RECOMMENDED OPTIONS FOR MAXIMUM WATER TEMPERATURE LIMITS AND MINIMUM DISSOLVED OXYGEN LIMITS AT A COMPLIANCE POINT FOR DISCHARGES FROM THE SOUTH BAY POWER PLANT IN SAN DIEGO BAY, NECESSARY TO PROTECT BENEFICAL USES

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INTRODUCTION

The purpose of this report is to evaluate and recommend two options for maximum temperature limits and minimum dissolved oxygen limits at a compliance point for discharges of thermal effluent from the South Bay Power Plant (SBPP), necessary to protect beneficial uses. Documentation for these recommendations is based in part on evidence from past temperature and dissolved oxygen measurements and biological field studies conducted to evaluate the ecological effects of thermal effluent from the SBPP on the adjacent marine environment of inner San Diego Bay. This documentation also is based on information from species-specific laboratory and field studies concerning temperature and dissolved oxygen tolerances of marine invertebrate and fish species that inhabit the inner Bay. Section 316(a) of the Clean Water Act (CWA) requires that States impose an effluent limitation with respect to the thermal component of a discharge, taking into account the interaction of this thermal component with other pollutants, that will assure the protection and propagation of balanced, indigenous populations of shellfish, fish, and wildlife in the receiving water. In 1972-73 a seasonal thermal effects study (Ford & Chambers 1973, 1974) was completed for the discharger, San Diego Gas & Electric Company, to investigate compliance with the State Thermal Plan and CWA Section 316(a). Evidence from both intertidal and subtidal sampling indicated that elevated water temperatures caused by the thermal effluent had adverse impacts to bay organisms that inhabited the discharge channel, particularly during late summer and early fall months. These effects were reduced during the winter and spring periods when ambient water temperatures and the temperatures of the thermal plume were lower. During all seasons, however, major adverse effects appeared to be confined to the discharge channel. The overall conclusion of these studies was that the thermal effluent from the SBPP had no major adverse effects on the benthic communities beyond the outer end of the discharge channel. Subsequent thermal effects studies and monitoring were conducted during the summer months by several research entities (See, for example, summary reports by Lockheed, 1981 and E.A. Engineering, Science, and Technology 1995). These later studies confirmed the general conclusions of Ford & Chambers (1973, 1974). However, all of these studies have occurred since the plant has been in operation. Because of this, no pre-operational baseline studies of the South Bay have been possible.

While the permitted thermal limits in effect at the time the previous 316(a) studies were conducted have not changed, the compliance point used for verification of compliance with those thermal limits was relocated in Order No 96-05 issued by the San Diego Regional Water Quality Control Board. An earthen dike extends from the northern side of the SBPP discharge basin into San Diego Bay, separating the inlet and discharge channels (Figure 1). The width of the SBPP discharge channel (cooling water channel) varies from approximately 100 feet at the Plant property line to approximately 1,200 feet at its widest point in the Bay. The length of the discharge channel is approximately 5,200 feet. The thermal limit compliance point in the 1970's through 1995 was located at the outer end of the dike separating the inlet and discharge channels (Figure 1). This point was approximately 5,000 feet downstream from SBPP property line. The designated compliance point for the thermal limits in the current NPDES permit is approximately 1,000 feet downstream of the SBPP property line (Figure 1). The earlier compliance point established was, therefore, approximately 4000 feet downstream of the current compliance point. This effectively provided a large dilution zone, allowing the SBPP to discharge more heat in thermal effluent to the cooling water channel than is possible in applying the current compliance location 1000 feet downstream from the property line of the SBPP.

Described in subsequent sections of this document are the lines of evidence employed to develop specific recommendations for establishing maximum water temperature limits and minimum dissolved oxygen limits at a point of compliance that can be expected to protect beneficial uses. Because issues concerning water temperature and dissolved oxygen are closely related, in some cases they are considered together.

TEMPERATURE AND DISSOLVED OXYGEN LIMITS: EVIDENCE FROM FIELD STUDIES

Evidence from Ecological Field Monitoring Studies 1968-1994

Introduction

In the summer of 1960 the San Diego Gas & Electric Company began operation of a major fossil fuel steam generation plant near the inner end of San Diego Bay, at an approximate axial distance of 14 miles from the bay entrance. A second generating unit was added to the system in the summer of 1962 and a third in the summer of 1964. A larger, fourth unit was placed in commercial service in August 1971. Water is drawn from the bay and the thermal effluent returned by way of a shallow discharge channel that is set off from the bay by an earthen dike (Figure 1). Prior to the addition of Generating Unit 4, the maximum extent of the thermal discharge was confined to a radius of approximately 1500-2000 yards (4500 – 6000 feet) from the outer end of the discharge channel, with that extent varying markedly both seasonally and in relation to the tidal cycle, as well as in relation to the generating units that are operating (A.S. DeWeese, South Bay Temperature Survey, Jun 9, 1965, SDG&C File NO. EPG 420, and Ford & Chambers1974). In 1973, the maximum extent of the thermal plume with all four generating units in operation was approximately 3000 yards or 9000 feet (Chambers & Chambers 1973, Ford & Chambers 1974).

Early Monitoring Studies

Early monitoring studies of the South Bay Power Plant (Ford, 1968, Ford et al 1960, 1971, 1972) provided comprehensive information about physical and biological conditions in South San Diego Bay, including particularly the nature of the thermal discharge prior to and immediately following the addition of Generating Unit 4, and the effects of this thermal effluent on marine life during the late summer and early spring months. These initial studies included quantitative sampling of intertidal and subtidal benthic algae and invertebrates, fishes, plankton, and other organisms.

Seasonal Monitoring Study of 1972-1973

A more comprehensive, quarterly seasonal monitoring study was conducted during 1972-1973 by Ford and Chambers (1973, 1974). The quarterly sampling was initiated in September 1972 and completed in July 1973. The primary purposes of this study were: 1) to provide additional specific baseline information on hydrographic and ecological conditions of the existing aquatic environment in South San Diego Bay on a seasonal basis, using standard methods established in the 1968 study (Ford, 1968); and 2) to assess the ecological effects of the thermal effluent on marine life and other beneficial uses through consideration of species composition, number and diversity of species, and the distribution, abundance, size and biomass of invertebrates and plants taken in grab and core samples.

Information was not obtained in the 1972-1973 study on fishes, aquatic birds, or plankton. Instead, the investigation was limited to species of benthic plants and invertebrate animals that could be sampled adequately by a large-volume grab. This was done because evidence from the 1968 and subsequent studies demonstrated that these species are the best and most easily evaluated indicators of thermal effluent effects. A primary reason for this is that they remain in the same location within or outside the thermal plume.

Eighteen subtidal stations for biological and hydrographic sampling were employed in the South San Diego Bay area, as shown in Figure 2. These were located in a pattern which allowed representative sampling of: 1) the area directly influenced by major segments of the cooling water plume from the South Bay Power Plant; 2: the general area of the power plant cooling water intake; and 3) adjacent control areas outside the direct influence of the thermal plume.

Standardized quantitative methods of biological, physical, and chemical sampling developed in the earlier studies were employed at these 18 subtidal stations during the period September – July, and at seven intertidal stations during the period September – April. Benthic algae and invertebrates were sampled quantitatively using replicate grab samples subtidally, and by means of replicate core samples in the intertidal mud flat zone. At each station repeated measurements were made of surface and bottom water temperatures, sediment temperatures, dissolved oxygen concentrations, salinities, sediment organic content, sediment grain size distributions, and other physical-chemical characteristics at each station, as described by Ford and Chambers (1973, 1974). It is important to note that this ecological monitoring study for the South Bay Power Plant remains the only one ever conducted on a full seasonal basis, making it particularly valuable in helping to establish ecologically meaningful temperature and dissolved oxygen limits for the current 1000 foot compliance point. The seasonal data obtained in this 1972 – 1973 study for water and sediment temperatures are summarized in Figures 3 & 4 and for dissolved oxygen in Figure 5.

Results and Conclusions of 1972-1973 Monitoring Study

The results obtained suggest that the species composition of benthic plant and invertebrate associations remained moderately stable throughout the year in South San Diego Bay, although there were some evident seasonal changes. In general, numbers of species and densities were lowest during the warm water conditions of late summer-fall.

As in previous studies conducted in the South Bay, evidence obtained from both subtidal and intertidal sampling during 1972-1973 suggested that high temperatures caused by the thermal discharge in the late summer-fall, and to a lesser extent in July, had adverse effects on the numbers, diversity, and abundance of many groups of species within the cooling channel itself (Stations E5, E7, and F4). However, these effects were much less obvious during the winter and spring periods when both ambient water temperatures and those within the thermal discharge pattern were lower. Much the same general pattern appeared to hold for both the intertidal and subtidal areas, which also share a majority of their species in common. During all seasonal periods, the most severe adverse effects appeared to be confined primarily to the inner portion of the cooling channel.

Mean bottom water temperatures measured at Station F4, F3 (outer end of cooling water channel) and other sites for one month periods prior to biological sampling are shown in Figure 3. At Station F4, these temperatures were highest in July (84.6°F), next highest in September-October (82.0°F), substantially lower in March-April (73.4°F), and lowest in the winter months of December-January (68.1°F). Mean sediment temperatures (Figure 4) were nearly the same in all cases. Mean dissolved oxygen concentrations measured at the time of biological sampling at Station F4 and other sites are shown in Figure 5. At Station F4, these means were lowest in April and September-October (6.2 and 6.7 mg/L) and highest in January (7.3 mg/L).

However, as shown in Figure 3, mean bottom water temperatures were considerably higher in the cooling water channel, ranging from 66.8°F in December-January 1972-1973 to 88.3°F in September-October 1973 at Station E5 (Figure 3). Mean sediment temperatures at Station E5 showed a similar trend, ranging from 70.9°F and 70.0°F in January and April to 88.0°F in September-October (Figure 4). Mean dissolved oxygen concentrations at Station E5 in the cooling water channel also showed a wider range of values, from 5.2 mg/L in July to 8.0 mg/L in September-October (Figure 5).

The results of statistical comparisons between the control and outer discharge pattern areas suggested that during the late September-October period of 1972, and to a lesser extent in July 1973, this portion of the thermal plume just beyond the end of the cooling channel (Station F4) apparently had some adverse effects on the infaunal invertebrates found there. This was reflected by lower numbers of invertebrate species, involving primarily polychaetes and crustaceans, and a lower number of species and of species and taxa diversity for all invertebrates combined (Ford and Chambers 1973, 1974). The trends in these values and associated trends in distribution and abundance were obvious within the station pattern. They suggested that the adverse effects detected by these tests were confined primarily to stations in the thermal effluent flow beyond the end of the cooling channel. However, most of these differences were relatively small, suggesting that the adverse effects apparently were not as severe as those observed within the discharge channel. However, it is important to recognize that they reflected an already artificially heated environment. The individual species involved were identified and their patterns of distribution and abundance described (Ford and Chambers 1974).

In contrast, the numbers of algal species forming the plant mat on the bottom were significantly greater within the outer discharge area then in the control area during this same period. If this represents a true difference, then it may suggest that thermal conditions for plants during this period were somewhat more stimulating to plant growth within the outer portion of the thermal plume than they were beyond it. This may be interpreted as a possible disturbance of the natural benthic community by the thermal plume.

There were no statistically significant differences for numbers and diversity of species between the outer discharge and control areas in either January or April 1973. This suggested strongly that most of the adverse effects described above were confined o to the summer and early fall period of higher ambient and effluent water temperatures. During the cooler winter and spring periods, no such adverse effects on the number or diversity of species apparently occurred.

As in the pre-1972 studies (Ford 1968, Ford et al 1970, 1971, 1972), diversity of taxa and abundances for several invertebrate groups sampled during the September-October and January periods showed significant inverse (negative) correlations with sediment and water temperatures (Ford & Chambers 1973, 1974). The number of individual groups that showed this correlation was reduced during the January and April sampling periods of lower water temperatures. However, as for the earlier periods, the total number of invertebrate species continued to show these inverse correlations with water temperature. These correlation results further indicated that, with the exception of sediment temperatures, no other physical factors considered had significant relationships to number and diversity of species, and abundance of the kind shown for these effluent temperature characteristics. This confirmed that there was, in fact, a meaningful temperature effect on these biological characteristics, rather than one involving some other physical variable separately or in parallel with temperature. The fact that sediment grain size and chemical characteristics were relatively uniform throughout the study area probably explains why there were few significant correlations with these physical variables. Dissolved oxygen concentrations showed no significant correlations with these biological characteristics. This is not surprising, because they showed little seasonal variation except those measured within the cooling water channel (Figure 5).

As in the pre-1972 studies, these significant inverse correlations with temperature indicated that higher sediment and water temperatures induced by the cooling water effluent had adverse effects on several major groups of benthic invertebrates by reducing the number and diversity of species and, in some cases, their abundances at a given location. The statistical comparisons among station groups, discussed earlier, indicated that these adverse effects were restricted primarily to the area within the cooling channel and that they varied seasonally. In contrast, the abundances of some major groups showed significant direct correlations with temperature.

The results of statistical comparisons suggested very strongly that there were no significant adverse effects of the thermal plume on the biomass of nearly all major groups of organisms inhabiting the outer discharge pattern area beyond the end of the cooling channel. Only the biomass values of decapod crustaceans and gastropod mollusks were significantly lower in the outer discharge area than at the control stations in July 1973. This generalization applied for all of the four seasonal sampling period. In fact, the opposite appeared to be true during the winter and spring because, in all cases where there was a significant difference, the biomass values in question were greater in the outer discharge area than in the control area. The individual groups that showed this difference besides benthic plants were cnidarians (coelenterates), ostracods, gastropod molluscs, and the brittle star *Amphipholis pugetana*. Two other major groups, the polychaete worms and bivalve molluscs, did not show this difference although they exhibited the same trend. The specific patterns involved in these differences and trends were described for major invertebrate groups by Ford and Chambers (1974).

Given that the control and outer discharge area thermal plume stations were similar in characteristics other than temperature, then the results concerning biomass could legitimately be interpreted as a disturbance effect of the thermal plume on these groups of species and the benthic community.

This effect definitely was related to temperature conditions within the thermal plume. It was not pronounced during the winter and spring periods of low ambient water temperatures. The most probable cause of these higher biomass values is the effect of higher temperatures in producing faster growth rates of the organisms involved. Other possible alternative or additional explanations for both the biomass and abundance effects include enhanced reproductive success and, less likely, the attraction of some species to warm water and their concentration there.

The biomass values for several major groups showed significant direct correlations with temperatures during each of the quarterly sampling periods (Ford and Chambers 1974). This was most pronounced during the spring (March-April) period.

The results of similar comparisons between station groups suggested that, as in the case of numbers and diversity of species, the biomass of many major groups was lower within the cooling channel than in the control area, undoubtedly because of high thermal effluent temperatures present there.

Comparison of data between the summers of 1968-1970 and winter-early spring 1971 (Ford 1968, Ford et al 1970, 1971, 1972) indicated that the biomass of the plant mat on the sediment was markedly reduced and its condition poor during the latter period.

Many of the changes in species composition, distribution, and abundance of small bottom fishes and invertebrates dependent upon the mat, which were observed between these two periods, probably were related to its decline.

This apparently was caused in part by seasonal lowering of water temperatures, a natural effect that is quite accentuated in South San Diego Bay. In addition, because it is a shallow area of silty sediment and much particulate matter, the area experiences high water turbidity during windy periods in the winter and spring as the result of wind wave action. This undoubtedly caused a marked reduction in the light available to benthic plants and probably contributed to the decline of the plant mat. This impact could be further augmented by the turbidity resulting directly from the power plant discharge.

A comparison of total mean biomass values for benthic plants within the station pattern suggested that these data showed somewhat greater variation among stations during 1972-1973 than during 1968 and 1971 (Ford & Chambers 1974). Statistical analysis used to determine if plant biomass differed significantly between the September-October, January, April and July sampling periods of 1972-1973 showed a significant difference attributable to lower values in July 1973. This suggested that the type of major seasonal change in the mat observed in 1968-1971 had not occurred during 1972-1973. Without additional, specific information on water turbidity and other factors, it would be difficult to assess the cause of this apparent difference between years. However, it is quite likely that seasonal changes in the plant mat vary from year to year.

In general, the intertidal algae and invertebrates showed trends that paralleled those of the very similar subtidal species assemblage. Analysis of the intertidal data was hampered because of the very limited numbers of stations and their placement. The difficulty of obtaining an adequate group of representative samples from this habitat because of the soft, cohesive nature of the sediment further compounded the problem. For these reasons, intertidal sampling was not continued beyond the April 1973 sampling period.

Statistical comparisons between 1968, 1972, and 1973, involving numbers of plant and invertebrate species, invertebrate species diversity, and biomass values for these groups obtained during July-October, suggested that these characteristics remained relatively stable over this five year period. This, in turn, provided general evidence that changes in the characteristics of the thermal discharge associated with the addition of Generating Unit 4 at the South Bay Power Plant had not resulted in major shifts in the numbers, diversity, or standing crop of plant and invertebrate species that form major components of the subtidal community.

General Conclusions of the 1972-1973 Monitoring Studies

There are several general conclusions that can be drawn from this evidence. The results of the seasonal monitoring study in 1972-1973 showed that thermal effluent from the South Bay Power Plant had some adverse effects on benthic invertebrates in the area, but that these were restricted primarily to the cooling channel area and to warmer periods of the year (Ford & Chambers 1974). Some effects of the thermal plume that could be interpreted as disturbances to the benthic community also were demonstrated. Thermal effluent from the South Bay Power Plant had no evident, major adverse effects on the benthic invertebrate assemblages beyond the end of the discharge channel during the period September 1972-July 1973.

NPDES Ecological Monitoring Studies of 1977-1994

Following a three-year hiatus in sampling, long-term receiving water and ecological monitoring studies of more limited scope were begun in 1977. This 18-year program was established as a condition of San Diego Gas & Electric Company's NPDES Permit for operation of the South Bay Power Plant. The studies were conducted once each year during the period 1977-1994, in compliance with California Regional Water Quality Control Board Permit No. CA A001368-San Diego Region. These studies involved sampling of benthic invertebrates and an array of physical and chemical parameters at 11 subtidal stations (Figure 6). The locations of the sampling stations were similar in position to 11 of the 18 sites (Figure 2) sampled during previous studies (Ford & Chambers 1973, 1974). Station placement was designed to allow representative sampling of; 1) the area most directly influenced by thermal effluent (the cooling water channel of the SBPP); 2) an area away from the effects of the highest effluent temperatures but still within the elevated temperature field; and 3) an area judged to be outside the influence of the thermal plume. As reported by E.A. Engineering, Science and Technology (1995), SDG&E and its scientific contractors submitted annual reports to the California RWQCB, San Diego Region on the results of these studies. Those reports were as follows:

The citations for each of these annual monitoring documents appear in the References section of this report.

A major summary report prepared by Lockheed Environmental Sciences (1980a) provided more detailed syntheses and evaluations of the data obtained during the first four years of these NPDES studies. Data obtained during the entire 18-year study period were similarly synthesized and evaluated in detail by E.A. Engineering, Science, and Technology (1995).

This 18-year receiving water and ecological monitoring program focused on the evaluating possible influences of thermal effluent from the SBPP on physical and chemical characteristics and benthic infauna in the South Bay during the late summer period. This focus on the invertebrate infauna had its origin in the studies of all the benthic categories (plankton, periphyton, fishes, and benthos) by Ford (1968). Based on the results from those studies, Ford (1968) and Ford & Chambers (1974) concluded that the infaunal assemblages were the best and most reliable indicator of responses to changes in the environment. These include sediment and water temperatures, dissolved oxygen, salinity, and organic carbon, and nitrogen concentrations in the sediment. The choice of the summer season was based on the decision that the combined effect of higher natural ambient temperatures present during the summer and higher thermal effluent temperatures at that time were likely to be most stressful of the year to the infauna and other species assemblages.

To some extent, the results reported by Ford and Chambers (1973, 1974) also supported a focus of this long-term monitoring program on the late summer period. They reported "that the species composition of benthic plant and invertebrate associations remained moderately stable throughout the year...although there were some evident seasonal changes. In general, numbers of species and densities were lowest during the warm water conditions of late summer-fall." Ford and Chambers (1973, 1974) further reported that their studies, ..."suggest that high temperatures caused by the thermal discharge in the late summer-fall, and to a lesser extent in July, had adverse effects on the number, diversity, and abundance of many groups of species within the cooling channel itself (Stations E5, E7, and F4). Importantly, however, these effects were much less obvious during the winter and spring periods when both ambient water temperatures and those within the thermal discharge were lower. Much the same general pattern appeared to hold for both the intertidal and subtidal areas, which also share a majority of their species in common...During all seasonal periods, the adverse effects appeared to be confined primarily to the inner portion of the cooling channel." In addition, they noted "there were no statistically significant differences for numbers and diversity of species between the outer discharge and control areas in either January or April 1973. This suggested strongly that the adverse effects...were confined only to the summer and early fall period of high ambient and effluent water temperatures." Obviously, the chief disadvantage of sampling only during the summer is that important seasonal differences in the effects of the thermal effluent were missed.

Results and Conclusions of the 1977-1994 NPDES Monitoring Studies

The yearly reports from this NPDES monitoring program all focused on evaluating whether or not there were differences among sampling stations in water temperatures and physical and chemical characteristics of the bottom sediment, and in ecological features of the infauna. Differences among stations were observed in the form of gradients from Stations E7 and E5 within the cooling water channel of the SBPP at the inner end of the Bay, bayward toward the far-field plume (Stations C3 and A3) and the control site (Station N2). These station locations are shown in Figure 6. Most notably, there were consistent gradients with distance from the cooling water channel. These included the obvious gradients of decreasing sediment and water temperatures, together with decreasing percent silt and clay fractions in the bottom sediment, as well as increasing dissolved oxygen concentrations and water transparency (LES 1980a, EAEST 1995).

The results of monitoring during the18-year period 1977-1994 (EAEST 1995) led to many of the same conclusions as those of the 1968-1973 studies (Ford 1968, Ford & Chambers 1974). The 1977-1994 studies showed that during the summer, diversity of species and taxa, abundance (densities) and, to some extent, the biomass of the infauna at stations within the cooling water channel were lower than those within the near-field thermal plume beyond the end of the dike and those at far-field sampling stations. These differences were attributed primarily to temperature effects of the thermal effluent. The results further indicated that there were few such evident adverse effects on the infauna beyond the outer end of the cooling water channel (Stations F3 and F4, Figures 2 and 6). Also in common with the results of the 1968-1973 studies, these studies in 1977-1994 suggested that the increases in water temperature by thermal effluent in the near-field area outside the cooling channel produced at least moderately higher biomass of infaunal groups. These elevated biomass values may represent a disturbance modification effect on the infauna due to increased growth and reproduction.

Both the individual contractors for the 1977-1994 studies and the four year synthesis by LES (1980a) employed multiple regression analyses in an effort to determine which of the physical and chemical gradients were most strongly related to infauna characteristics of diversity, numerical abundance, and biomass. Generally, the reported inverse correlations were strongest with increased percent silt and clay, with increased water and sediment temperatures, and with COD and TKN in the sediment. Strongest direct correlations were with increased amounts of algae and plant detritus. The studies concluded that percent of silt/clay in the sediment was the principal factor regulating infaunal community structure, as secondarily modified by water and sediment temperatures. Both sediment grain size and temperature were significant factors within the cooling channel. However, multiple regression analyses were not capable of separating the relative influence of sediment grain size versus temperature within that channel (EAEST 1995).

From their 18 year synthesis, E.A. Engineering Science, and Technology (1995) reported that there were the expected year-to-year variations within sampling stations for all parameters, but that at a given station there were no appreciable long-term trends upward or downward among important factors such as water temperature, sediment temperature, COD, TKN, grain size characteristics, dissolved oxygen, salinity, or transparency. A slight trend downward in water and sediment temperatures at the discharge cooling channel stations was evident from the 1970s into the 1980s.

EAEST (1995) also reported on the gradients in physical, chemical, and certain of the invertebrate infaunal characteristics from the inner end of the Bay northward toward the far-field and control sampling stations that also were evident in the yearly set of data. They found that the gradients in infaunal characteristics noted in the yearly studies also were evident from overall analyses of the 18-year data set, especially for infaunal diversity, number of species and taxa, and to a lesser extent for the total abundance of benthic invertebrates. However, there was little evidence for the gradient of increased infaunl biomass from the cooling channel stations bayward toward the far-field and control stations, as reported in the earlier studies. However, it should be noted that these data for 1977-1994 were all from the summer. As a result, the lack of seasonal data may have masked evidence of such gradients in biomass of the infauna. EAEST (1995) reported that their evaluation of the 18-year data set supports the major conclusions from the previous studies: 1) that the species composition, mean diversity, and mean densities of the infauna were lower within the cooling water channel than at the near-field, far-field, and control sampling stations; and 2) that those lower values probably were related to the combined effects of thermal effluent from the SBPP and the natural physical characteristics of the inner Bay. They reported that there were few, if any, adverse effects on the infauna outside of the cooling channel.

E.A. Engineering, Science & Technology (1995) noted that the cooling water flow of Generating Unit 4 represents 33 percent of the total flow at the SBPP, and that the size of the thermal plume is also approximately one-third smaller when Unit 4 is not operating. The smaller thermal plume was directly reflected by a general downward trend in summer water and sediment temperatures observed at the near-field and discharge cooling channel sampling stations when Unit 4 was not on line. This is a particularly important point, because it emphasizes the very direct effects that the number of generating units in operation at a given time, and the cooling water requirements of each unit, have on the temperature characteristics and extent of the thermal plume. During the current energy crisis, it is likely that all four generating units of the SBPP will be used to a greater extent, leading to a correspondingly greater thermal loading in the plume. This will tend to accentuate effects on marine organisms in the cooling water channel and possibly in adjacent areas of inner San Diego Bay.

In common with the conclusions from earlier studies (Ford 1968; Ford and Chambers 1973, 1974; Michael Brandman Associates 1990), analysis of the 18-year data set indicated that the physical and chemical characteristics and infauna of San Diego Bay are similar to those of other bays along the California coast. A general conclusion reported by E.A. Engineering, Science & Technology (1995) was that the species composition, relative abundance, and total abundance of the infauna in the study area remained very similar in 1994 to those determined in 1977. They concluded further that most of the environmental conditions monitored did not show any appreciable long-term changes. Similarly, information concerning marine species of inner San Diego Bay as a whole suggests that the species composition, relative abundances, and biomass of the infauna the fish fauna, and other species assemblages remained very much the same over the 21-year period 1968-1989 (Michael Brandman Associates 1990).

Evidence From NPDES and Other Water Column Monitoring Studies 1996-Present

Based on the review of the 18-year monitoring program described in the preceding section, the San Diego Regional Water Quality Control Board determined that further monitoring of the sediment and invertebrate infauna was unnecessary at that time. Accordingly, the Board amended the permit requirements. For the amended program, temperature, dissolved oxygen concentrations, salinity and light extinction in the water column have been sampled monthly on a continuing basis.

These continuing monitoring studies have been and are now conducted by MEC Analytical Systems, Inc. (See, for example, MEC 1997, 2001). Prior to April 1999, the monthly reports were submitted to the Regional Board on behalf of the San Diego Gas & Electric Company. On April 23, 1999, Duke Energy Power Services assumed operating responsibilities for the South Bay Power Plant, and the monthly monitoring reports are now submitted to the Regional Board on behalf of that discharger.

MEC has continued to employ the same 11 receiving water stations (Figure 6) used in the more extensive monitoring of 1972-1994. Measurements have been made monthly at each of the 11 stations for air and water temperatures, dissolved oxygen concentrations, salinities, and water transparency, primarily by employing a scanning data logger (MEC 2001). Except for air temperature and transparency, the measurements have been made at 2-3 foot depth intervals through the water column.

These monitoring reports by MEC provide a very representative, recent data set that is useful in establishing temperature and dissolved oxygen limits for the 1000 ft compliance point in the cooling water channel of South Bay Power Plant. Their specific use is considered in the following subsection and in final section of this report entitled Recommendations.

Applied Science Associates (1998) conducted an evaluation of dissolved oxygen concentrations and associated biological and hydrographic processes in South San Diego Bay. This report included as its primary goal the formulation of a proposed water quality objective for dissolved oxygen in South San Diego Bay, as requested by the San Diego Regional Water Quality Control Board and the San Diego Gas & Electric Company.

Other than the diurnal and other changes in dissolved oxygen concentrations measured and described, the contents of this report are substandard in most respects. Most disappointing of all is the water quality objective for dissolved oxygen proposed by Applied Science Associates (1998). Their report concluded:

> "Accordingly, the following narrative water quality objective for South San Diego Bay is proposed:

> *The dissolved oxygen concentrations of South San Diego Bay shall not be depressed to levels that adversely affect beneficial uses as a result of controllable water quality factors.*
>
> By definition, this water quality objective is protective of the beneficial uses of South San Diego Bay from the potential adverse effects of low dissolved oxygen resulting from other than naturally occurring events. Analysis of available information demonstrates that all designated beneficial uses of the Bay are being protected here and hence this proposed water quality objective for dissolved oxygen is currently being achieved."

This is a very poor water quality objective for several reasons. It is far too vague. Compliance with it would be almost impossible to validate. Without truly comprehensive ecological studies, how can one demonstrate that no beneficial uses of the inner bay, including those of estuarine invertebrate and fish populations, have been adversely affected by low dissolved oxygen levels associated with the thermal plume? In addition there is no real proof or "demonstration" of the justification statement in the last sentence quoted above. This is particularly true for the area within the cooling water channel, where beneficial uses involving estuarine animals are adversely affected by both increased temperatures and correspondingly reduced dissolved oxygen concentrations.

In any case, this general and vague narrative water quality objective has no real practical value as it might apply to a compliance point in the discharge channel of the South Bay Power Plant. Numeric water quality limits for dissolved oxygen concentrations must be used instead. The existing Basin Plan water quality objectives is entirely appropriate to inner San Diego Bay from an ecological standpoint. It states: "Dissolved oxygen levels shall not be less than 5.0 mg/L in inland surface waters with designated MAR or WARM beneficial uses. The annual mean dissolved oxygen concentration shall not be less that 7 mg/L more that 10% of the time." This scientifically valid objective must be met in operating the South Bay Power Plant.

Conclusions from the Field Monitoring Studies as they Apply to Setting Temperature and Dissolved Oxygen Limits at the Compliance Point

The results from the ecological monitoring studies of 1968-1994, as described in preceding sections, all point to the same conclusion. It is that most adverse ecological effects produced by thermal effluent from the South Bay Power Plant are restricted primarily to the area of the discharge channel (Figures 1 & 6). This suggests that water temperatures and dissolved oxygen concentrations measured at Station F3 (Figure 6), located just beyond the end of the cooling water channel, might be the most pertinent values to employ in setting maximum water temperature and minimum dissolved oxygen concentration limits for the compliance point. Station F3 might be the logical choice because it is located just beyond the downstream end of the cooling water channel in an area where few adverse effects on the invertebrate infauna were detected in the studies of

1968 – 1994 (Ford and Chambers 1974; EAEST 1995). However, evidence presented in the following section concerning laboratory and field studies of individual indicator species strongly contradicts that conclusion.

The most recent, long-term data sets for water temperatures and dissolved oxygen concentrations at Station F3 and elsewhere in the thermal plume are those obtained monthly by MEC Analytical Systems, Inc. (see, for example, MEC 1997, 2001). Therefore, it is logical that a representative set of these measurements be used. Data summaries for water temperatures and dissolved oxygen concentrations measured at Station F3 are shown in Table 1. These data summaries are for the six full calendar years 1997 – 2002. For dissolved oxygen, they combine values measured both near the surface and just above the bottom of the shallow water column at Station F3. For water temperatures, they combine values measured at 2-3 foot depth intervals in that water column from the surface to just above the bottom. It is important to note that dissolved oxygen concentrations reported by MEC were all measured during the day. Major diurnal changes occur in dissolved oxygen concentrations of inner San Diego Bay and other estuarine areas, resulting primarily from the changing balance between combined photosynthesis and respiration during daylight periods and respiration only during non-daylight periods (see, for example, Applied Science Associates 1998). Because of this, it is important to ensure that any limit applies to both day or night time periods.

In addition, it is obvious that ambient temperatures and those added by the thermal effluent change fairly markedly seasonally and from month to month (Tables 1 - 4). Because of this, it is logical and important to establish upper temperature limits for the compliance point that consider these month-to-month and seasonal changes.

These conclusions regarding water temperatures and dissolved oxygen concentrations were employed in setting limits for the compliance point. They form part of the final sections entitled Recommendations.

TEMPERATURE AND DISSOLVED OXYGEN LIMITS: EVIDENCE FROM LABORATORY AND FIELD STUDIES OF INDIVIDUAL SPECIES

Introduction

Effects of water temperatures and dissolved oxygen concentrations on marine invertebrates and fishes, as well as related temperature-salinity, temperature-toxicant, and oxygen-temperature interactions affecting these animals, have been studied extensively. See, for example, Kinne (1966, 1967, 1971), Newell (1970, 1973), Newell et al (1972), and Vernberg (1977). This has produced a substantial knowledge of the processes involved. However, only a few specific studies of this kind have been conducted for invertebrate and fish species inhabiting inner San Diego Bay.

Combined laboratory and field studies have been conducted concerning the temperature tolerances and preferences of four major species of larger marine animals that are important components of bottom communities in South San Diego Bay. They are the suspension feeding bivalve molluscs *Solen rosaceus* (rosy razor or pencil clam), *Tagelus californianus* (California jackknife clam), the filter feeding bivalve *Chione fluctifraga* (smooth cockle), and *Paralichthys californicus* (California halibut). These three bivalve species are dominant members of the benthic community. The smooth cockle also is important in recreational clamming and the pencil and jackknife clams are often used as bait by recreational fishermen. Juvenile and adult California halibut are important predators in South San Diego Bay and elsewhere. In addition, this demersal fish species supports major commercial and recreational fisheries in southern California. Areas such as inner San Diego Bay are thought to be nursery grounds for juvenile California halibut (Ford 1968, Michael Brandman Associates 1990). The studies concerning temperature relationships of these species are important to consider in setting temperature limits at the 1000-foot compliance point for the SBPP.

Rosy Razor Clam and California Jackknife Clam

Merino (1981) reported the results of a comprehensive field and laboratory study to evaluate the temperature tolerances of two important bivalve mollusc species common in South San Diego Bay. They are *Solen rosaceus* and *Tagelus californianus*. This study was conducted in conjunction with the early field studies for the South Bay Power Plant (Ford 1968; Ford et al 1970, 1971, 1972; Ford & Chambers 1973, 1975). The station designations he employed are those used in the initial studies by Ford (1968) and Ford et al (1970, 1971, 1972). Theses stations are shown in Figure 7.

Merino (1981) reported that the objectives of his study were to: 1) describe the physical environment in which both species exist; 2) describe their distribution and dispersion patterns in South San Diego Bay; 3) describe their important population characteristics; 4) evaluate the possible factors regulating these populations in both the natural and thermally altered environments of the inner Bay; and 5) describe and evaluate from laboratory and field studies effects of increased temperature on observed patterns of growth, reproduction and longevity in those natural and thermally altered environments. A major question was whether or not the elevated water temperatures in the vicinity of the cooling water channel of the SBPP were sufficient to change distribution and abundance patterns and the population characteristics of *S. rosaceus* and *T. californianus*.

The densities of *S. rosaceus* and *T. californiamus* in intertidal areas adjacent to the cooling water channel of the SBPP were influenced primarily by tidal elevation, water and sediment temperatures, recruitment and mortality (Merino 1981). High densities and large seasonal fluctuations in density were characteristic of *S. rosaceus* at the control stations. Low densities of *S. rosaceus* were characteristic of the thermal plume stations. Ford (1968), Ford et al (1970, 1971, 1972) and Ford & Chambers (1973, 1974) found few *S. rosaceus* in samples from within the cooling water channel, which apparently reflected their low resistance to elevated water temperatures in that channel area. Greatest densities of *S. rosaceus* were observed subtidally rather than at MLLW in the control station areas. At the stations outside the cooling water channel, densities were similar for both of these tidal elevations (Merino 1981). A possible explanation for this is that elevated water temperatures in the vicinity of the thermal plume stations that adversely affected *S. rosaceus* did so at both tidal elevations. That appears to be a logical explanation.

Merino (1981) found that *Tagelus californianus*, a much larger species, had much lower densities than *S. rosaceus*. This species also showed distinct seasonal fluctuations in abundance. Densities of *T. californianus* at both the outer thermal plume and control stations were similar but significantly greater than densities at the cooling channel and near field stations closest to the point of discharge from the SBPP. With respect to tidal elevation, densities of *T. californianus* at mid-intertidal locations were greater than those determined at low intertidal locations, except at the far field stations where densities were similar for both tidal levels. No *T. californianums* were found subtidally at the Station D2 (Figure 7) in the cooling channel, closest to the point of discharge. Water temperatures at this location apparently were too high for survival of the species.

Tagelus californianus was primarily a mid-intertidal species in the South Bay study areas (Merino 1981). It was not as abundant as *S. rosaceus* in either control or thermal plume station locations. This probably reflects differences in the body size and other biological characteristics of each species, rather than lack of resistance to high water temperature on the part of *T. californianus*. The greatest region of overlap between the two species occurred at the MLLW tide level.

The evidence from this study indicated that elevated water temperatures in the vicinity of the South Bay Power Plant were important in determining the large-scale distribution patterns and population characteristics of *S. rosaceus* and *T. californianus* (Merino 1981). The temperature buffering ability of the sediments offered some protection to *S. rosaceus* from upper lethal water temperatures. However, this species was restricted in distribution to areas where sediment temperatures rarely exceeded 82.4° F. On the other hand, the more temperature tolerant *T. californianus* were present, at least temporarily, where sediment and water temperatures approached 93.2° F.

Densities of *S. rosaceus* at the outer thermal plume stations were significantly less than those at the control stations (Merino (1981). These individuals grew faster; however, they attained a smaller maximum size, indicating that they were adversely affected. Similarly, densities of *T. californianus* within the cooling water channel were affected by the thermal effluent; their densities were less than those living at the control and outer thermal plume stations, indicating another adverse effect. The growth rate of *T. californianus* within the cooling water channel was greater than that of individuals living in areas beyond the end of the channel. They also attained a smaller maximum size in the channel, an indication of adverse effects. It is significant that the differences Merino (1981) observed within South San Diego Bay over a distance of only about three miles have been reported in the literature for this species only over latitudinal distances of hundreds of miles.

Merino (1981) found that reproduction of *S. rosaceus* and *T. californianus* may be "enhanced" within the thermal plume of the SBPP. This may be interpreted more properly as an adverse effect on these two species, rather than a beneficial "enhancement." The weight gains for individuals of both species suggested that spawning in the plume area extended into the late summer months. Indirect evidence for this extension of the spawning period also was indicated by the presence of juvenile *S. rosaceus* as small as 1.4 mm in shell length from samples taken during the winter months, and the presence of juvenile *T. californianus* in samples throughout much of the year.

Merino (1981) found that annual mortality rates of *S. rosaceus* were significantly higher at stations within the inner thermal plume (Stations D2 - D7) and concluded that this was due to higher water temperatures. The annual mortality rate of *T. californianus* was highest at Station D2 (Figure 7), a point very near to the initial discharge of thermal effluent from the SBPP. At this location *T. californianus* became an annual species. Recruitment into that group of individuals occurred in later summer and early fall, and the cohort died out completely during the next summer. Ford and Chambers (1973, 1974) reported such "annual species" effects for these and other bivalve molluscs present at the inner cooling water channel stations

An analysis of size-frequency distribution histograms suggested that *S. rosaceus* populations were characterized by one and possibly two recruitment waves per year in South San Diego Bay (Merino 1981). The apparent second wave was likely an extension of the spawning season in the thermal plume near the cooling water channel. A similar analysis for *T. californiamus* indicated that these populations were characterized by constant recruitment, exponentially decaying growth, and increasing mortality (Merino 1981).

The predominant random small-scale dispersion pattern of *S. rosaceus* and *T. californianus* in a fairly homogeneous environment, and the strongly size-class dominant populations, suggested insignificant adult-adult and significant adult-larval interactions, a possible regulating factor in their populations (Merino 1981). Regulation may occur by adults filtering spat and recently settled juveniles of their own species from the water column or resuspended sediments, causing reduced or failed recruitment.

Laboratory thermal tolerance and resistance studies indicated very clearly that *T. californianus* can withstand higher water temperatures than *S. rosaceus* (Merino 1981). The data obtained concerning resistance "effective time" predicts that *S. rosaceus* should not occur much closer to the point of thermal discharge than Station D7 (now designated F4) and D5 (Figures 6 & 7). This was verified by the results of the field studies. In contrast, the higher resistance to thermal effluent by *T. californianus* allowed this species to occur well within the cooling channel of the SBPP (Merino 1981).

Life history traits of both clam species differed between control and thermal plume station locations because of the influence of elevated water temperatures. Individuals from the inner thermal plume station locations were characterized by more variable reproductive effort, fewer young, (as determined by juvenile densities) and a shorter life span, while individuals from the control station locations were characterized by a more predictable breeding cycle resulting in numerous young. A longer life span and larger size also were characteristic of the sub-population unaffected by the increased temperatures in South San Diego Bay (Merino 1981).

Smooth Cockle

Kellogg (1975) conducted a similar combined laboratory and field study to consider the specific ecological and physiological effects of high water temperatures in the South San Diego Bay area on another dominant member of the benthic community, the smooth cockle, *Chione fluctifraga.* His approach allowed specific evaluations of growth rates, size-frequency relationships, temperature tolerances, mortality rates, and behavioral phenomena not possible or not easily discernable in a field study of infaunal species assemblages. Such specific lethal and sublethal effects of thermal effluent may be important at the species level and may lead to large-scale changes in distribution, abundance, species diversity and other ecological characteristics within the community (Kellogg 1975).

The specific effects of thermal effluent on *Chione fluctifraga* investigated by Kellogg (1975) included: 1) heat death under known thermal conditions; 2) altered growth rates in the field; 3) altered metabolism under measured thermal conditions in the laboratory; and 4) observations of behavioral phenomena related to thermal loading under laboratory conditions. The study was conducted, partly in conjunction with those of Ford and Chambers (1973, 1974), over the one-year period October 1971- September 1972 in order to obtain data on a long-term and seasonal basis. The station designations and positions employed by Kellogg (1975) were those of the original monitoring study (Ford 1968). They are shown in Figure 7.

Effects of Elevated Temperatures on Growth Rate

Kellogg reported that one important effect of elevated temperatures on the metabolism of *C. fluctifraga* was the acceleration of normal growth rates. Acceleration of growth rates was first observed in the cooling water channel at Station D5 (Figure 7), near the outer end of the channel during the period November 1971-April 1972. At that time growth rates at Station D5 (1.00 mm/month) were approximately five times greater than those at the control station (0.18mm/month) for the same period. The mean summer growth rate (0.77 mm/month) at the control station was similar to the mean winter growth rate at Station D5 (1.00 mm/month). Temperatures of 69.8°F-78.8° F, characteristic of the cooling channel water during winter months, corresponded to water temperatures recorded during summer months at the control station. Kellogg concluded that the accelerated growth rates at Station D5 during winter months were the result of interjecting a warm water temperature regime in the thermal plume during a period when growth was normally reduced in the natural population. This clearly represents an adverse effect.

Growth rates at Station D7 (now designated F4 in Figure 6) were not significantly higher than those at the control station during any month of the study. Conversely, Kellogg (1975) observed that growth rates at Station D6 (Figure 7), nearby but just inside the cooling channel, were significantly higher than those at the control station during several months (April-July 1972). Because of the similarity in tidal elevation, sediment type, and water quality of Stations D6 and D7, water temperature differences between the two stations were the most apparent causal factor. Based in part on transplantation experiments in the field, Kellogg (1975) concluded this was strong evidence that accelerated growth rates of *C. fluctifraga* in this area of South San Diego Bay were due primarily to elevated water temperatures produced by the SBPP. He reported that at Stations D5 and D6 initial accelerated growth rates were not sustained beyond 4-6 months, regardless of the season in which he transplanted cockle clams into these cooling channel sites. Therefore, it is possible that for sustained, accelerated growth rates of *C. fluctifraga* to occur, an optimum temperature regime for tissue weight gain would have to prevail. This optimum temperature regime for tissue weight gain may be of a lower order than the optimum temperatures for shell growth.

Effects of Elevated Temperatures on Mortality

Kellogg (1975) found that mortality rates at the stations from D5 outward into the bay (Figure 7) varied appreciably from the mortality rates at the control station for both the whole local population and for individual age classes. However, mortality rates at Station D2 (Figure 7), located very near the point of discharge, were significantly higher during the summer months than mortality rates at the control station for the same period. Temperatures recorded at Station D2 during this period were in the range of 95.0°F-102.2°F; these corresponded to the range of lethal temperatures determined for *C. fluctifraga* in laboratory tests (Kellogg 1975).

In October 1973, one year after the end of regular monthly observations, an inspection of sampling stations revealed that a large number of mortalities of marked *C. fluctifraga* had occurred at all outer cooling channel stations (D5, D6, D7.) This observation suggested to Kellogg (1975) that although shorter (less than 1 year) mortality rates may not be affected by elevated temperatures throughout much of the cooling channel, long term (greater than 1 year) mortality rates can be affected substantially. Possible causes for high long-term mortality rates may include a basic metabolic disturbance, as indicated by evidence that was found of tissue weight loss (Kellogg1975). Further evidence of high long-term mortality rates included the repeated collections of small-sized live individuals (first-year age class), but rarely of larger-sized individuals (second and third live-year classes).

Thermal Resistance

Thermal resistance effective times determined by Kellogg (1975) for laboratory test temperatures of 98.6°F and 102.2° F were 27 hours and 21 hours, respectively. This indicates that *C. fluctifraga* was protected from lethal effects due to short-term, high temperature thermal discharges throughout the cooling channel, because water temperatures in excess of 102.0 F were not sustained for periods of greater than 20 hours during any month of the study. However, slightly lower temperatures of approximately 95.0°F were sustained at Station D2 during the summer season for periods that can produce a lethal effect (effective time of 164 hours). Therefore, heat death of *C. fluctifraga* due to long-term exposure (>160 hours) would be expected to occur at locations in close proximity to the point of discharge during these temperature conditions. High mortality rates at Station D2 were, in fact, observed in July and August of 1972 (Kellogg 1975).

An experimental procedure of subjecting *C. fluctifraga* to fluctuating temperatures was used to duplicate thermal conditions most often experienced by animals within the cooling water channel of the SBPP. Kellogg (1975) found that thermal resistance of animals subject to experimentally fluctuating temperatures did, in fact, vary significantly from estimates of thermal resistance made at similar but constant test temperatures. Effective time at a constant temperature of 98.6°F was 27 hours. However, when subjected to fluctuating temperatures in the range of 85.1°F-95.9°F, the cockle clams showed no significant mortality (Kellogg 1975). Those subjected to conditions of alternating temperature were able to survive a total exposure to a normally lethal temperature (98.6°F) for a period of 100 hours. The low number of mortalities at Stations D5, D6 and D7, where maximum temperatures of 98.6°F occurred frequently but seldom persisted for more than 6 hours, provided direct field evidence for the survival of *C. fluctifraga* at what would normally be considered lethal temperatures. This shows that the results of such tests run at fixed temperatures may miss important features of the temperature tolerance process.

The survival of *C. fluctifraga* during periods of high and rapidly fluctuating temperatures within the cooling channel may be the result of its preadaption to naturally occurring extreme temperature conditions. For example, *C. fluctifraga* at the control station were regularly exposed to water temperatures of 86.0°F and wide diurnal temperature fluctuations during tidal changes in the intertidal zone during the summer months. Based on this evidence, Kellogg (1975) concluded that innate heat resistance displayed by *C. fluctifraga* when subjected to fluctuating and elevated temperatures from the thermal discharge may reflect the preadaptions of an estuarine animal that has been historically exposed to relatively variable and severe natural temperature regimes.

The relationship between size and heat resistance of *C. fluctifraga* was not clearly evident (Kellogg 1976). There was limited evidence, although not statistically significant, of increased heat resistance with decreasing animal size. For example, at a test temperature of 102.2F the smallest size class (20-25 mm shell length) showed a slightly longer thermal resistance effective time than that of larger size classes. On the other hand, because this possible relationship between size and lethal temperature response could not be established in a more definitive manner, the significance of size-temperature responses was not addressed in his study.

Kellogg (1975) evaluated the ability of *C. fluctifraga* to carry on normal activities corresponding to the narrowest range of temperature within the zone of tolerance. This was done to distinguish subtle changes in normal activity patterns, indicating sublethal temperature stress, which could not be detected in studies of thermal resistance.

The most obvious deviation from observed normal activity patterns reported by Kellogg (1975) was decreased burrowing activity. This pattern was observed for a significant number (28/30) of animals after transfer to an aquarium held at a constant water temperature of 89.6°F. Conversely, all animals (30/30) held in control aquaria at a temperature of 73.4°F were found to be successfully burrowed in the substrate after approximately 15 minutes.

Decreased burrowing activity by cockles subjected to elevated temperatures in the cooling channel almost certainly would result in increased predation on *C. fluctifraga*. During periods of elevated temperature, significant numbers of cockles may be exposed on mudflats or in shallow water due to their decreased burrowing capacities. Given these conditions, increased predation by several known predators of *C. fluctifraga,* including shorebirds, rays and other fishes, could result. In fact, there was evidence for high levels of predation occurring on mudflats bordering the cooling channel (Kellogg 1975). Numerous shell fragments were observed on the sediment surface and also deposited in fecal material of unidentified shorebirds. Shell fragments were observed much less frequently on the nearby Sweetwater mudflats, suggesting a lower level of predation at those otherwise similar sites than that observed on mudflats bordering the cooling channel of the SBPP

Effects of Elevated Temperature on Oxygen Consumption

When temperature is increased abruptly, most poikilotherms show an initial overshoot in oxygen consumption, called a "shock reaction" (Kellogg 1975). In laboratory tests, the initially high oxygen consumption rates of *C. fluctifraga* stabilized in 1 to 2 hours. This probably was attributable to such a "shock reaction". Whatever the specific cause, the cumulative effect of frequent "shock reactions" to high temperatures would add to long-term metabolic stress of the individuals, producing adverse effects..

The Significance of Q_{10} Measurements

As indicated by Kellogg (1975), Q_{10} has often been applied in an effort to characterize metabolic rate responses of ectotherms to temperature. Normal Q_{10} values range from 2.0 to 3.0 for a variety of bivalve species. Values higher or lower than this have been interpreted as indicating metabolic sensitivity or insensitivity, respectively, to the temperature range involved.

The Q_{10}s determined for *C. fluctifraga* were relatively high for the temperature range of 73.4°F-82.4°F (Kellogg 1975). Q_{10}s of 4.4, 5.76, and 10.2 for the three respective age 1, 2 and 3 classes reflect a significant increase in the temperature-dependent Active Metabolic Rate (AMR) between these two temperatures. Q_{10}s less than one were reported for all age classes in the temperature range 82.4°F-91.4°F. Similar reductions in Q_{10} at high temperature levels have been reported for other bivalve species.

Kellogg (1975) suggested that the sharp decline of Q_{10} in the 82.4°F-91.4°F temperature range was caused by a shift in oxygen consumption rates from the AMR, which was displayed at lower temperatures, to a SMR. This was recorded for animals at 91.4°F. The assumption of a temperature independent minimum rate of oxygen consumption (SMR), resulting in the decline of Q_{10} as lethal temperatures are approached, is well documented in the literature for a number of bivalve species.

In the normal environment, the standard rate of respiration of *C. fluctifraga* is presumably not affected appreciably by short-term fluctuations in temperature, such as those that would occur during tidal changes. However, the active rate of metabolism probably varies markedly with short-term temperature fluctuations, as demonstrated by Kellogg (1975) in laboratory testing of oxygen consumption rates. As a result, adjustments to brief diurnal periods of high temperature could result from a suppression of the Active Metabolic Rate.

In the discharge area of the South Bay Power Plant, periods of high temperature occur frequently and mean water temperatures are sustained at moderately high levels during much of the year. Metabolic adjustments are necessarily long-term in nature under these circumstances, rather than short-term as they are in response to the ebb and flow of tides (Kellogg 1975). Moderately high temperatures of 82.4°F could result in a significant stimulation of the Active Metabolic Rate, as demonstrated in laboratory testing. Such a long-term stimulation of metabolic rate functions would eventually result in increased energy requirements for the cockles. However, if food supplies were not adequate to meet these higher metabolic needs, starvation or poor condition could occur (Kellogg 1975).

Kellogg concluded that temperatures of 91.4°F or higher that occur in the cooling channel could result in additional problems involving long-term metabolic adjustments. Ordinarily the decline in the AMR and the assumption of SMR as short-term lethal temperatures are approached functions to conserve energy. However, the long-term result of restricting oxygen consumption to the SMR, and thus limiting activity levels at high temperatures, would be detrimental. Many vital life activities would be restricted, including feeding, predator avoidance and reproduction. As indicated by Kellogg (1975), the limitation of any one of these could result in the reduced abundance of cockles exposed to sustained high water temperatures.

California Halibut

Innis (1980, 1990) conducted laboratory simulation studies of juvenile California halibut, *Paralichthys californicus*, relevant to establishment of thermal limits. His objectives in this study were to evaluate behavioral responses of this species to a gradient of temperature and the effect of elevated temperatures in thermal effluent on growth. The results are of significant practical importance, as they describe the reactions of an important commercial and recreational species to thermal alterations of its natural habitat.

Temperature Preference Behavior

Innis (1980) reported that seven temperature preference experiments were conducted, using a total of 33 individuals, to study the response behavior of juvenile California halibut in a laboratory thermal gradient. These preference experiments were all carried out after a minimum of two weeks acclimation of the test animals at different temperatures.

The initial and final selected temperatures, as well as the shape of the frequency distribution of the temperatures selected, were used to describe the behavioral responses of *P. californicus* to temperature during each experiment (Innis 1980). The initial temperatures selected by California halibut in a thermal gradient after approximately the first 0.25-1.0 hour were generally similar in all tests. In all but one run, juvenile halibut were initially widely dispersed throughout the entire gradient chamber and did not display a uniform response relative to the newly formed thermal field. Instead, their response positions were related to their initial position in the chamber prior to the time when the gradient was formed.

Following the initial exposure to different temperatures, the juvenile halibut eventually began moving within the gradient, apparently testing the thermal field. In some cases, this response did not occur until after 2 hours of exposure, when extreme temperatures (78.8°F –82.4°F) apparently forced their movement. This "sitting" or "positioned" response (Ehrlich et al 1979) occurred commonly throughout all the experiments. The juveniles in these instances remained in one compartment, and withstood a wide range of temperatures for one hour or longer (Innis 1980). Occasionally, they moved into the extreme ends of the gradient as long as temperatures were within threshold temperature extremes, either warm or cool.

After the initial response to the gradient, in all but one case, the halibut continued to select a wide temperature range during the mid-portion (hours 2-5) of each experiment. During the last one-hour, groups of fish were still dispersed throughout the gradient. The separation of the fish groups was about the same as during the mid-experiment period, although these groups had shifted their positions.

The responses of juvenile halibut in the thermal gradient, despite wide ranging movements and separation of groups, was characterized by distinct modes in the frequency distributions of preferred temperatures selected (Innis 1980). In most instances, the modal selected temperatures were within the range of the initial and final selected temperature ranges.

Of the juvenile *P. californicus* tested, approximately half demonstrated a relationship between selected temperatures and their thermal history. The other half, for unknown reasons, appeared not to be influenced by the temperatures at which they were acclimated (Innis 1980).

Responses to temperature by *P. californicus* in an artificial thermal gradient, though varied, reflected natural behavioral responses. Temperatures of southern California bottom waters on the open coast, the habitat of larval, post-larval, and adult *P. californicus*, normally decrease with increasing depth, creating a gradient over a wide area. Differences in bottom temperatures with depth occur year round, but form to the greatest extent during winter. At that time, complete mixing of the water column causes bottom temperatures to increase. This occurs after a thermally stratified or upwelling season in which cool bottom water originating from the California Current reduce both nearshore bottom temperatures and depth-temperature differences substantially. In semi-enclosed marine areas, such as inner San Diego Bay and other estuaries and lagoons, the predominant environmental characteristics are the relatively wide and variable gradients in temperature and other factors. Tidal action is the most important ecological factor, with ebb and flow, as well as changes in water depth, quickly changing the structure of natural temperature gradients.

Thermal gradients also develop in association with the thermal effluent discharged from electrical generating stations. Thermal effluent plumes are variable in extent because of the changing intensity and direction of prevailing winds and tide flow. Start-up procedures and shutdown of units, as well as heat treatments to eliminate biofouling, can suddenly create, intensify or diminish thermally modified environments. The associated gradients of temperature radiating outward from point source discharges also will be affected by power plant operations.

Innis (1980) concluded that the behavioral responses exhibited by juvenile *P. californicus* reflect the varied environmental conditions occurring in estuaries. From the laboratory simulations, he observed different behavioral patterns, in which half of the juveniles selected warm temperatures, while the other half selected cool temperatures. This may represent a natural response rather than a laboratory artifact. Reactions of juvenile California halibut to thermal gradients are obviously eurythermal. This adaptive quality would be important for orientation and survival in an estuarine environment.

P. californicus changes habitats throughout its life cycle, with juveniles living in bays and estuaries and most adults moving to the open coast. Because of this, different temperatures become "optimal" at each major life history stage. Therefore, the eurythermal behavior of smaller, estuarine juvenile California halibut is naturally different from that of larger adults resident offshore. For larger individuals, a narrower temperature range would be optimal, because offshore areas are thermally less variable than nearshore or estuarine habitats (Innis 1980).

Both juvenile and adult *P. californicus* have relatively sedentary behavior. Methods of capturing prey and cryptic coloration with the sandy bottom reflect "ambush predator" habits, in which they lie in wait for prey. Coloration and the tendency to remain motionless to avoid predators also add to this general pattern of limited movement.

Innis (1980) concluded that this temperature response behavior of juvenile halibut observed in the gradient system probably was similar to the behavior they show in nature. The estuarine environment is highly dynamic and moderate changes in temperature occur in a diel cycle. Reactions by *P. californicus* in the artificial thermal gradient appeared to reflect similar response patterns (Innis 1980). Gradually increasing warmer temperatures, as generally found in a thermal plume, eventually evoked an avoidance response by *P. californicus* at 75° F-82.4°F, while decreasing temperatures did not elicit avoidance movements by some individuals. In general, this species can tolerate a wide range of temperature, and juveniles seem to prefer relatively warm (59.0° F-73.5° F) temperatures.

This evidence suggested that juvenile *P. californicus* would not normally be affected by temperature conditions in thermal plumes from coastal generating stations (Innis 1980). Upon encountering the leading edge of a thermal plume, under most circumstances, juvenile California halibut would not avoid a 1° F ΔT. This would be the typical exposure from thermal effluent plumes on the open coast in southern California. In contrast, Innis (1980) concluded that thermal plumes in enclosed bays may elicit avoidance behavior because of the higher temperatures in such areas (i.e. South San Diego Bay: Ford 1968, Ford and Chambers 1974).

It is important for the reader to note that such avoidance behavior by juvenile *P. californicus* in South San Diego Bay may be a matter of ecological concern. Even though mobile animals such as the California halibut are able to avoid unsuitably high water temperatures in a thermal plume, this avoidance then prevents them from using the affected, high temperature area as a feeding or resting site. This may deprive individuals, particularly small juveniles, of their required food supply and some of their living space within parts of the thermal discharge pattern that they avoid all or part of the time. In addition, the absence of their predatory feeding activity may cause unnatural changes in their prey populations within thermally altered areas.

Thermal discharges from coastal generating stations with direct oceanic discharges also are known to act as attractive environments for *P. califo*rnicus (Stephens 1976, 1978). As reported by Innis (1980), it is likely that higher metabolic and growth rates are associated with their preference of warmer temperatures. One theory hypothesized by Webb (1978) was that predators at higher tropic levels, such as the top carnivore *P. californicus*, may take advantage of increased metabolic activity available when residing in or near discharge plumes. According to Webb's hypothesis, such discharge-orienting predators would have a "metabolic edge" over prey species because the predators usurp the localized areas of a thermal discharge. At higher metabolic rates, these fish could swim at faster bursts of speed in catching prey.

As a result, predators such as *P. californicus* within a warmer discharge area could obtain prey more easily. This mechanism would be advantageous to the California halibut, as their prey pursuit generally begins from a standing start as they burst out of the sediment. Many fish species in nearshore and bay environments of southern California appear to be attracted to the warmer temperatures near discharges, including those of inner San Diego Bay (Ford 1968). This would increase feeding opportunities of predators that orient to the thermal plume (Stephens 1977, 19780). However, from an ecological standpoint, all of these effects represent disturbances to both the fish populations and the natural marine communities involved.

Growth Studies

Innis (1980, 1990) investigated the possible long-term effects of thermal effluent on the growth rates of juvenile and sub-adult *P. californicus* (100-350 mm total length). Test animals captured at Agua Hedionda Lagoon by otter trawl during October and November 1976 were held in large, rectangular fiberglass troughs for approximately four weeks of laboratory acclimation. Test animals were fed daily in excess.

At the beginning of the four-week acclimation period, individuals of different size were distributed into two experimental tanks by randomization. After the individuals began to feed, one experimental group of 35 individuals was acclimated to 71.5°F, a temperature corresponding to that typical of conditions in the thermal plume into the nearshore ocean from the adjacent Encina Power Plant. Temperature in this tank was increased at a slow rate from 59.0°F-71.5°F. The experimental temperatures were developed by mixing ambient temperature seawater from Agua Hedionda Lagoon with thermal effluent. The free-flowing mixture of the two water types was controlled by a pneumatic, Teflon coated mix-valve and epoxy coated pressure-proportioning thermostat (Ford et al. 1975). As a control, 34 individuals were held in flowing seawater at fluctuating ambient temperatures.

Using this system, the long-term effects of thermal effluent on growth were determined between 11 October and 27 August 1977, a 259-day period. Halibut held under ambient conditions in the laboratory experienced the coolest temperatures (57.2°F-59.0°F) during March and the warmest (72.5°F-77.0°F) during late July and early August. Thermal conditions in the mixed effluent-ambient treatment were warmer (71.6°F±2.9°F), and varied less than in the ambient temperature control water. Low rates of growth experienced by age class 2+ individuals held in both the control and thermal effluent treatment groups were due to the limited confines of the experimental system. Otherwise, growth of all age classes in the thermal effluent treatment was greater than in the ambient temperature control (Innis 1980, 1990). This result simply reflected the effect of moderately higher temperatures on the rate of growth. Because higher temperature conditions in a thermal effluent plume were not simulated in these experiments, the results are of limited use in predicting the effects on growth of California halibut in the warmer thermal discharge areas from the South Bay Power Plant.

Conclusions from the Studies of Individual Species as they Apply to Setting Temperature and Dissolved Oxygen Limits for the Compliance Point in the Discharge Channel of the South Bay Power Plant

The results of these combined laboratory and field studies of four important indicator species provide an additional dimension to the evaluation process. They help to explain the specific causes and processes involved in results obtained from the general ecological field monitoring studies of 1968-1994. For example, we know that *Solen rosaceus* was found only infrequently in samples within the discharge channel, and at different densities in other areas and within different tidal levels elsewhere. Specific knowledge of its thermal tolerances helps to understand what produced these observed distribution patterns.

In addition, these specific laboratory and field studies of individual species identified many more subtle, yet extremely important, adverse effects on growth, reproduction, burrowing activity, and other behavioral responses resulting from exposure to high temperatures in different parts of the inner and outer thermal plume. Such effects are seldom evident from typical field studies of the infaunal or fish species assemblages.

The results of these important species-specific studies must be considered in establishing temperature and dissolved oxygen limits at the compliance point that truly will protect beneficial uses of inner San Diego Bay. The studies indicate that water temperatures and dissolved oxygen concentrations measured monthly at Reference Station N2, located near, but outside the limits of the thermal plume (Figure 6), are the most suitable ones for establishing these limits. These data, obtained during the six full calendar years 1997-2002 as part of the NPDES monitoring, are summarized by month in Table 1. Using these data to set temperature and dissolved oxygen limits for the compliance point would provide the required protection of beneficial uses. These limits and their application are described in the following section entitled "Recommendations Employing Data from Station N2.

As an alternative, use of temperature and dissolved oxygen data from thermal plume Station F3 (Figure 6) to establish limits for the compliance point would provide only partial protection of beneficial uses. That would be a far less satisfactory solution. These limits and their application are described in the second section that follows, entitled Alternative Recommendations Employing Data from Station F3.

RECOMMENDATIONS EMPLOYING DATA FROM STATION N2

The following specific recommendations are made to establish maximum water temperature limits and minimum dissolved oxygen concentration limits for a compliance point in the discharge channel of the South Bay Power Plant. The results and information discussed in all previous sections of this report provide the specific data and justifications for these recommendations.

Recommendation 1

During each calendar month, maximum water temperatures of thermal effluent at the compliance point shall not exceed the individual monthly values shown in Table 2. These limits are based on the six-year (1997-2002) monthly data set obtained at Station N2 (Table 1).

Recommendation 2

During each calendar month, the concentrations of dissolved oxygen in thermal effluent at the compliance point shall not be lower than the specific monthly minimum limits shown in Table 2. This shall apply at all times of the day or night. Note that the lowest allowable concentration of dissolved oxygen recommended is 5.0 mg/L, as specified by the existing Basin Plan. That minimum value shall apply even during the warmest months of July-September. This is an ecologically sound overall minimum dissolved oxygen concentration for both freshwater and shallow, estuarine marine habitats. As indicated by Applied Science Associates (1998), "...a review of numeric water quality objectives for dissolved oxygen in other California regions and in other states with similar climatic conditions, revealed that 5 mg/L is a commonly used objective." Therefore, on both ecological and well-established regulatory grounds, setting the overall minimum concentration of dissolved oxygen at 5.0mg/L is logical and well justified for inner San Diego Bay.

Recommendation 3

In addition, as stated in the existing Basin Plan, the following specific water quality objective for dissolved oxygen shall apply: "The annual mean dissolved oxygen concentration shall not be less than 7 mg/L more than 10% of the time." (Basin Plan page 3-8).

Recommendation 4

At the compliance point, surface and bottom water temperatures shall be recorded continuously, to the nearest 0.1° F, using a data logger or similar device. At hourly intervals during the period 4am-5pm, dissolved oxygen concentrations shall be measured and recorded to the nearest 0.1 mg/L just below the water surface and near the bottom at the compliance point. A field polarographic oxygen electrode sampler or similar device accurate to at least 0.1 mg/L shall be employed.

Recommendation 5

These daily records of temperature and dissolved oxygen shall be reported to the San Diego Regional Water Quality Control Board, and used by both the Board and the discharger to assure compliance with the established maximum water temperature and minimum dissolved oxygen concentration limits.

Recommendation 6

As a means of assessing the effectiveness of the established temperature and dissolved oxygen limits, a seasonal, quantitative marine ecological monitoring program shall be conducted at the compliance point and at a series of other representative stations within and outside the extent of the thermal plume, including Station F3 and Station N2 (Figure 6). This shall consist of taking and analyzing a minimum of five replicate, 0.1 sq.m Van Veen grab samples at the compliance point and at the other station sites. These biological samples shall be taken and analyzed seasonally on at least a quarterly basis. Quantitative data for the invertebrate infauna from these sediment samples shall be evaluated on a comparative basis, using the approaches employed by Ford and Chambers (1973, 1974) and as summarized by E.A. Engineering, Science, and Technology (1995). A primary emphasis of this ecological monitoring shall be to determine whether or not temperature and dissolved oxygen conditions at the compliance point in the discharge channel have had any significant adverse effects on the infauna. If so, then the temperature and dissolved oxygen limits for the compliance point shall be modified to eliminate those adverse effects.

ALTERNATIVE RECOMMENDATIONS EMPLOYING DATA FROM STATION F3

Recommendation 1

During each calendar month, the maximum water temperature limits of thermal effluent at the compliance point shall not exceed the individual monthly limit values shown in Table 4. These limits are based on a six-year (1997-2002) monthly data set for Station F3 (Table 3).

Recommendation 2

During each calendar month, the concentration of dissolved oxygen in thermal effluent at a compliance point shall not be lower than the minimum limit shown in Table 4. These minimum limits shall apply at any time of day or night. Note also that the lowest allowable concentration of dissolved oxygen recommended is 5.0 mg/L, as specified in the existing Basin Plan. That minimum value shall apply even during the warmest months of July-September. This is an ecologically sound overall minimum dissolved oxygen concentration for both freshwater and shallow, estuarine marine habitats. As indicated by Applied Science Associates (1998), "...a review of numeric water quality objectives for dissolved oxygen in other California regions and in other states with similar climatic conditions, revealed that 5 mg/L is a commonly used objective." Therefore, on both ecological and well-established regulatory grounds, setting the overall minimum daytime concentration of dissolved oxygen at 5.0mg/L is logical and well justified for the compliance point of the South Bay Power Plant.

Recommendation 3

In addition, as stated in the existing Basin Plan, the following specific water quality objective for dissolved oxygen shall be met: "The annual mean dissolved oxygen concentration shall not be less than 7 mg/L more than 10% of the time." (Basin Plan page 3-8).

Recommendation 4

At the compliance point, surface and bottom water temperatures shall be recorded continuously, to the nearest 0.1°F, using a data logger or similar device. At hourly intervals during the period 4am-5pm, dissolved oxygen concentrations shall be measured and recorded to the nearest 0.1 mg/L just below the water surface and near the bottom at the 1000 foot compliance point. A field polarographic oxygen electrode sampler or similar device accurate to at least 0.1 mg/L shall be employed

Recommemndation 5

These daily records shall be reported to the San Diego Regional Water Quality Control Board, and used by both the Board and the discharger to assure compliance with the established maximum water temperature and minimum dissolved oxygen concentration limits.

Recommendation 6

As a means of assessing the effectiveness of the established temperature and dissolved oxygen limits, a seasonal, quantitative marine ecological monitoring program shall be conducted at the compliance point and at a series of other representative stations within and outside the extent of the thermal plume, including Station F3 and Station N2. This shall consist of taking and analyzing a minimum of five replicate, 0.1 sq.m Van Veen grab samples at the compliance point and at the other thermal plume and reference station sites. These biological samples shall be taken and analyzed seasonally on at least a quarterly basis. Quantitative data for the invertebrate infauna from these sediment samples shall be evaluated on a comparative basis, using the approaches employed by Ford and Chambers (1973, 1974) and as summarized by E.A. Engineering, Science, and Technology (1995). A primary emphasis of this ecological monitoring shall be to determine whether or not temperature and dissolved oxygen conditions at the compliance point in the discharge channel of the SBPP have had any significant adverse effects on the infauna. If so, then the temperature and dissolved oxygen limits for the compliance point shall be modified to eliminate those adverse effects.

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TABLE 1

Summary of water temperatures and dissolved oxygen concentrations measured monthly at Station N2 in South San Diego Bay (Figure 6) during the six full calendar years 1997-2002. Data are those reported to the San Diego RWQCB by MEC Analytical Systems, Inc., Carlsbad, CA. Water temperature measurements were made at 2-foot depth intervals in the water column from near the surface to just above the bottom on each date. Dissolved oxygen concentration data (DO) include daytime measurements made near the surface and just above the bottom on each date. All data were pooled for each month.

	Water Temperature (°F)		**Dissolved Oxygen (mg/L)**	
Month	**Max. Temp.**	**Temp. Range**	**Min. DO**	**DO Range**
January	62.4	57.0-62.4	8.0	8.0-10.3
February	62.2	55.0-62.2	7.6	7.6-8.17
March	66.6	59.4-66.6	7.5	7.5-8.4
April	68.4	60.7-68.4	6.4	6.4-8.9
May	72.4	69.8-72.4	6.5	6.5-7.7
June	76.1	72.5-76.1	6.7	6.7-8.0
July	78.1	72.5-78.1	6.5	6.5-8.0
August	79.9	76.1-79.9	6.2	6.2-8.5
September	78.1	73.0-78.1	4.7	4.7-8.6
October	73.2	70.2-73.2	5.9	5.9-8.2
November	67.9	60.4-67.9	7.1	7.1-9.1
December	66.7	56.3-66.7	7.0	7.0-8.4

TABLE 2

Recommended maximum water temperatures and minimum dissolved oxygen concentrations for the compliance point in the cooling water channel of the South Bay Power Plant. These limits are shown separately for each calendar month. The values shown are based on the six-year monthly data summaries for Station N2 provided in Table 1. Temperatures were rounded up or down to the nearest whole number. The lowest overall dissolved oxygen concentration recommended is 5.0 mg/L.

Month of	**Max. Temp. (°F)**	**Minimum Daytime Dissolved Oxygen Conc. (mg/L)**
January	62	8.0
February	62	7.6
March	67	7.5
April	68	6.4
May	72	6.5
June	76	6.7
July	78	6.5
August	80	6.2
September	78	5.0
October	73	5.9
November	68	7.1
December	67	7.0

TABLE 3

Summary of water temperatures and dissolved oxygen concentrations measured monthly at Station F3 in South San Diego Bay (Figure 6) during the six full calendar years 1997-2002. Data are those reported to the San Diego RWQCB by MEC Analytical Systems, Inc., Carlsbad, CA. Water temperature measurements were made at 2-foot depth intervals in the water column from near the surface to just above the bottom on each date. Dissolved oxygen concentration data (DO) include daytime measurements made near the surface and just above the bottom on each date. All data were pooled for each month.

	Water Temperature (°F)		**Dissolved Oxygen (mg/L)**	
Month	**Max. Temp.**	**Temp. Range**	**Min. DO**	**DO Range**
January	68.7	59.1-68.7	5.9	5.9-9.2
February	66.9	58.8-66.9	6.7	6.7-8.0
March	67.5	61.3-67.5	6.5	6.5-7.8
April	76.3	63.8-76.3	5.4	5.4-7.8
May	81.4	70.3-81.4	5.0	5.0-6.6
June	84.2	74.4-84.2	5.0	5.0-6.5
July	85.5	77.7-85.5	4.8	4.8-6.6
August	85.4	78.6-85.4	5.2	5.2-7.8
September	83.8	75.8-83.8	4.2	4.2-7.8
October	77.5	72.8-77.5	5.0	5.0-6.6
November	73.8	63.7-73.8	6.3	6.3-9.7
December	66.0	58.9-66.0	6.3	6.3-9.6

TABLE 4

Recommended maximum water temperatures and minimum dissolved oxygen concentrations for the compliance point in the cooling water channel of the South Bay Power Plant. These limits are shown separately for each calendar month. The values shown are based on the six-year monthly data summaries for Station F3 provided in Table 3. Temperatures were rounded up or down to the nearest whole number. The lowest overall dissolved oxygen concentration recommended is 5.0 mg/L.

Month of	Max. Temp. (°F)	Minimum Daytime Dissolved Oxygen Conc. (mg/L)
January	69	5.9
February	67	6.7
March	67	6.5
April	76	5.4
May	81	5.0
June	84	5.0
July	85	5.0
August	85	5.2
September	84	5.0
October	78	5.0
November	74	6.3
December	66	6.3