intertidal to 49 m. demersal; marine ; depth range - 49 m	planktonic		
Smoothhead sculpin	*Artedius lateralis*	Cottidae	demersal; marine ; depth range 0 - 13 m. Occurs in the intertidal (common) and to 13 m depth May remain out of water under rocks or seaweeds Breathes air when out of water	planktonic		
Snubnose sculpin	*Orthonopias triacis*	Cottidae	10.0 cm TL max size, demersal; marine. Occurs from intertidal rocky areas to about 30 m depth.			

Species	*Scientific name*		*ADULT*	*JUVENILE*	*EGG*	*SPAWNING*
Cabezon	*Scorpaenichthys marmoratus*	Cottidae	99.0 cm TL max. Inhabits rocky, sandy and muddy bottoms as well as kelp beds	planktonic		
White croaker	*Genyonemus lineatus*	Sciaenidae	41.0 cm TL, benthopelagic; marine ; depth range - 183 m. Found over sandy bottoms. Prefer shallow water near shore. Inhabits both inshore and offshore waters up to 100 meters in depth	Ca. 2.2-2.8 mm TL or less. Found in open water and shallows inshore of embayments, estuaries, and coastal waters. Juveniles found mostly near bottom. Early juveniles remain in the bay and estuary; most large juveniles gradually move to the ocean.	0.5-0.9 mm Most eggs are found over sand-gravel bottoms. Pelagic. Nonadhesive	
Monkeyface prickleback	*Cebidichthys violaceus*	Stichaeidae	76.0 cm TLmax, demersal; marine ; depth range - 0 m. Common inshore, in tidepools or shallow rocky areas, from the intertidal zone to 24 m depth. May remain out of water under rocks or seaweed. Breathes air when out of water. Crevices of rocky pools in bays or on outer coast	7.5-8.0 mm TL. Pelagic, found in San Francisco Bay near Angel Island, Potrero Power Plant, and in Horseshoe Cove. Juveniles prefer intertidal areas near bottom.	Ca. 2.7 mm Adhesive, adhering to rocks, Demersal.	spawning occurs from January to May
kelpfishes				Hatching size is ca. 7.0 mm TL or slightly less. Pelagic, shallow inshore water (Gibbonsia sp.)	Unfertilized mature eggs, ca. 1.3 mm; fertilized eggs 1.4-1.7 mm. Demersal. Assumed adhesive (Gibbonsia sp.)	demersal eggs deposited in the kelp beds and rocky areas (Gibbonsia sp.)

Species	*Scientific name*		*ADULT*	*JUVENILE*	*EGG*	*SPAWNING*
Blackeye goby	*Coryphopterus nicholsi*	Gobiidae	15.0 cm TL, demersal; marine ; depth range - 106 m, Found usually in sandy areas near rocks. Occurs from intertidal areas to 106 m depth. Prefers subtidal and intertidal coastal waters may occur in bays.	2.5-2.8 mm TL. The larger juveniles (ca. 21-28 mm TL and greater) gradually settle into their demersal habitat in rocky reefs.	Long axis 2.10 mm, short axis 0.84 mm Deposited on substrate in single layer. Deposited on substrate in single layer. Demersal.	spawn from January through August.
Sanddabs	*Citharichthys spp*	Paralichthyidae	41.0 cm TL, demersal; marine ; depth range 0 - 549 m, Found on sand bottoms	Young may occur at depth less than 9 m		
California halibut	*Paralichthys californicus*	Bothidae	Shallow coastal waters. Prefer a sandy bottom although they can be found on the hard bottom areas, muddy bottom areas, gravel bottoms, sand dollar and clam beds, and even around structure such as reefs, rock piles, kelp, and lobster traps.	2.0 mm TL Bays, harbors, and leeward sides of points and islands can produce warmer water temperatures and create a stable growth environment.	Average, 0.9 mm Pelagic, nonadhesive	California Halibut will move up into shallower water to spawn in Spring and Fall months.