Recommendations to Update the Interim Mitigation Cost Calculation for Once-Through Cooling Intake Use Leading to Marine Life Entrainment and Impingement

The goal of this model is to determine a funding approach for use of water in once-through systems (power plants) that is based on mitigation compensatory to impacts of impingement and entrainment. Specifically, we were asked to review the ERP II report (2012) and the 2015 update to that report as needed to develop an estimate (or range in estimates) that would be sufficient to provide compensatory mitigation based on 2023 costs of construction.

A note about key terms in the document
There are two sets of terms that are important to describe before reading the document. These will also be described in contextual and mathematical detail later in the document.

1. *What habitats to include in the calculations?* The first set of terms relates to the habitats used to estimate Area of Production Foregone (APF) and to estimate the cost of habitat creation. Generally, species entrained or impinged come from three benthic habitats (or are pelagic): rocky reef, wetland (almost always this would be estuarine), or open coast-subtidal soft bottom (hereafter referred as sandy bottom). APF values have been estimated for all of these habitats but cost of habitat creation has only been done for rocky reef and wetland habitats (below we discuss approaches to "convert" sandy bottom to other habitats). We use the term "Common Habitat" to mean the use of APF estimates for species from all habitats and we use the term "Specific Habitat" to mean the use of APF estimates for only a particular habitat. In addition, if we use the Specific Habitat calculation for a site, we would also calculate the amount of that habitat that would replace the lost resources. Guidance for the use of both Common and Specific Habitat calculations is presented below.
2. *How information from sites is used to cost once through use of seawater*? The general approach is to link intake of seawater, impact due to entrainment or impingement and calculated cost of the impact. We use the word "Default" to describe the use of all sites for which we have estimates of seawater use and entrainment / impingement. The default approach is the same used in earlier assessments (in 2012 and 2015). Using these data, a general calculation is made for the area of production foregone for either entrainment of impingement losses due to power plant operations. For example, if the best estimate of the relationship between impact (e.g. APF) and million gallons of water used per day = Y, we would use Y as the Default estimator of impact. This value Y could then be monetized through use of the cost of replacing the lost resources. Here the recommendation is based on the cost of habitat creation sufficient to produce the lost resources.

   An alternative approach to the Default and one recommended for impingement but not entrainment (reasons described below) is called Site-Specific. Site-Specific costing is done by using the actual (impingement) data from the site of interest and estimating the cost of that impact. As an example, when contrasting the Site-Specific calculation to Default calculation, the Default calculation would use the relationship between sea water intake and biomass impinged across all sites where such information exists to calculate the *expected biomass* of impingement per level of intake (i.e., million gallons of water use per day). This general calculation would then be used to determine the cost of impingement for a specific site (i.e. an individual generating station) by calculating the area and cost of creation of habitat required to produce *the expected biomass* lost due to impingement. Using the Site-Specific approach, we would simply use the *actual impingement biomass* for the site of interest to calculate the area and cost of creation of habitat sufficient to mitigate that loss.

When we present options below we will almost always combine the two sets of terms with #2 preceding #1, as an example: Default-Common Habitat.

Basis and key assumptions of the payment-based approach as mitigation for impacts of use of seawater leading to entrainment and impingement

Understanding the payment-based approach in terms of its methodology and resultant values relies on a series of definitions and assumptions. First, we are defining compensatory mitigation as an action or set of actions that fully compensate for an impact. In its simplest version the relationship can be defined as compensatory mitigation occurs when mitigation (M) is equal to impact (I).

(1) $M = I$

However, this simple definition is unrealistic because impacts are never instantaneous, hence a more understanding is that for mitigation to be compensatory the mitigation integrated over time is equal to impact integrated over the time (that it occurs).

(2) $\sum_{t=1}^{n} M_t = \sum_{t=1}^{n} I_t$, t=time

A very simple version of equation 2 occurs when the impact occurs over the same number of years as the mitigation action: T (or any time interval) and that within a year (or any time interval) the benefit of the mitigation is equal to the lost benefit due to the impact. This can be expressed as:

(3) $MT = IT$

Note that T means only time, not calendar period; meaning that mitigation occurs over the same number of time periods (e.g., years) not the same calendar interval.

This equation has been used implicitly or explicitly for most assessments of compensatory mitigation resulting from to use of seawater for the operation of coastal powerplants recently in California.

The next step is understanding the metric used to measure impact such that mitigation can be directly estimated. For powerplants facilities in California, Area of Production Foregone (APF), also called Habitat Production Foregone (HPF), has been used for over 20 years as a form of habitat equivalency analysis, especially for entrainment. The core idea of APF is that if is possible to determine the amount of habitat that would produce the resources lost due to an impact then that area would, if added to the environment, be fully compensatory. For entrainment, another model used to inform APF calculations is Empirical Transport Modeling (ETM) which allows calculation of proportional mortality of species due to entrainment and the area from which the entrained individuals come from. Here the product of the area and proportional mortality yields an estimate of APF. Details of the logic and calculations of ETM/APF can be found in Raimondi 2011, (PIER REPORT, Variation in entrainment impact estimation based on different measures of acceptable uncertainty). APF can also be estimated for impingement using a different (not ETM) coupling model, as shown below. Because APF allows estimation of spatial loss, the impact can be calculated, based on equation 3, by knowing how long the impact will last. The tradition has been to use 30 years as an estimate of the period of impact for facilities in California. This means that fully compensatory mitigation (compensating for IT acre years of impact) will occur if the mitigation action produces MT acres years of satisfactory performance. Satisfactory here means that the design attributes of the mitigation are met for the same number of years as the period of impact (T). Importantly this also implies that for fully compensatory mitigation to be ensured there is some process for evaluating if the design attributes are met over the entire period of the impact (T).

This logic and approach provide the basis for the payment-based model for impacts due to entrainment and impingement. In sections below there are detailed descriptions for data sources for APF for both entrainment and impingement, but the most important point is that all estimates came from facilities where in addition to APF values there were estimates for use of water, using the units million gallons of water used per day (MGD). For each facility there were typically two estimates: design MGD and average MGD, the latter is based on the average use over a year. Average use is always less than Design use. Having estimates for both APF and MGD for facilities allowed calculation of the number of acres of impact per million gallons (MG) of water used.

Next, we gathered information on the cost of created habitat that could produce resources comparable to those lost due to the impacts. Here, we gathered information on the cost per acre of estuarine wetland (tidal marsh habitats) created or substantially restored or reef created. The product of acres APF/MG and Cost/acre yields Cost/MG, which can be thought of as value, which if paid, could lead to fully compensatory mitigation.

The main rationale for the payment basis is that it is expected for operation of most powerplants to be likely less than 30 years, whereas mitigation via habitat creation (which the basis of monetization) is expected to persist and be compensatory for 30 years minimum, so there needs to be a way to pro-rate the cost of mitigation relative to equation 3. The solution is to understand that compensatory mitigation MT (equation 3) is equal to 30 yearly increments of APF/30, each of which will perform for 30 years.

(4) $$\sum_{y=1}^{T} \left(\frac{APF}{30}\right)_y \; x\; 30\; years = MT$$

Where T = period of performance habitat created (assumed to be 30 years) and y = year of habitat creation. With respect to costing the mitigation using equation 4, there needs to be a cost escalator applied to account for changes in the cost of habitat creation over time. Without the escalator the monetization of APF will be incorrect and almost certainly too low. A recommendation for an escalator is given below.

The last part of this general introduction is to introduce the idea of Default and Site-Specific costing rates. A Default rate is based on the idea that facilities and APF values are essentially replicates in a general solution for compensatory cost for use of water. Site-Specific rates are based on the idea that there are unique attributes of facilities that make the Default rate unfair and inaccurate. Discussion of and recommendations for Default and Site-Specific rates will be presented below.

Specific details and recommendations

1) Cost per acre of habitat mitigated came from two general sources (specific sources are provided in the Tables). First, projects that were included in the 2015 update. Second, we added a set of new projects. For both, we estimated the cost in 2023 dollars. For those projects included in earlier reports, we used as base values the estimated cost in those reports. For newer projects, we used the date of cost estimation (either the year of construction or year cost was estimated).

2) We calculated cost per million gallons (MG) of seawater using a resampling approach. This approach allows estimation of mean values that could come from the product of two separate sets of data (see details below) and produces a continuous probability distribution of means of costs per MG. From this we show the median, the average, the 5th percentile and 95th percentile, although any percentile could be derived. We recommend that the median value be used. This is the best estimate of the ***mean*** cost per million gallons of seawater.

3) For this report we were asked by the State Water Board (*Proposal: Update One Component (Annual Escalator) of the Interim Mitigation Payment*) to evaluate a series of cost escalators (alternatives 1-4). The alternatives in the proposal are based on the consumer price index for urban consumers (CPI-U) either on US or State costs. In addition, there was a request to make a recommendation as to the period over which the escalator would be calculated (latter year or average of values for both years). We note that the escalator will be used in two ways. First, to update costs of construction of wetland and reef habitat construction to 2023 values. The second is to update cost for use of sea water in facilities for each year in the interim mitigation period. We also want to note that for both, the escalator is to account for increases in cost of non-building construction (infrastructure). Neither the California nor the US CPI-U are based on construction costs. We added an index based on non-building construction costs (https://edzarenski.com/category/inflation-indexing/) to those presented by the State Water Board staff. Of the State Water Boards alternatives we strongly recommend the use of CA CPI-U because the costs are more likely to track state values than the US values and we support the staff recommendation of Alternative 1. We also recommend that the source be the California Department of Finance rather than the average of regions (MSA) in California reported by the U.S. Bureau of Labor Statistics.

   While we support alternative 1 among the State Water Board alternatives, we believe the non-building construction alternative is likely to better estimate the actual increase in cost of mitigation and therefore would be superior to an escalator based on CPI.

   We will discuss estimation of monetization of impact resulting from impingement in detail later in the document; however, we note here that in contrast with the current approach, we strongly recommend that the cost for impingement be subject to annual escalation, using the same escalator proposed for entrainment cost: the non-building construction index. This change is driven by the proposed approach for estimation of impingement cost, which is explicitly linked to the same cost basis as used for entrainment. The previous approach was to calculate the annual value of species lost to impingement as annual impingement in lbs. x cost per lb. The cost per lb. was set at $0.80. This value, $0.80 / lb. was left unchanged over time. This was an unanticipated mistake. That value should have been escalated, most appropriately by some CPI escalator as this reflects cost of purchase. The approach proposed in this update is based, like entrainment, on APF. That is the cost of providing habitat sufficient to provide lost resources. That cost is affected by increases (or decreases) in construction costs. Because the payments are paid annually on a prorated basis, adjustment in payment should reflect change in costs for compensatory mitigation; here this means the cost of construction of wetland or reef habitat.

4) We did not directly include the cost of monitoring in the models. However, as directed, after estimating the expected cost of mitigation (ECM) we added cost of monitoring as a percentage of ECM ranging from 10-25%. See below for more information about the importance of inclusion of monitoring costs.

5) The APF for each project is, as noted, the area that if created would provide compensatory mitigation for the entrainment impact. This model was originally designed for long term projects where mitigation impacts were likely to occur for decades. Given this, the longevity of the mitigation project was largely irrelevant to costing. However, for shorter term impacts, it may be appropriate to incorporate the estimated life of the mitigation project to adjust the cost for the benefit provided by the mitigation post- impact period. Hence, two additional terms might be important to consider: (1) estimated life of the mitigation project and (2) estimated period of continued operation of the once-through use of water. This could provide a prorated cost. Alternatively, if assumptions are made that the funds are appropriately estimated (see above) and that they are used for long term benefit, then annual funding should be compensatory for total annual impacts. As discussed above, one additional assumption is necessary to ensure compensation – that is that the payment is adjusted annually by an appropriate cost inflation index. This assumption has always been a part of the fund-based approach, however, we wanted to explicitly lay it out in this report.

6) There is another key assumption to this model; it is that the mitigation project that is the basis for monetizing the impact would be fully compensatory if completed. This means two things must occur. First, the mitigation project must perform as designed. This means that the project must be monitored for biological performance. Second, the area of the mitigation project must not decrease or else the APF threshold would not be met. Therefore, the cost for monitoring, maintenance and potential remediation for non-performance must be incorporated into the total cost. Depending on the projected mitigation project this would add 10-25% to the cost.

7) Cost based interim mitigation can be based on Default or Site-Specific rates. Default rates occur when the same rate per MG of water is used for all facilities, whereas Site-Specific rates would be based on characteristics of specific facilities

8) For entrainment it is widely thought and empirically verified that ETM/APF calculations using species as replicates are comparable to estimates using volumetric approaches. This is largely because entrainment is almost always of small organisms that have little to no behavior useful for escape from intakes. This means that a larval organism moves similarly to a particle of water, thus volumetric approaches based on (particles of) water often have results similar to approaches based on larvae or other propagules. This is not true for impingement where organisms are much larger, have strong behaviors and can often swim against intake velocities. In general, in part because of the species traits listed, impingement is higher for facilities with intakes that are further from shore and that have high intake velocity.

   Importantly these attributes, especially intake velocity, mean facility modifications can have profound effects on the impingement per MG of water used. Simple enhancement such as velocity caps on intakes or lowering intake volume, which also lowers intake velocity produce non-linear decreases in impingement. What this means is that reduction of intake volume by 50%, will lead to reduction of impingement from two sources. First, by simple reduction of volume, impingement will decrease by an expected 50%. However, there will be an added reduction based on reduction of intake velocity (more individuals will escape). Hence the impingement will decrease by more than the expected 50%.

For impingement a more equitable basis to the Default rate is to have the impingement cost be based on site-specific annual impingement (or estimate of it), as described below. This approach could be distinguished as the Site-Specific rate for impingement.

9) Cost for both entrainment and impingement can also be calculated on either a Common or Specific *Habitat* basis. The Common Habitat basis is when cost per acre created is derived from both wetland and reef creation projects. The Specific Habitat basis is when cost per acre created is derived separately for reef and wetland projects. The logic for the use of Common or Specific Habitat basis is linked the species affected at a facility. Because species specific data on entrainment (in particular) is almost never (see Diablo Canyon for an exception) collected for more than a single year (or potentially over a series of single years coinciding with permit requirements), species dynamics are not captured. In addition, entrainment is assessed using a temporal and spatial sampling design that while robust for impact assessment, only produces data on a tiny fraction of the organisms that are entrained. While these attributes are unlikely to be a problem with the estimation of impact using ETM/APF models, it does make a characterization of proportional habitat representation of entrained species more difficult. Compounding this difficulty is that for entrainment the affected individuals are planktonic and could have been transported over long distances before entrainment. This makes assignment of habitats affected less linked to geographic distance. Impingement is somewhat different. First, impinged individuals largely are not planktonic and are often adults and hence more often are likely to be local. Second, many facilities have longer time series for the species composition of impingement. Finally, the fraction of individuals sampled that are impinged is vastly greater than for individuals that are entrained.

In addition to the complications described above, there is a final complication, which occurs regardless of the quality of information concerning the habitats represented by entrained or impinged species. In fact, increasing quality of information makes one potential problem more evident. The basis of the cost-based approach for interim mitigation is, in part, the cost of wetland and reef creation. This is because APF estimation produces an estimate of acreage that would, if created, produce resources equivalent to those lost. There is good information for the cost of compensatory mitigation through the construction and performance monitoring of reef and wetland habitats, but no such information exists for sandy bottom areas, which are habitats for many species that get entrained or impinged. We know this because detailed information exists for impingement and entrainment at some facilities and individuals from all three habitats (wetland, reef, and sandy bottom) are killed due to once-through use of water.

The arguments above are caveats for use of Specific Habitat basis, especially for entrainment. However, at least in some cases, there is sufficient information to make informed decisions concerning the use of Specific Habitat calculation. For some of those cases, the majority of species may come from one habitat type, and it would be fair to use that single habitat as a basis for cost. In others, where a mixture of habitats are represented in entrainment and or impingement a weighted calculation could be used. For the weighted approach, the weighting for sandy bottom species would be based on conversion equations, which have been used in estimation of APF and estimation of compensatory acreage in regulatory actions in California. The potential utility of this approach could easily be evaluated by doing: (1) a comprehensive literature review of the National Pollutant Discharge Elimination System determinations of the federal Clean Water Act 316(b) as well as similar state assessments for power and desalination facilities (which are assessed identically to once through use of water determinations for powerplants) followed by, (2) a facility-based calculation of weightings and conversion values.

General approach for entrainment effects

The general approach that has been used to determine impacts resulting from entrainment has been to use what has been called the ETM/APF coupled model (See Foster et al., 2012). ETM is empirical transport modeling and is used to estimate entrainment loss. The key result of ETM is an estimate of Proportional Mortality (P_m) that is calculated for each species evaluated. These values (P_m) are then used to calculate the area of production foregone (APF, sometimes called HPF), which represents the area of habitat that would be sufficient to produce resources equivalent to those lost due to entrainment. The details of these calculations are somewhat complex and specific to particular entrainment assessments but are described in detail in Raimondi (2008). In general, the APF values for ETM/APF assessments have been based on either coastal estuary/wetland or rocky reef habitats depending on the composition of species that were lost to entrainment. For example, entrainment at Diablo Canyon Power Plant (DCPP) is primarily made up of larvae from species associated with kelp forests (rocky reef habitat), whereas at Moss Landing Power Plant (MLPP) entrainment primarily of larvae from estuarine species. Accordingly, the APF at DCPP was based on acres of kelp forest required to produce the larvae lost to entrainment and at MLPP it was acres of estuarine habitat. The underlying logic of this approach is based on two key assumptions: (1) the acres required are the area required to produce reproduction sufficient to produce the same number of larvae that are lost to entrainment via habitat for adults, and (2) compensatory mitigation APF acres should be either new acres or substantial restoration/enhancement of existing acres – in practice this usually results in reef or wetland creation.

In earlier models or updates to those models (e.g., 2017), we used case studies that had two important attributes: (1) reviewed ETM/APF modeling and, (2) either actual mitigation or proposed and monetized mitigation plans that was or would be fully compensatory based of calculated project APF. This means that for each study we had an estimate of impact and an estimate of cost for compensatory mitigation. Because ETM/APF is dependent, in part, on the amount water used for once-through cooling or desalination activities, it was possible to estimate the cost per million gallons of water used per day (MGD) that would provide funds that could be compensatory for lost resources from entrainment. This is a simple equation:

$$\frac{APF\ (Acres)}{Volume\ of\ water\ used\ (MGD)}\ x\ \frac{Cost}{Acres\ (mitigation)} = \frac{Cost}{MGD} \quad (5)$$

In order to generalize equation 1 we define the following:

A_i = APF in acres for project i

V_i = Volume of water (MGD) used for once-through purposes for project i

CA_i = Cost per acre for compensatory mitigation (habitat creation) for project i

CM_i =Cost per MGD of water use

Hence, equation 5 can be expressed as:

$$\frac{A_i}{V_i} x\ CA_i = CM_i \qquad (6)$$

We then calculated summary values for the cost of compensatory mitigation (e.g., mean, 95% confidence limit) for studies i=1 through n.

$$\sum_{i=1}^{n} \frac{CM_i}{n} \text{, which is the average cost of mitigation per MGD} \qquad (7)$$

In this update (2023) we are using the same approach but in a way that allows inclusion of more ETM/APF and habitat creation projects. Here, instead of using only coupled projects (ETM/APF and mitigation) for each study, we gathered information for once-through projects that had ETM/APF assessment, which, by definition, must also have MGD values, and/or habitat creation projects for which we were able to get cost per acres of habitat created (or substantially restored). Using the modified approach, the expected cost of mitigation per MGD (ECM) is calculated as

$$ECM = \sum_{j=1}^{n_a} \left(\frac{\frac{A_j}{V_j}}{n_a} \right) x\ \ \sum_{i=1}^{n_m} \frac{CM_i}{n_m} \qquad (8)$$

Where n_a is the number of ETM/APF assessments (1-n_a) and n_m is the number of mitigation projects(1-n_m). The calculation of ECM is relatively straightforward. However, estimation of the confidence interval around ECM is somewhat more difficult. There are two ways to estimate the confidence interval. First, assuming no covariance, the variance of the product of 2 independent variables is the product of the variance of those variables. This estimate can be used to calculate the expected confidence interval for ECM. Second, resampling can be used to create a distribution of products of the two key variables (acres per MGD, cost per acre). This distribution then can be used directly to provide an expected value and confidence interval for ECM. Here we use the latter approach.

The next step is to produce an estimate of the daily cost of ECM (ECM_d). This is calculated as:

$$ECM_d = \frac{ECM}{365} \qquad (9)$$

The final step is to calculate the annualized daily cost. This value is based on the following assumptions: (1) The mitigation for a once-through use of seawater project would if done be compensatory for the impact. (2) Given that compensatory mitigation here is based on APF (acreage), the expectation is that habitat creation will persist and be fully compensatory for the typical period over which the impact occurs. (3) The impact in any year (I) should be fully compensated by the mitigation (M) project that same year (I=M). We have been using 30 years as the estimated time period of performance for a hypothetical mitigation project for a facility. This is important because under I=M logic we assume that the impact will continue for 30 years, and the mitigation will perform for 30 years and each year the impact should be offset by the mitigation. However, what happens if the impact is only for 5 years, but the mitigation will function for 30? In cases where the period of the impact < period of mitigation provided; the cost of mitigation needs to be prorated. Here we calculate an annual cost that will be the cost for a 30-year mitigation project that is compensatory every year and then divide that cost by 30, resulting in the annual cost. If the facility operates for a full 30 years, then the sum of the annual costs (including cost escalators) will be the estimated total cost for the full project. Hence, the prorated daily cost per million gallons of water entrained is PDC_{mg}:

$$PDC_{mg} = \frac{ECM_d}{y} \quad (10)$$

Where y is the number of years over which the mitigation would be considered to be compensatory.

As an example of the calculations, recall that equation 8 is:

$$ECM = \sum_{j=1}^{n_a} \left(\frac{\frac{A_j}{V_j}}{n_a} \right) x \;\; \sum_{i=1}^{n_m} \frac{CM_i}{n_m} ,$$

Assume that the average number of acres/MGD is 0.4 and that the average cost per acre = $200,000. Here ECM would be $80,000. ECM_d, would be $80,000 / 365 = $219.18 and assuming a 30-year mitigation period PDC_{mg} would be $219.18 / 30 = $7.30 per million gallons of water used. Now apply this to a facility that uses 500 MGD. Here the annual cost for use of water would be 500 MGD x 365 days x $7.30 per MG = $1,332,250.

As noted above, the actual calculation of PDC_{mg} is based on resampling. Here we first created a distribution of possible average values of acres/MGD and separately a distribution possible average values for cost/acre. This was done by sampling the values for each variable with replacement creating 2500 sets of values for each. The average for each set was then calculated producing the distribution of possible means. A distribution of the products of the means was then calculated producing 2500 values. This is the distribution of possible ECM values (means) that could result from the data. This distribution was used to develop a cumulative distribution function. This distribution allows calculation of the percent of possible ECM values < a particular value. The distribution was then converted to a cumulative distribution of PDC_{mg} values, which is shown in Figure 1 and Table 1a. Figure 1 and Table 1 are based on what we call Common Habitat rates – that is the rate is based on cost of acres created using values from both wetland and reef construction. The logic for the Common rate is based on data from most entrainment studies showing that species from three marine habitats are typically entrained at most facilities: reef, sandy bottom, and wetland associated species. Below we discuss alternative approaches, which could be used either solely or as part of a weighted equation if there is adequate data to derive the proportion of species coming from each habitat.

Based on the Default-Common Habitat basis (and other approaches such as Default-Specific Habitat basis) one can calculate the value for any percentile of interest. For example (Table 1a), based on the non-building escalator, 90% of possible values are between $4.18 and $13.52 per MG of intake water. The median value is $7.72 per MG of intake water. The mean value is $8.07 per MG of intake water. All these values are in 2023 dollars and would need to be adjusted annually to account for inflation.

As noted above (see specific details #4). Once a decision is made concerning the percentile of interest then, for the reason addressed below, the value should be used as a basis for adding monitoring costs. Based on precedents from existing and proposed mitigation projects monitoring costs should add 10-25% to the cost per MG. Using the example above, and assuming the cost per MG was the median value

($7.72 per MG) the added cost of monitoring would be between $0.77 and $1.93 per MG for a total range for the combined costs between $8.49 and $9.65 per MG.

Finally, the Default-Specific Habitat basis (Table 1b) could be used either solely or as part of a weighted equation if there were adequate data to derive the proportion of species coming from each habitat. The modeling for this basis is identical to that for the Default-Common Habitat basis, except that the cost of acreage created is calculated for reef and wetland habitats separately. See **Recommendations** for guidelines and data requirements for the use of this basis.

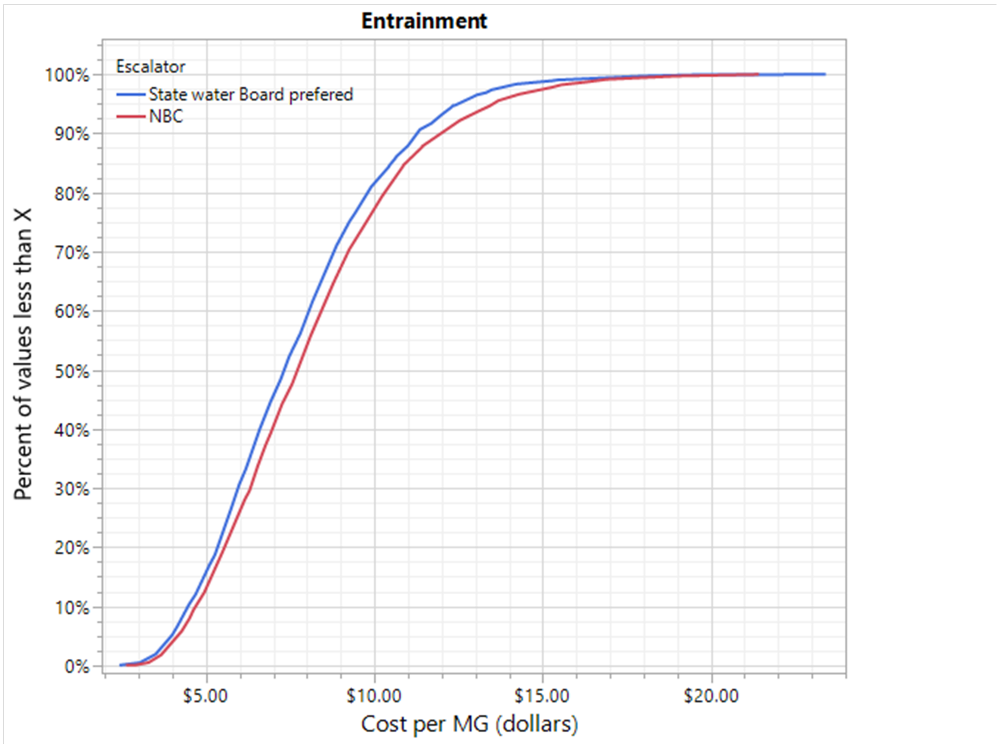

Figure 1: Cumulative Distribution Plot (CDF) of annual cost per million gallons of water used based on entrainment impacts. This CDF has been prorated based on a presumed 30-year duration of impact and 30-year benefit for mitigation. The two lines represent two cost escalators (see item 3 in “specific details for the update”). NBC is the non-building escalator and the other is the recommended approach from the State Water Board.

General approach for impingement effects

The approach used for estimation of cost per MG of water used based on impingement effects is different from that for entrainment impacts. This is because ETM/APF modeling has not typically been used for impingement effects. Hence, a somewhat different approach was taken. The goal was the same – to monetize the use of water based on compensatory mitigation and the mitigation options were again based on creation of reef or wetland habitat. Hence, we were able to use all the information collected on cost per acre of reef or wetland mitigation (which is CA_i = Cost per acre for compensatory mitigation (habitat creation) for project i, see equations 5 and 6). What was needed was a way to estimate the acres required to compensate for impingement losses. We estimated these values based on estimates of standing stock of fish biomass density in wetlands and reef habitats. There are good sources of information on biomass density for fish for both and based on a review of impingement for 23 coastal California powerplants (PIER PROGRAM FINAL REPORT - Publication # 600-01-014), 98% of impinged species were fish (2 percent were invertebrates), therefore biomass density estimate based on fish should be adequate. For biomass density in wetlands, we used Allen et al., 2002 for San Diego Bay from 1994-1999 and for reef biomass density we used data from the San Onofre Nuclear Generating Station (SONGS) mitigation monitoring program (https://marinemitigation.msi.ucsb.edu/) kelp bed annual surveys for three reefs over the period 2009-2022. Based on these sources we calculated the average pounds (lbs.) per acre from the measured biomass per meter square of habitat. The estimated means for wetland and reef habitats were 62.89 lbs. and 184.25 lbs. per acre, respectively. These values were used along with cost per acre of mitigation (see above) to estimate cost per MG of water used for impingement impacts using the same resampling approach described above.

Based on the approach detailed above, we calculated the cost per MG water used for impacts due to impingement, again using two escalators: non-building construction costs (https://edzarenski.com/category/inflation-indexing/) and the State Water Board staff recommended Alternative number 1. For example, based on the non-building escalator, 90% of possible values are between \$1.26 and \$3.48 per MG of intake water. The mid-point in the range of values, the median, is \$2.15 per MG of intake water. The mean value is \$2.24 per MG of intake water. All these values are in 2023 dollars and would need to be adjusted annually, exactly as described for entrainment.

Finally, as noted above, once a decision is made concerning the percentile of interest, then, for the reason addressed below, the value should be used as a basis for adding monitoring costs. Based on precedents from existing and proposed mitigation projects monitoring costs should add 10-25% to the cost per MG. Using the example above, and assuming the cost per MG was the median value (\$2.15 per MG) the added cost of monitoring would be between \$0.22 and \$0.44 per MG for a total range for the combined costs between \$2.37 and \$2.69 per MG. The results of impingement modeling are shown in Table 1a and Figure 2.

The approach used above is called the Default rate basis. It assumes that MG of water is a good estimator for both entrainment and impingement and because of this, it is possible to apply the same rates to all facilities. For reasons documented above, the Default rate is reasonable for entrainment and not reasonable for impingement. To account for site-specific differences, we developed a site-specific rate basis for impingement (Table 2). We also included impact habitat estimates (reef, wetland) recognizing that impingement impacts also differ depending on where the intake is relative to habitat type. We used a resampling approach similar to that described for the Default rates, here though the inputs were cost per acre (reef or wetland) and lbs. per acre (reef or wetland). An important example of how this could affect cost estimates comes from Diablo Canyon Power Plant (DCPP). It currently has the highest intake of ocean water (typically ~ 2300 MGD) of any facility in the state. However, its intake is at the shoreline and has a huge opening, which leads to a very low intake velocity and hence very low impingement. Based on a Default rate basis and using the calculated median cost per MG with 10% monitoring cost and the non-building construction escalator for 2023, the payment would be $2.37 per MG. The average use of water at DCPP is ~2300 MGD or 839,500 MG per year. Therefore, the annual cost for use of water based on impingement and the Default rate (Table 1) of $2.37 per MG would be $1,989,615 (after prorating for 30 years). However, following a Site and Specific Habitat rate basis (Table 2), using the average actual impingement at DCPP (~710 lbs. per year), recognizing that most impinged species at DCPP are reef species and using the median cost per lb. with 10% added for monitoring ($27.97 per lb.), the annual cost would be $19,859. These two estimates are extraordinarily different, with one based on a Default rate appearing punitive.

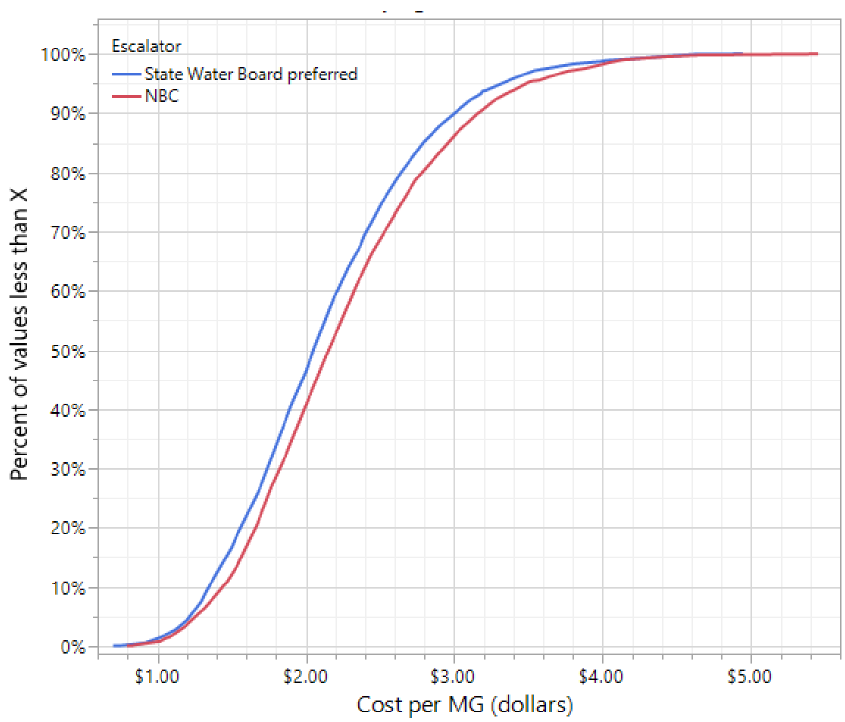

Figure 2: Cumulative Distribution Plot (CDF) of annual cost per million gallons of water used based on impingement. This CDF has been prorated based on a presumed 30-year duration of impact and 30 year benefit for mitigation. The two lines represent two cost escalators (see item 3 in "specific details for the update"). NBC is the non-building escalator and the other is the recommended approach from the State Water Board.

Case Study: Diablo Canyon Power Plant (see Tables 1-5)
As an example of the estimation of the cost for impacts due to once-through use of water related to both entrainment and impingement, we use DCPP facility, which is the largest powerplant in California and uses the most seawater for its cooling operations. For this example, we make the following assumptions: cost basis is the median estimate (the 50th percentile of possible means), use of water is based upon design capacity (2528 MGD), monitoring at a level of 10% of annual cost, cost escalator is based on non-building construction.

Example 1: Both entrainment and impingement are based on Default Site Common Habitat rates (Table 1a). The cost for 2023 entrainment would be 2528 (MGD) x 365 (days in year) x $8.49 (cost per MG, with 10% for monitoring) = $7,833,893. The cost for 2023 impingement would be 2528 (MGD) x 365 (days in year) x $2.37 (cost per MG, with 10% for monitoring) = $2,186,846. The total cost would be $10,020,739.

Example 2: Entrainment is based on Default site rates (Table 1a) and impingement is based on Site and Specific Habitat rates (Table 2). The cost for 2023 entrainment remains the same and would be 2528 (MGD) x 365 (days in year) x $8.49 (cost per MG, with 10% for monitoring) = $7,833,893. The cost for 2023 impingement would be based on 785 lbs. per year impinged (at 2528 MGD) x $27.97 per lb. = $21,956. The total cost would be $7,855,849.

Example 3: Entrainment is based on Default-Specific Habitat rates (Table 1b) and impingement is based on Site Specific- Specific Habitat rates (Table 2). The cost for 2023 entrainment would be 2528 (MGD) x 365 (days in year) x $7.44 (cost per MG, with 10% for monitoring) = $6,865,037. The cost for 2023 impingement would be based on 785 lbs. per year impinged (at 2528 MGD) x $27.97 per lb. = $21,956. The total cost would be $6,886,993.

Based on the composition of species entrained and impinged, we recommend either of the options shown in examples 2 and 3.

These are only examples of the calculations that could be made. Tables 1-5 provide a basis for making calculations for many combinations of variables: monitoring costs, escalators, and value percentile (e.g., mean, median, 5th and 95th percentiles). Not shown are Site and Habitat Specific cost for impingement as they are facility specific. However, these are easily estimated using the last column in Table 4 (average total annual impingement in lbs. per facility) and multiplying by the appropriate value in Table 2.

Finally, it should be noted that most facilities take in a combination of reef, sandy bottom, and wetland species. Hence in most cases it makes sense to use the Default-Common Habitat basis for entrainment. Table 1a shows rates for MG of water used irrespective of species. For impingement it does not make sense to use Default rate, however for the same reason as described for entrainment, it may make sense to use a Common Habitat basis (combining wetland and reef values). This could be done either evenly (i.e., the average of the two rates) or using a weighted average (weighting reef and wetland values by their relative impingement proportion). This is harder to do for entrainment because the value of the species for entrainment is based not on effect on numbers or biomass lost, it is instead based on proportion of population size lost, which is calculated for many fewer species than are entrained. Moreover, as noted above, entrainment for most facilities is made up of species that come from all three marine habitats: reef, wetland, and sandy bottom. If habitat specific rates are going to be used for entrainment (Table 1b) then first there should be an evaluation of habitat associations for species entrained at the facility so that weighing of the equations can be used to develop an informed model. Note also that there is precedent in APF calculations for conversion of sandy bottom impacts to wetland and rocky reef acreage. Using these precedents facilitates the use of the Specific Habitat basis.

			Escalator	
Impact type	**Monitoring**	**Metric**	**NBC**	**SWB- preferred**
Entrainment	No Monitoring	Lower 5%	$4.18	$3.98
		Mean	$8.07	$7.66
		Median	$7.72	$7.31
		upper 95%	$13.52	$12.51
	10% of base cost	Lower 5%	$4.60	$4.38
		Mean	$8.88	$8.43
		Median	$8.49	$8.04
		upper 95%	$14.87	$13.76
	25% of base cost	Lower 5%	$5.23	$4.98
		Mean	$10.09	$9.58
		Median	$9.65	$9.14
		upper 95%	$16.90	$15.64
Impingement	No Monitoring	Lower 5%	$1.26	$1.21
		Mean	$2.24	$2.13
		Median	$2.15	$2.05
		upper 95%	$3.48	$3.32
	10% of base cost	Lower 5%	$1.39	$1.33
		Mean	$2.46	$2.34
		Median	$2.37	$2.26
		upper 95%	$3.83	$3.65
	25% of base cost	Lower 5%	$1.58	$1.51
		Mean	$2.80	$2.66
		Median	$2.69	$2.56
		upper 95%	$4.35	$4.15

Table 1a: *Default-Common Habitat basis* for entrainment and impingement. Table of modeled cost (per MG of water used) for entrainment and impingement impacts. Included are payment amounts for ranges of monitoring (none, 10% and 25% of annual cost) and for two different cost escalators (non-building construction and State Water Board preferred alternative 1).

			Escalator	
Habitat	**Monitoring**	**Metric**	**NBE**	**SWB-preferred**
Reef	No Monitoring	Lower 5%	3.62	3.42
		Mean	$7.26	6.93
		Median	$6.76	6.47
		upper 95%	$12.43	12.09
	10% of base cost	Lower 5%	$3.98	$3.76
		Mean	$7.99	$7.62
		Median	$7.44	$7.12
		upper 95%	$13.67	$13.30
	25% of base cost	Lower 5%	$4.53	$4.28
		Mean	$9.08	$8.66
		Median	$8.45	$8.09
		upper 95%	$15.54	$15.11
Wetland	No Monitoring	Lower 5%	$4.16	3.96
		Mean	$8.88	8.34
		Median	$8.31	7.85
		upper 95%	$15.51	14.69
	10% of base cost	Lower 5%	$4.58	$4.36
		Mean	$9.77	$9.17
		Median	$9.14	$8.64
		upper 95%	$17.06	$16.16
	25% of base cost	Lower 5%	$5.20	$4.95
		Mean	$11.10	$10.43
		Median	$10.39	$9.81
		upper 95%	$19.39	$18.36

Table 1b: *Default-Specific Habitat basis* for entrainment. Table of modeled cost (per MG of water used) for entrainment and impingement impacts. Included are payment amounts for ranges of monitoring (none, 10% and 25% of annual cost) and for two different cost escalators (non-building construction and State Water Board preferred alternative 1).

			Cost per lb. (30 year basis)	
Species impinged	Monitoring	Metric	NBE	SWB-preferred
Wetland species	No Monitoring	Lower 5%	$72.20	$68.21
		Mean	$119.60	$114.16
		Median	$116.50	$111.50
		upper 95%	$176.83	$171.99
	10% of base cost	Lower 5%	$79.42	$75.03
		Mean	$131.56	$125.58
		Median	$128.15	$122.65
		upper 95%	$194.51	$189.19
	25% of base cost	Lower 5%	$90.25	$85.26
		Mean	$149.50	$142.70
		Median	$145.63	$139.38
		upper 95%	$221.04	$214.99
Reef species	No Monitoring	Lower 5%	$17.16	$16.34
		Mean	$25.87	$24.30
		Median	$25.43	$24.02
		upper 95%	$35.33	$33.46
	10% of base cost	Lower 5%	$18.88	$17.97
		Mean	$28.46	$26.73
		Median	$27.97	$26.42
		upper 95%	$38.86	$36.81
	25% of base cost	Lower 5%	$21.45	$20.42
		Mean	$32.34	$30.37
		Median	$31.79	$30.03
		upper 95%	$44.16	$41.83

Table 2: *Site-Specific, Specific Habitat rate basis* for impingement. Table of modeled cost (per lb. of fish impinged, annually) for site specific impingement impacts using recommended NBC escalator and the SWB preferred option. Site specific means that actual level of impingement (lbs. per year) is used to calculate payment. Included are payment amounts for ranges of monitoring (none, 10% and 25% of annual cost).

Data used in the modeling

The data used in the entrainment modeling are shown in Tables 3 and 4. Table 3 lists the entrainment studies that were reviewed for inclusion in the calculation of the relationship between intake water use (leading to entrainment) and estimates of APF. The entrainment studies that were used are indicated and notation is presented for those that were not. Table 4 lists wetland and reef creation or restoration projects that were reviewed for inclusion in calculation of cost per acre of habitat creation. The projects that were used are indicated and notation is presented for those that were not. Data used to calculate the Default rate for impingement are shown in Table 5.

Facility	Intake Volume (MGD)	APF (acres)	Mitigation Type	Reef type	acres/MGD	Used in Model	Why not used
Moss Landing Combined cycle	360	840	wetland		2.333333333	No	enhancement project
Morro Bay	371	760	wetland		2.04851752	No	enhancement project
Poseidon Carlsbad	304	66.4	wetland		0.218421053	Yes	
Huntington Beach	126.5	66	wetland		0.52173913	Yes	
Diablo	2486	543	Rocky reef	Low Relief/Low Density	0.21842317	Yes	
Diablo	2486	543	Rocky reef	Low relief/Medium Density	0.21842317	No	Only one value per design
Diablo	2486	690	Rocky reef	Low Relief/Low Density	0.277554304	Yes	
Diablo	2486	690	Rocky reef	Low relief/Medium Density	0.277554304	No	Only one value per design
Diablo	2486	543	Rocky reef	Low relief/High Density	0.21842317	No	Only one value per design
Diablo	2486	690	Rocky reef	Low relief/High Density	0.277554304	No	Only one value per design
Poseidon Hunt Beach	106.7	100.4	Wetland		0.940955951	Yes	
Humbolt	11.88	34.2	Wetland		2.878787879	No	enhancement project
ENCINA	863.5	188.61	Wetland		0.218425014	No	Only one value per design

Table 3: Entrainment studies that were reviewed for inclusion in the calculation of the relationship between intake water use (leading to entrainment) and estimates of APF.

Year or base year (see 2017 update)	Project	Reef or tidal marsh?	reef type	Acres	Cost per acre (without monitoring) - base estimate year	cost per acre (2023)	Use	Why not used
2022	Hester/Elkhorn Slough	Tidal marsh		120	100000	104700	Yes	
2022	Poseidon Restoration	Tidal marsh		125	196000	205212	Yes	
2022	North Campus Open Space, UCSB	Tidal marsh		40			No	enhancement project
2022	Bunker Point Reef	Reef	varied relief clusters	40	162500	170137.5	Yes	
2022	Wheeler North Reef	Reef	Low Relief/Low Density	210	95238.09524	99714.29	Yes	
2017	San Dieguito Lagoon	Tidal marsh		165	190251.897	271603	Yes	
2017	Moss Landing Combined cycle	Tidal marsh		840	17976.19048	25662.75	No	enhancement project
2017	Morro Bay	Tidal marsh		760	17976.19048	25662.75	No	enhancement project
2017	Poseidon	Tidal marsh		37	300000	428279	Yes	
2017	Huntington Beach	Tidal marsh		66	74660	106584.4	Yes	
2017	Diablo	Reef	Low Relief/Low Density	543	68400	97647.62	Yes	
2017	Diablo	Reef	Low relief/Medium Density	543	135000	192725.6	Yes	
2017	Diablo	Reef	Low Relief/Low Density	690	68400	97647.62	No	Only one value per design
2017	Diablo	Reef	Low relief/Medium Density	690	135000	192725.6	No	Only one value per design
2017	Diablo	Reef	Low relief/High Density	543	247500	353330.2	Yes	
2017	Diablo	Reef	Low relief/High Density	690	247500	353330.2	No	Only one value per design
2017	ENCINA	Tidal Marsh		188.61	300000	428279	N	Only one value per design (Poseidon)

Table 4: Wetland and reef creation or restoration projects that were reviewed for inclusion in calculation of cost per acre of habitat.

Operating as of 2023	Plant	Design Flow (MGD)	Avg MGD (2000-2005)	lbs (annual avg)	lbs (avg Heat Treatment)	N HT per year	avg lbs annual +HT
Yes	**Alamitos Generating Station Units 1-6**	1273	815	2249	0	0	2249
Yes	**Diablo Canyon Power Plant**	2528	2287	710	0	0	710
Yes	**El Segundo Generating Station Units 1&2**	207	69	89	72.18	1.3	182.834
Yes	**El Segundo Generating Station Units 3&4**	399	265	662	94.6	3.7	1012.02
No	**Encina Power Plant**	857	621	5806	747.7	6	10292.2
Yes	**Harbor Generating Station**	108	59	3498	0	0	3498
Yes	**Haynes Generating Station**	968	258	390	0	0	390
Yes	**Huntington Beach Generating Station**	514	179	1487	338.7	4.8	3112.76
No	**Mandalay Generating Station**	253	234	2553	4.2	1.4	2558.88
No	**Morro Bay Power Plant**	668	257	1313	0	0	1313
Yes	**Moss Landing Power Plant Units 1&2**	361	193	406	0	0	406
Yes	**Moss Landing Power Plant Units 6&7**	865	387	4060	0	0	4060
Yes	**Ormond Beach Generating Station**	685	521	3112	4.5	4.5	3132.25
No	**Potrero Power Plant**	231	193	2371	0	0	2371
Yes	**Redondo Generating Station Units 5&6**	217	51	63	7.32	2	77.64
Yes	**Redondo Generating Station Units 7&8**	675	254	785	37.9	4.8	966.92
No	**San Onofre Nuclear Generating Station Units 2 and 3**	2438	2293	28094	627.8	5.2	31358.56
Yes	**Scattergood Generating Station**	495	309	9185	788.4	5.2	13284.68
No	**South Bay Power Plant**	601	417	751	0	0	751

Table 5: Impingement estimates for California Powerplants. Heat treatments are used to clean intake structures of fouling organisms. Some of the facilities listed are no longer operating or are operating at reduced levels or with modifications that could affect impingement.